Upper Deschutes Watershed Council

Technical Report

2020 Whychus Creek Stage 0 Restoration Effectiveness Monitoring

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1. Introduction

Upper Deschutes Watershed Council (UDWC) and local partners including Deschutes Land Trust, USFS, and others have collaborated since the early 2000s to restore stream habitat in Whychus Creek for native fish, and specifically for summer steelhead and spring Chinook salmon reintroduction efforts in the Upper Deschutes basin starting in 2007 and 2009, respectively. In August 2016, UDWC and USFS implemented the first phase of restoration along 1 mile and across approximately 40 acres of Deschutes Land Trust's Whychus Canyon Preserve. We used a novel, valley-reset, process-based restoration design to re-establish the geomorphic, hydrologic, and biological processes that historically created networks of braided channels and floodplain supporting wet woodlands and grasslands across the western US, a suite of conditions and stage of stream evolution defined by Cluer and Thorne (2014) as "Stage 0". The Geomorphic Grade Line restoration design (GGL; Powers et al 2018) uses the valley slope and field markers to identify reference elevations throughout the project reach; during project implementation, high areas were graded down to and the incised channel was filled up to the approximate target project elevations provided by the GGL. The resulting newly constructed floodplain surface was roughened with locally-sourced wood and sedge mats sourced on-site, and the stream was diverted onto the roughened floodplain, re-activating the floodplain and beginning the process of channel and bedform evolution and floodplain building.

UDWC monitored the project reach pre- and post-restoration using data collected by UDWC and restoration partners following traditional survey and sampling methods. We used descriptive statistics and developed new analyses to use available data to better answer monitoring questions and quantify key restoration outcomes (Mork 2022). Through our own observations and ongoing dialogue with other restoration practitioners and researchers, we began to recognize that monitoring methods and metrics created for single-channel streams, many or most of which had been degraded and simplified by the time these methods were designed, likely did not adequately describe or provide information about the important and novel habitat features and processes occurring in the complex, connected and heterogeneous reaches restored using a GGL, valley-reset approach designed to achieve a multi-channel, anastomosing, wet woodland and meadow, Stage 0 condition. Traditional survey and sampling methods were also proving laborious and time-intensive and therefore expensive to implement across the relatively large spatial extents of new aquatic, wetland, floodplain, and riparian habitats created by these restoration projects. Aerial imagery from UAVs, acquired to specifications tailored for analysis of specific metrics, presented a potential opportunity to more efficiently, and possibly more cost-effectively, quantify key attributes of Stage 0 streams.

In fall 2018, UDWC, in close collaboration with restoration practitioners from Willamette National Forest, began conceptualizing a monitoring approach to 1) more efficiently and cost-effectively measure key outcomes of restoration designed to achieve a Stage 0 condition and 2) explore and identify metrics that would better account for and describe novel or previously rare habitat features and processes occurring in post-restoration, Stage 0 reaches.

In fall 2019, Oregon Watershed Enhancement Board funded three interrelated efforts to increase knowledge and understanding about the outcomes of Stage 0 restoration. UDWC on Whychus Creek, and McKenzie Watershed Council on the South Fork McKenzie River (SFMR), both in cooperation with USFS, designed and implemented coordinated Stage 0 Effectiveness monitoring projects in our respective geographies. Alongside this work, USFS Pacific Northwest Research led a series of Stage 0 restoration practitioners' workshops to build out a definition, key attributes of, and a structured decision model for, restoration toward Stage 0. Restoration practitioners from UDWC, McKenzie Watershed Council, USFS and Pacific Northwest Research, and other entities participated in these workshops and contributed to development of workshop products.

This report summarizes the resulting Stage 0 Effectiveness Monitoring project developed for and implemented on Whychus Creek in summer 2020, and presents monitoring results in the context of traditional monitoring approaches and complementary biological data. We provide recommendations for refining methods used in 2020 for future Stage 0 effectiveness monitoring on Whychus Creek, incorporated into the accompanying 2024 Whychus Creek Stage 0 Effectiveness Monitoring Study Plan and Protocol.

2. Methods

2.1. Project goal and objectives

This project aimed to develop and test methods for using geospatial analysis of remotely sensed data in combination with data from existing ground-based monitoring methods to better and more cost-effectively quantify pre- and post-restoration geomorphic and habitat conditions in Stage 0 stream restoration projects. We identified three specific project objectives to guide project development and implementation:

1. Develop and implement (test) remote sensing approaches to quantify key geomorphic and habitat metrics and indicators of Stage 0 on Whychus Creek restoration projects;
2. Generate new, high-resolution, spatially-referenced information about geomorphic and habitat conditions in restored and unrestored (baseline data) stream reaches;
3. Develop a monitoring study plan and protocol for monitoring future phases of Stage 0 restoration.

2.2. Approach

2.2.1. Technical Advisory Committee

To identify and develop a monitoring approach for using UAS and complementary ground-based measurements, UDWC convened a Technical Advisory Committee (TAC) of remote sensing experts and stream habitat restoration practitioners and researchers (Table 1). The TAC provided technical expertise to guide project development and design, including identifying geomorphic and habitat metrics we might be able to measure from imagery and complementary data we would need to collect on the ground to support analysis from imagery. The TAC also presented considerations and trade-offs for project technical aspects such as imagery specifications and software selection for imagery analysis that would influence cost and ability to apply the resulting methods. The TAC included USFS staff who were leading the parallel South Fork McKenzie River Stage 0 Effectiveness Monitoring project to facilitate shared learning and coordination.

Alongside recruitment of TAC members, UDWC partnered with USFS to submit the proposed monitoring approach for consideration by the USFS Geospatial Technology and Applications Steering Committee (GEOTASC). GEOTASC selects projects for analysis for the purpose of testing and advancing use of remote sensing for measuring and monitoring landscape metrics; selected projects are developed in close collaboration with the applicant and completed by Geospatial Technology and Applications Center

(GTAC) contractors. The project UDWC and USFS submitted, to include analysis of a subset of the Stage 0 metrics identified by UDWC and the TAC, was selected by GEOTASC, establishing GTAC as the entity that would perform analysis from imagery for some metrics.

Table 1. Technical Advisory Committee members, title, affiliation, and expertise (alphabetical).

Name	Title	Affiliation	Expertise
Matt Barker	Doctoral Student	Oregon State University	Remote sensing
Jonathan Burnett	Research Forester	USFS Pacific Northwest Research Station	Remote sensing
Kain Kutz	Remote Sensing Specialist	USFS Geospatial Technology and Applications Center	Remote sensing
Wyatt McCurdy	Remote Sensing Specialist	USFS Geospatial Technology and Applications Center	Remote sensing
Brandon Overstreet	Hydrologist	USGS Oregon Water Science Center	Remote sensing and hydrology
Cari Press	Hydrologist	USFS Sisters Ranger District	Hydrology and stream restoration
Abbey Schaaf	Remote Sensing Project Manager	USFS Geospatial Technology and Applications Center	Remote sensing
Dan Scott	Postdoctoral Research Associate	University of Washington	Remote sensing and fluvial geomorphology
Colin Thorne	River Scientist	University of Nottingham, Wolf Water Resources	Fluvial geomorphology
Joe Wheaton	Professor of Riverscapes	Utah State University	Fluvial geomorphology
Steve Wondzell	Research Ecologist	USFS Pacific Northwest Research Station	Riparian ecohydrology

2.2.2. Reach selection

We considered for inclusion Deschutes Land Trust Preserve reaches that had been restored or would be restored to a Stage 0 condition (Figure 1; Table 2):

- Camp Polk: Restoration implementation at Camp Polk Meadow Preserve using a modified Natural Channel Design had been completed in 2012. By 2020 the upstream 0.3 mile (project reaches 1 and 2) had evolved to an anastomosing, multi-channel condition; in downstream reaches, the channel had cut down away from the floodplain, degrading and widening.
- Whychus Canyon: Phase 1 of restoration using a Geomorphic Grade Line design was implemented at Whychus Canyon Preserve in 2016;
- Whychus Canyon at Rimrock Ranch: Restoration at Rimrock Ranch downstream was slated to occur in two subsequent sub-phases, 2a and 2b.
- Willow Springs: Restoration at a third Land Trust Preserve, Willow Springs, was being designed with Anabranch Solutions using a Low-Tech Process Based approach.

We selected all reaches described above except the downstream Camp Polk reaches for inclusion in 2020 Stage 0 effectiveness monitoring. Although including the downstream Camp Polk reaches would have presented the opportunity to compare outcomes of the two different restoration approaches, Natural Channel Design and process-based with Stage 0 as a target condition, the downstream Camp Polk reaches didn't exhibit the characteristics and attributes of Stage 0 we were wanting to better quantify and understand through the proposed monitoring project. Including these reaches would have also further stretched our already-lean capacity and budget.

We selected reaches that had been or would be restored toward Stage 0, with the intent to compare the same reaches pre- and post-restoration, or over time since restoration. Monitoring to support this comparison in all five reaches will be completed following restoration in the reaches unrestored as of 2020. Because some reaches surveyed in 2020 were unrestored and some restored, the 2020 datasets lend themselves to comparison of geomorphic and habitat metrics between unrestored and restored reaches in 2020. We make this comparison recognizing that the unrestored or pre-restoration condition on Whychus Creek varies across reaches; unrestored reaches monitored through this project were not selected for their similarity to the pre-restoration condition of restored reaches; and comparison of unrestored and restored reaches based on monitoring data from this project may provide limited or misleading information about the effectiveness of restoration and this should be considered when interpreting results.

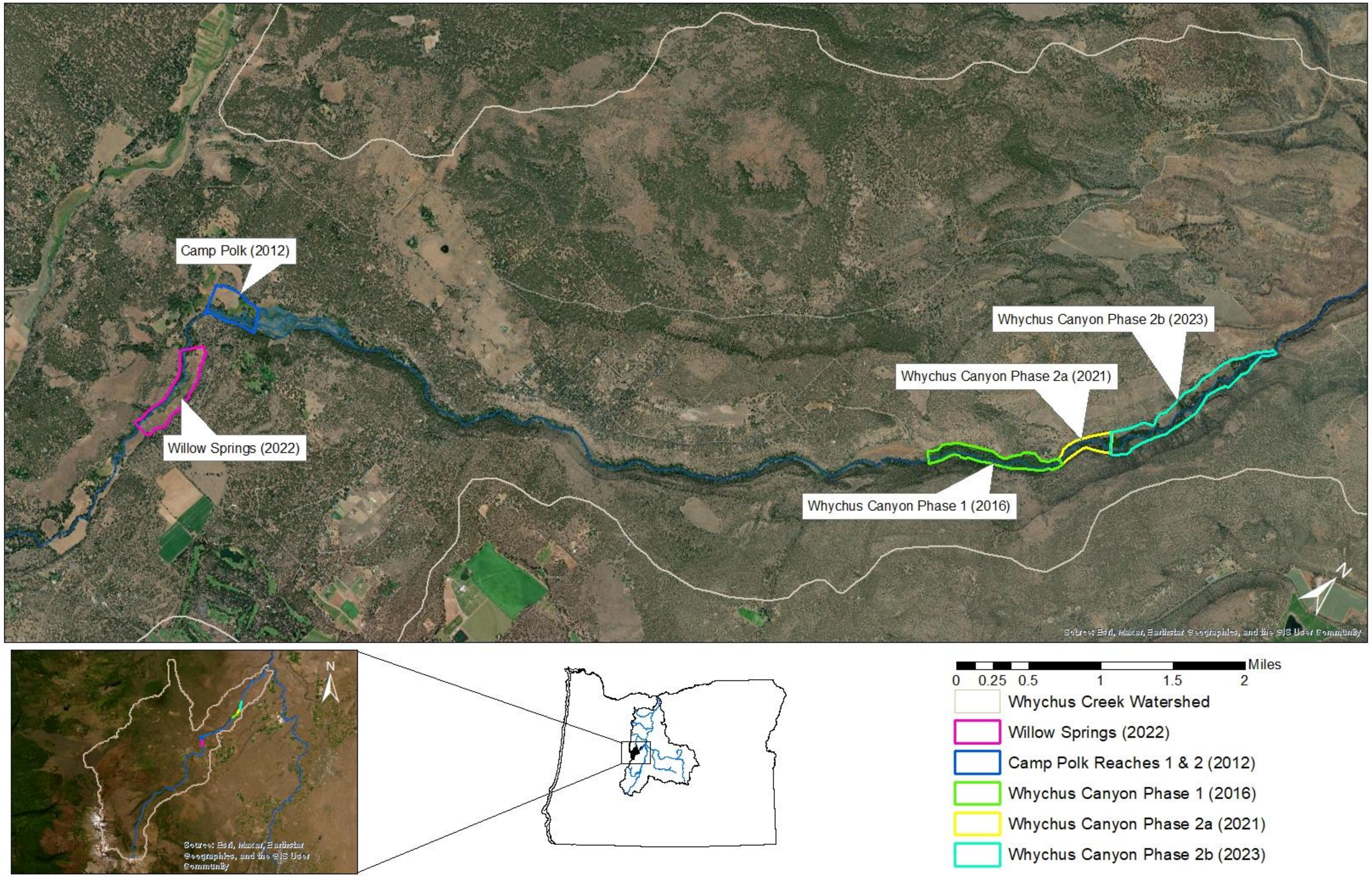


Figure 1. Whychus Creek reaches selected for 2020 Stage 0 Effectiveness Monitoring, within Deschutes Land Trust's Willow Springs, Camp Polk Meadow, and Whychus Canyon Preserves. Dates represent the year restoration implementation was completed.

Table 2. Deschutes Land Trust Preserve reaches considered for inclusion in 2020 Stage 0 Effectiveness Monitoring

Site	Valley Length (mi)	Acres	Notes	Justification
SELECTED				
POST-RESTORATION				
Whychus Canyon Phase 1	1	40	Stage 0 design (Geomorphic Grade Line; GGL), implemented in 2016	Only Stage 0 restoration project on Whychus Creek implemented using a GGL design approach at study initiation.
Camp Polk Reaches 1-2	0.3	~13	Modified Natural Channel Design but demonstrating Stage 0 characteristics, implementation completed in 2012	Stream and floodplain restoration project where Stage 0 characteristics have evolved in upper two project reaches, providing the most mature and complete example of a Stage 0 condition on Whychus Creek
PRE-RESTORATION				
Whychus Canyon at Rimrock Ranch Phase 2a	0.5	10	Stage 0 design (GGL), implemented in 2021	Next phase of restoration designed using a GGL approach to be implemented in 2021 on Whychus Creek. Inclusion will provide baseline imagery and data.
Whychus Canyon at Rimrock Ranch Phase 2b	1.5	~80	Stage 0 design (GGL), implemented in 2023	Subsequent phase of restoration designed using a GGL approach to be implemented on Whychus Creek. Inclusion will provide baseline imagery and data. Monitoring may be implemented together with Phase 2a
Willow Springs	1	40	Stage 0 design (Low-Tech Process-Based Restoration; LTPBR), implementation in 2022	Restoration project designed with the objective to achieve Stage 0 using a LTPBR approach.
TOTALS	**4.3**	**183**		
CONSIDERED BUT NOT SELECTED				
Camp Polk Reaches 3-5	~0.7	~52	Post-restoration, modified Natural Channel Design	Camp Polk Reaches 3-5 do not exhibit the characteristics and attributes of Stage 0 we are wanting to better quantify and understand through the proposed monitoring project.

2.2.3. Metric selection

The TAC remote sensing experts provided a preliminary list of geomorphological, hydrologic and fish habitat metrics that had been successfully measured from aerial imagery and citations for the corresponding publication for each, along with an assessment of the technical difficulty analyzing each metric would entail. The UDWC restoration design team reviewed the preliminary list of metrics as measures of stream evolution stage and fish habitat quantity and quality. Each design team member ranked metrics according to the team member's individual assessment of the value of each metric for providing information about the geomorphic, hydrologic, habitat, and biological conditions characterizing pre- and post-restoration reaches. This exercise resulted in a list of nine ranked metrics (Table 3). UDWC vetted the resulting ranked list of metrics with the TAC and provided the metrics to the GTAC team for them to select those metrics they felt best equipped to analyze within their scope as determined by the UDWC-USFS GEOTASC proposal. Of the design team's ranked metrics, GTAC selected inundated area (rank = 1), wet and dry substrate classification (rank = 4 and 9), wood abundance (rank = 6), and woody riparian vegetation (rank = 9) for analysis. USGS agreed to perform a preliminary analysis of velocity (rank = 2), and UDWC contracted with Anabranch Solutions to digitize geomorphic units (rank = 7). Water depth, and local and global erosion and deposition volume, ranked 3 and 8 respectively, were not selected for analysis due to high technical difficulty associated with using a Structure from Motion photogrammetry approach and prohibitive costs for acquiring bathymetric LiDAR.

Table 3. Ranked geomorphic and habitat metrics considered for analysis from imagery and proposed complementary field measurements.

Metric	Design team rank	Imagery product	Selected analysis method	Analyst	Field measurement(s)	What it tells us about Stage 0
ANALYZED FROM IMAGERY						
Inundated area (surface water)	1	6-cm resolution Red Green Blue (RGB) orthomosaic	Supervised classification using NDWI from NIR band + area under canopy from ground-based geomorphic unit surveys	GTAC	Area of active channel geomorphic units under canopy	Total area of aquatic habitat; possible to derive measures of channel network complexity, e.g. nodes per Hall et al (2018).
Velocity	2	30-second videos of wet plots, flown at 20 m Above Ground Level (AGL)	Large-Scale Particle Image Velocimetry (LSPIV)	USGS	Velocity	Dispersion of stream energy; range and diversity of velocities and associated processes, e.g. deposition
Wet and dry sediment size classification	4 (wet); 8 (dry)	2-cm resolution photoplots flown at 7 m AGL	Manual delineation by human interpreters	GTAC	Measurement of B-axis of 50 randomly selected clasts per plot; 0.3 m GPS locations at plot center	Substrate grain size distribution, including proportion of gravels for spawning. Might be possible to derive indices of patchiness, diversity, evenness.
Woody riparian vegetation	5	6-cm resolution RGB orthomosaic	Supervised classification using Normalized Difference Water Index (NDWI) from Near Infrared (NIR) band	GTAC	Vegetation rapid assessment method and design developed with GTAC	Total area of target vegetation community; Provides qualitative information about extent of hydrologic connectivity and floodplain roughness
Wood abundance	6	6-cm resolution RGB orthomosaic	Manual digitization	GTAC	Large wood diameter and length, percent area of coarse and fine woody material	Net wood storage; qualitative information about amount of structure present to cause hydraulic forcing
Geomorphic units: without canopy (Wheaton et al 2015 fluvial taxonomy definitions)	7	6-cm resolution RGB orthomosaic	Manual digitization based on fluvial taxonomy definitions	Anabranch Solutions	Geomorphic unit identification at each subplot	Number and richness of units; total area and area by unit type; improved classification of riffles with regard to provision of spawning habitat; more nuanced representation of geomorphic units than from AIP surveys; opportunity to use geomorphic units with depth

Metric	Design team rank	Imagery product	Selected analysis method	Analyst	Field measurement(s)	What it tells us about Stage 0
						and velocity measurements to evaluate habitat
ADDITIONAL METRICS FROM FIELD MEASUREMENTS						
Geomorphic units: below canopy		None	LTPBR survey protocol modified through consultation between UDWC and Anabranch Solutions to make metrics comparable	Anabranch Solutions	Geomorphic unit and structure surveys according to modified LTPBR protocol	Number and richness of units; total area and area by unit type; improved classification of riffles with regard to providing spawning habitat; more nuanced representation of geomorphic units than from Aquatic Inventory Protocol (AIP) surveys; opportunity to use geomorphic units with depth and velocity measurements to evaluate habitat
Wood abundance: below canopy		None	LTPBR survey protocol modified through consultation between UDWC and Anabranch Solutions to make metrics comparable	Anabranch Solutions	Geomorphic unit and structure surveys according to modified LTPBR protocol	Net wood storage; qualitative information about amount of structure present to cause hydraulic forcing
Depth		None	Descriptive	UDWC	Depth	Range and distribution of depths; depth-velocity combinations; association between depths and geomorphic units in subplots
Temperature		None	Descriptive	UDWC	Temperature	Range and distribution of stream temperatures in a representative sample of plots
Canopy Cover		None	Descriptive	UDWC	Densiometer readings	Provides information about shading in channels active at baseflow

2.2.4. Sampling design

UDWC considered plots and valley-wide transects as prospective sampling designs for collecting ground-based measurements that would support metric calibration and validation from imagery or provide additional and complementary information about geomorphic, hydrologic, biological, and fish habitat conditions. Both sampling designs had been used on other Stage 0 projects in Oregon. We selected plots to align with the sampling approach being used for the parallel monitoring effort in South Fork McKenzie River project reaches.

Plot Generation

To support consistency between monitoring approaches and leverage experience gained on the SFMR, UDWC established an MOU with Oregon State University's Aerial Information Systems (OSU AIS) Laboratory for sampling plot generation and imagery acquisition, following methods used for the SFMR. UDWC worked with the AIS Lab to generate sampling plots for photoplot (sediment analysis), video plot (velocity analysis), and ground-based measurement collection, following methods used for the SFMR. Lab staff generated hexagonal plots with a 3.14 m^2 area approximating the area of a 1 m radius circular plot across the entirety of a polygon shapefile for each project area. The polygon shapefiles providing wetted area, bare substrate, and wood boundaries had been created from an existing manual digitization of wetted channels, bare substrate and wood mapped from 2017 imagery. The resulting continuous mesh of hexagonal plots was subsampled using a tessellation to result in 100 randomly located plots in each of two strata, 100 in areas mapped as surface water, and 100 in areas mapped as bare substrate or wood, with the intention to survey and fly 10 wetted and dry plots each in Willow Springs and Camp Polk and 20 wetted and dry plots each in Whychus Canyon Phase 1 and in Whychus Canyon Phase 2. Plots were allocated by reach based on reach restoration status, with relatively more plots allocated to restored reaches expected to exhibit higher variability than unrestored reaches; and based on reach area (Table 4). Plots were generated for Whychus Canyon Phases 2a and 2b together rather than for each of these reaches because it had not yet been determined whether restoration would be implemented as one project covering both reaches or as two projects in sub-reaches.

Table 4. Plots as generated for ground-based measurements, photo plots, and video plots, by reach, strata (wetted or dry), and restoration status.

	Restored			Unrestored		
	Camp Polk	Whychus Canyon Phase 1	Total	Willow Springs	Whychus Canyon Phase 2	Total
Wetted	20	20	40	20	40	60
Dry	20	20	40	20	40	60
Total	40	40	80	40	80	120

2.3. Data collection

2.3.1. Imagery acquisition

TAC discussion and SFMR methods informed imagery specifications that would support analysis for each metric selected. Multi-spectral orthomosaic imagery that included a near infrared (NIR) spectral band was prioritized to support an object-based image analysis supervised classification approach for automated classification analysis of inundated area and vegetation. This approach was chosen as it could potentially make classification more efficient compared to delineating inundated area and vegetation by hand, and to achieve greater repeatability and accuracy in mapping these metrics. Photoplots to support sediment size classification were flown at wet and dry ground-based survey plot locations, and videoplots to support velocity analysis were additionally flown at wet ground-based survey plot locations.

UDWC worked with the OSU AIS Lab to acquire multi-spectral aerial imagery across all selected reaches, and aerial photos and videos of plots over survey plots where geomorphic and velocity measurements were collected. Imagery acquisition occurred between July 7th and July 14th, 2020. Methods including flight planning and specifications and image processing and data product results are summarized in the technical memo "Whychus Creek UAS Monitoring July 2020" (Appendix A). Imagery and all other spatial data products are available in an ArcGIS Online map: [Whychus Creek 2020 Stage 0 EM Map (arcgis.com)].

2.3.2. Plot surveys

UDWC used a plot survey protocol modified from one developed for the SFMR to collect ground-based measurements (Table 5). Some of these measurements were collected to calibrate and validate analysis of metrics from imagery; the remaining measurements were identified by UDWC and the TAC as providing additional and complementary information about geomorphic, hydrologic, biological, and fish habitat conditions.

UDWC marked and surveyed plots between June 30th and July 16th, 2020. We used an Arrow 100 GNSS Receiver with Avenza maps to navigate to plots. Because wet and dry plot strata represented 2017 conditions and much change had occurred in dynamic restored reaches, many plots fell in locations that were not occupied by the target stratum. We established the following rules for accepting, re-locating, or rejecting plots where the condition on the ground was not consistent with the target plot stratum:

1. Where a plot within the wetted strata fell in a vegetated location very close to a channel (within ~1 m) we moved the plot 1 m into the channel, perpendicular to the channel, to provide a 1 m radius.
2. Where the plot was the other strata, i.e wetted or bare substrate, we accepted the plot and surveyed measurements for the strata observed (e.g. all measurements for wetted plots, or only pebble counts for dry plots).
3. We eliminated plots occupied by wood on the floodplain, for two reasons: Our interest in describing and measuring wood was primarily in the context of its regular interaction with water, and wood encountered in floodplain plots was often in the midst of dense vegetation and therefore time-intensive to measure.

At each plot where the condition on the ground was consistent with the stratum type (i.e. where wetted plots occurred in surface water and wood interacting with surface water and where dry plots occurred in bare sediment) we marked the plot center with a washer 1.5"-2" in diameter, heavy enough not to be entrained in the current (if in an active channel), and tagged it with flagging to improve visibility. We fixed the end of a transect tape in the plot center with a cobble placed on the end of the tape or rebar hammered into the substrate. We marked the point 1 meter north of the plot center with a second flagged washer, to support calibration of distance from video, and extended the transect tape downstream from the plot center to 1 meter, using the meter radius in both directions as a visual guide for estimating a 1-m radius circular plot.

To facilitate measurement of distances on the ground for calibration of distance in velocity videos we measured and marked 29, 20 m x 10 m video plots centered on wetted survey plots at Camp Polk (11 plots) and Whychus Canyon Phase 1 (19 plots) (Figure 2) with the long end of the plot in the east-west direction. We used a compass to orient video plots north-south. Two surveyors set up each video plot. From the plot center we measured 5 meters to the north. From that location we measured 10 meters to the east and west to locate the northeast and northwest corners of the video plot, which we marked with flagging at the highest point (e.g. on vegetation) to be visible in imagery. We repeated the process to locate and mark the southwest and southeast corners of the plot. We measured the resulting east and west plot sides between the southeast and northeast, and southwest and northwest, plot corners, respectively, then measured the southwest to northeast and southeast to northwest diagonals. This resulted in known distances for each plot side and two diagonals, with marked corners anticipated to be visible in video plots. We located and surveyed these plots first so that video plots would be marked prior to imagery and video acquisition.

Plot survey data were recorded in an excel file on an iPad; locations of surveyed plots were recorded in the Survey123 ESRI app using spatial location data from the Arrow 100 GNSS receiver and later synced to ArcGIS Online. We recorded date and time for each plot sampled. In each wetted plot we recorded geomorphic unit as defined according to fluvial taxonomic definitions (Wheaton et al 2015). We selected this system of geomorphic unit definitions over more standard slope and velocity-based classification systems because:

1) it uses topographic forms as the basis for identifying units, thought to be more objectively recognizable than units defined by slope and velocity;
2) it differentiates riffles as the specific, channel-spanning, saddle-shaped topographic form that forces hyporheic flow and the oxygenation of water that fish cue on for spawning, as contrasted with the shallow planar unit identified as a riffle in slope and velocity-based unit classification systems; and
3) because we were considering using the Geomorphic Unit Tool (Riverscapes Consortium, 2023) based on the same fluvial taxonomy classification system for classifying geomorphic units from imagery.

We assessed and recorded whether the plot area was experiencing structural change, i.e. deposition or scour, as a result of nearby wood in the active channel (within the zone of influence of wood). We measured depth, velocity, flow azimuth, and canopy at the plot center. We used a transect tape to measure depth, and used a Marsh McBirney flow meter and USGS top-setting wading rod to measure velocity at 60% depth and just below the water surface. We measured canopy closure at the plot center using a spherical densiometer modified by taping a “V” on the mirrored surface to use only 17 of 37 possible line intersections, holding the densiometer 0.3 m above the water surface and recording the number of line intersections surrounded by vegetation in four directions: directly upstream relative to flow direction, facing the right channel edge, directly downstream, and facing the left channel edge (OWEB 1999; Fitzpatrick et al 1998). Where individual pieces of wood greater than 1 m long by 10 cm in diameter (following ODFW Aquatic Inventory Project criteria for large wood) or wood jams intersected the plot we measured the individual piece or jam length end to end along the longest axis, width from edge to edge at the midpoint of the piece or jam, and depth from the top of the jam to the bottom of the jam. If the bottom of the jam was submerged, where possible we measured to the bottom of the wood comprising the jam.

We measured sediment using modified Wolman pebble counts in wetted plots within active channels and in dry plots outside of active channels. We considered sediment in active channels to represent sediment size classes as a component of fish habitat and considered sediment within and outside of active channels collectively to represent the sediment size class distribution resulting from sediment deposition in each reach. We eliminated dry plots where vegetation appeared dense enough to interfere with analysis of sediment size from imagery, as ground-based sediment measurements were intended in part to be used to validate sediment size class data generated from photo plots. We randomly selected 50 clasts within each plot by taking a step, reaching down past the boot toe with an index finger, and retrieving the first clast contacted. We measured each clast by passing the b-axis of the clast (vertically like a raindrop) through the smallest possible hole in a gravelometer. We used standard size classes for sand (< 2 mm), gravel (2-64 mm), cobble (65-256 mm), boulder (257-2048 mm), and bedrock (> 2048 mm). For six plots where sediment smaller than 2 mm visually appeared to make up 95% or more of the sediment composition of the plot, we measured between 1 and 11 clasts, recorded a note observing the estimated percentage of the plot comprised by gravel, and recorded the remaining clasts as < 2 mm without measuring them.

We returned to all plots and removed all flagging and washers following video and photoplot acquisition.

Table 5. Data and measurement, location, and measurement technique for ground-based plot surveys.

Data or Measurement	**Location**	**Measurement Technique**
Instantaneous flow at Sisters (cfs)		· Record before leaving town
Date and time started		· Record at first plot
Surveyors		Record at first plot
Plot ID		· Record Plot ID (W, wetted, D, nonwetted, X, number) and FID from ArcGIS
GPS location	At plot center	· Record GPS points within 0.3m accuracy using Arrow GNSS receiver and Survey123 app
Video plot sides and diagonals		· Locate flagged washers at corners of video plot by measuring 5 m upstream and downstream of plot center, then 10 m toward each channel margin. · Measure all four sides and two diagonals
Geomorphic unit	Geomorphic unit at plot	· Select from: Bar (Convexity: Mound); Riffle (Convexity: Saddle); Planar (Plane); Pool (Concavity: Bowl); Mid-channel Bar (Convexity: Mound; dry plots only); Trough (Concavity: Trough); Non-primary
Zone of influence of wood		· Is the plot within the zone of influence of upstream or downstream wood? (Is flow velocity or direction influenced by upstream or downstream wood? Does there appear to be sediment scour or deposition resulting from altered hydraulics?)
Water depth	At plot center	· Measure with wading rod or engineer's rule at plot center.
Water velocity	At plot center	· Measure velocity in maximum flow direction with Marsh McBirney velocimeter · at 60% depth · at surface · Record azimuth of maximum flow direction
Water temperature	At plot center	· Use National Institute of Standards and Technology (NIST) thermometer to measure
Canopy cover	At plot center	· Facing upstream, left channel margin, downstream, right channel margin, read number of intersections out of 17 that are reflecting canopy · Divide densiometer reading by 17 and multiply by 100 to calculate percent canopy represented by each reading; average four readings to calculate average percent canopy cover for each plot
Wood jams: Area and depth	Any jam intersecting plot area	· Measure jam length, width, and depth with transect tape (3 measurements)

Data or Measurement	Location	Measurement Technique
Wood jams: Large wood (> 1 m length and 10 cm diameter)	Any jam intersecting plot area	· Count number of pieces of wood > 1m and 10 cm diameter in jam or single pieces
Sediment	Within 1 m radius plot	· Measure b-axis of 50 randomly selected clasts per plot with a gravelometer.

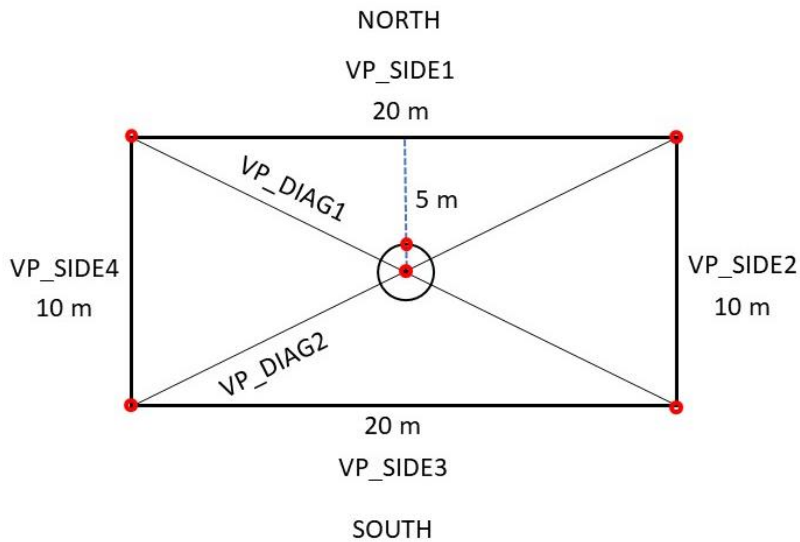


Figure 2. Diagram of video plot layout. Red circles indicate locations marked with washers and/or flagging; the black circle represents the 1-m survey plot

2.3.3. Surveys under canopy

UDWC contracted with Anabranch Solutions to conduct geomorphic unit and wood surveys in restored reaches where these features were expected to be obscured in aerial imagery by tree canopy. UDWC and Anabranch consulted to establish definitions and criteria for identifying geomorphic units that would be consistently applied in plot surveys, under-canopy surveys, and in desktop digitization of geomorphic units, and to agree on specifications for surveying wood under canopy. Anabranch Solutions conducted under-canopy surveys on August 21st and 24th, 2020, at baseflow discharge, shortly following imagery acquisition. Survey methods and results are summarized in the technical memo "Whychus Creek Monitoring: Geomorphic Unit and Woody Debris Jams – 2020 Field Monitoring Supplementation" (Anabranch Solutions, 2020; Appendix B).

2.3.4. Vegetation rapid assessment

UDWC consulted with GTAC and Aequinox Habitat to create a rapid assessment vegetation sampling design that would support an accuracy assessment of woody and herbaceous riparian vegetation classification from imagery.

Aequinox conducted rapid assessment surveys from July 27th to 29th, 2020, to classify plots centered on random points as one of five vegetation cover classes and an "other" class. Vegetation classes included:

- Riparian shrub;
- Riparian tree;
- Upland shrub;
- Upland tree; and
- Herbaceous

Twenty points each were surveyed in pre-restoration and post-restoration reaches, except in Whychus Canyon Reach 4, where 40 points were surveyed to capture higher variability across a large area. Aequinox staff navigated to each point using an Avenza map, displaying reaches and points, loaded onto an iPad mini receiving locations from an Arrow 100 GNSS receiver. At each point, Aequinox staff recorded cover class and dominant species in an electronic excel file on the iPad mini. Tree, shrub, and herbaceous points were classified using the following rules:

1. Points with tree cover ≥ 30% within a 10' radius were assigned to the tree cover class; plants ≥ 6 ft in height were considered trees.
2. Points with < 30% tree cover and ≥ 30% shrub cover were assigned to the shrub cover class; plants < 6 ft in height were included with shrubs (e.g. if cottonwood was present, but all plants were < 6 ft tall, the point would be considered shrub cover class; if a tree species was > 6 ft tall, the point would be considered tree cover class).
3. Points with < 30% tree and < 30% shrub but a combined tree and shrub cover of ≥ 30% were assigned to the shrub cover class
4. Points with < 30% tree and shrub combined cover were assigned to the herbaceous cover class
5. For points classified as tree, dominant species were surveyed and recorded within a 10' radius around each point.
6. For points classified as shrub or herbaceous, dominant species were surveyed and recorded within a 5' radius around each point.
7. At herbaceous points, the dominant species was used to assign the point as upland, riparian, or riparian/upland, indicated in a "notes" field.

Non-vegetated areas, such as water, bare substrate, or wood, were classified as "other". Rapid assessment data and point locations were provided to GTAC for use in their accuracy assessment of classification of woody riparian vegetation from imagery.

2.4. Data analysis

2.4.1. GTAC analysis

GTAC staff developed methods to analyze four of the selected metrics from imagery:

1) inundated area;
2) land cover, including riparian vegetation;
3) wood; and
4) sediment size.

Their methods and results are summarized in the technical report "Remote sensing methods for monitoring Stage 0 metrics on Whychus Creek using high-resolution imagery" (McCurdy et al, 2021; Appendix C). Based on guidance from UDWC and the TAC, GTAC staff developed analysis methods in ArcGIS Pro rather than in e-Cognition software to increase the accessibility and repeatability of analyses by UDWC or others, considering both technical ability required to perform analyses as well as the relative affordability of the two software platforms. Where possible GTAC used object-based classification as an approach that can be more efficient, objective, and repeatable than hand-delineation. GTAC analysis workflows for each metric are summarized in a series of instructional guides (Appendix D) and are demonstrated in a July 2021 remote sensing analysis methods training video (https://www.youtube.com/watch?v=8hhFFt233Io).

2.4.2. Inundated area

GTAC developed an object-based classification method to estimate inundated area. They calculated two spectral bands, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index

(NDWI), from the spectral bands acquired, as candidate bands to use in a segmentation. The final segmentation used NIR (Near Infrared), longwave infrared (thermal) and the NDWI band as inputs. GTAC used the Random Trees method with representative samples from the segmentation to run a random forest classification, then refined the classification by completing 2-3 iterations of sampling, classification, and inspection, and making minor manual edits in ArcGIS Pro.

UDWC compared inundated area calculated from the GTAC classification (Appendix C) to inundated area calculated from geomorphic units delineated and surveyed by Anabranch Solutions (Anabranch Solutions 2021; Appendix E) and from the most recent ODFW Aquatic Inventory Project stream habitat survey data available for each reach. We excluded units delineated as bars, which were uniformly identified as dry units (0% wet) as verified against the "Whychus_GeoUnits_2020.shp" shapefile attribute table, and excluded dry and dry channel units from AIP data, from the analysis.

2.4.3. Vegetation

To classify vegetation, GTAC developed a land cover classification including the following seven classes:

1. Water
2. Upland tree/shrub
3. Low riparian tree/shrub
4. Mid-height riparian tree/shrub
5. High riparian tree/shrub
6. Visible herbaceous
7. Bare/other

GTAC used their inundated area classification to define the water cover class.

To identify and differentiate riparian and upland trees and shrubs, UDWC and GTAC selected an approach that used elevation bands representing height above the Geomorphic Grade Line (GGL; Whychus Canyon Phase 1) or above the water surface (all other reaches) to infer whether tree and shrub vegetation was upland (xeric) vegetation or riparian (mesic) vegetation. UDWC and USFS district staff evaluated vegetation in 2020 imagery relative to 2017 LiDAR cross-section elevations to define elevation bands for riparian and upland vegetation for each project reach (Table 6). These elevation bands were the basis for classifying tree and shrub vegetation as riparian or upland. We reviewed orthomosaic imagery and the Relative Elevation Model (REM) for the four reaches to inform selection of elevation thresholds for:

1) an elevation threshold below which riparian vegetation occurs, as well as
2) frequency of wood interacting with water to support analysis of wood inundation frequency.

For riparian vegetation in pre-restoration reaches, we used 3D Analyst tools in ArcGIS to draw cross-sectional profiles and create profile graphs. Along each profile we identified locations that we recognized as riparian vegetation based on site-specific knowledge and visual review of orthomosaic and LiDAR imagery, and referenced elevations in profile graphs to calculate the highest elevation of riparian vegetation relative to the elevation of the water surface. Approximately half of riparian vegetation elevations were within 3 ft of the water surface; riparian vegetation elevations in areas of less continuous vegetation characterized by mature cottonwoods (based on site knowledge), were between 3 and 4 ft above the water surface elevation. Based on this exercise we selected 3 ft above the water surface elevation in pre-restoration reaches as the threshold below which riparian vegetation is very likely to occur. This threshold is conservative in that it would under-represent, rather than over-represent, riparian vegetation. Vegetation more than 3 ft above the water surface in pre-restoration reaches that appears to be riparian based on form and color might also be riparian, specifically mature cottonwoods and vegetation in areas below the pond at Rimrock Ranch (Whychus Canyon Phase 2b) that likely receive subsurface flow draining from the pond.

In post-restoration reaches including Camp Polk and Whychus Canyon Phase 1 we reviewed imagery and the REM to inform the elevation threshold at and below which riparian vegetation occurred. In post-restoration reaches we observed cottonwoods to occur between two and three feet above the GGL, with the majority of vegetation known to be riparian occurring below two feet. We selected three feet as the threshold below which vegetation is very likely to be riparian in post-restoration reaches.

Because Camp Polk was not constructed using the GGL and preliminary data products indicated the GGL elevation was not capturing or including all surface water detected using surface area inundation methods, at Camp Polk we applied the elevation thresholds for riparian vegetation and for wood using the water surface elevation as represented by the surface area inundation layer rather than the GGL elevation as our zero elevation.

Table 6. Riparian vegetation elevation thresholds in pre- and post-restoration reaches

Height			**Indicates**
Pre-restoration	Post-restoration: Camp Polk	Post-restoration: Whychus Canyon Ph 1/R4	
WS to 3 ft	WS to 2 ft	GGL ± 0.3 ft to 2 ft	Very likely riparian vegetation
3 ft to 4 ft	2 ft to 3 ft	2 ft to 3 ft	Very likely riparian vegetation. Riparian vegetation in this elevation band may include dry-tolerant mature cottonwoods; cottonwoods established pre-restoration (post-restoration reaches); vegetation receiving groundwater inputs from pond (Rimrock Ranch)
> 4 ft	> 3 ft	> 3 ft	Very likely upland vegetation

GTAC overlaid a Canopy Height Model (CHM) derived from 2017 LiDAR onto the riparian/upland elevation bands and inundated area classification to differentiate between shrub- and tree-height and herbaceous vegetation. CHM pixels at least one foot in height above the GGL (Whychus Canyon Phase 1) or water surface (all other reaches) were classified as tree/shrub. GTAC created an additional class, riparian tree/shrub/water, to represent areas where the riparian tree/shrub class intersected the water class.

To classify herbaceous vegetation, GTAC masked areas already classified as tree/shrub and water. In the remaining unclassified areas they performed a segmentation in ArcGIS Pro. For each reach they visually examined different combinations of the available spectral bands to select the combination that best highlighted (or differentiated) herbaceous vegetation (GTAC 2021). They selected red, green, and blue as the imagery bands that best highlighted herbaceous vegetation, performed the segmentation, and ran a random forest classification, resulting in an herbaceous cover class. Areas not included in this herbaceous cover class were classified as bare/other. Areas classified as bare/other likely include sparse, dry, and hydrologically disconnected vegetation such as cheatgrass, as well as bare sediment, which could in restored reaches include bare sediment deposited through floodplain building and channel evolution.

To apply vegetation rapid assessment data to assess the accuracy of the resulting land cover classification, GTAC re-defined vegetation rapid assessment classes to align rapid assessment data with land cover classification data. Riparian and upland shrub and tree rapid assessment classes and data were combined into upland and riparian tree/shrub, respectively; riparian tree/shrub classes by elevation were evaluated as a single class. The land cover classification water class was converted to an "other" class, and the tree/shrub/water class was converted to a riparian tree/shrub class. GTAC compared the number of accurate classifications to the number of inaccurate classifications for each class to quantify the number of times the classification mistakenly identified a specific class (commission error, or user's accuracy) and the number of times the classification failed to identify a specific class represented in the vegetation rapid assessment data (omission error, or producer's accuracy).

2.4.4. Wood

Delineation from imagery

GTAC initially attempted to use an object-based automated classification approach in ArcGIS Pro to detect wood from imagery. The similar optical properties of wood and surrounding bare ground resulted in inaccurate classification or omission of wood, and the low elevation profile of wood rendered use of elevation data ineffective to improve detection of wood. When GTAC tested a hand-delineation approach, this approach took less time than the amount of time required to train a classifier given the problems identified above. GTAC accordingly selected a manual delineation approach to create a wood layer from imagery.

GTAC initially used the classified inundated area to estimate wood interacting with water at baseflow, providing aquatic habitat and promoting hydrogeomorphic process, but this approach resulted in inaccurate estimates of wood interacting with water due to misclassifications of water in areas with wood accumulations. To more accurately classify wood interacting with water, GTAC delineated wood within elevation bands corresponding to inundation frequency.

In Whychus Canyon Phase 1 we were able use elevation bands from the LiDAR bare earth-based Relative Elevation Model (REM) to estimate wood interacting with water at base flow, therefore annually; wood inundated at a minimum every five years; and wood inundated at a minimum every ten years (Table 7). For all other reaches we paired the classified water surface with LiDAR bare earth elevations and identified elevations above the classified water surface corresponding to inundation every five and every ten years based on expert local knowledge. We based thresholds for wood interaction with water on return intervals for high flows on Whychus Creek and site knowledge relative to channel confinement. For pre-restoration reaches we used the water surface to represent base flow (20-30 cfs) because 2020 orthomosaic imagery was flown at base flow.

We selected water surface (pre-restoration) or the GGL ± 0.3 ft (post-restoration) as the elevation where wood is very likely to interact with flow every year during base flow, from approximately July 15 to October 15. For Whychus Canyon Reach 4 we used the GGL represented in the REM, ± 0.3 ft, to represent base flow, with the GGL representing as-built channel elevations on the project. For Camp Polk we used the water surface elevation as represented by the classified inundated area as our zero elevation. Because of the relative lack of channel confinement in restored reaches, we selected two feet above the GGL (Whychus Canyon Phase 1) or water surface (Camp Polk) as the elevation threshold at which wood is likely to interact with flow on a five-year basis. Because of channel confinement in pre-restoration reaches, and based on review of depths at flows modeled using HEC-RAS, we selected three feet above the water surface as the elevation threshold at which wood is likely to interact with flow on a five-year basis. Wood above these elevations is not expected to interact with flow except on a decadal to multi-decadal timeframe. Wood delineation using elevation bands resulted in two wood metrics: area (ft^2), and inundation frequency.

Table 7. Wood elevation thresholds estimated to correspond to annual, five-year, and decadal inundation frequencies in pre- and post-restoration reaches.

Height			**Indicates**
Pre-restoration	Post-restoration: Camp Polk	Post-restoration: Whychus Canyon Ph 1/R4	
WS	WS	GGL ± 0.3 ft	Likely interacts with base flow annually between July 15 and October 15
WS to 3 ft	WS to 2 ft	GGL ± 0.3 ft to 2 ft	Likely interacts with flow between baseflow and a 5-year flow
> 3 ft	> 2 ft	> 2 ft	Likely interacts with flow on a decadal to multi-decadal time scale

Plot data analysis

Wood delineated from imagery represents a census of wood in project reaches while wood measured in plots represents a sample; project reaches are different lengths and are characterized by differing degrees of variability, and for this reason different numbers of plots were surveyed in different reaches. We calculated wood area per 100 m valley length, and used the total rather than average wood area measured in plots in each reach to support the most representative comparison among reaches and between results from the two methods.

Because ODFW Aquatic Inventory Project stream habitat surveys report wood volume but do not provide values used to calculate wood volume, we were not able to compare the amount of wood surveyed during AIP surveys (volume) to the amount of wood measured through delineation (area).

2.4.5. Geomorphic Units

UDWC contracted with Anabranch Solutions to hand-delineate geomorphic units from 2020 multi-spectral orthomosaic imagery. Delineation of units was intended to provide an account of geomorphic feature types and distributions that are descriptive of fish habitat quantity and quality and restoration effectiveness in enhancing riverine and aquatic processes. Definitions used for delineating geomorphic units followed those in Wheaton et al (2015) and were consistent with those used for geomorphic unit surveys under canopy and for identifying geomorphic units at plots. Following the completion of field surveys and hand delineation of geomorphic units, Anabranch Solutions staff reviewed the target field survey areas and the georeferenced location of each unit observed in the field to identify any areas where surveyed units were also delineated and ensure no section of channel was “double-counted” by the two survey approaches. Delineated units that were identified as also having been surveyed in the field were denoted as "desk-field" in a "field_obs" attribute field in the final delineation shapefile. Flagging these units for exclusion when making calculations from or otherwise merging or combining the two datasets avoided double-counting units where the two survey methods may have overlapped. Anabranch Solutions staff merged the two datasets and excluded "desk-field" units, resulting in one shapefile and associated data representing all units delineated or surveyed in 2020 ("Whychus_GeoUnits_2020.shp"). Methods and results are summarized in the technical report "Whychus Creek Geomorphic Unit Assessment: Delineation of Channel Geomorphic Features from UAV Imagery" (Appendix E).

Because the geomorphic unit classification system we used for delineation, surveys under canopy, and plot surveys includes bars, which by definition are dry units, and AIP survey data includes dry units but not bars, we excluded bars from delineation and under-canopy survey data and excluded dry units from AIP survey data. This allowed us to compare the number of geomorphic units and number per kilometer identified by the two methods.

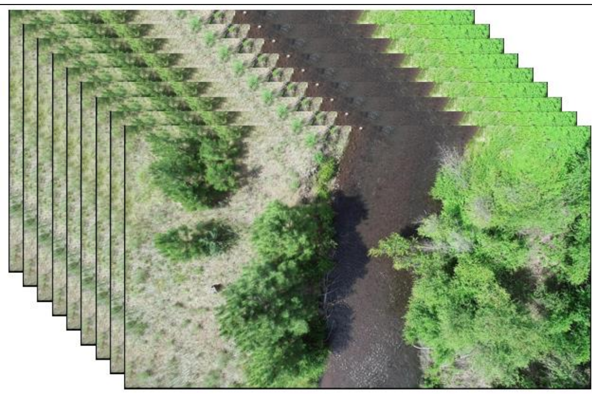
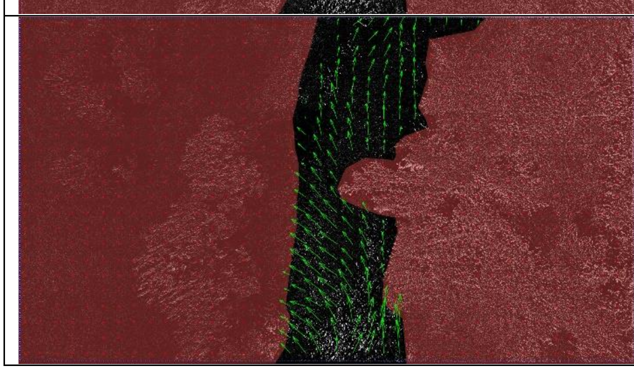
Using plot survey data, we calculated and compared the number of units by type in restored and in unrestored reaches. To evaluate the accuracy of hand-delineation in identifying geomorphic units, we visually reviewed delineated units ("Whychus_GeoUnits_2020.shp") and units surveyed in plots ("Plot Data Analysis GUs.xlsx") to compare and validate the unit type delineated against the unit type identified during plot surveys, and to evaluate the utility of the suite of geomorphic units selected for delineation and surveys.

2.4.6. Velocity & flow direction

LSPIV analysis

UDWC contracted with USGS to test a particle image velocimetry (PIV) approach to measure velocity and flow direction from video recordings collected from a small unoccupied aircraft system (sUAS; Appendix F). The PIV approach uses consecutive images from a short video of a flowing stream to track displacement of artificial or natural tracers on the water surface. The displacement of particles within the video is then used to measure the downstream and cross-stream components of stream velocity. At the time of this analysis, PIV approaches had been tested in laboratory settings, large rivers, or in small channels seeded with artificial particles. While examples of the PIV method applied in small, clear-flowing streams like Whychus Creek are less common, the PIV approach captures a wider spatial footprint than traditional flow measurement transects in the stream and therefore could be beneficial for measuring streamflow velocities as well as direction of flow in complex, stage-zero restoration sites.

Videos for PIV analysis were collected from a stationary sUAS hovering approximately 20 meters above the water surface (Appendix A). The field crew placed two large washers on the stream bed separated by one meter. The washers provided a method for scaling the video frames from pixel coordinates to real-world coordinates. PIV analysis was conducted using two opensource software packages: RIVer (Rectification of Image Velocity Results), and PIVLab (Patalano et al, 2017; Thielicke et al, 2014). The UAS video was collected for approximately 30 seconds at each site at a frame rate of 30 frames per second. USGS used RIVer software to extract image frames and subsampled the video frames to a frame rate of 2 frames per second (Figure 3). The USGS removed frame-to-frame spatial shifts due to aircraft motion using USGS Video-Stabilizer software (https://github.com/frank-engel-usgs/Video-Stabilizer) prior to PIV assessment. USGS used PIVLab to create a channel mask for each image that allowed selection of the channel and exclusion of the adjacent floodplain for analysis. Using PIVLab, USGS computed a mean pixel value for each image to reduce image texture and provide a clearer view of the streambed, then subtracted the mean image intensity from each image frame. Subtracting the mean image intensity from each image frame highlighted waves and ripples on the water surface which served as natural tracers for measuring surface flow. In the resulting image, USGS defined an interrogation area 4x larger than the maximum displacement between the 2 image frames for analysis; from that interrogation area they defined a smaller interrogation area with finer resolution, allowing for correlation between the two resulting moving windows and creating a grid of points at which to compute velocity. In PIVLab, USGS computed velocity magnitude and direction at each point in the grid, for each of 60 image sets representing one time step, then calculated the mean of the resulting velocity magnitude and vector values for each point in the grid from all 60 image sets. The grid of velocity vectors defined streamflow in units of pixels/second. USGS calibrated the resulting velocity magnitudes to meters per second by measuring the distance between washers in the video frames (spaced 1 meter apart) to identify real-world distance that each pixel in the image represented.

	Step 1: Extract image frames from video and stabilize images to remove aircraft motion.
	Step 2: Create mask of non-channel features and increase image contrast to enhance water surface features. Red areas of the image were excluded from the analysis.
	Step 3: Measure tracer displacement between image frames using automated particle image velocimetry. The green vectors are the PIV-derived magnitude and direction of the flow.

	Step 4: Scale the PIV outputs using washers placed on the riverbed with 1 meter spacing. This step converted PIV outputs from image pixel units to true ground distance.

Figure 3. Processing steps used in the PIV analysis.

The resulting scaled PIV outputs provided velocity information in meters/second, but no geographic positions were provided. To assign spatial dimensions to PIV-derived surface velocity outputs, PIV outputs were scaled from image coordinates to real-world distances using markers placed in the video frame at the time of video collection. In many instances markers were not visible in the video and co-collected orthoimagery was used to scale the outputs. Scaling using this method required an additional GIS analysis step to identify and match tie points (natural landmarks) visible in both the video and orthoimagery (Figure 4). Mismatched resolution of the orthoimagery, collected at lower resolution, and video, collected at higher resolution, made tie point identification difficult and therefore time-intensive.

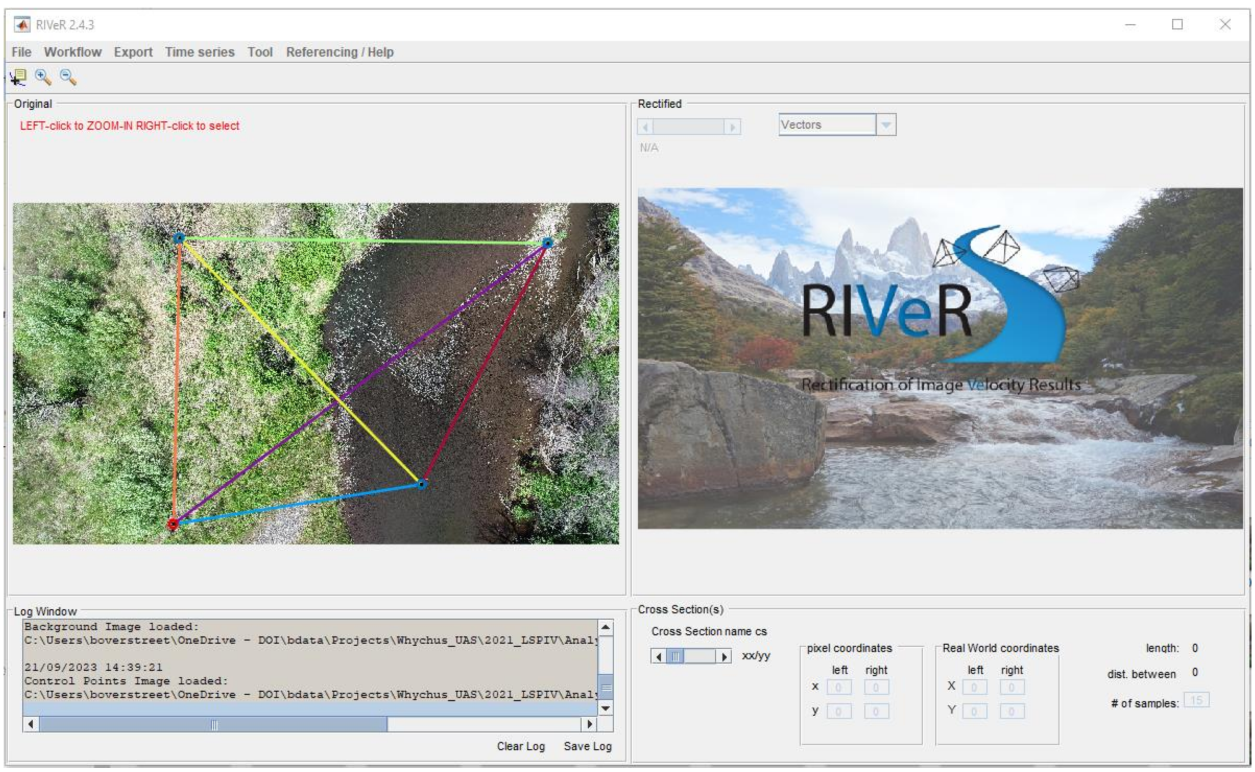


Figure 4. Two-dimensional rectification module in the RIVer software requires known distances between ground features. The USGS used co-collected orthoimagery and video to identify common features in both datasets and GIS analysis to identify distances between features.

Plot data analysis

UDWC compared measures of dispersion (minimum and maximum) and measures of central tendency (median and mean) to understand the range as well as average condition of velocities at 60% depth and at the surface, and flow directions at the surface, in each project reach and in restored compared to unrestored reaches. We compared these values for velocities at 60% depth and at the surface to understand the relationship between surface velocity and velocity at 60% depth and how representative surface velocity was of velocity at 60% depth.

To evaluate flow direction in each reach and in restored compared to unrestored reaches we assigned each azimuth measurement to the sixteen principal and half-wind directions, each separated by 22.5 degrees. We compared the frequency of azimuth records in each of the sixteen directions to understand if flow direction varied differently in restored and in unrestored reaches. Flow azimuth records also supported validation of flow direction analyzed from imagery.

2.4.7. Sediment

Analysis approaches considered for sediment size classification from imagery included mixed pixel analysis and photosieving using existing software packages. GTAC evaluated use of a photosieving software package, PebbleCounts (Purinton and Bookhagen, 2019), but the algorithm did not support analysis of inundated sediment. GTAC selected hand-delineation of sediment by human interpreters to define sediment size class distributions. This approach entailed calculating ground sampling distance for each photoplot then digitizing sediment sizes within the photoplot using a random sampling approach, essentially performing a "virtual pebble count". GTAC staff selected a random sampling scheme as the most efficient approach due to time and budget constraints and to obtain representative size class distributions. They selected hand delineation over using an algorithm because of the challenges associated with breaking out small versus large sediment sizes and with training a classifier to identify different sediment size classes. GTAC sediment size classification methods are summarized in the report "Remote sensing methods for monitoring Stage 0 metrics on Whychus Creek using high-resolution imagery" (McCurdy et al 2021; Appendix C).

UDWC compared average percentages of sediment size classes in wet survey plots in restored and unrestored reaches and compared average percentages of sediment size classes in wet and dry plots by reach.

2.4.8. Canopy cover

UDWC divided densiometer readings from each of four directions by 17 and multiplied the resulting number by 100 to calculate percent canopy cover in each direction, then averaged those four percentages to calculate an average percent canopy cover for each plot. We used boxplots to visually compare the median and range of canopy cover over wetted survey plots by reach and by restoration status.

2.4.9. Depth

UDWC used boxplots to visually compare the median and range of depth at the center of wetted survey plots, by reach and by restoration status.

2.4.10. Temperature

We used a scatterplot to identify temperature trends by time of day and reach and compared minimum and maximum stream temperatures by reach to the range of dates surveyed, instantaneous flows, and maximum air temperatures.

3. Results

3.1. Survey plot sample size

We surveyed a total of 105 plots in five reaches, approximately evenly split between wetted and dry plots in each reach (Table 8). Photoplots were flown over all surveyed plots. Video plots were flown over all 11 wet plots in Camp Polk and over 14 wet plots in Whychus Canyon Phase 1.

Table 8. Final plots surveyed and flown by strata, reach, and 2020 restoration status.

	Restored			Unrestored			
	Camp Polk	Whychus Canyon Phase 1	Total	Willow Springs	Whychus Canyon Phase 2a	Whychus Canyon Phase 2b	Total
Wetted	11	18	29	10	4	14	28
Dry	9	14	23	9	2	14	25
Total	20	32	52	19	6	28	53

3.2. Inundated area

Inundated area classification results are described in detail in the GTAC report "Remote sensing methods for monitoring Stage 0 metrics on Whychus Creek using high-resolution imagery" (McCurdy et al 2021; Appendix C). Inundated area raster data included class (water/non-water) and area (m2).

Inundated area per valley mile calculated from the classification from imagery was similar in unrestored and restored reaches, ranging from 3.3 to 3.8 ac per mile in restored reaches and from 2.6 to 4.3 ac per mile in unrestored reaches (Table 9). Inundated areas calculated from delineated geomorphic units were higher than areas calculated from the classification and there was a greater difference between inundated area in restored and unrestored reaches, ranging from 5.6 to 5.7 ac per mile in restored reaches and from 3.9 to 4.3 ac per mile in unrestored reaches.

Years for which the most recent ODFW AIP stream habitat survey data were available for the five reaches ranged from 2008 (Whychus Canyon Phases 2a and 2b) to 2018 (Willow Springs). Inundated area and inundated area per mile calculated from the 2020 classification, 2020 delineated geomorphic units, and from AIP survey data were similar for Whychus Canyon Phase 2b and Willow Springs, both unrestored reaches. Inundated area from the three methods varied for Phase 2a, with area from the latter two methods up to 1.5x the area calculated from the classification. Our best explanation for this lower amount of inundated area in Phase 2a indicated by the 2020 classification relative to the amount calculated from AIP data is that AIP surveys captured the full width of the Phase 2a channel including margins that might have been obscured by canopy in 2020 imagery and therefore not classified as water. For restored reaches, differences in inundated area as calculated from the three methods were slightly higher, with areas from delineated units and from AIP data 1.5 - 4.2x higher than those calculated from the classification, respectively. This is somewhat unsurprising given the complexity present in restored reaches and the resulting challenges associated with detecting surface water under canopy, whether along the extensive margins of active channels within a complex channel network, or off-channel pockets of standing water under mature canopy preserved during restoration implementation that were detected during surveys on the ground but not from imagery using a classification approach.

Table 9. Reach length in miles and inundated area in acres and acres per mile calculated from three survey methods.

	Reach length (mi)	Class (ac)	Delin GUs (ac)	AIP (ac)	Class (ac/mi)	Delin GUs (ac/mi)	AIP (ac/mi)
Camp Polk	0.5	1.7	2.8	6.9	3.3	5.6	13.9
WC 1	1.0	3.7	5.7	6.8	3.8	5.7	6.9
WC 2a	0.4	1.0	1.5	1.4	2.6	3.9	3.6
WC 2b	1.3	5.5	5.8	6.2	4.1	4.3	4.7
WS	0.7	3.0	2.9	2.9	4.3	4.1	4.2

3.3. Vegetation

Land cover classification results including vegetation are described in detail in the GTAC report "Remote sensing methods for monitoring Stage 0 metrics on Whychus Creek using high-resolution imagery" (McCurdy et al 2021; Appendix C).

Land cover, and specifically riparian vegetation, varied among project reaches and showed no clear trends between restored and unrestored reaches (Figure 5). Overall classification accuracy was 36.67%, and varied widely between reaches, classes, user's accuracy (commission error, mistaken identification as a specific class) and producer's accuracy (omission error, failure to recognize a specific class that was represented).

Riparian tree and shrub cover per 100 m valley length was higher in Whychus Canyon Phases 2a and 2b than in other reaches, consistent with the known existence of wide galleries of diverse woody riparian vegetation in these reaches where some geomorphic and biological recovery has occurred since the stream was channelized during the 1900s (Figure 5). Herbaceous vegetation in parts of Whychus Canyon Phases 2a and 2b is also anecdotally very dense, possibly reflecting relatively shallow groundwater or subsurface flow, and likely contributing to the high area of visible herbaceous vegetation in these reaches.

Elevation bands used for Whychus Canyon Phase 1 may inflate or over-represent vegetation classified as upland tree and shrub. The classification shows a higher upland tree and shrub acreage and acreage per 100 m valley length at Whychus Canyon Phase 1 than in other reaches; review of the classification, interpreted using local site knowledge, shows that the majority of vegetation classified as upland in this reach is mature pre-restoration riparian canopy that was retained during project implementation, albeit at a pre-restoration elevation. This interpretation could be validated using canopy heights from the Canopy Height Model and field surveys within areas classified as upland vegetation. Re-classifying all vegetation reported as upland tree and shrub for this reach as riparian tree and shrub would increase the area of riparian tree and shrub vegetation to 1.3 acres per 100 m valley length.

The high acreage classified as “other” at Camp Polk is an artifact of the entire valley floor in this reach being included in the study area, despite a large proportion of this area having a higher floodplain surface that remains disconnected from the restored floodplain elevation. This area was included to support detection and evaluation of any new hydrologic connectivity that might develop as a result of the restoration project. But, elevations within the Camp Polk study area selected for imagery acquisition and analysis were not evaluated during selection of the study area, and elevations across much of the valley floor included in the analysis are likely prohibitively high to experience enhanced hydrologic connectivity. Interestingly, the high acreage classified as “other” at Willow Springs appears to accurately represent vegetation that was likely dry and hydrologically disconnected in this unrestored reach which we hope to convert to riparian vegetation through restoration implementation.

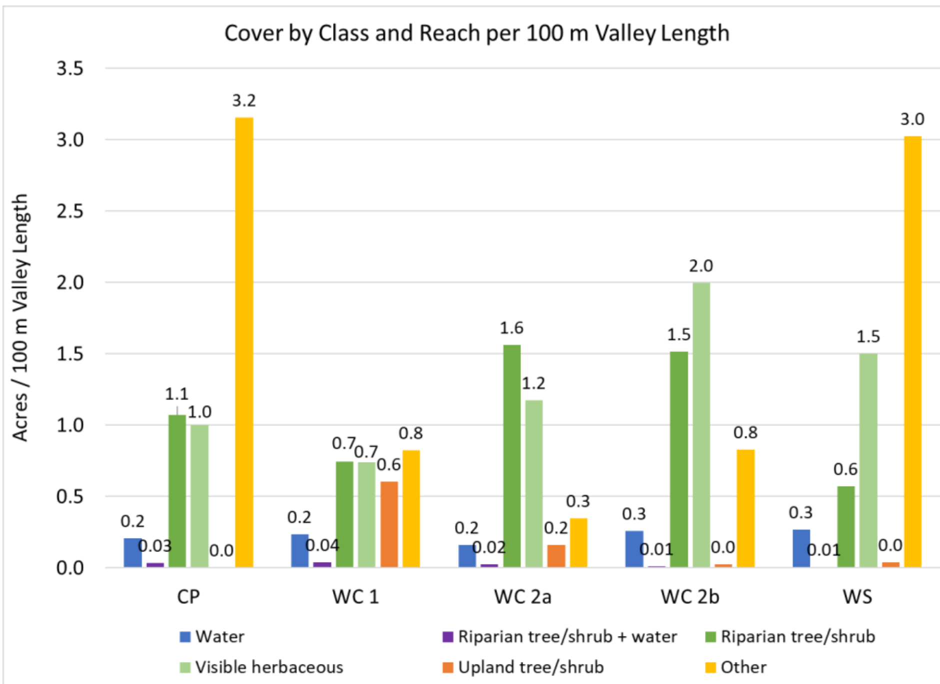


Figure 5. Land cover by class (ac per 100 m valley length) in five study reaches.

In 2017 UDWC contracted with a consultant (EDC) to acquire imagery and produce a cover classification along ~17 miles of Whychus Creek slated for stream habitat restoration, for the purpose of quantifying change in riparian vegetation as an indicator of floodplain reconnection and hydrologic connectivity following restoration (Garono et al 2018). Acquiring imagery over the desired spatial extent and at the desired spatial resolution within the budget available foreclosed the option of acquiring more expensive multi-spectral imagery (Mork 2021). An initial unsupervised classification and a subsequent semi-supervised classification were performed in ArcGIS on the resulting RGB orthomosaic imagery, but neither accurately distinguished vegetative cover classes, and EDC proceeded to create a classification using a rule-based hand delineation approach. Riparian vegetation calculated from this classification for Whychus Canyon Phase 1, the only reach for which the spatial extent analyzed was directly comparable to the Whychus Canyon Phase 1 reach in the current study, totaled 34.9 ac or 2.2 ac/100 m valley length compared to the 24.3 ac or 1.5 ac/100 m valley length of riparian vegetation calculated from the GTAC classification for this reach. An accuracy assessment of the 2017 classification using field survey data from herbaceous plots in Willow Springs, Camp Polk, and Whychus Canyon Reach 5 (Phase 2a and ½ mile of Phase 2b) showed an average 65% accuracy (percent of plots correctly assigned as riparian or upland) across these three reaches. Accuracy assessment field survey data to evaluate the 2017 classification were not collected in Whychus Canyon Phase 1 because accuracy assessment surveys were conducted in 2019, two years following imagery acquisition for the classification and three years post-restoration at Whychus Canyon representing a time during which substantial vegetation change was expected to occur.

3.4. Wood

Wood delineation results are described in detail in the GTAC report "Remote sensing methods for monitoring Stage 0 metrics on Whychus Creek using high-resolution imagery" (McCurdy et al 2021; Appendix C). Wood decked in the Phase 2b unrestored reach in preparation for restoration implementation was included in wood area for this reach, inflating total wood area and misrepresenting floodplain wood (five- and ten-year inundation frequencies); but, because the decked wood was above the annual frequency elevation, the value of wood inundated annually is still accurate and comparable to other estimates of wood in and interacting with active channels. Because we know wood in Phase 2b above the annual inundation frequency elevation inaccurately represents wood area, we do not report values for five- and ten-year inundation frequency classes here. Wood area as calculated from manually delineated wood was markedly higher in the two restored reaches, where wood was added during restoration implementation, than in the two restored reaches, on average 12x higher in restored than in unrestored reaches (Figure 6, Figure 7).

The amount of wood area at baseflow calculated from imagery and anecdotal knowledge of study reaches suggest that our plot sampling design did not effectively sample wood. In Camp Polk (restored) and Whychus Canyon Phase 2b (unrestored), none of the plots surveyed included wood, and wood recorded in Willow Springs (unrestored) was similar to the amount of wood recorded in Whychus Canyon Phase 1 (restored), a very different result than from delineation or AIP surveys (Figure 6; AIP data not shown) and inconsistent with site knowledge of wood addition to Phase 1 during restoration. Wood was present in only 10 of the total 57 wetted plots surveyed across all reaches. Wood was not detected in any plot in Camp Polk (restored; 10 plots) nor in Whychus Canyon Phase 2b (unrestored; 14 plots). Total wood area summed from plots for each reach and averaged across restored reaches per 100 m valley length was nonetheless 4x that in unrestored reach plots, owing to the greater amount of wood occurring in plots in Whychus Canyon Phase 1 than in Willow Springs.

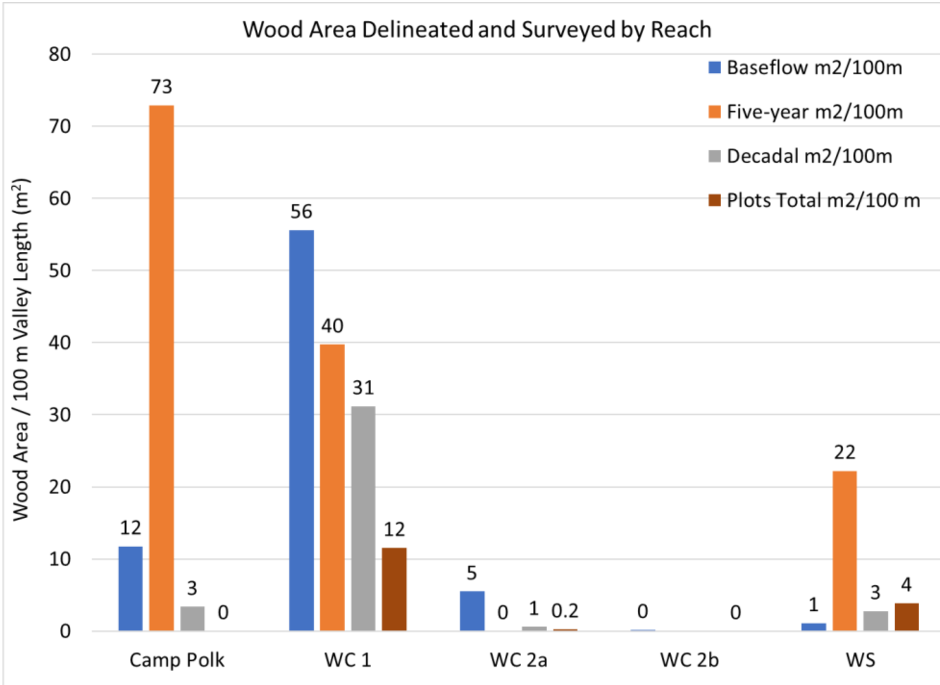


Figure 6. Wood area (m2) per 100 m valley length in five reaches as calculated from manually delineated wood and from total wood measured in all wetted plots in each reach.

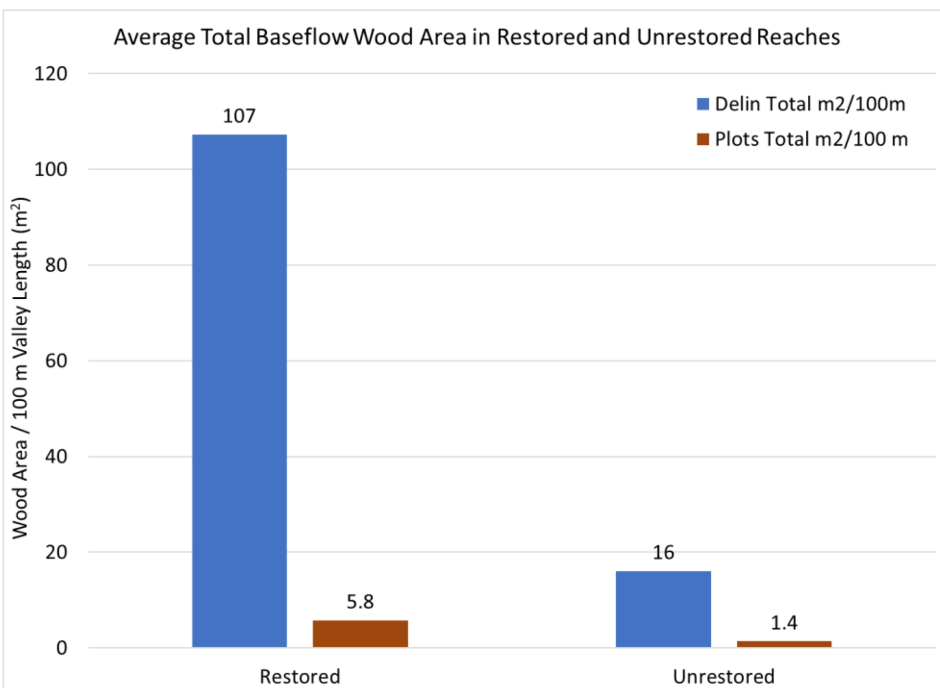


Figure 7. Total baseflow (annually inundated) wood area (m^2) per 100 m valley length, calculated from manually delineated wood and from total wood measured in all wetted plots in each reach, averaged for restored and for unrestored reaches.

3.5. Geomorphic Units

Results from manual delineation of geomorphic units from imagery are described in detail in the report "Whychus Creek Geomorphic Unit Assessment: Delineation of Channel Geomorphic Features from UAV Imagery" (Anabranch Solutions, 2021). Delineation of geomorphic units from imagery indicated 4x as many units per kilometer on average in restored reaches compared to unrestored reaches, with 3x as many pools, 3x as many pools and troughs collectively, and 3x as many riffles per kilometer on average in restored compared to unrestored reaches (Figure 8). Non-primary and wetland units represented a higher proportion of units in restored reaches compared to unrestored reaches, with 9x and 12x as many of these units respectively per kilometer on average in restored compared to unrestored reaches.

Surveys under canopy in Camp Polk and Whychus Canyon Phase 1 added 15 and 74 units respectively to the total for these two reaches, not including 19 units identified by both methods.

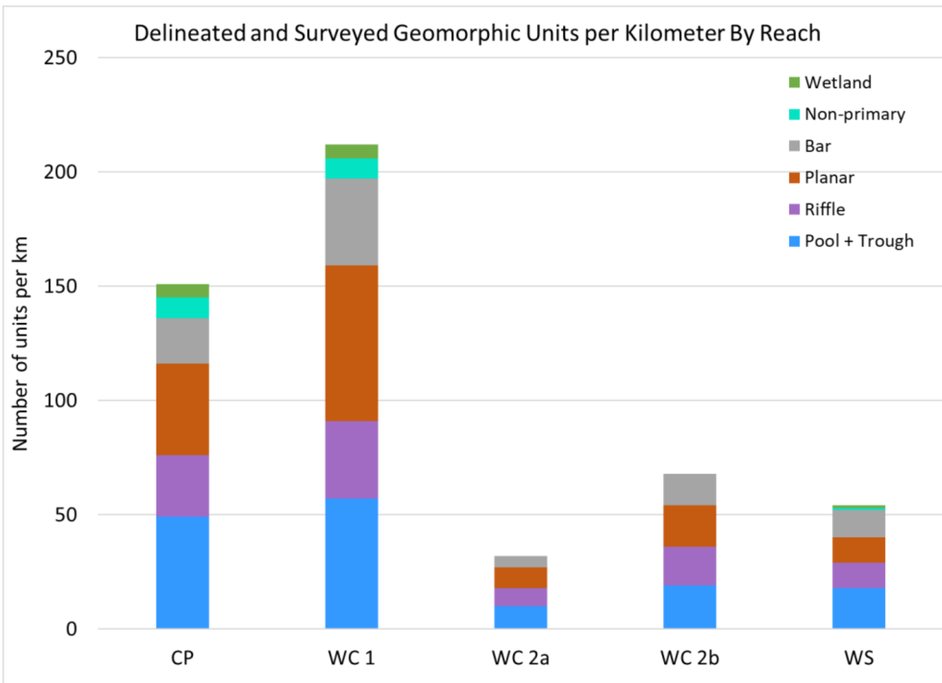


Figure 8. Units delineated and surveyed by unit type and reach showed 4x as many total units, 3x as many pools and troughs, 3x as many riffles, 9x as many non-primary and 12x as many wetland units on average in restored compared to unrestored reaches.

The total number of wet units delineated and surveyed was similar to the number of wet geomorphic units inventoried in ODFW Aquatic Inventory Project surveys (Table 10). AIP surveys showed 60% more geomorphic units per kilometer than the number delineated and surveyed at Camp Polk, 40% fewer than the number delineated at Whychus Canyon Phases 2a and 2b, and very close to the same number as were delineated and surveyed at Whychus Canyon Phase 1 and Willow Springs. The number of wet units delineated and surveyed was most similar to the number from AIP surveys in reaches where AIP surveys had been conducted more recently, in Whychus Canyon Phase 1 and Willow Springs.

Table 10. Number of delineated wet geomorphic units and number per km compared to number of wet units identified during ODFW Aquatic Inventory Project surveys.

	Reach length (m)	Delin Wet GUs	AIP Wet GUs	Delin Wet GUs (#/ km)	AIP Wet GUs (#/ km)	Fold Difference	AIP Year
Camp Polk	801	105	179	131	223	1.7	2016
WC 1	1597	278	317	174	198	1.1	2019
WC 2a	642	17	11	26	17	0.6	2008
WC 2b	2149	117	68	54	32	0.6	2008
WS	1124	47	46	42	41	1.0	2018
Restored	--	192	248	153	211	1.4	--
Unrestored	--	60	42	41	30	0.7	--

The proportions of geomorphic unit types identified at plot locations in restored and unrestored reaches were very similar (Figure 9). Defining riffles as only the saddle-shaped deposition at a pool tail crest resulted in identification of only one unit as a riffle, with an abundance of planar units, representing both units more traditionally defined as riffles and as runs. Plot data showed pools, defined as a concave bowl shape, to be more abundant in restored reaches, with troughs, defined as an elongated concave shape, more abundant in unrestored reaches.

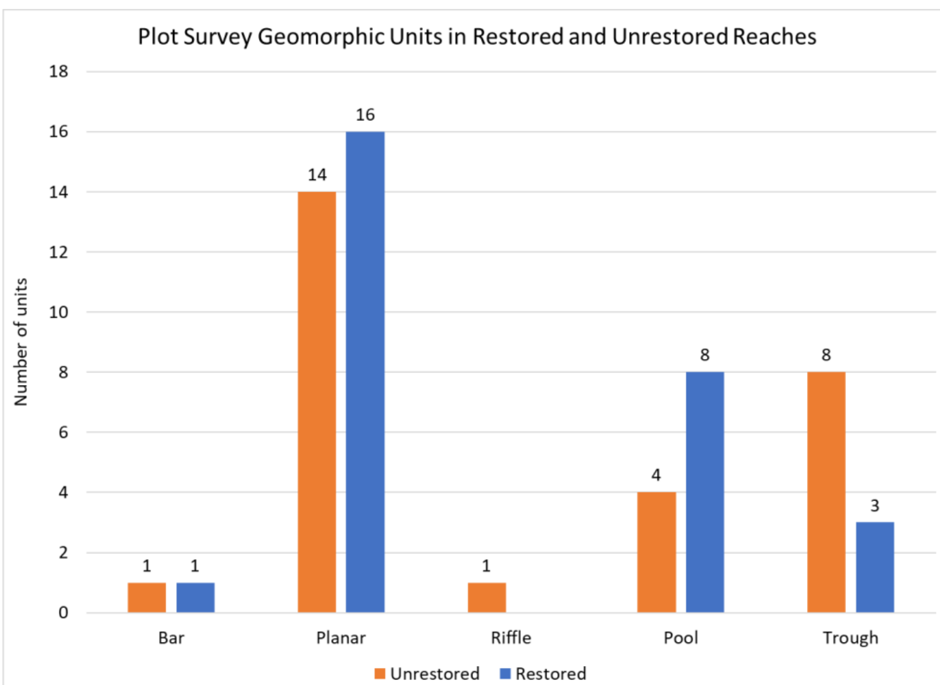


Figure 9. Geomorphic units from plot surveys by type and restoration status showed little difference in proportion of unit types in restored compared to unrestored reaches.

Of 53 units delineated where the surveyed plot location fell within the delineated geomorphic unit, 31 delineated units (58%) matched the unit identified during plot surveys. Two units delineated as pools were identified as troughs during surveys, and the two unit types are topographically and functionally similar (both convexities characterized by greater depths). When we considered pool/trough mismatches as matches, 33 delineated units (62%) matched the unit identified during plot surveys. Planar units were most consistently identified as the same unit type in delineation and plot surveys, with 26 of 37 units (68%) delineated as planar also identified as planar in plots surveys; 5 units (13%) delineated as planar were surveyed as pools, and 7 units (18%) delineated as planar were surveyed as troughs. Four of ten (40%) delineated pools were identified as pools in plot surveys; when combined with units identified as troughs in plots surveys, this number increased to 6 of 10 (60%). We noted seven units delineated as one unit type and surveyed as a different unit type as possibly resulting from a scale or location mismatch, where typically a plot fell in a unit smaller than half a channel's width, the minimum size threshold established for assigning units, or the plot location as shown in GIS was outside a delineated unit. Not one riffle delineated as such was identified as a riffle during plot surveys and vice versa. We noted two of these mismatches as resulting from a scale mismatch, and two reflected an interpretation of the "bar" unit type by the survey crew (as a fully submerged, convex "mound" feature, without the longitudinal concavity or "saddle" that characterizes a riffle) that was different than by the Anabranch staff delineating units, who interpreted dry sediment bars, not riffles, as convex units.

Table 11. Comparison of units identified from hand delineation and from plot surveys. Columns show units assigned from delineation; rows show units identified during plot surveys.

		Delineated							
		Pool	Trough	Planar	Wetland	Non-primary	Riffle	Bar	Surveyed Total
Surveyed	Pool	4	0	5	0	1	1	0	11
	Trough	2	0	7	0	0	0	0	9
	Planar	2	0	26	0	1	1	0	30
	Wetland	0	0	0	0	0	0	0	0
	Non-primary	0	0	0	0	0	0	0	0
	Riffle	1	0	0	0	0	0	0	1
	Bar	1	0	0	0	0	1	0	2
	Delineated Total	10	0	38	0	2	3	0	

3.6. Velocity & flow direction

3.6.1. LSPIV analysis

The USGS tested the PIV workflow (provided in Figure 3 in Methods) in variable channel environments including pools, riffles, glides and a more complex post-restoration, multi-channel configuration (Figure 10). Debris or bubbles on the water surface were present in some of the plots and provided natural tracers of the water surface velocity. Texture and waves on the water surface provided the dominant source of velocity information in the videos.

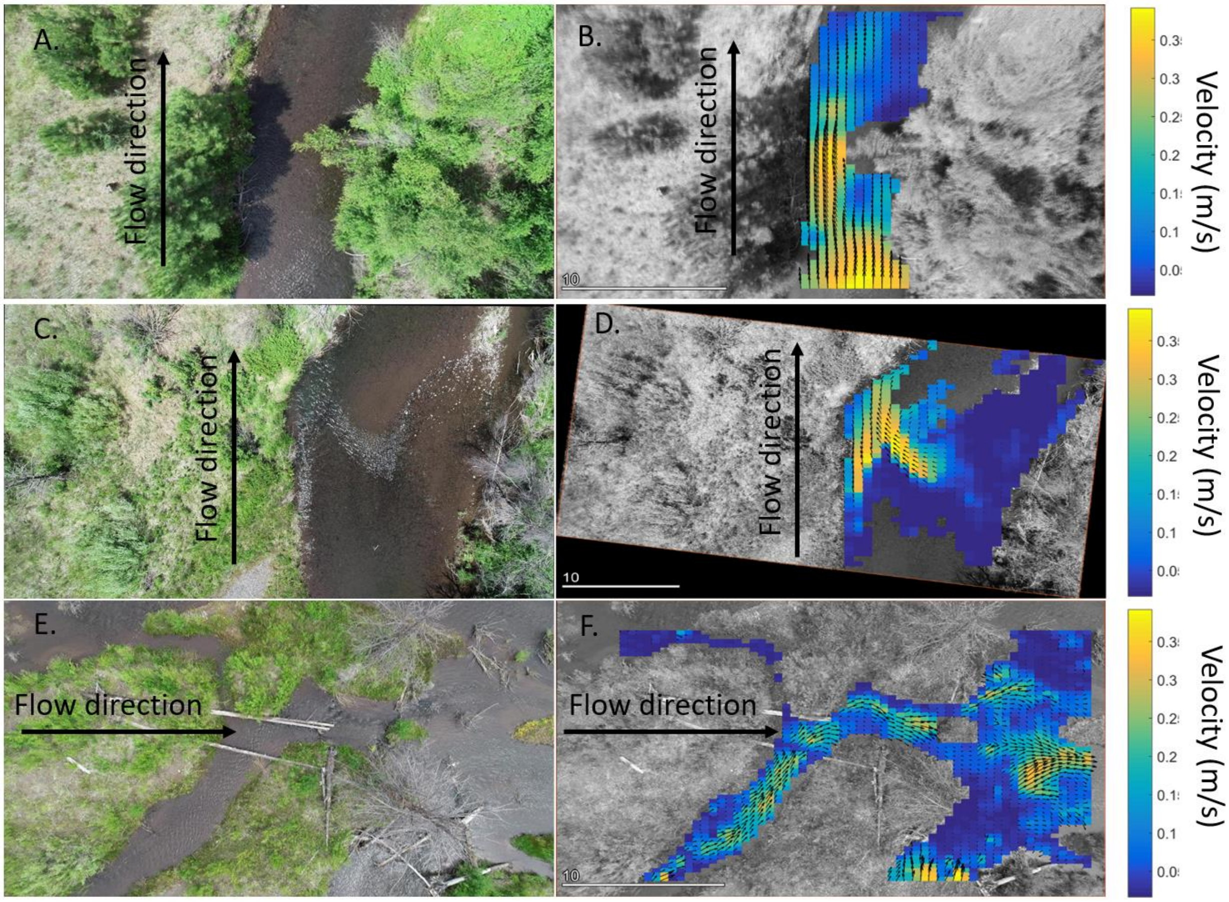


Figure 10. Results from PIV analysis for three velocity plots on Whychus Creek. The velocity plots selected for analysis spanned the range of geomorphic conditions found on Whychus Creek.

Single frames from videos of the three velocity plots (Figure 10 A, C, E) and the PIV mean velocity outputs (Figure 10 B, D, F) are shown in Figure 10. The mean velocity magnitude for each (Figure 10 B, D, F) corresponds to the color bars on the right side of Figure 10. The direction and magnitude of flow in each panel are indicated by black arrows in each figure. Panels A and B correspond to a single-thread channel in an unrestored reach of Whychus Creek (Whychus Canyon Phase 2b). Water surface texture was consistent throughout the video plot which resulted in measurable features throughout the video plot. The PIV velocity shows higher velocity near the outside of the slight bend (yellow cells, Panel B) with velocity vectors curving to the right which is consistent with the geometry of the channel.

Panels C and D correspond to a video plot in an unrestored, single-thread channel. However, the channel geometry was more complex than the plots in A and B, consisting of a pool-riffle transition with variable water surface texture. The PIV algorithm successfully measured velocity patterns in the riffle where there was substantial water surface texture but was unable to track any surface features in the pool at the upstream end of the video plot as indicated by the dark blue and empty cells in Panel D. While the velocity in the pool was unresolved, the PIV velocity vectors in the riffle show a complex flow pattern that was successfully resolved using the PIV analysis.

Panels E and F correspond to a reach of Whychus Creek that was recently modified using a Geomorphic Grade Line restoration approach to promote evolution toward Stage Zero. The video plot includes multiple channels with channel-spanning wood in some locations (Figure 10 E). The complex channel and in-channel obstructions produced surface texture that provided suitable tracers for the PIV analysis. Velocity patterns indicated by the velocity vectors (Figure 10 F) show divergence of flow at the upstream end of islands and convergence of flow downstream of islands and at confluences, consistent with the expected flow patterns.

An advantage of PIV is that it provides a two-dimensional representation of velocity patterns which is difficult to capture with field measurements, especially in complex or multi-thread channels. The two-dimensional PIV outputs are summarized in windrose plots in Figure 11 for representative simple channel (top row) and complex channel (bottom row) video plots on Whychus Creek. The windrose plot is a histogram in a circular format where all PIV-derived vectors are grouped into bins based on flow direction. Each flow direction bin is represented by a spoke on the windrose diagram and the length of each spoke represents the frequency at which flows occur in that direction. Flow directions that are most frequent have longer spokes whereas less frequent flow directions have shorter spokes. The colors within each spoke represent the proportion of the velocity vectors in velocity classes defined by the legend in each plot. In other words, the colors within each spoke form a bar graph where blue colors represent slowest velocity and yellow colors represent the fastest velocity. The PIV-output velocity vectors represent flow direction in image space and the flow angles represented in the windrose diagrams do not represent cardinal direction. We rotated the windrose diagrams in Figure 11 so that the dominant flow direction (the longest spoke) plotted at 0 degrees to facilitate direct comparison between velocity plots.

The windrose diagrams in Figure 11 represent both the range of flow direction and flow velocity in each velocity plot. The simple channel (top row, Figure 11) has a narrow range in flow direction when compared to the complex post-restoration channel (bottom row, Figure 11). The post-restoration channel also had flows occurring at a higher frequency over a wider range in flow direction indicating more complex flow dynamics.

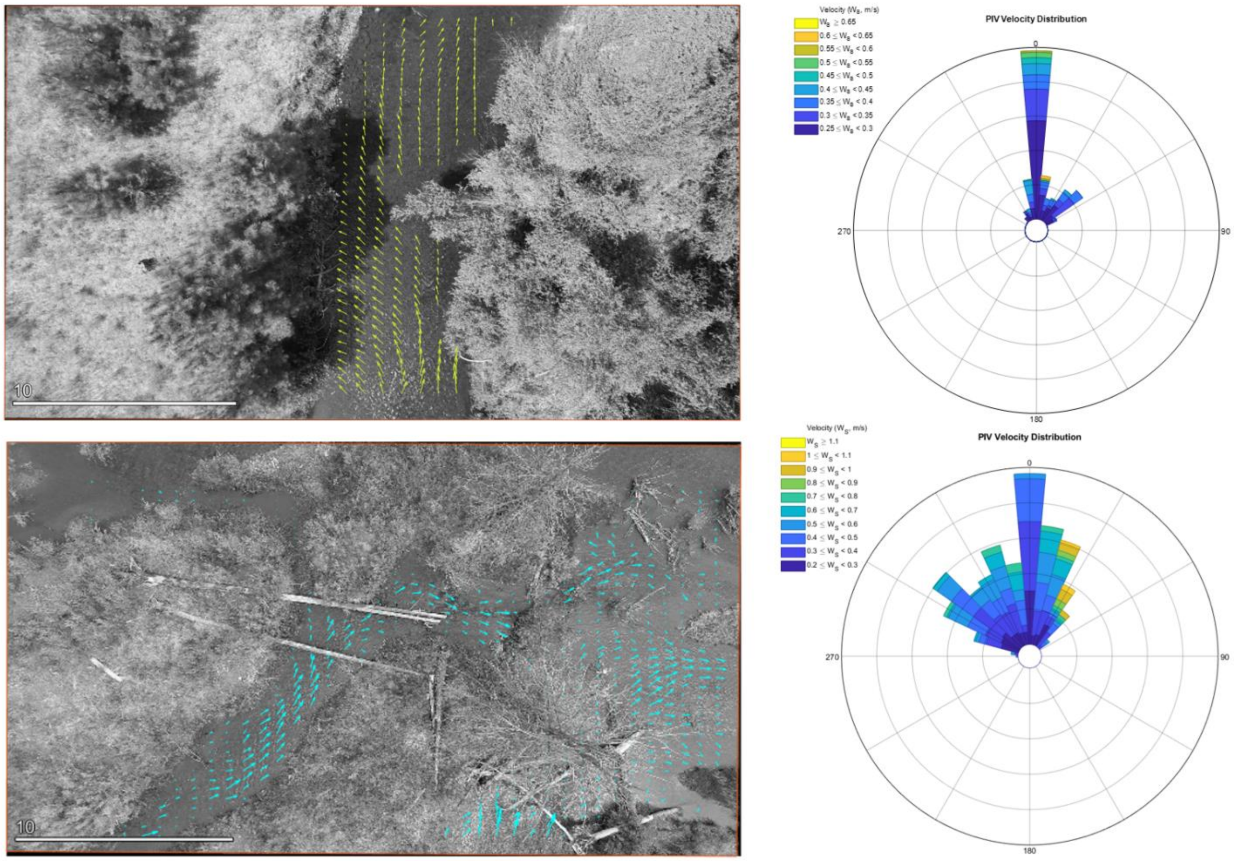


Figure 11. Windrose plots showing velocity distribution for two velocity plots on Whychus Creek.

Maximum PIV-derived flow velocities ranged from 0.65 to 1.1 meters/second at the sites analyzed for this work (Figure 11). The UDWC measured stream velocity just below the water surface using a Marsh McBirney flow meter within two weeks of and at similar flows as during video acquisition. Measured surface velocity ranged from 0.89 to 1.16 m/s indicating the field-measured surface measurements are higher than PIV-derived velocity. The source of the low velocity bias is currently being investigated by the USGS but could be related to image scaling, frame-to-frame time steps, or the PIV algorithm used in this study.

3.6.2. Plot velocity data

The range of velocities at 60% depth was wider, and the median velocity 0.5 ft/s lower, in restored compared to unrestored reaches (Table 12, Figure 12). Surface velocity generally tracked velocity at 60% depth; at higher velocities, surface velocity was often higher than at 60% depth. The similarity between surface velocity and velocity at 60% depth, the standard depth at which velocity is measured, supports the suitability and utility of applying surface velocity measured from imagery to represent velocity conditions for fish habitat.

Flow direction (azimuth) measurements showed no apparent trend differentiating flow direction in restored and unrestored reaches (Figure 13). The Whychus Creek valley trends northeast; only in the unrestored Willow Springs reach does the valley trend northwest for a short distance. Flow direction measurements from restored reaches included 1-3 more measurements in some directions (NNW, NNE, E, SW) and measurements from unrestored reaches included 1-3 more measurements in other directions

(W, WNW, NW, ENE). Restored reaches and unrestored reaches each included flow direction measurements in two directions not represented in the other dataset. Westerly flow directions in unrestored reaches are consistent with those reaches including Willow Springs and Whychus Canyon Phases IIa and IIb where the valley trends more northerly than easterly compared to the Camp Polk and Whychus Canyon Phase 1 reaches included in this study.

Table 12. Minimum, median, maximum, and average velocities at 60% depth and at the surface in restored and unrestored reaches along Whychus Creek in July 2020

	Restored						Unrestored							
	Camp Polk		WC Phase 1		All Restored		WC Phase 2a		WC Phase 2b		Willow Springs		All Unrestored	
	60%	Surface	60%	Surface	60%	Surface	60%	Surface	60%	Surface	60%	Surface	60%	Surface
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.0	0.5	0.0
Median	0.8	0.7	1.1	0.9	0.9	0.9	1.3	1.2	1.5	1.5	1.5	0.8	1.5	0.8
Maximum	2.7	2.6	3.2	3.3	3.2	3.3	2.1	1.9	3.0	4.3	3.0	3.1	3.0	3.1
Average	0.9	0.9	1.2	1.3	1.1	1.1	1.1	1.1	1.6	1.8	0.9	1.0	0.9	1.0

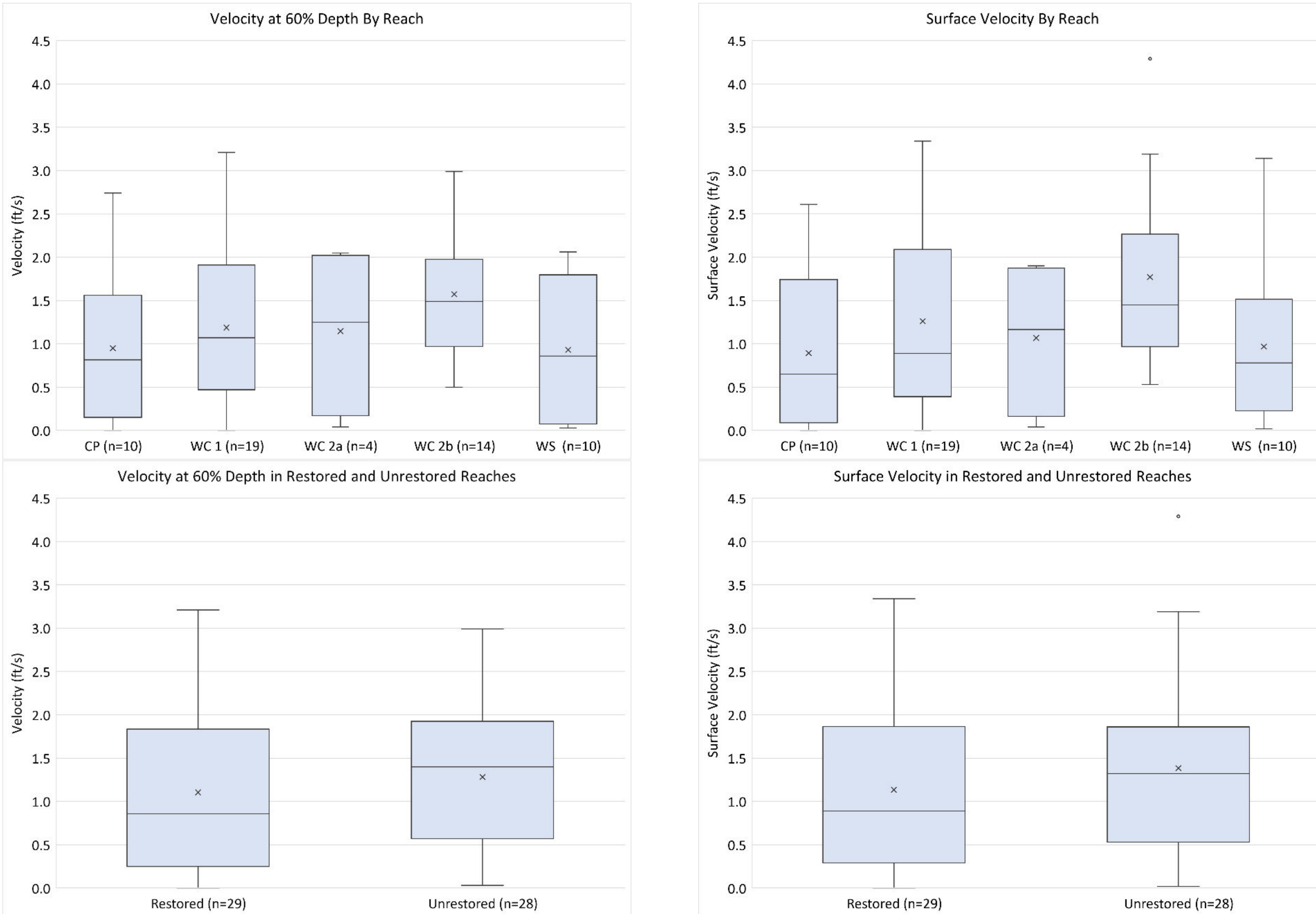


Figure 12. Velocity at 60% depth and at (just below) the water surface by reach and by restoration status. Median velocity was slightly lower and the range of velocities slightly larger in restored compared to unrestored reaches.

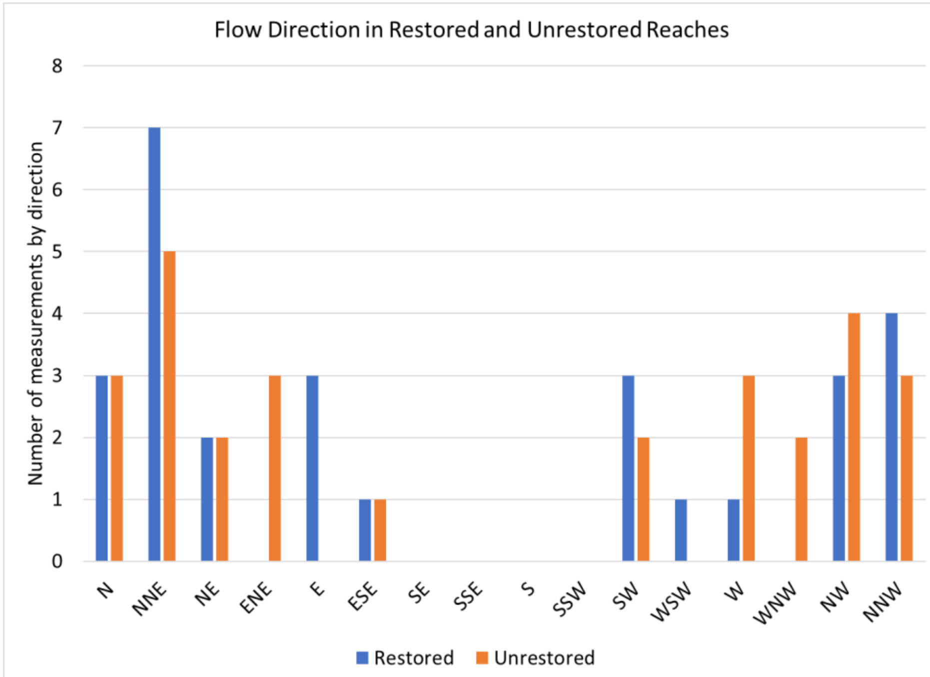


Figure 13. Flow direction in restored and unrestored reaches showed no apparent pattern. Whychus Creek flows northeast but in some reaches trends more northerly than easterly as reflected in flow directions trending toward west.

3.7. Sediment

We measured sediment in 29 wetted and 23 dry plots in restored reaches and in 28 wetted and 25 dry plots in unrestored reaches. In response to preliminary analysis showing one of the plots where we had estimated the sizes of clasts inflated averages to indicate more sediment < 2 mm in unrestored reaches than in restored reaches, counter to prevailing knowledge and existing data, we removed the six estimated plots from subsequent analysis. This resulted in sediment measurements for 26 wetted and 23 dry plots in restored reaches and 27 wetted and 23 dry plots in unrestored reaches (Table 13). As a result of candidate plots having been generated for Phases IIa and IIb collectively rather than for each reach individually and because the geographic extent of Phase 2a represents only a quarter of the length of the two reaches combined, the number of plots in 2a is proportionately small.

Table 13. Final wetted and dry plots included in sediment size class analysis.

	Restored			Unrestored			
	Camp Polk	Whychus Canyon Phase 1	Total	Willow Springs	Whychus Canyon Phase 2a	Whychus Canyon Phase 2b	Total
Wetted	11	15	26	9	4	14	27
Dry	9	14	23	8	2	13	23
Total	20	32	49	17	6	27	50

Wetted plots in restored reaches were characterized by low percentages of sand and cobble and high percentages of gravel (Figure 14). Wetted plots in unrestored reaches were characterized by low percentages of sand, moderate quantities of gravel, and relatively higher percentages of cobble compared to restored reaches. Wetted plots in restoration reaches exhibited on average approximately 20% more gravel and 20% less cobble than wetted plots in unrestored reaches. Boulders were rare in wetted plots in both restored and in unrestored reaches.

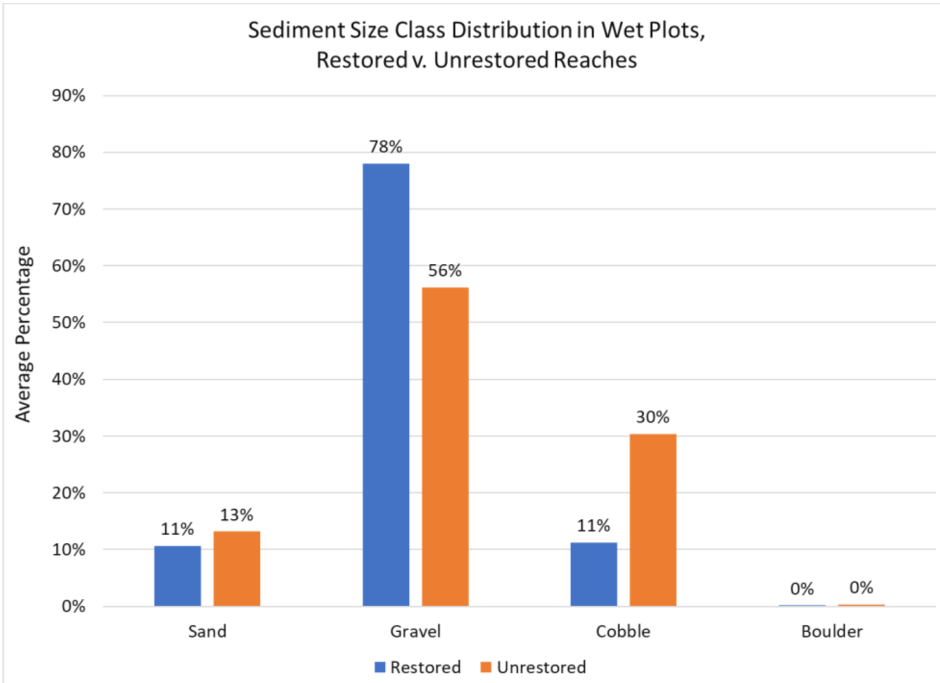


Figure 14. Average percentages of sand, gravel, cobble, and boulder in restored and unrestored reaches from pebble counts conducted in plots.

The average percentage of sand in wetted plots was similar in restored and unrestored reaches and unexpectedly remained slightly higher in unrestored reaches after removing the six plots where sediment was estimated to be < 2 mm. Visual estimates of percent sediment by size class from 2019 AIP surveys in Whychus Canyon Phase 1 showed higher percentages of sand post-restoration compared to pre-restoration (UDWC 2022), and pebble counts from Whychus Canyon Phase 1 and Camp Polk (both restored), and Whychus Canyon Reach 3 (unrestored) showed the proportion of sand in restored reaches to be 3x to 8x that observed in the unrestored Reach 3 (Scagliotti and Mork, 2019). This result suggests the higher average percentage of sand in unrestored reaches calculated from pebble counts in plots might reflect sampling error and that our subsampling number of 50 clasts might be too low and our sample size too small to represent the true frequency distribution of sediment classes.

Wet and dry plots had similar percentages of gravel whether in restored or in unrestored reaches, with differences between wet and dry plots ranging from 2-7% (Figure 15). Percentages of cobble were also similar in wet and dry plots in restored reaches and in Whychus Canyon Phase 2a, which had not yet been restored as of 2020. Percentages of cobble in both Phase 2b and Willow Springs were on average 10% higher in wet plots than in dry plots, possibly an artifact of mobilization and deposition of the smaller classes, but not cobble, outside of active channels, i.e. where dry plots were located, during flood flows in confined, unrestored reaches.

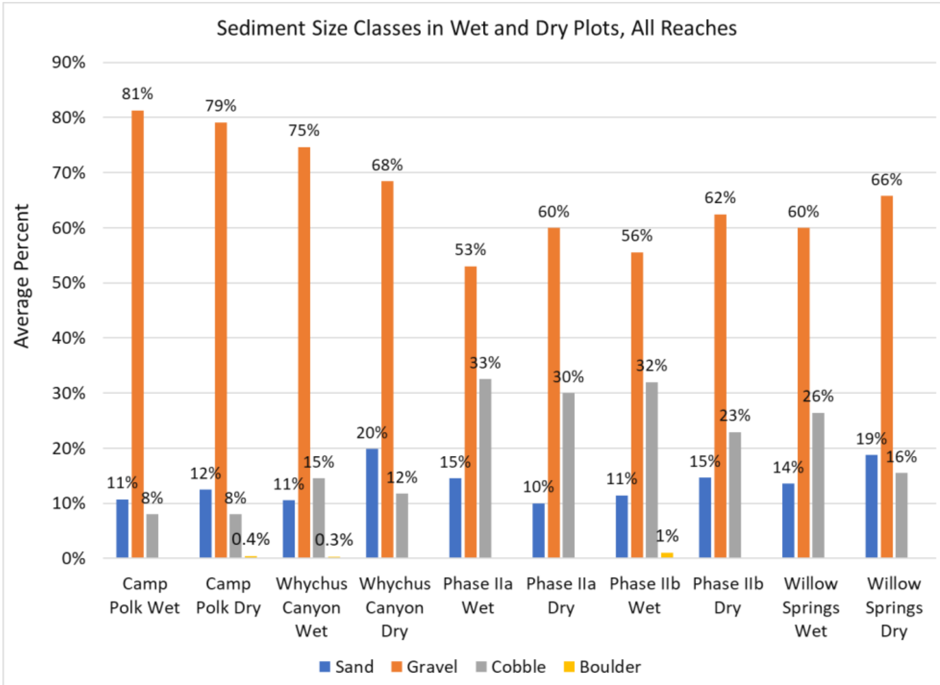


Figure 15. Average percentages of sand, gravel, cobble, and boulder by wet and dry plots in each reach.

One limitation of pebble counts is that the standard protocol does not differentiate among grain sizes smaller than 2 mm. In practice, this means this method fails to differentiate between sand (0.062-2 mm), and silt and organics (0-0.062 mm). However, based on the results from a meta-analysis by Jensen et al (2009), even increases in sand and fine gravels (<3.4-4.6 mm) have been shown to result in a material (7.1%) decrease in odds of egg-to-fry survival of pacific salmon species.

3.8. Depth

Plot data showed little variation in depth among two restored and three unrestored reaches (Figure 16). Camp Polk (restored) and Whychus Canyon Phase 2a (unrestored) exhibited the deepest measured depths and a higher proportion of depths greater than the median depth (right-skewed distribution). Median and average measured depths were similar across the five reaches, ranging from 0.16 m to 0.21 m and 0.18 m to 0.29 m, respectively; the median measured depth across restored reaches was 0.16 compared to 0.19 in unrestored reaches, and the average was 0.22 m in both restored and unrestored reaches. Only two outlier measurements were greater than 0.52 m (1.7 ft).

AIP survey data showed deeper median and average depths across all reaches than those measured in plots, and showed median and average depth values in unrestored reaches up to 0.2 m deeper than in restored reaches (Camp Polk median = 0.25 m, average = 0.40 m; Phase 1 median = 0.25 m, average = 0.33 m; Phase 2a median = 0.45 m, average = 0.55 m; Phase 2b median = 0.35 m, average = 0.56 m; Willow Springs median = 0.35 m, average = 0.49 m). AIP depths are measured at the maximum depth of each unit whereas our plot survey depth measurements were at plot center.

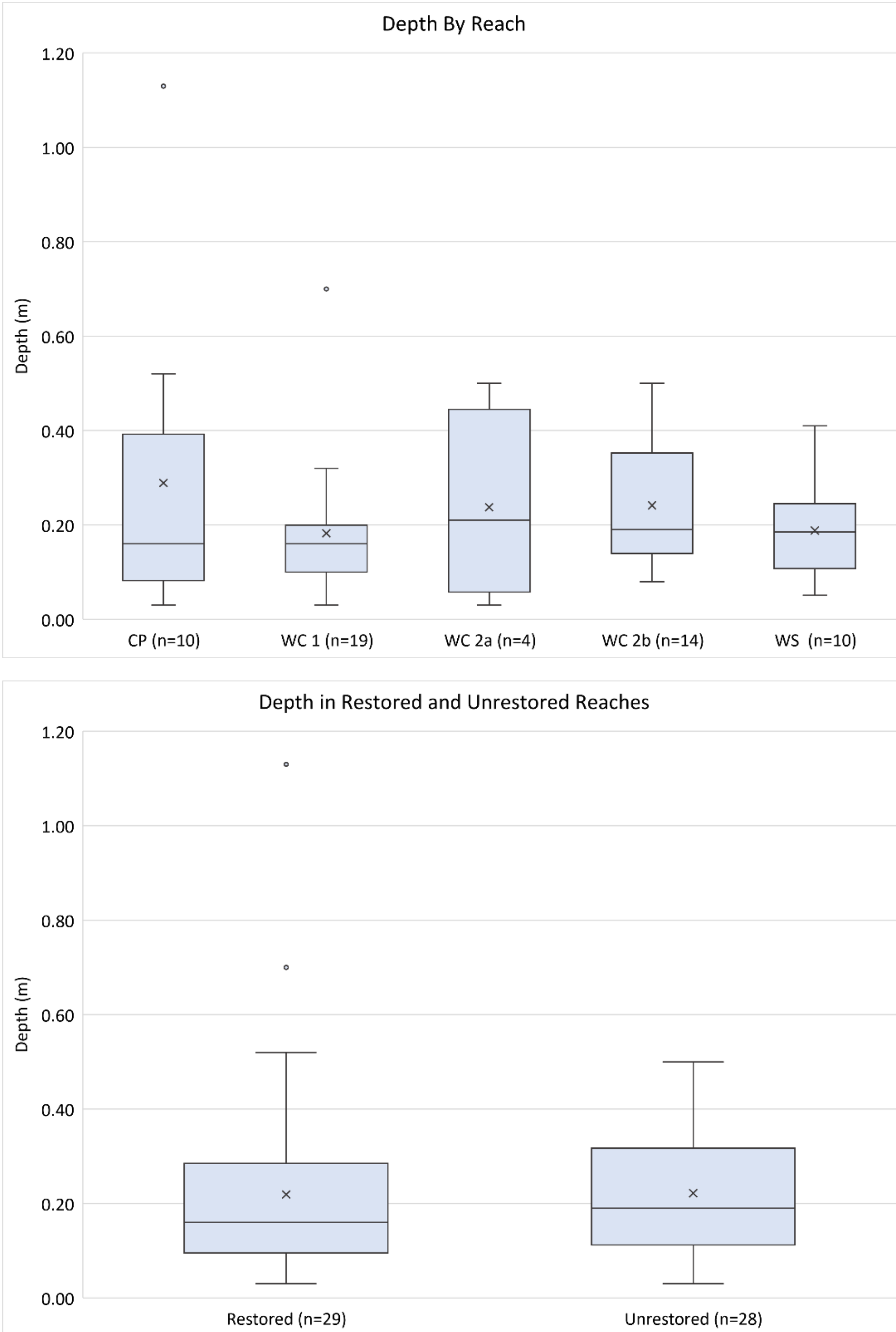


Figure 16. Depth at plot center by reach (top) and by restoration status (bottom).

3.9. Canopy cover

Canopy cover over the center of wetted plots varied among reaches, with wider variation and heterogeneity and higher maximum values in restored reaches than in unrestored reaches (Figure 17). Median canopy cover was similar in Camp Polk and Whychus Canyon Phase 1 (both restored), and slightly higher in both than in Whychus Canyon Phase 2b and Willow Springs (both unrestored). There was a wider range of canopy cover values and higher maximum values in the two restored reaches compared to in these two unrestored reaches. In Whychus Canyon Phase 2a, also unrestored, where only 4 plots were surveyed, median canopy cover was markedly higher than in any other reach and the distribution of values was similarly wide as in the two restored reaches.

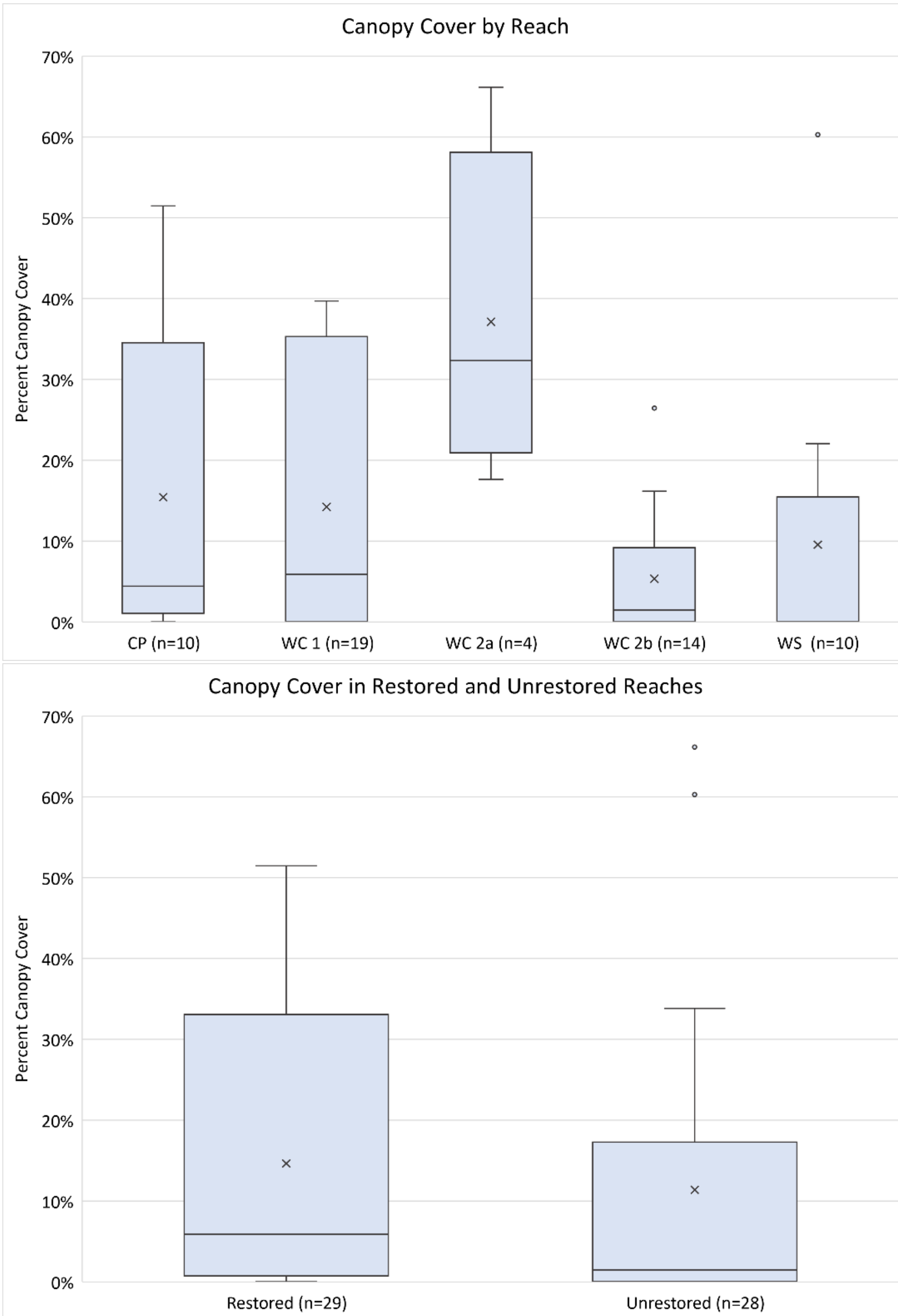


Figure 17. Canopy cover calculated from four densiometer measurements recorded over the center of wetted survey plots by reach (top) and by restoration status (bottom).

AIP surveys measure shade from the center of the stream using a clinometer. Clinometer angle measurements are converted to percent shade for each habitat unit. Shade as measured during AIP surveys and averaged across the habitat units included in the spatial extent of each study reach was 25% in Camp Polk Reaches 1 & 2 (2016); 51% in Whychus Canyon Phase 1 (2019); 50% in Whychus Canyon Phase 2a (2008); 37% in Whychus Canyon Phase 2b (2008) and 30% in Willow Springs (2018).

3.10. Temperature

Temperature data were missing for Whychus Canyon Phase 2a and for four Phase 2b plots due to the NIST thermometer being dropped in the water and not reading temperatures for the remainder of the field day. Sampling time data were missing for an additional seven Camp Polk plots and two Whychus Canyon plots. We populated approximate times for the two Whychus Canyon Phase 1 plots based on date and the survey time of plots surveyed before and after and included the corresponding temperatures in our analysis. Because no survey times were recorded for two Camp Polk survey dates, we were not able to extrapolate approximate times and did not include these temperatures in our analysis.

Stream temperatures were recorded between June 30 and July 16, at instantaneous flows ranging from 13.7 cfs to 33.5 cfs and maximum air temperatures ranging from 18.3 to 32.8 (Table 14). As expected, stream temperatures generally increased with distance downstream (Figure 18), with the lowest temperatures at Camp Polk (but not at Willow Springs) and the highest temperatures at Whychus Canyon Phase 2b, and with time of day, with the lowest temperatures in the morning and the highest temperatures in the afternoon. Temperatures at Whychus Canyon Phase 1, the only restored reach for which a complete dataset was available, showed more variation at the same times of day than temperature at the two unrestored reaches (Willow Springs and Whychus Canyon Phase 2b), suggesting thermal heterogeneity among plots surveyed at Phase 1 that wasn't occurring in the two unrestored reaches. Additionally, despite Whychus Canyon Phase 1 being ~10 miles further downstream than Willow Springs and Camp Polk, and air temperatures during surveys at Willow Springs being only slightly higher than those during Phase 1 surveys, most Phase 1 stream temperatures were as low as or lower than those in the two upstream reaches at the same times of day.

Table 14. Dates surveyed, instantaneous flow, maximum air temperature, and minimum and maximum stream temperature in two restored and two unrestored reaches. WS = Willow Springs, CP = Camp Polk, WC 1 = Whychus Canyon Phase 1, and WC 2b = Whychus Canyon Phase 2b.

	Dates surveyed	Inst Flow (cfs)	Max Air Temp (°C)	Min Stream Temp (°C)	Max Stream Temp (°C)
WS	7/13, 7/16	13.7-25.3	27.8-31.7	12.6	18.1
CP	6/30, 7/1	15-26.4	18.3-19.4	11.2	16.4
WC 1	7/8-7/10	22.2-33.5	25.6-29.4	11.7	18.5
WC 2b	7/15	14.2-24	32.8	13.5	20.7

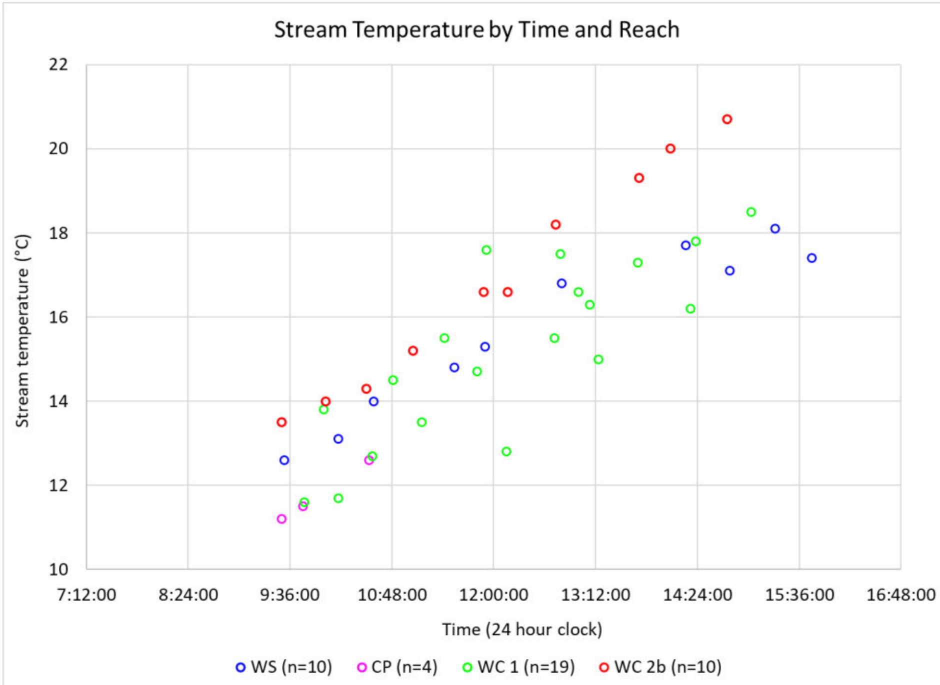


Figure 18. Stream temperature by time of day in two restored reaches (CP = Camp Polk; WC 1 = Whychus Canyon Phase 1) and two unrestored reaches (WS = Willow Springs; WC 2b = Whychus Canyon Phase 2b).

3.11. Complementary Biological data

3.11.1. Macroinvertebrate community data

Macroinvertebrate community data from 2020 are summarized in the technical report "Macroinvertebrate Monitoring at Selected Sites in Whychus Creek, Sisters, OR, 2020" (Mazzacano, 2021). Macroinvertebrate samples were collected in 2020 in all five Whychus Creek Stage 0 Effectiveness monitoring reaches including from Camp Polk (WC1950) and Whychus Canyon Phase 1 (WC1100, 4 sampling reaches), both restored reaches; and from Whychus Canyon Phase 2a (WC0850), Phase 2b (WC0900 and WC1025), and Willow Springs (WC2000, WC2050), unrestored as of 2020. A combination of Proportional Multihabitat (PM) and Riffle Targeted (RT) macroinvertebrate sampling protocols were used.

Macroinvertebrate data from restored reaches were characterized by increased total and EPT taxa, and, at Camp Polk, high numbers of sensitive taxa, compared to pre-restoration. Higher numbers of taxa in part reflect use of a proportional multi-habitat sampling protocol that proportionally samples all habitats compared to the riffle targeted protocol that only samples riffles, but also reflect the presence of habitats in restored reaches that weren't present in the unrestored condition.

The WC1950 sampling reach begins downstream of the Camp Polk bridge and extends downstream into Reach 1 of the Camp Polk Meadow restoration project. The PM sample collected at this site in 2020, eight years after restoration, had the most total (65), EPT (24), and sensitive taxa ever taken at the site. Relative abundance of the dominant taxon has fluctuated post-restoration, but in 2020 was the lowest observed in any sampling year (7.1%) and the lowest among all 16, 2020 samples, indicating evenness of taxa characterizing the community.

Four samples, including three PM and one RT sample, were collected in multiple channels across and along the Whychus Canyon Phase 1 valley floor in 2020. Eight taxa were present for the first time in 2020 in samples from this site; total (44) and EPT (19) taxa richness in the RT, primary channel sample were 1.5-2x greater than in pre-restoration samples, and total (51-64) and EPT taxa richness in the PM samples was even higher (x-23). Dominance of the top taxon was low (range = 12.6-25.6%).

With the exception of the upstream site at Whychus Canyon Phase 2b (WC0900), unrestored reaches were also characterized by surprisingly low abundance of the most abundant taxon and high total taxa and EPT richness. The 2020 sample from WC0900, sandwiched between WC1025 in Phase 2a and WC0850 at the downstream end of Phase 2b, appears to represent among the worst conditions on the creek in this year, despite "good" scores on par with those from restored reaches for many macroinvertebrate metrics at the unrestored sites upstream and downstream.

WC1025 in Whychus Canyon Phase 2a was sampled using the RT protocol from 2011 to 2017 and using the PM protocol in 2019 and 2020. Total (57 taxa) and EPT richness (22 taxa) increased with use of the PM sampling technique, with four taxa new to the site taken in 2020. Relative abundance of the top taxon was the lowest in 2020 since 2017 (at 15%), and for the first time since 2017 the most abundant taxon was sensitive and associated with cold fast flows. Numbers of sensitive and sediment-sensitive taxa have increased since 2017, while relative abundance of sediment-tolerant organisms decreased in the same span. Community sediment optima, which increased steadily through 2019, were lower for the first time in 2020, and the community temperature optima of the 2020 sample was lower than the previous year. It is likely that this reach was disturbed by the restoration activities conducted upstream at the WC1100 site within Phase 1, and that the community here has been recovering as well as potentially receiving positive impacts from the restored habitat upstream.

WC0900 and WC0850 are in Whychus Canyon Phase 2b; both were sampled from 2011 to 2017 using the RT sampling protocol, and neither were sampled in 2018 or 2019. WC0900 was sampled in 2020 using the RT protocol, and WC0850 was sampled in 2020 using the PM protocol. Richness in the WC0900 sample was similar to earlier years, with two taxa new to the site taken, both with warmer temperature associations. WC0900 had the fewest taxa (35 total taxa and 16 EPT taxa) and lowest organismal abundance of any of the 2020 samples. While the sample was the most balanced of any prior year (at 13% relative abundance), the dominant taxon was a tolerant and sediment tolerant snail associated with warm temperatures and higher sediment; this result was consistent with more organisms associated with warm temperatures, the highest community temperature optima observed except for in 2009 and the highest in the 2020 sample set, more sediment-tolerant organisms than in any year since 2012 and the highest community sediment optima of any year at this site. In contrast, the 2020 WC0850 PM sample downstream had almost twice as many taxa as in earlier years (55 in 2020), EPT richness at the high end of the range for this site (19 taxa in 2020), eight new taxa for the site, most associated with colder, faster flows and one new to the complete Whychus Creek dataset, and the lowest relative abundance of the dominant taxon (12.6%) of any year.

WC2000 and WC2050 in Willow Springs were sampled for the first time in 2020 to provide baseline data prior to restoration. PM and RT samples were collected downstream at WC2000, and a PM sample was collected upstream at WC2050. Both WC2000 samples were characterized by high total richness (PM = 62; RT = 48), high EPT richness (PM = 19, RT = 20), and high evenness indicated by low relative abundance of the dominant taxon (7.7% of total abundance in the PM sample and 14.6% in the RT).

These samples were characterized by notably high numbers of DEQ cool indicator taxa (5 in the PM and 6 in the RT sample), exceeded in the 2020 dataset only in the Whychus Floodplain project upstream of Sisters (WC2600; 8 taxa), and low numbers of DEQ warm indicator taxa (3 in the RT sample at WC2000, range on Whychus in 2020 = 1-8), likely associated with the known, abundant and cold spring inputs in the Willow Springs reach. At WC2050, relative abundance of the top taxon was low at 10.3%. Sample richness was intermediate among the 2020 sample set (53 taxa) and EPT richness was at the upper end of the 2020 range (21 taxa). Similar to WC2000, the number of DEQ cool indicator taxa were at the upper end of the 2020 sample range (6 taxa).

3.11.2. Fish data

A combination of mark-recapture fish population estimates and redd counts have been conducted on Whychus Creek to monitor resident native redband trout and reintroduced summer steelhead (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha)* and brown trout (*Salmo trutta*) populations. All mark-recapture fish population estimates were conducted following the ODFW Whychus and McKay Creeks Draft Fish Sampling Protocol, v4 (ODFW, 2013). No fish population data are available from Willow Springs.

Summer steelhead were reintroduced to Whychus Creek as fry and smolts beginning in 2007, and Chinook salmon were reintroduced as fry and smolts beginning in 2009. Release of summer steelhead as fry was discontinued in 2019 following a 2015 genetic study that showed ~90% of the O. mykiss were descended from the reintroduction hatchery stock and that native resident redband comprised a very small proportion of the population. Population trends observed for O. mykiss should be interpreted within this context.

Population estimates

ODFW and USFS conducted electrofishing surveys to support mark-recapture fish population estimates at Camp Polk Meadow pre restoration in 2006, and post restoration in 2017 and 2018. Post-restoration O. mykiss density per $100m^2$ was 8x higher in Camp Polk Reach 2 (33 ± 9) in 2017 and 5x higher in Camp Polk Reach 4 (20.9 ± 3.6) in 2018 than pre-restoration in 2006 (4.2 ± 2) (Figure 19). 2017 and 2018 data likely reflect both the effects of restoration and the effects of annual O. mykiss fry and smolt releases through the reintroduction program.

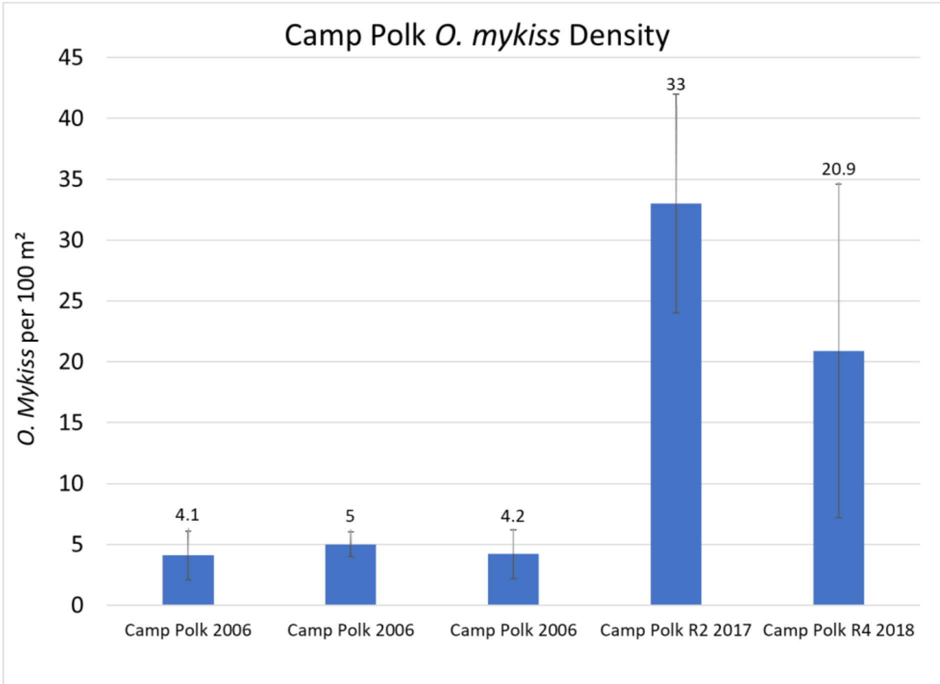


Figure 19. Fish density trends pre- (2006) and post-restoration (Reach 2, 2017; Reach 4, 2018) at Camp Polk Meadow on Whychus Creek.

ODFW and USFS conducted mark-recapture electrofishing surveys and produced population estimates in Whychus Canyon Phase 1 in 2015 and 2018. They conducted surveys and produced population estimates in an adjacent unrestored reach upstream, Whychus Canyon REach 3, in 2017 and 2018. One randomly selected ~200-m sampling reach was established in Whychus Canyon Phase 1 in 2015. The same reach and an additional ~200 m sampling reach were sampled in 2018, denoted as lower and upper Whychus Canyon Phase 1; the upper reach was sampled again in 2022. Sampling was conducted in a ~200 m reach in Whychus Canyon Reach 3 in 2018 and was repeated in the same reach in 2022.

O. mykiss data are available from Whychus Canyon Phase 1 from 2015 (upper), from 2018 (lower and upper), and from 2022 (upper); and from Whychus Canyon Reach 3 from 2018 and 2022 (Figure 20). *O. mykiss* populations were 3.5 higher in the Whychus Canyon Phase 1 upper survey reach in 2018 post-restoration than in 2015 pre-restoration (38 ± 3 in 2018; 11 ± 2 in 2015), and were twice O. mykiss numbers in the unrestored Reach 3 in 2018 (16 ± 2). O. mykiss numbers in Whychus Canyon Phase 1 in 2022, four years later and following the cessation of O. mykiss fry releases, were ~20% of pre-restoration, 2015 numbers (2.3 ± 1) and only 6% of 2018 numbers. 2022 O. mykiss numbers in the unrestored Reach 3 were similarly low (2.7 ± 2).

Spring Chinook and brown trout data are available from upper Whychus Canyon Phase 1 and from Whychus Canyon Reach 3 from 2018; brown trout data are also available from both reaches from 2022. Spring Chinook were 24x higher in Upper Whychus Canyon Phase 1 (14.4 ± 2.3) and 6x higher in Lower Whychus Canyon Phase 1 (3 ± 1) than in the unrestored Reach 3 (0.6 ± 0.2) in 2018. Brown trout numbers in 2018 followed a similar trend as O. mykiss, with twice as many brown trout in the Whychus Canyon Phase 1 restored reach (26 ± 4) compared to the Whychus Canyon Reach 3 unrestored reach (14 ± 3). Brown trout were 17x as abundant as O. mykiss in Whychus Canyon Phase 1 in 2022 (39 ± 6). There were ~5x as many brown trout in Whychus Canyon Phase 1 in 2022 as in the unrestored Reach 3.

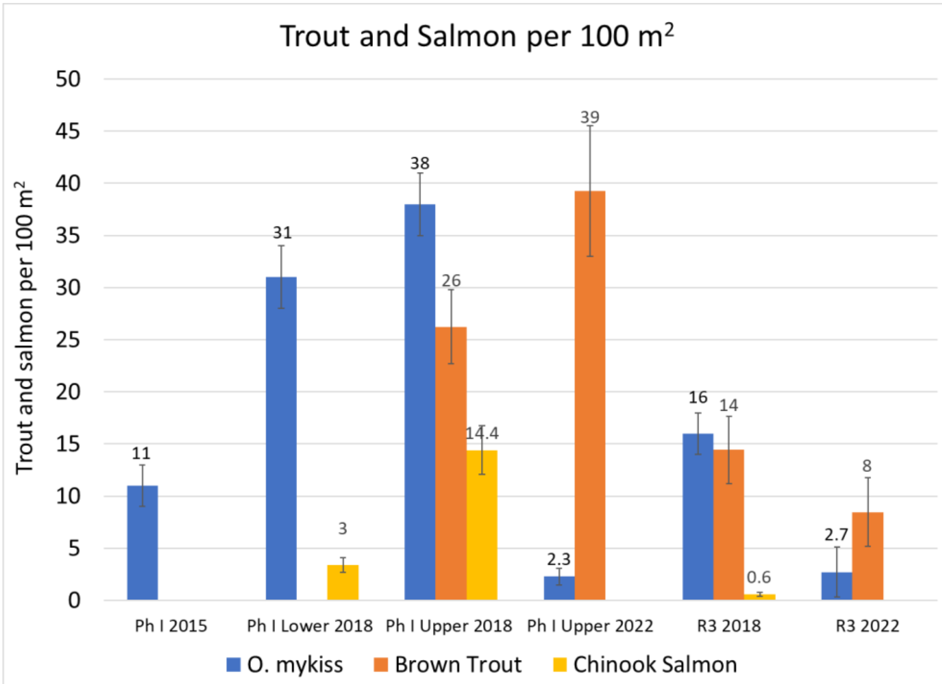


Figure 20. O. mykiss, brown trout and Spring Chinook densities pre- (2015) and post-restoration (2018; 2022) in Whychus Canyon Phase 1 and in the adjacent unrestored Whychus Canyon Reach 3 upstream of Phase 1.

No fish population estimates have been conducted in Whychus Canyon Phases 2a and 2b at Rimrock Ranch. However, during implementation of the Phase 2b stream restoration project in 2023, a 1.5-mile fish salvage was completed over 7 days, providing total fish numbers by species. A total of 4,525 fish were captured and identified. Weights and lengths were recorded for *O. mykiss,* Spring Chinook, and brown trout. Longnose dace were the most common fish species observed with 2,635 individuals (66.7%), followed by brown trout (1,035 individuals, 22.9%) and *O. mykiss* (305 redband, 74 left-maxillary clipped steelhead smolts released through reintroduction; 8.4%). One Spring Chinook (.02%) individual was observed.

Redd counts

USFS, ODFW, and PGE conduct redband redd surveys annually in a selection of reaches along Whychus Creek. To ensure detection of redds and establish redband spawning timing (temporal distribution), surveyors count redds every two weeks from March through July. One or two surveyors walk downstream at each site to identify redds and place flagging next to each redd detected to avoid recounting redds on subsequent surveys.

Of the reaches monitored in 2020, Whychus Canyon Phase 1 had the most redds per km (6/km), followed by the lower Whychus Canyon Phase 2b survey reach (4/km), Whychus Canyon Phase 2a (3 redds/km), and Camp Polk (1 redd/km) (Figure 21). No redds were detected in Willow Springs but the reach immediately downstream had 2 redds/km in 2020. In all reaches except Camp Polk, the number of redds per km in 2020 was slightly higher than the 2006-2019 average. Of the 49 total O. mykiss redds detected in Whychus Creek in 2020, Whychus Canyon Phase 1 accounted for 12% (6 redds); Whychus Canyon Phase 2b accounted for 8% (4 redds); and 6% (3 redds) were found in Whychus Canyon Phase 2a and in Camp Polk.

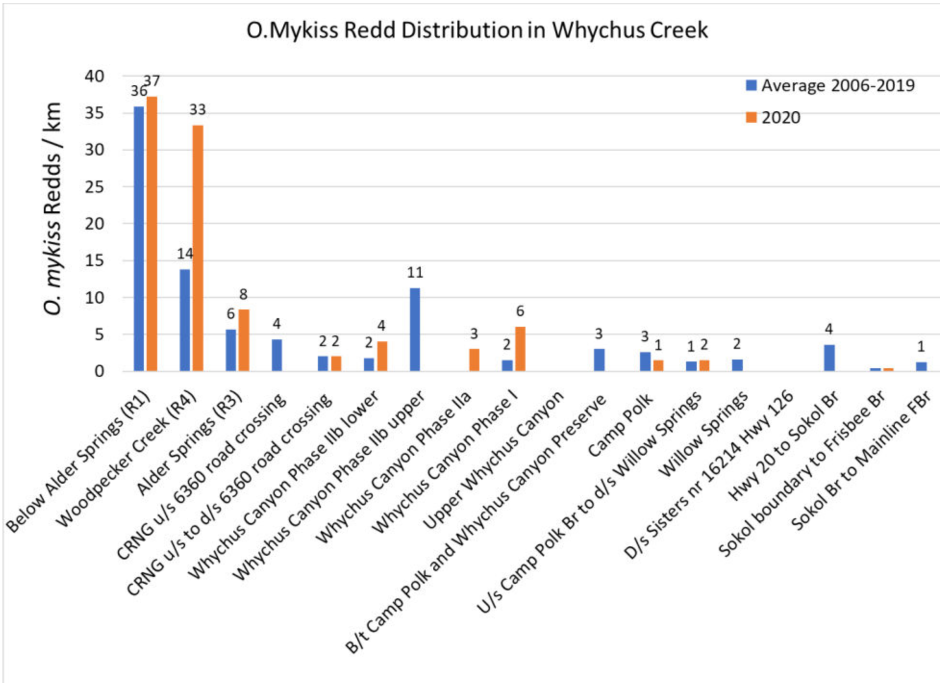


Figure 21. Average redds per kilometer at sites along Whychus Creek from 2006-2019, and in 2020.

3.12. Summary of metrics

To evaluate the condition of the five survey reaches based on 2020 physical and vegetative data and interpret geomorphic and habitat benefits or adverse impacts, we compiled values for all 2020 monitoring metrics analyzed as well as available biological metrics (Table 15).

Values for some metrics clearly differentiate between restored and unrestored reaches and indicate functioning geomorphic processes and resulting physical conditions in restored reaches. Data showed much more wood in restored reaches; far more geomorphic units (excluding dry units); and much more gravel and less cobble. For other metrics different methods produced varying results. Inundated area was higher in restored reaches as calculated from delineated units and from AIP data, but was within the same range as unrestored reaches as calculated from the 2020 GTAC classification. Because AIP unit areas are calculated from unit length and the average of three width measurements and summed to estimate inundated area, we consider inundated area calculated from AIP survey data to be the most accurate of the three methods; according to AIP values, there is more inundated area (aquatic habitat) in restored reaches than in unrestored. For yet other metrics there was little difference or no consistent difference. Values for vegetation cover classes were within the same range in restored and unrestored reaches. Velocities and depths were similar in restored and unrestored reaches and slightly lower in restored reaches. Canopy cover was similar in restored and unrestored reaches and very low, except in Phase 2a where only four plots were surveyed and one outlier measurement inflated median cover. Minimum and maximum stream temperatures were mostly lower in restored reaches, but these reaches were surveyed earlier and at lower air temperatures than the unrestored reaches. Taken together, these data show more aquatic habitat and more structurally diverse habitat characterized by large amounts of wood and high numbers of geomorphic units in restored reaches, with smaller sediment suggesting lower stream energy; slightly lower velocities; and slightly less vegetation than in unrestored reaches.

Ranges for macroinvertebrate taxa and EPT taxa richness were higher in restored reaches than in unrestored reaches but only slightly so, and relative abundance of the top taxon was similar across restored and unrestored reaches, with the highest relative abundance of the five reaches in a restored side channel. Fish population data were not comparable across the restored and unrestored reaches monitored in 2020, but data from the unrestored Whychus Canyon Reach 3 and from Whychus Canyon Phase 1 showed 4-5x as many trout per 100 m^2 in 2018 and 2022 in the restored reach. Whychus Canyon Phase 1 supported more redds per km than any unrestored reach in 2020, but Camp Polk supported only 1 redd/km in the same year.

Table 15. Values for all metrics analyzed from 2020 imagery and data, and for complementary physical and biological data from study reaches where available.

	Camp Polk	Whychus Canyon Phase 1	Whychus Canyon Phase 2a	Whychus Canyon Phase 2b	Willow Springs
Inundated Area, ac/mi					
2020 GTAC classification	3.3	3.8	2.6	4.1	4.3
2020 Delineated GUs	5.6	5.7	3.9	4.3	4.1
ODFW AIP survey data	13.9	6.9	3.6	4.7	4.2
Vegetation, ac/100 m					
Riparian tree/shrub	1.1	0.7	1.6	1.5	0.6
Upland tree/shrub	0.0	0.6	0.2	0.0	0.0
Visible herbaceous	1.0	0.7	1.2	2.0	1.5
Total tree/shrub	1.1	1.3	1.7	1.5	0.6
Total vegetation	2.1	2.1	2.9	3.5	2.1
Wood Area, m^2/100 m					
Annual	12	56	5	0	1
Five-year	73	40	0	nr	22
Decadal	3	31	1	nr	3
Total	88	127	6	nr	26
Geomorphic Units (wet only), #/km					
2020 Delineated GUs (wet)	131	174	26	54	42
ODFW AIP surveyed GUs (wet)	223	198	17	32	41
Velocity, ft/s					
Median 60% Depth	0.8	1.1	1.3	1.5	1.5
Sediment size class (wet only), %					
Sand	11%	11%	15%	11%	14%
Gravel	81%	75%	53%	56%	60%
Cobble	8%	15%	33%	32%	26%
Boulder	0%	0%	0%	10%	0%
Depth, m					
Median depth (plot center)	0.16	0.16	0.21	0.19	0.19
Canopy, %					
Median % canopy cover (plot center)	4%	6%	32%	1%	0%
Water temperature, °C					
Min raw temperature	11.2	11.7	no data	13.5	12.6
Max raw temperature	16.4	18.5	no data	20.7	18.1
Macroinvertebrates					
Sample type	PM	RT & PM	PM	RT & PM	RT & PM
Relative abundance of the top taxon	7.1%	12.6-25.6%	15%	12.6-13%	7.7-14.6%
Total taxa richness (#)	65	44-64	57	35-55	48-62
EPT taxa richness (#)	24	19-23	22	16-19	19-21
Fish Density	fish/100m2		Raw number		
Year	2017	2022 (2018)	2023		--
O. mykiss	33 ± 9	2.3 ± 1	379		no data
Brown Trout	no data	39 ± 6	1,035		no data
Spring Chinook	no data	(14.4 ± 2; 3 ± 1)	1		no data
Redd counts, # / km					
O. mykiss redds / km	1	6	3	4	0

3.13. Cost effectiveness

2020 Stage 0 Effectiveness Monitoring including imagery acquisition and ground-based plot surveys supported analysis of six metrics available from ODFW AIP stream habitat survey data: geomorphic units, wetted area, wood in active channels, sediment size class distribution, depth, and canopy cover. Imagery acquisition and plot surveys additionally supported a land cover classification that provided information about riparian and upland vegetation communities, analysis of floodplain wood visible from imagery, and stream temperature analysis.

ODFW AIP stream habitat survey data, including a shapefile with habitat unit locations and an attribute table, cost approximately ~$4,800 per mile in 2020; PGE staff time for additional data management and analysis totals $4,000 annually, so the per-mile total varies with the number of miles surveyed per year (calculated from data provided by B. Wymore and P. Kavanagh, personal communication, October 7-8, 2019). This dollar amount does not include analysis or reporting on specific habitat attributes by reach performed by UDWC staff.

To acquire imagery and produce geomorphic unit, wetted area from geomorphic units, and wood jam data along 4.2 miles from 2020-2021 cost $25,600, calculating to approximately $6,100 per mile for imagery plus these three metrics (Table 16). These data get us part of the way to the key geomorphic and habitat attributes provided by ODFW AIP stream habitat survey data.

Creation of an analysis approach for classification of inundated area and subsequently land cover, wood delineation, and sediment size classification cost $24,000. This amount was heavily subsidized by GTAC to complete analysis of these metrics. GTAC estimated completion of analysis and reporting for these metrics took 18 analyst weeks and 2 project manager weeks in addition to the time funded by the initial $24,000; multiplied by 2020 consultant rates for these roles, this conservatively works out to $98,400 in additional costs for analysis of these metrics. Vegetation rapid assessment surveys to support an accuracy assessment for classification of vegetation as riparian or upland cost another $2,600.

Field surveys required ~300 people hours over two weeks, totaling ~$14,000 of UDWC staff and intern time, or $3,300 per mile for video plot marker installation and measurements and data collection in survey plots including wood, geomorphic unit identification, velocity and flow direction, sediment size, depth, canopy cover, and temperature measurements.

Preliminary development and reporting of velocity analysis methods from aerial video cost ~$1800 per mile but do not include costs for video plot marker installation and measurements.

At the “in-house”, USFS, substantially subsidized rate provided by GTAC to complete analysis and reporting of the metrics they selected within the GeoTASC project, imagery acquisition and analysis plus ground-based survey measurements comes to ~$17,550 per mile. This amount is roughly 3x per mile the total cost for delivery of ODFW AIP stream habitat survey data through PGE and does not include any UDWC staff time for project design and management, analysis, synthesis, and reporting. Costs will also vary widely based on whether work is completed at an in-house rate or a consultant rate. Costs reported here include relatively large costs for project development including defining a monitoring approach and metrics, designing the study, and developing work flows for analysis of metrics from imagery, as well as substantial data management, formatting, and analysis for survey plot data. Costs could potentially be reduced by simply repeating analyses described at an in-house rate, but analyses for most metrics require further refinement. These approaches also might become cost-effective when applied over larger scales with longer driving distances for field crews, e.g. at a watershed or basin scale measured in tens or hundreds of miles rather than miles.

While costs to acquire imagery, conduct plot surveys on the ground to supplement imagery, and analyze metrics from the resulting data are substantially higher than the cost of ODFW AIP stream habitat surveys per mile, some elements of a remote sensing approach provide information or data products not available from AIP survey data. Aerial imagery (RGB or multi-spectral) supports many uses including restoration design and map making to support monitoring and communicate about restoration. Delineation of geomorphic units from imagery provides the geomorphic unit and inundated area data available from AIP stream habitat survey data in a spatial data format that is accessible and easy to interpret. With further refinement, land cover classification, specifically classification of woody riparian vegetation, will provide key information about the extent and location of plant communities supported by shallow groundwater, data not otherwise available. Velocity is another high-value measure of fish habitat that is not readily available from other surveys. Some metrics, like depth, canopy cover, and sediment size class, duplicate data available from ODFW AIP surveys. When ODFW AIP data are available within a suitable timeframe to provide desired information about evolution during a specific interval post-restoration, it is likely not worth the cost to collect these measurements in plots.

Table 16. Costs for 2020 imagery acquisition, analysis of metrics from imagery, and ground-based plot surveys along 4.2 miles of Whychus Creek. Costs presented do not include project and data management, plot survey data analysis, or synthesis and reporting.

Product	Description	Metrics costs	Cost per mile	Consultant cost (estimated)	Consultant cost per mile (estimated)
Imagery acquisition 4.2 mi	Included: Plot generation (120 plots), multi-spectral orthoimagery for 4.2 miles valley length; x, 30-second videos flown at 20 m elevation and 60 photos flown at 7 m elevation; tech memo	$14,200	$3,400		
Geomorphic unit delineation + report		$6,200	$1,500		
Geomorphic Unit and wood jam surveys + memo		$5,200	$1,200		
Inundated area, cover classification, wood delineation, sediment size classification	Contract modification amount for GTAC analysis and reporting for inundated area, vegetation, wood, and sediment size classification	$24,000	$5,700	$122,400	$29,100
Vegetation rapid assessment surveys		$2,600	$600		
Velocity analysis		$7,500	$1,800		
Plot survey data collection		$14,000	$3,300		
Totals		$73,700	$17,500		$37,600

4. Discussion

4.1. Inundated Area

Visual comparison of inundated area from the classification and from delineated geomorphic units shows both areas where the classification underrepresents or does not include or account for what can be visually inferred to be water (errors of omission), and areas where delineated units appear to overrepresent or include areas that don't look like water (errors of commission). Notably, AIP data, representing empirical measurements in the field, consistently result in the highest calculated inundated area; width for each unit, from which area is calculated, is reported as the average of three width measurements, increasing accuracy of this metric. Delineated and surveyed geomorphic unit area were most similar, and classification data less similar, to AIP area. This suggests delineating units from imagery might better represent inundated area than calculating area from inundation as classified. More broadly, all three methods are likely to describe change from pre-restoration to post-restoration; comparing post-restoration data collected using these three methods will allow us to better evaluate strengths and weaknesses of the three to quantify change in inundated area. Calculated inundated area is available from AIP stream habitat survey data, but mapped (spatially referenced) inundated area is not.

Superficially, the relatively small difference between inundated area in unrestored and in restored reaches as calculated from the classification could suggest that restoration is not meaningfully changing inundated area. Classified inundated area in restored reaches does not account for inundated area under canopy, likely underestimating inundated area in restored reaches; geomorphic units under canopy were surveyed and the resulting inundated area added to that calculated from geomorphic units, but these additional units are not represented in the classified inundated area total. In addition, unrestored reaches along Whychus Creek present and represent differing degrees of recovery from channel straightening, berming, and incision, and direct comparison of individual reaches before and after restoration will provide the most meaningful, accurate, and informative measure of restoration effectiveness.

Camp Polk inundated area calculated from 2016 AIP data appears impossibly high given the short length and relatively small area of this project reach. Unit data included in the shapefile attribute table show 4.9 of those 6.9 acres of habitat designated as secondary and tertiary channel, including isolated and backwater pools and alcoves not represented in the shapefile polyline, suggesting extensive off-channel inundation in this reach four years post-restoration, which could be plausible. Instantaneous flows of 21-66 cfs during 2016 Camp Polk surveys were not dramatically different from the 13-77 cfs during 2019 Whychus Canyon Phase 1 surveys nor from the 15-40 cfs during 2020 imagery acquisition and field surveys.

4.2. Vegetation

Classification of vegetation cover in Whychus Creek project reaches aims to map and measure riparian vegetation for the purpose of evaluating change in the extent of riparian vegetation post-restoration. Riparian vegetation can be defined in a number of ways; our objective was and is to map and measure riparian plant communities supported by shallow groundwater within the ~2 foot rooting depth typical of riparian species. Whereas riparian communities are often defined by their species composition, identifying plant species from imagery (even large tree species such as cottonwood), while possible, is time- and labor-intensive, with ample opportunity for inaccuracy. UDWC and EDC's 2017 classification

(Garono et al 2018) used visually-interpreted “greenness” inferred to indicate connection to groundwater, and proximity to stream channels, as proxy measures to define vegetation as riparian. GTAC’s 2020 classification (McCurdy et al 2021) used elevation above the GGL elevation in Whychus Canyon Phase 1, and elevation above water surface in all other reaches, as proxy measures to define vegetation as riparian. Field surveys to provide data to assess the accuracy of these classifications have used species wetland indicator status to assign survey plots as riparian or upland, presenting an inherent mismatch with the information available from imagery.

NDVI, Normalized Difference Vegetation Index, and NDWI, Normalized Difference Water Index, are spectral bands that have both been applied extensively in combination with other geospatial datasets to map riparian vegetation and groundwater dependent ecosystems, with varying degrees of accuracy (McGwire 2019). NDVI uses the spectral signatures of green plants, which absorb red wavelengths (chlorophyll) and reflect near-infrared waves (cell structures) to identify actively photosynthesizing and growing plants, and therefore can be used to detect and quantify green vegetation – both the “greenness” and the density – from imagery. NDVI derived from Landsat imagery has been shown in multiple studies to successfully discriminate relative levels of water availability within a given plant community. McGwire (2019) used NDVI to identify anomalously abundant or vigorous vegetation in Landsat imagery across Nevada, thereby relying on contrast in water availability between riparian and adjacent environments and focusing on relative vigor of vegetation rather than species composition. He applied a minimum NDVI threshold of 0.194, similar to the 0.2 minimum NDVI used in other riparian studies, for vegetation to be considered potentially riparian, and used an elevation increment to determine elevation strata. Flitcroft et al (2022) used Landsat imagery and NDVI in an isocluster unsupervised classification to analyze vegetation density in Whychus Canyon Phase 1 and reported accuracies of 82% - 88% based on visual comparison of stratified random points from the density classification to the color infrared image.

On Whychus, our objective in monitoring vegetation from imagery is to detect change in vegetation from pre-restoration, hydrologically disconnected, dry communities typically characterized by relatively few dry-tolerant and remnant agricultural species (e.g. pasture grasses, cheatgrass, mullein, tumblemustard, rabbitbrush), to post-restoration, hydrologically connected, species-rich communities comprised largely of riparian species with facultative or wetter wetland indicator statuses. Although NDVI was not selected for the 2020 classification among the bands that best differentiated herbaceous vegetation, it was not evaluated for vegetation taller than 1 ft according to the Canopy Height Model. Visual examination of vegetation over time in Whychus Canyon Phase 1 using Google Earth imagery and photos shows a clearly discernable difference in vegetation greenness and density (Figure 22), suggesting NDVI, possibly in combination with other geospatial datasets such as elevations from LiDAR, may prove a more accurate approach than the classifications previously employed to map and measure change in riparian vegetation post-restoration along Whychus Creek. Overlaying planting polygons from post-restoration reaches representing known species compositions could guide interpretation of vegetation community type and help to parameterize a classification using NDVI.

Figure 22. Visually observable differences in vegetation greenness and density in Whychus Canyon Phase 1 pre-restoration in July 2014 (top) and post-restoration in July 2022 (bottom) suggest NDVI or NDWI might be good candidate methods for classifying riparian vegetation in restoration reaches.

4.3. Wood

Hand-delineation of wood from imagery based on visual interpretation indicated large areas occupied by wood in restored reaches and far smaller areas occupied by wood in unrestored reaches. This is consistent with the relative amounts of wood we would expect to see in restored and unrestored reaches and suggests that a large amount of wood added to restoration reaches has been retained eight (Camp Polk) and four years (Whychus Canyon Phase 1) post-restoration in restored reaches. Because hand-delineation relies on the interpretation of the observer; imagery resolution was high; and wood is highly visible in the imagery, we have confidence that this approach is able to capture, with high accuracy, wood that is not obscured by vegetation and that is not under water at low flow. As time since restoration implementation increases and shrub and tree canopies grow, and barring other major disturbances (e.g. a 100-year flood or wildfire), delineating wood from imagery (as well as using automated methods to classify wood from imagery) will become a less effective approach to detect wood. This also goes for other key attributes of Stage 0 systems that will be obscured by canopy, such as channels that avulse to flow into an existing woodland. Timing imagery acquisition at base flow and during winter leaf-off might allow detection of wood and surface water over a longer period of time after restoration, and on Whychus Creek low flows do occur outside of irrigation season during "stock runs" to fill ponds for livestock, making this a potentially feasible approach.

Wood measurements in survey plots were recorded for the purpose of calibrating and validating classification from imagery but were ultimately not used for this purpose because wood was visually identified and hand-delineated by GTAC staff. Our plot sampling design did not effectively sample wood, a relatively rare feature within the large spatial extent of aquatic habitat in restored reaches and even in the relatively smaller spatial extent of unrestored reaches, with wood present in only 10 of 57 wetted survey plots across all reaches and not present in any plots in two reaches including a restored reach (Camp Polk). These results do not align with the amount and distribution of wood delineated and are very likely not representative of true wood area. Plot surveys did show 4x as much wood on average in restored compared to unrestored plots, and thus survey data did capture the trend in restored and unrestored plots, but with what we can conclude to be very low accuracy.

As with inundated area, although with 2020 wood data we are able to compare trends in unrestored reaches to trends in restored reaches, the 2020 study was designed to provide pre-restoration data or post-restoration data at a point in time as the basis for measuring change over time when imagery acquisition, plot surveys, and analysis are repeated in the future. It is important to consider this intended future application and use of 2020 methods alongside the comparisons of unrestored and restored reaches that we present here. Even in this context, plot surveys as designed were ineffective at sampling wood. There may be ways to improve our sampling design through stratification to better sample wood, and measuring wood in plots might provide a coarse before-after comparison of amount of wood in restoration reaches.

Even though both plot survey data and ODFW Aquatic Inventory survey data support calculation of wood volume, comparing wood volume as measured using the two methods is problematic for several reasons. As noted, because our sampling design did not effectively sample wood, wood measured in plot surveys is very likely not representative of the true population of wood. Because ODFW AIP surveys and our plot surveys both use direct measurements of length, width, and height to calculate volume, the volume of any given piece of wood or jam calculated using both methods should be similar or identical. However, no ODFW AIP surveys were conducted in our study reaches in 2020 and therefore a direct comparison of wood measured in survey plots to wood measured during AIP surveys (e.g. by identifying the AIP survey unit in the location of the surveyed plot) is not possible. And, because wood is very likely to move during annual high flow events, there would be high uncertainty associated with any comparison of wood measured in survey plots to wood measured in prior-year AIP surveys because it's not possible to know if wood in a prior-year AIP unit moved in the interim between surveys.

Preliminary analyses compared average wood area at baseflow (annually inundated) in restored and unrestored reaches to the before-to-after restoration change in wood area calculated from ODFW AIP stream habitat survey data from Whychus Canyon Phase 1. Average wood area at baseflow as hand-delineated from imagery was 29x higher in restored reaches compared to unrestored reaches, and average wood area calculated from AIP surveys was 30-36x higher in Whychus Canyon after restoration than before. These similar results could be interpreted to suggest that delineation of wood from imagery in unrestored and restored reaches approximated the magnitude of the difference in wood quantity pre- to post-restoration in one restoration reach calculated from AIP survey data. However, when average wood at baseflow in restored and unrestored reaches is calculated per 100 m valley length, that difference drops to 15x as much annually-inundated wood area per 100 m valley length in restored compared to unrestored reaches, less similar to the pre- to post-restoration difference calculated from AIP data from Whychus Canyon Phase 1. The initial analysis also assumes that a similar magnitude of difference in wood quantity can be expected pre- to post-restoration in one reach as would exist on average in unrestored reaches as compared to restored reaches. This essentially applies a Before-After Control-Impact approach to assume that unrestored reaches in 2020 represent a sufficiently similar condition to the pre-restoration 2016 condition of Whychus Canyon Phase 1. This assumption hasn't been quantitatively evaluated (e.g. by comparing pre-restoration amounts of wood calculated from AIP survey data in Whychus Canyon Phase 1 and the three unrestored reaches in this study). A comparison of the difference in wood quantity delineated from pre-and post-restoration imagery to the difference in wood quantity calculated from AIP stream habitat surveys pre- and post-restoration is likely the best comparison of the two methods that we will be able to make in terms of the similarity of the results from each method.

Wood is one of the only metrics for which we can relatively easily provide an as-built quantity which serves as a relatively good measure of wood quantity in a restoration project reach, even though that wood does move and aggregate over time, likely changing total wood area. AIP stream habitat surveys inventory volume of large wood in active channels but do not account for fine wood, an important driver of geomorphic process in lower stream energy environments in Whychus Creek. Neither of these methods can provide area or volume of wood on the floodplain or accumulation of fine wood in active channels for years post-restoration. Refining monitoring questions to specifically target the role and function of wood, including "floodplain wood" (wood on the floodplain) and fine wood, during specific modes, e.g. at baseflow or during floodplain inundation, and at key time intervals post-restoration, will allow us to better refine our monitoring approach to track wood over time. Valley-wide transect cover surveys could be one candidate method to provide a simple measure of wood across the floodplain (Scagliotti and Mork 2019), and wood jam survey methods developed for Low-Tech Process Based Restoration (Weber et al 2020) could supplement or be used in place of AIP surveys to track fine wood in active channels. These methods or others could complement or replace delineation from imagery as time since restoration increases and renders delineation from imagery less effective.

4.4. Geomorphic Units

Recognizing that topography and bathymetry are continuous and that geomorphic unit delineation and identification are somewhat subjective and inevitably represent a simplification of physical habitat conditions, delineation from imagery was successful in approximating the number of geomorphic units per 100 m valley length identified during AIP surveys and in differentiating restored and unrestored reaches based on number of geomorphic units. Delineation of geomorphic units from imagery supplemented by field surveys appears to be a sufficiently accurate method to quantify geomorphic units and the geomorphic and habitat complexity they represent. The comparison of the number of units identified through delineation from imagery supplemented by surveys under canopy and through ODFW AIP surveys suggests analysis from imagery may underestimate the number of geomorphic units in restored reaches, where complexity is high and units may be hidden under canopy or lumped in analysis from imagery. Our use of a topographic-based geomorphic unit classification system that has far fewer geomorphic unit types than the classification system used by the Aquatic Inventory Project methods also likely combines units that are differentiated in the AIP schema. Analysis of geomorphic units from imagery appears to overestimate the number of units in unrestored reaches. However, notably, AIP data from Whychus Canyon Phases IIa and IIb, both unrestored as of 2020, were from 2008, and these two reaches have experienced visible recovery such that an increase in the number of geomorphic units in these reaches in the intervening 12 years is very plausible.

Further qualitative comparison of units could provide additional information about the degree to which using two different geomorphic unit classification systems contributed to the discrepancy in the number of units as well as about the proportion of units by type (e.g. pool, riffle, etc.) identified by analysis from imagery and from AIP surveys. A unit-type-by-unit-type evaluation and refinement of the specific units included in delineation from imagery and corresponding field surveys in relation to the specific units included in AIP survey methods might allow better alignment between the two systems while still allowing for defensible and repeatable delineation from imagery.

The comparison of units delineated to units surveyed provides insight and direction for future delineation and surveys. Planar units were reliably and consistently delineated from imagery, although in some instances concave units (pools and troughs) might have been mistaken for planar ones. Pools were also delineated with fair success. Although unit identification during plot surveys was intended to provide data to evaluate and validate analysis of geomorphic units from imagery, interpretation of units during plot surveys appears to have been inconsistent with interpretation during delineation in several respects. Possibly because of the 1-m scale of survey plots, units were in some cases identified at a scale smaller than the minimum half-channel width used to delineate units from imagery; for example, one plot fell in a deep pool on a channel margin that could not have been considered a riffle, but the channel-wide delineated unit included that pool, the pool tail crest, and the resulting riffle and was identified as a riffle unit. This scale mismatch represents a challenge for using surveyed units to validate the accuracy of delineated units.

While the field crew surveying plots and the Anabranch staff delineating units did establish and review guidelines and criteria for identifying units together, the crew had limited experience surveying units and specifically utilizing the topography-based fluvial taxonomy unit classification schema, which likely contributed to both the scale mismatches observed as well as inconsistent identification of units. This experience gap was evident specifically in identifying riffles. Review of the delineation and imagery show riffles clearly and consistently identified as encompassing three components: 1) the downstream portion of a pool; 2) the transition between pool and riffle which is the pool tail crest and is fundamentally the topographic feature which functions as a riffle; and 3) a short distance downstream of that transition. Rather than cueing on this sequence of features, the field crew primarily used the topographic shape of a riffle, i.e. a longitudinal concavity or saddle in a lateral convexity, and ultimately did not identify any surveyed unit as a riffle. If plot surveys are used to validate delineation from imagery, scheduling additional training days that include identifying units together in the field and reviewing a delineation of the same reach is one approach to improve alignment between delineation from imagery and units surveyed in plots. Another approach could be to have the same individual delineate units and survey units in plots. Eliminating use of “trough” and using only “pool” to denote concave units might also increase agreement and would simplify the classification scheme with minimal loss of meaning.

The relatively high proportion of units added from surveys under canopy in Whychus Canyon Phase 1 (74 of 174, 43%) suggests surveys under canopy are an important supplemental approach to delineating units from imagery. The 20-m accuracy of the iPad used to survey geomorphic units under canopy introduces uncertainty about the location of geomorphic units recorded and whether they duplicate units detected in digitization. Use of a GPS or GNSS receiver with accuracy scaled to channels will increase the accuracy of geomorphic unit location and thereby increase confidence when merging delineated and surveyed units and facilitate a more accurate calculation of inundated area from geomorphic units.

4.5. Velocity

Initial results from PIV analysis of 2020 videos showed that velocity could be mapped from UAS videos in both simple and complex channel arrangements where there was sufficient texture created by waves on the water surface. Velocimetry was not feasible in test plots with little water surface texture such as in pools or slow-flowing channel margins due to the lack of detectible features in the videos. Additionally, although the 2020 workflow was able to capture general velocity patterns at a single site, mapping these patterns at the reach scale would have been extremely time consuming due to the number of manual processing steps required.

Assigning spatial dimensions to allow scaling of PIV-derived surface velocity outputs was problematic given the available video and orthoimagery. Where markers placed in the video frame at the time of video collection were not visible in the video and orthoimagery was used to identify and match tie points (natural landmarks) visible in both the video and orthoimagery, mismatched resolution of the orthoimagery, collected at lower resolution, and video, collected at higher resolution, made tie point identification difficult and therefore time-intensive.

2020 imagery and video acquisition on Whychus Creek represented a preliminary attempt to capture imagery and video to support analysis of Stage 0 metrics, including velocity. Key insights gained through analysis of 2020 video informed the following lessons:

- 2020 analysis showed that videos collected at ~66 feet (20 m) above ground level (AGL) provided more than enough detail to extract velocity information, and 30 second videos at 30 frames per second provided more than enough data for PIV analysis.
- PIV requires visible tracers on the water surface. In lab settings this is done by seeding the water surface with floating objects such as woodchips or plastic pellets. Seeding is not feasible in natural systems. In the absence of seeding, natural features on the water surface, like bubbles or the downstream translation of small waves on the water surface, can provide trackable features to measure stream velocity. The 2020 analysis showed that stream velocity could be measured using PIV in areas with water surface texture such as riffles and runs, but slower moving areas of the channel such as pools and channel margins did not have adequate tracers.
- The 2020 analysis highlighted the key importance of camera orientation to highlighting water surface texture. Improper camera orientation can lead to saturation of the video with sun glint such that no data can be derived from the video.

- The 2020 analysis used ground scaling. As an alternative to ground scaling, aircraft position and altitude could allow georeferencing of velocity outputs, which would facilitate surface velocity mapping.
- Some of the 2020 videos were collected in high wind conditions which impacted water surface texture and also led to false velocity results due to movement of riparian vegetation. Future acquisitions should target low wind conditions for best results as well as for improved video stability.

Following conclusion of this analysis, new tools were developed by the USGS to automate the georectification process (Legleiter, 2022). New software tools and collection strategies refined through this project may improve the utility of the PIV method for mapping velocity patterns in shallow channels where traditional velocity measurement methods are limited.

4.6. Plot Measurements

Plot sampling design and survey measurements were modified from those developed for the parallel monitoring project on the South Fork McKenzie River and were intended to collect geomorphic and hydrologic data that would both complement and serve to validate and calibrate analysis of metrics from imagery. Rather than using traditional stream survey channel-centric geomorphic or habitat units as the sampling unit, the spatially balanced sampling design was informed by a valley-centric approach wherein plots were located throughout project reaches in target strata (e.g. water, bare sediment, wood) and survey measurements were collected relative to the plot center. This approach reflects the emerging recognition that functioning, connected rivers and streams move across their valleys over time. In response the SFMR sampling design adapted for Whychus Creek therefore scales to the valley floor or the process space rather than to the channel. This approach is well-suited to post-restoration reaches of the South Fork McKenzie River, where extensive swaths of the valley floor are inundated, bathymetry is complex at multiple scales, and what we typically call geomorphic units are less well-suited to describing habitat. In contrast, while restoration reaches on Whychus Creek are characterized by a network of channels across the valley floor, these channels are defined with relatively less heterogeneity in bathymetry. Therefore, geomorphic units that are more easily defined allow for scaling surveys to the channel rather than the valley floor. This in turn might better describe the range of aquatic habitat conditions on restored reaches of Whychus Creek.

Depth and canopy cover are two metrics for which collecting measurements in more traditional locations relative to the channel may provide more useful information about key attributes of aquatic habitat on Whychus Creek. Measuring depth at the maximum depth of a geomorphic unit rather than at the plot center will better represent the range of maximum depths throughout a project reach, rather than simply the range of depths in a project reach, and will make measurements comparable to AIP depth measurements. On Whychus, where AIP surveys are often repeated within a few years of restoration, this comparability is valuable for measuring change over time. Similarly, measuring canopy cover from the center of the channel rather than in a plot center will provide a more standard measurement and data that is more comparable to other datasets.

Plot surveys presented the opportunity to measure water temperatures in random (spatially balanced) locations throughout study reaches and raw temperature data suggested interesting trends, namely that the range of measured temperatures was wider and minimum temperatures lower in Whychus Canyon Phase 1, a restored reach, than in two unrestored reaches. But, stream temperature is both influenced by upstream temperature and by stream temperature over previous hours and days (spatially and temporally autocorrelated) and apparent trends might not reflect an effect of restoration but rather an effect of the day and time of day plots were surveyed. Refining stream temperature monitoring questions and designing a monitoring approach specific to those questions, as well as collecting continuous temperature data rather than individual measurements to eliminate day and time of day confounding results, could provide more useful and informative temperature data.

Pebble count surveys in plots remain a reliable and widely accepted approach for accurately estimating sediment size class distributions. Analyzing sediment size class distributions from aerial photos resulted in limited success, and pebble counts are more objective and accurate than the visual estimates of sediment size classes used in AIP stream habitat surveys. Gravel and cobble distributions from pebble counts followed trends observed from AIP data from Whychus Canyon Phase 1 (Mork 2022) and in other Stage 0 projects across Oregon (Flitcroft et al 2022). Similar sand values in unrestored and restored plots suggest that our sampling design might not have representatively sampled the range of sediment conditions in our study reaches. One approach to more representatively sample the range of sediment conditions would be to stratify plots to target the range of sediment conditions (and conditions of other metrics; B. Flitcroft, personal communication, September 19, 2022). For sediment, we could use the 2020 delineated unit layer to stratify plots by places that are shallow and fast (e.g. riffles and planar units) and places that are slow and deep (e.g. pools) to representatively sample all sediment sizes.

Measuring velocity at the surface and at 60% depth showed the same velocity trends and similar values at the two depths, supporting use of velocimetry from imagery as a measure of velocity. Measuring velocity provides data not otherwise available and these measurements are needed to assess the accuracy of LSPIV analysis. A 2022 effort to advance LSPIV analysis in Whychus Canyon Phase 2a collected video along selected channel lengths for LSPIV analysis, to allow analysis over a continuous area, and recommended velocity measurements to assess the accuracy of LSPIV analysis be collected along transects within the selected channel lengths rather than in plots as was done in 2020.

Plot measurements are perhaps the most clear element of 2020 monitoring to consider eliminating in attempting to elevate the amount and quality of data available about Stage 0 restoration reaches on Whychus Creek without collecting redundant information, particularly if and when AIP stream habitat survey data are available at key intervals after restoration. AIP data include geomorphic unit, depth, shade, and sediment size class distribution data; wood measurements from AIP data and from hand delineation provide sufficient information about amount of wood and better information than produced through 2020 plot surveys; and velocity measurements to support LSPIV analysis will be collected along transects within selected channel sections and therefore do not need to be collected in plots.

5. Recommendations

Based on results and findings from 2020 imagery and video acquisition, sampling design, plot surveys, analysis of selected metrics from imagery, and data resulting from these, we identified recommendations and considerations for designing and implementing these elements for future monitoring. For some recommendations or considerations, additional information-gathering through consultation with technical experts will be helpful to improve on our 2020 approach, methods and resulting data. UDWC restoration and monitoring staff and key technical advisors will evaluate alternatives in the context of specific monitoring questions and select a preferred approach for repeating

2020 monitoring on Whychus Creek restoration reaches, post-restoration and with four additional years of evolution and ecosystem response beginning in summer 2024.

Although we've identified many modifications to improve how monitoring was implemented in 2020, from imagery acquisition to which analysis approaches provide the most informative data, changing our methods for 2024 will introduce confounding variables into analysis of change from 2020 conditions. As one example, if we were to acquire imagery during winter leaf-off at base flow and hand-delineate geomorphic units and wood, the resulting delineations would likely capture areas of both that wouldn't have been visible from imagery acquired during full leaf-out in 2020. If we were to compare values from the new delineations to those from the 2020 imagery and delineations, we would have no means by which to discern what amount of any change observed was from the change in methods versus a reflection of the actual change in the condition of the metric on the ground. For this reason we provide recommendations for future monitoring but will evaluate any changes for 2024 monitoring considering how they will affect our ability to measure ecological change.

5.1. Imagery acquisition

- Consider two separate imagery acquisitions within the same year: One RGB acquisition during leaf-off, likely in November but possibly in early April, to support hand-delineation of wood and geomorphic units; and one multi-spectral and/or thermal and/or LiDAR acquisition in early to mid-July during peak greenness, peak stream temperatures, and at baseflow to support riparian vegetation and land cover analysis and water surface temperature analysis.
- Consider using a fixed-wing plane with a 10-band sensor to support riparian vegetation/land cover classification from imagery; evaluate suitability of resulting 30-cm pixel resolution for all metrics to be analyzed from resulting imagery (per recommendation by Brandon Overstreet, personal communication, June 18, 2023).

5.2. Sampling design

- Use a combination of 2020 plot locations where the target stratum hasn't changed (e.g. where a wetted plot is still a wetted plot) and supplemental/new plots to increase sample size where needed and replace plots where the target stratum has changed since 2020 (through restoration or channel evolution and floodplain building).
- Stratify new plots by specific metrics of interest to ensure a sufficient sample size for each metric. Stratify for: Depth (deep to shallow); and sediment (small to large); evaluate approach to stratify for canopy cover. Use transect-based, not plot-based measurements for velocity analysis (LSPIV) per recommendations from 2022 LSPIV analysis for Phase 2a (Mork 2023).
- For depth and sediment, using delineated geomorphic units as a proxy for deeper, slower, and lower-energy water with less capacity to entrain sediment (pools) and shallower, faster, and higher-energy water with more capacity to entrain sediment (planar units and riffles) is one approach that might support a stratification for these metrics that results in a representative sample. Stratifying by delineated bars and wet channel units could provide a representative sample for wet and for dry sediment.
- Generate new plots from a sufficiently recent classification (2023 for Willow Springs; 2020 for Camp Polk and Whychus Canyon Phase 1; consider utility of 2022 inundated area classification for Phase 2a, restored in 2021; and evaluate options, including as-built pool spatial data, for Phase 2b, restored in 2023). For 2020, plots were generated from a classification from 2017

imagery which resulted in many plots being located in a stratum other than the one they were intended to fall in.

- Consider whether there is a need to survey wood on the ground. If so, consider including as a metric for survey plot generation.
- Evaluate whether dry plots are needed for sediment size classification, considering whether sediment in mid-channel and point bars would be a different size than sediment that is still inundated, and considering what we want sediment to tell us about hydrogeomorphic process and stream habitat (per comment by Colin Thorne, personal communication, May 13, 2021.)

5.3. Inundated area

- Repeat inundated area classification developed by GTAC in 2020 and compare to inundated area calculated from delineated geomorphic unit dataset and from most recent AIP survey data.
- Evaluate if classification from 2024, post-restoration data presents same trend in terms of accuracy relative to area from delineated geomorphic units and AIP data.
- If so, and inundated area from classification is the least accurate of the three methods, evaluate whether producing a water/inundated area class is integral to a riparian vegetation and land cover classification or if it's not needed.

5.4. Vegetation

- With UDWC restoration & monitoring team and technical experts, discuss, and refine as needed, objective to map and measure areas of green, dense, hydrologically connected riparian plants from imagery and evaluate approaches.
- Evaluate cover classes; revise to make relevant to selected approach. Woody riparian vegetation is ultimately the cover class we really care about measuring in terms of establishment, geomorphic function, and hydrologic connectivity.
- Use planting polygons representing known species compositions from post-restoration reaches to guide interpretation of vegetation community type and help to parameterize a classification using NDVI.
- Consider: Flitcroft et al 2022 vegetation density mapping from LandSat; McGwire 2019 use of NDVI to map riparian areas in Nevada; Albano et al 2021 Harney Basin groundwater dependent vegetation study; 2022 Wolf Water Resources approach developed using Phase 2a imagery; 2020 GTAC approach.
- Consider choosing one reach in which to pilot the selected approach to limit effort invested in testing the approach.
- Consider and revise as needed design for accuracy assessment surveys.
- Ensure accuracy assessment survey classes provide data specific to classification cover classes.

5.5. Wood

- Evaluate opportunities to acquire imagery at base flow and during winter leaf-off to allow detection of wood and surface water under deciduous canopy and over a longer period of time after restoration.
- Verify that RGB imagery would be sufficient to support hand-delineation of wood from imagery.
- Identify other metrics, if any, that could be analyzed equally effectively from RGB imagery and don't require multi-spectral imagery. Hand-delineated geomorphic units are one candidate.

- Consider refining monitoring questions to specifically target the role and function of wood, including "floodplain wood" (wood on the floodplain) and fine wood, during specific modes, e.g. at baseflow or during floodplain inundation, and at key time intervals following restoration, to better refine our monitoring approach to track and understand the role of wood over time.
- If data about wood additional to area from hand delineation are deemed to be needed, valley-wide transect cover surveys could be one candidate method to provide a simple measure of wood across the floodplain (Scagliotti and Mork 2019), and wood jam survey methods developed for Low-Tech Process Based Restoration (Weber et al 2020) could supplement or be used in place of AIP surveys to track fine wood in active channels. Alternatively, wood could be considered as a metric for survey plot generation to more effectively sample wood on the ground.
- Merge data from wood and wood jam surveys under canopy with hand-delineated wood shapefile and attribute table to represent the complete wood dataset and calculate the most accurate wood area estimate.

5.6. Geomorphic Units

- Combine pool and trough unit types as pools, resulting in geomorphic unit types including pool, riffle, planar, bar, non-primary, and wetland.
- Consider acquiring RGB imagery during leaf-off for hand-delineation of geomorphic units.
- Discuss and evaluate adding length measurement for each GU to provide total channel length.
- Evaluate information benefit of potentially adding an approach to enumerate stream nodes or vegetated islands as proxy measures of channel network complexity.
- Stage 0 systems characterized by a network of channels defy the classification of one primary channel with multiple non-primary channels. We considered assigning additional primary and non-primary channel type designations to units, beyond simply identifying units themselves as non-primary, for the purpose of calculating a non-primary to primary channel length or area ratio, but identifying one channel as primary seems like an artificial distinction in Whychus Creek reaches restored to multi-channel systems.
- Schedule training day or half-day for geomorphic unit delineation team and survey crew to identify units together in the field, possibly at Willow Springs (proximity to Bend and recent, 2023 survey and delineation updated to incorporate learning from 2020 monitoring). Review and agree on rules for minimum unit size. Review delineation from imagery together to inform field identification of geomorphic units following approach used for Willow Springs 2023 monitoring.
- For field surveys under canopy, use UDWC Arrow GNSS receiver to increase accuracy of geomorphic unit locations.

5.7. Velocity

- Future video acquisition for velocity analysis should conduct test videos at a variety of camera orientations and times of day to identify the optimal collection condition to ensure sufficient sun glint to highlight surface waves but not so much that the image becomes saturated such that no data can be derived from the video.
- In general, the pixels with the most sun glint occur at the edge of the video frame in the direction of the sun and the pixels in the center of the video frame have the least sun glint. For

this reason, consider collecting several overlapping videos over the target area to ensure that the target is covered with optimal viewing conditions.

- The 2020 analysis used ground scaling. As an alternative to ground scaling, aircraft position and altitude could allow georeferencing of velocity outputs, which would facilitate surface velocity mapping.
- Future acquisitions should target low wind conditions for best results as well as for improved video stability. Some of the 2020 videos were collected in high wind conditions which impacted water surface texture and also led to false velocity results due to movement of riparian vegetation.
- Collect velocity measurements to assess the accuracy of LSPIV analysis along transects within the channel lengths selected for LSPIV analysis at the same time as UAS flights.
- Review and reference 2022 Whychus Canyon Phase 2a LSPIV report, “Mapping continuous spatial heterogeneity in stream velocity using image velocimetry from Unoccupied Aerial Systems” (Mork 2023) for additional recommendations.

5.8. Sediment

- Stratify sampling design by slow/fast, shallow/deep, and possibly also wet/dry to representatively sample all sediment sizes.
- Evaluate number of clast measurements needed; reference Hinshaw et al 2021 and as needed consult with a technical expert.
- Consider simplifying size classes to only include sand, gravel, cobble and boulder to increase survey efficiency; could tape off intermediate holes in gravel card to only use size thresholds for these four classes.
- Consider the benefit of surveying sediment within this monitoring approach, in addition to, or in place of, timed relative to spawning of target fish species (e.g. O. mykiss) to more accurately represent fine sediment conditions for spawning fish.

5.9. Depth

- Measure maximum depth in geomorphic unit in which survey plot falls instead of at plot center to better represent range of maximum depths within project reaches.

5.10. Canopy Cover

- Measure canopy cover from center of channel longitudinally even with plot center to produce canopy cover measurements that are comparable to standard measurements.

5.11. Stream Temperature

- Deploy new continuous temperature dataloggers in key locations from April to October to evaluate change in stream temperature through project reaches: 1) upstream of Whychus Canyon Reach 3 (unrestored); 2) immediately upstream of Whychus Canyon Phase 1; and 3) between Phase 1 and Phase 2 in a location with the largest proportion of stream flow consolidated into one channel. Continue to deploy dataloggers downstream of Whychus Canyon Phase 2b and upstream and downstream of Camp Polk. No pre-restoration temperature data are available for Willow Springs and stream temperature in this reach is influenced by substantial groundwater inputs, reducing the utility of adding temperature dataloggers upstream and downstream of this reach to understand changes resulting from process-based habitat restoration.

- With collaborators, continue to investigate methods to detect and measure thermal heterogeneity in Stage 0 project reaches.
- Track USFS PNW Research Station temperature analyses from 2022 imagery acquisition and evaluate future/parallel application to Whychus Creek.

6. Conclusions

6.1. Monitoring approach

For some metrics, analysis from 2020 imagery provided data that were as informative as or more informative than data from ground-based survey methods. Geomorphic unit delineation from imagery approximated the trends for number of geomorphic units and inundated area observed from AIP stream habitat surveys, at a similar or slightly higher cost. Consideration of refinements to geomorphic unit delineation including adding a length measurement and potentially enumerating stream nodes or vegetated islands could add valuable information to this dataset for potentially low effort and cost. Hand-delineation of wood also appears to have successfully quantified wood trends while providing information about floodplain wood that is not available from AIP survey data. Other metrics show promise for measurement from imagery. Although classification of riparian and dry communities from imagery has presented challenges, continuing to refine the information we want from this exercise may help us also refine the approach we use to provide it. Velocity is a fundamental and important attribute of juvenile fish rearing habitat and is a habitat metric that is time-intensive to measure in the field and which is not collected as part of the AIP stream habitat surveys used by PGE to monitor native fish habitat on Whychus Creek. Methods and software packages for analyzing velocity from imagery have improved since the analysis presented in this report was performed, and measuring velocity in representative sections of channel seems to be a feasible approach to provide far better and more velocity and flow direction data than is available otherwise.

Of the metrics analyzed from imagery, only classification of inundated area using an object-based approach and sediment size classification appeared to perform poorly. Based on comparison to inundated area from stream habitat surveys, classified inundated area underrepresented surface water in more complex reaches with canopy cover, by 30-80%. Inundated area from delineated geomorphic units was more similar to area from AIP surveys. Inundated area was an intermediate product used for land cover classification in the analysis methods developed by GTAC, and while area from delineated units provides a better measure of surface water, we will likely produce inundated area in future analyses as part of the land cover classification process. Sediment size classification from imagery using the selected approach amounted to pebble counts from imagery and the approach was rendered less effective by vegetation and water obscuring sediment in photo plots, leading us to conclude that sediment size is best measured in the field at the scale of restoration on Whychus Creek.

Similarly, some plot survey measurements provide informative and accurate data that is not otherwise available or not always available at the desired interval. With refinements to the sampling design and survey protocol, geomorphic unit type, water velocity, sediment size, depth, and canopy cover represent data at a finer spatial resolution or temporal frequency than is otherwise available; surface water velocity measurements are needed for validation of velocimetry measurements. Measurement of wood pieces and jams in plots appears to duplicate delineation of wood from imagery, and our 2020 sampling design failed to representatively sample wood. Any future measurement of wood in survey plots would need to be paired with a sampling design that increased our success detecting wood in survey plots, including the fine wood that is anecdotally integral to hydrogeomorphic process and channel evolution on Whychus. Using dataloggers to record continuous temperature data will improve our ability to interpret and understand stream temperature in restoration reaches and eliminate the confounding variables introduced by measuring temperature in survey plots.

6.2. Stream habitat and biological response

2020 monitoring data showed more aquatic habitat (inundated area), habitat complexity and diversity (number of geomorphic units), more wood in active channels (annually-inundated) and on the floodplain, and more gravel and less cobble in restored reaches than in unrestored reaches. Restored reaches were characterized by more channels and more non-primary and wetland units than unrestored reaches. These data and other physical and biological data from restored reaches on Whychus Creek suggest large extents of these reaches are exhibiting a Stage 0, multi-channel, wet woodland and grassland condition. At Whychus Canyon Phase 1, maximum groundwater depths decreased from between -8.3 and -5.6 ft pre-restoration to remain within -1.8 ft of the average floodplain surface during annual baseflow over five years post-restoration (Mork 2022, Mork 2023), demonstrating the high floodplain connectivity characteristic of Stage 0 of stream evolution per Cluer and Thorne (2014). Native riparian plant species richness, including emergent, riparian, and floodplain species, as well as riparian plant cover doubled in this reach within two years post-restoration, demonstrating sufficient floodplain hydrologic connectivity to support these mesic species (Mork 2022). Macroinvertebrate taxa richness and EPT taxa richness ranges and maximum values were higher in restored reaches and there were more trout in 2018 and 2022 in Whychus Canyon Phase 1 (restored) compared to the adjacent unrestored reach; trout numbers in this reach were similar to numbers in Camp Polk. Macroinvertebrate data suggest marginally better habitat in restored reaches; the fish story seems to indicate that habitat is substantially more suitable in restored reaches compared to unrestored reaches.

2020 imagery acquisition and plot surveys were designed to support analysis of change in geomorphic and habitat conditions in individual reaches pre- and post-restoration and over time after restoration. Data collection in both restored and unrestored plots in 2020 presented an opportunity to compare conditions in restored plots to conditions in unrestored plots. As noted, unrestored reaches along Whychus Creek were not selected on the basis of similarity to the pre-restoration condition of the restored reaches monitored in 2020 or for the purpose of representing control reaches. Since unrestored reaches display differing degrees of recovery from channel straightening, berming and incision, direct comparison of individual reaches before and after restoration will provide the most meaningful, accurate, and informative measure of restoration effectiveness. Repeating the approach developed for 2020 monitoring post-restoration and with additional time since restoration in the same five reaches, and incorporating the refinements and recommendations identified, will provide new information and insights about the ability of the selected monitoring approach to measure change, and about that change itself: the geomorphic and habitat outcomes of restoration toward Stage 0.

7. References

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8. Appendices

8.1. Appendix A. Technical Memo: Whychus Creek UAS Monitoring July 2020. Matthew Barker; Michael Wing, PhD; Katharine Nicolato. Oregon State University Aerial Information Systems Laboratory.

8.2. Appendix B. Whychus Creek Monitoring: Geomorphic Unit and Woody Debris Jams – 2020 Field Monitoring Supplementation. Anabranch Solutions.

8.3. Appendix C. Remote sensing methods for monitoring Stage 0 metrics on Whychus Creek using high-resolution imagery. GTAC-10196-RPT1. Wyatt McCurdy, Brenna Schwert, Abigail Schaaf, Julie Davenport, Kain Kutz, Haans Fisk, Lauren Mork, Cari Press.

8.4. Appendix D. Whychus Creek 2020 Remote Sensing Analysis Instructional Guide. GTAC.

8.5. Appendix E. Whychus Creek Geomorphic Unit Assessment: Delineation of Channel Geomorphic Features from UAV Imagery. Anabranch Solutions.

8.6. Appendix F. Presentation: Whychus Creek Preliminary UAS Velocimetry Analysis. Brandon Overstreet, USGS Oregon Water Science Center.