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September 13, 2021

Remote sensing methods for monitoring Stage 0 metrics on Whychus Creek using high-resolution imagery

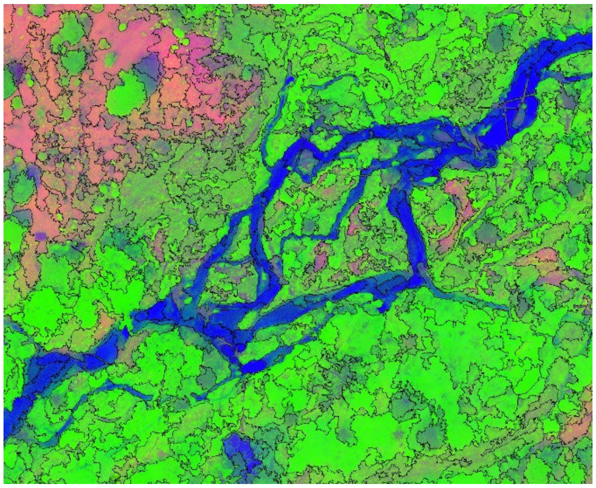

Figure 1: Section of a segmented false-color image from Whychus Canyon Phase I.

Forest Service

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Abstract

The Upper Deschutes Watershed Council and the United States Department of Agriculture, Forest Service (USFS) are collaborating to carry out and monitor Stage 0 restoration projects on Whychus Creek, a tributary to the Deschutes River. This area has been degraded by human land use, and Stage 0 restoration aims to alter the floodplain for the benefit of aquatic and riparian ecosystems. This Geospatial Technology and Applications Steering Committee project is designed to explore monitoring techniques and analyses that will help measure the impacts of Stage 0 restoration using remotely sensed data. We chose four metrics to monitor: inundated area, riparian land cover, large woody debris, and sediment grain size. In post-restoration reaches, the creek followed a branching pattern, while in pre-restoration reaches, the creek was a straight single channel. In post-restoration reaches, water often infiltrated areas that analysis from imagery suggested contained upland vegetation, showing a more distributed flow with the potential to influence species distributions now and in the future. Wood, including both large and fine wood, was more abundant in post-restoration reaches, which promotes development of more diverse fish habitat as well as floodplain building through sediment deposition. Sediment size results were mixed but may indicate increased deposition in post-restoration reaches.

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Introduction

Whychus Creek and surrounding areas in the Upper Deschutes Watershed have been impacted locally by a national trend of channel degradation by human land use. Land use practices contributing to degradation include homesteading, agriculture, and flood control (Cluer and Thorne, 2014; Wohl et al. 2021). These practices have led to straighter, faster, and incised channels that drain valley bottoms and transport out the sediment, nutrients, and wood necessary for a sustainable, healthy ecosystem (Wohl et al. 2021; Cluer and Thorne, 2014; Beechie et al., 2010; Bellmore et al., 2013).

The Upper Deschutes Watershed Council, in conjunction with the United States Department of Agriculture, Forest Service (USFS) has been implementing Stage 0 restoration projects designed to reactivate and reestablish historic river wetland corridors (depositional valley floors) as described in Wohl et al. (2021). They attempt to achieve a Stage 0 condition by cutting valley floor surfaces and filling incised channels to match a target valley slope elevation informed by the geomorphic gradeline as described in Powers et al. (2018). The aim of this modification is to restore the underlying natural processes to increase the quantity and diversity of aquatic habitat. Stage 0 refers to an anastomosing stage (e.g., diverging or branching) of stream evolution for depositional valley types proposed by Cluer and Thorne (2013) as a precursor to the sinuous, single-thread Stage 1 channel described in Simon and Hupp’s (1986) Channel Evolution Model. The scarcity and importance of this initial stage in depositional valley types, also called a river wetland corridor, is further described in Wohl et. al. (2021). As this stream type has often been overlooked or misinterpreted, traditional stream habitat monitoring metrics have not accounted for the diversity of habitat features of this type of restored system and thus we need a new monitoring approach to measure restoration progress.

In 2019, Cari Press from the Deschutes National Forest in the Pacific Northwest Region (Region 6) and Lauren Mork from the Upper Deschutes Watershed Council submitted a project proposal to the Geospatial Technology and Applications Steering Committee (GeoTASC) to calculate and evaluate monitoring metrics for stream reaches on Whychus Creek, a tributary of the Deschutes River, in order to assess effectiveness of Stage 0 restoration practices being implemented in the area. The USFS and the Upper Deschutes Watershed Council proposed that 1) inundated area, 2) riparian land cover, 3) large woody debris (LWD), and 4) sediment grain size be monitored.

The USFS and the Upper Deschutes Watershed Council anticipate that Stage 0 restoration will introduce more fluvial and habitat diversity than what traditional stream habitat monitoring metrics (e.g., deep pools per mile, LWD per mile, and percent fine sands in riffles) are able to represent. Traditional metrics and survey methods were developed for simpler, single-thread streams with lower variability. Using remote sensing imagery to assess and monitor riparian conditions has a lot of potential and has been proven to be a substitute for traditional ground-based measurements (Lane, 2000; Tamminga et al., 2014). Unlike discontinuous in situ point measurements, remote sensing offers the ability to provide nearly continuous measurements of riparian conditions supportive of the ‘river continuum concept’ that describes river systems’ physical structure and biota as smoothly changing (Vannote et al., 1980). Continuous measurements offered by remote sensing methods illustrate the spatial distribution of different metrics for this gradually changing environment.

Our goal was to determine the feasibility and utility of workflows and resulting metrics for measuring the impacts of Stage 0 restoration in Whychus Creek. We wanted to develop useful, reproducible workflows that the Upper Deschutes Watershed Council and other organizations could use and improve upon. Cooperators have selected four metrics to evaluate: area of surface water or inundated area, extent of LWD, sediment size, and land cover. These four metrics will help them determine if the project has been effective and is trending towards Stage 0 conditions.

The inundated area metric will provide cooperators with information on changes in baseflow wetted area for both pre-restoration and post-restoration reaches. Maps of inundated area will provide cooperators with a characterization of spatial patterns including braiding and branching. Braiding and branching patterns, in conjunction with extent of riparian vegetation, are an indicator that a stream has reached Stage 0 conditions (Cluer and Thorne, 2013). Wood retention is another indicator of Stage 0 conditions, providing complexity to the valley bottom as well as improved aquatic habitat. Sediment size distribution across the valley bottom provides information about stream power and aquatic habitat. The extent of riparian vegetation is indicative of a variety of geomorphic processes as it moderates water temperature through shading, allocthonous input and large wood recruitment, and supports primary and secondary production and diversity (Wohl et al. 2021; Cluer and Thorne 2014).

The objectives of this project were to: (1) develop an accessible, repeatable, and reliable workflow to derive the four metrics; (2) derive the four metrics for five reaches of the Whychus Creek (including three pre-restoration reaches and two post-restoration reaches); and (3) create step-by-step user guides to walk individuals through creating the four metrics in the future.

Study Area

The study area covers around four miles and 275 acres of the valley bottom, in total, of Whychus Canyon and surrounding areas in Whychus Creek, a tributary of the Deschutes River in the Upper Deschutes Watershed, near Sisters, Oregon. The area sits at an elevation ranging from 2585 ft - 3038 ft, experiences an average annual precipitation of 13.53 in, and has average summer high temperature of 61°F with an average winter low temperature of 32°F. Five reaches were designated as our study reaches, some post-restoration and some pre-restoration:

- Phase I – post-restoration
- Phase IIa – pre-restoration
- Phase IIb – pre-restoration
- Camp Polk – post-restoration
- Willow Springs – pre-restoration

Within the context of this project, reaches are stream segments of varying lengths (~0.5 mi – 1 mi) within Whychus Canyon Preserve, Camp Polk Meadow Preserve, and Willow Springs Preserve, all owned by Deschutes Land Trust, and are labelled according to restoration project phase. Phase I restoration was implemented in summer of 2016, while Phases IIa is being implemented during summer of 2021 and IIb is scheduled for summer of 2023. The project area is located on three Deschutes Land Trust preserves between upstream and downstream USFS boundaries.

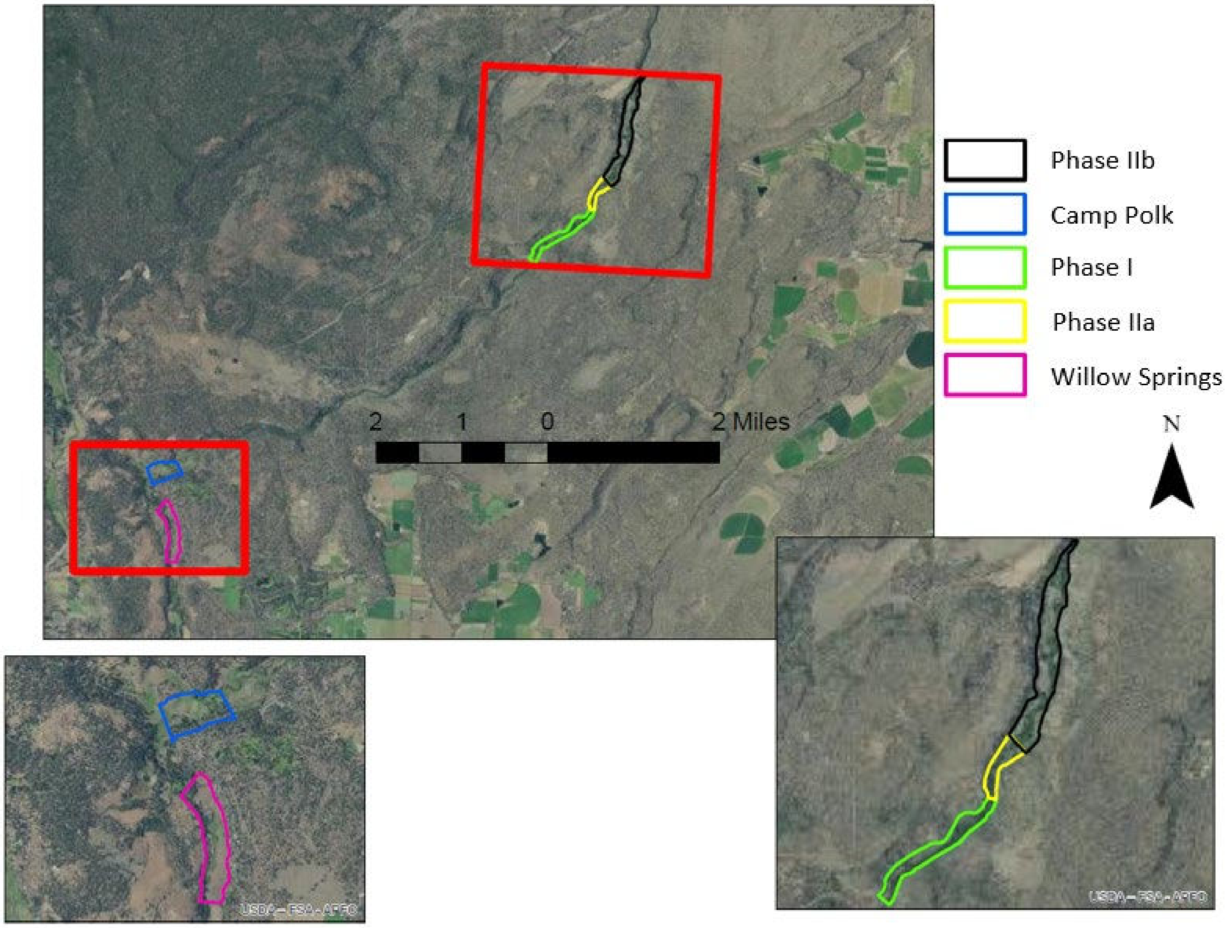


Figure 2: Project study areas on Whychus Creek, a tributary of the Deschutes River near Sisters OR.

Data

Six-band orthoimagery

Orthomosaic flights were flown in July 2020, using a UAS platform and a Micasense Altum combination multispectral/thermal sensor. Flights were flown separately for all the study reaches for this project. The data were collected as six-band imagery, with red, green, blue, red edge, near infrared (NIR), and longwave infrared bands included. The data are fine resolution, with pixel sizes of approximately 5 cm. The data were acquired and provided by Matthew Barker, Michael Wing, and Katharine Nicolato from the Oregon State University (OSU) Aerial Information Systems (AIS) Laboratory. The authors reported that some small portions in orthoimagery had areas of high brightness, but this was not a large issue and did not detract from the classification. Imagery acquisition methods and specifications are provided in a separate technical memo (Barker et al., 2020).

Vegetation rapid assessment

In July 2020, the Upper Deschutes Watershed Council contracted with Aequinox Habitat to complete a vegetation rapid assessment. Aequinox collected 120 points in total, and assigned each point to one of the following classes:

1. Riparian shrub
2. Riparian tree
3. Upland tree
4. Riparian Herbaceous
5. Upland Herbaceous
6. Riparian/Upland Herbaceous

These points are distributed equally through the pre-restoration and post-restoration reaches, with 20 points in each of four restoration reaches; 40 points were allocated to Phase I because of the complexity and size of this reach relative to other restoration reaches. The vegetation rapid assessment points were used to perform an accuracy assessment on the classification.

Photo-plots

Matthew Barker and Katharine Nicolato from the OSU AIS lab surveyed each reach using a low flying UAS, taking photo and video of wetted and non-wetted areas. They surveyed 17 - 26 plots (with sizes around 12 m by 16 m, but varying individually) for each reach, taking video and multiple photos. These photo-plots were high-resolution true color images with a pixel size of around 2 mm (with some variation between photoplots). These methods are further described in a separate technical memo (Barker et al., 2020).

Lidar-derived canopy height model (CHM)

We used a canopy height model (CHM) derived from LiDAR acquired by USFS in 2017, with vertical units measured in feet and a 0.5 m horizontal resolution. We used the CHM to detect trees and shrubs in our study area. We accessed this file from the USFS storage (T:) drive.

Methods

We developed separate methods to measure 1) inundated area, 2) riparian and non-riparian land cover, 3) LWD, and 4) sediment grain size. For inundated area and land cover, we developed different object-based classifications. For sediment size measurements, we randomly sampled photo plots within the reaches and manually measured individual sediment grains. We hand-delineated LWD. All the above analyses were done in ArcGIS Pro.

Inundation

We developed an object-based classification method to estimate inundated area. We first calculated two additional bands – Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) – to supplement existing bands.

$NDVI = (NIR - red) / (NIR + red)$

$NDWI = (green - red) / (green + red)$

We then used the ArcGIS Pro Image Classification Toolbox to run a segmentation on this imagery, using NIR, longwave infrared (thermal), and NDWI bands as inputs. The segmentation used a spectral detail parameter of 9.5 and a spatial detail parameter of 1, as well as a minimum segment size (in pixels) of 475. We took representative samples throughout the stream area and non-stream area and used the Random Trees method to run a random forest classification. The Random Trees classifier used a maximum trees parameter of 5,000, a maximum tree depth parameter of 3,000, and a maximum number of samples of 1,000. We used segment attributes: "active chromaticity color," "mean DN," and "standard deviation." We completed 2-3 iterations of sampling, classification, and inspection before settling on a classification. We then used ArcGIS Pro to make minor manual edits.

Land Cover

We sorted land cover into 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 (we do not distinguish between riparian and upland herbaceous cover)
7. Bare/Other

To define land cover, we first superimposed our inundation classification onto our imagery, defining our water class. We then created elevation zones surrounding the stream to represent approximations of riparian zones.

Riparian zone elevation bands

We created elevation bands using two methods. For Phase 1, USFS created a Relative Elevation Model (REM) based on the constructed geomorphic gradeline (GGL) for the valley type in which Phase I is located. A REM is meant to show elevation relative to a target, design, or as-built valley slope elevation. The GGL was constructed to provide the design target longitudinal elevations for the 15-mile depositional valley in which all the project reaches are located and was constructed using methods in Powers et al. (2018) For Phase I, we assigned cover classes to elevations relative to geomorphic gradeline elevations as follows:

- GGL REM < 0.3 ft: Very likely either riparian vegetation or already classified as water.
- GGL REM ± 0.3 – 2 ft: Very likely riparian vegetation.
- GGL REM 2 – 3 ft: Very likely riparian vegetation. This vegetation may include more dry-tolerant species.
- GGL REM > 3 ft: Very likely upland vegetation.

Of the two restored reaches, Phase I was the only reach restored using the GGL, as Camp Polk was restored prior to the development of the GGL method. Therefore, assigning cover classes based on elevations relative to the GGL was applied at Camp Polk using it for our other areas of interest would not accurately predict vegetation as riparian or upland because of the variation in elevations among reaches relative to the valley GGL. For all other reaches, we used a region grow method as follows: using classified inundated area, we used the Region Grow function in ArcGIS Pro to create elevation bands relative to the water surface elevation and grown up using specific elevation increments (shown below). For example, the first elevation band/contour for a post-restoration reach would be all areas from the water surface to 2 ft above the water surface.

Table 1: Zone definitions for riparian vegetation in Whychus Creek.

Height (pre-restoration reaches)	**Height (post-restoration reach-, Camp Polk)**	**Indicates**
Water surface to 3 ft	Water surface to 2 ft	Very likely riparian vegetation
3 ft to 4 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 (Phase IIb)
> 4 ft	> 3 ft	Very likely upland vegetation

After defining elevation contours, we thresholded our CHM: we classified all CHM pixels at least one foot in height as tree/shrub. We overlaid this tree/shrub layer on our existing water and riparian elevation layers. We masked the areas of our orthomosaics that we had already classified as tree/shrub or water, which left only herbaceous cover and bare ground as unclassified. In these unclassified areas, we performed a segmentation in ArcGIS Pro and then ran a random forest classification to classify herbaceous vegetation. The herbaceous segmentation used the following parameters:

- Band 1: red
- Band 2: green
- Band 3: blue
- Spectral detail: 15.5
- Spatial detail: 15
- Min. segment size: 20 pixels

Our random forest classification (for herbaceous cover) used the following parameters:

- Max number of trees: 5,000
- Max tree depth: 3,000
- Max number of samples per class: 1,000
- Segment attributes:
    - Active chromaticity color
    - Mean digital number

Following our classification of each reach, we performed an accuracy assessment for each of our reaches using vegetation rapid assessment data provided by Lauren Mork from the Upper Deschutes Watershed Council and collected by Karen Allen of Aequinox Habitat. The rapid assessment data included the classes:

- Riparian tree
- Riparian shrub
- Upland tree
- Upland shrub
- Herbaceous
- Other

We aligned these classes with our land cover classifications classes, which are listed below:

- Riparian tree/shrub
- Upland tree/shrub
- Visible herbaceous
- Other

During rapid assessment surveys, the “other” class was used to designate non-vegetated areas, such as water, bare substrate, or wood. In the cover classification from imagery, the “other” class was used to denote areas that were not classified as a vegetation class by the segmentation classification approach. There were very few “other” points in the rapid assessment dataset whereas extensive areas were classified as “other” in the cover classification from imagery, so we expected this to produce a result that may not be representative.

In order to merge the vegetation rapid assessment data into classes that we could match to our classification, we combined our riparian tree and riparian shrub class into a single riparian tree/shrub class. We combined our upland tree and upland shrub class into a single upland tree/shrub class. In order to merge the results from our classified map so that they fit our classification described above, we converted our water class to an “other” class. We also combined our multiple riparian tree/shrub classes (differentiated by elevations above GGL for Phase I or the water surface for all other reaches) into one riparian tree/shrub class. Additionally, we converted our tree/shrub/water class into a riparian tree/shrub class.

For our accuracy assessment, we compared the number of accurate classifications to the number of inaccurate classifications for each class. For each class, we compared both 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 recognize a specific class when the class was represented in the reference data (omission error, or producer’s accuracy).

Sediment Size.

To determine sediment size for our reaches, we randomly sampled and performed manual measurements on our photoplot data both in wetted and non-wetted areas. We defined sediment size classes as follows:

1. Boulder: > 256 mm
2. Cobble: 64 – 256 mm
3. Gravel: 2 – 64 mm
4. Sand, silt and organics: < 2 mm

Before sampling and measuring our photoplot data, we assigned a minimum mapping unit (MMU) to each photoplot. We used elevation information for each photoplot to calculate the MMU and wrote .JGW files (world files) to use in ArcGIS Pro to calculate pixel size. We associated elevation information with each image and wrote .JGW files for each image using a short Python script.

After we calculated pixel size for each photoplot, we analyzed each photoplot in ArcGIS Pro. For each photoplot, we generated and randomly distributed 100 points through the plot extent. For each point, we manually measured the sediment grain size on the second-longest visible axis (this was meant to be an estimation of the “b-axis” used in pebble counts). We created two attributes for each of these points: (1) wetted/non-wetted and (2) size class, assigning size class based on our measurements and providing an “N/A” value if the point fell on an un-interpretable location. We measured the size of sediment grains at each point location, and compiled summary statistics for all points in the reach, for each reach except Willow Springs.

We analyzed 13 (out of 17) photoplots from Phase 1, 33 (out of 36) photoplots from Phase IIa and Phase IIb combined, and 24 (out of 26) photoplots from Camp Polk, for a total of 70 photoplots analyzed. The photoplots analyzed were not necessarily distributed over wetted and non-wetted areas, but instead were analyzed if we were able to accurately calculate ground sampling distance (GSD). With 100 points per sample, our total number of samples was 7,231 with 2,439 points interpretable.

Large Woody Debris

We manually digitized LWD for each reach. We used our orthoimagery, displayed in ArcGIS Pro in true color, to digitize all visible LWD. We digitized most visible woody debris, including LWD rafts and branches in the stream channel, fallen trees in the valley, and other logs in the valley.

Using the same approach as for riparian vegetation elevation contours, we created elevation contours to put LWD into classes representing estimated inundation period based on Cari Press and Lauren Mork’s knowledge of the site and hydrograph. These classes are in table 2.

Table 2: Inundation period zones for Large Woody Debris in the floodplain for Whychus Creek.

Height (pre-restoration)	**Height (Camp Polk)**	**Height (Phase 1)**	**Indicates**
Water Surface (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 to 2 ft	Likely interacts with flow between baseflow and annual high flows
> 3 ft	> 2 ft	> 2 ft	Likely interacts with flows greater than annual high flows

Technology Transfer

We created step-by-step user guides to walk analysts through the creation of the above metrics. The user guides feature ArcGIS Pro and provide detailed instructions on how to derive inundated area, land cover, sediment size, and LWD metrics.

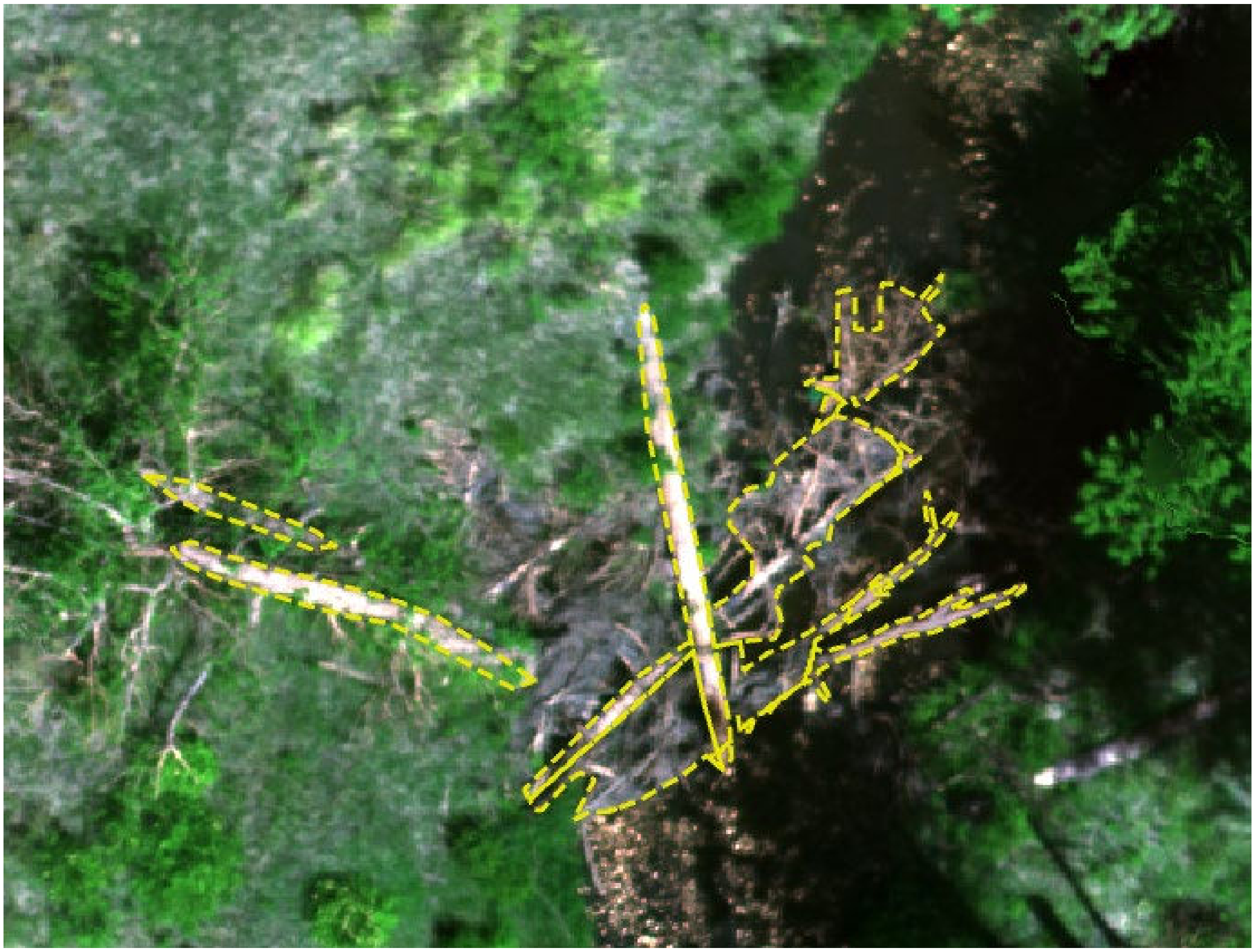


Figure 3: Example of a hand-delineated section of Large Woody Debris in the Camp Polk valley bottom.

Results

Inundated area

We created inundated area rasters for each of our five reaches. Our inundated area rasters had attributes for class (water/non-water) and area (m^2). Though we did not have field reference data with which to perform an accuracy assessment on water, we visually compared the classifications to visible water in our orthoimagery and we received input from Lauren Mork and Cari Press, who are very familiar with the area. Qualitatively, the results were very good and captured the primary channel as well as most non-primary channels. Some very narrow channels were not classified as water or had sections missing in the classification. The classification also missed some small pools located some distance from active channels. Future analysis could use LiDAR bare earth data and site knowledge to digitize the areas that were missed in the original object-based classification method. Inundated area is reported as the “water” land cover class for each reach (Tables 9 – 13).

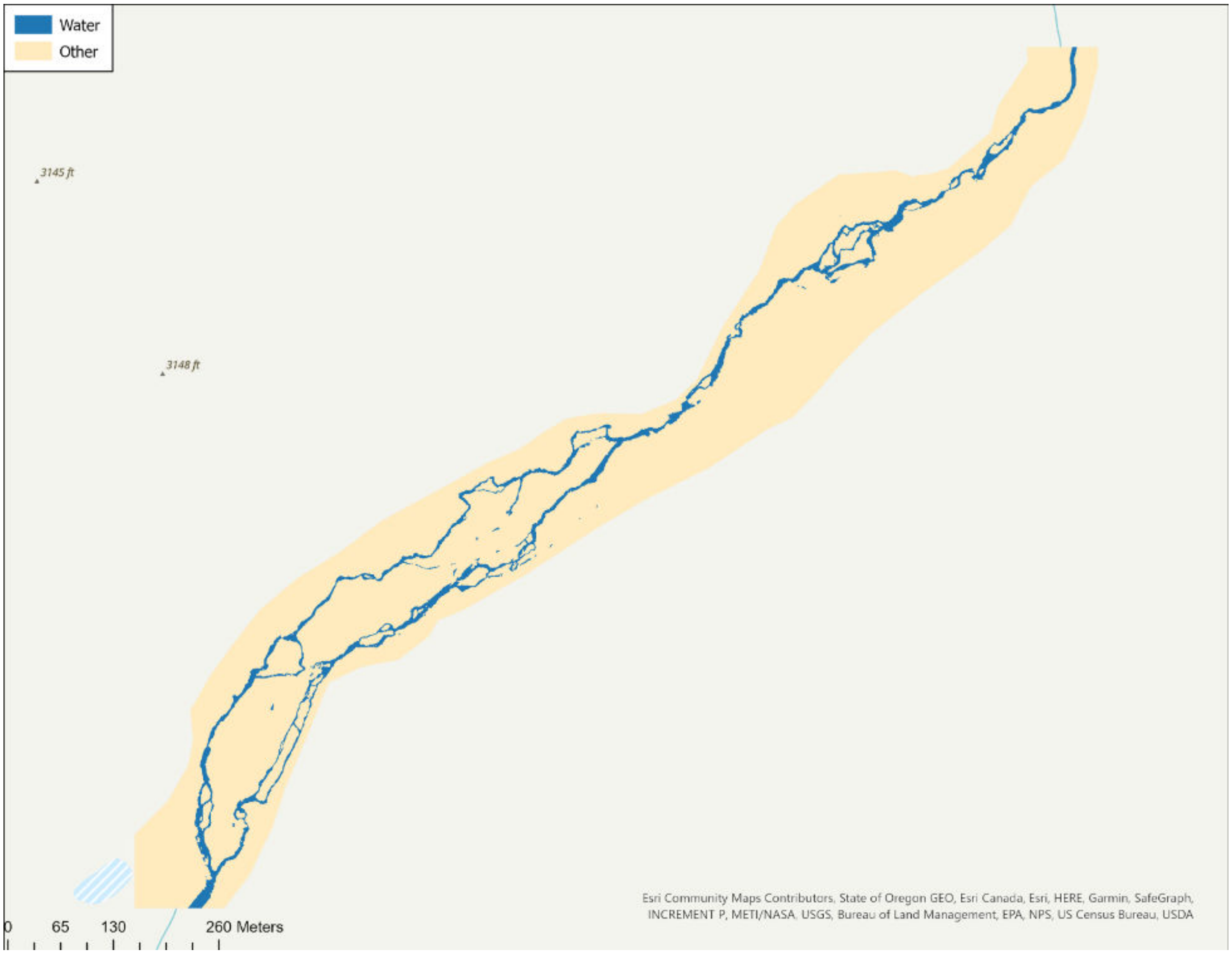
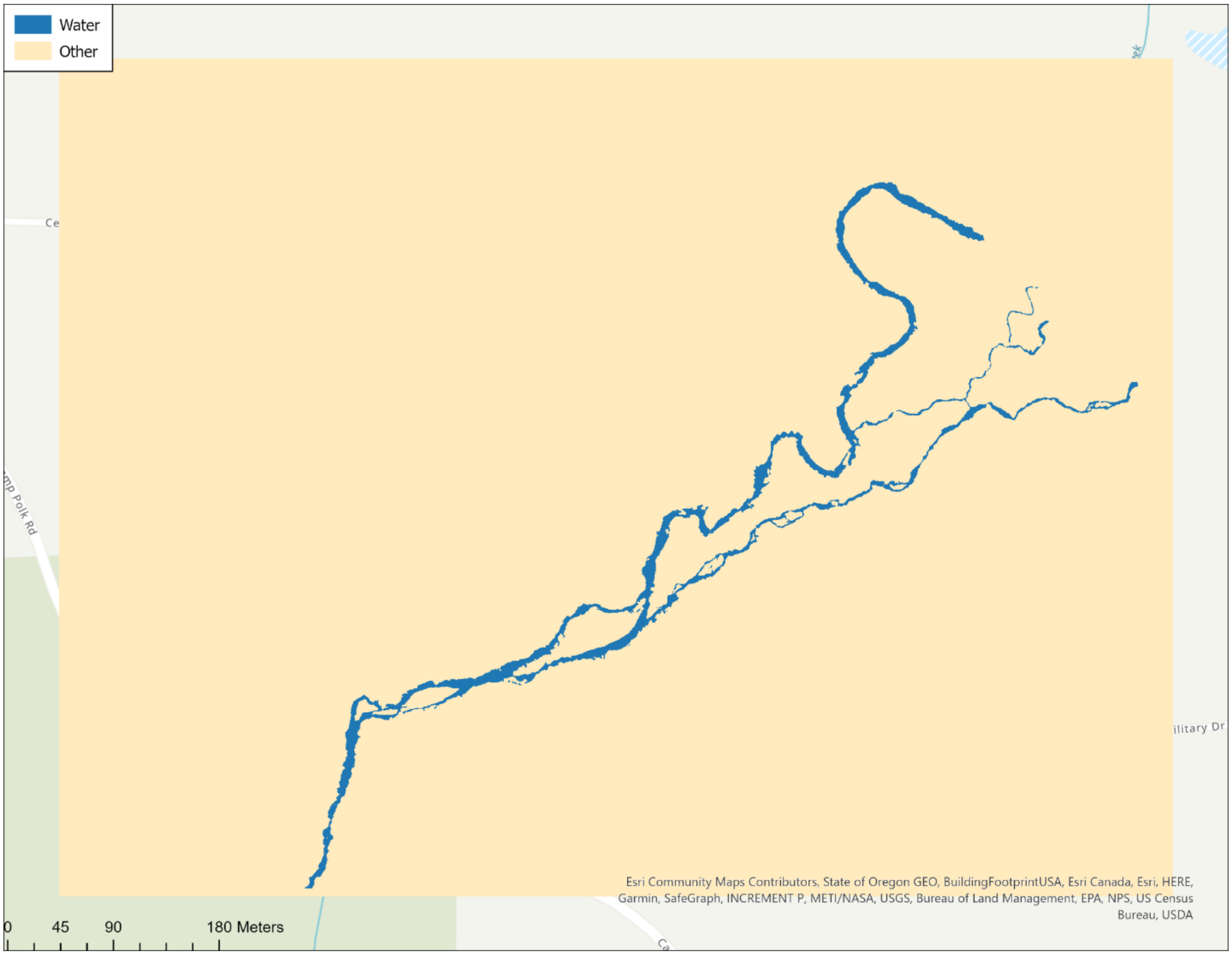


Figure 4: Whychus Canyon Phase 1 inundated area classification derived from June 2020 UAS orthoimagery.



Esri Community Maps Contributors, State of Oregon GEO, BuildingFootprintUSA, Esri Canada, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA

Figure 5: Camp Polk inundated area classification from June 2020 UAS orthoimagery.

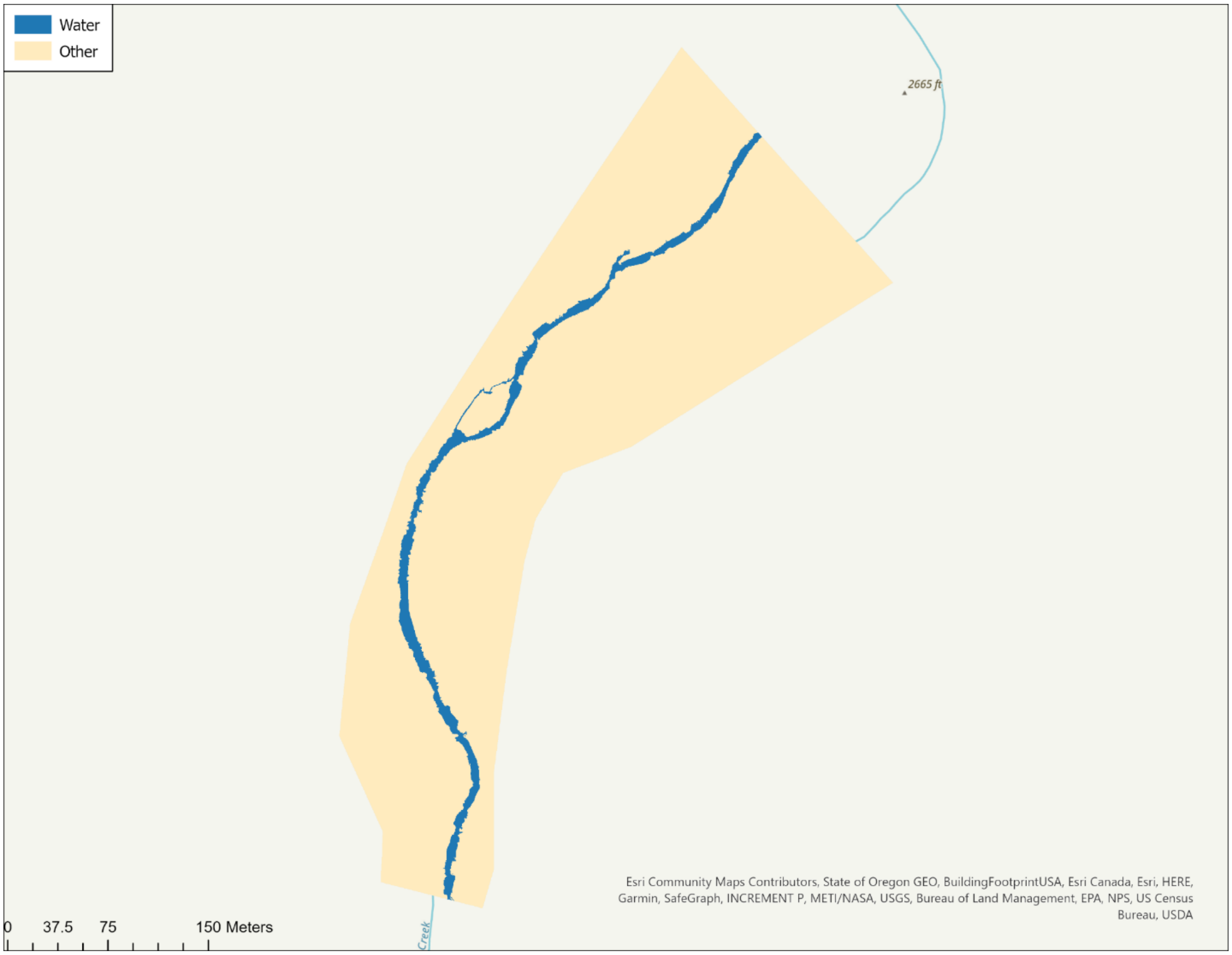


Figure 6: Whychus Canyon Phase 2a inundated area classification derived from June 2020 UAS orthoimagery.

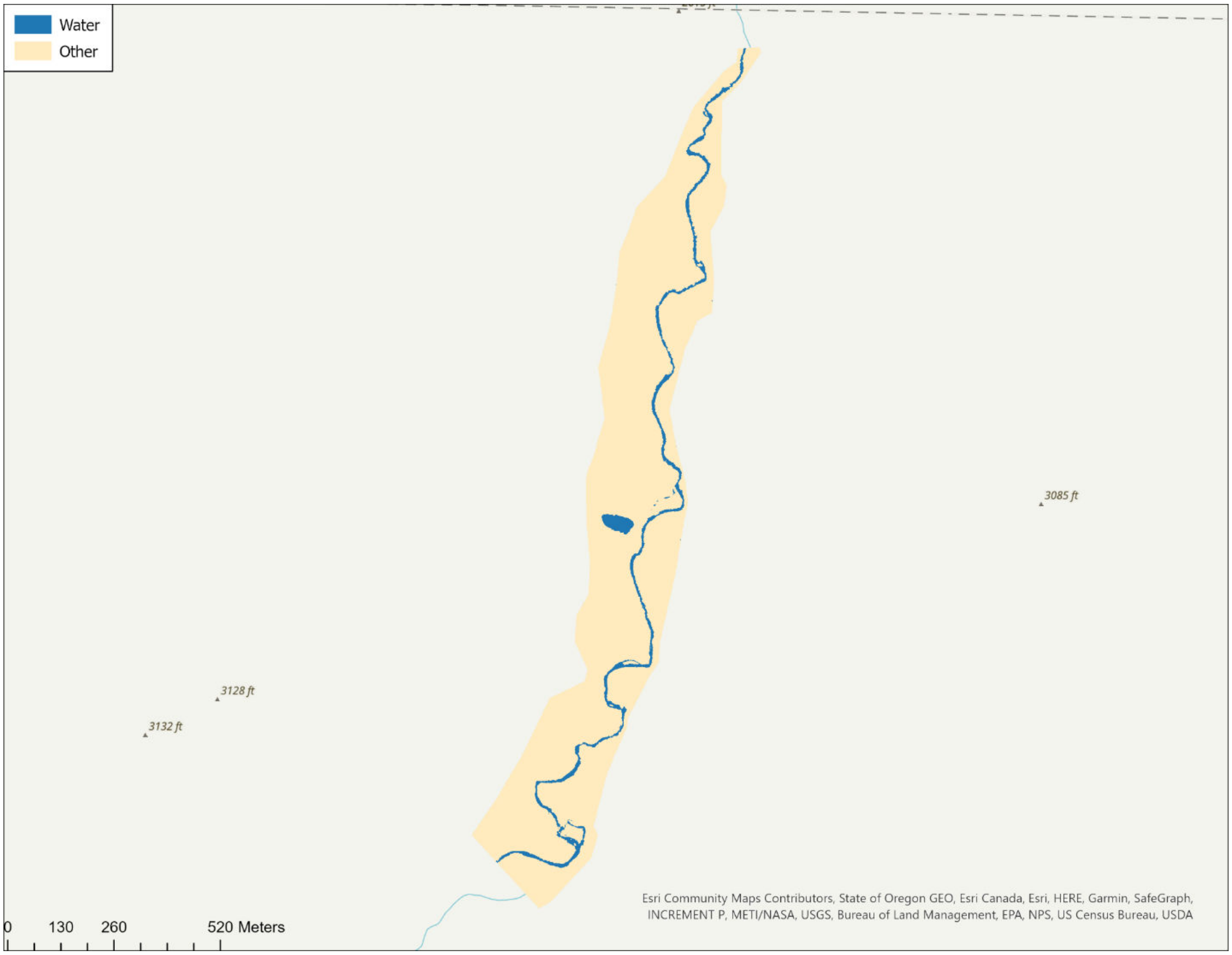


Figure 7: Whychus Canyon Phase 2b inundated area classification derived from June 2020 UAS orthoimagery.

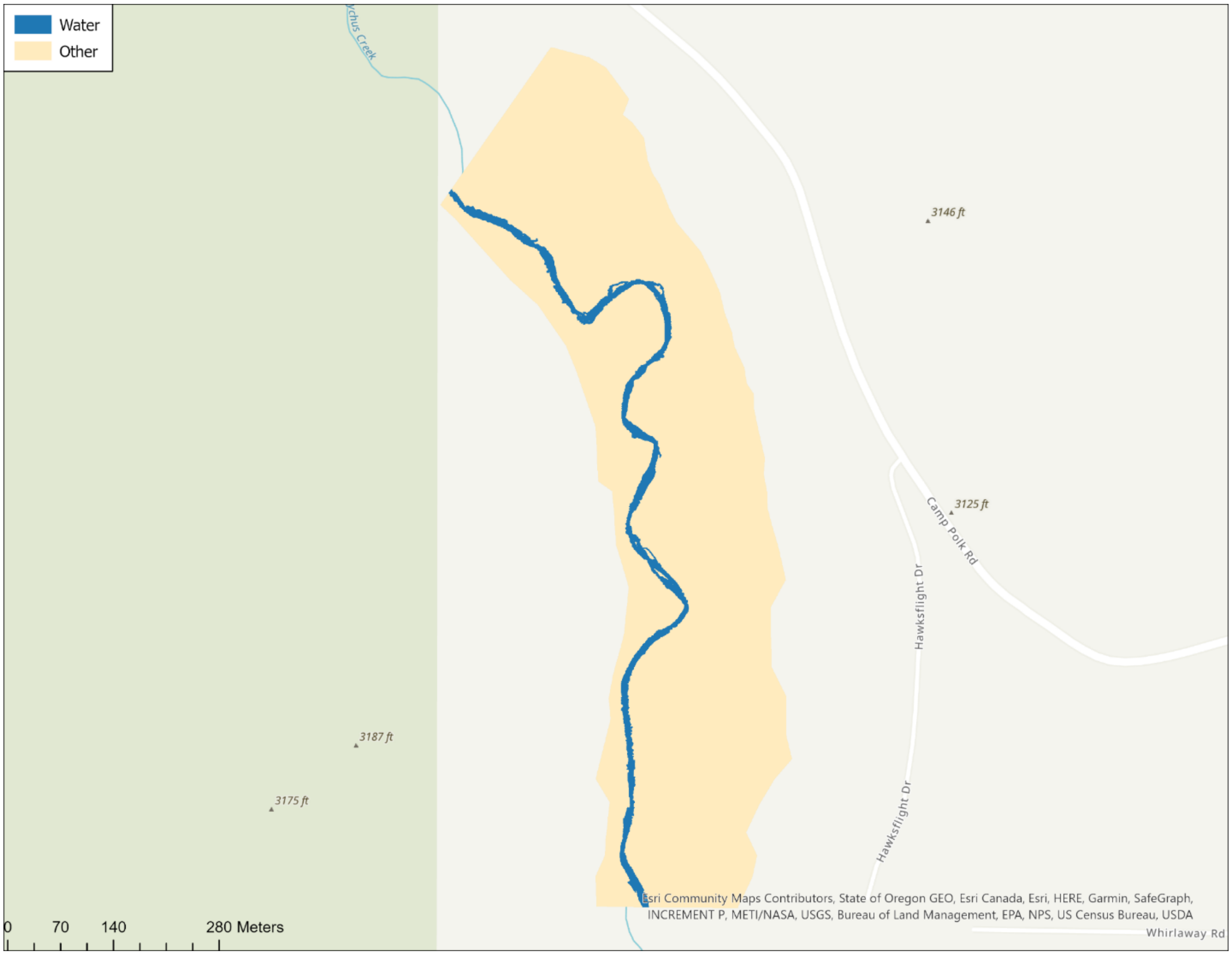


Figure 8: Willow springs inundated area classification derived from June 2020 UAS orthoimagery.

Land cover

We created land cover classification rasters for each of our reaches. These classifications each had eight classes, including water, and were represented at a final resolution of ~5.3 cm. Our overall classification accuracy was 36.67%, and accuracies varied widely between reaches and classes, and even between user's accuracy and producer's accuracy for the same land cover class. For example, in Phase IIa herbaceous cover had a user's accuracy of 12.5%, indicating that only 12.5% of vegetation identified as herbaceous cover was actually herbaceous cover according to vegetation rapid assessment data, while upland tree/shrub had a user's accuracy of 100%, indicating all vegetation identified as upland tree/shrub was also classified as upland tree/shrub according to vegetation rapid assessment data (in contrast, a producers accuracy of 100% would have meant that 100% of reference sites were correctly classified). Accuracy for riparian tree/shrub tended to be higher than accuracy for herbaceous and other, but again varied widely between 100% and 0% within a reach (see tables 3-13).

Land Cover Accuracy Assessment

Table 3: Confusion matrix for all Whychus Creek vegetation rapid assessment reference points over all reaches. Cells that are located along the diagonal represent correctly modeled classes and cells that fall on the off-diagonal represent errors.

reference column	**Upland tree/shrub**	**Riparian tree/shrub**	**Herbaceous**	**Other**	**Total**	**Producer Accuracy**
Upland tree/shrub	4	8	9	8	**29**	**13.79%**
Riparian tree/shrub	5	23	11	7	**46**	**50.00%**
Herbaceous	1	2	15	25	**43**	**34.88%**
Other	0	1	0	0	**1**	**0.00%**
Total	**10**	**34**	**35**	**40**	**119**	
User Accuracy	**40.00%**	**67.65%**	**42.86%**	**0.00%**		

Table 4: Confusion matrix for vegetation rapid assessment points from Whychus Canyon Phase I. Cells that are located along the diagonal represent correctly modeled classes and cells that fall on the off diagonal represent errors.

reference column	**Upland tree/shrub**	**Riparian tree/shrub**	**Herbaceous**	**Other**	**Total**	**Producer Accuracy**
Upland tree/shrub	3	1	4	1	**9**	**33.33%**
Riparian tree/shrub	5	8	5	2	**20**	**25.00%**
Herbaceous	1	2	0	6	**9**	**11.11%**
Other	0	1	0	0	**1**	**0.00%**
Total	**9**	**12**	**9**	**9**	**39**	
User Accuracy	**33.33%**	**66.67%**	**0.00%**	**0.00%**		

Table 5: Confusion matrix for vegetation rapid assessment reference points from Whychus Canyon Phase IIa. Cells that are located along the diagonal represent correctly modeled classes and cells that fall on the off-diagonal represent errors.

reference column	**Upland tree/shrub**	**Riparian tree/shrub**	**Herbaceous**	**Other**	**Total**	**Producer Accuracy**
Upland tree/shrub	1	1	4	1	**7**	**14.29%**
Riparian tree/shrub	0	9	3	0	**12**	**75.00%**
Herbaceous	0	0	1	0	**1**	**100.00%**
Other	0	0	0	0	**0**	**null**
Total	**1**	**10**	**8**	**1**	**20**	
User Accuracy	**100.00%**	**90.00%**	**12.50%**	**0.00%**		

Table 6: Confusion matrix for vegetation rapid assessment reference points from Whychus Canyon Phase IIb. Cells that are located along the diagonal represent correctly modeled classes and cells that fall on the off-diagonal represent errors.

reference column	**Upland tree/shrub**	**Riparian tree/shrub**	**Herbaceous**	**Other**	**Total**	**Producer Accuracy**
Upland tree/shrub	0	1	0	1	**2**	**0.00%**
Riparian tree/shrub	0	2	2	2	**6**	**33.33%**
Herbaceous	0	0	8	4	**12**	**66.67%**
Other	0	0	0	0	**0**	**null**
Total	**0**	**3**	**10**	**7**	**20**	
User Accuracy	**null**	**66.67%**	**80.00%**	**0.00%**		

Table 7: Confusion matrix for vegetation rapid assessment reference points for Camp Polk. Cells that are located along the diagonal represent correctly modeled classes and cells that fall on the off diagonal represent errors.

reference column	**Upland tree/shrub**	**Riparian tree/shrub**	**Herbaceous**	**Other**	**Total**	**Producer Accuracy**
Upland tree/shrub	0	5	0	0	**5**	**0.00%**
Riparian tree/shrub	0	2	1	3	**6**	**33.33%**
Herbaceous	0	0	3	6	**9**	**33.33%**
Other	0	0	0	0	**0**	**null**
Total	**0**	**7**	**4**	**9**	**20**	
User Accuracy	**null**	**28.57%**	**75.00%**	**0.00%**		

Table 8: Confusion matrix for vegetation rapid assessment reference points for Willow Springs. Cells that are located along the diagonal represent correctly modeled classes and cells that fall on the off diagonal represent errors.

reference column	**Upland tree/shrub**	**Riparian tree/shrub**	**Herbaceous**	**Other**	**Total**	**Producer Accuracy**
Upland tree/shrub	0	0	1	5	**6**	**0.00%**
Riparian tree/shrub	0	2	0	0	**2**	**100.00%**
Herbaceous	0	0	3	9	**12**	**25.00%**
Other	0	0	0	0	**0**	**null**
Total	**0**	**2**	**4**	**14**	**20**	
User Accuracy	**null**	**100.00%**	**75.00%**	**0.00%**		

Table 9: Land cover by area (acres) for Whychus Canyon Phase I.

Land cover type	**Area (acres)**	**Percent Area**
Water	3.15	6.34%
Upland Tree/Shrub	9.68	19.47%
Visible Herbaceous	11.84	23.82%
Riparian Tree/Shrub/Water	0.59	1.19%
Other/Bare	13.16	26.48%
Riparian Tree/Shrub (<= 0.3 ft)	4.17	8.40%
Riparian Tree/Shrub (0.3 – 2 ft)	5.00	10.05%
Riparian Tree/Shrub (2 – 3 ft)	2.11	4.25%
Total Inundated (riparian tree/shrub/water + water)	**3.74**	**7.53%**
Total	**49.72**	**100.00%**

Table 10: Land cover by area (ac) for Camp Polk.

Land cover type	**Area (acres)**	**Percent Area**
Water	1.40	3.23%
Upland Tree/Shrub	0.03	0.07%
Visible Herbaceous	8.02	18.51%
Riparian Tree/Shrub/Water	0.26	0.61%
Bare/Other	25.29	58.37%
Riparian Tree/Shrub (WS – 2 ft)	8.18	18.89%
Riparian Tree/Shrub (2 – 3 ft)	0.15	0.34%
Total Inundated	**1.66**	**3.83%**
Total	**43.32**	**100.00%**

Table 11: Land cover by area (ac) for Whychus Canyon Phase IIa.

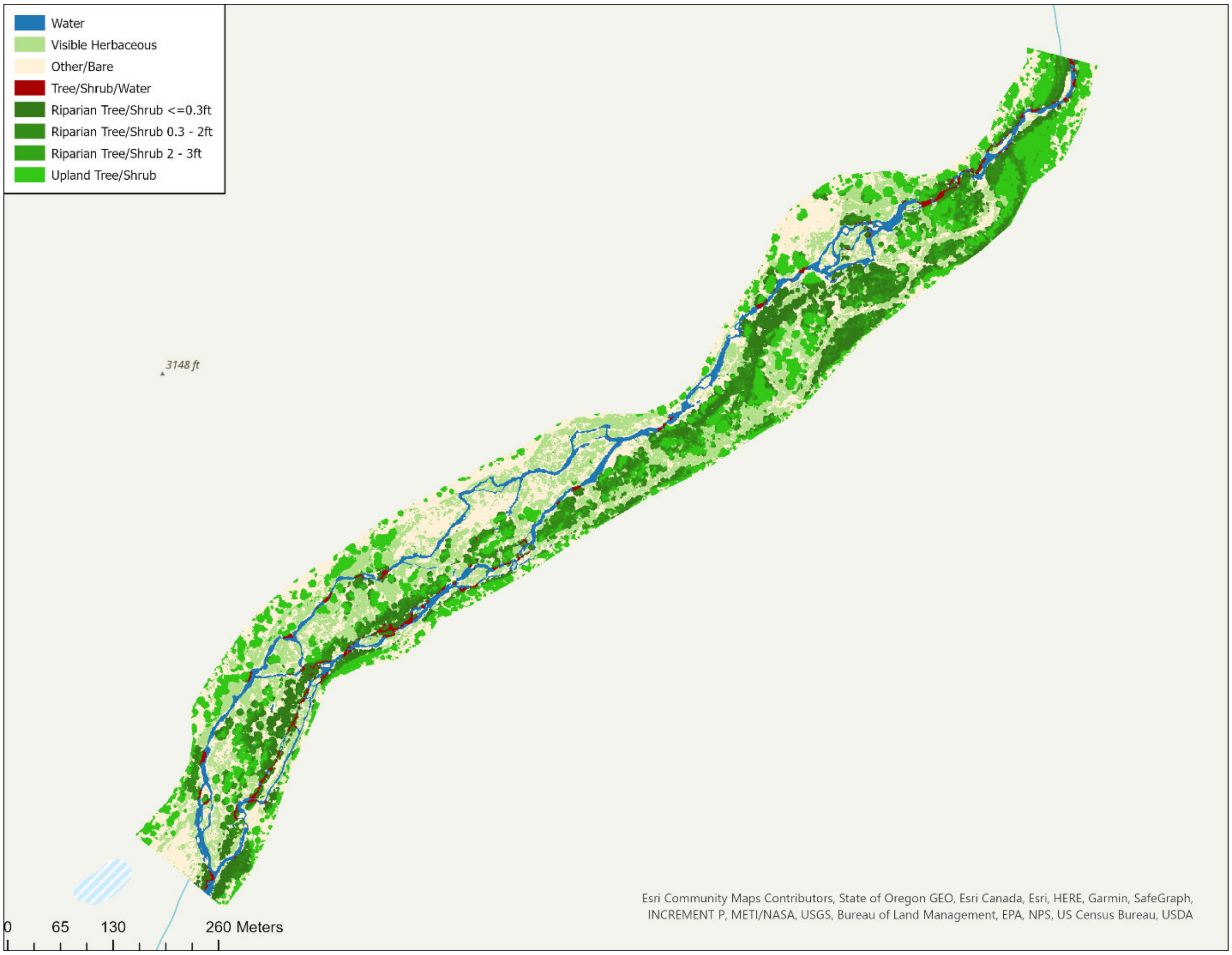
Land cover type	**Area (acres)**	**Percent Area**
Water	0.87	4.01%
Upland Tree/Shrub	1.03	4.74%
Visible Herbaceous	7.55	34.76%
Other/Bare	2.24	10.31%
Riparian Tree/Shrub/Water	0.16	0.74%
Riparian Tree/Shrub (WS – 3 ft)	9.76	44.94%
Riparian Tree/Shrub (3 – 4 ft)	0.11	0.51%
Total Inundated	**1.02**	**4.70%**
Total	**21.72**	**100.00%**

Table 12: Land cover by area (ac) for Whychus Canyon Phase IIb.

Land cover type	**Area (acres)**	**Percent Area**
Water	5.28	5.33%
Upland Tree/Shrub	0.54	0.55%
Visible Herbaceous	42.86	43.27%
Other/Bare	17.83	18.00%
Riparian Tree/Shrub/Water	0.25	0.25%
Riparian Tree/Shrub (WS – 3 ft)	31.98	32.28%
Riparian Tree/Shrub (3 – 4 ft)	0.32	0.32%
Total Inundated	**5.53**	**5.58%**
Total	**99.06**	**100.00%**

Table 13: Land cover by area (ac) for Willow Springs.

Land cover type	**Area (acres)**	**Percent Area**
Water	2.91	4.80%
Upland Tree/Shrub	0.42	0.69%
Visible Herbaceous	16.89	27.84%
Other/Bare	34.02	56.07%
Riparian Tree/Shrub/Water	0.08	0.13%
Riparian Tree/Shrub (WS – 3 ft)	6.2	10.22%
Riparian Tree/Shrub (3 – 4 ft)	0.15	0.25%
Total Inundated	**2.99**	**4.90%**
Total	**60.67**	**100.00%**



Esri Community Maps Contributors, State of Oregon GEO, Esri Canada, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA

Figure 9: Land cover classification for Whychus Canyon Phase 1.

Figure 10: Land cover classification for Whychus Canyon Phase 2a.

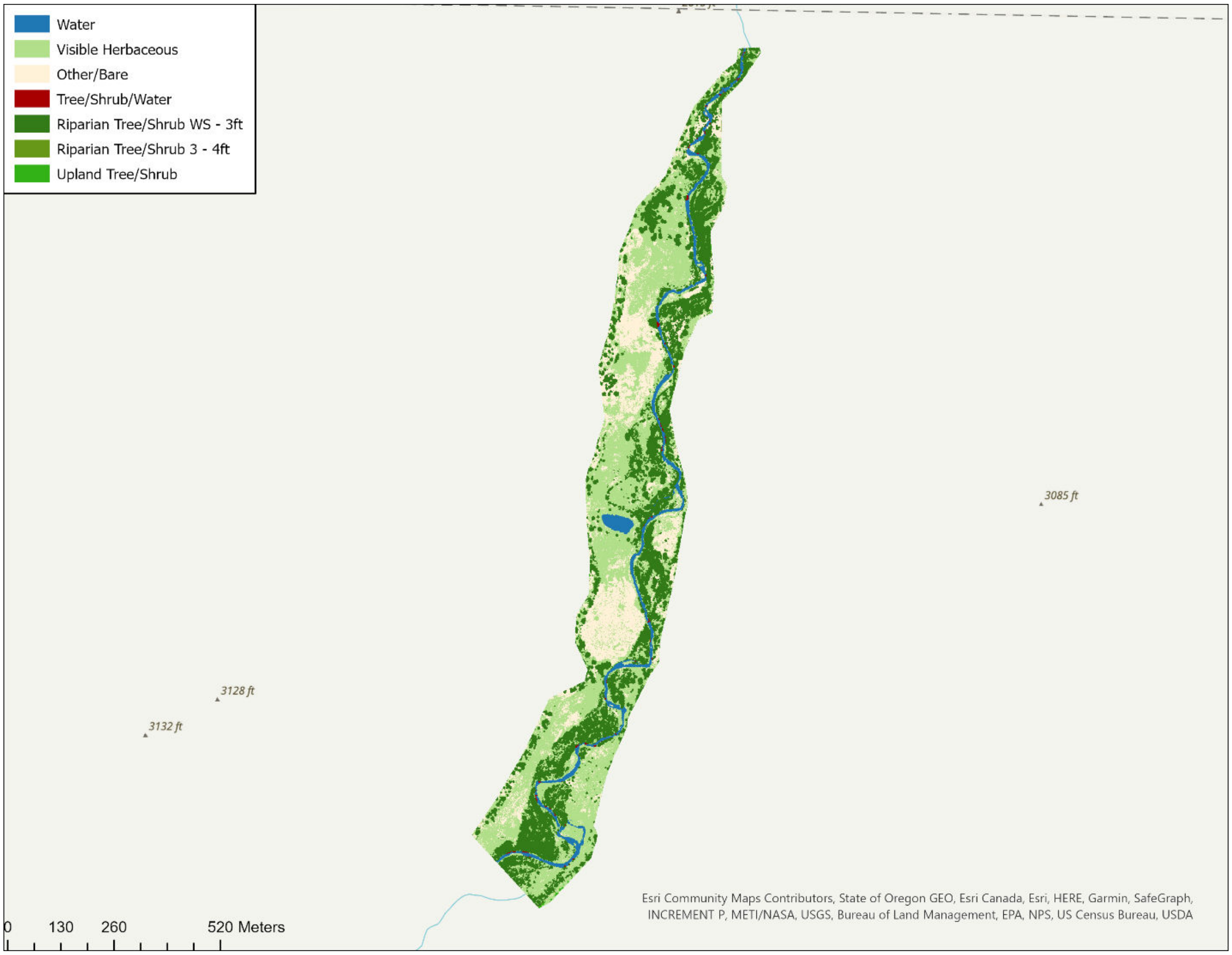
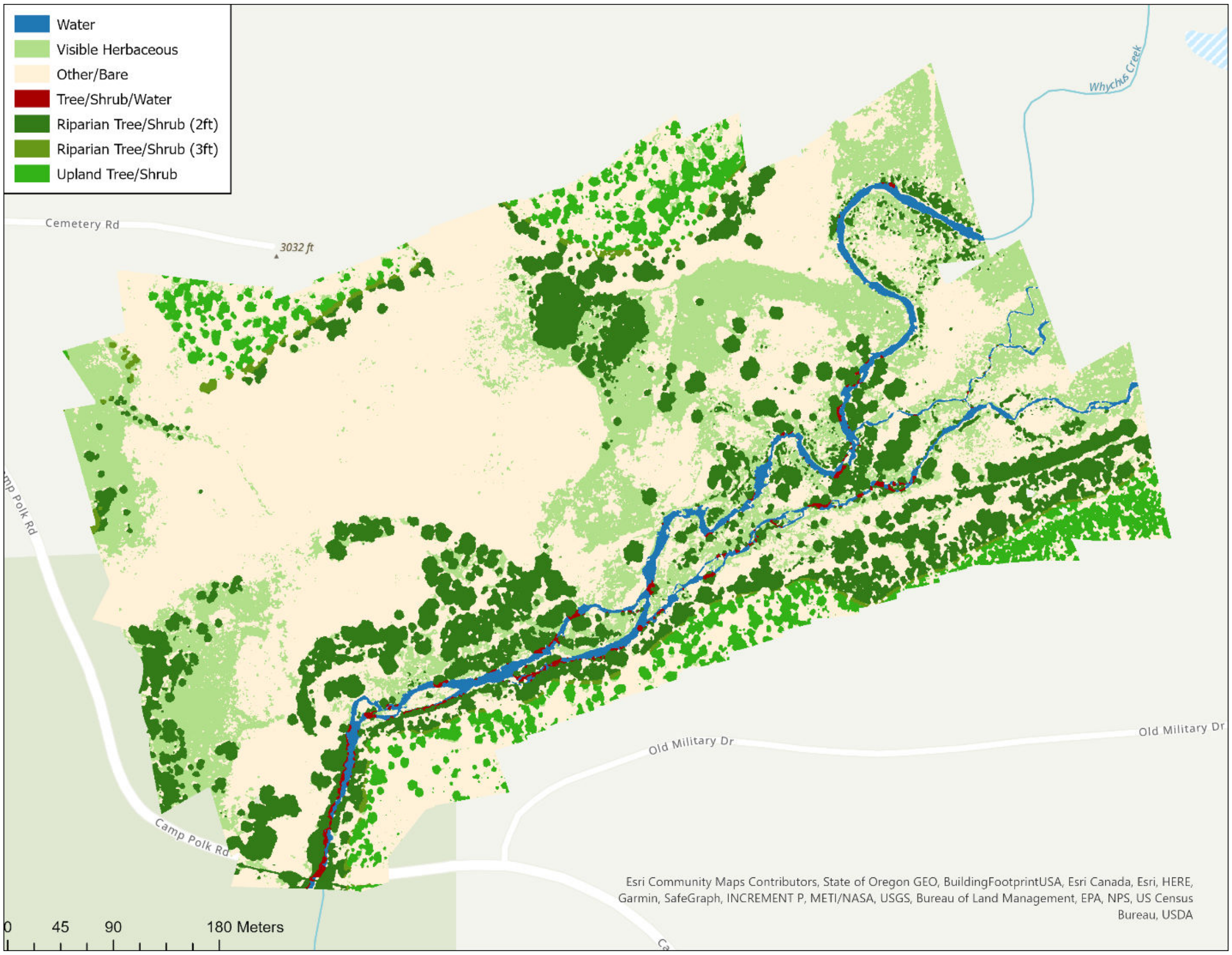


Figure 11: Land cover classification for Whychus Canyon Phase 2b.



Esri Community Maps Contributors, State of Oregon GEO, BuildingFootprintUSA, Esri Canada, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA

Figure 12: Land cover classification for Camp Polk.

Figure 13: Land cover classification for Willow Springs.

Large Woody Debris

We created a polygon shapefile for LWD with two attributes, area (ft^2) and inundation frequency. Flow period refers to the approximate recurrence interval and stage of the streamflow for which the LWD would be interacting. Baseflow is the summer low flow period and is approximately 20 cfs. Annual high flow is approximately 300 cfs and greater than annual high flow can range from 300 cfs to 2000 cfs. In post-restoration reaches, LWD occurred in higher amounts than in pre-restoration reaches. Phase IIb, a pre-restoration reach, is an exception. It appears that wood was added in a large pile to the reach before the flight, and this inflated the amount of debris within the reach. Based on visual inspections and inspections of the tables below, there does not appear to be a numeric or spatial pattern in LWD distribution through the three inundation frequency zones.

Table 14: Large woody debris area by inundation period for Whychus Canyon Phase I.

Inundation frequency	**Area (square feet)**	**Percent of total wood area**
Baseflow	9558.76	43.95%
Annual high flow	6831.61	31.41%
> Annual High Flow	5358.92	24.64%
Total	**21749.29**	**100.00%**

Table 15: Large woody debris inundation frequency by area for Whychus Canyon Phase IIa.

Inundation frequency	**Area (square feet)**	**Percent of total wood area**
Annual	378.80	87.5%
Five-year	0	0.00%
Decadal / Multi-decadal	39.95	12.5%
Total	**418.75**	**100.00%**

Table 16: Large woody debris inundation frequency by area for Whychus Canyon Phase IIb.

Inundation frequency	**Area (square feet)**	**Percent of total wood area**
Annual	36.23	11.43%
Five-year	182.01	57.45%
Decadal / Multi-decadal	98.59	31.12%
Total	**316.83**	**100.00%**

Table 17: Large woody debris inundation frequency by area for Camp Polk.

Inundation frequency	**Area (square feet)**	**Percent of total wood area**
Annual	1012.93	13.34%
Five-year	6288.74	82.84%
Decadal / Multi-decadal	290.01	3.82%
Total	**7591.68**	**100.00%**

Table 18: Large woody debris inundation frequency by area for Willow Springs.

Inundation frequency	**Area (square feet)**	**Percent of total wood area**
Annual	132.02	4.18%
Five-year	2688.42	85.2%
Decadal / Multi-decadal	335.17	10.62%
Total	**3155.61**	**100.00%**

Sediment size

Out of 7,231 points, we were able to interpret 2,439 points, with the rest of our generated points classified as uninterpretable ("N/A") because of either ripples, glare, shadows, tree cover, etc... All reaches were made up of mostly N/A values and had very few boulders. Given the high number of N/A values this method may not be accurately represent percent sediment size classes. Of the visible/measurable photo plots, data showed a higher proportion of gravel and smaller sediment (silt, fines, and organics) in post-restoration reaches (Phase 1 and Camp Polk) than in the pre-restoration reaches (Phase IIa and Phase IIb). Likewise, pre-restoration reaches had a higher proportion of cobble.

Table 19: Sediment sample point data from Phase I photoplots.

Type	Count non-wetted	Count wetted	Count combined	Percent of Total sampled
Boulder	2	1	3	0.20%
Cobble	39	30	69	4.51%
Gravel	133	182	315	20.57%
N/A	632	284	916	59.83%
Sand, Silt and Organics	103	125	228	14.89%
Total	**909**	**622**	**1531**	**100.00%**

Table 20: Sediment sample point data from Camp Polk photoplots.

Type	Count non-wetted	Count wetted	Count combined	Percent of Total sampled
Boulder	1	4	5	0.21%
Cobble	70	54	124	5.17%
Gravel	366	120	486	20.25%
N/A	1057	504	1561	65.04%
Sand, Silt and Organics	118	106	224	9.33%
Total	**1612**	**788**	**2400**	**100.00%**

Table 21: Sediment sample point data from Phase IIa and Phase IIb photoplots.

Type	Count non-wetted	Count wetted	Count combined	Percent of Total sampled
Boulder	3	4	7	0.21%
Cobble	176	185	361	10.94%
Gravel	340	51	391	11.85%
N/A	1364	951	2315	70.15%
Sand, Silt and Organics	93	133	226	6.85%
Total	**1976**	**1324**	**3300**	**100.00%**

Discussion

One of the first decisions we made was which platform to use for analyzing the data. For our inundated area classification, we debated between using ArcGIS Pro, a GIS software, and eCognition, an image processing software designed specifically for segmenting and classifying imagery. We chose ArcGIS Pro for our analyses because 1) it is a more general-purpose tool that more organizations are likely to have access to; 2) it generally has a less steep learning curve than eCognition; and 3) it can produce quality land cover classifications.

Inundated area results

The inundated area classification captured most visible water while still being moderately easy to replicate by a less experienced remote sensing practitioner. We used an object-based classification method to create inundation maps because of the performance of this approach and the gains in speed possible using a semi-automated method. While the classification generally captured water very well, there were areas where water was not detected, including areas where trees overhang water and where LWD block water visibility. Glare also made it more difficult to classify water but was less of an issue than canopy cover and LWD. We manually edited some of these misclassified areas to ensure continuity between stream segments.

Stream area during baseflow did not change much between post-restoration and pre-restoration reaches. However, the amount of stream branching between pre-restoration and post-restoration reaches was noticeable and significant. Post-restoration reaches had much more branching than pre-restoration reaches, which is consistent with the goals of a Stage 0 restoration (Powers et al. 2018; Cluer and Thorne, 2013). Figure 12 shows an example of the difference between a post-restoration reach and a pre-restoration reach.

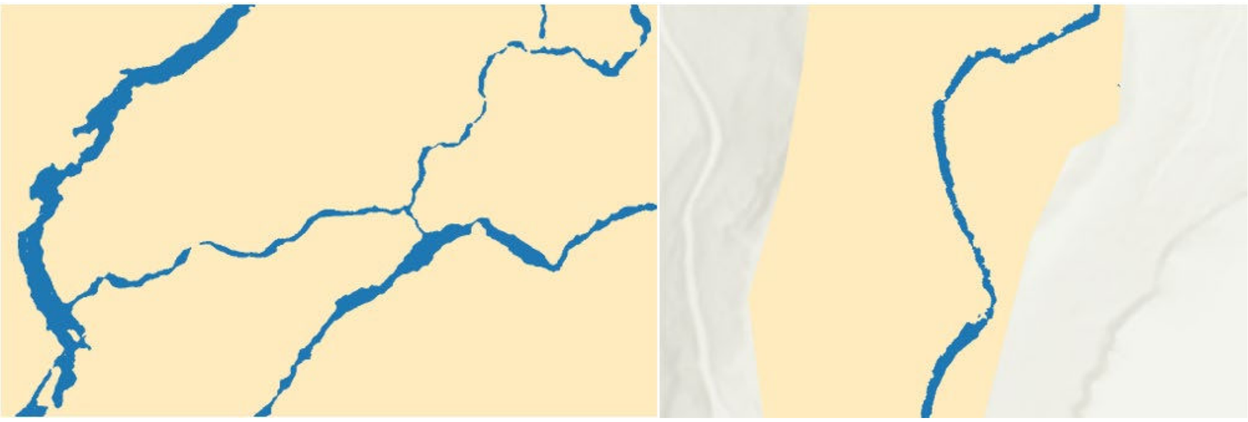


Figure 14: Snapshots of the channel from a post-restoration reach (left) and a pre-restoration reach (right).

The simple object-based approach that we chose achieved its intended use. Though we needed to do some manual editing at the end of the process, our semi-automated approach sped up our workflow. Now that the method has been developed, it will save time for evaluations in the future as more areas are restored and monitored. However, as vegetation gets denser in restored reaches, this approach might become more difficult as more areas would require manual digitization.

Land Cover Classification

The land cover classification provides useful information for the Upper Deschutes Watershed restoration project despite its low accuracy scores. Accuracy scores for all reaches were highly variable, but we do not believe this points to significant issues in the land cover classification. In our classification review with cooperators, we came to a consensus that the maps were likely largely representative of the area despite some known issues. Possible sources of error from known issues could include misclassification of dry and/or sparse herbaceous cover as bare ground, misclassification of trees and shrubs as herbaceous as a result of height thresholds, or misclassification of upland trees and shrubs as riparian trees and shrubs and vice-versa. In addition to known issues, there could be slight differences in location of reference points and classified objects. The classified map has a high enough resolution that the scale of the 5' radius plot used for shrubs and herbaceous plants and the 10' radius plots used for trees in the vegetation rapid assessment is mis-matched to the resolution of the classified map, which could impact the accuracy assessment. It would likely be better (from a land cover mapping perspective) to take reference plots at the resolution of the GPS receiver. From our communications with cooperators, we expect that the land cover maps, and mapping workflow will be useful going forward.

Tree/Shrub classification

Our visual inspection showed good agreement between imagery and classification for trees and large shrubs. Through observation, large shrubs appear better classified than small shrubs, with small shrubs sometimes being classified as herbaceous cover. This potential for misclassification of shrubs as herbaceous cover or bare ground is because we used a one-foot CHM threshold when classifying trees and shrubs. While this allows us to capture large trees and shrubs with high confidence, we expected to sometimes omit smaller shrubs. This being said, using a height threshold to classify trees and shrubs performed very predictably and captured the significant trees and shrubs reliably (this from our visual inspection of output classifications versus imagery). Because we use two separate masking steps – using our water classification and canopy height threshold – we found that tree cover often overlaps with water. This was an added benefit to running a multi-step classification rather than a one-step classification, adds accuracy to the product, and provides information about vegetation shading active channels, as areas classified as tree/shrub/water represent places where vegetation overhangs and shades the stream.

We sorted trees and shrubs into riparian and upland classes. We then sorted riparian trees and shrubs into sub-classes based on elevations relative to the GGL (Phase I) or inundated layer elevation (all other reaches). From inspections of mapped riparian area within our group, we discovered that using elevation in relation to water to predict whether trees/shrubs are riparian is often inaccurate. For example, upland-adapted conifers near a new branch of a stream in a post-restoration reach would be classified as riparian. This misclassification was more common in post-restoration reaches than pre-restoration reaches. We draw two conclusions from this observation. Our first conclusion is that estimates of elevation from both water surface and GGL REM may need to be revised to properly define riparian zones. The second conclusion is that conditions are still changing in post-restoration reaches, and that our map reflects riparian vegetation that is expected to develop over time near new channels and in response to shallow groundwater accessible by plant roots.

Visible herbaceous and bare/other classification

Though the accuracy assessment was not able to provide a metric for bare/other accuracy, cooperators noticed that herbaceous cover is often misclassified as bare ground, which we think is mainly because xeric plants are not as visible in the UAS imagery. We think that xeric, upland, and sometimes invasive species of plants in the floodplain are green earlier in the season and for a short duration; that these plants dominate the areas they do because of lower hydrologic connectivity (greater depth to groundwater); and that our UAS acquisition did not occur while these species were green and thus only revealed areas of herbaceous vegetation as visible where hydrologic connectivity and groundwater depth was sufficient to support riparian species or possibly upland species that stayed green longer because of hydrologic connectivity. Therefore, experts in the field may need to update these maps based on their knowledge.

Large Woody Debris

We found that delineating LWD by hand was the most effective method available to us. Hand-delineation was not overly time consuming, and it was also very accurate compared to initial segmentation efforts. Though there are some methods that allow automated delineation of LWD, they require significant up-front time and money investments (Ortega-Terol et al., 2014; Dauwalter et al., 2015; Perschbacher, 2011) and were not well-suited for this project and for Whychus Creek given the interest in using ArcGIS Pro rather than e-Cognition and given the relatively lower amount of wood on Whychus Creek as compared to Stage 0 restoration reaches such as the South Fork McKenzie River. We found more LWD in post-restoration reaches than in pre-restoration reaches, in terms of comparisons between total LWD from individual reaches. The increased amounts of LWD in post-restoration reaches was expected because large numbers of pieces of LWD were placed in the valley bottom as part of Stage 0 restoration, particularly at Phase I which was designed as a Stage 0 project as compared to Camp Polk which has evolved toward a Stage 0 condition despite having been designed with more of a Natural Channel Design approach. Increasing LWD in the floodplain and stream is important because it promotes geomorphic processes that result in creation of habitat units and channel evolution, and creates habitat for steelhead, salmon, native fish populations, and other aquatic species.

Sediment Size

For our methods, we chose to use a manual sampling approach because human interpretation is often more accurate than automated methods, and because automated methods still require more development (Woodget et al., 2017; Woodget et al., 2015). After we did some initial testing to try and determine sediment size classes automatically, we decided that an automated classification would require a lot of up-front time investment with a less accurate outcome. Since we sampled 70 photoplots in total, time spent manually interpreting grain sizes was not prohibitive and made more sense.

Two specific points should be noted about the results of the sediment size analysis concerning visibility. First, most sediment sample points were not visible, or a sample point fell outside of an area where sediment existed. We categorized these points as “N/A”. This was mostly the result of a large portion of our imagery being non-interpretable because of glare, vegetation, water depth or water turbulence. This has potential consequences for bias towards detecting larger sediment versus smaller sediment. For example, in choppy areas, there is a much higher chance of being able to distinguish cobble than of being able to distinguish gravel or smaller sediment. This could either be because of a lack of visibility due to glare or a heightened amount of fine sediment transport in these areas due to faster water velocities. During subsequent conversations with cooperators, we discussed the possibility of better targeting specific areas where sediment is clearly visible, and deliberately collecting data from these highly visible areas of sediment. If future sediment size analyses were to focus on specific areas of a high-resolution image instead of the whole image, such as the 1-m radius circular plot used for ground-based pebble counts within each photo plot, analysts might be able to achieve better, more representative, results.

The second point of concern regarding visibility is that we can also only see two dimensions in our imagery. During a pebble count, it is possible to find the second-longest axis (B axis) of each sediment grain, which may not be oriented in an XY plane. Using a remote sensing approach the B axis could be buried and would not be possible to measure which introduces uncertainty into our estimates of sediment size.

The sediment size distribution method yielded only partial results for many reaches due to data and visibility constraints. The main issue was that the sediment size dataset we gathered contains many “N/A” values due to non-interpretable points. In the future, we may need to find alternative remote sensing methods that will yield better results. It is also possible that ground-based methods will consistently give better results than remote sensing methods. Even acknowledging the limitations and room for improvement in the remote sensing method, the results still give us insights into the effects of the Stage 0 restoration.

Our sediment size dataset suggests that in post-restoration reaches, there were more gravel and fine sediment sizes than in pre-restoration reaches. There was also less cobble in post-restoration reaches than in pre-restoration reaches. This could mean that these areas are more depositional than before thereby depositing more gravels and fine sediment. Small sediment sizes are an indicator of a depositional environment and slower velocities suggesting a change to a Stage 0 condition. Smaller sediment sizes and slower velocities provide important aquatic habitat for rearing, spawning, and primary production which are all important parts of a successful Stage 0 restoration (Arif et al., 2017; Bangen et al., 2013; Maddock, 1999).

Conclusion

Overall, the workflows provide useful information on metrics quantifying success of a Stage 0 restoration project. Inundated area, land cover, and LWD are represented well. Streams are represented well by the model and are represented very well when some manual delineation is applied. Land cover methods could distinguish between woody and herbaceous vegetation and even riparian woody vegetation, but it did not distinguish between riparian herbaceous and xeric herbaceous vegetation. Also, small shrubs may at times be confused with herbaceous vegetation and xeric herbaceous vegetation may be delineated as bare ground. We did not find a way to represent LWD accurately and efficiently through any process but manual delineation, but manual delineation was not prohibitively time consuming and generated very good results. We identified several areas of improvement for sediment size analysis, but our analysis was consistent with what we would expect from a Stage 0 restoration. Importantly, the workflows that we created can be reproduced in ArcGIS Pro, which is becoming a standard software in the Forest Service and in many partner agencies and organizations.

In the five reaches that we analyzed, we found results that were consistent with our initial expectations. Streams had much more of a branching pattern following Stage 0 restoration, LWD were more abundant and distributed more widely through the floodplain, and smaller sediment sizes appeared to be more abundant in post-restoration areas of Whychus Creek. Land cover changes may take longer to come about, but it is reasonable to expect that future monitoring efforts will see changes in vegetation abundance and composition in response to altered inundated area location. These changes should have comprehensive positive effects on the floodplain and valley habitat. A benefit that cannot be understated is that the workflow can be re-used and improved upon by any organization with access to ArcGIS Pro.

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