

AN ABSTRACT OF THE THESIS OF

Lesley M. Jones for the degree of Master of Science in Water Resources Science presented on March 10, 2011.

Title: Evaluation of Instream Flow Restoration Targets and the Carrying Capacity of *Oncorhynchus mykiss* according to Temperature, Whychus Creek, Deschutes Basin, Oregon

Abstract approved:

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The Pelton Round Butte Hydroelectric Project (Oregon) was built between 1957 and 1964. As a result the anadromous steelhead trout was extirpated from the upper Deschutes Basin by 1968. The Deschutes Basin is a model for instream flow restoration projects in the Pacific Northwest that are largely driven by the reintroduction of anadromous steelhead trout into the upper Deschutes Basin and in particular have focused on Whychus Creek Watershed. Current instream flow restoration targets for Whychus Creek are based on certified instream water rights, derived from habitat surveys. This paper quantifies instream flow restoration targets for Whychus Creek based upon flow, temperature, and estimated steelhead trout carrying capacity. It is suggested that instream flow restoration targets are not fully resolved and additional flows may be needed to meet a restoration goal for temperature in Whychus Creek. It is proposed that estimates of steelhead trout carrying capacity that are based upon the Upper John Day Subbasin steelhead trout densities are an appropriate measure of potential steelhead trout numbers within Whychus Creek and are appropriate for refining instream flow restoration targets.

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Evaluation of Instream Flow Restoration Targets and the Carrying Capacity of
Oncorhynchus mykiss according to Temperature, Whychus Creek, Deschutes Basin,
Oregon

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Lesley M. Jones, Author

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Evaluation of Instream Flow Restoration Targets and the Carrying Capacity of *Oncorhynchus mykiss* according to Temperature, Whychus Creek, Deschutes Basin, Oregon

Chapter 1. Instream Flow Restoration Targets

1.1 Introduction

The Pelton Round Butte Hydroelectric Project was built between 1957 and 1964. As a result the anadromous steelhead trout was extirpated from the upper Deschutes Basin by 1968 (Nehlsen, 1995). The 'Deschutes above Pelton Round Dam' major population group (MPG) was effectively disconnected from its parent Middle-Columbia Steelhead Trout distinct population segment (DPS). The Middle-Columbia River Steelhead DPS is listed as threatened under the Environmental Species Act (ESA). Successful establishment of a sustainable Deschutes above Pelton Round Dam MPG of steelhead trout will contribute to the viability of the greater Middle-Columbia Steelhead Trout DPS and reintroduction efforts have embarked upon this effort.

The Deschutes Basin, Oregon is a model for instream flow restoration projects in the Pacific Northwest that are largely driven by the goal of supporting the reintroduction of steelhead trout (Aylward & Golden, 2006) (CBWTP, 2010) (DRC, 2010) (OWRD, 2010 a). Whychus Creek, located within the upper Deschutes Basin and a key location of steelhead trout reintroduction, is an experiment in instream flow restoration.

In Whychus Creek, instream flow restoration activities aim to achieve the restoration goal of improving temperatures to meet the needs of the reintroduced steelhead trout (UDWC, 2009). Instream flow restoration efforts have established instream flow targets to meet the restoration goal. Instream flow restoration targets are based upon certified instream water rights and this evolved out of the history of water management in Oregon. Current Oregon water code polices that support water banking have emerged. Water banking, such as leasing and buying of water rights, is the primary mechanism to

achieve instream flow restoration targets in the Deschutes Basin (Aylward & Golden, 2006). The experiment of instream flow restoration in Whychus Creek presents an opportunity to assess instream flow restoration targets and their ability to meet the restoration goal. It is of interest if the certified instream water rights are an appropriate instream flow restoration target and if additional flows may be needed to meet the restoration goal in Whychus Creek.

1.1 The Deschutes Basin

The Deschutes Basin is located within the greater Columbia Subregion (Figure 1) (USGS, 2010 a) and has a drainage area of 26,860 km² (10,371 mi²) (USGS, 2010 b). The basin resides within the Eastern Cascade Slopes and Foothills of the Western Forested Mountains Ecoregion (CEC, 1997). Open forests of ponderosa pine and lodge pole pine distinguish this region from the mountains to the west where spruce fir forests are common, and the arid areas to the east where shrubs and grasslands are predominant. The vegetation is adapted to the prevailing dry continental climate and is highly susceptible to wildfire. Volcanic cones and buttes are common in much of the region and have contributed to sedimentary, igneous and metamorphic rocks that range between 250 million years old to as young as 1,300 years old (Connor, Grant, & Haluska, 2003).

Located in the rain shadow of the Cascade Mountains, the basin's climate exhibits great temperature extremes that range from -1.1 °C to 37.8 °C (30 to 100 °F) and annual precipitation ranging from 356 cm (140 in) in higher elevations down to 25 cm (10 in) in the Deschutes Valley and the eastern part of the basin (PRISM, 2010).

The headwaters of the Deschutes River originate within Lava Lake in the Cascade Mountains and the river is joined by the Metolius and Crooked Rivers on its way to the Columbia River. The Pelton Round Butte Dam complex forming Lake Billy Chinook and Lake Simtustus represents a division between the upper and lower Deschutes Basin

(Figure 2). The beneficial uses of water within the upper Deschutes Basin can be categorized into consumptive and environmental uses (Table 1).

The upper Deschutes Basin is categorized as 'impaired' on the Oregon Department of Environmental Quality (ODEQ) Section 303(d) list 2004/2006. The primary impairment is elevated stream temperatures that do not meet the state criterion set to protect salmon and trout rearing and migration. This impairment is a concern because of reintroduced steelhead trout into the region who may be exposed to temperature stress resulting in limited growth and reduced overall productivity (ODEQ, 2010 b) (UDWC, 2009) (Feldhaus, Heppell, Hiram, & Mesa, 2010) (Cramer & Beamesderfer, 2002, 2006).

Anadromous steelhead trout, under the ESA, are federally listed as a species of concern, a threatened species, and an endangered species within the Columbia Subregion (NOAA, 2010). The Interior Columbia Technical Recovery Team (ICTRT) is a team of scientists appointed by the National Marine Fisheries Service (NMFS) to provide a solid scientific foundation for recovery planning and viability assessment. The ICTRT uses abundance, productivity, spatial structure, and diversity at the MPG level to determine the viability of a DPS. The Middle-Columbia River Steelhead DPS is listed under the ESA as threatened because the sum of its MGPs is not considered viable.

The Deschutes above Pelton Round Dam MPG and the John Day River MGP are two of the 20 MPGs that comprise the greater Middle-Columbia River Steelhead DPS. The Deschutes above Pelton Round Dam MGP is considered extirpated and does not contribute to the viability of the Middle-Columbia Steelhead Trout DPS. The reintroduction of steelhead trout into the Deschutes above Pelton Round Dam into historically accessible habitat (Whychus Creek) should help improve the viability of the currently threatened Middle-Columbia River Steelhead DPS.

The Deschutes above Pelton Round Dam MPG is not included in the ESA threatened listing for the Middle-Columbia River Steelhead DPS because steelhead trout

populations were reintroduced in 2007 after the current ESA listings were re-assessed in 2006 (NOAA, 2010).

Steelhead trout are dark-olive in color and silvery-white on the underside. They are heavily speckled and have a pink to red stripe running along their sides. Their maximum age is approximately 11 years, and they can reach up to 25 kg (55 lb) in weight and 120 cm (45 inches) in length, although average size 3.6 kg – 5.0 kg (8 – 11 lbs) (NOAA, 2010). The steelhead trout that utilize the Deschutes River primarily spawn in the spring and July represents an important rearing time period characterized by low instream flow and elevated water temperatures that are of concern. Their life history stages are described in Figure 3.

Steelhead trout rearing can occur over one to four years in the Lower Deschutes River. The Middle-Columbia steelhead trout generally smolt after two years in freshwater (McClure, Holmes, Sanderson, & Jordon, 2003). Males mature generally at two years and females at three. They can then remain at sea for up to three years before returning to freshwater to spawn. These combined behaviors produce steelhead trout that range between three and seven years of age at the time of spawning (McClure, Holmes, Sanderson, & Jordon, 2003). They can spawn more than one time (called iteroparity); some populations return to freshwater after their first season in the ocean, but do not spawn and then return to the sea after one winter season in freshwater. Evidence from primary areas of Middle-Columbia steelhead trout production suggest the capacity for summer steelhead trout are generally limited by summer rearing habitat (Cramer & Beamesderfer, 2002, 2006). This is a period of elevated instream water temperatures commonly attributed to low instream flows.

1.2 Whychus Creek

Wychus Creek is a useful case study within the Deschutes Basin because the history, issues, and current restoration activities within this watershed mirror those of the

Deschutes Basin and the watershed is the primary historic spawning habitat for steelhead trout above the Pelton Round Butte Dam complex.

The Whychus Creek Watershed is located within the Deschutes Basin (Figure 2) (USGS, 2010 a), has a drainage area of 648 km² (250 mi²), and has a 2,440 meter (8000 ft) gradient from 3,048 m (10,000 ft) in the vicinity of the Three Sisters Mountains to 640 m (2,100 ft) at the mouth (USGS, 2010 b). The watershed is reflective of the greater Deschutes Basin and resides in the Eastern Cascade Slopes and Foothills of the Western Forested Mountains (CEC, 1997). The headwaters are characterized by montane, subalpine, and alpine forest. The majority of the watershed falls within the ponderosa pine/bitterbrush woodland type. The eastern portion of the watershed primarily lies within the Deschutes River Valley consisting of juniper rangelands.

The watershed's climate also is characteristic of the greater Deschutes Basin. Precipitation ranges with elevation; approximately 0.36 meters (14 inches) per year in the vicinity of the confluence with the Deschutes River, to over 2.54 meters (100 inches) in headwater areas (PRISM, 2010).

Wychus Creek serves as the primary drainage for the watershed. Whychus Creek headwater is from seven remnant ice age glaciers within the Three Sisters Wilderness area located within the Cascade Mountains. The creek travels approximately 66.0 km (41 mi) from the Cascade Mountains to the confluence with the Deschutes River (USFS, 2007). The creek is created by glacier melt, is perennial, and due to the unique hydrology and geology of the volcanic area, 89% of the water flows as groundwater under the creek to emerge as springs downstream (USFS, 2007). Whychus Creek has an annual average daily flow of 2.97 cms (105 cfs) and a 500 year event flow of 96.29 cms (3400 cfs) (USFS, 2007) (USDA, 2010).

The beneficial uses of Whychus Creek are characteristic of the Deschutes Basin and include consumptive and environmental uses (State of Oregon, 2010 b) (Table 1). A

primary consumptive use in the watershed is irrigation. Whychus Creek water rights total approximately 390 cfs of instantaneous flow of which 70% is for irrigation purposes (Watershed Professionals Network, 2009). A primary environmental use in the watershed is fish and aquatic life. A primary fish species within Whychus Creek include the resident redband trout and the reintroduced anadromous steelhead trout both considered *O. mykiss*.

The entire extent of Whychus Creek is listed on the state of Oregon Section 303(d) list as needing a Total Maximum Daily Load (TMDL) allocation for exceeding, along sections of the creek, the temperature criterion set to protect salmon and trout rearing and migration (ODEQ, 2010 b). The Oregon Administrative Rule (OAR) states: Temperatures shall not exceed 18 °C in order to protect the beneficial use of salmon and trout rearing and migration. This criterion applies all year (State of Oregon, 2010 b). Instream flow restoration is the primary activity aimed at lowering instream temperatures along Whychus Creek (UDWC, 2009).

Whychus Creek is divided into three reaches termed the Upper, Middle, and Lower Reaches of Whychus Creek (Figure 4). A defining feature of Whychus Creek is the Three Sisters Irrigation District (TSID) diversion located at kilometer 43.5 (river mile 27) and this represents the division between the Upper and Middle Reaches. The Lower Reach is defined by the Alder Springs complex which contributes groundwater flow into the system downstream of kilometer 2.4 (river mile 1.5).

Key gage and temperature monitoring stations measure flow and temperature along Whychus Creek (Figure 4 and Table 2). Flow gage stations are identified according to Oregon Water Resources Department (OWRD) station identification numbers (Station IDs). Temperature stations are identified according to creek name and distance from the mouth in kilometers (i.e. WC 2.4 is Whychus Creek at kilometer 2.4 upstream from the mouth).

Evaluation of the flow record from two gages 2000 – 2009 demonstrates the TSID diversion affect on Whychus Creek hydrology (Figure 5). Upstream of the TSID diversion, Whychus Creek exhibits a hydrographic regime typical of eastside Cascade streams; wintertime rain on snow events and spring-snowmelt that occur outside of the-irrigation season (Watershed Professionals Network, 2009). Flows during irrigation season are characterized by smaller magnitude, higher frequency events and the TSID diversion reduces these peak values by approximately 20 to 60%. (Watershed Professionals Network, 2009). The instream flow target is rarely met between July and October (Figure 5, Figure 6, and Figure 7).

It is valuable to look at the temperature and flow along Whychus Creek during the hottest water day of the year to demonstrate the relationship between flow and temperature along Whychus Creek (Figure 6). The hottest water day of the year since the previous state assessment for the Section 303(d) list in 2004 occurred July 25, 2007. Whychus Creek is Section 303(d) listed due to the elevated temperatures that occur along the Middle Reach (ODEQ, 2010 b). Comparing temperature and flow from the headwater to the mouth demonstrates the impact of the TSID diversion on temperatures within the Middle Reach of Whychus Creek (Figure 6).

Whychus Creek has natural flows of 3.5 cms (124 cfs) and cool temperature of 15.5 °C (59.9 °F) in the Upper Reach above the TSID diversion at kilometer 43.45 (river mile 27.0). From TSID canal at kilometer 43.45 (river mile 27.0) until Camp Polk Springs complex at kilometer 29.77 (river mile 18.5), Whychus Creek is reduced to approximately 0.28 cms (10 cfs) average daily flow. At this point the water temperatures equal 20.3 °C (68.5 °F) and exceed the state temperature criterion set to protect salmon and trout rearing and migration. The Camp Polk Springs complex contributes approximately 0.14 cms (5.0 cfs) of cool flow yet temperatures at USFS Road 6360 at kilometer 9.60 equal 27.0 °C (80.6 °F) and continue to exceed the state temperature criterion. Downstream, the Alder Springs complex at kilometer 2.41 (river

mile 1.5) contributes approximately 2.69 cms (95 cfs) of cold groundwater into Whychus Creek just prior to its confluence with the Deschutes River; Temperatures are reduced to 17.3 °C (63.1 °F) and meet the state temperature criterion.

Whychus Creek has a notable history with its name. Senate Bill 488 banned the use of the term 'Squaw' on public place names in 2001, and as a result in 2006 Squaw Creek was renamed Whychus Creek. Whychus is derived from the native Sahaptin language and is interpreted to mean: 'The place we cross the water.'

1.3 Water Management

In 1805, Lewis and Clark encountered the Deschutes River known as Towaernehiooks (meaning River on which the Snake Indians live) (McArthur, 2003). The name of the Deschutes River has its foundations in French to mean River of the falls referring to Celilo Falls or Wyam (meaning echo of falling water) (McArthur, 2003). Celilo was the oldest continuously inhabited community on the North American continent until 1957 when the falls and nearby settlements were inundated by the construction of the Dalles Dam (Dietrich, 1995) (FCRPS, 2001).

In 1862, the Homestead Act was passed by Congress and allowed settlers to establish a homestead on the lands in the Public Domain (Library of Congress, 2010). Water diversions occurred in the watershed as early as 1869, and the first appropriated water right from Whychus Creek occurred in 1872 (SCHS, 2010) (OWRD, 2010 e). The first Whychus Creek Canal was built in 1889 (SCHS, 2010). Squaw Creek Irrigation Company (SCIC) Incorporated in 1895 (TSID, 2010). The area was first recognized in 1805 and 84 years later water management was shaping Whychus Creek into the waterway we are familiar with today.

In 1909, the Prior Appropriation Doctrine established an era of water management and formed the basis of Oregon Water Code by stating that:

- ~ Water belongs to the public;
- ~ The state assigns the right to use water;
- ~ Water rights follow a strict hierarchy: Those with earlier priority dates get their water before any junior right; and
- ~ Water permits are issued only for beneficial uses without waste.

By 1912, the summer flow in the area of Whychus Creek near Sisters was entirely diverted for irrigation (Nehlsen, 1995) (USGS, 1914). In 1914, the Oregon State Legislature passed a law allowing for the formation of irrigation districts. As a result, SCIC became Squaw Creek Irrigation District (SCID) or currently known as the Three Sisters Irrigation District (TSID) (TSID, 2010). In 1915 and again in 1924, Whychus Creek was documented as an overallocated system and it was concluded that water should not be available for priorities subsequent to 1895 (USDI, 1915) (USDI, 1924). The SCID (TSID) voted to install the current TSID diversion in 1919 in an attempt to conserve water (TSID, 2010).

A weir was installed at Camp Polk at kilometer 25.75 (river mile 16.0) in 1951 and operations ended in 1956 (Nehlsen, 1995). The weir functioned for egg collection for Wizard Falls Hatchery and to support the reintroduction of steelhead trout in the basin (King, 1966) (Nehlsen, 1995) (OSGC, 1952). Downstream of the weir, fishing was closed to conserve adult and juvenile steelhead trout (King, 1966). Between 1951 and 1966, the Oregon State Game Commission (OSGC) performed steelhead trout counts at the weir that resulted in a range between 62 and 619¹ steelhead trout, with an estimated maximum of 1000 spawning steelhead trout in 1953 (King, 1966) (Nehlsen, 1995).

In 1955, pertinent sections of the Oregon water code established the Oregon State Water Resources Board (OSWRB) and declared that (OSGC, 1971):

¹ All counts are considered index counts rather than estimates of the total abundance because several factors affected the accuracy of the counts including problems keeping the weir functional, effects of the weir on upstream migrants, and poaching (King, 1966) (Nehlsen, 1995).

“The Board shall proceed as rapidly as possible to study...existing and contemplated needs and uses of water for domestic, municipal, irrigation, power development, industrial, mining, recreation, wildlife, and fishlife uses and for pollution abatement, all of which are declared to be beneficial uses.”

“The maintenance of minimum perennial stream flows sufficient to support aquatic life and to minimize pollution shall be fostered and encouraged if existing rights and priorities under existing laws will permit.”

Although this did not protect the public instream uses of the water, determining stream flow requirements became necessary.

The Pelton Round Butte Hydroelectric Project was built between 1957 and 1964. The project resulted in three dams. The uppermost dam in the system is Round Butte, which forms Lake Billy Chinook. Pelton, the middle dam, forms Lake Simtustus. The lowermost dam is the re-regulating dam and is used to balance river flows to meet peak power demands. The project was originally constructed with both upstream and downstream fish passage facilities. However, once the dams were built, water temperature and currents made it difficult for the steelhead trout to find the downstream passage (PGE, 2010). By 1968, extirpation of steelhead trout in upper Deschutes Basin was realized (Nehlsen, 1995).

Between 1970 and 1971, the OSGC performed assessments similar to the Tennant Method² to determine stream flows for fish in Oregon and the Deschutes Basin. From

² The Tennant Method was developed by Donald L. Tennant, Bureau of Sport Fisheries and Wildlife, Billings, Montana. He presented the Tennant Method (also known as the Montana Method) at the Pacific Northwest River Basins Commission, Instream Flow Requirement Workshop held at the Bonneville Power Auditorium Portland, Oregon in 1972. His paper entitled, “A Method for Determining Instream Flow Requirements for Fish, Wildlife, and the Aquatic Environment” was presented parallel to a paper by Ken Thompson, Oregon State Game Commission entitled “Determining Stream Flows for Fish Life” Both papers describe the determination of instream flows for fish based upon physical habitat assessments, both result in flat line hydrographs, and both papers recognized that water quality and fish biomass assessments are needed. The Tennant Method uses a percentage of average annual flow (AAF) to determine fish habitat quality; 10% of AAF is the minimum for short term fish survival, 30% of AAF is

these habitat based assessments, optimum flow level recommendations were made within an OSWRB report (OSGC, 1971). The optimum flow level recommendations made are highly caveated with the need for further research of flow as it relates to water temperature and fish production. The habitat based, optimum flow levels recommended by the OSWRB report became the current day ODFW recommended minimum instream flows, certified instream flow water rights, and instream flow restoration targets.

In 1972, the Clean Water Act required states to establish water quality regulations (USEPA, 2010). This is the foundation of the state of Oregon Section 303(d) listing and Total Maximum Daily Load (TMDL) allocation process used to regulate state water quality.

The Instream Water Rights Act was passed in 1987 and led to the primary mechanism for restoring instream flows today; water banking. The Act specifies instream uses as a beneficial use. The Act provides three ways to create instream water rights summarized as follows:

1. Oregon Department of Fish and Wildlife (ODFW) can apply based on physical habitat recommendations of OSGC (1972);
2. ODEQ can apply based on state water quality criteria; and/or
3. Leasing, buying, or converting water rights.

The first two of these options are initiated by state agencies and result in the creation of instream water rights with relatively junior priority dates. The third option allows private parties to transfer water rights instream by purchasing, leasing, or accepting a donation of existing water rights for conversion, with the same priority date as the original rights. The older the priority date, the better the chance that the water will

considered to be able to sustain fair survival conditions, and 60% of AAF is excellent to outstanding habitat. The method employed by Oregon used flow depth and velocity requirements. (PNRBC, 1972 b) (PNRBC, 1972 a)

remain instream during the irrigation season. In 1990, ODFW utilized the optimal flow recommendations based on habitat surveys to apply for instream water rights and deemed these water rights to represent the minimum flows needed for fish.

There are restrictions noted on the certificate of instream water right that state:

“For the purposes of water distribution, this instream water right shall not have priority over human or livestock consumption.”

“The instream flow allocated pursuant to this water right is not in addition to other instream flows created by a prior water right or designated minimum perennial stream flow.”

This may be interpreted as protecting consumptive over environmental uses of water and limiting the quantity of restored flow to that designated under the certified instream water right.

In 2001, instream flow restoration in upper Deschutes Basin began. The Deschutes River Conservancy (DRC) began to utilize the state certified instream water rights as instream flow restoration targets and began a restoration campaign based on these targets. In Whychus Creek, the ODFW certified instream water right of 0.93 cms (33 cfs) was adopted as the instream flow restoration target. Restoration efforts sought to secure senior water rights diverted at TSID, since the TSID diversion is the location for the diversion of up to 90% of the natural flow within Whychus Creek during the summer irrigation season (Figure 4) (Watershed Professionals Network, 2009).

In 2002, the Oregon Water Resources Department (OWRD) reported on surface water availability in Oregon whereby natural streamflow, storage, consumptive uses, and streamflow were considered (OWRD, 2002). Whychus Creek was deemed an over-allocated system and no more water rights were granted.

In 2003, Oregon adopted Oregon Administrative Rule (OAR) 340-041-0028 and established temperature criteria to protect fish spawning, rearing, and migration (ODEQ, 2010 a) and these rules apply to Whychus Creek.

In 2004, the Federal Energy Regulatory Commission (FERC) relicensed the Pelton Round Butte Hydroelectric Project and mandated steelhead trout reintroduction and passage. As a result, over 250,000 hatchery steelhead trout fry were released in May 2007 and May 2008. The steelhead trout are considered to have a high potential for supporting self-sustaining populations and therefore were targeted for release (PGE, 2008). A new fish passage facility was completed in 2009. In February 2010, the first steelhead trout was recorded leaving Lake Billy Chinook and passed the Round Butte Dam (PGE, 2010).

1.4 State of Oregon Water Code

The following provides a summary of current state of Oregon water code provisions that apply to all water rights (OWRD, 2010 d):

Beneficial uses: Surface water or groundwater may be legally diverted only if used for a beneficial purpose.

Senior priority over junior rights: The more senior a water right, the more priority to be served and the longer water is available during a time of shortage.

A water right is attached to the land where it was established, as long as the water is being used. If the land is sold, the water right goes with the land to the new owner.

Use it or lose it: A water right is valid as long as it is put to beneficial use once every five years. After five years of non-use, the right is considered forfeited.

According to the instream water rights act of 1987, water instream is considered a beneficial use, therefore a water right can be maintained by utilizing it instream (State

of Oregon, 2010 a). The ability to use water instream as a beneficial use led to a system of water banking to secure instream flows. One detail regarding water banking to restore instream flows is that Oregon water code serves and protects consumptive use over environmental use of water trumping the priority date associated with the water right. The logic can be described as follows:

- ~ If there is a conflict between uses, the date of priority normally determines who may use the available water;
- ~ If the rights in conflict have the same date of priority, then the law indicates domestic use and livestock watering have preference over all other uses; and
- ~ If a drought is declared by the Governor, OWRD can give preference to stock watering and household consumptive purposes, regardless of the priority dates of instream water rights (OWRD, 2010 c).

Water banking, the primary mechanism to restore instream flow, includes leasing, buying, conserving, and cancelling of water rights (OWRD, 2010 d). The following is a summary of these mechanisms:

Leasing

Water rights may be leased for instream uses. Instream leases must show that injury will not occur and that a beneficial use will be made of the water, such as fishery habitat or flow augmentation to improve water quality. Instream leases carry the priority date of the original right therefore the water may not be diverted by any junior user while it is instream. The term of an instream use lease cannot exceed five years, but it may be renewed.

Buying

The instream water right statutes allow a water right to be permanently transferred to instream use and these transfers carry the priority date of the original right.

Conserving

Water saved by improved technology and efficient practices cannot automatically be put to uses beyond those specified in a water right. State law allows a water right holder to submit a conserved water application (from say a piping project) to the OWRD and receive authorization to use a portion of the conserved water on additional lands, apply the water to new uses, or dedicate the water to instream use. The percentage of saved water that may be applied to new uses or lands depends on the amount of state or federal funding contributed to the conservation project. The law requires that the remaining percentage of the saved water be returned to the stream for improving instream flows.

Canceling

Once a water right has been unused for five consecutive years or more, it is subject to cancellation even if the property owner begins to use the water again. Under the law, the right is presumed to be forfeited and reuse does not reinstate the right. This is true even if the current owner did not own the property when use was discontinued. Cancellation of a forfeited water right is not automatic and requires a legal proceeding. Submitting evidence, such as aerials photos, to the OWRD, is one approach to retiring unused consumptive water rights so that instream water rights that are junior may be served.

By working within the current water management code policies and as of 2009, the DRC has secured 0.23 – 0.26 cms (8 to 9 cfs) of permanently protected instream water rights toward the 0.93 cms (33 cfs) target during the summer months, with average annual instream leasing totaling 0.17 cms (6 cfs) (Watershed Professionals Network, 2009). These environmental, instream water rights are served according to their priority dates, yet their allocation is contingent on serving consumptive water rights first since Oregon water code specifies that consumptive uses have priority over all other uses.

1.5 Discussion

Instream flow restoration targets are not fully resolved and additional flows may be needed to meet the restoration goal in Whychus Creek. Using certified instream water rights as the instream flow restoration target may limit the quantity of water that can be restored and protected instream. Instream beneficial use of water is inherently junior under current Oregon water code because the assignment of consumptive beneficial uses of water first in time. Restrictions are noted on the instream water right certificate that protect consumptive over environmental uses of water and limit the quantity of restored flow to that designated under the certified instream water right. If more water is needed instream than what is designated by the instream water right certificate, it may be difficult to serve or protect this additional water instream.

Using certified instream water rights as the instream flow restoration target may underestimate the quantity of water needed to achieve the restoration goal of decreasing temperatures for steelhead trout. Instream flow restoration targets originate from the OSWRB optimal flow recommendations that later were adopted by ODFW (formally the OSGC) as minimum flows needed to support fish rearing, spawning and migration. The OSWRB optimal flow recommendations were based on a physical habitat assessment similar to the Tennant Method. Not only did the OSWRB recommend these flows with many caveats regarding the need to determine relationships between flow and temperature and flow and steelhead trout production

(PNRBC, 1972 a) (PNRBC, 1972 b), but the Tennant Method approach has been shown to produce insufficient flows when considering temperature (Mann, 2006). In Whychus Creek, determining relationships between flow and temperature and flow and steelhead trout production may result in a more appropriate instream flow restoration target.

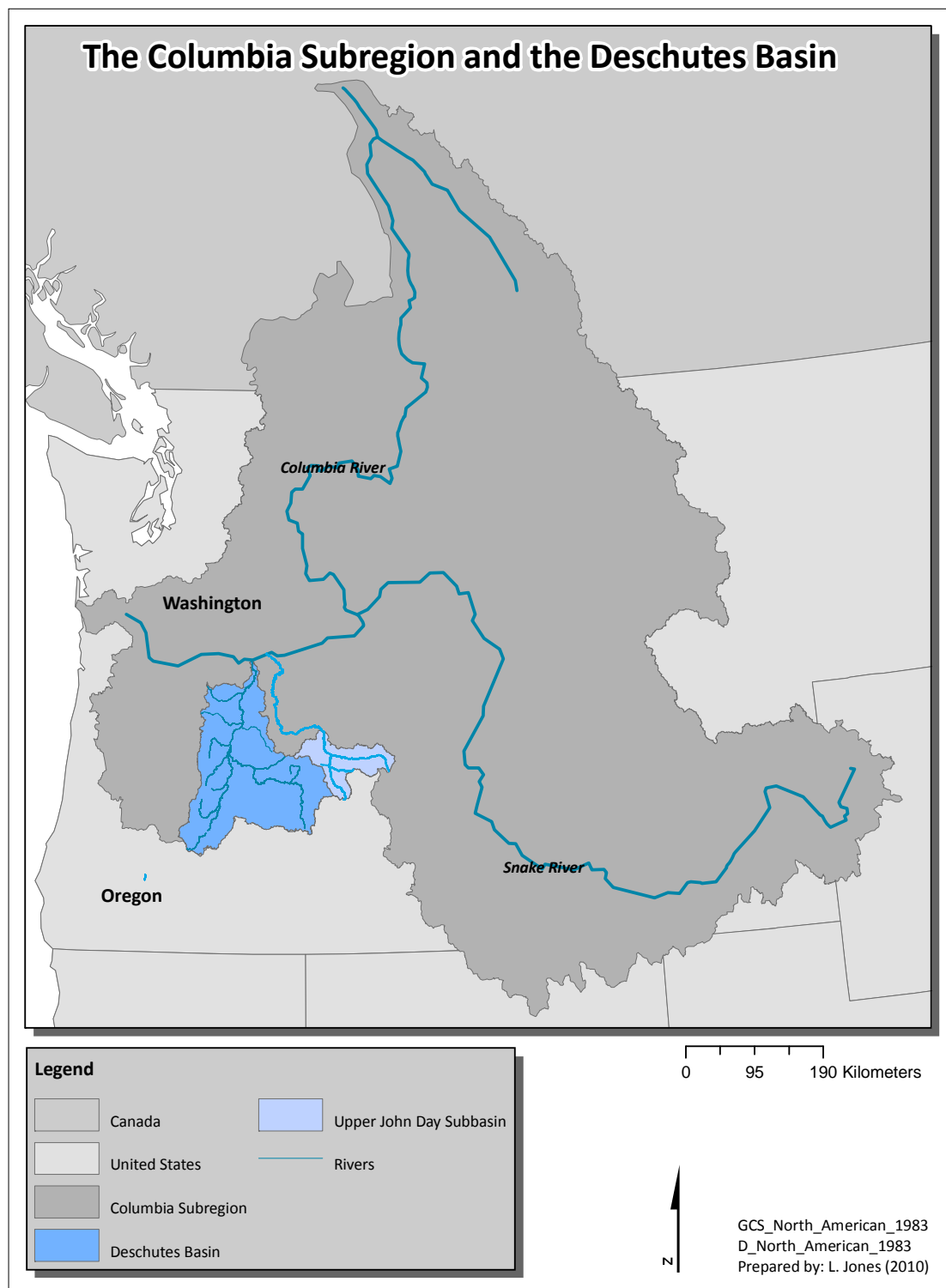


Figure 1 Map of the Deschutes Basin

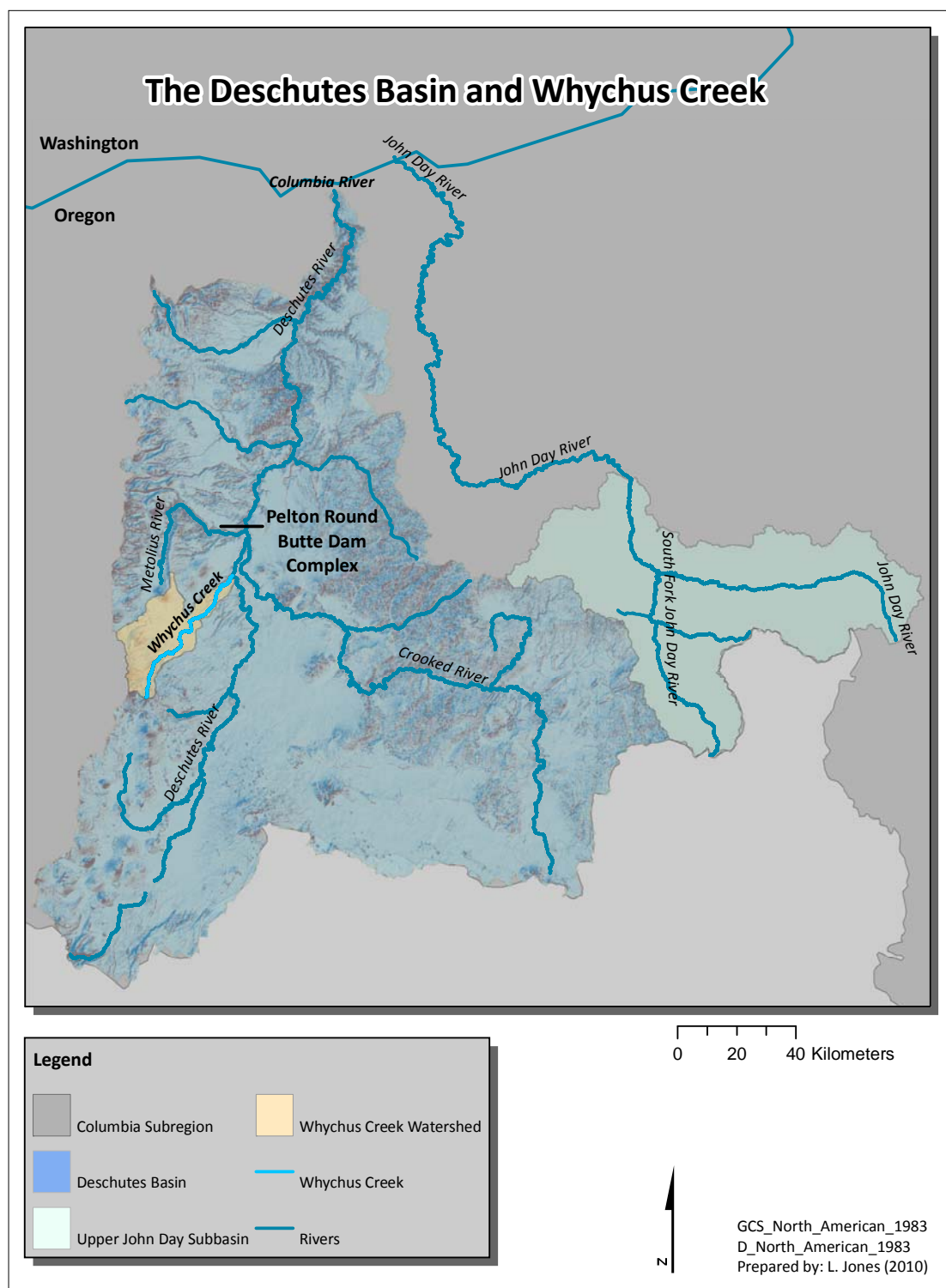
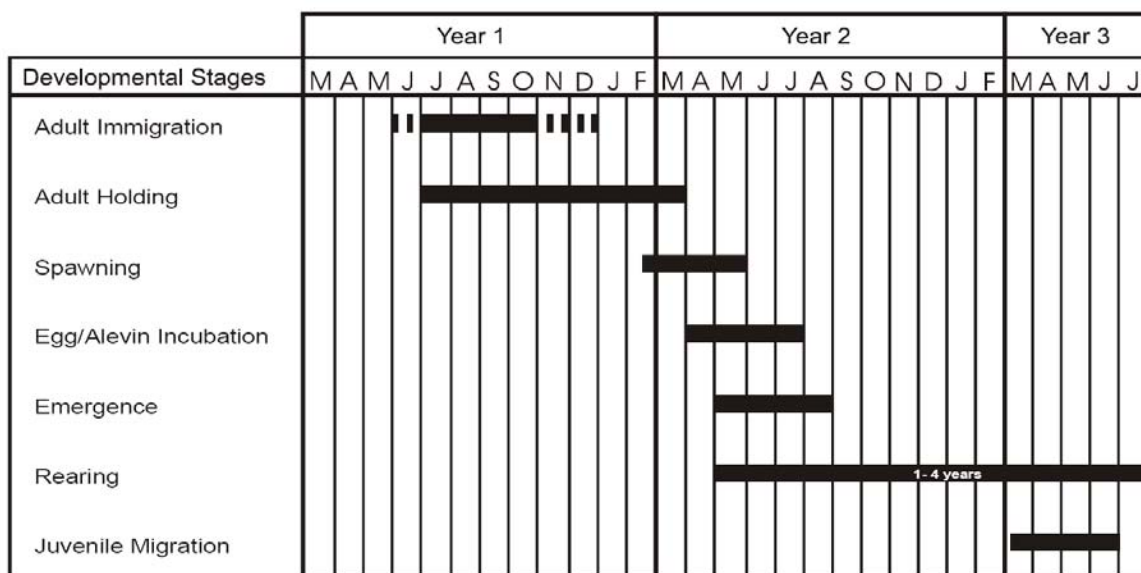


Figure 2 Map of the Deschutes Basin and Whychus Creek

Table 1 Consumptive and environmental beneficial uses

	Beneficial Uses of the Deschutes Basin Waterways	Deschutes Basin	Whychus Creek Watershed
Consumptive Use	Public Domestic Water Supply	X	X
	Private Domestic Water Supply	X	X
	Industrial Water Supply	X	X
	Irrigation	X	273 cfs
	Livestock Watering	X	X
	Hydro Power	X ³	
Environmental Use	Fish and Aquatic Life	X	33 cfs
	Wildlife and Hunting	X	
	Fishing	X	
	Boating	X	
	Water Contact Recreation	X	
	Aesthetic Quality	X	

Note: Commercial Navigation and Transportation is not a beneficial use within the Deschutes Basin.
(From Table 130A, OAR 340-41-0139) (State of Oregon, 2010 b)

**Figure 3 Deschutes River summer steelhead trout freshwater life history stages**

(Cramer & Beamesderfer, 2002, 2006) (ODFW, 1996).

³ Applies to the Deschutes River Main Stem from Pelton Regulating Dam to Bend Diversion Dam and for the Crooked River Main Stem only.

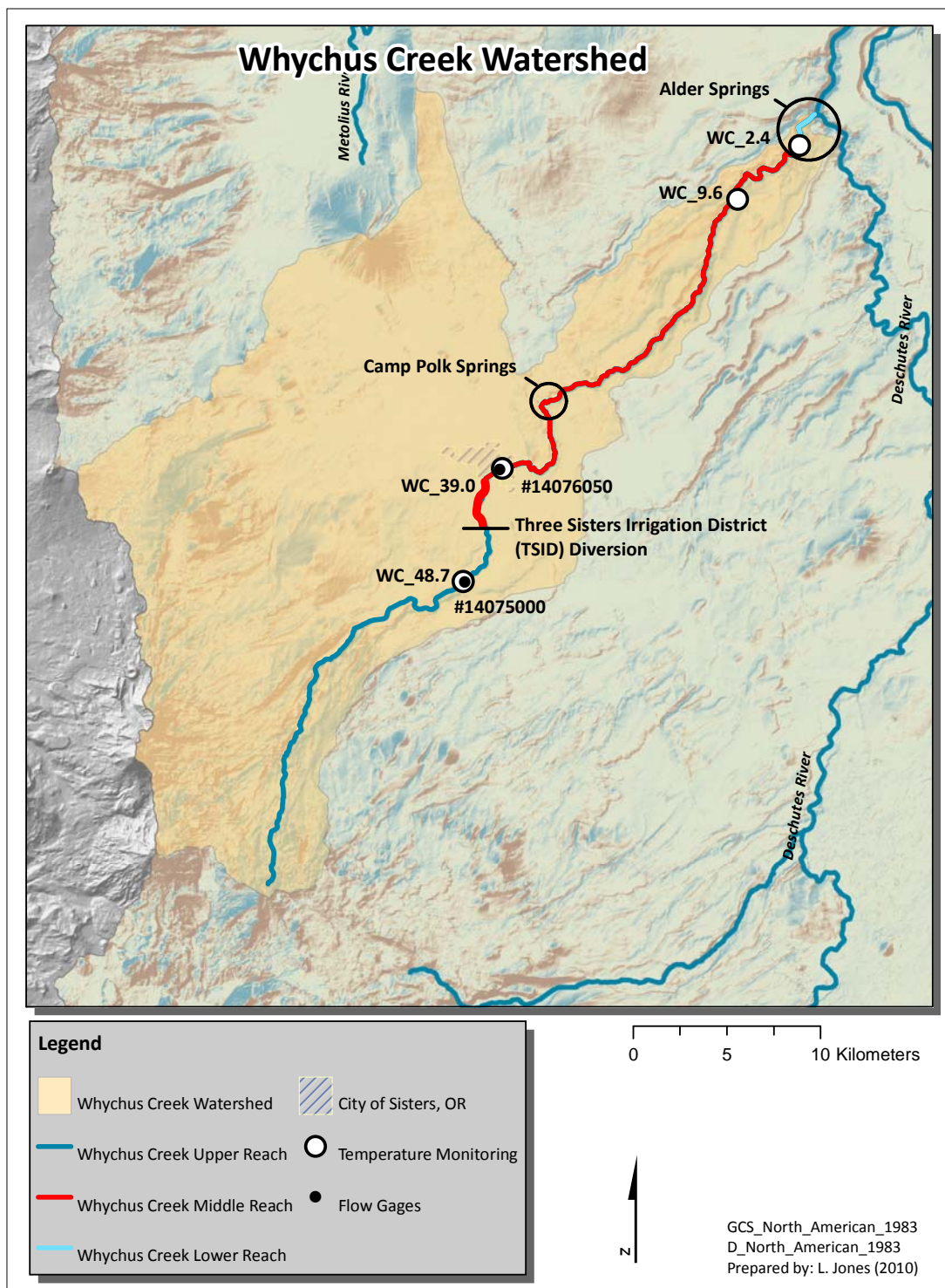


Figure 4 Map of the Whychus Creek monitoring stations, reaches, and landmarks

Table 2 Location of flow gage and temperature monitoring stations along Whychus Creek

Station ID	Station Name	Description	Latitude	Longitude	Elevation (m)
14075000	Whychus Creek nr Sisters	OWRD flow gage	44.23401	-121.56690	1068.9
WC 48.7	Whychus Creek at OWRD gage nr Sisters	Temperature monitoring	44.23401	-121.56690	1068.9
14076050	Whychus Creek at Sisters	OWRD flow gage	44.28836	-121.54182	969.3
WC 39.0	Whychus Creek at OWRD gage at Sisters	Temperature monitoring	44.28836	-121.54182	969.3
WC 9.6	Whychus Creek at Road 6360	Temperature monitoring	44.41875	-121.38635	777.2
WC 2.4	Whychus Creek d/s Alder springs	Temperature monitoring	44.44491	-121.34543	682.8

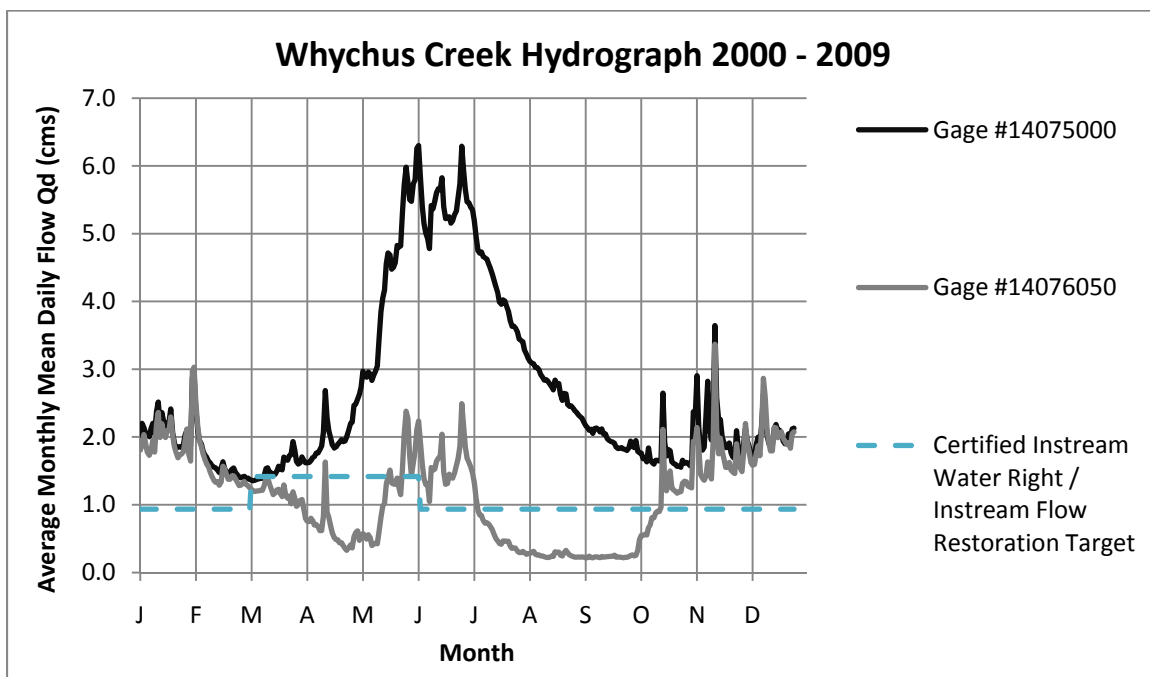


Figure 5 Whychus Creek hydrograph (2000 – 2009)

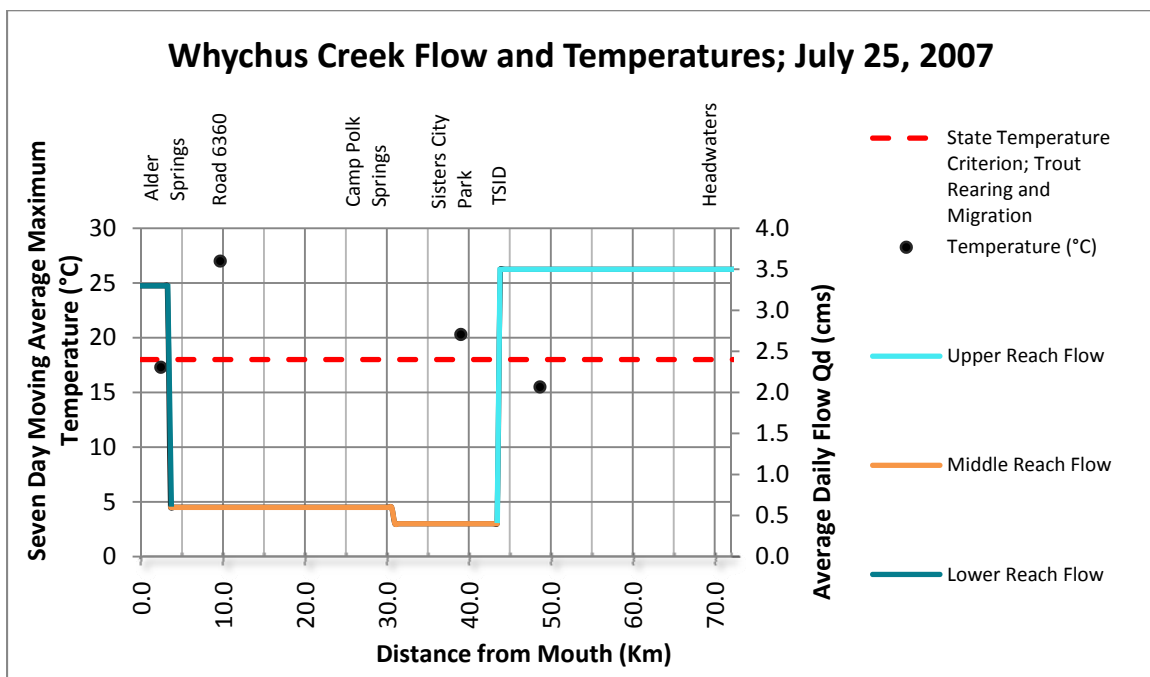


Figure 6 Whychus Creek flow and temperature summary on the hottest day

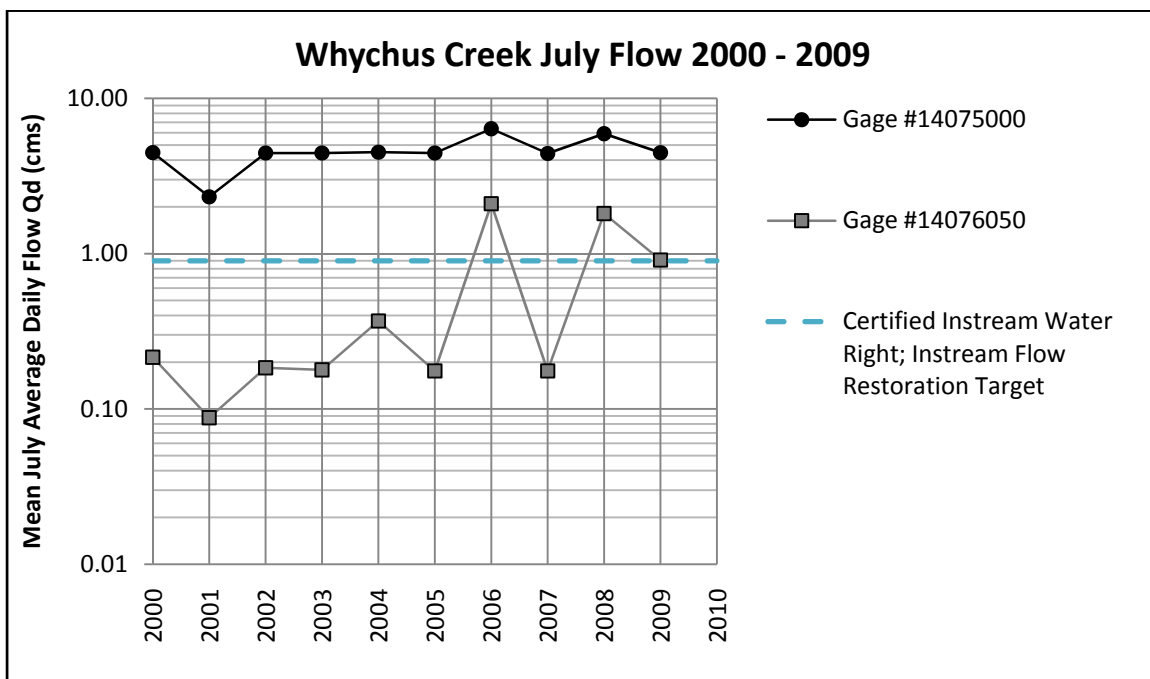


Figure 7 Whychus Creek instream flow restoration progress (2000 – 2009)

Chapter 2. Instream Flow Restoration Targets according to Water Temperatures

2.1 Introduction

Whychus Creek, located within the upper Deschutes Basin and a location of steelhead trout reintroduction, is a case study for implementing instream flow restoration. In Whychus Creek, agencies and organizations have embarked on a creek-scale restoration effort collaborating on a range of projects from site-specific land acquisition and channel reconstruction to coordinated barrier removal (DBLT, 2010) (OWEB, 2010 a) (UDWC, 2009) (USDA, 2010). Under this coordinated approach, instream flow restoration activities aim to achieve the restoration goal of improving temperatures to meet the needs of the reintroduced steelhead trout (UDWC, 2009).

Instream flow restoration targets are not fully resolved and additional flows may be needed. Instream flow restoration targets originate from the OSWRB optimal flow recommendations that later were adopted by Oregon Department of Fish and Wildlife (ODFW) (formally the OSGC) as minimum flows needed to support fish rearing, spawning and migration. The OSGC optimal flow recommendations were based on a physical habitat assessment similar to the Tennant Method. Not only did the OSGC recommend these flows with many caveats regarding the need to determine relationships between flow versus temperature and flow versus steelhead trout production, but the Tennant Method approach has been shown to produce insufficient flows when considering temperature (Mann, 2006).

The ability of these targets to achieve the restoration goal of improving temperatures to meet the needs of reintroduced steelhead trout is of interest. To evaluate instream flow requirements for steelhead trout according to water temperature responses, the following two questions are addressed:

- ~ *Does the certified Instream water right of 0.93 cms (33 cfs) result in temperatures that meet state water quality criteria?*

~ *What is the flow needed to achieve the state of Oregon temperature criterion along Whychus Creek?*

In 2006, the U.S. Geological Survey (USGS) Institute for Water and Watersheds (IWW) funded monitoring along Whychus Creek and preliminary analysis toward the goal of understanding the relationship between water temperature and instream flow along Whychus Creek (Jones & Reuter, 2007). Preliminary analysis included a peer reviewed time-series autocorrelation study to establish the appropriate time interval (month, season, or year) to avoid misleading results that over estimate or underestimate the target (OSU, 2007) (USGS, 1991). The results of the preliminary analyses indicate that it is appropriate to estimate instream flow restoration targets based upon temperature by aggregating flow and temperatures within a month over multiple years then applying a regression analysis.

2.2 Materials and Methods

The monitoring activities that support this analysis were part of a regional, coordinated monitoring effort and are described in more detail in Appendix A.

Parameters

Parameters that were evaluated include average daily flow (Q_d) in cubic meters per second (cms) and seven day moving average maximum (7DMAX) temperatures in degree Celsius (°C). Average daily flow is the unit to describe certified water rights and instream flow restoration targets (OWRD, 2010 e). Flow data were collected by OWRD and is available online (OWRD, 2010 b). The 7DMAX temperature is the unit to evaluate temperatures against the state of Oregon temperature criterion (ODEQ, 2010 a). Data are available online at the Upper Deschutes Watershed Council website (UDWC, 2010). July was selected as the month to evaluate since the hottest water days occur in July (UDWC, 2009), and July had a range of flows above and below the current instream flow restoration target (Figure 5). July was appropriate for evaluating temperatures that

affect steelhead trout because their capacity has been generally limited by summer rearing habitat (Cramer & Beamesderfer, 2002, 2006).

Monitoring Stations

Data collected from two monitoring stations and one gage station were used for the temperature and flow analyses (Table 3 and Figure 4). These locations allowed instream flow targets to be assessed at the upstream end of the Middle Reach near the point of instream flow restoration and at the downstream end of the Middle Reach approximately 20 miles from the point of instream flow restoration.

Data were collected between 2000 and 2009 by multiple monitoring efforts. In 2006, temperature data were collected under the USGS IWW grant (Jones & Reuter, 2007). Additional temperature monitoring was conducted by ODEQ, UDWC, and USFS between 2000 and 2009.

Quality Assurance / Quality Control

All flow data used in this evaluation were graded by OWRD. All temperature data used in this evaluation were collected and graded using standard operating procedures (APHA, 1998) (ODEQ, 2009) (UDWC, 2008). Vemco temperature loggers were used to collect hourly temperature data between April and October (Vemco, 2011). These loggers were calibrated in the factory and audited by the National Institute of Standards and Technology (NIST) traceable thermometers prior to deployment, monthly in-situ, and post deployment. Data were downloaded and graded for quality (A through F) according to standards set forth by ODEQ (ODEQ, 2009). Only data that were considered B quality or better are used in this evaluation as these are the data accepted by the state of Oregon for Section 303(d) assessments. The Oregon Data Quality Matrix describes in detail how parameters are evaluated and graded on this scale (ODEQ, 2009). Quality flow and temperature data during July 2000 -2009 were available for most years (Table 4).

Metrics

The OAR that pertained to steelhead trout in Whychus Creek during July states:

Temperatures shall not exceed 18 °C in order to protect the beneficial use of salmon and trout rearing and migration. This criterion applies all year (State of Oregon, 2010 b).

Another useful index to evaluate temperatures for steelhead trout in Whychus Creek included a physiological index for trout conditions developed for the Upper John Day Subbasin (Feldhaus J. , 2006). The basin is an arid region neighboring the Deschutes Basin and Whychus Creek watershed. The steelhead trout in both basins are considered part of the Middle-Columbia Steelhead Trout DPS. The index is as follows:

- ~ Optimal temperature = ≤ 18.0 °C
- ~ Sub-optimal temperature = 18.0 – 21.0 °C
- ~ Moderate temperature = 21.1 – 23.0 °C
- ~ Poor temperature = ≥ 23.1 °C

Analysis

The following statements detail the steps in temperature and flow analysis used in this work:

1. Locations where instream flow and temperature relationships are of interest were established.
2. 7DMAX temperature and natural logarithm average daily flow ($\ln Q_d$) data for each location (from this point forward referred to as temperature and flow data) were compiled.
3. From the temperature and flow data, July data for all years of interest were isolated.

4. The daily temperature and flow data were matched into temperature, flow pairs.
5. Flows were ranked and assigned temperatures according to each rank (For example, at 4.1 Ln Q_d there may be 20 temperatures). Flow data with temperature sample size $n \leq 1$ were excluded.
6. The mean temperature at each flow level was established.
7. A plot of the flow Ln Q_d versus the mean temperature was regressed and the R^2 value was evaluated. A Confidence Level was assigned and a Confidence Interval was calculated.
8. The derived regression equation was used to describe the relationship between flow and temperature at the selected location.

The equation is applicable to describing 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. If all apply, then the results of the regression equation demonstrate to a level of confidence the relationship between flow and temperature 2001 - 2009. If not all apply, then the results of the regression equation are predictive and a greater Confidence Interval (known as a Predictive Interval) should be calculated.

Validation of Results

ODEQ collected intensive data two weeks over the summer of 2001 to develop a Heat Source model for Whychus Creek (Watershed Sciences, Inc.; MaxDepth Aquatics, Inc., 2007). Comparison of regression analysis results to the Heat Source model outputs was performed. Several flow scenarios were evaluated using the Heat Source model and were available to compare to the results of this analysis. Validation of results of this analysis by comparison to the Heat Source model results was important because:

- ~ The Heat Source model was used within the ODEQ TMDL process that results in regulation and the results of this analysis may ground-truth the Heat Source model providing confidence in its predictions.
- ~ Comparing the two approaches provided confidence to using this approach in other areas where appropriate data exists, yet a more comprehensive model will not be developed.
- ~ This approach provides temperatures at an incremental range of flows unlike a comprehensive model which usually results in one temperature per one flow input.

2.3 Results

Based upon temperature and flow data collected during July 2000 – 2009 (Figure 8), a regression equation of best fit to the data (R^2 value = 95.4%) ($N = 46$) describes the relationship of flow and temperature at the Sisters City Park with Equation 1. Based upon temperature and flow data collected during July 2000 – 2009 (Figure 9), a regression equation of best fit to the data (R^2 value = 93.5%) ($N = 40$) describes the relationship of Sisters City Park flow and temperature at USFS Road 6360 (Equation 2).

$$\text{Mean 7DMAX} = 16.0 - 3.4 \ln Q_d + 0.2 \ln Q_d^2 + 0.3 \ln Q_d^3 \quad (1)$$

Where:

Q_d = Average daily flow (cms)

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

Where:

$$Z_{1-\alpha/2} = Z_{1-0.05/2} = Z_{0.475} = 1.9$$

Y = Mean 7DMAX ($^{\circ}\text{C}$)

S = Standard distance from regression line

N = Number of samples

$$\text{Mean 7DMAX} = 20.5 - 3.7 \ln Q_D - 0.4 \ln Q_D^2 + 0.2 \ln Q_D^3 \quad (2)$$

Where:

Q_d = Average daily flow (cms)

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

Where:

$$Z_{1-\alpha/2} = Z_{1-0.05/2} = Z_{0.475} = 1.9$$

Y = Mean 7DMAX (°C)

S = Standard distance from regression line

N = Number of samples

The key questions are addressed using Equation 1 and Equation 2.

Does the certified Instream water right of 0.93 cms (33 cfs) result in temperatures that meet state water quality criteria?

Sisters City Park (WC 39.0) The temperature in July at Sisters City Park at kilometer 39.0 (river mile 24.25) equals a mean 7DMAX temperature of 15.8 ± 1.7 °C. (95% CL) and meets the state temperature criterion (Figure 8).

USFS Road 6360 (WC 9.6) The temperature in July at USFS Road 6360 at kilometer 9.6 (river mile 6.0) equals a mean 7DMAX temperature of 20.8 ± 1.8 °C (95% CL) and does not meet the state temperature criterion (Figure 9).

What is the flow needed to achieve the state of Oregon temperature criterion of 18 °C along Whychus Creek?

USFS Road 6360 (WC 9.6) The regression of temperature versus flow demonstrates that during July 2000 – 2009, $0.64 \ln Q_D$ ($1.90 \text{ cms} = 67 \text{ cfs}$) is

needed in Sisters City Park to achieve a mean 7DMAX temperature of $18.0 \pm 2.1^{\circ}\text{C}$ (95% CL) at USFS Road 6360 at kilometer 9.6 (river mile 6.0) (Figure 9).

Validation of Results

The results from this analysis compared to the results of the Heat Source model⁴ are fully validated at the Sisters City Park at kilometer 39.11 (river mile 24.3) and at USFS Road 6360 at kilometer 9.66 (river mile 6.0) (Figure 10).

For Whychus Creek at Sisters City Park at kilometer 39.11 (river mile 24.3), a Heat Source scenario has been run with 0.93 cms (33 cfs) instream, with the resulting temperatures at this location predicted to be approximately $15^{\circ}\text{C} (\pm 1^{\circ}\text{C})$ (Watershed Sciences, Inc., 2008). The results of the regression analysis presented in Figure 8 demonstrate temperatures that equal $15.8 \pm 1.7^{\circ}\text{C}$. The resulting temperature values fall within the comparative confidence interval (Figure 10).

For Whychus Creek at USFS Road 6360 at kilometer 9.6 (river mile 6.0), a Heat Source scenario has been run with 1.75 cms (62 cfs) instream at this location, with the resulting temperatures predicted to be $18.5^{\circ}\text{C} (\pm 1.0^{\circ}\text{C})$ (Watershed Sciences, Inc.; MaxDepth Aquatics, Inc., 2007). Using the regression equation derived from this analysis of the relationship between flow at Sisters City Park and temperature at USFS Road 6360, 1.75 cms (62 cfs) results in $18.3 \pm 2.1^{\circ}\text{C}$ (Figure 9). The resulting temperature values fall within the comparative Confidence Interval (Figure 10).

2.4 Discussion

To reduce instream temperatures to meet state temperature criteria for steelhead trout in Whychus Creek, 1.90 cms (67 cfs) of flow is recommended during July. The OSWRB recommend flows were adopted as instream flow restoration targets and were

⁴ Note: Heat Source model uses seven day moving average maximum temperatures (a daily statistic) while the regression model in this analysis uses the mean seven day moving average maximum temperature for July (a monthly statistic).

originally made with many caveats regarding the need to determine relationships between flow and temperature and flow and steelhead trout production (PNRBC, 1972 a). The results of this analysis provide equations that describe the relationship between flow and temperature in Whychus Creek. Although temperatures are considered optimal ($<18^{\circ}\text{C}$) at the Sisters City Park at kilometer 39.0 (river mile 24.25), the current target of 0.93 cms (33 cfs) provides sub-optimal ($18.1 - 21^{\circ}\text{C}$) temperatures of $20.8 \pm 2.1^{\circ}\text{C}$ for steelhead trout downstream at USFS Road 6360 at kilometer 9.6 (river mile 6.0). To achieve the temperature criterion of 18.0°C for steelhead trout downstream at USFS Road 6360 at kilometer 9.6 (river mile 6.0), 1.90 cms (67 cfs) is suggested.

Validation of results supports the use of this approach in setting instream flow restoration targets in appropriate cases where:

- ~ The creek has a strong correlation between temperature and flow;
- ~ There is a need to establish instream flow targets that reduce temperatures;
- ~ There is not a comprehensive model completed or planned, or validated;
- ~ There is flow and temperature data; and
- ~ There is a need to develop a scale of temperature responses at various flow levels.

Estimating the carrying capacity of steelhead trout at habitat based instream flow targets compared to temperature based flow targets may help to further improve instream flow restoration targets.

Table 3 Temperature monitoring and flow gage stations

Station ID	Station Name	Description	Latitude	Longitude	Elevation (m)
14076050	Whychus Creek at Sisters	OWRD flow gage	44.28836	-121.54182	969.3
WC 39.0	Whychus Creek at OWRD gage at Sisters	Temperature monitoring	44.28836	-121.54182	969.3
WC 9.6	Whychus Creek at Road 6360	Temperature monitoring	44.41875	-121.38635	777.2

Table 4 Available temperature and flow data July (2000 – 2009)

Station ID	Station Name	Description	Available July Data									
			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
14076050	Whychus Cr at Sisters, Or	Flow	X	X	X	X	X	X	X	X	X	X ⁵
WC 39.0	Whychus Creek at Sisters City Park	Temp	X	X	X	X	X	X	X	X	X	
WC 9.6	Whychus Creek at Road 6360	Temp	X	X	X			X	X	X		X

⁵ This data is considered provisional data by OWRD.

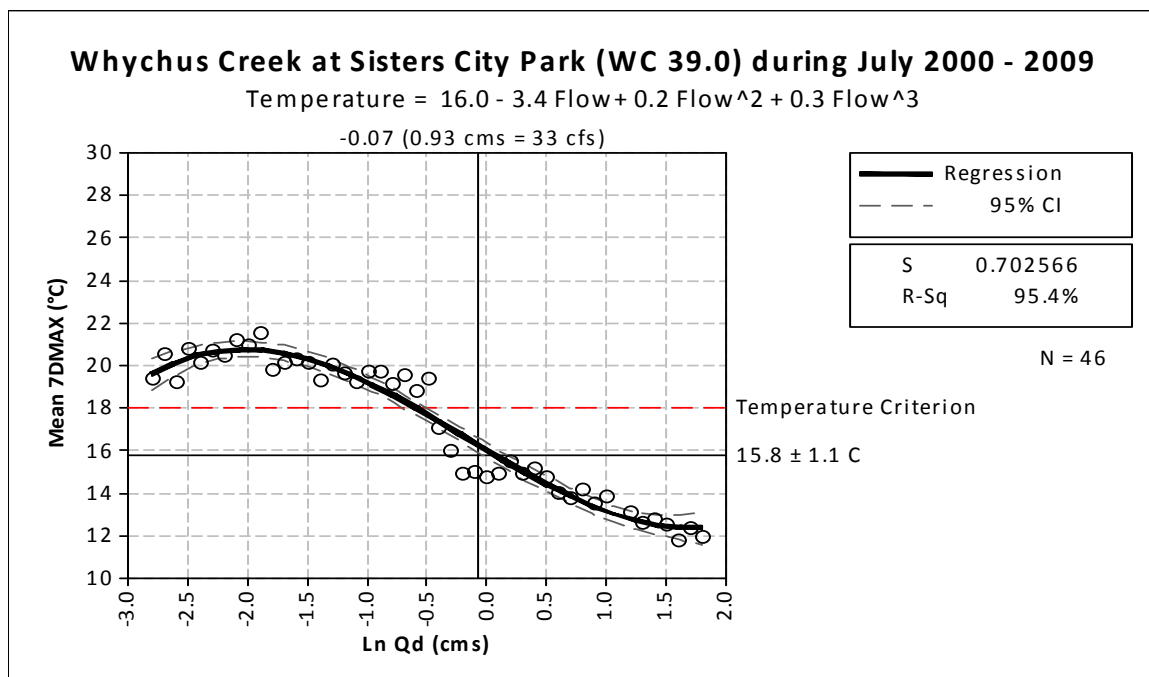


Figure 8 Flow and temperature at Whychus Creek Sisters City Park (2000 – 2009)

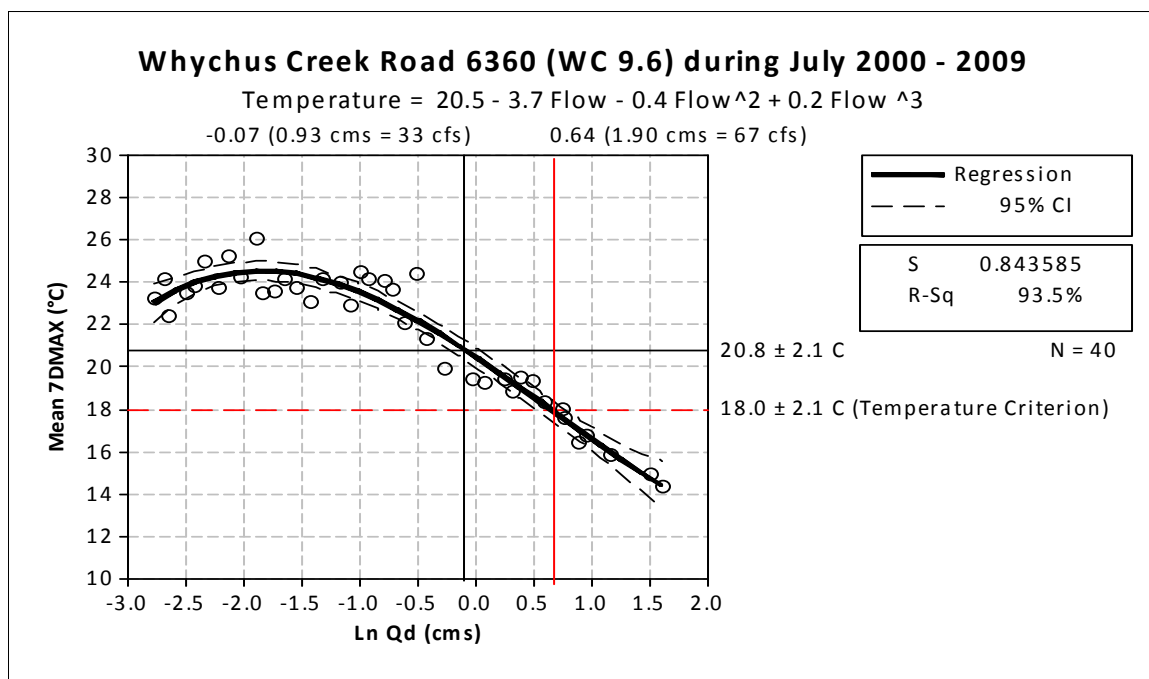


Figure 9 Flow and temperature at Whychus Creek USFS Road 6360 (2000 – 2009)

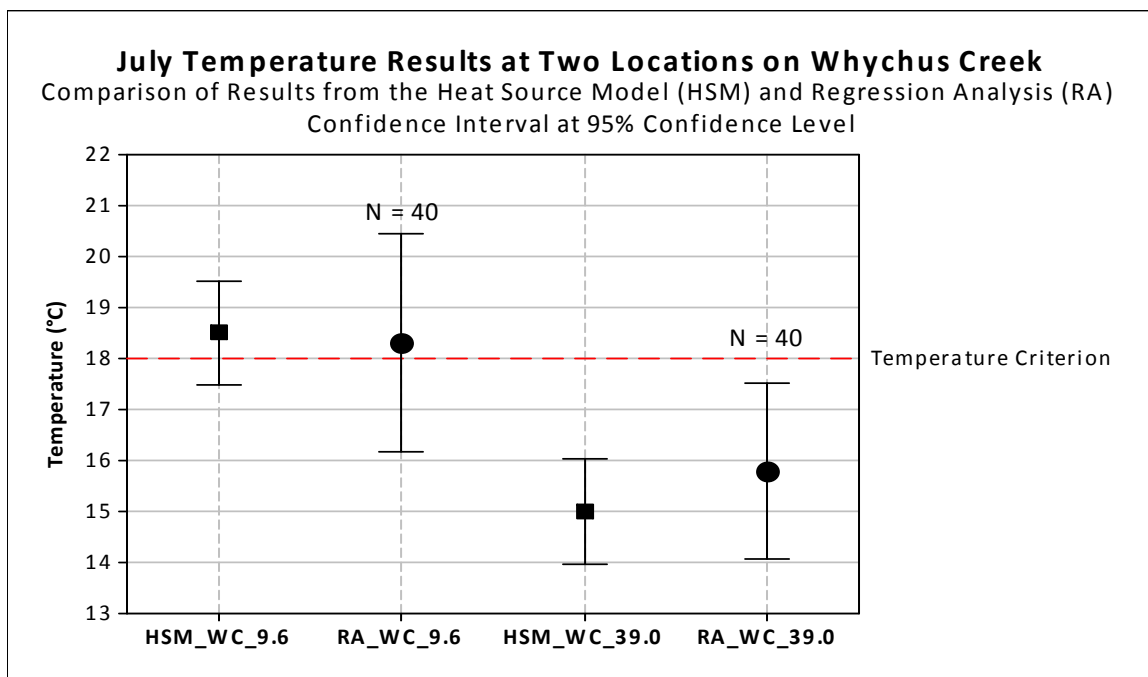


Figure 10 Comparison of results from the Heat Source model and regression analysis

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⁶ Note: Heat Source model uses seven day moving average maximum temperatures (a daily statistic) while the regression model in this analysis uses the mean seven day moving average maximum temperature for July (a monthly statistic). Temperature is the output of the Heat Source model therefore there is no temperature N.

Chapter 3. Instream Flow Restoration Targets and Carrying Capacity of Steelhead Trout

3.1 Introduction

The over-arching goal of instream flow restoration is to contribute to conditions that support healthy fish populations and the specific goal of instream flow restoration is to improve temperatures to meet the state temperature criteria and the needs of reintroduced steelhead trout (UDWC, 2009). Current instream flow restoration targets are based on certified instream water rights, derived from habitat surveys during the 1970's, and these water rights amount to 0.93 cms (33 cfs). It has been suggested that instream flow restoration targets are based upon what is needed to achieve the ODEQ state temperature criterion (18.0 °C) 1.90 cms (67 cfs) (see Section 2). Of interest are the estimated carrying capacities of steelhead trout considering habitat compared to temperature based instream flow restoration scenarios.

An understanding of the relationship between flow and steelhead trout populations has long been of interest. There are no viable steelhead trout populations in the upper Deschutes Basin to gather information regarding steelhead trout densities. Prior to the extirpation of steelhead trout above Pelton Round Dam, there were an estimated 1,000 steelhead trout spawning in Whychus Creek during 1953 when flows upstream Camp Polk were depleted and flows downstream of Camp Polk approximated 0.57 cms (20 cfs) (Nehlsen, 1995).

With the pending reintroduction of steelhead trout into the upper Deschutes Basin, multiple models were developed to predict how many smolts are needed to be reintroduced in order to provide for the greatest passage of adults at the Pelton Round Dam (Figure 2) (Cramer & Beamesderfer, 2002, 2006) (ODFW, 2003). These models largely rely on physical habitat assessments. From these models and for the purpose of estimating the number of smolts to reintroduce into each stream system, the estimated steelhead trout smolt carrying capacity for Whychus Creek was predicted and the

results of various models are provided in Table 5. These models individually are useful in planning by deciphering which reaches offer the greatest predicted carrying capacity comparatively. These models have not been validated for the upper Deschutes Basin because there are no viable steelhead trout populations in the area.

New information regarding flow, temperature, and steelhead trout carrying capacity in arid regions has emerged and can be used to improve our understanding (Madriñán, 2008). In the Upper John Day Subbasin, temperature alone at large spatial scales (i.e. reach to basin) explained most of the distribution of trout and habitat characteristics were more important at small spatial scales (i.e. riffle vs. pool). At the reach scale, stream temperatures can be used to indicate steelhead trout carrying capacity.

The Deschutes above Pelton Round Dam MPG and the John Day River MGP are two of the 20 MPGs that comprise the greater Middle-Columbia River Steelhead DPS. It is now possible to utilize the temperature and steelhead trout density information established for Upper John Day River Subbasin to evaluate instream flow restoration scenarios in other areas that provide habitat for this DPS. This is particularly useful in situations where there is a strong relationship between temperature and flow yet an inability to monitor steelhead trout density information such as Whychus Creek where steelhead trout have been extirpated.

Establishing instream flow targets based upon physical habitat studies or temperature responses creates different instream flow restoration recommendations. From the analysis presented here, water resource managers who work toward restoring instream flow can refine instream flow restoration targets to meet steelhead trout population goals. Two key questions are addressed:

What is the estimated carrying capacity of steelhead trout within Whychus Creek under a habitat based instream flow target of 0.93 cms (33 cfs)?

What is the estimated carrying capacity of steelhead trout within Whychus Creek under a temperature based instream flow target of 1.90 cms (67 cfs)?

3.2 Materials and Methods

The carrying capacity of Whychus Creek was estimated using the results from temperature and flow analysis (see Section 2) in combination with analysis of maximum temperature and trout biomass by stream reach for the Upper John Day Subbasin (Madriñán, 2008). Carrying Capacity of a stream was defined as the number of steelhead trout juveniles the stream can support given flow and temperature during the designated time period and along the designated reach.

The Upper John Day Subbasin was considered a strong candidate for surrogate biomass in Whychus Creek because both drainage areas are located on the same latitude, both drain mountain headwaters, and both contribute trout in the Middle-Columbia Steelhead Trout DPS. Since biomass was a function of temperature and reach area and since the John Day study evaluated conditions during the low flow, warm summer months, flow levels were not directly compared between Whychus Creek and the Upper John Day Subbasin. Rather, temperature was the link between flow and surrogate biomass therefore the temperatures that went into analyses for this project and the Upper John Day Subbasin study are compared to demonstrate the appropriateness of utilizing the surrogate biomass.

A summary of index flow levels and corresponding temperature and biomass was first calculated then a regression analysis of flow, biomass was performed. The regression equation was used to interpolate the number of steelhead trout individuals at incremental flow levels and temperatures given the Historic Reach and Restored Reach parameters.

The number of steelhead trout was based on flow, temperature, reach area, and surrogate biomass. Three estimates were made: adult abundance during the 1950's

prior to the construction of the Pelton Round Butte Dam, juvenile carrying capacity, estimated adult returns providing survival rates for steelhead trout passing the Pelton Round Butte Dam (Figure 11).

The results can be used to inform water resource decisions regarding the possible biological outputs of attaining instream flow restoration targets.

Time Interval

July was selected as a representative month for estimating steelhead trout carrying capacities because July temperatures were elevated during multiple steelhead trout life stages. Adult summer steelhead trout migrate upstream in the Columbia River from March through October with most of the run entering from late June through mid-September (Cramer & Beamesderfer, 2002, 2006). July temperatures were elevated not only during adult migration and holding, but also during steelhead trout egg incubation, emergence, and juvenile rearing life stages (Figure 3).

Reach

Two reaches were of interest due to future restoration activities planned for Whychus Creek and are described as follows:

The *Historic Reach* was defined upstream by the Camp Polk Springs complex and downstream by the Alder Springs complex because this reflects the historically accessible steelhead trout habitat along Whychus Creek and allows for comparison of these results to the 1950's population counts and estimates (Figure 4).

The *Restored Reach* was defined upstream by the TSID Diversion above Sisters and downstream by the Alder Springs complex. The TSID diversion was the location of instream flow restoration and there were extensive efforts to restore

the spawning habitat between TSID and the Camp Polk Springs complex (Figure 4).

The reach width was established via field measurements of wetted width collected at multiple flow levels during July 2009 at WC 9.6. This relatively unaltered, reference location was selected to establish reach wetted width because Whychus Creek was undergoing a series of small to large scale restoration actions along the longitudinal extent of the creek which were expected to affect reach width. These actions include: removal of berms and barriers, riprap alternatives, bridge replacements, and widening of the channel to eliminate pinch points (Watershed Professionals Network, 2009). Typical cross sections in restoration designs for Whychus Creek describe bank full wetted widths between 7.62 - 9.14 meters (25 – 30 feet) and were similar to the reference location WC 9.6 (Watershed Sciences, Inc., 2008).

Flow

Four index flow levels based upon historic and target flow levels were selected:

1. *A historic instream flow level of 0.43 cms (15 cfs).*
2. *A habitat based certified instream flow at Sisters of 0.57 cms (20 cfs).*
3. *A habitat based instream flow target of 0.93 cms (33 cfs).*
4. *A temperature based instream flow target of 1.90 cms (67 cfs).*

Temperature

The instream temperatures in the arid Whychus and John Day study areas were compared to evaluate if the John Day biomass and temperature information would serve as a good surrogate for future Whychus Creek steelhead trout estimations. The mean 7DMAX temperatures for Whychus Creek in July 2000 – 2009 collected from WC 9.6 and used in this analysis were compared at the 95% confidence level to the maximum temperatures captured during the late summer 2003 – 2004 used in the John

Day study. Using Equation 2 derived from flow conditions and temperature collected at WC 9.6, temperatures were calculated at each index flow level.

Biomass

The biomass of steelhead trout was obtained by evaluating temperature as described in Feldhaus (2006) and Madriñán (2008):

~ Optimal temperature =	$\leq 18.0^{\circ}\text{C}$	= 24.2 g/m ² biomass
~ Sub-optimal temperature =	18.0 – 21.0 °C	= 6.87 g/m ² biomass
~ Moderate temperature =	21.1 – 23.0 °C	= 5.25 g/m ² biomass
~ Poor temperature =	$\geq 23.1^{\circ}\text{C}$	= 1.73 g/m ² biomass

In-situ, members of a healthy fish population range in age and size. A fish population consisting of 1814 g (4.0 lb) steelhead trout adults and a population consisting of 340 g (0.75 lb) juvenile⁷ was used to calculate numbers of estimated fish. These weights were based upon the average weight of steelhead trout in the lower Deschutes River. The estimates for adults were based upon all members of the population weighing 1814 g (4.0 lb) because steelhead trout runs at the Pelton trap in the summer historically averaged 1361 – 2268 g (3-5 pounds) (Gunsolus & Eicher, 1962) (Cramer & Beamesderfer, 2002, 2006). The carrying capacity calculations for juveniles were based upon all members of the population weighing 340 g (0.75 lb)⁸ per USFS Fish Biologist estimates for the average juvenile weight in the lower Deschutes River⁹ (Dachtler, 2011).

⁷ Juvenile are defined here as ranging from parr to smolt.

⁸ The Unit Characteristic Model is based on steelhead that are in year one and year two of rearing and 340 g (0.75 lb) is a professional approximation of the size of steelhead during this life stage (Cramer & Beamesderfer, 2002, 2006).

⁹ A request for field measurements regarding fish size and weight has been submitted to ODFW and PGE since they are currently collecting that data.

Validation of Results

There was a lack of steelhead trout juvenile and adults to count until the return of populations expected near 2012 (PGE, 2010). Results were compared to previous counts for Whychus Creek during the 1950's that ranged between 62 and 619 adults, with an estimated maximum of 1,000 spawning steelhead trout in 1953 (King, 1966) (Nehlsen, 1995). Results were also compared to the outputs of the Unit Characteristic Method that estimate the carrying capacity to be 17,346 juvenile in Whychus Creek (Cramer & Ackerman, 2009). The Unit Characteristic Method estimates future steelhead capacity in the upper Deschutes Basin by analyzing upper Deschutes habitat features (i.e. pool, riffle, and glides), reproduction and survival rates modeled for the lower Deschutes River Steelhead, and densities derived from west coast streams. Results are compared to the HABRATE model that estimates 255,200 juveniles in Whychus Creek and is an ODFW habitat based model.

3.3 Results

The instream temperatures in the Whychus Creek and John Day study areas are statistically equal therefore using the John Day biomass and temperature information as a surrogate for future Whychus Creek steelhead trout estimations is supported (Figure 12). The reach width is established via field measurements of wetted width collected at multiple flow levels during July 2009 at WC 9.6 and is described by Equation 3 (Figure 13).

$$\text{Flow} = 5.22 + 3.68 \text{ Wetted width} \quad (3)$$

Where;

Flow = Natural logarithm of the average daily flow ($\ln Q_d$) in cms

Wetted width = Wetted width in meters

A summary of index flow levels and corresponding temperature and biomass is provided in Table 6. The results of flow and biomass regression analysis are described by Equation 4 (Figure 14).

$$\text{Biomass} = 9.20 + 16.38 \ln Q_d + 10.36 \ln Q_d^2 \quad (4)$$

Where:

Q_d = Average daily flow (cms)

$$60\% \text{ Confidence Level (NIST, 2009)} = Y \pm Y^{((Z_{1-\alpha/2} s(x) / \sqrt{N}))}$$

Where:

$$Z_{1-\alpha/2} = Z_{1-0.40/2} = Z_{0.200} = 0.5$$

Y = Mean 7DMAX (°C)

S = Standard distance from regression line

N = Number of samples

The estimated number of adults in the 1950's is calculated as:

$$\text{Estimated number of adults during the 1950's} = \text{Historic Reach area} \cdot \text{biomass} / 1814 \text{ g fish}$$

The estimated number of juvenile carrying capacity:

$$\text{Estimated number of juvenile} = \text{reach area} \cdot \text{biomass} / 340 \text{ g fish}$$

The estimated number of returning adults is described by a linear relationship created by regression of the number of juveniles, returning adults documented in Cramer et.al. (2006) and used in outplanting strategies for steelhead trout reintroduction (Equation 5 and Figure 15).

$$\text{Adults} = -93.59 + 0.02325 \text{ Juveniles} \quad (5)$$

Where;

Adults = Number of adults passing Pelton Round Dam

Juveniles = Carrying capacity

Incremental flow levels and the results of temperature, wetted width, reach dimensions, biomass, and estimated steelhead trout individuals for the Historic Reach and Restored Reach are in Table 7. The flow, temperature, and biomass information in Table 7 can be used to inform water resource decisions regarding the possible biological outputs of instream flow restoration targets and their corresponding temperatures. The results of analysis are used to address key questions:

What is the estimated carrying capacity of Whychus Creek under a habitat based instream flow target of 0.93 cms (33cfs)?

At the habitat based instream flow target of 0.93 cms (33 cfs) and along the Restored Reach extent a corresponding temperature of 20.8 ± 2.1 °C is attained and 4874 ± 1013 steelhead trout juveniles are estimated (Table 7). This number of steelhead trout juveniles may return an estimated 4 steelhead trout adults to the upper Deschutes Basin.

What is the estimated carrying capacity of Whychus creek under a temperature based instream flow target of 1.90 cms (67 cfs)?

At the temperature based instream flow target of 1.90 cms (67 cfs) and a Restored Reach extent a corresponding temperature of 18.0 ± 2.1 °C is attained and $21,869 \pm 2022$ steelhead trout juveniles are estimated (Table 7). This number of steelhead trout juveniles may return an estimated 344 steelhead trout adults to the upper Deschutes Basin.

Validation of Results

Validation of results demonstrates that steelhead trout carrying capacities based upon the Upper John Day Subbasin steelhead trout densities are an appropriate measure of

potential steelhead trout numbers within Whychus Creek. Estimates are compared to the historic steelhead trout adult counts observed in Whychus Creek during the 1950's, the results of the Unit Characteristic Method predictions of future steelhead juveniles in Whychus Creek, and to the predictions of the HABRATE model (Table 8).

The flow levels reported for the 1950's equaled 0.57 cms (20 cfs) downstream of the Camp Polk weir (equal to 0.43 cms (15 cfs) at Sister City Park). The count of 62 – 619 steelhead trout at the Camp Polk weir¹⁰ is validated by this analysis; at historic flow and along the Historic Reach prior to the impact of Pelton Round Butte Dam complex the estimated carrying capacity is 81 ± 38 steelhead trout adults (Table 8). According to this analysis, flow levels in the Historic Reach would need to approach 1.19 cms (42 cfs) to carry 1026 ± 156 steelhead trout adults in order to agree with the steelhead trout estimates of 1953 (Table 8). Since the population of Mid-Columbia River Steelhead trout has been on decline and steelhead trout were being stocked in Whychus Creek during the 1950's, it is expected that comparing estimates from population densities would underestimate the historic steelhead trout abundance in Whychus Creek. There is some evidence to demonstrate that stocking hatchery steelhead may cause the total number of steelhead to exceed the carrying capacity and trigger density dependent mechanisms that impact wild steelhead productivity (Kostow & Zhou, 2006). Further, this analysis indicates that at flows ≤ 1.10 cms (≤ 39 cfs) and after the Pelton Round Butte Dam installation the carrying capacity of steelhead trout juvenile would not have resulted in returning adults (Table 7).

According to the Unit Characteristic Method, the carrying capacity of spawning steelhead trout in the Whychus Creek is estimated at 17,346 steelhead trout juveniles at 1.70 cms (60 cfs). The HABRATE model estimates 255,200 juvenile for Whychus Creek (flow level unknown) (Cramer & Ackerman, 2009). The results of this analysis estimate

¹⁰ It is important to note that according to (King, 1966) several factors rendered counts minimal and there were problems keeping the weir functional therefore these counts are considered index counts and not abundance counts.

17,976 \pm 1847 steelhead trout juveniles and validate the Unit Characteristic Method estimates for the upper Deschutes Basin and do not support the estimates reported by the HABRATE model (Table 8). Cramer et al. (2006) emphasizes that the HABRATE model predicted a high capacity of steelhead trout in the Metolius River where steelhead trout were not historically found, overestimated the empirical counts for Trout Creek (lower Deschutes Basin), and has never been validated.

Populations are expected to return to Whychus Creek (PGE, 2010) in the future and once these populations become self-sustaining, the results from this analysis can be ground-truthed.

3.4 Discussion

Steelhead trout are reintroduced into the Deschutes above Pelton Round Dam major population group (MPG) (NMFS, 2009). This MPG is one of 20 MPGs that comprise the greater Middle-Columbia River Steelhead DPS. This MPG is considered extirpated and does not contribute to the viability of the Middle-Columbia Steelhead Trout DPS. The reintroduction of steelhead trout into the Deschutes above Pelton Round Dam into historically accessible habitat (Whychus Creek) should help improve the viability of the currently threatened Middle-Columbia River Steelhead DPS.

The Interior Columbia Technical Recovery Team (ICTRT) is a team of scientists appointed by NMFS to provide a solid scientific foundation for recovery planning and viability assessment. The ICTRT uses abundance, productivity, spatial structure, and diversity at the population and MPG level to determine the viability of a DPS. The ICTRT considers populations with fewer than 500 individuals at high risk for inbreeding, depression, a variety of genetic concerns, and minimally viable. (McClure, Holmes, Sanderson, & Jordon, 2003) (NMFS, 2009).

To support steelhead trout reintroduction efforts, flow recommendations for Whychus Creek can be made based upon biomass of steelhead trout from the Upper John Day

Subbasin. Historic counts and estimates validate the results of this approach, and the Unit Characteristic Method estimates for steelhead trout juveniles are validated and support the use of this approach in Whychus Creek.

Deschutes above Pelton Round Dam MPG and the John Day River MGP are two of the 20 MPGs that comprise the greater Middle-Columbia River Steelhead DPS. Current instream flow targets are based upon physical habitat studies that did not include temperature and steelhead trout biomass information. The results of this analysis indicate at the current target of 0.93 cms (33 cfs), July temperatures equal 20.8 ± 2.1 and do not meet the state criteria. An estimated $4,874 \pm 1013$ steelhead trout juveniles may result and an estimated 4 steelhead trout adults would return to the upper Deschutes Basin. If the goal was to reduce temperatures for steelhead trout then, to achieve the state criterion of 18.0°C in July, 1.90 cms (67 cfs) of instream flow may result in an estimated $21,869 \pm 2022$ steelhead trout juveniles may result and an estimated 344 steelhead trout adults would return to the upper Deschutes Basin. This would contribute to a more viable MPG within the Middle-Columbia River Steelhead DPS.

Comparing the results of this analysis with future counts from self-sustaining steelhead trout populations in Whychus Creek may offer further insight into the value of using flow, temperature, and biomass in setting instream flow restoration targets and the usefulness of this approach to water resource managers.

Table 5 Model estimates for steelhead trout carrying capacity, Whychus Creek

Model	Estimated Steelhead in Whychus Creek	Source
HABRATE	255,200 juvenile	(ODFW, 2001)
Unit Characteristic Method	17,346 juvenile 500 – 4000 adults	(Cramer & Ackerman, 2009)

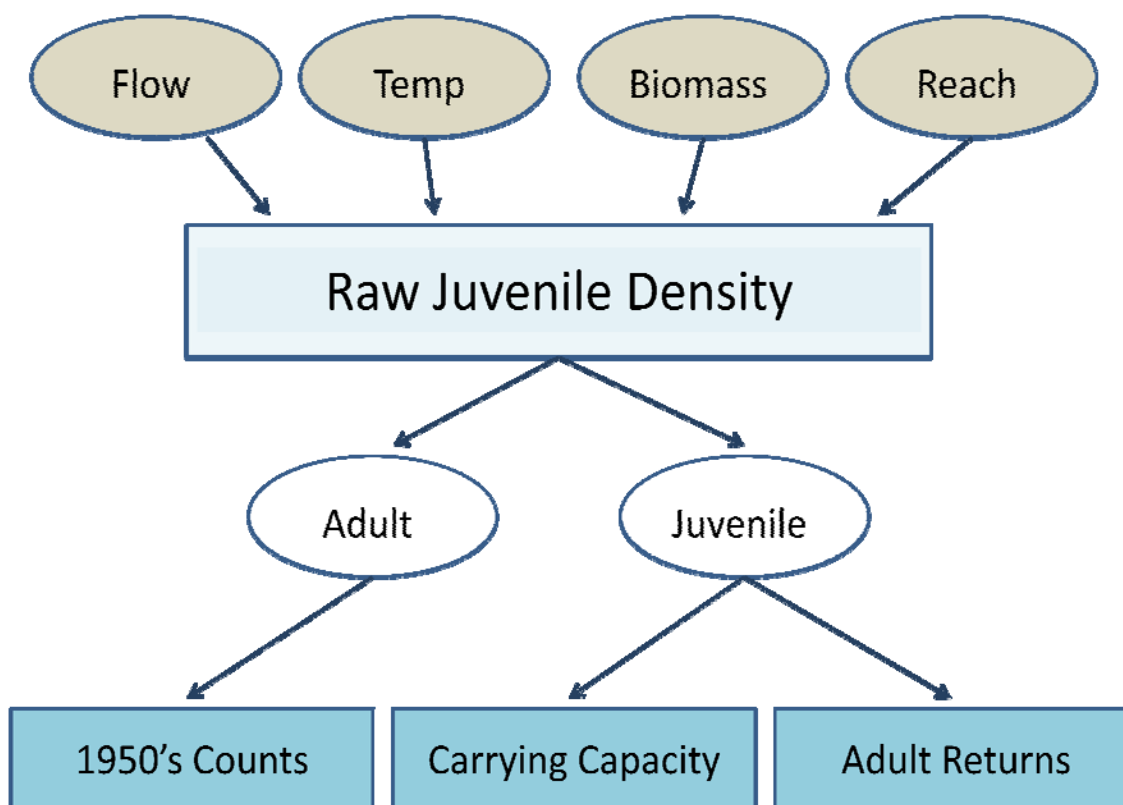


Figure 11 Inputs and outputs of analysis

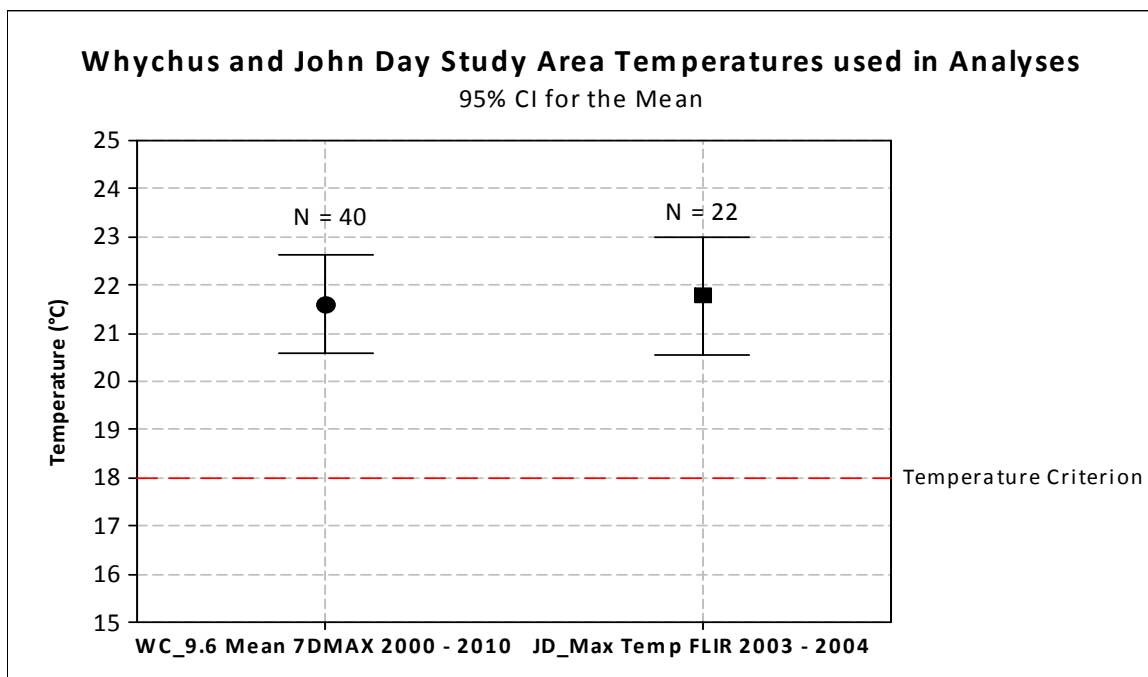


Figure 12 Whychus and John Day Study area instream temperatures

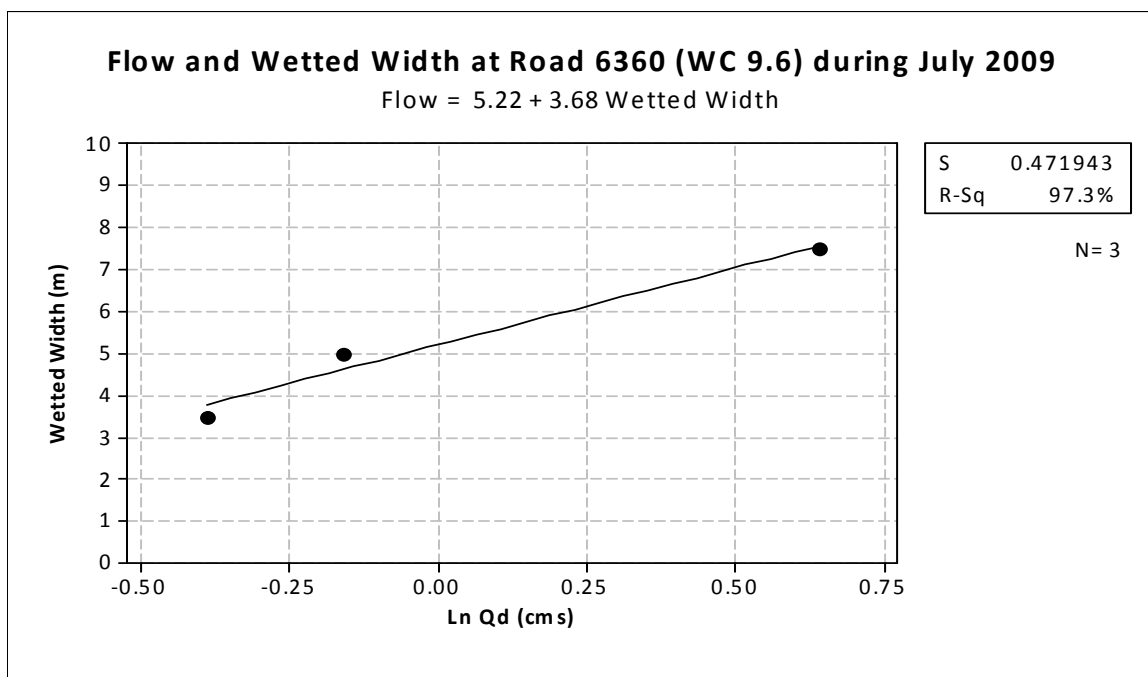
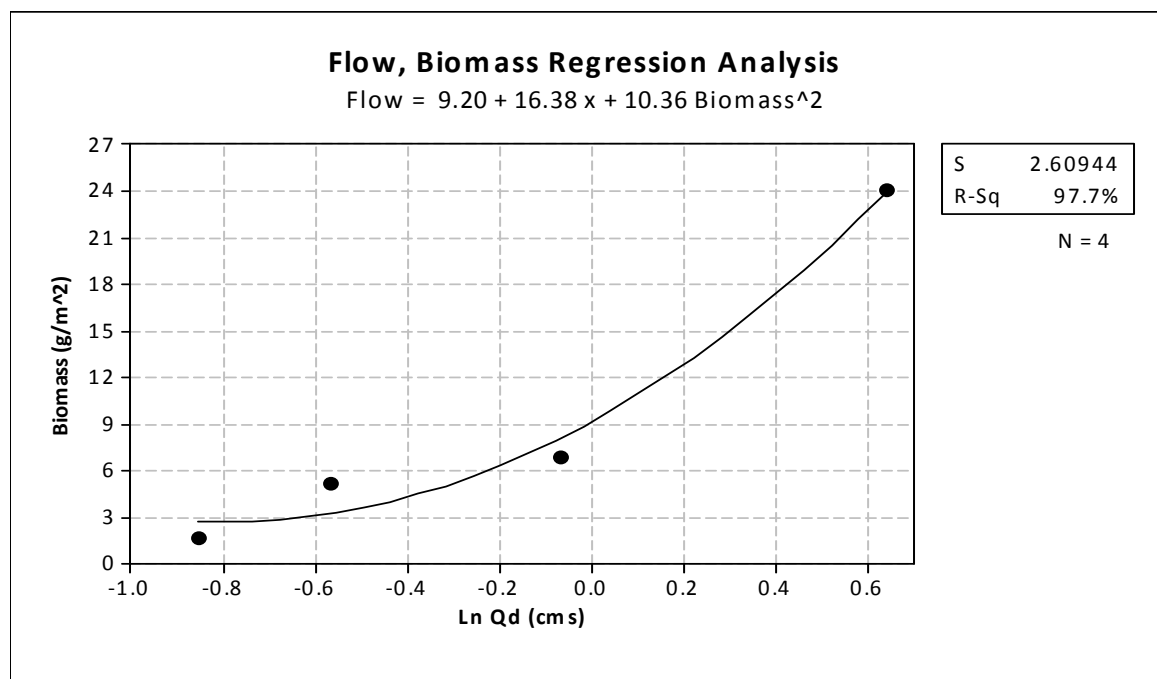


Figure 13 Summary of flow and wetted width at USFS Road 6360

Table 6 Temperature and biomass given index flow levels

Index Flow Levels Gage at Sisters City Park (WC 39.0)			Temperature at Rd 6360 (WC 9.6) ¹¹	Biomass at Temperature Range
(cfs)	(cms)	Ln Qd	(°C)	(g/m ²)
15	0.42	-0.86	23.3	1.73
20	0.57	-0.57	22.4	5.25
33	0.93	-0.07	20.8	6.87
67	1.90	0.64	18.0	24.2

**Figure 14 Regression analysis of flow verses estimated steelhead trout carrying capacity**¹¹ Obtained from Equation 2 Section 2.

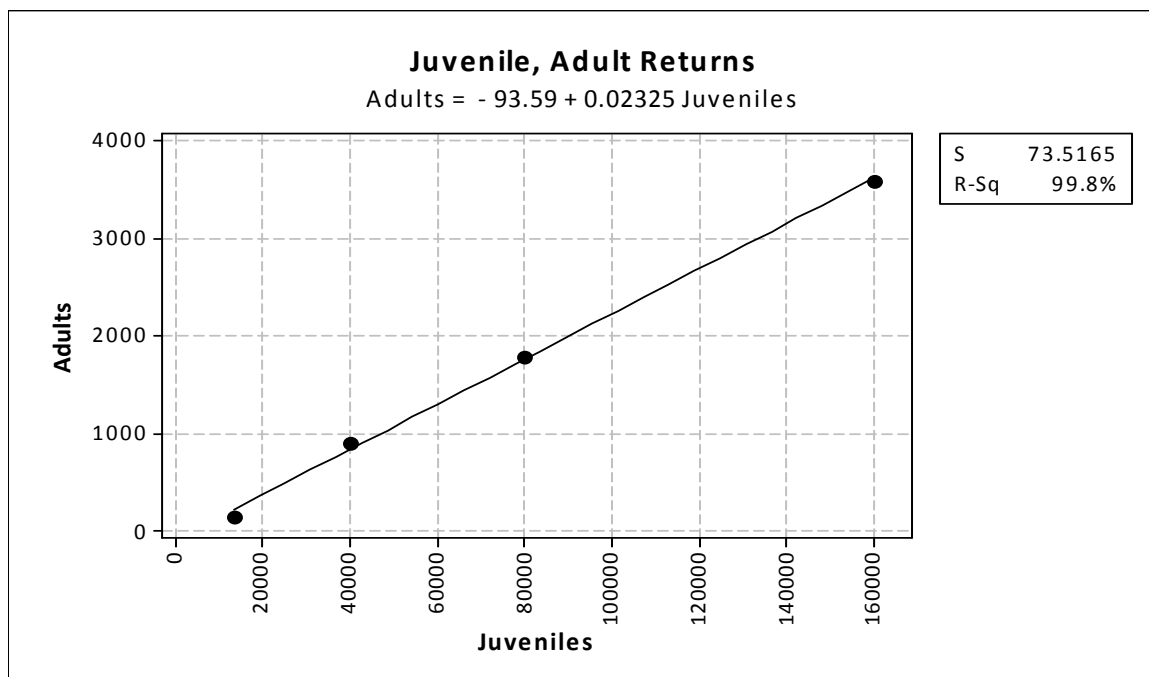


Figure 15 Estimation of juvenile, adult returns from outplanting strategies

Table 7 Flow and steelhead trout carrying capacity along the Historic Reach and Restored Reach of Whychus Creek

Flow at Gage at Sisters City Park (WC 39.0)			Temp at Road 6360 (WC 9.6) (95% CL) ¹²		Wetted Width ¹³	Reach Area ^{14,15}		Biomass (60% CL) ¹⁶		Estimated Number of Adults 1950's (60% CL)		Estimated Number of Juvenile (60% CL)				Estimated Number of Returning Adults based on Juvenile Estimates ¹⁷	
cfs	cms	LnQD cms	°C	± °C	m	Historic m ²	Restored m ²	g/m ²	±	Historic Reach	±	Historic Reach	±	Restored Reach	±	Historic Reach	Rest. Reach
15	0.42	-0.86	23.3	2.2	2.07	53219.50	84818.58	2.8	1.3	81	38	434	202	691	322	0	0
16	0.45	-0.79	23.1	2.2	2.30	59335.05	94565.25	2.7	1.3	89	42	476	224	758	357	0	0
17	0.48	-0.73	22.9	2.2	2.53	65079.73	103720.83	2.8	1.3	99	46	529	247	842	393	0	0
18	0.51	-0.67	22.8	2.2	2.74	70495.95	112352.94	2.9	1.3	111	51	594	270	947	430	0	0
19	0.54	-0.62	22.6	2.2	2.94	75619.26	120518.21	3.0	1.3	126	55	673	293	1072	467	0	0
20	0.57	-0.57	22.4	2.2	3.13	80479.72	128264.57	3.2	1.3	143	59	765	317	1220	506	0	0
21	0.59	-0.52	22.3	2.2	3.31	85102.99	135632.90	3.5	1.4	163	64	871	342	1389	545	0	0
22	0.62	-0.47	22.1	2.2	3.48	89511.14	142658.39	3.8	1.4	186	69	991	367	1580	584	0	0
23	0.65	-0.43	22.0	2.2	3.64	93723.31	149371.54	4.1	1.4	211	73	1124	392	1791	624	0	0
24	0.68	-0.39	21.9	2.2	3.80	97756.18	155798.92	4.4	1.4	238	78	1269	417	2023	664	0	0
25	0.71	-0.35	21.7	2.2	3.95	101624.39	161963.90	4.8	1.5	267	83	1427	442	2274	704	0	0
26	0.74	-0.31	21.6	2.2	4.09	105340.88	167887.04	5.1	1.5	299	87	1596	467	2543	744	0	0
27	0.76	-0.27	21.5	2.2	4.23	108917.08	173586.62	5.5	1.5	333	92	1776	492	2830	783	0	0
28	0.79	-0.23	21.3	2.2	4.36	112363.21	179078.89	5.9	1.6	369	97	1966	516	3134	823	0	0
29	0.82	-0.20	21.2	2.2	4.49	115688.40	184378.41	6.4	1.6	406	101	2167	541	3453	861	0	0
30	0.85	-0.16	21.1	2.2	4.62	118900.85	189498.25	6.8	1.6	445	106	2377	565	3788	900	0	0

¹² Obtained from flow and temperature regression analysis summarized in Figure 2 and Equation 2.

¹³ Obtained from field observations and summarized in Figure 13, Equation 3.

¹⁴ Historic reach length of 25,749.50 m (16.0 miles) as reported in (Nehlsen, 1995)

¹⁵ Restored Reach length of 41,038.27 (25.5 miles) obtained from TSID and ODEQ ArcGIS Section 303(d) database (ODEQ, 2010 b).

¹⁶ Obtained from Upper John Day Subbasin densities and summarized in Figure 14, Equation 4.

¹⁷ Obtained from juvenile carrying capacity estimates and expected adult returns above Pelton Round Dam (Figure 15 and Equation 5).

Flow at Gage at Sisters City Park (WC 39.0)			Temp at Road 6360 (WC 9.6) (95% CL) ¹²		Wetted Width ¹³	Reach Area ^{14,15}		Biomass (60% CL) ¹⁶		Estimated Number of Adults 1950's (60% CL)		Estimated Number of Juvenile (60% CL)				Estimated Number of Returning Adults based on Juvenile Estimates ¹⁷	
cfs	cms	LnQD cms	°C	± °C	m	Historic m ²	Restored m ²	g/m ²	±	Historic Reach	±	Historic Reach	±	Restored Reach	±	Historic Reach	Rest. Reach
31	0.88	-0.13	21.0	2.2	4.74	122007.95	194450.20	7.2	1.6	487	110	2596	588	4137	938	0	0
32	0.91	-0.10	20.9	2.2	4.86	125016.40	199244.91	7.7	1.7	529	115	2823	612	4499	975	0	0
33	0.93	-0.07	20.8	2.1	4.97	127932.27	203892.07	8.1	1.7	573	119	3058	635	4874	1013	0	4
34	0.96	-0.04	20.6	2.1	5.08	130761.08	208400.49	8.6	1.7	619	123	3301	658	5262	1049	0	12
35	0.99	-0.01	20.5	2.1	5.18	133507.88	212778.21	9.0	1.7	666	128	3552	681	5660	1085	0	20
36	1.02	0.02	20.4	2.1	5.29	136177.30	217032.60	9.5	1.8	714	132	3808	703	6070	1121	0	28
37	1.05	0.05	20.3	2.1	5.39	138773.58	221170.42	10.0	1.8	763	136	4072	725	6489	1156	0	36
38	1.08	0.07	20.2	2.1	5.49	141300.62	225197.88	10.4	1.8	814	140	4341	747	6919	1191	0	45
39	1.10	0.10	20.1	2.1	5.58	143762.00	229120.72	10.9	1.8	865	144	4616	769	7357	1225	0	54
40	1.13	0.12	20.0	2.1	5.68	146161.07	232944.24	11.4	1.8	918	148	4896	790	7804	1259	4	62
41	1.16	0.15	19.9	2.1	5.77	148500.90	236673.33	11.9	1.9	971	152	5182	811	8259	1292	10	72
42	1.19	0.17	19.8	2.1	5.86	150784.34	240312.57	12.3	1.9	1026	156	5472	831	8721	1325	16	81
43	1.22	0.20	19.8	2.1	5.94	153014.05	243866.16	12.8	1.9	1081	160	5767	851	9191	1357	22	90
44	1.25	0.22	19.7	2.1	6.03	155192.49	247338.06	13.3	1.9	1137	163	6066	872	9668	1389	28	100
45	1.27	0.24	19.6	2.1	6.11	157321.98	250731.93	13.8	1.9	1194	167	6370	891	10152	1420	34	109
46	1.30	0.26	19.5	2.1	6.19	159404.66	254051.20	14.2	1.9	1251	171	6677	911	10641	1452	40	119
47	1.33	0.29	19.4	2.1	6.27	161442.55	257299.09	14.7	2.0	1310	174	6987	930	11136	1482	46	129
48	1.36	0.31	19.3	2.1	6.35	163437.53	260478.59	15.2	2.0	1369	178	7301	949	11637	1512	52	139
49	1.39	0.33	19.3	2.1	6.42	165391.37	263592.53	15.7	2.0	1428	181	7619	968	12143	1542	59	149
50	1.42	0.35	19.2	2.1	6.50	167305.75	266643.56	16.1	2.0	1488	185	7939	986	12653	1572	65	159
51	1.44	0.37	19.1	2.1	6.57	169182.21	269634.17	16.6	2.0	1549	188	8263	1004	13169	1601	72	170
52	1.47	0.39	19.0	2.1	6.64	171022.23	272566.71	17.1	2.0	1610	192	8589	1022	13688	1630	78	180
53	1.50	0.41	18.9	2.1	6.71	172827.20	275443.38	17.5	2.0	1671	195	8917	1040	14212	1658	85	191

Flow at Gage at Sisters City Park (WC 39.0)			Temp at Road 6360 (WC 9.6) (95% CL) ¹²		Wetted Width ¹³	Reach Area ^{14,15}		Biomass (60% CL) ¹⁶		Estimated Number of Adults 1950's (60% CL)		Estimated Number of Juvenile (60% CL)				Estimated Number of Returning Adults based on Juvenile Estimates ¹⁷	
cfs	cms	LnQD cms	°C	± °C	m	Historic m ²	Restored m ²	g/m ²	±	Historic Reach	±	Historic Reach	±	Restored Reach	±	Historic Reach	Rest. Reach
54	1.53	0.42	18.9	2.1	6.78	174598.43	278266.28	18.0	2.1	1733	198	9249	1058	14740	1686	91	201
55	1.56	0.44	18.8	2.1	6.85	176337.16	281037.38	18.5	2.1	1796	202	9582	1075	15271	1714	98	212
56	1.58	0.46	18.7	2.1	6.91	178044.56	283758.55	18.9	2.1	1859	205	9918	1092	15806	1741	105	223
57	1.61	0.48	18.7	2.1	6.98	179721.74	286431.56	19.4	2.1	1922	208	10255	1109	16344	1768	112	233
58	1.64	0.50	18.6	2.1	7.04	181369.75	289058.07	19.9	2.1	1986	211	10595	1126	16885	1795	118	244
59	1.67	0.51	18.5	2.1	7.11	182989.59	291639.69	20.3	2.1	2050	214	10936	1143	17430	1821	125	255
60	1.70	0.53	18.5	2.1	7.17	184582.20	294177.91	20.8	2.1	2114	217	11279	1159	17976	1847	132	266
61	1.73	0.55	18.4	2.1	7.23	186148.49	296674.18	21.2	2.1	2179	220	11624	1175	18526	1873	139	277
62	1.75	0.56	18.3	2.1	7.29	187689.30	299129.86	21.7	2.2	2244	223	11970	1191	19078	1899	146	288
63	1.78	0.58	18.3	2.1	7.35	189205.47	301546.25	22.1	2.2	2309	226	12318	1207	19632	1924	153	299
64	1.81	0.59	18.2	2.1	7.41	190697.75	303924.58	22.6	2.2	2374	229	12667	1223	20188	1949	160	310
65	1.84	0.61	18.1	2.1	7.46	192166.90	306266.03	23.0	2.2	2440	232	13018	1238	20747	1973	167	321
66	1.87	0.62	18.1	2.1	7.52	193613.62	308571.74	23.5	2.2	2506	235	13369	1253	21307	1998	174	333
67	1.90	0.64	18.0	2.1	7.57	195038.58	310842.77	23.9	2.2	2572	238	13722	1269	21869	2022	181	344
68	1.92	0.65	18.0	2.1	7.63	196442.43	313080.16	24.4	2.2	2638	241	14076	1284	22433	2046	188	355
69	1.95	0.67	17.9	2.1	7.68	197825.79	315284.88	24.8	2.2	2705	243	14430	1298	22999	2069	195	366
70	1.98	0.68	17.8	2.1	7.74	199189.24	317457.88	25.2	2.2	2771	246	14786	1313	23565	2093	202	378

Table 8 Counts and estimates of steelhead trout in Whychus Creek

Study	Steelhead Trout Population in Whychus Creek		Estimated from Surrogate Biomass ¹⁸	
Steelhead trout counts 1950's ¹⁹	15 cfs	62 - 619 ²⁰ adults	15 cfs	81 ± 38 adults
Steelhead trout estimated 1953	15 cfs	1000 adults	42 cfs	1026 ± 156 adults
Unit Characteristic Method Upper Basin estimate ²¹	60 cfs	17,346 juveniles	60 cfs	17,976 ± 1847 juveniles
HABRATE	unknown	255,200 juveniles		

¹⁸ Table 7.¹⁹ (King, 1966) (Nehlsen, 1995)²⁰ All counts are considered index counts rather than estimates of the total abundance because several factors affected the accuracy of the counts including problems keeping the weir functional, effects of the weir on upstream migrants, and poaching (King, 1966) (Nehlsen, 1995).²¹ (Cramer & Ackerman, 2009)

Chapter 4. Limitations, Applications, and Additional Studies

4.1 Acknowledgement of Limitations

Capturing, analyzing, and understanding the important parameters and their variation across a complex hydrologic system is a common challenge in watershed science. Identifying limitations along each step of the analysis that is presented here is crucial in appropriately applying this approach toward future use and applications. In addition, understanding the limitations of this analysis provides for future research and improvement of this approach. Table 9 provides the steps used in this analysis, descriptive statistics for the regressions, and the degree of uncertainty for each step in analysis.

Flow, Temperature

There is a low degree of uncertainty regarding the flow and temperature steps in analyses because the number of samples is large, the regression fit is good, and the standard deviation is low for each step. The results of flow and temperature regression analysis are applicable to the range of flows in the dataset. The relationship between flow and temperature may change with changes in the surface to groundwater interactions due to climate change and restoration projects.

Flow, Wetted Width

There is a medium degree of uncertainty regarding the flow and wetted width step in analysis because although the regression fit is good and the standard deviation is low, the sample size is small. In addition, ongoing and future restoration projects along with instream flow restoration along Whychus Creek will change the profile of the flow and wetted width. The wetted width data used here is collected from a representative cross section of future conditions.

Flow; Biomass

There is a medium degree of uncertainty regarding the flow and biomass step in analysis because although the regression fit is good, there is a small sample size and there is a large standard deviation. The biomass data is derived from the relationship between temperature and biomass in the Upper John Day Subbasin, and the scale assigns biomass to four

temperature categories. Incorporating the quantitative equations for temperature and biomass regression analysis performed in Madriñán et al. (2009) can lower the degree of uncertainty in this step in analysis. There is a predominately wild steelhead trout population in the Upper John Day Subbasin, while the Whychus Creek steelhead population is a reintroduced population. Competitive juvenile interactions are maximized when the hatchery and wild fish share juvenile life histories and habitat requirements, such as the resident rainbow trout and reintroduced anadromous steelhead trout in Whychus Creek (McMichael, Pearsons, & Leider, 2000). Interactions between hatchery and wild steelhead juveniles may be particularly high because the species is aggressive and territorial (Slaney, McPhail, Radford, & Birch, 1985).

Juvenile, Adult Returns

There is a high degree of uncertainty regarding the juvenile and adult returns step in analysis because although the regression fit is good, there is a small sample size and there is a large standard deviation. The juvenile and adult returns dataset is derived from the outplanting strategies used for the reintroduction of steelhead into the Upper Deschutes above Pelton Round Dam. These outplanting strategies are based upon the equilibrium steelhead trout numbers relative to carrying capacity and productivity as estimated by the Unit Characteristic Method for the upper Deschutes Basin (Cramer & Beamesderfer, 2002, 2006) (Cramer & Ackerman, 2009). The model results were extremely sensitive to passage survival assumptions for the Pelton Round Butte Dam complex meaning the relationship of carrying capacity and returning adults passing the dam complex is highly sensitive to increases in mortality due to passage. This step in analysis assumes minimum juvenile and adult passage mortality as a result of passing the Pelton Round Butte Dam complex. Calculating number of juveniles and number of adults from biomass also offers a challenge. In-situ populations vary in age, size, and weight and this step in analysis utilizes an average steelhead trout juvenile weight that is based upon a USFS Fish Biologist opinion and measured steelhead trout adult weights from the Pelton Trap. A request for field measurements regarding steelhead size and weight for the lower Deschutes has been submitted to ODFW and PGE since they are currently collecting this data. In addition to the limitations and the degree of uncertainty described in Table 9, hydrological analysis is generally limited by:

- ~ The spatial variability in hydrology and water quality can be a challenge to capture at all scales; coarse and fine. Ground-level measurements are particularly difficult to upscale to larger spatial extents. In addition, the degree to which parameters affect each other is not fully understood in the context of spatial water quality analysis.
- ~ Land use patterns that change over time and current land use patterns that are a remnant of history. As a result, human impacts are evident across landscapes making comparison to historic conditions a challenge. In some cases, historic conditions are not well understood, while in other cases human impact may be permanent. Understanding the future conditions that will shape the landscape and its hydrology is key in removing limitations and decreasing the degree of uncertainty.
- ~ Climate change that affects the hydrology and future changes in the timing, duration, and magnitude of hydrologic events. The amount of precipitation reaching the groundwater or discharging as surface water may be altered due to climate changes that may result in warmer winters (Nolin & Daly, 2006). Warmer winters may be characterized as having more winter rains and less winter snow events. If warmer winters occur and result in less snow, the magnitude of spring rain on snow events may change. Changes in the timing, duration, and magnitude of peak flows from rain on snow events may cause changes in sediment distribution, which is important for fish habitat, may cause changes in the availability of water to serve water rights, and may result in changes in the surface, groundwater interactions.
- ~ Interactions between wild and hatchery steelhead trout populations indicate that hatchery steelhead cause the carrying capacity to be exceeded triggering density dependant mechanisms that reduce the wild population (Kostow 2006). It is unclear if the mixed hatchery and wild population will result in changes in productivity of wild steelhead trout in the Mid-Columbia Steelhead Trout DPS (NOAA, 2010).

It is important to remember that measured values are more accurate than model predictions. Since spatial variability exists, land use patterns change over time, climate changes affect the hydrology of a system, and interactions between hatchery and wild steelhead trout are not fully

understood, ongoing monitoring captures changes and reflects the effect of complex pressures on system parameters such as flow, temperature, and biomass.

4.2 Potential Applications

While analytical methods exist for describing complex interactions within hydrological processes, applying such techniques may be beyond the scope and resources available for a project. This approach seeks to simplify the description of complex interactions that is performed by complex models into fundamental parameters that upon analysis can result in the information needed for natural resource managers. This approach may be applied to understanding systems where:

- ~ There are large historic datasets;
- ~ There are strong correlations between parameters such as flow and temperature;
- ~ There is an appropriate surrogate for parameters, such as biomass, that have a lack of data to base future estimations; and
- ~ The resource for a complex model is not available, yet there is a need to inform natural resource managers regarding possible project outputs.

4.3 Studies Used in Analysis

There are two key studies performed in the Upper John Day Subbasin that are used in this analysis to relate temperature and biomass and two models with predictions that are used to validate the results of this analysis. Both studies link temperature and trout while both models are based upon physical habitat studies and relate habitat to temperature and habitat to fish density. The analysis presented here utilizes the links between flow and temperature and temperature and trout then compares results to the results of the habitat based models. These studies and models are described in more detail below.

Upper John Day Subbasin Studies

Feldhaus et al. (2010) examined tissue specific levels of heat shock protein 70 (hsp70) and whole body levels of lipids in redband trout juveniles from the Upper John Day

Subbasin. They used a combination of laboratory experiments and field sampling to establish levels of hsp70 as it relates to temperature stress. They argue that the fitness of thermally stressed trout is compromised and is coupled with a decrease in growth. This supports the need to include temperature in management criteria for salmon bearing streams. Feldhaus, J. W. (2006) proposed as a doctorate dissertation at Oregon State University in the Department of Fisheries and Wildlife that the following scale qualifies the relationship between trout and temperature:

- ~ Optimal temperature = $\leq 18.0^{\circ}\text{C}$
- ~ Sub-optimal temperature = $18.0 - 21.0^{\circ}\text{C}$
- ~ Moderate temperature = $21.1 - 23.0^{\circ}\text{C}$
- ~ Poor temperature = $\geq 23.1^{\circ}\text{C}$

Madriñán, L. F. (2008) recognized in his doctorate dissertation at Oregon state University in the Department of Fisheries and Wildlife that the inclusion of water temperature alone at large spatial scales explained most of the distribution of trout and that in the Upper John Day Subbasin stream temperature can be used as an index to carrying capacity. This study used forward looking infrared (FLIR) to map the longitudinal stream temperature profiles when the stream flows were at base level (average depth of $< 1\text{ m}$) in the late summer of 2003 and 2004. The average maximum reach temperature was used to assign reaches into four habitat categories based on the temperature index described by Feldhaus, J. W. (2006). Steelhead trout densities were established by snorkel surveys and examined at the tributary, reach, and habitat unit (i.e. pool, riffle, or glide). Using regression analysis of trout biomass per pool and per reach against reach water temperature, Madriñán (2008) showed a strong inverse significant relationships with water temperature and that the biomass at the reach scale explained a higher proportion of the data variation when compared to the pool scale. He concluded that stream temperature can be used as an indicator of trout carrying capacity along the reach scale and established the following association:

~ Optimal temperature =	$\leq 18.0\text{ }^{\circ}\text{C}$	= 24.2 g/m ² biomass
~ Sub-optimal temperature =	18.0 – 21.0 °C	= 6.87 g/m ² biomass
~ Moderate temperature =	21.1 – 23.0 °C	= 5.25 g/m ² biomass
~ Poor temperature =	$\geq 23.1\text{ }^{\circ}\text{C}$	= 1.73 g/m ² biomass

Heat Source Model

The Heat Source model is used by ODEQ to simulate stream thermodynamics and hydrology. It was developed by Boyd, M. S. (1996) as a master thesis at Oregon State University in the Department of Bioresources and Civil Engineering. ODEQ currently maintains the Heat Source methodology and computer programming. The Heat Source model utilizes high resolution spatial data coupled with deterministic modeling of hydrologic and landscape processes to predict the effective shade, heat and mass transfer, and water temperature. The inputs for the Heat Source model are complex yet can be generally explained as:

Stream temperature = the accumulative affects of *channel morphology*, *hydrology*, and *near stream vegetation*.

Where;

Channel morphology includes gradient and sinuosity, bank erosion, stream and floodplain connection, channel width and depth, channel geometry, and substrate.

Hydrology include flow volume and regime, shear velocity, point sources, withdrawals and augmentation, hyporheic flows, and sedimentation.

Near stream vegetation include vegetation conditions and type, effective shade, floodplain roughness, bank stability, and microclimate.

The Heat Source model for Whychus Creek utilizes data that was collected over two weeks during the summer of 2001. One limitation is the simulation duration is limited

to three weeks due to output storage. A limitation in regards to instream flow restoration is that the model utilizes flow as an input with the output of temperature therefore the model cannot calculate the flow needed to achieve a temperature goal without reiterative model runs.

Unit Characteristic Method

The Unit Characteristic Method developed by Cramer et al. (2009) estimates the carrying capacity of salmonids by using the channel unit (i.e. pool, riffle, or glide) to assign a standard density for each fish species to each unit type. The general form of the predictor for a given species in a specific stream reach is:

$$Capacity_i = (\sum area_k \cdot den_j \cdot chnl_{jk} \cdot cvr_{jk}) \cdot prod_i$$

Where;

i = stream reach

j = channel unit

$area$ = area (m^2) of channel unit k

den = standard fish density for a given species in unit type j .

dep = depth

cvr = cover

$chnl$ = channels

$prod$ = productivity

The general form of the productivity for a given species in a specific stream reach is:

$$prod_i = turb_i \cdot drift_i \cdot fines_i \cdot alk_i$$

Where;

$turb$ = turbidity

$drift$ = percentage of reach area in fast water

$fines$ = percentage of substrate in riffles

alk = alkalinity

HABRATE

HABRATE was developed by ODFW and utilizes ratings of high, medium, and low for each stream survey habitat variable and for each stream rearing life stage (ODFW, 2003). Variable scores were combined to provide a rating for each life stage at the micro and meso scale. Substrate ratings for fines, gravel, and cobble, were combined to create a rating for substrate. Habitat unit level information such as pools, depth, large boulders, and large woody debris were combined into a rating for habitat complexity. The ratings were then combined and the total smolt capacity was estimated based on total wetted area and habitat quality. This model has not been validated.

Uncertainties are a result of describing dynamic and complex systems with field measurements and analytical techniques. Understanding the limitations and degree of uncertainty that accompany the results of analysis are paramount to interpreting results and understanding the potential applications of representing complex systems using a subset of fundamental parameters, such as flow, temperature, and surrogate biomass.

Table 9 Steps in analysis and the degree of uncertainty.

Steps in Analysis	N	R²	S	Degree of Uncertainty
Flow, Temperature WC 39.0 (Sisters City Park)	46	95.4%	0.703	Low
Flow, Temperature WC 9.6 (Road 6360)	40	93.5%	0.843	Low
Flow, Wetted Width WC 9.6 (Road 6360)	3	97.3%	0.472	Medium
Flow, Biomass (Upper John Day Subbasin)	4	97.7%	2.609	Medium
Juvenile, Adult Returns passing Pelton Round Dam (Outplanting)	4	99.8%	73.52	High

Chapter 5. Conclusions

Instream flow restoration targets are not fully resolved and additional flows may be needed to meet the restoration goal in Whychus Creek. Using certified instream water rights as the instream flow restoration target may limit the quantity of water that can be restored and protected instream. Instream beneficial use of water is inherently junior under current Oregon water code because the assignment of consumptive beneficial uses of water first in time. Restrictions are noted on the instream water right certificate that protect consumptive over environmental uses of water and limit the quantity of restored flow to that designated under the certified instream water right. If more water is needed instream than what is designated by the instream water right certificate, it may be difficult to serve or protect this additional water instream.

Using certified instream water rights as the instream flow restoration target may underestimate the quantity of water needed to achieve the restoration goal of decreasing temperatures for steelhead trout. Instream flow restoration targets originate from the OSWRB optimal flow recommendations that later were adopted by ODFW (formally the OSGC) as minimum flows needed to support fish rearing, spawning and migration. The OSWRB optimal flow recommendations were based on a physical habitat assessment similar to the Tennant Method. Not only did the OSWRB recommend these flows with many caveats regarding the need to determine relationships between flow and temperature and flow and steelhead trout production (PNRBC, 1972 a) (PNRBC, 1972 b), but this approach has been shown to produce insufficient flows when considering temperature (Mann, 2006). In Whychus Creek, determining relationships between flow and temperature and flow and steelhead trout production may improve the instream flow restoration target.

The OSWRB recommended flows were adopted as instream flow restoration targets and were originally made with many caveats regarding the need to determine relationships between flow and temperature and flow and steelhead trout production. The results in Section 2 provide equations that describe the relationship between flow and temperature in Whychus Creek.

Although temperatures are considered optimal ($<18^{\circ}\text{C}$) at the Sisters City Park at kilometer 39.0 (river mile 24.25), the current target of 0.93 cms (33 cfs) provides sub-optimal ($18.1 - 21^{\circ}\text{C}$) temperatures of $20.8 \pm 2.1^{\circ}\text{C}$ for steelhead trout downstream at USFS Road 6360 at kilometer 9.6 (river mile 6.0). To reduce instream temperatures to meet state temperature criteria for steelhead trout in Whychus Creek, 1.90 cms (67 cfs) of flow is recommended during July.

Validation of results supports the use of this approach in setting instream flow restoration targets in appropriate cases. Estimating the carrying capacity of steelhead trout at the habitat based instream flow target of 0.93 cms (33 cfs) and the temperature based instream flow target of 1.90 cms (67 cfs) may help to further improve instream flow restoration targets.

To support steelhead trout reintroduction efforts, flow recommendations can be made based upon estimated biomass of steelhead trout in Whychus Creek. Current instream flow targets are based upon physical habitat studies that did not include temperature and/or steelhead trout biomass information. Models have been developed to evaluate the number of smolts that need to be reintroduced to support steelhead trout populations in the upper Deschutes Basin, yet these models do not provide information regarding instream flow restoration targets.

It is proposed that estimates of steelhead trout carrying capacity that are based upon current day conditions in Upper John Day Subbasin are an appropriate measure of potential steelhead trout numbers within Whychus Creek and are appropriate for refining instream flow restoration targets. Utilizing the biomass estimates from the Upper John Day Subbasin as a surrogate for steelhead trout estimates in Whychus Creek is appropriate because these estimates:

- ~ Are based upon actual populations within the same DPS and a similar geographical MPG area;
- ~ Reflect the stresses and current day conditions that the steelhead trout in this DPS experience as a result of anadromy;

- ~ Are validated by the steelhead trout counts along Whychus Creek during the 1950's and the upper Deschutes Basin population estimates from the Unit Characteristic Method; and
- ~ Are constructed to inform instream flow restoration activities regarding the estimated biological outcomes of attaining instream flow targets.

Steelhead trout are reintroduced and once established will comprise the Deschutes above Pelton Round Dam MPG, yet this MPG is currently considered extirpated and does not contribute to the viability of the Middle-Columbia Steelhead Trout DPS. The ICTRT, a team of scientists appointed by NMFS, assesses viability based upon abundance, productivity, spatial structure, and diversity at the MPG level to determine the viability of a DPS. The ICTRT considers populations with fewer than 500 individuals at high risk for inbreeding, depression, a variety of genetic concerns, and minimally viable.

The results of this analysis indicate at the current target of 0.93 cms (33 cfs), temperatures equal 20.8 ± 2.1 and do not meet the state criteria. An estimated $4,874 \pm 1013$ steelhead trout juveniles may result and an estimated four steelhead trout adults would be expected to return to the upper Deschutes Basin. If the goal was to reduce temperatures for steelhead trout then, to achieve the state criterion of 18.0 °C, 1.90 cms (67 cfs) of instream flow may result in $21,869 \pm 2022$ steelhead trout juveniles may result and an estimated 344 steelhead trout adults would be expected to return to the upper Deschutes Basin. This would result in a more viable Deschutes above Pelton Dam MPG within the Middle-Columbia River Steelhead DPS. Further, this analysis indicates that at flows ≤ 1.10 cms (≤ 39 cfs) and after the Pelton Round Butte Dam installation the carrying capacity of steelhead trout juvenile in Whychus Creek in the late 1950's would not have resulted in returning adults.

The ODFW certified instream flows of 1990 are based upon the habitat studies and recommendations of the SWRB in 1972, which are caveated with the need to incorporate temperature and fish population information. The appropriateness of using the certified instream flows as instream flow restoration targets may underestimate the quantity of water needed to meet the state temperature criterion and may limit the quantity of water that can be

secured and protected legally instream. In addition, climate change may also provide a reason to rethink the use of certified instream water rights as instream flow restoration targets.

Whychus Creek is dominated by glacier snow melt and is characterized by peak flows resulting from rain on snow events. Climate change in the region may result in warmer winters meaning more winter rain and less winter snow, and the amount of precipitation reaching the groundwater or discharging as surface water may also be altered (Nolin & Daly, 2006). If warmer winters occur and result in less snow, the magnitude of spring rain on snow events may change. These changes may cause reductions in the availability of water to ultimately serve the certified instream flow water rights.

Comparing the results of this analysis with future counts from self-sustaining steelhead trout populations in Whychus Creek may offer further insight into the value of using flow, temperature, and surrogate biomass estimates in setting instream flow restoration targets and the usefulness of this approach to water resource managers.

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Abbreviations

Organizations

DRC	Deschutes River Conservancy
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
ICTRT	Interior Columbia Technical Recovery Team
IWW	Institute for Water and Watersheds
NIST	National Institute of Standards and Technology
NMFS	National Marine Fisheries Service
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OSGC	Oregon State Game Commission
OSWRB	Oregon State Water Resources Board
OWEB	Oregon Watershed Enhancement Board
OWRD	Oregon Water Resources Department
PGE	Portland General Electric
SCIC	Squaw Creek Irrigation Company
TSID	Three Sisters Irrigation District
UDWC	Upper Deschutes Watershed Council
USFS	United States Forest Service
USGS	United States Geological Survey

Technical Terminology

7DMAX	Seven day moving average maximum temperature
°C	Degree Celsius
cfs	Cubic feet per second
cms	Cubic meters per second
CI	Confidence Interval
CL	Confidence Level
CWA	Clean Water Act
DPS	Distinct population segment
ESA	Environmental Species Act
ESU	Evolutionarily significant unit
°F	Fahrenheit
ft	Feet
HSM	Heat Source model

Technical Terminology (Continued)

IDs	Identification numbers
km	Kilometer(s)
lb	Pound(s)
m	Meter(s)
mi	Mile(s)
MPG	Major population group
N	Sample size
OAR	Oregon Administrative Rules
QA/QC	Quality assurance / quality control
R ^s	Measure of model fit to data
RA	Regression analysis
S	Standard distance from regression line
TMDL	Total Maximum Daily Load

Appendix A Regional, Coordinated Monitoring Effort

The monitoring activities that produced the data used in the Evaluation of Instream Flow Restoration Targets and the Carrying Capacity of *Oncorhynchus mykiss* according to Temperature analyses are part of a larger, upper Deschutes Basin regional monitoring effort that I coordinated between 2003 and 2010. Included in the upper Deschutes Basin are the Upper Deschutes and Little Deschutes Subbasins that are further delineated into nineteen watersheds. There are over 1800 river miles across this mountainous and arid region. A major concern for natural resource managers in the region are the multiple state of Oregon Section 303(d) listed impaired reaches for multiple concerns including elevated temperatures, low dissolved oxygen, pH, and turbidity due to sedimentation. These water quality impairments are of concern because they negatively affect resident and reintroduced anadromous steelhead trout (*Oncorhynchus mykiss*). To address this concern, I facilitated over \$500,000 in grants from multiple funders that supported coordinated, regional monitoring including:

- ~ City of Bend
- ~ Columbia River Water Transaction Program
- ~ Deschutes River Conservancy
- ~ Oregon Department of Environmental Quality
- ~ Oregon Watershed Enhancement Board
- ~ U.S. Geological Survey; Institute for Water and Watersheds, OSU Corvallis

The regional monitoring effort that I facilitated required the coordination of multiple partners. These partners served under a Memorandum of Understanding between 2003 and 2010. Each had a representative to serve on the Water Quality Committee and the coordinated monitoring effort was guided by the members of this committee:

- ~ Bureau of Land Management
- ~ City of Bend
- ~ Crooked River Watershed Council
- ~ Deschutes River Conservancy
- ~ Oregon Department of Environmental Quality

- ~ Oregon Department of Fish and Wildlife
- ~ Oregon State University Cascades Campus
- ~ Oregon Water Resources Department
- ~ Portland General Electric
- ~ Upper Deschutes Watershed Council
- ~ U.S. Forest Service Deschutes National Forest
- ~ U.S. Forest Service Ochoco National Forest

Between 2003 and 2010, I coordinated monitoring between these partners to serve their multiple monitoring objectives. This was accomplished by facilitation of the Water Quality Committee that worked together to refine monitoring locations and parameters to meet multiple monitoring objectives of each organization. I compiled the monitoring methods used regionally and documented all methods in Standard Operating Procedures for the Field (SOP) to standardize all monitoring activities in the region. I created ODEQ approved Quality Assurance Project Plans (QAPPs) to document monitoring activities, equipment, and procedures (UDWC, 2008) (UDWC, 2008 b). I provided training to the partners, staff, and volunteers in standard methods. I created multiple technical reports detailing water quality analyses and results to support the multiple monitoring objectives. I created a online, regional database to house all the data collected by coordinated monitoring and to share this data between partners (UDWC, 2011). The SOP, QAPPs, technical reports, and data produced under the coordinated monitoring effort are available online at:

www.restorethedeschutes.org/What_We_Do/Monitoring/Water_Quality/.

Multiple stations and multiple parameters were monitored under the coordinated monitoring effort. There are over 200 historic water quality monitoring stations and approximately 100 active monitoring stations across the Upper and Little Deschutes Subbasins. All monitoring stations have continuous temperature monitoring using Vemco data loggers (Vemco, 2011). Six monitoring stations have continuous multiple parameter monitoring using YSI 6360 sondes that capture temperature, dissolved oxygen / percent saturation, pH, conductivity, and turbidity/total dissolved solids (YSI, 2011). Approximately 20 monitoring stations have grab

sample monitoring using a YSI 556 handheld meter that captures temperature, dissolved oxygen / percent saturation, pH, conductivity, and turbidity/total dissolved solids (YSI, 2011). Urban monitoring locations have additional monitoring that is processed by the City of Bend Laboratory to evaluate nutrients and other stormwater compounds of potential concern (City of Bend, 2011).

I designed deployment setups to secure the monitoring equipment in the field, to reduce vandalism, and to be adjustable to various flow levels. Working with the City of Bend Laboratory the final designs were produced (Figure 1 and Figure 2). These units improved the overall data quality and quantity that was collected under the coordinated monitoring effort.

In order to increase the monitoring capacity of the coordinated monitoring effort, I created the UDWC/OSU Cascades Campus Undergraduate Internship that was offered between 2004 and 2009. The goal of the Internship was to support state water quality monitoring objectives while providing a challenging, learning opportunity that increases hands on experiences and prepares the participating intern for a career in water resources. Each year an intern was competitively selected out of the Natural Resources Program to serve a ten month internship in exchange for a stipend and four upper division graded credits to put towards their degree. Each intern received hands on experience in equipment calibration, deployment and auditing, data management, and data analyses. In addition, each intern shared their work via presentations to the local community and natural resource managers. The successful collaboration between the OSU Cascades Campus and the UDWC spawned the creation of a joint Water Resources Laboratory located on the OSU Cascades Campus and staffed by the UDWC and OSU Undergraduate Interns. In 2010, I received an OWEB River Restoration Northwest Design Scholarship to present a poster of this successful internship program and its accomplishments.

The coordinated monitoring effort has become a model for other regions and I have shared this approach and monitoring results at local, state, federal, and international meetings, seminars, and conferences including:

- ~ Oregon State University Cascades Campus, Bend, Oregon, 2006 - 2010. **Speaker**
(multiple water resource and water policy topics; most recent topic): *History of Instream Water Rights in the Deschutes Basin, Oregon.*
- ~ River Restoration Northwest; 9th Annual Northwest Stream Restoration Design Symposium, Skamania, Washington, 2010. **Poster:** *Whychus Creek Stream Temperatures during Oncorhynchus mykiss Spawning, Rearing and Migration, 2005 – 2008, Deschutes Basin, Oregon.* **Poster:** *Water Resources Laboratory; OSU/UDWC Undergraduate Internship.*
- ~ Columbia Basin Water Transaction Program Annual Meeting; Bonneville Power Administration, Northwest Power and Conservation Council, and the National Fish and Wildlife Foundation, Portland, Oregon 2008. **Speaker:** *Monitoring the Effectiveness of Instream Flow Restoration to Improve Water Quality for Fish.*
- ~ Water in the Pacific Northwest; Moving Science to Policy Conference, Skamania, Washington, 2007. **Poster:** *Restoration Effectiveness Monitoring in Priority Watersheds of the Deschutes Basin.*
- ~ 10th International River Symposium and Environmental Flows Conference, Brisbane, Australia, 2007. **Speaker:** *Restoration Effectiveness Monitoring in Priority Watersheds of the Deschutes Basin.*
- ~ Upper Deschutes Watershed Council Riverfest, Whychus Creek Watershed, 2005 - 2007. **Guide:** *Discover Alder Springs.*
- ~ Upper Deschutes Watershed Council Riverfest, Whychus Creek Watershed, 2004 -2008. **Guide:** *Wonders of Whychus Creek.*
- ~ Oregon Watershed Enhancement Board 8th Biennial Conference, Water Quality Monitoring Summit, Ashland, Oregon, 2004. **Speaker:** *Upper Deschutes Watershed Council Water Quality Monitoring Program.*

Other roles that I have participated in under the coordinated monitoring approach include serving as a water resource professional on local committees including:

- ~ **Committee Member:** *Stormwater Advisory Committee, City of Bend, Oregon 2003 – Current.*
- ~ **Committee Facilitator:** *Water Quality Committee, Upper Deschutes and Little Deschutes Subbasins, Deschutes Basin, Oregon 2003 – 2010.*
- ~ **Committee Member and Elected Representative:** *State of Oregon Independent Multidisciplinary Science Team for Freshwater Ecosystems, Corvallis, Oregon 2006 .*
- ~ **Committee Advisor:** *Central Oregon Stormwater Management Plan Task Force, City of Bend, City of Redmond, and City of Sisters, 2006*

My experience facilitating a regional coordinated monitoring approach as I concurrently pursued my academic goals at OSU Corvallis has enhanced my graduate experience. I have gained skills beyond the classroom and have learned how to share technical and complex information with multiple audiences. In addition, I have gained strong program management skills that include grant writing and reporting, staff management, and the ability to work collaboratively and productively in challenging environments.

Figure 1. Continuous temperature monitoring deployment setup

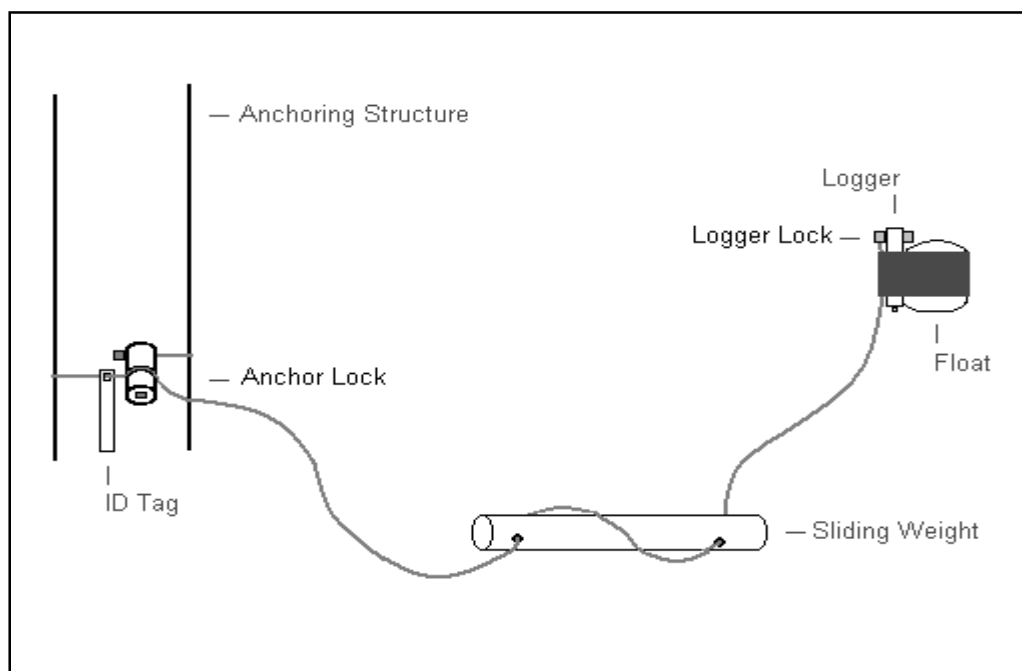
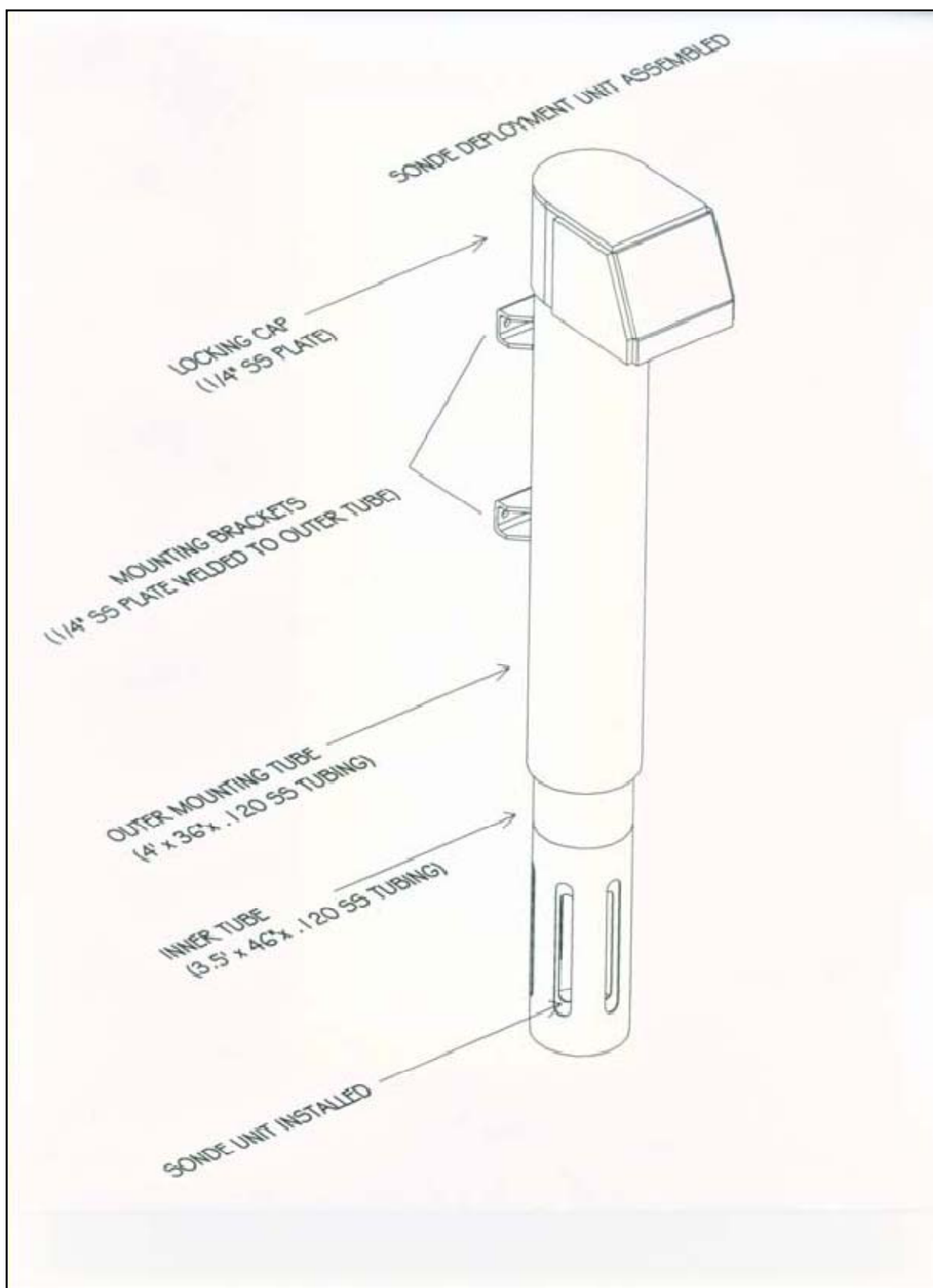


Figure 2. Continuous multiparameter monitoring deployment setup



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Jeremy Giffen	Oregon Water Resources Department
Jonathan LaMarche	Oregon Water Resources Department
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