Puyallup River Gorge - Aerial Mapping Survey

Summary Report

Prepared by:

Northwest Hydraulic Consultants Inc.
12787 Gateway Drive S.
Seattle, WA 98168
Tel: 206.241.6000
www.nhcwater.com

Prepared for:

Electron Hydro, LLC
1800 James Street, Suite 201
Bellingham, WA 98225

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Report prepared by:

Peter Hurst
UAS Remote Pilot
Aerial Mapping

Annie Dufficy
UAS Remote Pilot
Aerial Mapping

Report reviewed by:

Jaron Brown, P.E.
Sr. Hydraulic Engineer
Project Manager

Ed Zapel, P.E.
Principal Hydraulic Engineer

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1 INTRODUCTION

Electron Hydro, LLC operates a run-of-river type hydropower facility on the Puyallup River. Constructed in 1904-1905, the facility consists of a diversion and intake (at approximately river mile (RM) 41.75), roughly 10 miles of elevated flume, which carries flow from the intake at the diversion to a forebay pond, penstocks, and a powerhouse (near RM 31), at which point the water returns to the Puyallup River.

At the request of Electron Hydro (Electron), Northwest Hydraulic Consultants (NHC) has performed aerial mapping and multispectral imaging via unmanned aircraft systems (UAS) to search for debris (artificial turf, HDPE, and fabric) from a construction project at the diversion in 2020.

At the diversion and down to RM 35, the Puyallup River is highly dynamic and carries a significant sediment load from the volcanic/glaciated upper watershed. At RM 35 the river enters a narrow bedrock gorge approximately 10 to 24 feet wide and 58 to 100 feet deep. This area is completely inaccessible by foot and only rarely floated by the whitewater kayak community and therefore it is largely unknown if any debris remains in the gorge. This report documents the methods and findings of the aerial survey used to interrogate this reach of the river for evidence of residual debris.

2 METHODS

2.1 Field Methods

NHC utilized a team of FAA certified remote pilots to conduct an unmanned aerial system (UAS) survey of the canyon between Electron Hydro Headworks and Powerhouse, from approximately RM 36 through RM 35 of the Puyallup River on September 12th, 2024. Electron Hydro staff escorted the remote pilots from Electron Hydro’s Upper Campus upstream to the area of interest (AOI) using the speeder car rail system. Drones took off from a flat platform trailered by the speeder car. The AOI was broken up into three sections to accommodate battery and remote signal limitations of the UASs, as seen in Appendix A.

Two drones were used for this aerial survey, a DJI Mavic 3 Enterprise Multispectral[1] and a DJI Mavic 2 Pro[2]. The Mavic 3 Enterprise Multispectral UAS was used to collect Red-Green-Blue (RGB) and multispectral nadir imagery (facing directly beneath the camera) to create RGB and multispectral orthomosaic maps of the AOI. Lower altitude oblique RGB and multispectral video

[1] https://dl.djicdn.com/downloads/DJI_Mavic_3_Enterprise/20240814/DJI_Mavic_3M_User_Manual_EN.pdf

[2] https://dl.djicdn.com/downloads/Mavic_2/Mavic+2+Pro+Zoom+User+Manual+V1.4.pdf

(1920 x 1080 resolution) of the AOI was also collected along the centerline of the river. The Mavic 3 has a 20 Megapixel (MP) RGB camera as well as a 5 MP multispectral camera that collects Near Infrared (NIR, 860 +/- 26 nanometers), Red Edge (RE, 730 +/- 16 nm), Red (R, 650 +/- 16 nm), and Green (G, 560 +/- 16 nm) wavelengths. A built-in sunlight sensor on the UAS captures solar irradiance to correct the image data according to the light conditions. The Mavic 2 Pro has a 20 MP RGB camera and was used to collect back-up videos of the AOI.

Prior to flying the reach, a calibration flight was made to capture the multispectral signature of the possible debris in the river. Two staff members hiked down into the canyon and placed sample pieces of debris that had been retrieved from other parts of the river and placed them in the channel upstream of the canyon entrance (Figure 1, photos of debris located in Appendix). A pilot then captured imagery of the river with the debris incorporated along the water's edge using the Mavic 3 for multispectral band calibration. The debris included artificial grass (turf), placed right-side up and upside-down, as well as black HDPE and fabric. All debris placed for calibration was then collected and returned to Electron Hydro.

Figure 1 Sample debris placed along river for multispectral camera calibration.

A total of three automatic and four manual flights were performed in the AOI. Automatic flights utilized a digital surface model (DSM) which is a three-dimensional portrayal of the earth’s surface including features such as buildings and trees. The UAS was set at an altitude of 250 feet above the DSM to safely navigate down the steep canyon and maintain a consistent ground sampling distance (GSD). Manual or “free flights” were flown at lower altitudes to capture oblique photos and videos. Flight altitude was limited by the UAV-controller connection, which was controlled by the topography of the canyon and dense canopy cover.

Flows on the Puyallup River were between 450 and 380 cubic feet per second (cfs) during the aerial survey (USGS Gage 12092000), steadily decreasing throughout the day along the falling limb of a moderate rain runoff event the night before. This flow represents a fairly low seasonal range of Puyallup River discharge, which presumably exposes as much of the riverbank and any possible residual debris as practical for this assessment. Weather conditions on the day of the survey were cloudy with intermittent fog and mist. Light conditions were therefore mostly consistent across flights, although darker than what would be considered optimal (full sun).

2.2 Data Processing

Multispectral imagery was processed using PIX4Dmapper photogrammetry software to produce georeferenced orthomosaic and reflectance maps with a resolution of 5.68 cm/pixel. A reflectance map corrects the image pixel value to achieve a radiometrically accurate measurement of the terrain reflectance compared to an orthomosaic map which applies color balancing to create a more appealing visual product.

The primary assumption of the multispectral analysis is that debris can be distinguished and isolated from the natural terrain using its unique spectral signature. In ArcGIS Pro, multiple geoprocessing methods were tested to identify and outline debris from the calibration flight. The first method, linear spectral unmixing, assumed each pixel was influenced by distinct materials or "endmembers." By analyzing the spectral reflectance of these endmembers, the method determined how much of each material was present in every pixel, helping to identify the different types of debris where it was deliberately placed for the calibration flights.

A second method utilized a mask of overlapping spectral signatures (NIR, RE, R, and G bands) to isolate locations where those spectral bands, and presumably debris, can be found in a given multispectral raster. To do this, the minimum and maximum spectral range for each light band was calculated from the calibration flight for each debris type (see Tables 1-4 for full range of statistical values). Then, for every debris type, a new raster, referred to as a mask, was created of all areas where the band ranges overlap spatially, therefore filtering or excluding any spatial areas that fall outside of this range. This mask can then be overlain on top of the orthomosaic to visualize and identify the possible locations of debris across the landscape, shown in Appendix B.

Additionally, a water mask was applied to exclude stream water and reduce noise, using the Normalized Difference Water Index (NDWI) formula: $NDWI = (G – NIR)/(G + NIR)$. Although this effectively identified and masked out much of the stream surface, wet rocks were also masked out incidentally, making it difficult to efficiently differentiate between the stream and exposed rock.

Surface reflectance examples, or endmembers, were selected by identifying pixels that represented the most ideal spectra best associated with each debris class. This process involved creating a shapefile of points that located these pixels at which each spectral class was observed.

These pixel points presumably would be most likely to include debris of interest but also was observed to include moss, rock, dark rock, and other features that matched these spectral classes. An R script was used to compute and visualize the surface reflectance values for each spectral band.

Spectral unmixing was then performed using the *mesma*[3] function from the RStoolbox[4] package. This function took the surface reflectance values of the different endmembers and the composite multiband raster, producing a raster for each class that represented the fractional influence of each class within a pixel.

3 RESULTS

3.1 Findings

Multiple methods of detecting debris were tested in the calibration flight prior to application over the full AOI. The mask of overlapping spectral signatures was chosen to apply to the full AOI dataset because it created the most focused spectral signal with the least amount of detected spectral range during the test screening using the calibration flight dataset. While the mask works well for turf in the upright (green-up) position, no method was successful in detecting and distinguishing the rest of the debris (turf down, HDPE, and fabric), all of whose spectral signatures were too closely similar to that of the surrounding vegetation and rocks. Spectral signatures of these debris types were identified throughout the AOI, but most, if not all, are indistinguishable from natural features. Spectral signatures matching those of the selected debris types were commonly found on top of rocks, around the base of rocks, near fallen logs, and in shaded canopy openings, even though no debris was observed physically in those locations. For upside down turf, HDPE, and black fabric, their spectral signatures are not unique or focused enough to apply an automated multispectral screening approach because the materials are indistinguishable from the terrain. These spectral signatures were detected at many points within the focused area interrogated during the calibration flight while there should have been only one or two signatures identified at the locations of the intentionally placed debris samples. For information on the limitations of the multispectral screening process, see Section 3.2.

When applying the debris masks to the full AOI dataset, the spectral signature closest to the turf-up sample material was found in only a very few locations. However, the calibration process and physical observations of the interrogated calibration flight area showed that several other natural features also matched that similar spectral signature.. Based on these confirmed calibration results for the turf-up material and the rarely observed similar signature within the

[3] https://www.rdocumentation.org/packages/RStoolbox/versions/0.4.0/topics/mesma

[4] https://cran.r-project.org/web/packages/RStoolbox/RStoolbox.pdf

AOI, i t can be said with higher confidence that no right-side-up turf is present within the AOI, based on the reliable classification of this debris type during the calibration test.

The results of this analysis are therefore inconclusive for the other debris types for which spectral signatures were determined, given the lack of confidence in isolating the fabric, HDPE and downward-facing turf signature from other natural features due to its spectral overlap with those natural elements within the surrounding terrain. Spectral signatures similar to the turf-down and HDPE sample material were more frequently observed along the water's edge, located in canopy openings, and between cobbles and boulders where water accumulates within the calibration area, though visual observation and inspection showed clearly that there were none of these materials present except for the limited number of samples that were intentionally placed. Spectral signatures of natural elements similar to the HDPE sample material were identified at many points throughout the calibration area and throughout the AOI, as their broader spectral range incidentally captured more of the surrounding natural terrain elements and could not be distinguished from the HDPE sample material. The relatively poor apparent distinction between HDPE and similar spectral signatures of the terrain made positive detection of HDPE material impossible.

3.2 Limitations

Logistical constraints for this operation included several critical factors. The flight window was limited by the availability of the rental equipment, constrained between the notice date of August 20 and the flight deadline of September 15. Weather conditions further reduced the available operational days. Additionally, UAS remote connectivity was limited by the canyon's topography. The rugged terrain obstructed signals and reduced communication with the remote pilot, especially flying in lower altitudes compromising flight control and safety.

Multispectral UAS sensors encountered limitations due to spectral overlap between debris types and the natural terrain. Specifically, the spectral signatures of dark wet rock and various vegetation types interfered with accurate differentiation of debris types, as seen in Figure 2. Isolating upright turf samples placed during calibration was more successful due to the contrast between the NIR and Red Edge signatures between the artificial turf and the moss. However, all spectral bands of rocks (of various darkness due to shadows and wetness) were extremely similar to those of the black or dark debris materials, namely downward facing turf, HDPE, and the fabric.

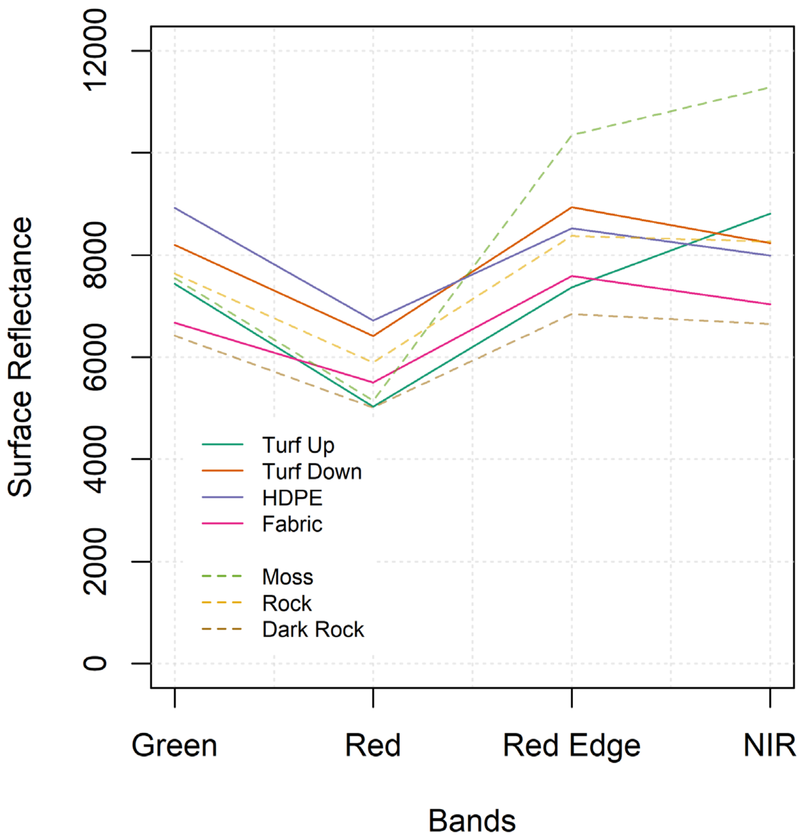


Figure 2 Graph illustrating average spectral band overlap between debris types and natural terrain.

This overlap reduced the effectiveness of the sensors in distinguishing between various types of materials on the surface, complicating debris identification and classification. Furthermore, varying light conditions, shadows, and moisture levels in the environment exacerbated these challenges, leading to inconsistent spectral readings and complicating data interpretation.

Additionally, using a classification method like segmented supervised classification is impractical due to the large number of distinct classes in the imagery, such as various types of foliage, water, aerated water, rocks, wet rocks, and debris. The workflow would require distinguishing between these categories, but many share similar spectral signatures, making this approach ineffective.

4 CLOSURE

The UAS aerial survey provided valuable insights into the spectral signatures of different debris types within the AOI along the Puyallup River. Despite the controlled placement of sample debris along the riverbank to simulate real-world conditions, significant challenges remain in accurately identifying actual debris. Debris in the environment is likely to exhibit different physical and spectral characteristics due to weathering, moisture levels, and other environmental factors. These variations complicate the ability of multispectral sensors to reliably capture and differentiate debris from surrounding terrain.

Most importantly, limitations posed by overlapping spectral signatures between debris and natural materials, such as wet rocks and vegetation, reduced the effectiveness of the multispectral analysis. While the use of advanced software like PIX4Dmapper and ArcGIS Pro allowed for detailed processing and reflectance mapping, the spectral overlap and the complexity of the terrain hindered definitive debris classification, which was the primary goal going into this analysis.

In summary, this study represents a comprehensive effort to fly the AOI reach, calibrate the imaging data, and detect debris from the 2020 construction project at the Electron headworks. We note that the spectral signature of right side up turf was able to be isolated from the calibration flights and no right side up turf was detected in the gorge. Although none of the other types of debris were detected using either the multispectral or aerial imagery, it is unlikely that a different UAS system would fare better in conclusively identifying those types of debris within the gorge. Furthermore, we would suggest that a lack of identified and confirmed right side up turf, would also imply that there is similarly a lack of any other kind of debris within the AOI.

TABLES

Table 1 Spectral zonal statistics of green reflectance calibration image.

Associated Items	Min (reflectance ratio)	Max (reflectance ratio)	Mean (reflectance ratio)
Moss, Rock, Turf Up	7136	7954	7616
Turf Down	6309	8695	7830
HDPE	7596	10357	8616
Dark Rock, Fabric	5942	7416	6697

Table 2 Spectral zonal statistics of near infrared reflectance calibration image.

Associated Items	Min (reflectance ratio)	Max (reflectance ratio)	Mean (reflectance ratio)
Turf Up	8591	9506	9160
Rock, Turf Down	6765	8892	7983
Rock, HDPE	7364	8957	7807
Dark Rock, Fabric	6493	7573	7028

Table 3 Spectral zonal statistics of red edge reflectance calibration image.

Associated Items	Min (reflectance ratio)	Max (reflectance ratio)	Mean (reflectance ratio)
Turf Up, Fabric	7145	7781	7457
Turf Down	6799	9432	8586
Rock, HDPE	7704	10061	8521
Fabric, Turf Up	6529	8437	7480

Table 4 Spectral zonal statistics of red reflectance calibration image.

Associated Items	Min (reflectance ratio)	Max (reflectance ratio)	Mean (reflectance ratio)
Moss, Dark Rock, Turf Up	4836	5284	5103
Turf Down	4992	6800	6213
HDPE	5851	7499	6435
Fabric	5035	6017	5521

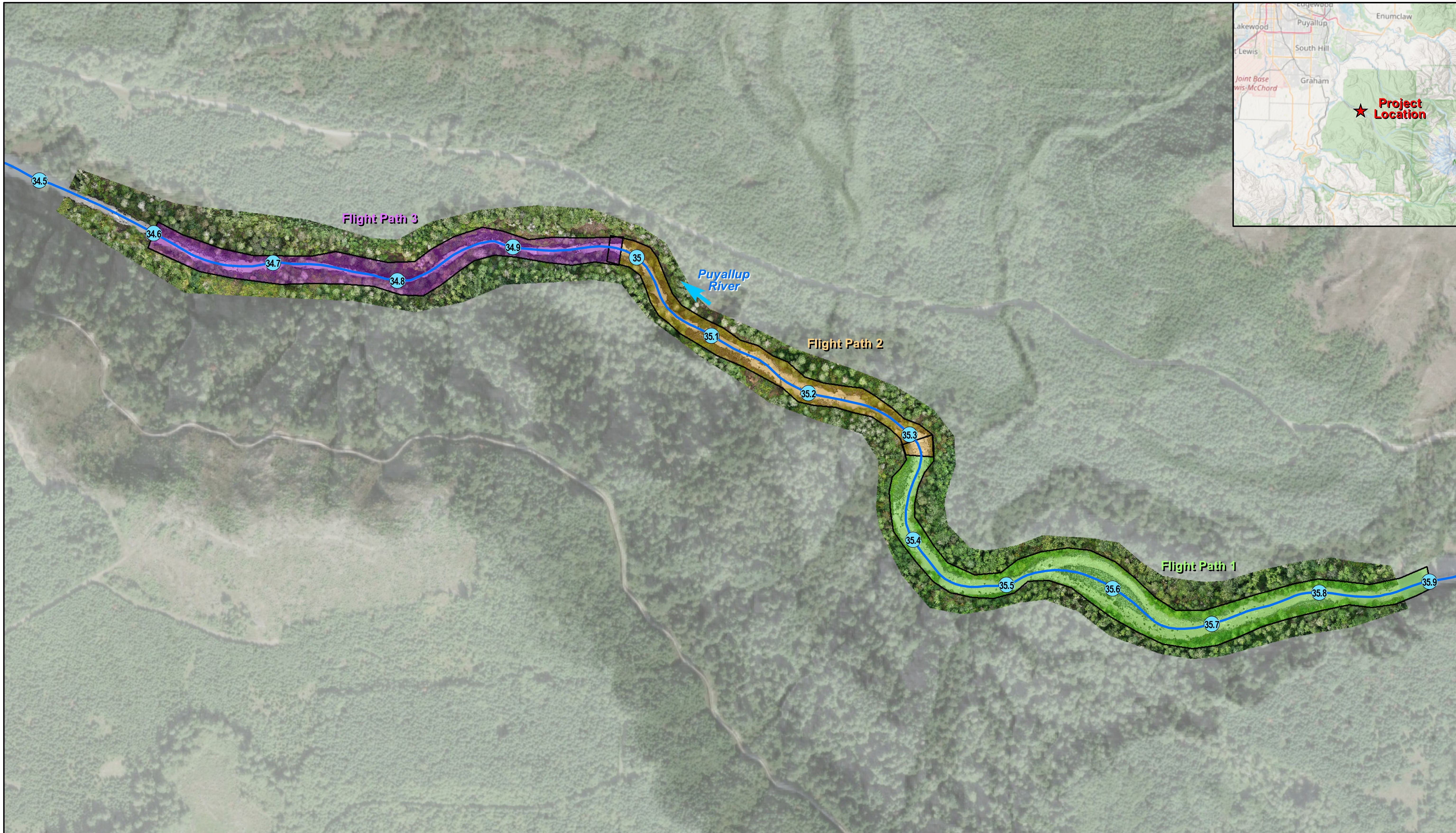
PHOTOGRAPHS

Photo 1 **Sample debris placed on river right for camera calibration flight. From bottom of photo to top: HDPE, turf upside down, and turf right side up shown**

Photo 2 **Sample debris placed on river right for camera calibration flight. From right to left: HDPE, fabric, and right side up turf.**

APPENDIX A

UAS FLIGHT PATH AREAS



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- River Miles
- Puyallup River Alignment
- Flight Path 1
- Flight Path 2
- Flight Path 3

DATA SOURCES:
UAS Aerial Imagery date 9/12/2024.
River Miles courtesy of Washington Department of Fish and Wildlife, August 2024.

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0 100 200 400 Feet
N

Coordinate System: NAD 1983 2011 STATEPLANE WASHINGTON SOUTH FIPS 4602 FT US

Job: 2009367 *Date: 27-SEP-2024*

PUYALLUP GORGE AERIAL MAPPING

UAS Flight Path Areas

APPENDIX A

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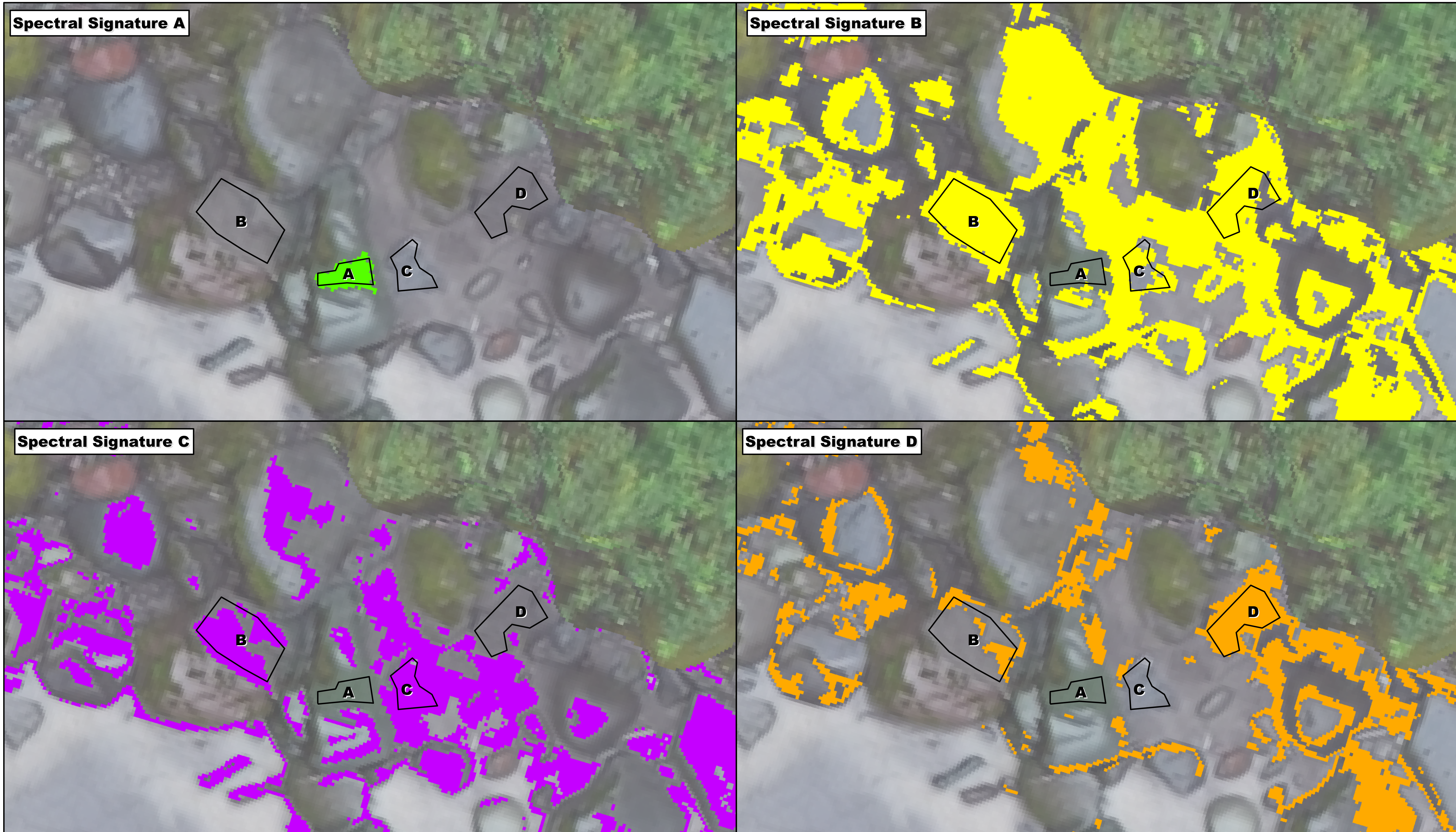
APPENDIX B

SAMPLE SPECTRAL SIGNATURE COMPOSITE MASKS MAP

(Calibration sample results)



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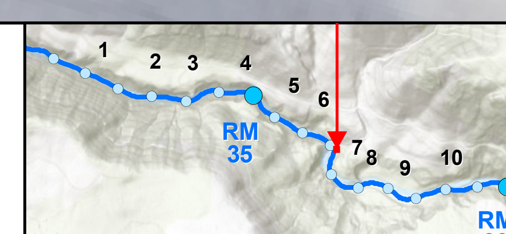
Legend

Approximate Spectral Signature *

- A
- B
- C
- D

***Note: No debris could be positively identified. A spectral signature is a unique combination of wavelength reflectance patterns that distinguishes one material from another. See Tables 1 through 4 for the approximate spectral signatures.**

DATA SOURCES:
UAS Aerial Imagery date 9/12/2024.
River Miles courtesy of Washington Department of Fish and Wildlife, August 2024.



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Coordinate System: NAD 1983 2011 STATEPLANE WASHINGTON SOUTH FIPS 4602 FT US

Job: 2009367 *Date: 27-SEP-2024*

PUYALLUP GORGE AERIAL MAPPING

Sample Spectral Signature Composite Masks Map

APPENDIX B

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APPENDIX C

SPECTRAL IMAGING COMPOSITE MASKS MAPS

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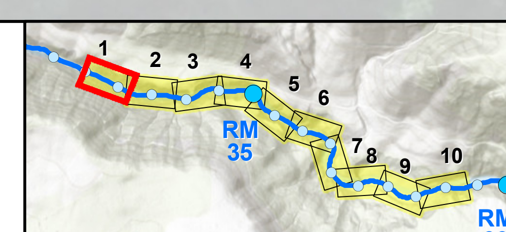

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PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

Sheet 1 of 10

APPENDIX C

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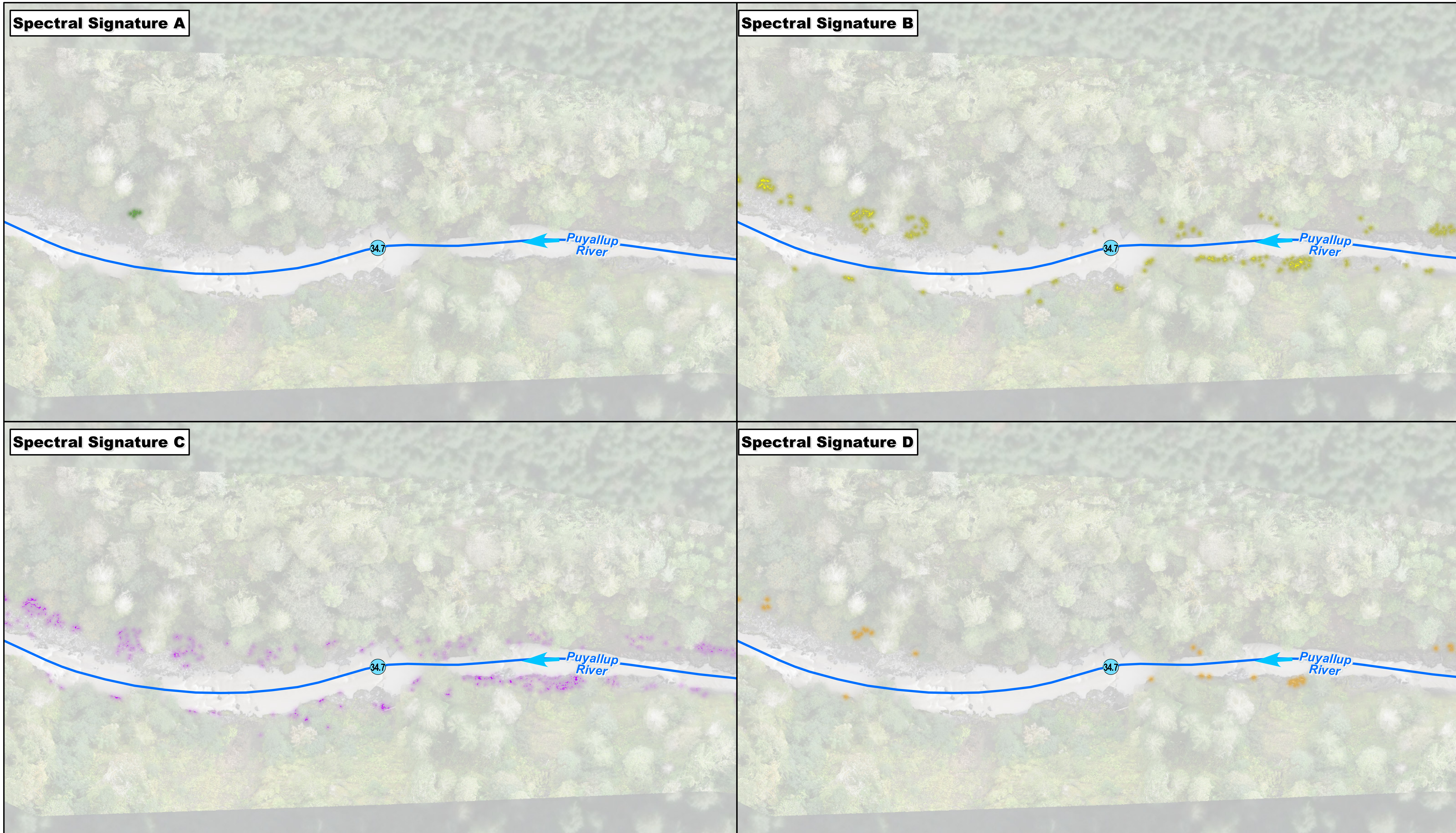

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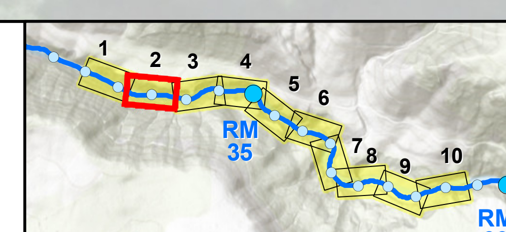

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Sheet 2 of 10

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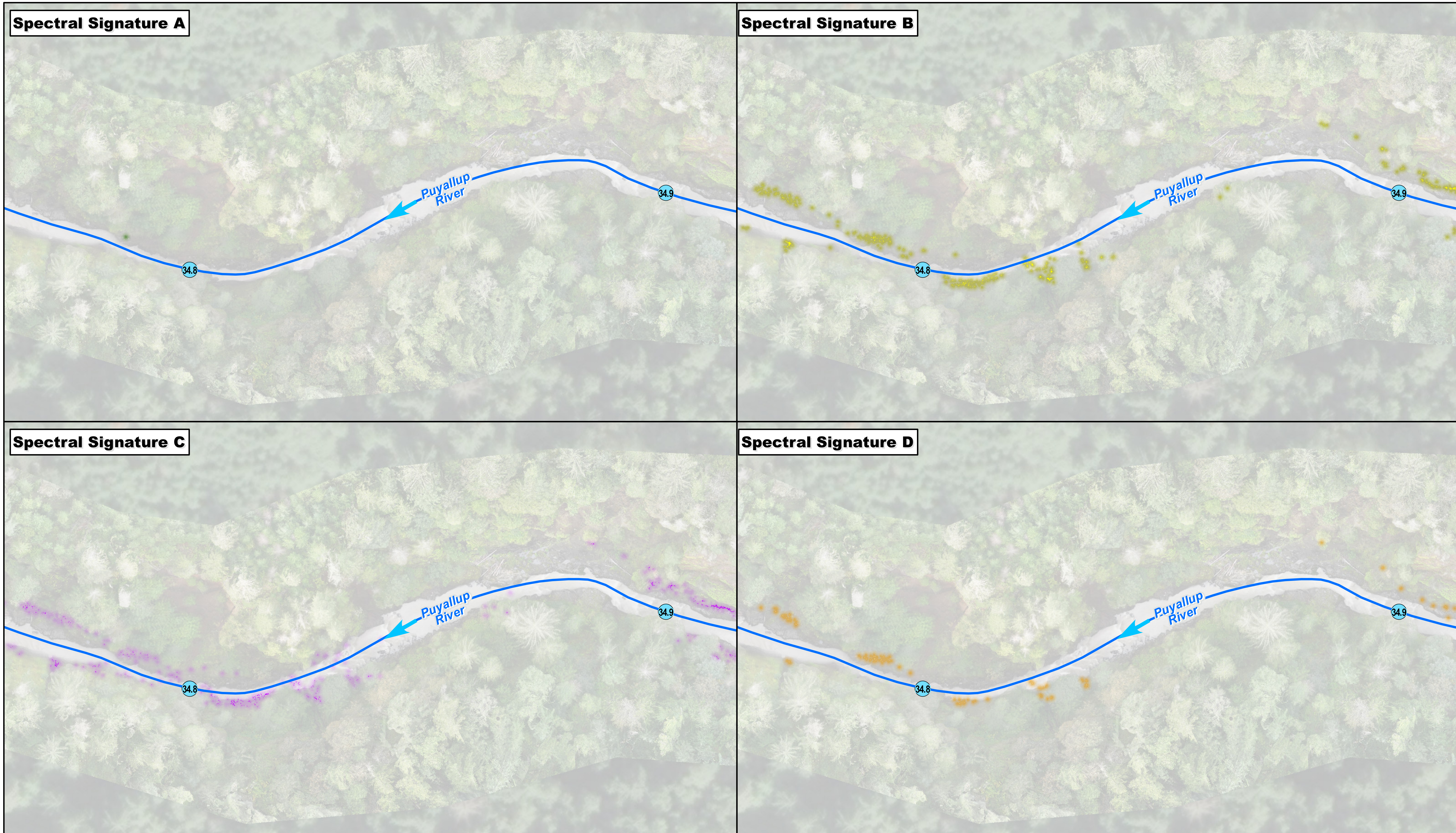

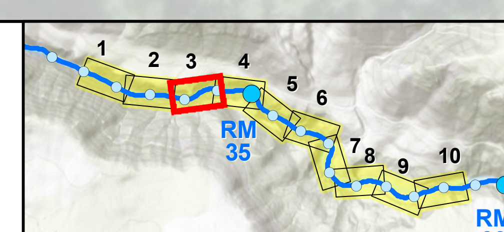

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Puyallup River Alignment

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0 25 50 100 Feet

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PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

Sheet 3 of 10

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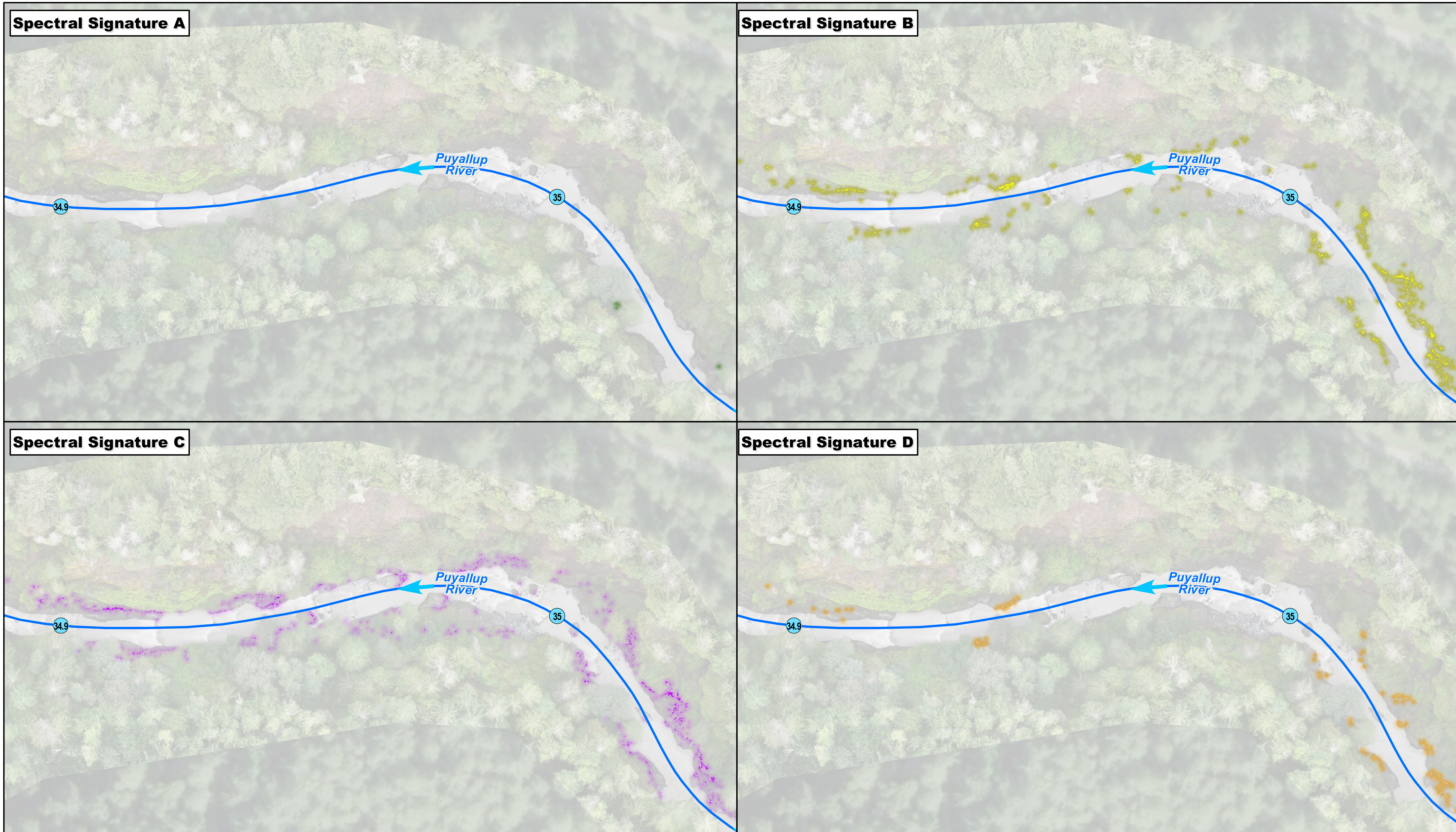

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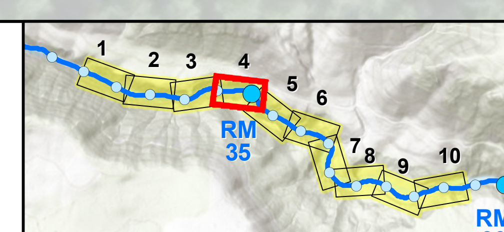

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Job: 2009367 | *Date: 27-SEP-2024*

PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

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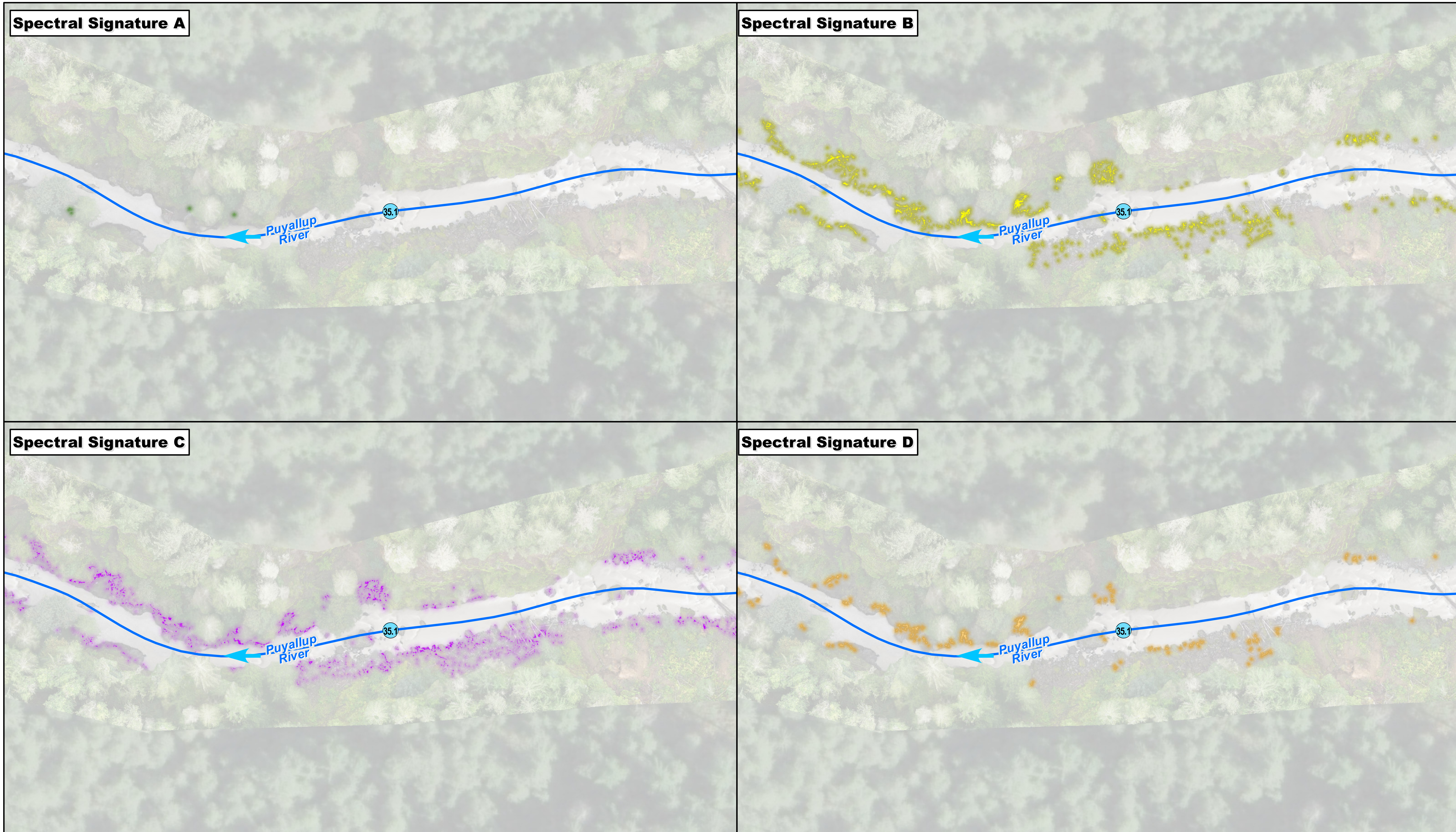
APPENDIX C



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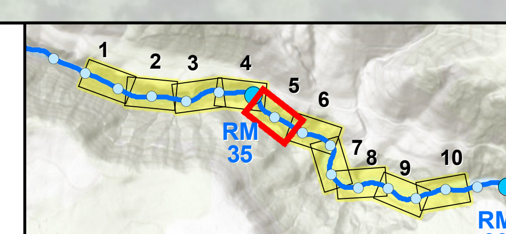

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PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

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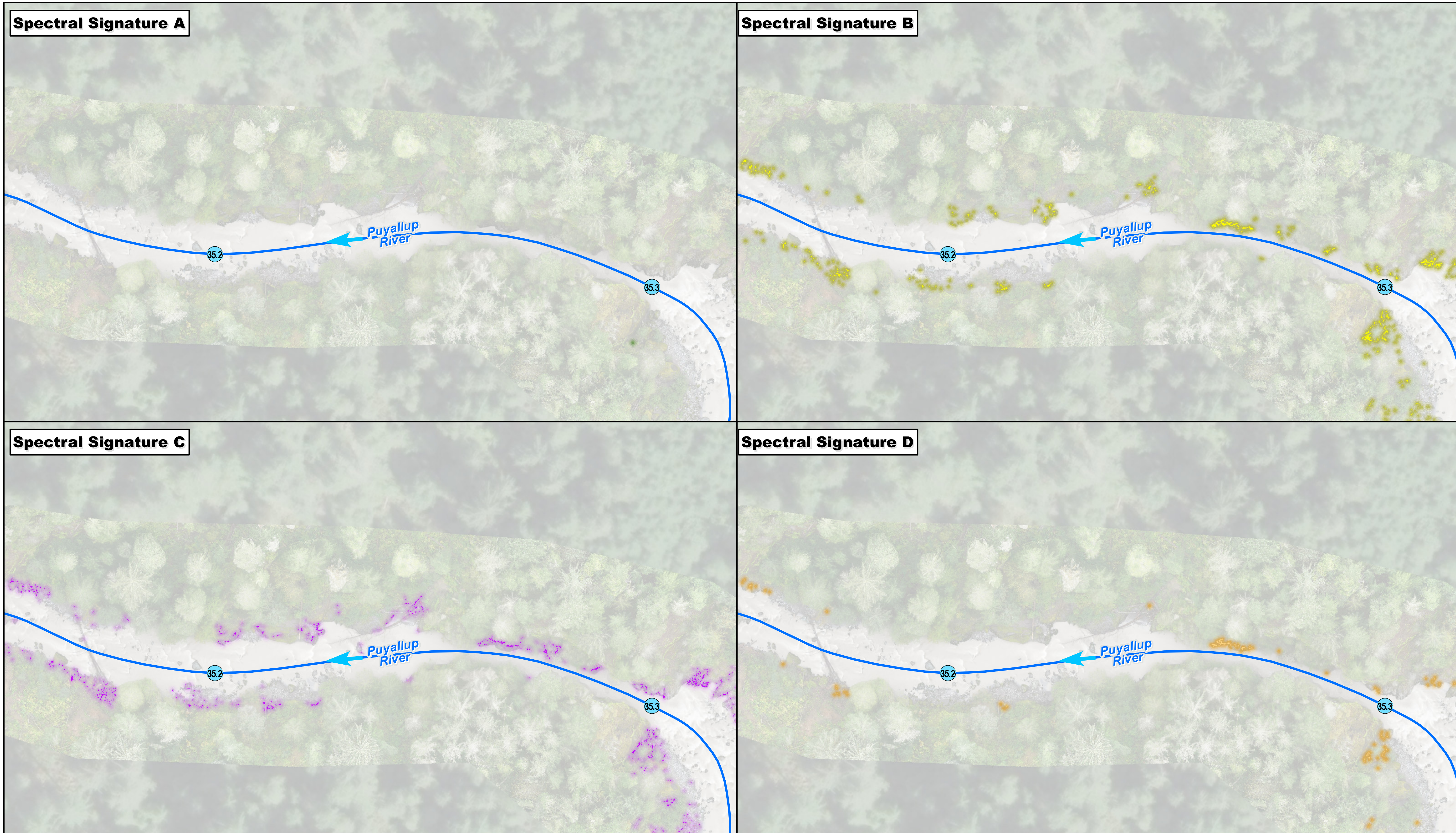

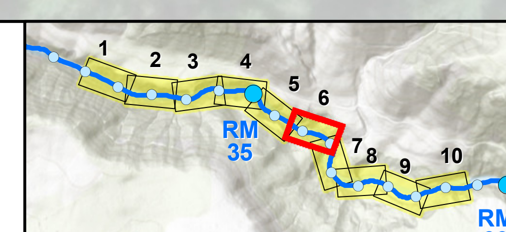

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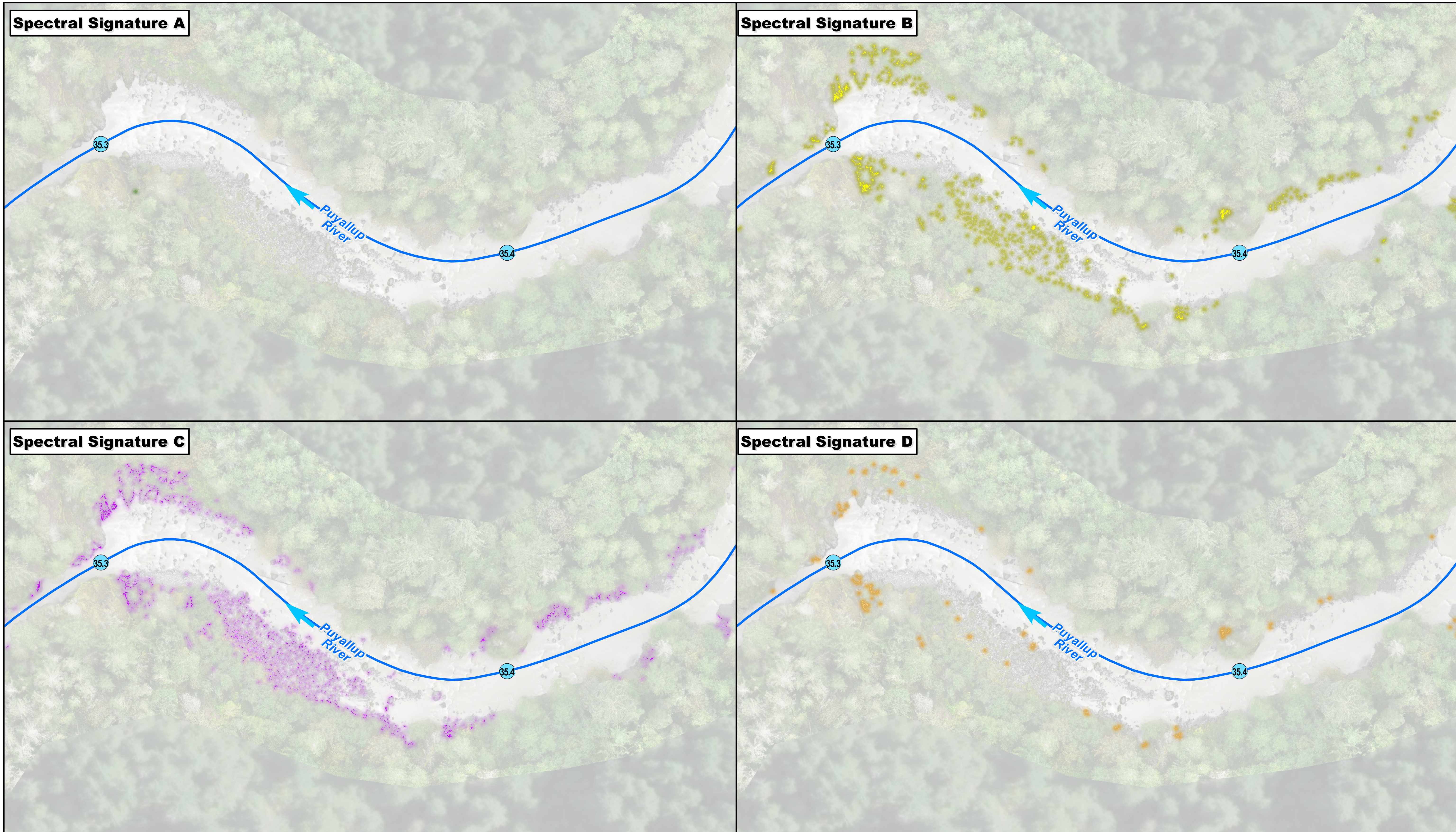
APPENDIX C

ABC, P:\2009367\95_GIS\00_MapDocuments\MXD\2009367_Composite_Masks_Map.mxd



Electron Hydro

nhc
northwest hydraulic consultants

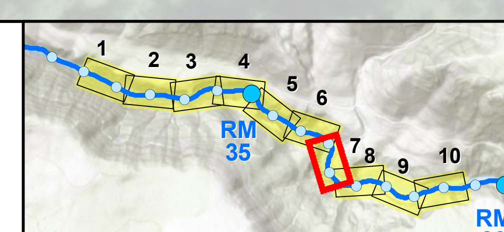
Legend

Approximate Spectral Signature *

- A
- B
- C
- D
- River Miles
- Puyallup River Alignment

****Note: No debris could be positively identified. A spectral signature is a unique combination of wavelength reflectance patterns that distinguishes one material from another. See Tables 1 through 4 for the approximate spectral signatures.***

DATA SOURCES:
UAS Aerial Imagery date 9/12/2024.
River Miles courtesy of Washington Department of Fish and Wildlife, August 2024.



SCALE - 1:1,200

0 25 50 100 Feet

N

Coordinate System: NAD 1983 2011 STATEPLANE WASHINGTON SOUTH FIPS 4602 FT US

Job: 2009367 | *Date: 27-SEP-2024*

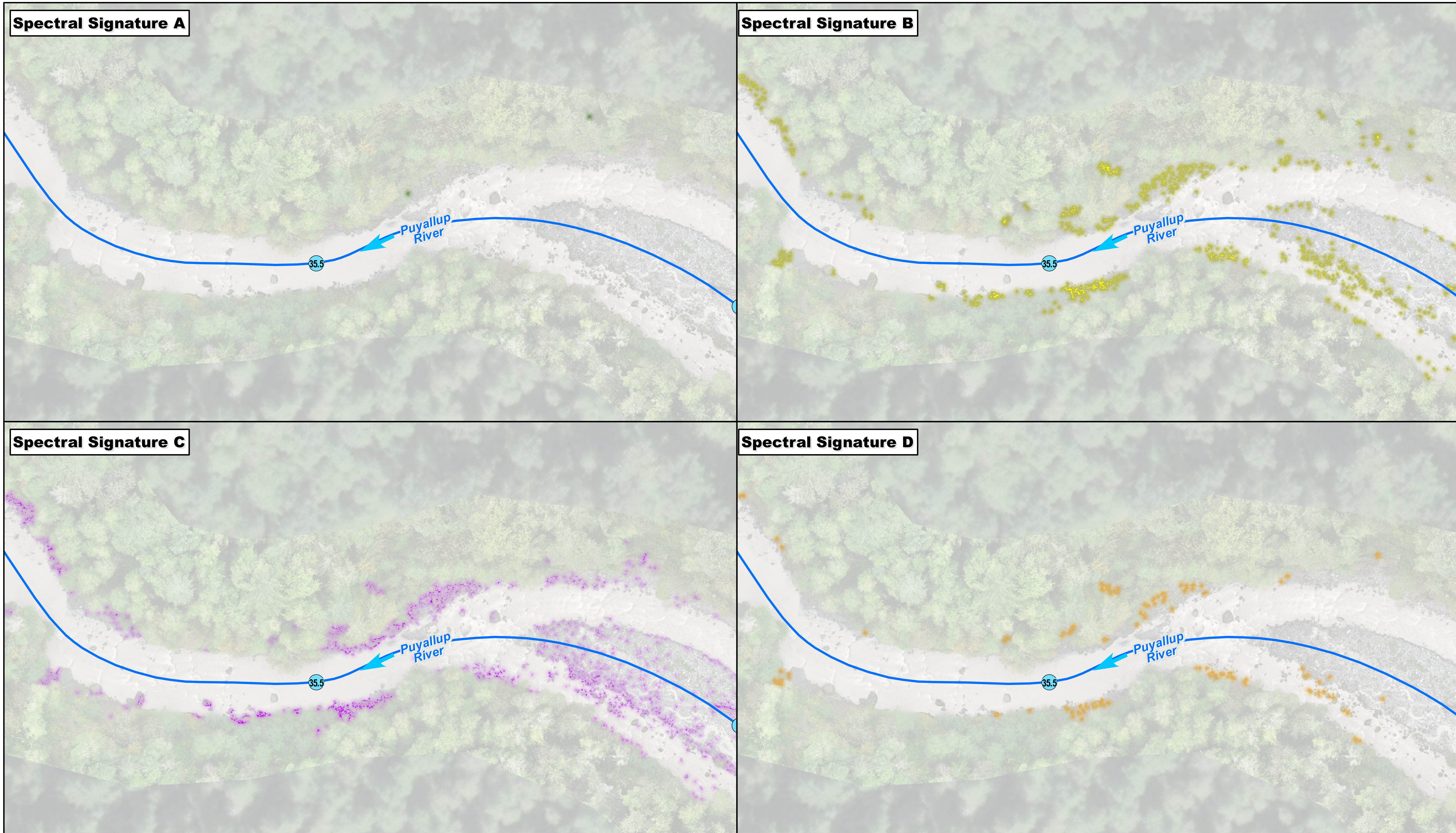
PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

Sheet 7 of 10

APPENDIX C

ABC, P:\2009367\95_GIS\00_MapDocuments\MXD\2009367_Composite_Masks_Map.mxd



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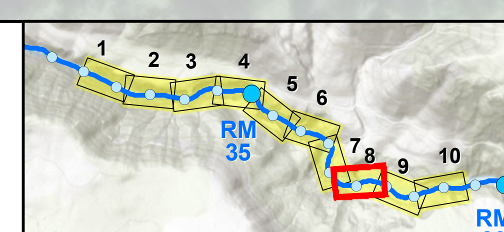

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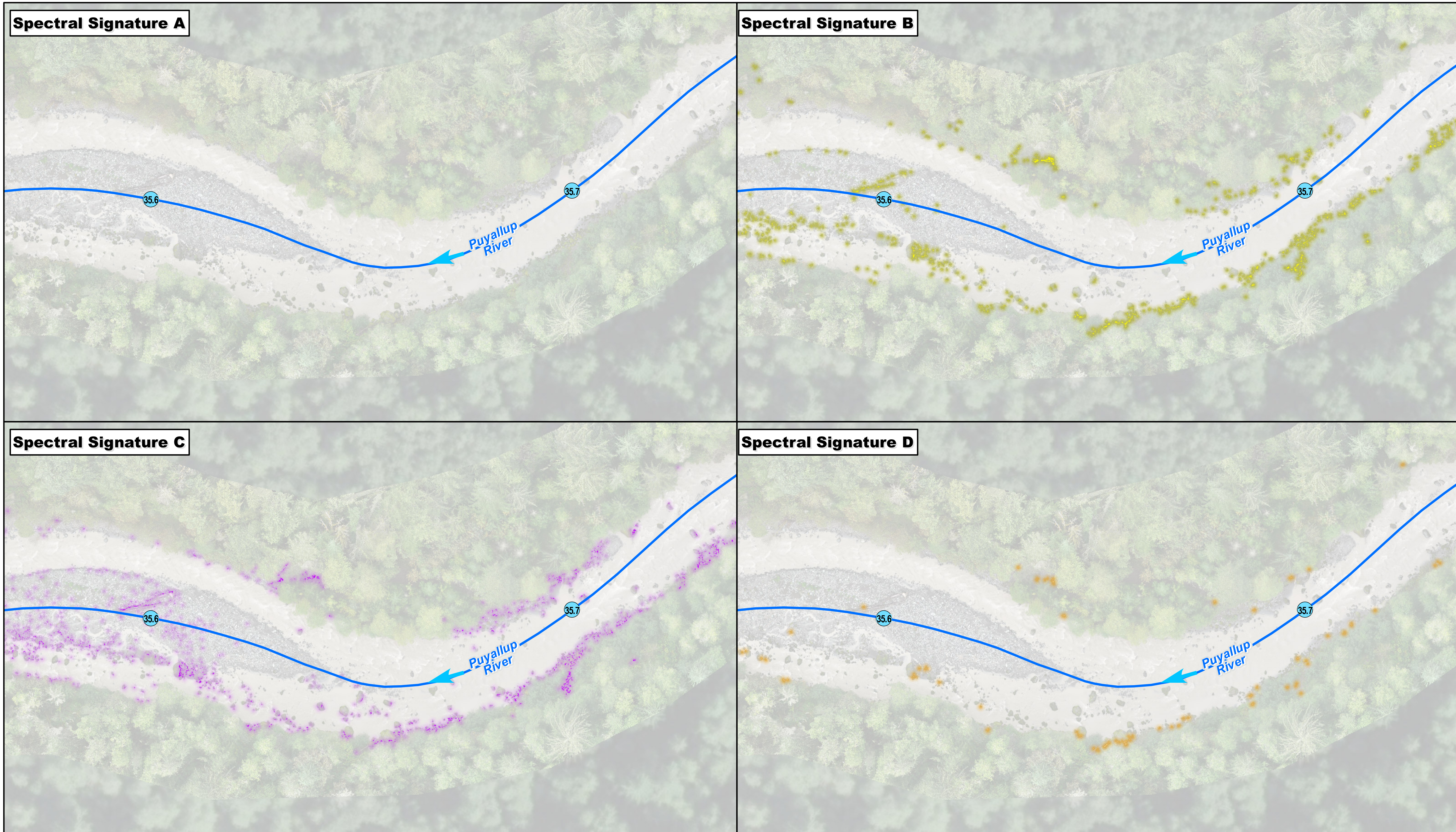
PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

Sheet 8 of 10

APPENDIX C

ABC, P:\2009367\95_GIS\00_MapDocuments\MXD\2009367_Composite_Masks_Map.mxd



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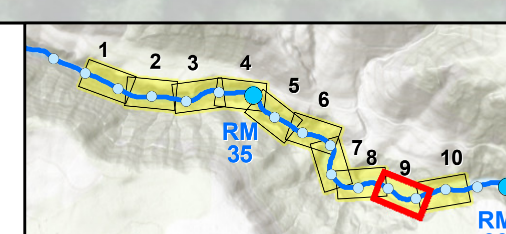

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PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

Sheet 9 of 10

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ABC, P:\2009367\95_GIS\00_MapDocuments\MXD\2009367_Composite_Masks_Map.mxd

Electron Hydro

Legend

Approximate Spectral Signature *

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River Miles

Puyallup River Alignment

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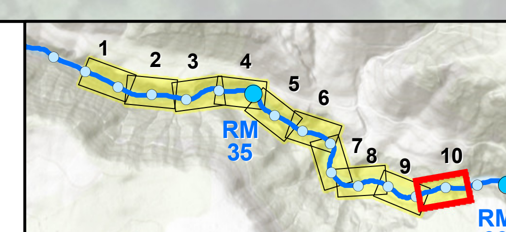

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PUYALLUP GORGE AERIAL MAPPING

Spectral Imaging Composite Masks Map

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