Upper Deschutes Watershed Council
Technical Report

2009 Whychus Creek Monitoring Report

Golden, B. 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

Brett Golden
Deschutes River Conservancy
700 NW Hill St
Bend, OR 97701
brett@deschutesriver.org

Ryan Houston
Upper Deschutes Watershed Council
700 NW Hill St
Bend, OR 97701
rhouston@restorethedeschutes.org

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 coordinatied 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, l*et al*one 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 baseline conditions in the creek prior to the implementation of a suite of restoration projects beginning in 2009.

In an ideal 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 affect 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. Each chapter of the 2009 Whychus Creek Monitoring Report assesses indicators in one of these categories.

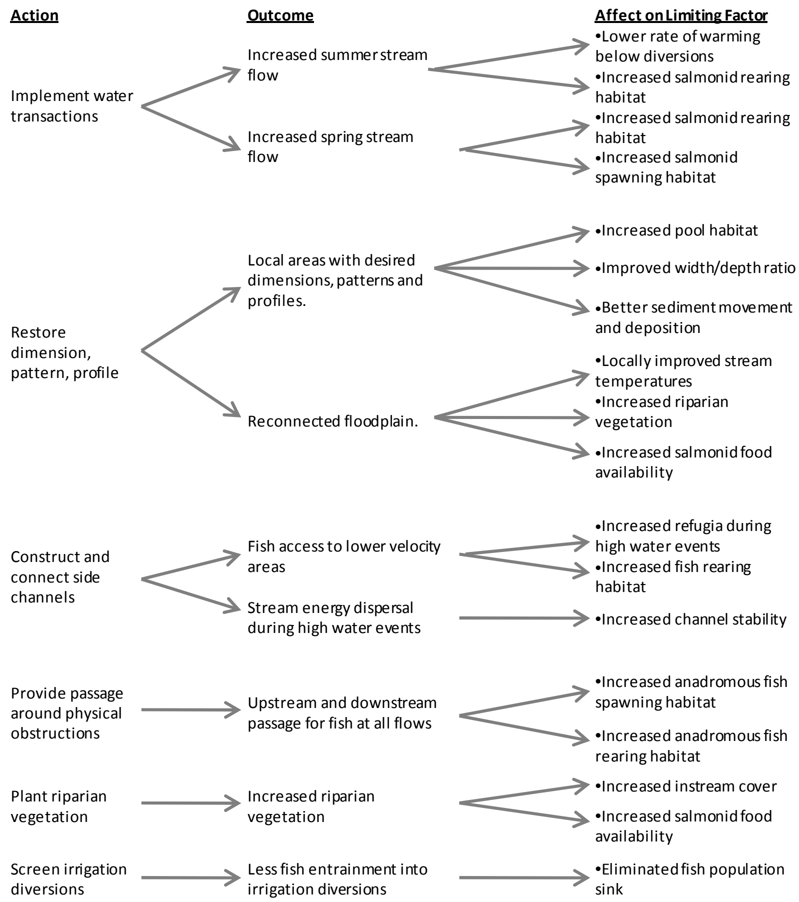

Figure 1.
This conceptual model illustrates the expected influences on each life stage of resident and anadromous salmonids in Whychus Creek. The UDWC expects that the ongoing restoration actions will affect the limiting factors identified in the conceptual model.

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 Alders Springs areas, increase flows by 25% to 300% (UDWC 2000). Tributaries to Whychus Creek include Snow Creek, Pole Creek, and Indian Ford Creek.

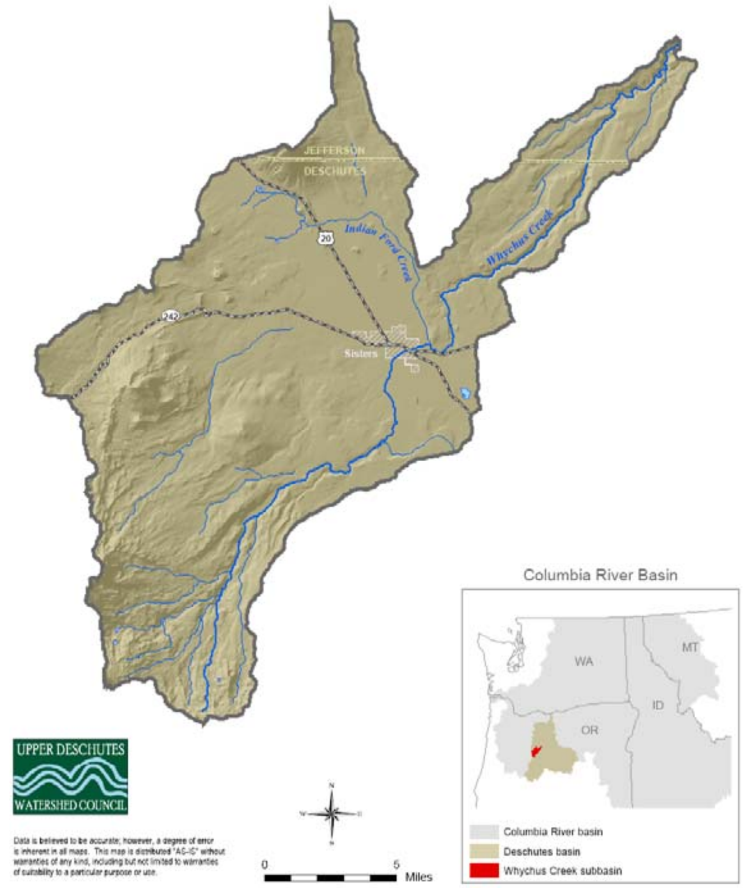

Figure 2.
Whychus Creek extends from the Cascade Range to the Deschutes River. The creek's watershed encompasses approximately 162,000 acres of Deschutes and Jefferson Counties in central Oregon

Irrigators cumulatively divert up to 95% 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. Six permanent or seasonal fish passage barriers associated with these diversions block upstream fish passage in Whychus Creek from approximately river mile 15 through river mile 25 (UDWC 2008). These fish barriers isolate upstream resident fish populations and will 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 habitat conditions do not 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 occurred in following years 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

The seven technical studies commissioned by the Model Watershed Program examine the status and trends of physical and biological indicators in Whychus Creek. These studies document conditions prior to the implementation of large scale habitat restoration actions along the creek. Some stream flow restoration has occurred prior to these studies but channel realignment, fish passage improvements, and other restoration actions have not occurred.

Golden (2010a) documents summer stream flow conditions in Whychus Creek from 2002-2008. It focuses on metrics representing low flow conditions in the creek. Jones (2010) answers questions related to stream temperatures, dissolved oxygen, and pH in Whychus Creek. It draws from ten years of data to examine water quality in relation to state standards and to stream flow restoration. Golden (2010b) focuses on habitat suitability for different life stages of steelhead trout and chinook salmon in 1997 and 2008/2009. Restored stream flow has likely affected metrics in each of these three reports.

Two reports outline baseline conditions in areas where no restoration has previously occurred. Perle (2010a) documents fish passage barriers along the creek. Restoration partners expect to provide passage at each of the six barriers identified in the report. Perle (2010b) outlines fish entrainment potential on the creek. It sets unscreened irrigation diversions as a proxy for entrainment potential with the expectation that restoration partners will screen each of these diversions in the future.

Two additional reports inform restoration partners about baseline biological conditions in the creek. Mazzacano (2010) highlights macroinvertebrate community composition before and after major stream flow restoration started in the creek. Kunkel (2010) builds off of PGE and CTWS's 2006-2008 steelhead and chinook surveys. It outlines the status of fish populations in the creek and provides suggestions for future research.

These seven reports provide baseline information for restoration that has occurred, is occurring, or will likely occur in Whycus Creek. 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 improve restoration implementation and monitoring in the creek.

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Whychus Creek Stream Flow

Brett Golden
Deschutes River Conservancy
700 NW Hill St
Bend, OR 97701
brett@deschutesriver.org

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 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. 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 48 cfs in 2005. August median flows also exhibited inter-annual and intra-annual variation. 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. They 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 refine their metrics to fully account for the different components of the hydrograph necessary to support desired conditions in Whychus Creek.

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 have diverted up to 95% 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 *et al* 2008), and riparian vegetation (Stromberg *et al* 2005). By removing up to 95% of the stream flow from Whychus Creek, irrigation diversions have 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 hydrograph that 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 represents alteration in all types of stream. 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, Table 1). 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.

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.

Table 1. Three metrics representing low flow discharge magnitude and timing.

Metric	Appears In
30 day minimum	Gao *et al* 2009, Richter *et al* 1996
May median flow	Gao *et al* 2009, Richter *et al* 1996
August median flow	Richter *et al* 1996

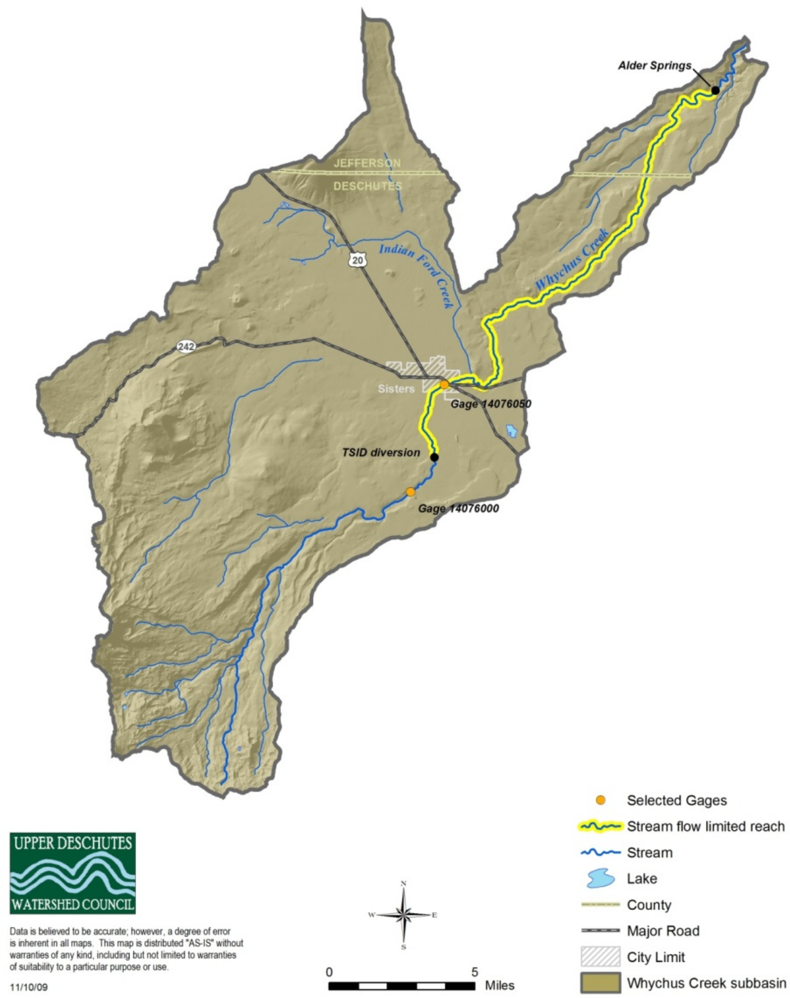

Figure 1.
Stream flow limits stream function in Whychus Creek downstream from the Three Sisters Irrigation District Diversion. Spring inputs near the mouth of Whychus Creek increase stream flow and improve conditions in the creek.

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 stress 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 2009. This report uses data from this gage.

OWRD operates another gage, 1407500, upstream from all diversions on Whychus Creek. They have published stream flow data for this gage from 1906 through 2008. 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 2008 reflects current conditions in the creek.

Gage 14076050 records 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 data from May 18, 2000 through September 30, 2008 when this report was prepared.

Data Analysis

The Deschutes River Conservancy (DRC) analyzed stream flow data for the entire period of record for gage 14076050. The DRC analyzed this data for each water year, extending from October 1 through September 30, between 2000 and 2008. 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.

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 2008.

The DRC used spreadsheet software to determine the median daily average flow during the month of May for years 2001 through 2008. The DRC only had partial data for 2000 and did not include that data in this analysis.

The DRC used spreadsheet software to determine the median daily average flow during the month of August for years 2000 through 2008. 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 (Table 2). 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.

Table 2. Minimum 30 day moving average discharge of Whychus Creek at OWRD gage 14076050.

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

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 4). Median flow during the month of May ranged from a low of 5.4 cfs in 2003 to high of 48 cfs in 2005. 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.

August Median

Median discharge during the month of August exhibited both inter-annual and intra-annual variation at gage number 14076050 (Figure 3). 2002 exhibited the lowest median discharge during the month of August, with a median daily average discharge of 2.6 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.

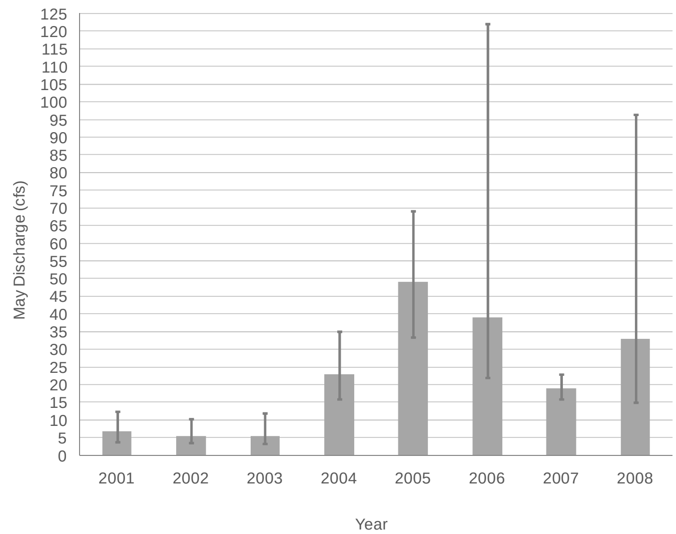

Figure 2.
The median of the average daily discharge of Whychus Creek at the Oregon Water Resources Department's gage number 14076050 during the month of May provides one indicator of low flow magnitude. Error bars represent the 20th and 80th percentile discharges during the month of May at this location.

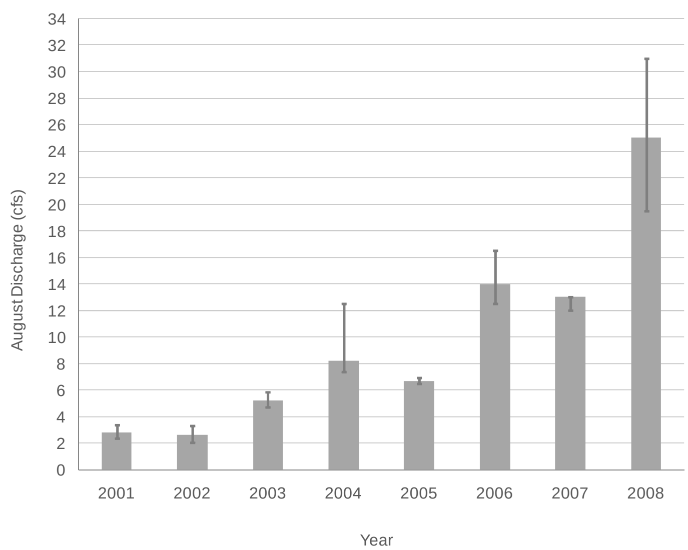

Figure 3.
The median of the average daily discharge of Whychus Creek at the Oregon Water Resources Department's gage number 14076050 during the month of August provides one indicator of low flow magnitude. Error bars represent the 20th and 80th percentile discharges during the month of August at this 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 2008, the entire period of record for the Oregon Water Resources Department's gage number 14076050. 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.

Late Spring/Early Summer Flows

May daily average stream flow results display a wide range of inter-annual and intra-annual variability (Figure 2). Although August monthly median flows tend to be lower than May monthly median flows (Figure 2, Figure 3), May monthly median flows appear to exhibit greater intra-annual variability.

The Oregon Department of Fish and Wildlife applied for and received instream water rights to support fish populations in Whychus Creek in the 1990s. These water rights provide one base flow target. Median daily average flow during the month of May exceeded the Oregon Department of Fish and Wildlife's 20 cfs instream water right for Whychus Creek upstream from Indian Ford Creek in four out of eight years (OWRD 1996, Figure 2). It never met the Oregon Department of Fish and Wildlife's March, April, and May instream water right of 50 cfs for Whychus Creek downstream from Indian Ford Creek (OWRD 1996, Figure 3).

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 (Oregon Department of Fish and Wildlife 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. Future restoration actions and restoration effectiveness monitoring should consider late spring/early summer base flows as critical to native fish production in 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 (Table 2). 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 Oregon Department of Fish and Wildlife's instream water rights again provide a rough base flow target in Whychus Creek. Median daily average flows during the month of August exceeded the Oregon Department of Fish and Wildlife's 20 cfs instream water right for Whychus Creek upstream from Indian Ford Creek only in 2008 (OWRD 1996a, Figure 3). They never met the Oregon Department of Fish and Wildlife's instream water right of 33 cfs for Whychus Creek downstream from Indian Ford Creek (OWRD 1996b, Figure 3). Late summer and early fall base flows 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

When stream flow restoration began in Whychus Creek, restoration partners focused on restoring base flows to a largely dewatered stream system. They used, and continue to use, the Oregon Department of Fish and Wildlife's requested instream water rights as stream flow targets. The Oregon Department of Fish and Wildlife based these instream water rights on minimum flows determined through the Oregon Method. The Oregon Method relates stream flow to habitat availability to determine stream flow recommendations for fish (Thompson 1972). This method was appropriate for determining stream flows in the absence of additional information. It does not fully express the range of flows necessary to support stream structures and functions. As stream flow restoration progresses in Whychus Creek, restoration partners should fully identify the components of the Whychus Creek hydrograph necessary to support stream structure and function. Selecting metrics and identifying targets based on these components will allow for ecologically relevant stream flow monitoring over the next ten years.

Over the last decade, the discourse around stream flow restoration has shifted from restoring minimum flows to restoring natural hydrographs (Poff *et al* 1997). The natural hydrograph approach may not be fully appropriate for Whychus Creek. Climate change will affect when precipitation occurs, what form it occurs in, and how quickly it moves through a system. The probability of an event occurring in the past no longer describes the probability that it will occur in the future (Milly *et al* 2009). The natural hydrograph described by historic records will not reflect the hydrograph seen in the future. Instead of focusing on restoring a natural hydrograph, restoration partners should focus on restoring a hydrograph that meets the perceived needs of the system. This hydrograph will likely be described by a new set of metrics representing the desired hydrograph components.

Although existing metrics do not fully describe Whychus Creek's hydrograph, existing monitoring stations do adequately measure stream flow in the creek. 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. These stations collect data that can be used with a wide range of metrics in the future. Currently, OWRD 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. Future analyses with different metrics may require 15 minute interval flow data to accurately describe conditions in Whychus Creek. Again, the 15 minute data collected by OWRD is adequate for review and revision in future analyses.

The metrics used in this report describe low flow conditions in Whychus Creek. They focus on stream flow conditions across the irrigation season with the assumption that stream flow generally relates to habitat availability. As restoration investments continue in Whychus Creek, restoration partners should develop a target hydrograph that fully accounts for both ecosystem needs and expected future hydrologic conditions. Metrics used in future analyses should directly relate to this target hydrograph.

Acknowledgements

The Oregon Water Resources Department provided the data necessary to complete this report. Their extensive gaging network, published data, and staff contributions were critical to its production. The Bella Vista Foundation, Oregon Watershed Enhancement Board, and National Fish and Wildlife's Columbia Basin Water Transactions Program have supported the stream flow monitoring necessary to understand restoration effectiveness in Whychus Creek.

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

Lesley Jones
Upper Deschutes Watershed Council
700 NW Hill St
Bend, OR 97701
ljones@restorethedeschutes.org

Abstract

This report addresses three questions related to water quality in Whychus Creek, a tributary to Oregon's Deschutes River. The report outlines the status of water quality in relation to state standards, evaulates changes in stream temperatures associated with stream flow restoration, and identifies stream flow restoration targets intended to meet temperature standards. Temperatures exceeded state standards during the spawning, rearing, and migration seasons during all but one year between 1995 and 2008. Temperatures exceeded lethal temperatures for fish during the rearing and migration season during most years. Dissolved oxygen and pH in Whychus Creek generally met state standards. BACI statistical analysis of temperature data indicated that stream flow restoration lowered stream temperatures downstream from the TSID diversion but raised them downstream from the Alder Springs Complex. Regression analysis of temperature data identified the stream flow necessary to meet state water quality standards at two locations. Under historic conditions, 20 cfs of flow downstream from the TSID diversion led to stream temperatures that met state standards at Sisters City Park. 60 cfs led to stream temperatures that meet state standards at USFS Rd 6360. These results inform ongoing restoration efforts in Whychus Creek.

Introduction

Restoration partners have identified the Whychus Creek watershed as a priority watershed for restoration and conservation within the upper Deschutes Basin (NWPPC 2004, UDWC 2006, UDWC *et al* 2006). The creek's hydrology, geology, and water resource management challenges are indicative of those found across the Deschutes Basin. An altered flow regime contributes to water quality impairments in the creek, particularly stream temperatures. Flow and habitat restoration projects along Whychus Creek seek to make reach level and localized improvements, respectively, to the creek by reducing warming rates, reconnecting the creek to floodplains and groundwater, and improving the extent of riparian shading. This report explores the status of water quality in the creek, trends in water quality associated with restoration, and stream flow targets that will improve water quality along the longitudinal extent of Whychus Creek.

For simplicity and discussion, this report divides Whychus Creek into three reaches termed the Upper, Middle, and Lower Reaches of Whychus Creek based on hydrology (Figure 1). Whychus Creek has natural flows in the Upper Reach above river mile 27, depleted flows (irrigation withdraws) in the Middle Reach between river mile 27 and river mile 1.5, and replenished flows from groundwater springs in the Lower Reach below river mile 1.5 (Figure 2, Figure 3). A major irrigation diversion feeding the Three Sisters Irrigation District (TSID) canal is located at river mile 27 upstream of the City of Sisters City Park stream gauging station at river mile 24.25. From the TSID diversion at river mile 27 until river mile 1.5, Whychus Creek is reduced to approximately 15 cfs. The Camp Polk Spring Complex located near river mile 18.5 contributes approximately 5 cfs of cool flow. Downstream of river mile 1.5, the Alder Springs

Complex contributes approximately 95 cfs of cold groundwater into Whychus Creek just prior to its confluence with the Upper Deschutes River. These natural and artificial changes in hydrology affect stream flow and water quality in the creek.

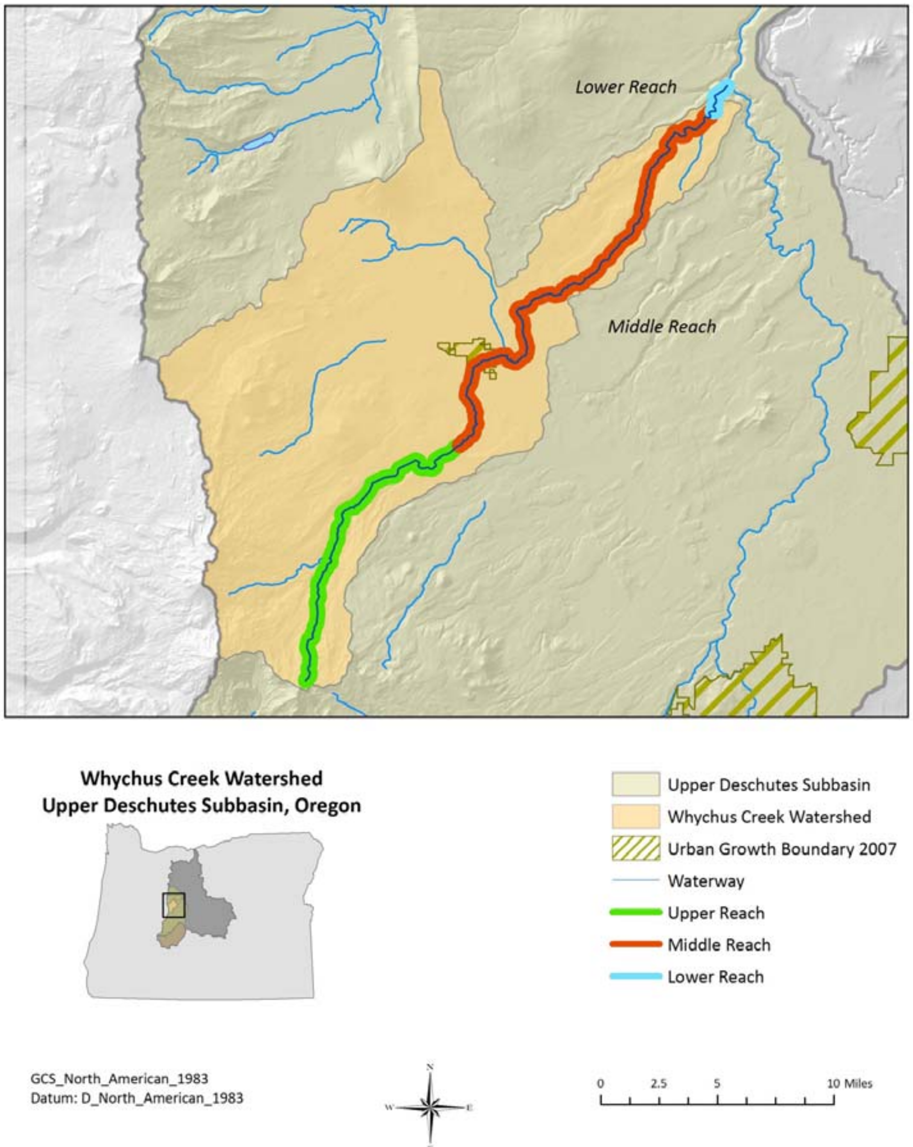

Figure 1.
For simplicity and discussion, Whychus Creek is divided into three reaches termed the Upper, Middle, and Lower Reaches of Whychus Creek. Whychus Creek has natural flows in the Upper Reach above river mile 27, depleted flows (irrigation withdraws) in the Middle Reach between river mile 27 and river mile 1.5, and replenished flows from groundwater springs in the Lower Reach below river mile 1.5

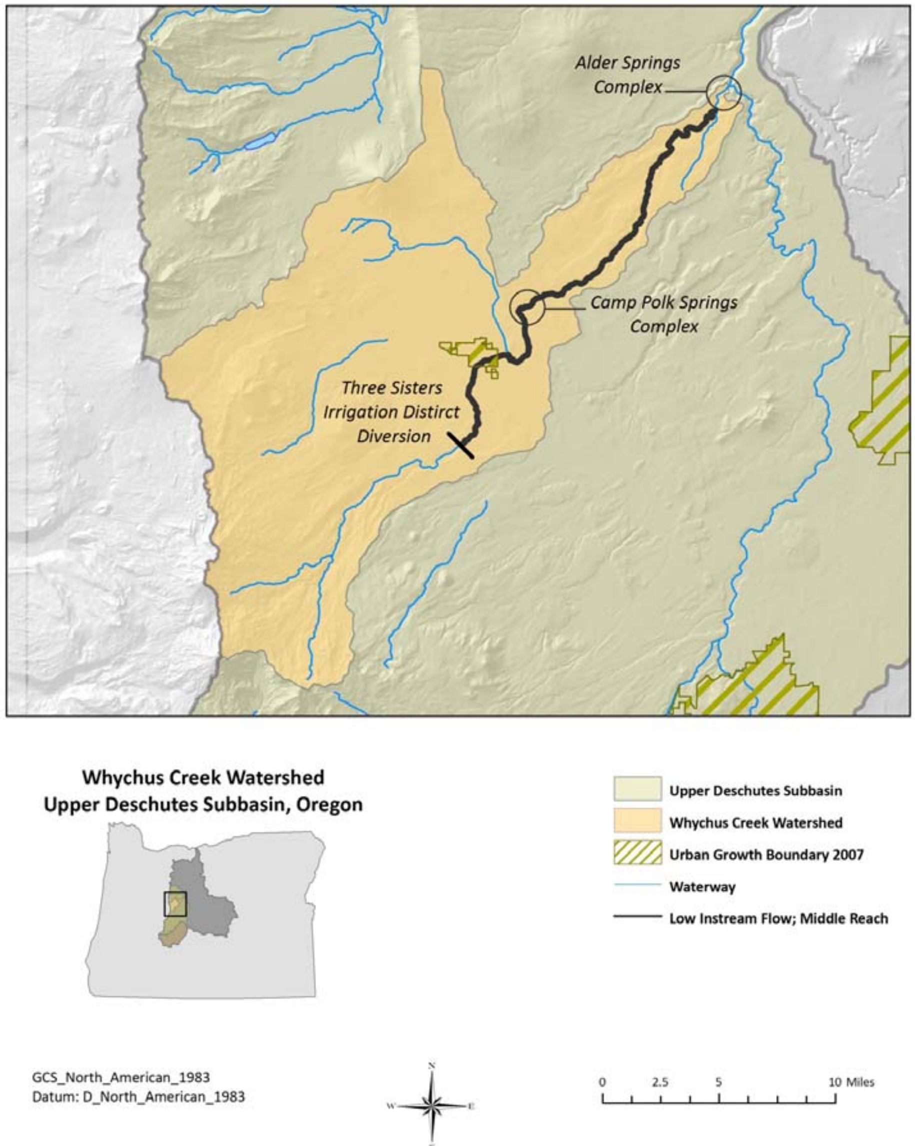

Figure 2.
The TSID Diversion, Camp Polk Spring complex, and Alder Springs complex all influence hydrology in Whychus Creek.

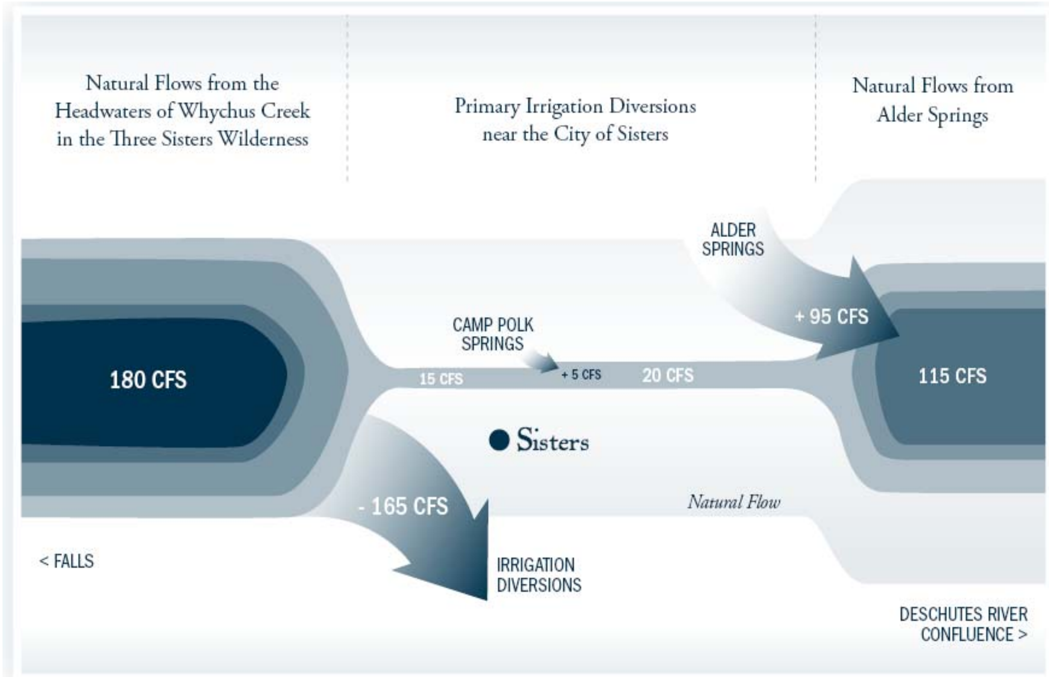

Figure 3. Natural flows in Whychus Creek vary based on spring inputs and irrigation diversions (UDWC 2008).

ODEQ has identified Whychus Creek as not meeting state temperature standards set to protect salmon and trout rearing and migration. Although most of the temperature impairments occur in the Middle Reach of Whychus Creek, Oregon's Clean Water Act Section 303(d) list includes all of the creek as temperature limited (Figure 4). Project partners expect to work with the ODEQ to develop Total Maximum Daily Loads (TMDLs) for temperature in the future.

Oregon's current 303(d) list includes data collected through 2003. EPA approved this list in 2007 (Table 1). The previous 303(d) list, released in 2002, also identified Whychus Creek as not meeting temperature criteria set to protect salmon and steelhead spawning. Spawning standards are stringent than rearing and migration standards. ODEQ removed this listing on subsequent publications because anadromous fish were not present in Whychus Creek when the 2002/2004 evaluation was done. The temperature standard for salmon and steelhead spawning will likely apply to Whychus Creek at some point in the future due to the reintroduction of salmon and steelhead. This standard will apply during the spawning season. Since spawning season had not yet been identified for this area, this report adopted the January 1-May 15 spawning season identified for anadromous tributaries in the Lower Deschutes Subbasin.

ODEQ has identified other water quality impairments in Whychus Creek as well. ODEQ lists Habitat Modification and Flow Modification as water quality impairments in Whychus Creek that do not need TMDLs because the impairments are not caused by a pollutant. Dissolved oxygen and pH are listed as not having enough data to assess.

Table 1. 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 @ 95% 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 2004

This report relies on data collected, analyzed, and published by the UDWC's Water Quality Monitoring Program (WQ Monitoring Program) is a coordinated, regional water quality monitoring effort. The WQ Monitoring Program was initiated in 2001 and is guided by the *USGS Framework for Regional, Coordinated Monitoring in the Middle and Upper Deschutes River Basin* (USGS 2000). The WQ Monitoring Program coordinates monitoring across the Upper Deschutes and Little Deschutes Subbasins. A Water Quality Committee representing local, state, federal, and private interests guides the program.

The WQ Monitoring Program consists of a Water Quality Specialist (WQS), a Water Quality Technician, and an Oregon State University Undergraduate Intern. The WQ Monitoring Program operates out of a Water Resources Laboratory located on the Oregon State University Cascades Campus in Bend, Oregon.

The WQ Monitoring Program conducts both continuous and grab sample monitoring as follows:

- Continuous Temperature
- Grab Sample Monitoring: dissolved oxygen concentration/percent saturation and pH
- Continuous Multiple Parameters: dissolved oxygen concentration/percent saturation and pH

Data were collected at thirteen monitoring stations between 1995 and 2008. Not all stations have data for every parameter between the years 2000 – 2008 (Table 2). The WQ Monitoring Program compiles data from multiple sources. The USFS and BLM Crooked River Grasslands monitored multiple locations along the creek from 2000 through 2003. In 2001, ODEQ collected water quality information from Whychus Creek for TMDL development. Starting in 2003 and continuing through 2008, the UDWC conducted comprehensive, multiparameter monitoring along the longitudinal extent of Whychus Creek.

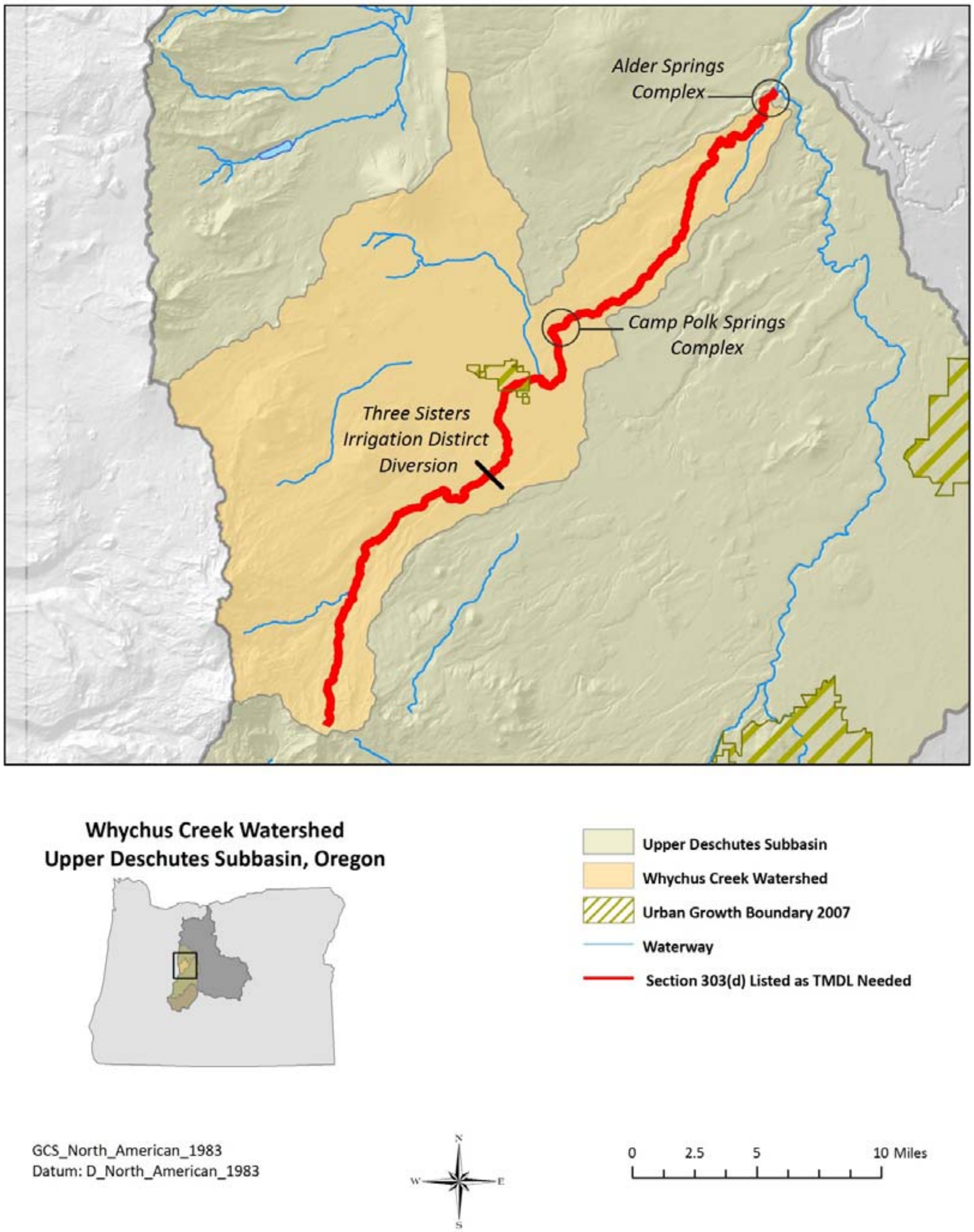

Figure 4.
Whychus Creek appears on the state of Oregon's 303(d) list for not meeting temperatire standards (ODEQ 1004).

Table 2. Water Quality Monitoring Stations

Station ID	System	Description	Continuous Temperature	Grab Sample	Continuous Multiple Parameter
WC 000.25	Whychus Creek	Mouth	X	X	
WC 001.00	Whychus Creek	Diamondback meadow	X	X	
WC 001.50	Whychus Creek	d/s Alder springs	X	X	
WC 003.00	Whychus Creek	u/s Alder springs	X		
WC 006.00	Whychus Creek	Rd 6360	X	X	X
WC 008.25	Whychus Creek	CRNG	X		
WC 009.00	Whychus Creek	Rim Rock Ranch	X	X	
WC 018.25	Whychus Creek	d/s end DBLT property	X	X	
WC 019.50	Whychus Creek	d/s Camp Polk Bridge	X	X	
WC 024.25	Whychus Creek	City Park gauge	X	X	X
WC 026.00	Whychus Creek	Rd 4606 footbridge	X	X	
WC 030.25	Whychus Creek	OWRD gauge	X	X	X
WC 038.00	Whychus Creek	Rd 1514	X	X	

The WQ Monitoring Program is conducted under a Quality Assurance Project Plan (QAPP) approved by ODEQ in 2002 (UDWC 2002). The UDWC updated and ODEQ reapproved the QAPP in 2006 and 2008 (UDWC 2006, UDWC 2008). Coordinated monitoring efforts are carried out according to standard methods and protocols that are summarized and referenced in the UDWC WQ Monitoring Program Standard Operating Procedures (UDWC 2009).

The first section of this report evaluates temperature, dissolved oxygen, and pH data in Whychus Creek against state standards. The second section of this report evaluates trends in temperature related to stream flow restoration. The final section of this report identifies the stream flow necessary to achieve state temperature standards in Whychus Creek. Together, these components of the report will help restoration partners to develop more effective restoration projects in Whyhcus Creek

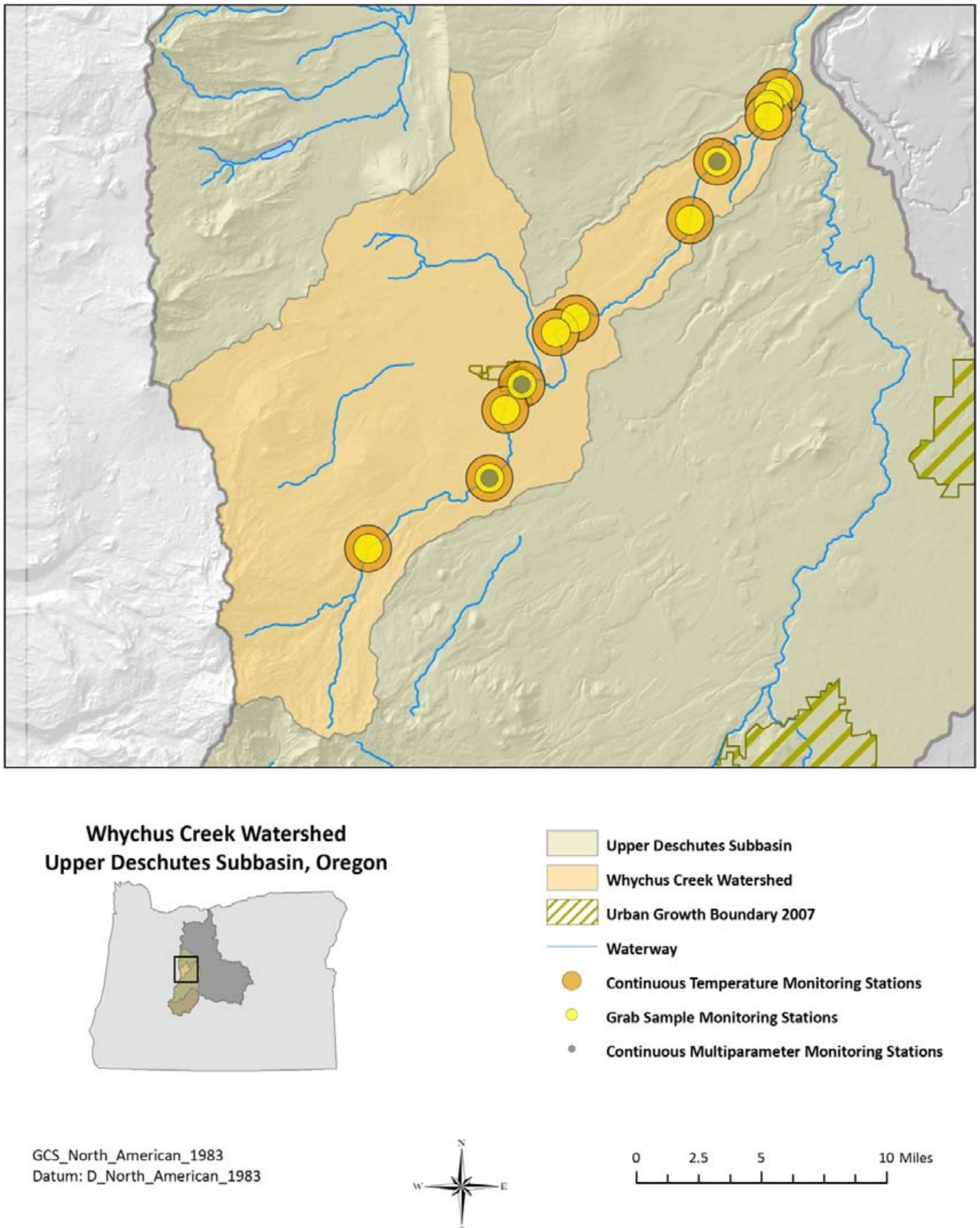

Figure 5.
The Water Quality Monitoring Program collects continuous temperature, grap, and continuous multiparamater samples at 13 stations throughout Whychus Creek

Water Quality Status

Introduction

This section of the report evalutes the status of water quality in Whychus Creek in relation to state temperature standards. It evaluates temperature, dissolved oxygen, and pH across the creek. Oregon's most recent 303(d) list, approved by the EPA in 2007, identifies Whychus Creek as not meeting state temperature standards for salmon and trout rearing and migration (Table 1). The list includes dissolved oxygen and pH as not having enough data for evaluation.

Temperature

The growth and survival of aquatic organisms is affected by the surrounding water temperature. Water temperature naturally fluctuates on both a daily and seasonal basis. Daily fluctuations are usually the result of the continuous changes in solar radiation and air temperatures. Seasonal fluctuations are a response to changes in climate, solar aspect, and to variable amounts of stream flows from snowmelt and precipitation. Water temperatures naturally increase as water flows downstream and water temperatures can decrease as a result of groundwater inflows (springs) or the inflow of cooler tributaries.

Oregon has set temperature standards to protect fish and aquatic life (ODEQ 2009). Oregon's temperature standards include a number of different provisions, including biologically based numeric criteria which are designed to protect different salmonid life cycle stages. The criterion which currently applies to Whychus Creek can be summarized as follows:

- *Salmon and trout rearing and migration* temperatures are not to exceed a seven day moving average maximum (7DMAX) temperature of 18 °C (64 °F). This standard applies all year.

The state also has a biologically based numeric temperature criterion designed to protect salmon and steelhead spawning use:

- The seven-day-average maximum temperature of a stream identified as having salmon and steelhead spawning use… may not exceed 13 °C (55.4 °F).

Whychus Creek is protected for salmon and trout rearing and migration and is listed for not meeting this temperature standard. Although steelhead trout were reintroduced into Whychus Creek as of 2007, there is no state standard set to protect steelhead spawning for Whychus Creek. Since steelhead were re-introduced into Whychus Creek in 2007, it is likely that the temperature standard will include a season for salmon and steelhead use in Whychus Creek at some point in the future. In order to better understand Whychus Creek temperatures as they relate to reintroduced steelhead trout populations, this analysis adopeted a temperature standard for steelhead trout from the state standard set for the Lower Deschutes River:

- Steelhead trout spawning temperatures are not to exceed a seven day moving average maximum (7DMAX) temperature of 13 °C (55 °F). This standard may apply January 1 – May 15.

Although it is not a standard, the State of Oregon 1992 – 1994 Water Quality Standards Review stated that lethal temperatures for salmon and trout are above 24 °C (75 ° F; ODEQ 1995). The UDWC applied this additional criterion in its analysis.

Dissolved Oxygen

A waterway naturally produces and consumes oxygen. The waterway produces through two processes; photosynthesis and aeration. Oxygen is consumed within the waterway when aquatic organisms degrade compounds and plant material. In a healthy waterway, a balance between consumers and producers exists and aquatic organisms acclimate to the daily and seasonal fluctuations in dissolved oxygen and percent saturation.

The concentration of dissolved oxygen within the waterway undergoes daily fluctuations as primary producers photosynthesize and aquatic organisms degrade compounds. During the day, aquatic plants utilize photosynthesis and produce oxygen. During the day and night, microbial actions that decompose organic and inorganic matter and consume oxygen. The balance between photosynthesis that produces oxygen and decomposition that consume oxygen affects the amount of dissolved oxygen levels in the waterway. The concentration of dissolved oxygen within the waterway also undergoes seasonal fluctuations. Warmer temperatures during summer months increase the rates of photosynthesis and decomposition. As plants die at the end of the season, decomposers consume oxygen to break down the organic plant compounds. This results in a seasonal fluctuation in dissolved oxygen concentrations.

Percent saturation is the amount of oxygen that can be held within the water. The percent saturation within the waterway is affected by temperature and altitude. Cold water holds more dissolved oxygen than warm water. Water at higher altitudes holds less dissolved oxygen than water at lower altitudes, because the degree of atmospheric pressure is less at higher altitudes.

Aquatic organisms are affected by the fluctuations in dissolved oxygen within the waterway. If oxygen is consumed at a faster rate than it is produced, dissolved oxygen levels decrease and aquatic organisms can be negatively affected. Salmon and trout, especially in their early life stages, are very susceptible to low dissolved oxygen concentrations. The state of Oregon's dissolved oxygen standard includes a number of different provisions, including biologically based numeric criteria which are designed to protect different salmonid life cycle stages. The criterion which currently applies to Whychus Creek can be summarized as follows:

- *Salmon and trout non-spawning* dissolved oxygen concentrations and percent saturations are not to drop below 8.0 mg/L as an absolute minimum or 90% saturation in areas designated as supporting cold-water aquatic life. According to DEQ's 2002/2004 Water Quality Assessment, this designation applies from river mile 13.3 to the headwaters of Whychus Creek. This criterion applies all year round.

- *Salmon and trout non-spawning* dissolved oxygen concentrations are not to drop below 6.5 mg/L as an absolute minimum in areas designated as supporting cool-water aquatic life. According to DEQ's 2002/2004 Water Quality Assessment, this designation applies from the mouth to river mile 13.3 on Whychus Creek. This criterion applies all year round.

- *Salmon and trout spawning* dissolved oxygen concentrations and percent saturations are not to drop below 11.0 mg/L and 95% saturation. This criterion applies January 1 – May 15.

The state of Oregon Clean Water Act Section 303(d) list categorizes dissolved oxygen as having insufficient data for assessment in Whychus Creek. This report evaluates data collected between 2006-2008 against state standards to fill this assessment gap.

pH

The measure of pH is the hydrogen ion concentration of a solution using a logarithmic scale of 0.0 to 14.0. Low pH of less than 7.0 is considered acidic while high pH greater than 7.0 is alkaline. Water pH can have both direct and indirect effects on the aquatic ecosystem. In general, aquatic organisms do best in a water pH range of 6.5 to 8.5. Water pH can impact both aquatic insect populations and salmon and trout by affecting egg development, egg hatching, and embryo development. Extreme pH levels can affect the availability and toxicity of certain pollutants such as heavy metals and ammonia, which can negatively affect fish.

Like temperature and dissolved oxygen, pH naturally varies both daily and seasonally. Daily fluctuations in pH are usually the result of the photosynthetic activity of aquatic plants. During the day when aquatic plants uptake carbon dioxide and release oxygen, the water becomes more alkaline; pH values increase. Conversely, during the night when plants are not actively photosynthesizing yet other aquatic organisms are producing carbon dioxide via respiration, the water becomes more acidic; pH values decrease. The daily peak in pH values occurs around mid to late afternoon while the lowest values occur just before sunrise. Seasonal fluctuations in pH are also due to the differences in the photosynthetic activity of aquatic plants, and fluctuations are affected by increased primary production during the summer and decreased primary production during the winter. A natural factor that affects pH values is the chemistry of the local substrate. The volcanic soils of the upper Deschutes Basin can drive pH to be more acidic.

To protect the fish and aquatic life, the state of Oregon has established the following pH standard for streams and rivers in the Deschutes Basin:

- *Deschutes Basin streams (except Cascade lakes)* pH values may not fall outside of the range 6.5 – 8.5. This standard applies over two seasons: fall/winter/spring October 1 – May 31 and summer June 1 – September 30.

The state of Oregon Water Quality Assessment categorizes pH as having insufficient data for assessment on Whychus Creek . This report evaluates pH data collected in 2006 through 2008 against state standards to fill this assessment gap.

Methods

UDWC and its partners collected continuous temperature data at 13 locations between river mile 38 and river mile 0.25 (Table 2). The WQ Monitoring Program compiled data collected between 1995 and 2008. Data collection and compilation followed ODEQ approved protocols (UDWC 2008).

The WQ Monitoring Program expressed continuous temperature as the seven day moving average maximum (7DMAX). The WQ Monitoring Program evaluated seven day moving average maximum (7DMAX) temperatures in Whychus Creek in relation to state standards for salmonids. Data were evaluated according to the methods described in the state of Oregon *Assessment Methodology for Oregon's 2004/2006 Integrated Report on Water Quality Status* (ODEQ 2006).

The WQ Monitoring Program collected and compiled continuous and grab sample dissolved oxygen data from locations along Whychus Creek (Table 2). Data were collected between 2006 – 2008. These data were analyzed according to the state assessment methodology of the Clean Water Act Section 303(d) report. This methodology requires at least five measurements collected on different days in one season. At least 10% of the samples collected must not meet the standard in order for the waterway to be considered impaired (ODEQ 2006). The WQ Monitoring Program's dissolved oxygen data collection and compilation follow ODEQ approved protocols (UDWC 2008).

The WQ Monitoring Program collected pH data from 11 sites along Whychus Creek (Table 2). They WQMonitoring Program compiled and evaluated continuous and grab sample pH data collected from 2006 through 2008 along Whychus Creek. The WQ Monitoring Program's pH data collection, compilation, and assessment follow ODEQ approved protocols (UDWC 2008).

Results

Temparature

7DMAX temperatures exceeded the state's 18 °C standard for salmon and trout rearing and migration during all years except 1997 (Figure 6). Temperatures exceeded this standard between the TSID diversion (river mile 27) and the Alder Springs Complex (river mile 3; Figure 7, Figure 8). In some years temperatures exceeded the lethal temperature for redband and steelhead trout (24 °C, ODEQ 1995).

Plotting longitudinal location against the 7DMAX temperature of the hottest water day of a year provides the longitudinal temperature profile of a river. The hottest water day during the salmon and trout rearing and migration time period for Whychus Creek occurred on July 7, 2007. 7DMAX temperatures on this day exceeded state temperature standards for salmon and trout rearing and migration (Figure 9). In the Middle Reach of Whychus Creek, 7DMAX temperatures climbed to nearly 26 °C and in the Lower Reach of Whychus Creek temperatures climb to 22 °C.

Both natural and anthropogenic factors drive temperature changes along Whychus Creek. The average rate of temperature change along Whychus Creek is 0.1 °C per mile (Figure 12). Natural drivers of temperature change are demonstrated by the rapid rate of cooling downstream of the springs originating from Camp Polk Spring Complex and Alder Spring Complex that equals up to a -2.4 °C per mile temperature reduction. Anthropogenic drivers of temperature change are demonstrated by the high rates of temperature warming downstream of the Three Sisters Irrigation Diversion and through the straight channel at Camp Polk Reserve. At the downstream end of the Middle Reach of Whychus Creek, temperatures are still increasing despite temperatures already rising to approximately 25 °C.

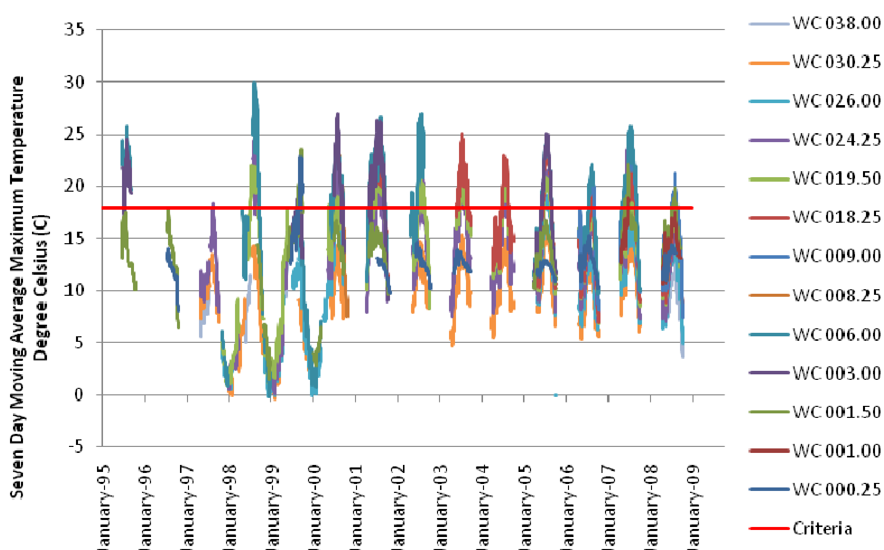

Figure 6.
7DMAX temperatures in Whychus Creek exceeded state standards for salmon and trout rearing and migration (18 °C) during all years except 1997.

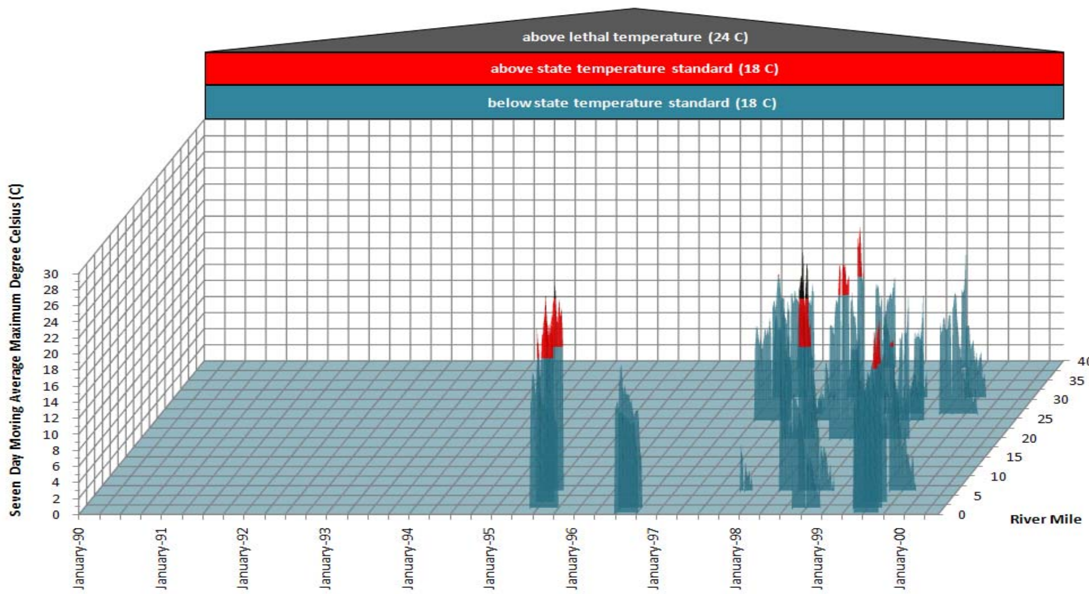

Figure 7.
7DMAX temperatures in Whychus Creek varied by year and by location between 1995 and 1999.

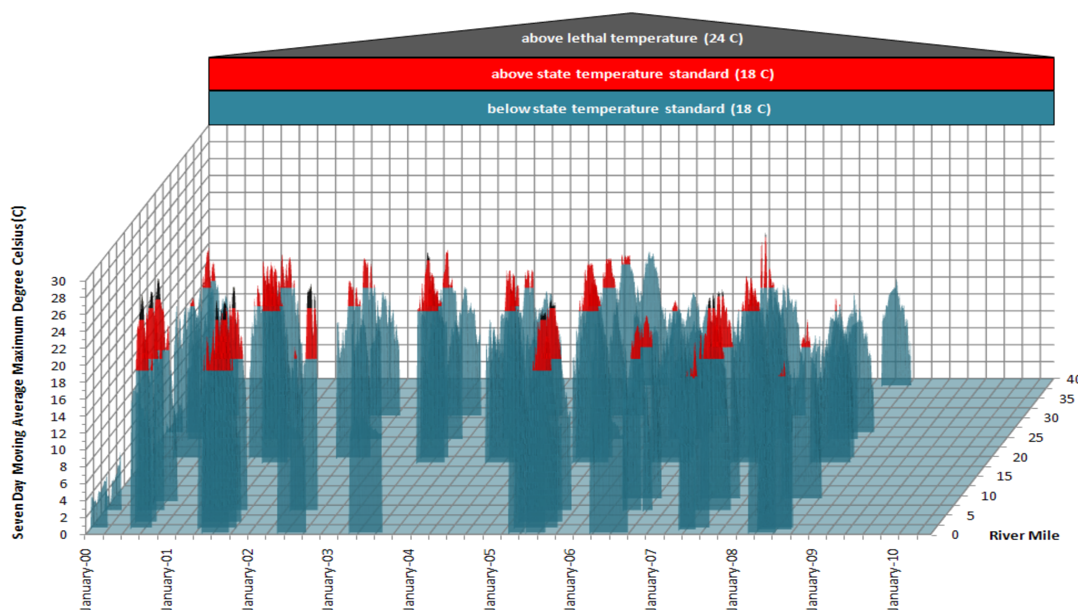

Figure 8.
7DMAX temperatures in Whychus Creek varied by year and by location between 2000 and 2008.

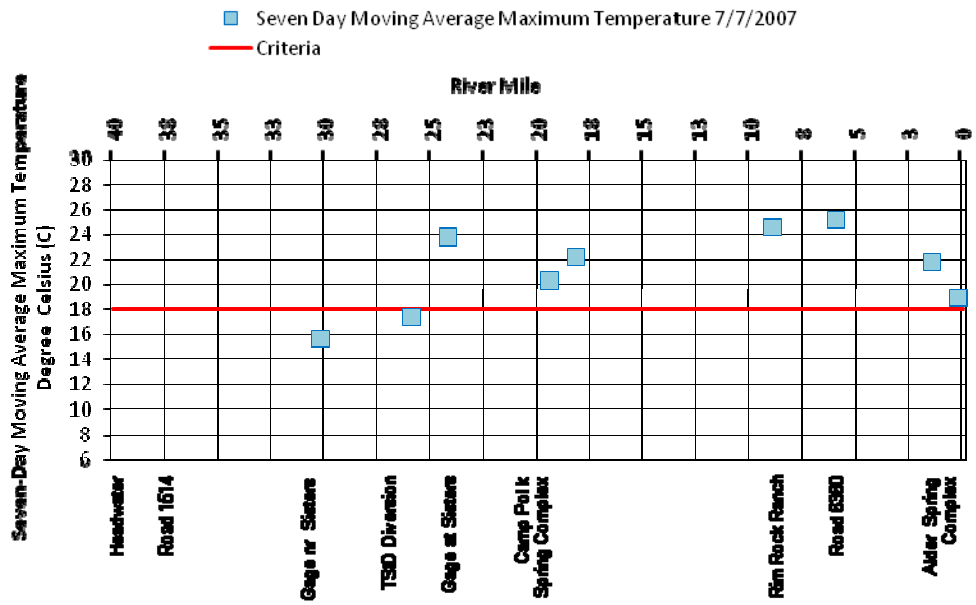

Figure 9.
The hottest day in 2007 and 2008 occurred on July 7, 2007. This longitudinal temperature profile reveals areas of cooling and warming along the creek. 7DMAX temperatures exceeded state standards for salmon and trout rearing and migration at most monitoring sites.

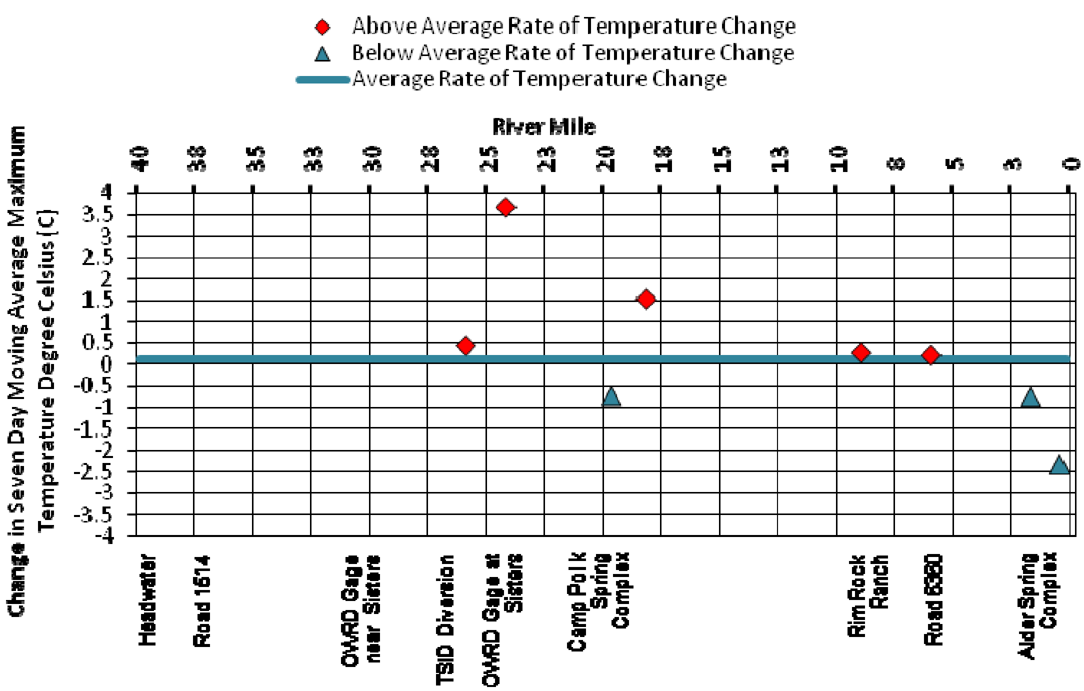

Figure 10.
The hottest day in 2007 and 2008 occurred on July 7, 2007. Longitudinal changes in 7DMAX temperatures on this day reveal rates of temperature change in Whychus Creek. Both anthropogenic and natural drivers contribute to these changes.

The WQ Monitoring Program evaluated temperatures during the steelhead spawning periods against the potential state standard for steelhead spawning. 7DMAX emperatures exceeded the standard for steelhead spawning (13 °C) during most years (Figure 11). There is no evidence that temperatures exceed the lethal temperature of 24°C during steelhead spawning.

The hottest water day during the steelhead spawning season in 2007 and 2008 occurred on May 7, 2007. Temperatures exceeded potential state standards on this day (Figure 12). In the Middle Reach of Whychus Creek, temperatures climbed to above 18 °C. In in the Lower Reach of Whychus Creek downstream of Alder Springs temperatures climbed above 14 °C.

The average rate of temperature change on May 7, 2007 along Whychus Creek was 0.1 °C per mile (Figure 13). Natural drivers of temperature change are demonstrated by the rapid rate of cooling downstream of the springs originating from Camp Polk Spring Complex and Alder Spring Complex that equals up to a -0.8 °C per mile temperature reduction. Anthropogenic drivers of temperature change are demonstrated by the high rates of temperature warming downstream of the Three Sisters Irrigation Diversion and through the straight channel at Camp Polk Reserve. At the downstream end of the Middle Reach of Whychus Creek, temperatures are still increasing as despite temperatures already rising above 18 °C.

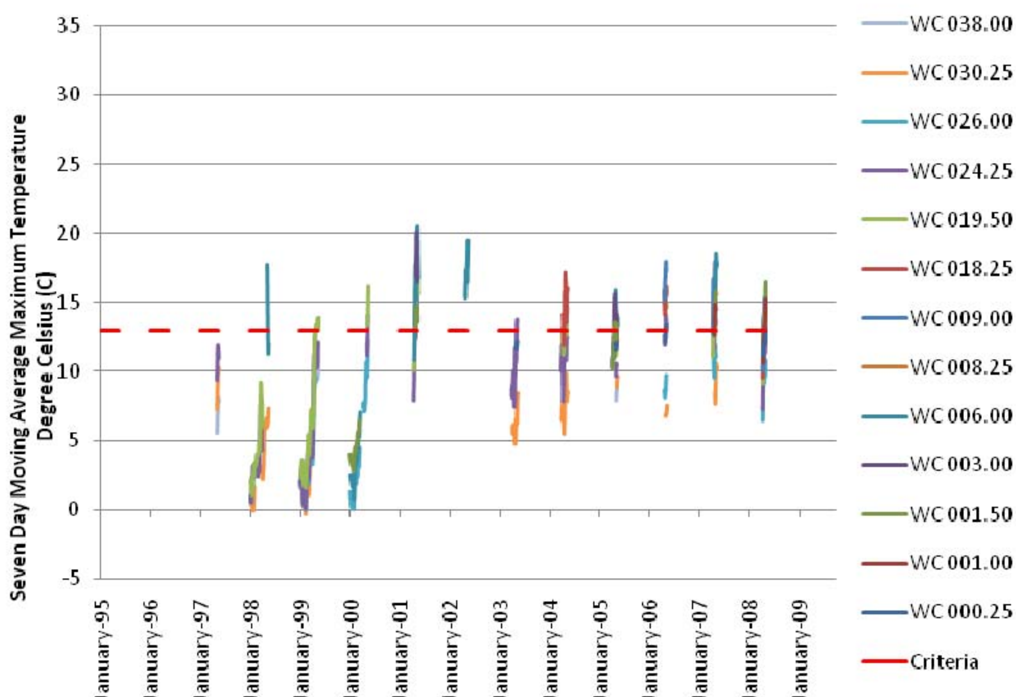

Figure 11.
7DMAX temperatures in Whychus Creek exceeded state standards for steelhead spawning (13 °C) during all years except 1997.

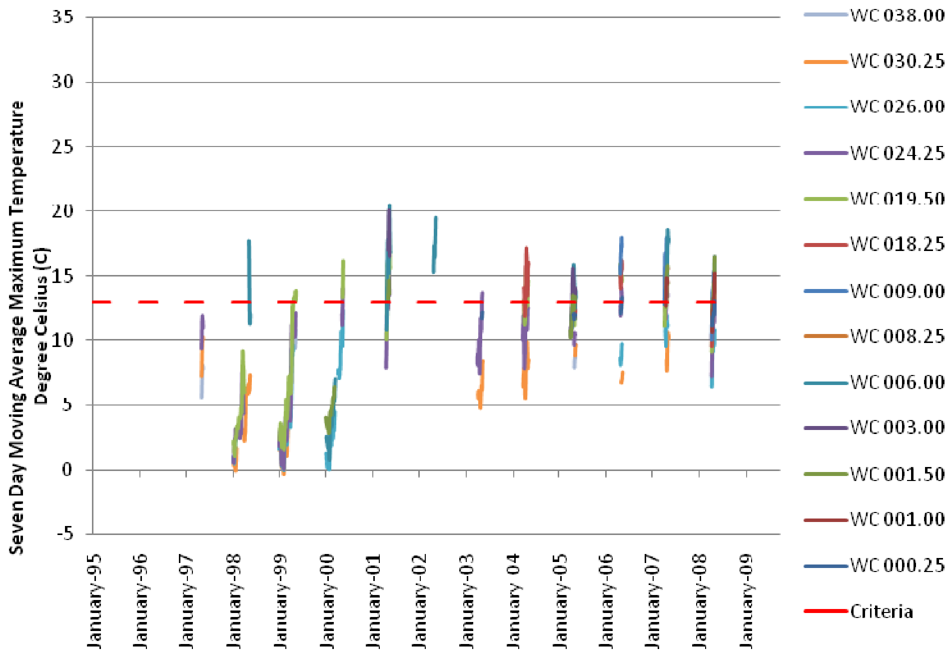

Figure 12.
The hottest day in 2007 and 2008 during potential steelhead spawning periods occurred on May 7, 2007. This longitudinal temperature profile reveals areas of cooling and warming along the creek. 7DMAX temperatures exceeded state standards for steelhead spawning at most monitoring sites.

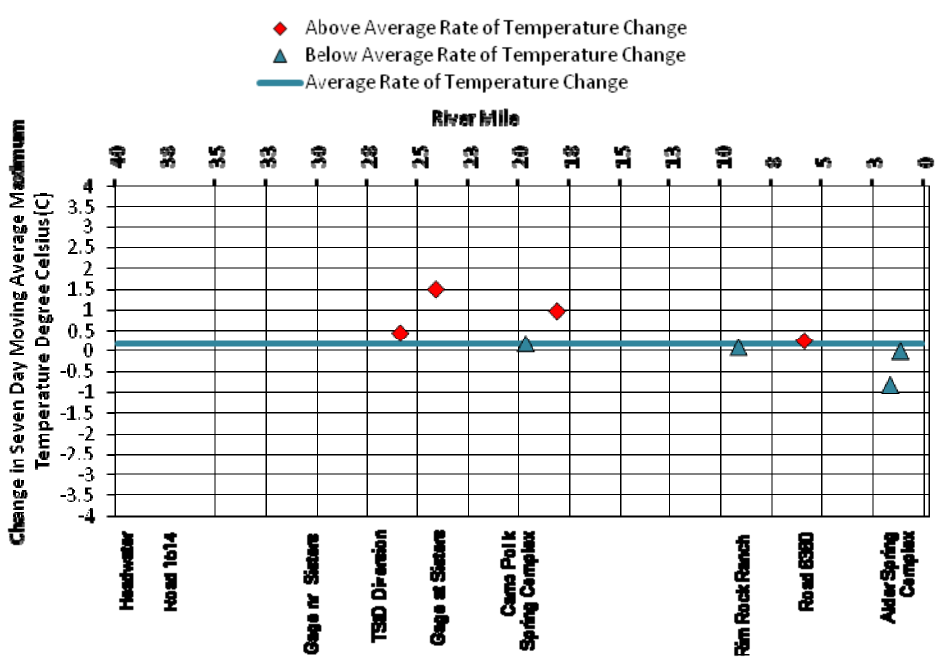

Figure 13.
The hottest day in 2007 and 2008 during potential steelhead spawning periods occurred on May 7, 2007. Longitudinal changes in 7DMAX temperatures on this day reveal rates of temperature change in Whychus Creek. Both anthropogenic and natural drivers contribute to these changes.

Dissolved Oxygen

The state of Oregon dissolved oxygen standard is designated to protect the minimum dissolved oxygen needed for salmon and trout spawning (11 mg/L) and non-spawning (8.0 mg/L) seasons. Monitoring data demonstrates that Whychus Creek meets state dissolved oxygen standards during the non-spawning season; there are no occurrences when dissolved oxygen data fall below standards (Figure 14, Figure 15).

Three of nineteen samples collected during the spawning period expressed dissolved oxygen concentrations that were below the spawning standard (Figure 16). All dissolved oxygen concentrations below the state standard have percent saturations that range between 99 – 104 % dissolved oxygen saturation. The high saturations mean that this water body maintains the maximum amount of oxygen at the given temperature and altitude. Data reflects only two different days of sampling in 2007 and 2008 so there is still insufficient data to evaluate the status of Whychus Creek dissolved oxygen concentrations during the spawning season

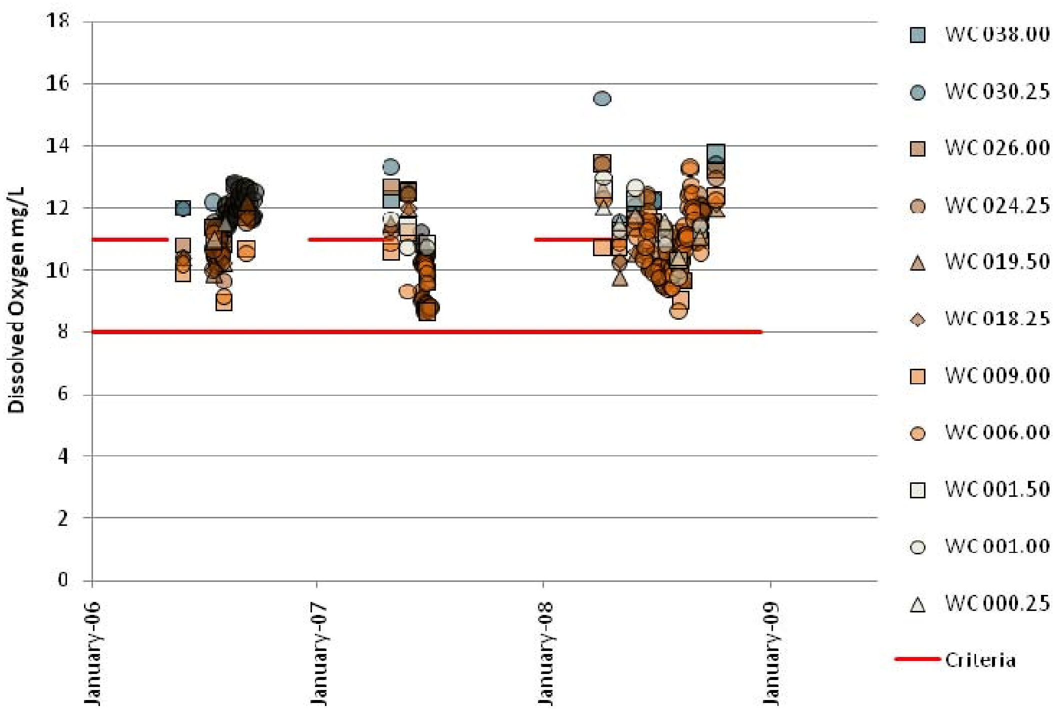

Figure 14.
The state of Oregon dissolved oxygen standard is designated to protect the minimum dissolved oxygen needed for salmon and trout spawning (11 mg/L) and non-spawning (8.0 mg/L) seasons (solid red line). There are no occurrences when the daily mean dissolved oxygen data falls below the state standard set to protect salmonids during the non-spawning season.

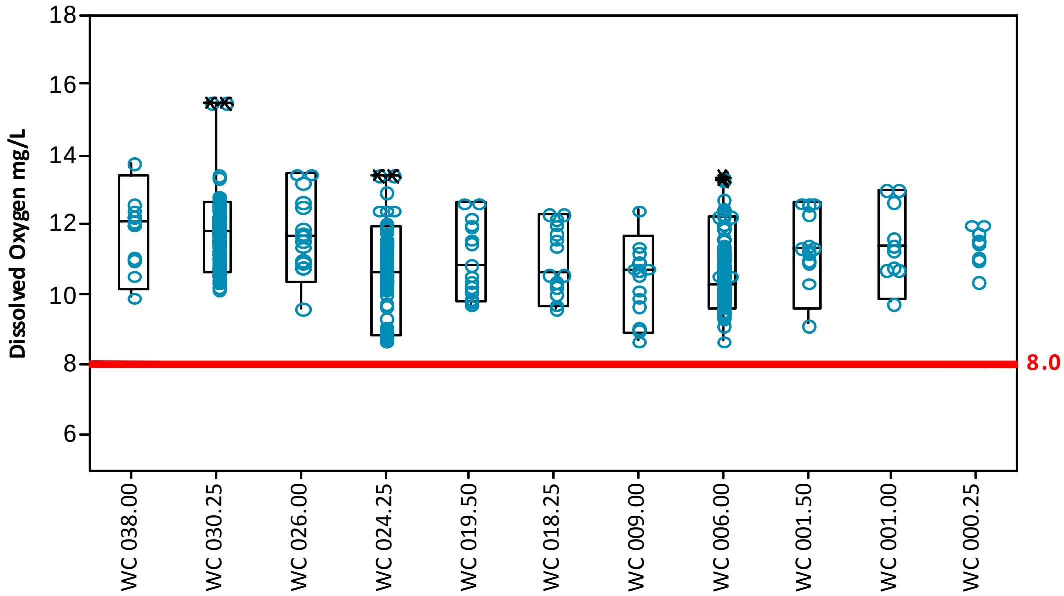

Figure 15.
Continuous multiparameter and grab samples show that Whychus Creek meets state dissolved oxygen standards set to protect fish during the non-spawning season.

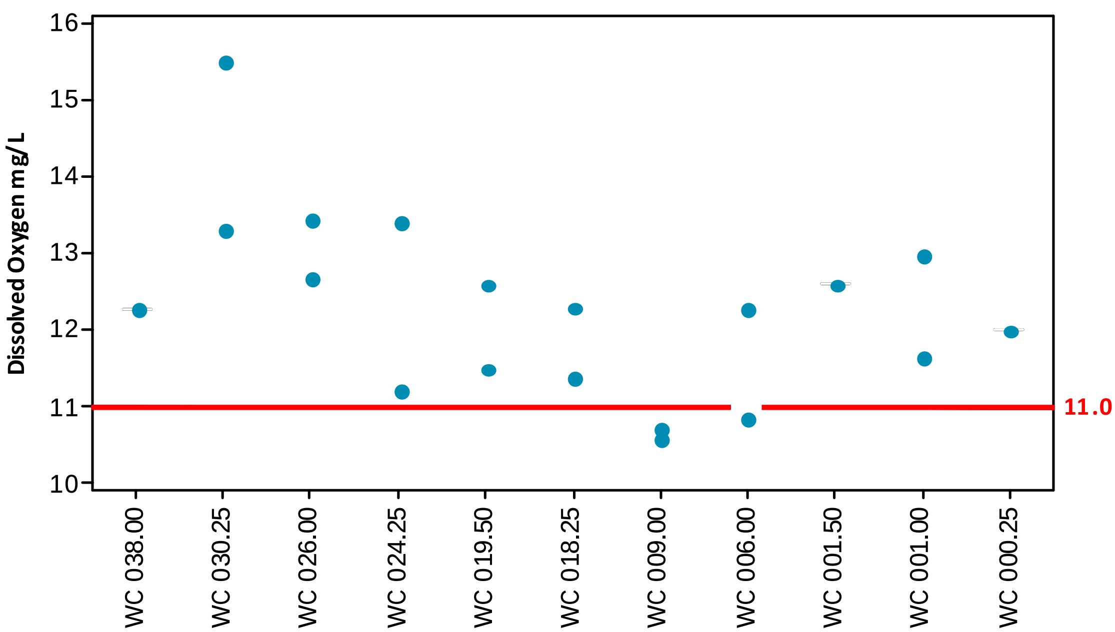

Figure 16.
Out of the nineteen dissolved oxygen samples collected during the 2006-2008 spawning period, three were below the spawning criteria of 11.0 mg/L dissolved oxygen from 2006 – 2008.

pH

Data reflects multiple days of sampling during 2006, 2007, and 2008. Whychus Creek pH values during the fall/winter/spring season met state maximum and minimum pH standards (Figure 17). Whychus Creek pH values during the summer season also met state maximum and minimum pH standards. There is only one occurrence when pH data exceeded the state maximum pH standard and it occurred downstream from Camp Polk.

The minimum pH values measured above river mile 26 at times dropped below state minimum pH standards and there is a general downstream increasing pH trend (analysis not shown). The acidity noted higher in Whychus Creek may be due to the volcanic soils, which can drive pH to be more acidic. This natural influence on pH is reflected in the state standard for Cascade Lakes above 3000 feet being lowered from a minimum pH value of 6.5 to a minimum pH value of 6.0.

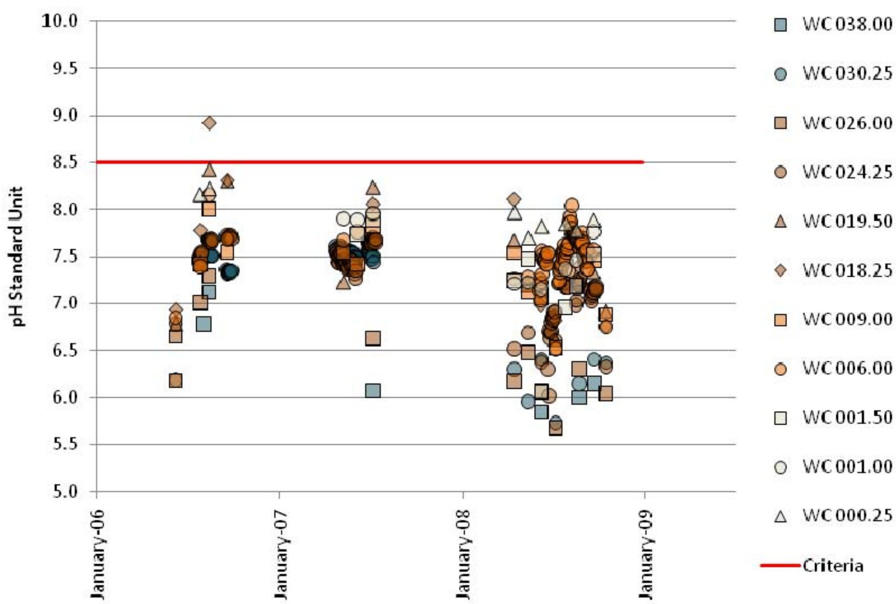

Figure 17.
Data reflects multiple days ofcontinous multiparameter and grab sampling during 2006, 2007, and 2008. It demonstrates that Whychus Creek pH values during the fall/winter/spring and summer season meet state maximum pH criteria.

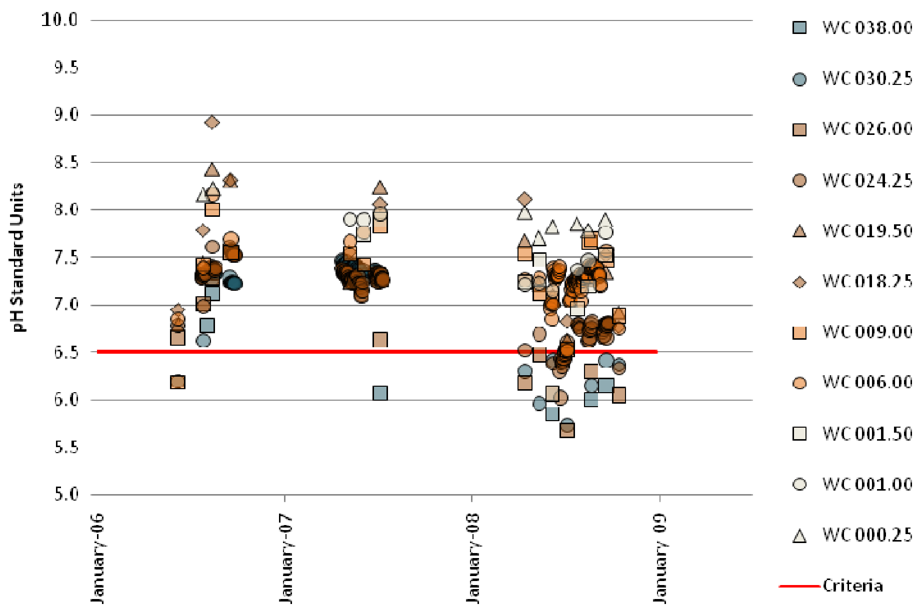

Figure 18.
Data reflects multiple days of continous multiparameter and grab sampling during 2006, 2007, and 2008. It demonstrates that Whychus Creek pH occasionally drops below state minimum pH criteria.

Discussion

Temperatures in Whychus Creek exceeded state standards for salmon and trout rearing and migration in most years. These standards currently apply in Whychus Creek. Temperatures also exceeded state standards for steelhead spawning during most years. These standards do not yet apply in Whychus Creek. Rates of temperature change in the creek suggest that both natural and anthropogenic drivers affect temperature in the creek. Restoration partners may explore addressing these drivers in reaches with relatively high rates of temperature change.

Dissolved oxygen in Whychus Creek meets criteria for salmon and trout rearing and migration. Although dissolved oxygen did not always meet spawning criteria, there is still insufficient data to evaluate the status of Whychus Creek dissolved oxygen concentrations during the spawning season. However, the UDWC does not believe that dissolved oxygen currently limits fish populations in Whychus Creek. The UDWC does not prioritize future dissolved oxgen monitoring based on this data.

Whychus Creek pH values met state standards based on 2006, 2007, and 2008 data during the fall, winter, and spring. Whychus Creek pH values measured above the City of Sisters fell below state minimum standards during summer. The UDWC believes that the natural influence of volcanic soils causes these low pH values. The UDWC does not expect low pH values to limit ecological functions in Whychus Creek.

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Table 3. Whychus Creek Status Summary 2007 – 2008.

	Parameter	**Temperature**		**Dissolved Oxygen**		**pH**	
	Beneficial Use	Salmon & Trout Rearing & Migration	Salmon & Steelhead Spawning	Salmon & Steelhead Non-Spawning	Salmon & Steelhead 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 @ 95% Sat	11.0 mg/L @ 90% Sat	6.5 - 8.5 SU	6.5 - 8.5 SU
ODEQ Reach	0 - 40.3	Consistent with Section 303(d) Listing; Standard Not Met	Potential Standard Not Met	Not Applicable	Insufficient Data for Section 303(d) Assessment	Not Consistent with Section 303(d) Listing: Standard Met	Not Consistent with Section 303(d) Listing: Standard Met
	1 - 13.3	Not Applicable	Not Applicable	Not Consistent with Section 303(d) Listing: Standard Met	Not Applicable	Not Applicable	Not Applicable
	13.3 - 40.3	Not Applicable	Not Applicable	Not Consistent with Section 303(d) Listing: Standard Met	Not Applicable	Not Applicable	Not Applicable

Stream Flow Restoration and Temperature Trends

Introduction

This section evalutes changes in stream temperature associated with stream flow restoration. Restoration partners expect that stream flow restoration will affect stream temperatures on Whychus Creek. Other restoration actions may affect temperature in the future but they have not been implemented at the scale necessary to cause reach level changes in the system.

Methods

Restoration partners selected July as a study period based on existing temperature analyses; the hottest water day of the year typically occurs during July. The WQ Monitoring Program defined restoration and reference reaches in Whychus Creek based on expected stream flow and temperature relationships. The WQ Monitoring Program identified a Control Reach and three Restoration Reaches, as appear below.

- Reference Reach (WC 038.00 – WC 030.25): Control to measure impact
- Restoration Reach One (WC 030.25 – WC 024.25): Local effect of stream flow restoration
- Restoration Reach Two (WC 030.25 – WC 006.00): Longitudinal effect of stream flow restoration
- Restoration Reach Three (WC 030.25 – WC 000.25): Effect downstream of Alder Springs Complex

The WQ Monitoring Program developed four hypotheses related to stream temperature in each of these reaches (Table 4). The UDWC compared changes in temperature within the Reference Reach to changes in temperatures within Restoration Reaches One through Three to evaluate these hypotheses. Data from five monitoring stations were used to evaluate trends (Table 5).

Table 4. Temperature Trend Hypotheses.

Null:	The mean of the Restoration Reach and Reference Reach daily median temperatures during July are equal.
H1:	The mean of the Restoration Reach and Reference Reach daily median temperatures during July are statistically different.
H2:	The mean of the Restoration Reach daily median temperatures during July is significantly less than the mean of the Reference Reach; Restoration Reach is relatively cooler.
H3:	The mean of the Restoration Reach daily median temperatures during July is significantly more than the mean of the Reference Reach; Restoration Reach is relatively warmer.

Table 5. July Temperature Monitoring Stations 1995 – 2009.

Station ID	Description	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
WC 000.25	Mouth		X			X		X	X	X	X	X	X	X	X	X
WC 001.00	Diamondback meadow	X												X	X	
WC 001.50	d/s Alder springs		X			X	X	X				X		X	X	
WC 003.00	u/s Alder springs	X			X	X	X	X				X				
WC 006.00	Rd 6360	X					X	X	X			X	X	X		X
WC 008.25	CRNG						X									
WC 009.00	Rim Rock Ranch												X	X	X	
WC 018.25	d/s end DBLT property							X		X	X	X	X	X	X	X
WC 019.50	d/s Camp Polk Bridge on DBLT property				X		X	X	X	X	X	X	X	X	X	X
WC 024.25	City Park gauge						X	X	X	X	X	X	X	X	X	X
WC 026.00	Rd 4606 footbridge					X	X						X	X	X	
WC 030.25	OWRD gauge						X		X	X	X	X	X	X		X
WC 038.00	Rd 1514				X				X				X		X	X

X	Reference Reach
X	Restoration Reach
X	Data Collected

The WQ Monitoring Program used a statistical analysis that backs out seasonal and climate drivers of water quality to detect changes in the stream temperature that can be attributed to stream flow restoration. Steps 1-7 below provide a simplified description of the steps in analyses. For a more detailed description of the BACI design reference the *Encyclopedia of Environmetrics* (Smith 2002). For a more detailed description of the Student's t-test reference *Statistical Methods in Water Resources* (Helsel and Hirsch 1991).

The Monitoring Program followed the following steps to evaluate whether restoration actions were changing water quality in the creek:

1. Establish control (upstream) and impact (downstream) stations for the Reference Reach and the Restoration Reach.
2. Calculate by month the daily median temperature for each station.
3. Calculate BACI for the Reference Reach and BACI for the Restoration Reach.

$$\text{BACI} = (B - A)\ \text{control station} - (B - A)\ \text{impact station}$$

4. Use a probability plot to test the normal distribution of the BACI results and if necessary remove any outliers at 90%.
5. Create a Paired BACI interval plot comparing BACI of the Reference Reach to the BACI of the Restoration Reach.

6. Perform Student's t-test (aka: two sample t-test) to statistically evaluate differences in the mean BACI of the daily median temperature for the Reference Reach and the Restoration Reach.
7. Evaluate hypotheses.

Data collected during 2002 and 2006 were used to evaluate changes in temperature expected with stream flow restoration (Figure 19). The Reference Reach is bracketed by the upstream control station (WC 038.00) and the downstream impact station (WC 030.25) and is designated due to the natural flow and temperature conditions above the Three Sisters Irrigation District (TSID) diversion. The Restoration Reaches are designated by the upstream control station (WC 030.25) and the downstream impact stations (WC 024.25, WC 006.00, and WC 000.25).

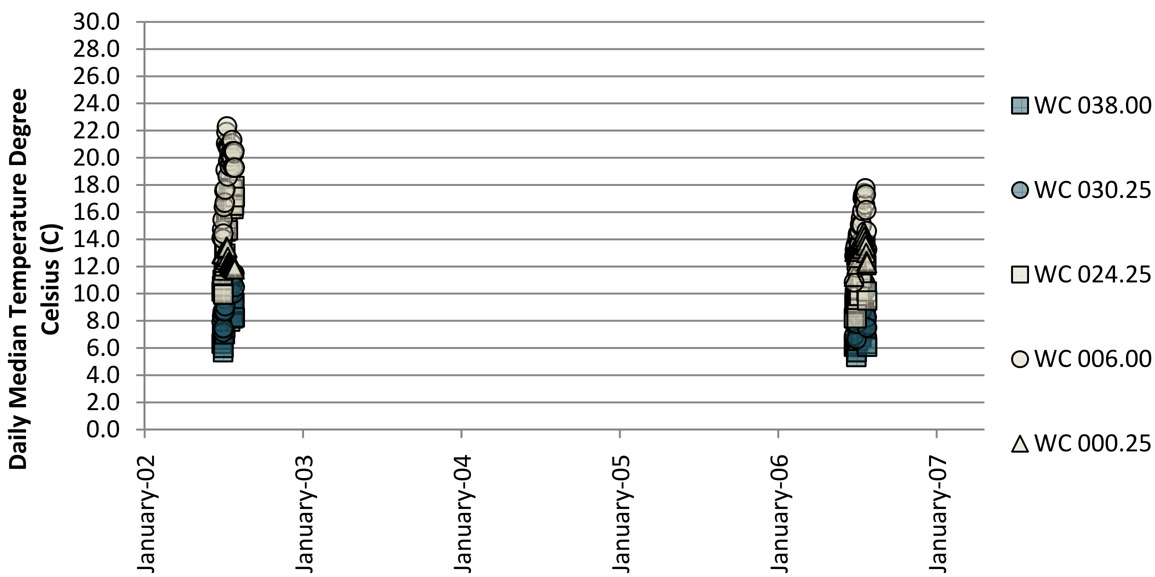

Figure 19.
Daily median temperatures in Whychus Creek during July 2002 and July 2006. The five monitoring stations included here define the Reference Reach and three Restoration Reaches used for evaluating temperature changes in the creek.

The WQ Monitoring Program selected July median temparatures for this evaluation. Using a limited time period within each year removes seasonal variations from the statistical analysis (Helsel and Hirsch 1991). July represents the hottest time period for Whychus Creek (UDWC 2003, UDWC 2005, UDWC 2008). Daily median temperatures are utilized because this statistic is expected to be sensitive to change due to stream flow restoration. The 7DMAX temperature statistic used by ODEQ in their stream temperature standards may not express any changes early during in-stream flow restoration.

A probability plot and a hypothesis test confirm that the Reference Reach and Restoration Reach BACI of daily median temperatures have a normal distribution (Figure 20, Table 6). Since the data are normally distributed they can be used in the Student's t-test to evaluate changes between reaches. The Student's t-test was used to evaluate the direction of relative change in temperature for the Restoration Reach compared to the Reference Reaches (Helsel and Hirsch 1991, NIST 2009).

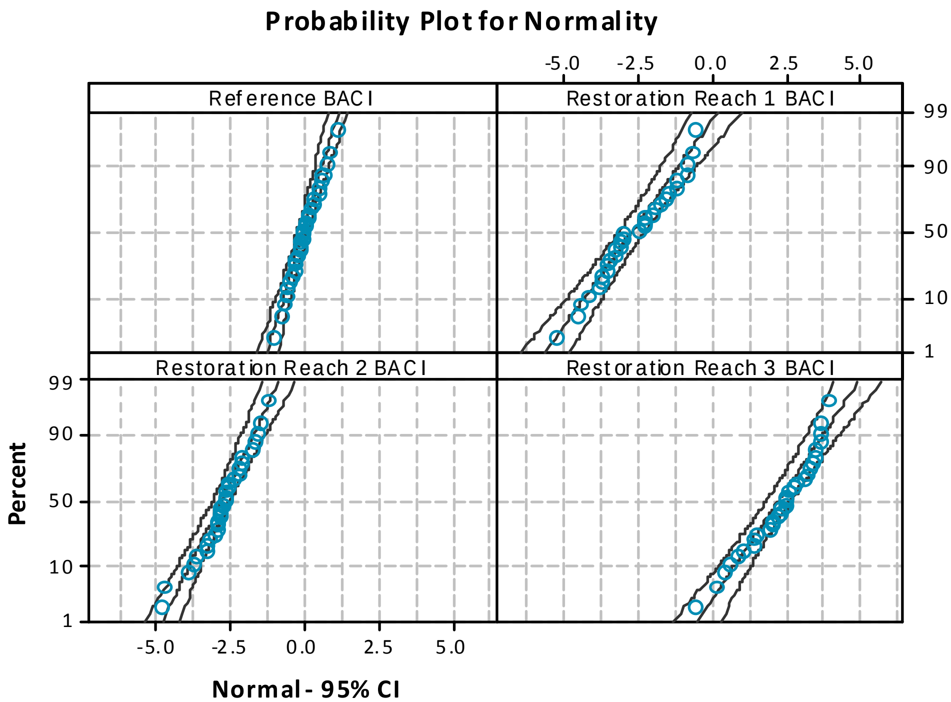

Figure 20.
A probability plot demonstrates the spread of data around its mean value and is used to evaluate the normality of the data. The Reference Reach and Restoration Reach BACI of daily median temperatures have a normal distribution within a 95% Confidence Interval.

Table 6. Probability Test for Normality.

Reach	Count	Mean	StDev	p-value	α-value	Result	Distribution
Reference Reach BACI	31	-0.09	0.53	0.94	0.05	P>α	normal
Restoration Reach One BACI	31	-2.78	1.26	0.55	0.05	P>α	normal
Restoration Reach Two BACI	31	-2.86	0.85	0.32	0.05	P>α	normal
Restoration Reach Three BACI	31	2.21	1.18	0.18	0.05	P>α	normal

p-value > α-value => Normal Distribution

Results

An interval plot provides the results of pairing the Reference Reach BACI to the Restoration Reaches One through Three BACI (Figure 21). The Paired BACI for 2002/2006 do not approximate zero and the 95% Confidence Intervals do not overlap zero, indicating that the Restoration Reach is behaving different than the Reference Reach. Daily median temperatures are changing differently within the reaches. H1 was selected with a 99 % Confidence Level (Table 7). The mean of the Restoration Reach and Reference Reach daily median temperatures during July are statistically different.

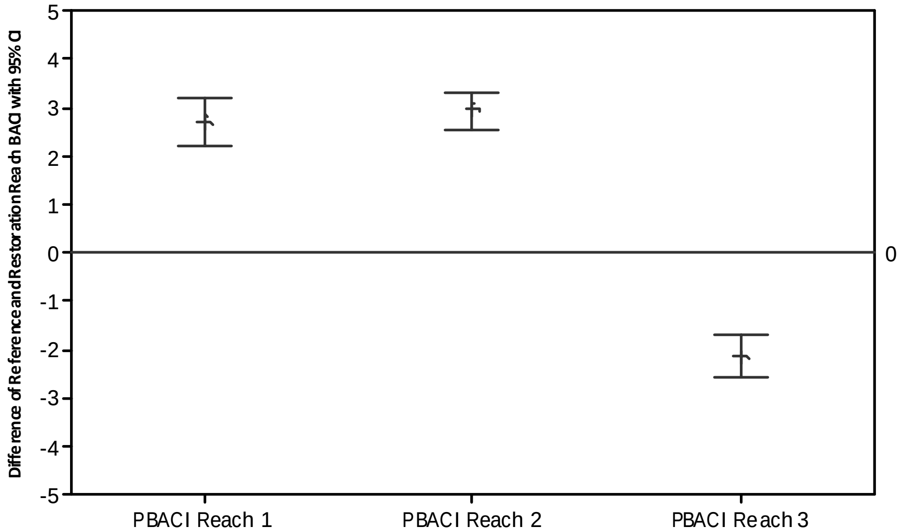

Figure 21.
The Paired BACI for 2002/2006 do not approximate zero and the 95% Confidence Intervals do not overlap zero, indicating that the Restoration Reach is behaving differently than the Reference Reach.

Table 7. Student's t-test of Null Hypothesis.

				95% CI		
PBACI	P-value	α-value	Result	5%	Difference in Means	95%
Reference Reach & Restoration Reach One	0.00	0.01	reject null, accept H1	2.205	2.69	3.174
Reference Reach & Restoration Reach Two	0.00	0.01	reject null, accept H1	2.42	2.772	3.123
Reference Reach & Restoration Reach Three	0.00	0.01	reject null, accept H1	-2.752	-2.294	-1.836

The Student's t-test is used to evaluate the direction of relative change in temperature for the Restoration Reach compared to the Reference Reach. Paired Reference and Restoration BACI analysis indicate that the mean of the Restoration Reach One and Restoration Reach Two daily median temperatures during July are significantly less than the mean of the Reference Reach daily median temperature. Restoration Reaches One and Two are relatively cooler with a 99% Confidence Level, supporting H2 (Table 8). Paired Reference and Restoration BACI analysis indicate that the mean of the Restoration Reach Three daily median temperatures during July are significantly more than the mean of the Reference Reach. Restoration Reach Three is relatively warmer with a 99% Confidence Level, supporting H3 (Table 8).

Table 8. Student's t-test of Alternative Hypotheses**.**

PBACI	df	T-value	Tα	Result
Reference Reach & Restoration Reach One	41	7.66	2.42	H2
Reference Reach & Restoration Reach Two	52	10.89	2.42	H2
Reference Reach & Restoration Reach Three	42	-13.39	2.42	H3

Discussion

The BACI analysis supports the assertion that stream flow restoration has affected temperatures in Whychus Creek. Stream temperatures decreased in Restoration Reach One, which extends for 6 miles downstream from the TSID diversion, relative to stream temperatures in the Reference Reach. Stream temperatures also decreased in Restoration Reach Two, which extends for 24 miles downstream from the TSID diversion, relative to stream temperatures in the Reference Reach. These differences are not due to climate variation but rather due to local and longitudinal affects of stream flow restoration. Stream temperatures increased in Restoration Reach Three, which extents from the TSID diversion to below the Alder Springs Complex, relative to stream temperatures in the Reference Reach. This difference is not due to climate variation but rather due to the affects of stream flow restoration increasing flows in the reach below the Alder Spring Complex. Increased volumes of relatively warm water have decreased the cooling affects of the Alder Spring Complex on Whychus Creek. Continued monitoring of these

Stream flow Targets Based on Temperature Responses

This report indentifies the stream flow necessary to meet state temperature standards in Whychus Creek. The DRC and its partners currently work towards ODFW's minimum stream flow targets in Whychus Creek. In 1990, Oregon Fish and Wildlife Department (OFWD) applied to the Oregon Water Resources Department (OWRD) for certified instream water rights in Whychus Creek (OWRD 1990, OWRD 2009). The certified stream flow rights are based upon OFWD minimum stream flow recommendations needed to support fish populations. Currently, the certified instream water rights for Whychus Creek are used by the DRC as the stream flow restoration target with a goal of improving water temperatures to support sustainable anadromous and resident O. mykiss populations. The DRC has applied a 20 cfs target from the headwaters of Whychus Creek to river mile 18 and a 33 cfs target from river mile 18 to the mouth. Preliminary results of temperature monitoring in Whychus Creek suggested that these targets may not provide for the water quality necessary to meet state temperature standards. This report applies statistical methods to evaluate the relationship between stream flow and stream temperature in Whychus Creek.

Methods

The WQ Monitoring Program applied a regression approach to define the relationship between stream flow and stream temperature at two locations along Whychus Creek. July 7DMAX temperatures were selected to develop this relationship for two reaons. First, using a limited time period within each year removes seasonal variations from the statistical analysis (Helsel and Hirsch 1991). Second, July represents the hottest time period for Whychus Creek (UDWC 2003, UDWC 2005, UDWC 2008).

The WQ Monitoring Program applied the following steps to define the relationship between stream flow and stream temperature:

1. Establish locations where stream flow and temperature relationships are of interest.
2. Compile seven day moving average maximum temperature and natural logarithm average daily flow (Ln QD) data for each location (from this point forward referred to as temperature and flow data).
3. From the temperature and flow data, isolate July data for all years of interest.

4. Match the daily temperature and flow data into temperature, flow pairs. Test to see if a simple plot of flow versus temperature with a regression results in an acceptable R^2 value, if not continue onto step 5.
5. Rank flows and assign temperatures to each rank (For example, at 4.1 Ln QD there may be 20 temperatures). Exclude outliers below 10% and above 90%.
6. Establish the temperature at each flow level.
7. Plot the flow Ln QD versus the mean temperature, add regression, and evaluate R^2 value. Assign a Confidence Level and calculate a Confidence Interval.
8. Use the derived regression equation to describe the relationship between flow and temperature at the selected location.

The developed equation describes the relationship between flow and temperature at (a) the selected location, (b) within the evaluated time period, and (c) within the original range of flows and temperatures. If all three criteria apply, then the results of the regression equation demonstrate to a level of confidence the relationship between flow and temperature. If not all apply, then the results of the regression equation are predictive and a greater Confidence Interval (known as a predictive interval) is expected.

Temperature data collected in July between 2000 and 2008 were used to evaluate stream flow and temperature relationships at two locations in the Middle Reach of Whychus Creek. The two locations are at the upstream and downstream ends of the Restoration Reach One and Two and are located at Whychus Creek Sisters' City Park (WC 024.25) and USFS Road 6360 (WC 006.00). These two locations allow stream flow targets to be assessed near the point of stream flow restoration and approximately twenty miles from the point of stream flow restoration. Due to the available range of temperature and flow data at these locations, target analyses identify the stream flow needed to achieve the state temperature standard at these two locations during conditions experienced between 2000 and 2008. Appendix A provides a summary of temperatures at a range of flows.

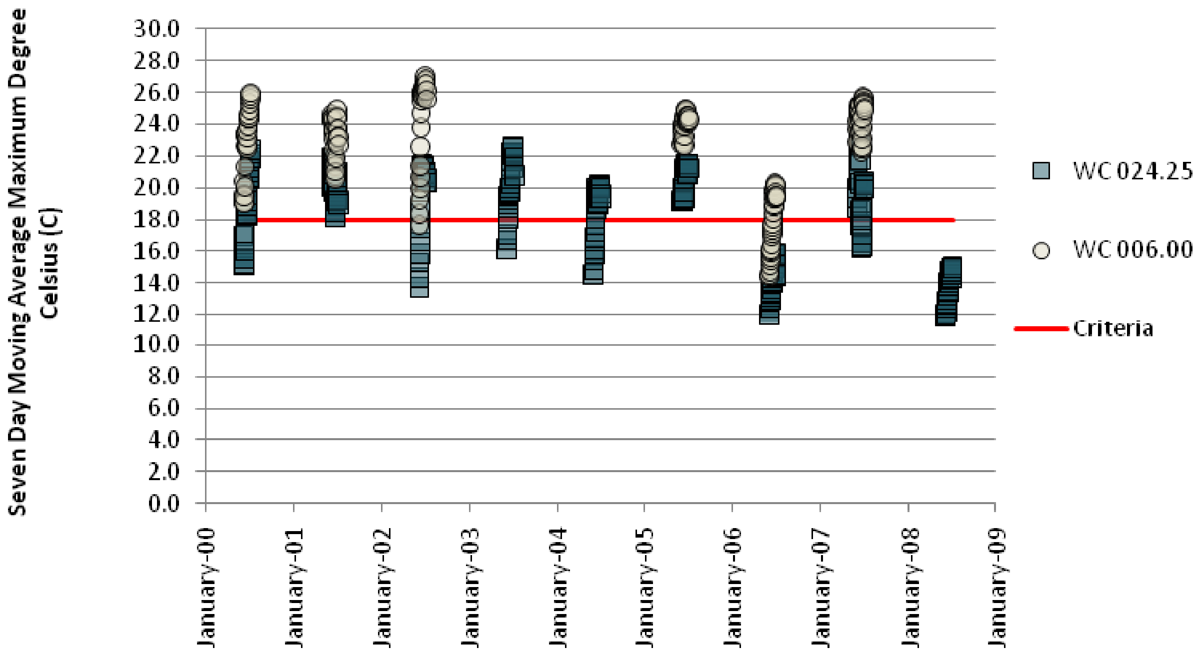

Figure 22.
In order to establish stream flow targets based upon temperature responses, 7DMAX temperature data collected in July between 2000 and 2008 were used to evaluate stream flow and temperature relationships at two locations in the Middle Reach of Whychus Creek. The two locations are Whychus Creek Sisters' City Park (WC 024.25) and USFS Road 6360 (WC 006.00).

Results

Sisters' City Park (WC 024.25)

How much stream flow does Whychus Creek need at Sisters' City Park (WC 024.25) in order to achieve a July mean 7DMAX temperature of 18 °C? A regression equation of best fit to the data describes the relationship of flow and temperature based on data collected during July 2000 – 2008 (Figure 23, Figure 24). The target analyses demonstrates that, during July 2000 – 2008 at Whychus Creek Sisters' City Park, 20 cfs (3.0 Ln QD, 95% confidence level) is needed to achieve a mean 7DMAX of 18.2 ± 1.7 °C in July.

$$\text{Mean 7DMAX} = 15.03 + 7.99\ (\text{Ln QD}) - 3.27\ (\text{Ln QD})^2 + 0.32\ (\text{Ln QD})$$

$$R^2 \text{ value} = 95.5\%,\ N = 47$$

$$\text{95\% Confidence Level (NIST 2009)} = M \pm M^{(Z_{1-\alpha/2}\ s(x)/\sqrt{N})}, \text{ where } M = X \text{ or } Y, \text{ where } Z_{1-\alpha/2} = Z_{1-0.05/2} = Z_{0.975} = 1.9$$

Figure 23.
This regression equation describes the relationship between flow and temperature at Whychus Creek Sister's City Park in July during 2000 thorugh 2008.

DEQ's Heat Source model has also been used to assess temperatures in Whychus Creek under different flow regimes.. There have not been any Heat Source scenarios run which evaluate instream temperatures observed with 20 cfs in Whychus Creek at the Sisters' City Park. A scenario has been run with 33 cfs instream at this location predicted a 7DMAX temperature of 15 °C (± 1°C; Watershed Sciences 2008). To enable a comparison between the two types of thermal analysis, the above target equation for Sisters City Park was also used to evaluate stream temperatures with 33 cfs (3.5 Ln QD) in the creek (with a 95% confidence level). With 33 cfs, temperatures equaled 16.7 ± 1.7 °C seven day moving average maximum temperature in July. This compares to the results of the Heat Source model. The results from this Technical Report indicate that the current target of 20 cfs (3.0 Ln QD) for Whychus Creek Sisters' City Park is likely to meet the state numeric temperature criterion of 18°C at that location.

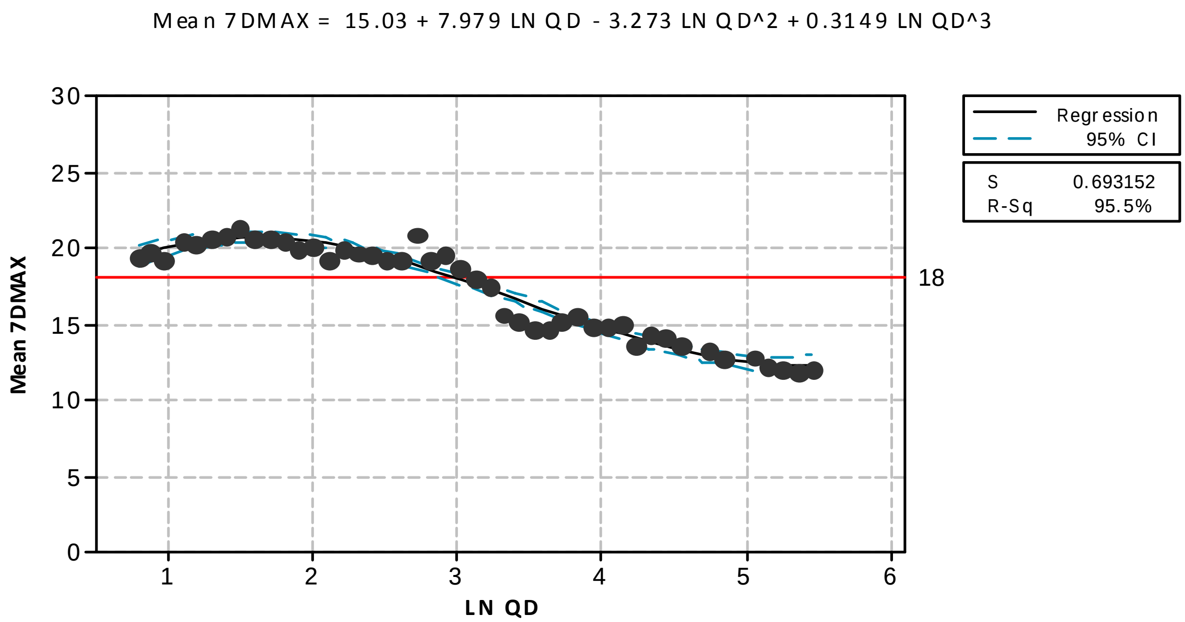

Figure 24.
This figure describes the relationship between flow and temperature at Whychus Creek Sister's City Park in July during 2000 thorugh 2008.

USFS Road 6360 (WC 006.00)

How much stream flow do we need at Sisters' City Park to achieve a July mean seven day moving average maximum temperature of 18 °C at USFS Road 6360? Based upon temperature and flow data collected during July 2000 – 2008, a regression equation describes the relationship of flow and temperature (Figure 25).

$$\text{Mean 7DMAX} = 17.88 + 8.30\,(\text{Ln QD}) - 2.99\,(\text{Ln QD})^2 + 0.25\,(\text{Ln QD})$$

$$(R^2 \text{ value} = 93.5\%,\ N = 43)$$

95% Confidence Level (NIST 2009) = $M \pm M^{(Z_{1-\alpha/2}\ s(x)/\sqrt{N})}$, where M= X or Y, where $Z_{1-\alpha/2} = Z_{1-0.05/2} = Z_{0.975} = 1.9$

Figure 25.
This regression equation describes the relationship between flow and temperature at USFS Rd 6360 in July during 2000 through 2008.

The target analyses demonstrates with a 95% Confidence Level that, during July 2000 – 2008, 60 cfs (4.1 Ln QD) is needed in Sisters' City Park to achieve a mean seven day moving average maximum temperature of 18.9 ± 2.0°C at USFS Rd 6360 (WC 006.00) in July. A Heat Source model scenario was run to evaluate instream temperatures with 62 cfs in the creek below Sisters. Under this scenario, the Heat Source model predicted instream temperatures of 18.5 °C (± 1°C) seven day moving average maximum temperature at USFS Road 6360. (Watershed Sciences and MaxDepth Aquatics 2007). Under this scenario, several kilometers of Whychus Creek above Alder Springs still exceed state temperature standars The combination of the Heat Source model results and the results from this Technical Report suggest that the current instream target of 33 cfs (3.5 Ln QD) for USFS Road 6360 is not likely to achieve state temperature standards. 60 cfs at Sisters' City Park may be a more appropriate stream flow target to achieve standards at USFS Rd 6360.

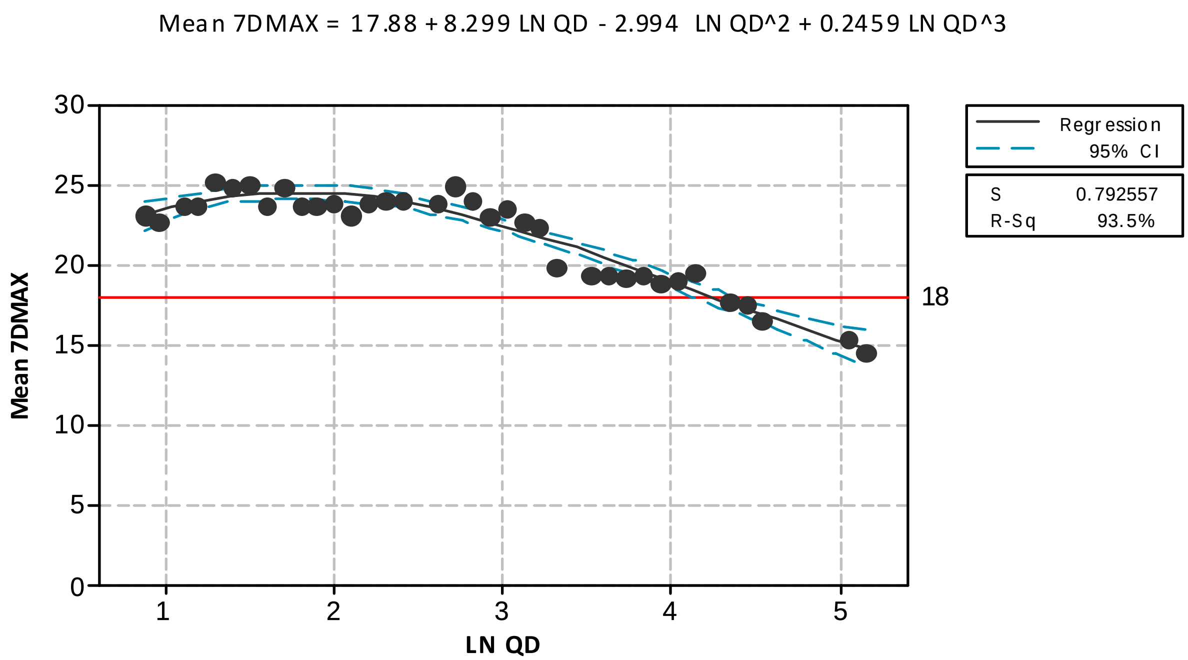

Figure 26.
This figure describes the relationship between flow and temperature at USFS Road 6360 in July 2000 through 2008.

Discussion

These results identify the target flows necessary to meet state water quality standards for temperature during the month of July. They apply at the selected locations, within the evaluated time period, and within the original range of flows and temperatures. Results suggest that stream flow targets will be adequate to achieve water quality standards at Sisters' City Park but not at some downstream locations. A 60 cfs target may be necessary to meet temperature standards at the most impaired locations during the hottest times of year under existing conditions. What does this mean for fish and aquatic life? Resident and anadromous fish adapt to high temperatures through migration, microhabitat use, and other techniques. The stream flow necessary to support self-sustaining fish resident and anadromous fish populations may be lower than the stream flow necessary to meet state temperature standards at the most impaired locations along Whychus Creek. Restoration partners will continue to use existing stream flow targets until evidence suggests that they are inadequate to support resident and anadromous fish populations.

Acknowledgements

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<u>Water Quality Committee</u>

Michelle McSwain	Bureau of Land Management
Wende Eddie	City of Bend
Brett Golden	Deschutes River Conservancy
Bonnie Lamb	Oregon Department of Environmental Quality
Ted Wise	Oregon Department of Fish and Wildlife
Kyle Gorman	Oregon Water Resources Department
Lori Campbell	Portland General Electric
Ryan Houston	Upper Deschutes Watershed Council
Marc Wilcox	USFS Deschutes National Forest & USFS Ochoco National Forest

<u>Contributing Partners</u>

Jonathan LaMarche	Oregon Water Resources Department
Drexell Barnes	City of Bend
Jeff Buystedt	City of Bend
Steve Prazak	City of Bend

<u>Water Quality Monitoring Program Staff and Interns</u>

Ryan Houston	UDWC Executive Director
Lesley Jones	UDWC Water Quality Specialist
Mike Logan	UDWC Water Quality Technician & UDWC/OSU Water Quality Intern 2007
Rachael Francois	UDWC/OSU Water Quality Intern 2005
Jason Brown	UDWC/OSU Water Quality Intern 2006
Coggin Hill	UDWC/OSU Water Quality Intern 2008

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Appendix A Temperature and Flow Table

Whychus Creek at Sisters' City Park (WC 024.25) Temperatures at Given Flow with a 95% Confidence Level

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	19.1	1.8	**57**	15.0	1.7	**112**	13.5	1.6	**167**	13.2	1.6
3	20.3	1.8	**58**	15.0	1.7	**113**	13.5	1.6	**168**	13.2	1.6
4	20.7	1.8	**59**	14.9	1.7	**114**	13.5	1.6	**169**	13.2	1.6
5	20.8	1.8	**60**	14.9	1.7	**115**	13.5	1.6	**170**	13.2	1.6
6	20.7	1.8	**61**	14.8	1.7	**116**	13.5	1.6	**171**	13.2	1.6
7	20.6	1.8	**62**	14.8	1.7	**117**	13.5	1.6	**172**	13.2	1.6
8	20.4	1.8	**63**	14.8	1.7	**118**	13.5	1.6	**173**	13.2	1.6
9	20.2	1.8	**64**	14.7	1.7	**119**	13.5	1.6	**174**	13.2	1.6
10	20.0	1.8	**65**	14.7	1.7	**120**	13.4	1.6	**175**	13.2	1.6
11	19.8	1.8	**66**	14.6	1.7	**121**	13.4	1.6	**176**	13.2	1.6
12	19.6	1.8	**67**	14.6	1.7	**122**	13.4	1.6	**177**	13.2	1.6
13	19.4	1.8	**68**	14.6	1.7	**123**	13.4	1.6	**178**	13.2	1.6
14	19.2	1.8	**69**	14.5	1.7	**124**	13.4	1.6	**179**	13.2	1.6
15	19.0	1.8	**70**	14.5	1.7	**125**	13.4	1.6	**180**	13.2	1.6
16	18.9	1.8	**71**	14.5	1.7	**126**	13.4	1.6	**181**	13.2	1.6
17	18.7	1.8	**72**	14.4	1.7	**127**	13.4	1.6	**182**	13.2	1.6
18	18.5	1.7	**73**	14.4	1.7	**128**	13.4	1.6	**183**	13.2	1.6
19	18.4	1.7	**74**	14.4	1.7	**129**	13.4	1.6	**184**	13.2	1.6
20	18.2	1.7	**75**	14.3	1.7	**130**	13.4	1.6	**185**	13.2	1.6
21	18.1	1.7	**76**	14.3	1.7	**131**	13.3	1.6	**186**	13.2	1.6
22	17.9	1.7	**77**	14.3	1.7	**132**	13.3	1.6	**187**	13.2	1.6
23	17.8	1.7	**78**	14.2	1.7	**133**	13.3	1.6	**188**	13.2	1.6
24	17.7	1.7	**79**	14.2	1.7	**134**	13.3	1.6	**189**	13.2	1.6
25	17.5	1.7	**80**	14.2	1.7	**135**	13.3	1.6	**190**	13.2	1.6
26	17.4	1.7	**81**	14.1	1.7	**136**	13.3	1.6	**191**	13.2	1.6
27	17.3	1.7	**82**	14.1	1.7	**137**	13.3	1.6	**192**	13.2	1.6
28	17.2	1.7	**83**	14.1	1.7	**138**	13.3	1.6	**193**	13.2	1.6
29	17.1	1.7	**84**	14.1	1.7	**139**	13.3	1.6	**194**	13.2	1.6
30	17.0	1.7	**85**	14.0	1.7	**140**	13.3	1.6	**195**	13.2	1.6
31	16.9	1.7	**86**	14.0	1.7	**141**	13.3	1.6	**196**	13.2	1.6
32	16.8	1.7	**87**	14.0	1.7	**142**	13.3	1.6	**197**	13.2	1.6
33	16.7	1.7	**88**	14.0	1.7	**143**	13.3	1.6	**198**	13.2	1.6
34	16.6	1.7	**89**	14.0	1.7	**144**	13.3	1.6	**199**	13.2	1.6
35	16.5	1.7	**90**	13.9	1.7	**145**	13.2	1.6	**200**	13.2	1.6
36	16.4	1.7	**91**	13.9	1.7	**146**	13.2	1.6	**201**	13.2	1.6
37	16.3	1.7	**92**	13.9	1.7	**147**	13.2	1.6	**202**	13.2	1.6
38	16.2	1.7	**93**	13.9	1.7	**148**	13.2	1.6	**203**	13.2	1.6
39	16.1	1.7	**94**	13.8	1.7	**149**	13.2	1.6	**204**	13.2	1.6
40	16.1	1.7	**95**	13.8	1.7	**150**	13.2	1.6	**205**	13.2	1.6
41	16.0	1.7	**96**	13.8	1.7	**151**	13.2	1.6	**206**	13.2	1.6
42	15.9	1.7	**97**	13.8	1.7	**152**	13.2	1.6	**207**	13.2	1.6
43	15.8	1.7	**98**	13.8	1.7	**153**	13.2	1.6	**208**	13.2	1.6
44	15.8	1.7	**99**	13.7	1.7	**154**	13.2	1.6	**209**	13.2	1.6
45	15.7	1.7	**100**	13.7	1.7	**155**	13.2	1.6	**210**	13.2	1.6
46	15.6	1.7	**101**	13.7	1.6	**156**	13.2	1.6	**211**	13.2	1.6
47	15.6	1.7	**102**	13.7	1.6	**157**	13.2	1.6	**212**	13.2	1.6
48	15.5	1.7	**103**	13.7	1.6	**158**	13.2	1.6	**213**	13.2	1.6
49	15.5	1.7	**104**	13.7	1.6	**159**	13.2	1.6	**214**	13.2	1.6
50	15.4	1.7	**105**	13.6	1.6	**160**	13.2	1.6	**215**	13.2	1.6
51	15.3	1.7	**106**	13.6	1.6	**161**	13.2	1.6	**216**	13.2	1.6
52	15.3	1.7	**107**	13.6	1.6	**162**	13.2	1.6	**217**	13.2	1.6
53	15.2	1.7	**108**	13.6	1.6	**163**	13.2	1.6	**218**	13.2	1.6
54	15.2	1.7	**109**	13.6	1.6	**164**	13.2	1.6	**219**	13.2	1.6
55	15.1	1.7	**110**	13.6	1.6	**165**	13.2	1.6	**220**	13.2	1.6
56	15.1	1.7	**111**	13.6	1.6	**166**	13.2	1.6	**221**	13.2	1.6

Whychus Creek at Sisters' City Park (WC 024.25) Flows at Given Temperature with a 95% Confidence Level

Temp (7DMAX)	Flow (cfs)	CI (±)
14.0	87	2
15.0	57	2
16.0	41	2
17.0	30	2
18.0	20	2
19.0	15	2
20.0	10	2

Note: Calculated values within the two tables do not exactly match because of inherent error in solving third order polynomials for f(x) rather than x. Temperatures at given flow are more accurate.

Whychus Creek at USFS Rd 6360 (006.00) Temperatures at Given Flow with a 95% Confidence Level

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	22.3	2.0	**57**	19.1	2.0	**112**	16.7	1.9	**167**	15.6	1.9
3	23.7	2.1	**58**	19.0	2.0	**113**	16.7	1.9	**168**	15.5	1.9
4	24.3	2.1	**59**	19.0	2.0	**114**	16.7	1.9	**169**	15.5	1.9
5	24.5	2.1	**60**	18.9	2.0	**115**	16.7	1.9	**170**	15.5	1.9
6	24.6	2.1	**61**	18.8	2.0	**116**	16.6	1.9	**171**	15.5	1.9
7	24.6	2.1	**62**	18.8	2.0	**117**	16.6	1.9	**172**	15.5	1.9
8	24.5	2.1	**63**	18.7	2.0	**118**	16.6	1.9	**173**	15.5	1.9
9	24.3	2.1	**64**	18.7	2.0	**119**	16.5	1.9	**174**	15.4	1.9
10	24.2	2.1	**65**	18.6	2.0	**120**	16.5	1.9	**175**	15.4	1.9
11	24.0	2.1	**66**	18.6	2.0	**121**	16.5	1.9	**176**	15.4	1.9
12	23.9	2.1	**67**	18.5	2.0	**122**	16.5	1.9	**177**	15.4	1.9
13	23.7	2.1	**68**	18.4	1.9	**123**	16.4	1.9	**178**	15.4	1.9
14	23.6	2.1	**69**	18.4	1.9	**124**	16.4	1.9	**179**	15.4	1.9
15	23.4	2.1	**70**	18.3	1.9	**125**	16.4	1.9	**180**	15.4	1.9
16	23.2	2.1	**71**	18.3	1.9	**126**	16.4	1.9	**181**	15.3	1.9
17	23.1	2.1	**72**	18.2	1.9	**127**	16.3	1.9	**182**	15.3	1.9
18	22.9	2.0	**73**	18.2	1.9	**128**	16.3	1.9	**183**	15.3	1.9
19	22.8	2.0	**74**	18.1	1.9	**129**	16.3	1.9	**184**	15.3	1.9
20	22.6	2.0	**75**	18.1	1.9	**130**	16.3	1.9	**185**	15.3	1.9
21	22.5	2.0	**76**	18.1	1.9	**131**	16.2	1.9	**186**	15.3	1.9
22	22.4	2.0	**77**	18.0	1.9	**132**	16.2	1.9	**187**	15.3	1.9
23	22.2	2.0	**78**	18.0	1.9	**133**	16.2	1.9	**188**	15.3	1.9
24	22.1	2.0	**79**	17.9	1.9	**134**	16.2	1.9	**189**	15.2	1.9
25	22.0	2.0	**80**	17.9	1.9	**135**	16.2	1.9	**190**	15.2	1.9
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27	21.7	2.0	**82**	17.8	1.9	**137**	16.1	1.9	**192**	15.2	1.9
28	21.6	2.0	**83**	17.7	1.9	**138**	16.1	1.9	**193**	15.2	1.9
29	21.5	2.0	**84**	17.7	1.9	**139**	16.1	1.9	**194**	15.2	1.9
30	21.4	2.0	**85**	17.7	1.9	**140**	16.0	1.9	**195**	15.2	1.9
31	21.2	2.0	**86**	17.6	1.9	**141**	16.0	1.9	**196**	15.2	1.9
32	21.1	2.0	**87**	17.6	1.9	**142**	16.0	1.9	**197**	15.1	1.9
33	21.0	2.0	**88**	17.5	1.9	**143**	16.0	1.9	**198**	15.1	1.9
34	20.9	2.0	**89**	17.5	1.9	**144**	16.0	1.9	**199**	15.1	1.9
35	20.8	2.0	**90**	17.5	1.9	**145**	15.9	1.9	**200**	15.1	1.9
36	20.7	2.0	**91**	17.4	1.9	**146**	15.9	1.9	**201**	15.1	1.9
37	20.6	2.0	**92**	17.4	1.9	**147**	15.9	1.9	**202**	15.1	1.9
38	20.5	2.0	**93**	17.4	1.9	**148**	15.9	1.9	**203**	15.1	1.9
39	20.4	2.0	**94**	17.3	1.9	**149**	15.9	1.9	**204**	15.1	1.9
40	20.4	2.0	**95**	17.3	1.9	**150**	15.8	1.9	**205**	15.0	1.9
41	20.3	2.0	**96**	17.2	1.9	**151**	15.8	1.9	**206**	15.0	1.9
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43	20.1	2.0	**98**	17.2	1.9	**153**	15.8	1.9	**208**	15.0	1.9
44	20.0	2.0	**99**	17.1	1.9	**154**	15.8	1.9	**209**	15.0	1.9
45	19.9	2.0	**100**	17.1	1.9	**155**	15.8	1.9	**210**	15.0	1.9
46	19.9	2.0	**101**	17.1	1.9	**156**	15.7	1.9	**211**	15.0	1.9
47	19.8	2.0	**102**	17.0	1.9	**157**	15.7	1.9	**212**	15.0	1.9
48	19.7	2.0	**103**	17.0	1.9	**158**	15.7	1.9	**213**	15.0	1.9
49	19.6	2.0	**104**	17.0	1.9	**159**	15.7	1.9	**214**	15.0	1.9
50	19.6	2.0	**105**	16.9	1.9	**160**	15.7	1.9	**215**	14.9	1.9
51	19.5	2.0	**106**	16.9	1.9	**161**	15.7	1.9	**216**	14.9	1.9
52	19.4	2.0	**107**	16.9	1.9	**162**	15.6	1.9	**217**	14.9	1.9
53	19.3	2.0	**108**	16.9	1.9	**163**	15.6	1.9	**218**	14.9	1.9
54	19.3	2.0	**109**	16.8	1.9	**164**	15.6	1.9	**219**	14.9	1.9
55	19.2	2.0	**110**	16.8	1.9	**165**	15.6	1.9	**220**	14.9	1.9
56	19.1	2.0	**111**	16.8	1.9	**166**	15.6	1.9	**221**	14.9	1.9

Whychus Creek at USFS Rd 6360 (006.00) Temperatures at Given Flow with a 95% Confidence Level

Temp (7DMAX)	Flow (cfs)	CI (±)	Temp (7DMAX)	Flow (cfs)	CI (±)
15.0	209	3	**21.0**	33	2
16.0	143	3	**22.0**	25	2
17.0	104	3	**23.0**	18	2
18.0	78	3	**24.0**	11	2
19.0	59	2			
20.0	44	2			

Note: Calculated values within the two tables do not exactly match because of inherent error in solving third order polynomials for f(x) rather than x. Temperatures at given flow are more accurate.

Habitat Quality in Whychus Creek

Brett Golden
Deschutes River Conservancy
700 NW Hill St
Bend, OR 97701
brett@deschutesriver.org

Abstract

Human actions have altered stream habitat in Whychus Creek, a tributary to Oregon's Deschutes River, for over 100 years. The Oregon Department of Fish and Wildlife surveyed physical habitat in the creek in 1997 and in 2008/2009 in support of an anadromous fish reintroduction effort. They surveyed approximately 27 miles of creek in 1997 and were unable to access 7 miles. They surveyed approximately 32 miles of creek in 2008/2009 and were unable to access 2 miles. Survey data were entered into the HabRate model to develop reach scale species and life stage specific habitat rankings for the creek. Results varied by species and by life stage. In 1997, habitat ratings were highest for the Age 0+ winter life stages of steelhead trout (*Onchorynchus mykiss*) and chinook salmon (*Oncorhynchus tshawytscha*). In 2008/2009, habitat ratings were highest for the Age 1+ winter life stage of steelhead trout and the Age 0+ winter life stage of chinook salmon. Changes in reach definitions between sampling periods make it difficult to assess changes in habitat conditions using existing HabRate results. Future analysis of existing data with smaller reaches that are consistent across years will allow for a better understanding of changes in habitat ratings.

Introduction

Human actions have altered stream habitat in Whychus Creek over the last 100 years. Irrigation diversions, channel straightening, riparian grazing and other actions have limited stream functions and affected riparian and aquatic habitat quality. According to NRC (2002), habitat alteration occurs through human disturbances or the prevention of natural disturbances. Both of these challenges have occurred in Whychus Creek.

Habitat alteration may improve or degrade habitat quality (NRC 2002). The specific outcomes of habitat alteration depend on the type of alteration and the altered stream system. Decreased riparian cover may lead to warmer stream temperatures (Poole and Berman 2000) and warmer stream temperatures may affect salmonid spawning timing and egg mortality (Richter and Kolmes 2005). In contrast, other alterations may lead to increased production for some species (NRC 2002). Variation in salmonid life history strategies makes it difficult to generalize about the affects of habitat alteration on specific populations.

Local restoration partners have explicitly identified the goal of providing the habitat necessary to support naturally reproducing resident and anadromous fish populations in Whychus Creek. They have recognized that, although they cannot manage fish populations or conditions outside of the creek, they can improve opportunities for survival and growth within the creek. Given this goal, habitat quality stands out as an indicator of restoration effectiveness in Whychus Creek.

Restoration partners expect that their actions, ranging from channel reconstruction to stream flow restoration, will improve conditions for anadromous fish. They have selected the Oregon Department of Fish and Wildlife's HabRate model as one tool to document any changes in habitat conditions that have occurred in Whychus Creek. HabRate applies field survey data and salmonid habitat criteria to develop species and life stage specific habitat rankings. It provides the basis for the habitat ratings appearing in this study.

Methods

Data Collection

This baseline analysis includes data collected from Whychus Creek in 1997 and in 2008. It does not include Indian Ford Creek or Pole Creek, both tributaries to Whychus Creek. These creeks historically connected to Whychus Creek. Indian Ford Creek typically dries up before reaching Whychus Creek under current conditions and Pole Creek had been diverted away from its mouth and into a new channel through 2008.

1997 Data

ODFW (ODFW) and the Forest Service surveyed Whychus Creek in 1997. ODFW surveyed from the mouth of the creek upstream to the Three Sisters Irrigation District Diversion. They surveyed eight reaches covering 15.2 miles. Landowners did not grant access to an additional four reaches covering 7.2 miles within this section of creek. The Forest Service surveyed the creek upstream from the Three Sisters Irrigation District Diversion (Spateholts 2009). They surveyed an additional five reaches covering 12.8 miles.

According to Burke *et al* (2003), surveyors based their survey methodology on Hankin (1984) and Hankin and Reeves (1988). Both the Forest Service and ODFW used modified versions of these survey methodologies. Their methodology varied slightly between years and agencies. Their qualitative and quantitative data remained consistent even with these variations (Burke *et al* 2003).

2008/2009 Data

Portland General Electric and the Confederated Tribes of the Warm Springs Reservation (Licensees) contracted with ODFW's Aquatic Inventory Project to survey Whychus Creek in 2008. ODFW surveyed the creek from July through September of 2008. They surveyed from the mouth of the creek upstream to the Plainview Ditch (ODFW 2008). Landowners did not grant access to four reaches covering 2.6 miles. The survey team surveyed the remaining sixteen reaches covering 22.6 miles.

ODFW followed standard survey methods in Whychus Creek (ODFW 2006). Surveyors identified the channel form, valley form, streamside vegetation characteristics, water temperature, stream flow, land use, and location for each reach. They further divided each reach into channel habitat units based on bedform, gradient, and substrate (ODFW 2006). Within each habitat unit, survey crews identified the channel form, channel characteristics, wood presence, and riparian conditions (ODFW 2006).

Licensees contracted with ODFW to survey additional reaches of Whychus Creek in 2009. They surveyed Whychus Creek from the Plainview Ditch to Whychus Creek Falls. Surveys followed methods used in 2008.

Data Analysis

Fisheries managers analyzed habitat data using the HabRate model. ODFW developed the HabRate model to rate stream habitat suitability for salmon and steelhead trout in the Deschutes Basin. The model combines stream survey data with physical habitat requirements. It estimates estimate habitat suitability for different life stages of steelhead trout, chinook salmon, and sockeye salmon (Burke *et al* 2003).

HabRate developers identified the habitat requirements necessary to support each life history stage of each species. They used a combination of literature reviews and professional judgment (Burke *et al* 2003). The model applies these habitat requirements to observed data and rates a series of habitat attributes as poor, fair, or good for each life stage of each species. A fair or good rating indicates a habitat attribute that will support fish survival.

HabRate combines the different habitat attribute ratings for each life stage of each species to create categorical habitat ratings. These categorical ratings account for habitat conditions that support or impair fish survival. HabRate assigns each reach an overall rating by species and life history stage based on these categorical ratings (Burke *et al* 2003). The lowest categorical rating limits the overall reach rating, identifying reaches that are inadequate for different life history stages.

1997 Data

Burke *et al* (2003) gathered existing survey data, reformatted it as necessary, and compiled it in a database format. They compiled it into reach level data appropriate for use with the HabRate model. This analysis does not use Burke *et al*'s (2003) HabRate results. Fisheries managers updated the HabRate model in 2007 to better reflect the current understanding of fish habitat needs in the Deschutes Basin. They applied the revised HabRate model to the 1997 data and produced reach level habitat ratings for each life stage of each species.

The UDWC quantified good, fair, and poor habitat ratings based on reach lengths determined through GIS analysis. The UDWC quantified the amount of habitat rated as good, fair, poor, or unsurveyed for each life history stage of each species based on GIS determined reach lengths. They included all surveyed reaches in their initial data compilation.

2008/2009 Data

Fisheries managers gathered the 2008/2009 survey data. They compiled channel unit level survey data into reach level data appropriate for use with the HabRate model. They entered this data into the revised HabRate model and produced reach level habitat ratings for each life stage of each species.

ODFW was unable to access and survey four reaches in 2008. Fisheries managers estimated habitat parameter for these reaches based on professional judgment (Spateholts 2009). The UDWC's analysis lists these reaches as unsurveyed and does not include estimated habitat ratings in their analysis.

The UDWC quantified good, fair, and poor habitat ratings based on reach lengths determined through GIS analysis. The UDWC quantified the amount of habitat rated as good, fair, poor, or unsurveyed for each life history stage of each species based on GIS determined reach lengths. They included all surveyed reaches in their initial data compilation.

Habitat Change

The UDWC analyzed habitat ratings from 1997 and 2008/2009 to determine how and if habitat quality had changed between the two survey periods. They obtained the 1997 and 2008 HabRate data setsfrom Licensees. The UDWC used the existing 1997 GIS data set for its analysis. Portland General Electric had not yet created a GIS data set for the 2008/2009 HabRate data. The UDWC created one using the 2008/2009 HabRate data and GIS data associated with ODFW's 2008/2009 habitat surveys.

Divisions between reaches, reach numbers, and unsurveyed reaches did not fully align between 1997 and 2008/2009. The UDWC's anaylsis focused on areas that were surveyed in both 1997 and 2008/2009. The UDWC created a new GIS data set based on the 1997 and 2008/2009 GIS data. They merged the 1997 and 2008/2009 data, creating a new data set. 1997 and 2008/2009 reaches did not fully align in some locations so this data set contains additional reach divisions. Each reach contains 1997 and 2008/2009 habitat ratings. Only reaches that were surveyed in both years received habitat ratings. The UDWC listed reaches that were not surveyed in one or both years as unsurveyed.

The UDWC used this new data set to determine the extent of habitat changes between 1997 and 2008/2009. They classified changes in reach conditions as improved, unchanged, declined, or unsurveyed based on changes in habitat ratings between 1997 and 2008/2009. The UDWC quantified the changes in habitat ratings for each life history stage of each species based on GIS determined reach lengths.

Results

The following sections document habitat ratings in 1997, habitat ratings in 2008/2009, and changes in habitat ratings between 1997 and 2008/2009. Surveyors divided the creek into different reaches during 1997 and 2008/2009 and were denied access to different reaches during each year. Habitat ratings for specific reaches may not be directly comparable between years because of these differences.

1997 Habitat Ratings

Habitat ratings for steelhead varied across the creek in 1997 (Figure 1to Figure 5). HabRate results suggest that Whychus Creek was less suitable for 0S and 1S steelhead than for other steelhead life stages in 1997 (Table 1). Conditions were most suitable for these life stages near the mouth of Whychus Creek and upstream from the City of Sisters (Figure 2,Figure 4). Results suggest that Whychus Creek was most suitable for Spawning steelhead (Table 1). Habitat was adequate for Spawning through all surveyed reaches (Figure 1).

Table 1. 1997 Steelhead Habitat Ratings.

1997 Reach Level Habitat Rating	Steelhead Life Stage Spawning and Rearing	Age 0+ Summer	Age 0+ Winter	Age 1+ Summer	Age 1+ Winter
Good	0	0	12.9	0	0
Fair	26.9	15.8	14.0	15.8	26.9
Poor	0	11.1	0	11.1	0
Unsurveyed	7.2	7.2	7.2	7.2	7.2

HabRate results suggest that Whychus Creek was less suitable for 0S chinook than for other life stages (Table 2). All surveyed reaches were inadequate for 0S chinook (Figure 7). Results further suggest that Whychus Creek was most suitable for 0W chinook (Table 2). Reaches downstream from the TSID diversion were ranked higher for 0W chinook than reaches upstream from the diversion (Figure 8).

Table 2. 1997 Chinook Habitat Ratings.

1997 Reach Level Habitat Rating	Chinook Life Stage Spawning and Rearing	Age 0+ Summer	Age 0+ Winter
Good	3.2	0	12.9
Fair	23.7	0	14.0
Poor	0	26.9	0
Unsurveyed	7.2	7.2	7.2

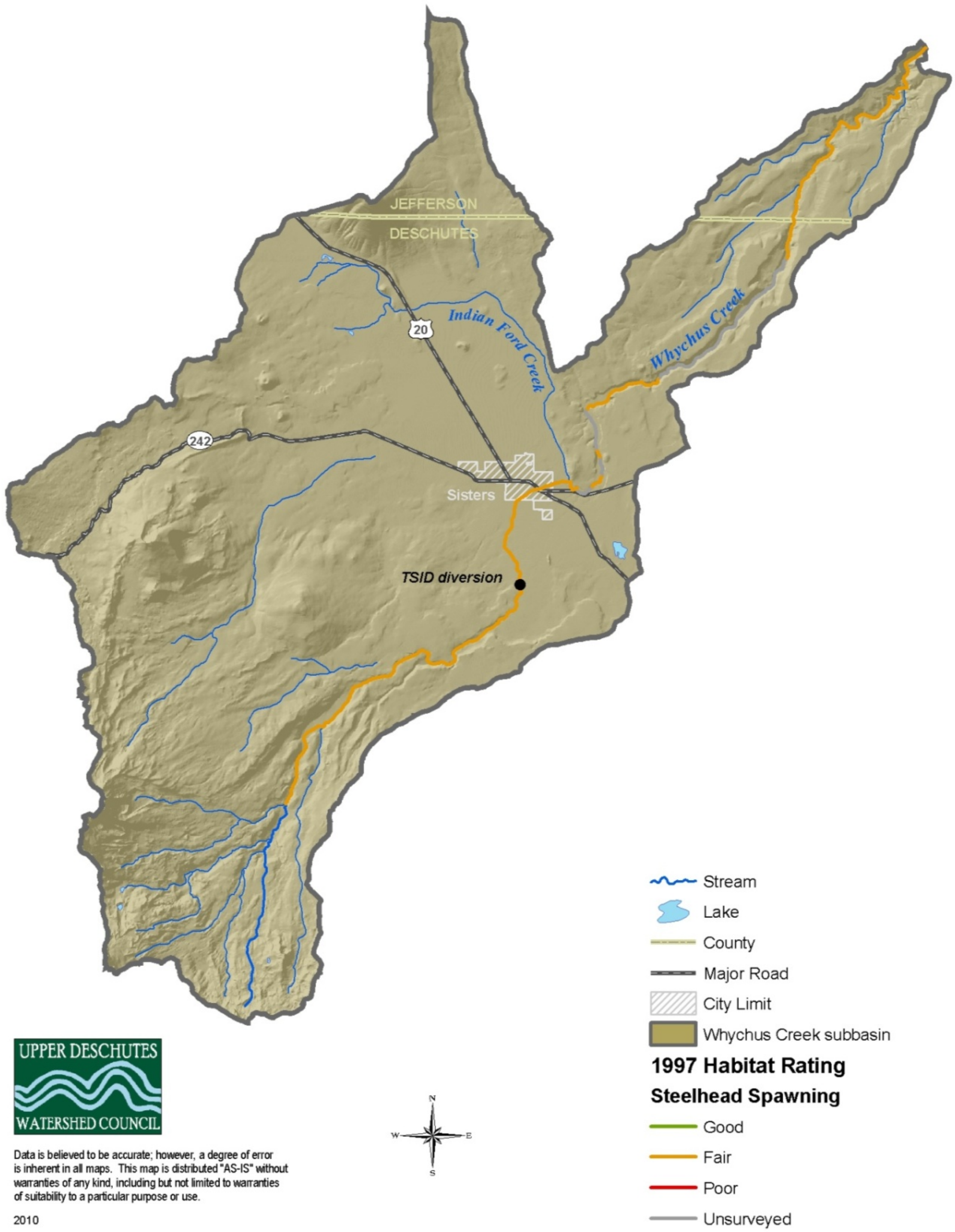

Figure 1.
This figure shows reach level habitat ratings for Spawning steelhead. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

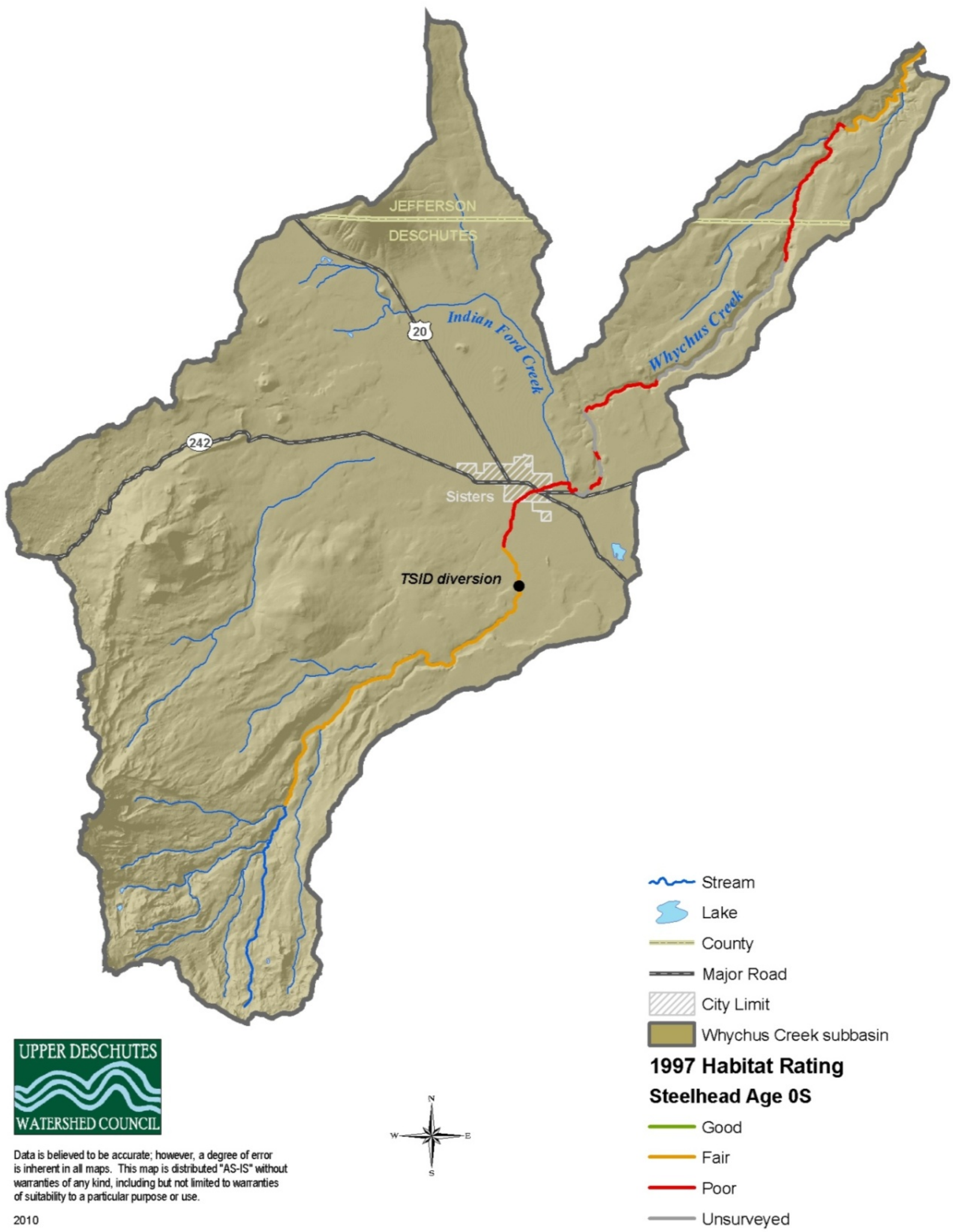

Figure 2.
This figure shows reach level habitat ratings for 0S steelhead. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

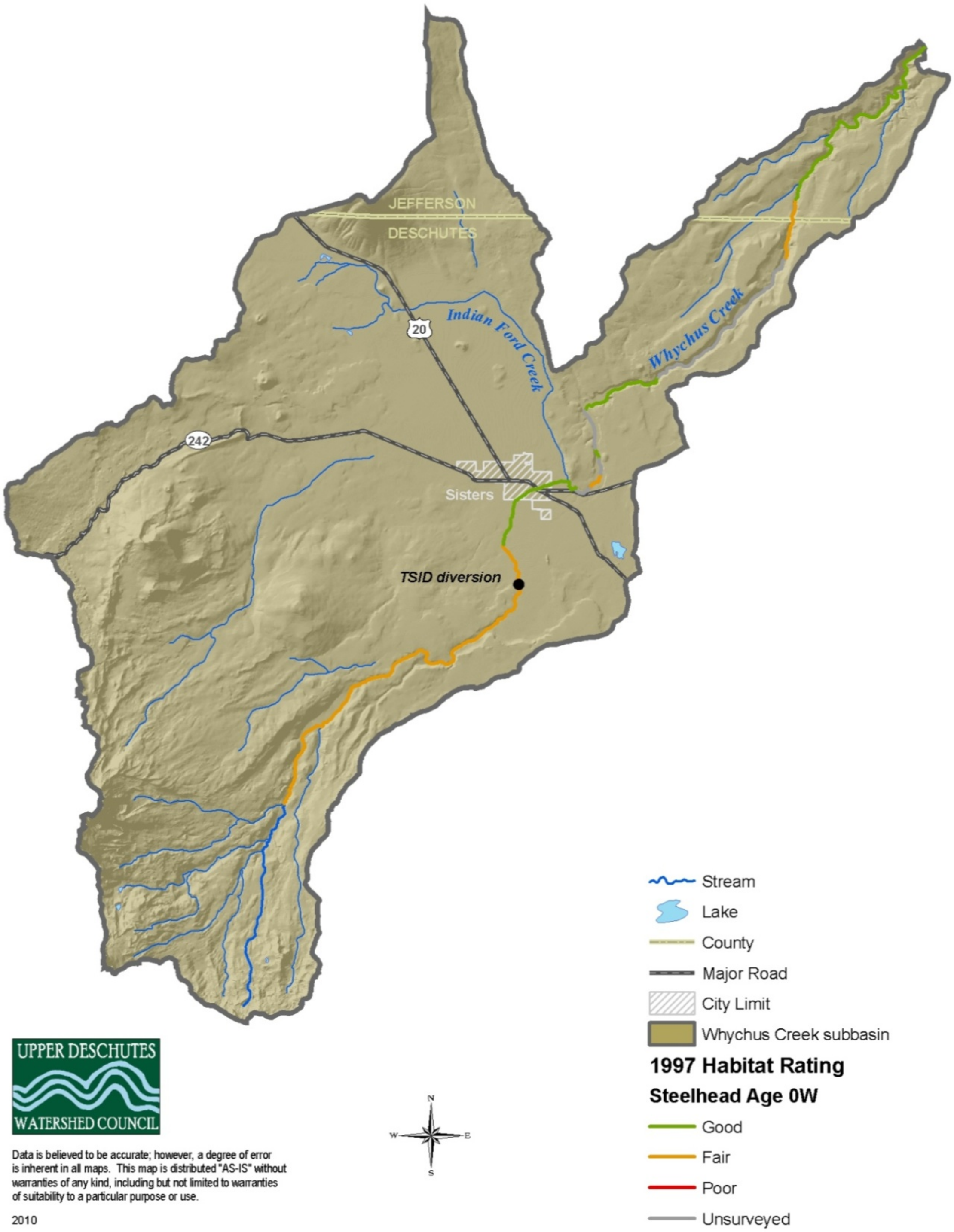

Figure 3.
This figure shows reach level habitat ratings for 0W steelhead. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

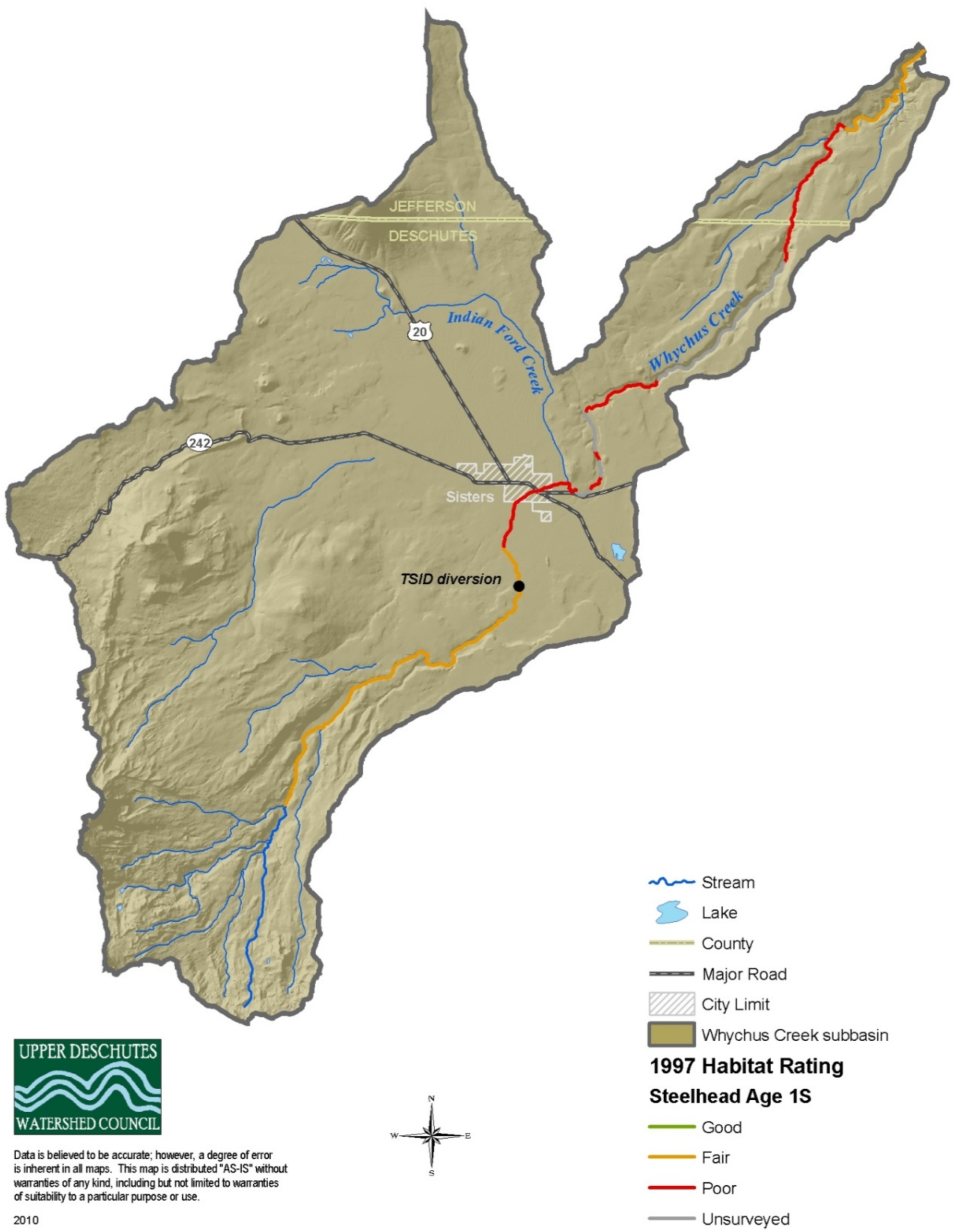

Figure 4.
This figure shows reach level habitat ratings for 1S steelhead. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

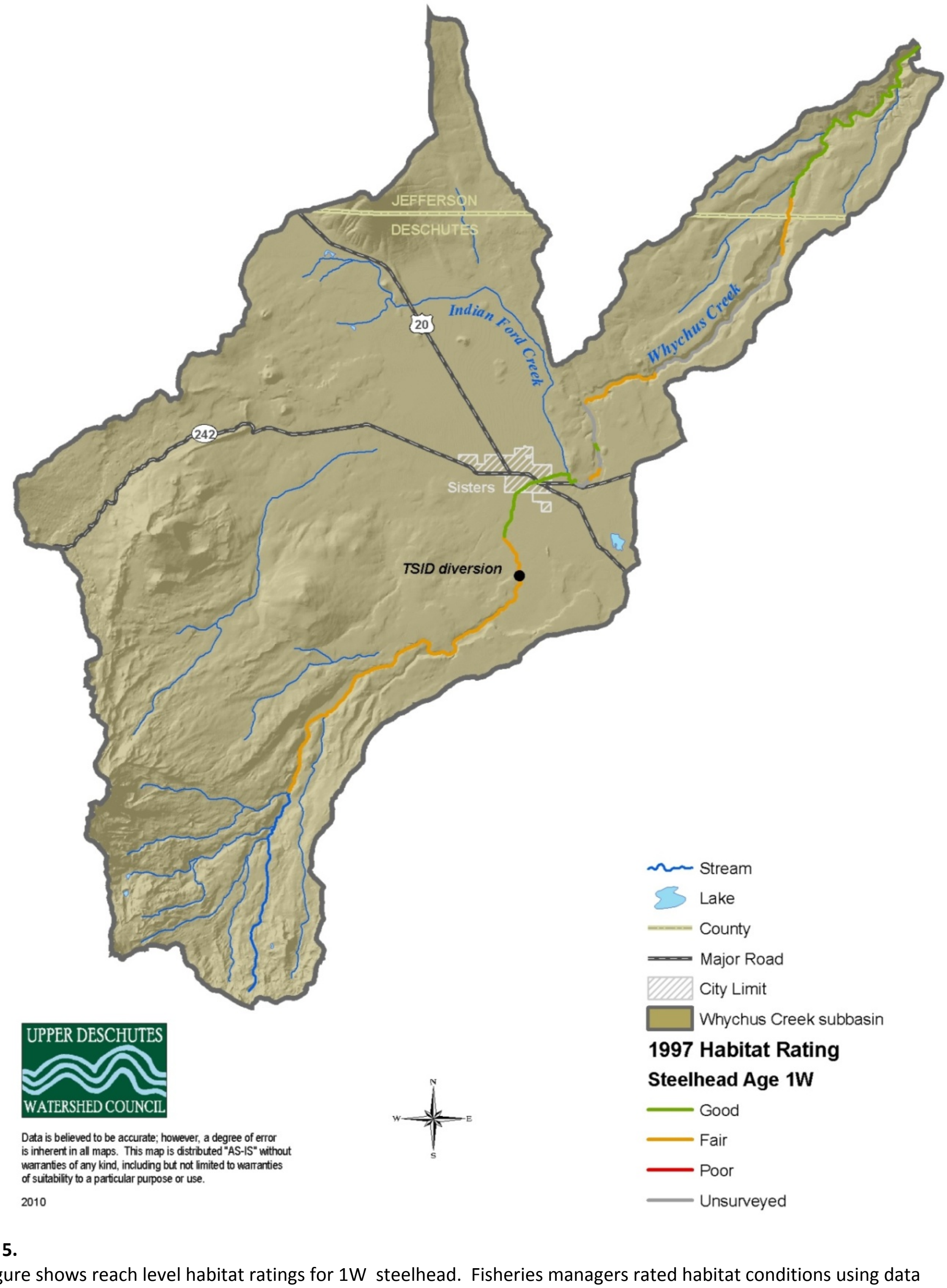

Figure 5.
This figure shows reach level habitat ratings for 1W steelhead. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

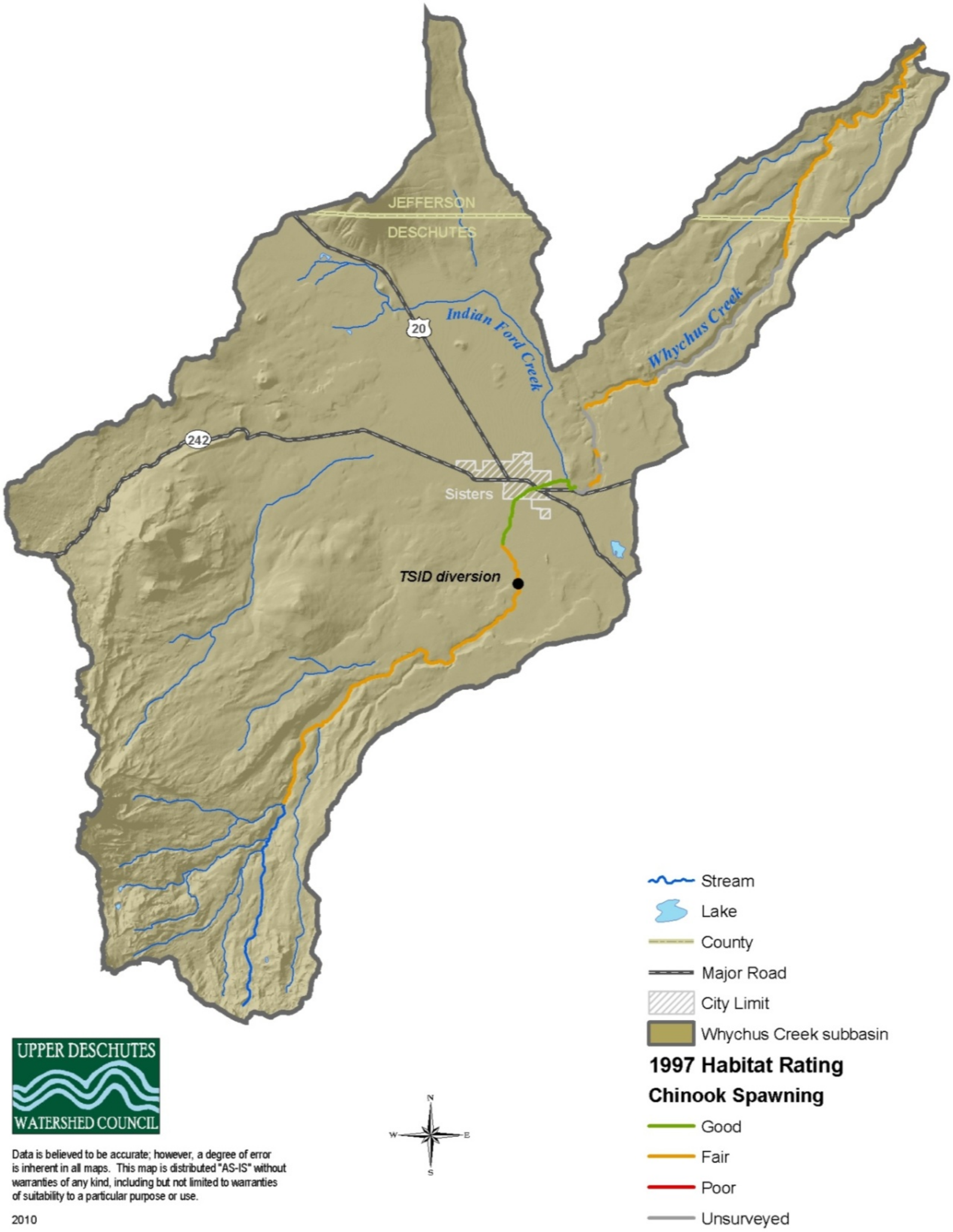

Figure 6.
This figure shows reach level habitat ratings for Spawning chinook. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

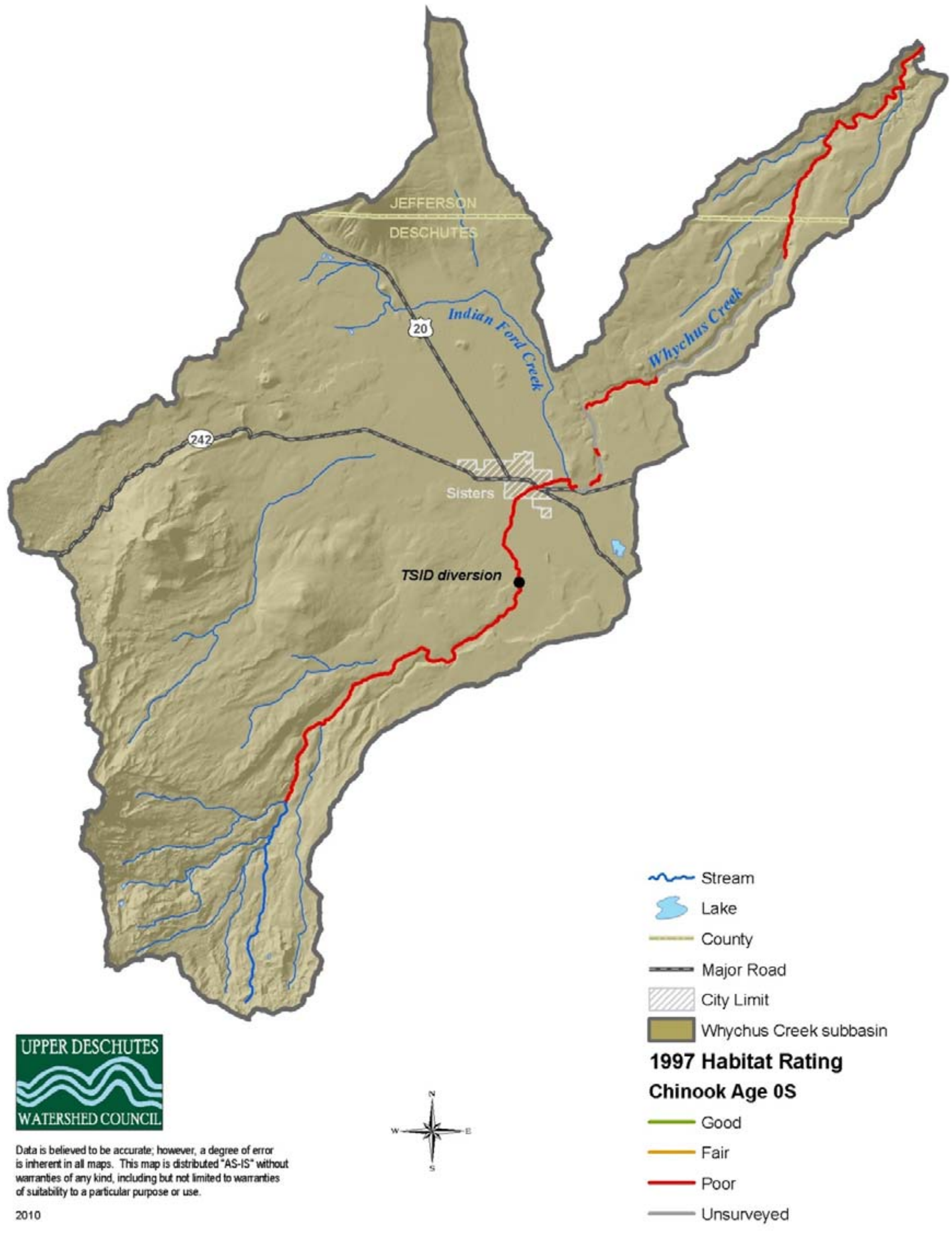

Figure 7.
1997 Habitat Ratings for Age 0+ Summer Chinook. This figure shows reach level habitat ratings for Age 0+ Summer chinook. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

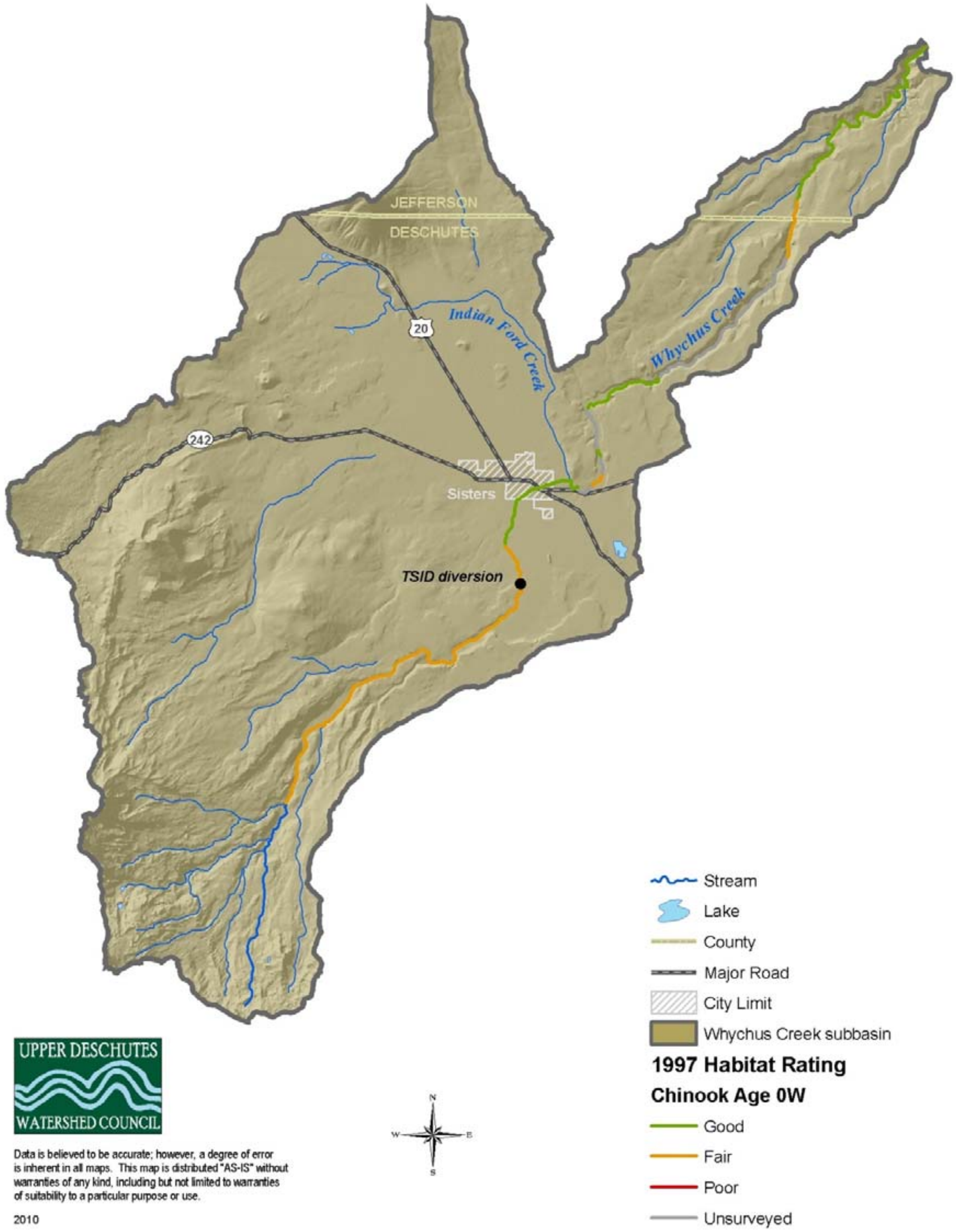

Figure 8.
This figure shows reach level habitat ratings for 0W chinook. Fisheries managers rated habitat conditions using data collected in 1997 and analyzed with HabRate in 2007.

2008/2009 Habitat Ratings

2008/2009 habitat ratings varied across Whychus Creek **(**Figure 9 to Figure 16**).** HabRate results indicate that habitat in Whychus Creek was more suitable for 0W and 1W steelhead than for other life stages in 2008/2009. Habitat in Whychus Creek was least suitable for 0S and 1S steelhead life stages (Figure 10, Figure 12)

Table 3). Only locations near the mouth of the creek provide adequate habitat for these life stages **(**Figure 10, Figure 12)

Table 3. 2008/2009 Steelhead Habitat Ratings.

2008 Reach Level Habitat Rating	Steelhead Life Stage Spawning and Rearing	Age 0+ Summer	Age 0+ Winter	Age 1+ Summer	Age 1+ Winter
Good	7.9	0	25.7	0	25.7
Fair	18.9	1.5	6.1	1.5	6.1
Poor	5.0	30.3	0	30.3	0
Unsurveyed	2.4	2.4	2.4	2.4	2.4

2008/2009 HabRate results suggest that Whychus Creek was most suitable for 0W chinook. Habitat conditions appear to be worst for 0S chinook (Table 4). Suitable habitat for this life stage only appears near the mouth of the creek (Figure 15).

Table 4. 2008 Chinook Habitat Ratings.

2008 Reach Level Habitat Rating	Chinook Life Stage Spawning and Rearing	Age 0+ Summer	Age 0+ Winter
Good	17.5	1.5	23.8
Fair	9.3	0	7.9
Poor	5.0	30.3	0
Unsurveyed	2.4	2.4	2.4

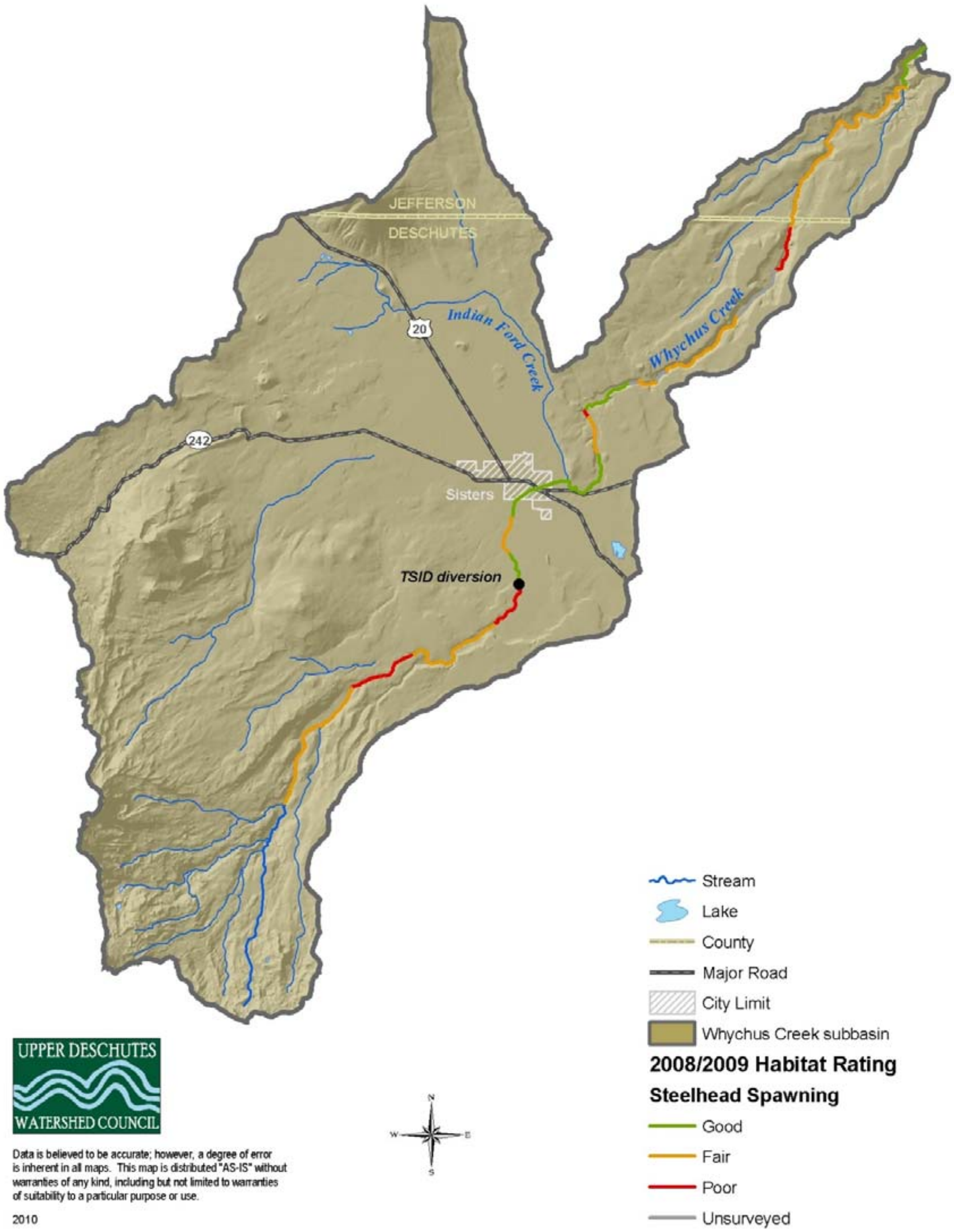

Figure 9.
This figure shows reach level habitat ratings for Spawning steelhead. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

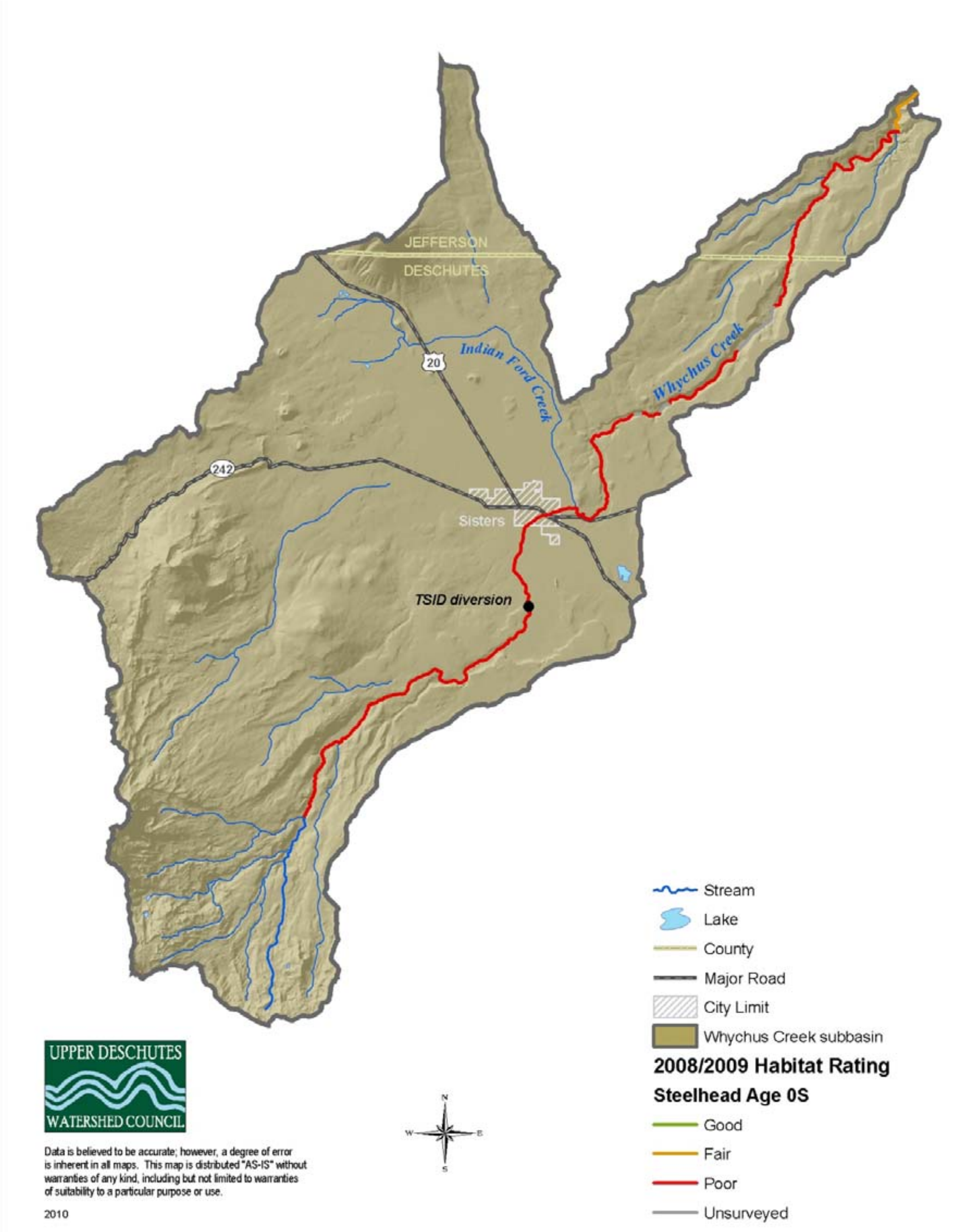

Figure 10.
This figure shows reach level habitat ratings for 0S steelhead. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

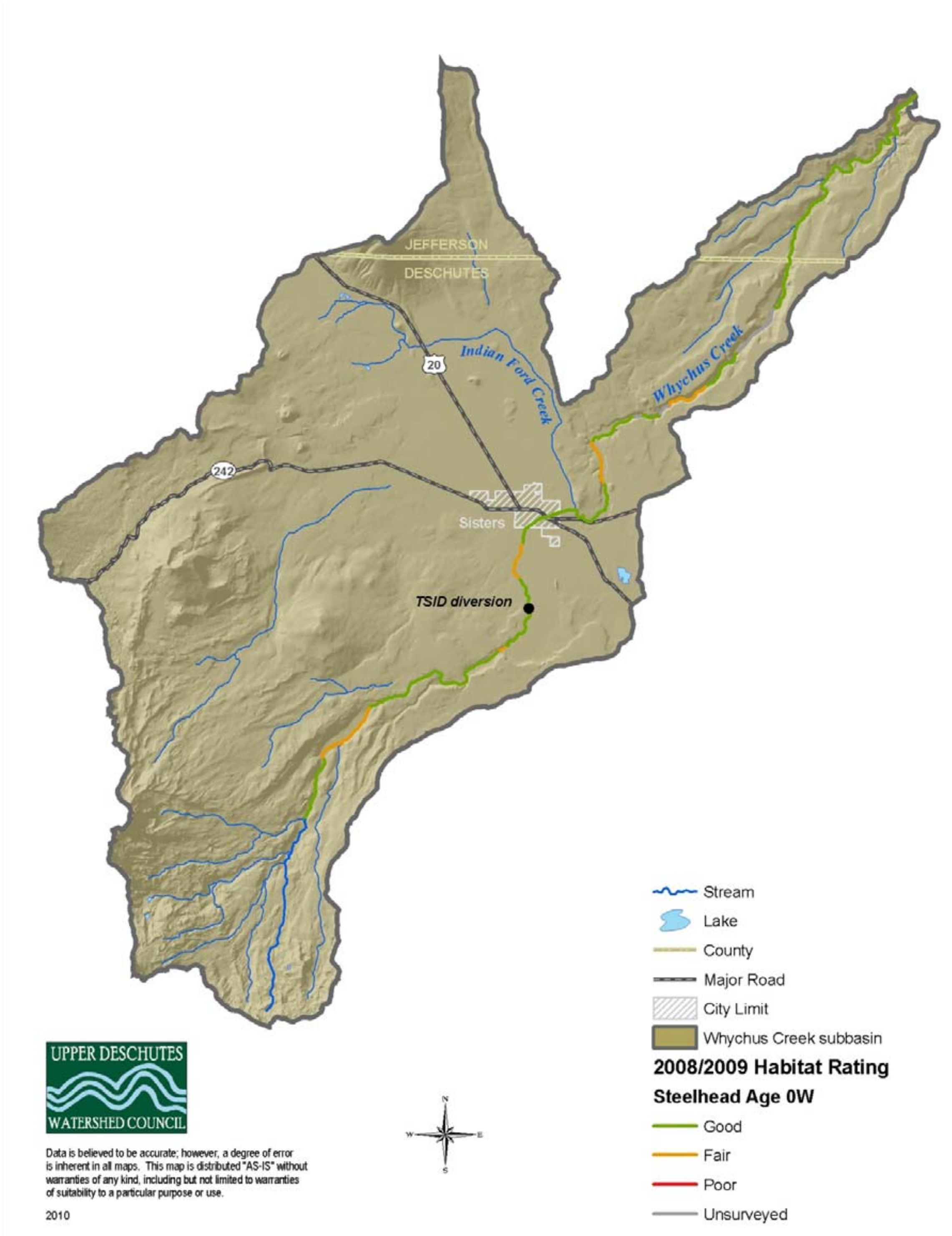

Figure 11.
This figure shows reach level habitat ratings for 0W steelhead. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

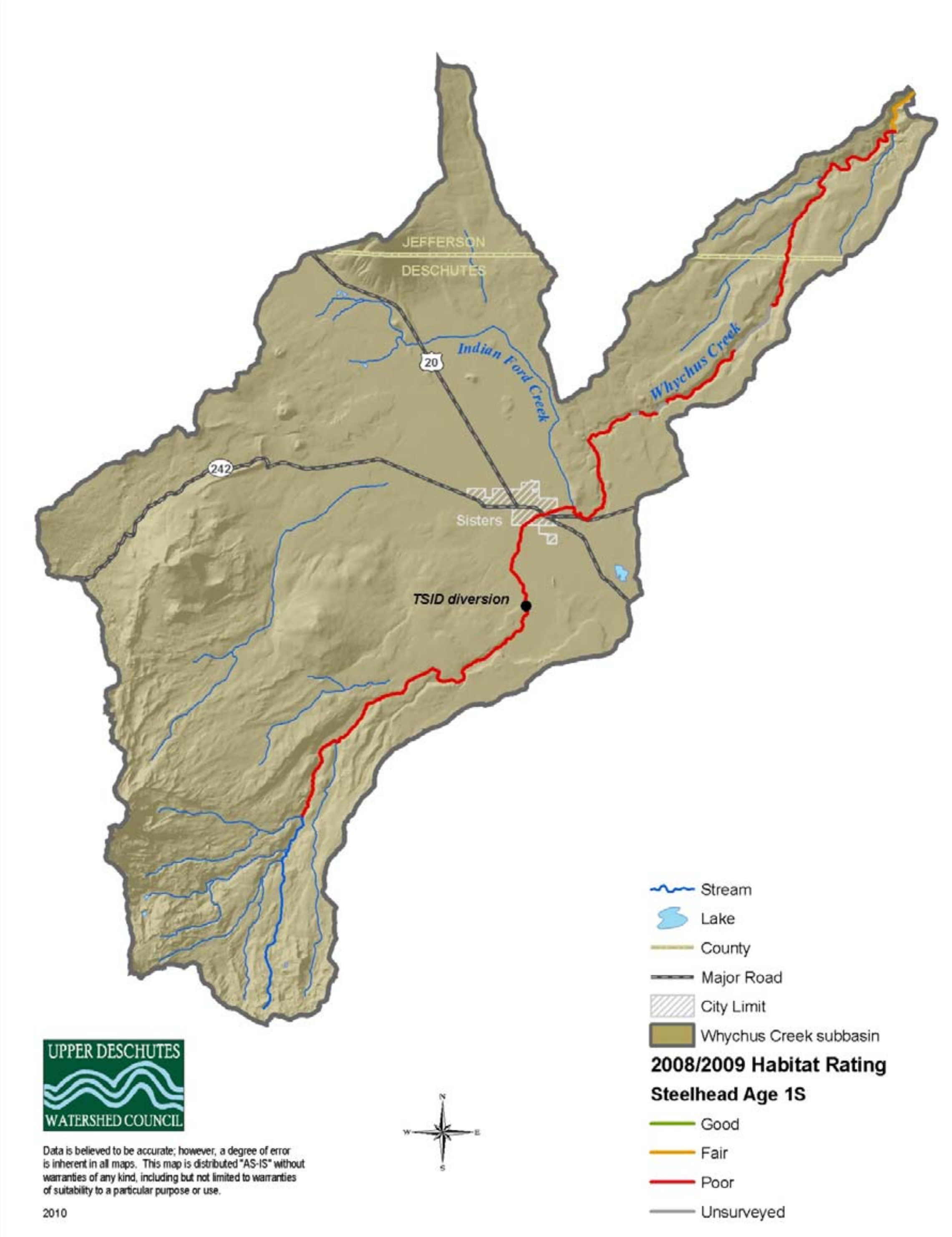

Figure 12.
This figure shows reach level habitat ratings for 1S steelhead. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

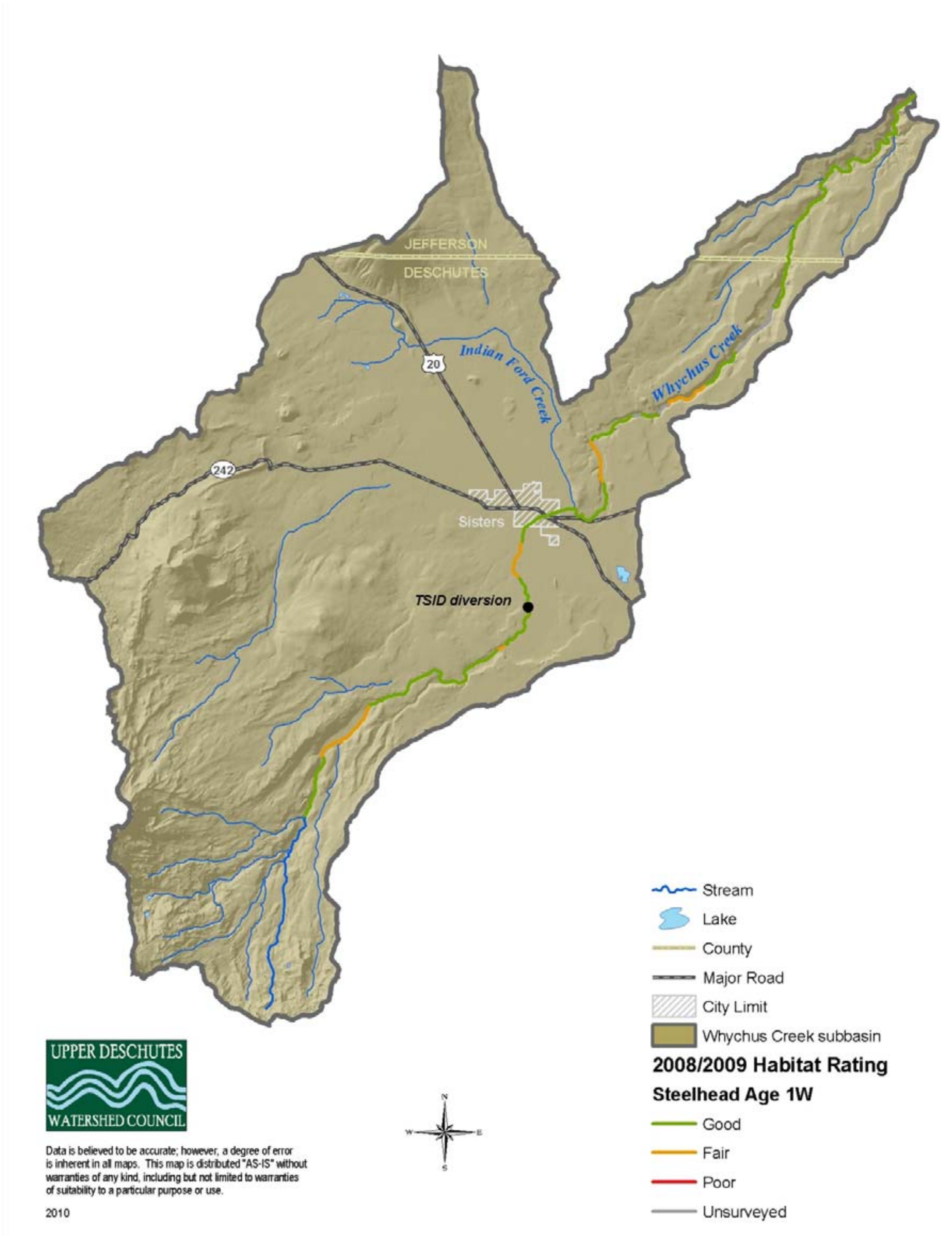

Figure 13.
This figure shows reach level habitat ratings for 1W steelhead. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

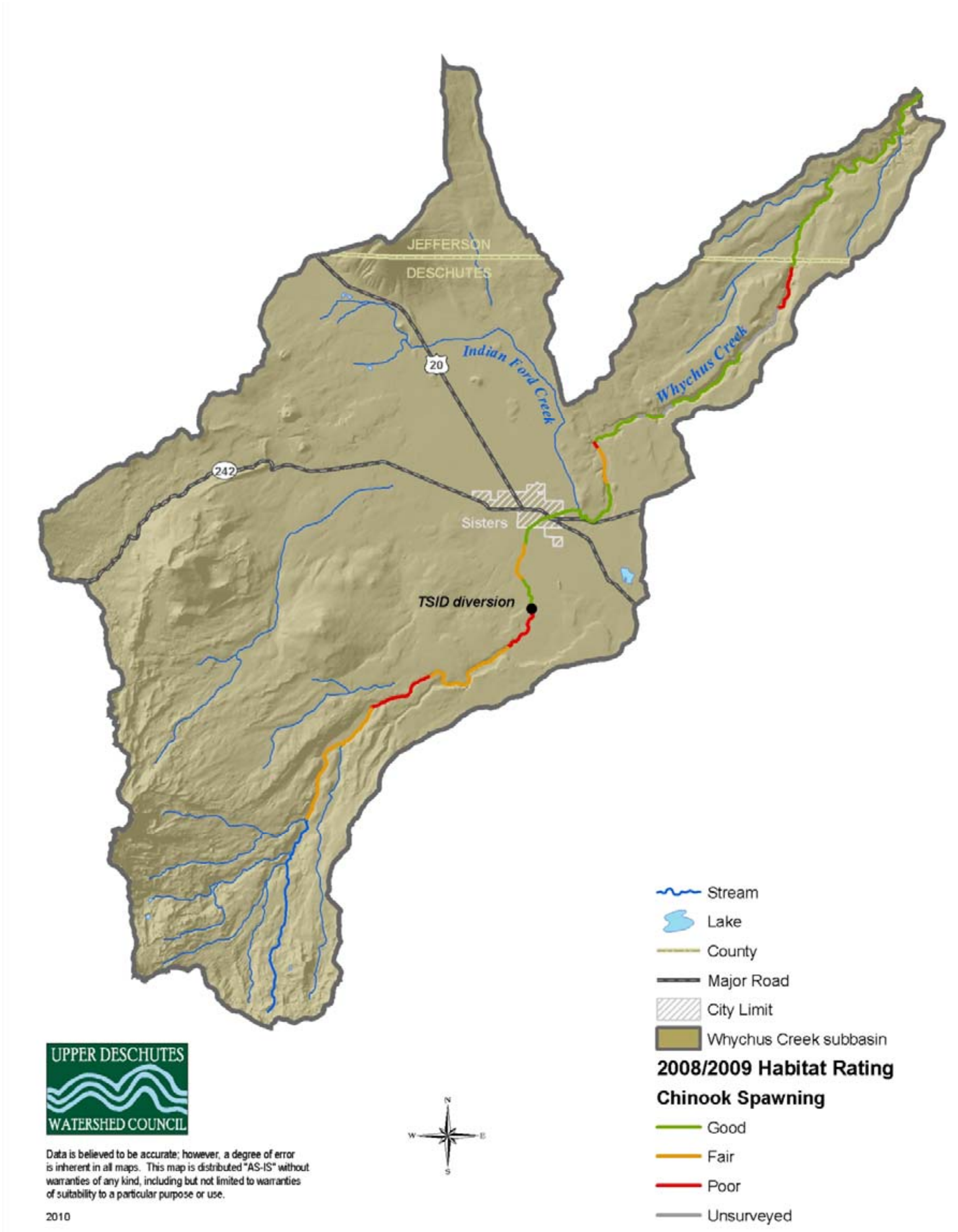

Figure 14.
This figure shows reach level habitat ratings for Spawning chinook. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

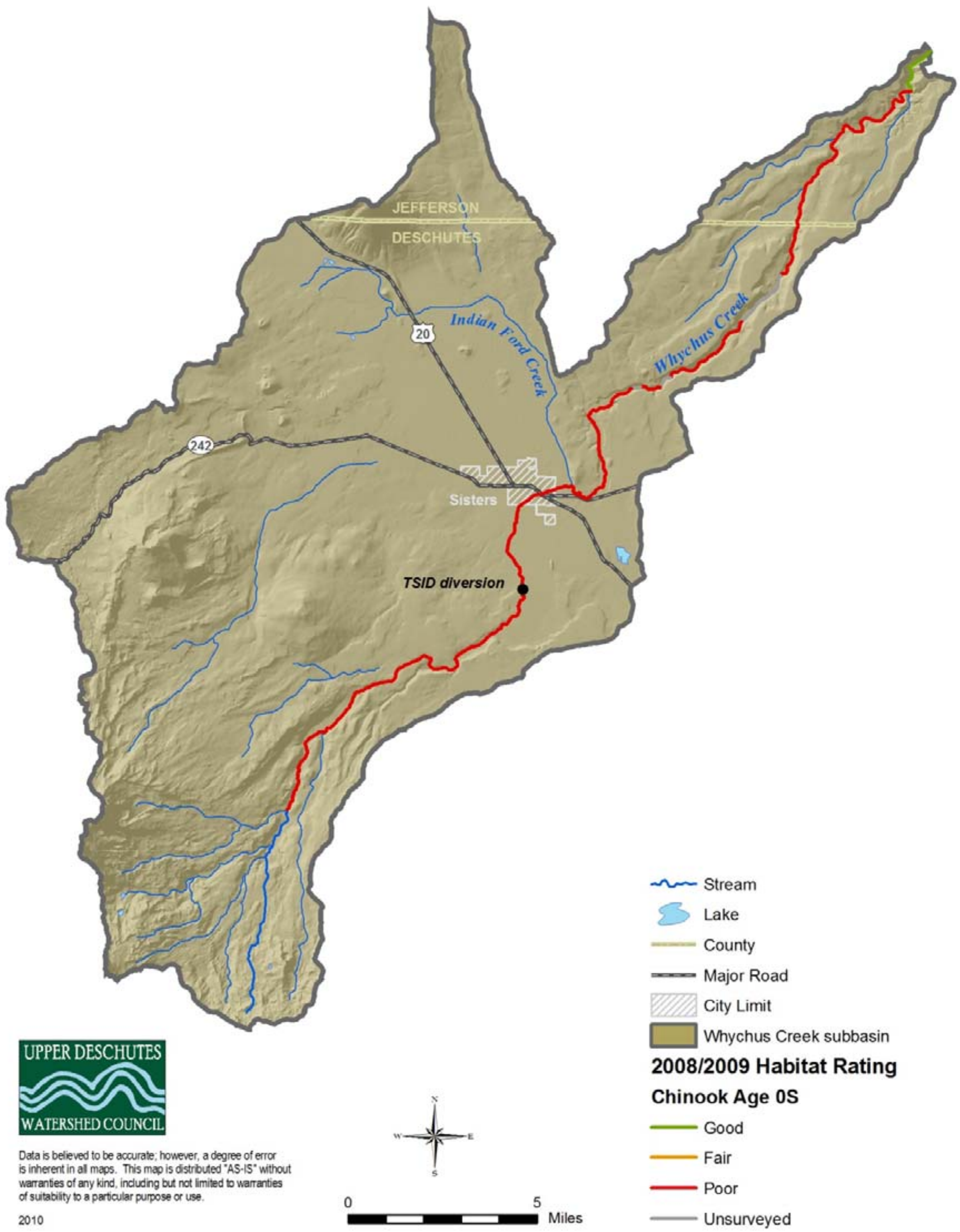

Figure 15.
This figure shows reach level habitat ratings for 0S chinook. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

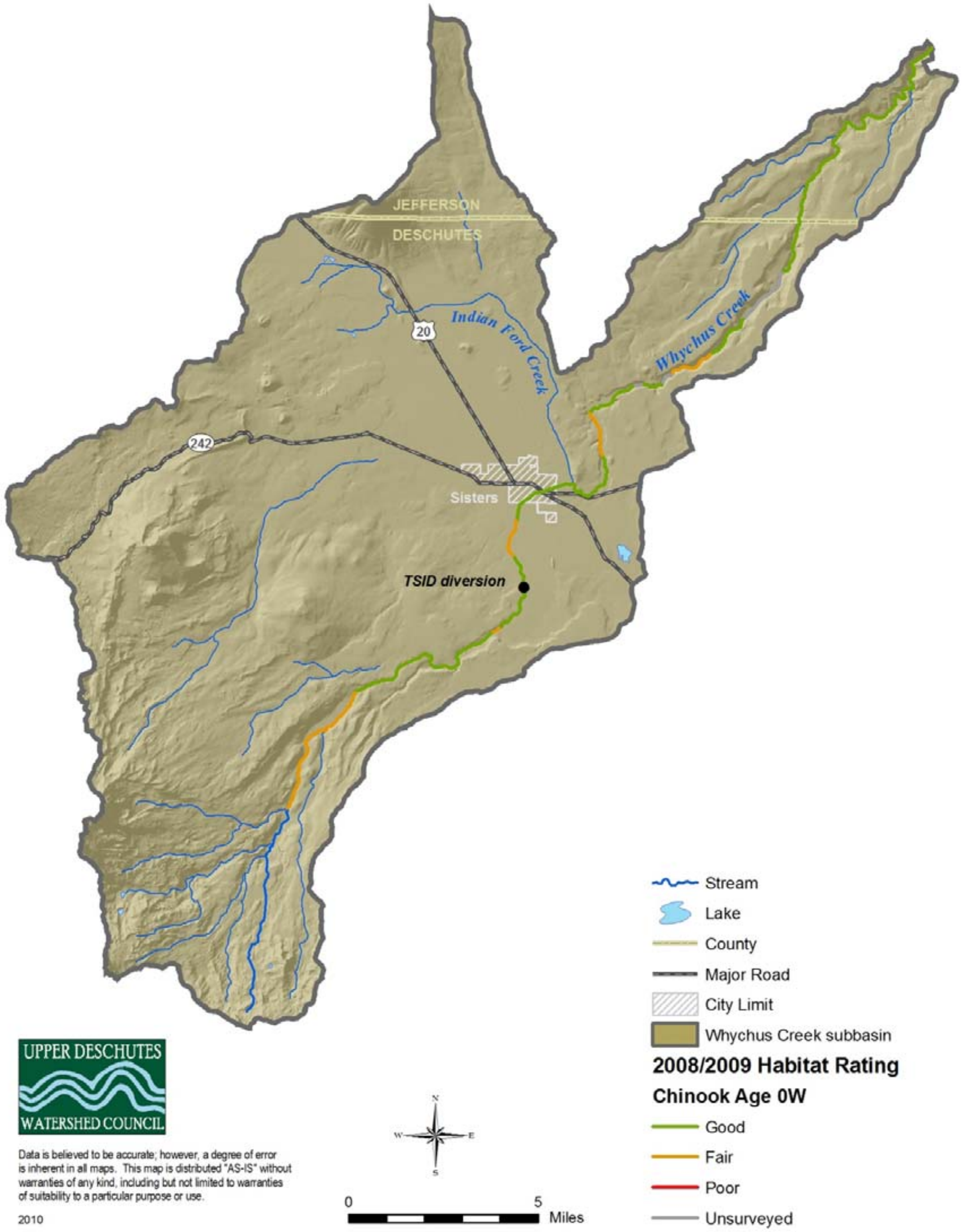

Figure 16.
This figure shows reach level habitat ratings for 0W chinook. Fisheries managers rated habitat conditions using data collected in 2008/2009 and analyzed with HabRate in 2010.

Changes in Habitat Ratings, 1997 to 2008/2009

Changes in reach level habitat ratings between 1997 and 2008/2009 surveys varied by species and by life stage (Figure 17 - Figure 24). Steelhead habitat ratings changed both upstream and downstream of the TSID diversion (Figure 17 - Figure 21).Stream habitat improved more for 1W steelhead than for any other life stage. Habitat ratings remained constant or declined for 0S and 1S steelhead (Table 5). Ratings declined upstream of the TSID diversion and downstream from the City of Sisters (Figure 18, Figure 20).

Table 5. Changes in Reach Level Habitat Ratings for Steelhead Life Stages.

Change in Reach Level Habitat Rating	Steelhead Life Stage Spawning and Rearing	Age 0+ Summer	Age 0+ Winter	Age 1+ Summer	Age 1+ Winter
Improve	6.8	0	11.2	0	13.2
No Change	15.3	12.1	14.3	12.1	12.3
Decline	4.3	14.4	1.0	14.4	1.0
Unsurveyed	7.6	7.6	7.6	7.6	7.6

Chinook habitat ratings changed across Whychus Creek between 1997 and 2008/2009. Stream habitat improved more for Spawning chinook than for any other life stage. Stream habitat also declined more for Spawning chinook than for any other life stage (Table 6). Spawning Chinook ratings improved between the TSID diversion and the mouth of the creek and declined at locations upstream and downstream from the TISD diversion (Figure 22). 0W chinook habitat improved at locations upstream and downstream from the diversion as well (Figure 23). 0S chinook habitat ratings mostly remained stable, with a short area of improvement at the mouth of Whychus Creek (Figure 24).

Table 6. Changes in Reach Level Habitat Ratings for Chinook Life Stages.

Change in Reach Level Habitat Rating	Chinook Life Stage Spawning and Rearing	Age 0+ Summer	Age 0+ Winter
Improve	11.3	1.5	9.4
No Change	10.1	25.0	16.2
Decline	5.1	0	1.0
Unsurveyed	7.6	7.6	7.6

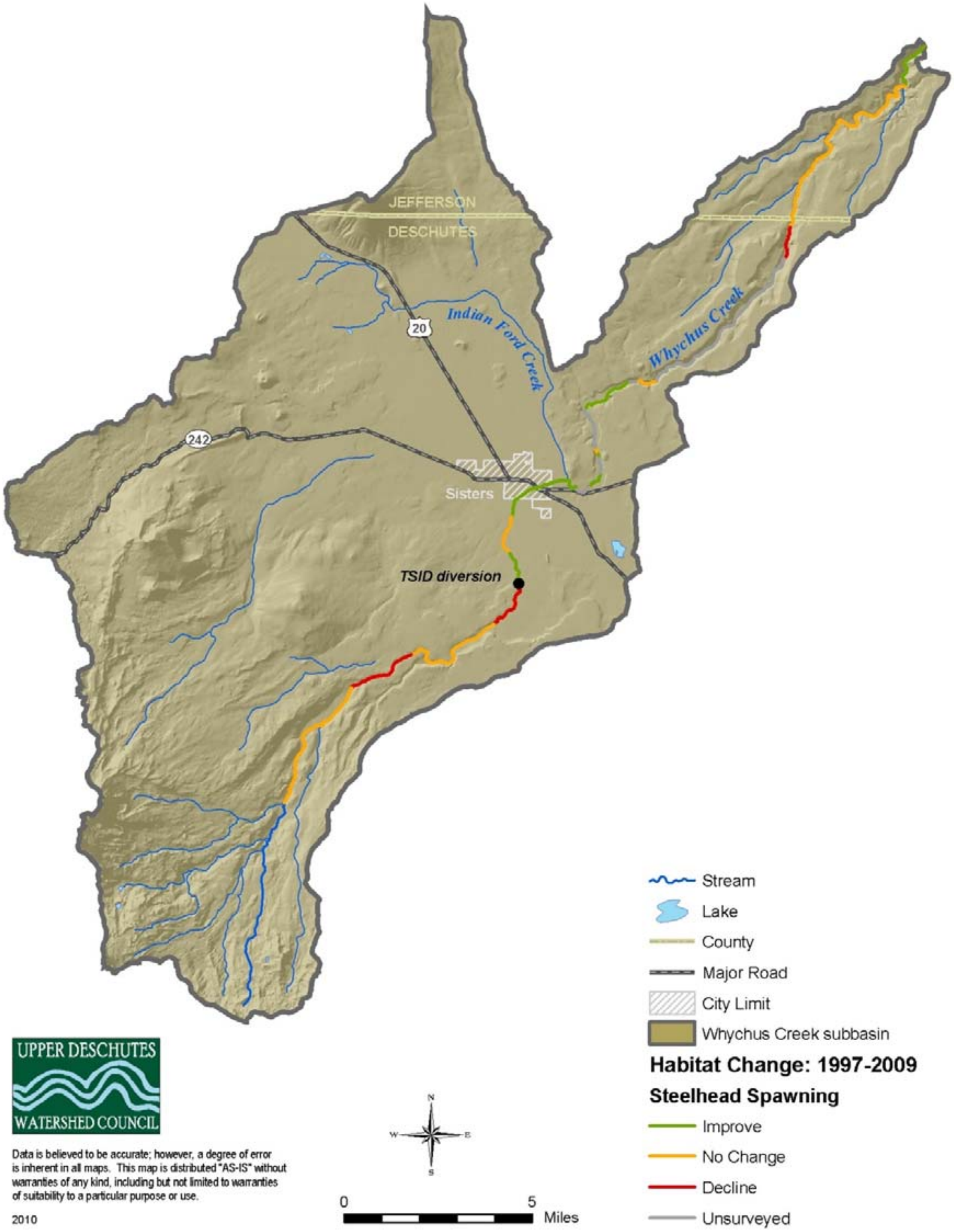

Figure 17.
This figure shows changes in reach level habitat ratings for Spawning steelhead in Whychus Creek based on 1997 and 2008/2009 habitat surveys.

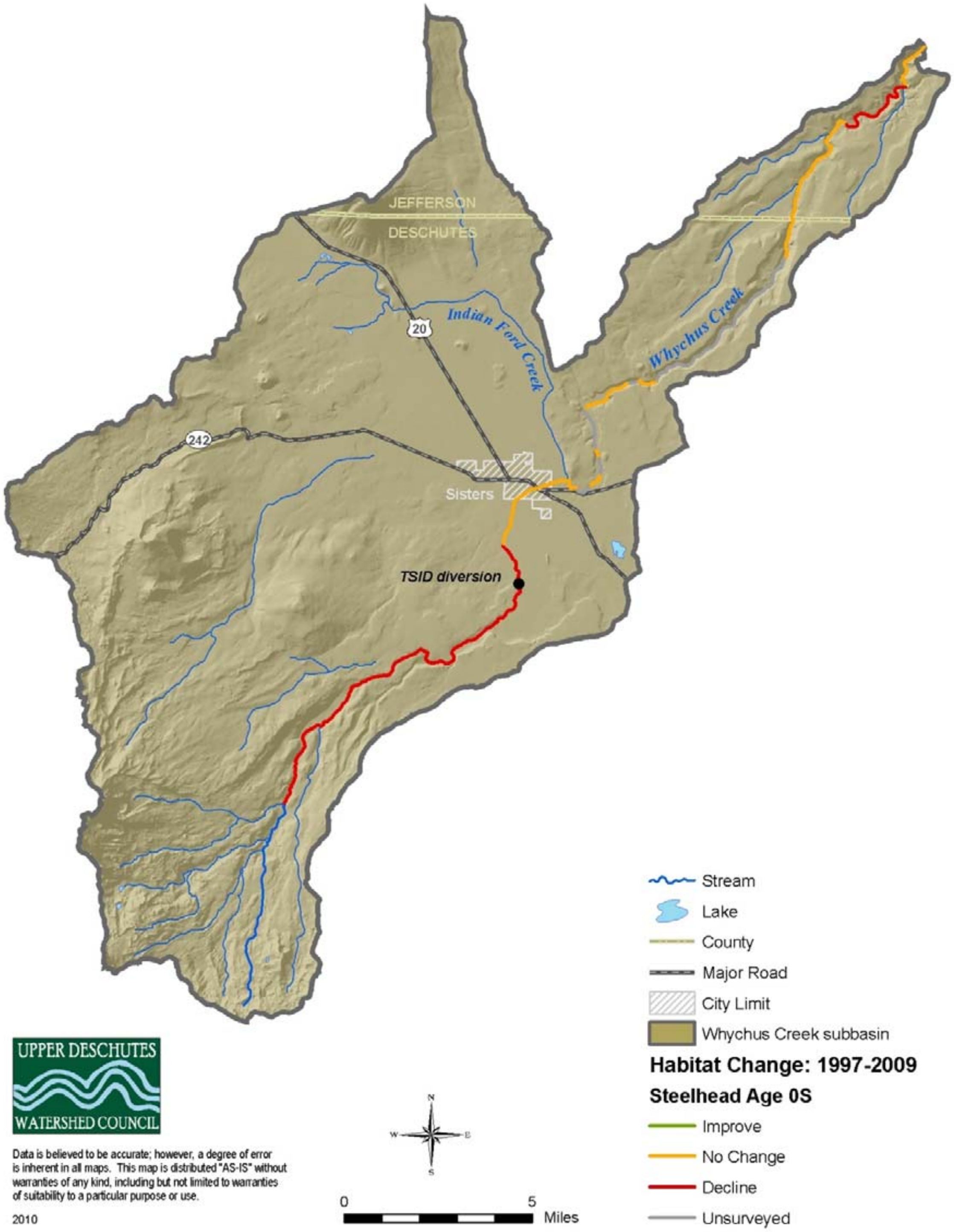

Figure 18.
This figure shows changes in reach level habitat ratings for 0S steelhead in Whychus Creek based on 1997 and 2008 habitat surveys.

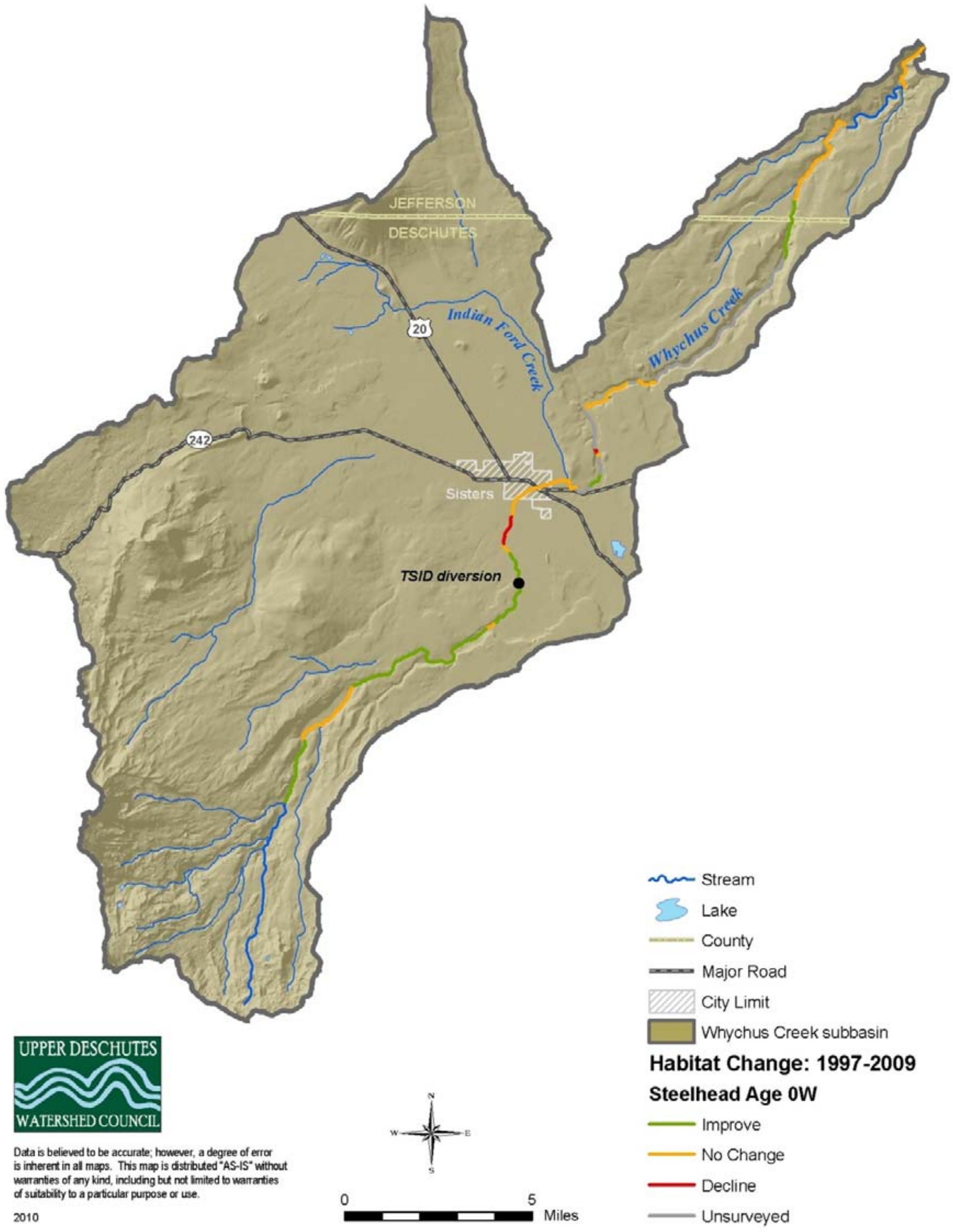

Figure 19.
This figure shows changes in reach level habitat ratings for 0W steelhead in Whychus Creek based on 1997 and 2008 habitat surveys.

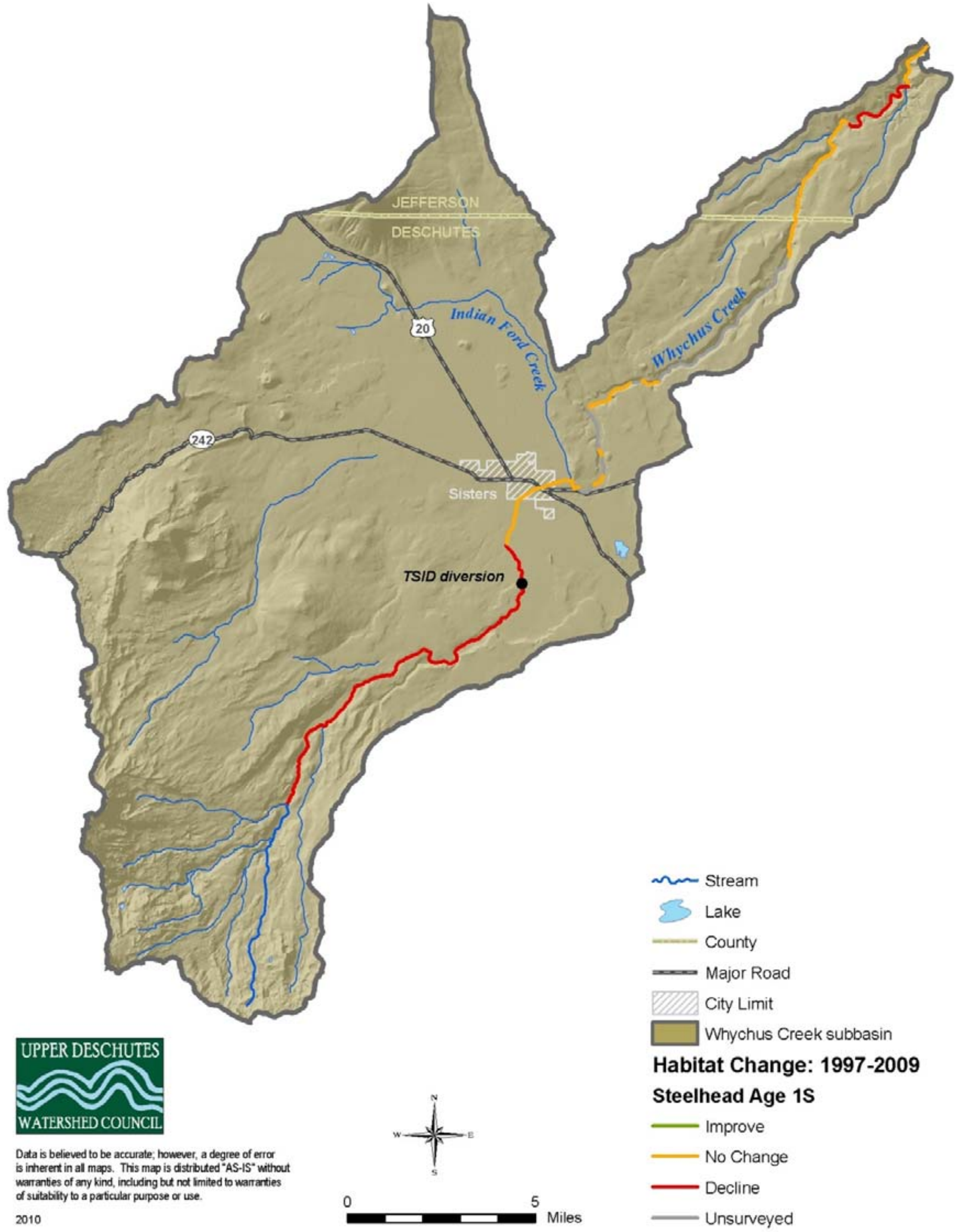

Figure 20.
This figure shows changes in reach level habitat ratings for 1S steelhead in Whychus Creek based on 1997 and 2008/2009 habitat surveys.

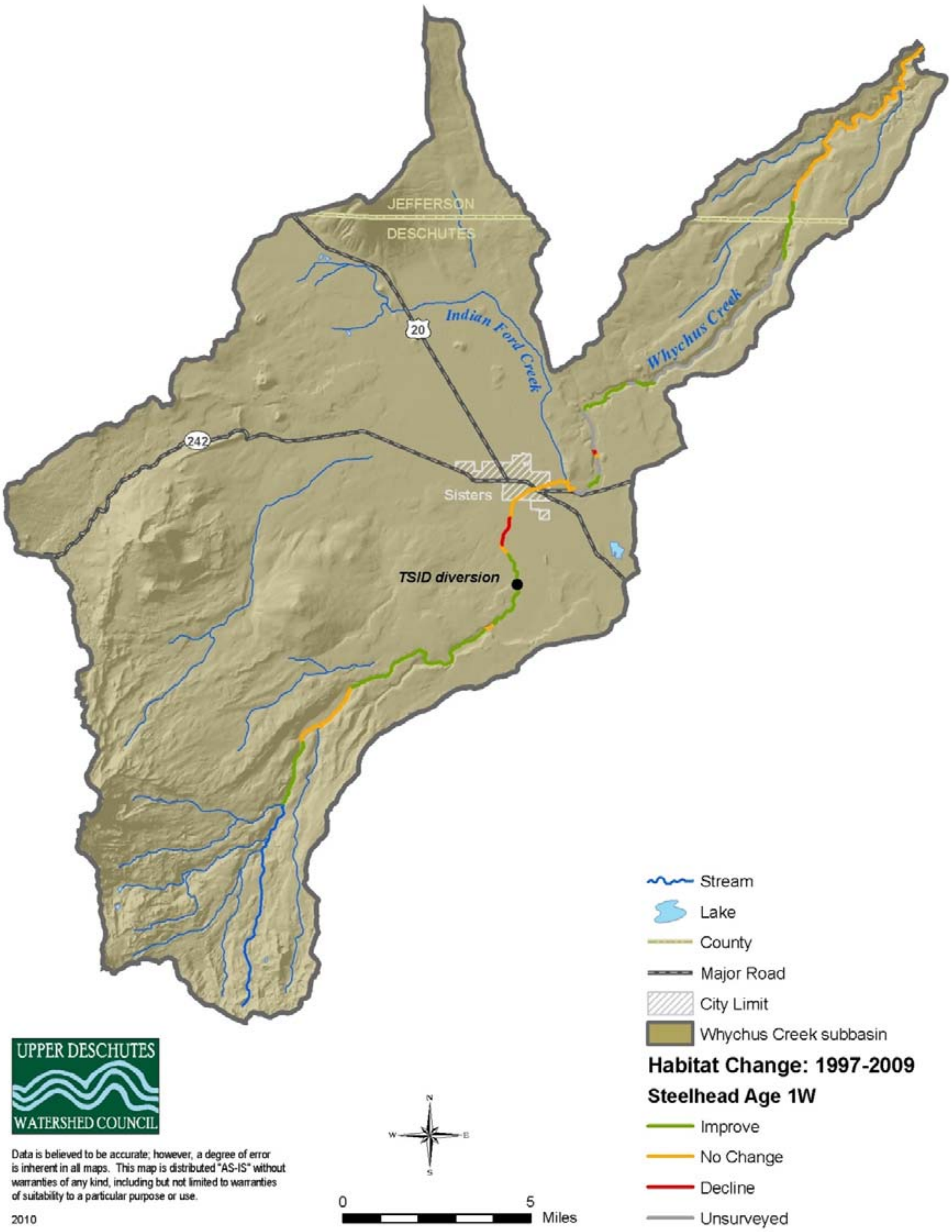

Figure 21.
This figure shows changes in reach level habitat ratings for 1W steelhead in Whychus Creek based on 1997 and 2008 habitat surveys.

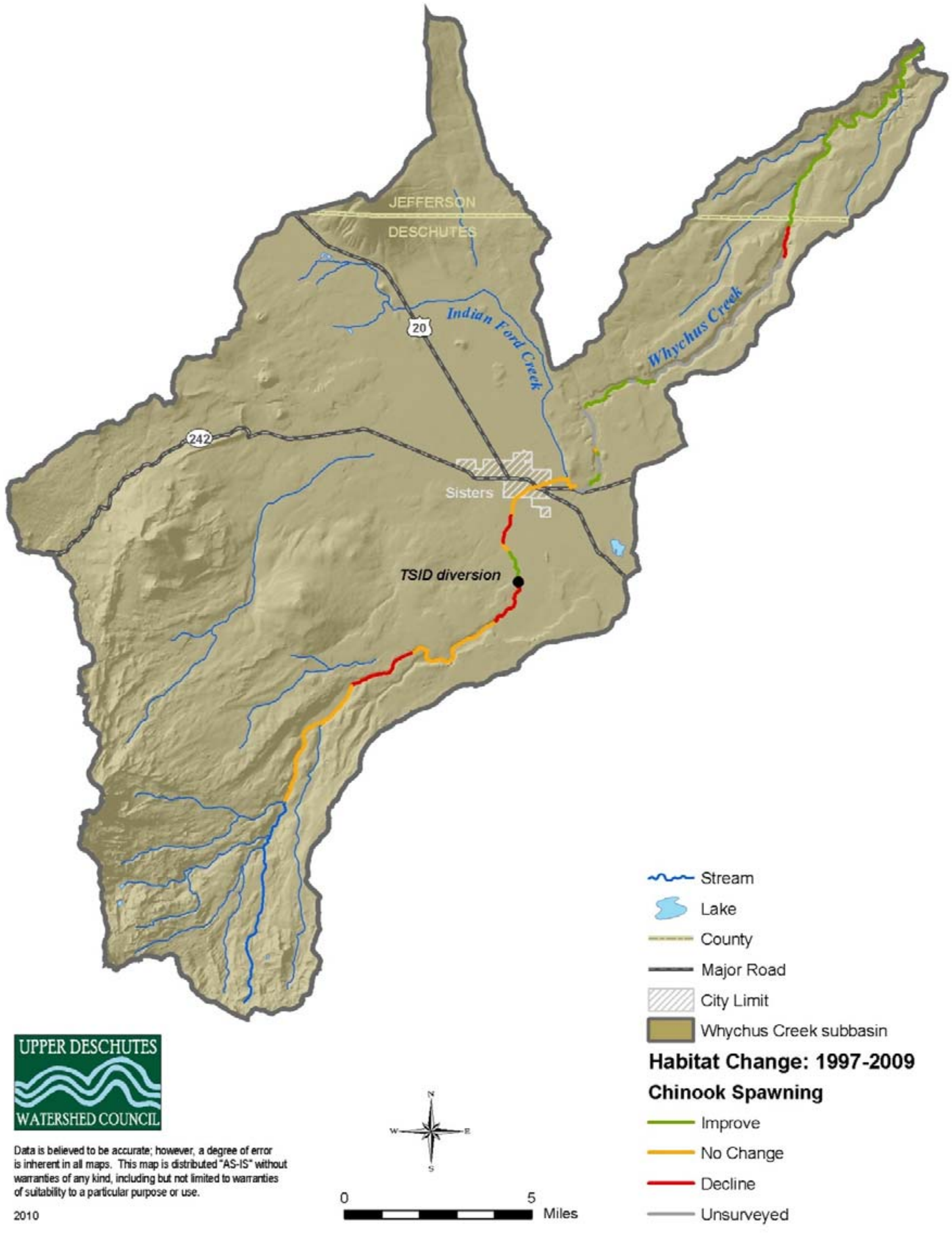

Figure 22. This figure shows changes in reach level habitat ratings for Spawning chinook in Whychus Creek based on 1997 and 2008/2009 habitat surveys.

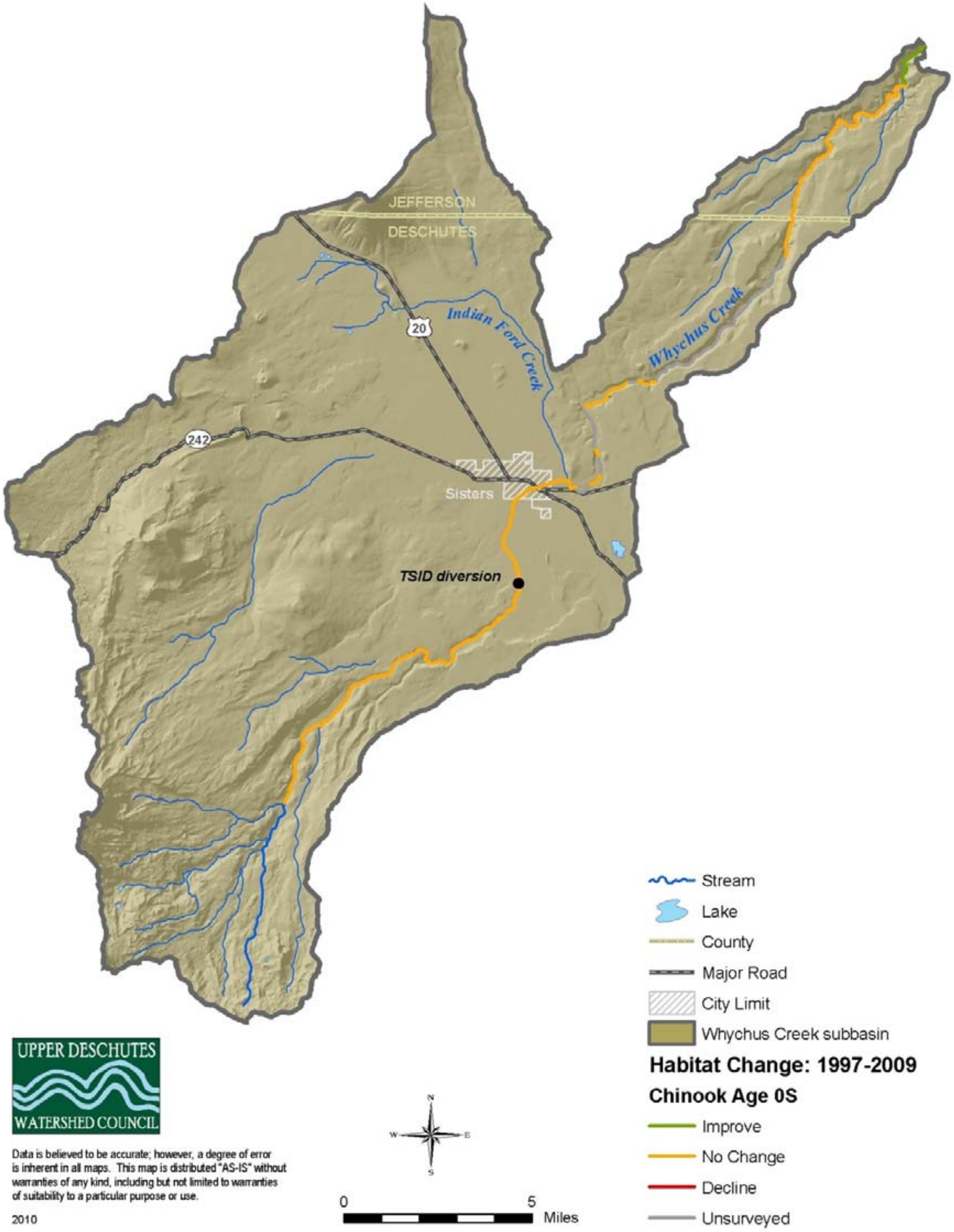

Figure 23.
This figure shows changes in reach level habitat ratings for Whychus Creek based on 1997 and 2008/2009 habitat surveys.

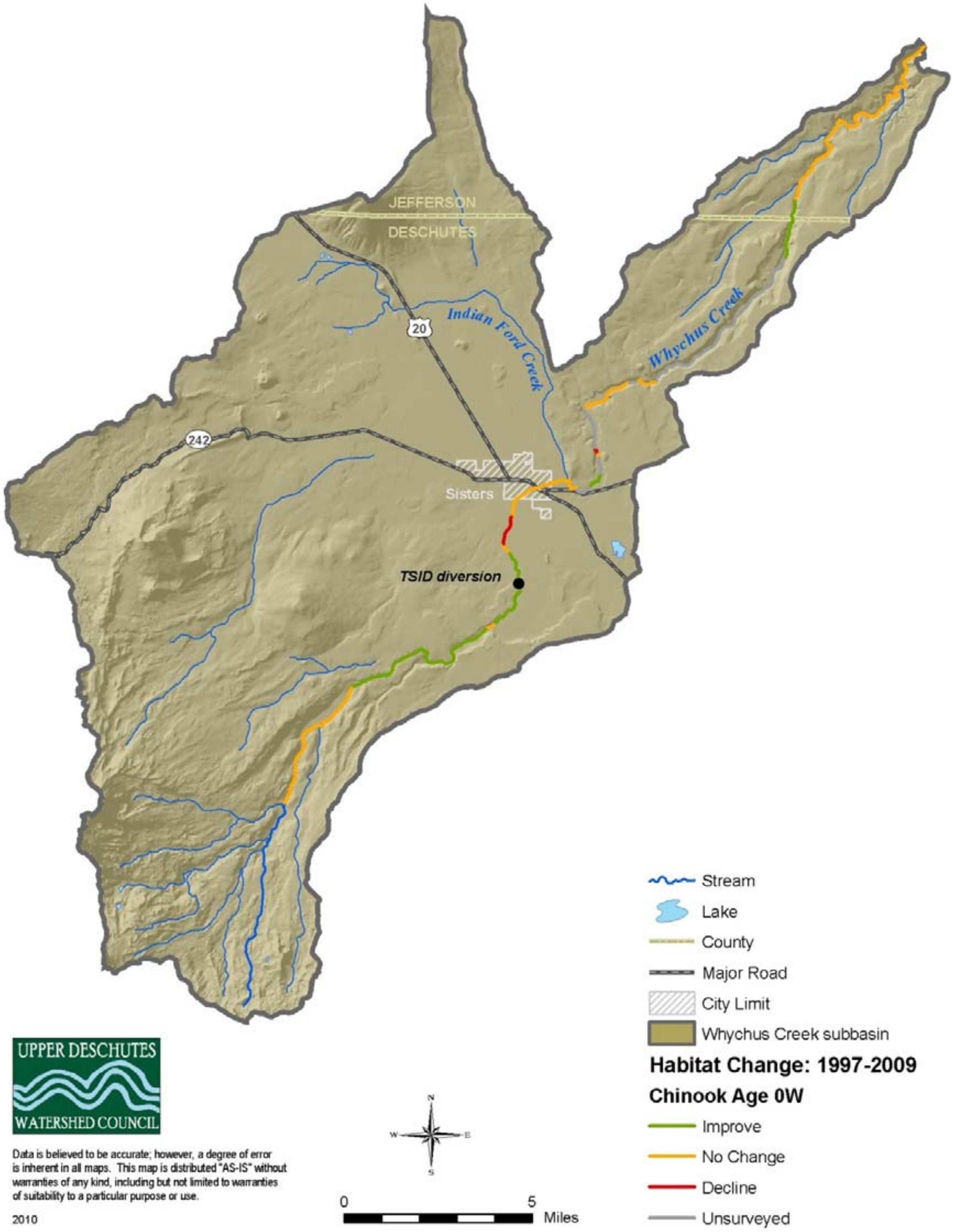

Figure 24. This figure shows changes in reach level habitat ratings for 0W chinook in Whychus Creek based on 1997 and 2008/2009 habitat surveys.

Discussion

1997 Conditions

HabRate results suggest that historic conditions in Whychus Creek might have been adequate to support steelhead and chinook. The creek contained relatively little adequate Spawning chinook, 0S chinook, 0S steelhead, and 1S steelhead habitat in 1997 (Figure 2, Figure 4, Figure 6, Figure 7). This habitat may not have been accessible to returning adults. Portions of it would not have been accessible to juveniles, due to passage barriers associated with irrigation diversions.

2008/2009 Baseline Conditions

2008/2009 baseline habitat ratings suggest that conditions in Whychus Creek are adequate to support most life stages of steelhead and chinook. Conditions for Spawning, 0W, and 1W. steelhead were largely adequate downstream from the TSID diverson (Figure 9, Figure 11, Figure 12). Conditions for Spawning and 0W chinook were also adequate downstream from the TSID diversion (Figure 14, Figure 16). HabRate suggested that conditions were largely inadequate for summer life stages of steelhead and chinook in 2008/2009. Fisheries surveys in 2008/2009 found juvenile steelhead in reaches with inadequate habitat ratings. Their presence might suggest that local habitat conditions are better than reach level habitat conditions, that HabRate does not fully reflect habitat conditions for these life stages, or that fish are migrating from reaches with better habitat conditions. HabRate rated all but the most downstream reach of Whychus Creek as inadequate for 0S and 1S steelhead, but juvenile fish may have migrated from unsurveyed reaches with unknown habitat conditions.

Changes in Reach Level Habitat Ratings, 1997 – 2008/2009

Habitat ratings along Whychus Creek have changed between 1997 and 2009. Results suggest that conditions have declined for some life stages in some locations while conditions have improved for some life stages in some locations. In some locations, results are not consistent with changes expected in the creek due to restoration actions.

Restoration partners expected that habitat conditions upstream from the TSID diversion would not have changed between 1997 and 2008/2009 surveys. HabRate results suggest that conditions declined for Spawning steelhead, 1S steelhead, 0S steelhead, and Spawning chinook upstream from the diversion (Figure 17, Figure 18, Figure 20, Figure 22). No large-scale management actions occurred upstream from the diversion. Any habitat changes that occurred between 1997 and 2008/2009 likely resulted from natural events in the creek as opposed to active management of the creek.

Natural events and changes in stream flow may have contributed to any changes in habitat conditions between the TSID diversion and Alder Springs. Restoration partners increased protected stream flows in Whychus Creek between 1997 and 2008/2009. HabRate includes stream flow, water depth, and stream temperature parameters. Increased protected stream flows have likely affected each of these parameters. Restoration partners expected to see improved habitat ratings in this reach due to improvements in summer stream flows. Habitat ratings improved for Spawning steelhead, 0W steelhead, 1W steelhead, Spawning chinook, and 0W chinook in some locations along this reach (Figure 17, Figure 19, Figure 21, Figure 22, Figure 24). Increased summer stream flows may directly contribute to improved spawning ratings in the creek and indirectly contribute to improved winter conditions.

The approach used in this report broadly identifies where habitat ratings have changed between 1997 and 2008/2009. The relatively coarse scale and the reach divisions used in the HabRate analysis both affect these results. 1997 HabRate analysis used different reaches than 2008/2009 habitat analysis. This analysis documents where the overlapping portions of these two reaches appear to have changed in habitat quality between 1997 and 2008. HabRate bases reach level habitat ratings on aggregated data collected throughout the reach. On the ground, the overlapping portions of these reaches may not have changed between 1997 and 2008/2009. Any apparent changes in habitat ratings may be due to changes occurring elsewhere in the reaches. These changes propagate through their respective reaches and affect reach level ratings.

One way to avoid these challenges in the future is to create smaller reaches that have reach breaks at the same locations as historic surveys. Both the existing survey data and the HabRate model can be used at smaller scales. Creating smaller reaches with consistent reach breaks between years will allow for a stronger analysis of inter-annual habitat quality change.

This analysis assumes that HabRate parameters accurately describe desired conditions for the species and life history stages described in this report. As fisheries managers continue to work in Whychus Creek, they may further revise their understanding of fish habitat needs in the creek. The HabRate model should be updated as their understanding improves, and historic data should be re-analyzed as managers update the model.

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Stream Connectivity in Whychus Creek

Mathias Perle
Upper Deschutes Watershed Council
700 NW Hill St
Bend, OR 97701
rhouston@restorethedeschutes.org

Abstract

The 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. The UDWC surveyed fish passage barriers along the creek prior to any barrier removals. They compared survey data to criteria established by both ODFW and NOAA to determine if inventoried barriers were passage barriers for anadromous and resident fish. A total of six barriers limit connectivity in Whychus Creek, effectively dividing the creek into seven reaches of varying length from one mile to 11 miles. The UDWC is actively working to provide passage at three of these barriers. Removal of these 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 2008.

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 (Berkamp *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). The 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, biological indicators such as 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 limit 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 in 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. In addition, NOAA 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 a good example of seasonal type passage barrier. In addition due 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 NOAA criteria for fish passage at the time of the survey.

Data Collection

Data were collected between 2002 - 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 NOAA (ODFW 2004, NOAA 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.

The 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 NOAA criteria at any time of the year.

Results

Results indicate that six fish passage barriers exist along Whychus Creek from river mile 14.7 to river mile 25.2 (Table 1, Figure 1). As mentioned in above, the UDWC and its partners are actively working with landowners and water right holders to remove or retrofit these fish passage barriers in order to provide fish passage for all life stages of anadromous and resident species on a year round basis at all flows.

Existing barriers affect the number of miles of contiguous stream habitat (Figure 2). Over time, as barriers are removed, contiguous habitat will increase. Currently the first 21.3 rivers miles of Whychus Creek are accessible to anadromous fish at different times of the year. Barrier No. 1 and 2 are considered partial barriers.

Table 1.
The UDWC collected 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	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
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
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%	5.0	54.0	18.0	Yes	Three Sisters Irrigation District Dam
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.*
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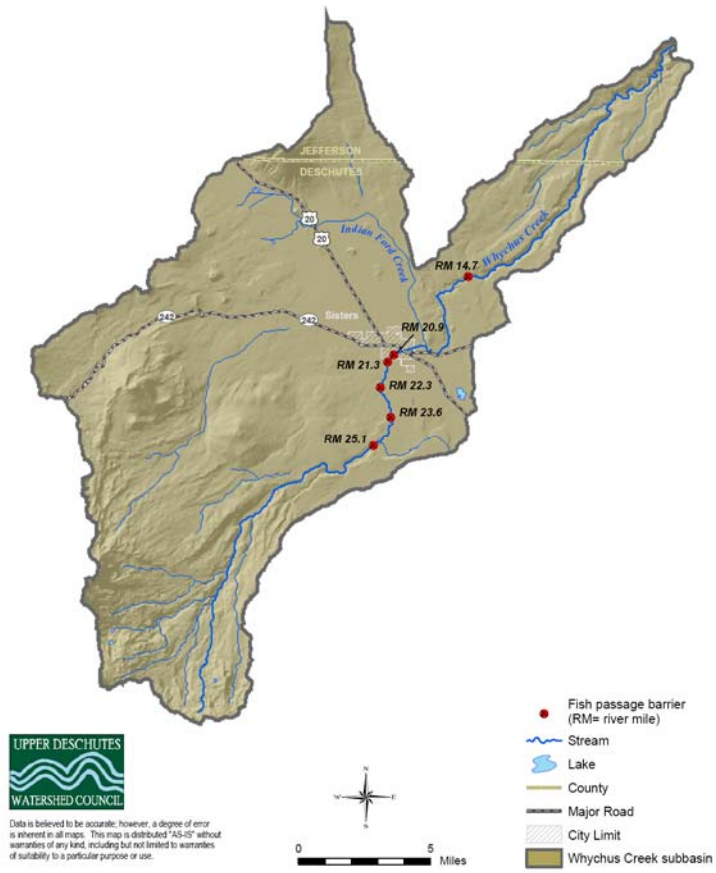

Figure 1.
The six barriers identified by the UDWC impair stream connectivity between river miles 14.2 and 25.1. The UDWC and its partners expect to provide passage at each of these barriers.

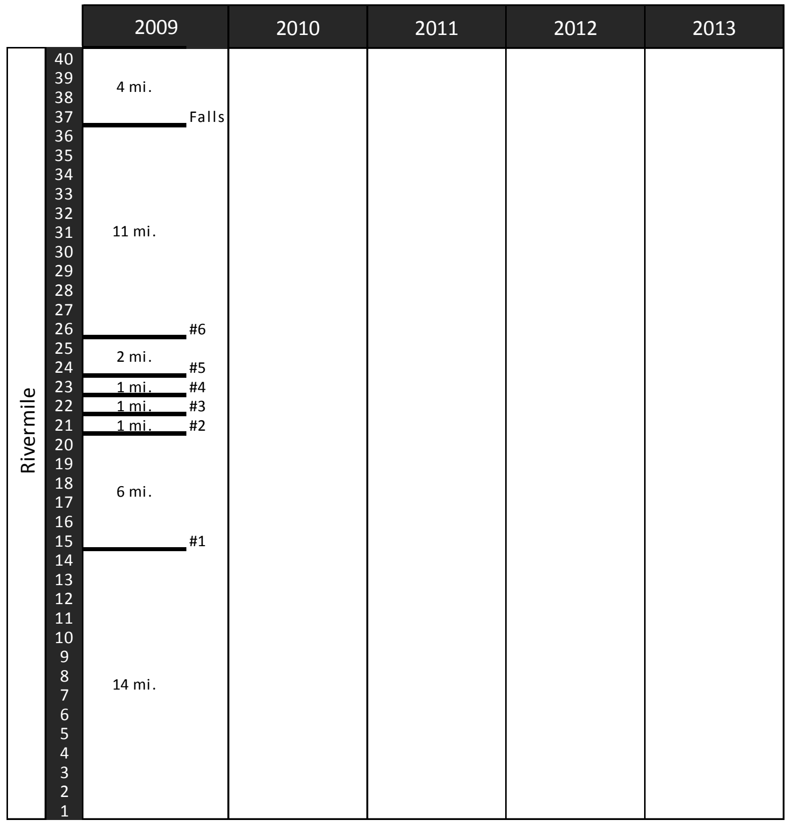

Figure 2.
Six existing barriers (numbered per Table 1) limit connectivity in Whychus Creek, effectively dividing the creek into seven reaches of varying length from one mile to 11 miles. Whychus Creek Falls, located between river mile 36 and 37 is a natural barrier.

Discussion

The UDWC is actively working to retrofit or remove fish passage barriers with water right holders and landowners who operate three (Barriers No. 3, 4 and 5) of the six passage barriers identified on Whychus Creek. Removal of these barriers could provide 15 additional miles of habitat connectivity for anadromous species. As these projects are implemented and this inventory updated every year, it will be possible to monitor the additional river miles of habitat opened to anadromous and resident fish.

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Fish Entrainment Potential in Whychus Creek

Mathias Perle
Upper Deschutes Watershed Council
700 NW Hill St
Bend, OR 97701
rhouston@restorethedeschutes.org

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. The 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 of associated with the irrigation diversion serve as coarse but cost-effective indicators of entrainment potential. 12 of the 13 active irrigation diversions along Whychus Creek do not currently have state and federally approved fish screens. Of the roughly 193 cfs of water diverted for irrigation, only 0.45 cfs or 0.02% of the water diverted for irrigation is currently diverted through state and federally approved fish screens. As of fall 2009, restoration partners are working to screen four of the unscreened irrigation diversions. Fish screening at these diversions could reduce the cumulative unscreened diversion rate from 193 cfs down to 32 cfs. It will be possible to monitor how fish entrainment risk declines over time as restoration partners screen existing irrigation diversions.

Introduction

The UDWC selected fish entrainment potential as an indicator of restoration effectiveness on Whychus Creek. The 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, as described by Perle (2010a), they potentially block fish passage. Second, unscreened diversions divert fish almost as effectively as they divert water. This technical report documents the potential for fish entrainment at irrigation diversions in Whychus Creek at the close of 2008.

Numerous studies have shown that unscreened irrigation diversions act as sinks for fish populations (Roberts *et al* 2008, Gale *et al* 2008, Carlson *et al* 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, the UDWC selected two simple metrics to estimate entrainment potential. The number of unscreened diversions and the total diversion rate of 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, the 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 data set 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 the NOAA Fisheries (NOAA). NOAA establishes fish screening criteria for anadromous species (NOAA 2008) and ODFW currently follows NOAA 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.

Data Analysis

The UDWC compared diversion screening data to screening criteria established by both ODFW and NOAA (NOAA 2008). They determined if 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. Base on flow conditions and barrier operation (i.e. irrigation diversion dams), instances occur where passage at barriers is provided at different times of year.

The 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 fish species. As one mode of establishing a baseline of risk factors linked to fish entrainment for future years, the total flow rate of unscreened water was tallied. It is expected that irrigation diversions in the coming years will be retrofit with state and federally approved fish screens. As one indicator for potential fish entrainment, the total flow rate of unscreened irrigation water diverted from Whychus Creek will decline as these projects are implemented in the years to come.

Results

12 of 13 active irrigation diversions along Whychus Creek do not currently have state and federally approved fish screens. These irrigation diversions extend from river mile 9.25 to river mile 25.25 (Table 1, Figure 1). The cumulative maximum irrigation diversion rate through unscreened diversions on Whychus Creek was found to be approximately 193 cfs (Table 1). These diversions represent over 90%

of streamflow during the low flow periods in the summer and fall. Of the roughly 193 cfs of water diverted for irrigation, only 0.45 cfs or 0.02% of the water diverted for irrigation is currently diverted through state and federally approved fish screens. The UDWC and ODFW, along with many of their partners, are actively working with landowners and water right holders to retrofit these irrigation diversions to provide 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.

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

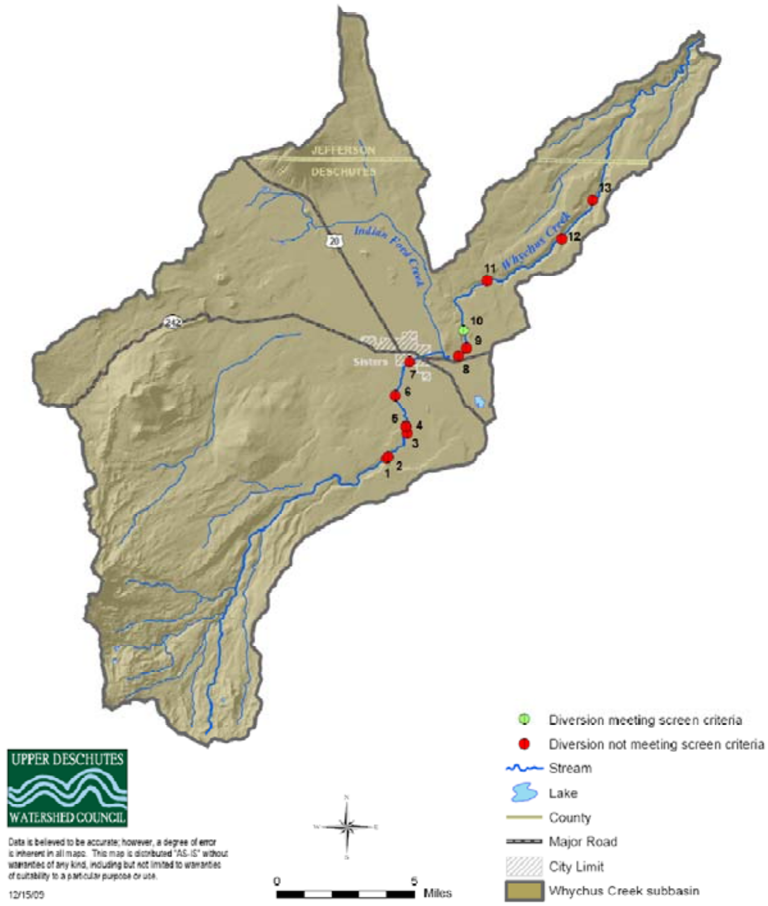

Figure 1.
The Upper Deschutes Watershed Council identified nine diversions that did not meet federal and state criteria for fish screens on Whychus Creek (NOAA 2008). They identified one diversion that did meet these criteria.

Discussion

The cumulative diversion rate through unscreened diversions on Whychus Creek is one method of characterizing fish entrainment potential risks to anadromous and native species. As mentioned in Section 2.0, the 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…). Current restoration efforts are focusing on retrofitting all diversions with state and federally approved fish screens. Based on this goal and the fact that the UDWC and its partners are not seeking to prioritize which unscreened irrigation diversion pose the most significant fish entrainment risk, cumulative diversion rates through unscreened diversions represents a good metric for determining progress on reducing fish entrainment over time.

As of fall 2009, the UDWC is actively working with water right holders and landowners to screen four (Diversions No. 4, 5, 6 and 7) of the 12 unscreened diversions. Fish screening at these diversions could reduce the cumulative unscreened diversion rate from 193 cfs down to32 cfs. By screening these four diversions, 87% of the water diverted for irrigation will be diverted through state and federally approved fish screens. As these projects are implemented and this inventory updated every year, it will be possible to monitor how fish entrainment risk is diminished over time.

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Whychus Creek Restoration:
Project Effectiveness Monitoring Using Benthic Macroinvertebrates

Celeste A. Mazzacano
Aquatic Conservation Coordinator
The Xerces Society for Invertebrate Conservation
4828 SE Hawthorne Blvd. Portland, OR 97215
celeste@xerces.org

Abstract

Macroinvertebrate monitoring was conducted in 2005 and 2009 at 10 sites along Whychus Creek from RM 30.25 to RM 0.5 to 1) determine baseline biological conditions and 2) assess the effects of flow restoration activities on stream biota. A CLUSTER analysis grouped samples based on the year sampled, indicating an overall change in macroinvertebrate community composition from 2005 to 2009. Biological integrity of sites based on PREDATOR score ranking changed with site location (reach), and both of these correlated with macroinvertebrate community similarity in CLUSTER analysis and MDS ordination. PREDATOR scores in 2005 rated four sampling sites as poor, four as fair, and two as good to slightly enriched. In 2009, only two sites received a poor rating based on PREDATOR scores, with five rated as fair and three rated as good. Sampling reaches furthest downstream (RM 0.5 to RM 9) showed the greatest average improvement in PEDATOR scores; mid-reach scores stayed about the same, and upstream reach scores were the same or slightly lower. Temperature may be implicated as a stressor for expected taxa that were missing from sites in 2005, but neither neither temperature nor sediment appeared to account for missing or replacement taxa in 2009. IBI assessment had a lower level of resolution compared to PREDATOR, but also reflected apparently improved biotic conditions, especially at downstream sites. While limited conclusions may be drawn from two isolated "snapshots" of benthic macroinvertebrates, these results suggest that the biological condition of Whychus Creek is improving. Continued annual sampling at these sites, ideally for one to three years following planned channel reconstruction at Camp Polk, will contribute to effectiveness monitoring and help reveal the response of the benthic macroinvertebrate community to existing and continuing restoration projects.

Background

Stream restoration and biological monitoring

Freshwater ecosystems are severely impacted by human activities, with 45% of our nation's waters currently classified as endangered or impaired (US EPA 2004). Stream restoration has become a common goal of many agencies and watershed organizations, and the number of stream restoration projects in the United States has increased exponentially during the past decade (Bernhardt *et al* 2005). At the same time, there is widespread agreement that appropriate evaluation of the success of stream restoration projects is generally lacking (Roni *et al* 2002, Bond 2003; Bernhardt *et al* 2005, Palmer 2005, Lepori *et al* 2005, Lake *et al* 2007, Bernhardt *et al* 2007), often because of a lack of discrete criteria as to what constitutes success. Absence of monitoring can be attributed to a variety of causes, including insufficient funding and/or personnel resources to sustain a monitoring program, lack of clearly stated monitoring objectives in project design or goals, and lack of a monitoring mandate in compliance and reporting.

Determining the ecological success of stream restoration projects includes examining the response of stream biota to changes made in the catchment or reach, a process known as biomonitoring. Biomonitoring allows the underlying health of a body of water to be evaluated by measuring the condition of its biological communities, such as plants, amphibians, algae, diatoms, or invertebrates (Rosenberg and Resh 1993, Karr and Chu 1999). If the habitat is impaired, the structure of these biological communities changes in response, based on individual species' sensitivity or tolerance to the different stressors. The communities assessed must generate a biological "signal" based on human impacts that can be detected apart from the "noise" of normal variation in space and time (i.e. as a stream flows from high-elevation headwaters to valley, or as spring turns to summer). Benthic macroinvertebrates are an extremely useful assemblage for biomonitoring: they are an important part of the food web, have relatively limited mobility that confines them to water for most or all of their life cycle, exhibit a range of responses to human-induced stressors, have a short generation time that allows changes in community structure to be detected rapidly, are ubiquitous and abundant, and sampling and identification are relatively straightforward, standardized, and cost-effective.

Biomonitoring is a vital component of measuring the ecological success of restoration projects, as it provides data about stream function that physical and chemical data alone do not address. However, biomonitoring is not necessarily a common component of restoration project evaluation. In a recent study interviewing 317 stream restoration project managers across the U.S. (Bernhardt *et al* 2007), 80% indicated that monitoring was conducted, but only 20% included biomonitoring, and nearly half of all respondents based their evaluation of project success on public opinion of the project's outcome, or on physical habitat outcomes (i.e. survival of streamside plantings, persistence of in-stream large woody debris placements, etc.). Many restoration projects are undertaken with the assumption that creating improved physical habitat automatically results in an increase in biodiversity, which in turn restores impaired or lost ecological processes. This concept is so prevalent that it has been termed "the field of dreams hypothesis" (Palmer *et al* 1997), but evidence suggests that it has not been consistently borne out in practice, and that a variety of reach- and catchment-specific influences must be considered when evaluating project outcomes (Roni *et al* 2002, Bond *et al* 2003, Palmer *et al* 2005, Lake *et al* 2007).

Restoration activities can improve habitat and water quality at the reach level, but streams experience significant watershed-wide stressors and degradation which site-specific activities may not completely remediate (Booth and Jackson 1997, Bohn & Kershner 2002, Bond & Lake 2003). Consequently, a variety of potential limiting factors must be taken into account when designing and implementing biomonitoring programs and interpreting the data. Many taxa have specific requirements for flow rate, substrate type, and water temperature, and can be distributed patchily in different microhabitats (Merritt *et al* 2008), which may not be fully represented in the sampling design. The time frame throughout which a monitoring program is conducted should also be realistic; stream degradation generally occurs over the long-term, and by the same token, recovery of stream biota is not instantaneous. As stream habitat improves, new individuals may be recruited into area, but the time frame needed for re-colonization and establishment of stable reproducing populations may be longer than that of many monitoring programs.

Barriers to re-colonization must also be considered. Many winged adult aquatic insects, including the three taxa most closely identified with quality stream habitat and biological integrity (Trichoptera, Ephemeroptera, and Plecoptera), primarily disperse longitudinally along the stream corridor (Bond *et al* 2003, Peterson *et al* 2004, Blakely *et al* 2006). Surrounding landscape usage can create barriers to the movement of colonists into restored reaches. In addition, individuals in many of these taxa do not fly long distances as adults, so movement along even an intact stream corridor may be slow in the short-term. The regional pool of potential colonists from surrounding waters must also be considered. If an entire watershed is degraded, the biotic community at other sites in the region may not be substantially different from that of a restored site, and the arrival of new colonists will not result in a noticeable shift in community species composition. If higher quality habitat is located further from the restored stream, and/or if stream network connectivity in a region has been disrupted, the arrival of colonists into a restored reach may be substantially delayed. The scale of stream restoration also influences the potential response of the biological community, as restoring riparian or in-stream habitat in a small reach in a stream whose upland or watershed is still subject to stressors such as sedimentation, pollution, or dewatering may be ineffective. Restoration projects that combine a watershed–wide approach with an assessment program that includes biological as well as physical and chemical monitoring have the greatest chance of improving a stream's ecological functions and the integrity of its aquatic biota (Bond *et al* 2003, Bohn *et al* 2002, Lake *et al* 2007).

Biotic assessment

Assessment of biological communities is frequently conducted via two major analytical approaches: predictive models and multimetric Indices of Biological Integrity (IBI). Predictive models compare the macroinvertebrate community at a given sampling site to the community present at reference or best available-condition streams in the same region with similar physical, chemical, and biological characteristics (Wright *et al* 2000). A PREDATOR predictive model (Predictive Assessment Tool for Oregon; Hubler 2008) has been constructed for two major regions in Oregon: the Marine Western Coastal Forest predictive model (Willamette Valley and Coast Range ecoregions) and the Western Cordillera and Columbia Plateau predictive model (Klamath Mountain, Cascades, East Cascades, Blue Mountains, and Columbia Plateau ecoregions). The model calculates the ratio of taxa observed at a site to the taxa expected (O over E) based on data from a large number of reference site communities. In general, an O/E value of less than one indicates loss of common taxa, while values greater than one may indicate taxa enrichment, potentially in response to pollution or nutrient loading. The model output also generates O/E scores for individual taxa at each sampling site, allowing specific taxa loss and replacement to be assessed.

Biological indices rate a combination of community attributes (metrics) that respond predictably to human-induced stressors (Karr and Chu 1999). Individual metrics are scored and summed to generate a total IBI value that reflects the biological condition of a site. Multimetric biological indices have been developed in Oregon for use with macroinvertebrate stream taxa identified either to family (Level 2 assessment) or to genus and species (Level 3 assessment; OWEB 2003). Genus/species-level identification is preferred over the broader family-level taxonomy for IBI assessment, as a single family often contains individual genera that differ in tolerances and response to disturbance. Level 3 IBI metrics delineated by OWEB are: total taxa richness; Ephemeroptera (mayfly) taxa richness; Plecoptera (stonefly) taxa richness; Trichoptera (caddisfly) taxa richness); # of sensitive taxa; # of sediment-sensitive taxa; % dominance of the top taxon; % tolerant taxa; % sediment-tolerant taxa; and modified Hilsenhoff Biotic Index (MHBI; Hilsenhoff 1987).

Metrics are based on the rationale that a less disturbed, healthier stream system has greater biodiversity and thus will be higher in both overall taxa diversity (Norris and Georges 1993; Barbour *et al* 1996) as well as in diversity of sensitive taxa such as mayflies, caddisflies, and stoneflies. However, moderate levels of disturbance may actually result in an increase in diversity before the disturbance becomes severe enough for the biotic community to be degraded (intermediate disturbance hypothesis; Connell 1978, Ward and Stanford 1983), so diversity metrics must be treated with caution. A healthy system is also expected to have a more balanced composition of taxa, such that a few genera or species do not dominate. A large abundance of a small number of taxa is indicative of impaired conditions and environmental stressors, as the macroinvertebrate community becomes dominated by one or a few more tolerant groups (Plafkin *et al* 1989, Barbour *et al* 1996). Thus, the proportion of the total number of organisms accounted for by the most abundant taxon is expected to be lower in a healthy stream.

Unlike the regionally-targeted PREDATOR models, the macroinvertebrate IBI currently in use in Oregon was developed from a smaller dataset and does not consider regional differences (Hubler, 2008 and pers. comm.). Thus, stream condition rankings based on IBI scores may be less accurate in different parts of the state.

Whychus Creek monitoring project

Whychus Creek has experienced significant habitat degradation from surrounding land use practices, including dewatering for irrigation, channelization, grazing, and stream-side development. This project was conducted as part of an ongoing a 10-year, monitoring-intensive effort to evaluate changes in watershed conditions in Whychus Creek as both large scale and site-specific restoration projects are implemented (Upper Deschutes Watershed Council 2009). Benthic macroinvertebrates are key biological indicators, as community composition at sampling sites from near the headwaters to the mouth can change over time in response to reach- and catchment-scale land management practices and habitat restoration activities.

In 2005, Xerces worked with the Upper Deschutes Watershed Council to collect benthic macroinvertebrate samples from 10 sites along Whychus Creek, from RM 30.25 to RM 0.5. This sampling was done prior to any large scale habitat restoration and before some stream flow restoration, to provide baseline data on existing macroinvertebrate communities along the stream. In 2009, sampling was repeated at the same sites to assess the macroinvertebrate community after large scale stream flow restoration had been conducted, but prior to intensive habitat restoration, especially moving the creek into its historic meandering channel at Camp Polk. It is anticipated that sampling will be repeated at these sites in 2014, following completion of the Camp Polk channel restoration project.

Methods

Sampling Sites

Ten sites along Whychus Creek were sampled in both years; a duplicate sample was taken at one site each year for quality assurance purposes. The sites selected are historic water quality monitoring stations where physical, chemical, and/or biological data has been collected previously (Table 1). Eight of the ten sites sampled in 2005 were re-sampled in 2009 at or very near the same river mile location; two of the ten sites sampled in 2009 were sampled in the same area as 2005 but a different river mile location (i.e. RM 0.5 and RM 3 in 2005 versus RM 1.5 in 2009; RM 23.5 in 2005 vs. RM 24.25 in 2009). Overall, sampling sites are distributed broadly along the stream into downstream (RM 0.5- 9), mid- (RM 18-19.5), and upstream reaches (RM 23.5 - 30.25).

Volunteer Training & Sampling Techniques

On August 20, 2005 and August 21, 2009, Upper Deschutes Watershed Council staff and volunteers assembled at City Park (Sisters, OR) and were trained by Xerces staff in macroinvertebrate monitoring protocols for wadeable streams in Oregon (OWEB 2003). Sampling protocol was demonstrated and each item on the datasheet was explained (see Appendix A for sample data sheet). Additional handouts on macroinvertebrate identification, including field guides to assist with family-level benthic macroinvertebrate identification (Adams *et al* 2003) and a guide to freshwater mussels of the Pacific Northwest (Nedeau *et al* 2009) were also provided in 2009, although volunteers were not expected to identify any organisms collected. The group divided into teams, each of which received the following equipment: D-frame kick net with 500 µm mesh, metal 500 µm sieve, forceps, thermometer, fiberglass tape measure, 10-gallon plastic bucket, hand lens, 1-liter Nalgene sample jars, 80% ethanol, datasheets, and clipboard.

Table 1. Whychus Creek sampling sites.

Site ID	Description	Coordinates	Year sampled
WC000.50	RM 0.50	44.45682, -121.34028	2005
WC001.50	RM 1.5, d/s Alder Springs	44.446681, -121.34727	2009
WC003.00a	RM 3, u/s Alder Springs	44.43458, -121.35976	2005
WC006.00b	RM 6, u/s Rd 6360	44.40412, -121.40259	2005 & 2009
WC009.00	RM 9, Rimrock Ranch	44.38463, -121.40772	2005 & 2009
WC018.00	RM 18	44.328342, -121.494534	2005
WC018.25	d/s end DBLT property	44.32689, -121.49913	2009
WC018.5	RM 18.5	44.324974, -121.503531	2009
WC019.00	RM 19	44.320742, -121.510808	2005 & 2009
WC019.50	RM 19.5, d/s Camp Polk Bridge on DBLT property	44.31855, -121.51500	2009
WC023.50	RM 23.5, Perit Huntington Rd.	44.29066, -121.53064	2005
WC024.25	City Park, RM 24.25, City Park, d/s gauge	44.28836, -121.54182	2005 & 2009
WC026.00	RM 26, 4606 Rd. footbridge	44.27362, -121.55481	2005 & 2009
WC030.25	RM 30.25, USGS gauge	44.23401, -121.56690	2005 & 2009

[a] a duplicate sample was taken at this site in 2005 for quality control

[b] a duplicate sample was taken at this site in 2009 for quality control

Macroinvertebrate samples were collected from riffle habitat at each site according to standardized protocols (OWEB, 2003). Sampling reaches were calculated as 40 times the average wetted width of the stream at the desired sampling point. Eight randomly selected riffle habitat areas were sampled within each stream reach. Each sample was collected from a one-foot by one-foot substrate area using a 500-micron D-frame kick net. Large rocks and debris in this sampling area were rinsed into the net to dislodge and collect any clinging organisms and set aside, and the substrate was then disturbed using a boot heel or brush handle to a depth of ~10 cm for approximately 30 seconds. The eight individual net samples at each site were placed in a bucket, large debris was rinsed and removed, sample material was poured through a sieve to remove the water, and the composited material was placed into 1-liter Nalgene jars with 80% ethanol added as a preservative. Jars were filled no more than halfway with sample material to ensure adequate preservation. The ethanol in each jar was replaced with fresh ethanol within 48 hours to maintain an 80% concentration, as water leaches from the initial sample material and dilutes the preservative. A simple physical habitat assessment was done at each site to provide data on human use and landscape alterations, substrate composition, water temperature and appearance, and wetted width and depth at each riffle sampled (Appendix A).

Sample Processing & Identification

Samples taken in 2005 were identified by Aquatic Biology Associates, Inc. (ABA; Corvallis, OR); samples collected in 2009 were identified by ABR, Inc. Environmental Research & Services (ABR; Forest Grove, OR). Greater taxonomic resolution was achieved for some groups in 2009 compared to 2005; in 2005, *Rhyacophila*, *Zapada*, *Baetis*, *Epeorus*, and *Ephemerella* were left at genus, whereas multiple different species within each of these genera were identified in 2009. To avoid artificially inflating the biodiversity and taxonomic differences in the 2009 sample, these groups were collapsed to genus-level for comparison with the 2005 data set.

Each composite sample was sub-sampled to a target of 500 organisms. In 2009, the target count of 500 organisms was attained for all sampling sites, with anywhere from 3-100% of the sample material picked. In 2005, the target count could not be achieved at one site (WC 030.35), which yielded only 397 organisms after the entire sample was picked.

Data Analysis

The benthic macroinvertebrate community was assessed using both multimetric and multivariate analysis. Sampling data for both years were entered into the PREDATOR predictive model for the Western Cordillera + Columbia Plateau (Hubler 2008). Observed over expected (O/E) scores associated with a probability of capture (P_c) > 0,5 were used (i.e. the model uses only invertebrates with greater than 50% likelihood of being collected at reference sites). The O/E benchmarks for describing biological conditions in the WC+CP model are:

Most disturbed: O/E = ≤0.78

Moderately disturbed: O/E = 0.79 – 0.92

Least disturbed: O/E = 0.93 – 1.23

Enriched: O/E = >1.23

PREDATOR scores are generated based on data submitted in a site habitat file and a sample data file. Model output includes site test results, which indicate whether the habitat data falls within the parameters of the model used; an O/E score for each site, which indicates site biological condition; a probability matrix that shows taxa expected to occur at each site but absent (missing taxa) as well as observed taxa that were not expected to occur at the site (replacement taxa); and a taxon occurrence summary that indicates the mean probability of capture of each taxon, the total number of sampling sites at which the taxon is expected, and the number of sites at which it was collected. A DEQ dataset containing optima values for both seasonal maximum temperature and percent fine sediments for macroinvertebrate taxa (Huff *et al* 2006) was used to investigate whether temperature or sediment stressors could explain missing or replacement taxa among sampling sites.

Stream biological condition was also assessed at each site using a multimetric Index of Biological Integrity (IBI). Biological indices rate a combination of individual community attributes that respond predictably to human-induced stressors, generating a single IBI score that reflects the biological condition of a site (Karr and Chu 1999). Individual metrics were calculated (OWEB 2003) and a total IBI score and corresponding stream condition was determined for each site. Metrics include the following macroinvertebrate community attributes: total taxa richness; Ephemeroptera (mayfly) taxa richness; Plecoptera (stonefly) taxa richness; Trichoptera (caddisfly) taxa richness); # of sensitive taxa; # of sediment-sensitive taxa; % dominance of the top taxon; % tolerant taxa; % sediment-tolerant taxa; and modified Hilsenhoff Biotic Index (MHBI).

Additional analyses to detect patterns in macroinvertebrate community composition were conducted using the PRIMER V6 ecological community statistics software package (Clarke and Warwick, 2001). CLUSTER analysis was conducted on a Bray-Curtis similarity matrix of square-root transformed data to investigate macroinvertebrate community similarity between sites and across years. The SIMPER routine was performed on the Bray-Curtis similarity matrix of square-root transformed data to examine the average similarity and dissimilarity between each site, and identify taxa that contributed the most to each. MDS ordination was done and overlaid with site PREDATOR rankings to examine community similarity.

Results and Discussion

PREDATOR analysis

Site test results

The site test results file associated with PREDATOR analysis in both 2005 and 2009 indicated that all predictor variables for the test samples were within the experience of the WC+CB model.

Site O/E

Overall, PREDATOR scores at sampling sites were slightly higher in 2009 compared to 2005, suggesting some improvement in biotic conditions (Table 2). PREDATOR scores at sites sampled in 2005 rated four sites as most disturbed (poor), four sites as moderately disturbed (fair), and two sites as least disturbed (good), with one of these sites slightly enriched. In 2009, PREDATOR analysis at the same sampling reaches rated only two sites as poor, with five sites in fair condition and three in good condition.

Downstream reaches (RM 0.5 to 9) showed the greatest improvement, with an average PREDATOR score of 0.68 across these reaches in 2005 increasing to 0.86 in 2009. Three of the four downstream reaches sampled in 2005 received a PREDATOR score indicating a most-disturbed condition, while in 2009, PREDATOR scores ranked the three downstream reaches sampled as moderately disturbed. The midstream reaches (RM 18-19.5) remained in roughly the same condition from 2005 to 2009. The average PREDATOR score across these reaches decreased slightly from 1.16 to 0.98, but the sites at RM 18 and 19 were still rated as least-disturbed, and an intermediate site at RM 18.5 ranked as moderately disturbed but with a score close to the higher least-disturbed benchmark. The average PREDATOR score across the upstream sampling reaches remained essentially the same in 2005 and 2009 (0.77 versus 0.75). However, the PREDATOR score at RM 26 indicated a decrease from fair to poor condition. The upstream-most sampling site still received poor rating, but the PREDATOR score in 2009 was much higher than in 2005, and although the site still received an overall poor condition rating, the PREDATOR score was much closer to the value for the moderately-disturbed benchmark.

Table 2. Whychus Creek sample site PREDATOR scores (Western Cordillera + Columbia Plateau Model, pc>0.5).

Site ID	Description	Coordinates	Year sampled
WC000.50	RM 0.50	44.45682, -121.34028	2005
WC001.50	RM 1.5, d/s Alder Springs	44.446681, -121.34727	2009
WC003.00a	RM 3, u/s Alder Springs	44.43458, -121.35976	2005
WC006.00b	RM 6, u/s Rd 6360	44.40412, -121.40259	2005 & 2009
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WC018.00	RM 18	44.328342, -121.494534	2005
WC018.25	d/s end DBLT property	44.32689, -121.49913	2009
WC018.5	RM 18.5	44.324974, -121.503531	2009
WC019.00	RM 19	44.320742, -121.510808	2005 & 2009
WC019.50	RM 19.5, d/s Camp Polk Bridge on DBLT property	44.31855, -121.51500	2009
WC023.50	RM 23.5, Perit Huntington Rd.	44.29066, -121.53064	2005
WC024.25	City Park, RM 24.25, City Park, d/s gauge	44.28836, -121.54182	2005 & 2009
WC026.00	RM 26, 4606 Rd. footbridge	44.27362, -121.55481	2005 & 2009
WC030.25	RM 30.25, USGS gauge	44.23401, -121.56690	2005 & 2009

Missing and replacement taxa

In 2005, three expected taxa were missing from seven or more of the ten sites sampled: *Calineuria* (a moderately sensitive perlid stonefly genus), *Epeorus* (a sensitive flathead mayfly genus), and Leptophlebiidae (a moderately sensitive pronggill mayfly family). In 2009, five expected taxa were absent from ≥7 of the ten sampling sites, two of which were also missing taxa in 2005: *Calineuria*, *Epeorus*, Tanypodinae (a common chironomid midge group), *Malenka* (a common small brown stonefly), and Pisidiidae (common and widespread fingernail clams). Replacement taxa found at ≥7 sampling sites in 2005 included Diamesinae (a chironomid midge froup), *Rhithrogena* (a common and abundant flatheaded mayfly genus), *Acentrella* (a common small minnow mayfly genus), and *Antocha* (a common, sediment-tolerant crane fly genus). Diamesinae, *Rhithrogena*, and *Acentrella* were also replacement taxa at ≥7 sampling sites in 2009, along with *Neoplasta* (a dance fly genus), *Atherix* (a common, tolerant watersnipe fly genus), *Narpus* (a common, moderately tolerant riffle beetle genus), *Serratella* (a commonly-collected genus of spiny crawler mayfly), *and Sweltsa* (a common widespread stonefly genus).

Sediment and temperature were examined as potential stressors influencing macroinvertebrate community composition. The Oregon DEQ developed a set of optima values for specific macroinvertebrate taxa for both seasonal maximum temperature and percent fine sediments (Huff *et al* 2006), which can be used to assess whether missing or replacement taxa among sampling sites share a range of optima. Among sites sampled in 2005, replacement taxa had a higher mean temperature optima (18.0^{o}C$\pm$2.1) than missing taxa (16.6 ^{o}C$\pm$0.96), suggesting that temperature may be a stressor. The mean sediment optimum was lower among replacement taxa (4.1$\pm$1.4) than for missing taxa (7.1$\pm$3.5), although sediment optima varied more widely. For sites sampled in 2009, there was little indication that either temperature or sediment were implicated as stressors when taxa identified as missing or replacements across at least seven of the ten sites sampled were examined. Missing taxa had a mean temperature optimum of 17.0 ^{o}C $\pm$ 0.83, while replacement taxa had a temperature optimum of 17.8 ^{o}C $\pm$ 2.8. Sediment optima varied more widely among both missing and replacement taxa, with the mean sediment optima value higher for the missing taxa (10.5 $\pm$ 6.6 and 5.6 $\pm$ 2.3, respectively). The higher temperature optima values seen for replacement taxa in 2005 but not in 2009 may reflect improved conditions following restoration of stream flow that occurred in 2006/2007.

Multimetric assessment

The OWEB Level 3 stream IBI consists of 10 individual metrics. The raw value of each metric is accorded a corresponding scaled score of 5, 3, or 1, with higher scores indicating better biological condition. Genus and species-level assessment metrics are shown below; the first number indicates the raw data range possible for each metric, and the corresponding scaled IBI score is in parentheses:

- Taxa richness (# of taxa at site): >35 (5), 19-35 (3), <19 (1)
- Ephemeroptera (mayfly) richness: >8 (5), 4-8 (3), <4 (1)
- Plecoptera (stonefly) richness: >5 (5), 3-5 (3), <3 (1)
- Trichoptera (caddisfly) richness: >4 (5), 2-4 (3), <2 (1)
- Number of sensitive taxa: >4 (5), 2-4 (3), <2 (1)
- Number of sediment-sensitive taxa: >2 (5), 1 (3), 0 (1)
- % dominance of the top taxon: <20 (5), 20-40 (3), >40 (1)
- % tolerant taxa: <15 (5), 15-45 (3), >45 (1)
- % sediment-tolerant taxa: <10 (5), 10-25 (3), >25 (1)
- Modified Hilsenhoff Biotic Index (MHBI): <4.0 (5), 4-5 (3), >5.0 (1)

Scaled values for individual metrics are summed to yield a single IBI score for each site, which can reflect a biological condition of minimal (IBI >39), slight (IBI 30-39), moderate (IBI 20-29), or severe impairment (score <20). Overall, IBI scores indicated better biotic conditions than did PREDATOR scores for the same sites (Table 3). However, the PREDATOR model is based on data from reference streams in different ecoregions of Oregon, whereas the current IBI has not been refined by ecoregion and may not be as sensitive or applicable to this area.

Table 3. Level 3 IBI scores for Whychus Creek sampling sites

2005				2009		
Site	IBI score	Impairment		Site	IBI score	Impairment
WC000.50	30	Slight		WC001.50	36	Slight
WC003.00	26	Moderate				
WC006.00	24	Moderate		WC006.00	30	Slight
WC009.00	32	Slight		WC009.00	32	Slight
WC018.00	32	Slight		WC018.25	34	Slight
				WC018.50	32	Slight
WC019.00	36	Slight		WC019.00	30	Slight
WC023.50	28	Slight		WC019.50	32	Slight
WC024.25	28	Moderate		WC024.25	34	Slight
WC026.00	28	Moderate		WC026.00	38	Slight
WC030.25	34	Slight		WC030.25	38	Slight

Macroinvertebrate Community

In 2005, 76 taxa were collected across all sampling sites, including a total of 42 EPT taxa (14 Ephemeroptera, 11 Plecoptera, and 17 Trichoptera). Eighty-five taxa were collected among all sites in 2009, including 47 EPT taxa (14 Ephemeroptera, 13 Plecoptera, and 20 Trichoptera). The proportion of total taxa comprised of EPT was the same in both years (55%). Comparing overall diversity between years is complicated by the fact that several EPT taxa identified only to genus in 2005 were identified to species in 2009 (i.e. *Ephemerella*, *Epeorus*, *Zapada*, and *Rhyacophila*. When these groups are collapsed to genus-level, there are 73 taxa in 2009 samples, 37 of which are EPT (12 Ephemeroptera, 12 Plecoptera, 13 Trichoptera; 51% of total taxa).

In both years, the most abundant and ubiquitous taxa included riffle beetles (Elmidae), midges (Chironomidae), blackflies (*Simulium*), and small minnow mayflies (Baetidae), which are all common taxa expected to occur widely. Many taxa were found at only a single site (29 taxa in 2005 and 30 taxa in 2009), and generally with anywhere from one to four individuals. Twenty-four taxa present in the 2005 samples were absent in 2009, and 19 of these were found at only one or two sites at very low abundance. Only three taxa found in 2005 but not in 2009 occurred at multiple sites and in slightly higher numbers (i.e. 4-20/site): *Chelifera* (a moderately tolerant and common empidid fly), *Wormaldia* (a philopotamid caddisfly found in a wide range of streams), and *Dicosmoecus* (a limnephilid caddisfly; species in this genus differ in their tolerances). *Chelifera* was present along the stream at all but two sampling sites, while both caddisflies were found at sampling sites in the mid-reaches of Whychus creek. Of the twenty-two taxa collected in 2009 that were not present in the 2005 samples, 20 were found at only one or two sites and at very low abundance. Of the remaining two, *Neoplasta*, a dance fly genus, was found at low numbers at all but one of the sites sampled, and *Suwallia*, a sallfly (stonefly), was moderately abundant along the mid- and upstream reaches of the creek.

About two-thirds of the total taxa were present among all the sites sampled in both years. However, the overall community composition at eac site in 2005 and 2009 differed sufficiently that a CLUSTER analysis grouped all 2005 samples together separately from all 2009 samples, with an average similarity between the two year clusters of 37.88% (Figure 1). Within-year clustering was influenced strongly by reach location in both years. Downstream (RM 0.5 - 9), mid-reach (RM 18 - 19.5), and upstream (RM 24.25-30.25) sites showed the greatest between-site similarities in both years, with the exception of the 2005 RM 0.5 sample, which clustered with mid-reach samples.

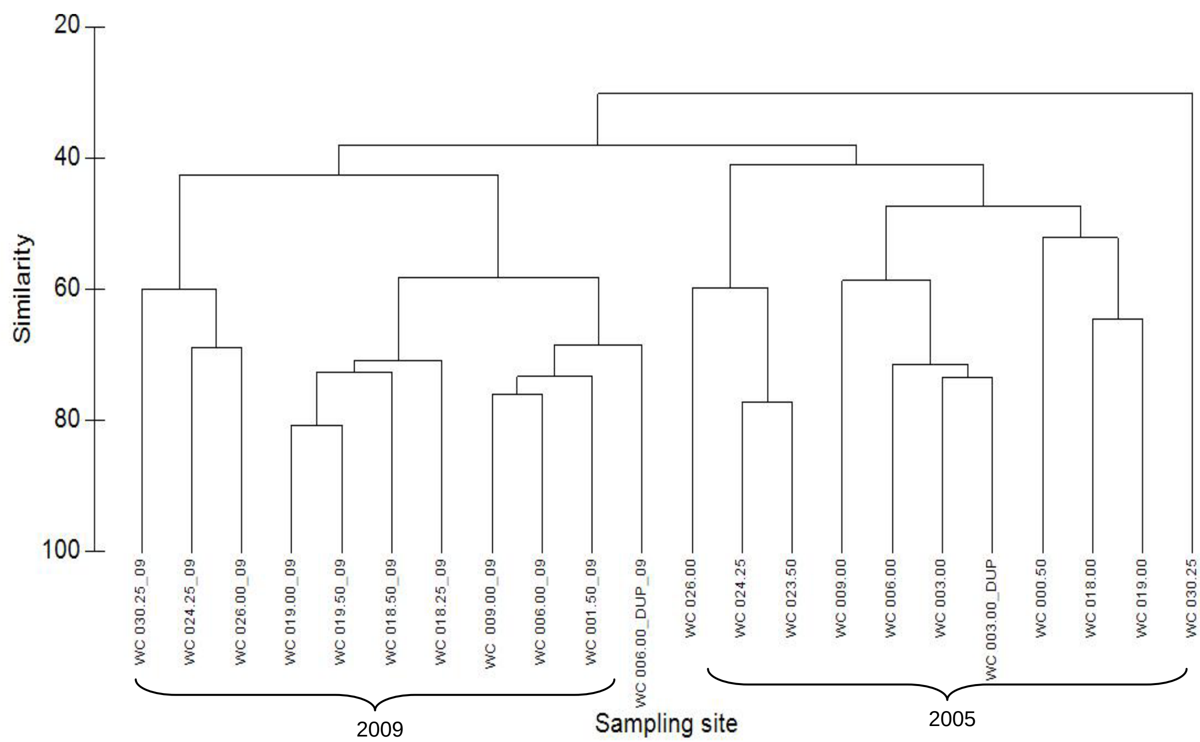

Figure 1.
CLUSTER analysis of sampling sites across 2005 and 2009. “DUP” in the site name indicates a replicate sample taken for quality control purposes.

MDS ordination showed correlation between macroinvertebrate community and reach location as well as with PREDATOR score ranking (Figure 2, Figure 3). Macroinvertebrate community composition clustered sites in the downstream reaches (RM 0.5 to 9.0), most of which had received a poor rating, as well as the mid-reach sites rated as good (RM 18 & 19), with more scattering among the sites furthest upstream (RM 23.5 to 30.25).

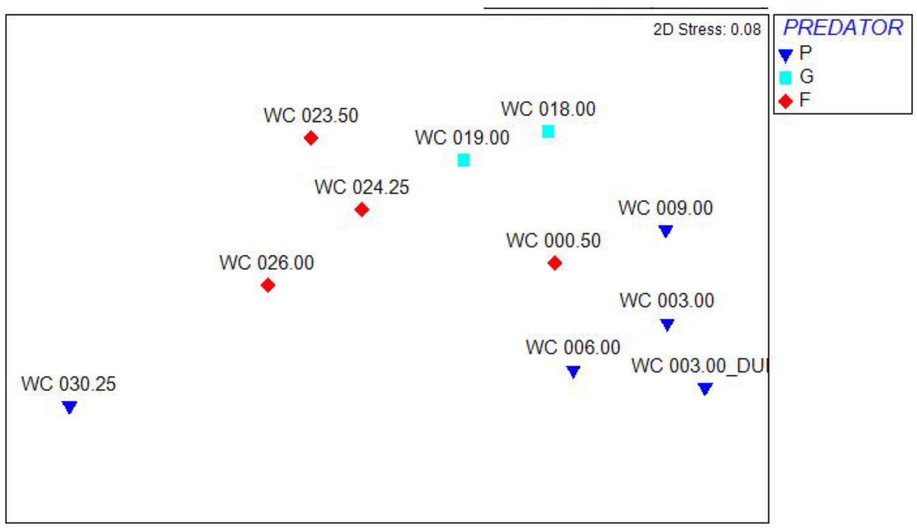

Figure 2.
MDS ordination of sampling sites showed correlation between macroinvertebrate community and reach location as well as with PREDATOR score ranking. 2005 samples; stress = 0.08

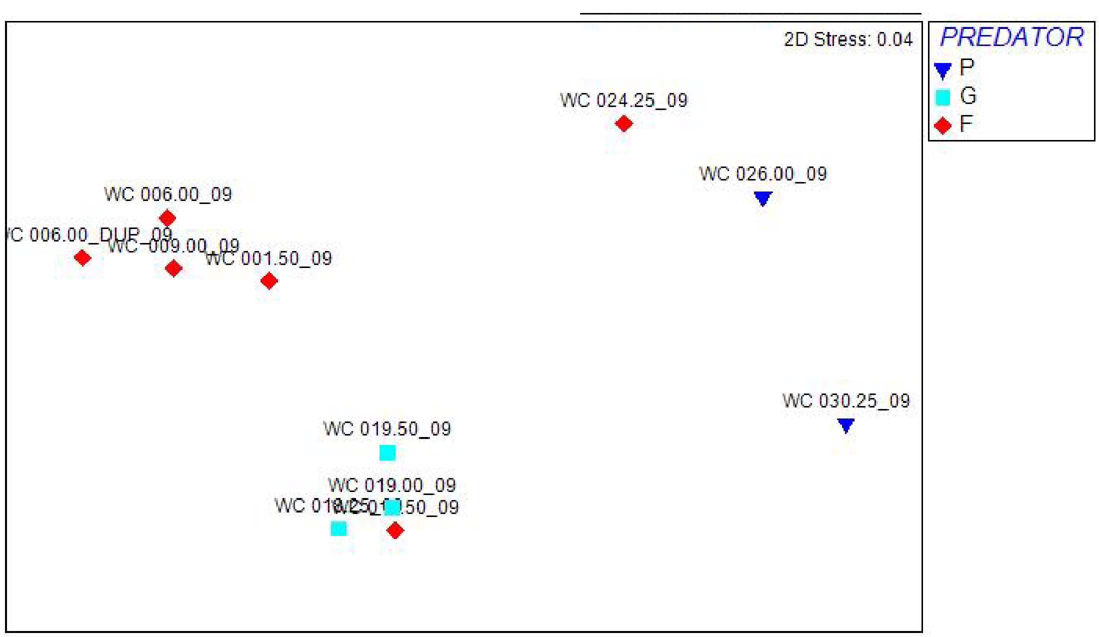

Figure 3
MDS ordination of sampling sites showed correlation between macroinvertebrate community and reach location as well as with PREDATOR score ranking. 2009 samples; stress = 0.04

The SIMPER routine was performed on the Bray-Curtis similarity matrix of square-root transformed data to identify taxa that contributed the most to the similarity between the site clusters observed in MDS. Sites that received a PREDATOR ranking indicating poor biotic conditions in 2005 had a 47.7% average similarity; taxa that contributed most to similarity between these sites were *Zaitzevia* (a common and tolerant elmid riffle beetle; 19.6%), Orthocladiinae (a moderately tolerant group of chironomid midges; 9.7%), and *Brachycentrus* (a moderately tolerant caddisfly; 7.1%). Sites that received a PREDATOR rank indicating fair conditions had a higher average community similarity (53.6%); Orthocladiinae was the greatest contributor to the average similarity (21.5%), with additional contributions from Chironominae (a moderately tolerant group of chironomid midges; 12.3%) and *Antocha* (a commonly collected, sediment-tolerant crane fly; 9.5%). Sites that received a good rating based on PREDATOR score in 2005 had the highest average similarity (64.4%); the three taxa contributing the most to average similarity among these sites were *Zapada* (a common stonefly; 19%), Chironominae (7.6%), and *Simulium* (a common, diverse black fly genus; 7.6%).

A similar pattern was seen in the results of SIMPER analysis on 2009 samples, with the greatest average similarity seen between sites with a PREDATOR score indicating good (least disturbed) conditions. Contributions from individual taxa to average similarity were lower overall, and the taxa that contributed the most to the average similarity between poor, fair, and good sites were common and ubiquitous types. Sites rated by PREDATOR as poor had an average similarity of 57.7%, due primarily to *Rhithrogena* (a common, abundant flatheaded mayfly; 16.4%), *Baetis tricaudatus* (a widespread, abundant small minnow mayfly; 16.2%), and Orthocladiinae (11%). Sites rated as fair had an average similarity of 57.2%, due mainly to Chironominae (9.6%), Orthocladiinae (9%), and *Simulium* (7.4%). The highest average similarity was seen among sites rated by PREDATOR as good, at 74.1%, due primarily to *Baetis tricaudatus* (9.1%), Oligochaeta (aquatic earthworms; 7.8%) and Orthocladiinae (7.1%).

Conclusions

- The composition of the benthic macroinvertebrate community in Whychus Creek has changed substantially from 2005 to 2009.
- While the macroinvertebrate community at the majority of sampling sites along the stream reflect moderate to severe impairment, both PREDATOR and IBI scores indicate improved biotic conditions.
- Sampling sites located in the downstream portions of the creek (RM 0.5 – RM 9) showed the greatest overall improvement.
- In 2005 samples, missing taxa had a lower mean maximum temperature optima (16.6^{o}C) than replacement taxa (18.0^{o}C), while in 2009 missing and replacement taxa had similar mean temperature optima values (17.0^{o}C vs. 17.8^{o}C, respectively), suggesting that improved flow conditions may have alleviated some temperature stress on stream biota.
- Continued monitoring at these sampling sites in the future will allow ongoing evaluation of stream biological integrity as changes in the macroinvertebrate community are detected, and enable responses of stream biota to ongoing and future restoration projects such as channel restoration at Camp Polk to be evaluated.

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Appendix A. Macroinvertebrate monitoring field datasheet

Site ID ____ Date___________

Sampled by: ____

Start time: _______ End time: _______ Air temp _____ °C / °F Water temp. ______ °C / °F

Lat./Long. (decimal degrees): N __________________________ W __________________________

Location verified by: GPS / Flags / Signs / Roads / Topo map / other (describe):

Sample Information:

# of riffles sampled: _____ Field duplicate collected: ___ yes ___ no

# of kicks composited ___ 8 x 1 ft² OR __other (describe): # Field duplicate jars _____

Jars _______

Human use & influence (check **all** that apply):

A = absent **B** = on bank **C** = ≤ 30 ft from bank **D** = > 30 ft from bank

Disturbance	Left bank	Right bank		Disturbance	Left bank	Right bank
Riprap/wall/dike/revetment				Landfill/trash		
Buildings				Park/lawn/informal rec.		
Industrial				Row crops		
Rural residential				Pasture/range/hay field		
Urban residential				Livestock w/stream access		
Pavement/cleared lot				Logging within last 5 yrs		
Road/railroad				Mining/sand & gravel		
Pipes (inlet/outlet)				Forest/woodland		
Other:						

Qualitative observations:

Water odors: none / organic / rotten eggs / fishy / chlorine / petroleum / other (describe):

Water appearance: clear / turbid / milky / dark brown / foamy / oily sheen / other (describe):

Dominant land use: Forest / agriculture (crops / pasture) / urban (industrial / residential) / other:

Extent of algae covering submerged materials: none / 1-25% / 25-50% / 50-75% / 75-100 %

Type of algae: none / filamentous (strands >2") / close-growing / floating clumps

Physical characteristics:

Substrate

% composition	Riffle1	Riffle2	Riffle3	Riffle4	Riffle5	Riffle6	Riffle7	Riffle8
Bedrock (continuous rock)								
Boulder (> 12 in.; larger than basketball)								
Cobble (2.5-12 in.; tennis ball to basketball)								
Gravel (0.6-2.5 in.; marble to tennis ball)								
Sand (< 0.6 in.; smaller than marble)								
Silt/clay/muck (fine suspended particles)								
Woody debris								
Other (describe)								

Water depth

Parameter	Riffle1	Riffle2	Riffle3	Riffle4	Riffle5	Riffle6	Riffle7	Riffle8
Wetted width (ft)								
Depth @ ¼ wetted width (in.)								
Depth @ ½ wetted width (in.)								
Depth @ ¾ wetted width (in.)								

Additional notes or observations (including other wildlife noted):

Appendix B. Macroinvertebrate Taxa List for Whychus Creek

Phylum/ subphylum	Class/ Subclass	Order	Family	Genus	Species	2005	2009
Platyhelminthes	Turbellaria					Y	Y
Annelida	Oligochaeta					Y	Y
Nematoda						Y	Y
Arthropoda/ Crustacea	Malacostraca	Decapoda	Astacidae	Pacifasticus			Y
Arthropoda/ Crustacea	Ostracoda					Y	
Athropoda	Arachnoidea	Trombidiformes				Y	Y
Athropoda	Insecta	Coleoptera	Elmidae	Narpus		Y	Y
Athropoda	Insecta	Coleoptera	Elmidae	Optioservus		Y	Y
Athropoda	Insecta	Coleoptera	Elmidae	Zaitzevia		Y	Y
Athropoda	Insecta	Coleoptera	Elmidae	Cleptelmis		Y	Y
Athropoda	Insecta	Coleoptera	Elmidae	Ampumixis		Y	Y
Athropoda	Insecta	Coleoptera	Elmidae	Lara	avara		Y
Athropoda	Insecta	Coleoptera	Dytiscidae			Y	
Athropoda	Insecta	Coleoptera	Dryopidae	Helichus			Y
Athropoda	Insecta	Coleoptera	Hydrophilidae	Hydroporinae			Y
Athropoda	Insecta	Odonata	Coenagrionidae			Y	
Athropoda	Insecta	Diptera	Empididae	Neoplasta			Y
Athropoda	Insecta	Diptera	Empididae	Hemerodromia		Y	Y
Athropoda	Insecta	Diptera	Empididae	Chelifera		Y	
Athropoda	Insecta	Diptera	Empididae	Clinocera		Y	Y
Athropoda	Insecta	Diptera	Empididae	Wiedemannia		Y	
Athropoda	Insecta	Diptera	Tipulidae	Antocha		Y	Y
Athropoda	Insecta	Diptera	Tipulidae	Cryptolabis		Y	
Athropoda	Insecta	Diptera	Tipulidae	Dicranota			Y
Athropoda	Insecta	Diptera	Tipulidae	Hesperoconopa		Y	Y
Athropoda	Insecta	Diptera	Tipulidae	Hexatoma		Y	Y
Athropoda	Insecta	Diptera	Tipulidae	Limnophila			Y
Athropoda	Insecta	Diptera	Tipulidae	Rhabdomastix			Y
Athropoda	Insecta	Diptera	Athericidae	Atherix		Y	Y
Athropoda	Insecta	Diptera	Dixidae	Dixa			Y
Athropoda	Insecta	Diptera	Chironomidae	Tanypodinae		Y	Y
Athropoda	Insecta	Diptera	Chironomidae	Chironominae		Y	Y
Athropoda	Insecta	Diptera	Chironomidae	Diamesinae		Y	Y
Athropoda	Insecta	Diptera	Chironomidae	Orthocladiinae		Y	Y
Athropoda	Insecta	Diptera	Ceratopogonidae	Ceratopogoninae			Y
Athropoda	Insecta	Diptera	Blephariceridae	Blepharicera		Y	Y
Athropoda	Insecta	Diptera	Simuliidae	Prosimulium		Y	Y
Athropoda	Insecta	Diptera	Simuliidae	Simulium		Y	Y
Athropoda	Insecta	Diptera	Ephydridae			Y	Y
Athropoda	Insecta	Diptera	Psychodidae	Pericoma		Y	Y
Athropoda	Insecta	Diptera	Psychodidae	Maruina			Y
Athropoda	Insecta	Diptera	Tabanidae				Y
Athropoda	Insecta	Ephemeroptera	Baetidae	Acentrella		Y	

Athropoda	Insecta	Ephemeroptera	Baetidae	Baetis		Y	
Athropoda	Insecta	Ephemeroptera	Baetidae	Baetis	tricaudatus		Y
Athropoda	Insecta	Ephemeroptera	Baetidae	Diphetor	hageni	Y	Y
Athropoda	Insecta	Ephemeroptera	Baetidae	Acentrella	turbida		Y
Athropoda	Insecta	Ephemeroptera	Ameletidae	Ameletus		Y	Y
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Attenella		Y	Y
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Serratella		Y	
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Ephemerella		Y	
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Ephemerella (Serratella)	tibialis		Y
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Ephemerella	excrucians		Y
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Caudatella	hystrix	Y	Y
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Drunella	spinifera	Y	
Athropoda	Insecta	Ephemeroptera	Ephemerellidae	Drunella	coloradensis		Y
Athropoda	Insecta	Ephemeroptera	Heptageniidae	Epeorus		Y	Y
Athropoda	Insecta	Ephemeroptera	Heptageniidae	Epeorus	grandis		Y
Athropoda	Insecta	Ephemeroptera	Heptageniidae	Epeorus	longimanus		Y
Athropoda	Insecta	Ephemeroptera	Heptageniidae	Rhithrogena		Y	Y
Athropoda	Insecta	Ephemeroptera	Heptageniidae	Cinygmula		Y	Y
Athropoda	Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes		Y	
Athropoda	Insecta	Ephemeroptera	Leptophlebiidae	Paraleptophlebia		Y	Y
Athropoda	Insecta	Megaloptera	Sialidae	Sialis		Y	
Athropoda	Insecta	Plecoptera	Perlidae	Calineuria	californica	Y	Y
Athropoda	Insecta	Plecoptera	Perlidae	Hesperoperla		Y	
Athropoda	Insecta	Plecoptera	Perlodidae	Isoperla			Y
Athropoda	Insecta	Plecoptera	Perlodidae	Megarcys			Y
Athropoda	Insecta	Plecoptera	Perlodidae	Rickera	sorpta		Y
Athropoda	Insecta	Plecoptera	Perlodidae	Kogotus		Y	
Athropoda	Insecta	Plecoptera	Perlodidae	Skwala		Y	Y
Athropoda	Insecta	Plecoptera	Chloroperlidae	Paraperla		Y	
Athropoda	Insecta	Plecoptera	Chloroperlidae	Suwallia			Y
Athropoda	Insecta	Plecoptera	Chloroperlidae	Sweltsa		Y	Y
Athropoda	Insecta	Plecoptera	Leuctridae	Despaxia	augusta		Y
Athropoda	Insecta	Plecoptera	Nemouridae	Visoka	cataractae	Y	Y
Athropoda	Insecta	Plecoptera	Nemouridae	Zapada		Y	
Athropoda	Insecta	Plecoptera	Nemouridae	Zapada	cinctipes		Y
Athropoda	Insecta	Plecoptera	Nemouridae	Zapada	columbiana		Y
Athropoda	Insecta	Plecoptera	Pteronarcyidae	Pteronarcys		Y	Y
Athropoda	Insecta	Plecoptera	Peltoperlidae	Yoraperla		Y	
Athropoda	Insecta	Plecoptera	Capniidae			Y	Y
Athropoda	Insecta	Trichoptera	Apataniidae	Pedomoecus			Y
Athropoda	Insecta	Trichoptera	Glossosomatidae	Agapetus		Y	Y
Athropoda	Insecta	Trichoptera	Glossosomatidae	Glossosoma		Y	Y
Athropoda	Insecta	Trichoptera	Hydropsychidae	Arctopsyche	grandis	Y	Y
Athropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsyche		Y	Y
Athropoda	Insecta	Trichoptera	Hydropsychidae	Parapsyche	elsis		Y
Athropoda	Insecta	Trichoptera	Brachycentridae	Micrasema		Y	Y
Athropoda	Insecta	Trichoptera	Brachycentridae	Brachycentrus	americanus	Y	Y
Athropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche		Y	
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila		Y	
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	arnaudi		Y

Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	Betteni gr.		Y
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	Brunnea/ Vemna Gr.		Y
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	Hyalineata gr.		Y
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	narvae		Y
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	grandis		Y
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	Vagrita gr.		Y
Athropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	valuma		Y
Athropoda	Insecta	Trichoptera	Hydroptilidae	Ochrotrichia		Y	Y
Athropoda	Insecta	Trichoptera	Hydroptilidae	Metrichia		Y	
Athropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila		Y	Y
Athropoda	Insecta	Trichoptera	Hydroptilidae	Agraylea		Y	
Athropoda	Insecta	Trichoptera	Lepidostomatidae	Lepidostoma			Y
Athropoda	Insecta	Trichoptera	Philopotamidae	Wormaldia		Y	
Athropoda	Insecta	Trichoptera	Philopotamidae	Dolophilodes		Y	Y
Athropoda	Insecta	Trichoptera	Limnephilidae	Dicosmoecus		Y	
Athropoda	Insecta	Trichoptera	Limnephilidae	Onocosmoecus		Y	
Athropoda	Insecta	Trichoptera	Limnephilidae	Psychoglypha		Y	
Mollusca	Gastropoda	Basommatophora	Ancylidae	Ferrissia		Y	
Mollusca	Gastropoda	Basommatophora	Physidae	Physa		Y	
Mollusca	Gastropoda	Neotaenioglossa	Pleuroceridae	Juga			Y
Mollusca	Gastropoda	Basommatophora	Planorbidae			Y	

Whychus Creek Baseline Technical Report: Native Fish Monitoring

Clair Kunkel
Fisheries Biologist
Bend, OR 97701

Abstract

This report evaluates the suitability of fish population monitoring in Whychus Creek for evaluating habitat restoration effectiveness. *Oncorynchus mykiss* populations were surveyed at four locations along the creek in 2006-2008. Population estimates were developed at each location. 2006 data are not comparable to later data due to changes in survey methods, but *O. mykiss* population estimates for 2007 and 2008 provide reliable data for comparison with future years. Surveys were unable to differentiate between redband and steelhead juveniles, making it difficult to draw conclusions about the relative densities of the two life history types. *O. mykiss* redds were also surveyed at four locations along the creek in 2006-2008. All redds observed during the March through July surveys are thought to be from redband trout as no adult steelhead returned to Whychus Creek during 2006-2008. Baseline information will be useful in future years when adult steelhead return to Whychus Creek. Anticipated changes in sampling methods will improve the use of fish population data in evaluating long term trends in Whychus Creek.

Introduction

This report reviews fish population monitoring data collected from Whychus Creek, a tributary to the upper Deschutes River, during the 2006 through 2008 field seasons. It determines the suitability of that data for evaluating the biological response to watershed restoration actions. Biologists working for Portland General Electric, with assistance from other agencies such as the USFS, have collected this data as part of an effort to restore anadromous fish runs above the Pelton Round Butte hydroelectric project dams, located at river mile 100 on the Deschutes River. Data on the population characteristics of native redband and bull trout, non-native brown and brook trout, and other fish species is desired to determine the success and impacts of re-establishing runs of summer steelhead and spring chinook in Whychus Creek. PGE has collected similar data in the Metolius and Crooked River subbasins.

Intuitively, the abundance and distribution of native fish appear to be good biological measures of the success of watershed restoration actions. As watershed health increases, the numbers and perhaps distribution of fish within the watershed can be expected to increase. 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 many 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.

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 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 subbasins.

Fish species presently occurring in Whychus Creek include native redband trout (*Oncorynchus mykiss*), non-native brown trout (*Salmo trutta*), non-native brook trout (*Salvelinus fontinalis*), bridgelip sucker (*Catostomus columbianus*), longnose dace (*Rhinichthys cataractae*), and sculpin (*Cottidae*). 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 (Hill 2009, personal communication) but none were captured during sampling in 2006-2008.

Sockeye salmon (*Onchorhyncus nerka*) historically occurred in Suttle Lake (Metolius subbasin), 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 if runs are reestablished above the dams.

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 watershed 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. It is likely that both resident and anadromous forms of *O. mykiss* historically occurred in Whychus Creek as well. Both life history forms will coexist again as fisheries managers reestablish steelhead runs in Whychus Creek. The habitats of juvenile redband and steelhead are similar. 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.

Portland General Electric's Native Fish Monitoring Reports

Portland General Electric (PGE) produced three annual reports that summarize their native fish monitoring efforts in the Upper Deschutes subbasin, including monitoring conducted in Whychus Creek (PGE and CTWS 2007, Hill and Quesada 2008, Quesada and Hill 2009). These reports summarize field work conducted during the 2006, 2007, and 2008 spring and summer field seasons, respectively.

The primary objective of PGE's native fish monitoring is to describe *O. mykiss* populations within the study reaches, including population size and size-frequency distributions. Two aspects of their native fish monitoring reports may be of particular interest for purposes of evaluating trends in fish habitat restoration in Whychus Creek:

(1) *O. mykiss* population estimates
(2) *O. mykiss* redd counts.

This technical report will focus primarily on the results of population estimates and redd counts of *O. mykiss*. PGE's reports contain additional information related to fish populations in Whychus Creek that this technical report does not consider.

O. mykiss Population Estimates

Methods

Fisheries managers chose four study reaches (Figure 1) to represent the range of habitats in Whychus Creek (Lewis 2003). Reach 1 is located downstream from Alder Springs at river kilometer 12.5. Reach 2 is downstream of USFS Road 6360 at river kilometer 9. Reach 3 is at Camp Polk at river kilometer 25.5. Reach 4 is downstream from Hwy 20 in Sisters at river kilometer 34.5.

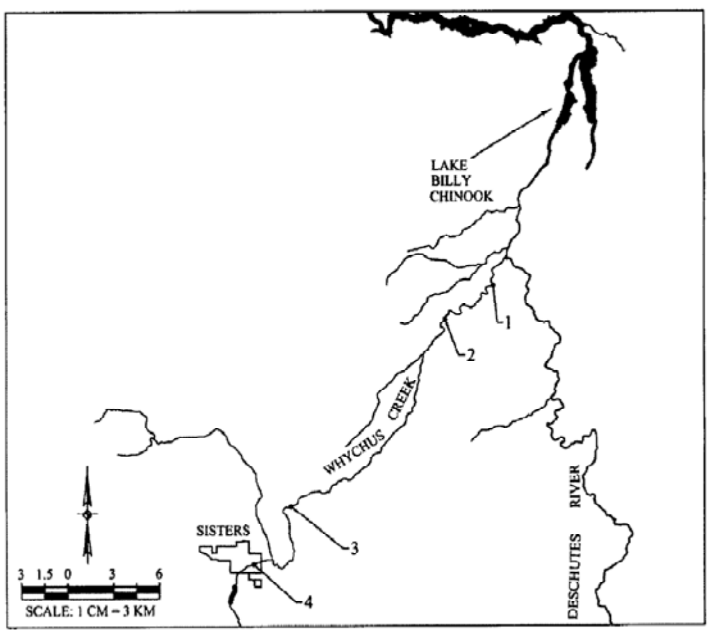

Figure 1.
Study reaches on Whychus Creek for fish population estimates. Steelhead fry were stocked in reaches 1-3 during May 2007 and in reaches 1-4 during May 2008. These reaches were surveyed in 2006, 2007, and 2008.

Fish population sampling was conducted during the low flow period in August and September of each year. Block nets were set at the upper and lower ends of selected habitat units within each study reach. A single electroshocker was used to capture fish. In 2006 a two-pass removal method (Seber and LeCren

1997) was used to estimate fish populations. In 2007 and 2008, mark-recapture electrofishing was conducted following protocols adapted from ODFW (Scheerer *et al* 2007). In 2007 fish population estimates were calculated using both the multiple pass removal method and Chapman's modification of the Peterson mark recapture model (Ricker 1975). A comparison of the results indicated that the mark-recapture method provided a higher degree of precision, so that method was chosen for use in 2008.

Results

The majority of fish captured in Whychus Creek were *O. mykiss*. Other species captured were brown and brook trout, sculpins, longnose dace, and bridgelip sucker. PGE's native fish monitoring reports provide limited information on the relative proportions of each species and no population estimates of species other than *O. mykiss*. Information on species other than *O. mykiss* may be useful for future baseline comparisons.

During the 2006 season, juvenile steelhead had not yet been stocked in Whychus Creek as part of the anadromous fish reintroduction effort. All *O. mykiss* captured in 2006 were redband trout. In 2007 and 2008, steelhead fry were stocked during the spring season. Numbers of 275,000 steelhead fry were stocked in Whychus Creek in 2007 and 290,650 steelhead fry were stocked in the creek in 2008. *O. mykiss* juveniles that were captured during 2007 and 2008 were a mix of redband and steelhead. In 2009, additional steelhead fry as well as chinook fry will be stocked in Whychus Creek.

A confounding factor in evaluating the relative abundance of redband and steelhead is the difficulty of identifying the difference between juveniles of the two different life history types, especially in the field. Juvenile redband and steelhead have very similar appearance and behavior. They also occur in the same habitats. PGE staff experimented with dye-marking of juvenile steelhead prior to stocking for purposes of subsequent identification in the field, but the dye was not detectable during sampling. Population estimates for 2007 and 2008 can only be reported as "*O. mykiss*", because it was not possible to identify the difference between juvenile redband and juvenile steelhead in the field.

The two-pass removal method used to estimate *O. mykiss* abundance in 2006 was substantially different than the mark-recapture method used in 2007 and 2008. PGE and CTWS (2007) found that the confidence intervals around the 2006 population estimates were too large to be meaningful, and catch-per-unit effort sampling used in prior years did not generate reliable population estimates. It is not possible to directly compare fish population estimates from earlier years with the 2007 and 2008 estimates.

The 2006 estimates excluded fish less than 80mm in length, while the 2007 and 2008 estimates included fish larger than 60mm. The 2006 report does present the numbers of *O. mykiss* less than 80mm that were captured during the electroshocking survey, which provides a limited means for comparison of relative abundance of fish in this size class. However, because the *O. mykiss* population estimates from 2006 are not directly comparable with those from 2007 and 2008, they are not reported here.

A comparison of the abundance estimates of *O. mykiss* in 2007 and 2008 is presented in Table 1. Although more steelhead fry were stocked in 2007 than in 2008, and some steelhead would be expected to carry over from 2007 and be present during the 2008 sampling, the estimated number of *O. mykiss* was less in 2008. A possible explanation for the lower abundance in 2008 is that relatively high stream flows occurred during the 2007 winter and following steelhead stocking in the spring of 2008 (Quesada and Hill 2009). These higher flows may have flushed steelhead fry out of Whychus Creek, affected the distribution of fry, or resulted in higher mortalities during 2008.

Table 1. *O. mykiss* abundance for 2007 and 2008 surveys. 2006 data was not comparable due to differences in sampling methods.

Reach	Fish/100m²	
	2007	2008
1 (Alder Springs)	48 (± 28)	24 (± 24)
2 (Road Crossing)	25 (± 10)	9 (± 3)
3 (Camp Polk)	60 (± 13)	52 (± 21)
4 (Sisters)	20 (± 10)	5 (± 2)

Hill and Quesada (2008) performed a thorough evaluation of the assumptions applied to their sampling methods and models used to estimate fish numbers. They calculated population estimates using mark-recapture data and multiple pass removal data for the same sampling sessions. Their mark-recapture estimates were more precise than their multiple pass removal estimates, and the mark-recapture estimates resulted in higher population estimates in some reaches (Figure 2). The precision of their mark-recapture estimates falls within the range of results reported by other studies of redband trout (Dachtler 2007, Temple and Pearsons 2006). Based on their evaluation, they chose to use the mark-recapture method for estimating fish numbers in 2008.

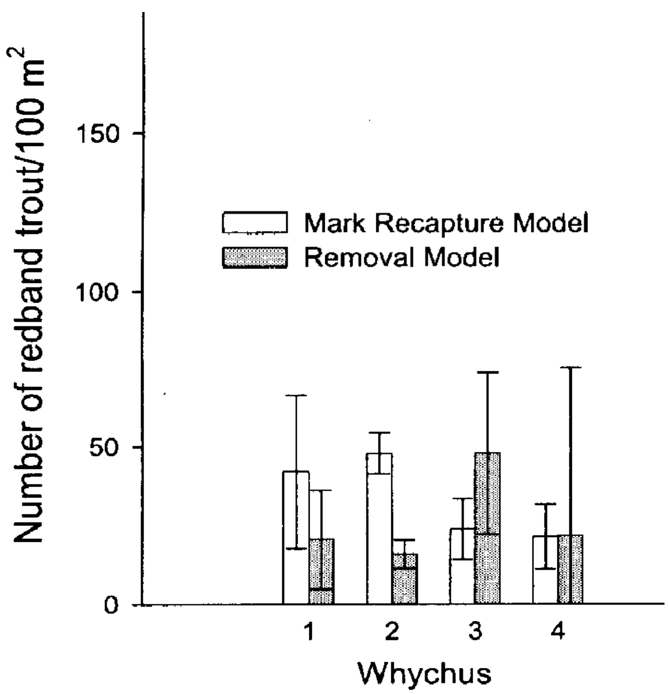

Figure 2.
Number of O. mykiss per 100m² estimated by mark-recapture and removal methods. Data were collected in 2008 in Whychus Creek. Reproduced with permission from Quesada and Hill (2009).

The capture probabilities calculated for Whychus Creek indicated that capture efficiency was higher for fish greater than 175mm (40% - 66.7%; Table 2). Capture efficiencies for *O. mykiss* presumed to be in the 0 age class (60-125mm) were relatively low (8.2% - 21.5%). In response to the low capture efficiency of smaller fish, PGE's work plan for the 2009 field season (Quesada and Hill 2009) includes provisions to increase the length of sample sections and to utilize two electroshockers to increase the capture efficiency of fish. Increasing the capture efficiency should increase the precision of fish population estimates.

Table 2. Capture probabilities (p) for three size groups of *O. mykiss* in Whychus Creek in three electrofishing passes. Data were collected in 2008.

Pass	Length 60-125 mm		126-175 mm		>175 mm	
	n	p	n	p	n	p
1	186	--	12	--	5	--
2	40	21.5%	0	0.0%	2	40.0%
3	12	8.2%	1	8.3%	2	66.7%

Discussion

Hill and Quesada compared their results with mark-recapture estimates conducted by the Forest Service in the Camp Polk reach in 2006 (Dachtler 2007). Dachtler estimated a density of 5 fish/100m² in 2006, compared to Hill and Quesada's estimates of 59 fish/100m² in 2007, and 52 fish/100m² in 2008. The magnitude of difference between the 2006 and 2007-2008 estimates probably indicates an actual change in fish density. The higher fish densities estimated in 2007-2008 may be attributable to the steelhead trout fry that were stocked in Whychus Creek during those years. The USFS (Riehle 2009, personal communication) plans to conduct a fish population estimate in Whychus Creek upstream from Sisters during the 2009 summer season that will be complementary to PGE's native fish monitoring.

Stocking levels of steelhead fry may have affected the abundance and distribution of resident redband trout in several ways. If stocking resulted in *O. mykiss* densities that exceeded the habitat capacity of sample reaches, competition would likely have resulted in displacement of redband or steelhead fry, or both. Fry may have been displaced to different locations in Whychus Creek, or they may have been displaced out of Whychus Creek and into the Deschutes River. The physical condition of fry may also have been affected if fry densities were high enough that food resources were limiting. High fry densities, displacement, and reduced physical condition could result in increased vulnerability to predation by larger redband, brown, and brook trout or other predators, as well as vulnerability to disease or other sources of mortality. Steelhead fry were stocked prior to the emergence of redband fry from the gravel, which may have given steelhead fry a competitive advantage. These factors are all very difficult to evaluate.

The *O. mykiss* population estimates for 2007 and 2008 provide reliable data for comparison with future years. The inability to differentiate between redband and steelhead juveniles makes it difficult to draw conclusions about the relative densities of the two life history types and any potential density interactions between the two. Methods to differentiate between redband and steelhead life history types of *O. mykiss* will be critical to future sampling efforts. PGE's hydro license does not require determination of proportions of steelhead vs. redband until five years and ten years after adult steelhead return to Whychus Creek (PGE and CTWS 2006). However it would be highly advantageous to obtain that information in the early stages of the reintroduction project if possible. The fish montoring work plan for 2009 (Quesada and Hill 2009) includes provisions to collect scales and tissue samples from *O. mykiss* juveniles during sampling for analysis to help identify redband vs. steelhead juveniles, however funding may not be available to complete genetic analysis of the samples.

PGE could use two methods to differentiate between redband and steelhead juveniles in future sampling. They could analyze strontium:calcium (Sr:Ca) ratios in otoliths and compare the freshwater growth portions of the otoliths (Zimmerman and Reeves 2002). They could also complete a genetic analysis of tissue samples from fish. Staff plan to investigate the utility of using one or both of these methods in the future. However, the first method requires killing the fish and the second method requires collecting appropriate tissue samples from fish in the field. Both methods require detailed laboratory analysis of samples and are relatively expensive.

PGE plans to utilize fish traps to estimate numbers of steelhead, chinook, and redband juveniles out-migrating from Whychus Creek and other tributaries in the future. Fish traps deployed in Whychus Creek in previous years have been difficult to operate effectively, primarily because of widely fluctuating flows during the downstream migration period (Hill 2009, personal communication). Flows drop so low that traps don't operate and then increase to the point that traps must be pulled. As staff gain experience with operating various fish traps in Whychus Creek, they may be able to collect reliable estimates of the number of steelhead and salmon out-migrants produced in Whychus Creek. Downstream migrants will not only consist of full-term smolts. Many juvenile steelhead and chinook will move out of Whychus Creek prior to achieving smolt size. These juveniles will rear in the Deschutes River and/or Lake Billy Chinook before migrating to the ocean.

Trapping on Whychus Creek and other upper Deschutes River tributaries will facilitate the marking of downstream migrants for later identification. Migrating juveniles will be collected at the new outlet facility on Lake Billy Chinook, and recovery of marked fish can provide data to estimate the relative contribution of smolts from each tributary. Downstream fish trapping will also provide data regarding out-migration of resident fish. Estimates of out-migrating resident and anadromous fish will only be meaningful if fisheries managers can differentiate between juvenile steelhead and redbands.

Hill and Quesada (2008) utilized a version of the habitat-based Unit Characteristic Method (UCM) (Ackerman *et al* 2007, Cramer and Ackerman 2009) to predict *O.mykiss* rearing densities for comparison with population estimates for the sample stream reaches. Habitat data collected during the 2007 electrofishing surveys were used to generate *O. mykiss* parr (85-125mm length) capacity estimates using the UCM. No consistent relationship was found between the UCM predictions and the population estimates for Whychus Creek (Table 3). The lack of consistency may be because the UCM has not been validated for relatively small streams like Whychus Creek.

Table 3. UCM predictions compared to mark-recapture population estimates of O. mykiss parr (85-125mm length) in Whychus Creek.

Reach	UCM Prediction	O. mykiss population estimate	
1	82	123	(± 122)
2	21	8	(± 2)
3	73	274	(± 74)
4	174	29	(±19)

Hill and Quesada (2008) discuss plans to work with a consultant to validate the UCM for Whychus Creek. This will involve increased sampling effort to improve capture efficiencies, collection of additional habitat data including turbidity and alkalinity, and use of a downstream migrant trap. A validated and reliable habitat-based model for Whychus Creek would be useful for monitoring the effectiveness of watershed restoration progress. It would allow the correlation of fish abundance with specific habitat parameters. As watershed conditions improve, the UCM should predict corresponding increases in fish habitat capacity, and mark-recapture population estimates should correlate with trends in fish habitat capacity.

A reliable habitat-based model for Whychus Creek would help to ensure that watershed restoration actions are producing the desired fish habitat attributes and that fish populations are responding as predicted. Initial attempts to validate such a model have not been encouraging, and this may be a more difficult endeavor than originally anticipated (Hill 2009, personal communication). High stream flow events which occur annually in Whychus Creek alter channel morphology, making it difficult to validate an effective habitat model.

O. mykiss Redd Counts

Methods

Four areas were identified as index sites for *O. mykiss* redd surveys (Figure 3). The four sites were subdivided into 10 individual reaches to help identify the distribution of redds within the index sites. PGE and the Forest Service surveyed the index sites every two weeks from March through July in 2006 – 2008. Relatively high stream flows and turbidity prevented surveys during some periods during 2006. 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.

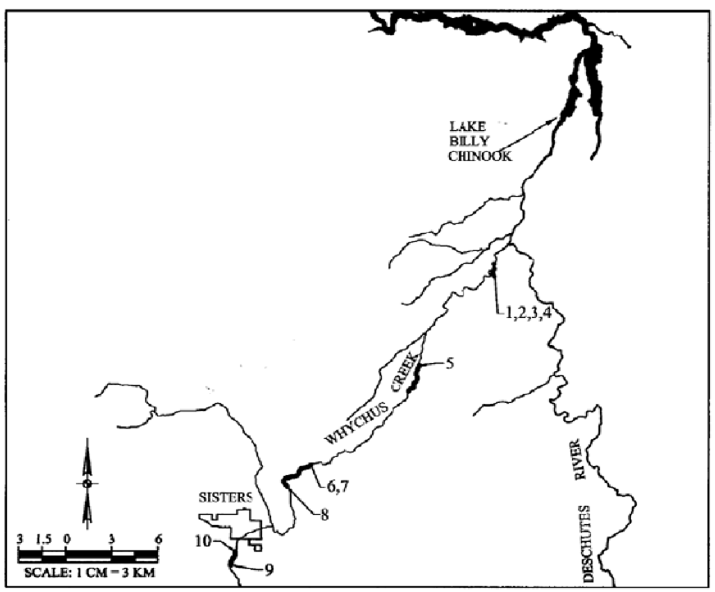

Figure 3. Whychus Creek redd count sites. Alder Springs (reaches 1-4), Rimrock Ranch (reach 5), Camp Polk (reaches 6-8), upstream (reaches 9-10). Reproduced with permission from Quesada and Hill (2009).

Results

All redds observed during the March through July surveys are thought to be from redband trout. No adult steelhead were returning to Whychus Creek during 2006-2008, and the other salmonid species occurring in Whychus Creek are fall-spawning fish. Baseline information regarding numbers and distribution of redband redds will be useful in future years when adult steelhead return to spawn in Whychus Creek.

Redd counts are summarized in Table 4. The highest numbers of redds were observed in the Alder Springs (reach sections 1-4) and Rimrock Ranch (reach section 5) areas. The Alder Springs and Rimrock

Ranch areas combined accounted for well over 80% of all redds observed each year. Very few redds were observed in reach sections 4, 9, and 10 during all three years. Barriers above and below reach sections 9 and 10 likely inhibited migration of spawning fish which may account for the low redd numbers. Reach section 4 is relatively poor in spawning gravel, and also suffers from relatively high summer temperatures.

Table 4. Total redd counts by stream reach in Whychus Creek, March – July of each year.

Reach Section	Year		
	2006*	2007	2008
1	14	51	27
2	2	5	11
3	0	12	9
4	2	1	1
5	30	38	18
6	2	6	0
7	2	11	5
8	6	4	3
9	0	0	0
10	0	1	0
Total	**58**	**129**	**74**

* Surveys were not completed every month for all reaches in 2006 due to unusually high water from late snow runoff.

Flow conditions during surveys in 2006 and 2008 were relatively high and turbid (Figure 4), making it difficult for surveyors to count redds. Drawing conclusions regarding the number and distribution of redds between years is problematic.

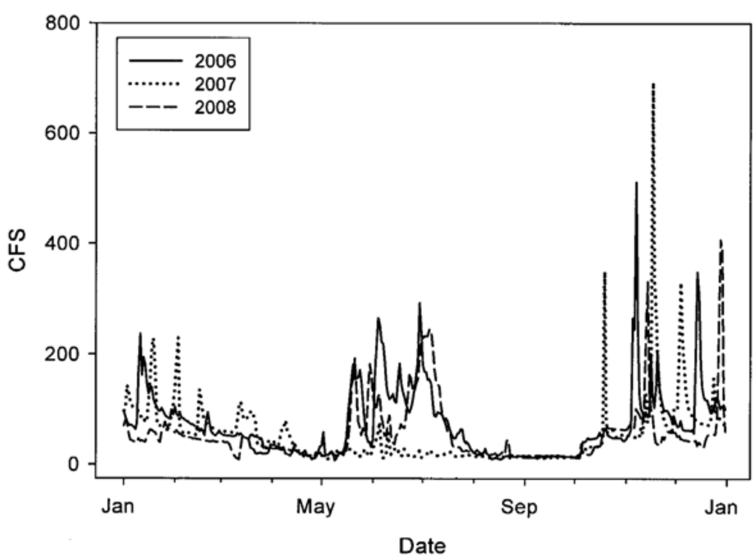

Figure 4. Whychus Creek flows in cubic feet per second (cfs). Measured at the Oregon Water ResourcesDepartment's gage at the City of Sisters. Reproduced with permission from Quesada and Hill (2009).

Discussion

Quesada and Hill (2009) have presented a work plan for 2009 that includes several changes in redd count methodology that will be implemented in 2010, with 2009 being a transitional year. A sampling design similar to ODFW Coastal Salmonid Inventory Project (ODFW 2007) and recommended by the American Fisheries Society (Gallagher *et al* 2007) will be used. This method should generate accurate annual spawner estimates and reliable data on spawner distribution.

During 2009, a sample of redband trout redds in Whychus Creek will be measured including length, width, depth, pot and tail spill, and substrate size (Gallagher *et al* 2007). This pre-steelhead redd data should allow differentiation between redband redds and steelhead redds when adult steelhead return to spawn in the future (Zimmerman and Reeves 1999).

Accurate information on numbers and distribution of spawning fish will be useful for documenting adult fish response to improving watershed conditions, and for planning future watershed restoration actions. As watershed restoration efforts continue and watershed conditions improve, the numbers and distribution of *O. mykiss* would be expected 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 may be responsible for any observed trends in spawning fish abundance, especially for anadromous steelhead and chinook. Smolts produced in Whychus Creek will be subject to many variables such as downstream passage and water conditions, predation, ocean survival, tribal, sport, and recreational fisheries, and adult passage back upstream. These variables typically fluctuate substantially between years and greatly affect smolt-to-adult survival.

Application of Results to Evaluating Habitat Restoration Effectiveness

Restoration partners originally expected that biological indicators would provide an effective means for evaluating trends in watershed restoration. Ideally, a biological indicator such as fish abundance would be measured before, during, and after the implementation of watershed restoration projects. Restoration partners expected that fish abundance would increase as habitat quality and quantity increase. This approach would work well if habitat quality and quantity were the main variables affecting fish abundance, but other variables may also affect fish abundance in Whychus Creek. These variables may cause actual or perceived changes in fish populations.

Changes in Habitat Conditions

Restoration partners initially hoped to attribute short term changes in ecological conditions to restoration in the creek. Restoration actions may not move the creek towards desired conditions until several years after their implementation. Restoration actions such as reconfiguring channelized stream reaches may even cause initial reductions in fish habitat quality or quantity until sediments, stream banks, aquatic and riparian vegetation, and stream flows stabilize and mature. Fish populations will respond to these short term changes, and short term trends in fish populations may not reflect long term trajectories in the creek.

Although restoration partners have focused on restoring base flows in the creek, stream flows fluctuate dramatically within and between years. Stream flows affect fish density and distribution. Fluctuations in fish numbers and distribution due to flow variability will likely mask the effect of watershed restoration on short-term trends in fish abundance. These variables make it challenging to relate changes in habitat conditions to short-term changes in fish populations.

Artificial Stocking

The artificial stocking of thousands of steelhead fry in Whychus Creek may have driven *O. mykiss* abundance in the sampled reaches in 2007-2008. In future years, fisheries managers will stock chinook salmon along with steelhead fry. The resulting changes in species composition will likely affect the relative abundance and distribution of fish species in the creek. Eventually, adult steelhead and chinook will pass the Pelton Round Butte project to spawn in Whychus Creek and other tributaries. Adult returns and spawning may also affect the distribution of juvenile fish. The early phase of the anadromous fish reintroduction program will add variables to Whychus Creek that will make it difficult to discern any changes in the system over short time periods.

The hatchery stocks selected for reintroduction provide an additional variable. Steelhead and chinook fry stocked in Whychus Creek came from hatchery stocks that may not be ideally adapted for survival under natural conditions. Reisenbichler and Rubin (1999) concluded that hatchery programs genetically change populations of steelhead and chinook. These programs reduce the reproductive success of stocked fish when the fish spawn in natural environments. Reisenbichler and Rubin's (1999) conclusion is based on the results from five studies of hatchery fish performance under natural conditions. Their conclusion suggests that it could take several generations before a population founded on hatchery fish genetically adapts to the new environment. Steelhead and hinook reproducing during the early stages of reintroduction may not perform as well as their descendants. Genetic adaptation may improve survival independent of any changes in habitat.

Sampling Scope, Scale, and Methods

The sampling scope, scale, and methods used by PGE all affect fish population estimates in Whychus Creek. Short term trends in fish populations may not represent long term trends in the creek as PGE has improved their sampling methods over the past three years. PGE used different sampling methods prior to 2007 than they used in 2007 and 2008. Fish population estimates calculated with pre-2007 data had relatively low precision and cannot be compared with the higher precision estimates from 2007 and 2008 with statistical reliability. Any short-term trends in watershed condition could not be detected by comparing fish abundance estimates through this period.

PGE's plans to improve capture efficiency and apply longer sample reaches in future sampling should provide fish population estimates of sufficient precision. These estimates will enable PGE to identify long term trends in fish abundance and correlate them to trends in habitat conditions. The development of a reliable UCM or a similar habitat model for Whychus Creek would provide a valuable means for correlating fish abundance with habitat parameters, and for guiding future stream restoration efforts. PGE has been working with a consultant in attempts to validate such a model, but to date the results have not been encouraging (Hill 2009, personal communication).

The inability to differentiate between redband and steelhead juveniles impedes restoration partners' understanding of the present and future dynamics between these two life history types of *O. mykiss*. The 2009 work plan presented by Quesada and Hill (2009) recognizes the need to collect scale samples and genetic material that may help identify redband vs. steelhead in future years. The collection and evaluation of otoliths, scales and genetic samples are strongly recommended to contribute to the understanding of dynamics between redband and steelhead.

The constraints identified above all refer to fish populations within Whychus Creek. The life histories and habitat requirements of the fish native to Whychus Creek are very complex, though, and understanding fish population dynamics will require looking beyond the creek. Witty (1999) provides an excellent overview of the relative life histories and habitat requirements of chinook salmon, steelhead, redband and bull trout in the Deschutes River system . Chinook salmon and steelhead exhibit complex life histories in this system. Some fry may move out of Whychus Creek soon after emerging from the gravel and rear to smolt size in the Deschutes River or in Lake Billy Chinook. This downstream movement may be caused by high stream flows, or initial high fish densities that result in competition and displacement. Some juveniles may initially rear in Whychus Creek, and migrate out of the creek to complete rearing. Other juveniles may complete their rearing to smolt size entirely within Whychus Creek and migrate out as smolts. Variables external to Whychus Creek that affect smolt-to-adult survival include downstream passage and water conditions, predation, ocean survival, tribal, sport, and recreational fisheries, and adult passage back upstream. Resident redband life histories are similarly variable. Each one of these life history variables will affect fish populations within Whychus Creek but may be independent of habitat restoration effectiveness.

Restoration partners have focused on tracking the status of and trends in redband trout, steelhead trout, and chinook salmon populations. As stream conditions improve, bull trout may be increasingly attracted to Whychus Creek. Bull trout observed in Whychus Creek in 1991 and 1995 appeared to be small adults. These fish probably migrated from Lake Billy Chinook or the Deschutes River to search for spawning habitat or to forage on spawning kokanee (Fies *et al* 1996). It is not clear whether bull trout have spawned or reared in Whychus Creek in recent years. As conditions improve, though, they may begin to spawn and rear in the creek and will be detecting by PGE's native fish monitoring. Restoration partners should consider bull trout populations as another indicator of conditions in the creek as restoration continues.

Recommendations

(1) Estimate the abundance of all fish species captured in sample reaches, including non-native brown and brook trout. Baseline information on existing non-native fish populations may interest restoration partners as restoration progresses and as the re-establishment of anadromous fish occurs. Non-native fish may compete with and prey on juvenile native fish.

(2) Restoration partners should design habitat restoration projects to enhance native fish and inhibit non-native fish. Reliable data on local native and non-native fish abundance may be useful in determining the effectiveness of restoration strategies in the future.

(3) Validate the Unit Characteristic Method or a similar habitat model for Whychus Creek and other upper Deschutes River tributaries. The model should reliably correlate fish abundance with specific habitat parameters. Hill and Quesada (2008) discussed plans to improve sampling efficiencies, collect additional habitat data, implement downstream trapping, and work with a consultant to validate the UCM for Whychus Creek. A reliable habitat-based model will ensure that watershed restoration actions are providing desirable fish habitat features, and that predicted response of key fish species is occurring.

(4) Improve the capture efficiency of small fish to increase the precision of population estimates. Quesada and Hill (2009) present a work plan for the 2009 season that includes specific actions to improve capture efficiency and precision, including use of two electroshockers and increasing the length of sample reaches.

(5) Develop and implement methods to differentiate juvenile redband and steelhead. Quesada and Hill (2009) discuss future plans to identify the two life history forms of *O. mykiss* in Whychus Creek and other tributaries. PGE is not required to determine the relative proportions of steelhead and redband until five years and ten years after adult steelhead return to the creek. Funding may not be available to conduct genetic analysis prior to that time. Restoration partners should work with PGE to secure additional funding to provide genetic analysis or other methods

necessary to differentiate between steelhead and redband juveniles early in the reintroduction project.

(6) Implement an effective downstream fish trapping methodology in Whychus Creek and other tributaries to the upper Deschutes River. PGE staff has tested various traps and will evaluate the traps and techniques that may be effective under the difficult conditions imposed by Whychus Creek and other tributaries. Effective trapping will be essential to monitor downstream migrating juveniles, and mark fish for future identification at the reservoir outlet structure.

(7) Develop an improved sampling design for conducting redd counts that provides a reliable index of spawning fish numbers. Quesada and Hill (2009) intend to implement a sampling design similar to ODFW Coastal Salmonid Inventory Project (ODFW 2007) and recommended by the American Fisheries Society (Gallagher *et al* 2007).

(8) Measure the physical characteristics and document the distribution of redband trout redds in Whychus Creek prior to the return of spawning steelhead. Physical parameters will help surveyors to differentiate between redband and steelhead redds when both forms of *O. mykiss* are spawning in Whychus Creek. Quesada and Hill (2009) plan to collect measurements of redband redds during the 2009 spawning season.

(9) Emphasize the coordination of monitoring efforts and resources between the various agencies and organizations working in Whychus Creek. The collective resources of stakeholders should be carefully coordinated to provide the most effective monitoring possible. The Upper Deschutes Watershed Council should investigate the potential for creating a working group to facilitate this coordination. All interested parties need to share monitoring responsibilities in order for this effort to be successful.

(10) The wide range of variables that affect fish numbers and distribution in Whychus Creek make it difficult to evaluate the influence of restoration efforts on fish abundance, particularly on a short-term basis. Many of the restoration projects planned for Whychus Creek will take many years to develop to full effect. Continual long-term monitoring (>10 years) will ensure adequate data to correlate future trends in fish abundance with trends in stream restoration.

Conclusion

The results presented in the *Native Fish Monitoring: Biological Component* reports provide valuable baseline data on present abundance and distribution of fish in Whychus Creek. Long term monitoring should document trends in fish populations as stream conditions improve and anadromous fish runs re-establish. PGE’s fish monitoring will help to ensure that the long-term objectives of the Upper Deschutes Model Watershed Program are being met.

Providing meaningful data is a huge challenge considering all the variables that are being introduced into Whychus Creek as a result of simultaneously re-establishing anadromous fish runs and implementing numerous restoration projects. PGE’s employees are performing an outstanding job of monitoring fish populations in Whychus Creek under challenging conditions. Their work complements the purpose of the Upper Deschutes Model Watershed Program. This intensive level of monitoring does not always occur in areas with extensive stream restoration in progress. PGE’s monitoring approach has been very innovative and adaptive in attempts to meet this challenge, and their employees are to be commended for their efforts.

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