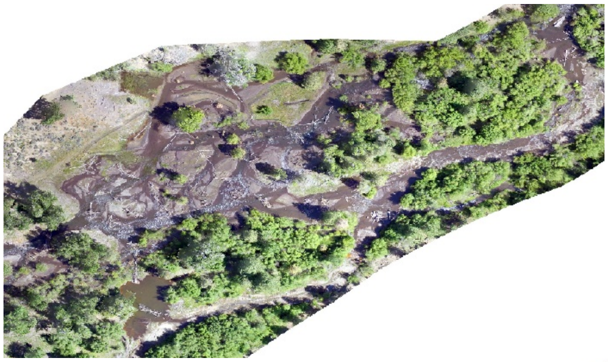

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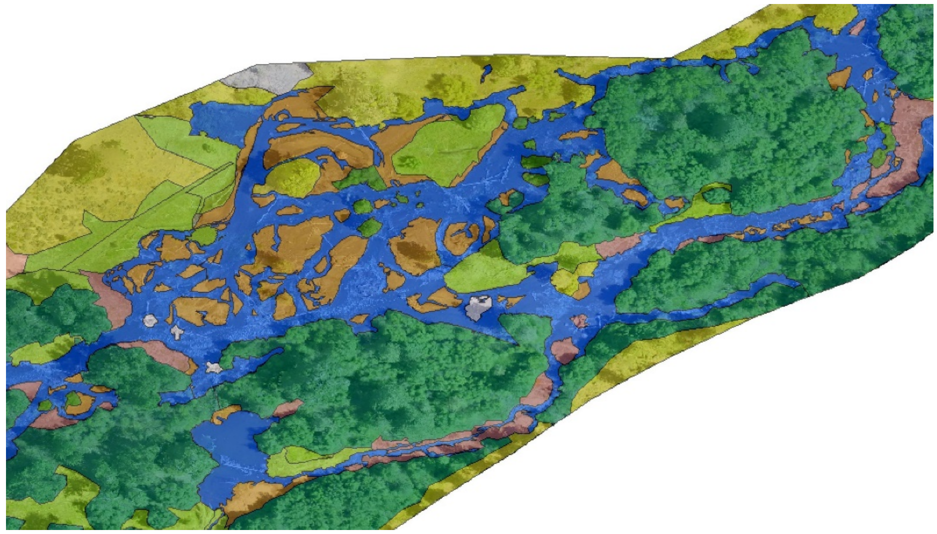

Unmanned Aerial Vehicle Photographic Survey of Whychus Creek and Adjacent Riparian Areas

MARCH 2018

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Introduction

Whychus Creek originates in the Cascade Mountains near Sisters, OR. The creek's watershed encompasses approximately 162,000 acres and 40 stream miles in Deschutes and Jefferson Counties in central Oregon. The watershed extends from the crest of the Cascade Mountains to the creek's confluence with the Deschutes River. Elevations range from 10,358 feet at the peak of South Sister to 2,100 feet at the confluence with the Deschutes River.

Stream habitat along Whychus Creek, a tributary to the Deschutes River, has been degraded and simplified by more than a century of flow diversions, channel and floodplain modification, livestock grazing, development, and flood control, including channelization of 18 miles of the creek in the 1960s (USFS 1998). These uses have led to a suite of factors limiting habitat for fish populations including: degraded riparian area and large wood recruitment; degraded floodplain connectivity and function; degraded channel structure and complexity; altered sediment routing; and altered hydrologic processes (Mork and Houston, 2014).

The Upper Deschutes Watershed Council (UDWC) has worked with non-profit and agency partners, including the Deschutes Land Trust (DLT) and U.S. Forest Service (USFS), since 2006 to restore stream habitat on Whychus Creek in key ecologically important, low-gradient, historically depositional valley reaches. These projects, implemented along a total of 20 stream miles and 388 valley bottom acres at Camp Polk Meadow Preserve, Whychus Floodplain, and Whychus Canyon Reach 4 as of 2017, are designed to improve the outcomes of stream restoration projects by restoring reach and watershed scale stream processes to create abundant, complex, self-sustaining stream habitat.

Floodplain connectivity, characterized by floodwaters spilling onto the floodplain, dispersing stream energy, depositing fine sediments, and recharging groundwater, is a key process these projects aim to restore. A species-rich, structurally diverse native riparian plant community is another critical component of a functioning riverscape. Native riparian plant communities provide floodplain roughness that dissipates stream energy, root masses that stabilize soils, and organic inputs, ranging from leaf litter to large wood, that provide food and habitat for stream organisms, and structure that promotes evolution of diverse bedforms and geomorphic units.

UDWC and DLT plan to restore an additional 7.5 miles along Whychus Creek. As the floodplain is recharged, hydrologic connectivity restored, and a diversity of native riparian, wet meadow, and wetland species planted in project reaches, we expect shallow floodplain groundwater to support re-establishment of a thriving, abundant, and species-rich riparian community. Accordingly, the presence of thriving hydrophytic riparian vegetation is a product and indicator of the hydrologic conditions we aim to restore.

UDWC contracted with Earth Design Consultants, Inc. (EDC), to produce: 1) protocols for aerial imagery flights and riparian community mapping, 2) baseline imagery, and 3) high spatial resolution maps of the extent of riparian vegetation along Whychus Creek in 2017. This imagery and accompanying protocols will support future evaluations of change in the extent of riparian vegetation communities as channel and floodplain restoration projects are implemented along approximately eight miles of Whychus Creek. This report describes protocols for the aerial imagery acquisition and riparian vegetation mapping completed from 2017-2018 along 37 miles of Whychus Creek (1,008 acres); presents a change analysis of riparian vegetation at Camp Polk, Whychus Floodplain, and Whychus Canyon Reach 4; and presents recommendations for future projects quantifying riparian vegetation.

EDC's classification and delineation of riparian vegetation (proximate to stream channel and presumably hydrologically connected) was based on visual interpretation of aerial imagery without additional field-collected data and was based solely upon what could be seen in the imagery. UDWC staff who were familiar with the study area also provided input to the classification. In this report, riparian means adjacent to or tightly associated with Whychus Creek. It was not possible to identify individual species using the spectral resolution of the RGB imagery alone. Results of this report, therefore, should be considered informative with respect to large-scale changes; however, we suggest follow-up studies be completed in order to verify specific riparian acreage analyses. Specifically, we recommend that GPS coordinates be collected by field teams for individual cottonwood trees since this species of interest would be tracked during the restoration process. We also recommend that shrub planting pallets be viewed in GIS along with mapped shrub polygons to better distinguish between desirable and undesirable shrub species. Finally, we recommend that herbaceous polygons, generated by this study, be visited by field teams and that quantitative plant community collected. Using the community data and ancillary data (e.g., depth to ground water, soils information, etc.) from each site, empirical relationships between the plant community data and predictive environmental variables could be generated. This information would be useful in setting quantitative restoration benchmarks and identifying plant communities of interest within GIS.

The primary purpose of this document is to provide information on the methods and spatial accuracy of the imagery collected during this study, and to summarize the results of the land cover change that occurred in some areas along Whychus Creek since restoration. Lauren Mork (UDWC) provided background information on the Whychus Creek areas of interest, partnerships, and restoration actions.

Methods

EDC acquired and processed Unmanned Aerial Vehicle (UAV) imagery and completed a land cover change analysis. Lauren Mork (UDWC) provided background information on each of the restoration projects, guidance for defining and recognizing cover classes, and ensuring that products from this study met the Council's long-term research and monitoring objectives.

This study occurred in four phases: 1) mission planning, 2) image acquisition, 3) image classification, and 4) change detection. UAV surveys require substantial pre-flight planning including evaluation of airspace and land ownership requirements (to obtain permission to fly over private land). Flight missions for data collection are detailed below. In order to assess post-restoration vegetation change, we sought to acquire the most recent pre-project color imagery available from open-source datasets to compare to the imagery collected by UAV in 2017. We then compared classifications completed with consistent methodologies and calculated percent change in upland and riparian acreages between pre and post project imagery. Below we describe each of these phases in more detail.

Mission Planning

At the outset of this project, the UDWC provided an area of interest (AOI) GIS shapefile to EDC. This area originally covered approximately 823 acres (333 ha). The AOI was later (following image acquisition) expanded to cover a slightly larger footprint (~ 1,000 acres/408 ha) to maximize inclusion of valley-bottom, historic floodplain topography that could be re-activated through stream restoration. Thirty flight "missions" were planned based on the initial shapefile in order to acquire complete coverage of the AOI (Figures 1a and 1b). GPS start points (UAV launch locations) and site access points were established in the office prior to deploying to the field. Images were planned to be acquired within +/- 4 hours of solar noon to minimize shadows in heavily forested and steep canyon areas. We planned to acquire images under Visual Flight Rule Requirement weather minimums with wind speeds < 10-12 mph. Lighting and camera exposure settings were also considered and adjusted to produce high quality images. We planned to launch UAVs from the valley floor and fly at an altitude of 350 feet above the ground to achieve comparable pixel sizes among images and missions, and to avoid high terrain along some stream reaches. Each mission consisted of a series of flight lines arranged to provide 70% sidelap and 75% frontlap. Whenever possible, at least three adjacent flight lines were planned for each mission to ensure complete coverage of the area of interest (Figure 1a). In addition to overlap of adjacent images, we also planned for mission areas to overlap (Figure 1b). Finally, care was taken to ensure that homes were not flown over without landowner permission.

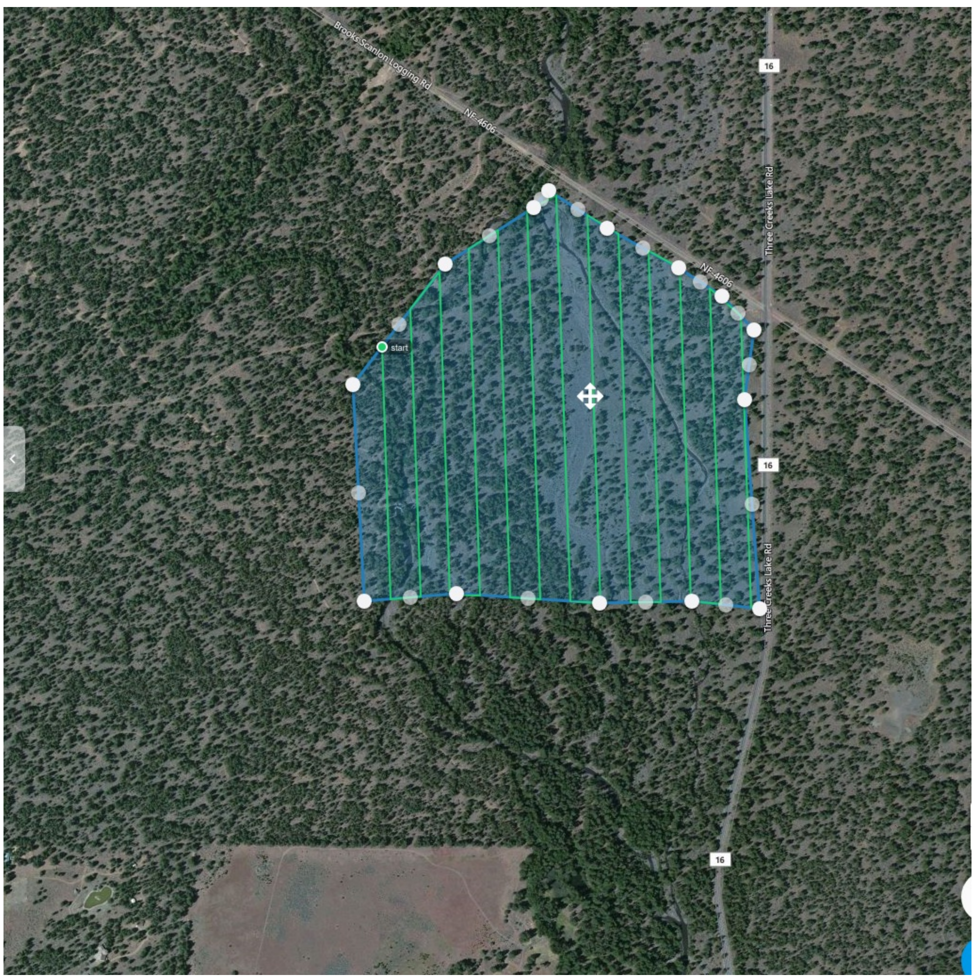

Figure 1a. Example of the arrangement of flight lines for a mission South of Sisters, OR. Green lines show the planned flight direction of the UAV.

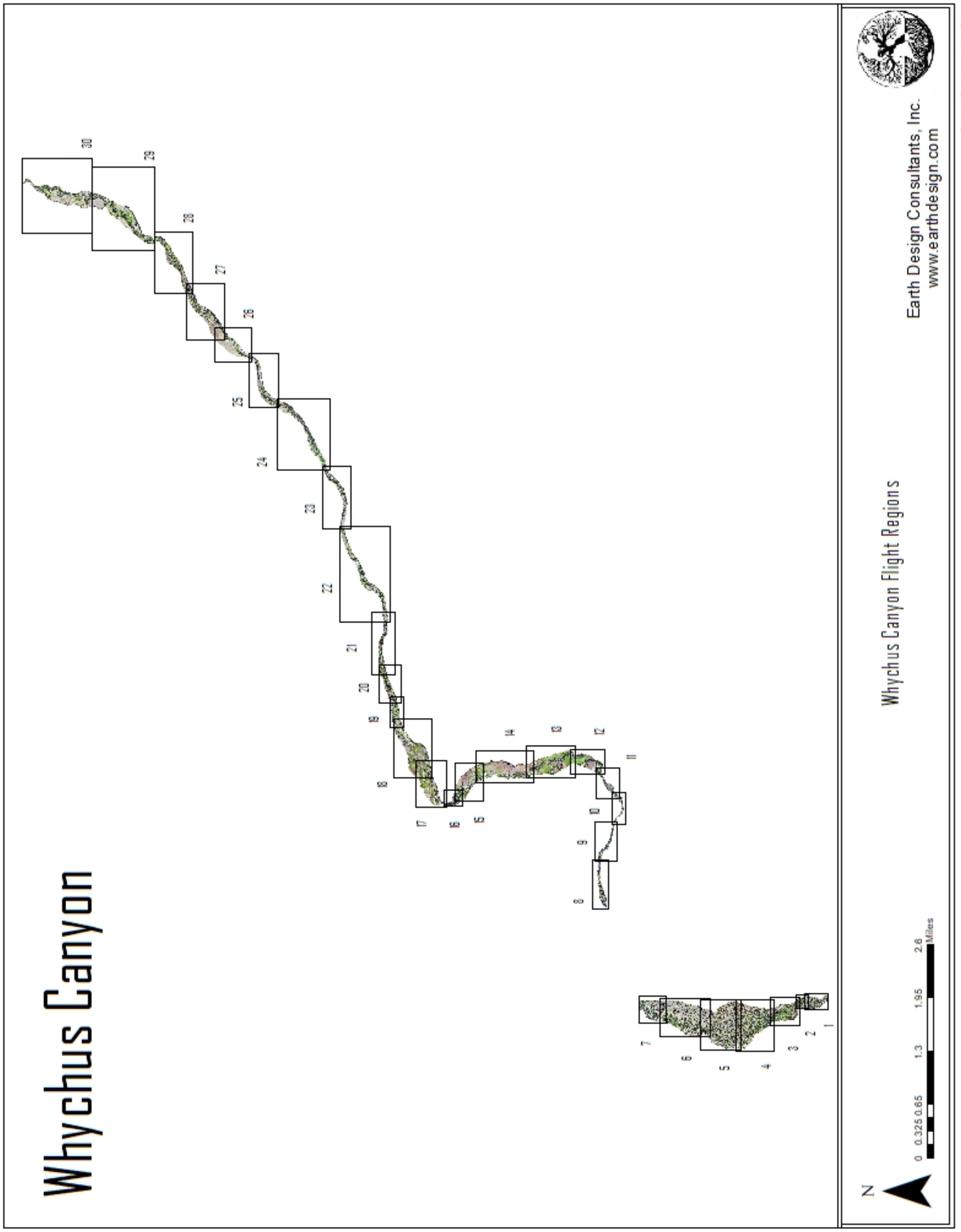

Figure 1b: Whychus Canyon and the 30 UAV flight mission planned by Earth Design Consultants, Inc. Area covered: ~1,000 acres.

Image Acquisition

2017 Image Acquisition

Two UAV crews, each consisting of an FAA Certificated Remote Pilot and Visual Observer, traveled to pre-determined launch sites on the valley floor to launch their UAV to complete each mission. UAV imagery was acquired for the area of interest between 17 -21 June 2017. Table 1 shows the dates, time, and crew for each mission.

Individual photos were mosaiced using two cloud-based imagery processing programs. Trade-offs of the two platforms (e.g., mosaic extent, mosaic quality, and cost-efficiency) were compared. Although there were differences, neither program was consistently better than the other. We selected the highest quality mosaic for classification and analysis.

Table 1: Mission characteristics of the Whychus Creek UAV flights. Shown are Mission Name, Latitude and Longitude of launch point, number of flight lines, date of acquisition, start and stop time, pilot and visual observer, UAV ID, and battery ID.

No.	Name	Lat	Long	No. Flight lines	Date Flown	Start Time	End Time	Pilot	VO	UAV ID	Bat ID
1	PMR-7L	44°15'10.43"N	121°32'59.86"W	3+	19-Jul-17	14:12	14:18	Garono	Staff	EDC-1	EDC-3B
2	PMR-6L	44°15'24.69"N	121°33'0.39"W	3+	18-Jul-17	11:32	11:43	Staff	Garono	EDC-1	EDC-1D
3	PMR-6X	44°15'24.69"N	121°33'0.39"W	3+	22-Jul-17	13:46	13:57	Garono	Staff	EDC-1	EDC-2C
4	PMR-1R	44°16'0.95"N	121°33'14.53"W	3+	18-Jul-17	12:15	12:39	Staff	Garono	EDC-1	EDC-1A
5	PMR-2R	44°16'16.02"N	121°33'13.81"W	3+	18-Jul-17	11:08	11:27	Bartlett	Gray	EDC-2	EDC-2C
6	PMR-4R	44°16'34.57"N	121°33'13.26"W	3+	18-Jul-17	12:34	12:50	Bartlett	Gray	EDC-2	EDC-2A
7	PMR-5R	44°16'45.74"N	121°32'58.84"W	3+	18-Jul-17	13:42	13:57	Bartlett	Gray	EDC-2	EDC-3A
8	CP-11L	44°17'22.88"N	121°32'1.62"W	2+	18-Jul-17	15:24	15:30	Staff	Garono	EDC-1	EDC-3B
9	CP-10L	44°17'18.97"N	121°31'9.11"W	3+	18-Jul-17	15:56	16:02	Garono	Staff	EDC-1	EDC-3B
10	CP10MME	44°17'18.97"N	121°31'9.11"W	3+	22-Jul-17	15:66	16:12	Garono	Staff	EDC-1	EDC-3B
11	CP-9LX	44°17'28.35"N	121°30'36.18"W	2	20-Jul-17	14:21	14:25	Garono	Staff	EDC-1	EDC-1B
12	CP-8LR	44°17'29.49"N	121°30'31.53"W	2+	20-Jul-17	14:12	14:19	Garono	Staff	EDC-1	EDC-2C
13	CP-7L	44°18'9.18"N	121°30'34.76"W	3	20-Jul-17	14:43	14:50	Garono	Staff	EDC-1	EDC-1B
14	CP-6L	44°18'37.89"N	121°30'32.56"W	3+	21-Jul-17	11:52	12:03	Garono	Staff	EDC-1	EDC-3A
15	CP-5L	44°18'54.45"N	121°30'49.88"W	3+	21-Jul-17	11:29	11:35	Garono	Gray	EDC-1	EDC-2C
16	CP-4MME	44°19'2.58"N	121°30'57.06"W	3	21-Jul-17	10:35	10:37	Garono	Gray	EDC-1	EDC-3C
17	CP-3R	44°19'16.58"N	121°30'51.94"W	3+	17-Jul-17	12:20	12:37	Bartlett	Staff	EDC-1	EDC-1A
18	CP-2R	44°19'30.36"N	121°30'18.70"W	3+	17-Jul-17	10:39	10:45	Bartlett	Staff	EDC-1	EDC-1C
19	CP-1MME	44°19'38.42"N	121°29'54.83"W	3+	17-Jul-17	11:21	11:37	Staff	Bartlett	EDC-1	EDC-1D
20	WC-9L	44°19'43.21"N	121°29'43.62"W	3	21-Jul-17	10:01	10:07	Garono	Gray	EDC-1	EDC-3C
21	WC-8L	44°19'45.35"N	121°28'47.22"W	3	21-Jul-17	9:53	10:04	Garono	Staff	EDC-1	EDC-1B
22	WC-7L	44°20'2.90"N	121°28'22.94"W	3+	21-Jul-17	11:01	11:05	Bartlett	Staff	EDC-2	EDC-1B
23	WC-6L	44°20'13.87"N	121°27'40.64"W	3+	21-Jul-17	10:00	10:15	Bartlett	Staff	EDC-2	EDC-1C

No.	Name	Lat	Long	No. Flight lines	Date Flown	Start Time	End Time	Pilot	VO	UAV ID	Bat ID
24	WC-5L	44°20'48.53"N	121°26'42.58"W	3+	22-Jul-17	--	--	Garono	Staff	--	--
25	WC-4L	44°21'4.80"N	121°26'21.01"W	3+	19-Jul-17	10:48	10:56	Staff	Garono	EDC-1	EDC-1B
26	WC-3L	44°21'23.57"N	121°26'1.82"W	3+	19-Jul-17	11:39	11:47	Bartlett	Gray	EDC-2	EDC-2A
27	WC-2L	44°21'38.09"N	121°25'43.75"W	3+	19-Jul-17	10:06	10:15	Bartlett	Gray	EDC-2	EDC-1D
28	WC-1L	44°21'52.48"N	121°25'23.70"W	3	19-Jul-17	10:49	10:57	Bartlett	Gray	EDC-2	EDC-2C
29	WC-UPALR	44°22'29.31"N	121°24'54.95"W	3+	20-Jul-17	10:40	10:57	Bartlett	Gray	EDC-2	EDC-1A
30	WC-UPBL	44°23'7.22"N	121°24'36.80"W	3+	20-Jul-17	11:56	12:09	Bartlett	Gray	EDC-2	EDC-3A

Table 2 shows the approximate number of acres covered by each mission and the spatial error.

Table 2: Mission characteristics of the Whychus Creek UAV flights. Shown are Mission Name, the approximate number of acres of each mission, the number of aerial photographs, the initial resolution (inches per pixel) and the spatial error in feet for X, Y, Z axes, and the initial overall Root Mean Square Error in feet.

No.	Name	Acres	No. Photos	Res (in/px)	X (Ft)	Y (Ft)	Z (ft)	RMSE (Ft)
1	PMR-7L	37.2	111	1.7	3.1	11.4	8.4	14.5
2	PMR-6L	64.1	137	1.6	4.3	14.4	8.5	17.3
3	PMR-6X	49	133	1.7	4.8	14.4	7.7	17
4	PMR-1R	151	348	1.5	5.6	15.2	21	26.5
5	PMR-2R	161	405	1.5	5.3	15.2	16.9	23.3
6	PMR-4R	164	328	1.7	6.9	15.4	25.4	30.5
7	PMR-5R	141	330	1.7	4.7	15.5	23.8	28.8
8	CP-11L	38	85	1.8	11.8	3.5	11.4	16.8
9	CP-10L	130	145	1.7	10.7	3.3	8.5	14.1
10	CP-10MME	130	145	1.7	10.7	3.3	8.5	14.1
11	CP-9LX	44.3	53	1.7	9	8.6	6.3	14
12	CP-8LR	55.7	96	1.8	4.8	12.2	11.8	17.6
13	CP-7L	86.3	116	1.7	6.5	16.2	17.9	25
14	CP-6LMME	80.8	196	1.9	3	18.3	10	21.1
15	CP-5LMME	49.8	93	1.7	9.2	10.1	6.3	15.1
16	CP-4L	13.3	58	1.7	5.3	12	3.3	13.6
17	CP-3R	208	412	1.7	16.8	3.8	18	24.9
18	CP-2R	75.3	125	1.6	12.6	13.9	11.4	21.9
19	CP-1	156	255	1.6	12.6	13.7	11.4	21.9
20	WC-9LR	91.9	313	1.6	14.9	6.1	7	17.6
21	WC-8L	64.2	163	1.5	15.9	2.7	6.5	17.4
22	WC-7LR	389	265	2.7	12.7	13.2	9.1	20.5
23	WC-6L	240	289	2.6	14.6	4.7	3.2	15.7
24	WC-5LRa	254	117	1.8	12.9	11.8	6.4	18.6
25	WC-4L	112	143	1.6	15.4	5.9	2.1	16.6

No.	Name	Acres	No. Photos	Res (in/px)	X (Ft)	Y (Ft)	Z (ft)	RMSE (Ft)
26	WC-3	114	165	1.6	9.1	11.8	10.1	18
27	WC-2	157	146	1.6	8.9	9.7	7.7	15.2
28	WC--1	185	120	1.6	9	7.5	6.8	13.5
29	WC-UPALR	310	364	1.5	9.2	14.7	18.9	25.7
30	WC-UPBL	197	236	2.4	3.8	16	15.9	22.9

Historic Imagery Acquisition

To analyze the change in the number of acres and type (cover class) of riparian vegetation due to stream restoration, which had been implemented prior to UAV image acquisition in 2017, we completed a cover-class comparison for four sites within the initial area of interest. The four sites were the Three Sisters Irrigation District (TSID), Camp Polk, Whychus Floodplain, and Whychus Canyon Reach 4; restoration project implementation was completed in 2010, 2012, 2014, and 2016, respectively. The four sites were delineated as GIS shapefiles and provided to EDC by UDWC. Table 3 shows the river mile, land ownership, date that each restoration project began (the cut-off date for pre-project imagery), the most recent known pre-project aerial color imagery available, imagery resolution, and where the imagery can be located online. Imagery was selected based on availability and image quality. Available imagery was compiled and sent to UDWC for the final determination on whether it was suitable for the change analysis (i.e., the historic images used for comparison).

Table 3: Aerial imagery data sources for comparison of stream channel and floodplain restoration project change analysis. Restoration projects were completed on Whychus Creek prior to July 2017.

River Mile	Description	Land owner status	Cut-off date for pre-project imagery	Imagery selected for pre-project analysis	Year of Imagery used	Imagery resolution	Imagery location
10.25 – 11	Whychus Canyon Reach 4	Owned by DLT	Reach 4 implementation broke ground August 2016	Real Geographics (J. Healy) July 2016 imagery	**2016**	Average Ground Sampling Distance (GSD) 2.78 cm / 1.09 in	UDWC server
15.8 – 17.2	Camp Polk	Owned by DLT	Project broke ground May 2008	2006 NAIP, Valtus, or other pre-2009 aerial imagery (2006 NAIP is latest pre-project available)	**2005**	NAIP: NAIP imagery is acquired at a one-meter ground sample distance (GSD) with a horizontal accuracy that matches within six meters of photo-identifiable	https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/ https://www.valtus.com/valtus-web-store/index.do

<table>
<tr><th>River Mile</th><th>Description</th><th>Land owner status</th><th>Cut-off date for pre-project imagery</th><th>Imagery selected for pre-project analysis</th><th>Year of Imagery used</th><th>Imagery resolution</th><th>Imagery location</th></tr>
<tr><td>23 – 24.5</td><td>Whychus Floodplain</td><td>USFS</td><td>Project broke ground between April and August 2014</td><td>2012 NAIP, Valtus, or other pre-2014 aerial imagery</td><td>2014</td><td rowspan="2">ground control points, which are used during image inspection.

Valtus: All NAIP imagery is collected at 30 cm resolution and resampled to 1 m resolution prior to delivery to the USDA. A company called Valtus is now selling the 30 cm resolution imagery.</td><td>https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

https://www.valtus.com/valtus-web-store/index.do</td></tr>
<tr><td>25 – 25.2</td><td>TSID</td><td>USFS; TSID infrastructure</td><td>Project broke ground September 2010</td><td>2009 NAIP, Valtus, or other pre-2010 aerial imagery</td><td>2009</td><td>https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

https://www.valtus.com/valtus-web-store/index.do</td></tr>
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Image Classification

The primary goal of the image classification process for this project was to identify riparian vegetation, represented by herbaceous, shrub, and forested cover classes in the low-gradient, historically depositional reaches along Whychus Creek where UDWC and partners plan to implement or have implemented restoration projects to restore stream habitat and reactivate adjacent floodplain. These cover classes were defined by UDWC and are described below. The distinction between riparian and upland cover classes is defined in this report as vegetation that is presumed to be hydrologically connected to Whychus Creek. This was based on proximity to the stream channel, first-hand knowledge of the site and/or other attributes visible in the imagery (e.g., greenness); irrigated regions are identified in the “notes” section of the GIS attribute tables.

Vegetation and additional cover classes, defined through a series of conversations and meetings with UDWC, were digitized manually using photo interpretation (a heads-up approach; see information on process below). The decision to use photo interpretation and heads-up digitization, rather than an unsupervised or semi-supervised classification using spectral information contained in the imagery, was based on best judgment of how to present the most ecologically useful information following our discussions with UDWC. All vegetative classifications were rule-based (described below) and were completed by a single individual to minimize representational bias and maximize consistency.

Classification review and edits were also made by a single individual employed by UDWC. Additional quality control and assurance by one person at a time is recommended.

Classification Methods

We cataloged and then clipped mosaiced images from the 30 flight missions to the floodplain shapefile provided by UDWC. Each of the 30 flight missions were classified independently of one another using consistent methods to avoid adjusting for time and weather conditions that vary between missions.

We performed an initial unsupervised classification in ArcGIS to determine if this automated approach provided spectrally distinct cover classes within the Whychus Canyon landscape. Unsupervised classifications consider both the variances and covariances of class signatures when assigning each cell to one of the classes represented a signature file. With the assumption that the distribution of a class sample is normal, the statistical probability is computed for each class to determine the membership of the cells to the class. Simply, each cell is assigned to the class to which it has the highest probability of being a member. Results showed that the unsupervised classification could successfully distinguish bare earth from vegetated areas but could not be used to distinguish between vegetative cover classes of interest to UDWC; for example, the unsupervised classification could distinguish individual trees but could not assign them and the space between them collectively as “coniferous sparse forest.” This was not unexpected considering the high spatial resolution of the imagery. In order to more accurately capture the vegetation cover classes UDWC identified, we performed a semi-supervised classification, which used both pixel adjustments and resampling techniques in ArcGIS. As before, we found that this method also required significant manual editing. Therefore, in consultation with UDWC, we decided to use traditional photo interpretation and heads-up digitization to manually delineate cover class polygons.

We created a shapefile by generating polygons manually via the “create feature” tool in ArcGIS. We presented a draft set of cover classes to UDWC and ultimately established the final set of cover classes (Table 4) (described below), along with straightforward rules to distinguish between adjacent polygons/cover types.

Table 4: Final hierarchical cover classes established by EDC and UDWC. Each polygon is attributed with a location, and geotype and a cover class (described in the text).

LOCATION	GEOTYPE	COVER CLASS
In-stream	Vegetation	Bare Earth
Riparian	Bare Substrate	Sand
Upland	Other	Rock
		Gravel
		Cobble
		Herbaceous
		Herbaceous-Isolated trees or shrubs
		Mixed Herbaceous Forest
		Shrub
		Mixed Forest
		Coniferous Sparse Forest
		Deciduous Sparse Forest
		Deciduous Forest

LOCATION	GEOTYPE	COVER CLASS
		Coniferous Forest
		Impervious Surface
		Building
		Unpaved Road
		Paved Road

We created database domains for the attribute table with the established cover classes (outlined below) in order to provide consistency and easy editing for future use. To draw polygons, we evaluated imagery at a scale between 1:200 and 1:600 to see both fine scale features and visualize the larger ecologically driven qualities of a feature (i.e., hydrologically connected as indicated by vegetation greenness).

Post-polygon creation, the first edits were done using a topology layer in ArcCatalog. This layer isolates errors based on rules the map-creator choses. In this case, we isolated gaps and overlaps between polygons and corrected the errors found.

The completed classification layer was then passed to UDWC for review and editing. Edits were recorded in multiple documents and sent back to EDC for the final editing of the classification layer. Edits included both simple attribute changes (i.e., "Polygon FID180: change from upland to riparian"), as well as alterations in the shape and size of polygons. These changes were made using the "Edit Feature" tool in ArcMap.

At the request of the UDWC, we created two separate geodatabases, one for the 2017 and historic (pre-2017) classifications, and one for the change analysis, to contain copies of classification layers in three different coordinate systems: **World Geodetic System 1984 (WGS84)** as the geographic coordinate system that is compatible with most GPS units, and two projected coordinate systems—**North American Datum (NAD83) and Universal Transverse Mercator Zone 10 (UTMZn10)**. Area calculations were done in NAD83 due to its preservation of shape as a projected surface.

Pre-restoration Classification and Comparison

To support a change analysis of riparian vegetation and other cover classes as desired at Whychus Creek restoration sites where projects were implemented prior to 2017, we developed a series of cover class polygons from available historical aerial photographs (Table 3). Restoration projects implemented prior to 2017 included Camp Polk, Whychus Floodplain, TSID, and Whychus Canyon Reach 4 (referred to here on out as Whychus Canyon).

Each of these restoration projects broke ground at different times, therefore the criteria for selecting the historic imagery for comparison to the 2017 imagery was based on collection dates being prior to the start of the restoration project, imagery of appropriate season, and image quality (e.g., spatial resolution, and degree of obscuration due to clouds and/or shadowing).

Camp Polk Meadow Preserve is owned by Deschutes Land Trust (DLT). UDWC and DLT partnered with USFS to design and implement a stream restoration project at the Preserve that included reconstruction of a sinuous, C-type meadow channel with connected side channels. Restoration work at Camp Polk broke ground in 2008 with project implementation completed in 2012. It included channel construction and multiple vegetation planting phases. Pre-restoration aerial imagery of Camp Polk was acquired from 2005 to be used as a comparison to the 2017 imagery classification in this report (Table 3).

Whychus Floodplain is on Deschutes National Forest land south of the City of Sisters and adjacent to private land with senior water rights. The Whychus Floodplain project included removal of a diversion dam and re-location of the point of diversion onto the property to which the water rights are appurtenant, and, as a result, created an opportunity to restore the stream to relic channels across the historic alluvial floodplain. Logjams were constructed and pools dug to create floodplain roughness and desired habitat. Following diversion of the stream into relic channels, the project was planted with desired native riparian species. Pre-restoration aerial imagery of Whychus Floodplain was acquired from 2014 to be used as a comparison to the 2017 imagery classification in this report. Imagery was also located for 2012 but it was of lower image quality (Table 3).

The **Three Sisters Irrigation District** (TSID) diversion is a major irrigation diversion on Whychus Creek. In 2010, construction began on a project to create a roughened riffle and low-flow channel that would provide fish passage by raising the stream bed to the lip of the concrete diversion dam. The roughened riffle filled the incised channel along approximately 1000 ft downstream of the dam, re-establishing floodplain connectivity. A diverse palette of native riparian species was planted along the stream and in areas where hydrologic connectivity was anticipated to be sufficient to support them. Pre-restoration aerial imagery of the TSID project was acquired from 2009 to be used as a comparison to the 2017 imagery classification in this report (Table 3).

Whychus Canyon Reach 4 represents approximately one mile of the DLT's six-mile Whychus Canyon Preserve. Restoration outcomes from Camp Polk and Whychus Floodplain informed a new restoration approach at Whychus Canyon Reach 4 designed to re-activate the floodplain and relic channels by cutting surfaces higher than, and filling areas lower than, the historic floodplain elevation, adding wood to provide floodplain roughness, and diverting the stream onto the new floodplain surface. This project was implemented in 2016 and planted with desired native riparian species in multiple phases post-implementation. Pre-restoration aerial imagery of Whychus Canyon was acquired from 2016 to be used as a comparison to the 2017 imagery classification in this report. Imagery was also acquired from 2014, but the image quality was poor, and areas covered by shadows were significant (Table 3).

Imagery collected for the restoration sites and the UAV imagery acquired in 2017 by EDC were all clipped to the same area. This permitted a direct comparison of the two image data sets.

A pre-project wetland delineation shapefile was also provided by UDWC. This shapefile was used in the final comparisons and edits in this region.

The pre-restoration classification was performed following the same methods used for the 2017 cover classification. As before, area calculations were made in ArcMap using the NAD83 geographic coordinate system.

The comparison between the historic imagery and the 2017 imagery was made by isolating the riparian polygons classified from both imagery datasets and generating simple statistics in ArcGIS to sum all riparian acreage present. Change in the area of each cover class was calculated in two ways, as discussed with UDWC: 1) as the difference in total acres of riparian vegetation cover pre-project and post-project, and 2) as the number of vegetation acres classified from 2017 imagery as "riparian" that had been classified from the historic imagery as "upland".

Geodatabase

DATABASE DEFINITIONS

The first geodatabase contains three Feature Datasets that display the same feature classes in each of the aforementioned coordinate systems requested by UDWC. Each Feature Dataset contains replicates of two layers—the Final 2017 Classification, and the Classification of Pre-restoration Sites. Each layer needs to be edited independently; they are not linked to each other.

Geodatabase Title: "WC_Full_Classification.mbd"			
	GCS_WGS_1984	***NAD83***	**UTMZn10**
Feature Class 1	"WC1_2017Final_Edits_GCS_WGS_1984"	"WC1_2017Final_Edits_NAD83"	"WC1_2017Final_Edits_UTMZn10"
Feature Class 2	"WC2_HistoricClassification_WithEdits_GCS_WGS_1984"	"WC2_HistoricClassification_WithEdits_NAD83"	"WC2_HistoricClassification_WithEdits_UTMZn10"

The second geodatabase again contains three Feature Datasets that display the same feature classes in each of the aforementioned coordinate systems requested by UDWC. Each Feature Dataset contains replicates of *three* layers: a clipped version of the 2017 classification (from the above geodatabase) and a clipped version of the historic classification (from the above geodatabase), as well as a layer displaying the change from upland to riparian based on the two clipped layers provided. The layers were clipped to the area coverage of the smaller extent of the two imagery datasets for analysis. The "Full_WasUpland_NowRiparian" feature class is the layer in which the change analysis statistics were run.

Geodatabase Title: "WC_ChangeAnalysis.mbd"			
	GCS_WGS_1984	***NAD83***	**UTMZn10**
Feature Class 1	"Full_WasUplad_NowRiparian_WGS_1984"	"Full_WasUplad_NowRiparian_NAD83"	"Full_WasUplad_NowRiparian_UTMZn10"
Feature Class 2	"WC2017_Change_WGS_1984_Clipped"	"WC2017_Change_NAD83_Clipped"	"WC2017_Change_WGS_1984_UTMZn10"
Feature Class 3	"WCHistoric_Change_WGS_1984_Clipped"	"WCHistoric_Change_NAD83_Clipped"	"WCHistoric_Change_WGS_1984_UTMZn10"

ATTRIBUTES

Both classification layers contain the same attribute tables. As mentioned above, we set up the classification attributes so that domains (i.e., drop-down menus) display when a layer is being edited in ArcGIS. Below we outline the contents of the attribute table (Table 5).

In consultation with UDWC, we attributed cover class polygons with three descriptors, *"Location", "Geotype",* and *"Cover Class"* (Table 4). A cover class hierarchy was established in order to provide the most flexibly and versatility in the dataset. The following categories offer different levels of detail and scale to the classification scheme. "Location" is used as a proxy for evaluating the amount of riparian coverage throughout the study area. This is a large-scale class that can quickly distinguish the presence of riparian and upland coverage. "GeoType" is a high-level cover class scheme to further distinguish between vegetative and non-vegetative cover classes within the riparian or upland classification. "Cover Class" most finely defines the primary surface coverage of each delineated polygon. A subset of the attribute table is displayed in Table 5. The table includes the flight code established by EDC (Tables 1 & 2); the cover class categories described above; the area and perimeter of each polygon (in acres and meters); and a "notes" column that identifies the restoration site the polygon exists in, if applicable.

Table 5: An example of the attribute table. The table includes an object identifier, flight codes established by Earth Design Consultants, Inc., Location, GeoType, Cover Class (described in text), the area and perimeter of each polygon (in acres), and a "notes" column that identifies the restoration site the polygon exists in, if applicable.

OBJECTID	Flight	GeoType	CoverClass	Location	Area (acres)	Perimeter (meters)	Notes
1	22-WC7L	Vegetation	Shrub	Upland	1.0207323	294.7249895	NULL
2	24-WC5L	Vegetation	Coniferous Sparse Forest	Upland	0.463368429	236.8828819	NULL
3	30-WCUPBL	Vegetation	Mixed Forest	Riparian	0.760328285	526.777692	NULL
4	17-CP3R	Vegetation	Herbaceous	Riparian	0.000173102	3.5374998	Restoration Site: Camp Polk
5	18-CP2R	Vegetation	Shrub	Riparian	0.001001049	7.633723679	Restoration Site: Camp Polk
6	18-CP2R	Bare Substrate	Sand	Riparian	0.000407019	6.21393698	Restoration Site: Camp Polk
7	18-CP2R	Vegetation	Herbaceous	Riparian	0.001713294	12.99342399	Restoration Site: Camp Polk
8	18-CP2R	Bare Substrate	Rock	Riparian	0.001224939	11.91916336	Restoration Site: Camp Polk
9	18-CP2R	Vegetation	Shrub	Riparian	0.000653192	6.680534753	Restoration Site: Camp Polk
10	18-CP2R	Vegetation	Herbaceous	Riparian	0.000252972	5.159188277	Restoration Site: Camp Polk

LOCATION:

In-stream: Any polygon depicting a piece of land that is fully surrounded by water. These areas may be split by multiple classes within the island features. All pieces within the island will be labeled as "In-stream." This cover class will also include bridges and fallen wood debris that exist within the water layer boundary.

Riparian: For the purpose of this analysis we defined riparian vegetation as vegetation, near or adjacent to Whychus Creek, that was likely to be a hydrophytic (facultative, facultative wetland, or obligate wetland) species. Polygons were classified as Riparian on a case-by-case basis as determined by the following criteria:

- Whether the area was touching or was in the immediate vicinity of water;
- Whether the majority of the area was characterized by "greenness," inferred to indicate lush vegetation that was retaining moisture;
- Whether the area was effectively riparian (i.e., supporting primarily riparian species, for ecological evaluations).

Editing sessions and discussion with UDWC led to additional rules about classifying polygons as riparian. Primarily, it was determined that green and lush vegetation holds precedent over distance from the stream when classifying a polygon as riparian. This decision was made because the ultimate goal of this project was to identify areas that are hydrologically connected and supporting riparian plant species, irrespective of the polygon's vicinity to water.

Upland: Polygons classified as Upland were determined on a case-by-case basis with the following considerations:

- Whether the area was distant from/ not adjacent to a previously determined riparian zone
- Whether the area was visually inferred to be dry and lacking in substantial moisture
- Whether the area extended significantly upland of the floodplain without a change in vegetative characteristics.

GEOTYPE:

Vegetation: Polygons classified as Vegetation were determined by any vegetative cover class; incorporating dry and drying vegetation in some instances. This includes the following: Shrub, Herbaceous, Herbaceous-Isolated trees or shrubs, Deciduous Forest, Coniferous Forest, Mixed Forest, Mixed Herbaceous Forest, and Deciduous Sparse Forest.

Bare Substrate: Polygons classified as Bare Substrate were determined by naturally occurring, non-vegetative surfaces. This includes the following: Bare Earth, Rock, Sand, Gravel and Cobble.

Other: Polygons classified as Other were determined by man-made surfaces or non-primary cover classes that obstructed the view of the primary cover class. This includes the following: Impervious Surface, Wood, Building, Unpaved Road, and Paved Road.

COVER CLASS:

Bare Earth: Polygons classified as Bare Earth were considered areas with no other surface coverage. Areas may occur in gaps between vegetative cover classes or in relation to high-traffic areas. Bare Earth mostly occurs in burnt or balding patches in sparsely shaded regions throughout the study site.

Sand: Polygons classified as Sand were considered areas of fine or smooth bare substrate that lacks any rocks or structural definition. This class could also be considered wet bare earth in some cases. This class includes silt and mud.

Rock: Polygons classified as Rock were defined by rocks along the riverbank and were most frequently only identified when clusters of three or more rocks of ~1m or larger in diameter appeared together.

"In-stream" rocks were isolated individually and single rocks (or boulders) were identified when they were ecologically relevant (diverting water or influencing vegetation growth/expansion).

Gravel: Polygons classified as Gravel were generally areas of Bare Substrate with a rocky surface, but without rocks larger than 40cm.

Cobble: Polygons classified as Cobble were areas of Bare Substrate with a rocky surface containing rocks larger than gravel but smaller than boulders (~40cm-1m).

Herbaceous: Polygons classified as Herbaceous were areas with any amount of vegetation on them. Grasses are included in this cover class, as well as short, dry patchy grasses. This also includes areas that may be qualified as "Bare Earth," but do have small amounts of grass visible.

Herbaceous-Isolated trees or shrubs: Polygons classified as Herbaceous-Isolated trees or shrubs were areas with low vegetation density, but contain grasses, isolated shrubs and/or trees dispersed throughout them.

Mixed Herbaceous Forest: Polygons classified as Mixed Herbaceous Forest were areas with a dense variety of grasses, small shrubs and/or young trees. In this class we also consider mixed herbaceous vegetation with few and/or young trees that are not yet dense enough to be considered for the other forested cover classes.

Shrub: Polygons classified as Shrub can be of two types, riparian and xeric. Generally riparian shrubs are dense and along the water line and categorized as "Riparian" by the *Location* classification; xeric shrubs are usually categorized by the "Upland" classification but are also dispersed and more isolated by nature—causing them to also exist in the "Coniferous Sparse Forest" classification. Xeric shrub patches are isolated independently when they are distinct from the surrounding forest.

Mixed Forest: Polygons classified as Mixed Forest were dense forested areas with a complete canopy cover. These are areas where the primary substrate is not visible due to forest density. It is assumed, at this stage, that all dense canopy forests are mixed forest composed of both coniferous and deciduous species unless reclassified by a Watershed Council employee based on personal knowledge.

Coniferous Sparse Forest: Polygons classified as Coniferous Spare Forest were forested areas that do not have a dense canopy cover, but where the trees are within 4-10m of each other. Some area of "Coniferous Sparse Forest" may be interchangeable with "Herbaceous-Isolated Trees or Shrubs".

Deciduous Sparse Forest: Deciduous Sparse Forest polygons were only identified by a Watershed Council employee based on personal knowledge and classified as such through the editing process.

Deciduous Forest: Deciduous Forest polygons were only identified by a Watershed Council employee based on personal knowledge and classified as such through the editing process.

Coniferous Forest: Coniferous Forest polygons were only identified by a Watershed Council employee based on personal knowledge and classified as such through the editing process.

Impervious Surface: Polygons classified as Impervious Surface include man-made structures that are fixed to one location for extended periods of time. Cars and construction equipment were not included in this classification and primary substrate was inferred by the surrounding attributes.

Building: Polygons classified as Building were presumably fixed structures. Houses, sheds, and barns are included in this class.

Unpaved Road: Polygons classified as Unpaved Road were strips of land that could potentially become vegetative surfaces but are clearly used frequently or have been heavily used in the past. Roads, turnouts, trails and paths are included in this class.

Paved Road: Polygons classified as Paved Road are also an impervious surface but are defined by the implication that the area is a highly used access point or thoroughfare.

Change Detection

For the purpose of evaluating riparian vegetation cover, vegetation polygons associated with in-stream features are included as riparian vegetation in analyses. The change in riparian coverage is compared in two ways: first, as total riparian coverage as of the pre-project imagery *vs*. the total riparian coverage of the 2017 imagery and the corresponding percent change for all four restoration sites as well as the total coverage for all sites combined (based on their respective pre-project start dates) (Table 5 & 6); and second, as the change from pre-project upland coverage to 2017 riparian coverage for all four restoration sites as well as the total coverage for all sites combined (again, based on their respective pre-project start dates) (Table 7). The change from upland to riparian vegetation gives us a more complete understanding of the change in hydrological connectivity with which post-project riparian vegetation is associated, rather than simply a change in riparian coverage with no known explanation.

Results

The 2017 image classification showed that out of about 1,000 acres, 321.7 acres are classified as riparian, 573.6 acres are upland, 13.9 acres are in-stream features and 61.3 acres are water.

Camp Polk was found to have 23.3 acres of riparian coverage in 2005 and 70.1 acres of riparian coverage in 2017. This is a 201.5% increase in riparian coverage since the onset of restoration efforts. Whychus Floodplain had 7.2 acres of riparian coverage in 2014 and was found to have 22.2 acres of riparian coverage in 2017—a 109.9% increase in those three years. TSID went from 1.1 acres of riparian coverage in 2009 to 5.4 acres of riparian coverage in 2017. This was a 379.6% increase in eight years. Whychus Canyon, with only a one-year gap between imagery datasets, went from 23.6 acres of riparian coverage to 34.9 acres of riparian coverage, creating a 47.9% increase in riparian coverage at that site.

Table 6: Total riparian coverage as of the pre-project imagery vs*. the total riparian coverage of the 2017 imagery and the corresponding percent change for all four restoration sites.*

Site	Time	Pre-project Riparian Coverage (acres)	2017 Riparian Coverage (acres)	Percent Change in Riparian Coverage
Camp Polk	2005-2017	23.2	70.1	201.5%
Whychus Floodplain	2014-2017	7.2	22.2	109.9%
TSID	2009-2017	1.1	5.4	379.6%
Whychus Canyon	2016-2017	23.6	34.9	47.9%

The total pre-restoration riparian coverage was 54.5 acres. The total riparian coverage in 2017 (all four restoration sites) was 122.0 acres. This is an increase of 67.5 acres and a 55.3% increase in riparian coverage for total current restoration efforts in these for sites.

Table 7: Total riparian coverage as of the pre-project imagery vs. the total riparian coverage of the 2017 imagery and the corresponding percent change for all sites combined (based off of their respective pre-project start dates)

Total Pre-project Riparian Coverage (acres)	Total 2017 Riparian Coverage (acres)	Change in Riparian Coverage from pre-project to 2017 (acres)	Total Percent Change
54.5	122.0	67.5	55.3% increase

The change from upland to riparian provides the percent of post-project, 2017 riparian coverage that was classified as upland coverage pre-project (Table 7). From 2005 to 2017, 47.6 acres classified as upland at Camp Polk from 2005 imagery were converted to riparian coverage. This is 68% of the 70.1 acres of 2017 riparian coverage (Figures 2,3 & 4), suggesting that almost all of the riparian vegetation at Camp Polk, classified as such from 2017 imagery, was upland vegetation pre-project. Ten acres (11.6 acres) classified as upland vegetation at Whychus Floodplain pre-project were converted to riparian coverage between 2014 and 2017. This acreage constitutes approximately 52% of the 22.2 acres of 2017 riparian coverage (Figure 5). The TSID project was found to have 4.4 acres of riparian vegetation in 2017 that was classified as upland from pre-project, 2009 imagery; accounting for 81% of the 5.4 acres identified as riparian in 2017 (Figure 6). Lastly, 11.8 acres classified as upland vegetation from 2016, pre-project imagery was converted to riparian vegetation between 2016 and 2017, representing 34% of the 34.9 acres of 2017 riparian coverage (Figures 7 & 8).

The total change from Upland to Riparian for all Restoration sites combined was 75.4 acres. This is 62% of the 2017 riparian coverage total of 122.0 acres.

Table 8: The change from pre-project upland coverage to 2017 riparian coverage for all four restoration sites as well as the total coverage for all sites combined (based off of their respective pre-project start dates).

Site	Time	Change from Upland to Riparian (acres)	2017 riparian coverage (acres)	Percent of current riparian coverage that used to be upland
Camp Polk	2005-2017	47.6	70.1	68.0%
Whychus Floodplain	2014-2017	11.6	22.2	52.0%
TSID	2009-2017	4.4	5.4	81.2%
Whychus Canyon	2016-2017	11.8	34.9	33.7%
All four sites combined	Respective pre-Project Dates	75.3	122.0	61.8%

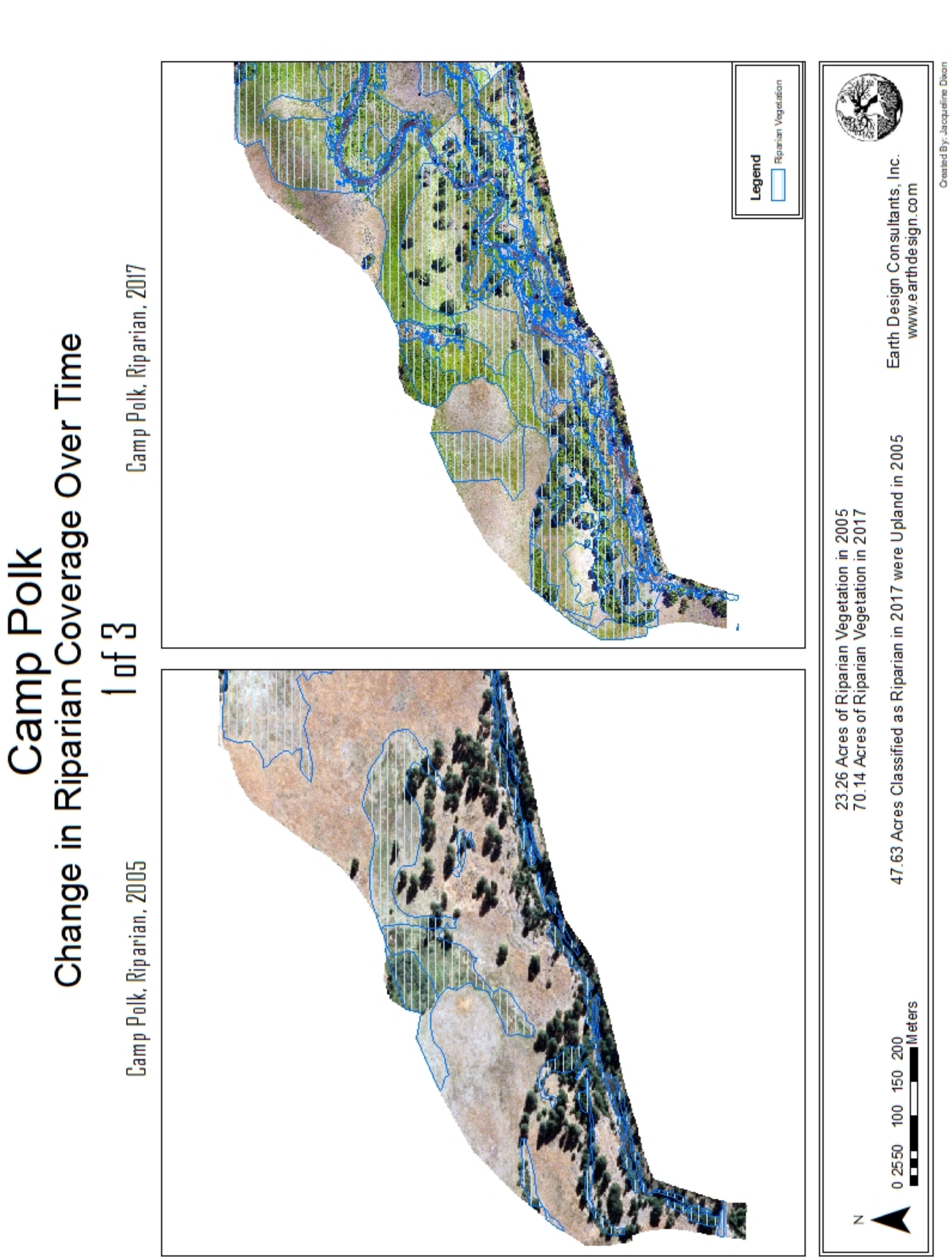

Figure 2: Camp Polk change in riparian coverage over time. Camp Polk was found to have 23.3 acres of riparian coverage in 2005 and 70.1 acres of riparian coverage in 2017. This is a 201.5% increase in riparian coverage since the onset of restoration effort. In 2005, Camp Polk converted 47.6 acres of upland coverage to riparian coverage. This is about 68% of the 70.1 acres of 2017 riparian coverage.

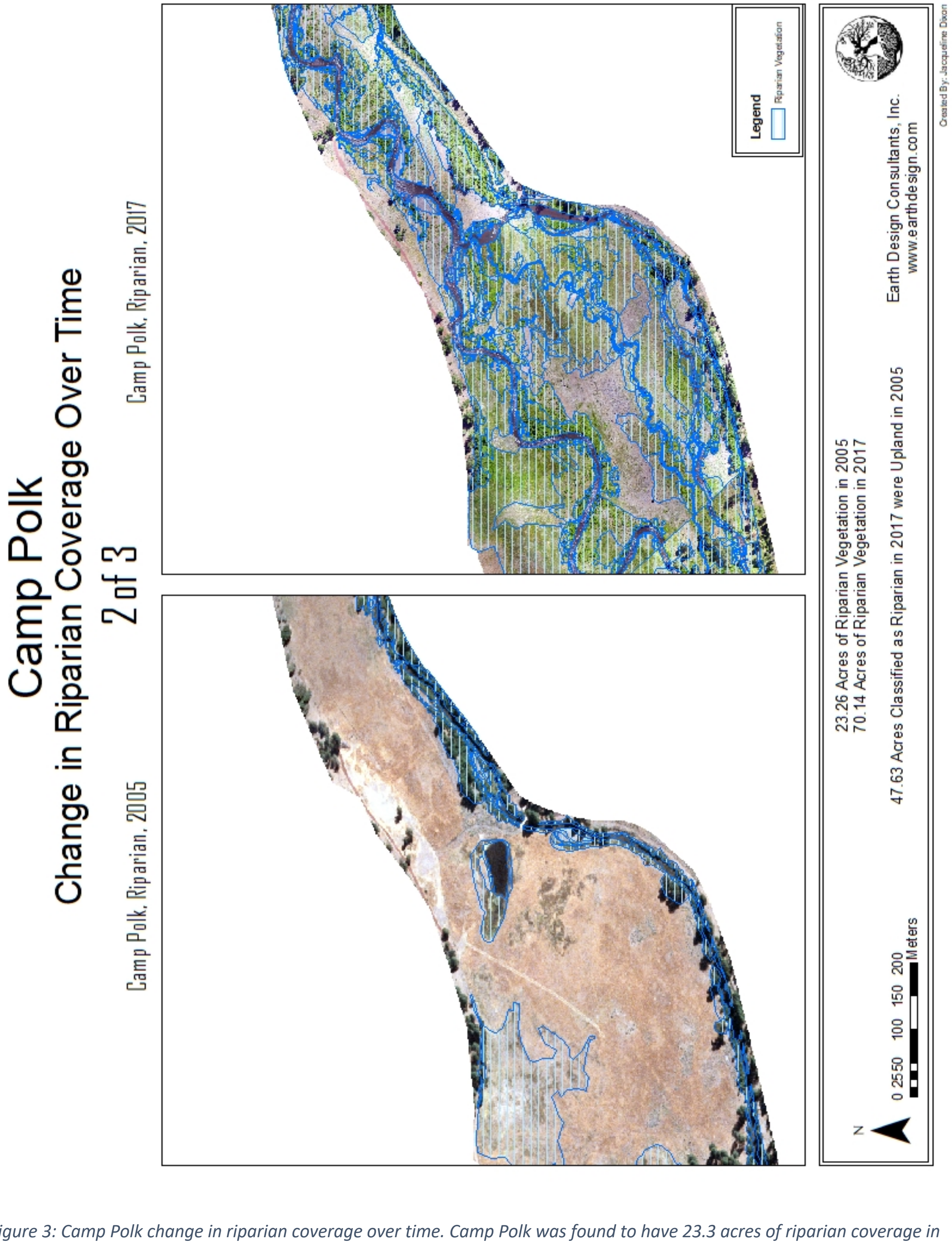

Figure 3: Camp Polk change in riparian coverage over time. Camp Polk was found to have 23.3 acres of riparian coverage in 2005 and 70.1 acres of riparian coverage in 2017. This is a 201.5% increase in riparian coverage since the onset of restoration effort. In 2005, Camp Polk converted 47.6 acres of upland coverage to riparian coverage. This is about 68% of the 70.1 acres of 2017 riparian coverage.

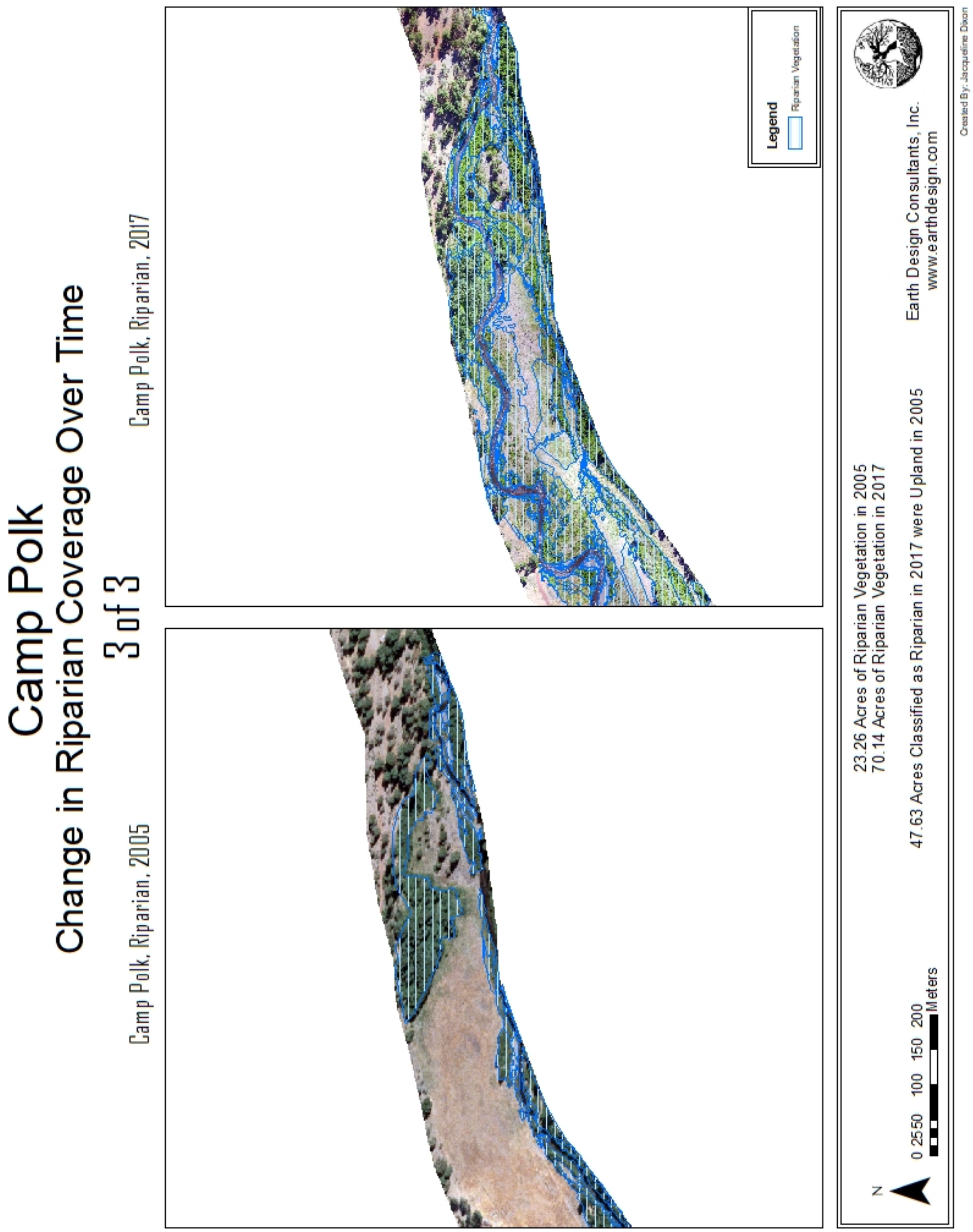

Figure 4: Camp Polk change in riparian coverage over time. Camp Polk was found to have 23.3 acres of riparian coverage in 2005 and 70.1 acres of riparian coverage in 2017. This is a 201.5% increase in riparian coverage since the onset of restoration effort. In 2005, Camp Polk converted 47.6 acres of upland coverage to riparian coverage. This is about 68% of the 70.1 acres of 2017 riparian coverage

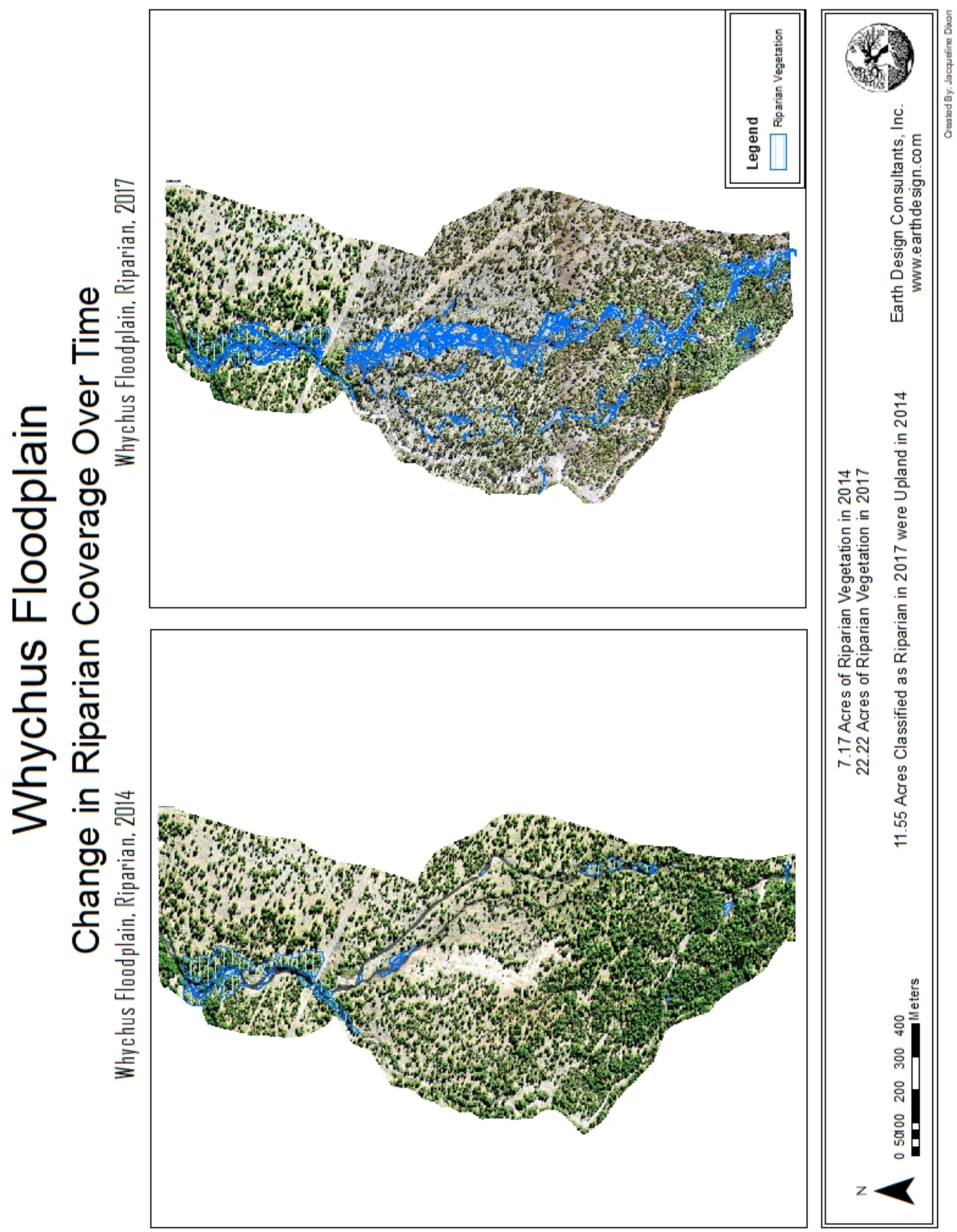

Figure 5: Whychus Floodplain Change in riparian coverage over time. Whychus Floodplain, North had 7.2 acres of riparian coverage in 2014 and was found to have 22.2 acres of riparian coverage in 2017—a 109.9% increase in those three years. Whychus Floodplain, North converted 11.6 acres of upland coverage to riparian coverage between 2014 and 2017. This is about a 52% of the 22.2 acres of 2017 riparian coverage.

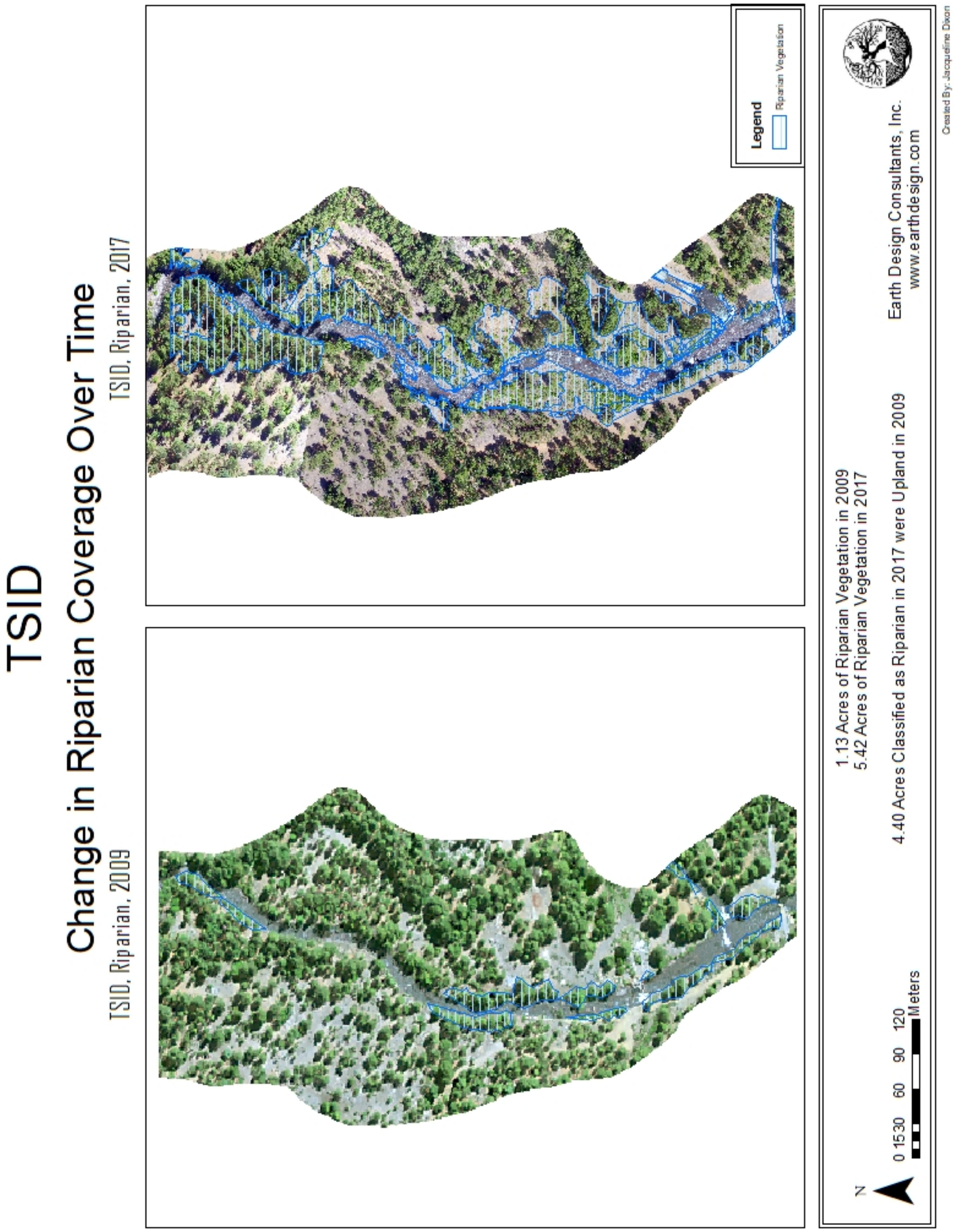

Figure 6: TSID change in riparian coverage over time. TSID went from 1.1 acres of riparian coverage in 2009 to 5.4 acres of riparian coverage in 2017. This was a 379.6% increase in eight years. Whychus Floodplain, South was found to have converted 4.4 acres from upland to riparian between 2009 and 2017; making this about 81 % of the 5.4 acres identified as riparian in 2017.

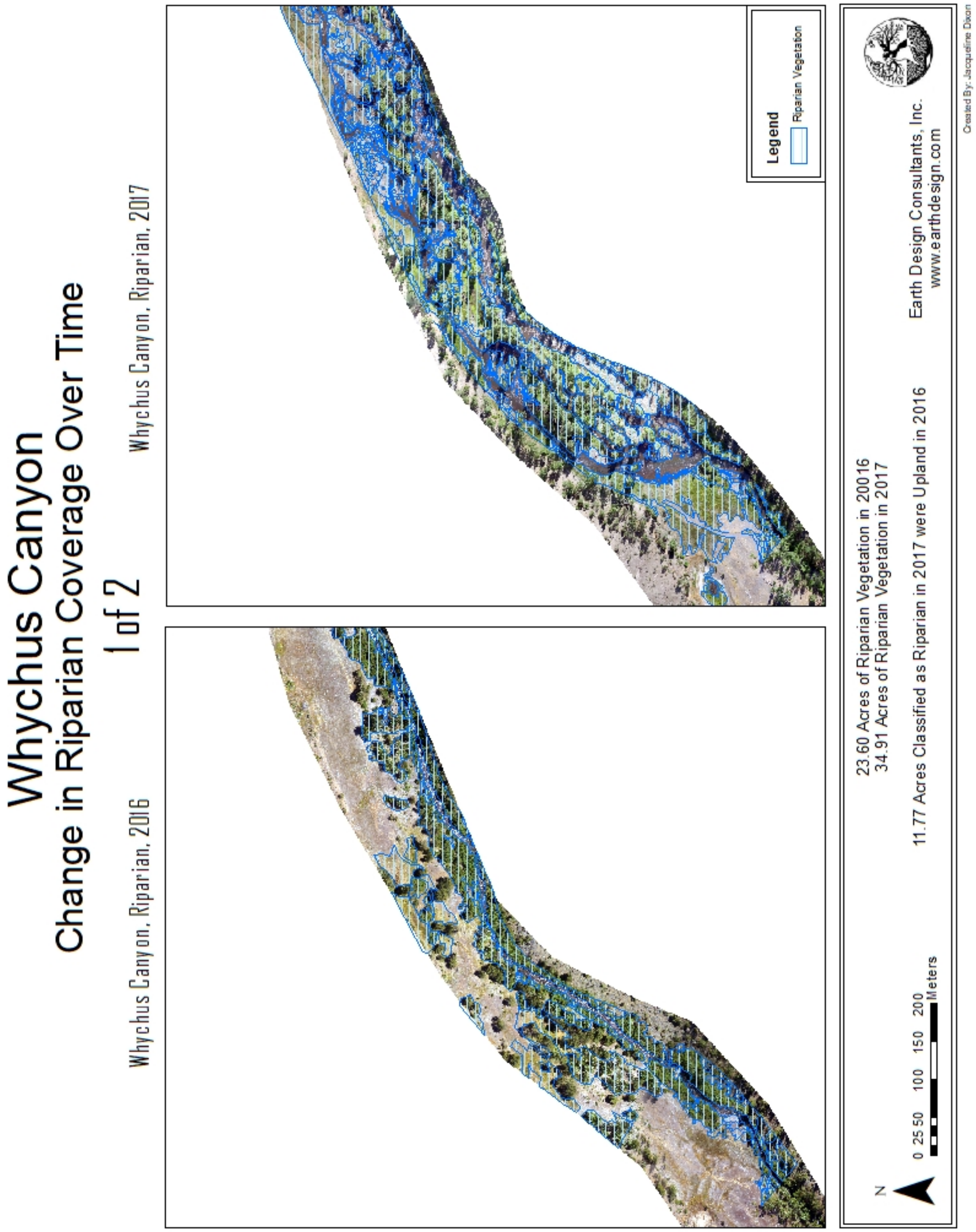

Figure 7: Whychus Canyon change in riparian coverage over time. Whychus Canyon went from 23.6 acres of riparian coverage in 2016 to 34.9 acres of riparian coverage in 2017, creating a 47.91% increase in riparian coverage at that site. Whychus Canyon converted 11.8 acres from upland to riparian between 2016 and 2017. This is about 34% of the 34.9 acres of 2017 riparian coverage.

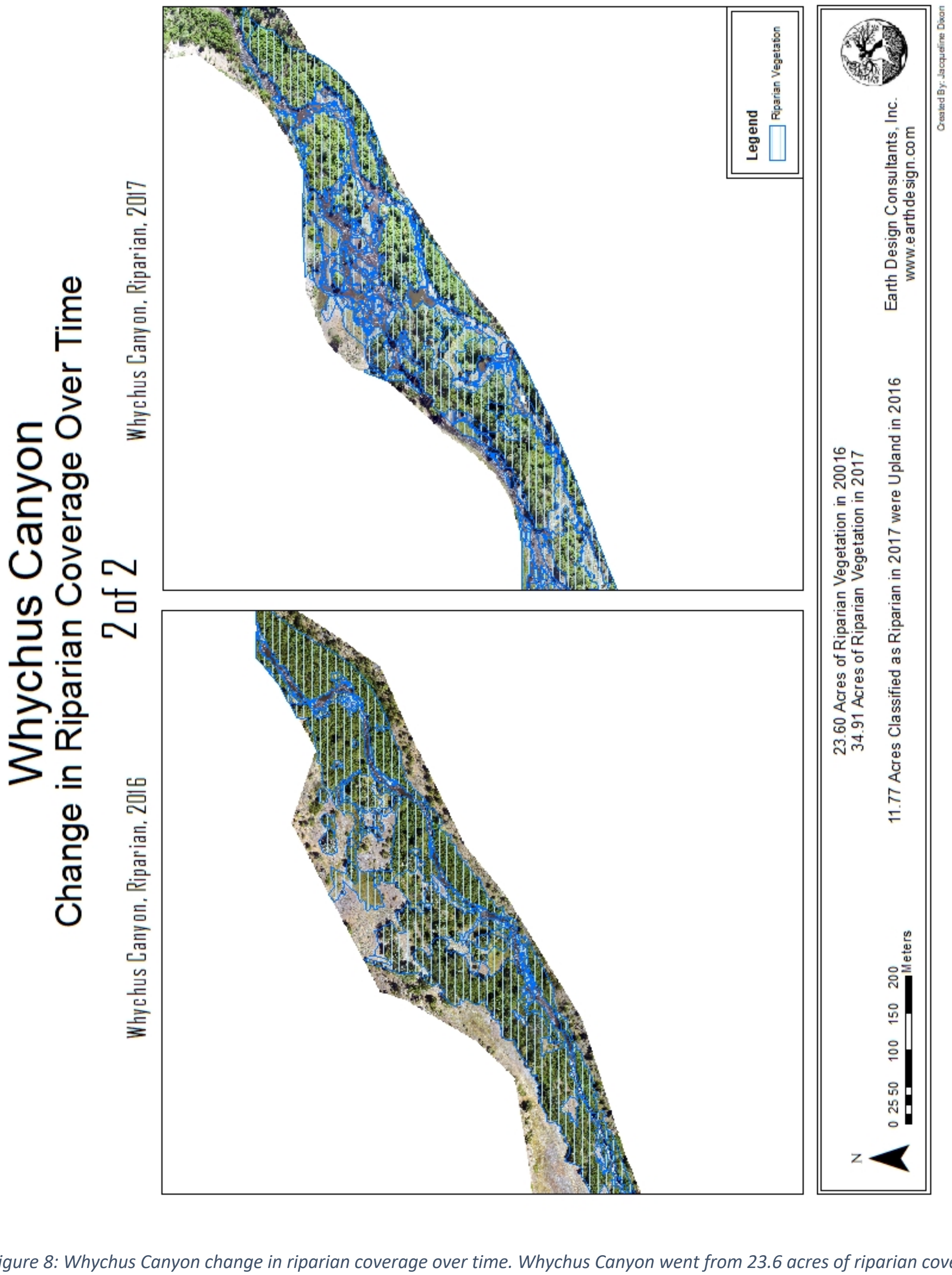

Figure 8: Whychus Canyon change in riparian coverage over time. Whychus Canyon went from 23.6 acres of riparian coverage in 2016 to 34.9 acres of riparian coverage in 2017, creating a 47.91% increase in riparian coverage at that site. Whychus Canyon converted 11.8 acres from upland to riparian between 2016 and 2017. This is about 34% of the 34.9 acres of 2017 riparian coverage.

Recommendations

We successfully used UAVs to develop mosaic aerial photographs of the riparian areas along Whychus Creek. Our approach of breaking up the flight missions into smaller, overlapping areas with pre-determined launch points worked well to capture high quality imagery while maintaining visual line of sight. As we expected, high steep banks and private land ownership prevented us from capturing imagery for the entire study area. Our recommendations concerning the project **planning phase** would include reaching out to homeowners within the area of interest to obtain permission to over fly their property and to gain access to suitable UAV launch points.

We also recommend that cover classes be completely defined for the project prior to **image acquisition**. This discussion should also include the suitability of the sensor and trade-offs between spatial and spectral resolution. For example, sensor payloads of UAVs could be compared to airborne and spaceborne sensors. As we understand the project, currently available UAV sensors could be used in future projects to map vegetation cover and, perhaps, soil moisture with adequate planning and budgets (e.g., may require multiple flight dates to capture imager under varying conditions, such as leaf-on/ leaf-off, after rain or snowmelt events ,etc.). Technology has not progressed to the point where available sensors can spectrally distinguish between mixed stands of grass species at the spatial resolution we were operating at.

Image processing in future work would undoubtedly rely upon traditional photointerpretation techniques. Due to the subjective nature of imagery interpretation, we recommend that classification rules be developed to ensure repeatability for future studies. We also recommend that a test of the classification results on a small set of representative streams reaches. This would help to identify methodological shortcomings prior to completing the final classification. Classification results of these reaches should be thoroughly reviewed by all decision-making parties to solidify the rule-based classification prior to the classification of the entire area of interest.

As an example, during the **classification phase** of this project, discussions with UDWC staff determined that green and lush vegetation outweighs distance from stream when classifying “riparian” and “upland” cover classes. It was also determined that vegetation immediately adjacent to the creek is often (although not always) riparian but, because of the degree to which the channel is incised in most places, beyond the “alder tunnel,” most vegetation is upland species. We recommend a pre-classification assessment of areas such as these by way of digital elevation models (DEMs) or field surveys that identify channel incision that might influence riparian cover classes.

During the **classification phase**, we found that editing sessions involving one editor and one reviewer worked well. We recommend that one editor be involved throughout the entire project to address bias that would be introduced by multiple editors. If workload requires additional editors, secondary editors should submit edits to the initial editor/reviewer. A specified editing routine should be established, and data files should be reviewed in a systematic fashion.

We recommend that future projects consider bundling the classification GIS files along with the aerial imagery in the same folder directory to avoid confusion when opening the classification files. In most cases, the GIS files are not directly linked to the aerial imagery and if the files become separated, future viewers may not be able to compare the classification to the appropriate imagery.

We recommend that future studies include work to verify the cover classes. As previously mentioned, GPS coordinates could be collected for specific species that are to be tracked throughout the restoration process (e.g., cottonwood trees). Ancillary data layers could be reviewed during the classification process (e.g., shrub planting pallets, forest inventories, etc.). If detailed plant community data are desired, we recommend that classification polygons, generated by this study, be visited by field teams and that quantitative plant community collected. Using the community data and other available data (e.g., depth to ground water, soils information, etc.) from each field site, empirical relationships between the plant community data and predictive environmental variables could be generated. This information would be useful in setting quantitative restoration benchmarks and identifying plant communities of interest within GIS. Data sets that could be used include other imagery, LiDAR, site grading plans, depth to ground water surface, soils layers, etc.

Work Cited

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