Upper Deschutes Watershed Council

Technical Report

# 2017-2019 Whychus Canyon Reach 4 Phase I Restoration Monitoring Report

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## Acknowledgments

This report represents the work of many individuals and partner organizations. Thanks to Oregon Watershed Enhancement Board for funding support for the monitoring and analyses that are the basis of this report. Monitoring by our partners at Oregon Department of Fish and Wildlife (ODFW), Portland General Electric (PGE), and U.S. Forest Service (USFS), and the 2018 University of Nottingham Field Study led by Colin Thorne, provided foundational information for this report. Sections from technical reports produced for Upper Deschutes Watershed Council (UDWC) by Ralph Garono and Jackie Dickson of Earth Design Consultants, LLC., and by Celeste Mazzacano of CASM Environmental, LLC. have been excerpted and included in this report and results specific to the restoration project at Whychus Canyon Reach 4 interpreted. Karen Allen at Aequinox designed and led vegetation transect monitoring and sections of the technical report she produced for UDWC are included. Pat Edwards (Portland State University), Alex Scagliotti (Oregon State University), and Tom Goss (University of Nottingham) conducted additional studies at Whychus Canyon Reach 4 summarized in complementary journal articles and reports. Special thanks to the restoration design team led by Mathias Perle at UDWC and to the cadre of Stage 0 restoration researchers and practitioners who have collaborated with UDWC and served as a community of practice to inform restoration and monitoring at Whychus Canyon Reach 4, and who continue to contribute both insight and expertise to our Stage 0 monitoring effort: Colin Thorne, Brian Cluer, Paul Powers, Cari Press, Johan Hogervorst, Paul Burns, Kate Meyer, Matt Helstab, and others.

## Introduction

Whychus Creek originates on the east slope of the Cascade Mountains in central Oregon and flows approximately 40 miles to its confluence with the Deschutes River. Historically Whychus Creek was an important spawning stream for Mid-Columbia summer steelhead, supporting up to 40% of the steelhead produced in the Upper Deschutes subbasin. Whychus also supported spawning and rearing for spring Chinook salmon, with as many as a thousand adult salmon returning to Whychus Creek annually into the 1950s. Beginning with European settlement of central Oregon in the late 1800s, diversion of stream flow for irrigation and floodplain modification associated with homesteading and agriculture initiated degradation of stream habitat in Whychus. Following a major flood event in 1964, 18 of the 40 miles of Whychus Creek from the city of Sisters downstream were straightened and bermed. This led to incision and the further unraveling of aquatic, floodplain and riparian habitat, characterized by: degradation, simplification or elimination of riparian communities and large wood recruitment; degradation and loss of floodplain connectivity and function; degradation of channel structure and complexity; impaired sediment routing; and impaired hydrologic processes. These specific physical and biological conditions represent the habitat attributes limiting native fish populations (limiting factors) as identified in recovery plans for Mid-Columbia summer steelhead and spring Chinook (NPCC 2004, NMFS 2009, ODFW 2010).

Alongside the degradation of stream habitat on Whychus Creek, the two dams of the Pelton Round Butte hydroelectric facility completed in 1956 eliminated passage for spring Chinook salmon and summer steelhead, eliminating annual spawning runs and decimating these populations upstream of the Pelton Round Butte project (Nehlsen, 1995). With FERC relicensing of the hydroelectric project in 2005, Portland General Electric and Confederated Tribes of Warm Springs initiated a historic effort to reintroduce steelhead and salmon into the Upper Deschutes subbasin, with fry and smolts first released in 2007 and 2009, respectively.

Upper Deschutes Watershed Council (UDWC) has worked with local partner organizations for two decades on land conservation (Deschutes Land Trust; the Land Trust), stream flow restoration (Deschutes River Conservancy; DRC), and stream habitat restoration (UDWC) to restore Whychus Creek and limiting factors for native fish, including reintroduced salmon and steelhead. Beginning in 2006 UDWC partnered with USFS to design a restoration project on Whychus Creek, at DLT's Camp Polk Meadow Preserve. Project implementation was completed in 2012 with diversion of Whychus Creek from the straightened, incised channel into a constructed sinuous meadow channel. This project informed design of the Whychus Floodplain stream restoration project, one mile upstream of the City of Sisters, implemented in 2014.

In 2016 UDWC implemented Phase I of the Whychus Canyon Preserve restoration project along ~ 1 valley mile of Whychus Creek, representing the fourth (from upstream to downstream) one-mile reach of the six-mile preserve, and referred to as Whychus Canyon Reach 4 (Figure 1). Designed by the same team that had designed the restoration projects at Camp Polk Meadow Preserve and Whychus Floodplain, Phase I of restoration at Whychus Canyon Preserve represented the culmination of four years of observing, monitoring, and evaluating the physical and biological outcomes of stream restoration projects on Whychus Creek and other tributary streams and rivers throughout the Pacific Northwest. The project was designed and implemented using a Geomorphic Grade Line (GGL) approach described in Powers et al (2018) to restore the valley bottom toward a Stage 0 condition. Stage 0 as defined by Cluer and Thorne (2013) refers to an anastomosing stream condition that occurs in unconfined, low-gradient valleys and is hypothesized to provide the greatest hydrogeomorphic function and most habitat and ecosystem benefits of any stage of stream evolution. The GGL design approach aims to re-establish hydrogeomorphic and biological processes by re-activating relict channels and the historic floodplain (valley bottom) at the hypothesized pre-European settlement valley elevation to create self-formed and self-sustaining wetland-floodplain complexes. The Whychus Canyon Phase I design included lowering disconnected terraces that were perched above the target valley elevation, filling the incised channel to the same target elevation, roughening the constructed floodplain surface with large wood and sedge mats, and diverting the stream into a network of relic channels and onto the constructed floodplain. Project goals for Whychus Canyon Reach 4 are:

Goal 1: Restore dynamic hydrologic function including floodplain connectivity, elevated shallow groundwater table, and sediment/nutrient storage. Dynamic hydrologic function includes but is not limited to:

- Development of vertical and horizontal variability on the floodplain;
- Activation of channels and floodplains at various flows; and
- Supporting a changing channel pattern that occurs through avulsion and formation of oxbows, point bars and mid-channel bars;

Goal 2: Provide dynamic, abundant and high-quality diverse habitat including slot pools, pocket pools, alcoves, mid-channel pools, backwater areas, glides, and riffles for redband trout, Chinook salmon, steelhead and bull trout.

Goal 3: Restore a diversity of riparian, wetland and wet meadow habitat for wildlife.

Project objectives defined in the Whychus Canyon Restoration Plan Design Report were based on analysis of pre-restoration conditions within the six-mile extent of the Whychus Canyon Preserve and were not specific to pre-restoration conditions within the one-mile Reach 4 where Phase I restoration was implemented. Objectives specific to restoration at Whychus Canyon Reach 4 are defined in the Whychus Canyon Reach 4 Monitoring Summary Table (Appendix A). Target values were defined for some metrics; for many metrics objectives described a hypothesized trajectory of change rather than a specific value.

Further discussion of Whychus Canyon Phase I design and implementation is provided in the Whychus Canyon Restoration Plan Design Report (UDWC 2014).

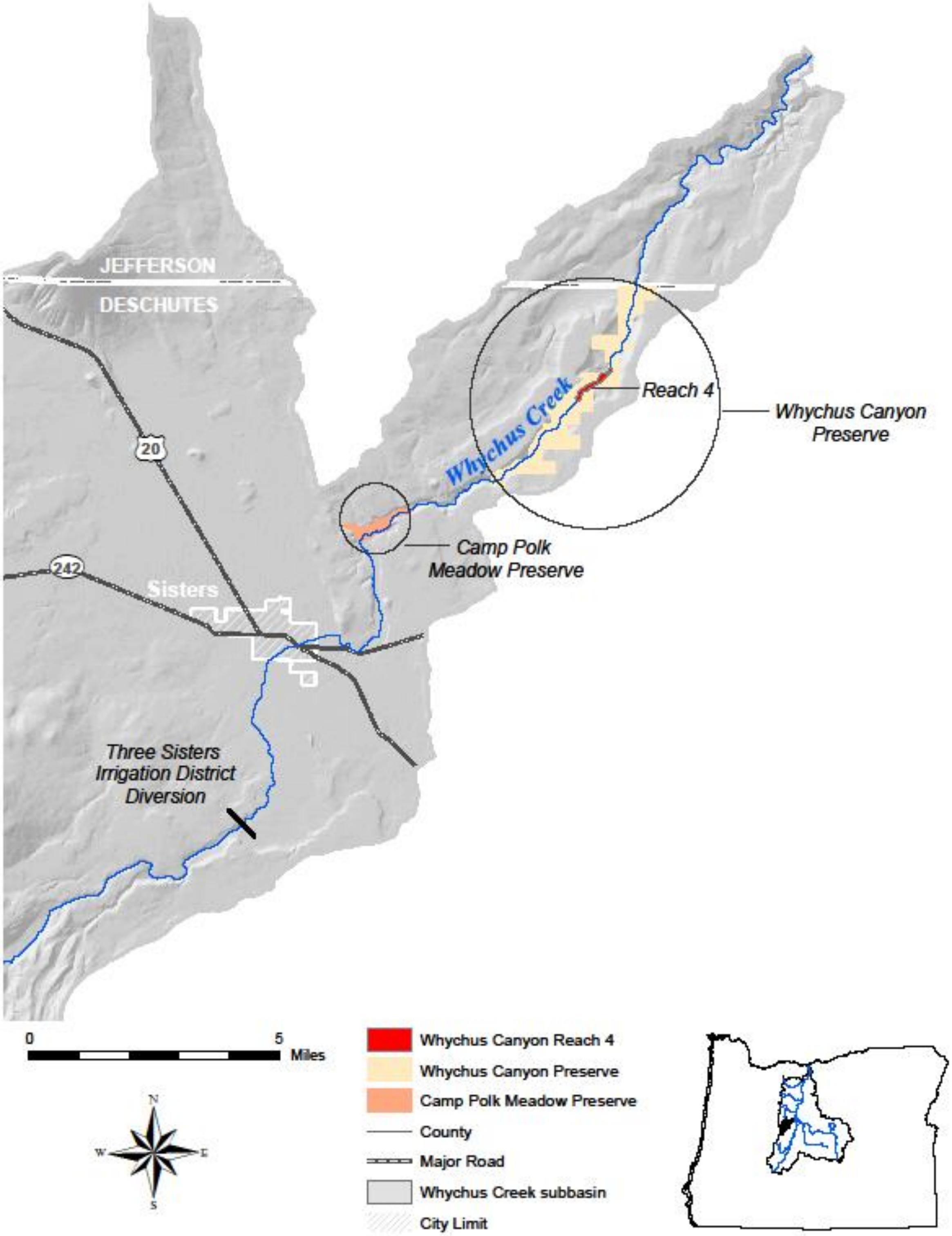


Figure 1. Deschutes Land Trust's Whychus Canyon Preserve and Camp Polk Meadow Preserves on Whychus Creek. Phase I of restoration at Whychus Canyon Preserve was implemented in 2016 along one valley mile in Whychus Canyon Reach 4.

## Monitoring Parameters and Metrics

UDWC identified monitoring parameters and specific metrics of interest for each parameter based on our conceptual model of physical and biological outcomes anticipated to occur in response to restoration implementation and on Cluer and Thorne's (2013) discussion of physical and vegetation attributes and habitat and ecosystem benefits associated with each stage of the Stream Evolution Model. The selected monitoring metrics reflect hypotheses about the specific geomorphic, habitat, and biological outcomes of the restoration project design and implementation. These metrics provide information to answer two overarching monitoring questions:

1) Is the project achieving or trending toward a Stage 0 condition as characterized by selected indicators of the physical and vegetative attributes and habitat and ecosystem benefits detailed by Cluer and Thorne (2013)?

2) Is the project providing abundant and high-quality fish habitat as measured by standard metrics used to evaluate fish habitat?

The monitoring parameters and metrics developed within this framework are additive and complementary to those identified in the Whychus Canyon Restoration Project Monitoring and Adaptive Management Plan (UDWC 2016) developed to meet NEPA requirements for threatened Bull Trout.

UDWC and restoration partners implemented monitoring for the selected parameters and metrics in the Whychus Canyon Phase 1 project reach from 2009 through 2019 per the Whychus Canyon Reach 4 Monitoring Summary Table (Table 1; Appendix A). Restoration partners modified monitoring activities to respond to emerging conditions and needs. Data from 2017, 2018, and 2019 represent Years 1, 2, and 3 post-project, respectively, with 2016, the year project implementation was completed, being Year 0.

This technical report presents pre- and post-restoration monitoring results for Whychus Canyon Reach 4 from 2009 through 2019 for the suite of monitoring parameters and metrics described below and listed in the Whychus Canyon Reach 4 Monitoring Summary Table. We evaluate results for each metric relative to specific project objectives defined for the Phase I/Reach 4 restoration project to assess the degree to which restoration implementation in 2016 has resulted in the desired conditions as of three years post-project, in 2019. Riparian vegetation area and macroinvertebrate community methods and results for Whychus Canyon Reach 4 and relevant additional sites are summarized from stand-alone reports for a watershed-scale cover classification and macroinvertebrate monitoring (Appendix B, Appendix C).

### *Additional Studies*

Additional studies were conducted at Whychus Canyon Reach 4 in 2018 and 2019 through monitoring partnerships with Oregon State University, the University of Nottingham, and Portland State University. Researchers from Oregon State University developed a monitoring protocol employing three methods, including a valley-wide transect method, to quantify and compare substrate heterogeneity in Whychus Canyon Reach 4; in Whychus Canyon Reach 3, an adjacent, upstream (unrestored) control reach; and in Reaches 1 and 2 of the Camp Polk Meadow Restoration Project, where restoration implementation was completed in 2012 (Appendix D). Researchers from the University of Nottingham collected primary geomorphic data in Whychus Canyon Reaches 3 and 4 to support a bankfull flow model and used a hydrogeomorphic-based assessment method to evaluate development of wetland functions in Whychus

Canyon Reach 4 from 2018 to 2019 (Appendix E). Researchers from Portland State University sampled the diatom community in Whychus Canyon Reaches 3 and 4 and at Camp Polk to identify differences among communities that provide information about physical conditions in restored and unrestored reaches (Edwards et al. 2020).

Table 1. Whychus Canyon Reach 4 monitoring parameters and years for which data are available for each.

| Monitoring Parameter | 2009 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|
| Project Year | | | | | 0 | 1 | 2 | 3 |
| *Groundwater* | | | | x | x | x | x | x |
| *Channel morphology and network* | | | | | | | | |
| Channel elevations | x | | | | x | x | x | x |
| Channel network | | | | | | x | | x |
| *Channel and floodplain features* | | | | | | | | |
| Geomorphic and habitat units | | | | | | x | | x |
| Wood | | | | | | | | |
| Substrate | | | | | | | x | x |
| Depth/Fish Passage | | | | | | x | x | x |
| *Stream temperature* | x | | x | x | x | x | x | x |
| *Riparian vegetation* | | | | | | | | |
| Riparian vegetation area | | | | | x | x | | |
| Community composition | | | | x | | | x | |
| *Macroinvertebrates* | | | x | x | | x | x | x |
| *Fish populations* | | | | | | | | |
| Redd surveys: O. mykiss | | x | | | | x | x | |
| Redd surveys: brown trout | | | | | | x | x | x |
| Density surveys | | | | x | | | x | |
| Adult migration | | | | x | | x | x | x |

## *Groundwater*

Depth to groundwater is an indicator of vertical hydrologic connectivity, a key attribute of the hydrologic regime characterizing anastomosing Stage 0 and Stage 0 systems. In these systems, groundwater close to the floodplain surface supports base flows and hyporheic exchange. Depth to groundwater, along with soil texture, plays an important role in determining the vegetation community supported in a given reach.

### *Channel morphology and network*

We identified five metrics that provide key information about channel morphology and channel network vertical and lateral connectivity and complexity: 1) channel elevations; 2) dispersal of flow among multiple channels; 3) total channel length; 4) the ratio of secondary to primary channel length; and 5) total wetted area. Channel elevations relative to the Geomorphic Grade Line elevation are an indicator of floodplain connectivity, demonstrating proximity to or departure from design and as-built elevations along the valley slope, and representing aggradation or degradation, respectively.

Dispersal of flow among multiple channels indicates hydrologic and geomorphic processes are continuing to maintain and create a complex channel network and, importantly, that flow is not confined in a single channel, which increases stream energy and can contribute to erosion, transport of sediment, and incision, processes which can simplify and degrade fish habitat. In terms of habitat and ecosystem benefits, multiple channels provide more shoal and edge habitat, as well as confluences and diffluences that have been demonstrated to be ecological hotspots (Benda et al 2004) and strong predictors of juvenile Chinook salmon productivity (Hall et al 2018).

Cluer and Thorne (2013) use length and complexity of the shoreline and total wetted area to represent the physical size and shape of the channel network. We selected total channel length and the ratio of secondary to primary channel length derived from ODFW Aquatic Inventory Project (AIP) stream habitat survey data to represent length and complexity of the shoreline, and use total wetted area calculated from AIP data to represent the physical size of the active channel network. All three metrics provide information about the quantity of aquatic habitat in the project reach. The ratio of secondary to primary channel length is an indicator of habitat complexity and has been shown to be a strong predictor of subyearling Chinook salmon productivity (Hall et al 2018).

### *Channel and floodplain features*

Channel and floodplain features such as geomorphic or habitat units, wood, and substrate, and metrics associated with these, contribute significantly to and are indicators of habitat quality, diversity, and complexity. Key metrics for all three are also commonly used to evaluate fish habitat quality, and numerical values associated with fish habitat quality have been identified in and from fish habitat literature for some metrics. The HabRate model developed for the Deschutes Basin (Burke et al 2010) identifies threshold values associated with good, fair, and poor habitat quality for a suite of geomorphic, wood, and substrate metrics.

Sediment size and spatial distribution resulting from sediment sorting reflect erosion, transport, and deposition processes and support important ecological and geomorphic functions. Sediment size class frequency distribution provides anecdotal information about stream energy, because higher stream energy will entrain and transport larger sediment particles. Relative proportion of gravel, cobble, and fine sediments affect habitat suitability for salmon, steelhead, and resident redband trout spawning, emergence, and rearing.

Total channel length and total wetted area at base flow are indicators of the sheer quantity of aquatic habitat; the ratio of lengths of secondary to primary channels provides information about the complexity, including sinuosity, that characterizes that aquatic habitat. Habitat unit abundance represented by the total number of habitat units in the reach and number of habitat units per 100 m, and habitat unit richness, the number of channel unit types recorded in the project reach, provide information about habitat complexity and diversity; both are maximized in a Stage 0 condition.

The relative abundance of riffles and pools, measured as percent of total number of units, percent of total wetted area, and area per 100 m provide partial information about fast-water and spawning habitat (riffles), and about slow-water, rearing and holding habitat (pools). Number of pools per 100 m, residual pool depth, and the number of pools ≥ 1 m deep provide additional information about the amount of pool habitat available to support juvenile rearing and adult holding. Number of complex pools per 100 m, defined as pools with 3 or more pieces of large wood, represents a measure of cover and habitat complexity for rearing fish, as well as potential habitat for macroinvertebrate taxa. Number of pieces and volume of wood per 100 m are indicators of habitat structure within the active channel at the time of the survey. Sediment size class distribution in riffles and area of gravels and fines in riffle units per 100 m provide information about the suitability of riffle habitat for spawning.

Riparian shading is measured as percent shade for each habitat unit and provides information about how much of the active channel is shaded by vegetation or topography at the time of the survey. Shading can reduce stream temperatures and buffer daily temperature fluctuations.

### *Continuous temperature*

Stream temperature is a key limiting factor for native trout and salmon in Whychus Creek, where up to 90% of stream flow is diverted for irrigation between April and October. Restoration approaches that divert a stream from an incised and simplified but shaded channel, including both channel construction (natural channel design) and geomorphic grade line designs, introduce factors that can contribute to stream warming, namely reduced shading, increased solar radiation, and increased residence time. Conversely, hyporheic exchange and geomorphic unit diversity created through hydrologic and geomorphic processes re-established by implementing a GGL Stage 0 restoration approach are hypothesized to contribute to cooler surface water, cold water upwelling, and thermal refugia, along with cooling effects from shading along active channels as woody riparian vegetation matures.

### *Riparian vegetation*

Riparian and wetland vegetation, from emergent wetland species like sedges and rushes to riparian trees like cottonwoods, represent primary production, perform important geomorphic, ecological, and habitat functions, and demonstrate a key biological response to hydrologically connected conditions. Area of riparian vegetation corresponds to the area where groundwater is close enough to the floodplain surface for riparian vegetation to become established. For many riparian and wetland species this depth is within two feet of the floodplain surface, although for woody riparian vegetation, once established, mature root systems can access deeper groundwater. Riparian vegetation area provides a measure of the spatial extent over which riparian vegetation provides riparian habitat for wildlife, topographic roughness to disperse energy of floodwaters, and vegetation with high moisture content that can increase resilience to and survival during drought and wildfire. Species richness and abundance, and number and percent of species that are native and that are wetland indicator species, provide information about the diversity and wetland function of the riparian vegetation community.

### *Macroinvertebrates*

Macroinvertebrates represent secondary production, an essential food source for fish, and the biological response to geomorphic and aquatic habitat conditions. Macroinvertebrate community data can also provide extensive additional information about physical conditions, including stream temperature, fine suspended sediment, flow velocity, and wood and vegetation habitats in active channels. Cluer and Thorne (2013) identify biodiversity, expressed through species richness and trophic diversity, as a representative biotic attribute that should vary in relation to morphological diversity of the channel as well as extent and frequency of floodplain connectivity. Macroinvertebrate data provide information about both species richness and trophic diversity.

### *Fish Populations*

Recovery of native resident and anadromous fish populations has been a primary driver of stream restoration in the Pacific Northwest and Rocky Mountains since the 1980s, and much of the funding for stream restoration is salmon recovery funding. For Whychus Creek, reintroduction of Mid-Columbia summer steelhead and Spring Chinook salmon beginning in 2007 to replace the populations lost with construction of the Pelton Round Butte Hydroelectric Project on the Deschutes River in the 1950s brought both renewed focus on habitat restoration and an influx of funding to the basin. Redd counts provide a measure of the suitability of habitat for spawning, assuming fish populations are large and well-distributed enough to support abundant spawning. Fish densities in a given reach provide information about the usability and quality of habitat for fish, rather than about a population response to restoration, and Chinook salmon and summer steelhead fry and smolts were released into some of the reaches for which densities are reported; while these releases certainly increased densities in those reaches initially, densities as measured through electrofishing surveys at a minimum demonstrate that reaches with high densities provided sufficient velocity refugia that released fish were able to remain in these reaches rather than being flushed downstream. Presence and movement of returning adult Chinook and steelhead provide information about adult anadromous fish use of habitat and provision of adequate connectivity through restoration reaches.

## Methods

### *Groundwater*

UDWC installed twelve groundwater wells in Whychus Canyon Reaches 3 and 4 in September, 2014 (Figure 2); four of the wells, including monitoring wells (MW) 8, 9, 10, and 11, were within Reach 4 and the Phase I project area. Following well installation, UDWC deployed a HOBO U20L water level datalogger (https://www.onsetcomp.com/products/data-loggers/u20l-01/; https://www.onsetcomp.com/products/data-loggers/u20l-04/) in each well and deployed a HOBO U20L datalogger in the MW 4 vault as a barometric transducer to record absolute pressure above sea level (ASL) for calibrating water level data. UDWC downloaded water level data in the field using the HOBO U-DTW-1 Waterproof Shuttle bi-annually from 2014 to 2016 and at additional intervals corresponding to monitoring and restoration implementation timelines. UDWC downloaded well data annually in fall 2017, 2018, and 2019 to capture both the lowest water levels and the point where groundwater began to increase each year, which we had observed from pre-restoration groundwater data to occur as late as October. In January 2015 we found the barometric transducer logger submerged in standing water in the MW 4 vault and moved it into the MW 11 vault. Prior to project implementation in August 2016 we moved the barometric transducer into the equipment shed in Whychus Canyon Reach 3 to prevent the logger from being submerged when groundwater was high enough to fill the well vaults.

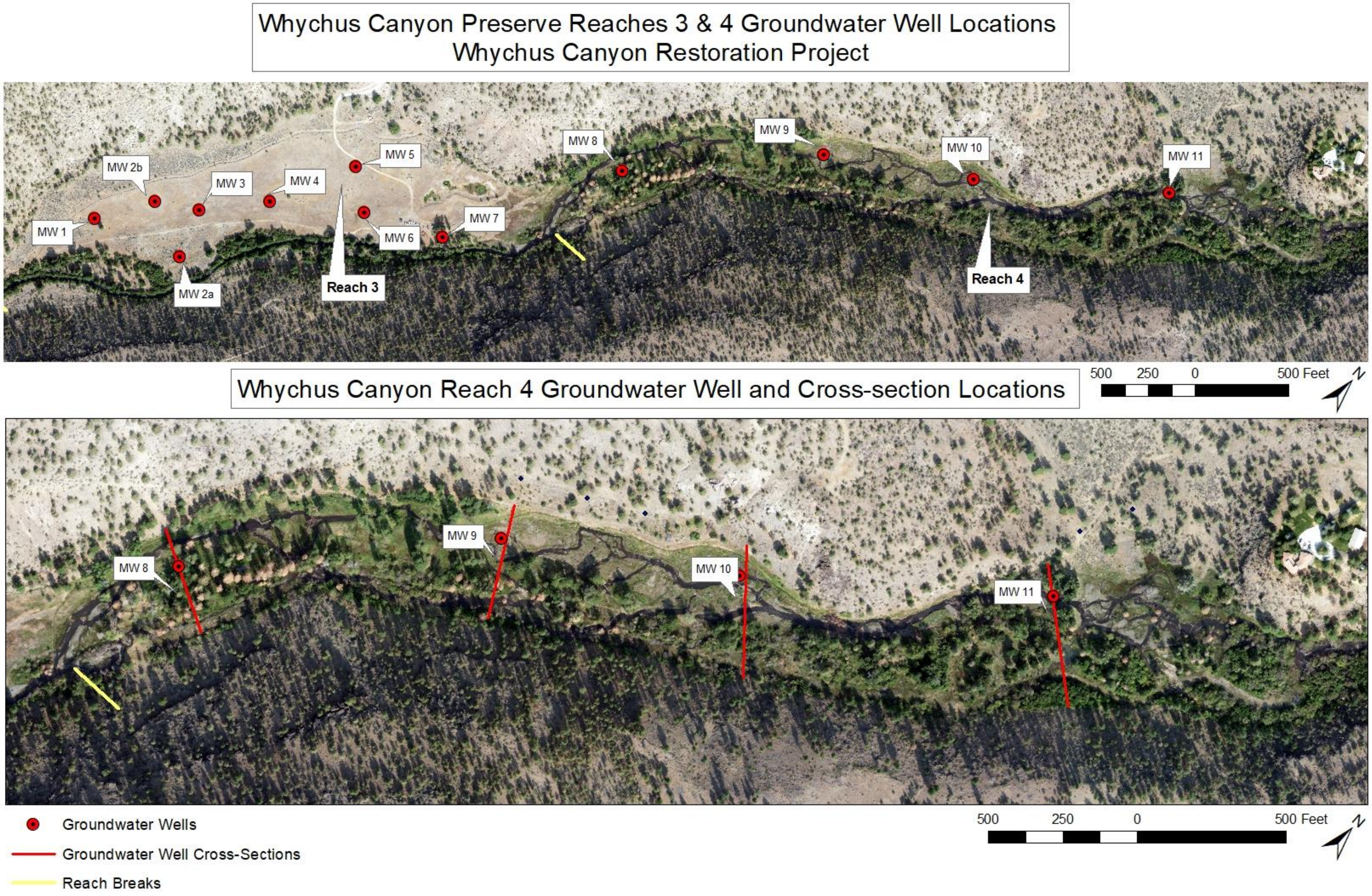


Figure 2. Groundwater wells installed in Whychus Canyon Reaches 3 and 4, and Whychus Canyon Reach 4 cross-section locations associated with groundwater wells.

We processed groundwater data using HOBOware Pro software to calculate hourly water depth relative to the top of the PVC well casing. We added the (negative) depth to water to the elevation of the top of the PVC casing Above Sea Level (ASL) to calculate hourly water level elevation ASL. Because wells had been installed at the pre-project floodplain elevation, and well casings and caps remained at the pre-project elevation following project implementation, to quantify depth from the floodplain surface to groundwater post-project we wanted to calculate a single post-project floodplain elevation as a point of comparison for depth to groundwater. We calculated maximum and minimum groundwater depths pre-project and one, two, and three years post-project as the difference between hourly groundwater elevations and the average floodplain elevation at each well cross-section, as calculated from the most recent and best available floodplain elevation data produced from total station surveys or LiDAR imagery (Table 2). To be consistent in how we calculated depth to groundwater pre-restoration and post-restoration, we calculated the pre-project maximum and minimum depths the same way we calculated post-project maximum and minimum depths, rather than reporting pre-restoration depths relative to the well cap elevation.

We calculated minimum and maximum depth to groundwater from 2014 to 2015, pre-restoration, and from 2017 through 2019 post-restoration, and identified dates associated with minimum and maximum depths to evaluate changes in annual timing of minimum and maximum groundwater depths. We evaluated average depth to groundwater for each well during July 15 to August 31 of each of these years to represent the period during the growing season when Whychus Creek is at baseflow and groundwater levels are the lowest that occur during the year and therefore the most limiting for riparian vegetation. This is also the period when stream and air temperatures are highest and any cooling effect from groundwater inputs to the stream at base flow or from hyporheic exchange would have the greatest benefit for stream temperature and fish habitat. For the July 15 to August 31 interval, to evaluate groundwater depth relative to the floodplain surface at each well cross-section (perpendicular to the valley) rather than only at the well location, we calculated depth to groundwater for each well cross-section as the average of the differences between the average groundwater elevation at the well over the specified timeframe, and cross-section elevations, from 2009 LiDAR for pre-project water level data, and from 2017 LiDAR (the most recent available) for post-project water level data. We used the average of the resulting average depths for the four wells in Reach 4 to represent depth to groundwater across the project area between July 15 and August 31.

Table 2. Restoration timeline interval, dates represented, and floodplain elevation data used for calculating maximum and minimum depths to groundwater pre- and post-restoration at Whychus Canyon Reach 4

| Interval | Dates | Floodplain elevation data |
|---|---|---|
| Pre-restoration | 7/15/2015 - 8/15/2016 | 2009 LiDAR |
| One year post- | 9/1/2016 - 8/31/2017 | 10/21/2016 Total Station Survey data |
| Two years post- | 9/1/2017 - 8/31/2018 | 2017 LiDAR |
| Three years post- | 9/1/2018 - 8/31/2019 | 2017 LiDAR |

## *Channel morphology, network, and features*

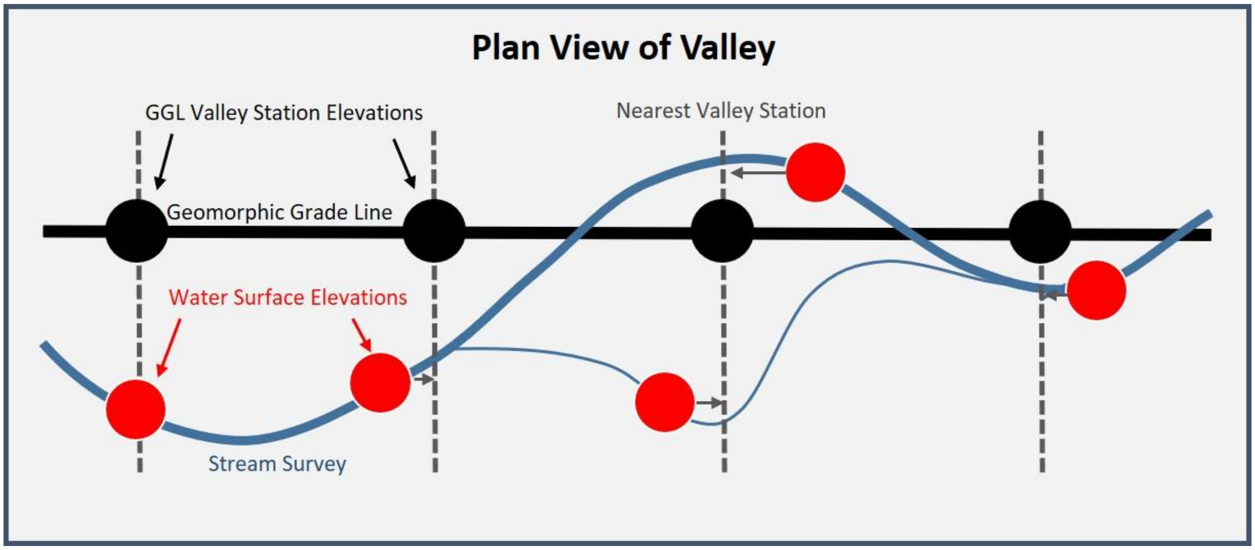
### Longitudinal profile surveys

Longitudinal profiles provide information about changes in channel elevations and can also be used to document channel evolution as new flow paths are created and channels meander or are abandoned. We used a Nikon Nivo 5.C total station instrument and followed standard surveying protocols to survey consecutive channel water surface and thalweg elevations along longitudinal profiles in the main channel and a subset of side channels in the project area over six survey events between November 2016, three months post-implementation, and October 2019, three years post-implementation. We defined the main (primary) channel as the channel carrying the greatest proportion of total flow as determined through local site knowledge, and defined all other channels as side (secondary; non-primary) channels.

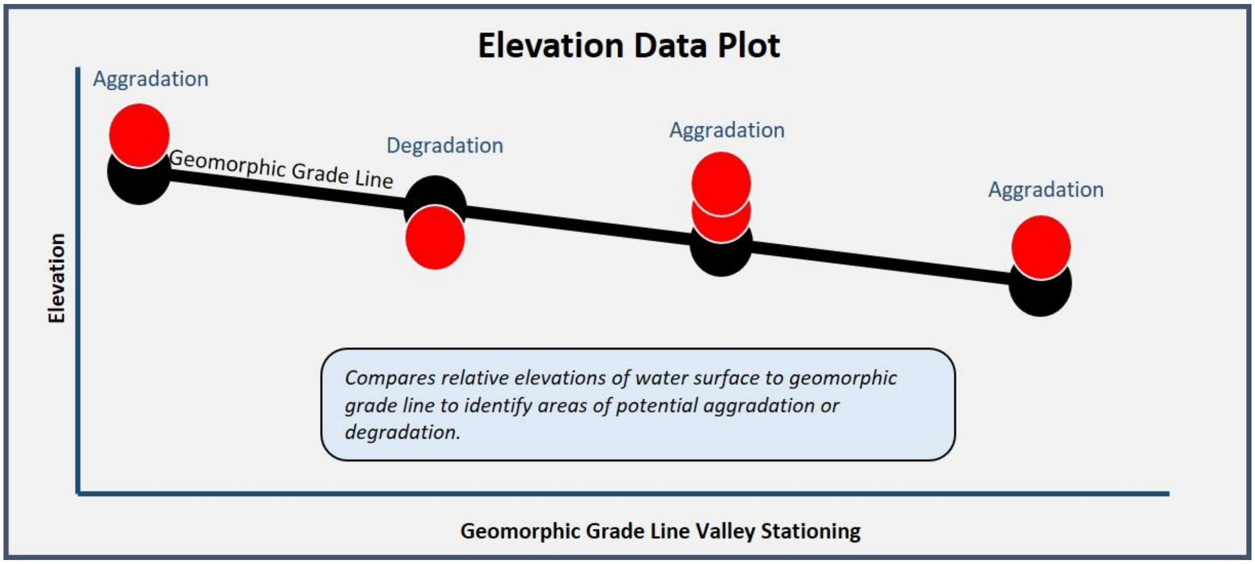
To evaluate departure of surveyed channel elevations from the target valley bottom elevation represented by the GGL, both above and below, we identified the GGL elevation nearest to each water surface elevation data point (Figure 3a). To do this, we created a GIS map displaying two layers: the Relative Elevation Model layer including the GGL elevation at each valley station (WhychusREM2.gdb), and a shapefile for each survey event including only the water surface total station data points. We used the Near (Analysis) tool in ArcGIS Desktop Advanced software, assigning the water surface elevation shapefile as the Input Feature and the REM layer as the Near Feature, to identify the GGL valley station nearest to each water surface elevation, represented in the resulting attribute table as a new field "NEAR_FID" with the same identifier as the GGL station "OBJECTID". We used the Join Data function to append the REM attribute fields and values to the water surface elevation attribute table for each paired GGL station and water surface elevation, using the "NEAR_FID" and "OBJECTID" fields as the basis for the join, resulting in a water surface shapefile attribute table relating the location and elevation of the valley station nearest to each water surface data point to the elevation of that water surface.

We exported the shapefile attribute table including GGL valley station locations and the GGL and water surface elevations into spreadsheet software to plot water surface elevations at the same longitudinal location as the nearest GGL elevation. To do this, we used a scatterplot chart to plot the longitudinal GGL valley station locations on the x-axis and elevations on the y-axis as one data series. For each channel surveyed and for each survey event, we plotted each total station water surface elevation using the nearest GGL valley station location as the x-axis value (Figure 3b). We created a new data column associated with each survey event to calculate the difference between the surveyed elevation and the nearest GGL valley station elevation. Elevations that are higher than the GGL elevations indicate aggradation resulting from deposition; elevations that are lower than the GGL and as-built elevations show degradation or channel lowering and potentially incision resulting from erosion. The channel elevation objective identified for the project is to maintain channel elevations within 1 ft of the GGL, which allows for channel adjustment in response to channel-forming flows and geomorphic processes, with flow dispersed among multiple channels. Channel elevations within 1 ft of the GGL would signal a high degree of vertical connectivity. As some channels cut lower than 1 ft below the GGL and the amount of departure from the GGL elevation increases, banks become higher, and the groundwater elevation lowers to the new channel elevation, the degree of vertical connectivity becomes less.

a.



b.



*Compares relative elevations of water surface to geomorphic grade line to identify areas of potential aggradation or degradation.*

Figure 3. Graphical representation of process to a) associate each surveyed water surface elevation with the nearest Geomorphic Grade Line valley station, and b) plot each water surface elevation against the associated GGL valley station at the longitudinal location of the GGL valley station.

## Channel inventory

We reviewed imagery from each year for which imagery was available to identify the number of channels visible in imagery at each cross-section. Imagery was collected in 2017 and 2018. Imagery was not collected in 2019 but imagery collected in 2020 was available as of the writing of this report. We used 2020 imagery as a proxy for 2019 imagery on the premise that channels visible from 2020 imagery were representative of the number of channels present in 2019. We created an ArcGIS map displaying 2017, 2018, and 2020 true color imagery for Whychus Canyon Reach 4 and total station survey valley cross-sections at each of our four project-reach groundwater monitoring wells. For each year we counted channels visible from imagery at each cross-section.

### ODFW AIP stream habitat surveys

ODFW AIP stream habitat surveys are conducted annually in the Deschutes Basin by ODFW crews under contract with Portland General Electric (PGE) within the area supporting anadromous reintroduction, including on Whychus Creek. Measurements collected under this protocol include key indicators of geomorphology and fish habitat selected to evaluate stream evolution stage and fish habitat quality in Whychus Canyon Reach 4.

Stream habitat surveys following ODFW AIP stream habitat survey methods (Moore et al. 2019) were conducted in Whychus Canyon Reach 4 in 2011 pre-restoration, and repeated in 2017 and 2019, one and three years post-project respectively, through coordination with PGE following implementation of the Whychus Canyon Reach 4 restoration project in 2016 and additional placement of wood in the project reach in 2018. Habitat survey data were provided by PGE as line (2011) or point (2017 and 2019) shapefiles with geomorphic unit-level survey data appended in attribute tables.

The reach surveyed in 2011 was longer than the restoration project reach surveyed in 2017 and 2019. To be able to compare only those geomorphic units and associated data pre- and post-restoration within the spatial extent of the restoration reach, we displayed the 2011, 2017, and 2019 survey shapefiles in ArcGIS Desktop Advanced. For 2011 data, we used the Select by Rectangle function to select and export all attribute table records within the Reach 4 project linear extent, and verified our selection by using the identify tool to identify the units at the upstream and downstream ends. The upstream- and downstream-most units extended outside the project reach boundary and were excluded. For 2017 and 2019 data, we discovered that not all habitat unit records and associated data included in the attribute table were displayed with a corresponding point in the shapefile, thus using the approach we had used for 2011 data under-represented surveyed units within the restoration reach. Because 2017 and 2019 surveys only included the Whychus Canyon Reach 4 project linear extent, with survey reach boundaries differing only slightly from project reach boundaries, we instead used the Select by Rectangle tool to select and identify those units outside of the linear extent of the project reach, exported the entire attribute table, and deleted records for the habitat units outside the project reach. We calculated specific metrics of interest for each year from the raw data and descriptively compared the resulting values for each metric (Table 3).

Because Stage 0 restoration is designed to re-activate the floodplain within the valley bottom rather than simply change channel dimension, pattern, and profile metrics, metric values per 100 meters represent values per 100 m valley length (calculated as the metric value divided by the valley length multiplied by 100) rather than per 100 m primary channel as traditionally reported. Valley length was measured along the valley center valley stationing line of the geomorphic gradeline shapefile for Whychus Creek using the Measure tool in ArcGIS.

Table 3. Channel network, habitat unit, wood, substrate, and riparian shading metrics derived from AIP stream habitat survey data, and how each metric was calculated for this report.

| Parameters and Metrics | Calculated as |
|---|---|
| Channel Network | |
| Primary channel length | Sum of the corrected lengths (COR_LENGTH) of units with channel types 00 (single channel) or 01 (primary channel) |
| Secondary channel length | Sum of the corrected lengths of units with all non-primary channel types, including: 02 (side channel), 10 (isolated, alcove, or backwater pools), 11 (primary channel of valley floor tributary), and 12 (side channel of valley floor tributary) |
| Total channel length | Sum of corrected length (COR_LENGTH) for all units included in Reach 4 linear extent |
| Ratio of secondary:primary channel length | Secondary channel length divided by primary channel length |
| Total wetted area | Sum of corrected area (COR_AREA) for all units in linear extent, dry units excluded. |
| Wetted area per 100m | Sum of corrected area (COR_AREA) for all units in linear extent, dry units excluded, divided by valley length, multiplied by 100 |
| Habitat Units | |
| Total number of habitat units | Sum of units in linear extent |
| Number of habitat units per 100 m | Sum of units in linear extent, divided by valley length, multiplied by 100 |
| Total number of riffles | Count of all riffle units |
| Percent riffle (numeric) | Total number of riffle units divided by total number of habitat units |
| Percent riffle area ($m^2$) | Sum of corrected area (COR_AREA) for riffle units divided by sum of corrected area for all units in linear extent |
| Riffle area per 100 m ($m^2$) | Sum of corrected area (COR_AREA) for riffle units in linear extent, divided by valley length, multiplied by 100 |
| Total number of pools | Count of all pool and subunit pool units, not including puddled units. |
| Percent pool (numeric) | Total number of pool and subunit pool units, not including puddled units, divided by total number of habitat units |
| Percent pool area ($m^2$) | Sum of corrected area (COR_AREA) for all pool and subunit pool units divided by sum of corrected area for all units in linear extent, dry units excluded |
| Pool area per 100 m ($m^2$) | Sum of corrected area (COR_AREA) for all pool and subunit pool units in linear extent, not including puddled units, divided by valley length, multiplied by 100 |
| # Pools per 100 m | Total number of pool and subunit pool units, not including puddled units, divided by valley length, multiplied by 100 |
| # Complex pools per 100 m | Sum of "COMPLEXPOOLS" (column added) calculated as pool units with ≥ 3 pieces of wood in column NPIECES, divided by valley length, multiplied by 100 |
| Pools ≥1m per 100m | Sum of pool units with depths ≥ 1 m, divided by valley length, multiplied by 100 |
| Average residual pool depth (m) | Average of residual depth of all pool and subunit pool units, not including puddled units. Residual depth is calculated as the difference between the pool depth and the depth at the pool tail crest. |
| Maximum, minimum, and median depths | Maximum, minimum, and median of all unit depths |
| Wood | |

| | |
|---|---|
| Number of pieces of wood per 100m | Sum of the number of pieces of wood (NPIECES), divided by valley length, multiplied by 100 |
| Wood volume per 100m | Sum of wood volume (WVOLUME), divided by valley length, multiplied by 100 |
| Sediment | |
| Percent silt/organics in riffles | Average of percent silt and organics (SO_ADJ) in all riffle units |
| Percent sand in riffles | Average of percent sand (SND_ADJ) in all riffle units |
| Percent gravel in riffles | Average of percent gravel (GRV_ADJ) in all riffle units |
| Percent cobble in riffles | Average of percent cobble (CBL_ADJ) in all riffle units |
| Percent boulder in riffles | Average of percent boulder (BLD_ADJ) in all riffle units |
| Percent bedrock in riffles | Average of percent bedrock (BRK_ADJ) in all riffle units |
| Area of gravels in riffles units per 100m (m2) | Average of silt, organics, and sand, multiplied by total channel area, multiplied by percent riffle, divided by valley length, multiplied by 100 |
| Area of fines in riffle units per 100m (m$^2$) | Sum of average of silt, organics, and sand, multiplied by total channel area, multiplied by percent riffle, divided by valley length, multiplied by 100 |
| Riparian Shading | |
| Percent shade | Average of shade (SHADE) values for all units in reach |

## Fine sediment surveys

We used the USFS AREMP (Aquatic and Riparian Effectiveness Monitoring Program) fine sediment survey protocol to survey fine sediment in pool tail crests (USFS 2016). Because we did not have baseline, pre-project data for fine sediment in pool tail crests, we surveyed an unrestored reach of Whychus Creek adjacent to and upstream of the Whychus Canyon Phase 1 project reach as a control reach. We also surveyed pools in Camp Polk Reaches 1 and 2 where an anastomosing floodplain condition has evolved since construction was completed in 2012.

We started at the downstream end of each reach and worked upstream to identify ten pools classified as plunge or scour pools. We used the ODFW AIP Stream Habitat Survey Methods geomorphic channel unit descriptions to assist in identifying pools as plunge or scour pools (Table 4). We marked each pool to be surveyed on an aerial photograph of the site, and recorded pool unit, length, and maximum depth.

Table 4. ODFW Aquatic Inventory Program Stream Habitat Survey Pool Unit Definitions. The water surface slope of units classified as pools is always zero (Moore et al. 2019).

| Unit | Description |
|---|---|
| Plunge Pool | Formed by scour below a complete or nearly complete channel obstruction (logs, boulders or bedrock). Substrate is highly variable. Frequently, but not always, shorter than the active channel width. |
| Straight Scour Pool | Formed by mid-channel scour. Generally with a broad scour hole and symmetrical cross section. |
| Lateral Scour Pool | Formed by flow impinging against one stream bank or partial obstruction (logs, root wad, or bedrock). Asymmetrical cross section. Includes corner pools in meandering lowland or valley bottom streams. |

In each selected pool, we measured percent surface fines within the pool tail. Moore et al (2019) define the pool tail crest as the location where the water surface slope breaks into the downstream habitat unit. Within the wetted area of the channel, we took measurements at 25%, 50%, and 75% of the distance across the pool tail crest from channel right to channel left (when looking downstream), following and placing the grid parallel to the contour of the pool tail crest. In narrow channels grid placements were allowed to overlap. Each of the three measurements was taken at a distance equal to 10% of the pool's length, or one meter, upstream of the pool tail crest, whichever distance was less. We estimated these distances visually.

To assess surface fines (sediment < 2 mm) at each of the three grid locations across the pool tail, we used a 14 x 14 inch grid with 49 evenly distributed intersections; inclusion of the top right corner of the grid provided a 50th intersection. We used cord 2 mm in diameter to thread the grid to facilitate evaluation of sediment size at each intersection. We recorded the number of intersections where the sediment clast directly below the intersection was < 2 mm in diameter at the b-axis. Where grid intersections fell over substrate > 512 mm, and where intersections fell over aquatic vegetation, organic debris, roots, or wood and we were not able to identify the underlying particle size, we marked the affected intersections as non-measurable. We calculated percent fines < 2mm for each of the three grid placements as the percent of the 50 intersections where we recorded fines < 2mm, and averaged the percent from the three grid placements to calculate an average percent fines in the pool tail crest for each pool.

We plotted the raw data for each of the three sites to visually compare the number of quadrats where fine sediment cover was below or above the 30% threshold identified in HabRate (Burke et al. 2010) as differentiating fair from poor spawning conditions, and calculated median fine sediment values for the three sites.

### Fish passage surveys

UDWC and U.S. Fish and Wildlife Service (USFWS) conducted fish passage surveys during base flow in September from 2017 to 2019 to assess presence of a continuous flow path meeting 7.2" depth through the project reach, as specified in UDWC's Whychus Canyon Restoration Project Monitoring & Adaptive Management Plan for Channel Reconstruction (UDWC 2016). The 7.2" criteria established for the project reach is sufficiently deep to provide passage for steelhead and large-bodied trout including bull trout (Thompson 1972).

UDWC and USFWS staff walked the primary channel beginning at the downstream end of the project reach. We used D-net handles marked at 7.2" to allow us to rapidly assess depth. Where the channel was shallower than 7.2" over a length greater than the channel width, we assessed nearby connected channels to evaluate if they met the 7.2" criteria. If no continuous flow path meeting 7.2" depth was found, the minimum depth and length of primary channel not meeting the criteria were measured and recorded and the center of that length marked on an aerial image using the Avenza app. UDWC and USFWS staff applied the same protocol along approximately a quarter-mile reach downstream and upstream of the restoration reach to assess whether depths in unrestored reaches met the depth criteria.

#### *Continuous temperature*

UDWC monitors continuous temperature at eleven locations along Whychus Creek from April through October, including at site WC 18.25 or river mile 16 (RM 16), approximately five miles upstream of the project reach, and at site WC 10.25 (RM 9.8), 0.25 miles downstream of the project reach. Site WC 10.25 was established in 2010 to replace site WC 09.00 (RM 8.6) in anticipation of restoration planned at WC

09.00 as of 2009. We used continuous temperature data from WC 18.25 from 2006-2015, from WC 10.25 from 2010-2015, and from WC 09.00 from 2006-2009 to calculate the maximum rate of temperature change per mile over ten years pre-restoration. To reduce the effects of inter-annual seasonal variation we limited the analysis to a 30-day period, and we selected July as the month during which the hottest water day occurred most often between 2006 and 2015. We calculated the maximum rate of temperature change per mile as the difference between the average July 7-day average daily maximum (7DADM) at the upstream and downstream sites divided by the number of miles between the two sites. The maximum average July rate of change from 2006-2015 at these sites was 0.36°C. We used continuous temperature data from RM 16 and from RM 9.8 to calculate the average July rate of temperature change per mile for 2017, 2018, and 2019, and compared the resulting rate of change to the ten-year pre-project maximum. Per UDWC's Whychus Canyon Restoration Project Monitoring & Adaptive Management Plan for Channel Reconstruction (UDWC 2016), an average July rate of warming per mile greater than the ten-year (2006-2015) maximum rate of 0.36 degrees per mile in July between RM 16 and RM 9.8 for three successive years post-project will trigger a review by the restoration review team identified in the same plan.

Data from July 2013 were not available for WC 010.25 thus 2013 is not included in the pre-project analysis.

### *Vegetation*

UDWC used two methods to measure plant communities within the Whychus Canyon Phase I project reach. In 2017, one year post-implementation, we worked with Earth Design Consultants, Inc. (EDC), to acquire aerial orthomosaic imagery and develop an approach to map riparian and upland vegetation from pre- and post-restoration imagery and quantify changes in the spatial extent of riparian vegetation following restoration (Appendix B). In 2018, two years post-implementation, UDWC collaborated with Aequinox and the University of Nottingham to conduct an intensive field study at Whychus Canyon Reach 4 and Camp Polk Reaches 1 and 2, including valley-wide point-intercept vegetation transects.

#### Cover class mapping

The primary goal of imagery acquisition and image classification was to identify and map riparian vegetation, represented by herbaceous, shrub, and forested cover classes, in the low-gradient, historically depositional reaches along Whychus Creek where UDWC and partners plan to implement or have implemented restoration projects to restore stream habitat and reactivate adjacent floodplains. Digital photography was selected over other types of imagery characterized by spectral data to cost-effectively achieve the target spatial resolution, as sensors that would support acquisition of other imagery bands were not available for UAV at the time of imagery acquisition. EDC acquired digital photograph imagery from Whychus Canyon Reach 4 between July 19 and 22, 2017. Imagery resolution ranged from 2.8-6.9 cm (1.5-2.7 in) per pixel and averaged 4.5 cm (1.75 in) per pixel. EDC used pre-restoration UAV orthomosaic imagery acquired in July 2016 by Justin Healy of Real Geographics to represent the pre-restoration cover class condition.

UDWC and EDC staff defined hierarchical cover classes through a process of imagery review and consultation during a series of meetings (Table 5). The Location class, including In-stream, Riparian, and Upland classes, identifies the location of a cover class relative to topography and hydrologic connectivity. Geotype, including Vegetation, Bare Substrate, and Other, identifies cover classes as within one of these three classes. Cover Class defines specific, distinct classes of vegetation, bare substrate, and man-made surfaces and structures. For the purpose of the classifying vegetation as riparian or upland, we defined riparian vegetation as vegetation interpreted to be hydrologically connected to groundwater based on greenness, proximity to the stream channel, and first-hand site knowledge. We selected a photo interpretation and manual digitization approach over an unsupervised or semi-supervised classification using spectral properties of the imagery, to present the most ecologically useful information according to best judgment following conversations between UDWC and EDC. Cover classes were rule-based, and classification was completed by a single individual to minimize representational bias and maximize consistency. Classification review and edits were made by a single UDWC staff. The resulting manual digitization classification approach was applied to 2017 imagery as well as to the pre-restoration 2016 imagery to support an analysis of change in riparian vegetation within the Whychus Canyon Reach 4 project reach one year post-restoration.

Initial analysis of change in riparian vegetation was performed by isolating the riparian polygons classified from both imagery datasets and generating simple statistics in ArcGIS to sum all riparian acreage present. EDC calculated change in the area of each cover class was in two ways: 1) as the difference in total acres of riparian vegetation cover pre-project and post-project, and 2) as the number of vegetation acres classified from 2017 imagery as “riparian” that had been classified from the historic imagery as “upland”.

To more accurately measure change in cover of riparian species from 2016 pre-restoration to 2017 post-restoration, UDWC iteratively displayed and calculated area for three class combinations. For each combination we included both In-Stream and Riparian Location classes and Vegetation Geotype. We calculated area for all vegetation cover classes excluding the two coniferous cover classes; for all vegetation cover classes including coniferous classes; and for only herbaceous and shrub cover classes, representing the classes for which the most change was anticipated to result from restoration implementation over the one-year analysis timeframe.

Table 5. Hierarchical cover classes established by UDWC and EDC. Each digitized polygon is attributed with a location, a geotype, and a cover class.

| Location | Geotype | Cover Class |
|---|---|---|
| In-stream | Vegetation | Bare Earth |
| Riparian | Bare Substrate | Sand |
| Upland | Other | Rock |
| | | Gravel |
| | | Cobble |
| | | Herbaceous |
| | | Herbaceous-Isolated Trees or Shrubs |
| | | Mixed Herbaceous Forest |
| | | Shrub |
| | | Mixed Forest |
| | | Coniferous Sparse Forest |
| | | Deciduous Sparse Forest |
| | | Deciduous Forest |
| | | Coniferous Forest |
| | | Impervious Surface |

| | |
|---|---|
| | Building |
| | Unpaved Road |
| | Paved Road |

## Vegetation transect surveys

UDWC and Land Trust staff worked with Aequinox to design and implement a vegetation monitoring transect survey protocol for restoration in Whychus Canyon Reaches 3 and 4. Vegetation monitoring using transect surveys was designed to answer the questions:

1. Have restoration project goals and objectives related to vegetation been met? (quantitative measurements)
2. Do we need to take adaptive management measures?

Additionally, we wanted vegetation monitoring transect data to inform the story of valley-wide evolution from pre-project conditions to post-restoration conditions in relation to Project Goal 3, Restore a diversity of riparian, wetland and wet meadow habitat for wildlife, as well as to the original Project Objective 2 defined in the 2014 Whychus Canyon Restoration Plan Design Report (UDWC 2014), Increase riparian and wetland plant species richness and distribution throughout the Project area (Table 6).

Table 6. Whychus Canyon Restoration Project Goals and Objectives related to vegetation

| Project Goal 3: Restore a diversity of riparian, wetland and wet meadow habitat for wildlife. | | |
|---|---|---|
| Whychus Canyon Restoration Plan Design Report Project Objective 2: | Measure or collect data to account for: | Data products: |
| Increase riparian and wetland plant species diversity /richness and distribution throughout the Project area<br>Monitoring question: What is the species richness (suite of species) and abundance characterizing the pre-and post- restoration plant community? | Species Diversity (Species Richness): Collect data by species. Point intercept along valley-wide transects.<br>Species Distribution: Distribute transects along length of R4 project area to document and show change in distribution of riparian and wetland species over time<br>Wetland Indicator Status: designates plant species' preference for occurrence in a wetland or upland<br>Height categories: Provides information about vertical structure of plant community and therefore time since establishment | Percent cover by species; mesic and xeric; native and non-native; and height, for five valley-wide transects distributed along the length of the project reach |

We selected valley-wide transects (perpendicular to the valley) as our sampling unit to be able to repeat the same transect over time; to capture valley-wide changes in vegetation anticipated to result from floodplain reactivation; and to respond to the Geomorphic Gradeline design approach that does not design channels in specific locations and accordingly did not provide information about which specific sites across the valley would be occupied by active channels over time following restoration. The number of transects (five) was determined based on the number of days we were able to allocate to surveys pre-restoration (two). Transect locations were established based on review of aerial imagery and site knowledge and were selected to capture the variation in existing conditions, restoration plans including areas designated for cut, fill, and planting, and desired future conditions.

Transects were surveyed within the following areas and characterize the following conditions:

1. A valley cross-section in Reach 3 that was planned to be (but was not ultimately) constructed with Reach 4;
2. A cross-section where the design specified rewatering relict channels and cottonwoods were plentiful, where no cut or fill was proposed, and a diversity of vegetation heights were present pre-restoration. This transect can give insight into change over time produced by introducing flows to relict channels alone;
3. A cross-section in the pre-project terrace where the design included both cut and fill and where islands were left higher than the Geomorphic Grade Line elevation to create initial flow paths;
4. A cross-section lower in the pre-project terrace in an area characterized by piles of gravel and cobble and proposed to be cut to the design elevation;
5. A cross-section toward the downstream end of the project reach in an area thought to historically support wetland vegetation.

We used valley widths measured in Google Earth to inform the sampling interval for the five transects. We measured transects from approximately the toe of slope at the northwest edge of the valley bottom to the southeast edge of the riparian vegetation on the southeast side of the stream. Based on the widths of the five transects we selected a consistent sampling interval of every four feet along each transect.

Land Trust and Aequinox staff conducted pre-restoration vegetation transect surveys on September 17 and 18, 2015 in Whychus Canyon Reaches 3 and 4. UDWC and Aequinox staff and recent graduates and researchers affiliated with the University of Nottingham repeated Whychus Canyon Reach 4 vegetation transect surveys on August 7th and 8th, 2018, two years after restoration. To establish transects, we used the Land Trust's Mobile Mapper GPS unit to collect a GPS point marking the origin of each transect on the northwest edge of the valley, and used a compass to identify the azimuth perpendicular to the valley. We used the azimuth to orient the transect and extended a transect tape from the transect origin across the valley toward the southeast-most edge of the riparian area on the southeast edge of the valley bottom. Because transect tapes were shorter than the valley width, we used multiple transect tapes or ran the same tape sequentially along multiple sections of a transect. For each transect we recorded the transect azimuth and the latitude and longitude of the transect origin. We took photos at intervals along each transect and recorded distance along the transect and azimuth for each photo.

We collected species and height data along each transect. Surveyors lowered a pin flag on the upstream side of the tape at 4-foot intervals starting at 4 feet and recorded each species (typically more than one) intercepted by the pin at each interval. Surveyors recorded species using the first two letters of the genus and first two letters of the species, and compiled a running plant list with these four-letter codes and other abbreviations used (Vegetation Monitoring at Addition Plant List 2015.docx). Aequinox, Land Trust, and UDWC staff added to the plant list species likely to be found in future years based on observations during surveys, presence of the added species at Camp Polk Meadow Preserve, and species planted and seeded in 2016 and 2017. We recorded living plants to species and dead plants as litter, following the convention in botanical surveys. Data collection earlier during the growing season helps with this distinction and facilitates positive plant identification.

Plant heights were categorized as follows:

| Height Category | Height Range |
|---|---|
| 1 | <1 ft |
| 2 | 1-3 ft |
| 3 | 3-5 ft |
| 4 | 5-10 ft |
| 5 | 10-30 ft |
| 6 | 30-50 |
| 7 | 50+ |

In 2015, species and height data were recorded in an Excel datasheet on an iPad mini (R4 2015 Data All.xlsx). In 2018, species and height data were recorded on paper datasheets. UDWC staff scanned 2018 datasheets to create a single PDF file, entered data into an Excel spreadsheet and created a final species list with associated four-letter codes. For both 2015 and 2018 data, we calculated the number of points on each transect as the length of the transect at the last 4-ft interval at which species data were recorded divided by four. We calculated the percent cover represented by each point as one divided by the number of points on each transect, and calculated percent cover of each species on a transect as the number of detections of that species multiplied by the percent cover represented by each point on that transect. Total cover represents the total number of species detections along the length of a transect; because multiple species representing multiple strata can be detected at any given point, total percent cover for a transect can exceed 100%.

For each transect, we calculated the percent of vegetation represented by each height category as the sum of all species detections in a given height class divided by the total number of species detections for the transect, resulting in percent cover for the seven height categories totaling 100% of species detections. We referenced the USDA Plants Database (https://www.plants.usda.gov/) to assign wetland indicator status and native or non-native (introduced) status to all species included in the final species list. We included species with obligate and facultative wet wetland indicator statuses as wetland indicator species. We did not include species with a facultative wetland indicator status as this designation defines a species as occurring in both wetlands and non-wetlands (ACE 2020), in contrast to the conventional wetland biology practice of including facultative species when considering if a community is hydrophytic or not.

### *Macroinvertebrates*

UDWC worked with CASM Environmental, LLC, state and federal agency staff representing ODFW, USFS, and USFWS, PGE staff, and community volunteers to collect macroinvertebrate samples at sites immediately upstream and downstream of the Whychus Canyon Reach 4 restoration project extent

(WC1150 and WC1025, respectively) and approximately halfway down the 1-mile project reach (WC1100). Sites WC1150 and WC1100 were established in 2014 as control and treatment sites respectively to evaluate the macroinvertebrate community response to restoration at Whychus Canyon Reach 4. The location of site WC1150 sampled in 2014 and 2015 was within the longitudinal extent of restoration implementation and was moved accordingly in 2016 to a new location immediately upstream of the project reach. During 2017 sampling we observed that backwatering and associated sediment deposition were occurring at the new WC 1150 location in response to project implementation, and we moved the site again to an upstream location outside of the hydrologic and geomorphic influence of the restoration project. The farthest upstream, 2018-2019 location of this site is within a quarter mile of the 2014-2015 site location. Site WC1025 has been sampled since 2011 during annual macroinvertebrate sampling as part of a watershed-scale monitoring program to produce information about the biological response to stream flow and stream habitat restoration. We did not sample the WC1100/WC1100-2 site within the project reach in 2016 due to restoration having been implemented only days prior to the 2016 sampling effort (Figure 4, Table 7).

Samples were collected between August 12 and 24 in all years from 2014-2019. On each day, CASM Environmental staff demonstrated sampling techniques and explained data sheet entries. Teams received sampling kits and directions and dispersed into the field. Teams returned their samples, data sheets, and equipment to CASM Environmental, who inspected each sample to ensure it was properly labeled and preserved.

From 2005 to 2017 UDWC used Oregon Department of Environmental Quality protocols for Oregon's wadeable streams to sample macroinvertebrates in Whychus Creek. These protocols target the macroinvertebrate community found in mainstem riffle habitat and do not account for macroinvertebrate communities from other stream habitats. To represent the diversity of habitats created by stream habitat restoration projects and specifically projects designed to achieve a Stage 0, anastomosing condition, beginning in 2017 we used a multi-habitat (2017) or proportional multi-habitat (2018-2019) sampling protocol to sample all habitats. At the WC1100 site representing Whychus Canyon Reach 4, we used this protocol to sample three secondary channel reaches in 2017 and four reaches that included both secondary and primary channel in 2018 and 2019; these reaches followed the same flow paths in 2018 and 2019 with one minor variation. We continued to use the targeted riffle protocol to sample key index and restoration sites along Whychus Creek to support comparison with data from previous years.

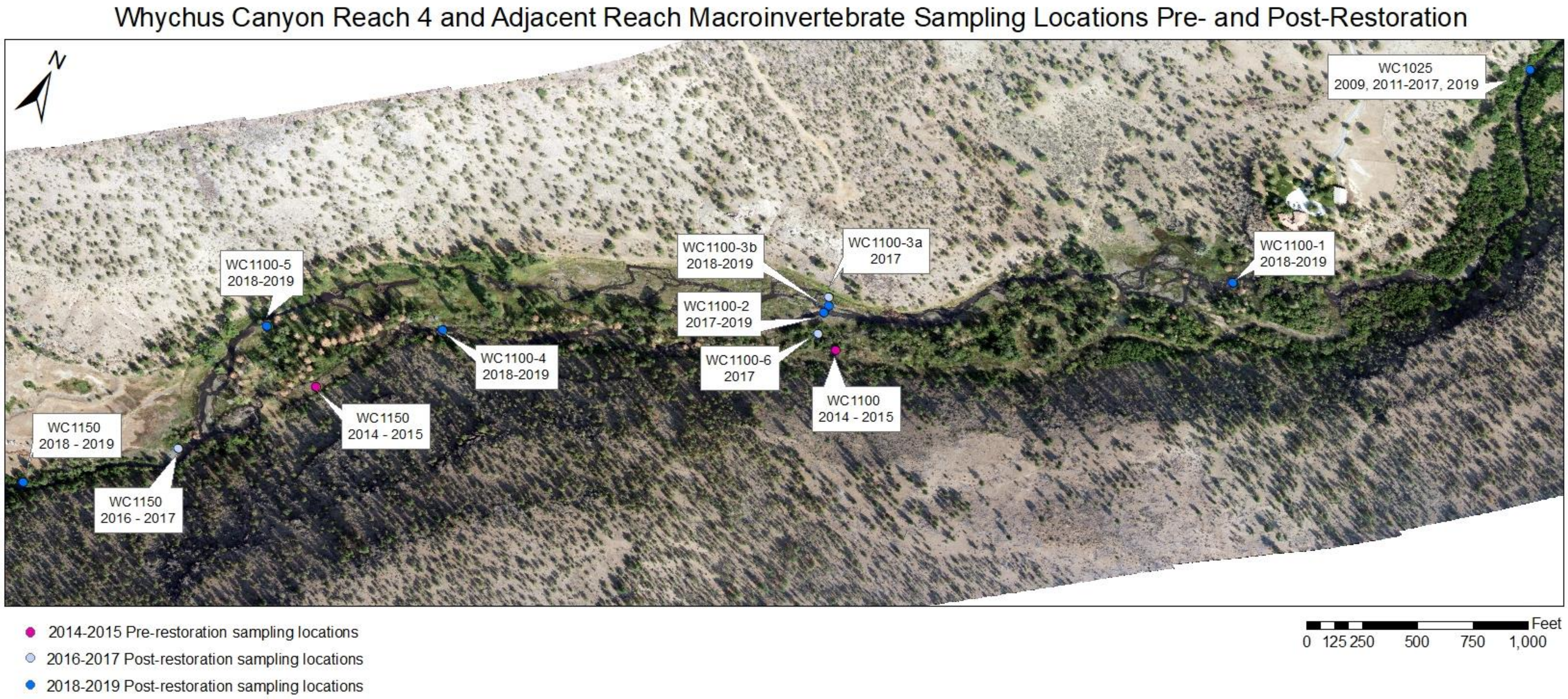


Figure 4. Macroinvertebrate sampling locations in Whychus Canyon Reach 4 (WC1100-1-WC1100-5) and in adjacent downstream and upstream reaches. WC1100 and WC1150 sites sampled in 2014 and 2015 were moved in 2016 (WC1150) and in 2017 (WC1100) following restoration to sample active channels and retain one site within and one site upstream of the project reach. Although upstream of the restoration reach, the WC1150 location sampled in 2016 and 2017 experienced backwatering effects and so was moved again in 2018 to better represent the unrestored condition. The 2018-2019 WC1150 sampling location is within a quarter mile of the 2014-2015 WC1150 location.

Table 7. Selected Whychus Creek macroinvertebrate monitoring sites sampled from 2005-2019. PC = Primary Channel, SC = Secondary Channel, RT = Riffle Targeted, PM = Proportional Multi-habitat. All macroinvertebrate samples from 2005-2016 were collected using the Riffle Targeted protocol.

| Site ID | Description | Coordinates | 2005 | 2009 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WC0600 | RM 6, u/s Rd 6360 | 44.40412, -121.40259 | x | x | x | x | x | x | x | x | RT | RT, PM | RT, PM |
| WC0850 | Rimrock Ranch d/s | 44.391278, -121.406182 | -- | -- | x | x | x | x | x | x | RT | -- | -- |
| WC0900 | RM 9, Rimrock Ranch | 44.384198, -121.407892 | x | x | x | x | x | x | x | x | RT | -- | -- |
| WC1025 | Rimrock Ranch u/s | 44.371534, -121.415865 | -- | -- | x | x | x | x | x | x | RT | -- | PM |
| WC1100-1 | Whychus Canyon Reach 4 D/S MW 11 PC/SC | | -- | -- | -- | -- | -- | -- | -- | -- | -- | PM | PM |
| WC1100-2 | Whychus Canyon Reach 4 U/S MW 10 PC | 44.36493, -121.422232 | -- | -- | -- | -- | -- | x | x | -- | RT | RT, PM | RT, PM |
| WC1100-3a | Whychus Canyon Reach 4 U/S MW 10 SC | | -- | -- | -- | -- | -- | -- | -- | -- | PM | -- | -- |
| WC1100-3b | Whychus Canyon Reach 4 U/S MW 10 SC | | -- | -- | -- | -- | -- | -- | -- | -- | PM | PM | PM |
| WC1100-4 | Whychus Canyon Reach 4 D/S MW 8 SC | | -- | -- | -- | -- | -- | -- | -- | -- | -- | PM | PM |
| WC1100-5 | Whychus Canyon Reach 4 MW 8 PC/SC | | -- | -- | -- | -- | -- | -- | -- | -- | -- | PM | PM |
| WC1100-6 | Whychus Canyon Reach 4 U/S MW 10 SC | | -- | -- | -- | -- | -- | -- | -- | -- | PM | -- | -- |
| WC1150[c] | Whychus Canyon Reach 3 | 44.35862, -121.43023 | -- | -- | -- | -- | -- | x | x | x | x | RT, PM | PM |
| WC1825 | Camp Polk downstream | 44.32781, -121.495406 | -- | x | x | x | x | x | x | x | x | -- | -- |
| WC1925 | Camp Polk Reach 1-2 | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | PM |
| WC1950 | Camp Polk upstream | 44.318741, -121.514961 | x | x | x | x | x | x | x | x | x | -- | RT, PM |
| WC2425 | Sisters City Park | 44.287806, -121.544229 | x | x | x | x | x | x | x | x | x | -- | -- |
| WC2600 | Whychus floodplain; 4606 Rd. footbridge | 44.27322, -121.5552 | x | x | x | x | x | x | x | x | x | RT, PM | RT, PM |

### Single habitat Riffle-Targeted protocol (RT)

Benthic macroinvertebrates were collected from mainstem riffle habitats according to Oregon Department of Environmental Quality (ORDEQ) protocols for Oregon's wadeable streams (OWEB, 2003). Reach lengths were calculated as 40 times the average wetted stream width at the desired sampling point (min. 500 ft./max 1000 ft.) and the upstream and downstream limit was flagged by UDWC staff. A site sample consisted of eight individual net sets taken in riffle habitat in the designated reach, each collected from a 1 $\text{ft}^2$ area using a D-frame kick net with 500 µm mesh and a 1-ft opening. In reaches with eight or more riffles, a single net set was taken in each of eight randomly selected riffles; in reaches with fewer riffles, two net sets were taken in each of four randomly selected riffles.

Large rocks and debris in the sampling area were rubbed and rinsed into the net to collect clinging organisms and set aside, then the substrate was disturbed thoroughly to a depth of 6-10 cm (2-4 in.) for 1-2 minutes. All eight net sets were pooled in a bucket, large debris was rinsed and removed, and sample material was poured through a sieve lined with a 500 µm Nitex membrane. This concentrated sample was transferred to a 1-liter Nalgene sample jar half-filled with 80% ethanol as a preservative. Jars were filled no more than 2/3 full of volume; sample material was divided among multiple jars if needed. CASM Environmental staff replaced the 80% ethanol in all jars with fresh within 48 hours to ensure preservation.

### Proportional Multihabitat sampling (PM)

A multihabitat approach samples a representative portion of all habitat types in a reach, including mineral and organic substrates, which improves sample representativeness and assessment of ecological condition and is also preferred in streams or reaches where riffle habitat is poorly represented (Barbour et al., 2006). Reach lengths for proportional multihabitat (PM) sampling were calculated and flagged as described above. At the index sites (WC0600, WC2600) and one restoration site (WC1950), PM and RT samples were taken in the same reach and at the same time. In sample reaches that included side channel habitats, UDWC staff flagged turning points and paths along the channel. Prior to sampling, teams walked the reach and used a worksheet to determine types of in-stream habitat present and their relative proportions. Habitat types were designated as follows:

- Bedrock/boulder (continuous rock/large mineral substrate > basketball size)
- Cobble (tennis ball- to basketball-size)
- Gravel (marble- to tennis ball-size)
- Sand/silt (fine sediment)
- Filamentous algae (long, flowing strands)
- Aquatic vegetation (herbaceous plants rooted or floating in the channel; excludes trees, shrubs, mosses, algae)
- Wood (tangles/piles of small wood < 30 cm diameter and large woody debris ≥ 30 cm diameter in wetted channel)
- Rootwads/undercut banks (root tangles extruding into flowing channel due to undercut banks)

Each sample was a composite of 10 net sets. In 2017, the 10 net sets were distributed at equal intervals along each side channel reach; In 2018 and 2019, the number of net sets taken in each type of habitat was determined by its proportional representation in the reach. Flow type in the habitat where each net set was taken was recorded (rapid, riffle, run, glide, pool), but no specific flow type was targeted.

## Sample identification

Samples were identified by Cole Ecological, Inc. (www.coleecological.com) after being first sub-sampled to a target count of 500 individuals by splitting the entire sample into equal aliquots which were then selected randomly and all individuals picked out. An aliquot in which the target number was reached was picked to completion, which explains differences in organismal abundance between samples (see Table 3 in Results).

Organisms were identified to the lowest practical taxonomic level using the standard taxonomic effort recommended by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP, 2015). The 2019 dataset reflects taxonomic changes resulting from recently published updates to taxonomic keys in the seminal reference *Aquatic Insects of North America* (Merritt et al., 2019). For ease of comparison to prior years, any changes are noted with the historic name first and the new current name in parentheses. Most of the changes occurred in the former family Tipulidae (crane flies); this group has now been elevated to a superfamily (Tipuloidea) containing four families, and multiple genera have undergone name changes.

## Biological/ecological traits of taxa

CASM Environmental reviewed primary literature to describe functional traits of macroinvertebrate taxa. Assessing functional traits (i.e., biological properties and ecological preferences) of macroinvertebrate taxa helps infer habitat conditions that shape the community, diagnose stressors or environmental filters, and predict restoration-related changes (Poff et al., 2006; Tullos et al., 2009; Culp et al., 2011; Van den Brink et al., 2011; White et al., 2017). Trait states relating to the ecology and life history of the macroinvertebrate community were assigned to species, genera, or families where data were available. Trait data were drawn from sources specific to Oregon and/or the west (ORDEQ, 2003; Vieira et al., 2006; Meyer & McCafferty, 2007; Huff et al., 2008; Richards & Rogers, 2011; Relyea et al., 2012; IDDEQ, 2015; SAFIT, 2016), as well as general and family-specific references (Pinder, 1986; Wiggins, 1996; Larson et al., 2000; Thorp & Covich, 2001; Stewart & Stark, 2002; Anderson et al., 2013; Merritt et al., 2019). Where multiple modalities existed for a given trait, the primary one for the genus or family was used. Community measures calculated from traits included:

- Community optima values for temperature and % fine suspended sediment (weighted averages): Some taxa are more strongly associated with cool/cold or warm flow conditions, either as stenotherms (narrow range) or eurytherms (wide range). Fine suspended sediment (FSS) is an environmental filter on macroinvertebrates with certain traits. Increasing sediment loads can decrease overall richness as well as the abundance of taxa that feed as scrapers or filterers, have a large maximum body size, soft exposed body, external exposed gills, associations with larger mineral substrata, and a crawling or sprawling habit. Conversely, taxa with operculate gills, smaller and more sclerotized bodies or cases/tubes, and a swimming or climbing/clinging habit may increase in abundance with increasing fine sediment stress (Beche & Statzner, 2009; Sutherland et al., 2012; Buendia et al., 2013; Bona et al., 2015; Murphy et al., 2017; Doretto et al., 2018; Akamagwuna et al., 2019).
- Trophic guild (functional feeding group), i.e., relative abundances of predator (PR), scraper (SC), shredder (SH), and collector (C; includes filterers and gatherers) organisms: Filterers can be negatively impacted by sedimentation as their feeding structures become clogged (Rabení et al., 2005; Wilkes et al., 2017); predator abundance may increase as increasing habitat diversity

and/or stability creates more abundant and diverse prey (Arce et al., 2014); scrapers can be more abundant on algae- and biofilm-coated mineral substrates; and shredders indicate more plant material and leaf litter input.

- Habit (locomotion) i.e., relative abundances of swimmer, clinger, burrower, climber, and sprawler organisms: Swimmers may be able to more rapidly escape disturbances such as sedimentation; burrowers may be selected for in sedimented habitat; sprawlers, clingers, and crawlers can be smothered and/or lose habitat as interstitial spaces are filled (Mather et al., 2017; Murphy et al., 2017).
- Voltinism (# generations per year) i.e., relative abundances of multivoltine (>1 generation/year), univoltine (one generation/year), and semivoltine <1 generation/yr) organisms. Multivoltinism is associated with more tolerant organisms and/or greater resilience in disturbed habitats, while semivoltine taxa require more stable conditions.
- Rheophily (flow preference), i.e, relative abundances of organisms associated with erosional, depositional, and mixed flow (members of taxon found in lotic and lentic habitats);
- Temperature associations, i.e., relative abundances of organisms with cool/cold or warm water temperature preferences (taxa with mixed or no particular preference were omitted from this analysis); and
- Maximum length, i.e., relative abundances of organisms with small (< 9 mm), medium (9-16 mm), and large (>16 mm) body length: Small body size is often associated with greater tolerance and rapid recolonization, which can be an advantage in disturbed sites, while larger-bodied insects may be slower to develop and more abundant in sites with greater habitat stability (Townsend & Hildrew, 1994; de Castro et al., 2018).

### Data analysis

CASM Environmental performed all macroinvertebrate data analysis. Analyses were done using PAST 4.0 statistical software (Hammer et al., 2001). CLUSTER ordinations and SIMPER tests were run on a Bray-Curtis similarity matrix of square-root transformed taxa abundances. Principal Component Analysis (PCA) was done using a variance-covariance matrix. When doing t-tests to compare means, a cutoff value of $p \leq 0.05$ was used for statistical significance.

Biological condition of RT sample reaches was assessed using the ORDEQ multimetric invertebrate-based index of biotic integrity (IBI), and the probability-based Predictive Assessment Tool for Oregon (PREDATOR) model (Hubler, 2008). For the IBI, 10 trait values are scored individually (1, 3, 5) then summed to give a number that corresponds to a level of impairment (Table 8). PREDATOR calculates the ratio of taxa observed at a sampling site to taxa expected if the site is not impaired (O/E), based on comparison to established reference communities. The model uses site elevation, slope, and longitude to select appropriate reference streams. O/E scores associated with a probability of capture ($P_c$) > 0.5 are used to avoid rare taxa bias and are assigned to biological condition categories of: poor (most disturbed; $\leq$0.78); fair (moderately disturbed; 0.79-0.92); good (least disturbed; 0.93-1.23); and enriched (>1.23). Whychus Creek is an outlier for the PREDATOR model because it has lower annual precipitation than any of the reference streams the model selects as most appropriate (Shannon Hubler, pers. comm. 2017).

Table 8. ORDEQ genus-level macroinvertebrate-based Index of Biological Integrity (IBI) metrics and scoring

| | Scoring Criteria | | |
|---|---|---|---|
| Metric | 5 | 3 | 1 |
| Taxa richness | >35 | 19-35 | <19 |
| Mayfly richness | >8 | 4-8 | <4 |
| Stonefly richness | >5 | 3-5 | <3 |
| Caddisfly richness | >8 | 4-8 | <4 |
| # sensitive taxa | >4 | 2-4 | <2 |
| # sediment-sensitive taxa | >2 | 1 | 0 |
| % dominancea | <20 | 20-40 | >40 |
| % tolerant taxa | <15 | 15-45 | >45 |
| % sediment-tolerant taxa | <10 | 10-25 | >25 |
| MHBIb | <4 | 4-5 | >5 |
| Summed Score & Condition | | | |
| Severely impaired | | <20 | |
| Moderately impaired | | 20-29 | |
| Slightly impaired | | 30-39 | |
| Minimally/not impaired | | >39 | |

### *Fish Populations*

#### Redd counts

USFS, ODFW, and PGE conducted redband redd surveys in Whychus Canyon Reach 4 in 2013, 2017, 2018, and 2019; they conducted redband redd surveys in Whychus Canyon Reach 3 in 2017 and 2018. PGE has conducted redband redd surveys at numerous additional sites along Whychus Creek since 2006 as part of native fish monitoring to fulfill their FERC license agreement.

To establish redband spawning timing (temporal distribution), PGE surveyors counted redds every two weeks from March through July. One or two surveyors walked downstream at each site to identify redds and placed flagging next to each redd detected to avoid recounting redds on subsequent surveys.

Because redband redd numbers have been low in all reaches of Whychus except downstream of Alder Springs (Madden et al. 2020), in 2017 USFS and ODFW began conducting brown trout redd surveys in Camp Polk and Whychus Canyon Reach 4 as an additional measure of the quality of spawning habitat in restored reaches. USFS and ODFW conducted brown trout redd surveys at Whychus Canyon Reach 4 and at Camp Polk on December 1, 2017 and December 3, 2018. They conducted brown trout redd surveys at Camp Polk on November 19, 2019. Surveyors walked downstream at each site to identify redds and recorded latitude and longitude coordinates for each redd.

#### Fish density

ODFW and USFS conducted electrofishing surveys in Whychus Canyon Reach 4 (Phase I) in 2015 pre-restoration and in 2018 post-restoration. They conducted surveys in Whychus Canyon Reach 3, the unrestored reach immediately upstream of Reach 4, in 2017 and in 2018. Surveys were conducted using mark-recapture sampling protocols developed by Portland General Electric (PGE) for annual fish monitoring conducted in Whychus Creek under PGE's FERC relicensing agreement (Quesada et al, 2013); the PGE protocol was adapted from ODFW protocols (Scheerer et al., 2007). Sampling was conducted during base flow to optimize sampling conditions and allow for smolt out-migration prior to sampling.

One randomly selected ~200-m sampling reach was established in Whychus Canyon Reach 4 in 2015. The same reach and an additional ~200 m sampling reach were sampled in 2018. Sampling was conducted in a ~200 m reach in Whychus Canyon Reach 3 in 2017 and was repeated in the same reach in 2018. Block nets were placed at the top and bottom of the study reaches to provide a closed system for population estimates. In Whychus Canyon Reach 4 post-restoration, block nets were placed at the top and bottom of each channel sampled within the study reach. Block nets were cleaned and inspected throughout the sampling event to prevent failure.

One backpack electrofisher was used in any given reach to capture fish; during some sampling events enough technicians and volunteers were present to break a sampling reach into two sub-reaches and operate two electrofishers simultaneously in the two sub-reaches. All salmon and trout collected during the initial pass were enumerated, measured to the nearest millimeter, weighed to the nearest gram, and marked with a caudal clip. Where more than one reach was sampled at a site (e.g. Whychus Canyon Reach 4 in 2018), caudal marks were alternated between upper and lower caudal clips at successive segments to reduce obtaining a biased population estimate from fish moving between study reaches. All other fish species and salmon and trout <60mm (total length) were released outside of the study area after a subsample were measured.

To maintain consistency with PGE's native fish monitoring efforts in Whychus Creek, electrofishing crews used continuous DC current rather than pulsed DC. Although using continuous DC current uses significantly more battery power, PGE has found that using this setting is more effective at drawing fish out of habitats with undercut and/or overhanging characteristics and results in higher capture efficiencies. Using continuous DC current has also been shown to reduce injury compared to pulsed current (McMichael, 1993).

Once a pass was completed through the study reach and all fish randomly distributed back into the segment, each area was left undisturbed for at least three hours before initiating another pass. After three hours, a second electrofishing pass was conducted and marked and unmarked salmonids enumerated. When less than 20% of the marked fish from the previous pass were recaptured, an additional recapture pass was performed. Fish captured from previous passes were released immediately downstream of block nets to prevent recapture and minimize holding time. To minimize negative effects of repeated electrofishing, no more than three recapture passes were conducted.

To estimate the population size of each sampling reach, ODFW and USFS used the Chapman's modification of the Peterson estimator. Chapman's modification reduces the tendency to overestimate population sizes when sampling small populations and/or the number of recaptures is low (Vincent, 1971).

## Adult migration

PGE monitors migration of adult steelhead and chinook salmon released upstream of the Pelton- Round Butte dams into Lake Billy Chinook under their 2005 FERC license.

Numbers of adult steelhead and Chinook returning to the Pelton trap were recorded by date. Returning adult steelhead and Chinook salmon of known origin (identified by an intact adipose fin, and a left or right maxillary clip, indicating they were released in the Upper Deschutes Basin as smolts or fry, respectively) that returned to the Pelton Trap were tagged with two fluorescent green anchor tags, to distinguish them from conspecifics on spawning grounds, and passed upstream of Round Butte dam. Adults meeting criteria for condition, minimum size, maxillary clip and presence of a PIT tag were tagged with Juvenile Combined Acoustic Radio Telemetry (JCART) tags that emit both a radio and an acoustic signal to allow PGE biologists to track fish using either method.

Fish were tracked from fixed radio or acoustic telemetry stations at the upper end of the Deschutes, Crooked, and Metolius river arms of Lake Billy Chinook, as well as from additional stations on all three rivers. Fixed stations were programmed to run 24 hours/day, seven days/week, and recorded date and time of detection, signal strength and direction. Once a JCART-tagged fish was detected in a tributary, mobile tracking ensued. Surveyors recorded locations using GPS and field maps, and recorded spawning activity in the surrounding area including whether fish were on active redds.

## Results and Discussion

### *Groundwater*

Pre-restoration, maximum groundwater depths in Whychus Canyon Reach 4 occurred in August and ranged from -8.3 ft at MW-9 to -5.6 ft at MW-11 (Table 9); minimum groundwater depths occurred between late December and mid-February and ranged from -3.8 ft at MW 10 to -0.9 ft at MW 11. Over three years post-restoration, maximum groundwater depths occurred between late July and mid-September and ranged from -1.8 to -0.3; one anomalous maximum groundwater depth occurred in early January 2017. Minimum groundwater depths occurred between late October and April and ranged from -0.3 ft to 0 ft.

Table 9. Maximum and minimum groundwater depths and associated date ranges in four Whychus Canyon Reach 4 groundwater wells pre-restoration and over three years post-restoration.

| | Max Depth (4 wells) | | Min Depth (4 wells) | |
|---|---|---|---|---|
| | Depth Range (ft) | Date Range | Depth Range (ft) | Date Range |
| Pre-restoration | -5.6 to -8.3 | 8/1/2015-8/27/2015; 8/8/2016-8/12/2016 | -0.9 to -3.8 | 12/22/2014 - 2/10/2015 |
| Year 1 Post | -0.3 to -1 | 1/7/2017; 8/7/2017 - 8/16/2017 | 0 | 12/9/2016 - 1/7/2017 |
| Year 2 Post | -0.8 to -1.7 | 7/29/2018 - 8/13/2018 | 0 | 10/22/2017 - 11/24/2017 |
| Year 3 Post | -1.3 to -1.8 | 9/2/2018; 8/12/2019 - 9/13/2019 | -0.3 to 0 | 2/27/2019 - 4/8/2019 |

Maximum groundwater depths increased over three years post-restoration but remained within 2 ft of the average floodplain surface elevation at each well cross-section (Table 10). Average maximum groundwater depth for the project area decreased from -6.8 ft pre-project to -0.7 ft one year post-restoration, -1.4 ft in the second year post-restoration, and -1.6 ft in the third year post-restoration (Table 3). During the third year post-project, the average maximum depth to groundwater was 5.2 feet shallower than the average maximum depth to groundwater pre-project and remained above the two-foot riparian rooting depth threshold. Minimum average calculated depths post-project were consistently greater than zero, indicating the minimum (shallowest) groundwater elevations recorded in the well were higher than the average floodplain elevation at the well cross-section as calculated from total station or LiDAR elevation data, suggesting surface connectivity at some times and locations along the well cross-section and throughout the project reach.

Table 10. Maximum and minimum depths for each of four groundwater wells (MW-8, MW-9, MW-10, and MW-11), and average depths for the four wells, pre-project and over three years post-project. Depths are measured and reported in feet.

| | Pre-Restoration | | Year 1 Post | | Year 2 Post | | Year 3 Post | |
|---|---|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | Max | Min | Max | Min |
| MW-8 | -6.6 | -3.4 | -0.9 | 0.0 | -1.7 | 0.0 | -1.8 | 0.0 |
| MW-9 | -8.3 | -3.7 | -0.8 | 0.0 | -1.6 | 0.0 | -1.5 | -0.3 |
| MW-10 | -6.7 | -3.8 | -0.3 | 0.0 | -0.8 | 0.0 | -1.3 | 0.0 |
| MW-11 | -5.6 | -0.9 | -1.0 | 0.0 | -1.6 | 0.0 | -1.7 | 0.0 |
| Average | -6.8 | -3.0 | -0.7 | 0.0 | -1.4 | 0.0 | -1.6 | -0.2 |

Average groundwater depth at the four wells during the July 15th to August 31st base flow period decreased from -6.1 ft (depth below the floodplain surface) in 2015, one year pre-project, to -1.1 ft in 2017, one year post-project, to -1.4 ft in 2018 and 2019, two and three years post-project, representing a 4.4 ft rise in average groundwater depth in late summer over pre-project conditions as of three years post-project (Table 11).

Table 11. Average depths at each of four groundwater wells, and the average of depths from all four wells, during the July 15th to August 31st base flow period in 2015, pre-project, and in 2017, 2018, and 2019, one, two, and three years post-project, respectively.

| Well | 2015 Jul15-Aug31 | 2017 Jul15-Aug31 | 2018 Jul15-Aug31 | 2019 Jul15-Aug31 |
|---|---|---|---|---|
| MW 8 | -6.5 | -1.3 | -1.5 | -1.5 |
| MW 9 | -6.3 | -0.9 | -1.5 | -1.3 |
| MW 10 | -6.3 | -0.7 | -0.8 | -1.2 |
| MW 11 | -5.5 | -1.4 | -1.8 | -1.7 |
| Average | -6.1 | -1.1 | -1.4 | -1.4 |

Data from the four groundwater wells in the project area from July 15th through August 31st, during the growing season and at base flow, show groundwater remaining above but approaching the two-foot objective and threshold for supporting establishment and maintenance of riparian vegetation within three years following project implementation. Because well casings and caps remain at pre-restoration elevations, comparing groundwater elevation ASL to the most recently collected floodplain elevations provides a more accurate evaluation of depth to groundwater from floodplain surfaces than evaluating groundwater depth relative to the well casing or cap. The choice of which floodplain elevation measurements to use for comparison to measured groundwater depths, as well as which are included in calculating the median floodplain elevation and the selection of the median rather than average floodplain elevation, all influence the calculated and reported depth to groundwater for each well. Our selected approach attempts to provide the most accurate representation of the depth to groundwater from post-restoration floodplain surfaces at any given point in time.

The January maximum depth measurement in the first year post-project is an artifact of the time intervals used to calculate maximum and minimum depths for each year post-restoration, which we aligned to years following project implementation in August 2016. Groundwater maximum depths occurred from July into late September and early October in the first three years post-project, therefore using a water year for analysis that corresponds to annual maximum depths, such as a November 1 to October 31 water year, could support a more clear evaluation of annual maximum groundwater depth and better align data analysis with annual groundwater highs and lows.

Golden and Wymore (2016) used a minimum 30-day moving average, selected from Indicators of Hydrologic Alteration (Richter et al 1996) to evaluate the timing and magnitude of low stream flow in Whychus Creek. They observed that low flow periods extended across the October 1 through September 30 water year used by irrigators and the state water resources department and thus did not fully represent the low flow periods experienced each season, and accordingly shifted the water year they used for analysis one month later, to November 1 through October 31, to capture low flow periods that extended across the state water year. We would expect surface water low flows and maximum depths to groundwater in restoration reaches to correspond, thus aligning our analysis year with that used for stream flow in Whychus Creek could improve consistency and opportunities for comparison between the two.

### *Channel morphology and network*

#### Channel elevations

Total station survey data showed most channel elevations remaining within two feet above and below the GGL elevation over three years post-restoration. By two years post-project, elevations at the downstream end of the project reach approached four feet below the GGL elevation, demonstrating channel lowering in this area (Table 12, Figure 5).

As of May 2017, nine months post-restoration, channel elevations remained within 1 foot below the GGL elevation, and had aggraded to 1.6 ft above the GGL elevation. By September 2017, 13 months post-restoration, elevations in the main channel and two side channels in the lower half of the pre-restoration “terrace” had lowered in some places to 1.6 and 1.7 ft below the GGL elevation and aggraded in other places to over 2 ft above the GGL elevation, demonstrating channel adjustment over 13 months post-restoration including some channel aggradation and some channel lowering. In the primary (main) channel we observed incision progressing upstream as evidenced by elevations from more recent surveys lower than those from earlier surveys (e.g. October 2019 and September 2017 elevations between Valley Stations 47000 and 47300, Figure 5), as well as incision at the downstream end of the project, surveyed in 2018 and 2019, where by November 2018 some elevations at the downstream end of the restoration reach had lowered to 3.7 ft below the GGL elevation.

Table 12. Minimum, maximum, and median channel elevations in feet below or above the Geomorphic Gradeline elevation in primary and side channels at six survey intervals between November 2016, three months post-implementation, and October 2019, three years post-implementation.

| Date | Channel | Min | Max | Median |
|---|---|---|---|---|
| Nov 10 2016 | Main Channel | -0.7 | 1.6 | -0.3 |
| May 2017 | Main Channel | -0.7 | 0.4 | 0.1 |
| | Side Channel 9 | -1.0 | -0.2 | -0.4 |
| Sep 27 2017 | Main Channel | -1.6 | 1.6 | 0.19 |
| and | Side Channel 1 | -1.7 | 2.1 | 0.0 |
| Jan 20 2018 | Side Channel 2 | -1.6 | 0.2 | -0.8 |
| | Side Channel 3 | -0.2 | 0.5 | 0.3 |
| | Side Channel 4 | -0.6 | 0.3 | -0.1 |
| | Side Channel 5 | 0.1 | 1.2 | 0.7 |
| | Side Channel 6 | -0.7 | 1.0 | 0.2 |
| | Side Channel 7 | -0.2 | 1.0 | 0.7 |
| | Side Channel 8 | 0.2 | 1.0 | 0.8 |
| Nov 7 2018 | Main Channel | -3.7 | 0.1 | -1.6 |
| Oct 16 2019 | Main Channel | -3.4 | 0.3 | -0.9 |

Channel elevations exceeded the 1 ft departure from the GGL objective in some areas within 13 months post-restoration but remained within 2 feet of the GGL throughout much of the project reach. In response to incision at the downstream end of the project, UDWC designed the subsequent phase of restoration, implemented in 2021, to occur in the half-mile immediately downstream of Whychus Canyon Reach 4 to promote aggradation in the incised extent of Reach 4. UDWC continues to use total station surveys to closely monitor headcutting in the primary channel, at approximately valley station 46650 as of 2019.

The objective established for channel elevations, to sustain elevations within 1’ of the GGL over time, was informed by the requirement of most riparian species to have access to groundwater within 2’ of the floodplain surface. Riparian vegetation that became sufficiently established and was able to grow a sufficient root system to access groundwater within the one year to 18 months post-restoration when channel elevations remained within 2 feet of the floodplain surface was likely able to persist in areas where channel elevations did lower below 2 ft. Channel elevations below two feet that cause groundwater elevations to lower below two feet below the floodplain surface might limit recruitment and establishment of new riparian vegetation.

For 2017-2019 channel elevation monitoring we compared channel elevation data to design GGL valley station elevations rather than to as-built elevations measured following project implementation. For this reason channel elevation changes observed might not be accurate in that the as-built elevations could have been lower or higher than design elevations.  For future monitoring, using surveyed as-built elevations as the basis for comparison of channel elevations will provide a more accurate assessment of how channel elevations change over time following restoration implementation.

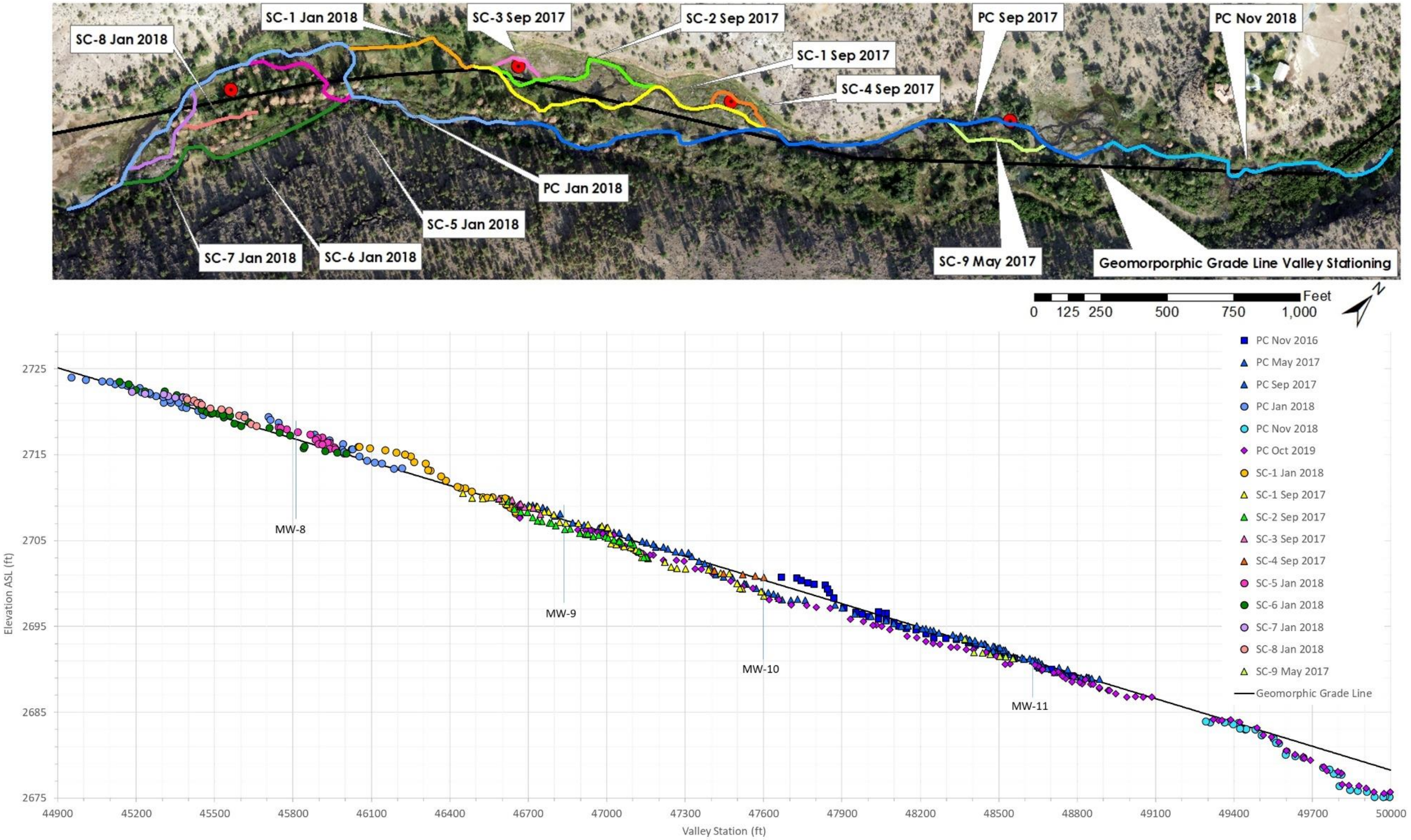


Figure 5. Top: The primary channel (PC) and side channels (SC) surveyed by date. Bottom: Channel elevation data collected during each survey event, plotted at corresponding valley station distances and elevations. Data point colors correspond to the colors of surveyed channels as drawn. Points above the Geomorphic Grade Line design elevation indicate aggradation resulting from deposition; points below the GGL elevation indicate channel lowering resulting from erosion. October 2019 primary channel survey elevations are plotted on the chart but not drawn on the aerial image.

## Number of channels

Over three years post-project, flow remained dispersed across a network of channels throughout the project reach (Table 13). The number of active channels and off-channel units at groundwater monitoring well cross-sections ranged from 3 at the MW-11 cross-section to eight at the MW-8 cross-section in 2017. In 2018 MW-8 and MW-10 cross-sections each exhibited four channels, and MW-9 and MW-11 cross-sections each exhibited three. As inferred from 2020 imagery, in 2019 at least three channels were active at MW-8, MW-9, and MW-11 cross-sections, with four active channels at the MW-10 cross-section.

The multiple channels visible from aerial imagery at groundwater monitoring well cross-sections over three years post-restoration indicates sustained horizontal hydrologic connectivity across the valley bottom and meets the objective of flow remaining dispersed within a network of channels. The number of channels visible from aerial imagery also demonstrates some consolidation of flow from 2017 to 2018, especially at MW-8. This observed consolidation might indicate the trajectory of channel network evolution in Stage 0 restoration projects in the absence of sufficiently large and frequent disturbance events.

Table 13. Active channels visible from imagery at four groundwater monitoring well cross-sections in 2017, 2018, and 2019.

| | Active Channels | | |
|---|---|---|---|
| | 2017 | 2018 | 2019 |
| MW 8 Cross-section | 8 | 4 | 3 |
| MW 9 Cross-section | 4 | 3 | 3 |
| MW 10 Cross-section | 5 | 4 | 4 |
| MW 11 Cross-section | 3 | 3 | 3 |

## Total channel length

Total channel length within the longitudinal extent of the Whychus Canyon Reach 4 project area increased from 1.1 mi in 2011, pre-project, to 3.7 mi in 2017, one year post-project, to 4.5 mi in 2019, three years post-project, representing 3.5 to 4.2 times the pre-restoration channel length (Table 14, Figure 6) and meeting the project objective to increase total channel length to greater than 3 miles.

Table 14. Channel network, habitat unit, wood, sediment, and riparian shading metrics and values from AIP stream habitat survey data from 2011 pre-restoration, 2017, one year post-restoration, and 2019, three years post-restoration, and times increase or decrease for each post-restoration year.

| Parameter | 2011 Pre-Project Survey | 2017 Post-Project Survey | 2019 Post-Project Survey | 2011 vs. 2017 Difference | 2011 vs. 2019 Difference |
|---|---|---|---|---|---|
| Total channel Length (mi) | 1.1 | 3.7 | 4.5 | 3.5x | 4.2x |
| Ratio of secondary : primary channel length (m) | 0.1 | 2.7 | 3.0 | 18.3x | 20.4x |
| Wetted area (ac) | 3.4 | 11.1 | 6.8 | 3.3x | 2.0x |
| Wetted area per 100 m valley length (ac) | 0.23 | 0.75 | 0.46 | 3.3x | 2.0x |
| Total number of habitat units | 54 | 302 | 340 | 5.6x | 6.3x |
| Number of habitat units per 100 m | 3.6 | 20.3 | 22.9 | 5.6x | 6.3x |
| Total number of riffles | 24 | 122 | 133 | 5.1x | 5.5x |
| Percent riffle (numeric) | 44% | 40% | 39% | 0.9x | 0.9x |
| Riffle area (percent of wetted area) | 66% | 60% | 60% | 0.9x | 0.9x |
| Total riffle area (ac) | 2.2 | 6.6 | 4.1 | 3.0x | 1.9x |
| Riffle area per 100 m (ac) | 0.15 | 0.45 | 0.28 | 3.0x | 1.9x |
| Total number of pools | 23 | 130 | 130 | 5.7x | 5.7x |
| Percent pool (numeric) | 43% | 43% | 38% | 1.0x | 0.9x |
| Pool area (percent of wetted area) | 33% | 34% | 34% | 1.0x | 1.0x |
| Total pool area (ac) | 1.1 | 3.9 | 2.3 | 3.4x | 2.1x |
| Pool area per 100 m (ac) | 0.08 | 0.26 | 0.16 | 3.4x | 2.1x |
| # Pools per 100 m | 1.5 | 8.8 | 8.8 | 5.7x | 5.7x |
| # Complex pools per 100 m | 0.3 | 2.8 | 2.1 | 8.4x | 6.2x |
| Pools ≥1m per 100 m | 1.3 | 0.6 | 0.7 | 0.5x | 0.5x |
| Average residual pool depth (m) | 0.72 | 0.38 | 0.43 | 0.5x | 0.6x |
| Number of pieces of wood per 100 m | 4 | 63 | 45 | 15.2x | 10.7x |
| Wood volume per 100 m ($m^3$) | 0.9 | 28.7 | 34.3 | 30.4x | 36.4x |
| Percent silt/organics in riffles | 5% | 23% | 9% | 4.6x | 1.8x |
| Percent sand in riffles | 9% | 31% | 34% | 3.4x | 3.8x |
| Percent gravel in riffles | 27% | 27% | 41% | 1.0x | 1.5x |

| | | | | | |
|---|---|---|---|---|---|
| Percent cobble in riffles | 45% | 18% | 13% | 0.0x | 0.3x |
| Percent boulder in riffles | 13% | 0% | 1% | -- | 0.1x |
| Percent bedrock in riffles | 1% | 0% | 3% | -- | 3.0x |
| Area of gravels in riffles per 100 m ($m^2$) | 112 | 330 | 297 | 3.0x | 2.7x |
| Area of fines in riffles (silt, organics and sand) per 100 m ($m^2$) | 58 | 660 | 312 | 11.4x | 5.4x |
| Percent shade | 49% | 53% | 51% | 1.1x | 1.0x |

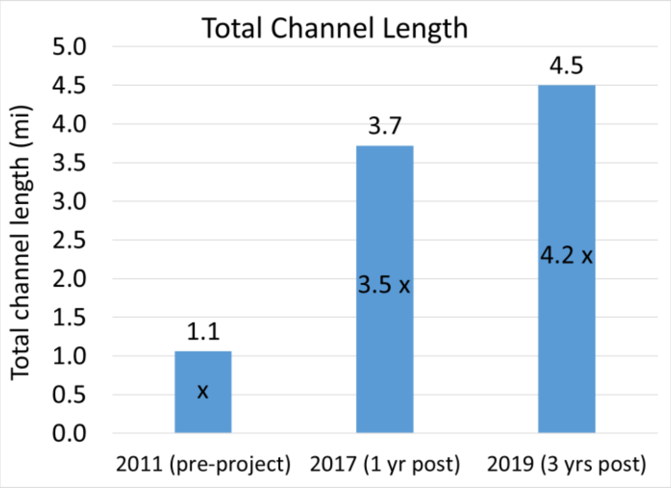


Figure 6. Total channel length in the Whychus Canyon Reach 4 project area was 3 and 4 times higher respectively in 2017 one year post-project and in 2019 three years post-project than in 2011 pre-project.

## Ratio of secondary to primary channel length

The ratio of secondary channel length to primary channel length increased from ten centimeters of secondary channel per meter of primary channel pre-restoration (0.1:1) to 2.7 meters of secondary channel for every meter of primary channel in 2019 (2.7:1), a 20-fold increase (Figure 7), exceeding the project objective of a secondary to primary channel length ratio greater than 1.5:1. The ratio of secondary channel length to primary channel length differed only slightly between 2017 (2.7:1) and 2019 (3:1).

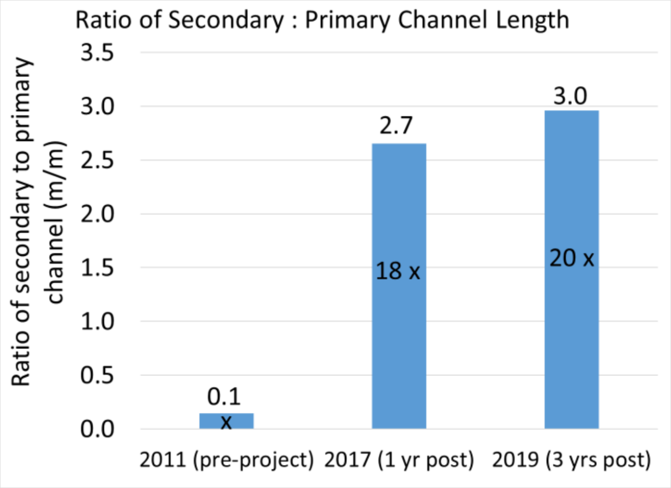


Figure 7. The ratio of secondary to primary channel length in the Whychus Canyon Reach 4 project area was 18 times higher in 2017 one year post-project and 20 times higher in 2019 three years post-project than in 2011 pre-project.

## Wetted area

Total wetted area within the project reach increased from 3.4 ac in 2011 to 11.1 ac in 2017 representing 3.3 times the pre-project amount of aquatic habitat (Figure 8). Total wetted area in 2019 was 6.8 ac, slightly less than twice the pre-project amount of aquatic habitat. Wetted area per 100 m valley length increased from 0.23 ac in 2011 to 0.75 ac in 2017, decreasing to 0.46 ac per 100 m valley length in 2019

(Figure 9). Flow levels during 2017 and 2019 surveys may explain the decrease in wetted area from 2017 to 2019. Instantaneous flows during the 2017 survey fluctuated from 16 cfs to 138 cfs, with mean daily flow spanning 19 cfs to 65 cfs; the maximum instantaneous flow during the 2019 survey was 77 cfs, about half that during the 2017 survey, with mean daily flows between 16 cfs and 33 cfs. No target value was defined for this objective, however, the change in wetted area observed over two successive surveys one and three years post-restoration provides some insight into the proportion by which we can expect wetted area to increase as a result of projects implemented using a similar design.

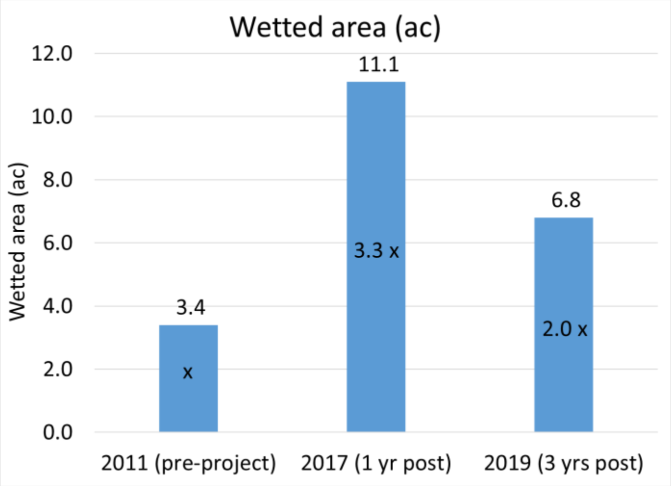


Figure 8. Acres of total wetted area in the Whychus Canyon Reach 4 project area was 3.3 and 2.0 times higher respectively in 2017 one year post-project and in 2019 three years post-project than in 2011 pre-project.

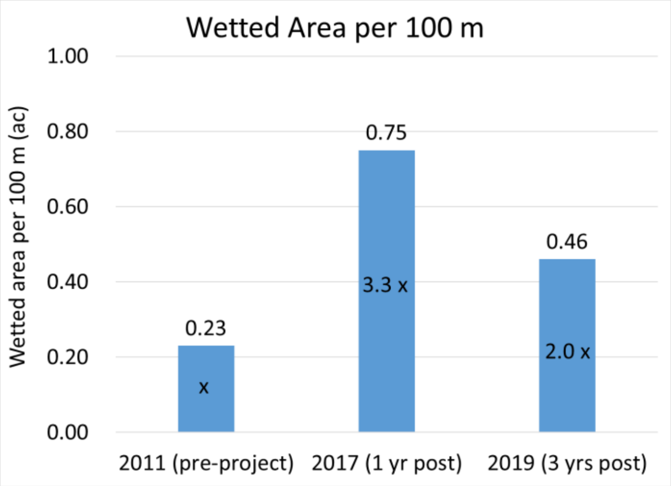


Figure 9. Wetted area per 100 m valley length in the Whychus Canyon Reach 4 project area increased from 0.23 ac per 100 m in 2011 pre-restoration to 0.75 ac per 100 m in 2017 one year post-project, decreasing in 2019 three years post-project to 0.46 ac per 100 m.

### *Channel and floodplain features*

#### Habitat units

Project objectives for habitat units included:

- Increase percent pool units and decrease percent riffle units
- Increase number (abundance) and richness (types) of habitat units
- Increase number and total area of pools and complex pools

As with wetted area, no specific target values were defined for these objectives, but results provide information about the degree of change that can be expected to occur in response to implementation of similar restoration designs.

The AIP stream habitat survey method classifies habitat units according to the slope of the water's surface, flow characteristics, and substrate. Fifty-four habitat units numbered 311 to 364 were surveyed within the Whychus Canyon Reach 4 restoration project longitudinal extent in 2011, equivalent to 3.6 units per 100 m valley length. Units 310 and 365 spanned the boundary of the restoration project reach and adjacent reaches and were excluded from analysis. Three hundred and two (302) habitat units numbered 2 to 303 were surveyed in the Whychus Canyon Reach 4 extent in 2017, 20.3 units per 100 m valley length and 5.6 times the pre-project number (Figure 10). Three hundred and forty habitat units numbered 3 to 277 and 283 to 347 were surveyed in the Whychus Canyon Reach 4 extent in 2019, 22.9 units per 100 m valley length and 6.3 times the pre-project number; units 278 through 282 were outside the upstream project boundary. The increase in the number of units from 2017 to 2019 indicates continued channel evolution and increasing habitat complexity over three years post-project.

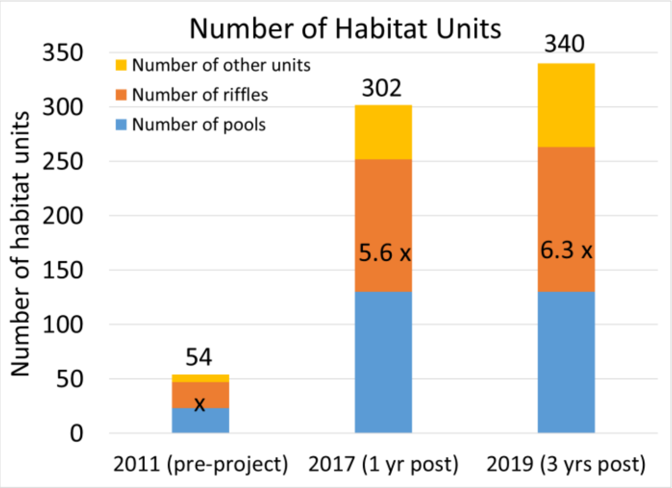


Figure 10. The number of habitat units in the Whychus Canyon Reach 4 project area was approximately 5.6 and 6.3 times higher respectively in 2017 one year post-project and in 2019 three years post-project than in 2011 pre-project.

Whereas the abundance of habitat units in the project reach increased dramatically, meeting this project objective, change observed in the richness of habitat unit types from 2011 to 2017 was not sustained from 2017 to 2019. The number of habitat unit types represented in the project reach increased from 11 in 2011 to 16 in 2017 and fell to 11 by 2019 (Figure 11). Unit types added from 2011 to 2017 included cascade/boulders, glides, alcove, isolated, and plunge pools, and step/cobble units. Riffles with pockets were present in 2011 but absent in 2017. In 2019 cascade/boulder and dry channel units were absent (although dry units increased); alcove, backwater, dammed, plunge, and straight scour pools were absent; and riffles with pockets remained absent. Rapid/bedrock and step/bedrock units were present in 2019 but not in the previous two survey events. Lateral scour pools and riffles accounted for the majority by far of units added from 2011 to 2017 and from 2017 to 2019; dry and puddled units both increased markedly in 2019 over 2011 and 2017 numbers; and step/cobble units were present in moderate numbers in 2017 and 2019 whereas they were absent altogether in 2011.

Increases in dry and puddled units in 2019 over both 2011 and 2017 numbers likely reflect both lower flows during 2019 surveys as compared to 2017 and possibly also channel consolidation and abandonment, although higher total channel length and ratio of secondary to primary channel lengths in 2019 than 2017 suggest avulsion and channel formation may have outpaced drying of channels. Dry and puddled units are included in calculating both total channel length and ratio of secondary to primary channel length.

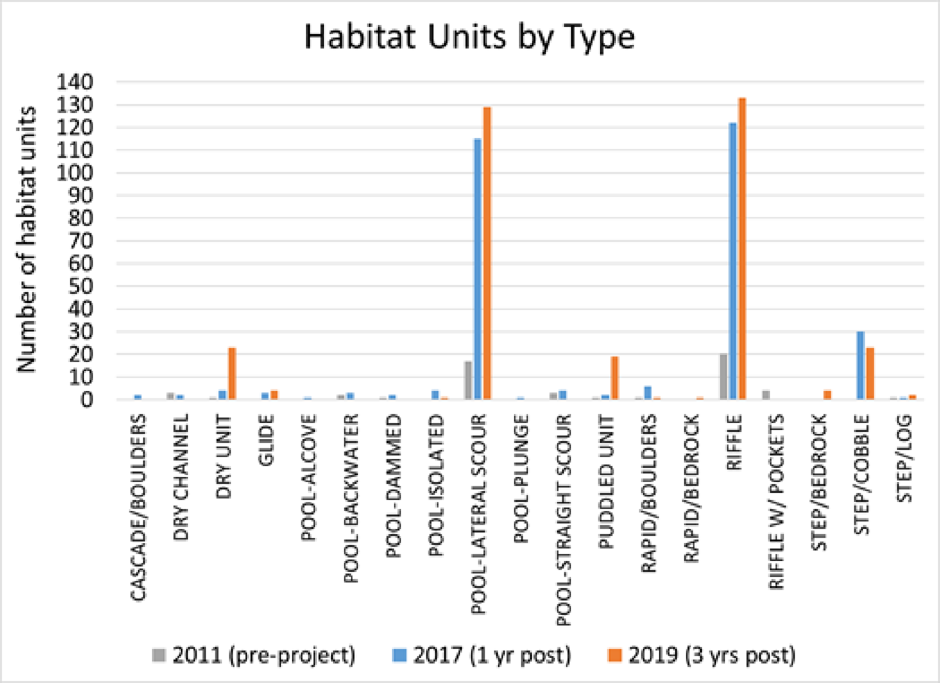


Figure 11. The number of different types of habitat units fluctuated between 11 and 16 from 2011 through 2019, with large increases in lateral scour pools, riffles, dry and puddled units, and step-cobble units accounting for the greatest change among years.

Riffles as defined using AIP survey methods are fast-water units characterized by fast, turbulent, shallow flow over submerged or partially submerged gravel and cobble substrates and slope typically within 0.5-2%. Riffles can often dominate simplified, degraded, and confined stream channels where stream energy is high and wood or other structural components to promote scour, pool creation, and deposition are absent. Riffles are traditionally associated with salmon spawning habitat; construction of redds is conventionally described as occurring in riffles and pool tailouts (the downstream margin of pools)(Foster et al., 2001).

The total number of riffles in the project reach increased from 24 in 2011 pre-restoration to 122 in 2017 one year post-restoration and increased again to 133 in 2019 three years post-restoration, over 5 times the pre-restoration number in both 2017 and 2019 (Figure 10, Figure 11). Forty-four percent of 2011 units were riffles; this percentage decreased to 40% in 2017 and 39% in 2019, an approximately 10%

decrease. Riffle units represented 64% of 2011 wetted area and 60% of wetted area in both 2017 and 2019 (Figure 12). In 2011, 2.2 ac of wetted area were riffle habitat, representing 0.15 ac of riffle area per 100 m valley length; in 2017, 6.6 ac of wetted area were riffle habitat, representing 0.45 ac of riffle habitat per 100 m valley length, 3.0x the 2011 area, and in 2019 4.1 ac of wetted area were riffle habitat, representing 0.28 ac of riffle habitat per 100 m valley length, 1.9x the 2011 area (Figure 13).

Pools as defined using AIP survey methods are units with a water surface slope of zero formed by scour or impoundment (Moore et al., 2019). Pools and especially deep pools are traditionally considered to provide slow water habitat and critical over-wintering and summer low flow habitat, including important resting areas (as less energy is required to hold in a pool than in fast water), refuge from predators, and rearing habitat. The bottoms of pools support the coolest temperatures and deeper pools may provide thermal refuges for all life stages during summer months. Complex pools characterized by three or more pieces of wood additionally provide cover and shade.

The total number of pools in the project reach increased from 23 in 2011 pre-restoration to 130 in both 2017 and 2019, one and three years post-restoration, respectively (Figure 10, Figure 11). Forty-three percent of all units were pools in both 2011 and 2017, decreasing slightly to 38% in 2019. Pool units represented 33% of 2011 wetted area and 34% of 2017 and 2019 wetted area (Figure 12). In 2011 1.1 ac of wetted area were pools, representing 0.08 ac of pool area per 100 m valley length; in 2017 3.4 ac of wetted area were pools, representing 0.26 ac of pool area per 100 m valley length, 3.4x the 2011 area, and in 2019 2.3 ac of wetted area were pools, representing 0.16 ac of pool area per 100 m valley length, 2.1x the 2011 pool area (Figure 13).

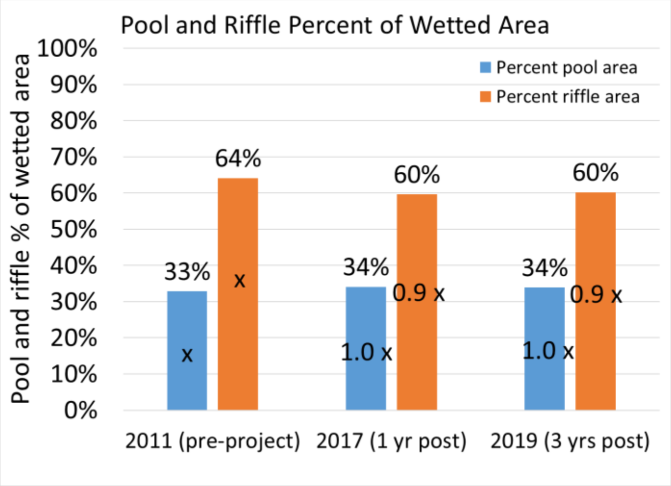


Figure 12. The percent of wetted area represented by pools and by riffles in the Whychus Canyon Reach 4 project area remained almost identical in 2017 one year post-project and in 2019 three years post-project compared to 2011 pre-project.

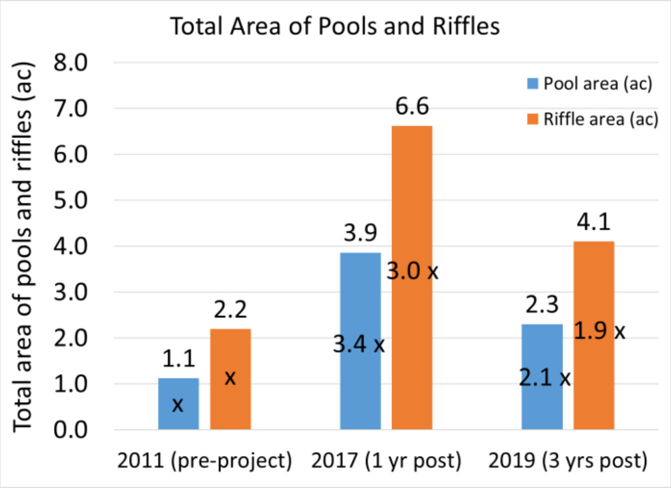


Figure 13. Total area represented by pools and by riffles in the Whychus Canyon Reach 4 project area increased to approximately 3x the 2011 area in 2017 one year post-project and decreased to approximately 2x the 2011 area in 2019 three years post-project for both unit types.

The number of pools per 100 m valley length increased almost 6-fold, from 1.5 in 2011 to 8.8 in 2017 and 2019, while the number of complex pools per 100 m valley length increased by 6- to 8-fold, from 0.3 in 2011 to 2.8 and 2.1 in 2017 and 2019 respectively (Figure 14, Figure 15); complex pools are defined as pools with at least three pieces of large wood, with large wood defined as being at least 15 cm in diameter and 3 m in length.

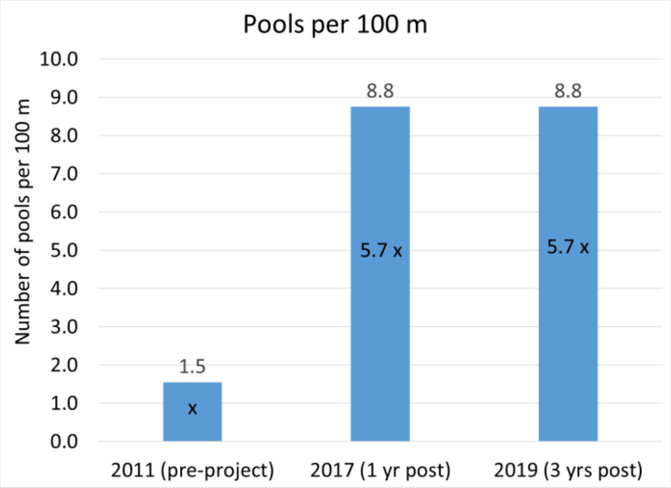


Figure 14. The number of pools per 100 m valley length in the Whychus Canyon Reach 4 project area was 5.7 times higher in 2017 one year post-project and in 2019 three years post-project than in 2011 pre-project.

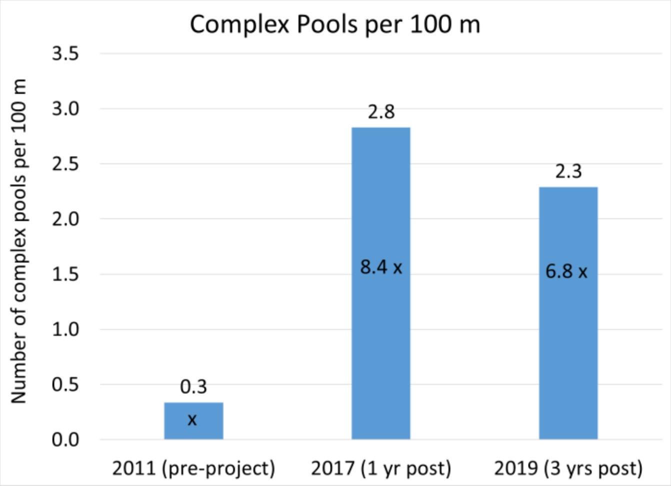


Figure 15. The number of complex pools in the Whychus Canyon Reach 4 project area was 8.4 and 6.8 times higher respectively in 2017 one year post-project and in 2019 three years post-project than in 2011 pre-project.

The number of pools one meter deep or deeper per 100 m valley length decreased by half, from 1.3 in 2011 to 0.6 in 2017 and 0.7 in 2019. The number of pools with a residual depth <0.8 m increased 11-fold from 2011 to 2019, while the number of pools with a residual depth ≥ 0.8 m remained the same between 2011 and 2019 (Figure 16). Average residual pool depth in the project reach decreased by about half, from 0.72 m in 2011 to 0.38 m in 2017 and 0.43 m in 2019.

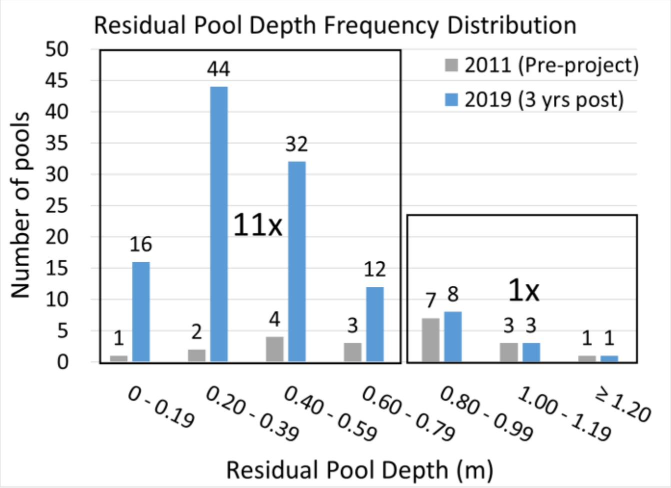


Figure 16. The number of pools with residual depths <0.80 m was 11 times higher respectively in 2019 three years post-project than in 2011 pre-project, while the number of pools with residual depths ≥0.8m remained the same from 2011 to 2019.

Restoration project objectives for habitat included decreasing the proportion and area of riffle habitat while increasing the proportion and area of pool habitat, and increasing the number and total area of pools, representing the hypothesized shift from a high-energy transport reach to a lower-energy depositional reach. Interestingly, the proportion of riffle and pool units and percent of wetted area remained similar post-restoration to pre-restoration, now distributed within 2-3x the wetted area. Also notably, the total numbers of riffles and pools were similar to each other pre- and post-restoration, with pools increasing by a slightly greater margin than riffles (5.7x and 5.5x, respectively). While the proportion of riffle to pool habitat did not meaningfully change in response to the restoration project, the numbers of both pools and riffles increased dramatically, and area of both pools and riffles were approximately twice the pre-restoration area by 2019 three years post-restoration.

Maximum depth for all units in the restoration project reach decreased from 1.9 m in 2011 to 1.2 m in 2017 but increased to 1.5 m in 2019; minimum depth decreased from 0.15 m in 2011 to 0.01 m in 2017 and 2019. Median unit depth decreased from 0.68 m in 2011 to 0.25 m in 2017 and 2019. These measures describe stream depth in the project reach becoming shallower overall, and shallower depths representing marginal deadwaters with slow velocities becoming more frequent post-restoration, while retaining deeper pools that continued to develop from 2017 to 2019.

### Wood

Under the AIP stream habitat survey protocol the minimum size criteria for wood is 15 cm diameter and 3 m length. The number of pieces of wood per 100 m valley length increased from 4 in 2011 to 63 in 2017, roughly 15 times the 2011 number, and decreased to 45, still over 10 times the 2011 number, in 2019 (Figure 17). The decrease from 2017 to 2019 could reflect channel migration away from pieces of wood or lower stream flow in 2019 that could have stranded pieces of wood counted in 2017.

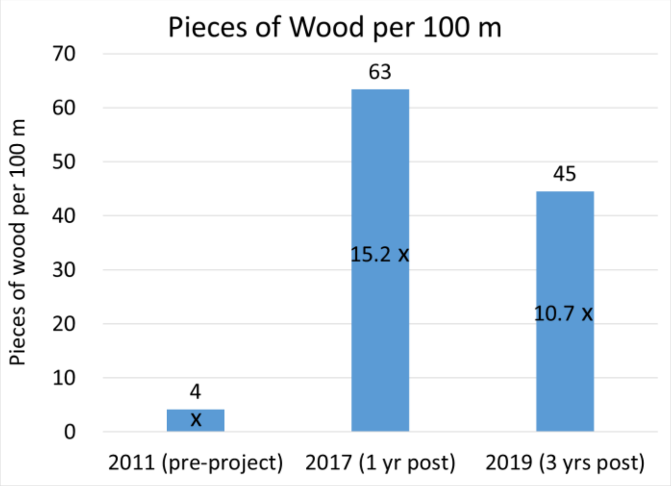


Figure 17. The number of pieces of wood per 100 m valley length was 15.2 and 10.7 times higher respectively in 2017 one year post-project and in 2019 three years post-project than in 2011 pre-project.

Wood volume per 100 m valley length increased from 0.9 $m^3$ in 2011 to 28.7 $m^3$ in 2017, a 30-fold increase, and to 34.3 $m^3$ in 2019, a 36-fold increase over the 2011 volume (Figure 18).

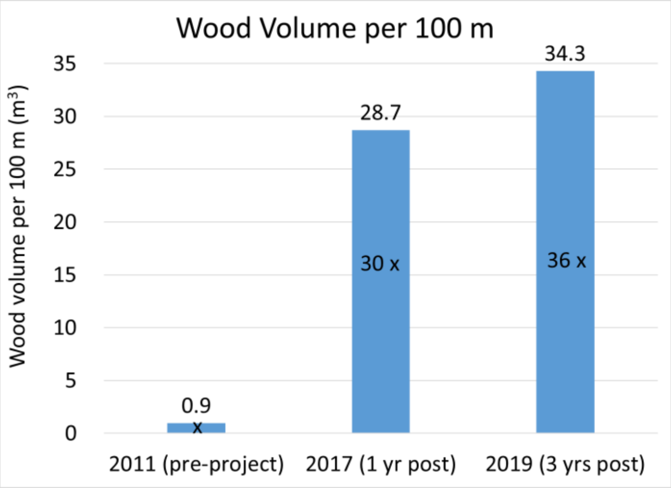


Figure 18. Wood volume per 100 m valley length was 30 and 36 times higher respectively in 2017 one year post-project and in 2019 three years post-project than in 2011 pre-project.

The observed increases in pieces of wood and wood volume are consistent with our project objective to increase the amount of large wood and wood complexes. Placement of large quantities of wood across the constructed floodplain during restoration implementation likely accounts for the majority of wood recorded in 2017 and in 2019, but recruitment of wood resulting from mortality of both large ponderosa pines and cottonwoods in the re-activated floodplain likely also contributed to 2017 and 2019 values. Adaptive management in 2018 to promote deposition and aggradation included placing additional wood in the project reach, possibly also reflected in 2019 wood numbers.

## Substrate

### AIP survey data

Substrate size class distribution is of particular interest for spawning, traditionally characterized as occurring in pool tailouts or the riffle unit immediately downstream of a pool tailout. We report average substrate size class distribution for all units and for riffles.

AIP stream habitat survey data from 2011, 2017, and 2019 showed a shift in the frequency distribution of sediment size classes in all units, as well as in riffles, toward smaller classes, with average percentage of silt and organics, sand, and gravel increasing, and average percent of cobble and boulder decreasing, from 2011 to 2019 (Figure 19, Figure 20). Gravels in all units and in riffles changed little within one year post-restoration but increased, by approximately 30% (all units) to 50% (riffles) from 2017 to 2019, suggesting continued deposition of gravels in the two-year interim. Silt and organics doubled or more than doubled in all units and in riffles one year post-restoration in 2017; silt and organics averaged for all units decreased in 2019 to below pre-restoration levels, and in riffles also decreased but remained almost twice the pre-restoration amount. The decrease in silt and organics could be explained by deposition on the floodplain during winter high flows and possibly by increased nutrient cycling related to a larger wetted area relative to flow and hydrologic connectivity among active channels, the floodplain, the hyporheic zone, and groundwater as described by Cluer and Thorne (2014). Percent cover of sand in 2017 was approximately 2 and 3 times 2011 values in all units and in riffles respectively, and increased slightly in all units and in riffles in 2019.

By 2019, percentages of silt and organics in all units and in riffles were 0.8 times and 1.8 times 2011 percentages, respectively; sand was 2.6 (all units) and 3.8 (riffles) times higher than in 2011; gravel was 1.3 (all units) and 1.5 (riffles) times 2011 percentages; and cobble was 0.4 (all units) and 0.3 (riffles) times 2011 amounts.

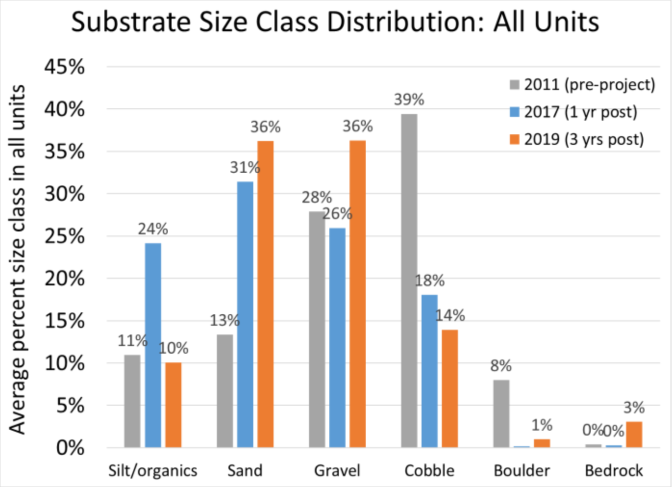


Figure 19. Average percentage of six substrate size classes in all habitat units in 2011 pre-restoration, 2017 one year post-restoration, and 2019 three years post-restoration.

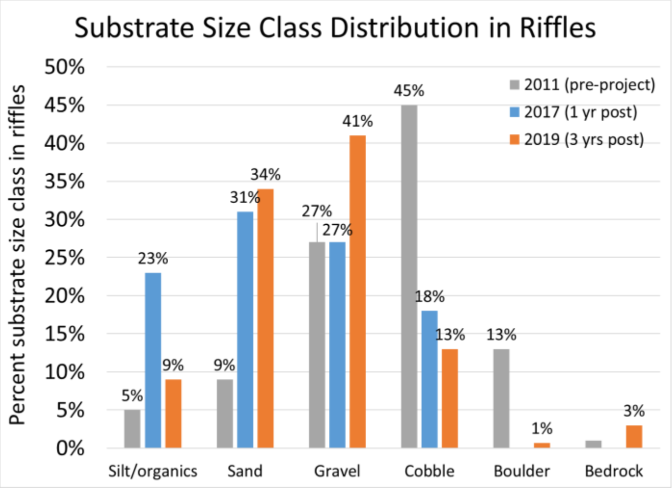


Figure 20. Average percentage of six substrate size classes in riffle habitat units in 2011 pre-restoration, 2017 one year post-restoration, and 2019 three years post-restoration.

Area of gravels in riffles per 100 m valley length increased from 112 $m^2$ in 2011 to 297 $m^2$ in 2019, 2.7 times the 2011 area per 100 m valley length. Area of fines in riffles per 100 m valley length, including silt, organics, and sand, increased from 58 $m^2$ in 2011 to 312 $m^2$ by 2019, consistent with a reduction in stream energy associated with restoring the stream from a confined, incised condition to an unconfined network of channels. Collectively, area of fines in riffles including silt, organics and sand in riffles was 5.4 times higher in 2019 than in 2011. Notably, area of gravels and riffles per 100 m valley length were similar (within 15 $m^2$ per 100 m valley length) by 2019.

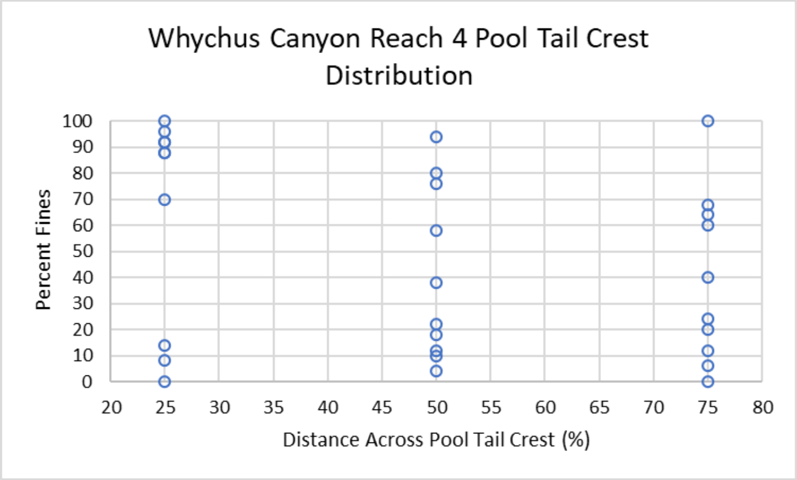
### Fine sediment surveys

Fine sediments were surveyed in ten pools in Whychus Canyon Reach 4 and in Camp Polk. In Whychus Canyon Reach 3, fine sediments were surveyed in the only four pools within the reach.

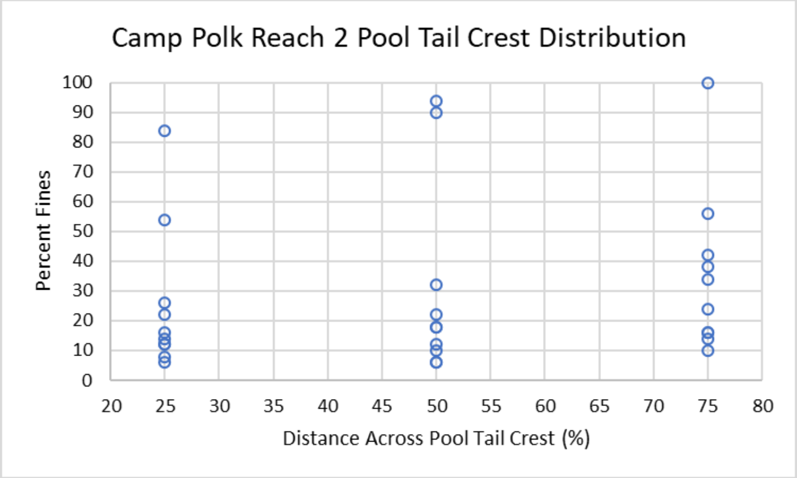
The range of fine sediment values at Whychus Canyon Reach 4 and Camp Polk was much larger than that observed in Whychus Canyon Reach 3 (Figure 21). All but one percent fines measurement from the four Whychus Canyon Reach 3 pools (11 measurements) were less than 30%. An equivalent or higher number of measurements from Whychus Canyon Reach 4 (13 measurements) and Camp Polk pools (20 measurements) showed less than 30% fines, suggesting the restored reaches provided an equivalent number of pool tail crests with <30% fines as did the unrestored reach. The remaining measurements from Whychus Canyon Reach 4 (17 measurements) and Camp Polk (10 measurements) were greater than 30% fines, indicating that restoration projects also added pools not represented in the unrestored reach with tail crests characterized by higher percentages of fines; rather than universally increasing the amount of fines in pool tail crests, restoration projects at Whychus Canyon and at Camp Polk instead appear to have increased the frequency distribution of percent fines in pool tail crests. The relatively lower number of fines measurements above 30% from Camp Polk, where restoration implementation was completed in 2012, suggests that the proportion of fines in pool tail crests might decrease with time since restoration.

Median percent fines in pool tail crests in Whychus Canyon Reach 4, Camp Polk, and Whychus Canyon Reach 3 were 49%, 18%, and 8%, respectively (data not shown).

a.



b.



c.

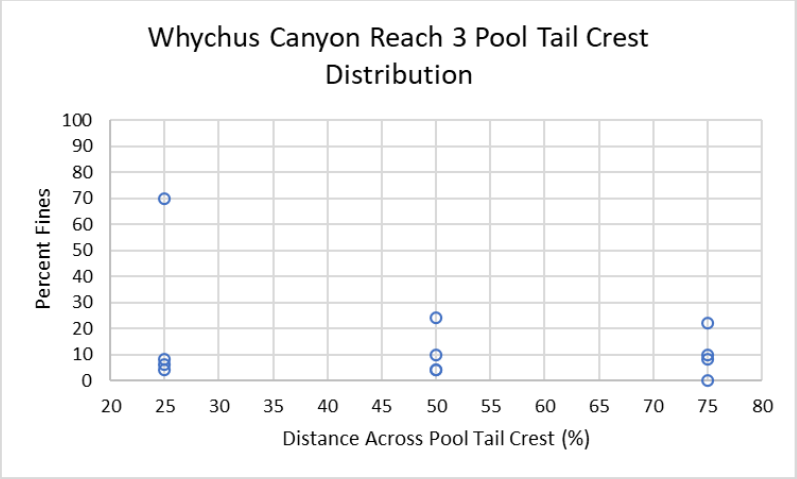


Figure 21. Percent fines measurements at 25%, 50% and 75% distances across tail crests of ten pools each in: a) Whychus Canyon Reach 4 and b) Camp Polk (restored in 2016 and 2012 respectively); and c) four pools in Whychus Canyon Reach 3 (unrestored).

Burke et al. (2010) reviewed available literature to assign threshold substrate values differentiating good, fair, and poor habitat for each life stage of Chinook salmon and summer steelhead. According to their review, gravels 2-64 mm in diameter greater than or equal to 30%, averaged for all units, are considered to provide good quality habitat; gravels between 15 and 30% are considered to provide fair quality habitat; and gravels less than 15% are considered to provide poor quality habitat for spawning Chinook and steelhead. Fine sediments including sand, silt and organics smaller than 2 mm less than or equal to 10%, averaged for all units and prior to redd construction, are considered to support a good habitat quality rating for spawning Chinook and steelhead; fine sediments between 10% and 20% are considered to support a fair habitat quality rating; and fine sediments greater than 20% are associated with poor habitat quality. For summer rearing and overwintering, the threshold between fair and poor habitat is 30% fines.

The average percentage of gravels in all units in Whychus Canyon Reach 4 hovered around 30% in all three surveys. Gravels in 2019 averaged for all units represented 36% of substrate, comfortably within the 30% threshold for good spawning and ≥ 15% threshold for Chinook summer 0+ rearing habitat quality. Fines, however, including sand, silt, and organics, totaled 46% in 2019, well above the 20% threshold for poor spawning habitat quality and the 30% threshold for poor summer 0+ rearing quality. The amount of fines in Whychus Canyon Reach 4 resulted in poor 2017 and 2019 HabRate model habitat quality ratings for Chinook salmon and summer steelhead spawning and rearing (PGE 2018, PGE 2020).

Repeat stream habitat surveys along Whychus Creek since 1997 suggest that Whychus has a high fine sediment load (UDWC 2012). Pre-restoration survey data show that even in unrestored, confined reaches of Whychus Creek characterized by high stream energy, where sediment is efficiently transported downstream, the average percent of fines for all habitat units exceeds the criteria established by Burke et al.'s HabRate model, resulting in poor ratings along Whychus for spawning and emergence. The historic distribution of Pacific lamprey, which require fine sediment for spawning and rearing, throughout the Columbia Basin including in the Upper Deschutes Basin (Kostow 2002) suggests high amounts of fine sediment in low-gradient, depositional reaches of Columbia Basin tributaries including Whychus Creek might have been characteristic of the pre-European settlement condition of these tributary streams.

### Riparian Shading

Percent shade over habitat units remained similar pre- and post-restoration, increasing slightly from 49% in 2011 to 53% in 2017 and falling to 51% in 2019. Anecdotally, pre-restoration, alder was abundant along channel margins, providing some shade, but the channel was uniformly wide, so much of the channel was not shaded. Post-restoration, riparian species were planted including along margins of evolving channels, and stands of ponderosa pine and cottonwood galleries were retained during the restoration project, providing shade over relict and new channels. The slight decrease in shading observed from 2017 to 2019 could represent differences in measurement between years or could reflect a real decrease in shading resulting from ponderosa pine mortality or bank erosion. These data demonstrate that, contrary to common perceptions of GGL Stage 0 restoration projects as increasing solar radiation on stream channels, at Whychus Canyon Reach 4, shading and inversely solar radiation changed very little following restoration implementation, and suggest that shading might have increased slightly following restoration.

## Fish Passage

UDWC and USFWS staff conducted fish passage surveys on August 30th, 2017; September 19th, 2018; and September 16th, 2019. Instantaneous flow between 9 am and 4 pm during surveys was similar on the three dates but slightly higher in 2017 and in 2019 (Table 15). The number of locations in the project reach where the primary channel or non-primary continuous flow path was shallower than 7.2” for a distance longer than the channel width increased from three in 2017 to seven in 2018 and six in 2019 (Table 15, Figure 22). Recorded depths in sections shallower than 7.2” ranged from 4.5” in 2017 along 34’ of channel, co-occurring with the lowest average daily flow of the three surveys, to 6.5” in 2019 along 13’ and 15’ of channel. Notably the highest instantaneous flows, in 2017, were associated with the fewest sections of channel not meeting passage criteria; 2017 also represents the most vertically connected condition of the three years with less channel evolution, aggradation, and degradation having occurred only one year post-restoration than in 2018 and 2019 two and three years post-restoration, as evidenced by longitudinal profile water surface elevation data (Figure 4). Sections of channel not meeting criteria were clustered in the downstream end of the project (the “lower delta”), and were interspersed along the valley-right channel in 2017, 2018, and 2019. One section in the lower delta and one section in the valley-right channel exhibited the same depths in successive years but the length over which the 7.2” depth criteria was not met more than doubled. Sections of channel not meeting passage criteria totaled 200 ft or 61 m in 2018 and 173 ft or 53 m in 2019, equivalent to 4% of the valley length or 3% of the primary channel length, at flows down to 13 cfs, suggesting the project provides passage for adult anadromous fish within the remaining 96% of the valley length or 97% of the primary channel length at very low flows. Adult salmon migration through the project reach also suggests the project provides sufficient passage. In 2019, five adult chinook salmon were detected upstream of Whychus Canyon Reach 4, and of those five, four were first detected upstream of Whychus Canyon Reach 4 on or after August 14th, suggesting these fish might have migrated through the project reach at base flow.

Average daily flows associated with fish passage surveys illustrate how this flow statistic masks instantaneous low flows that contribute to shallow stream depths and warm stream temperatures. In 2017, with an 18 cfs minimum flow during the passage survey, only three locations were identified where a continuous flow path through the project reach was interrupted by depths shallower than 7.2”; in subsequent years, with a minimum instantaneous flow of 13 cfs but a higher average daily flow of 28 cfs, more locations did not meet the passage criteria.

Table 15. Survey date, depth and length of section of channel not meeting 7.2” criteria, average daily flow, and instantaneous flow during surveys, measured at the OWRD gage at Sisters.

| Date | Depth | Length | Average Daily Flow | Instantaneous Flow |
|---|---|---|---|---|
| 8/30/2017 | 6" | 12' | 22 cfs | 18-23 cfs |
| | 5.5" | 33' | | |
| | 6" | 23' | | |
| 9/19/2018 | 5" | 44' | 16 cfs | 13-18 cfs |
| | 5" | 19.2' | | |
| | 5" | 10.2' | | |
| | 6" | 9.5' | | |
| | 6" | 39.3' | | |
| | 4.5" | 34' | | |
| | 6" | 44' | | |

| | | | | |
|---|---|---|---|---|
| 9/16/2019 | < 7.2" (not recorded) | 25.4' | 28 cfs | 13-25 cfs |
| | 6.5" | 15' | | |
| | 6.5" | 13' | | |
| | 5" | 45' | | |
| | 6" | 51' | | |
| | < 7.2" (not recorded) | 23.6' | | |

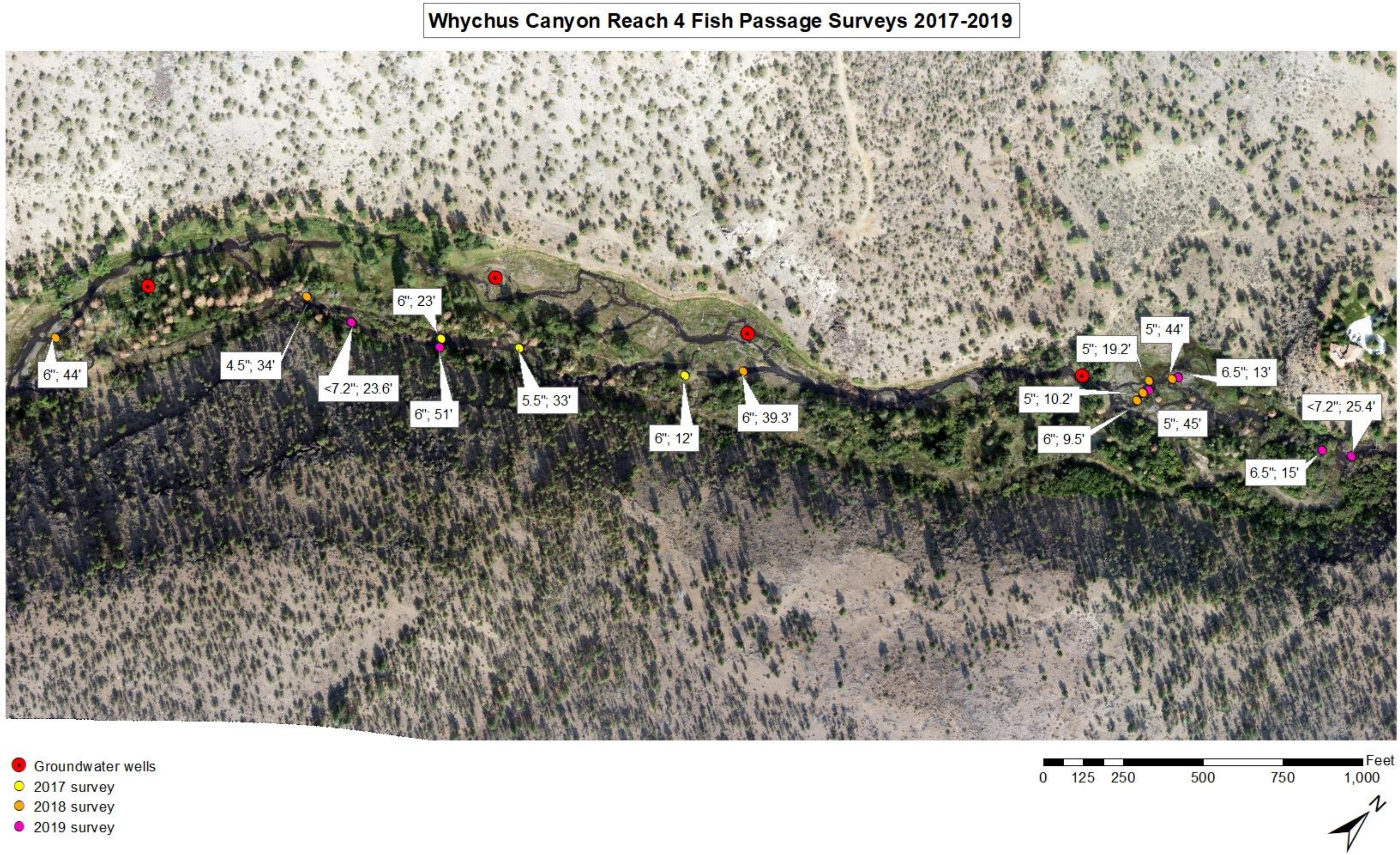


Figure 22. Locations in 2017, 2018, and 2019 where water depth within a continuous flow path from the downstream to upstream end of the project reach was shallower than 7.2" over a distance longer than the channel width in that location; depths and distances are labeled.

### *Continuous Temperature*

The pre-restoration average July rate of stream temperature change per mile ranged from less than a tenth of a degree (0.1°C) in 2015 and 2016 to a 10-year maximum rate of change per mile of 0.4°C (0.36°C) in 2007 (Table 16). The average rate of change in stream temperature per mile over three years post-restoration remained below the 0.4°C pre-restoration 10-year maximum rate of change, the threshold identified in UDWC's Monitoring and Adaptive Management Plan (UDWC 2016) as a trigger for initiating discussion to evaluate the need for adaptive management. The post-restoration rate of change per mile over three years remained constant at 0.1°C despite a wide range of median July average daily flows for the three years, similar to trends observed pre-restoration from 2011 to 2014.

Relocation of the WC 09.00 monitoring site 1.2 miles upstream in 2010 necessitated using pre-restoration data from two different sites to calculate a pre-project maximum rate of stream temperature change per mile and prevents a direct comparison of post-restoration data to pre-restoration data; however, because we calculate rate of change per mile, the difference in site location is not expected to have any effect on results.

Table 16. July average seven-day average daily maximum (7DADM) stream temperature in degrees Celsius at three monitoring sites, upstream to downstream difference, resulting rate of stream temperature change per mile, and corresponding median July average daily flow at Sisters, for ten years pre- and three years post-restoration at Whychus Canyon Reach 4.

| | WC 09.00 (RM 8.6) | WC 10.25 (RM 9.8) | WC 18.25 (RM 16) | Difference of Averages | Temperature increase rate per mile | Median July Average Daily Flow (cfs) |
|---|---|---|---|---|---|---|
| Pre-restoration | | | | | | |
| 2006 | 17.7 | | 16.0 | 1.7 | 0.2 | 74 |
| 2007 | 23.7 | | 21.0 | 2.7 | 0.4 | 16 |
| 2008 | 17.0 | | 15.7 | 1.3 | 0.2 | 64 |
| 2009 | 21.1 | | 19.0 | 2.1 | 0.3 | 27 |
| 2010 | | 18.4 | 17.4 | 0.9 | 0.2 | 35 |
| 2011 | | 14.0 | 13.5 | 0.6 | 0.1 | 119 |
| 2012 | | 15.0 | 14.4 | 0.6 | 0.1 | 118 |
| 2014 | | 18.7 | 18.1 | 0.5 | 0.1 | 49 |
| 2015 | | 20.9 | 20.9 | -0.1 | 0.0 | 23 |
| 2016 | | 19.3 | 19.2 | 0.1 | 0.0 | 29 |
| Post-restoration | | | | | | |
| 2017 | | 17.5 | 16.8 | 0.7 | 0.1 | 77 |
| 2018 | | 22.3 | 21.7 | 0.6 | 0.1 | 18 |
| 2019 | | 20.1 | 19.7 | 0.4 | 0.1 | 27 |

The rate of increase in stream temperature per mile over three years post-restoration suggest that known and hypothesized changes to surface water residence time, water depth, and shading resulting from the restoration project have not translated into an increase in the rate of stream temperature change per mile and that no net warming above pre-restoration rates is occurring, meeting the project objective for the rate of warming to remain below the 10-year pre-restoration maximum rate of warming. In contrast, rates of temperature change post-restoration that are similar to rates of change observed at much higher flows pre-restoration (e.g. 2008, 2011, 2012 and 2014 compared to 2017, 2018, and 2019) suggest that vertical hydrologic connectivity between surface water and groundwater and hyporheic exchange resulting from hydraulic forcing in the structurally diverse stream bed might be buffering and cooling, rather than warming, stream temperatures.

The distance of the upstream datalogger from the upstream end of the project reach (approximately five miles) results in averaging the rate of stream temperature change over a longer distance than the project reach. For future phases of restoration along Whychus Creek, collecting at least two years of continuous stream temperature data from immediately upstream and downstream of the restoration reach will improve the accuracy of our analysis of the rate of temperature change through the project reach by limiting the linear extent over which the rate of change is calculated to the project area.

While rate of temperature change through the project reach provides a coarse measure of restoration project effects on stream temperature, exchange of water between the hyporheic zone and the stream has been shown to buffer stream temperatures; complex streambed topography characterized by alternating pool/riffle sequences, and the development and presence of mid-channel bars, meander bends, side channels, backwaters, and abandoned channels, drive hyporheic flow (Poole and Berman, 2001). Researchers from Portland State University implemented a study in 2021 to measure thermal heterogeneity in restored and unrestored reaches on Whychus Creek; results from this study will provide additional insight into stream temperature dynamics in Whychus Canyon Reach 4.

### *Riparian Vegetation*

#### Cover classification and change analysis

Classification of riparian vegetation from July 2016 aerial orthophoto imagery, not including coniferous cover classes, categorized 18.3 acres within the Whychus Canyon Reach 4 restoration project area as riparian. Classification from imagery acquired in July 2017, just shy of a year after project implementation in August 2016, categorized 30.7 acres as riparian vegetation. Visual comparison of the 2016 and 2017 riparian vegetation maps and imagery showed stands of trees not classified as riparian in 2016 subsequently classified as riparian in 2017. To attempt to increase the consistency in the two classifications we re-calculated riparian vegetation for both years to include coniferous forest, despite our two coniferous species, ponderosa pine and juniper, both being xeric, upland species, resulting in 23.1 acres reported as riparian in 2016 and no change in the 30.7 acres reported as riparian in 2017. Because some of the same trees assigned in 2017 to the riparian location class were assigned in 2016 to the upland location class, discrepancies persisted in some of the same trees that were excluded from riparian vegetation calculations for 2016 being included in riparian vegetation calculations for 2017, which we know is not accurate as they are the same individual trees. To better account for change in riparian vegetation from 2016 to 2017 resulting from the implementation of the restoration project, we calculated riparian vegetation for only herbaceous and shrub cover classes (Herbaceous, Herbaceous-isolated tree and shrub, and Shrub), given these are the cover classes in which the most change was effected through restoration implementation whereas little change in tree cover was expected to occur over one year post-restoration. Herbaceous and shrub riparian cover classified from 2016 imagery accounted for 4.6 acres of vegetation; herbaceous and shrub riparian cover classified from 2017 imagery accounted for 12.3 acres of vegetation, 2.7 times the 2016 cover (Figure 23).

The project objective defined for acreage of desired riparian and wetland vegetation communities along the six miles of Whychus Canyon Preserve was to increase these communities by greater than 20 acres.

This objective was never downscaled for the one-mile Whychus Canyon Reach 4, and no timeframe was identified for achieving this objective. Results showing almost three times the vegetation classified as herbaceous and shrub one year post-restoration compared to pre-restoration suggest that the riparian vegetation was actively establishing and recruiting in the year post-project. Continued vegetation monitoring at Whychus Canyon Reach 4 will provide information about the extent of riparian vegetation communities that become established in the project area over time and inform riparian vegetation objectives for future phases of restoration.

UDWC consulted with EDC and Aequinox to design and implement vegetation plot surveys in summer 2019 to provide information about the accuracy of classification as riparian or upland (UDWC 2021). These surveys did not include plots in Whychus Canyon Reach 4. This decision was made in part to prioritize plots in reaches where change in riparian cover from 2017 to 2019 was expected to be low, in contrast to Whychus Canyon Reach 4, where change in riparian cover from 2017 to 2019 was expected to be relatively higher as riparian vegetation established in 2017 continued to mature. Despite the lack of ground-truthing data from Whychus Canyon Reach 4, our approach of comparing only change in herbaceous and shrub riparian vegetation reduces the error associated with inclusion of forest classes and any error likely over-represents pre-restoration riparian herbaceous and shrub vegetation.

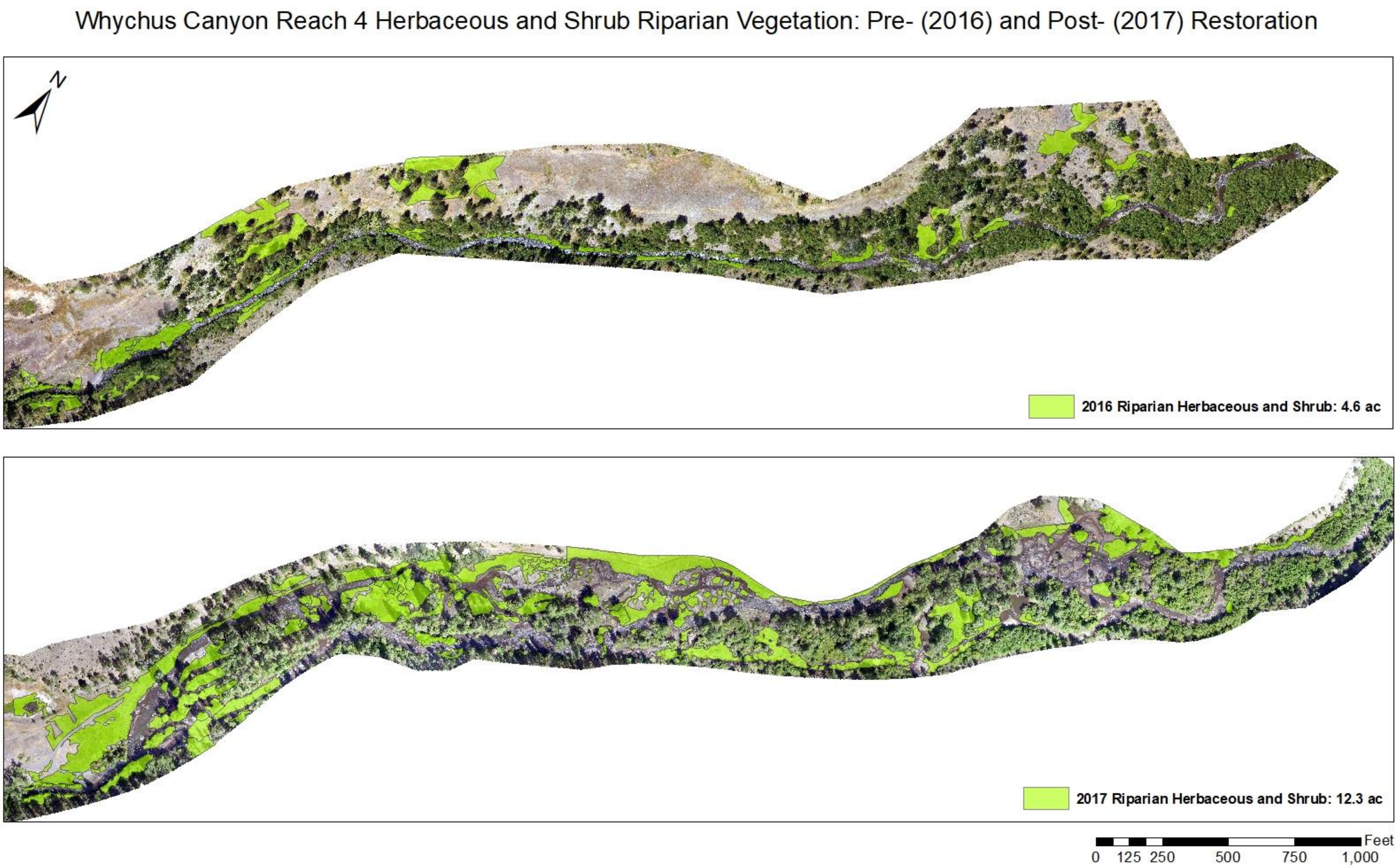


Figure 23. Vegetation classified as riparian herbaceous and shrub increased from 4.6 ac in 2016 pre-restoration to 12.3 ac in 2017 one year post-restoration, approximately 3x the 2016 acreage for these classes.

## Community composition

Species richness metrics, including total species richness, the number of native and non-native species, and the number of wetland indicator species all increased from 2015 to 2018, between 2 to 3 times 2015 values (Table 17, Figure 24). In contrast, some abundance metrics, measured as percent cover, increased from 2015 to 2018 while some exhibited little change and others showed large reductions. Total percent cover, native species cover, and cover of native wetland indicator species with obligate or facultative wet status all approximately doubled; non-native species cover and percent cover of herbaceous species tripled; and percent cover of tree species fell by approximately half, while percent cover of planted species and shrub species stayed similar to pre-project. Reed canarygrass, *Phalaris arundinacea*, is identified as a native species in the USDA plants database but because of its highly invasive habit in the western US we included it with non-native species in our analysis[1].

Table 17. 2015 and 2018 average values for four species richness and eight percent cover plant community metrics, and times increase or decrease pre- (2015) to post- (2018) restoration.

| Plant community metric | 2015 Average | 2018 Average | Change |
|---|---|---|---|
| Total number of species | 16 | 38 | 2.4x |
| Number of native species | 9 | 24 | 2.9x |
| Number of non-native species | 3 | 9 | 3.1x |
| Number of wetland indicator species | 6 | 12 | 2.0x |
| Total vegetation % cover | 97 | 166 | 1.7x |
| Native species % cover | 63 | 104 | 1.7x |
| Non-native species % cover | 10 | 31 | 3.2x |
| Native wetland indicator percent cover | 44 | 87 | 2.0x |
| Percent cover of planted species | 34 | 30 | 0.9x |
| Percent cover of tree species | 27 | 10 | 0.4x |
| Percent cover of shrub species | 8 | 9 | 1.2x |
| Percent cover of herbaceous species | 38 | 116 | 3.0x |

Vegetation heights shifted from the greatest proportion of plants detected (58%) being less than a foot tall pre-restoration to approximately equal representation of plants under a foot (40%) and up to three feet tall (38%) in 2018, two years post-restoration (Figure 25). Data also showed a small increase from 2015 to 2018 in the percentage of plants three to five feet tall. These results are consistent with increasing species richness as well as representation of taller shrubs both planted and naturally recruited into the project reach.

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[1] Hitchcock and Cronquist (2018): “Collections from before 1860 are apparently the native North American race, but [are] inseparable morphologically from the invasive European introduced race in our area used for rangeland improvement by +/- 1885.”

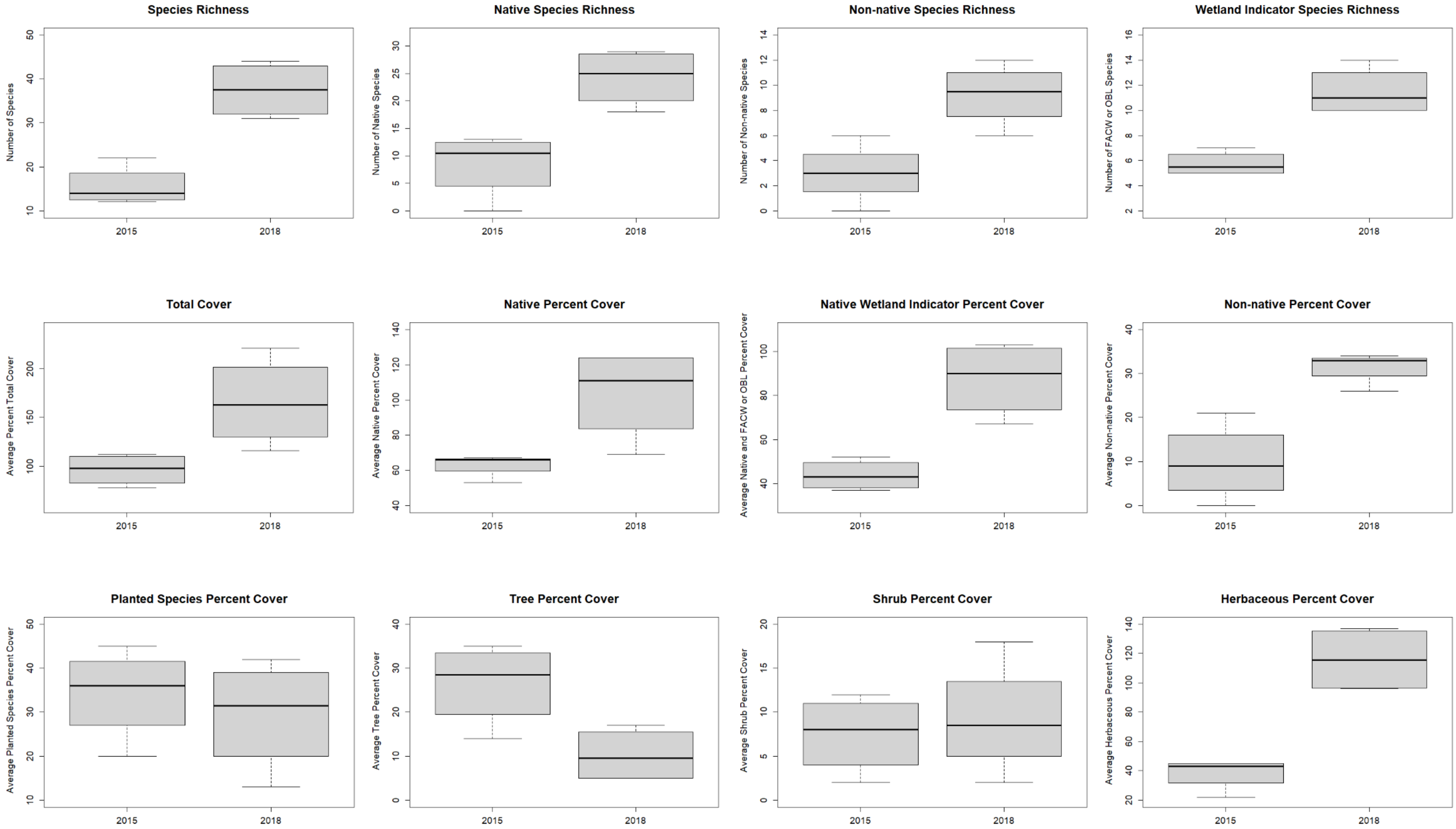

Figure 24. Boxplots illustrating median (bold horizontal line), 25% and 75% quartiles (box), and minimum and maximum values (whiskers) for 2015 pre-restoration and 2018 post-restoration species richness and percent cover metrics.

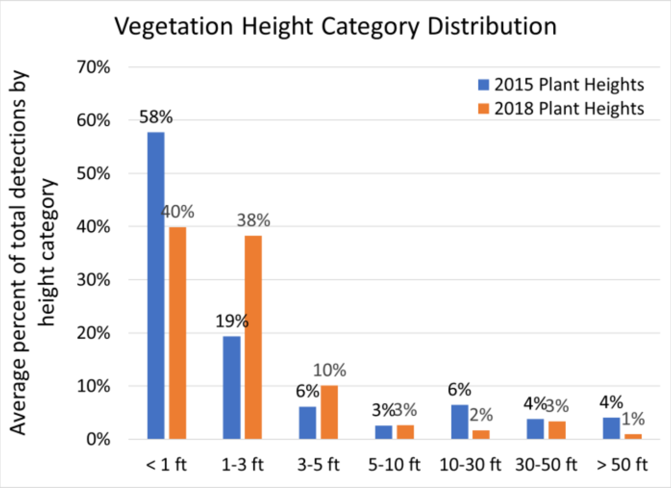

Figure 25. Plant heights shifted to fewer short and more taller plants from 2015 to 2018, consistent with planting, seeding, and natural recruitment of native grasses, sedges, rushes, bulrushes, shrubs and trees during restoration that exhibit greater structural diversity than the pre-restoration community.

Unexpected results for some metrics including the apparent reduction in tree species and slight decrease in percent cover of planted species may reflect sampling error resulting from our small sample size of four transects and failure to locate transects precisely when repeating sampling in 2018. Five transects were established and sampled in 2015 but the upstream-most transect was not ultimately included in the final restoration project extent and therefore was not sampled in 2018. Transect ends were monumented in 2015 but were not able to be located in 2018. Instead, 2018 transect origins were located as close as possible to 2015 transect origins using Avenza maps of aerial imagery and 2015 transects on an iPad and were laid out from those origins using the same azimuth as in 2015. Even if we had been able to locate monumented transect ends, very slight variations in tape placement resulting from how it falls on vegetation can easily result in detecting different species than those detected in an earlier sampling event.

Community composition results show both species richness and abundance doubling or tripling post-restoration for most metrics. Project Objective 2 as initially written was to increase riparian and wetland plant species diversity (a measure of species richness and evenness) and distribution throughout the project area; we instead report only species richness which we have since come to consider to be an equally suitable measure of project success. Although restoration project hypotheses and objectives did not specifically address plant community species richness and abundance, and richness and abundance of specific desired components of the plant community such as native and wetland indicator species, the observed increase in most metrics is consistent with vegetation characteristics of anastomosing stream evolution stages wherein dynamic channels connected to the floodplain support the highest possible biodiversity, both species richness and trophic diversity; highest proportion of native species; and highest primary (as well as secondary) productivity (Cluer and Thorne, 2013).

### *Macroinvertebrates*

#### Whychus Canyon Reach 4: WC1100

Most macroinvertebrate community metrics assessed in samples taken in the post-restoration primary channel at WC1100 show a strong initial negative impact from restoration activities followed by a rapid recovery to conditions equivalent to or better than those observed pre-project, consistent with trends observed following restoration at Camp Polk Meadow Preserve and Whychus Floodplain (Mazzacano 2017). The only year in which the target number of subsampled organisms was not attained at WC1100 was 2017, one year following restoration (45 organisms total; Figure 26). By 2018, and again in 2019, abundance was similar to that observed pre-restoration with the exception of the PM2 (Proportional Multi-habitat) sample collected in 2019 from the WC1100-1 reach in the “Lower Delta”, which encompassed lengths of both primary and side channel. Total diversity and EPT richness nearly doubled post-restoration in RT (Riffle Targeted) and PM primary channel samples, and both taxa richness and EPT richness in RT samples were significantly higher post-restoration (Figure 27). Similarly, IBI and PREDATOR scores, which plummeted in 2017, recovered post-restoration. Whereas pre-restoration IBI scores indicated moderate to slight impairment, 2018 and 2019 IBI scores indicated unimpaired conditions. PREDATOR scores suggested a less dramatic recovery, to the same good to near-fair conditions observed pre-restoration (Figure 28).

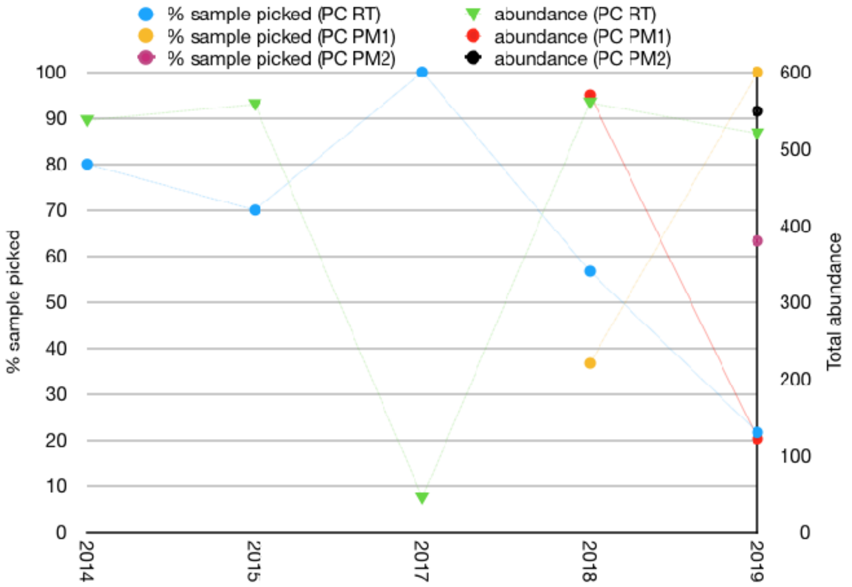

Figure 26. Proportion of sample needed for sub-sampling and resulting organismal abundance at WC1100 in all sampling years. Only samples taken in the primary channel (PC) are shown. The PM1 (Proportional Multi-habitat 1) and RT (Riffle Targeted samples were taken in the same reach at the same time in 2018-2019.

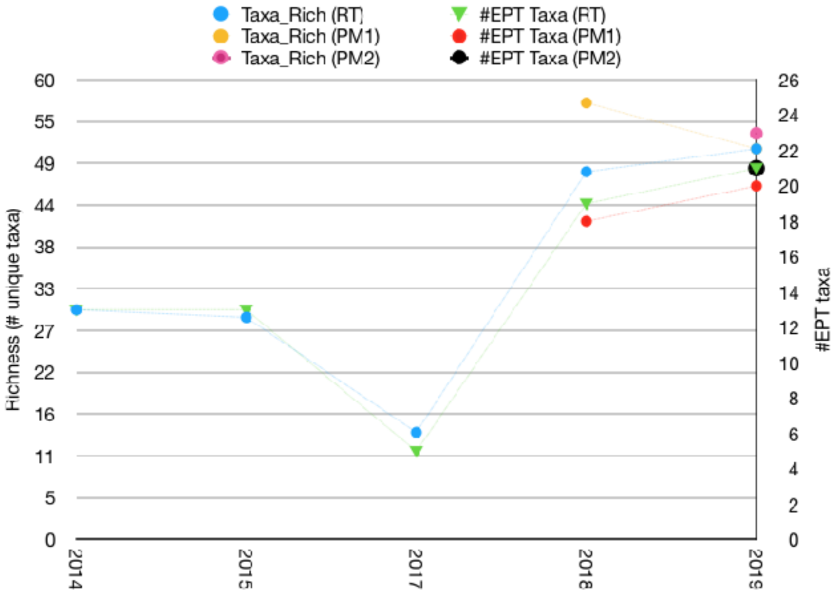

Figure 27. Sample richness and EPT diversity at WC1100 in all sampling years. Only samples taken in the primary channel are shown. The PM1 and RT samples were taken in the same reach at the same time in 2018-2019. For this metric in the ORDEQ IBI, > 35 total taxa receives the highest scaled score.

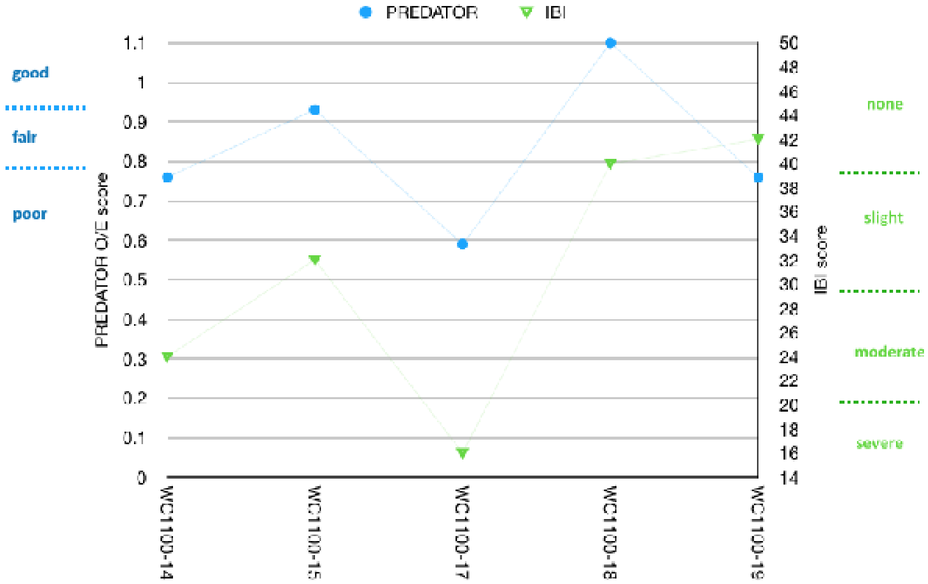

Figure 28. PREDATOR O/E and ORDEQ IBI scores at WC1100 from 2014-2019 Only RT samples taken in the primary channel are shown.

Taxa characterized as sensitive, which indicate cooler and lower-sediment conditions, and taxa characterized as tolerant, which indicate warmer and higher-sediment conditions, both increased over pre-project numbers following restoration. Sensitive taxa were not collected in any pre-restoration sample at the WC1100 site but were collected in numbers ranging from 3 to 5 in 2018 and 2019 RT and

PM samples (Figure 29). The number of sediment-sensitive taxa, while low, increased after 2017 to exceed pre-restoration numbers in 2019. Relative abundances of tolerant and sediment-tolerant taxa stabilized at or slightly above pre-restoration numbers after peaking in 2017 (Figure 30). In 2019, the relative abundance of tolerant organisms remained at or below the cutoff to receive the highest scaled IBI score (<15%) in RT and PM samples, despite being slightly higher than pre-restoration. The proportion of sediment-tolerant taxa remained very low at 1% in the RT and PM sample from the same reach, well below the cutoff to receive the highest scaled IBI score (<10%).

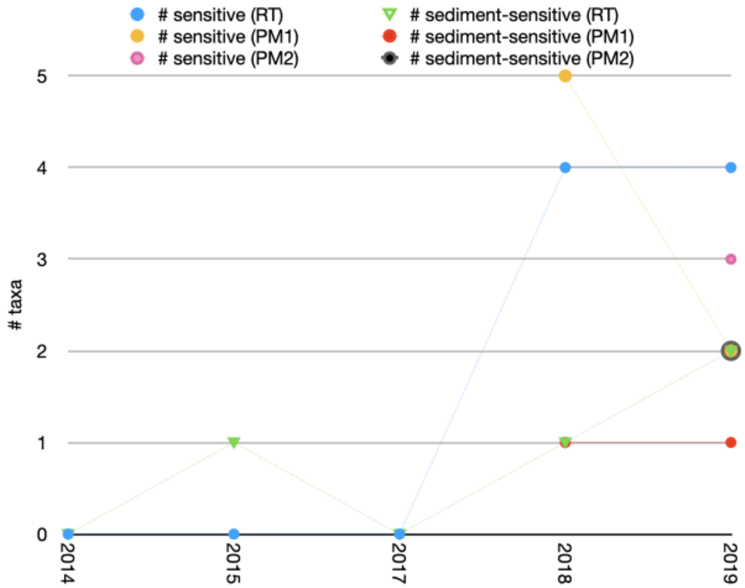

Figure 29. Numbers of sensitive and sediment-sensitive taxa at WC1100 in all sampling years. Only samples taken in the primary channel are shown. The PM1 and RT samples were taken in the same reach at the same time in 2018-2019. In the ORDEQ IBI, the highest scaled score correlates with >4 sensitive and >2 sediment-sensitive taxa.

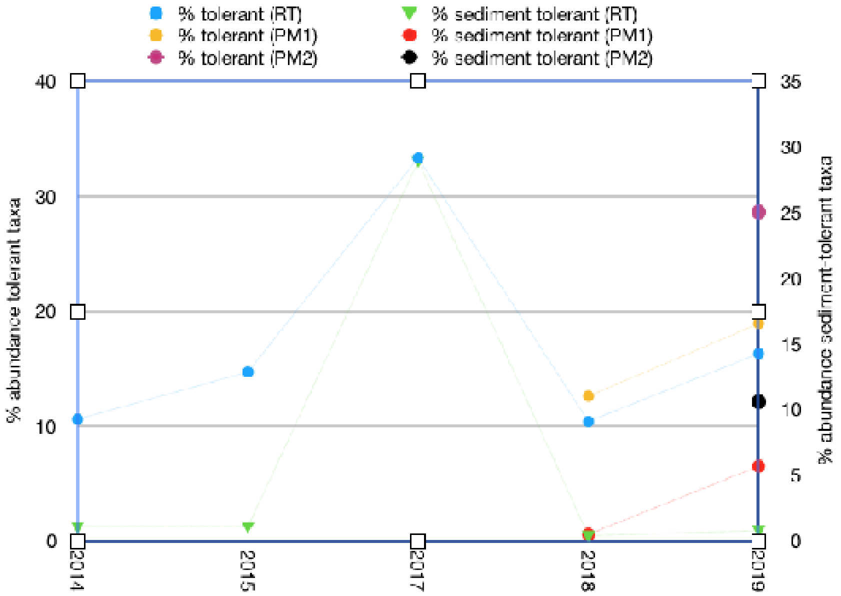

Figure 30. Numbers of tolerant and sediment-tolerant taxa at WC1100 in all sampling years. Only samples taken in the primary channel are shown. The PM1 and RT samples were taken in the same reach at the same time in 2018-2019. In the ORDEQ IBI, the highest scaled score correlates with <15% tolerant and <10% sediment-tolerant taxa

Since restoration, the community in RT samples is more balanced than pre-restoration, with dominant taxa that prefer faster flows and are present at lower overall abundances (Figure 31). In no pre-restoration sampling year nor in 2017 was the top taxon abundance low enough to receive the highest scaled score in the IBI for this metric (<20%), with almost a third of the 2017 RT sample consisting of tolerant and sediment-tolerant burrowing worms (Oligochaeta). With the exception of one PM sample, top taxon abundance in 2018 and 2019 samples was low enough to receive the highest scaled score in the IBI, and in both 2018 and 2019 the dominant taxon in RT samples and in one PM sample was a sediment-sensitive DEQ low sediment indicator taxon which prefers clear flowing water (*Baetis tricaudatus*, small minnow mayfly); in both years the remaining PM samples were dominated by a tolerant and ubiquitous non-biting midge adapted to a wide range of habitats and ecological conditions (*Tanytarsus)*.

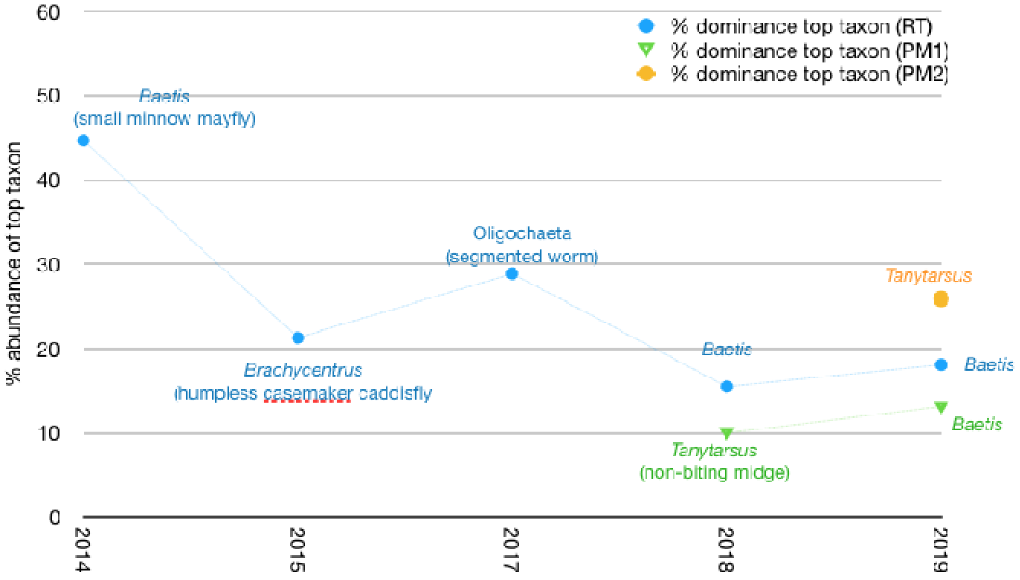

Figure 31. Relative abundance of the numerically dominant taxon at WC1100 in all sampling years. Only samples taken in the primary channel are shown. The PM1 and RT samples were taken in sampling reach WC1100-2 at the same time in 2018-2019, and the PM2 sample was collected from sampling reach WC1100-1 in the “lower delta” in 2019. In the ORDEQ IBI, the highest scaled score correlates with <20% abundance of the top taxon.

There was no significant difference between the pre- and post-project means for sediment or temperature optima or the number of any DEQ sediment or temperature indicator taxa. Community temperature optima were almost identical in every sampling year (17.0-17.1°F) and were slightly higher in PM samples than in RT samples; community sediment optima reflect the pattern described above for sediment-tolerant organisms (Figure 32). The number of DEQ warm temperature indicators has consistently exceeded cool indicators at this site, both pre- and post-restoration, and in RT samples is similar pre-and post-restoration, with 1-3 more warm temperature indicator taxa in PM samples than in RT samples post-restoration (Figure 33). Cool indicator taxa recovered following restoration, with more cool indicator taxa in the 2019 RT sample than in any other year. Sediment indicator taxa show a similar pattern, with high sediment indicators outnumbering low in every sampling year both pre- and post-restoration, and higher by one taxon in RT samples post-restoration. The number of high sediment indicator taxa in PM samples collected in 2018 and 2019 was higher than numbers observed in RT samples, with 6-10 high sediment indicator taxa compared to five in RT samples in these years. The number of low sediment indicators in RT samples increased after 2017 to equal the number observed pre-restoration (Figure 34).

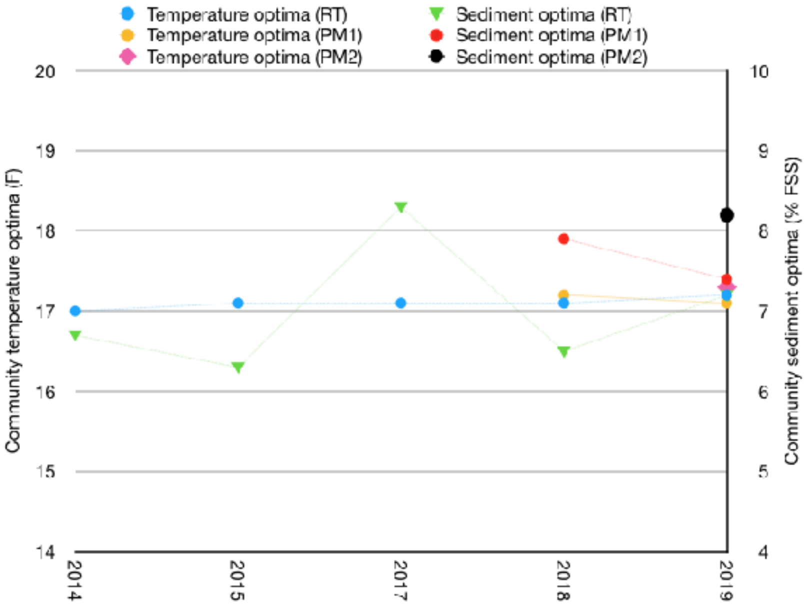

Figure 32. Temperature and fine sediment optima of the community at WC1100 in all sampling years. Only samples taken in the primary channel are shown. The PM1 and RT samples were taken in the same reach at the same time in 2018-2019.

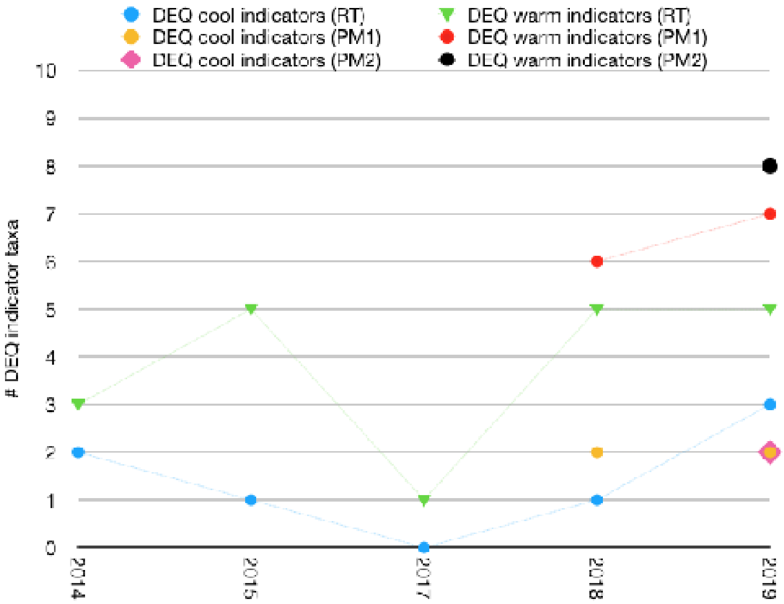

Figure 33. Number of ORDEQ cool and warm temperature indicator taxa at WC1100 in all sampling years. Only samples taken in the primary channel are shown. The PM1 and RT samples were taken in the same reach at the same time in 2018-2019. Note that these taxa do not account for the temperature associations of all taxa in a sample.

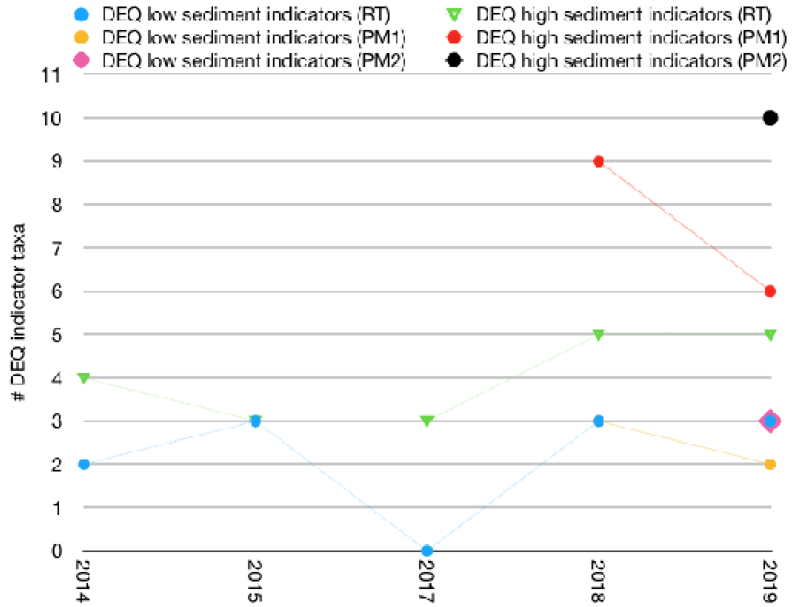

Figure 34. Number of ORDEQ low and high sediment indicator taxa at WC11100 in all sampling years. Only samples taken in the primary channel are shown. The PM1 and RT samples were taken in the same reach at the same time in 2018-2019. Note that these taxa do not account for the sediment associations of all taxa in a sample.

CLUSTER analysis differentiates the 2018 and 2019 macroinvertebrate communities from pre-restoration communities, with the highly disrupted post-restoration community in 2017 as an outlier (Figure 35), with secondary channel communities becoming more similar to primary channel communities in 2018 and 2019 than in 2017. The overall average dissimilarity between pre-project (primary channel) and post-project (2018-2019, primary and primary/secondary channel only) samples was 47.5%; taxa that contributed the most were a tolerant tribe of non-biting midge characterized by lower abundance post-project (Chironominae); the sediment-sensitive DEQ low sediment indicator *Baetis tricaudatus* also characterized by lower abundance post-project (but the dominant taxon in RT samples in 2018-2019); and another non-biting midge tribe, Tanytarsini, which are tolerant of warmer and more sedimented habitats and were more abundant post-project.

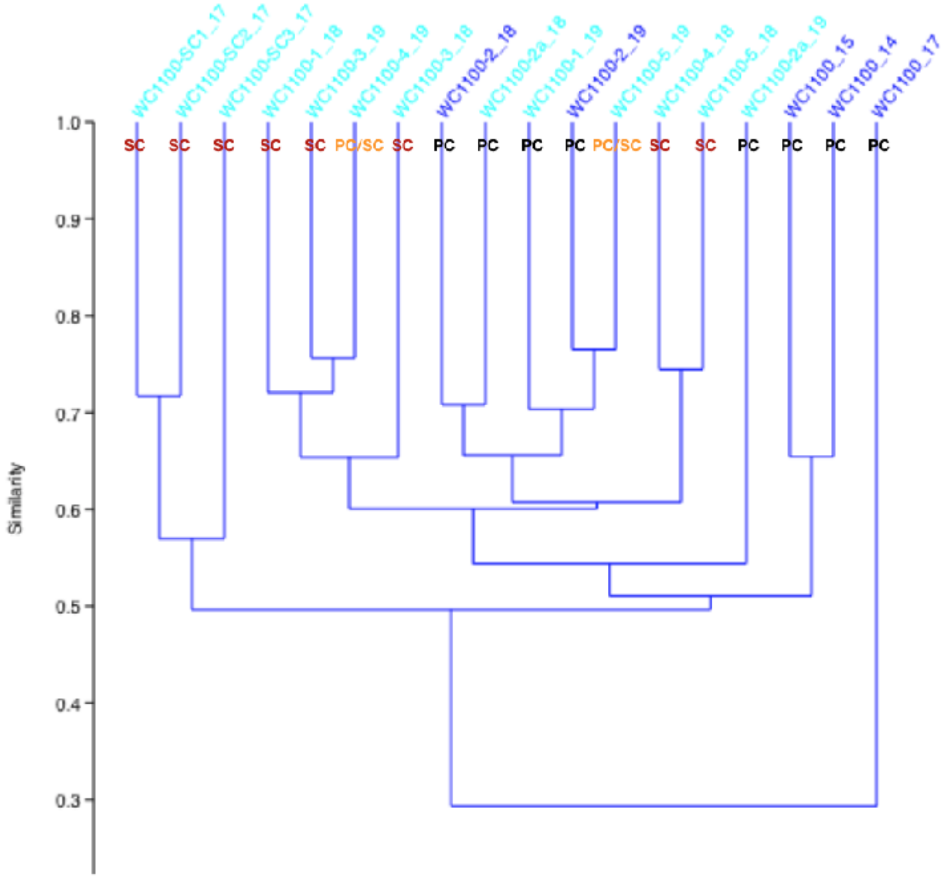

Figure 35. CLUSTER dendrogram of the WC1100 macroinvertebrate community in all sampling years. Blue = RT, aqua = PM. The numeral in each label indicates the sampling year.

Similarly, in a PCA ordination of taxa from all years and channel types, taxa with the highest loading on axis 1, which explained 26% of the total variation, were Chironomini and Tanytarsini; taxa with the highest loading on axis 2, which explained an additional 17% of variation, were *Simulium* black flies*,* collector-filterers in fast waters and often a post-restoration pioneer species*;* and *Zapada cinctipes*, a spring stonefly that feeds by shredding and is associated with cold waters in a variety of flows (abundant in 2017 side channel samples).

In a PCA ordination of traits measured as relative abundances for all years and channel types, axis 1 explained 57% of the variation; factors with the highest loading were relative abundances of collectors (overall more abundant in RT samples prior to 2018) and of predators (more abundant in 2017 side channels). Axis 2 explained an additional 17% of variation, with relative abundance of the dominant taxon (lower after 2017) and of scrapers (overall more abundant in 2019) having the highest loading. In traits from just the 2018-2019 communities (Figure 42), axis 1 of the PCA explained 50% of the variation, with relative abundance of erosional- and mixed flow-associated taxa, which tend to distinguish RT from PM samples, having the highest loading; and on axis 2, which explained an additional 27% of the variation, relative abundance of multivoltine (higher in 2018 samples) and cool/cold-associated individuals (higher in 2019 samples) had the highest loading.

## Downstream of Reach 4: WC1025

Macroinvertebrate community data from site WC 10.25, approximately a quarter mile downstream of the Whychus Canyon Reach 4 Phase I restoration project, provide some additional insight into stream temperature and fine suspended sediment conditions pre- and post-restoration. This site was not sampled in 2018; in 2019 we collected a PM sample at this site for the first time did not collect an RT sample. Because PM samples are collected from all habitats represented in a sampling reach, including sand and silt substrates, and flow type is incidental, whereas RT samples are collected only in riffles, PM samples by design represent a broader range of habitat conditions, including a broader range of stream temperature and sediment conditions.

At WC 10.25, temperature optima and cool and warm indicator taxa suggest an increase in temperature from 2017 to 2019 (Figure 36, Figure 37). Whereas community temperature optima in targeted riffle samples changed little pre-restoration to one year post-restoration in 2017, the temperature optima of the 2019 proportional multihabitat sample was the highest of any year, at 18°C. The number of DEQ cool indicator taxa increased from 2015 through 2017 and fell in 2019, while warm indicator taxa exhibited the opposite trend. Both cool and warm indicator taxa in 2019 were within the range observed pre-restoration.

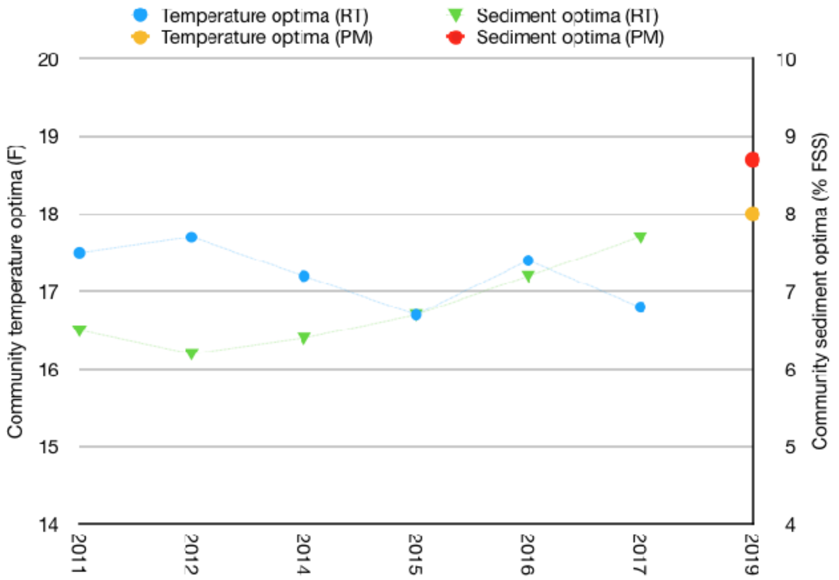

Figure 36. WC 10.25 macroinvertebrate community temperature optima from 2011 through 2019. The site was not sampled in 2018 and in 2019 a proportional multi-habitat sample was collected.

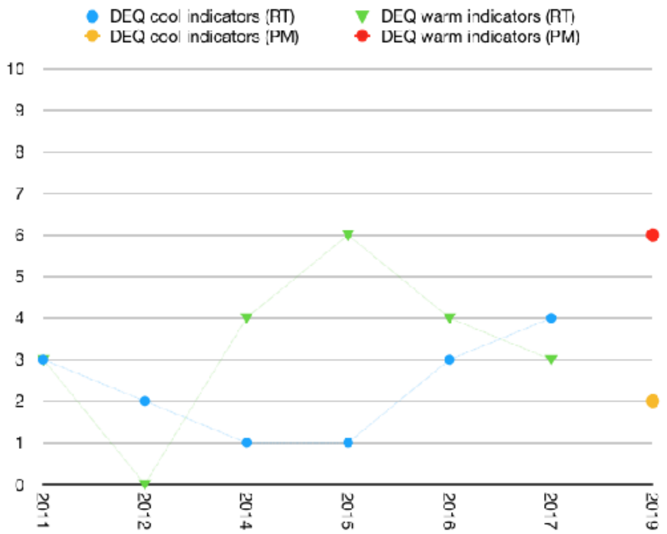

Figure 37. WC 10.25 DEQ cool and warm indicator taxa numbers from 2011 through 2019. The site was not sampled in 2018 and in 2019 a proportional multi-habitat sample was collected.

DEQ sediment optima at WC 10.25 show a consistent increasing trend beginning in 2012 that was unchanged by restoration implementation at Whychus Canyon Reach 4 in 2016 (Figure 38). The increase in fine sediment optima is slightly higher from 2017 to 2019 than between previous years, likely reflecting both the use of the PM protocol instead of the RT protocol in 2019 and the absence of 2018 data. The number of DEQ low sediment indicators has remained consistent since 2011 regardless of sampling protocol, with one less taxon in 2014 than in other sampling years. Consistent with sediment optima results at this site, DEQ high sediment indicator taxa numbers increased from 2012 to 2014, fell in 2016 and 2017 (during and one year after restoration project implementation one-quarter mile upstream), and dramatically increased in 2019, coincident with the introduction of the PM sampling protocol at this site.

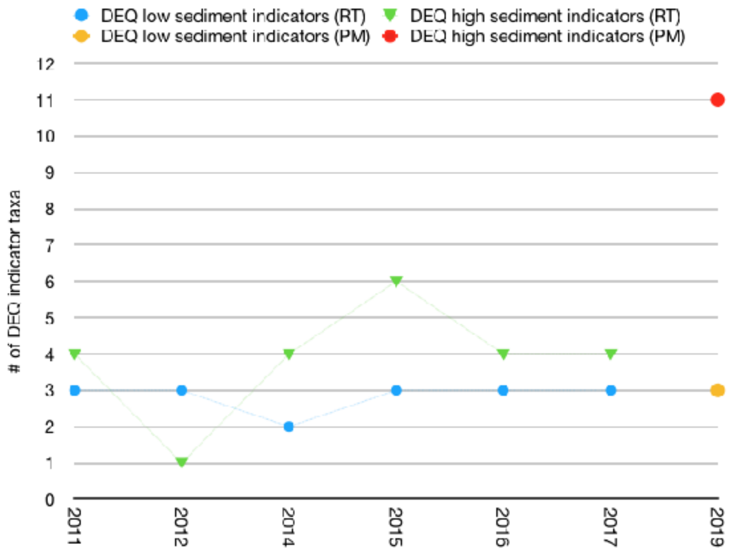

Figure 38. Number of ORDEQ low and high sediment indicator taxa at WC1025 in all sampling years. RT samples were taken in every sampling year except 2019, when a PM sample was taken. Note that these taxa do not account for the sediment associations of all taxa in a sample.

Macroinvertebrate community metrics describe a diverse community responding to heterogeneous flow, temperature and sediment conditions, with marked increases in taxa richness and values for many Index of Biological Integrity metrics better than those observed within the project reach at any previous time. Raw abundance of macroinvertebrates in collected samples did not increase. But, macroinvertebrate abundance as measured in collected samples was as of 2019 multiplied across twice the amount of aquatic habitat characterizing the project reach post-restoration. Taxa richness increased significantly as did richness of sensitive, EPT taxa, supporting our hypothesis that increased habitat diversity would support higher taxa richness.

2018 and 2019 were the first years in which IBI scores indicated an unimpaired stream condition at the WC1100 site, the best possible status, and in which the top taxon abundance was low enough to receive the highest scaled score in the IBI. While PREDATOR scores fluctuating between poor and good conditions over three years post-restoration did not support the improvements suggested by the IBI, the PREDATOR model has consistently resulted in lower scores indicating worse conditions than the IBI on Whychus Creek.

Sensitive taxa associated with cool temperatures and low sediment conditions never before found at WC1100 were found for the first time in 2018 and again in 2019, suggesting post-restoration stream conditions are cool and clear enough to support these taxa whereas pre-restoration stream conditions were not. Similar relative abundances of tolerant and sediment-tolerant taxa pre- and post-restoration suggest stream conditions did not become more favorable for these taxa post-restoration.

Multiple macroinvertebrate community temperature metrics suggest stream temperatures within the project reach did not change following restoration, with cool indicator taxa in 2019 higher than in any other year pre- or post-restoration suggesting a possible cooling effect. Little to no change in community temperature optima pre- and post-restoration, warm indicator taxa numbers within pre-restoration ranges, and numbers of cool indicator taxa equal to or higher than pre-restoration all suggest the macroinvertebrate community is experiencing similar or cooler stream temperatures post-restoration as prior to project implementation. Sediment optima means pre- and post-restoration were not significantly different, but high sediment indicator taxa in post-restoration targeted riffle and proportional multiple habitat samples suggest some increase in sediment conditions.

Results from WC1025 indicating an increase in temperature and sediment from 2017 to 2019 are consistent with results over this interval from other sampling locations both upstream and downstream on Whychus Creek (Mazzacano 2020). Interestingly, cool and warm indicator taxa at WC 10.25 closely track stream flow trends (2015 and 2019 were drought years and 2017 was a wet year), whereas cool and warm indicator taxa at WC 11.00 do so less, suggesting a possible buffering effect of the restoration project on the environmental variability experienced by macroinvertebrates within the project reach. It is also important to note that the WC 10.25 site had not been restored during the years for which data are presented and was characterized by a simplified, confined channel disconnected from the floodplain, so any temperature benefits associated with floodplain re-activation in the upstream, restored WC 11.00 site that the macroinvertebrate community there might have been responding to, such as hyporheic exchange, groundwater inputs, and structural diversity, would not be expected to be occurring at WC 10.25.

## *Fish Populations*

### Redd Counts

PGE conducted redband redd counts at Whychus Canyon in 2013 and in 2017 through 2019, as well as in additional reaches along Whychus Creek. The 2013 survey reach was designated only as “Whychus Canyon site” and no coordinates were recorded; although it’s not possible to determine whether 2013 redd surveys were conducted in restoration Reach 4 or Reach 3, the survey represents pre-restoration data and provides information about pre-restoration spawning habitat.

Redband redd counts in Whychus Canyon Reaches 3 and 4 show little change in number of redds pre- and post-restoration (Table 18). One redd was detected over the course of four survey events in 2013 pre-restoration. Post-restoration, four total redds were detected during five survey events in Whychus Canyon Reach 4 between 2017 and 2019. One redd was detected in Reach 3 during two survey events from 2017 to 2018. Reach 3 was not surveyed in 2019.

Redband redd numbers observed at Whychus Canyon Reaches 3 and 4 were similar to numbers observed in other reaches where extensive modifications to the stream channel and stream habitat have occurred. Redd numbers were somewhat higher at Camp Polk, where restoration implementation was completed in 2012, and notably higher at RKM 2, Wood Pecker, and Alder Springs sites (PGE site names Reach 2, Reach 2a, and Reach 2 b).

Table 18. PGE redband redd survey data in 2013, before implementation of restoration at Whychus Canyon Reach 4, and from 2017 through 2019, one to three years after restoration, from all Whychus Creek sites surveyed. “Ns” indicates not surveyed.

| Site Description | PGE Site Name | 2013 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| RKM 2 | Reach 2 | 14 | 2 | 15 | 9 |
| Lewis Woodpecker Creek | Reach 2a | 2 | 0 | 2 | 3 |
| Alder Springs | Reach 2b | 4 | 0 | 8 | 0 |
| Road 6360 | Reach 10 | ns | 0 | 1 | 1 |
| Rimrock Ranch | Reach 13 | ns | 0 | 2 | 1 |
| Whychus Canyon Reach 4 | Reach 17 | 1 | 2 | 1 | 1 |
| Whychus Canyon Reach 3 | Reach 18 | ns | 0 | 1 | ns |
| Aspen Hollow | Reach 24 | ns | ns | 1 | 0 |
| Camp Polk | Reach 25 | 2 | 3 | 4 | 5 |
| Willow Springs (Cyrus) | Reach 26 | 1 | 2 | 1 | 1 |
| Floodplain | Reach 35 | ns | 1 | 1 | 2 |

ODFW and USFS conducted brown trout redd counts in Whychus Canyon Reach 4 in 2017 and 2018, and in Camp Polk from 2017 through 2019, to provide additional information about spawning habitat in restored reaches (Table 19). In contrast to numbers of redband redds in the two reaches, which were consistently higher at Camp Polk, numbers of brown trout redds were similar in the two reaches in 2017 and 2018, suggesting similar spawning habitat quality in the two reaches in these years.

Table 19. Brown trout redd survey data from 2017 through 2019 at Camp Polk and at Whychus Canyon Reach 4. Restoration implementation at Camp Polk was completed in 2012; implementation at Whychus Canyon Reach 4 was completed in 2016. “Ns” indicates not surveyed.

| Site Description | 2017 | 2018 | 2019 |
|---|---|---|---|
| Whychus Canyon Reach 4 | 3 | 6 | ns |
| Camp Polk | 4 | 6 | 30 |

Redband trout redds at Whychus Canyon Reach 4 remained low through 2019. The number of redds detected at Whychus Canyon Reach 4 in each year it was surveyed pre- and post-restoration was similar to the number at every other survey reach upstream of Alder Springs, except in the restoration reach at Camp Polk where numbers were slightly but consistently higher. Notably, redband redd numbers at Whychus Floodplain, restored in 2014, were also not higher than in other unrestored reaches. Redband redd numbers have consistently been highest in the reaches surveyed in the vicinity of Alder Springs. Although brown trout redd survey data are limited, Whychus Canyon supported very close to the same numbers of redds as Camp Polk in 2017 and 2018, suggesting fall spawning habitat quality for brown trout in this reach might be similar to that at Camp Polk.

Although brown trout and redband spawn at different times of year, redband in late winter to early spring and brown trout in the fall, they otherwise have similar spawning requirements. Stream habitat survey data from 1997, prior to meaningful stream flow or habitat restoration in Whychus Creek, resulted in poor ratings for steelhead and Chinook spawning and emergence along 13.6 miles of Whychus; this rating was driven by fine sediments exceeding the 20% maximum fine sediment criterion. Habitat survey data from 2008, 2009, and 2011, subsequent to meaningful flow restoration but prior to stream habitat restoration, resulted in poor ratings for spawning and emergence driven by fine sediments > 20% (8.2 miles) and by gravels < 15% and cobble < 10% (1.8 mi). Additionally, partners have expressed concerns about fine sediment deposition in the Whychus Canyon Reach 4 project reach reducing the quality of spawning habitat in riffles. Because redband trout spawn in late winter and early spring, after winter high flows and while flows are still high before diversion for irrigation begins in April, we would expect fine sediment in riffles to be lower during redband spawning than during brown trout spawning, potentially providing better spawning conditions.

Abundant groundwater inputs enter the historic Whychus Creek floodplain at Camp Polk from the surrounding geology but are not present at Whychus Floodplain or at Whychus Canyon. One possible explanation for higher rates of spawning observed at Camp Polk indicating better spawning habitat quality could be oxygenation of groundwater inputs through hyporheic exchange associated with the surrounding geology. The restoration project at Camp Polk Meadow is also the oldest of the three, with implementation completed in 2012 compared to 2014 at Whychus Floodplain and 2016 at Whychus Canyon Reach 4, with channel-forming processes including erosion and deposition having been occurring over a longer period, potentially resulting in higher-quality spawning habitat or a broader range of habitat conditions including higher-quality spawning habitat.

## Density

Electrofishing mark-recapture surveys were conducted in Whychus Canyon Reach 4 in 2015 and in 2018, and in Whychus Canyon Reach 3 in 2018. In 2018, two reaches of Whychus Canyon Reach 4 were surveyed, denoted as Lower and Upper Whychus Canyon Reach 4. O. mykiss data are available from Whychus Canyon from 2015 and from 2018, and from Whychus Canyon Reach 3 in 2018. Spring Chinook data are available from Whychus Canyon Reaches 3 and 4 from 2018.

O. mykiss data support both a Before-After and a Post Treatment comparison of density per 100 $m^2$ and per 100 m channel length (Table 20). There were 2.8 and 3.5 as many O. mykiss/ 100 m2 in Lower and Upper Whychus Canyon Reach 4, respectively, in 2018 as there were in Whychus Canyon Reach 4 in 2015, and there were 4.1 and 4.3 as many O mykiss / 100 m channel length in the Lower and Upper survey reaches in 2018 as there were in Whychus Canyon Reach 4 in 2015. Two years post treatment, in 2018, there were 1.9 and 2.4 as many O. mykiss/ 100 $m^2$ in Lower and Upper Whychus Canyon Reach 4 as there were in Reach 3 upstream, which is a control, unrestored reach representing the pre-restoration condition.

Table 20. Densities of O. mykiss/ 100 m2 and O. mykiss/ 100 m, confidence intervals, Before-After increase comparing pre- and post- restoration values in Whychus Canyon Reach 4, and Post-Treatment (PT) difference comparing 2018 values in Whychus Canyon Reach 4 to the unrestored control Reach 3.

| | Whychus Canyon Reach 4 – 2015 (pre) | | Whychus Canyon Reach 3 – 2018 (unrestored) | | Whychus Canyon Reach 4 – 2018 (3 yrs post) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower | | | | Upper | | | |
| | Density | CI | Density | CI | Density | CI | BA Change | Δ PT | Density | CI | BA Change | Δ PT |
| O. mykiss/ 100 m2 | 11 | 2 | 16 | 2 | 31 | 3 | 2.8 | 1.9 | 38 | 3 | 3.5 | 2.4 |
| O. mykiss/ 100 m | 108.4 | 24.7 | 120 | 18 | 447 | 46 | 4.1 | 3.7 | 463 | 42 | 4.3 | 3.9 |

Juvenile spring Chinook data support a comparison between the restored Whychus Canyon Reach and the unrestored (control) Whychus Canyon Reach 3 in 2018 (Table 21, Figure X). In Lower Whychus Canyon Reach 4 there were 6x as many spring Chinook per 100 $m^2$ and 16x as many spring Chinook per 100 m as in Whychus Canyon Reach 3. In the Upper survey reach there were 25x as many spring Chinook per 100 $m^2$ and 59x times as many spring Chinook per 100 m channel length as in Whychus Canyon Reach 3.

Table 21. Densities of juvenile spring Chinook/ 100 m2 and juvenile spring Chinoook/ 100 m in Whychus Canyon Reach 4 (restored, treatment) and Reach 3 (unrestored, control) in 2018.

| | Reach 3 - 2018 | | Reach 4 Lower - 2018 | | | Reach 4 Upper - 2018 | | |
|---|---|---|---|---|---|---|---|---|
| | Density | 95% CI | Density | 95% CI | Difference | Density | 95% CI | Difference |
| Spring Chinook/ 100 m2 | 0.6 | 0.2 | 3.4 | 0.7 | 5.7x | 14.4 | 2.3 | 24.5x |
| Spring Chinook/ 100 m | 4.4 | 1.3 | 48.6 | 10.1 | 16.4x | 176.1 | 28.2 | 59.4x |

Electrofishing data from 2015 and 2018 demonstrate that Whychus Canyon Reach 4 is supporting 3 to 4 times the number of resident and juvenile O. mykiss as it did pre-restoration, suggesting the project reach is providing higher-quality rearing habitat than pre-restoration (Figure 39). Data from Whychus Canyon Reach 4 and the adjacent unrestored control Reach 3 from 2018 show Reach 4 supporting 2 to 4 times as many juvenile and resident O. mykiss and 6 to 40 times the number of juvenile spring Chinook salmon as Reach 3 (Figure 40), indicating the restored reach is providing higher-quality habitat that better supports juvenile rearing than the unrestored reach.

O. mykiss and Chinook salmon fry and smolts have been released in multiple reaches of Whychus Creek over multiple years, including in 2018, both upstream and downstream of the Whychus Canyon Reach 4 restoration project. Restoration reaches have been prioritized as fry and smolt release sites because of the diverse habitat and velocity refugia they provide relative to unrestored, incised, and confined reaches. Although there is no question that fry and smolt releases artificially increased initial juvenile fish densities in Whychus Canyon Reach 4 when releases occurred in early spring in 2018, persistence of densities in this reach dramatically higher than pre-restoration or in the adjacent unrestored reach five or more months after releases at the time of electrofishing surveys suggests that habitat in Reach 4 was providing suitable velocities and other habitat features, such as cover, for rearing fish to be able to remain and survive in the restoration reach at higher numbers.

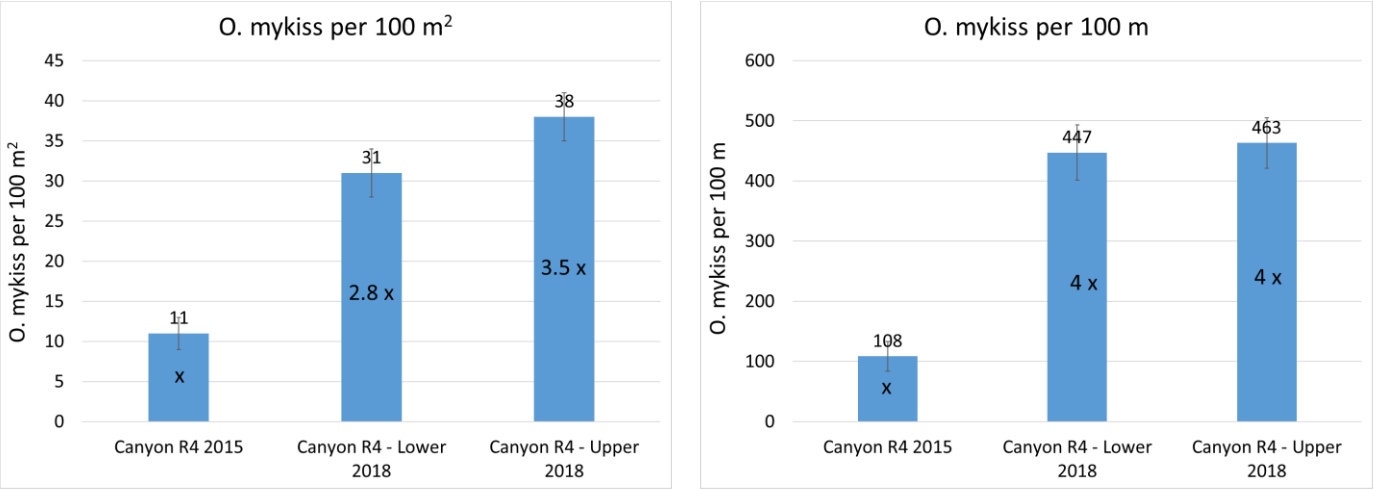

Figure 39. Resident and juvenile O. mykiss per 100 m$^2$ and per 100 m in Whychus Canyon Reach 4 in 2015 pre-restoration and in Lower and Upper survey reaches in Whychus Canyon Reach 4 in 2018, two years post-restoration.

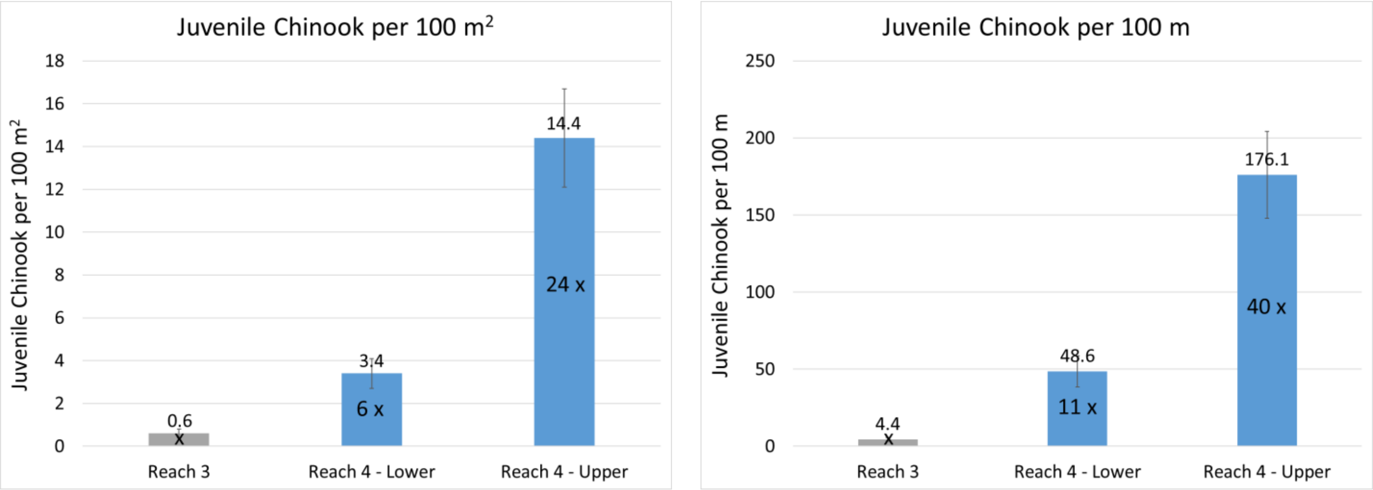

Figure 40. Juvenile spring Chinook salmon per 100 m$^2$ and per 100 m in the unrestored control Whychus Canyon Reach 3 and in Lower and Upper survey reaches in Whychus Canyon Reach 4 in 2018, two years post-restoration.

## Adult Migration

### 2017

Twenty adult spring Chinook salmon returned to the Pelton Trap at the Pelton Round Butte Hydroelectric Project in 2017. PGE captured and radio-tagged all 20 and released them into Lake Billy Chinook. Because of low visibility resulting from wildfire smoke, PGE was not able to use a helicopter to track radio-tagged fish in Whychus Creek in 2017. Two female Chinook were detected at the Scout Camp fixed station at the confluence of Whychus Creek and the Deschutes and might have entered Whychus, but no adult Chinook were detected in Whychus Creek in 2017 (Table X; R. Burchell, personal communication, email received Nov 10, 2017).

Thirty adult steelhead were captured at the Pelton Trap between September 23, 2016 and March 17, 2017. Four of the 2016-2017 run steelhead were detected at the Scout Camp fixed station during helicopter flights in November 2016 and February 2017, but none were detected in Whychus (R. Burchell, personal communication, email received Nov 10, 2017).

### 2018

Five Spring Chinook salmon returned to the Pelton Trap in 2018 and were passed above the Round Butte Dam. One male was detected at the Scout Camp fixed station on the Deschutes River Arm between July 19 and 22, and between July 26 and September 6. His carcass was discovered in Whychus Canyon Reach 4 September 19, and his tag was detected in Whychus Creek ~0.2 mi from the mouth on September 28, 2018.

Seventeen steelhead were passed above the Round Butte Dam during the 2017 to 2018 run. Four of these were detected at the Scout Camp fixed station. Of the four, one was detected in Whychus Creek ~1.25 miles from the mouth of the creek.

### 2019

In 2019, 47 known origin Spring Chinook returned to the Pelton Trap. Eleven of these (23%) entered Whychus Creek; one (300-93) was detected within Whychus Canyon Reach 4 on August 21 and September 16, 2019, but was subsequently detected by September 27 at the Scout Camp and DRA fixed stations. Ten (21%) remained in Whychus Creek. Of these, five were detected upstream of Whychus Canyon Reach 4, and of those five, four were first detected upstream of Whychus Canyon Reach 4 on or after August 14th, suggesting these fish might have migrated through the project reach at base flow. Four of the ten Chinook or their tags were last detected within Whychus Canyon Reach 4; two of these were radio tracked to deep pools, one was found as a carcass, and the fourth fish was not found but its tag was recovered. The farthest upstream detection for the tenth Chinook was in Whychus Canyon Reach 5.

Thirty-six adult steelhead returned to the Pelton Trap between September 17, 2018 and April 1, 2019; twelve of these were smolts that had been released into and outmigrated from Whychus Creek as indicated by a coded wire tag. All were released upstream of Round Butte Dam, and 35 were radio tagged. Four were detected at the Deschutes River Arm (DRA) fixed station. One of these (200-58) was detected in Whychus on four occasions between March 26 and April 17, 2019, between RKM 8 and 11, above and below the Road 6360 crossing. A second steelhead (200-15) which had been initially detected at the Crooked River Arm fixed station was detected in Whychus Creek on multiple occasions between March 26th and April 29th, 2019 but returned to the Deschutes River Arm.

Table 22. Returning adult Chinook and Steelhead tagged and released upstream of Round Butte Dam, last detected in Whychus Creek, last detected in Whychus Canyon Reach 4, and last detected upstream of Reach 4, from 2013 through 2019.

| | Chinook | | | | Steelhead | | | |
|---|---|---|---|---|---|---|---|---|
| | Tagged | Whychus | Reach 4 | Upstream of Reach 4 | Tagged | Whychus | Reach 4 | Upstream of Reach 4 |
| 2013 | 22 | 3 | 0 | 0 | 34 | 1 | 0 | 0 |
| 2014 | 24 | 0 | 0 | 0 | 49 | 0 | 0 | 0 |
| 2015 | 51 | 1 | 0 | 0 | 90 | 2 | 0 | 0 |
| 2016 | 54 | 5 | 0 | 0 | 45 | 2 | 0 | 0 |
| 2017 | 20 | 0 | 0 | 0 | 30 | 0 | 0 | 0 |
| 2018 | 5 | 1 | 1 | 0 | 17 | 1 | 0 | 0 |
| 2019 | 47 | 10 | 4 | 5 | 35 | 2 | 0 | 0 |

Prior to restoration at Whychus Canyon Reach 4 in 2016, the final detections for 9 Chinook salmon and 5 steelhead were in Whychus Creek. Two of these 14 fish were last detected in Whychus Canyon Reach 5 (Rimrock Ranch), the reach immediately downstream of Whychus Canyon Reach 4; the rest remained lower in the system, most below Alder Springs. Since restoration, eleven Chinook and three steelhead have entered and remained in Whychus. Ten of these 14, or 71%, were last detected in or upstream of the project reach, compared to none (0%) of the 16 adult Chinook and steelhead last detected in Whychus before restoration, although one steelhead was detected at Camp Polk (upstream of Whychus Canyon Reach 4) in 2016, pre-restoration, before descending to Rimrock Ranch. These data suggest that restoration at Whychus Canyon Reach 4 might have improved or provided access into and upstream of Reach 4 or made habitat within the project reach more attractive to returning Chinook and steelhead. However, an alternative explanation for the last detection of returning adults in the project reach is that passage was not sufficient for these fish to successfully migrate through the project reach. Pre-restoration depth data from 2011 stream habitat surveys show that 9% of habitat units were shallower than the 7.2” depth criteria UDWC uses to assess passage for adult Chinook and steelhead; further analysis could determine the cumulative length of habitat units shallower than the 7.2” depth criteria and over what total channel length depth was sufficient to provide passage. Although instantaneous flow for 2011 survey dates are not available, mean daily flow during the 2011 survey was 61 to 167 cfs, whereas 65 cfs and 33 cfs were the maximum mean daily flows during the 2017 and 2019 surveys, respectively, thus flow likely contributed to deeper stream depths during the 2011 survey relative to 2017 and 2019. Stream temperature could also have influenced adult migration upstream of Whychus Canyon Reach 4 pre- and post-restoration. Excessively high stream temperatures can also create thermal barriers to fish passage. Stream temperatures in reaches downstream of Whychus Canyon Reach 4 regularly exceed the 20˚C state temperature standard for migration corridor use, and in some years exceed the lethal 24˚C threshold, including in 2019 when 9 Chinook were last detected in or above Reach 4. Any cold water refugia that might be occurring in Whychus Canyon Reach 4 as a result of hyporheic exchange and late-summer groundwater inputs to surface water could be providing suitable temperature conditions in comparison to hotter downstream temperatures.

## Conclusions

Most geomorphic and habitat metrics monitored at Whychus Canyon Reach 4 demonstrate dramatic improvements in hydrologic connectivity and geomorphic and habitat heterogeneity and complexity and meet project objectives where defined, with trends supporting project hypotheses. These include the maintenance over three years post-restoration of groundwater within two feet of the floodplain surface, modest (2x) to dramatic (20x) increases in measures of amount and complexity of aquatic habitat, and large increases in key fish habitat features such as number of habitat units (6x), number of pools and complex pools (6x), pieces of wood (11x), and area of gravels (3x).

Multiple lines of evidence including both stream temperature data and macroinvertebrate community data indicate stream temperature has not increased in the project reach nor has the rate of warming through the project reach increased, with rates of warming similar to lower rates of warming observed pre-restoration and well below the pre-restoration ten-year maximum rate of warming. Multiple macroinvertebrate community temperature metrics suggest stream temperatures within the project reach did not change following restoration, with cool indicator taxa in 2019 higher than in any other year pre- or post-restoration suggesting a possible cooling effect.

For some geomorphic and habitat metrics we saw unexpected results (proportions of pools and riffles), results that represented an improvement over pre-restoration conditions but did not meet project objectives (channel elevations), or flat or negative trends for some metrics that can be interpreted as indicating specific habitat quality attributes are no better or worse than pre-restoration (percent fine sediment and number of pools ≥ 1 m deep). Although the number and area of both pools and riffles increased dramatically, the proportions of pools and riffles as number of units and as percent of wetted area changed very little following restoration, in contrast to the project hypothesis that percent pool would increase and percent riffle decrease, and the project objective to increase the percent pool habitat. Channel elevations that adjusted over three years post-project to lower than 2 feet below the target Geomorphic Grade Line indicated incision and a geomorphic trajectory toward simplification, and as a result prompted adaptive management of restoration project phases to reverse incision and promote aggradation at the downstream end of the project. Most surveyed elevations remained within 2 feet below or above the target elevation, indicating connectivity of channels to the floodplain surface at the threshold of the depth required for riparian vegetation establishment.

Percent cover values for fine sediment including sand, silt and organics increased post-restoration and three years post-restoration remained above 20%, resulting in a poor HabRate habitat quality rating for Chinook and steelhead spawning for the restoration project reach. Very similar AIP stream habitat survey fine sediment values were observed at the restoration project at Camp Polk Meadow Preserve four years after restoration (Mork and Zamarippa 2019); data are available to evaluate change in fine sediment at the Whychus Floodplain restoration project but have not been analyzed. AIP stream habitat surveys conducted in 1997 prior to meaningful stream flow restoration resulted in poor spawning habitat quality ratings driven by fine sediments > 20% (the threshold between fair and poor quality for both species) for 13.6 miles of Whychus Creek including the reach immediately downstream of Whychus Canyon Reach 4, which was not surveyed due to lack of access; 2008 surveys following meaningful stream flow restoration resulted in poor spawning habitat quality ratings for 10.5 miles of Whychus Creek including Whychus Canyon Reach 4. These data and the historic distribution of Pacific Lamprey in the Upper Deschutes Watershed suggest a higher proportion of fine sediment might be a natural condition in Whychus Creek, particularly in lower-gradient reaches of the creek; indeed, reaches that received fair or good spawning habitat quality ratings based on 2008 survey data largely represent confined canyon, higher-gradient transport reaches (Mork 2013). Ultimately it is not surprising that restoration projects that are designed to increase deposition and storage such as that implemented at Reach 4, rather than to balance sediment transport, also increase the amount and proportion of fine sediment characterizing restoration reaches.

Biological response to restoration as indicated by riparian vegetation, macroinvertebrate community metrics, juvenile fish densities, and adult migration into and through the restoration project has been overwhelmingly positive. Riparian vegetation data show the number of native species tripling, and total vegetation cover, native species cover, and wetland indicator cover doubling two years post-restoration. Although the number and percent cover of non-native species also tripled, the vast majority of these species are not invasive. Riparian herbaceous and shrub cover including sapling trees also approximately tripled, indicating establishment and recruitment of riparian herbaceous, shrub, and tree species across the new, connected floodplain one year following restoration. Macroinvertebrate community metrics describe a diverse community responding to heterogeneous flow, temperature and sediment conditions, with marked increases in taxa richness and values for many Index of Biological Integrity metrics better than those observed within the project reach at any previous time. Juvenile O. mykiss and Chinook salmon density data show habitat in the project reach supporting up to 4x as many juvenile fish as pre-restoration, and up to 59x as many juvenile fish as in the unrestored upstream reach. Adult migration data show that before restoration project implementation at Whychus Canyon Reach 4 only one returning adult steelhead or Chinook salmon had migrated upstream of this reach, whereas between 2017 and 2019 following project implementation 10 out of 14 total returning adult Chinook salmon and steelhead migrated as far upstream as the restoration project and beyond. Evidence of adult Chinook salmon and steelhead migrating through the project reach demonstrate the project provides passage, although it is not known whether these fish migrated at base flow. Passage surveys suggest the project reach provides passage for adult anadromous fish at flows down to 13 cfs along most (≥ 96%) of the length of the project; with installation of an automated SCADA (Supervisory Control And Data Acquisition) system to regulate headgates at the Three Sisters Irrigation District diversion, the frequency with which instantaneous flow falls below 15 cfs is expected to decrease. Although the number of redband redds has remained low in Whychus Canyon Reach 4, consistent with other reaches of Whychus Creek, the number of brown trout redds detected in Whychus Canyon Reach 4 in 2017 and 2018 was very similar to that at Camp Polk, where numbers of both brown trout and redband redds have been high compared to most other reaches of Whychus Creek, suggesting spawning habitat quality in Whychus Canyon Reach 4 might be similar to that at Camp Polk.

These data largely suggest the Whychus Canyon Reach 4 Stage 0 restoration project has resulted in dramatically improved aquatic habitat quantity and quality, a proliferation of macroinvertebrate taxa, increased fish use, and an expanded and more species- and structurally- diverse riparian vegetation community. UDWC will continue to monitor this and other habitat restoration projects on Whychus Creek to improve our understanding of habitat evolution including sediment dynamics. We will also continue to refine our monitoring methods and metrics. Opportunities for future monitoring include identifying and measuring metrics to better evaluate habitat quality for fish, resilience to climate change, and carbon sequestration and storage.

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## **APPENDIX A**: Whychus Canyon Reach 4 Monitoring Summary Table

**APPENDIX B**: Unmanned Aerial Vehicle Photographic Survey of Whychus Creek and Adjacent Riparian Areas (Garano et al. 2018).

**APPENDIX C**: Macroinvertebrate Monitoring at Selected Sites in Whychus Creek, Sisters, OR, 2019 (Mazzacano, 2020).

**APPENDIX D**: Whychus Creek Substrate Analysis: Quantifying Geomorphic Responses of Habitat Restoration Projects (Scagliotti, 2019).

**APPENDIX E**: Assessing the Wetlands of a Stage 0 River Restoration Project on Whychus Creek, Deschutes County, Oregon (Goss, 2020).