BUREAU OF RECLAMATION

Technical Report No. ENV-2024-077

Chewuch River Risk Assessment and Restoration Design Concepts

Methow River Sub-Basin, Okanogan County, Washington
Columbia-Pacific Northwest Region

U.S. Department of the Interior

September 2024

Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Photo – The Chewuch River in Okanogan County, Washington (Colin Byrne/Bureau of Reclamation)

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Prepared by:

Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Acronyms and Abbreviations

2D	two-dimensional
BDA	beaver dam analog
DEM	digital elevation model
ft	feet
ft/s	feet per second
ft^3/s	cubic feet per second
GIS	Geographic Information System
IDW	inverse distance weighted
LW	large wood
NAIP	National Agriculture Imagery Program
PALS	post-assisted log structure
Qa	Holocene alluvium
Qac	active channel
Qb1	vegetated islands
Qb2	unvegetated bars
Qfan	fans
Qls	landslides
Qoc	overflow channels
Qsc	side channels
Reclamation	Bureau of Reclamation
REM	relative elevation model
RM	River Mile
RMC-BestFit	Risk Management Center BestFit 1.0
SMS	Surface-water Modeling System
SRH-2D	Sedimentation and River Hydraulics Two-Dimensional
TSC	Technical Service Center
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
yr	year

Symbols

ρ	density of water ($slugs/ft^3$)
d	depth of water (ft)
g	gravitational constant (ft/s^2)
%	percent
S	slope of river (ft/ft)
ω	unit stream power (lb/ft-s)
V	velocity of water (ft/s)

Contents

Page

Tables

Figures

1.0 Introduction

1.1 Background

The Bureau of Reclamation's (Reclamation) Technical Service Center (TSC) was tasked with generating restoration design concepts for the Confederated Tribes of the Colville Reservation along two reaches of the Chewuch River in Okanogan County, Washington; a reach from River Mile (RM) 33 downstream from RM 29 and a reach from RM 20 downstream to RM 9 (figure 1). As part of this effort the TSC completed the following tasks: 1) determined appropriate flow conditions for restoration concept development, 2) conducted a geomorphic assessment, 3) modeled existing flow conditions, 4) conducted a large wood risk assessment for the RM 20 to 9 reach, and 4) developed design concepts for each reach.

1.2 Fire and Flood History

The Chewuch River basin has a history of recent fire and flooding that can induce channel change in the river. In 2001, the Thirtymile Fire burned over 9,000 acres that affected the RM 33 to 29 reach (USDA 2001). This fire removed most of the evergreen (Lodgepole, Spruce, and Douglas-Fir Pine) and Cottonwood trees within the valley floor and along the canyon walls, making the steep slopes more susceptible to erosion. The Cub Creek Fire burned more than 70,000 acres, affecting the RM 20 to 9 reach, in 2021 (Hanrahan et al. 2023). The channel in this reach is still responding to large inputs of fine sediment from debris flows in the tributaries to the mainstem Chewuch.

The largest known floods in the Methow basin were in 1894, 1948, and 1972 (Beck 1973). High water marks were used prior to streamflow records to estimate the peak discharge of the 1894 flood at 50,000 cubic feet per second (ft^3/s). The largest flood of record in the Methow basin occurred in 1948 at the Pateros, Washington United States Geological Survey (USGS) gage 12449950 near the mouth of the Methow River with a magnitude of 46,700 ft^3/s. The 1972 flood had a peak discharge of 28,800 ft^3/s at the same gage. This flood had two peaks approximately two weeks apart but was less damaging than the 1948 flood (Beck 1973). The largest flow recorded on the Chewuch River at Winthrop (USGS gage 12448000) was in 2018 at 8,910 ft^3/s. Most recently, the river experienced a 5-year (yr) recurrence interval flow (discharge of 5,940 ft^3/s) in 2023.

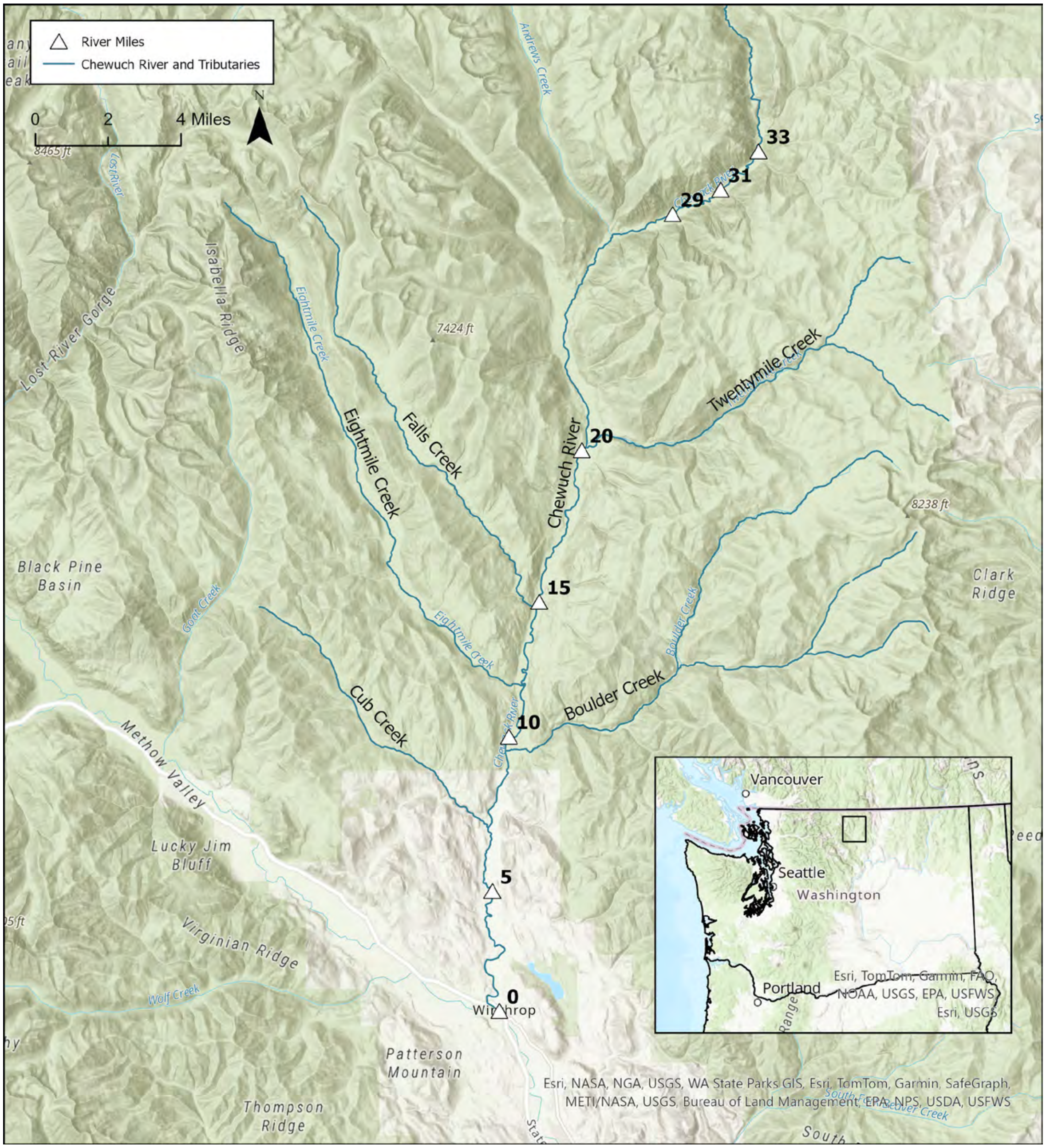


Figure 1.—Overview of the Chewuch River. River Mile 0 is at the confluence with the Methow River and river miles increase in the upstream direction.

2.0 Hydrology

2.1 Chewuch River Gage

Hydrology for the Chewuch River was calculated using data from USGS gage 12448000 located in Winthrop, Washington immediately upstream of the Chewuch and Methow Rivers confluence (RM 0). A peak flow analysis between 1992 and 2023 was conducted using the United States Army Corps of Engineer's Risk Management Center – BestFit 1.0 (RMC-BestFit). Within RMC-BestFit, a Log-Pearson Type III fit was used to calculate annual exceedance probability peak flows (table 1). In addition to annual exceedance probability peak flows, several ecologically relevant flows were calculated from the gage data as well (table 2). Within this report we focus on the July mean and September mean flows. July represents a month in which moderate summer flows occur on the falling limb of the snowmelt-driven hydrograph. September represents the month when the lowest flows typically occur.

Table 1.—Predicted annual exceedance probability peak flows for the Chewuch River at USGS gage 12448000

Annual exceedance probability	Recurrence interval (year)	Predicted flow (ft^3/s)	5.0% Confidence Interval flow (ft^3/s)	95.0% Confidence Interval flow (ft^3/s)
0.99	1.01	689	330	1328
0.98	1.02	923	487	1516
0.95	1.05	1333	816	1872
0.9	1.11	1762	1223	2287
0.8	1.25	2382	1849	2938
0.7	1.43	2917	2356	3528
0.667	1.5	3087	2516	3716
0.5	2	3977	3308	4720
0.3	3.33	5254	4433	6172
0.2	5	6136	5186	7215
0.1	10	7427	6294	9071
0.05	20	8612	7179	11272
0.04	25	8939	7427	12037
0.02	50	10240	8048	14741
0.01	100	11770	8490	17804

Table 2.—Ecologically relevant flows calculated for the Chewuch River at USGS gage 12448000

Flow description	Flow at Chewuch Gage (ft^3/s)
Mean annual low	47
September mean	79
March mean	142
July mean	412

2.2 River Mile 33 to 29 Modeled Hydrology

Two methods were considered to estimate flows between RM 33 and 29: an area-weighted calculation of annual exceedance probability peak flows based on the gage data and an estimation based on the USGS StreamStats program (USGS 2019, Mastin et al. 2016). Because of the large distance from the USGS gage (33 river miles) and the lack of any local flow data, StreamStats was used to estimate annual exceedance probability peak flows at RM 33. It was assumed there were no major perennial tributaries to the Chewuch River between RM 33 and 29. Therefore, in modeling efforts described below, all models are representative of the RM 33 inflow estimation. The StreamStats annual exceedance probability peak flow estimates are documented in table 3. Since the StreamStats program does not estimate flows lower than the 50 percent (%) probability flow, an area-weighted calculation was used to estimate lower, ecologically relevant flow conditions (table 4). The contributing area at RM 33 is approximately 119 square miles compared to 524 square miles at the Chewuch River gage.

Table 3.—StreamStats estimated annual exceedance flows at RM 33 of the Chewuch River

Annual exceedance probability	Recurrence interval (year)	StreamStats predicted flow (ft^3/s)	StreamStats lower prediction interval (ft^3/s)	StreamStats upper prediction interval (ft^3/s)
0.5	2	432	142	1320
0.2	5	682	247	1880
0.1	10	872	304	2500
0.04	25	1120	352	3560
0.02	50	1340	385	4660
0.01	100	1550	410	5860

Table 4.—Area-weighted, ecologically relevant flows based on USGS 12448000 flow data

Flow description	Chewuch gage flow (ft^3/s)	RM 33 estimated flow (ft^3/s)
Mean annual low	47	11
September mean	79	18
March mean	142	32
July mean	412	94

2.3 River Mile 20 to 9 Modeled Hydrology

Because the gage is located at approximately RM 0 and several significant tributaries are located between RM 0 and 20, flows at RM 20 and at each significant tributary from RM 20 to 0 were weighted by area to calculate an approximate recurrence interval flow. Five tributaries between RM 0 and 20, in addition to the mainstem Chewuch River upstream of RM 20, were identified as significant: Twentymile Creek, Falls Creek, Eightmile Creek (at approximately RM 12), Boulder Creek, and Cub Creek (figure 1). Table 5 shows the area-weighted flows for these creeks derived from the Chewuch River gage. Although Cub Creek was included in the calculation of area-weighted flows, only Twentymile, Falls, Eightmile, and Boulder Creeks are relevant to the RM 20 to 9 modeling effort. Cub Creek is included in table 5 to show the accumulation of area-weighted flows to the USGS gage total.

Table 5.—Area-weighted contributing flows in the mainstem Chewuch River and significant tributaries

Flow description	Chewuch River upstream of Twentymile Creek (ft^3/s)	Twentymile Creek (ft^3/s)	Falls Creek (ft^3/s)	Eightmile Creek (ft^3/s)	Boulder Creek (ft^3/s)	Cub Creek (ft^3/s)	Chewuch Gage (ft^3/s)
Mean annual low	22	5	3	4	8	4	47
September mean	36	9	5	7	14	7	79
March mean	65	16	9	13	25	13	142
July mean	189	47	26	39	72	39	412
1.01-yr event	317	79	43	64	121	64	689
1.05-yr event	613	153	84	125	234	125	1333
1.11-yr event	810	202	111	165	309	165	1762
1.25-yr event	1096	273	150	223	418	223	2382
1.5-yr event	1420	353	194	289	542	289	3087
2-yr event	1829	455	250	372	698	372	3977
2023 Peak	2732	680	374	555	1043	555	5940
5-yr event	2822	703	386	574	1077	574	6136
10-yr event	3333	830	456	678	1272	678	7247
25-yr event	3961	986	542	805	1512	805	8612
50-yr event	4710	1173	645	958	1798	958	10240
100-yr event	5413	1348	741	1101	2066	1101	11770

3.0 Topographic Surface Development

Topobathymetry used for analysis and conceptual design was limited to available lidar resources. A 2022 lidar dataset provided topobathymetry (above and below water elevations) for a large portion of the Chewuch River main channel (NV5 Geospatial 2023). However, the 2022 lidar did not encompass the entire floodplain surface. Therefore, the 2022 lidar was mosaicked with topographic lidar (above water only) from 2015 and 2018 in RM 33 to 29 and RM 20 to 9, respectively (figure 2 and figure 3) (Quantum Spatial 2016; Atlantic 2018). Although the 2022 lidar included bathymetric returns, there were locations in which bathymetry could not be accurately measured. This was especially true in the RM 33 to 29 reach. For these gaps in bathymetry, a lower channel bottom was interpolated based on nearby bathymetric returns to approximate the true channel bottom (figure 2). Bathymetric returns were highly successful from RM 20 to 9. Inundated side channel bottoms that exist between RM 20 to 9 were not mapped appropriately in the 2018 dataset. To more accurately describe those side channel conditions, side channel bottoms were linearly interpolated from upstream to downstream using elevations where the channel crossed back into the 2022 topobathymetric lidar (figure 3).

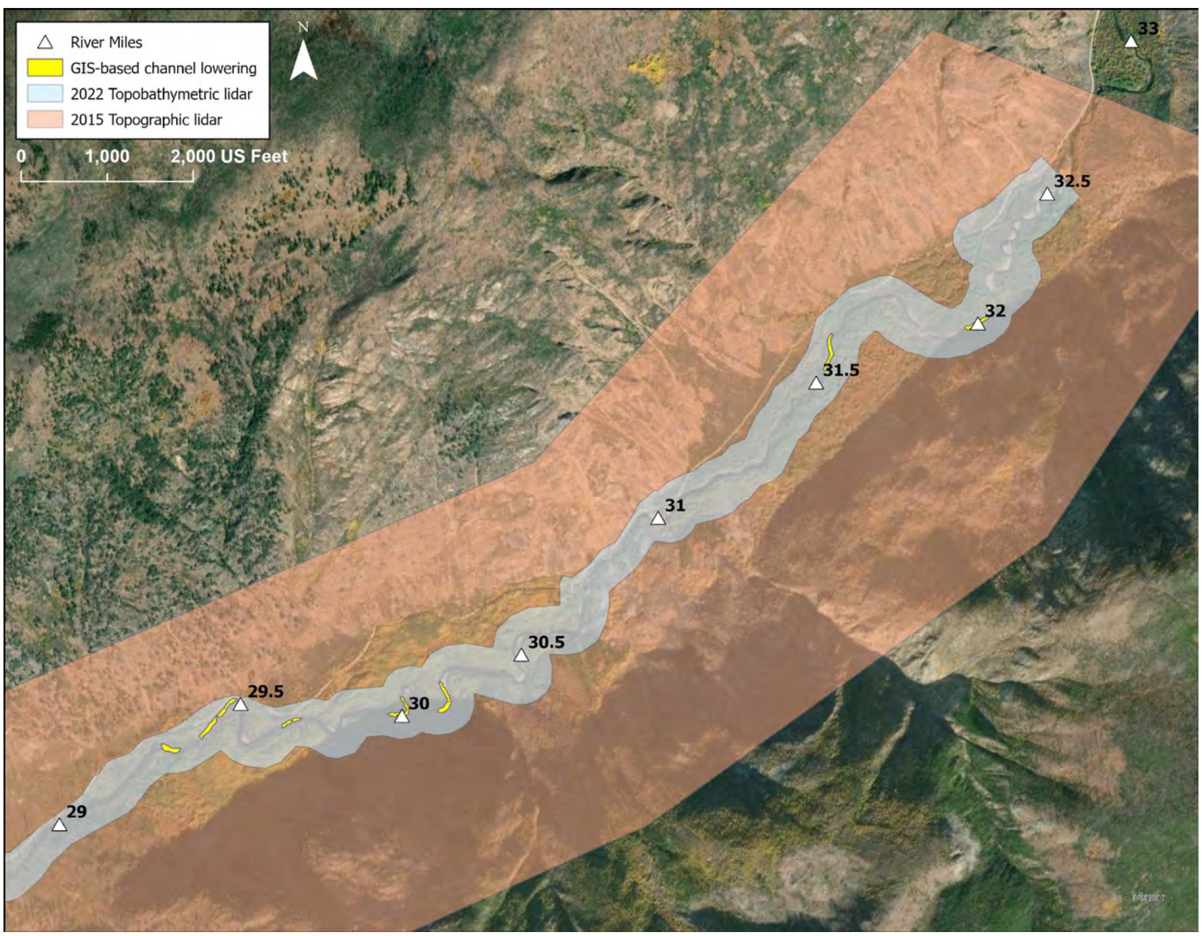


Figure 2.—Lidar and main channel lowering extents between RM 33 and 29.

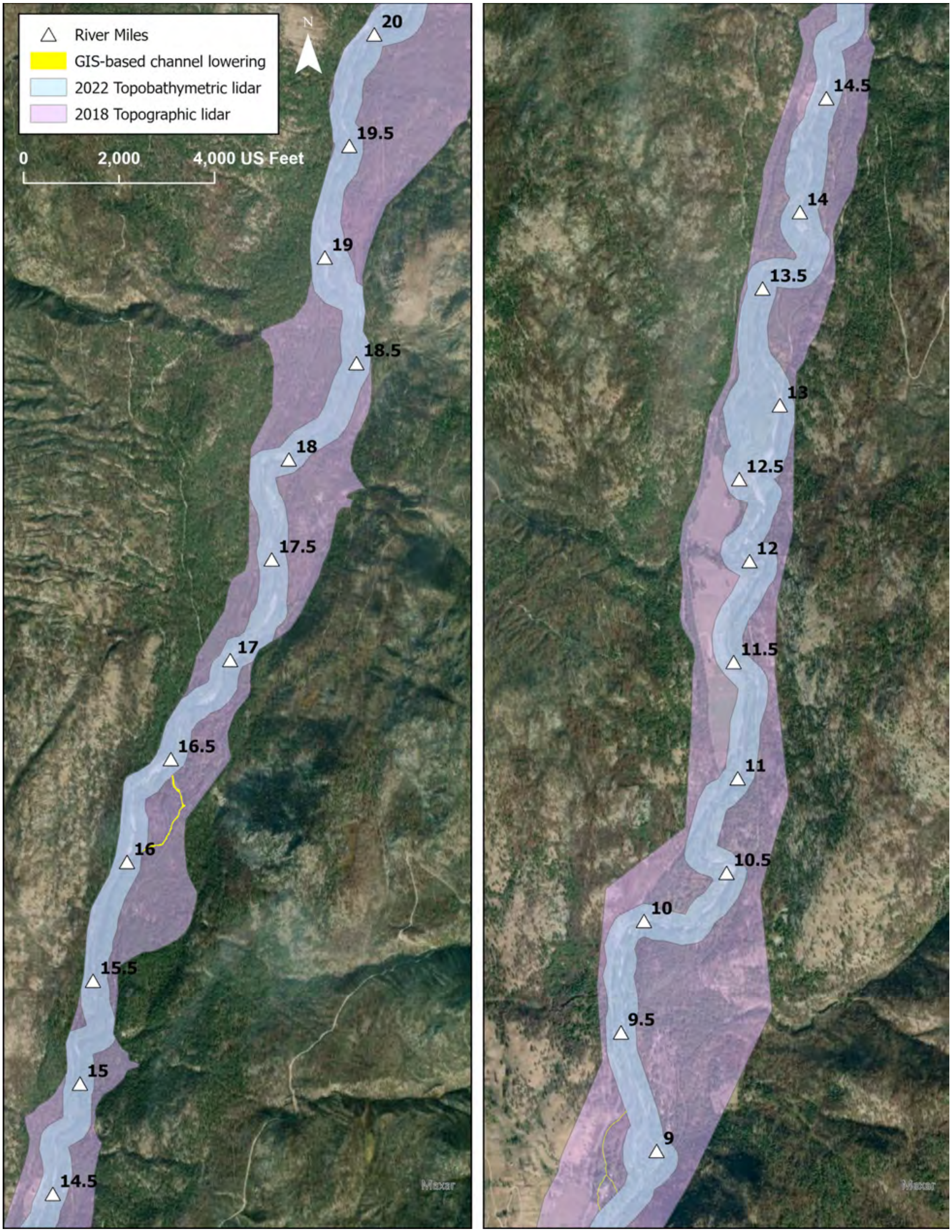


Figure 3.—Lidar and side channel lowering extents between RM 20 and 9.

4.0 Geomorphology

4.1 Methods

4.1.1 Aerial Imagery Mapping

4.1.1.1 *Imagery Sources*

Eight geomorphic features (4.1.1.3) were mapped along the Chewuch River on aerial and satellite imagery datasets using Esri ArcGIS® Pro. Mapping of both RM 20-9 and 33-29 utilized 7 years of imagery. The sources for the mapping were a combination of historical imagery downloaded from USGS EarthExplorer, historical imagery from a previous mapping effort in the Methow basin (1988, Reclamation 2008), United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) imagery (2006, 2013), and TerraColor NextGen imagery from the Esri World Imagery Basemap (2023). The historical imagery sources covered 1947, 1957, and 1975 for RM 20 to 9 and 1953, 1968, and 1975 for RM 33 to 29. The other imagery sources (1988 to 2023) were used for both sections of the river (table 6).

Table 6.—Aerial imagery years and sources for geomorphic mapping of RM 20–9 and RM 33–29

River Mile	Year	Source
RM 9-20	1947	USGS EarthExplorer
	1957	USGS EarthExplorer
	1975	USGS EarthExplorer
	1988	Methow Tributary Assessment
	2006	USDA NAIP
	2013	USDA NAIP
	2023	Esri World Imagery Basemap
RM 29-33	1953	USGS EarthExplorer
	1968	USGS EarthExplorer
	1975	USGS EarthExplorer
	1988	Methow Tributary Assessment
	2006	USDA NAIP
	2013	USDA NAIP
	2023	Esri World Imagery Basemap

The imagery from 1988 and later was georeferenced prior to the start of this mapping effort. We georeferenced any imagery prior to 1988 using a spline transformation in ArcGIS® Pro. The spline transformation is based on a spline function and is optimized for local, but not global accuracy. The spline transformation moves source control points exactly to the location of target control points, minimizing error. Pixels at a distance from the control points are not guaranteed to be accurate.

4.1.1.2 *Relative Elevation Models*

We created relative elevation models (REMs) for both reaches of the Chewuch River (figure 4). REMs are used to show the elevations in the valley relative to the elevation of the bed of the main channel. To create the REMs, we used the same topobathymetric, lidar-derived digital elevation models (DEMs) that were used in the modeling efforts. For each reach, we create a channel centerline feature. We then generate points along that line that are spaced at approximately the channel width of 50 feet (ft). The 'Extract Values to Points' tool is used to extract elevation values from the DEM raster. The inverse distance weighted (IDW) tool is then used to create an interpolated raster that represents the channel bed elevation projected across the floodplain. This raster is set to have the same extent and cell size as the original DEM. The IDW DEM is then subtracted from the original DEM to create the REM. We used the REMs and lidar hillshade to aid in the geomorphic mapping, especially for the modern imagery years.

Anywhere that the REM is negative, the original DEM elevation is lower than the adjacent riverbed elevation. Anywhere the REM is positive, the original DEM elevation is higher than the riverbed. This is especially useful to identify side channels and overflow channels in densely vegetated areas of the floodplain. We also created height above water surface REMs using the model results outlined in Section 5.0 (Jones 2006). These maps show the land surface relative to the water surface elevation for different magnitude flows to visualize inundation (appendix A).

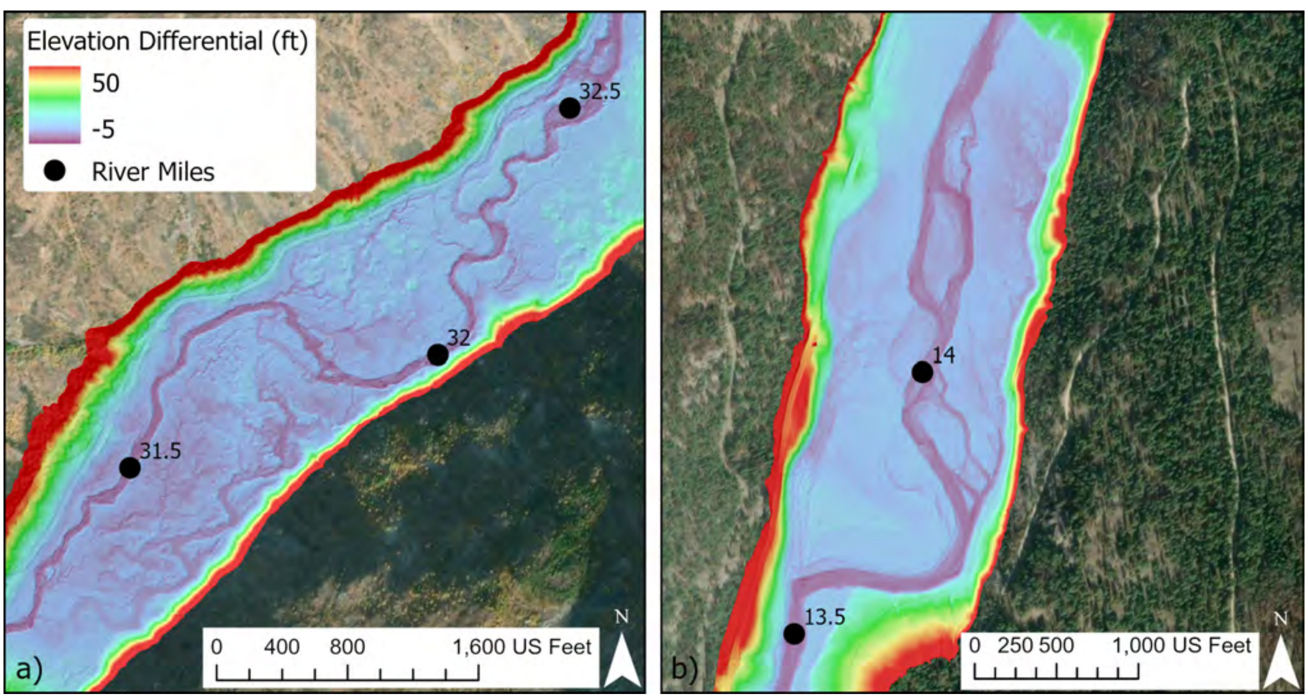


Figure 4.—Example relative elevation models (REMs) for the upper (a) and lower (b) reaches of the Chewuch River. Elevations are colored relative to the bed elevation along the channel centerline. Positive values are higher than the elevation of the channel, and negative values are lower. Anywhere with a lower elevation (purple colors) is either already connected to the main channel or would be a low effort to reconnect.

4.1.1.3 *Geomorphic Units*

Once the imagery was georeferenced, we used it as a base for mapping the following geomorphic units:

1. **Active channel (Qac)** is mapped at the wetted perimeter of the active channel in the aerial imagery. Where multiple channels are present, the widest channel is mapped as the Qac.

2. **Side channels (Qsc)** are channels with defined beds and banks that have inlet and outlet connections to the mainstem channel. In older imagery years where channels are difficult to distinguish, this serves as a higher confidence rating than an overflow channel.

3. **Overflow channels (Qoc)** are channels with defined beds and banks that only receive flow at high discharges. They can originate from another channel or from unvegetated alluvium.

4. **Vegetated islands (Qb1)** are bars vegetated with dense shrubs or trees that are surrounded by channel (active channel, side channel, or overflow channel).

5. **Unvegetated bars (Qb2)** are bars that are bare or sparsely vegetated with small shrubs and grasses, indicating frequent inundation. This includes lateral bars, point bars, and mid-channel bars.

6. **Fans (Qfan)** are deposits of sediment at the mouth of tributary or debris flow channel junctions with the main valley. This includes alluvial fans and debris flow fans.

7. **Holocene alluvium (Qa)** includes valley alluvium that lies outside of the mapped active geomorphic features outlined above. This ranges in age from abandoned floodplain to Holocene. The boundary of the Holocene alluvium was mapped at the edge of the main valley. This unit typically comprises vegetated glacial till.

8. **Landslides (Qls)** are mapped in areas of hillslope displacement and are often noted by lack of vegetation in early years. These features can be located within or outside of the bounds of Qa.

We define the active geomorphic corridor as the combination of channels (Qac, Qsc, Qoc) and unvegetated bars (Qb2) to represent the portion of the mapped area that is frequently inundated and dynamic. This defines the part of the valley bottom that exhibits connected floodplains and actively used channels. When the river erodes into previously vegetated areas, the size of the active corridor, and therefore the geomorphic diversity, increases. Conversely, vegetation encroaching on previously bare bars or overflow channels stabilizes the banks of the channels and decreases the active corridor area and mobility of the channel.

For each year of available imagery, we mapped the geomorphic units in the reach. The older imagery (1988 and prior) was of worse quality and resolution than the newer imagery, and therefore confidence levels are lower for these years. These imagery datasets were also black and white, while the newer imagery was in color. When possible, we used consecutive imagery years to help in defining geomorphic units. The REM was used to help identify fans and channels in all years. For RM 29-33, we created a separate shapefile with point locations of observed large wood (figure 5). A single point was placed for each cluster of wood within the active channel and any side channels. No large wood was observed in the lower reach.

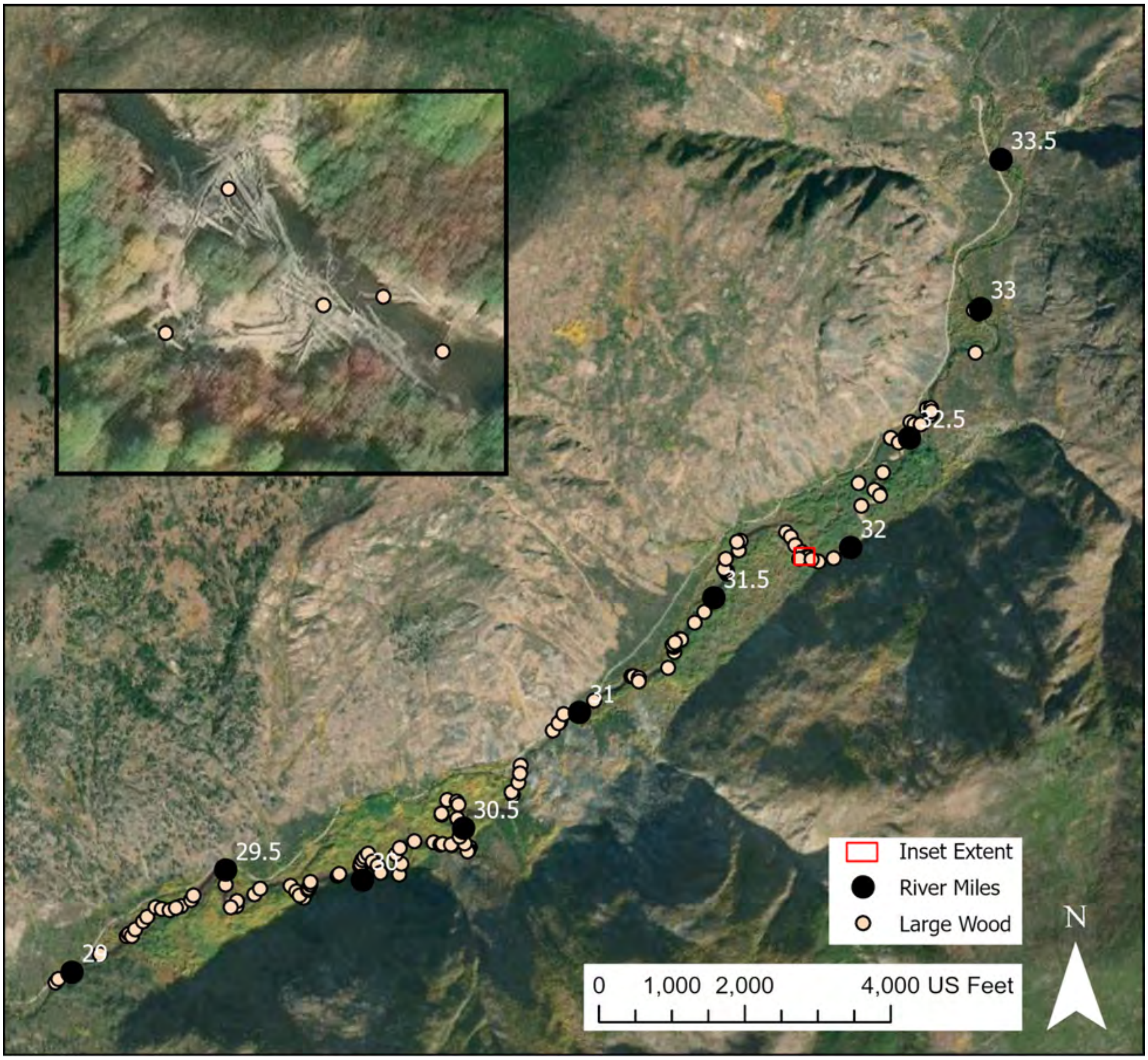


Figure 5.—Large wood mapping from River Miles 33 to 29. A point represents each cluster of large wood within the main channel and side channels (see inset). Wood is present throughout the entire reach.

4.1.2 Field Mapping

We conducted a field mapping effort in October 2023 to validate the aerial and satellite imagery mapping outlined above. In the field, we used the program StraboSpot installed on an iPad® to create shapefiles of observed features. We waded the river from upstream to downstream. Anywhere there was a flow split, one person traveled down each flow path. We noted anywhere we saw evidence of side channels and overflow channels, including flotsam, which is evidence of recent flow. As we mapped, we used the REM and aerial imagery as a basemap and tried to confirm evidence of low-confidence channels from the REM. We also made observations of bank erosion and channel bed composition (figure 6). We did not map wood in the field but did note locations of observed beaver dams (figure 7).

Figure 6.—Bank erosion in the vicinity of River Mile 31.25 is indicative of channel widening or lateral migration (photo by Aaron Hurst/Bureau of Reclamation).

Figure 7.—A large, channel-spanning beaver dam near River Mile 31.5. Photo taken looking upstream (photo by Aaron Hurst/Bureau of Reclamation).

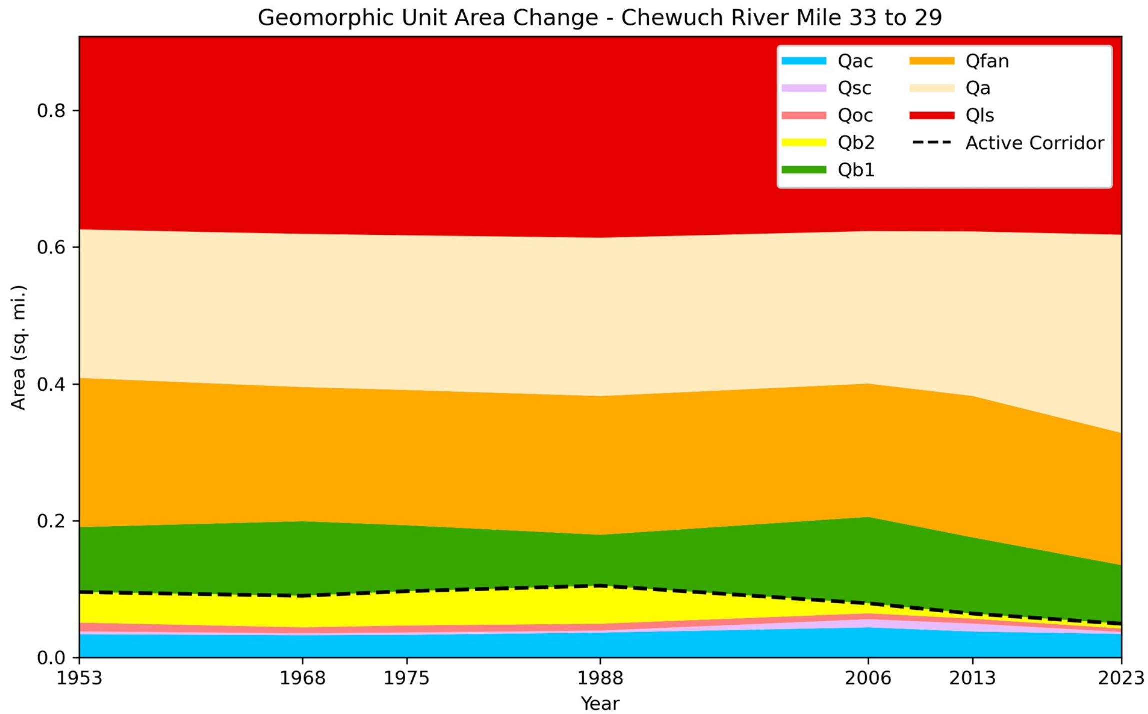
For the upper reach, we started at RM 33 and walked downstream to RM 29. We stepped out of the river to the road between RM 30.75 and RM 29.75, which is noted in the field mapping shapefile. In the RM 20 to 9 reach, we started at Twentymile Creek (approximately RM 20) and walked downstream to RM 2.5. We stepped out of the river to walk on the road between RM 17 and 16.5, 16 and 14.5, 12 and 10.5, and 10 and 9.25.

We used the field map and notes to validate the Geographic Information System (GIS) mapping effort from 2023 aerial imagery. If a channel inlet and outlet were noted on the field map and the channel was visible on the REM but not in the aerial imagery, we used the REM to include that channel in the 2023 map. If the channel was not visible in either the REM or the aerial imagery, which was only the case for flow around bars, we did not include it in the final map but left the field note in the field map for reference.

4.2 Historical Geomorphic Change

4.2.1 River Miles 33 to 29

The river channel from RM 33 to 29 has experienced little change in the area of the active corridor between 1953 and 1988 (figure 8). There has been a steady decline in the active corridor area since 1988, decreasing by a total of 47%. Unvegetated bars and wetland complexes upstream of the large landslide at RM 31 have shrunk in size and been replaced by Holocene alluvium (figure 9). However, the area of side channels slightly grew in the mid-2000s before declining back to 1988 levels. This could be a result of post-fire sediment and wood in the channel damming it and creating backwater channels. This reach has exhibited active landslides and steep hillslope transport throughout the entirety of the available imagery. It is likely that the most significant geomorphic changes in this section of river occurred prior to the available aerial imagery during and after logging in the 1800s. The effects of the historical floods cannot be seen in the aerial imagery mapping.



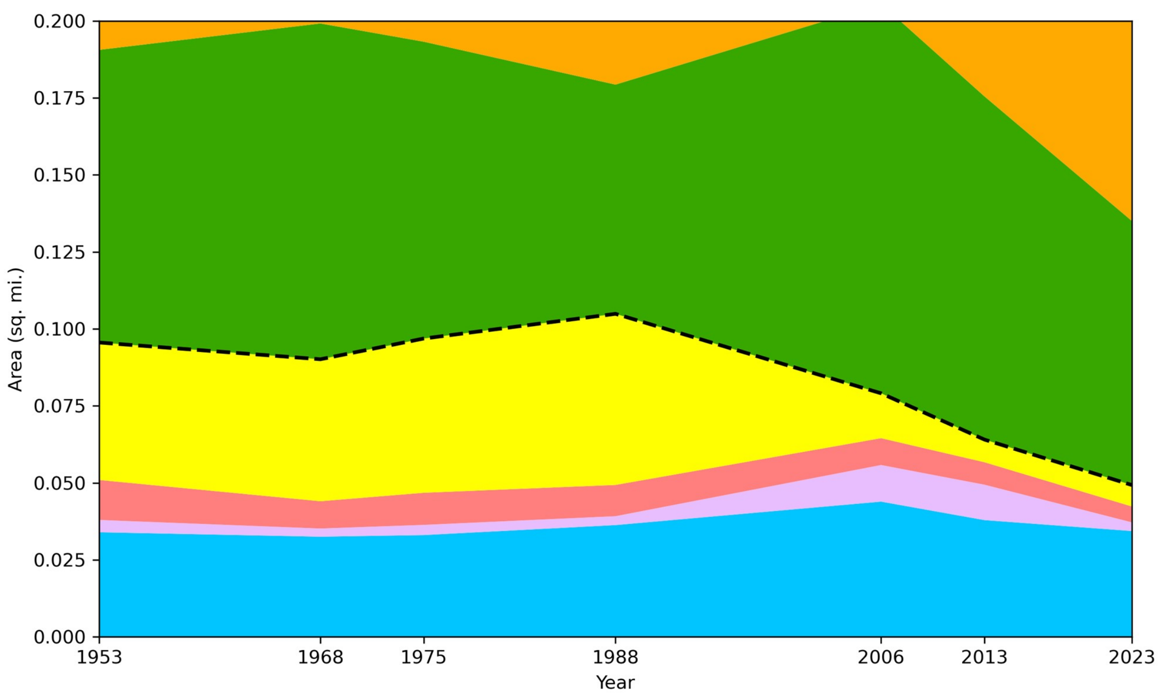


Figure 8.—Geomorphic unit area change from RM 33 to 29. The active channel (Qac), side channels (Qsc), overflow channels (Qoc), and unvegetated bars (Qb2) comprise the active geomorphic corridor. Vegetated bars (Qb1), fans (Qfan), Holocene alluvium (Qa), and landslides (Qls) are outside of the active corridor. The top figure shows the change in all geomorphic units. The zoomed in area in the bottom figure shows a decline in the active corridor area replaced by Holocene alluvium, indicating a decline in geomorphic diversity.

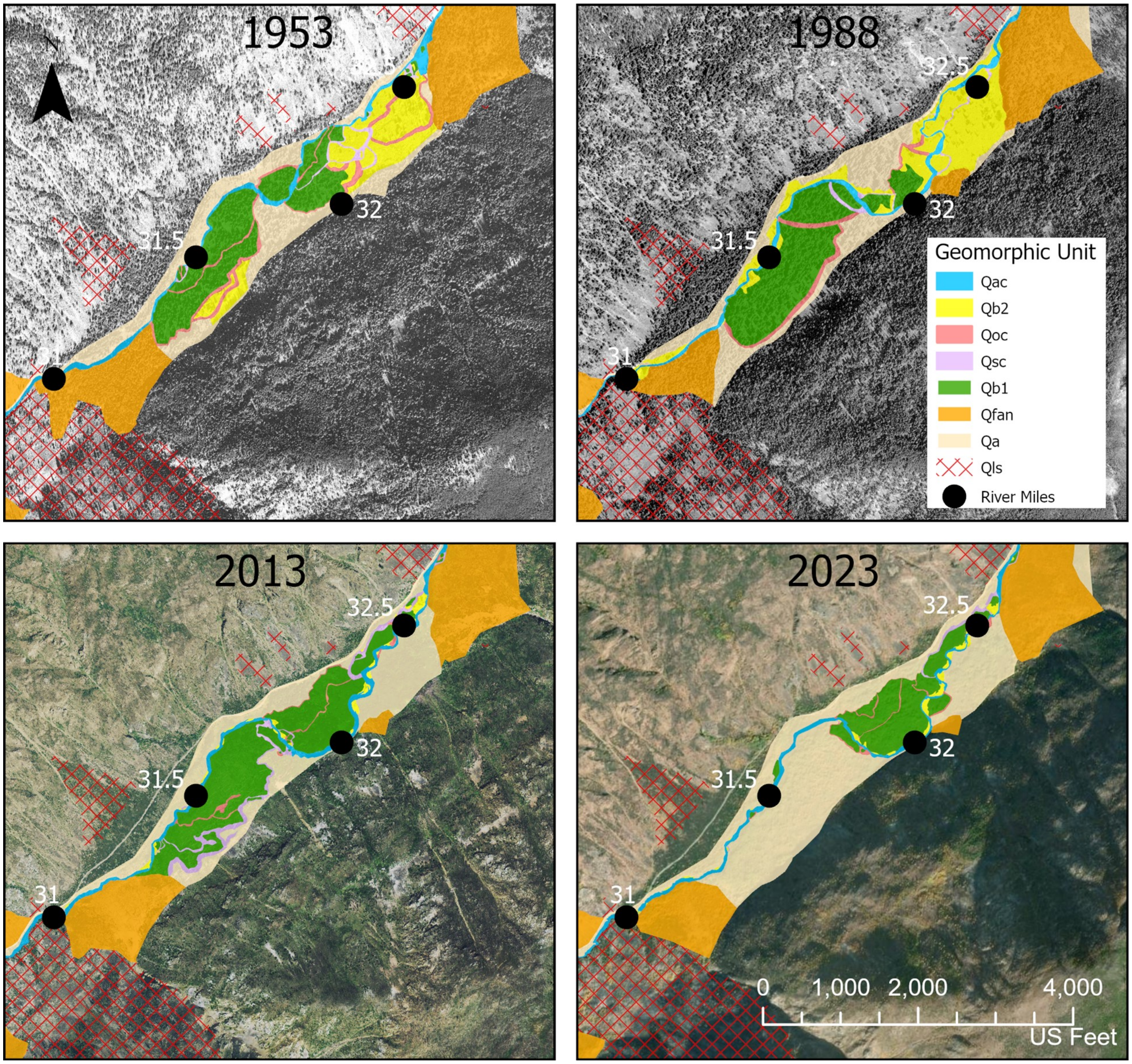


Figure 9.—Geomorphic change upstream of the large landslide at RM 31 (modern river miles). From 1953 to 2023, the large side channel complex has shrunk in size and been replaced by Holocene alluvium (Qa).

4.2.2 River Miles 20 to 9

The river channel from RM 20 to 9 has similarly experienced little change in the active geomorphic corridor (figure 10). A slight increase in unvegetated bars occurred between the 1947 and 1957 imagery, which could be a result of increased sediment transport following the 1948 flood. After 1957, the size of the geomorphic corridor remained relatively consistent until 1988, at which point it slowly declined as the area of unvegetated bars, side channels, and overflow channels decreased. However, this area decrease was not from vegetation of bars, as vegetated bar area decreased as well, but rather from an increase in fans confining the channel area. It is important to note that some of this change could be due to changes in image quality as more modern technology allows for higher resolution imagery in the later years (post-1988). It is also likely that this reach experienced the most change in the 1800s because of logging. The 2021 Cub Creek Fire had little effect on the geomorphology observed from imagery, but did affect the sediment in the channel, which we outline below. It is possible that the fire effects were not visible by 2023 but will become apparent in future mapping efforts.

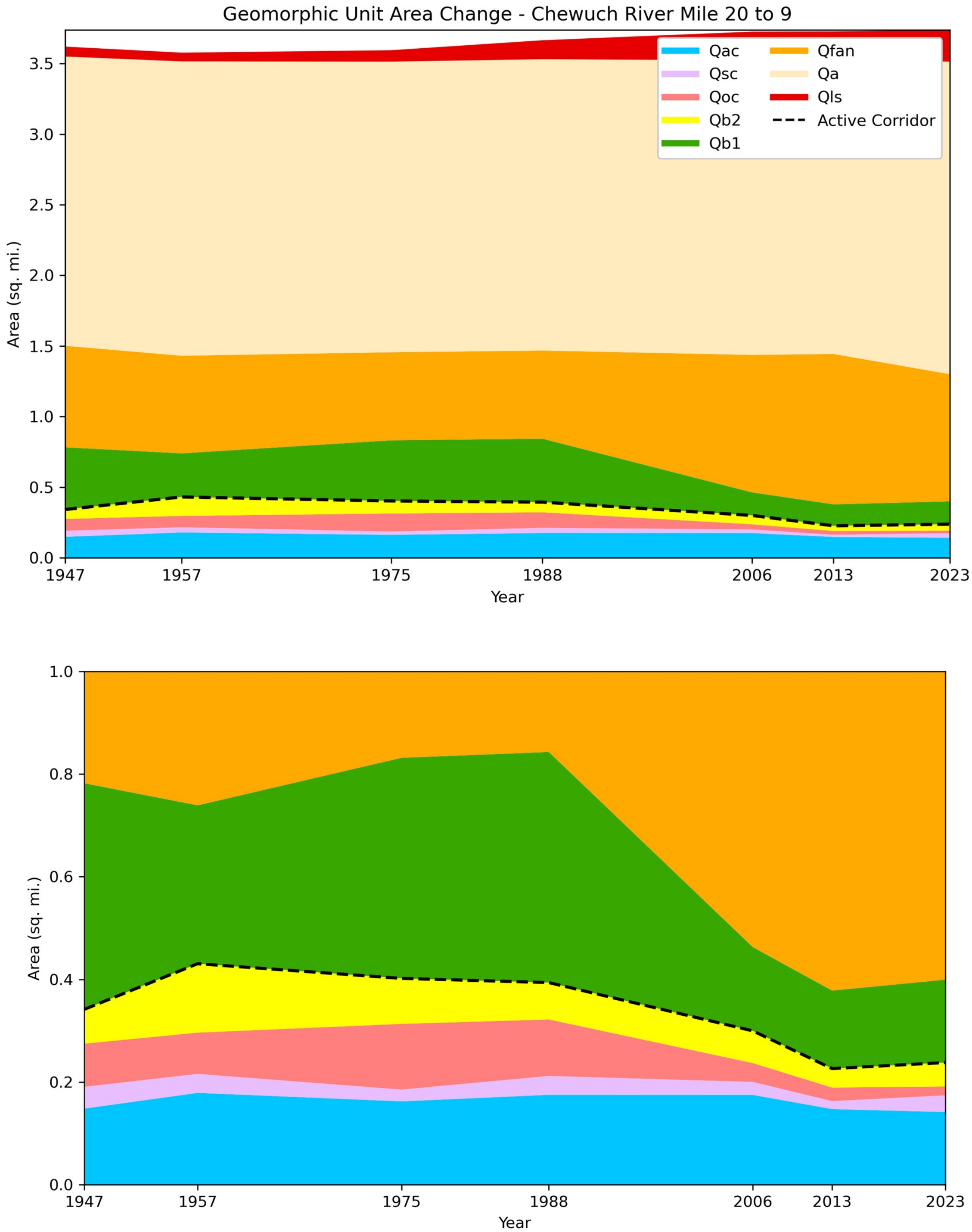


Figure 10.—Geomorphic unit area change from RM 20 to 9. The active channel (Qac), side channels (Qsc), overflow channels (Qoc), and unvegetated bars (Qb2) comprise the active geomorphic corridor. Vegetated bars (Qb1), fans (Qfan), Holocene alluvium (Qa), and landslides (Qls) are outside of the active corridor. The top figure shows the change in all geomorphic units. The zoomed in area in the bottom figure shows a decline in the active corridor area replaced by Holocene alluvium, indicating a decline in geomorphic diversity.

4.3 Current Geomorphic Conditions

4.3.1 River Miles 33 to 29

The reach from RM 33 to 29 has the characteristics of a rapidly uplifting valley out of equilibrium with the frequent mass wasting on the valley walls. If it was ever glaciated, it likely was covered by purely erosional ice with no glacial deposits left behind. No glacial till was observed in the hillslopes, but the section of river upstream of this reach and the downstream sections of the Chewuch River are eroding into glacial till deposits. The valley walls are steep, and the channel is wide. Large boulders, debris flow chutes and fans that often indicate flow reactivation, and avalanche scars that result in shallow slope failures dominate the valley walls. Rock fall covers the slopes in talus. The valley walls are bare of vegetation, but it is not possible to determine if this is from rockfall or from the 2001 Thirtymile Fire. A massive landslide displaces material deep into the fractured bedrock adjacent to RM 31 (figure 11). These highly active hillslopes and valley walls exert a major control on the channel mobility and erosion in this reach.

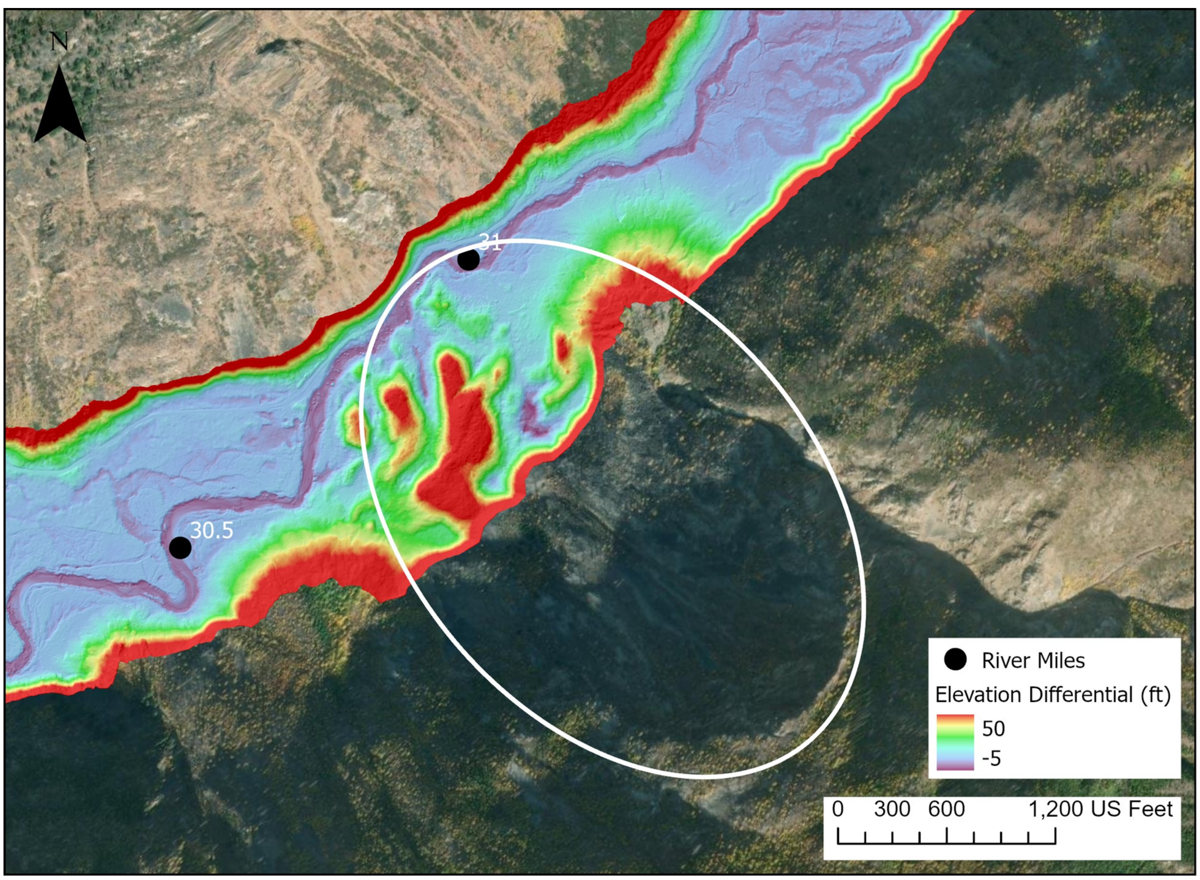


Figure 11.—The large landslide adjacent to River Mile 31 is circled in white. The scar can be seen in the underlying 2023 Esri World Imagery basemap and the deposits stand out in red in the relative elevation model.

The landslide at RM 31 is exerting the primary control on the gradient of the upper portion of the reach, with the upstream valley exhibiting a flat gradient that steepens through the landslide deposits. The landslide and large alluvial fans at RM 29 and RM 33 pin the channel against the right valley wall at those locations. The alluvial fans similarly create a lower gradient channel in the sections upstream of them. This results in the entire reach exhibiting long pools due to the landslide depositing large boulders that are difficult for the river to transport. These boulders serve as key pieces that rack large wood and create localized pools upstream. Beavers and naturally rafted wood impart a secondary control on the extent of the pools upstream of the landslide and downstream of the alluvial fan. Much of the wood in the channel is between 6-inches and 2-ft in diameter. Downed trees on the hillslopes from the 2001 fire will further contribute to wood loading in the reach.

The banks lining the pools on both sides of the channel are often silty, well-developed soils that indicate less recent deposition. Progressing upstream in the channel, the banks exhibited younger silts that were more recently sourced from channel overtopping. These banks are laterally eroding, especially downstream of the landslide at RM 31. There was no clear evidence of vertical incision. The grain size distribution in the channel is bimodal: sand and pea gravel and very large (5–10-ft diameter) boulders.

4.3.2 River Mile 20 to 9

RM 20 to 9 is largely characterized by past glaciation. The valley is wider than that from RM 33 to 29 and is underlain by thick deposits of granitic glacial till. The river has eroded through the till to contribute a large range of sediment sizes to the channel. This serves as the primary source of sediment on the bars and within the channel for most of the reach. The entirety of the reach showed minimal beaver activity, with only three beaver dams observed in the 11-mile reach at the outlet to three different side channels. Most of the wood within this segment of channel is from constructed engineered log jams, with minor natural wood rafting on bars. Several of these structures burned in the 2021 Cub Creek Fire (Hanraham et al. 2023).

From RM 20 to 10.5, the active channel has minimal direct connection with the existing available floodplain. The only connected side channels are around bars throughout most of this section of river. The exception to this is a side channel from RM 16.5 to 16 and the side channel complex at RM 13 (figure 12). Fluvial terraces up to 13-ft high along the channel could possibly be reconnected by the 10- or 100-yr recurrence interval flood (appendix A). The surfaces of these terraces are well-sorted sand. Side channels on these surfaces are typically perched above the main channel and could be previous main channel locations (figure 13). Overland flow appears to collect on these terrace surfaces and channelize, rather than connecting to the main channel at the inlet. The connected overflow channels had abundant flotsam that sometimes reached 2 ft in height. The bed material in the main channel exhibited evenly distributed grain sizes comprised of golfball to softball-sized cobbles and boulders with some interstitial sands. In the upper part of this segment, the mouths of some of the overflow channels had golf-ball sized gravels.

Downstream, the channel bed transitioned to volleyball-sized cobbles in the main channel with sand and gravel on the bars. The bars don't alternate regularly, perhaps because the channel is too narrow or steep. Downstream of RM 17, the channel had more heterogeneity with pool-riffle sequences, split flows around islands and bars, and an abundance of deep pools. Downstream of Boulder Creek (RM 10), the channel was steep with large boulders in the bed.

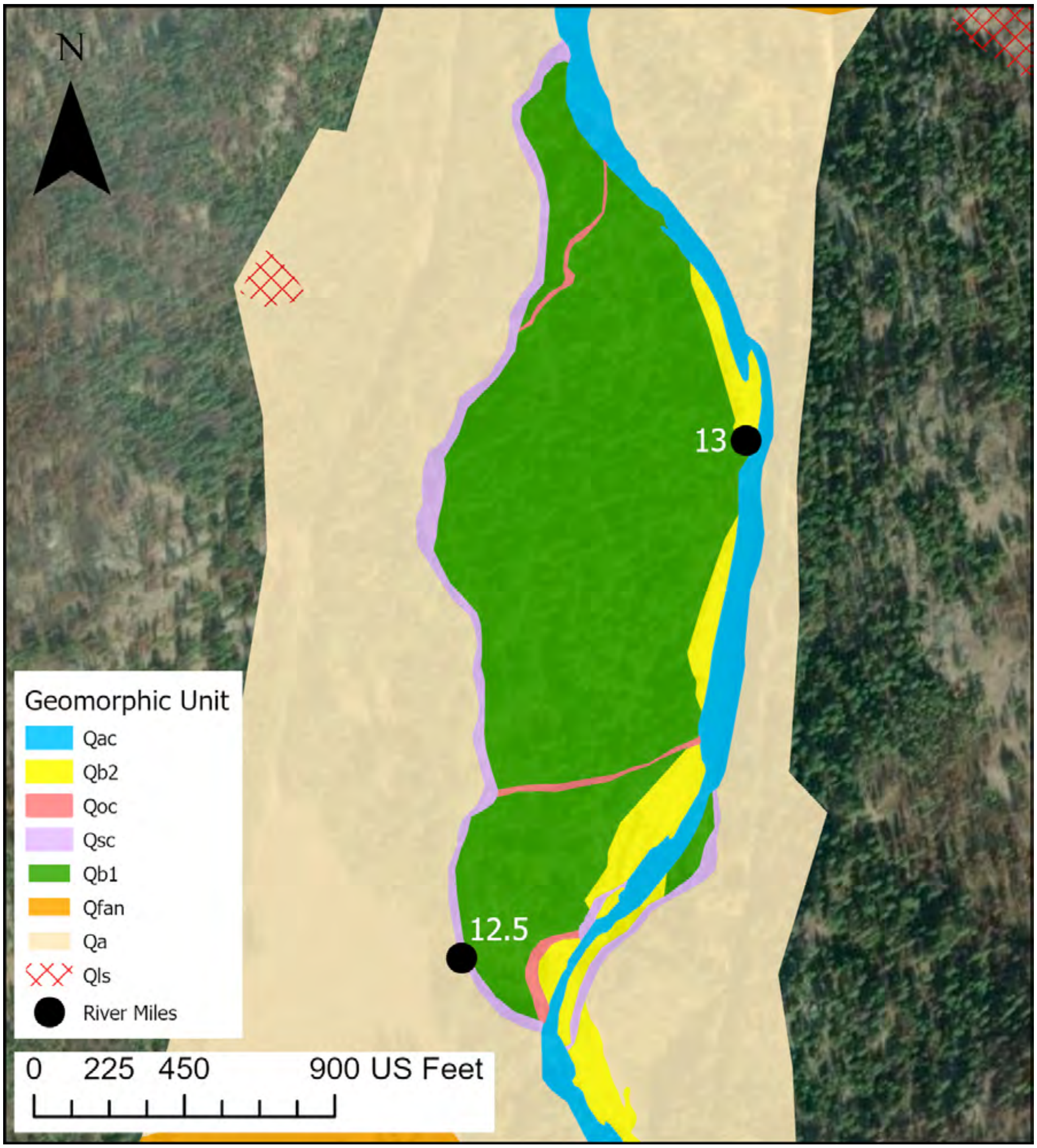


Figure 12.—Side channel complex near RM 13 in 2023. The active channel (Qa), side channels (Qsc), overflow channels (Qoc), vegetated and unvegetated bars (Qb1 and Qb2), alluvial and debris flow fans (Qfan), Holocene alluvium (Qa), and landslides (Qls) are mapped on 2023 aerial imagery.

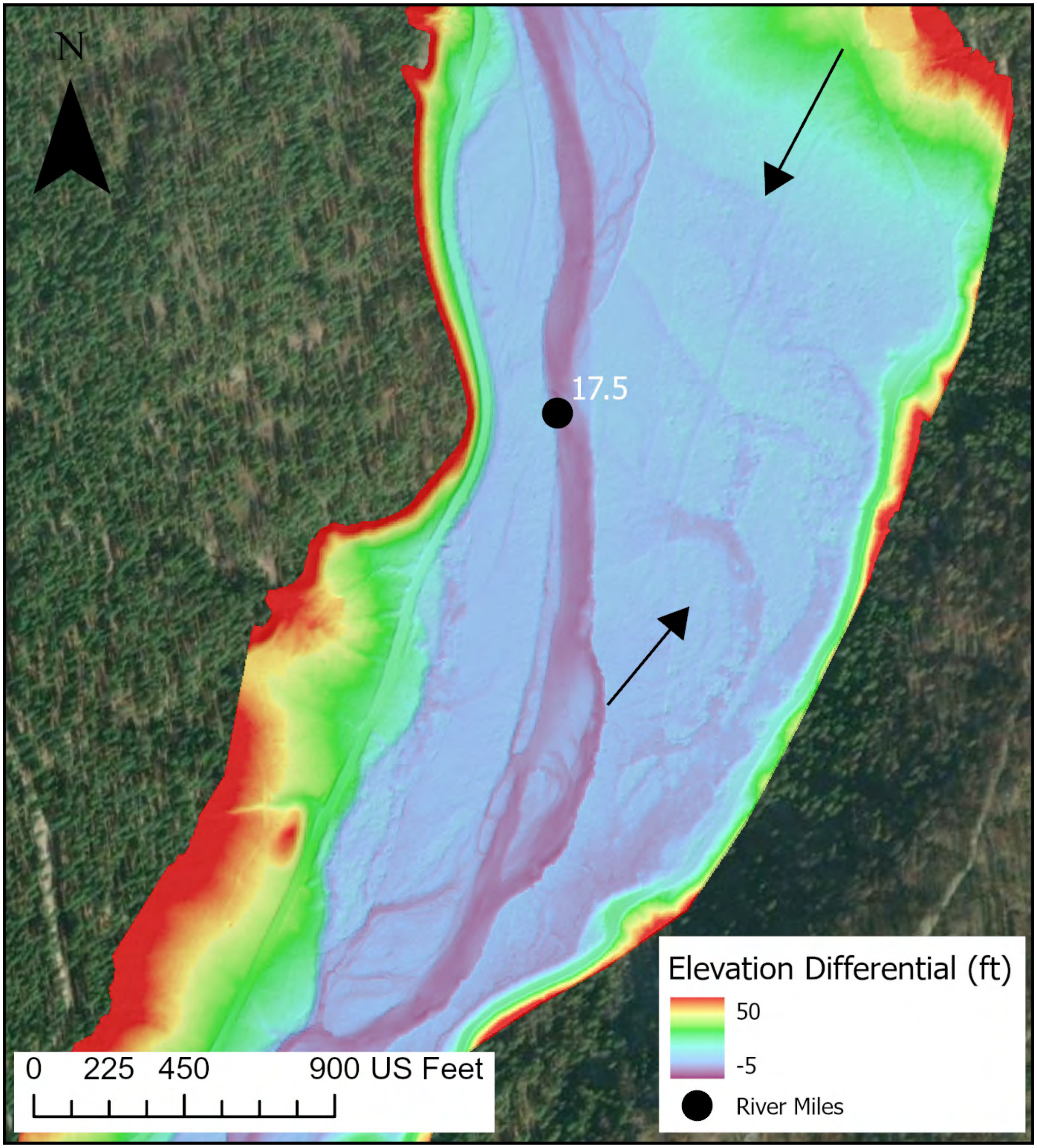


Figure 13.—Disconnected channels on the terrace near RM 17.5. The black arrows point to some of the relict channels on the relative elevation model.

Few tributary inputs were observed between Twentymile Creek (RM 20) and Fall Creek (RM 15), but they could be perched above the main channel. Downstream of RM 15, the channel displays increasing amounts of fine sediment input. This material ranges in size from mud and silt to sand and is likely related to the 2021 Cub Creek Fire. This fire removed a lot of vegetation in the tributaries to the Chewuch River, triggering landsliding that contributed large quantities of sediment to the tributary channels. A lot of the sand from the tributaries has deposited within the Chewuch River and is still being reworked downstream, filling many of the large pools in the channel and depositing on bars. Some of the riffles downstream of RM 11 were buried in fine sediment.

Several spots along this channel segment display undercut banks that indicate lateral fluvial erosion. At these locations, trees at the river's edge that are close to toppling could be felled to trigger additional natural wood rafting for restoration purposes.

5.0 Numerical Modeling

5.1 Modeling of River Conditions

Reclamation's Sedimentation and River Hydraulics Two-Dimensional 3.6.2 model (SRH-2D) was used to assess flow hydraulics along the Chewuch River. Aquaveo's Surface-water Modeling System 13.3 (SMS) was used to create model meshes, parameterize Manning's roughness, and set boundary conditions. For this effort, the fixed bed numerical model with no sediment transport was utilized. The model simulated a range of steady-state discharges to predict two-dimensional (2D) hydraulics for a range of flow conditions and topobathymetric surfaces.

5.1.1 River Miles 33 to 29 Models and Mesh

Two separate models were created between RM 33 and 29 based on the defining geomorphic characteristics of the reach. A large historical landslide has split the reach into two relatively flat valley bottoms with a steeper section approximately halfway through the reach. Therefore, models for RM 33 to 31 and RM 31 to 29 were created. Modeled terrain was derived from topobathymetric lidar collected in 2022 (NV5 Geospatial 2023). Because the 2022 bathymetric lidar focused on the main channel of the Chewuch River, elevation data were supplemented with 2015 terrestrial lidar to fully encompass the floodplain (Quantum Spatial 2016). Each model used an average channel element size of approximately 15-square feet, which expanded to approximately 100-square feet at the outer floodplain margins.

5.1.2 River Miles 20 to 9 Models and Mesh

Two overlapping models were developed extending from approximately RM 20 to 15, and RM 15 to 9. Model results were then stitched together to create a seamless prediction of existing conditions approximately between the Chewuch River confluence with Boulder Creek at the downstream extent and the Chewuch River confluence with Twentymile Creek at the upstream extent. Modeled terrain utilized a combination of the 2022 bathymetric lidar and 2018 terrestrial lidar where 2022 lidar was not available (NV5 Geospatial 2023; Atlantic 2018). The 2018 terrestrial lidar was not available between RM 33 and 29. Both lower reach models used an average channel element size of approximately 32-square feet, which expanded to approximately 400 square feet at the outer floodplain margins.

5.1.3 Model Roughness

Roughness, representing resistance to flow, is defined within the models using Manning's roughness coefficient. Coefficients were defined based on channel form, substrate, and floodplain vegetation characteristics. Values for Manning's roughness were informed based on historical literature and local modeling of the Methow River downstream of the Chewuch River (Chow 1959; Reclamation 2019). Roughness type boundaries were digitized using aerial imagery and informed based on observations during a site visit. Roughness values used in the two models are detailed in table 7 and table 8.

Table 7.—Land cover type and associated Manning's roughness *n*-values for River Miles 33 to 29

Land cover type	Roughness
Pool-riffle channel	0.035
Step-pool/cascade channel	0.045
Side channel	0.045
Road	0.023
Dense floodplain vegetation	0.09
Alluvial fan	0.08
Mountain slope	0.08
Boulders	0.06
In-channel large wood	0.15

Table 8.—Land cover type and associated Manning's roughness *n*-values for River Miles 20 to 9

Land cover type	Roughness
Main channel	0.03 to 0.045
Moderate density floodplain vegetation	0.06
Side channel	0.045
Vegetated bar	0.023
Forest	0.08
Prairie/open field	0.035
Open water	0.02
Concrete remnants in channel	0.15
Boulders	0.06
In-channel large wood	0.15

5.1.4 Model Boundary Conditions

Boundary locations were placed at locations upstream and downstream of areas of interest. Due to the lack of field data, downstream boundary conditions could not be calibrated. Normal depth was calculated for the downstream boundary based on local roughness and channel slope values. For the RM 33 to 29 models, the downstream boundaries of both models were placed in steep sections on the downstream end of the relatively flat valleys to best limit any boundary error propagation upstream.

For the RM 20 to 9 models, the individual RM 20 to 15 and RM 15 to 9 models were developed to overlap and boundary effects between RM 20 and 9 were removed. Within overlapping areas, boundary effects were removed by examining both model outputs and prioritizing results from the downstream model where the two models did not match. This ensured that the upstream model had no downstream boundary impacts, and the downstream model had no upstream boundary impacts to flow predictions. The RM 9 to 0 model continued through the confluence of the Chewuch River with the Methow River to a location on the Methow River. Methow River flows were modeled as a mean July flow (1,520 ft^3/s) or a 2-yr recurrence interval flow (9,860 ft^3/s) for Chewuch River flows below and above the 2-yr recurrence interval flow, respectively.

Upstream and tributary boundaries were defined by the range of inflow as defined in Section 2.0 Hydrology. For RM 33 to 29, we modeled the mean annual low, July mean, 2-yr, and 10-yr flows (table 3 and table 4). For RM 20 to 9, we focused on the September mean, July mean, 2-yr, and 10-yr flows (table 5). The RM 33 to 29 models were only defined by an upstream boundary, while the RM 20 to 15 models included an upstream Chewuch River boundary as well as tributary inflow boundaries (figure 1)for Twentymile and Falls Creeks. The RM 15 to 9 model included an upstream Chewuch River boundary and tributary inflow boundaries for Falls, Eightmile, and Boulder Creeks. The RM 9 to 0 model included an upstream Chewuch River boundary, a Cub Creek tributary boundary, and a Methow River inflow boundary.

5.1.5 Modeling of Design Features

Design features for the restoration concepts included beaver dam analogs (BDAs), post-assisted log structures (PALSs), large wood (LW), and boulders. These features were directly incorporated to the topography by increasing the channel elevation at feature locations. Topography for the BDAs and PALSs were raised approximately three feet above the lowest elevation along the structure length. The BDAs and PALSs were enforced within the model mesh for one cell width to ensure the feature was represented. Elevations at LW features were raised based on the number of overlapping logs within the structure. Structures with two logs were raised approximately three feet while structures with three logs were raised approximately 5 ft to approximate the 18-inch diameter size of the wood. Individual LW logs within the design concepts were created to be 40-ft in length. Mesh elements completely within the boundary of a wood structure were raised, while only mesh element nodes that intersected with the wood were raised if the entire element was not within the bounds of the LW structure.

5.1.6 Model Performance and Limitations

Modeling for the development of restoration concepts was conducted without field collected calibration data. A high-water mark elevation from the spring of 2023 was available. At this location the model water surface was within 0.2 ft, which is a fairly accurate result. Typically, roughness values would be altered to calibrate the model or improve performance metrics. However, with only one data point, the model was not calibrated as one data point was not enough information to know if changes to roughness values were altering model performance in a detrimental way in other locations.

In addition to the lack of field data for model calibration or performance testing, the modeling was limited to existing flow information. As discussed in the hydrology section of this report, USGS StreamStats helped to inform flows between RM 33 and 29. For RM 20 to 9, an area-weighted approach was applied based on the only available gauge data at RM 0. Future modeling and design would likely benefit from improved understanding of flows between RM 33 and 29 and the contribution of flows from tributaries along RM 20 to 0 and how these contributions accumulate to the USGS Chewuch River gage.

As discussed in Section 3.0 Topographic Surface Development, modeling was conducted using the most recent lidar data along each reach of the Chewuch River. Two main issues were identified in the lidar data: 1) within RM 33 to 29, the 2022 lidar failed to record accurate channel bathymetry in many locations, and 2) along RM 20 to 9, the 2018 lidar failed to accurately measure two side channels. Both the RM 33 to 29 main channel and the RM 20 to 9 side channels were adjusted using GIS methodologies. Modeling would be improved by field surveys in these areas.

For restoration design concepts, BDAs, PALSs, and LW were represented as elevated obstructions from the channel bed. There is not a perfect way to represent LW, BDAs, or PALSs within a two-dimensional hydraulic model (Addy and Wilkinson 2019; Sixta and Ubing 2019).

All three types of structures are porous. Currently there is no method in which a computational cell can be represented with a porosity instead of a fully porous or fully obstructed cell. Therefore, elevations were raised for the core of these structures. It is assumed that the constructed BDAs, PALSs, and LW structures in the concept designs would be relatively dense, thus justifying the raised bed elevations. Bed elevations at the outer edges of the LW structures were not raised as protruding root wads and ends of the logs would not reduce conveyance as much as the denser parts of the structures. Roughness was increased for the entire structure based on if the center of the computational cell was within the structure roughness boundary. These representation techniques are thought to be conservative from a risk perspective and should be considered when viewing and/or utilizing results for feature design.

6.0 Chewuch River Large Wood Risk Assessment

6.1 Background

A large portion of the concept level restoration designs involve the addition of LW in several forms. Placing LW is a common approach to river restoration strategies in the Pacific Northwest and continues to be understood as increasingly important to river heterogeneity. However, constructed LW features within river restoration projects can increase risk due to the inherent mobility of wood in dynamic river environments. Although LW and movement of LW was historically common in rivers across the world, wood should not be added to contemporary river corridors without considering the risks to existing land ownership and infrastructure.

This section details the quantification of risk along the Chewuch River in the project area between RM 20 to 9. RM 33 to 29 is deemed to be low risk based on the lack of infrastructure in the area and is not analyzed here. The lower reach risk assessment was developed based on Reclamation's Property Damage Risk Matrix (Reclamation 2014, figure 14). Instead of the qualitative approach in the 2014 Reclamation guidelines, the TSC applied the model results to quantitatively assign portions of the river with a risk score based on river form, flow characteristics, and channel vicinity to non-Federal property and infrastructure. LW risk in relation to recreation was not assessed here.

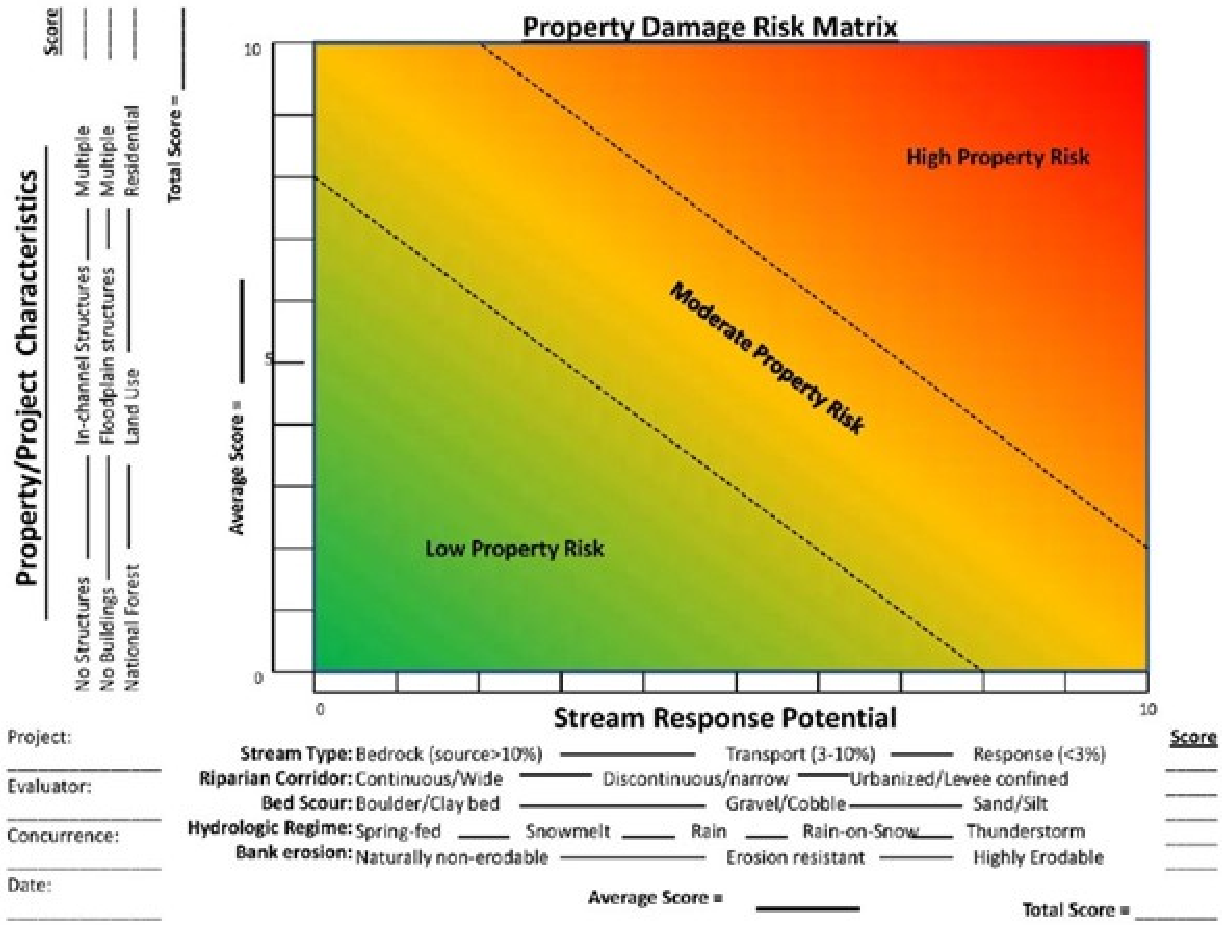


Figure 14.—The property damage risk matrix developed by Reclamation (2014).

6.2 Methodology

6.2.1 Calculation of Risk Assessment Input Parameters

Risk parameters were calculated in 1/8-mile segments. Median channel width within these segments was approximately 139 ft, while median channel length was approximately 710 ft. Therefore, 1/8-mile segments represent about five bankfull channel widths. For each segment, a relative risk value was calculated based on the same x- and y-axes approach of the property damage risk assessment matrix introduced above.

6.2.1.1 *Stream Response Potential*

6.2.1.1.1 Unit Stream Power Calculation

Unit stream power was used as an analog for stream response potential, which represents the x-axis of the risk matrix. Here, unit stream power was calculated as:

$$\omega = \rho g d V S \qquad \text{Equation (1)}$$

Where ω is unit stream power (pounds per feet per second [lb/ft-s]), ρ is the density of the water (slugs per cubic feet [slugs/ft^3]), g is the gravitational constant (feet per second squared [ft/s^2]), d is water depth (ft), V is velocity magnitude (feet per second [ft/s]), and S is the slope of the river (feet by feet [ft/ft]). Water depth and velocity were extracted from model results on a 3-ft grid, which determined the resolution of the unit stream power calculations. In ArcGIS® Pro, slope was calculated at 250-ft increments by extracting elevations along the thalweg. A moving average of slope was calculated across 10-sequential, thalweg points resulting in an average slope for each 2500-ft river segment. An inverse distance weighted interpolation was then used to develop a raster from the thalweg points to use in the unit stream power calculation.

Stream power was calculated within the “bankfull” channel inundation boundary, which was defined by the inundation boundary of the modeled 1.5-yr recurrence interval peak flow. Flow characteristics (i.e., depth and velocity) used in the risk assessment results are based on the 10% probability peak flow (10-yr recurrence interval). The minimum and maximum values of unit stream power were assigned risk values of 0 and 10, respectively. All other risk values were linearly interpolated to rescaled values between 0 and 10.

6.2.1.2 *Property Characteristics*

The y-axis of the risk matrix was defined by the vicinity of non-Federally owned property and infrastructure along the Chewuch River corridor.

6.2.1.2.1 Lateral Distance to Infrastructure

Lateral distance for each 1/8-mile risk assessment river length was calculated using the Near function in ArcGIS® Pro. The nearest distance from the bankfull channel boundary to either a road or structure was calculated. The distance in feet was then rescaled by the median channel width of 139 ft to calculate a lateral distance in channel widths.

Risk was assigned to the lateral channel width distance using a piecewise linear interpolation method. This method placed more risk on values within 1.5 channel widths and less risk on values greater than 1.5 channel widths than a single linear interpolation method (figure 15).

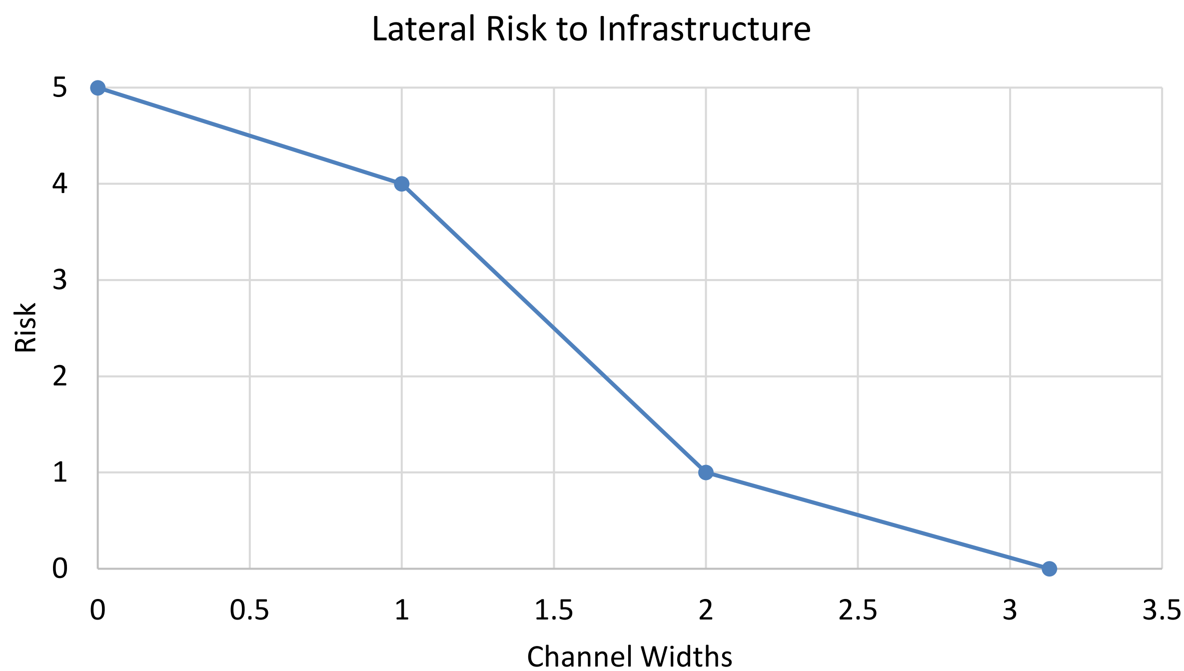


Figure 15.—Piecewise linear function used to calculate lateral risk to infrastructure.

6.2.1.2.2 Downstream Distance to non-Federal Land

Downstream distance for each 1/8-mile risk assessment river length was calculated as the thalweg distance between the downstream extent of the risk segment and the upstream extent of non-United States Forest Service (USFS) land ownership. Downstream distances were calculated by river miles and converted to channel widths.

Risk was assigned to the downstream distance using a piecewise linear interpolation method. This method placed more risk on values within 75 channel widths and less risk on values greater than 75 channel widths than a single linear interpolation method (figure 16). Multiples of 10 channel widths were used to assign risk as a conservative estimate of the number of depositional zones wood may encounter if transported from the original design location. This is based on the idea that within a pool-riffle channel type bedforms often repeat at approximately every 5–7 channel widths. The Chewuch River generally exhibits gravel-cobble, pool-riffle characteristics and riffle crests often represent a channel widening and depositional zone along a river.

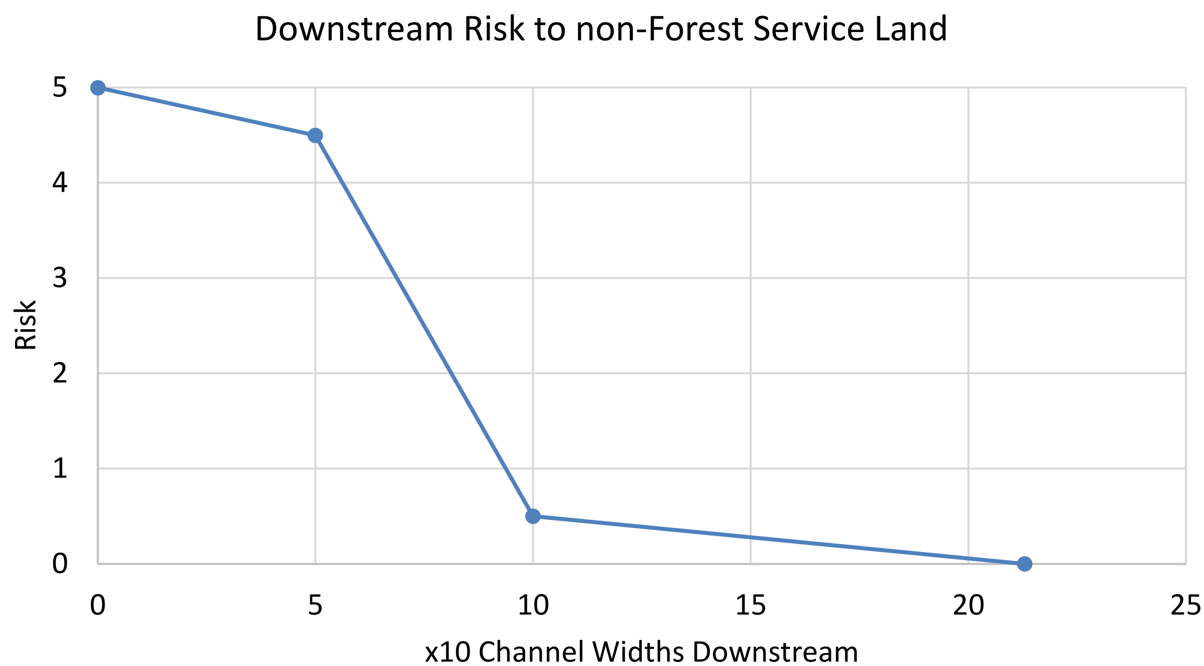


Figure 16.—Piecewise linear function used to calculate downstream risk to non-Federal properties.

6.2.1.2.3 Total Property Risk

Total property risk was calculated as the sum of lateral and downstream risk discussed above.

6.3 Chewuch River Relative Risk

Relative risk along the Chewuch River was assessed based on geomorphically-scaled distances and relevant stream characteristics. Those geomorphic distances and response potential attributes of each risk segment are summarized in figure 17.

Because the upper five miles of the Chewuch River between River Miles 20 and 15 is Federally owned, LW risk generally increases from RM 20 downstream to RM 9 as downstream distance to non-USFS land decreases (figure 18). Total risk is calculated as property risk plus stream response risk. Variations in risk are defined by larger valley bottom distances, which means roads adjacent to the Chewuch River on valley walls are further from the river. The lowest risk in this reach is just upstream of RM 18. Tributaries drive increases in unit stream power. Not only does increased flow from the contributing area increase the total flow in the Chewuch River, but slope also often steepens on the downstream side of tributary confluences, which increases unit stream power. Boulder Creek downstream of RM 10 drives large increases in unit stream power making that portion of the river relatively high risk as compared to other locations. Figure 19 plots the risk scores, delineated by RM location, in a similar style chart as that developed by Reclamation (2014).

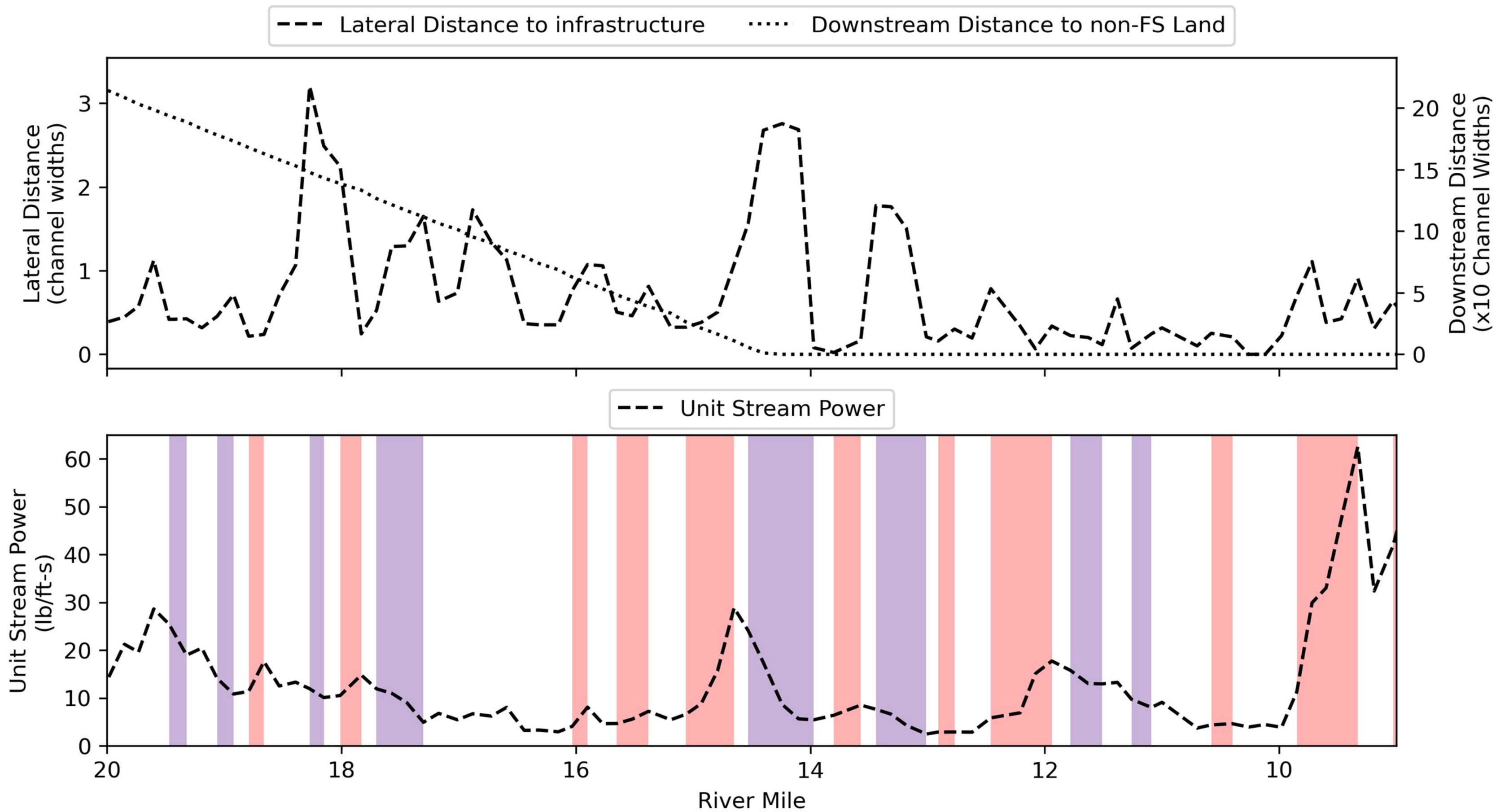


Figure 17.—Upper most plot shows lateral and downstream distances to infrastructure and non-Federal property. The lower plot shows unit stream power values and change in unit stream power. Lengths of river where unit stream power is either increasing or decreasing for at least two 1/8-mile risk segments are represented by red and purple shading, respectively.

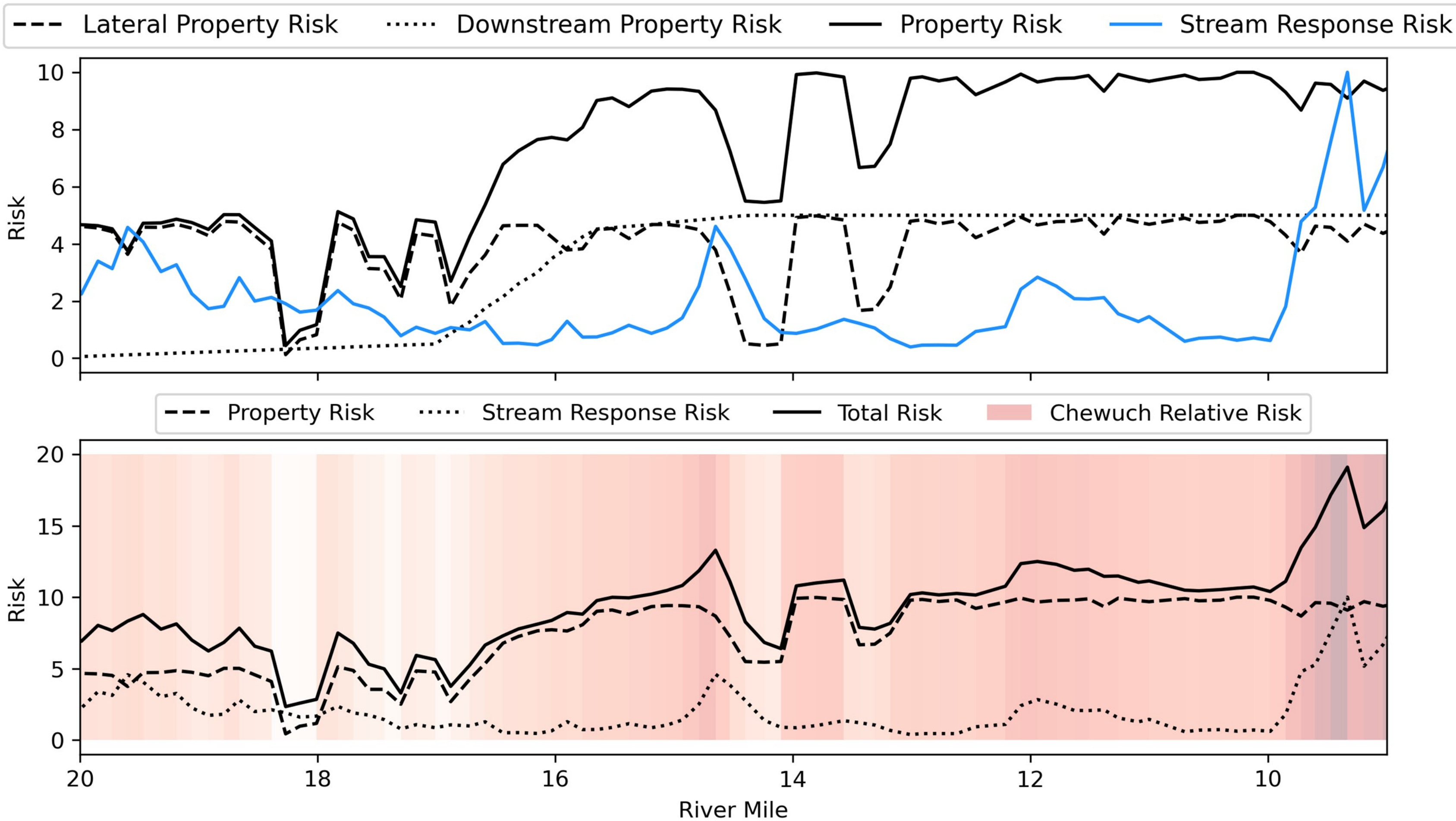


Figure 18.—Components of risk computation and overall risk score calculated at each 1/8-mile segment. The top plot shows the individual risk scores for lateral and downstream property risk as well as stream response risk. The bottom plot shows property risk and stream response risk, which are combined to estimate total risk. Darker shades of red represent more risk.

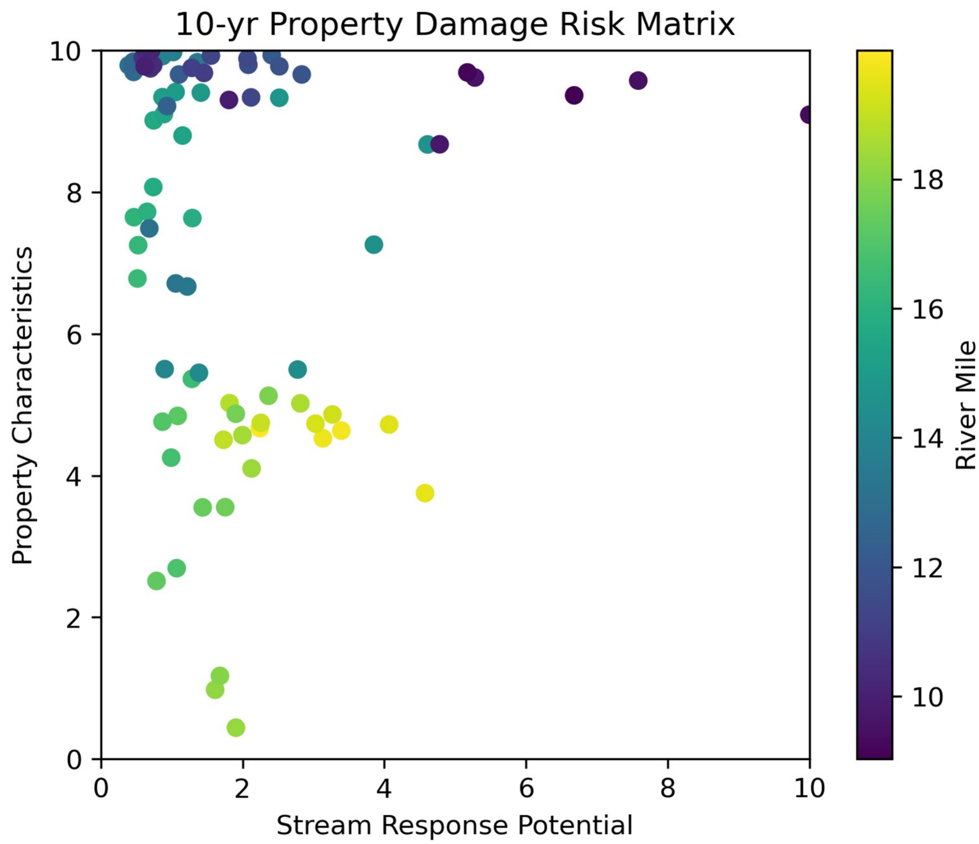


Figure 19.—Quantitative property risk matrix for Chewuch River for RM 20 to 9.

7.0 Restoration Design Concepts

7.1 Restoration Context

7.1.1 River Miles 33 to 29

RM 33 to 29 is defined by two relatively flat valley segments separated by a steep section of river that is forced against the western valley margin by a hillslope failure of the adjacent eastern mountainside. The river in both valley segments is less connected to the floodplain than would be expected based on the geomorphic setting. This is especially true in the downstream valley (RM 31 to 29) where an estimated 10-yr flow under existing conditions minimally inundates the floodplain. The channel is highly uniform through the flatter subreaches with consistent depths, velocities, and cross section shape. Except for a few log rafts (e.g., near RM 32) and beaver dams (figure 7), there is little complexity or cover within the main channel. Existing conditions model results are depicted in appendix B.

The restoration alternatives considered for these valley segments were developed with the following assumptions in mind:

- Hydrology is a major uncertainty within the reach as the Chewuch USGS gauge is at approximately river mile 0. Therefore, the recurrence intervals of flows required to inundate the floodplain are also highly uncertain.

- The reach is located within USFS land. Due to the distance upstream from private land and infrastructure, there is relatively low risk when considering the placement of mobile wood or structures that may mobilize during floods.

- The floodplains of the valley surfaces are covered in dense vegetation as the surface recovers from wildfire. Any potential construction activities should minimize disturbance to this floodplain vegetation.

7.1.2 River Miles 20 to 9

RM 20 to 9 is defined by alternating transport and depositional reaches. The river valley is confined to partly-confined by valley walls and alluvial fans, which leads to floodplain expansion and narrowing. A few split flow reaches and side channels exist, but dynamic, multi-thread channels do not exist within the reach. While there are some natural wood jams and engineered wood structures, there is a lack of large wood and key pieces within many reaches. In addition, several of the constructed engineered wood jams from previous restoration projects have burned during recent wildfires.

Unlike RM 33 to 29, risk is an important consideration along RM 20 to 9 as the river transitions from USFS land to private land ownership in the downstream subreaches. The need to consider risk was the reasoning behind development of the large wood property risk assessment described in Section 6.0 Chewuch River Large Wood Risk Assessment. As discussed above, unit stream power, land ownership, and infrastructure vicinity were considered for the risk assessment. Two major findings from the risk assessment were:

- The upper 5.5 miles (RM 20 to 14.5) is entirely on USFS land. There is state land ownership between RM 14.5 and 12.5. Private land ownership is mixed in below RM 12.5.

- Higher stream power is typically created downstream of tributaries where the river steepens.

The restoration design concepts focused on the use of helicopter placed LW or boulders with the understanding that LW structures may need to be ballasted or engineered in higher risk locations.

7.2 Restoration Objectives

Restoration objectives focused on producing geomorphic change and hydraulic complexity for both the RM 33 to 29 and RM 20 to 9 restoration reaches. The assumption is that increasing geomorphic and hydraulic diversity will create more heterogeneity in habitat types throughout a given reach. In addition, an increase in hydraulic variability should create patches of different bed material grain sizes rather than the current uniform substrate. To summarize, the objectives for the conceptual designs were:

- Increase complexity in both reaches including:
    - Hydraulic variability
    - Depositional and erosional zones within the channel (substrate sorting)
    - Variability in bedforms and geomorphic units (reduction in uniform channel dimensions)
    - Cover and refuge for aquatic species
- River Mile 33 to 29
    - Aggrade channel to improve connectivity with the floodplain
- River Mile 20 to 9
    - Initiate geomorphic process where risk tolerance allows for wood mobility and channel change

7.3 Conceptual Designs

7.3.1 River Miles 33 to 29

The TSC developed three conceptual designs for the RM 33 to 29 upper valley segments. The three concepts differed by construction method and structure density. The three designs use progressively increasing feature densities to explore the potential impact that density has on hydraulics and inundated area (table 9). The main goal of different structure densities was to represent how structure density influences water surface elevations and conveyance through the channels. Examples of each of the three design concepts can be found in figure 20. Mapped conceptual designs for RM 33 to 29 with inundation and velocity comparisons to existing conditions can be found in appendix D.

7.3.1.1 *Low-Tech Concept*

The low-tech approach included a combination of BDAs and PALSs placed at locations where the structures would have the most impact toward restoration goals. The low-tech concept had the lowest density of structures. Placement locations of BDAs and PALSs included:

- PALSs on inside bends to enhance geomorphic process along outer bends
- PALSs on outside bends near the road where lateral erosion of banks is not desired
- Mid-channel PALSs to create split flow and mid-channel bar development
- Alternating PALSs on each side of the main channel to produce a more meandering main flow path
- BDAs as the most downstream structures to raise water surface elevations and provide base level control
- BDAs to fortify existing or enhance blown out beaver dams
- BDAs placed throughout the reach to increase water surface elevations and promote deposition within the main channel
- PALSs and BDAs at locations of side channel connections where increased water surface elevations may promote increased side channel or floodplain surface connectivity

7.3.1.2 *Hybrid Concept*

The hybrid concept included both low-tech structures (e.g., BDAs and PALSs) and helicopter LW and boulders. The hybrid concept had the middle density of structures. The BDAs and PALSs placed in the low-tech concept were largely kept in place and LW structures and boulders were added at locations to further enhance channel complexity and achieve restoration goals.

7.3.1.3 *Helicopter Concept*

The helicopter concept only included helicopter placed LW and boulders. The BDAs and PALSs in the low-tech and hybrid concepts were replaced with LW structures to achieve the same results. Generally, the LW structures are represented as larger features in the conceptual design and modeling. In addition, more LW and boulders were added to the helicopter concept beyond the amount added in the hybrid concept. This produced the highest density of structures within the reach.

Table 9.—Quantity of design features included in each design concept

Concept	BDAs	PALSs	Boulders	Large wood pieces	Large wood structures
Low-tech	10	65	--	--	--
Hybrid	8	55	44	420	57
Helicopter	--	--	93	1800	176

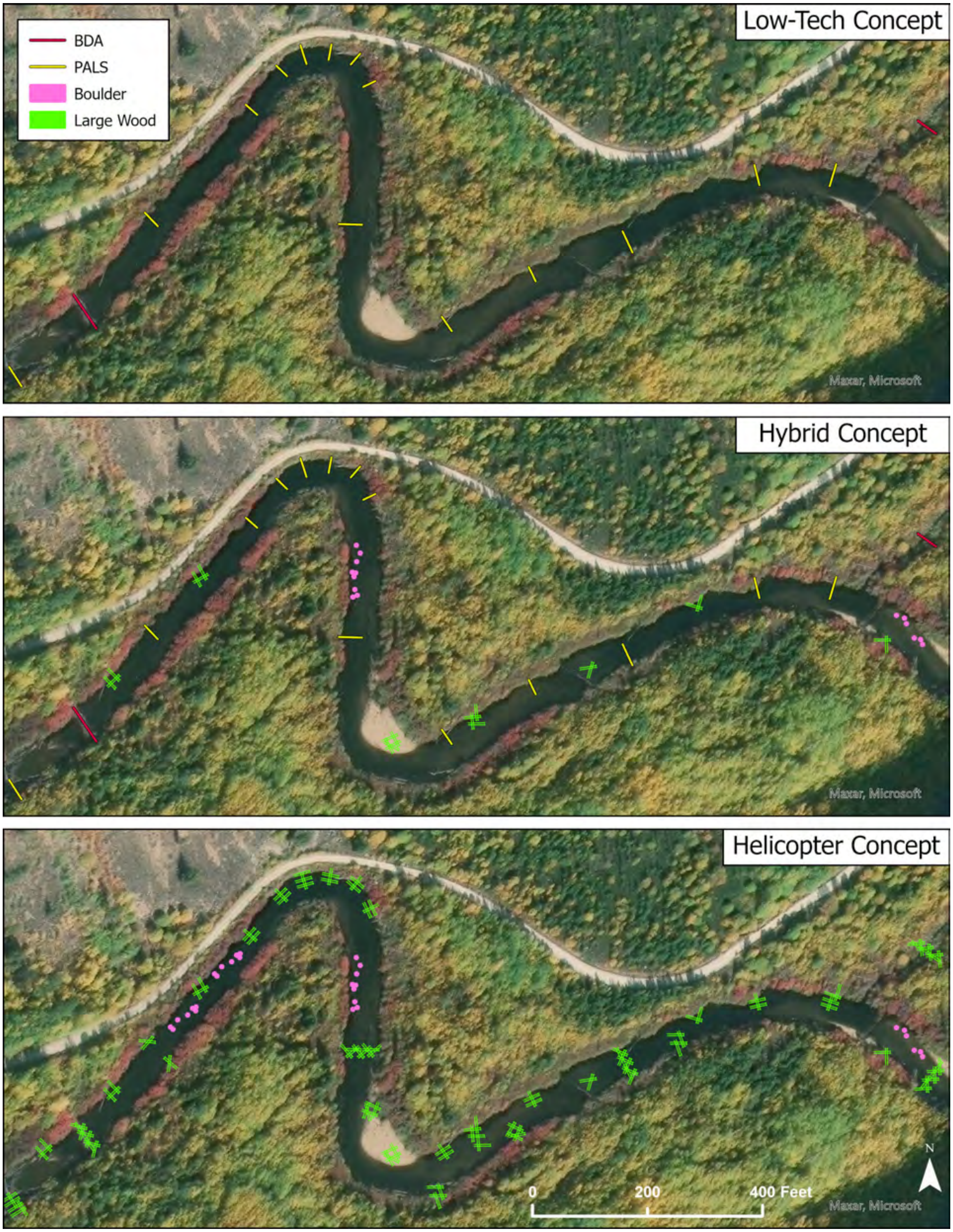


Figure 20.—Example of the different structure types and structure densities in each of the three design concepts between RM 33 and 29.

7.3.2 River Miles 20 to 9

Restoration concepts for RM 20 to 9 were created using the large wood property damage risk assessment developed from existing conditions modeling, land ownership, and existing infrastructure locations. Instead of producing restoration concepts for the entire 11 miles of river, the focus of restoration concept development was to create three different alternatives that could be approached using different restoration strategies. Based on the scores of the risk assessment, three stretches of river were the focus of RM 20 to 9 design concepts, each with a different approach (figure 21):

- RM 17.5 to 16 – dynamic process-based
    - The dynamic process-based approach would exclusively use helicopter constructed LW structures or boulders to achieve the desired restoration objectives. The LW structures would be self-ballasted by stacking wood to different heights.
- RM 14.5 to 13.5 – moderate process-based
    - The moderate process-based approach would use helicopter constructed LW structures and boulders in combination with engineered log structures where needed in areas with less risk tolerance.
- RM 10 to 9.5 – static habitat-focused engineered wood
    - The static habitat-focused approach would use engineered log structures to create habitat. The structures would locally alter flow and impact channel geomorphology, but no major changes to the river corridor would be expected. In addition, the concept tried to minimize hydraulic changes along an upstream road embankment and inundation patterns on an upstream floodplain that contains infrastructure.

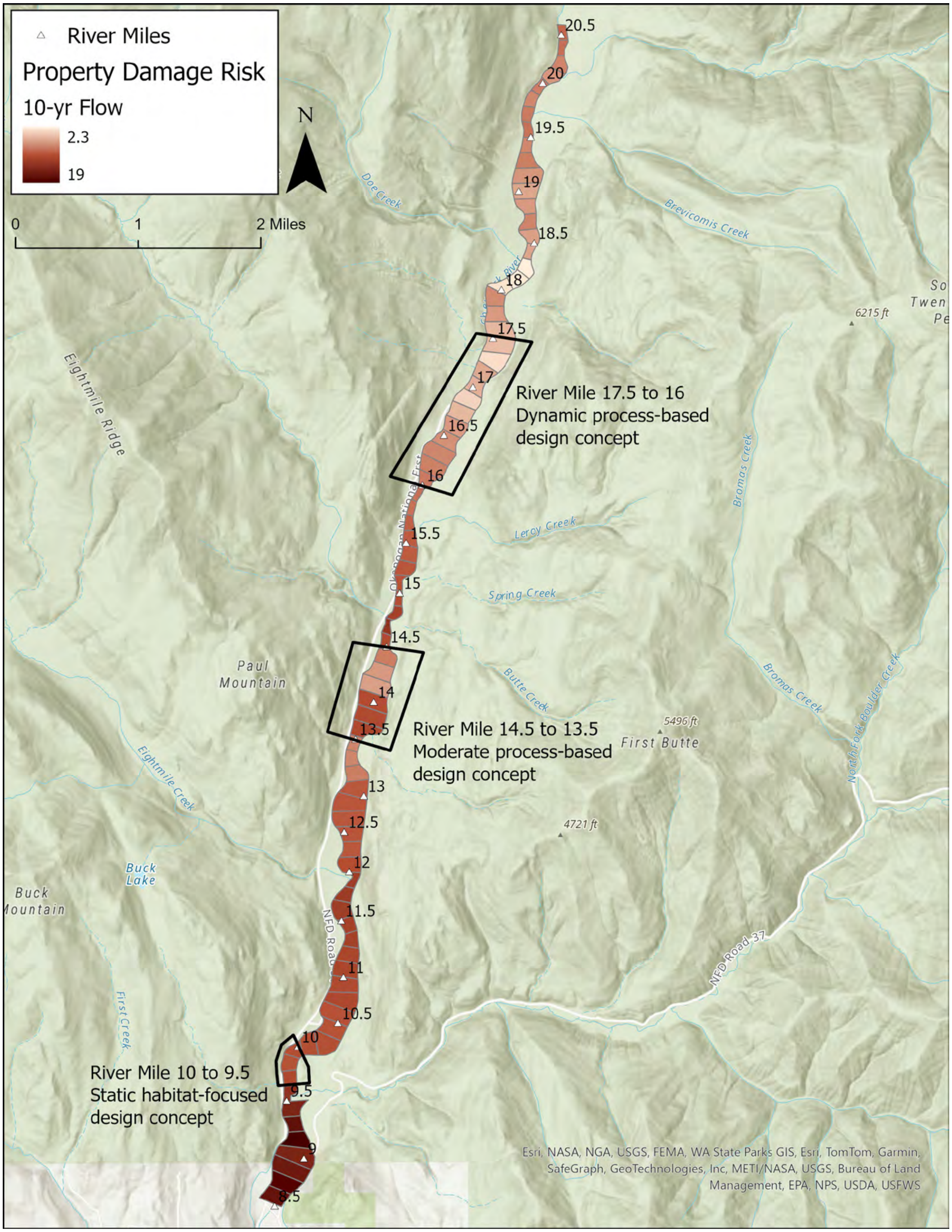


Figure 21.—Location of restoration design concepts for RM 20 to 9 and associated property damage risk.

Based on existing conditions modeling (appendix C), initial designs were developed and modeled with LW placed at locations to create flow complexity, geomorphic process, and increased floodplain connectivity to align with restoration objectives. All designs focused on the LW and boulders with minimal desire for regrading of the main or side channels within the reach. Concept 1 designs and model results for each river segment are included in appendix E. These are the initial designs developed after the October 2023 site visit.

After additional field reconnaissance in May 2024 to consider potential design adjustments, the amount of large wood was increased in RM 17.5 to 16 and RM 14.5 to 13.5 (figure 22). Boulders were also added within the RM 14.5 to 13.5 reach (figure 23). A slight change to the RM 10 to 9.5 restoration concept was also made by increasing the size of an apex jam within that reach (figure 24). The Concept 2 design and model results can be found in appendix F.

Figure 22.—Example of differences between Concept 1 and Concept 2 designs for RM 17.5 to 16.

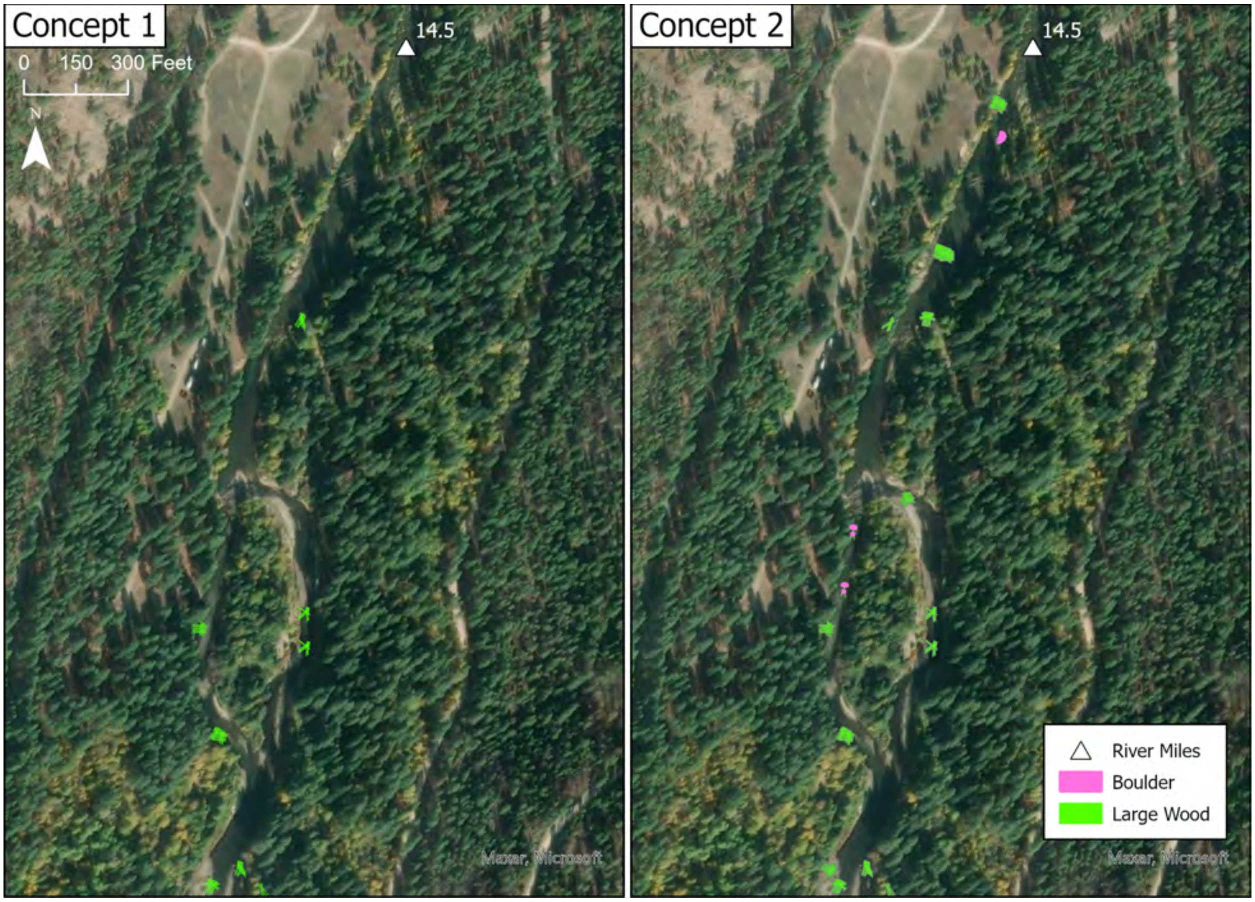


Figure 23.—Example of differences between Concept 1 and Concept 2 designs for RM 14.5 to 13.5.

Figure 24.—Example of differences between Concept 1 and Concept 2 designs for RM 10 to 9.5. The only difference between these two concepts is a slightly larger apex structure.

7.4 Conceptual Design Analysis

We spatially and numerically compared conceptual design models to existing conditions. Spatial comparisons included inundation depth and extent as well as velocity changes. Because model outputs and design concept results are complex and variable between sites and within a site, we quantified changes in depth and velocity by two methods: 1) we quantified the area inundated using depth and velocity bins, and 2) we calculated the coefficient of variation in depth and velocity for each site. The inundated areas for each 1-ft depth bin and 1-ft/s velocity bin were calculated at the upstream valley segments and each downstream restoration concept site for a range of flows. Coefficient of variation is a measure of variability and is calculated as the standard deviation divided by the mean for depth or velocity at a given flow. In regard to restoration, the higher the coefficient, the greater the depth or velocity variability, and the more impactful the restoration concept. We calculated coefficient of variation at both valley segments in RM 33 to 29 and at all three sites between RM 20 and 9. Coefficient of variation in depth and velocity are subsequently referred to as depth variability and velocity variability, respectively.

7.4.1 River Miles 33 to 29

Model results indicate that the design concepts are successful in both increasing inundated area and creating more hydraulic variability throughout the valley segments. At all flows, nearly all channel and floodplain depths increase in area (figure 25). Because the structures reduce conveyance in the main channel and raise water surface elevations, the main channel effectively becomes deeper at all flows and the floodplain engages to a higher degree at lower flows relative to existing conditions. This leads to relatively minimal change in depth variability within the channel (figure 26 and figure 27). When floodplain areas are included, there is a sharp increase in depth variability when new portions of the floodplain are inundated, which provides a wide range of depths across the channel and floodplain. As more floodplain is inundated, the large area of floodplain inundation likely reduces depth variability since there is such an expansive area with a relatively similar small depth (figure 25). It should be noted that these results assume a static bed within the models except raised elevations between existing and concept alternatives where structures were added. In reality, the installation of structures will drive changes in bed topography, which will alter the calculated results presented here.

Velocities are relatively slow for a large proportion of the valley segments for all modeled discharges under both existing and design concept conditions. The addition of structures for all concepts decreases velocities in much of the channel but does increase velocities adjacent to structures (see velocity differences in appendix D). The decrease in velocity for much of the channel is due to a loss of conveyance, which also promotes earlier inundation of adjacent surfaces. Those newly inundated surfaces are likely to have slow velocities as well. Because so much of the channel is already within the 0 to 1 feet per second (ft/s) bin under existing conditions at low flows, adding structures increases channel velocity variability for both the RM 33 to 31 and RM 31 to 29 segments. There is less change in velocity variability within the channel at higher flows. Channel and floodplain velocity variability shows similar patterns for low flows since most of the flow is within the main channel. The greatest increases in velocity variability were found for the RM 31 to 29 valley segment. This valley segment floodplain is highly disconnected under existing flows. The addition of structures increases floodplain connectivity and velocity variability across all flows.

Restoration concepts were developed with an increasing amount of structure density from lowest densities for the low-tech concept, moderate densities for the hybrid concept, and highest densities for the helicopter concept. In addition, LW structures can be physically taller than the BDAs or PALSs due to construction techniques and fish passage limitations with BDAs. As expected, increasing the density of structures generally increases floodplain connectivity due to decreased channel conveyance. Trends in depth and velocity total area and variability tend to follow a pattern in which the helicopter concept (highest density) is either the maximum or minimum value as compared to less dense counterparts and existing conditions. Increasing density tends to accentuate a statistical result due to the decreased channel conveyance and increased floodplain inundation.

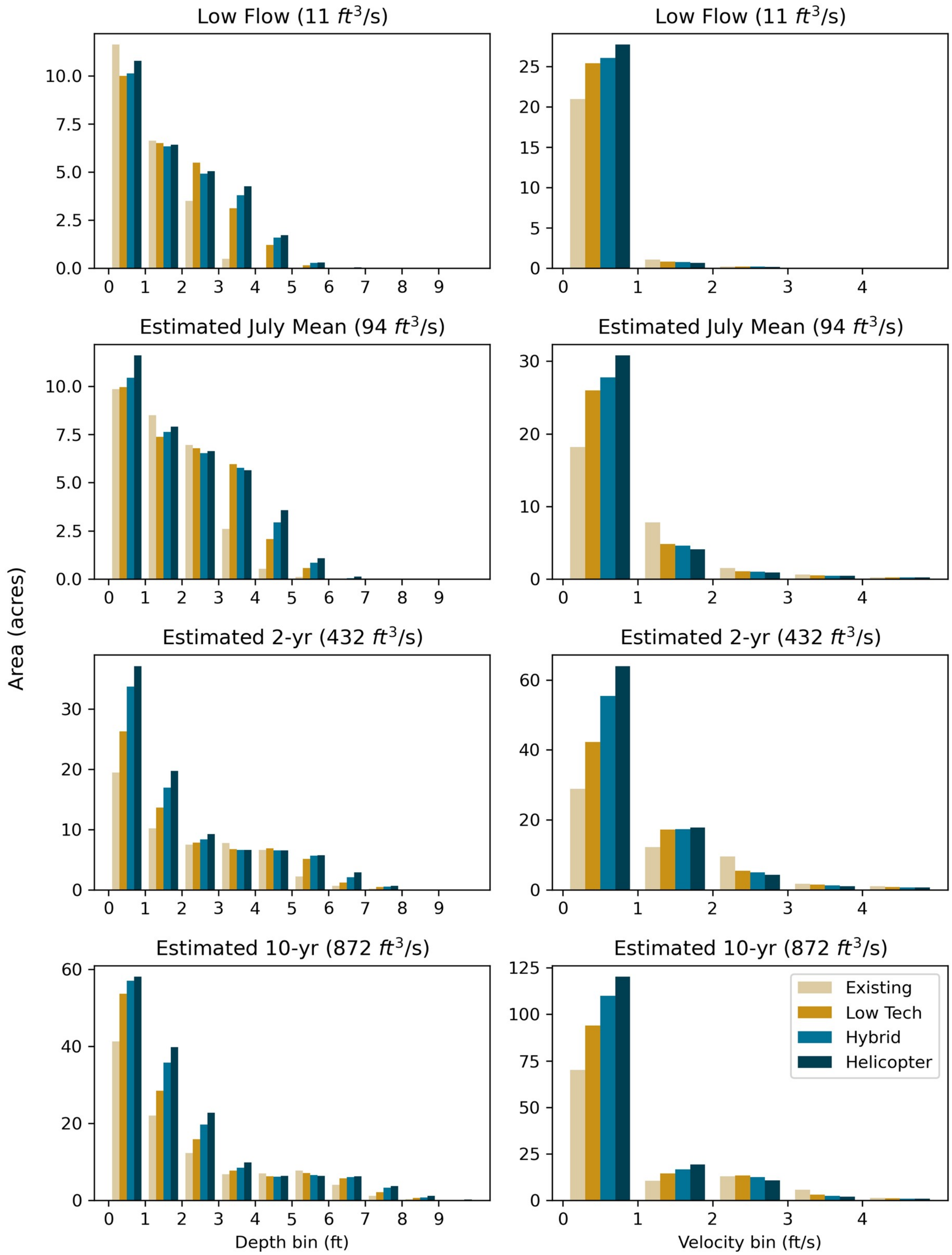


Figure 25.—Depth and velocity histograms for RM 33 to 29 existing and conceptual design conditions.

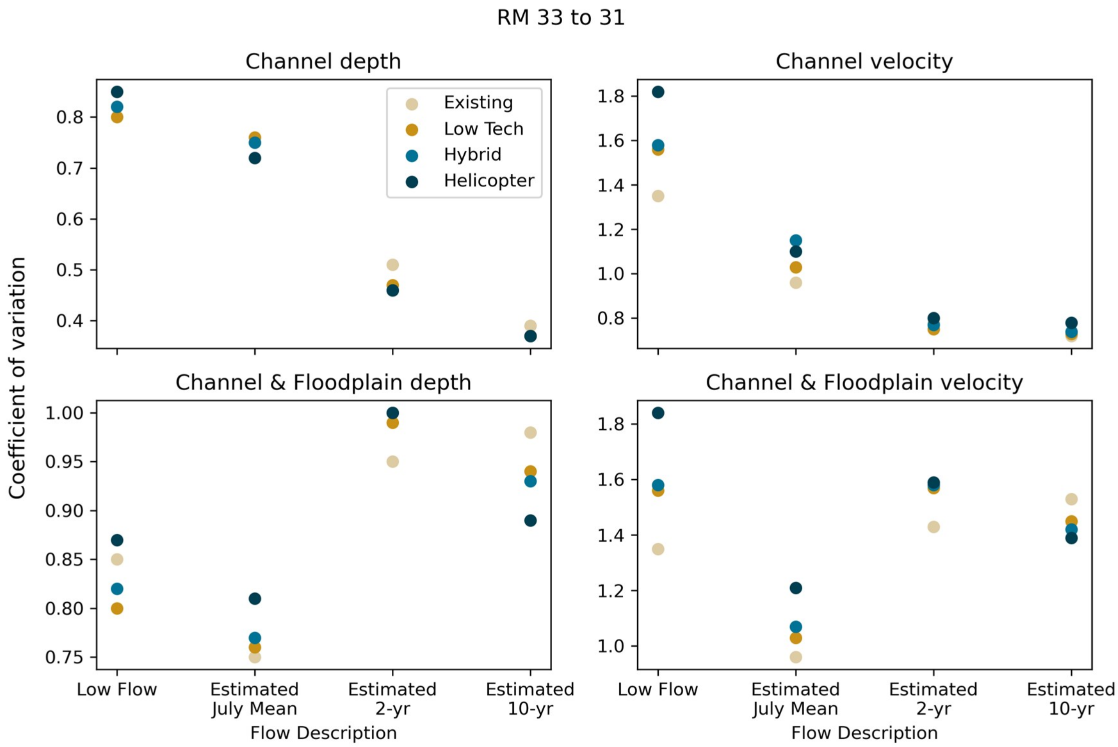


Figure 26.—Coefficient of variation in depth and velocity along the RM 33 to 31 valley segment.

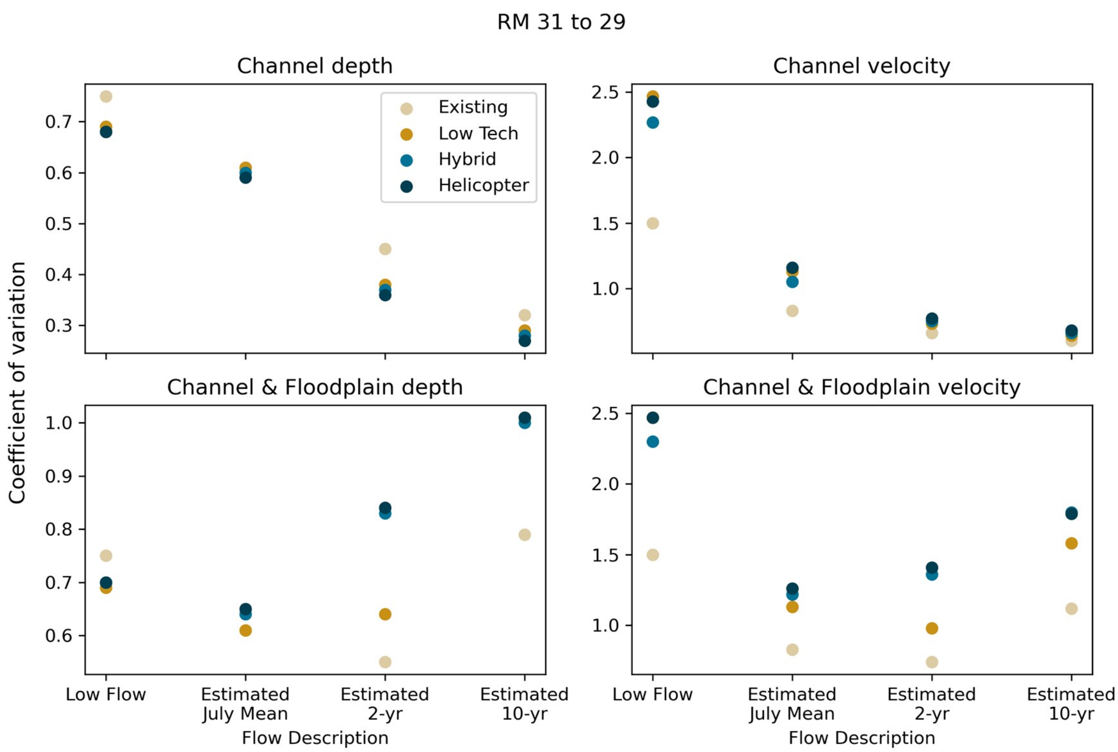


Figure 27.—Coefficient of variation in depth and velocity along the RM 31 to 29 valley segment.

A goal of the restoration concepts along the RM 33 to 29 reach was to increase the heterogeneity of bed material and promote channel aggradation. Bed sediments and sediment transport are likely to be similarly correlated to the increased hydraulic variability, however, were not directly modeled in this restoration concept development. Decreased in-channel flow velocities will likely lead to more deposition within the channel, especially in eddies behind structures. Adjacent to structures, especially LW, more complex three-dimensional flow hydraulics are likely to drive scour and create pools. Two-dimensional modeling of the estimated 2-yr flow does predict more complex patterns of sediment transport as displayed for a portion of the RM 33 to 29 reach in figure 28. Though predicted mobile sediments on top of structures are unlikely to be accurate due to roughness parameterization, the mobile grain sizes for the channel bottom are likely more accurate. The uniform nature of the existing conditions channel is broken up by the structures and is predicted to allow for small gravels and likely larger sand classes behind structure locations. In comparison, sands are likely transported easily through the channels under existing conditions at the estimated 2-yr flow.

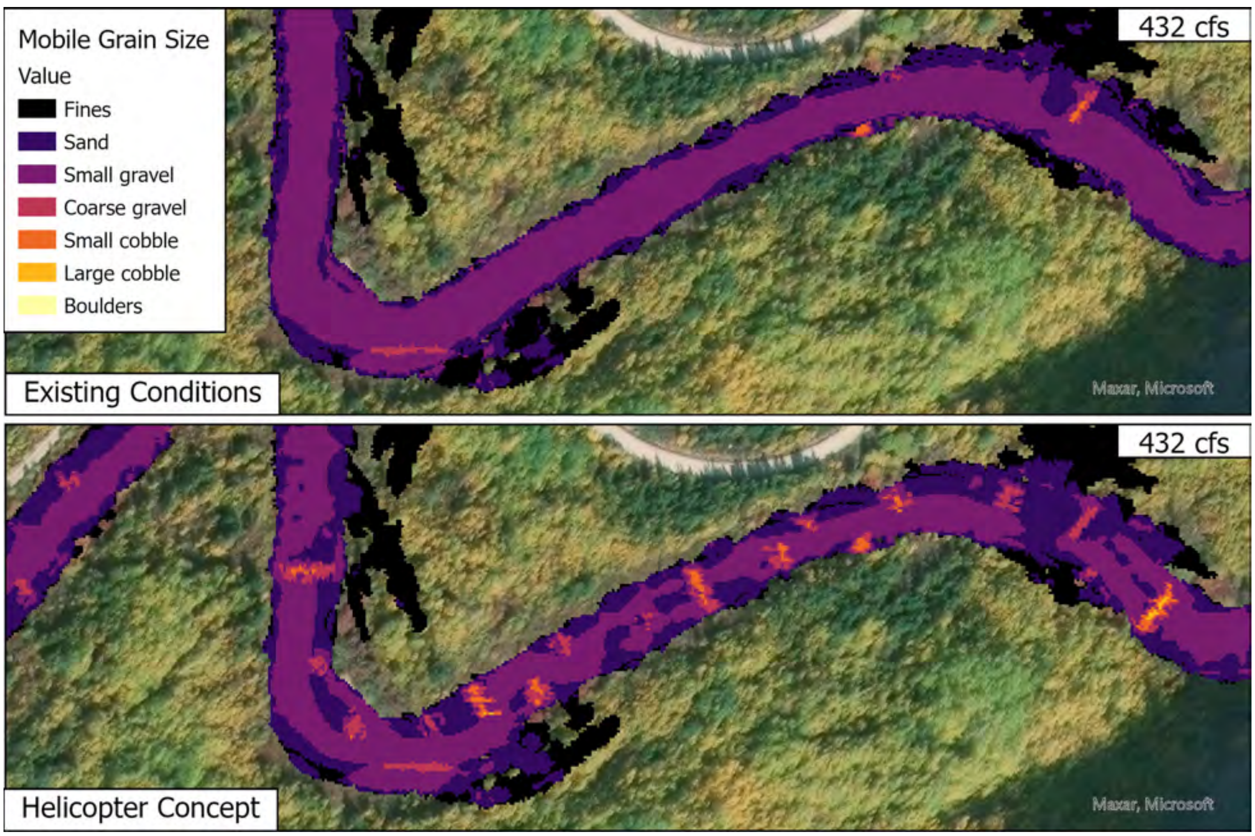


Figure 28.—Differences in the predicted mobile grain size between existing and helicopter concept conditions under the estimated 2-yr recurrence interval flow.

To summarize, key observations and findings from the conceptual development, modeling, and a post-concept development field visit include:

- At low flows, increasing density of design features will drive more hydraulic variability.

- At high flows, increasing density of design features decreases channel conveyance, decreases in-channel velocities overall, and increases inundated area, floodplain flow, and floodplain velocities.

- The downstream control is a key feature within these reaches and can drive backwatered connections onto the floodplain. A rock ramp is likely not desired as a more natural, less engineered surface is desired. If BDAs are used at the downstream end, likely a series of BDAs will be necessary to achieve fish passage requirements.

- BDAs/PALSs can be used in shallower locations where sediment is appropriate for driving posts. Other locations of the main channel may be too deep for posts or not appropriate for BDAs.

- An idea discussed during the May 2024 site visit was to try gravel loading in stretches with LW. The LW is likely to drive greater flow complexity and more complex flow paths for gravels versus sand grain sizes. Pairing gravel augmentation with wood will reduce the tendency for sand to deposit on top of the gravel by providing hydraulic sorting. Gravel paired with LW will also work toward the goal of increasing the channel bed elevation and the floodplain connection. Without supplemental gravel, the existing sand sediment supply may not be enough to raise the bed.

7.4.2 River Miles 20 to 9

The same analyses were conducted for the three sites chosen for conceptual designs between RM 20 and 9. Spatial results for Concept 1 and Concept 2 are displayed in appendices E and F, respectively. Quantified depth and velocity areas and variability are discussed in the following sections.

7.4.2.1 *River Mile 17.5 to 16*

The RM 17.5 to 16 reach was designed as the dynamic, process-based reach in which LW would be placed by helicopter and structures would be self-ballasted with a given amount of LW stacking. Movement of the wood would be expected to some degree. Results from concept modeling indicate that large wood will alter channel and floodplain depths and velocities to a large extent, especially at the modeled 2-yr and 10-yr recurrence interval flows. Channel velocities are increased adjacent to the LW structures, but generally main channel flow sees a decrease in velocity (appendix E and appendix F). Inundation extents and velocities on the floodplain are increased. While both Concept 1 and 2 show increases in floodplain inundation between RM 17.5 and 17, the increased LW in Concept 2 drives a substantial increase in inundation between RM 17 and 16.5. Differences in total area inundated at the lowest depths and velocities under 2-yr flow conditions show the impact of the increased LW loading (figure 29). Concept 2 approximately doubles the area inundated through the reach as compared to existing conditions.

Depth and velocity variability follow similar patterns as the area of depth and velocity bins (figure 30). As mentioned for RM 33 to 29, channel depth variability is relatively unaltered. However, as water inundates the floodplain at earlier flows as compared to existing conditions, the range of inundation depths increases substantially. The same is true for velocity variability. High variability in depth and velocity is representative of heterogeneous flow conditions, which is likely beneficial to fish species. Changes in velocity variability track with changes in depth variability. The concepts slightly increase velocity variability at low flows, but the greatest increases are found at the 2-yr flow (figure 30).

Geomorphically, the addition of LW will likely lead to substantial changes in bed and channel morphology. Reducing channel conveyance is likely to lead to deposition of sediments, especially in locations with channel spanning LW. Deposition within the channel will likely lead to complex flow paths and multiple channel threads. Deposition may also aggrade the channel to a point that floodplain connectivity increases to an even greater degree. Increases in velocity adjacent to LW structures and due to complex three-dimensional flow around the structures will also likely lead to scour pools throughout the reach that is not taken into account in this analysis. With increased flow complexity, sediment sorting is likely to be more complex as well.

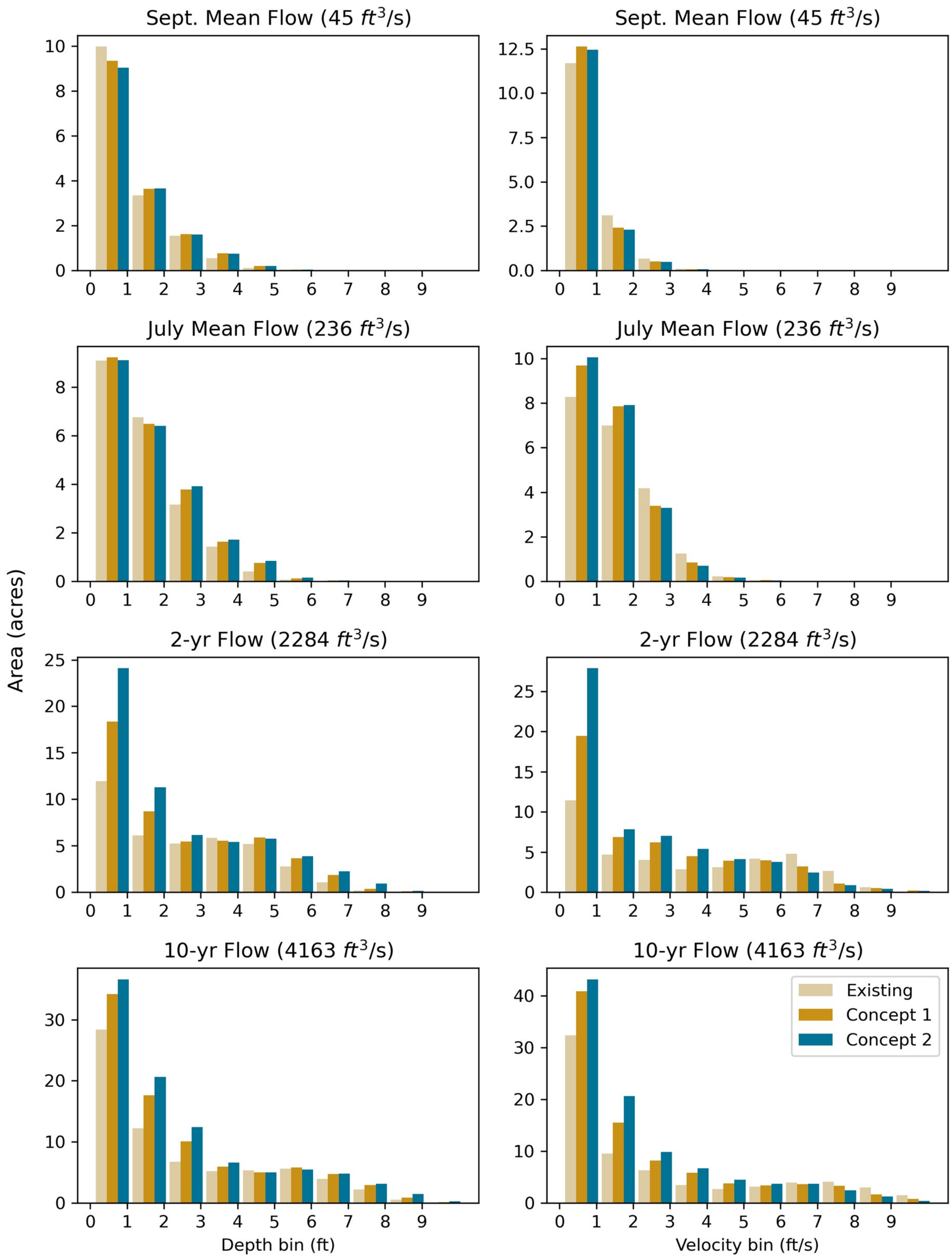


Figure 29.—Depth and velocity histograms for RM 17.5 to 16 existing and conceptual design conditions.

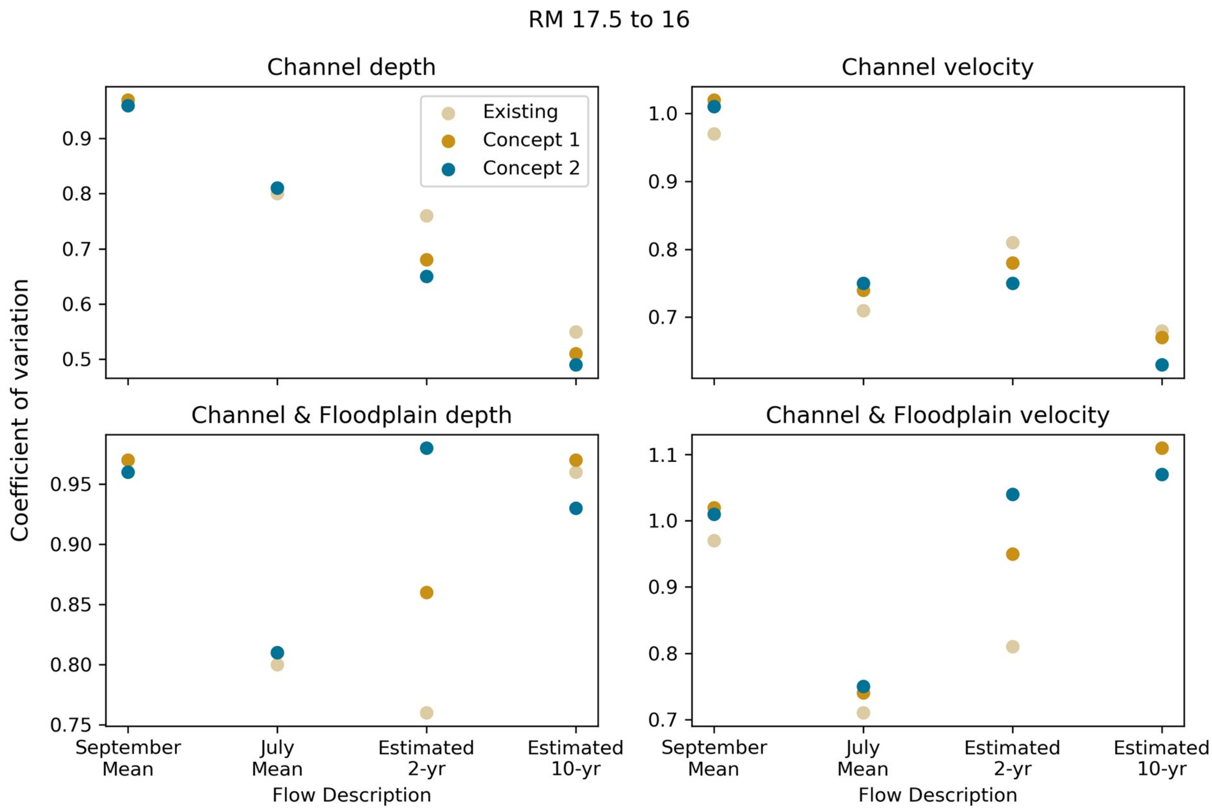


Figure 30.—Coefficient of variation in depth and velocity along the RM 17.5 to 16 site.

7.4.2.2 *River Miles 14.5 to 13.5*

The RM 14.5 to 13.5 reach was designed as a moderate, process-based concept with the understanding that some structures within the reach may need to be appropriately ballasted or engineered to prevent downstream movement. Like the RM 17.5 to 16 reach, differences between concept and existing conditions included increased flow velocities adjacent to LW structures and boulders and decreased overall main channel velocities (appendix E and appendix F). While the RM 14.5 to 13.5 Concept 1 did produce more inundation and changes in velocity distributions, Concept 2 shows that additional LW can have a considerably larger benefit (figure 31 and figure 32). A key feature in Concept 2 that was not in Concept 1 was the second LW structure downstream of RM 14.5 (appendix F). That LW structure was predicted to be successful at connecting a high flow floodplain channel at the 2-yr recurrence interval flow instead of the current 10-yr event. Geomorphic changes to the main channel within the RM 14.5 and 13.5 reach, including sediment sorting, depositional and erosional zones, and localized channel aggradation, are likely to be similar to those discussed for the RM 17.5 to 16 reach.

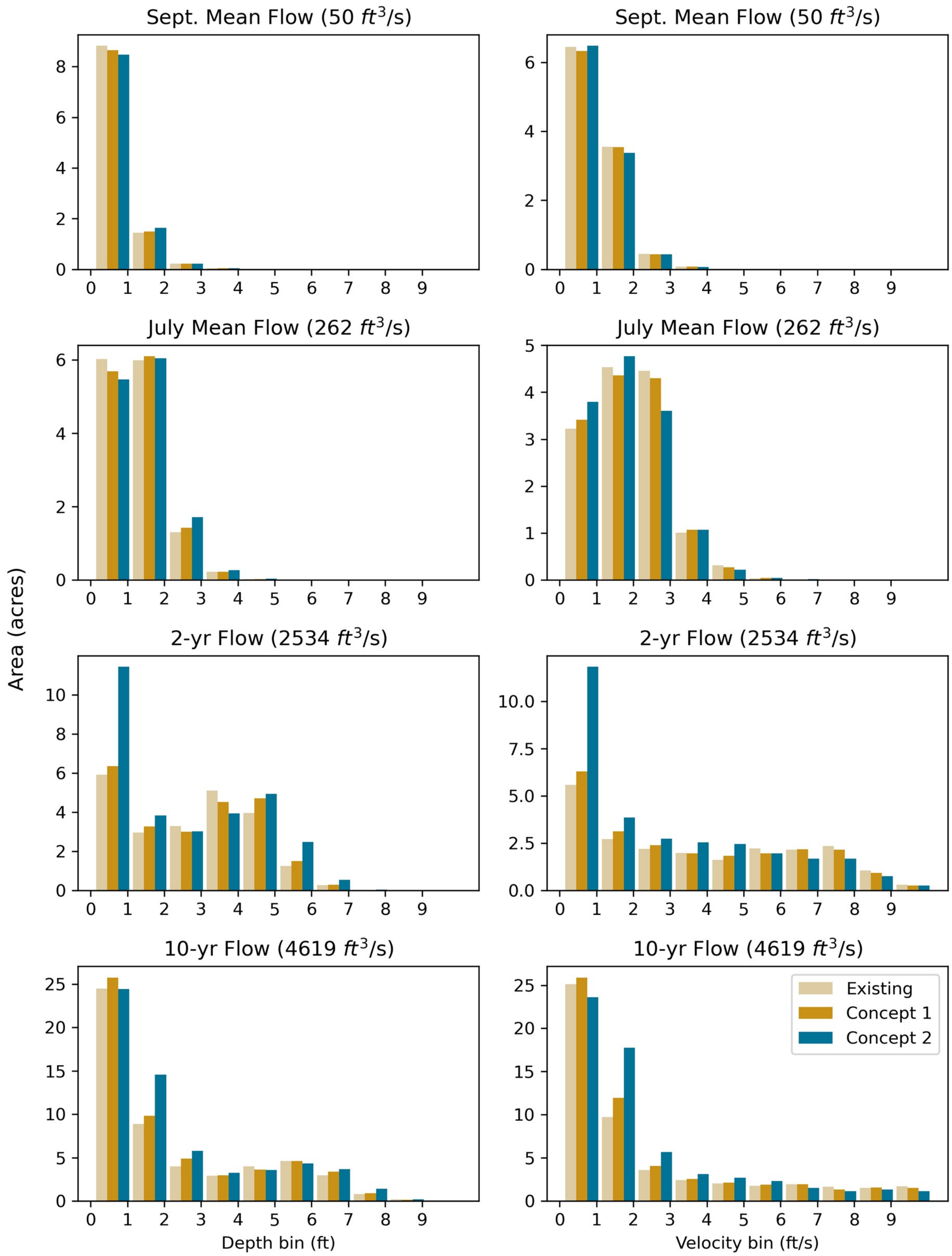


Figure 31.—Depth and velocity histograms for RM 14.5 to 13.5 existing and conceptual design conditions.

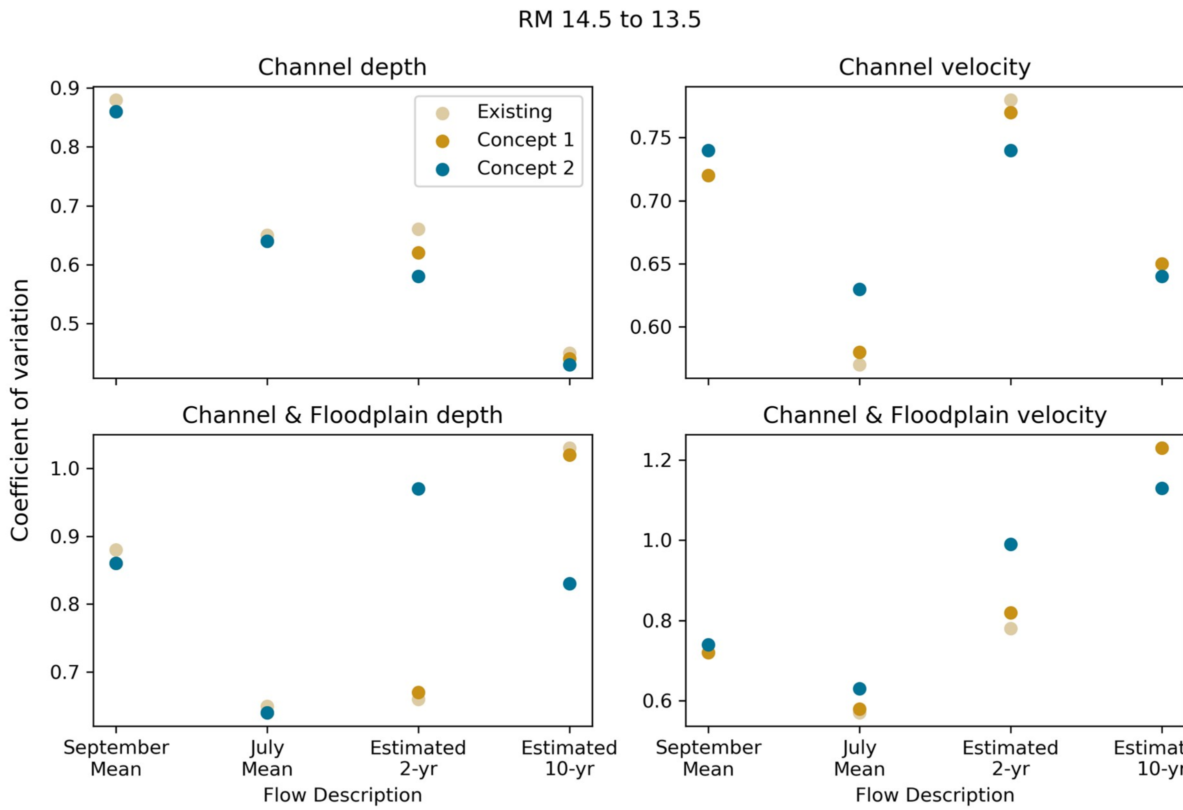


Figure 32.—Coefficient of variation in depth and velocity along the RM 14.5 to 13.5 site.

7.4.2.3 *River Miles 10 to 9.5*

The RM 10 to 9.5 reach was designed as a static, habitat focused concept. Due to the infrastructure constraints and elevated risk within RM 10 to 9.5, the amount of LW added to the channel was considerably less than the other restoration concept reaches. The addition of LW is predicted increase velocities around an apex jam (see appendix E and appendix F for maps), while decreasing velocities across a mid-channel bar and in the shadow of other LW structures. Inundation depths and velocities are not greatly altered in terms of spatial area (figure 33). Unlike some of the larger changes in depth variability at the more process-based restoration concept sites, there is minimal change in depth variability between the concept and existing conditions (figure 34). This is likely due to the lack of expansive floodplain adjacent to the LW structures in this reach. In a mobile bed system, depth changes are likely to occur due to scour around the LW structures, but that scour was beyond the scope of the modeling conducted here. Therefore, there are likely to be localized geomorphic changes to the reach that provide greater depth variability and localized fish habitat. Finally, there are only minimal changes in velocity variability. The most observable change in velocity variability is a slight decrease at flood flows, which is likely a product of decreased areas of higher velocities.

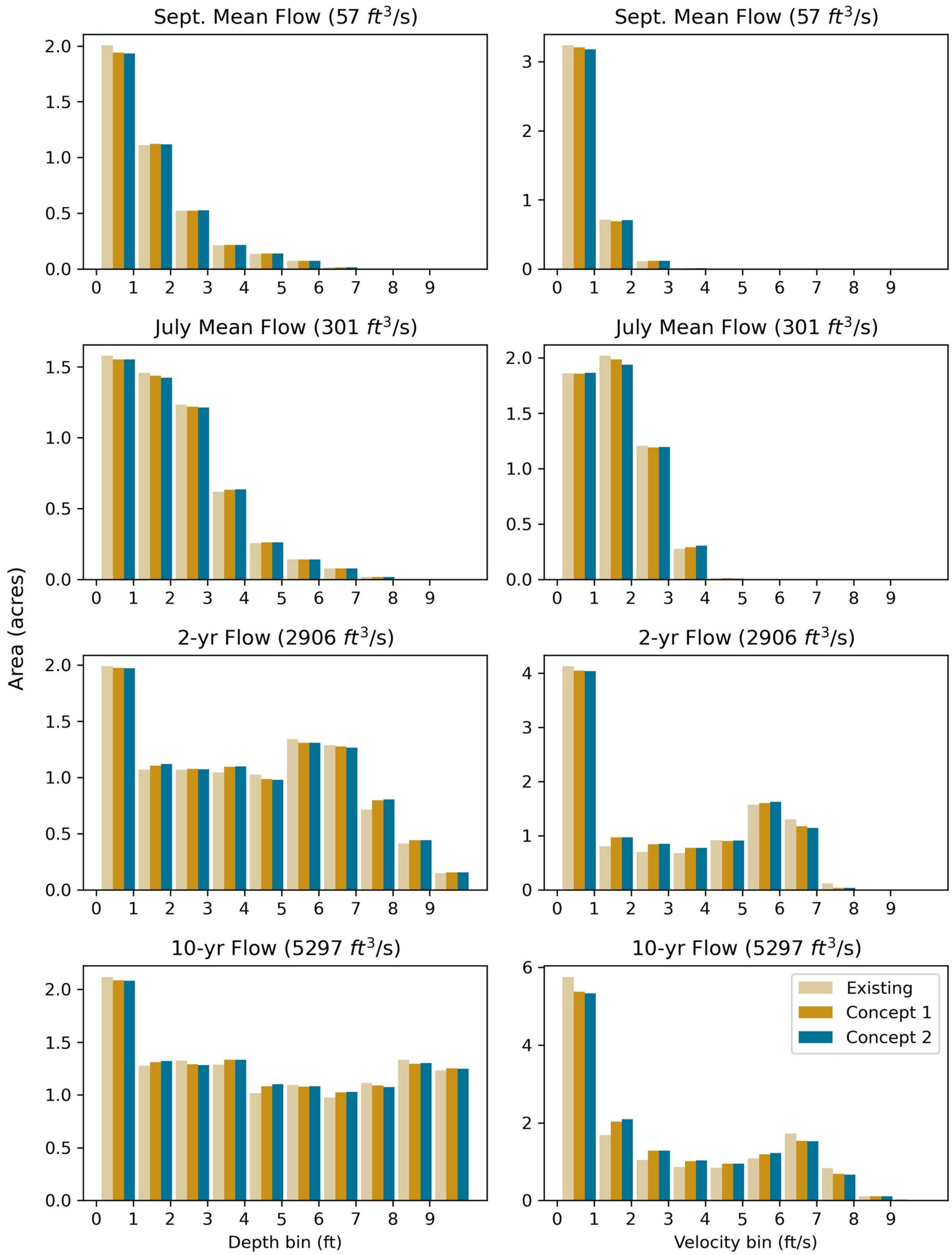


Figure 33.—Depth and velocity histograms for RM 10 to 9.5 existing and conceptual design conditions.

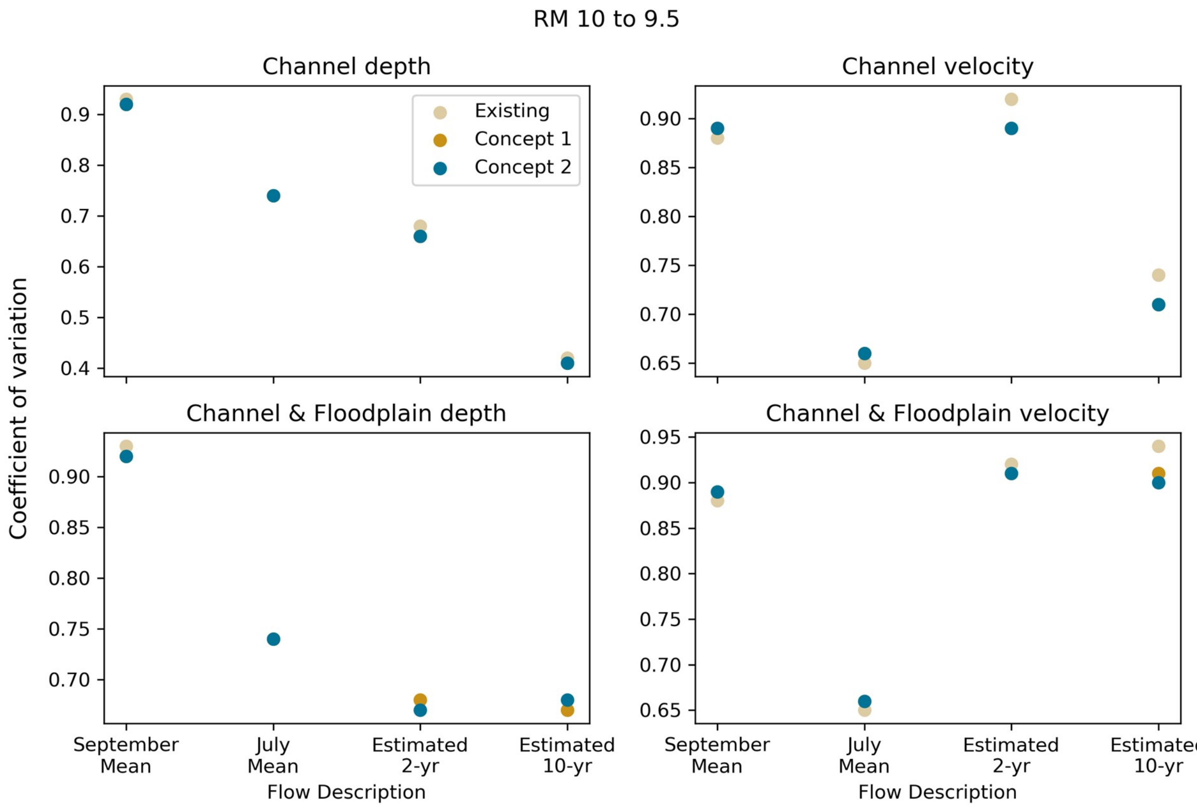


Figure 34.—Coefficient of variation in depth and velocity along the RM 10 to 9.5 site.

7.4.2.4 *River Miles 20 to 9 Summary*

To summarize, key observations and findings from the conceptual development, modeling, and a post-concept development field visit include:

- Wood loading is predicted to increase the variability in main-channel flow conditions locally at LW structures, but generally the addition of LW decreases conveyance leading to decreased main channel velocity.
- Decreased main channel conveyance due to LW leads to floodplain connectivity at lower flows.
- Due to increased flow on the floodplains, floodplain velocities are predicted to increase.
- Concept 1 wood loading between RM 17.5 and 17 produces increased floodplain connectivity, decreasing the recurrence interval of 10-yr inundation to approximately the 2-yr flow.
    - Increased wood loading in Concept 2 between RM 17 and 16 has a similar impact, increasing the frequency of floodplain inundation. Therefore, the second iteration of design with more wood is suggested if this is a desired goal.

- At RM 14.5 to 13.5, increased wood loading (in Concept 2) as the river transitions from transport to depositional was successful in creating a high flow side channel (2-yr recurrence) where the initial design did not connect. Further downstream, the two design iterations had more similar inundation extents, but the increased number of structures would increase in-channel flow variability and provide increased heterogeneity.

- The current design between RM 10 to 9.5 is predicted to be successful at providing more in-channel wood structure leading to increased cover and heterogeneity within this depositional reach upstream of Boulder Creek. The current design concept also decreases velocities along the upstream road embankment. The design would only slightly raise water surface elevations in upstream portions of the floodplain outside of USFS land, but those increases would be unlikely to impact existing infrastructure. On a field site visit after initial concepts were developed, a discussion about the rip rap along the road embankment indicated that the rip rap is currently providing relatively good habitat for juvenile fish.

8.0 Summary

The SRH group from Reclamation's TSC was tasked with developing restoration concepts for two segments of the Chewuch River: RM 33 to 29 and RM 20 to 9. To develop these concepts, SRH developed hydrology from existing data sources, performed a geomorphic assessment, and created an existing conditions model of the river miles of interest. For RM 33 to 29, three restoration concept designs were developed: a low-tech, a hybrid, and a helicopter approach. These concepts differed by types of structures and density of structures. For RM 20 to 9, SRH created a methodology to better understand the relative risk that mobile LW may have in relation to existing infrastructure. This risk assessment was used to choose locations to develop concepts and included a dynamic process-based approach (RM 17.5 to 16), a moderate process-based approach (RM 14.5 to 13.5), and a static habitat-focused approach to design (RM 10 to 9.5). Initial concepts were assessed during a May 2024 field visit and a second concept was developed with increased wood and boulder loading to the Chewuch River channel. For both RM 33 to 29 and RM 20 to 9, increased densities of structures led to increased floodplain connectivity. An increased number of structures also decreases main channel conveyance and velocities, however, adjacent to structures velocities are often locally increased. Geomorphically, it is expected that concept structures will increase local hydraulic variability and by association create more dynamic sediment sorting.

9.0 References

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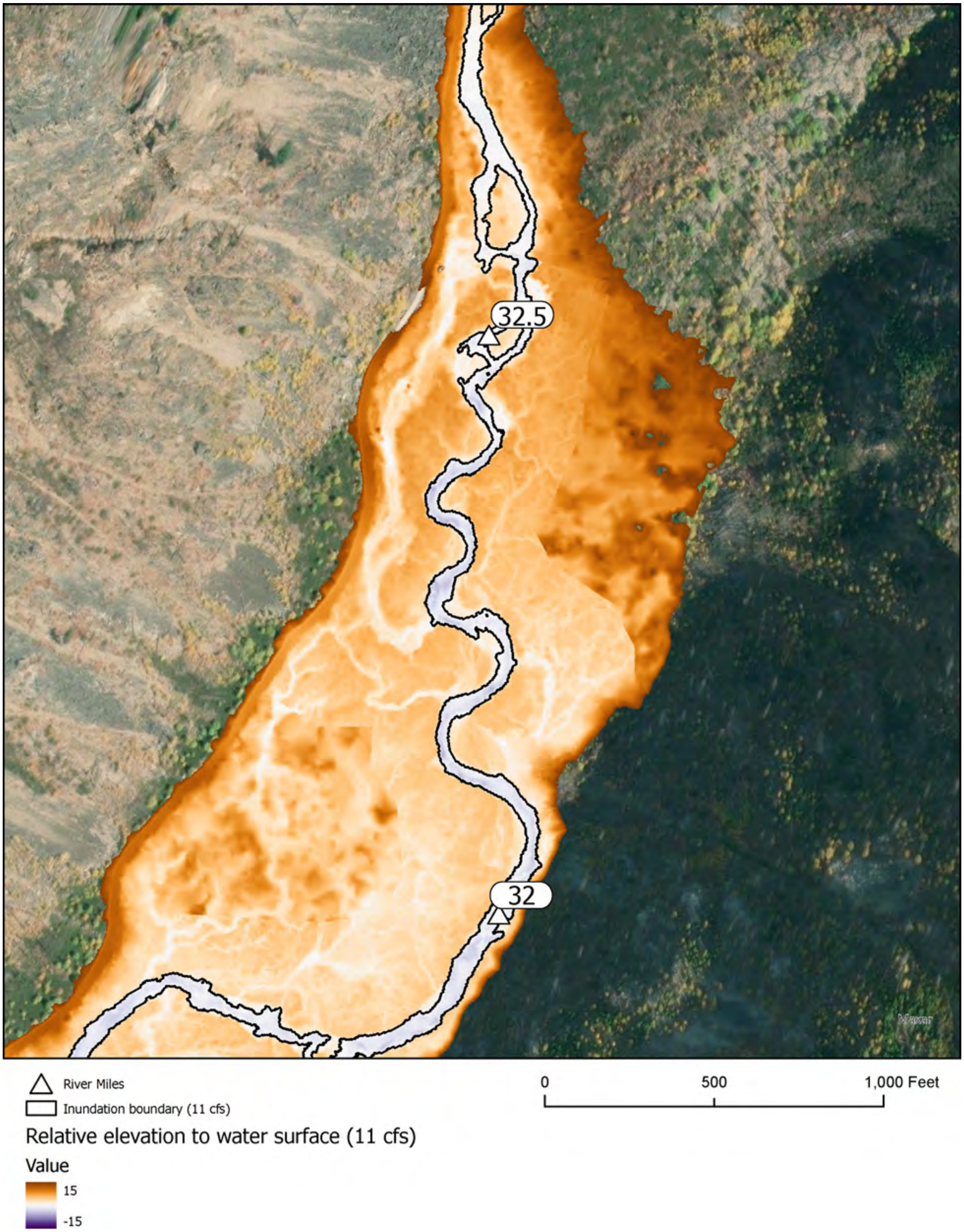
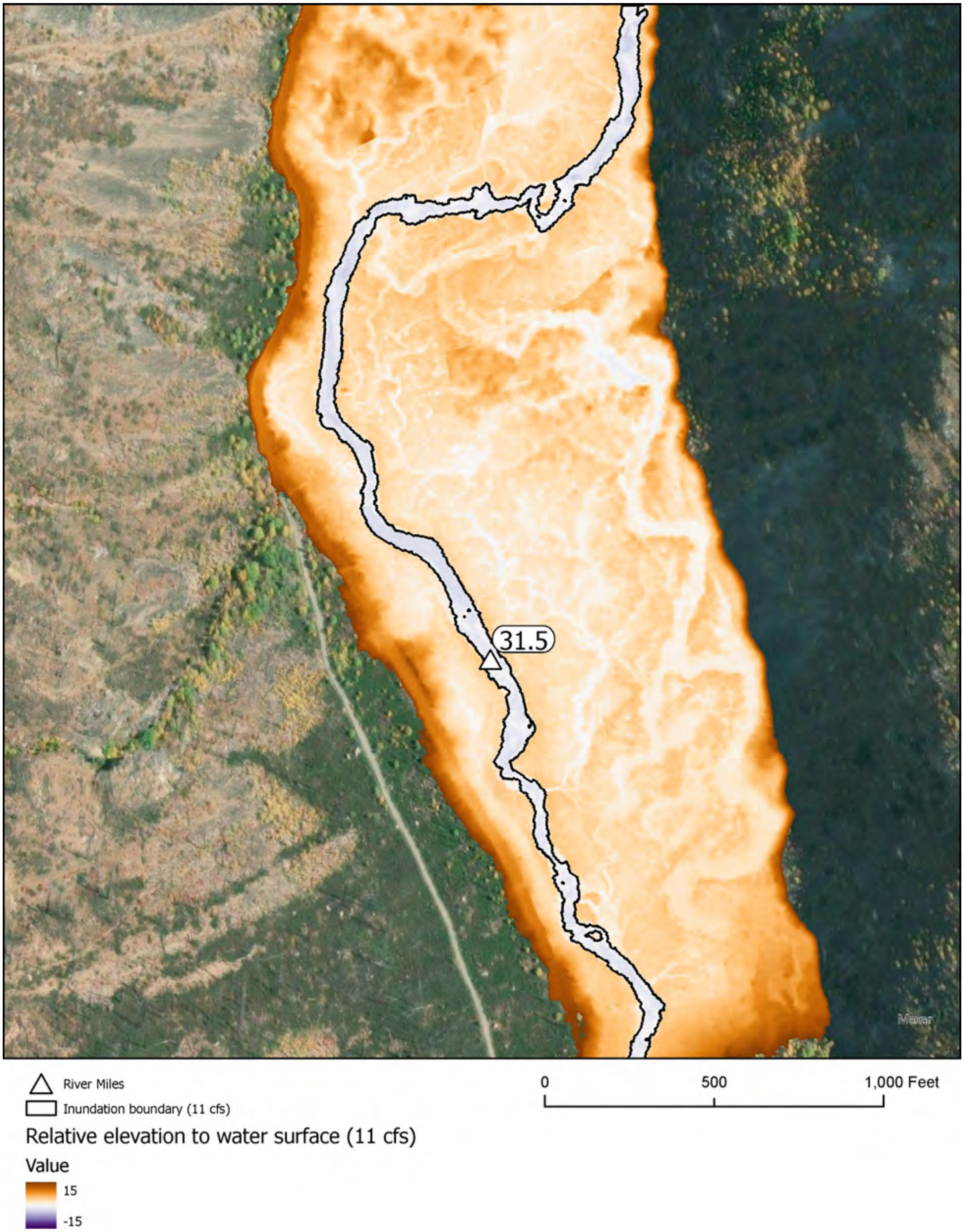
Appendix A

Relative Elevation – Height Above Water Surface Maps


32.5
32
Maxar
River Miles
Inundation boundary (11 cfs)
Relative elevation to water surface (11 cfs)
Value
15
-15
0
500
1,000 Feet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River Miles
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Relative elevation to water surface (11 cfs)
Value
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-15
0
500
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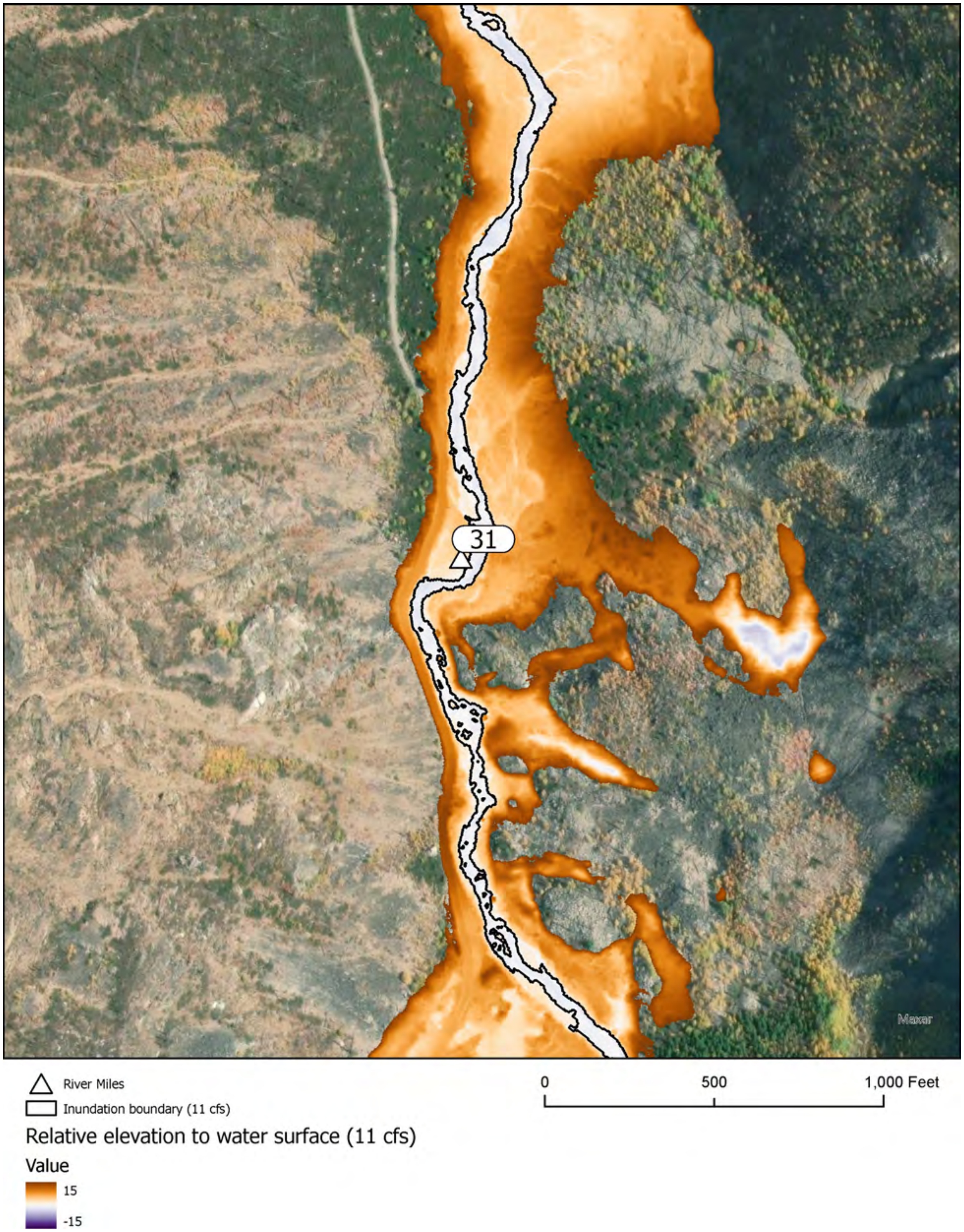
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River Miles
Inundation boundary (11 cfs)
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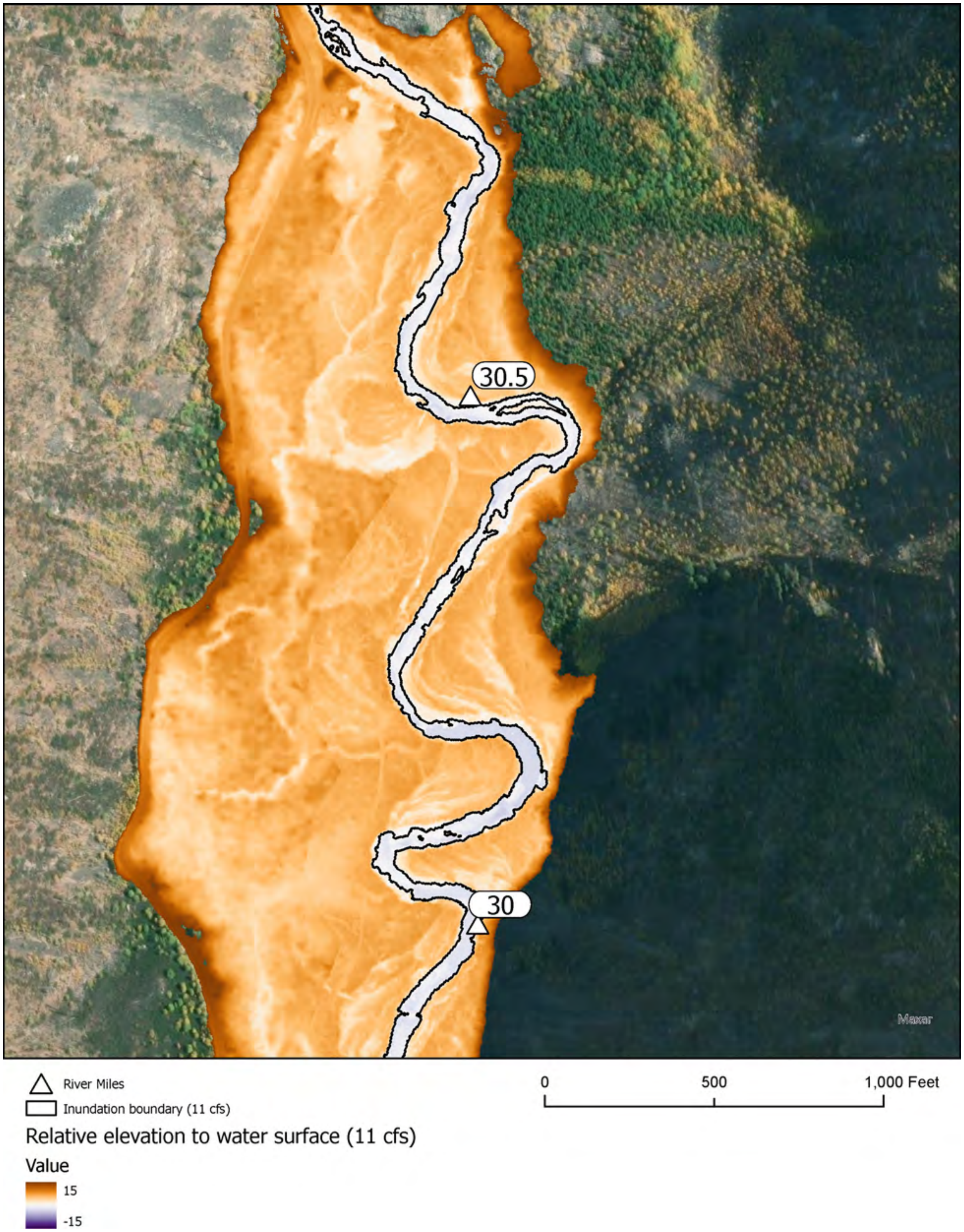
-15
0
500
1,000 Feet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30
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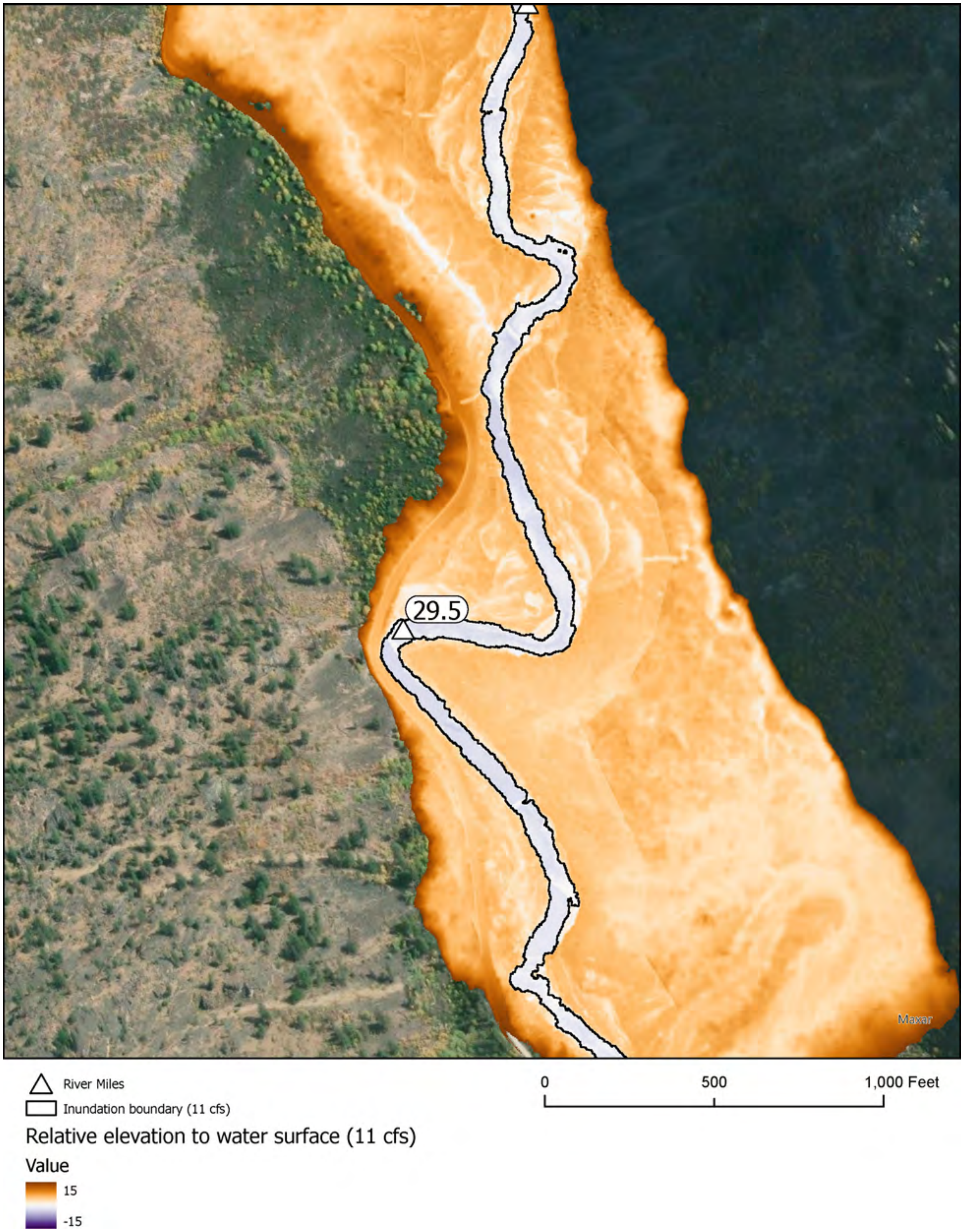
Value
15
-15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Maxar
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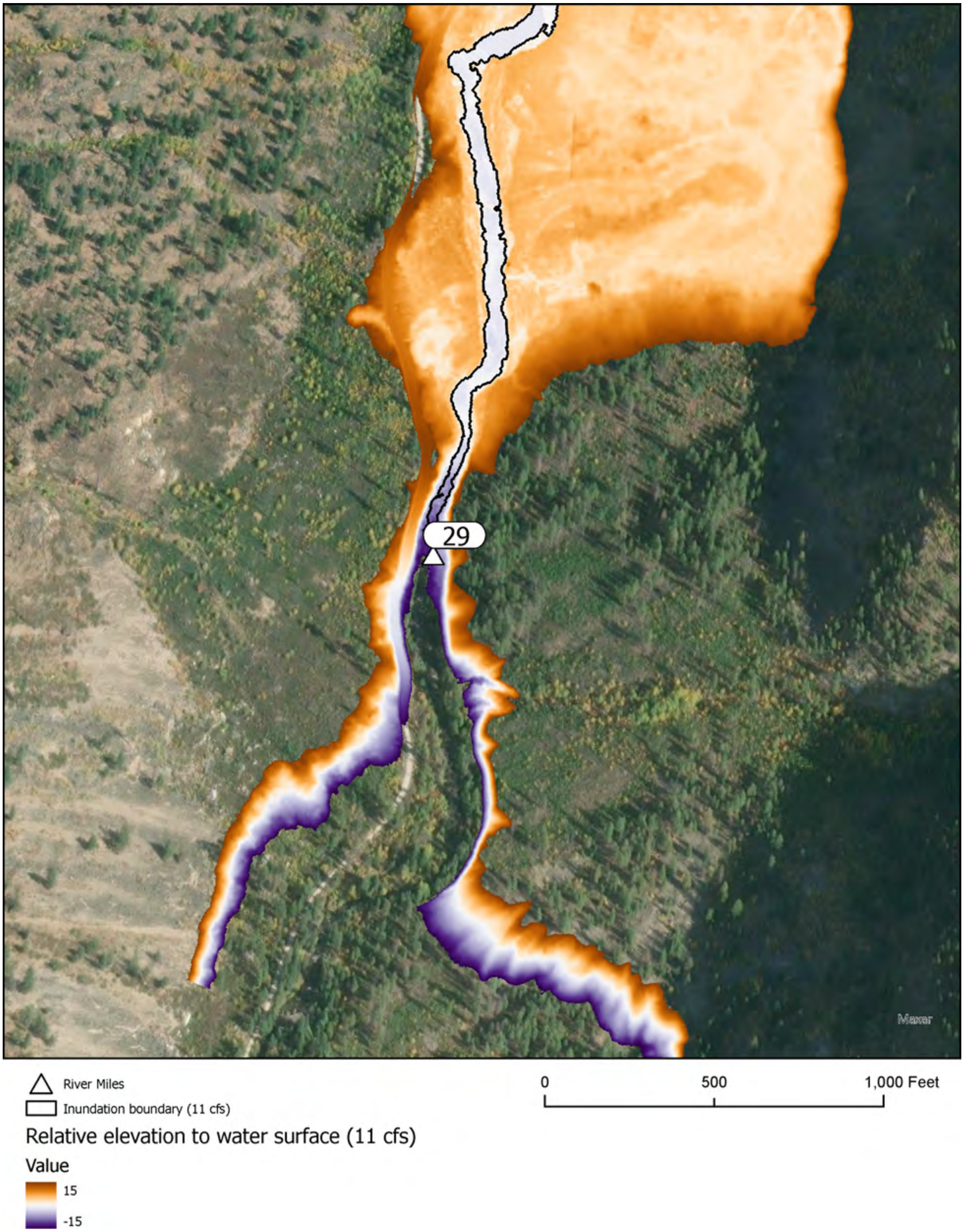
29
Maxar
River Miles
Inundation boundary (11 cfs)
Relative elevation to water surface (11 cfs)
Value
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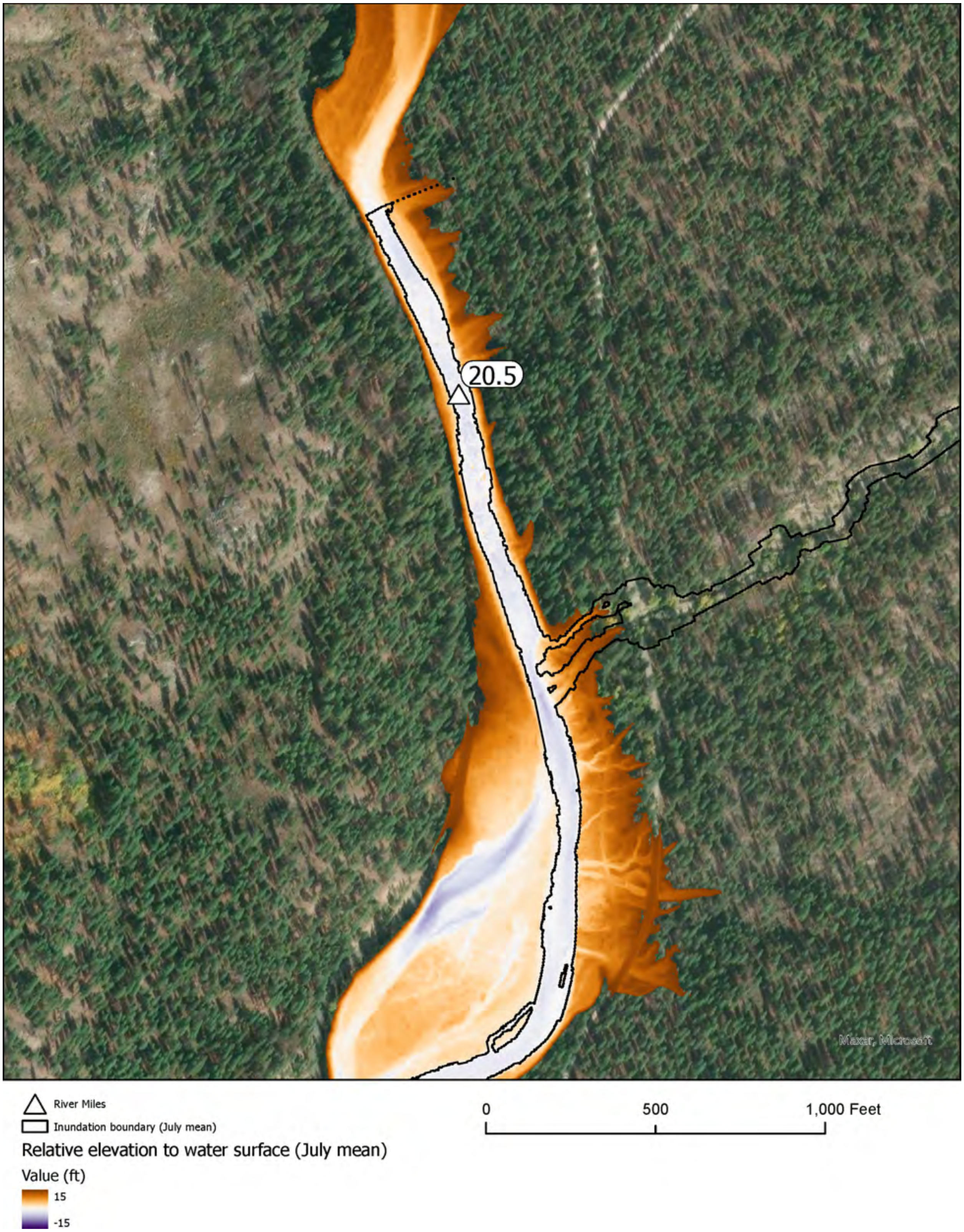
0
500
1,000 Feet


20.5
Maxar, Microsoft
River Miles
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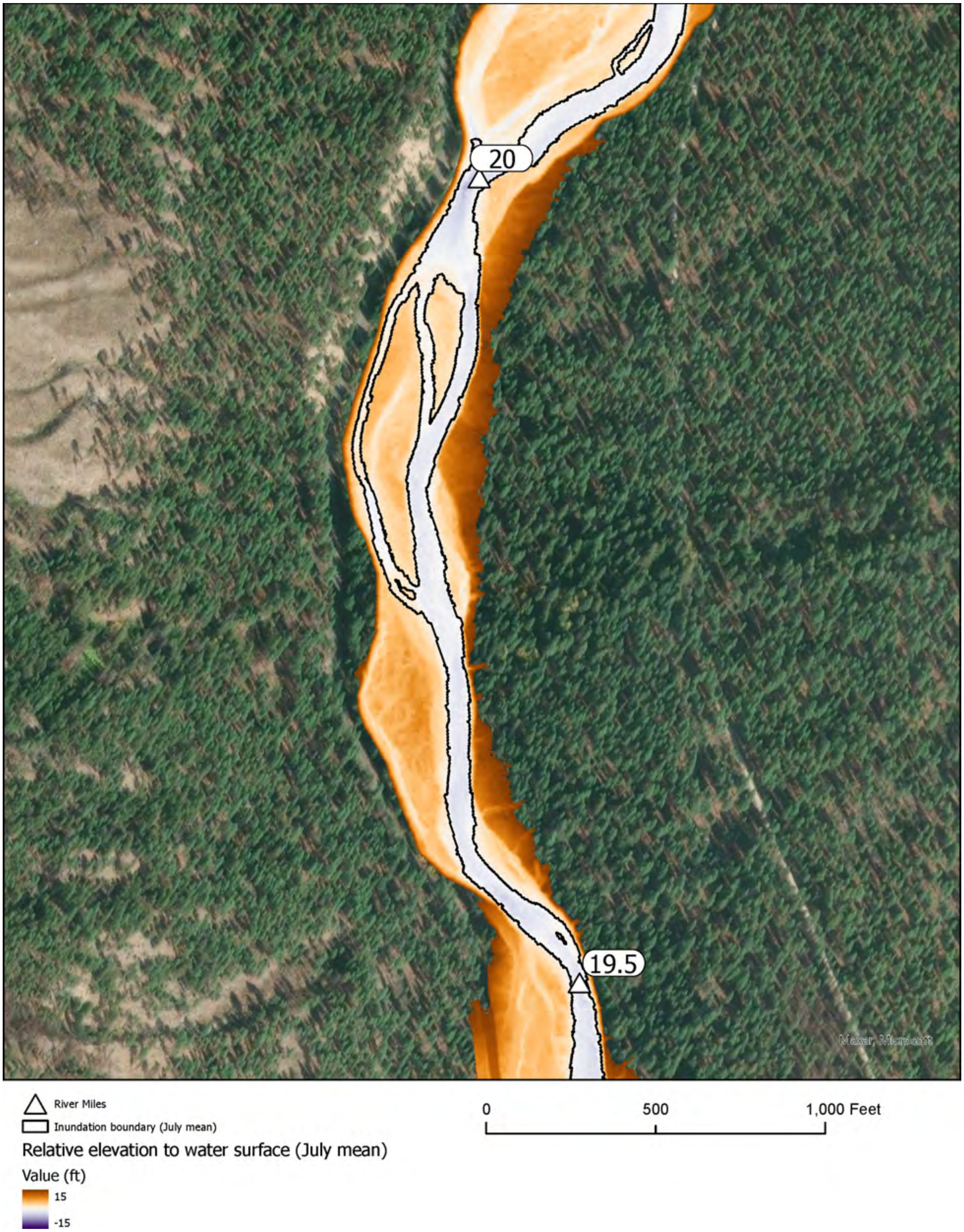
500
1,000 Feet
Relative elevation to water surface (July mean)
Value (ft)
15
-15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Relative elevation to water surface (July mean)
Value (ft)
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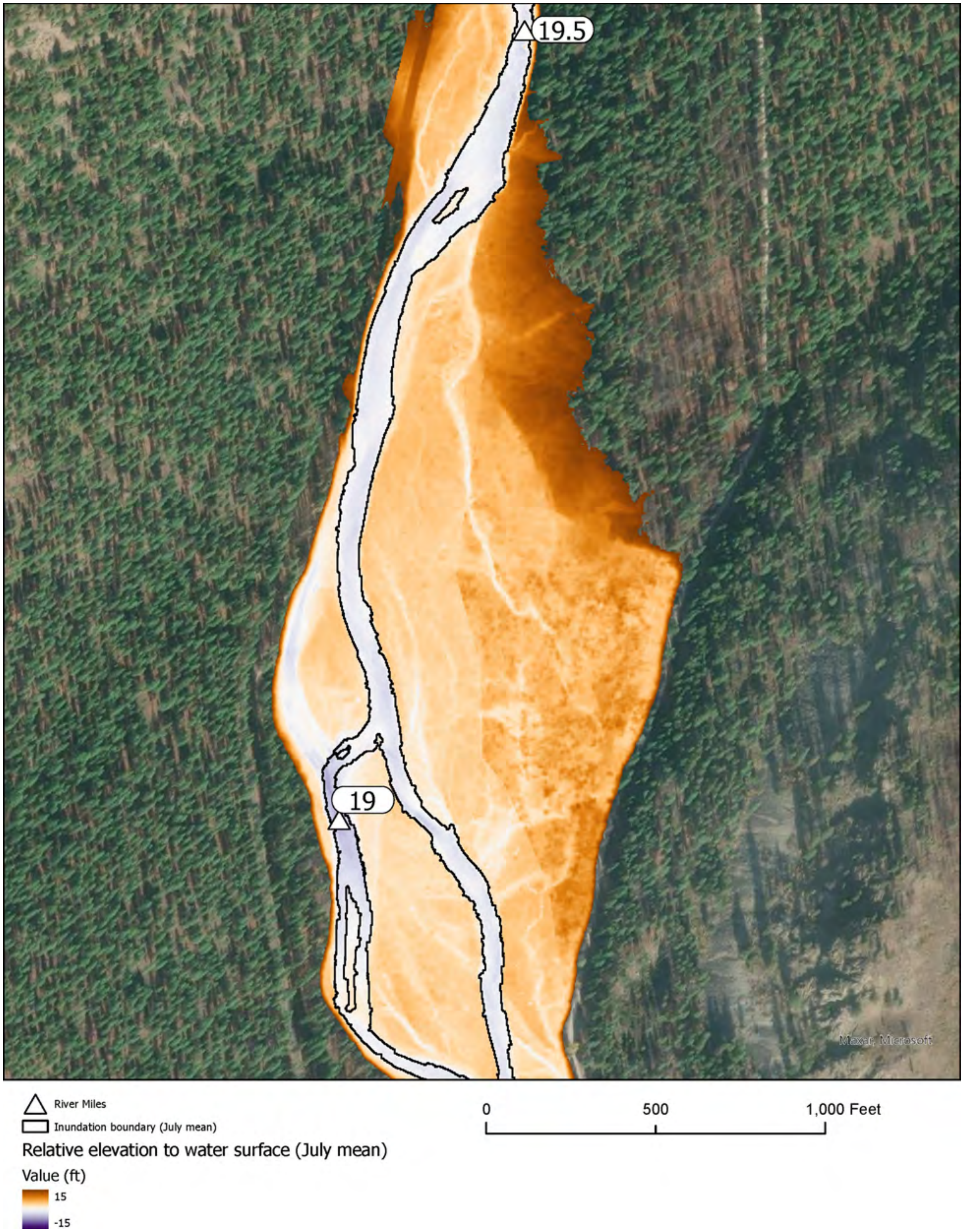
500
1,000 Feet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River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet


18.5
Maxar, Microsoft
River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet


18
Maxar
River Miles
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Value (ft)
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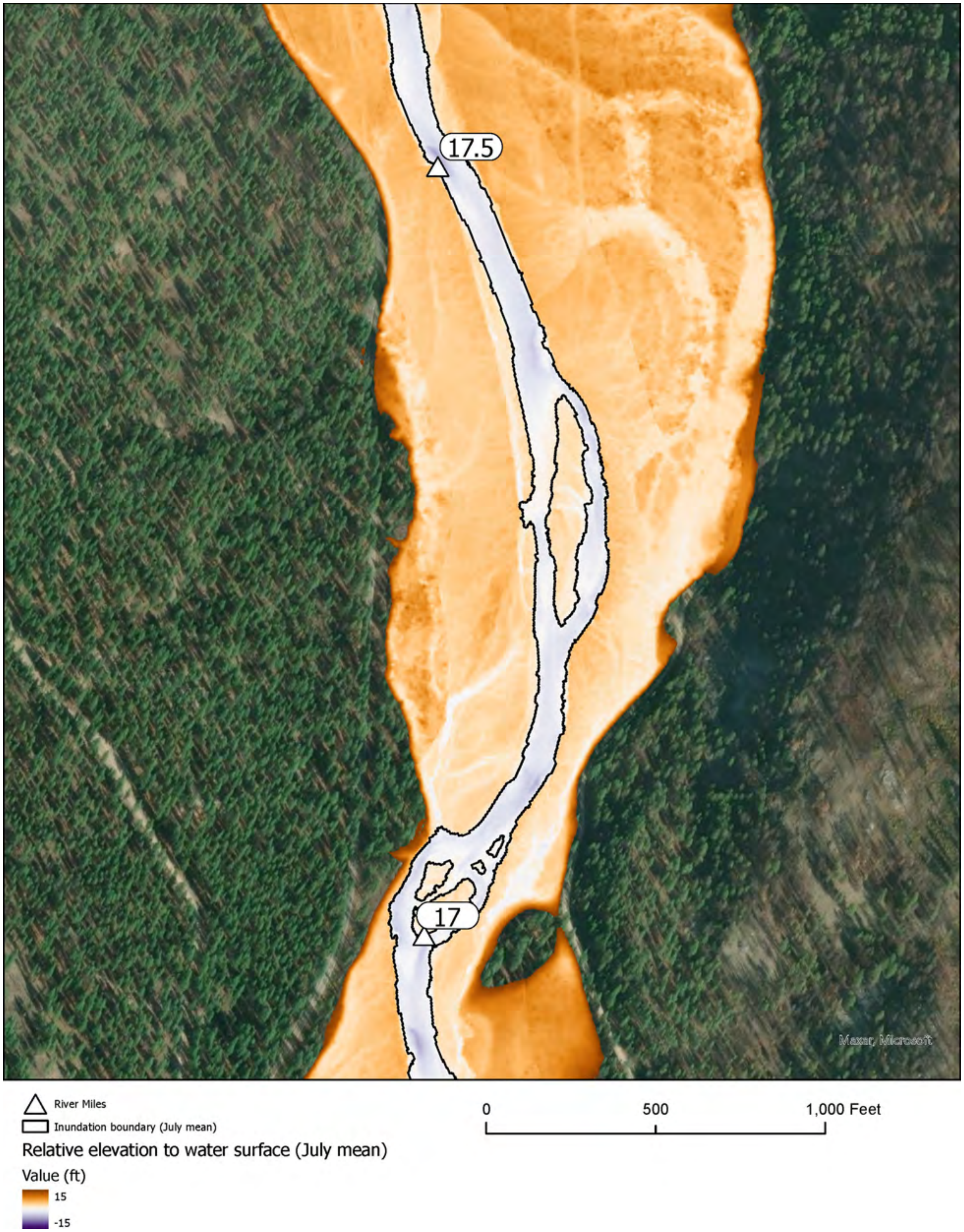
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Relative elevation to water surface (July mean)
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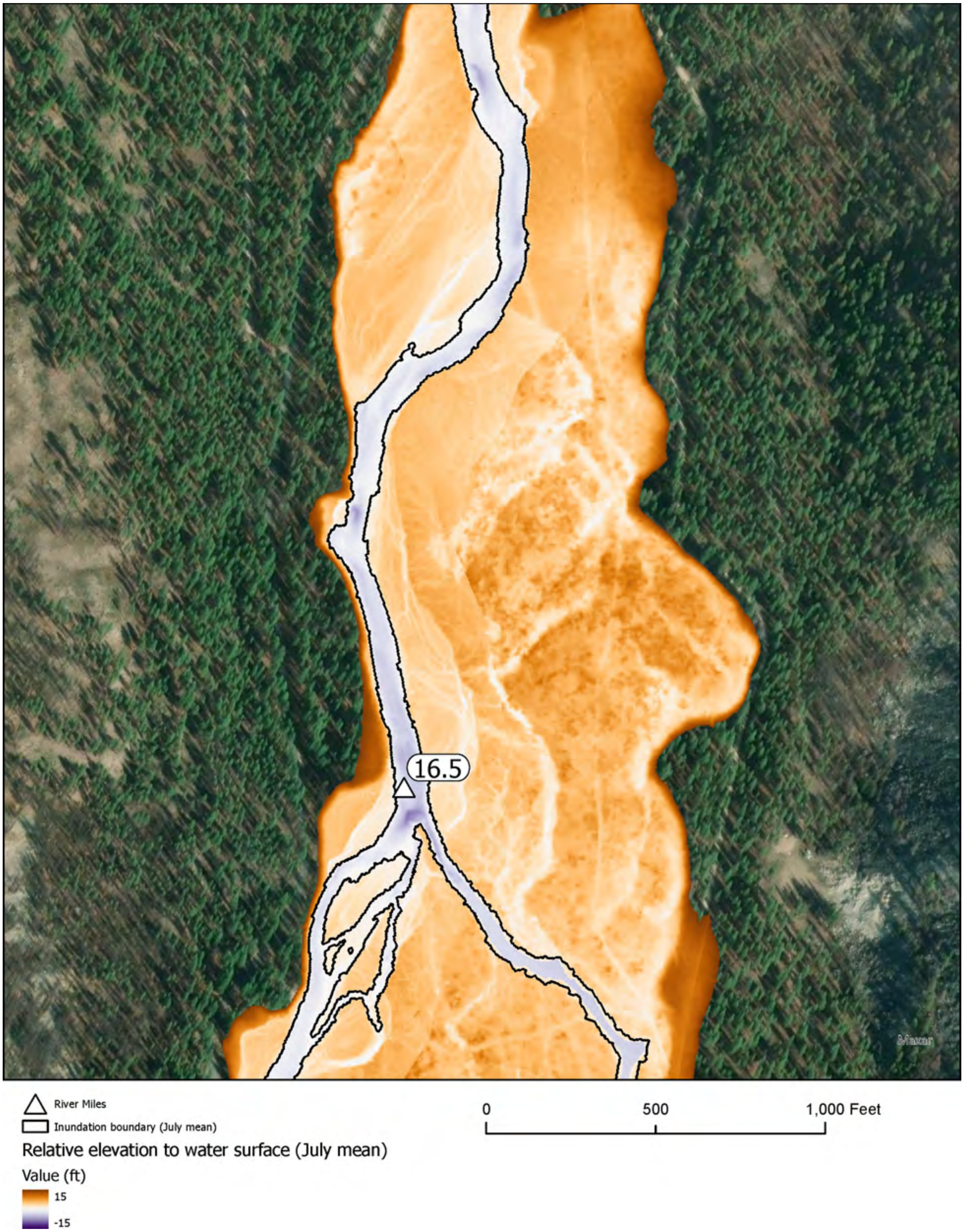
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Value (ft)
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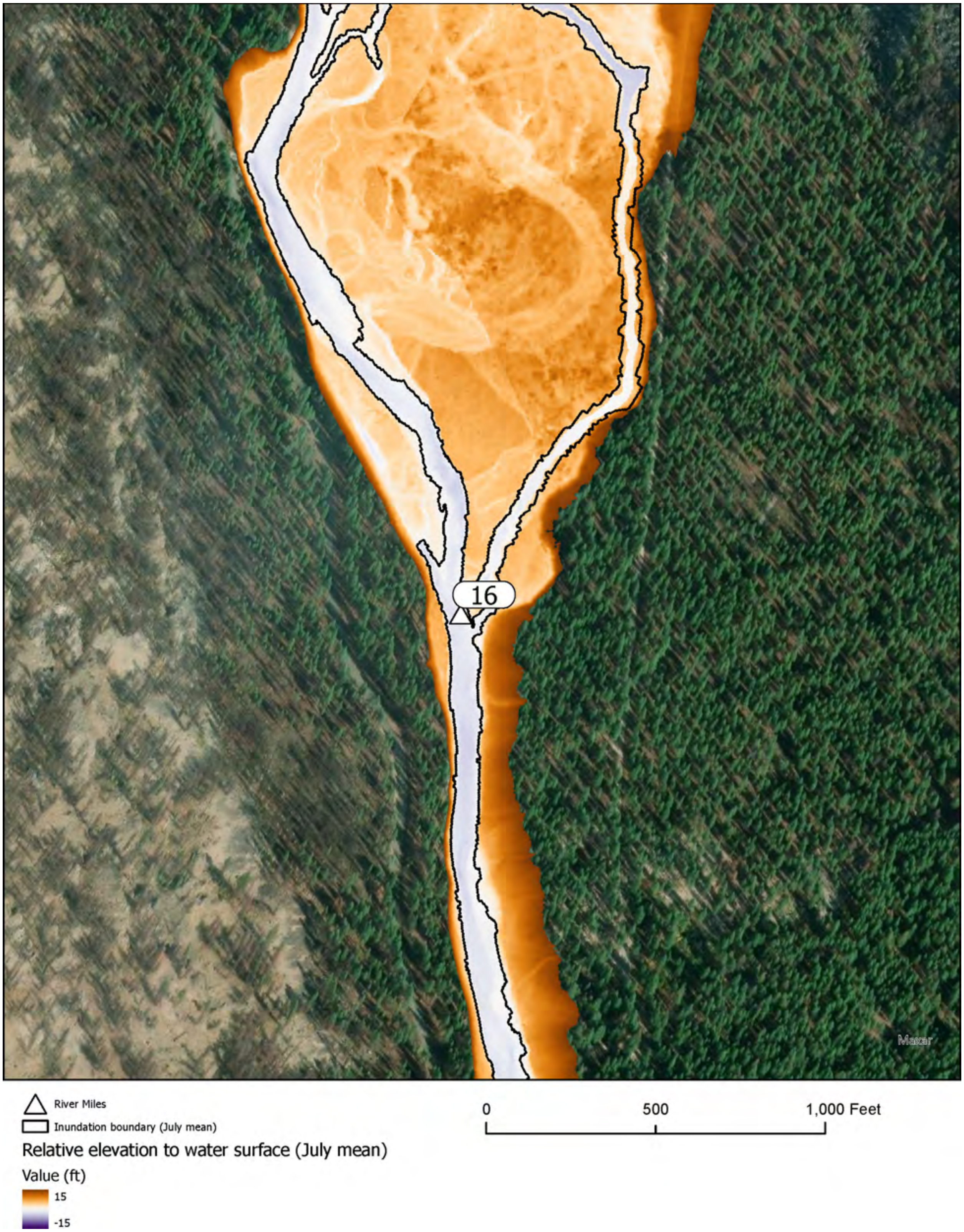
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Relative elevation to water surface (July mean)
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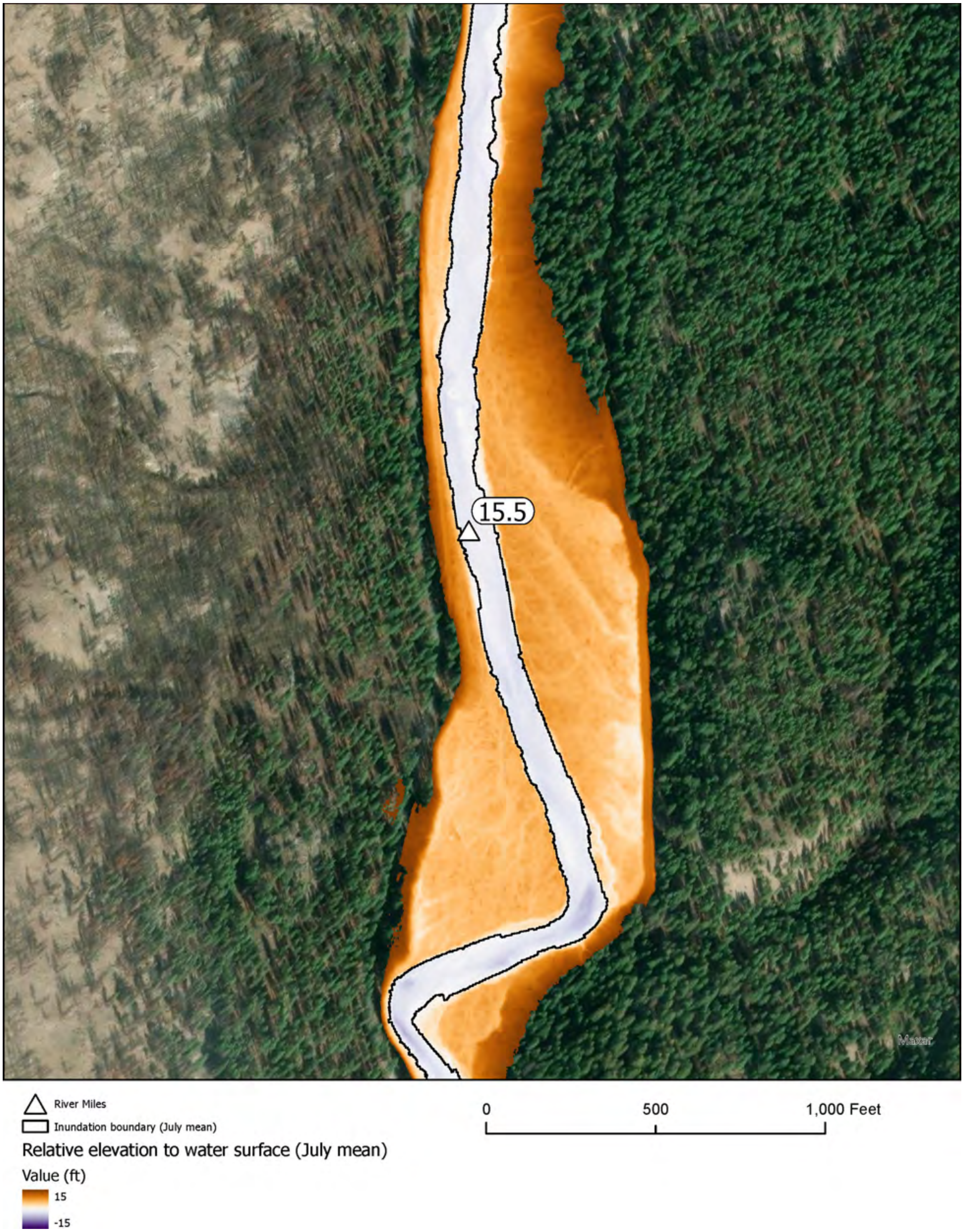
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0
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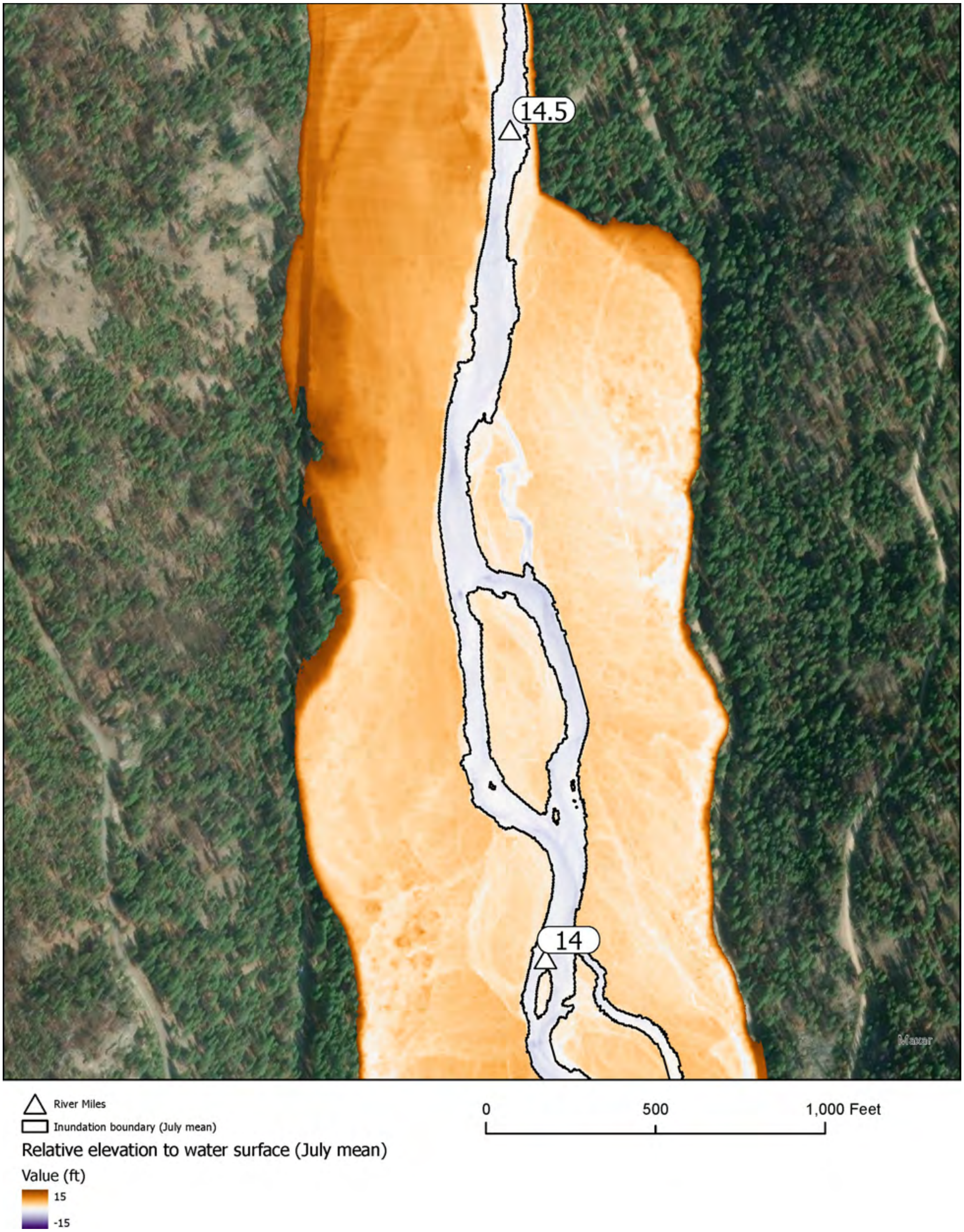
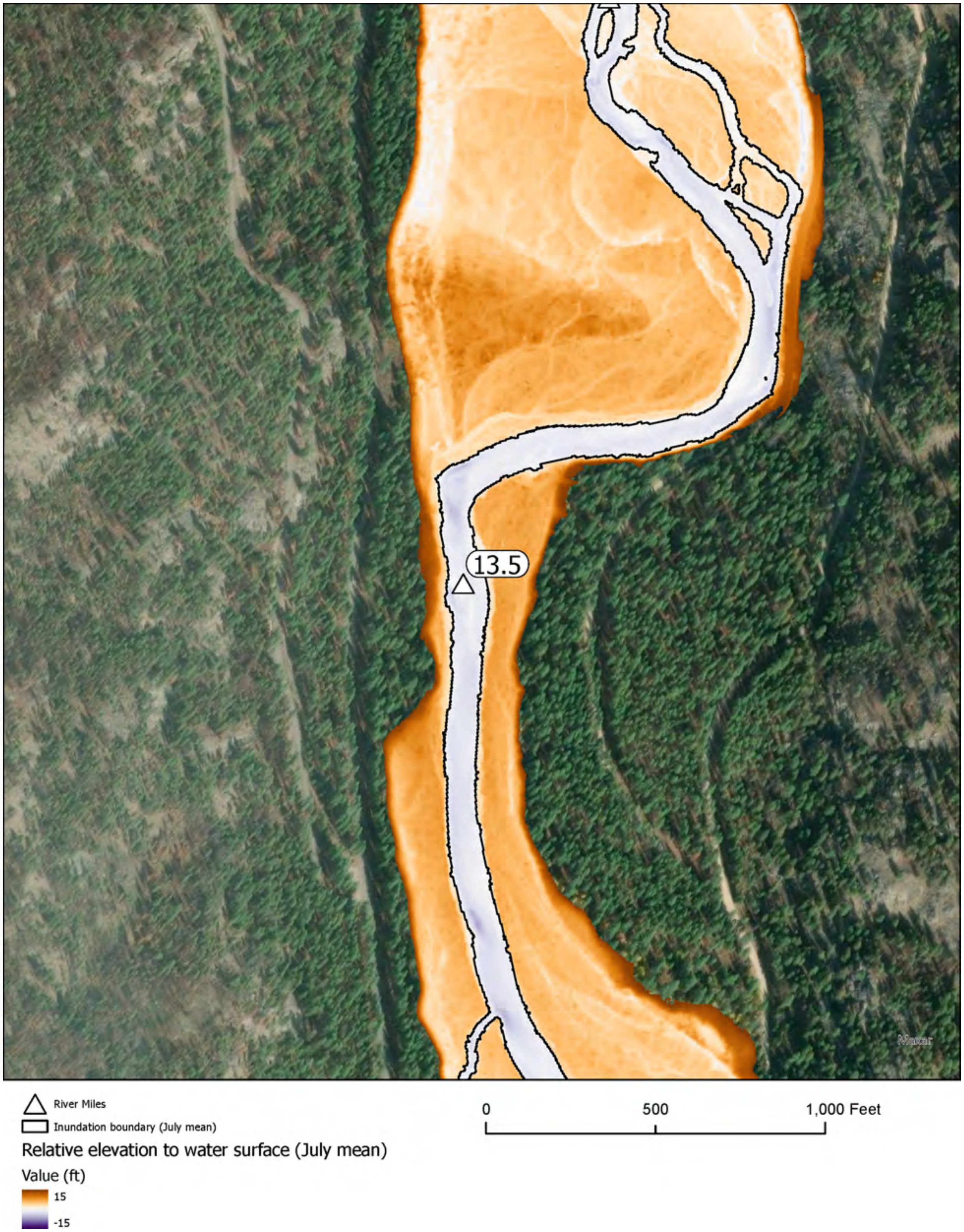
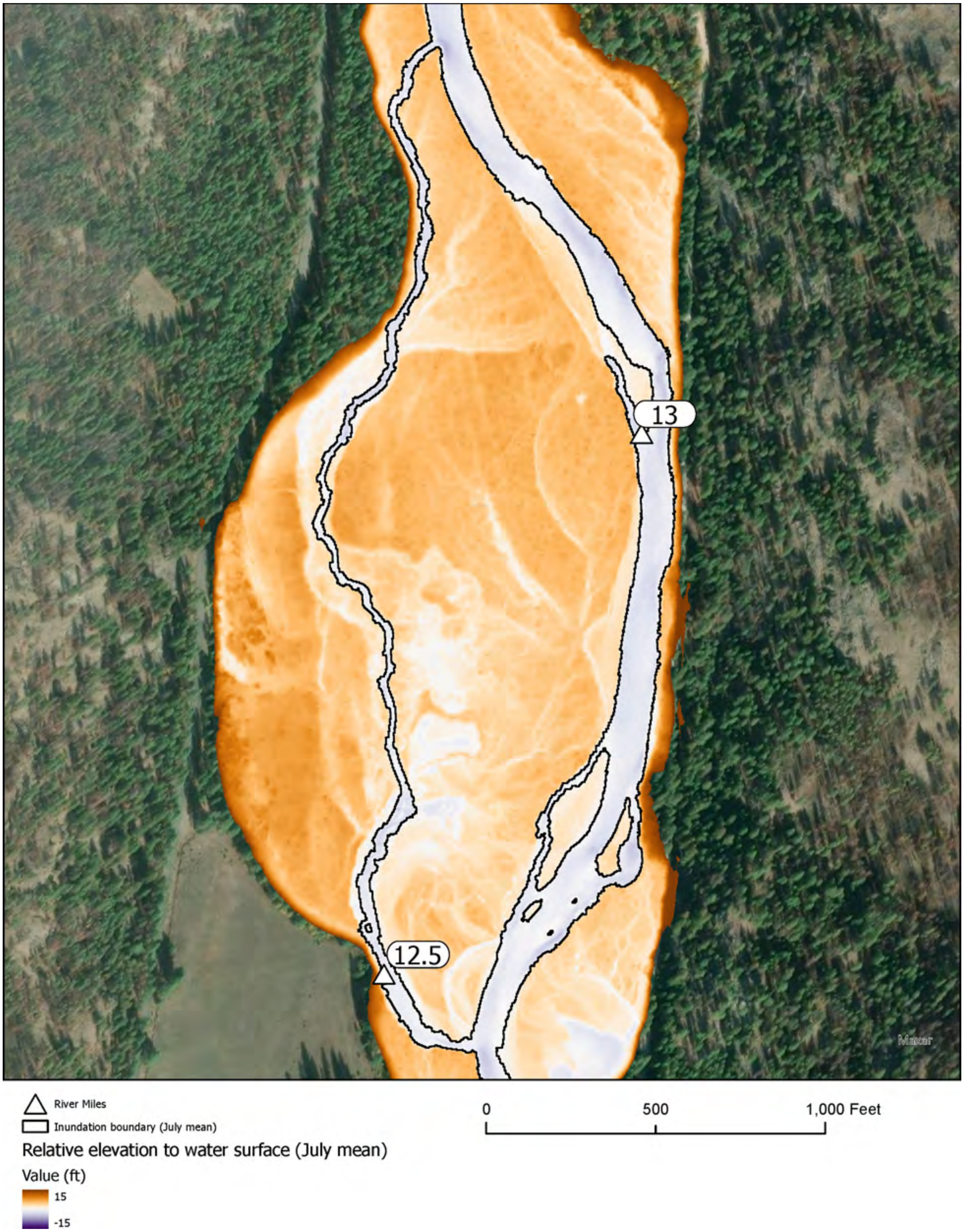
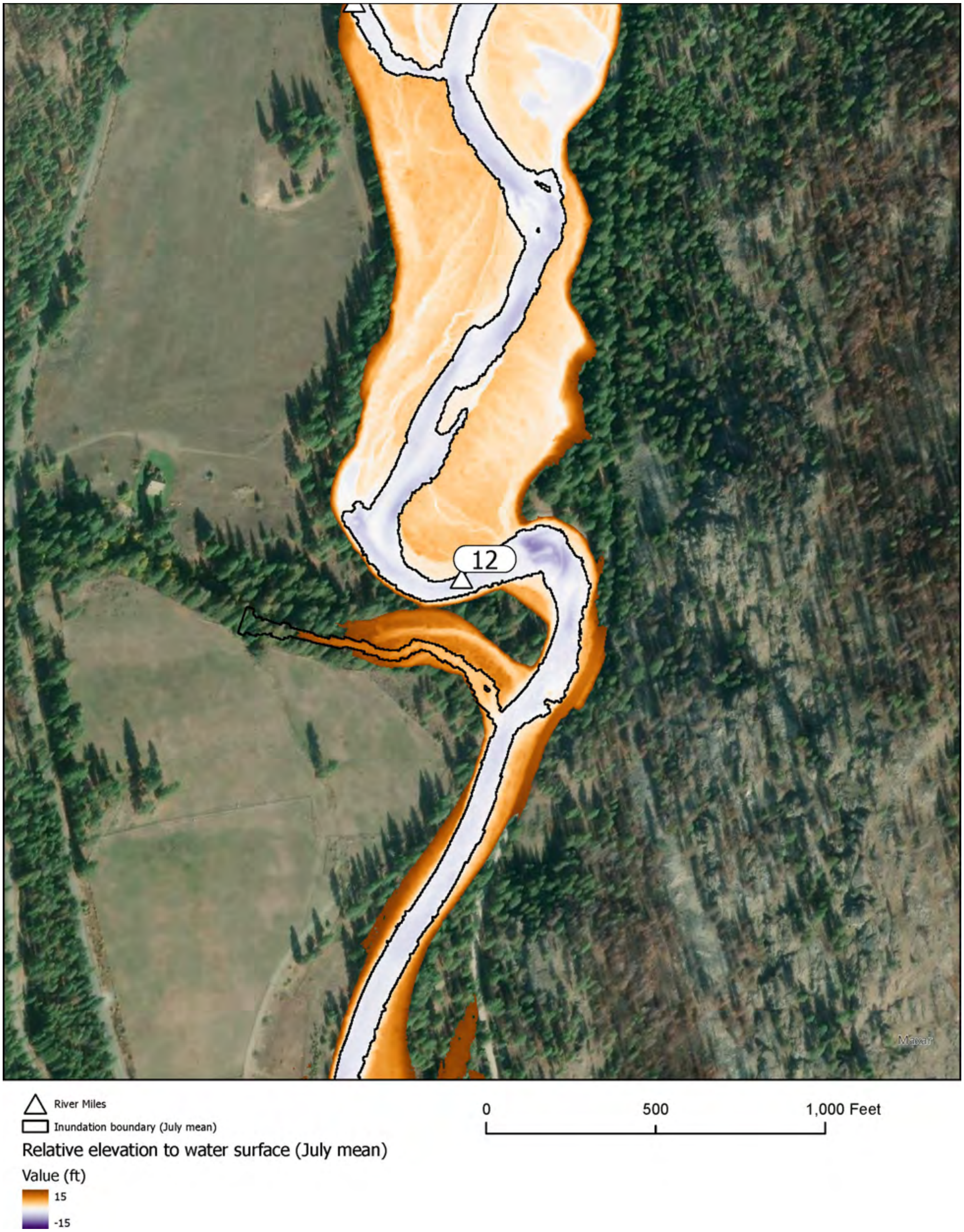
1,000 Feet
Relative elevation to water surface (July mean)
Value (ft)
15
-15

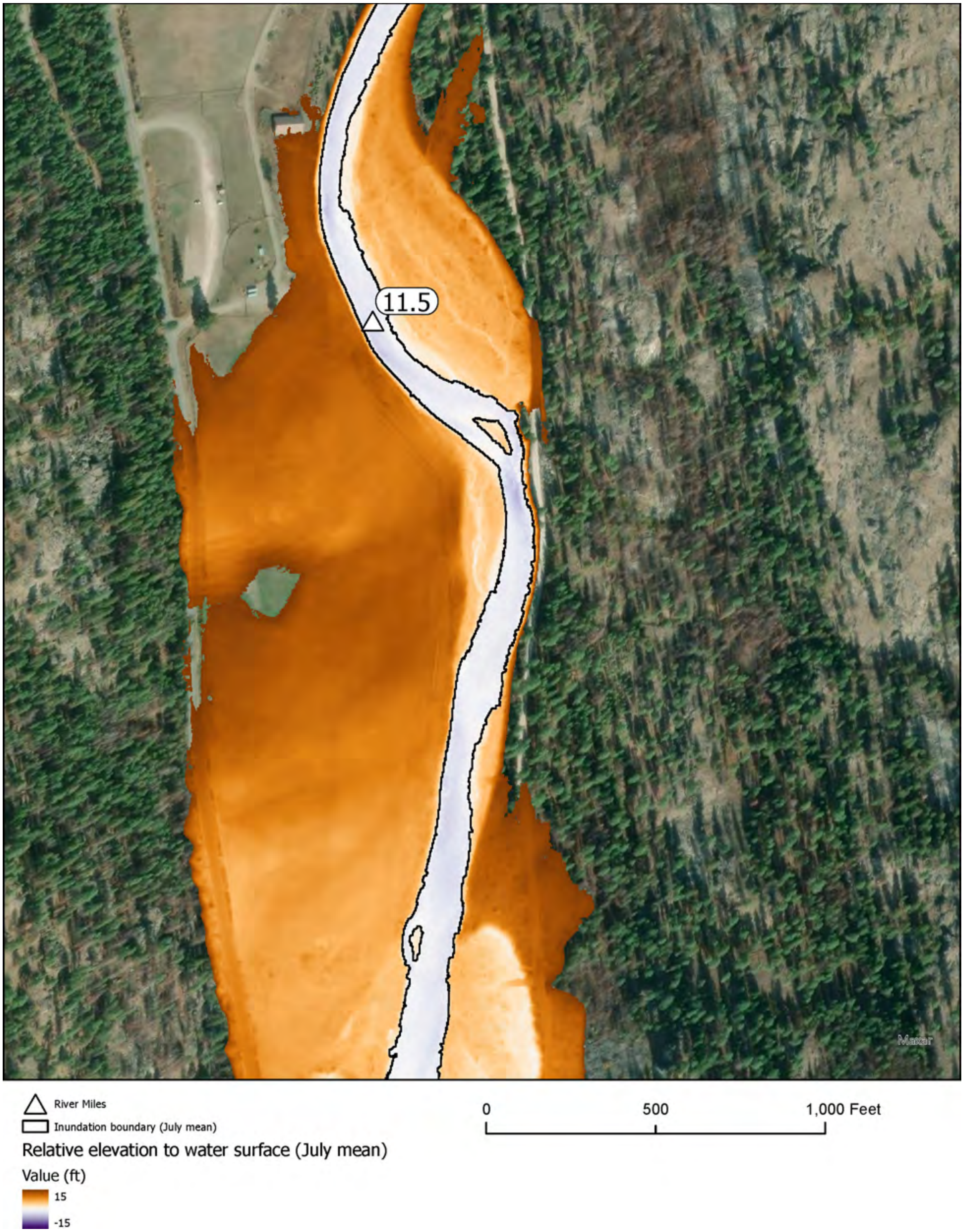

15
Maxar
River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet


14.5
14
Maxar
River Miles
Inundation boundary (July mean)
0
500
1,000 Feet
Relative elevation to water surface (July mean)
Value (ft)
15
-15


13.5
River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet

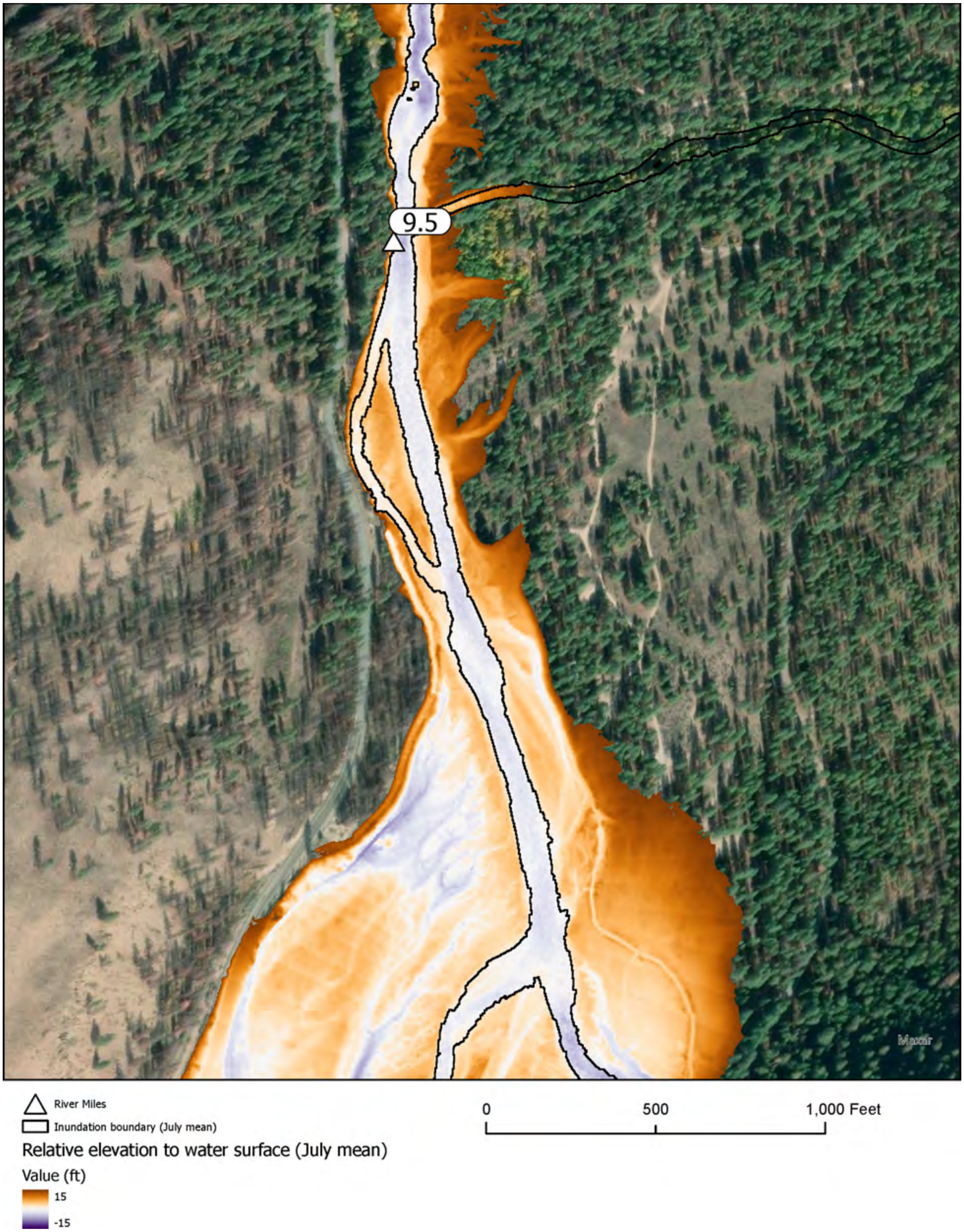

13
12.5
Maxar
River Miles
Inundation boundary (July mean)
0
500
1,000 Feet
Relative elevation to water surface (July mean)
Value (ft)
15
-15

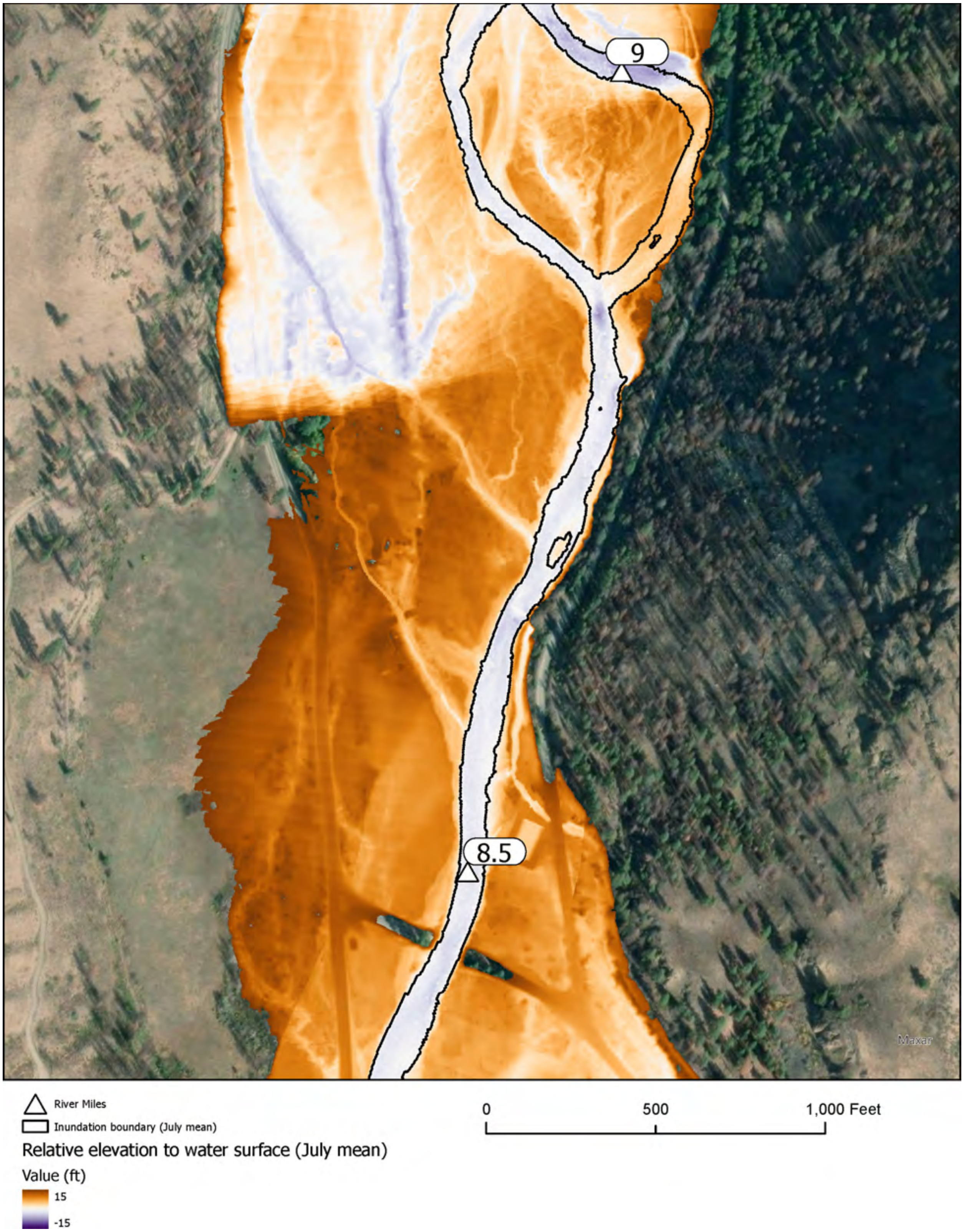

12
Maxar
River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet


11.5
Maxar
River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet


11
10.5
Maxar
River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet

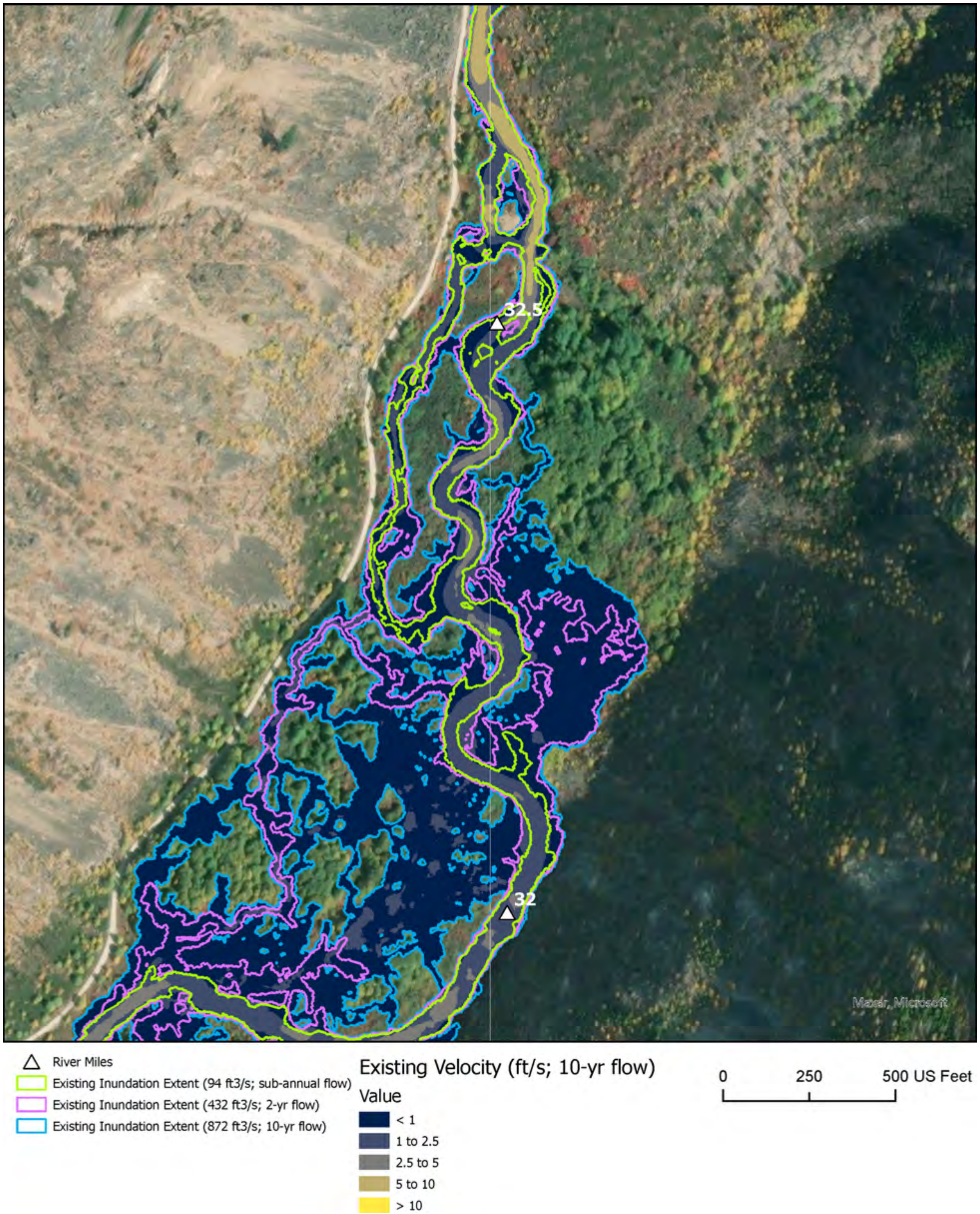

10
River Miles
Inundation boundary (July mean)
0
500
1,000 Feet
Relative elevation to water surface (July mean)
Value (ft)
15
-15


9.5
Maxar
River Miles
Inundation boundary (July mean)
Relative elevation to water surface (July mean)
Value (ft)
15
-15
0
500
1,000 Feet

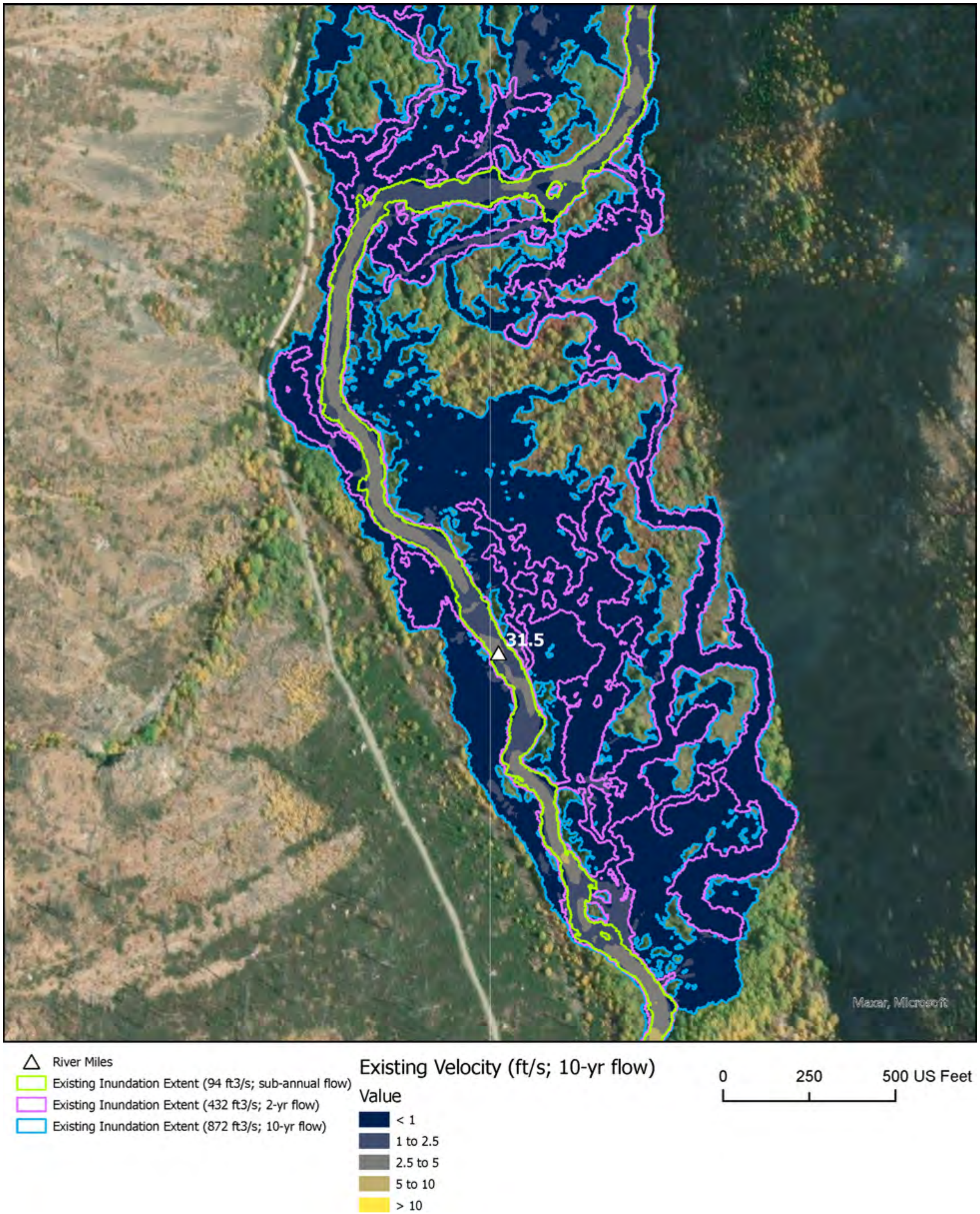

9
8.5
Maxar
River Miles
Inundation boundary (July mean)
0
500
1,000 Feet
Relative elevation to water surface (July mean)
Value (ft)
15
-15

Appendix B

Existing Conditions Model Results for Sites within River Miles 33 to 29

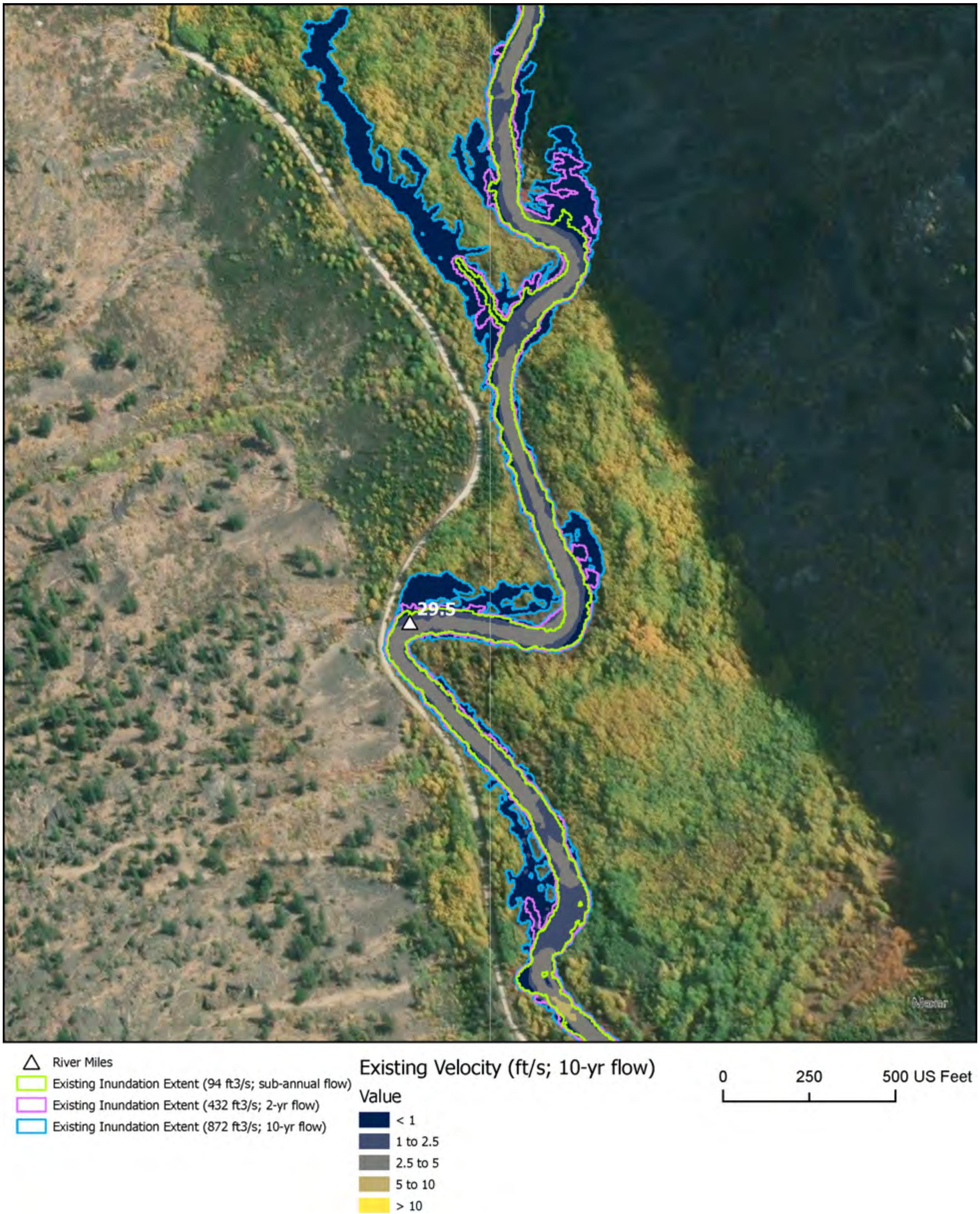


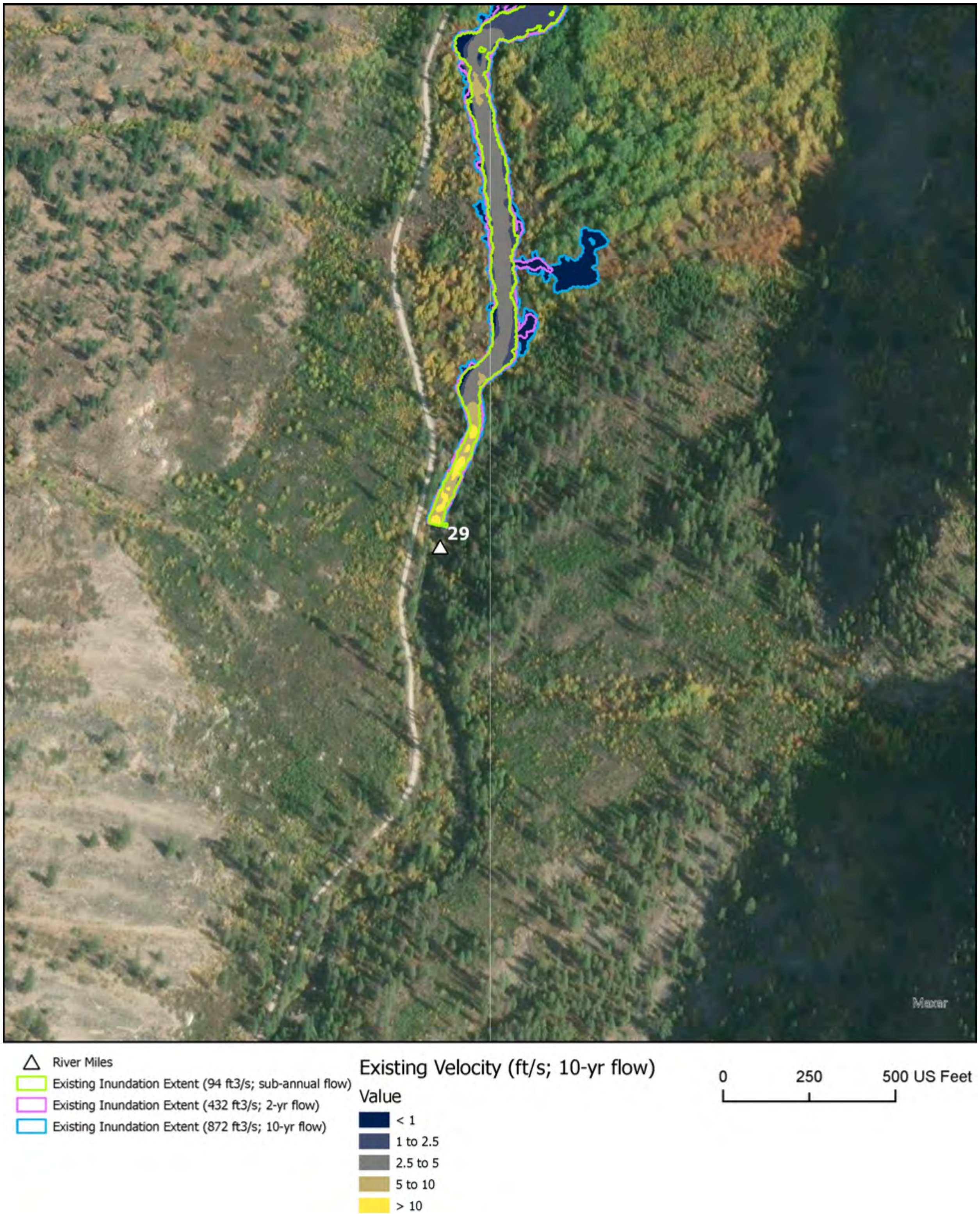
32.5
32
Maxar, Microsoft
River Miles
Existing Inundation Extent (94 ft3/s; sub-annual flow)
Existing Inundation Extent (432 ft3/s; 2-yr flow)
Existing Inundation Extent (872 ft3/s; 10-yr flow)
Existing Velocity (ft/s; 10-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
250
500 US Feet


31.5
Maxar, Microsoft
River Miles
Existing Inundation Extent (94 ft3/s; sub-annual flow)
Existing Inundation Extent (432 ft3/s; 2-yr flow)
Existing Inundation Extent (872 ft3/s; 10-yr flow)
Existing Velocity (ft/s; 10-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
250
500 US Feet


31
Maxar
River Miles
Existing Inundation Extent (94 ft3/s; sub-annual flow)
Existing Inundation Extent (432 ft3/s; 2-yr flow)
Existing Inundation Extent (872 ft3/s; 10-yr flow)
Existing Velocity (ft/s; 10-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
250
500 US Feet

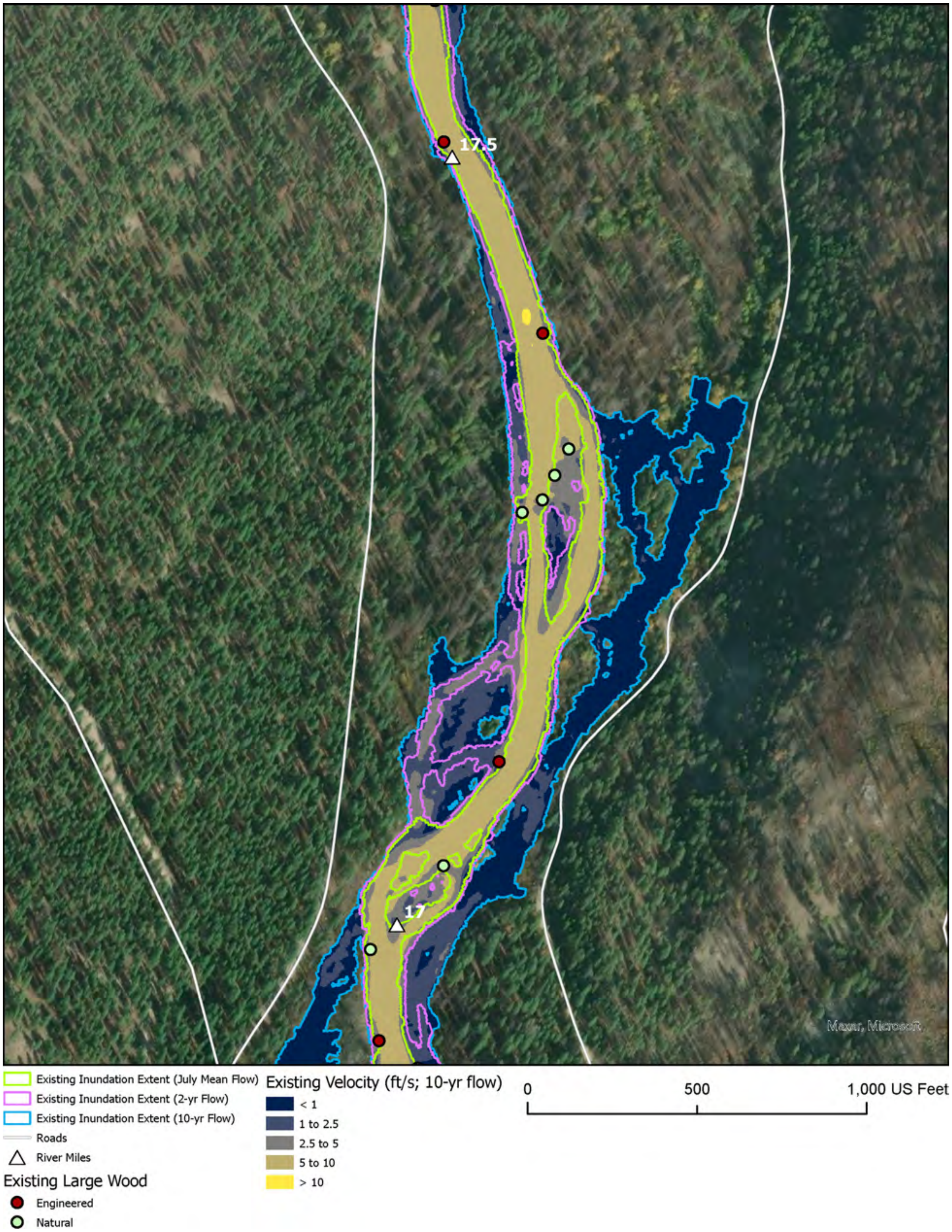

30.5
30
Maxar
River Miles
Existing Inundation Extent (94 ft3/s; sub-annual flow)
Existing Inundation Extent (432 ft3/s; 2-yr flow)
Existing Inundation Extent (872 ft3/s; 10-yr flow)
Existing Velocity (ft/s; 10-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
250
500 US Feet


29.5
River Miles
Existing Inundation Extent (94 ft3/s; sub-annual flow)
Existing Inundation Extent (432 ft3/s; 2-yr flow)
Existing Inundation Extent (872 ft3/s; 10-yr flow)
Existing Velocity (ft/s; 10-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
250
500 US Feet

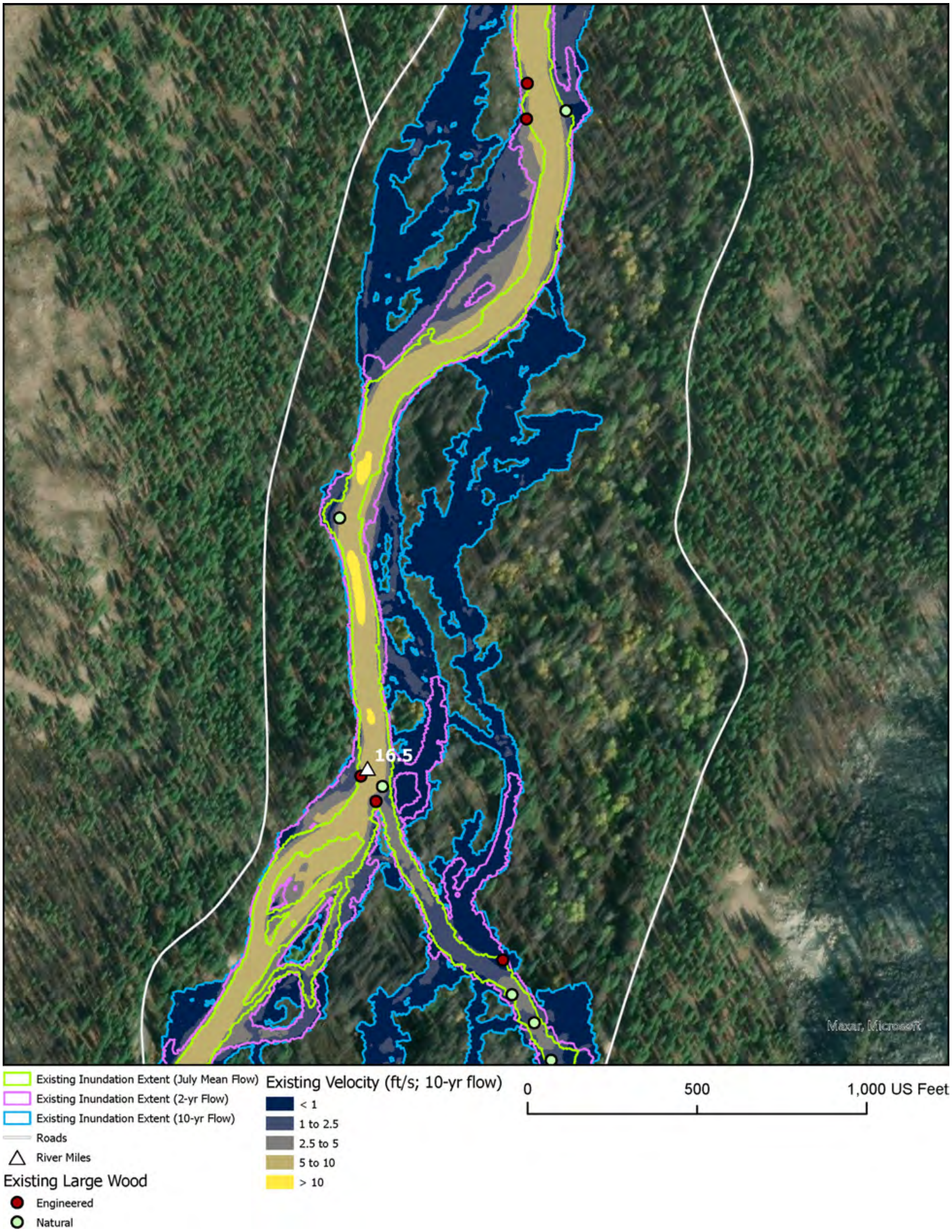

29
Maxar
River Miles
Existing Inundation Extent (94 ft3/s; sub-annual flow)
Existing Inundation Extent (432 ft3/s; 2-yr flow)
Existing Inundation Extent (872 ft3/s; 10-yr flow)
Existing Velocity (ft/s; 10-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
250
500 US Feet

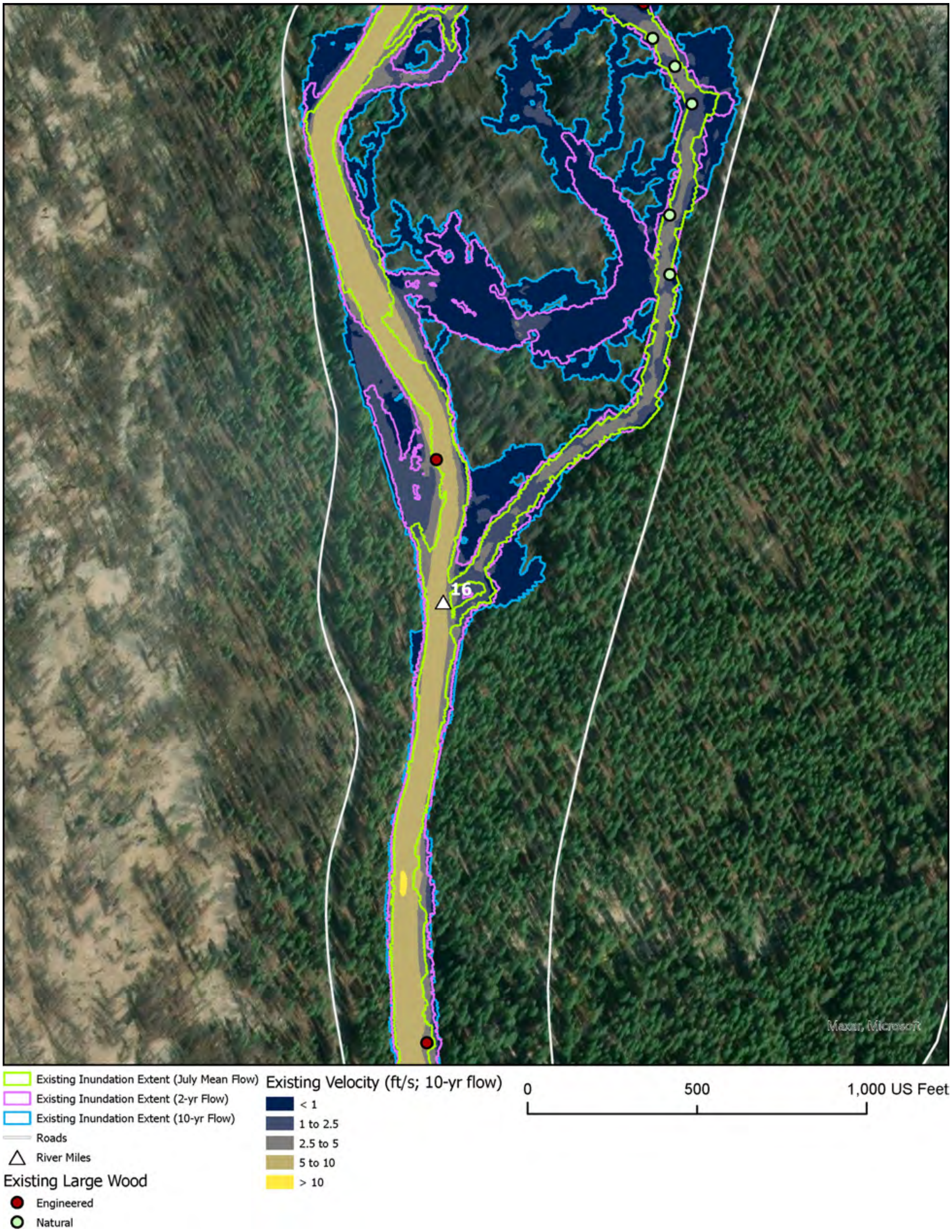
Appendix C

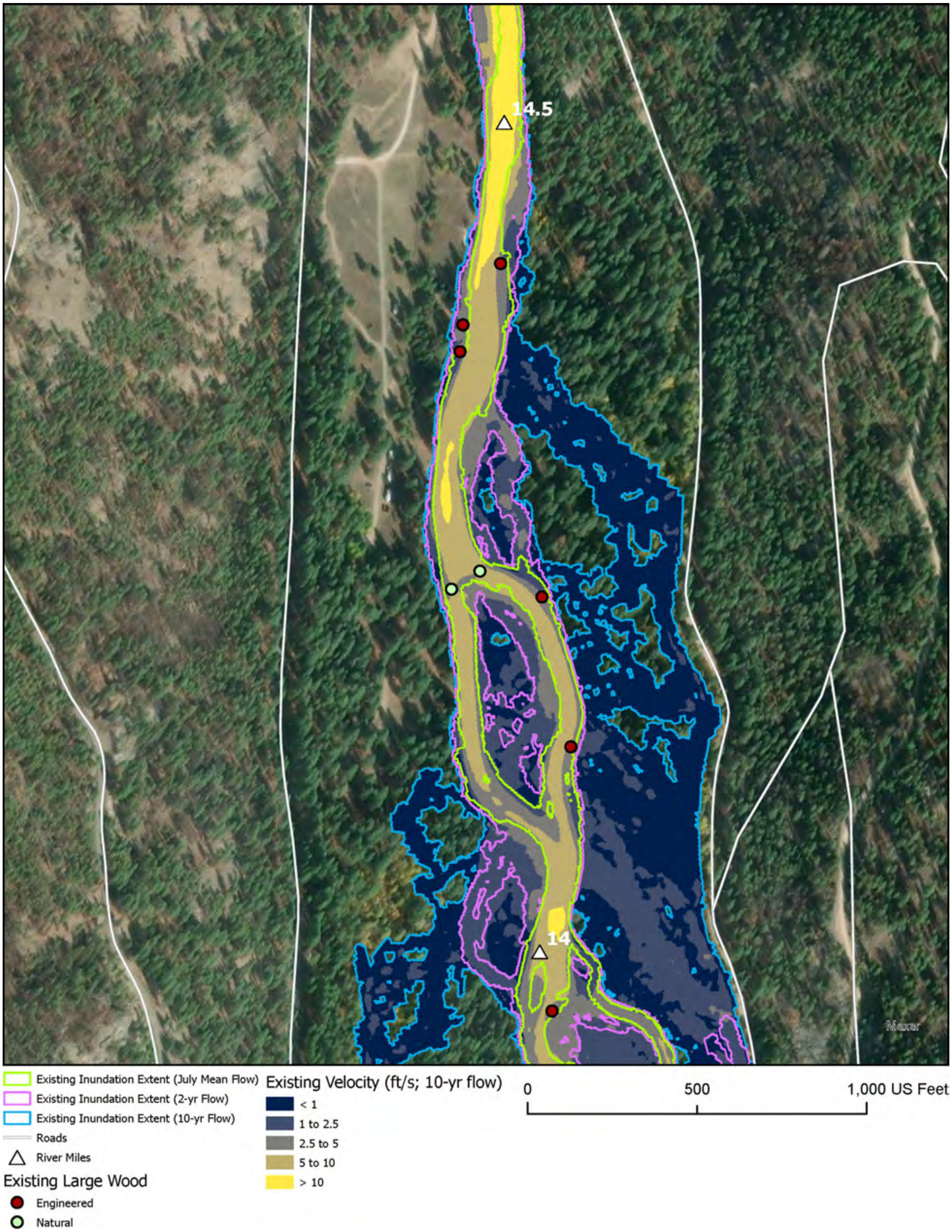
Existing Conditions Model Results for Sites within River Miles 20 to 9

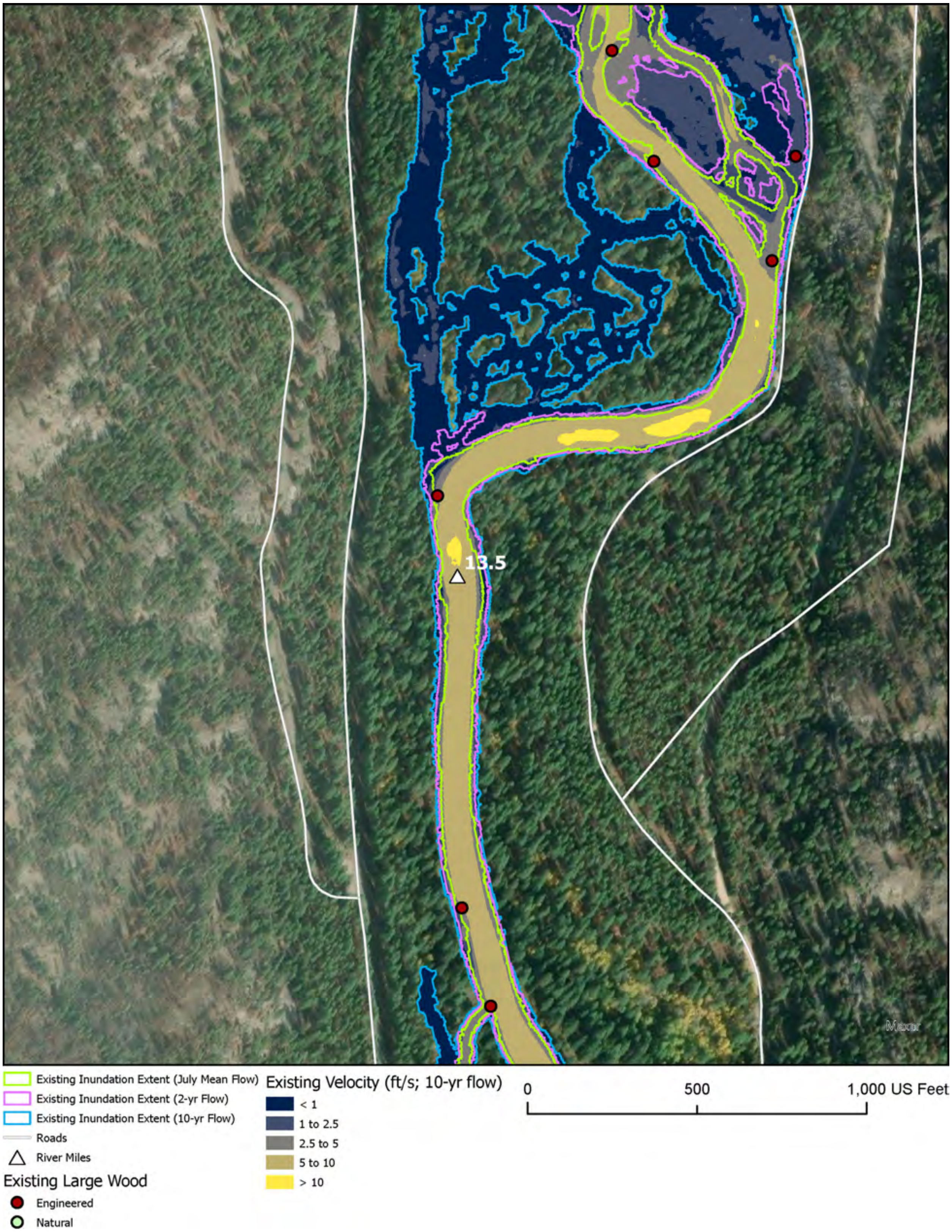


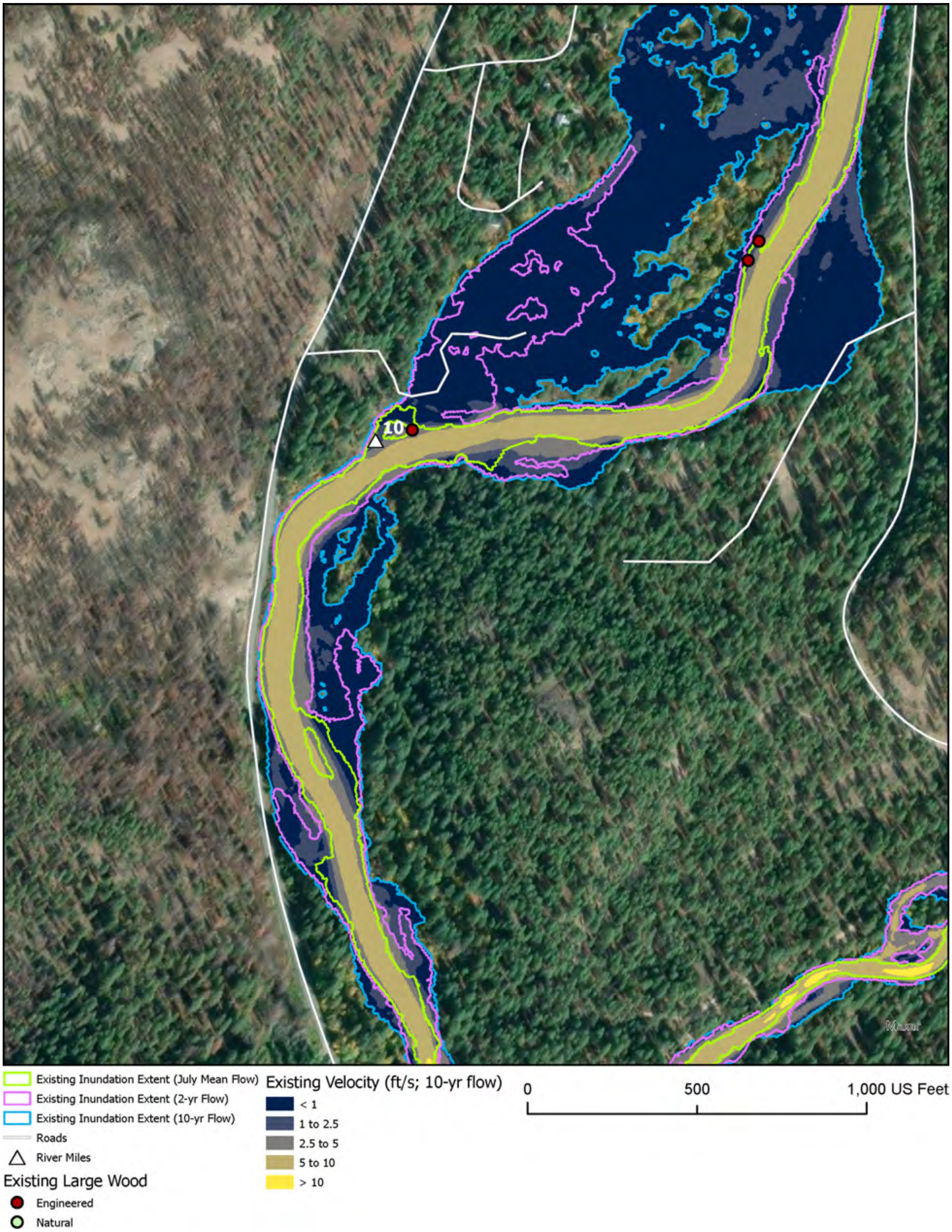
17.5
17
Maxar, Microsoft
Existing Inundation Extent (July Mean Flow)
Existing Inundation Extent (2-yr Flow)
Existing Inundation Extent (10-yr Flow)
Roads
River Miles
Existing Large Wood
Engineered
Natural
Existing Velocity (ft/s; 10-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet


16.5
Maxar, Microsoft
Existing Inundation Extent (July Mean Flow)
Existing Inundation Extent (2-yr Flow)
Existing Inundation Extent (10-yr Flow)
Roads
River Miles
Existing Large Wood
Engineered
Natural
Existing Velocity (ft/s; 10-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet


16
Maxar, Microsoft
Existing Inundation Extent (July Mean Flow)
Existing Inundation Extent (2-yr Flow)
Existing Inundation Extent (10-yr Flow)
Roads
River Miles
Existing Large Wood
Engineered
Natural
Existing Velocity (ft/s; 10-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet

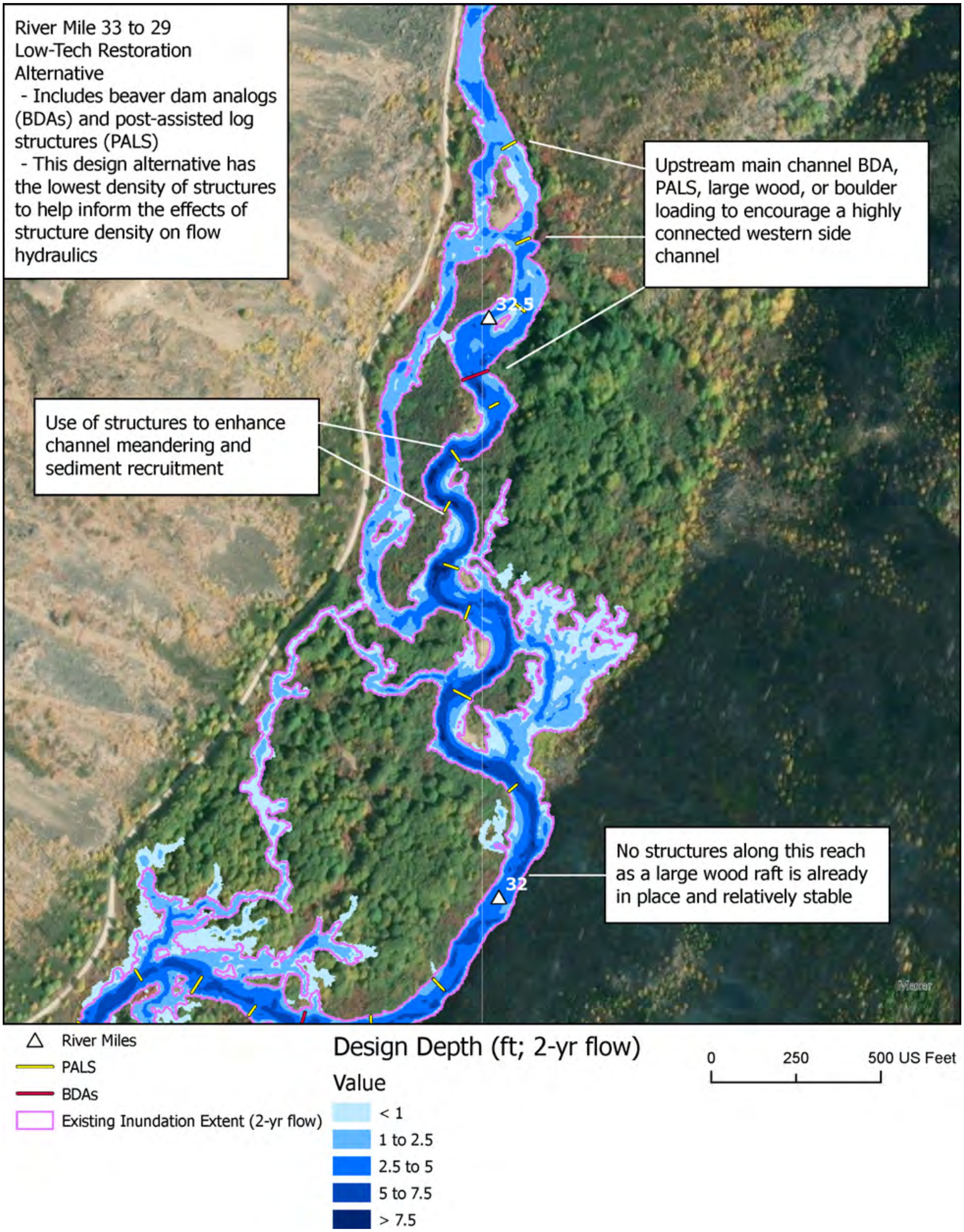

14.5
14
Maxar
Existing Inundation Extent (July Mean Flow)
Existing Inundation Extent (2-yr Flow)
Existing Inundation Extent (10-yr Flow)
Roads
River Miles
Existing Large Wood
Engineered
Natural
Existing Velocity (ft/s; 10-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet

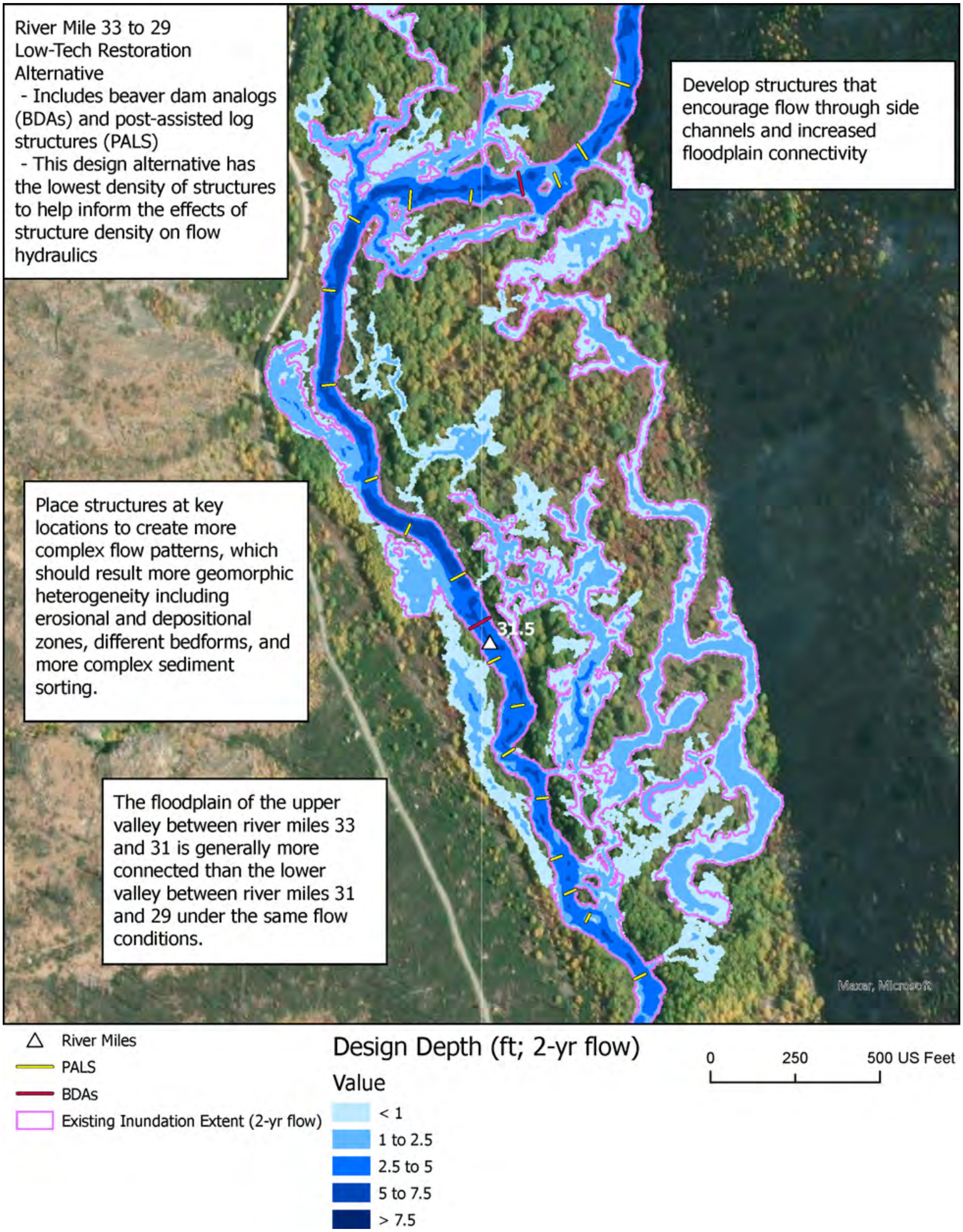

13.5
Existing Inundation Extent (July Mean Flow)
Existing Inundation Extent (2-yr Flow)
Existing Inundation Extent (10-yr Flow)
Roads
River Miles
Existing Large Wood
Engineered
Natural
Existing Velocity (ft/s; 10-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet

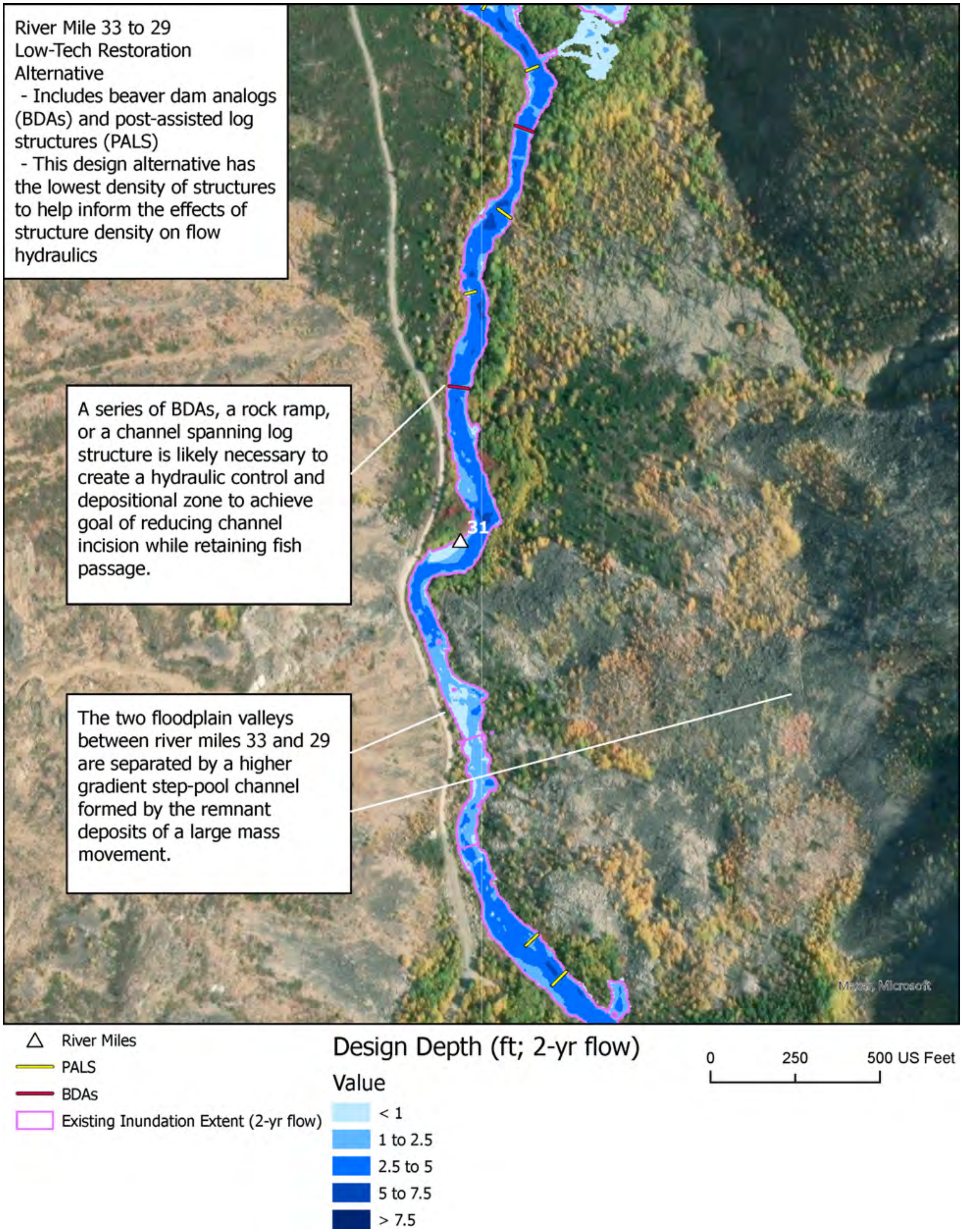

10
Existing Inundation Extent (July Mean Flow)
Existing Inundation Extent (2-yr Flow)
Existing Inundation Extent (10-yr Flow)
Roads
River Miles
Existing Large Wood
Engineered
Natural
Existing Velocity (ft/s; 10-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet

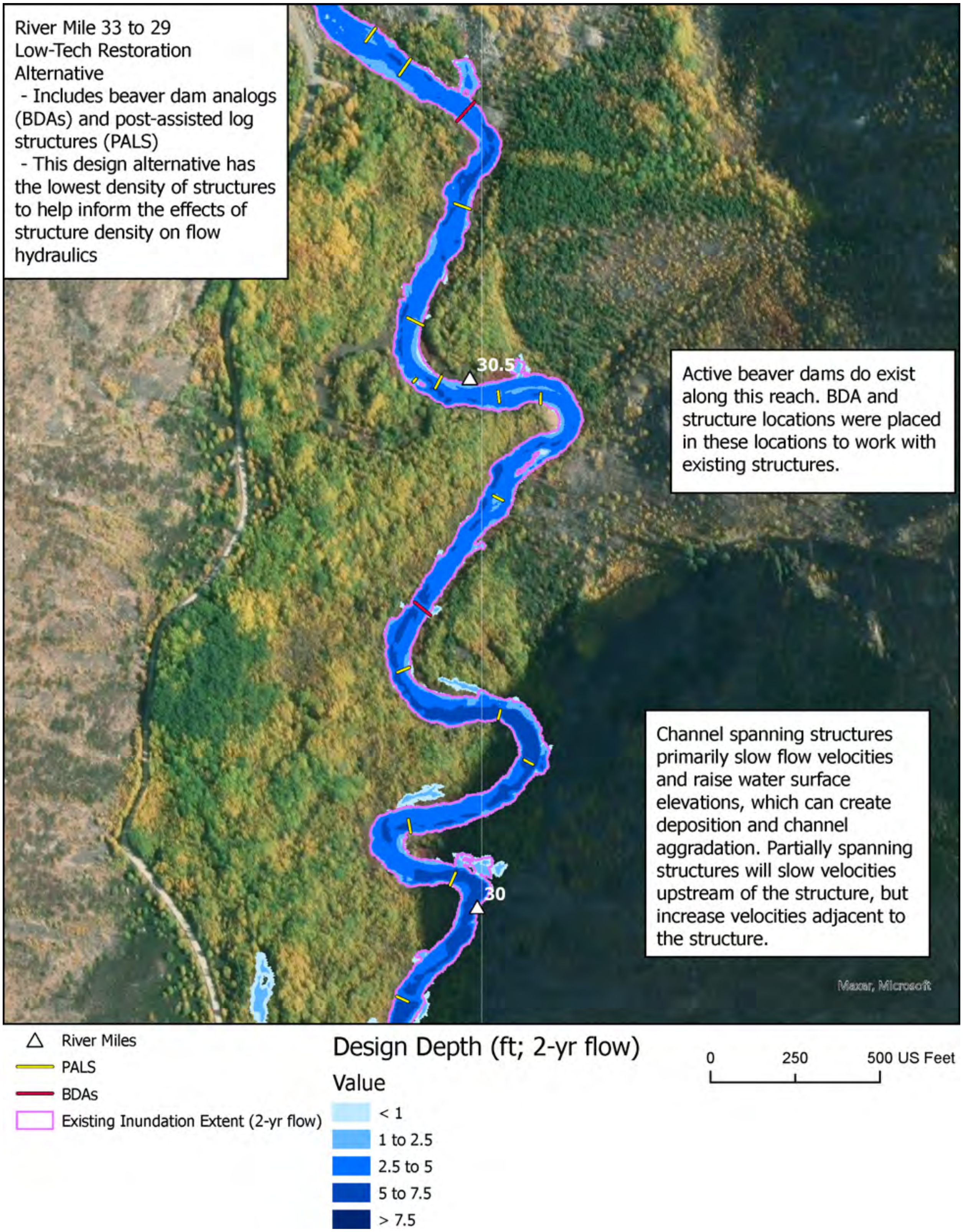
Appendix D

Design Concepts and Model Results for River Miles 33 to 29

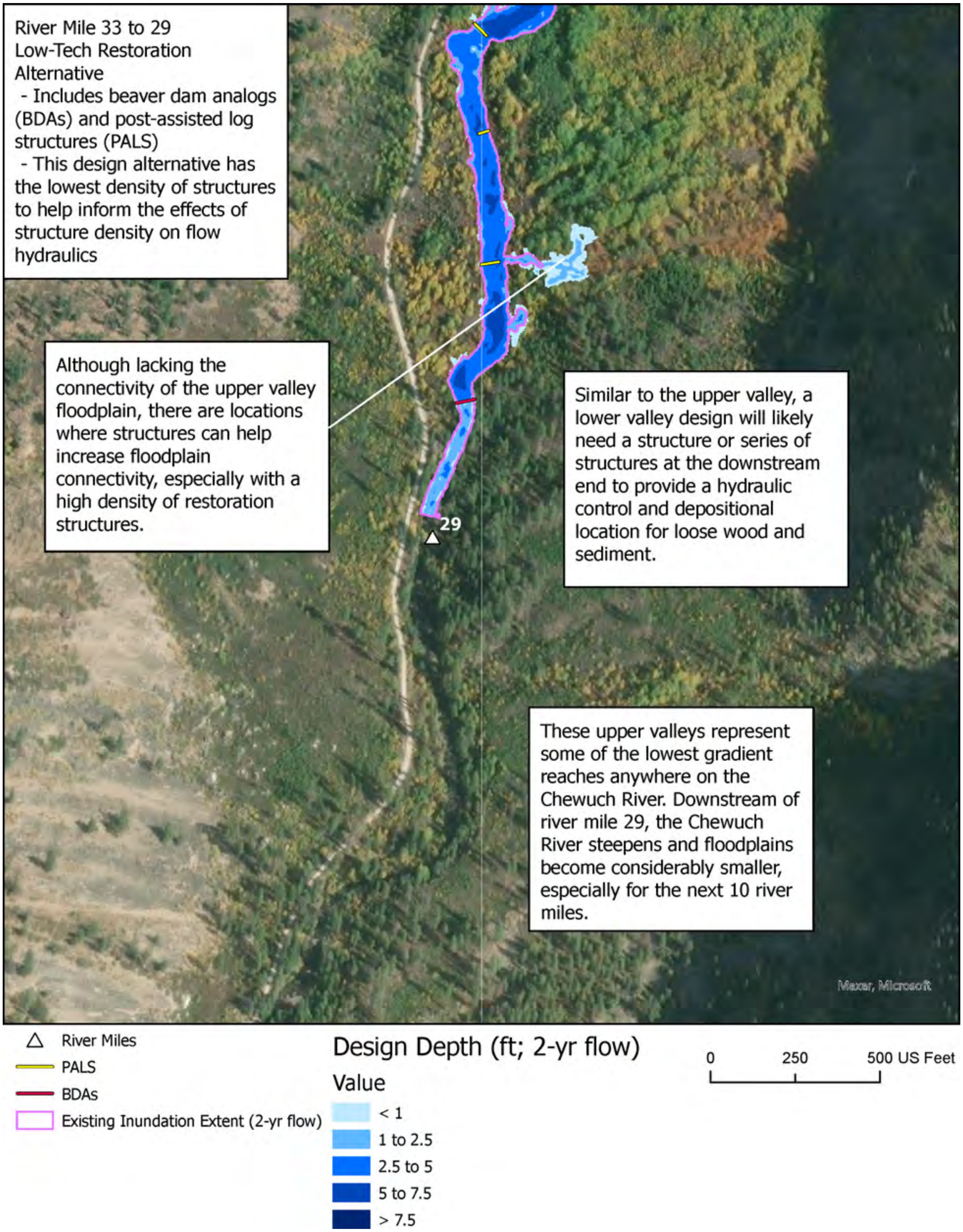

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Upstream main channel BDA, PALS, large wood, or boulder loading to encourage a highly connected western side channel
Use of structures to enhance channel meandering and sediment recruitment
32.5
32
No structures along this reach as a large wood raft is already in place and relatively stable
River Miles
PALS
BDAs
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet

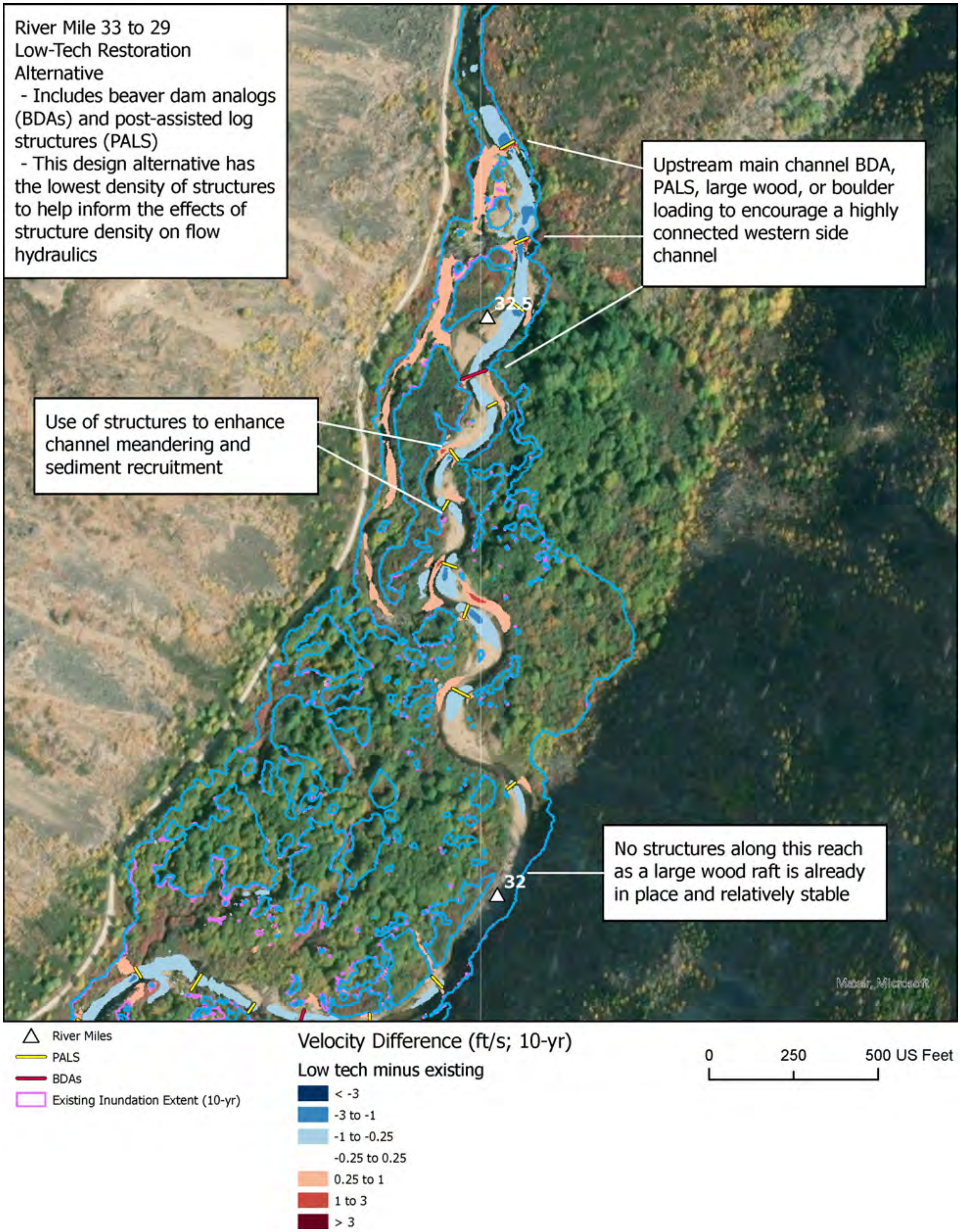

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Develop structures that encourage flow through side channels and increased floodplain connectivity
Place structures at key locations to create more complex flow patterns, which should result more geomorphic heterogeneity including erosional and depositional zones, different bedforms, and more complex sediment sorting.
31.5
The floodplain of the upper valley between river miles 33 and 31 is generally more connected than the lower valley between river miles 31 and 29 under the same flow conditions.
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet

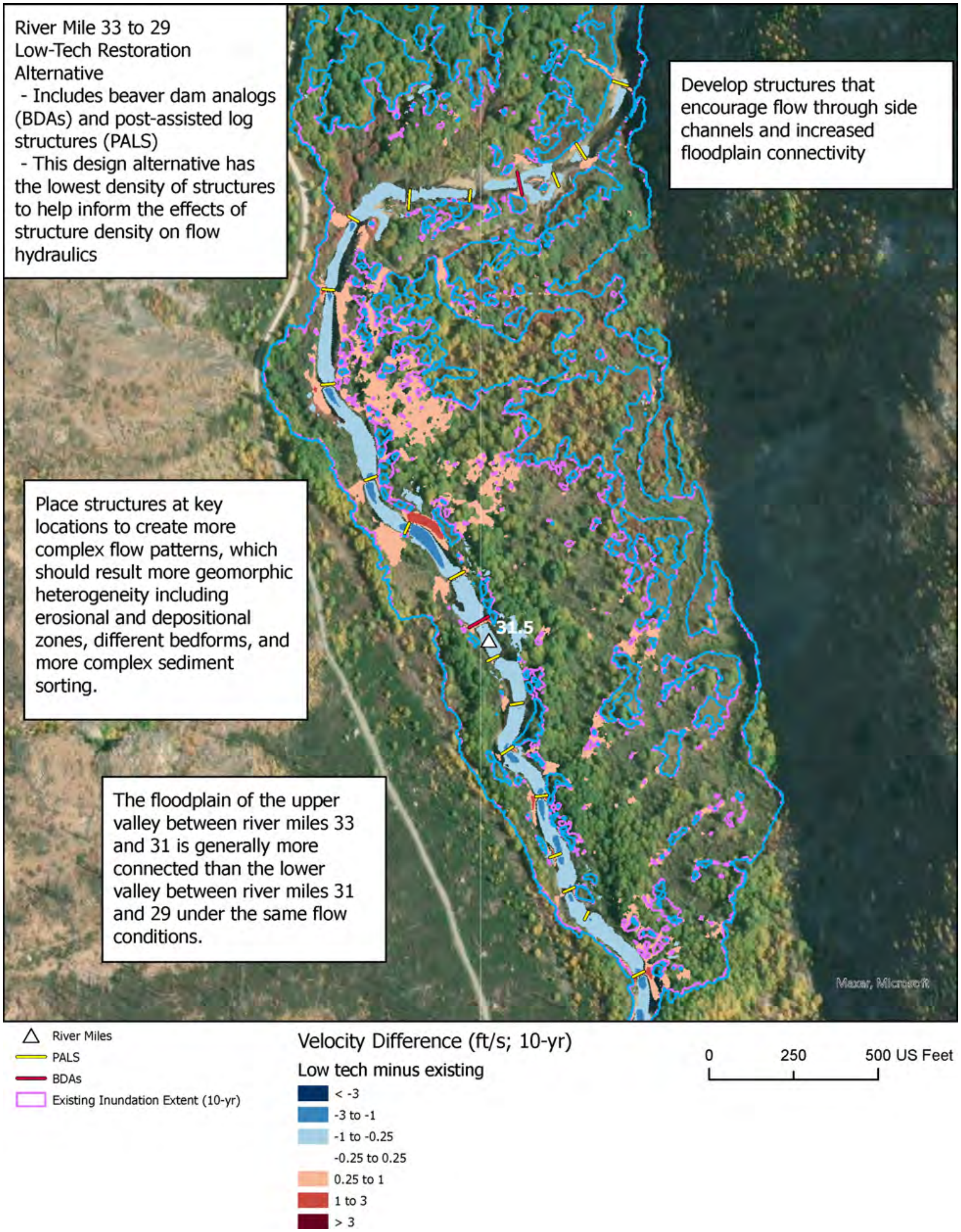

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
A series of BDAs, a rock ramp, or a channel spanning log structure is likely necessary to create a hydraulic control and depositional zone to achieve goal of reducing channel incision while retaining fish passage.
31
The two floodplain valleys between river miles 33 and 29 are separated by a higher gradient step-pool channel formed by the remnant deposits of a large mass movement.
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet

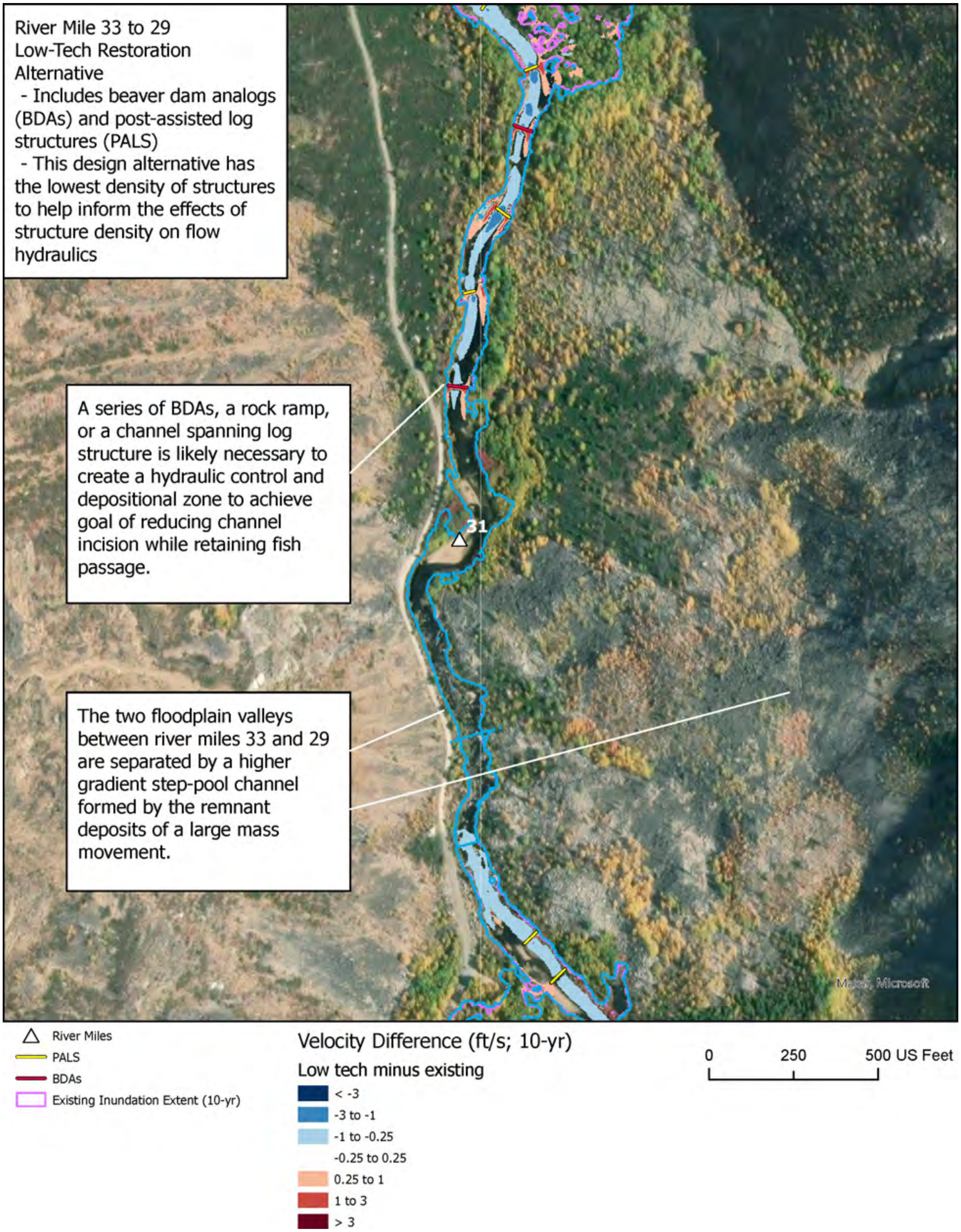

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Active beaver dams do exist along this reach. BDA and structure locations were placed in these locations to work with existing structures.
30.5
30
Channel spanning structures primarily slow flow velocities and raise water surface elevations, which can create deposition and channel aggradation. Partially spanning structures will slow velocities upstream of the structure, but increase velocities adjacent to the structure.
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet

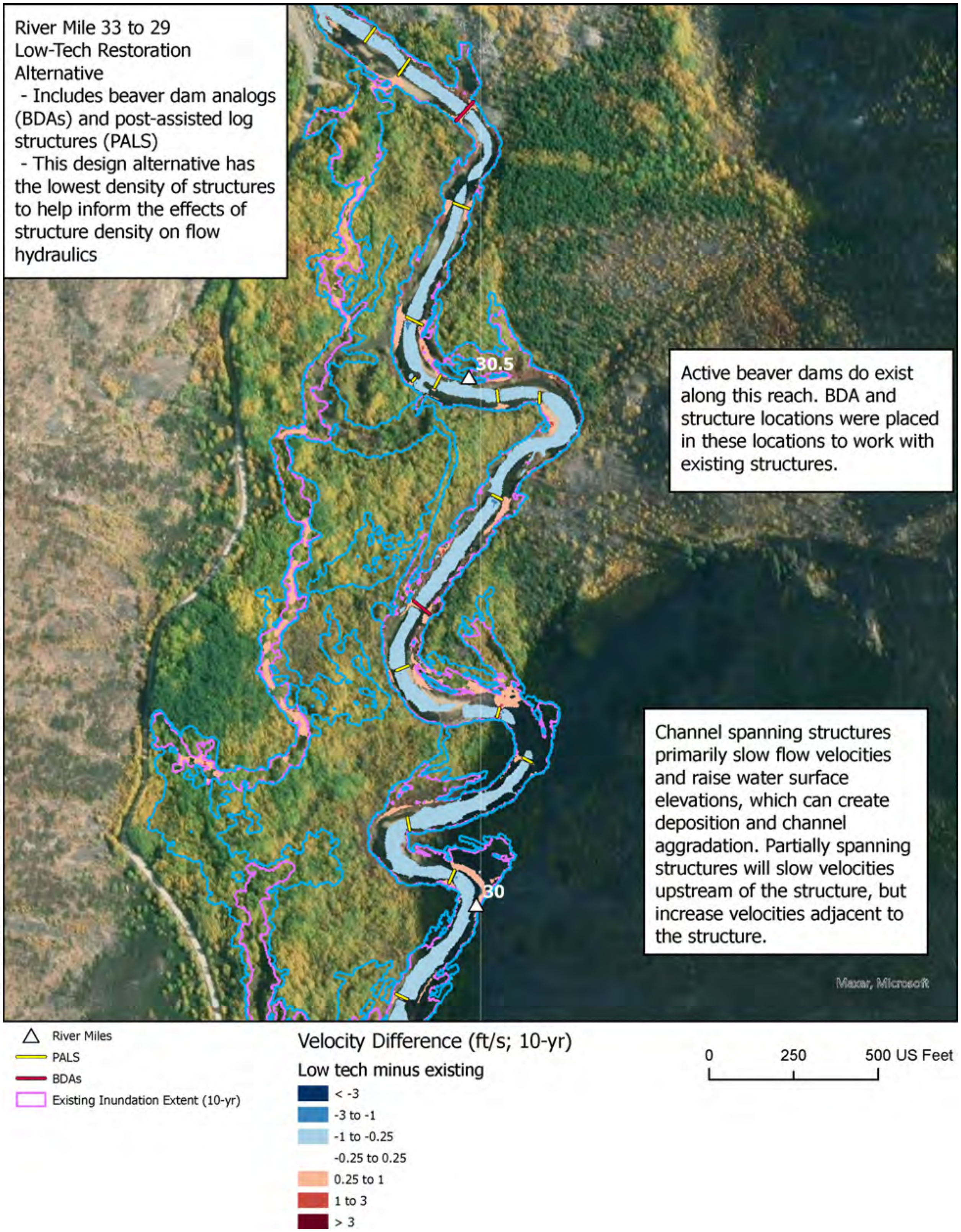

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Low-tech PALS, large wood, or boulders placed to both alter flow patterns and provide road protection along the outer bank of a meander.
Structures placed at the upstream and downstream end of side channels can help to increase inundated at lower flows and ideally create a more geomorphically active side channel
29.5
River Miles
PALS
BDAs
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet

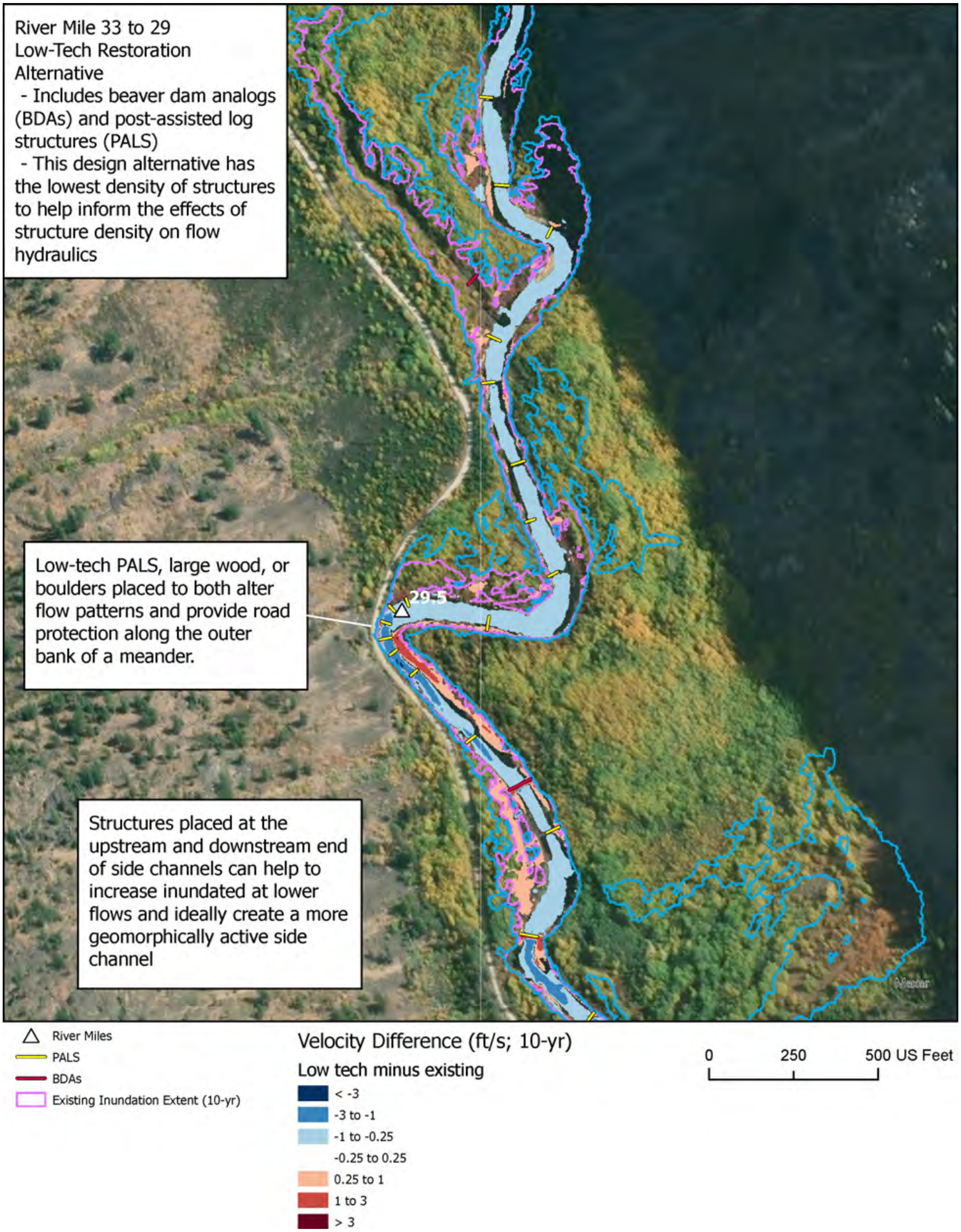

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Although lacking the connectivity of the upper valley floodplain, there are locations where structures can help increase floodplain connectivity, especially with a high density of restoration structures.
Similar to the upper valley, a lower valley design will likely need a structure or series of structures at the downstream end to provide a hydraulic control and depositional location for loose wood and sediment.
These upper valleys represent some of the lowest gradient reaches anywhere on the Chewuch River. Downstream of river mile 29, the Chewuch River steepens and floodplains become considerably smaller, especially for the next 10 river miles.
29
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet

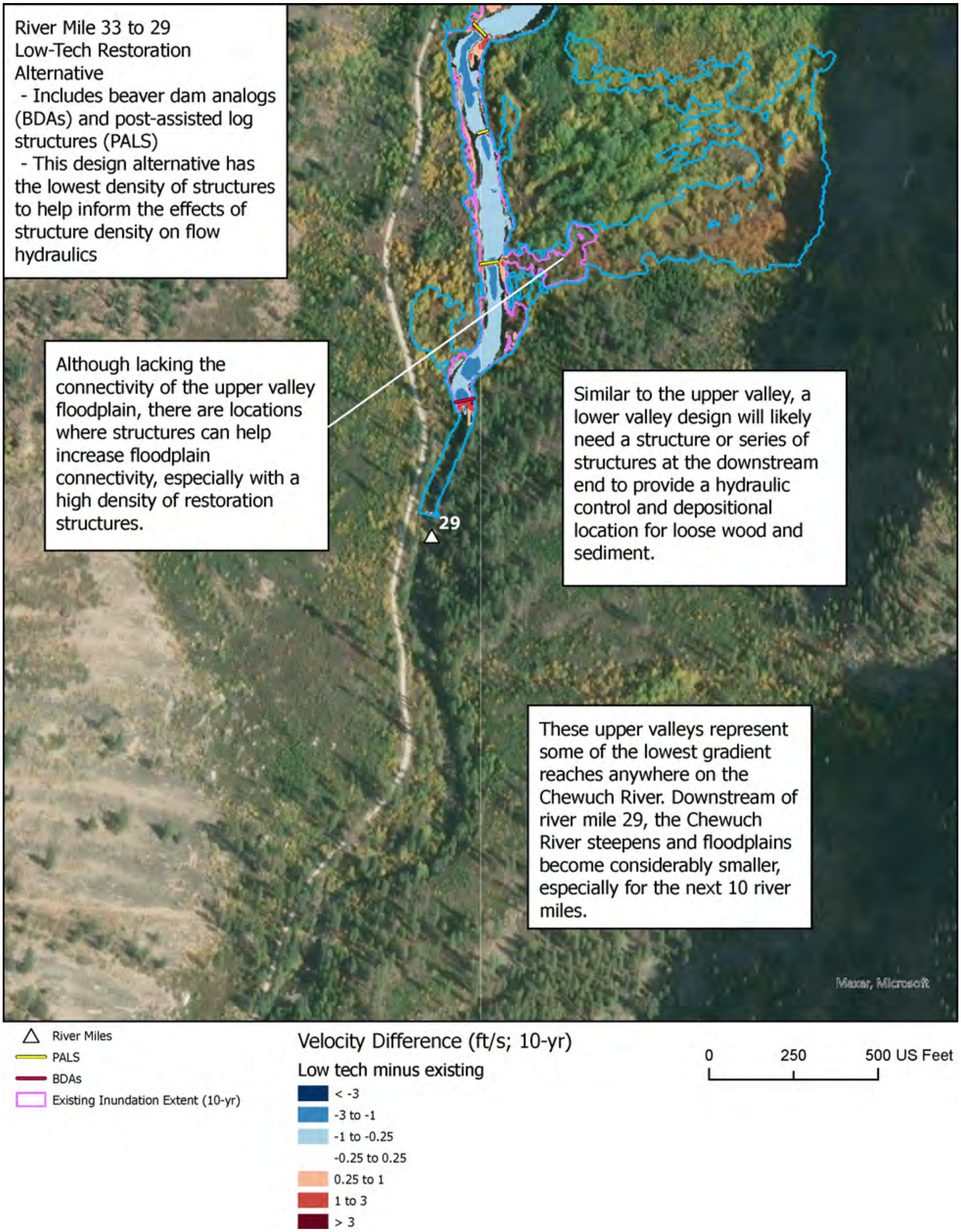

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Upstream main channel BDA, PALS, large wood, or boulder loading to encourage a highly connected western side channel
32.5
Use of structures to enhance channel meandering and sediment recruitment
No structures along this reach as a large wood raft is already in place and relatively stable
32
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Low tech minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet

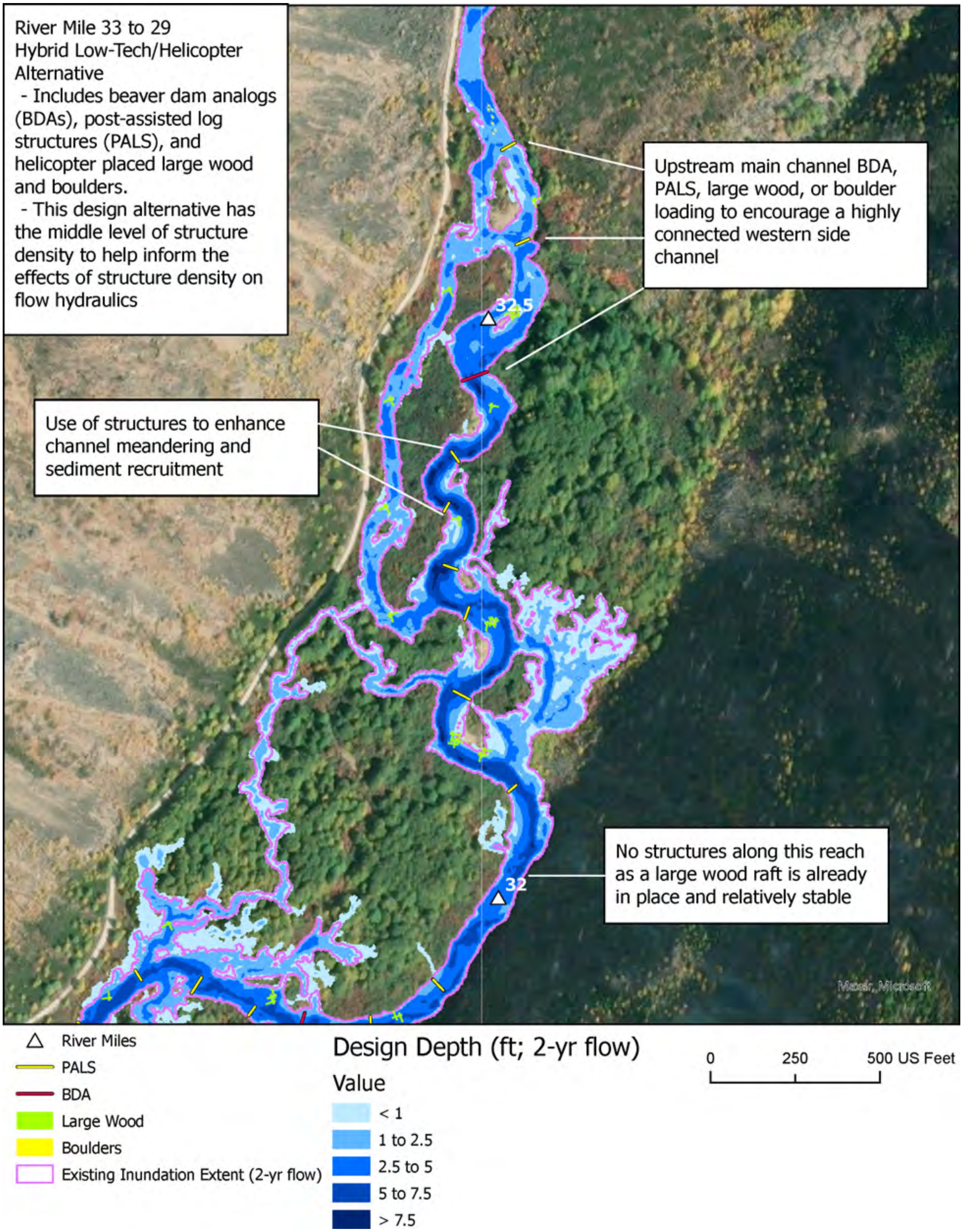

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Develop structures that encourage flow through side channels and increased floodplain connectivity
Place structures at key locations to create more complex flow patterns, which should result more geomorphic heterogeneity including erosional and depositional zones, different bedforms, and more complex sediment sorting.
The floodplain of the upper valley between river miles 33 and 31 is generally more connected than the lower valley between river miles 31 and 29 under the same flow conditions.
31.5
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Low tech minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet

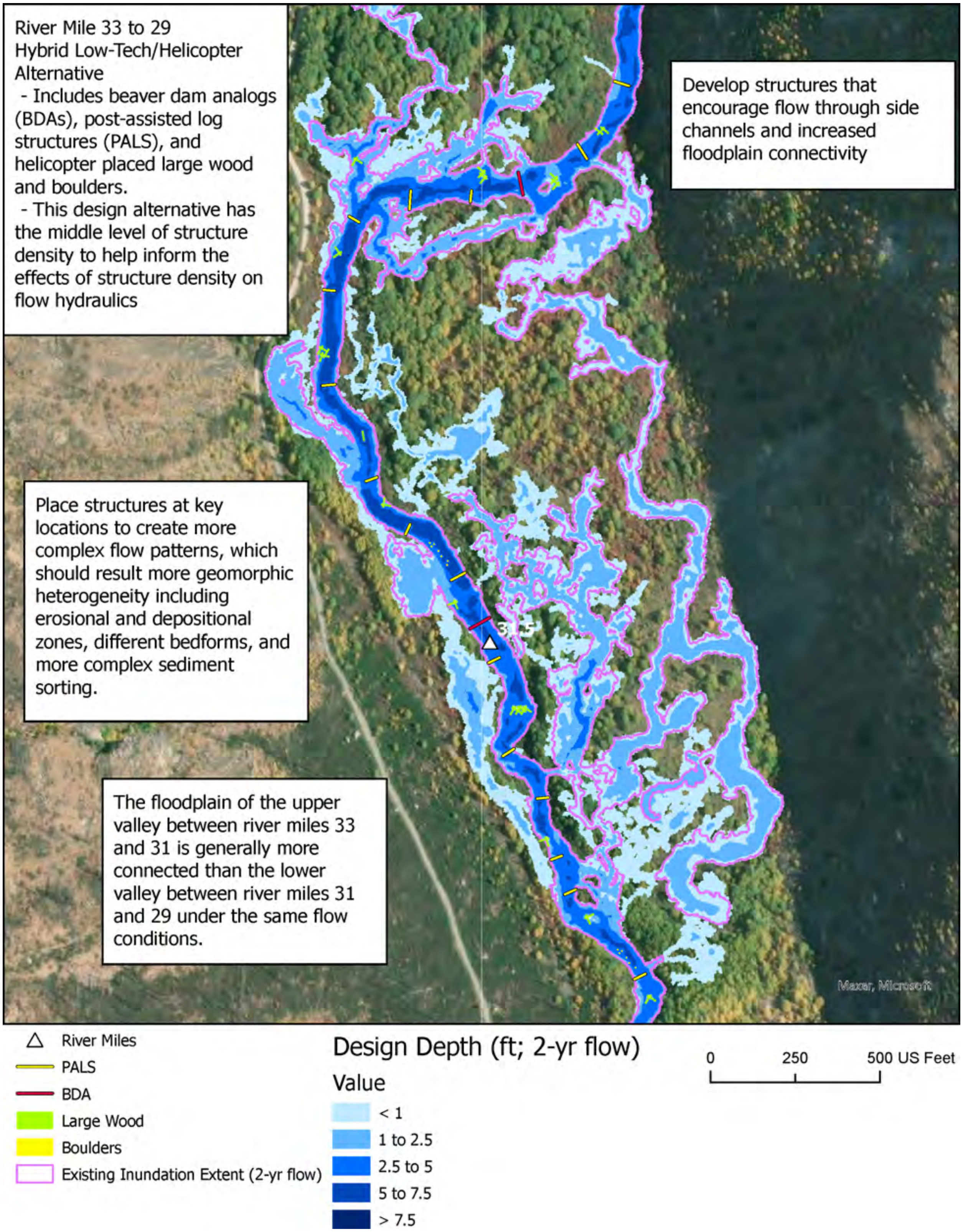

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
A series of BDAs, a rock ramp, or a channel spanning log structure is likely necessary to create a hydraulic control and depositional zone to achieve goal of reducing channel incision while retaining fish passage.
The two floodplain valleys between river miles 33 and 29 are separated by a higher gradient step-pool channel formed by the remnant deposits of a large mass movement.
31
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Low tech minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet

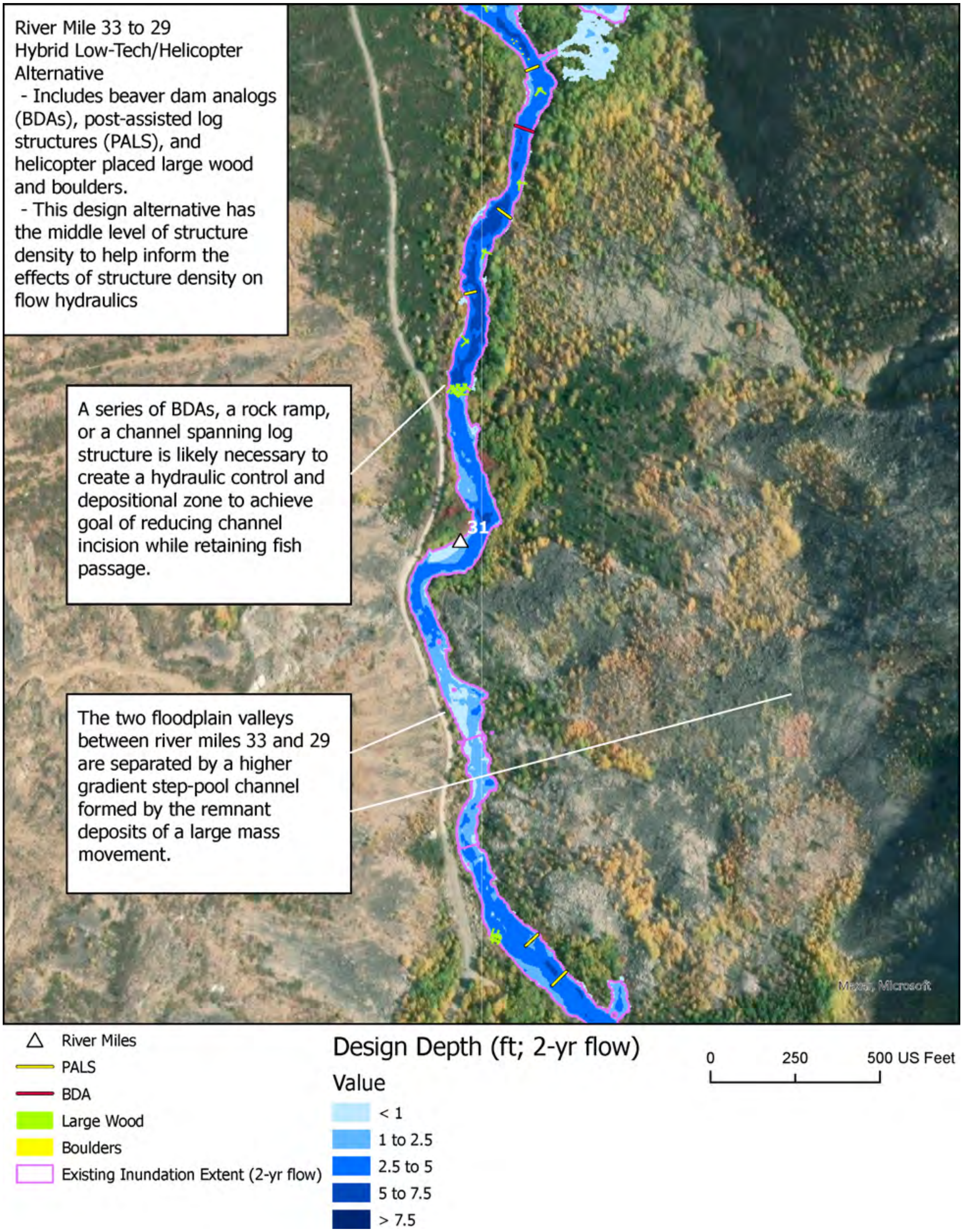

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
30.5
Active beaver dams do exist along this reach. BDA and structure locations were placed in these locations to work with existing structures.
Channel spanning structures primarily slow flow velocities and raise water surface elevations, which can create deposition and channel aggradation. Partially spanning structures will slow velocities upstream of the structure, but increase velocities adjacent to the structure.
30
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Low tech minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet

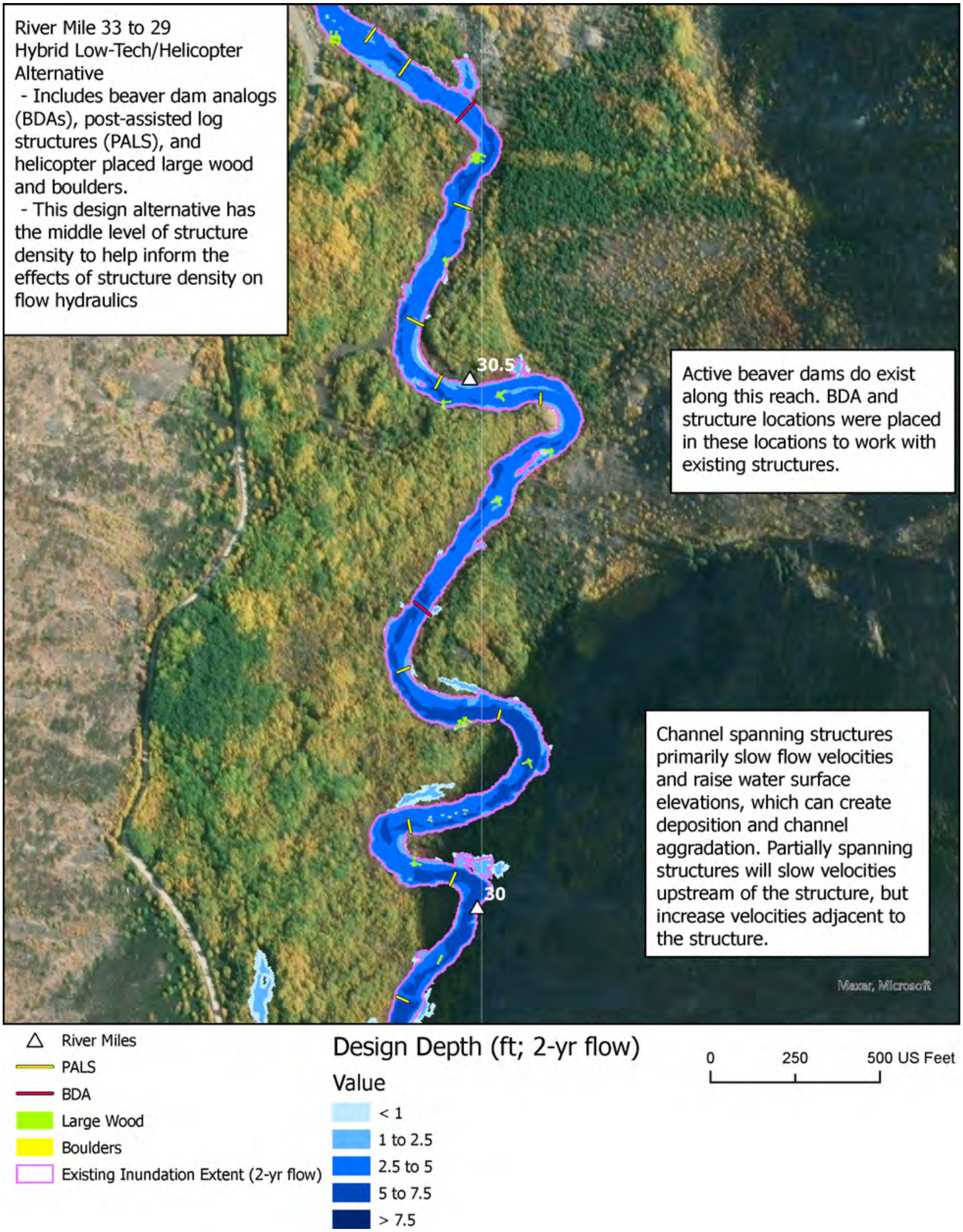

River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Low-tech PALS, large wood, or boulders placed to both alter flow patterns and provide road protection along the outer bank of a meander.
29.5
Structures placed at the upstream and downstream end of side channels can help to increase inundated at lower flows and ideally create a more geomorphically active side channel
River Miles
PALS
BDAs
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Low tech minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet


River Mile 33 to 29
Low-Tech Restoration Alternative
- Includes beaver dam analogs (BDAs) and post-assisted log structures (PALS)
- This design alternative has the lowest density of structures to help inform the effects of structure density on flow hydraulics
Although lacking the connectivity of the upper valley floodplain, there are locations where structures can help increase floodplain connectivity, especially with a high density of restoration structures.
Similar to the upper valley, a lower valley design will likely need a structure or series of structures at the downstream end to provide a hydraulic control and depositional location for loose wood and sediment.
These upper valleys represent some of the lowest gradient reaches anywhere on the Chewuch River. Downstream of river mile 29, the Chewuch River steepens and floodplains become considerably smaller, especially for the next 10 river miles.
29
Maxar, Microsoft
River Miles
PALS
BDAs
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Low tech minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet

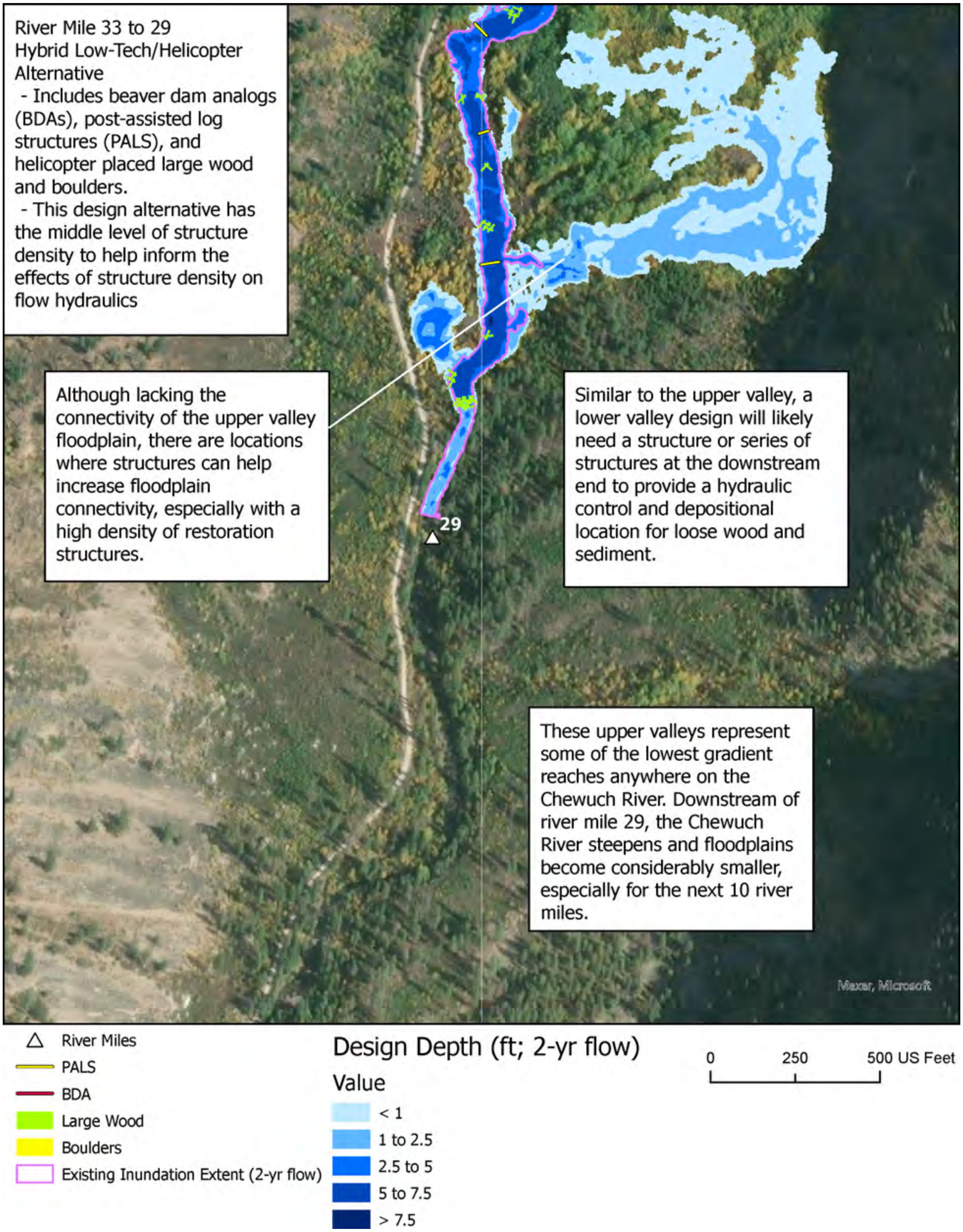

River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
- Includes beaver dam analogs (BDAs), post-assisted log structures (PALS), and helicopter placed large wood and boulders.
- This design alternative has the middle level of structure density to help inform the effects of structure density on flow hydraulics
Upstream main channel BDA, PALS, large wood, or boulder loading to encourage a highly connected western side channel
Use of structures to enhance channel meandering and sediment recruitment
32.5
No structures along this reach as a large wood raft is already in place and relatively stable
32
Maxar, Microsoft
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
- Includes beaver dam analogs (BDAs), post-assisted log structures (PALS), and helicopter placed large wood and boulders.
- This design alternative has the middle level of structure density to help inform the effects of structure density on flow hydraulics
Develop structures that encourage flow through side channels and increased floodplain connectivity
Place structures at key locations to create more complex flow patterns, which should result more geomorphic heterogeneity including erosional and depositional zones, different bedforms, and more complex sediment sorting.
The floodplain of the upper valley between river miles 33 and 31 is generally more connected than the lower valley between river miles 31 and 29 under the same flow conditions.
Maxar, Microsoft
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
- Includes beaver dam analogs (BDAs), post-assisted log structures (PALS), and helicopter placed large wood and boulders.
- This design alternative has the middle level of structure density to help inform the effects of structure density on flow hydraulics
A series of BDAs, a rock ramp, or a channel spanning log structure is likely necessary to create a hydraulic control and depositional zone to achieve goal of reducing channel incision while retaining fish passage.
31
The two floodplain valleys between river miles 33 and 29 are separated by a higher gradient step-pool channel formed by the remnant deposits of a large mass movement.
Maxar, Microsoft
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
- Includes beaver dam analogs (BDAs), post-assisted log structures (PALS), and helicopter placed large wood and boulders.
- This design alternative has the middle level of structure density to help inform the effects of structure density on flow hydraulics
30.5
Active beaver dams do exist along this reach. BDA and structure locations were placed in these locations to work with existing structures.
Channel spanning structures primarily slow flow velocities and raise water surface elevations, which can create deposition and channel aggradation. Partially spanning structures will slow velocities upstream of the structure, but increase velocities adjacent to the structure.
30
Maxar, Microsoft
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
- Includes beaver dam analogs (BDAs), post-assisted log structures (PALS), and helicopter placed large wood and boulders.
- This design alternative has the middle level of structure density to help inform the effects of structure density on flow hydraulics
Low-tech PALS, large wood, or boulders placed to both alter flow patterns and provide road protection along the outer bank of a meander.
29.5
Structures placed at the upstream and downstream end of side channels can help to increase inundated at lower flows and ideally create a more geomorphically active side channel
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
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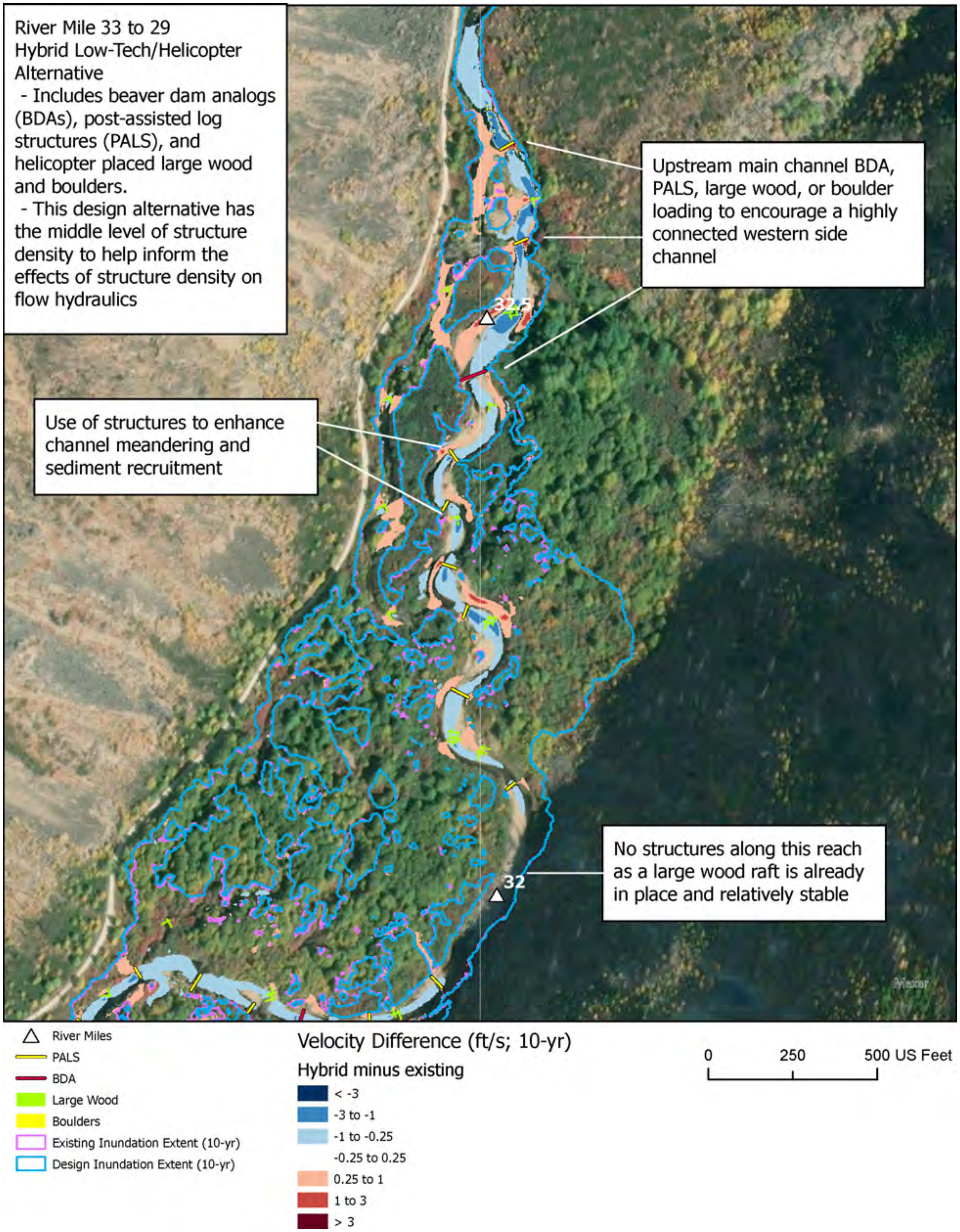
Similar to the upper valley, a lower valley design will likely need a structure or series of structures at the downstream end to provide a hydraulic control and depositional location for loose wood and sediment.
These upper valleys represent some of the lowest gradient reaches anywhere on the Chewuch River. Downstream of river mile 29, the Chewuch River steepens and floodplains become considerably smaller, especially for the next 10 river miles.
29
Maxar, Microsoft
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet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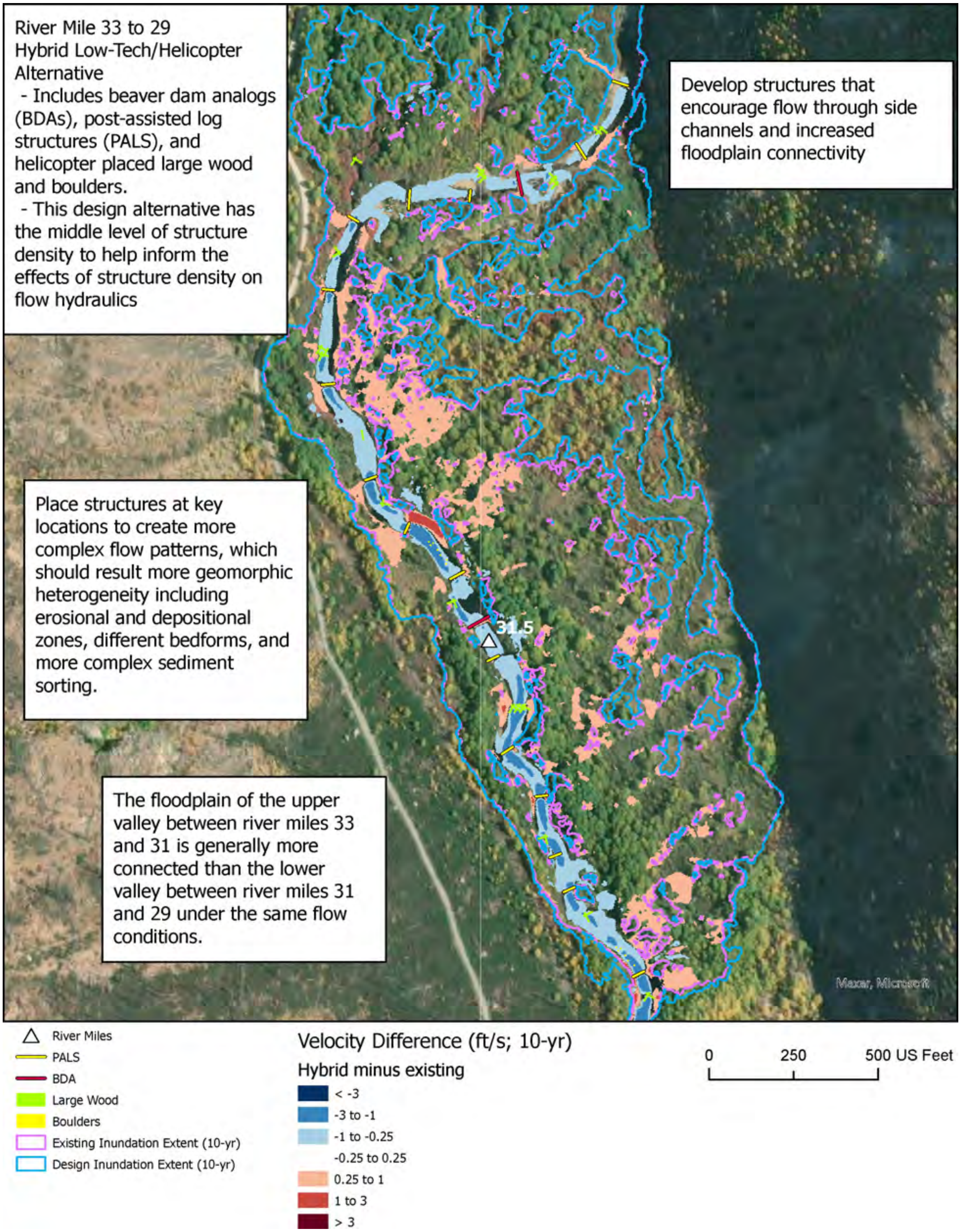
Upstream main channel BDA, PALS, large wood, or boulder loading to encourage a highly connected western side channel
Use of structures to enhance channel meandering and sediment recruitment
No structures along this reach as a large wood raft is already in place and relatively stable
32.5
32
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Hybrid minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet


River Mile 33 to 29
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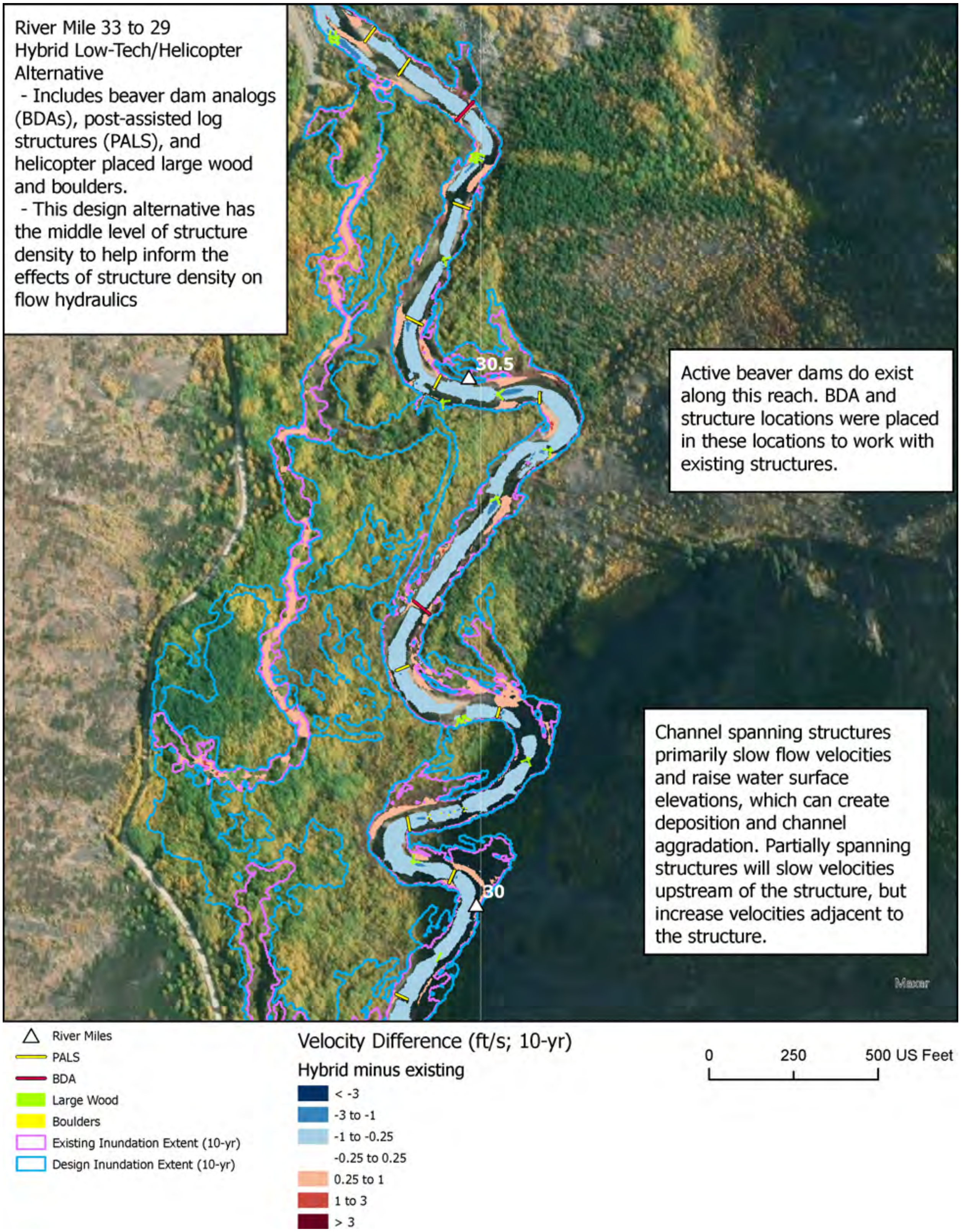
31.5
Maxar, Microsoft
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Hybrid minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet


River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
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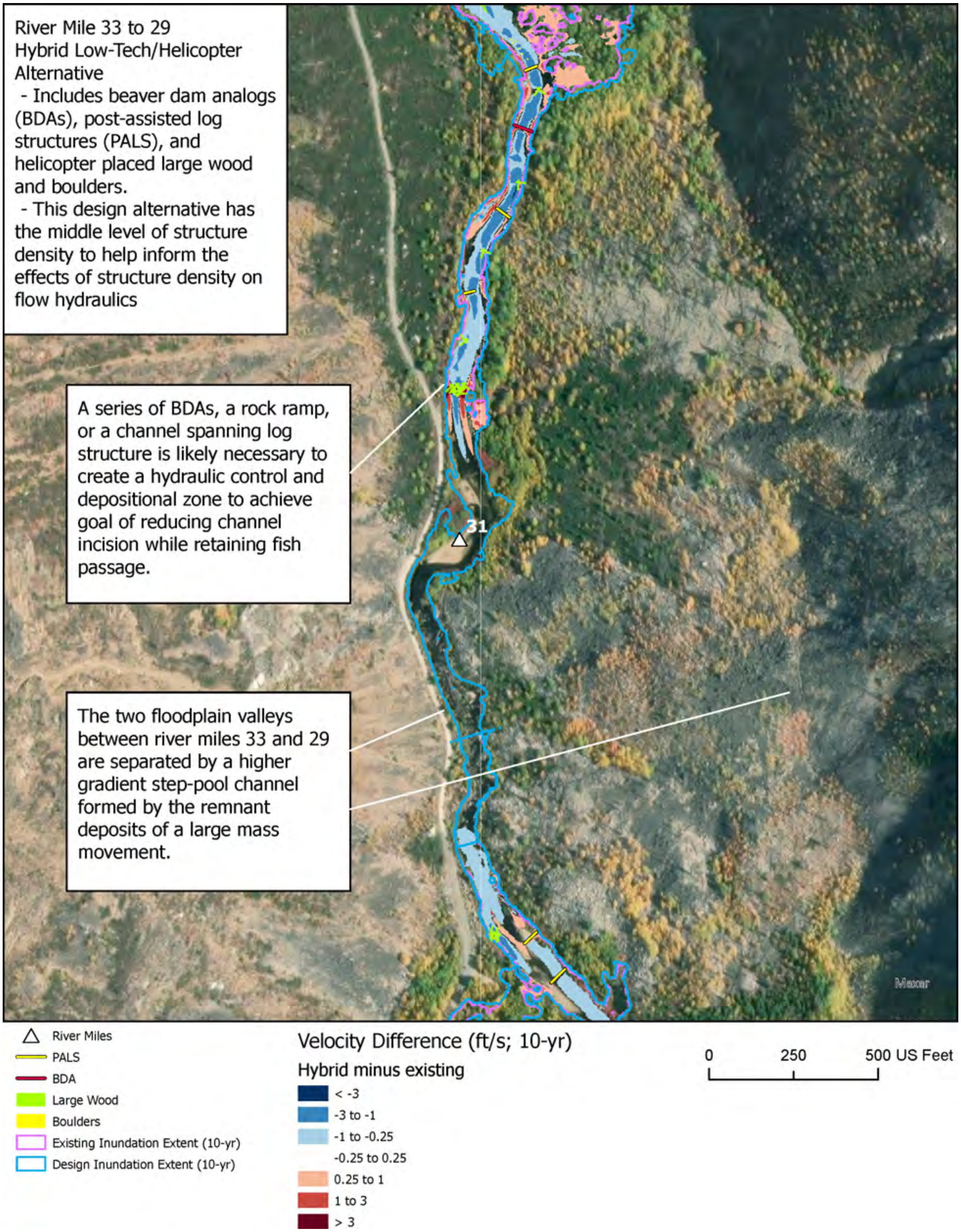
30
Maxar
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Hybrid minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet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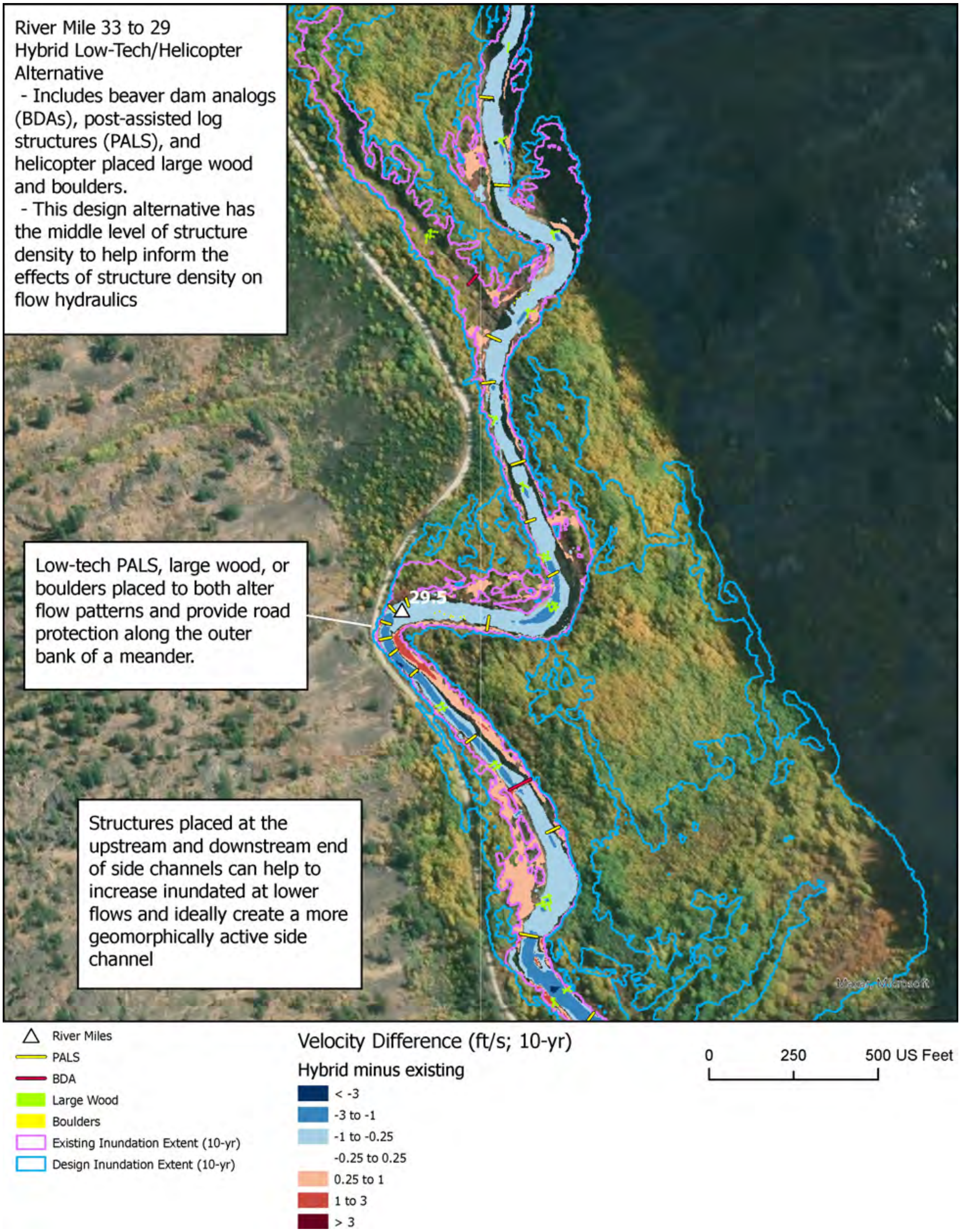
Maxar
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Hybrid minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet


River Mile 33 to 29
Hybrid Low-Tech/Helicopter Alternative
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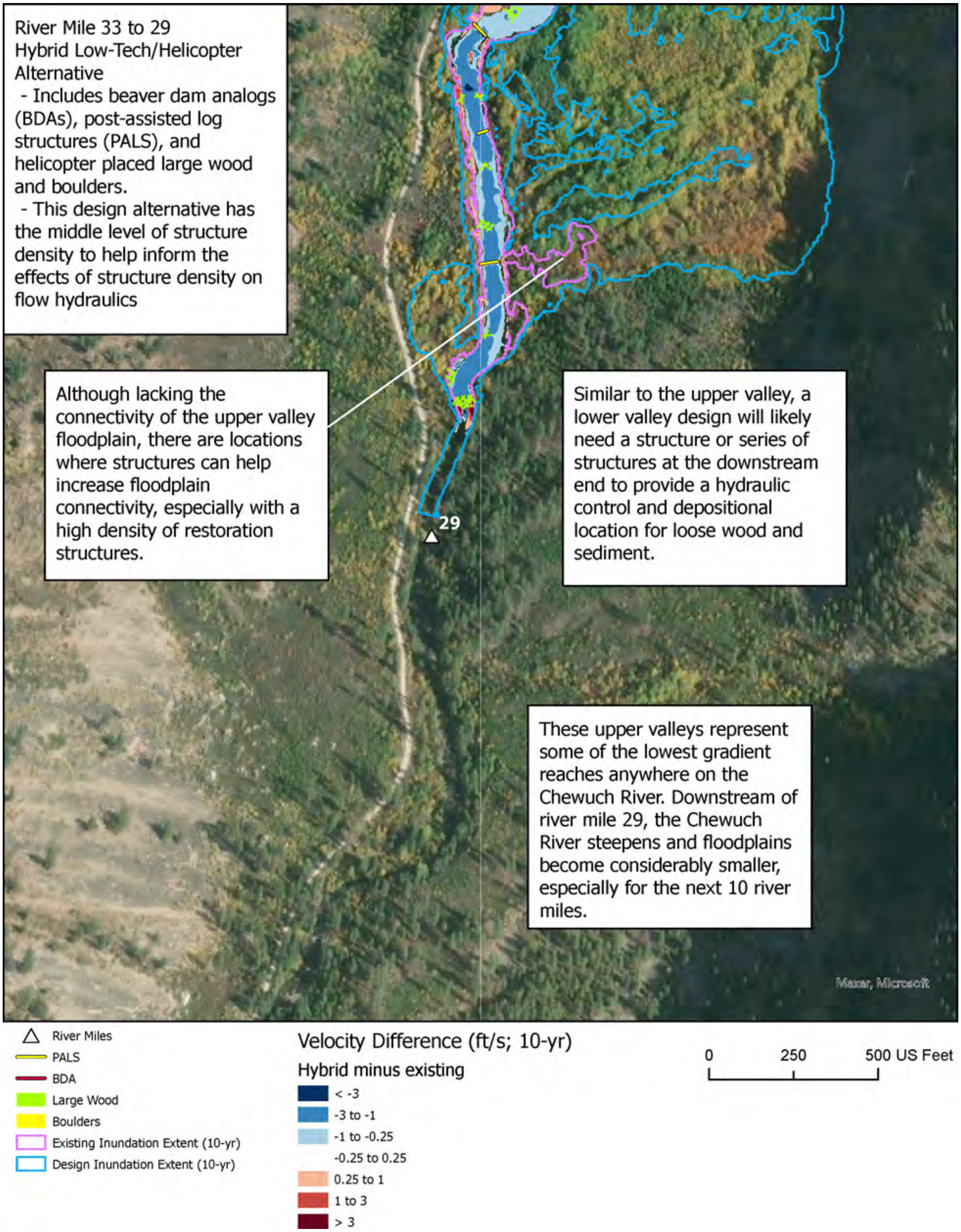
Low-tech PALS, large wood, or boulders placed to both alter flow patterns and provide road protection along the outer bank of a meander.
Structures placed at the upstream and downstream end of side channels can help to increase inundated at lower flows and ideally create a more geomorphically active side channel
29.5
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Hybrid minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet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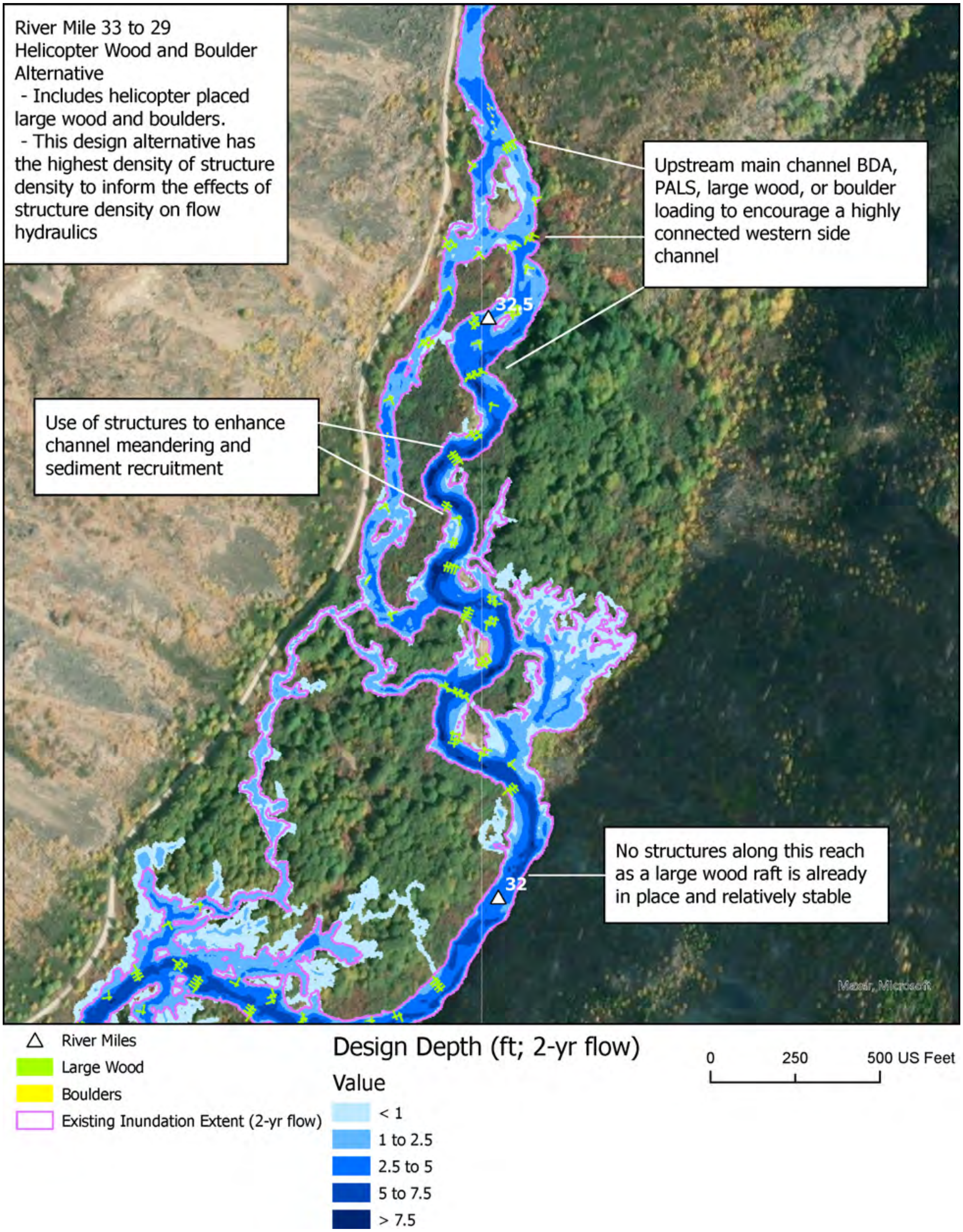
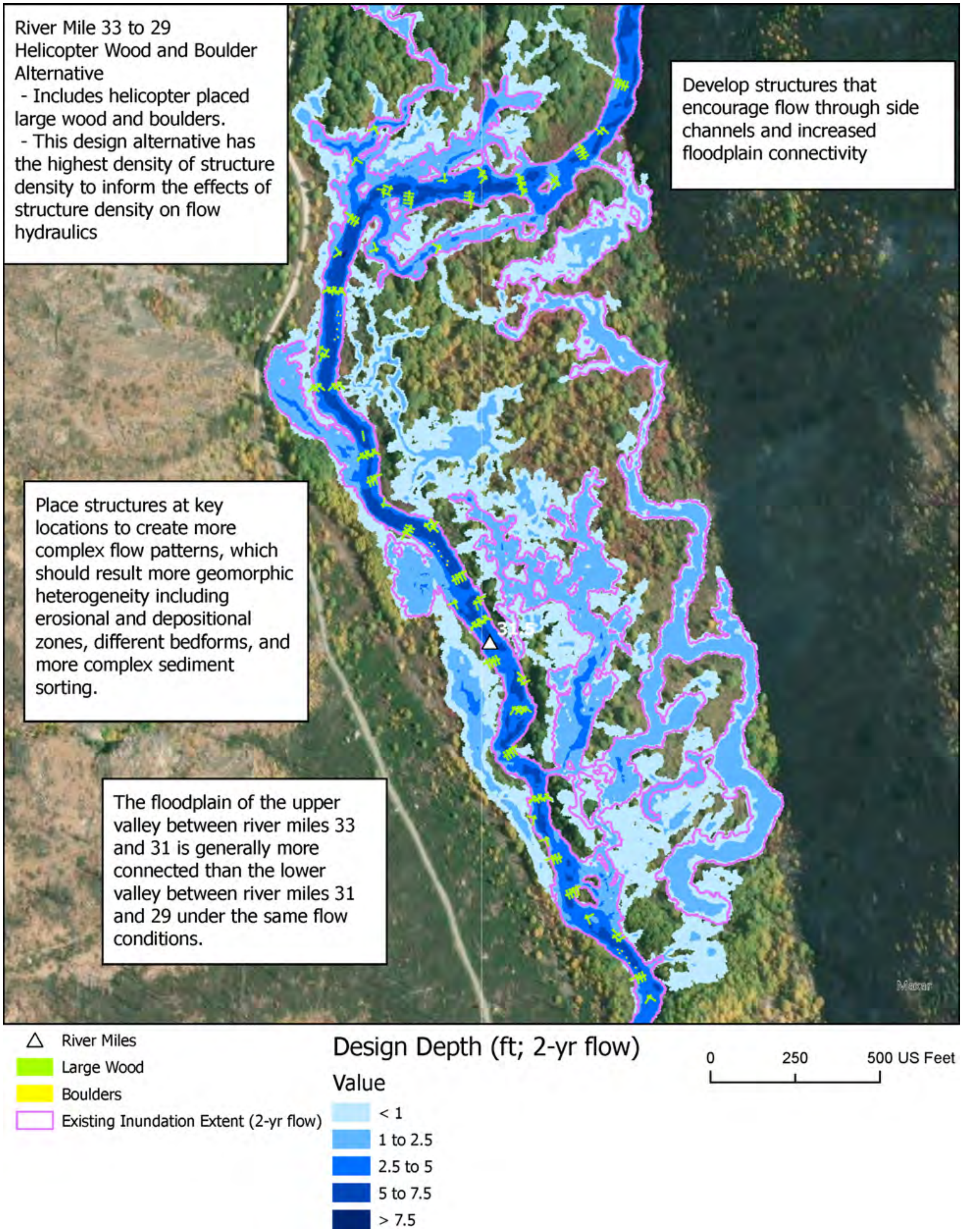
29
Maxar, Microsoft
River Miles
PALS
BDA
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Hybrid minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet


River Mile 33 to 29
Helicopter Wood and Boulder Alternative
- Includes helicopter placed large wood and boulders.
- This design alternative has the highest density of structure density to inform the effects of structure density on flow hydraulics
Upstream main channel BDA, PALS, large wood, or boulder loading to encourage a highly connected western side channel
32.5
Use of structures to enhance channel meandering and sediment recruitment
No structures along this reach as a large wood raft is already in place and relatively stable
32
Maxar, Microsoft
River Miles
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
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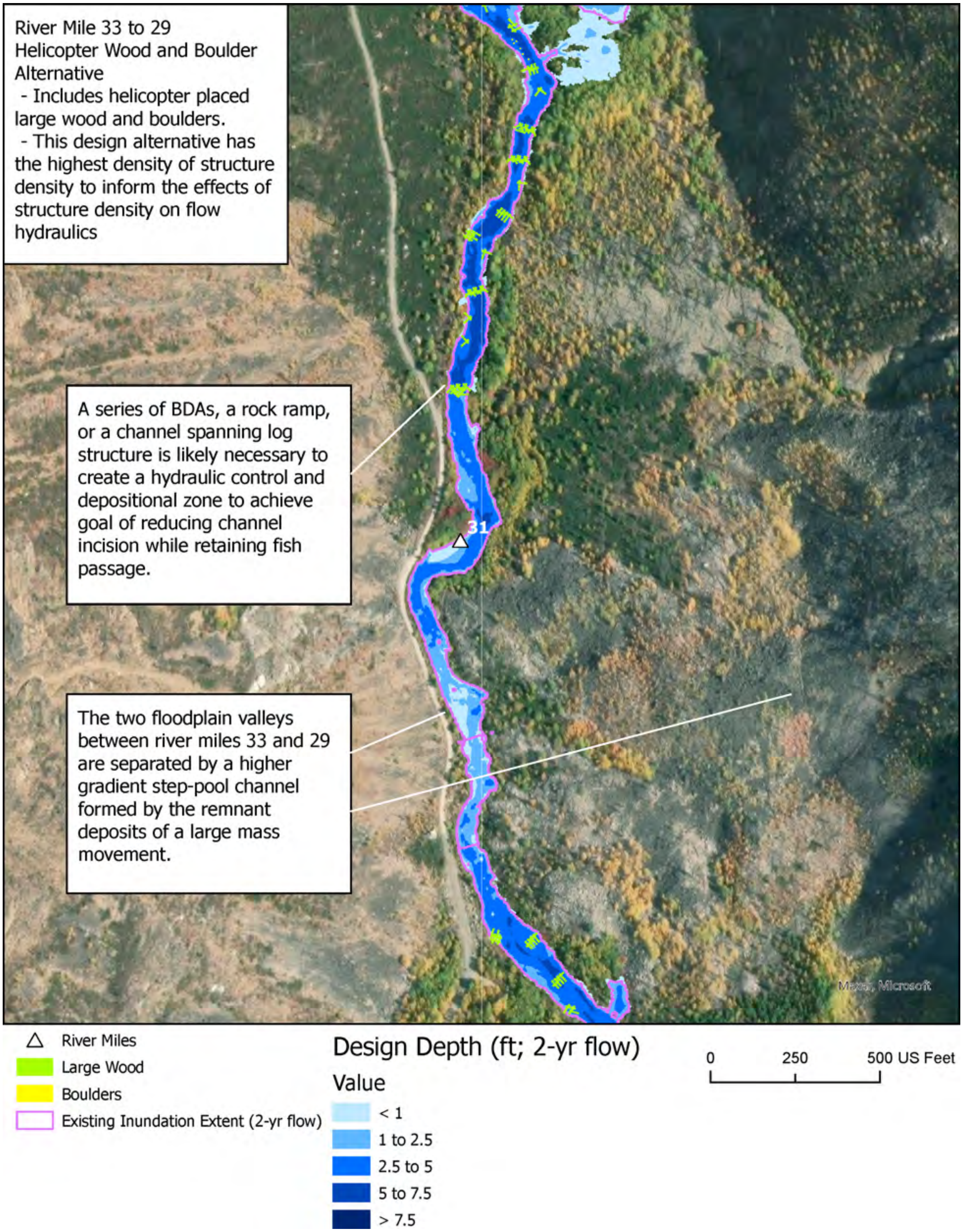
The floodplain of the upper valley between river miles 33 and 31 is generally more connected than the lower valley between river miles 31 and 29 under the same flow conditions.
31.5
River Miles
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet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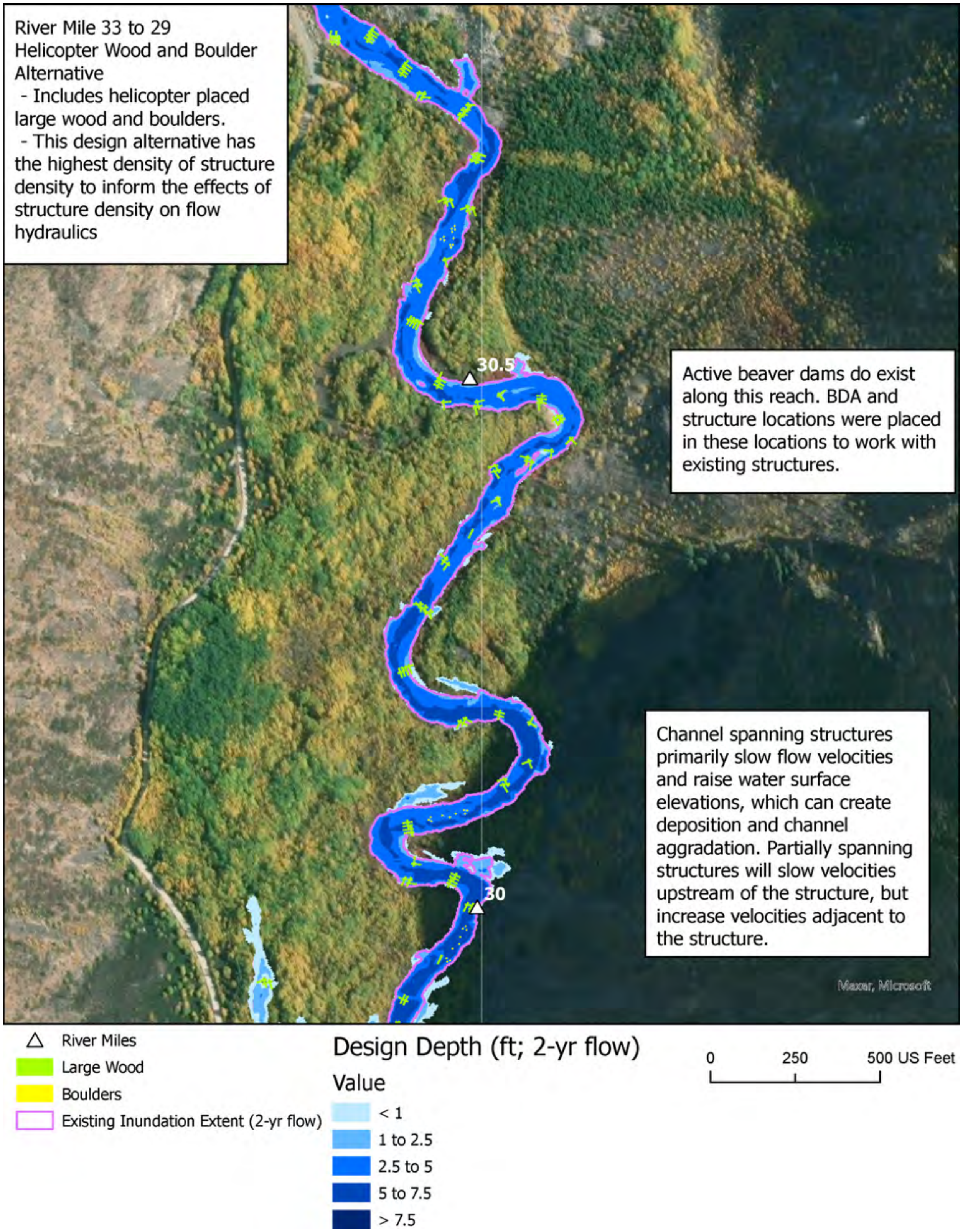
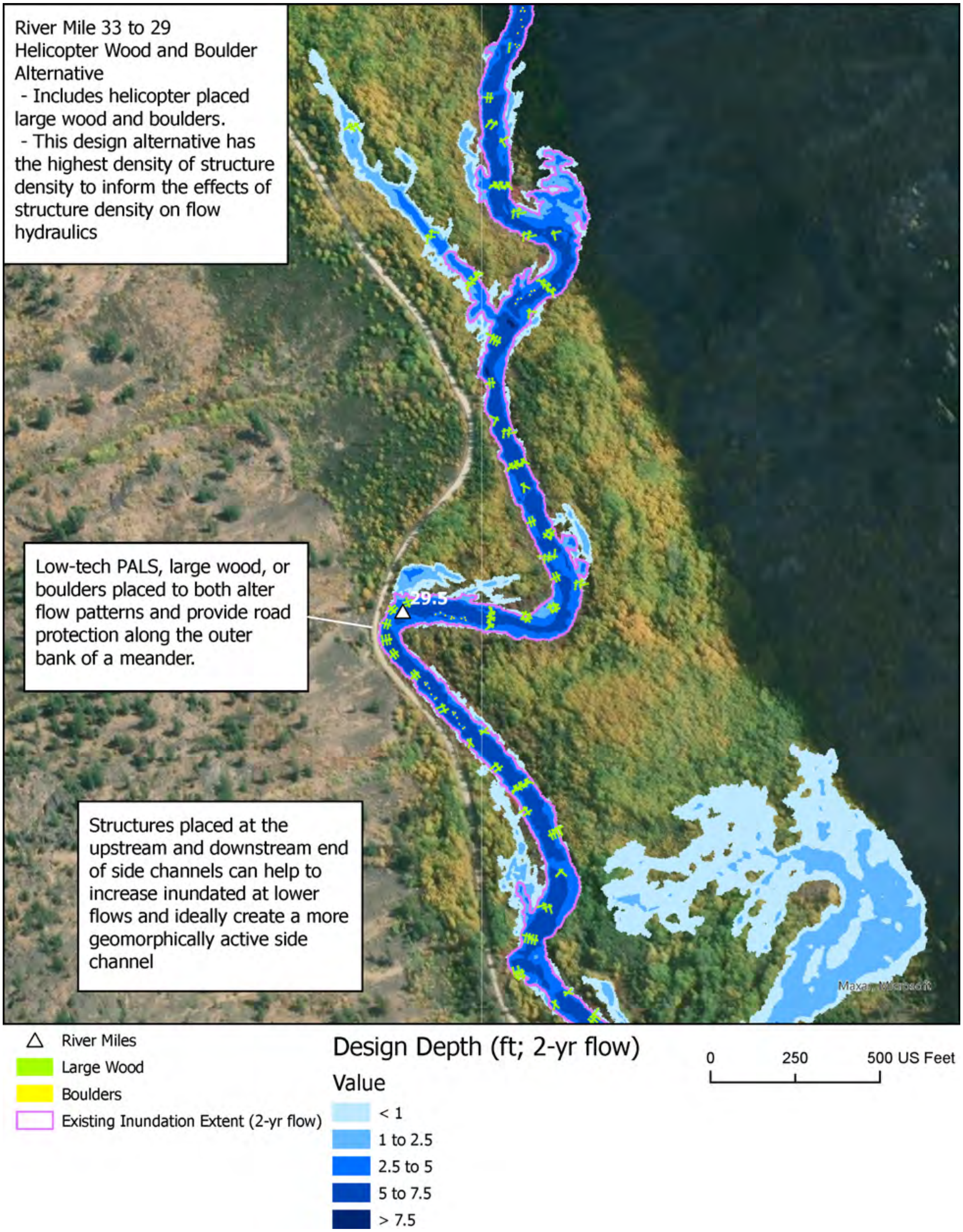
The two floodplain valleys between river miles 33 and 29 are separated by a higher gradient step-pool channel formed by the remnant deposits of a large mass movement.
Maxar, Microsoft
River Miles
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
Helicopter Wood and Boulder Alternative
- Includes helicopter placed large wood and boulders.
- This design alternative has the highest density of structure density to inform the effects of structure density on flow hydraulics
30.5
Active beaver dams do exist along this reach. BDA and structure locations were placed in these locations to work with existing structures.
30
Channel spanning structures primarily slow flow velocities and raise water surface elevations, which can create deposition and channel aggradation. Partially spanning structures will slow velocities upstream of the structure, but increase velocities adjacent to the structure.
Maxar, Microsoft
River Miles
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet


River Mile 33 to 29
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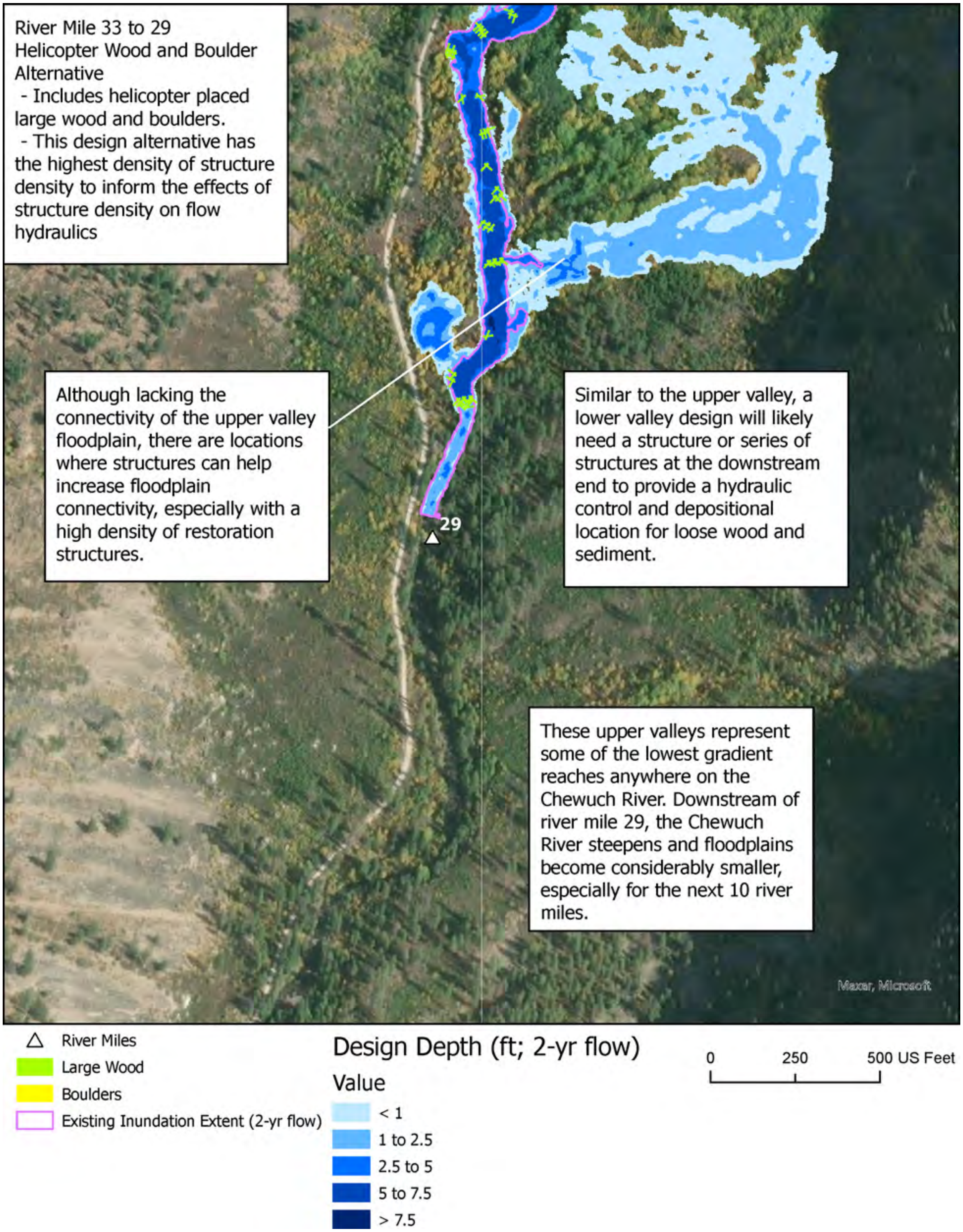
River Miles
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet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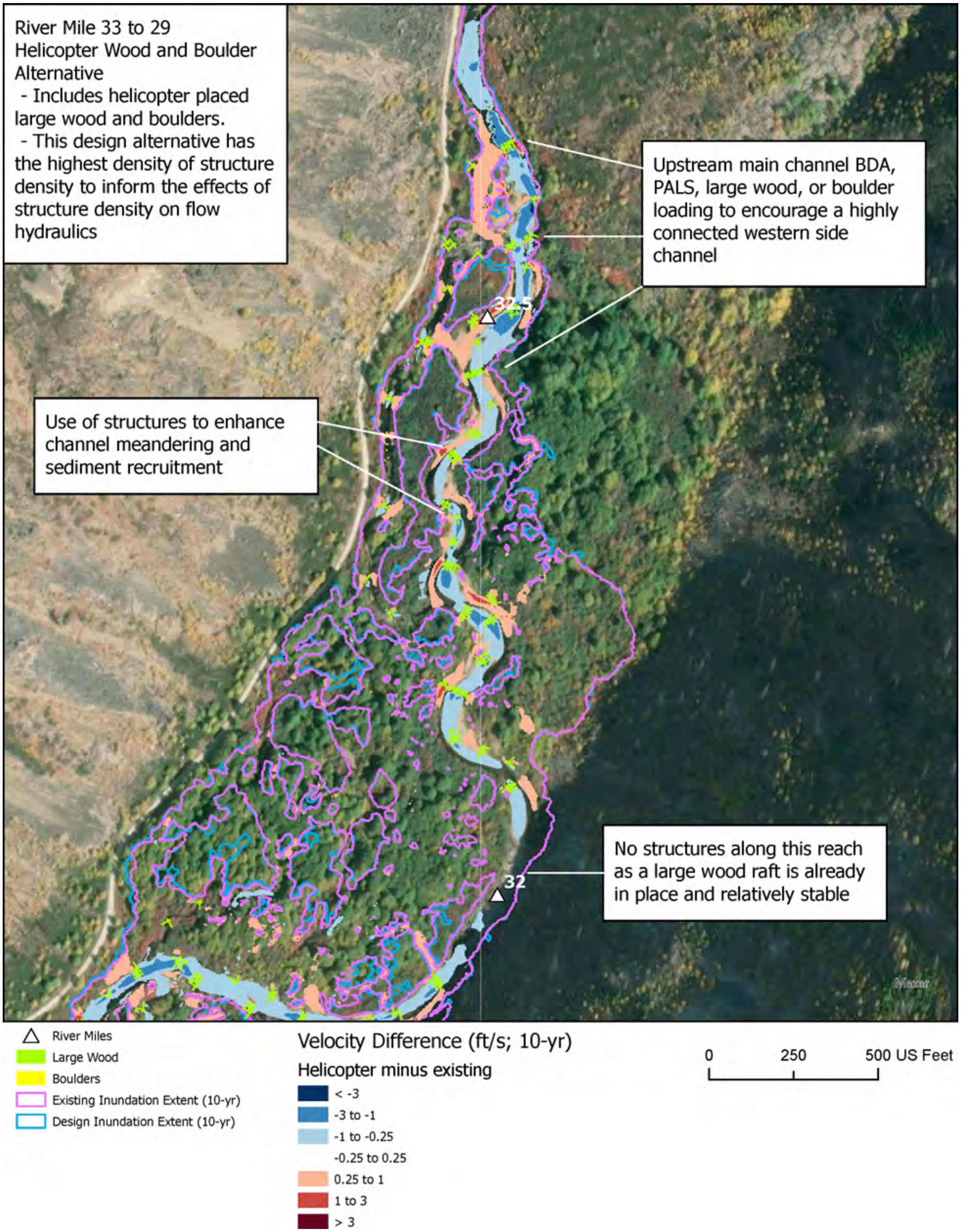
Maxar, Microsoft
River Miles
Large Wood
Boulders
Existing Inundation Extent (2-yr flow)
Design Depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 7.5
> 7.5
0
250
500 US Feet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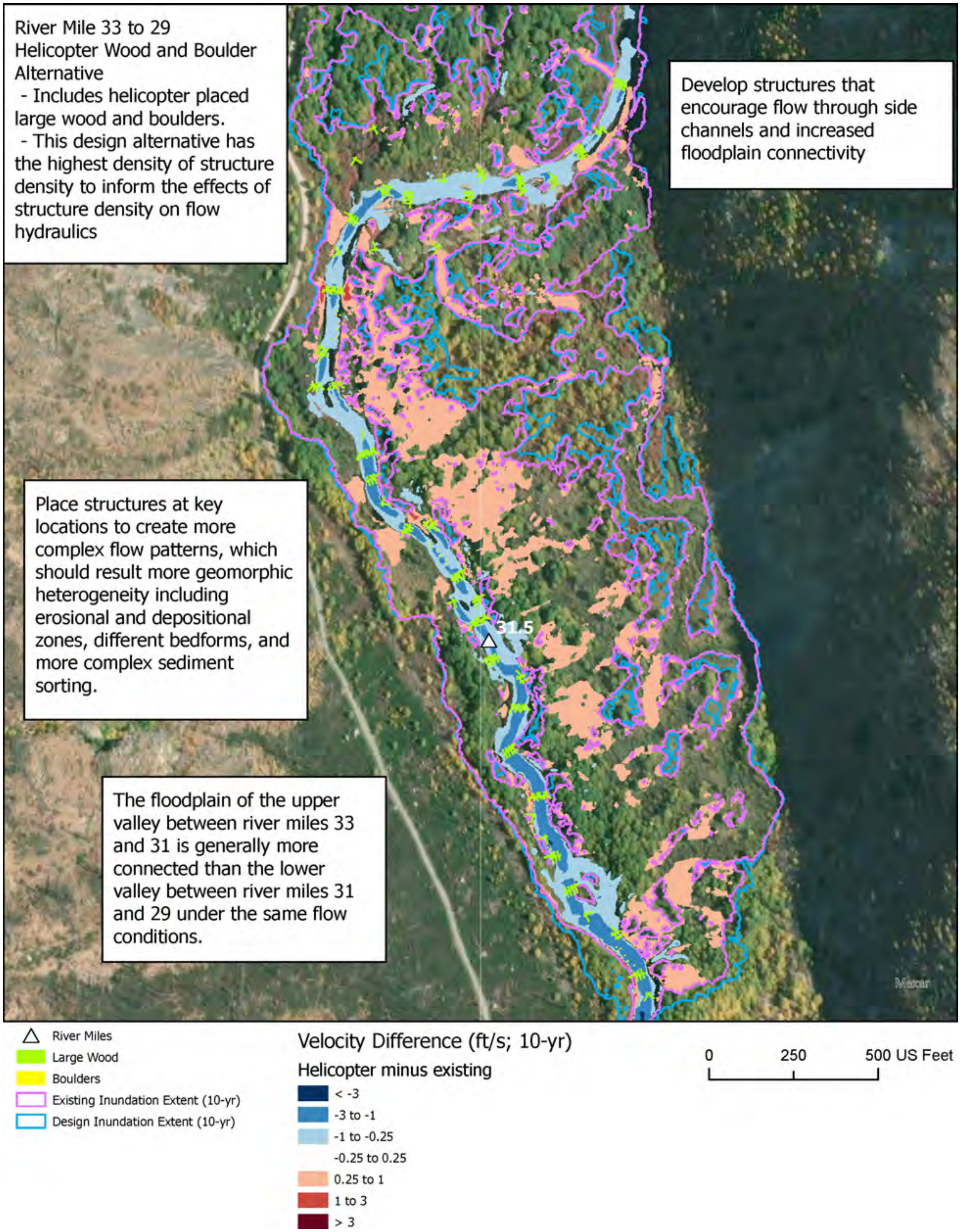
- This design alternative has the highest density of structure density to inform the effects of structure density on flow hydraulics
Upstream main channel BDA, PALS, large wood, or boulder loading to encourage a highly connected western side channel
32.5
Use of structures to enhance channel meandering and sediment recruitment
32
No structures along this reach as a large wood raft is already in place and relatively stable
River Miles
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Helicopter minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet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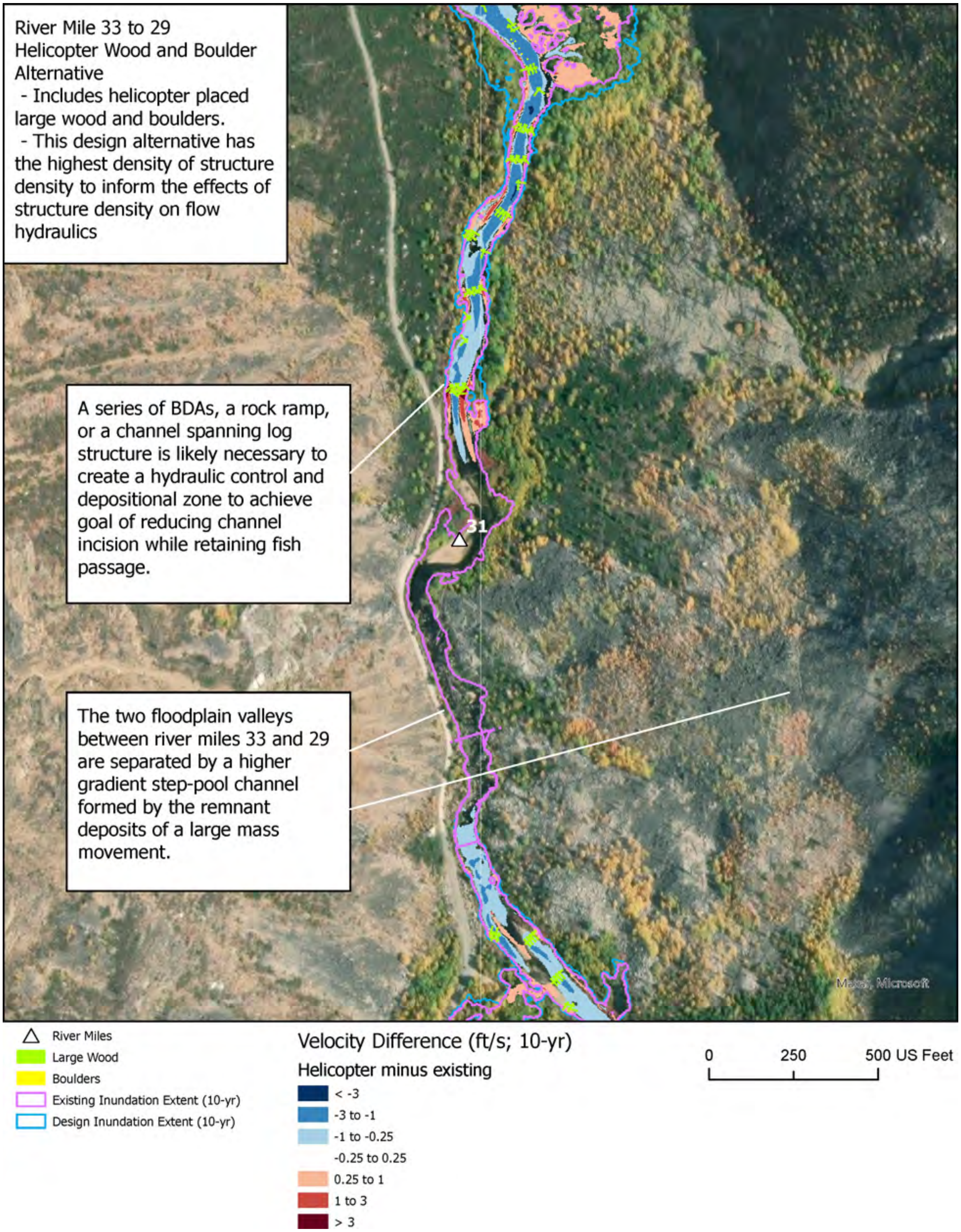
31.5
River Miles
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Helicopter minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet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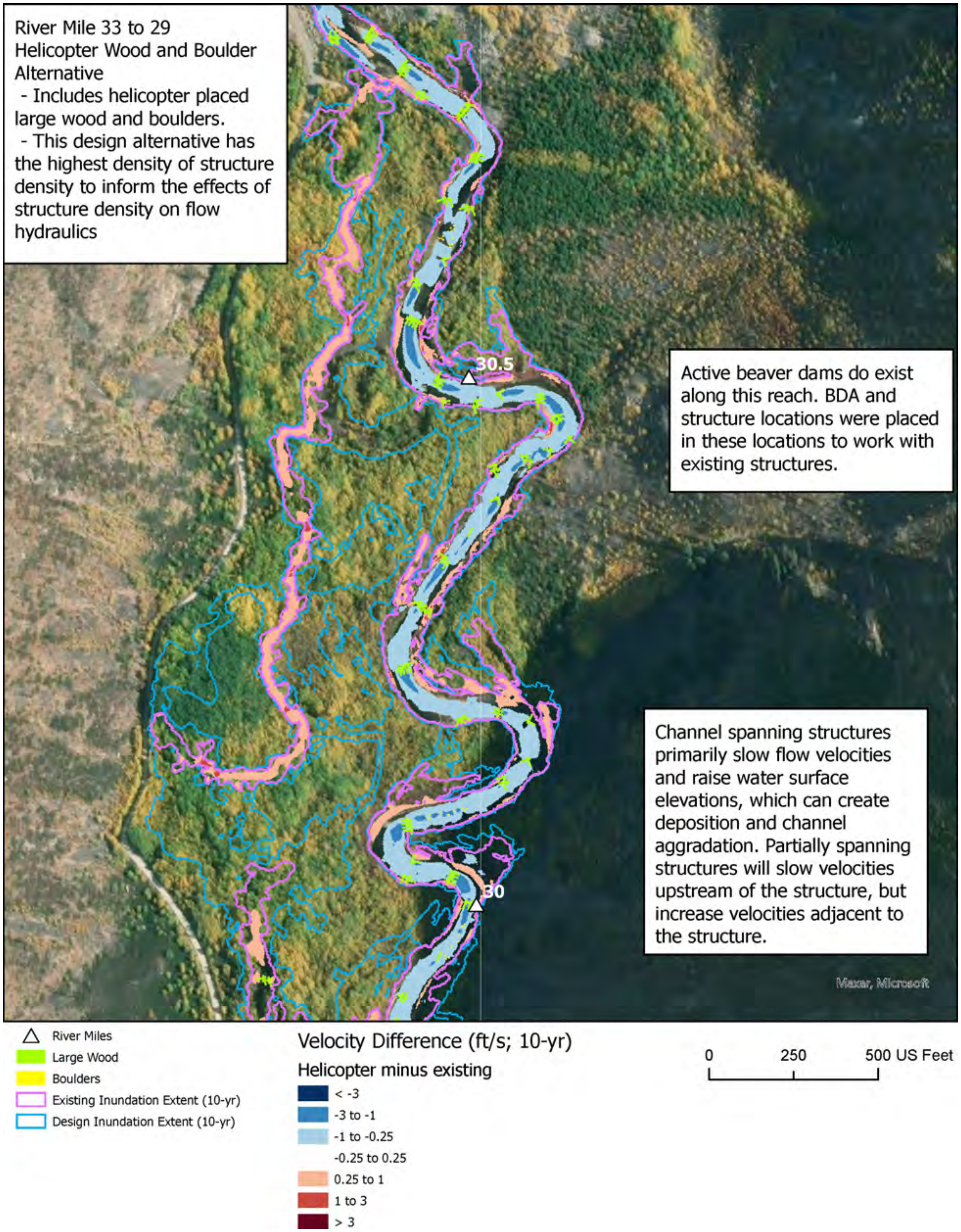
Maxar, Microsoft
River Miles
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Helicopter minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet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Helicopter Wood and Boulder Alternative
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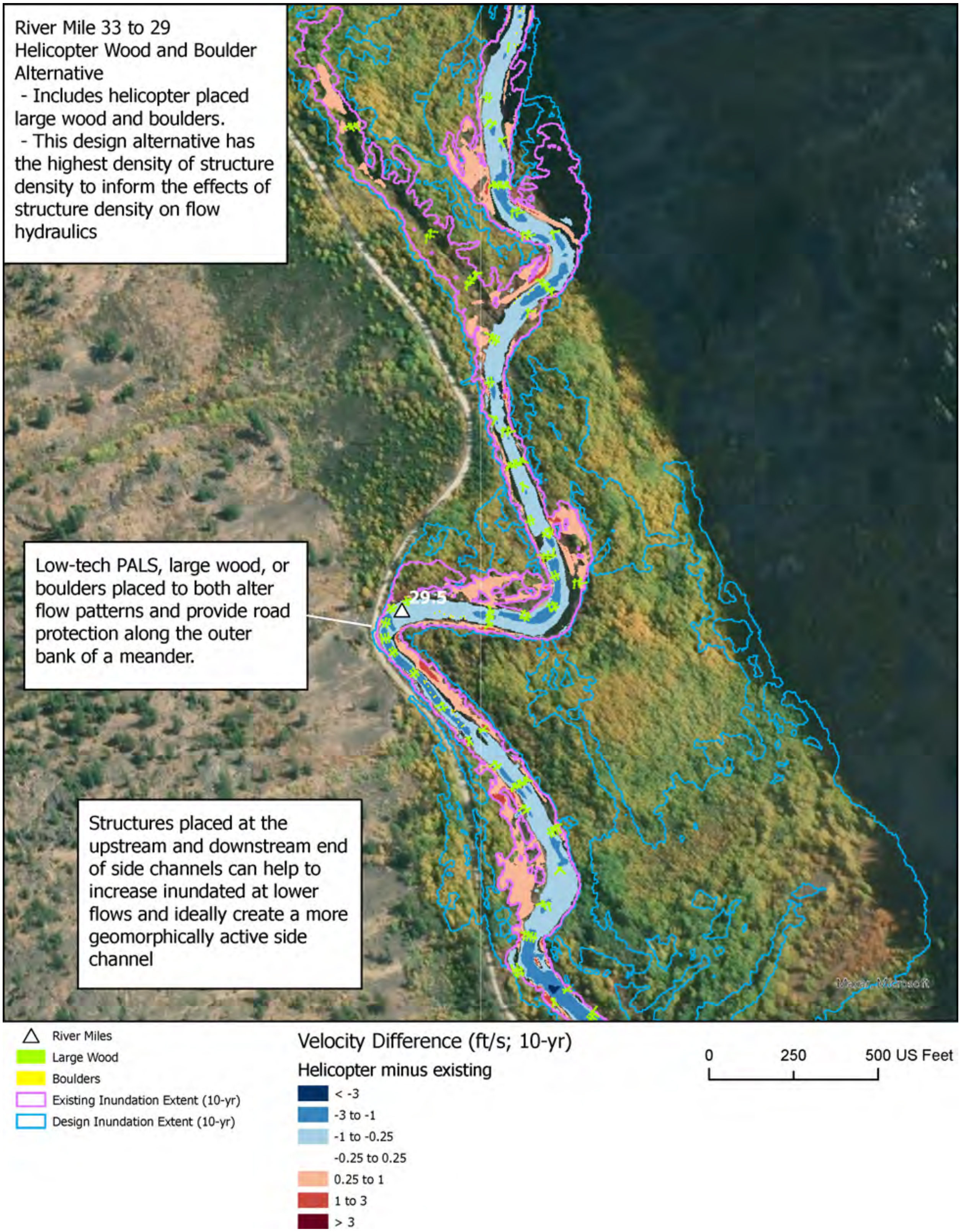
Maxar, Microsoft
River Miles
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Helicopter minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet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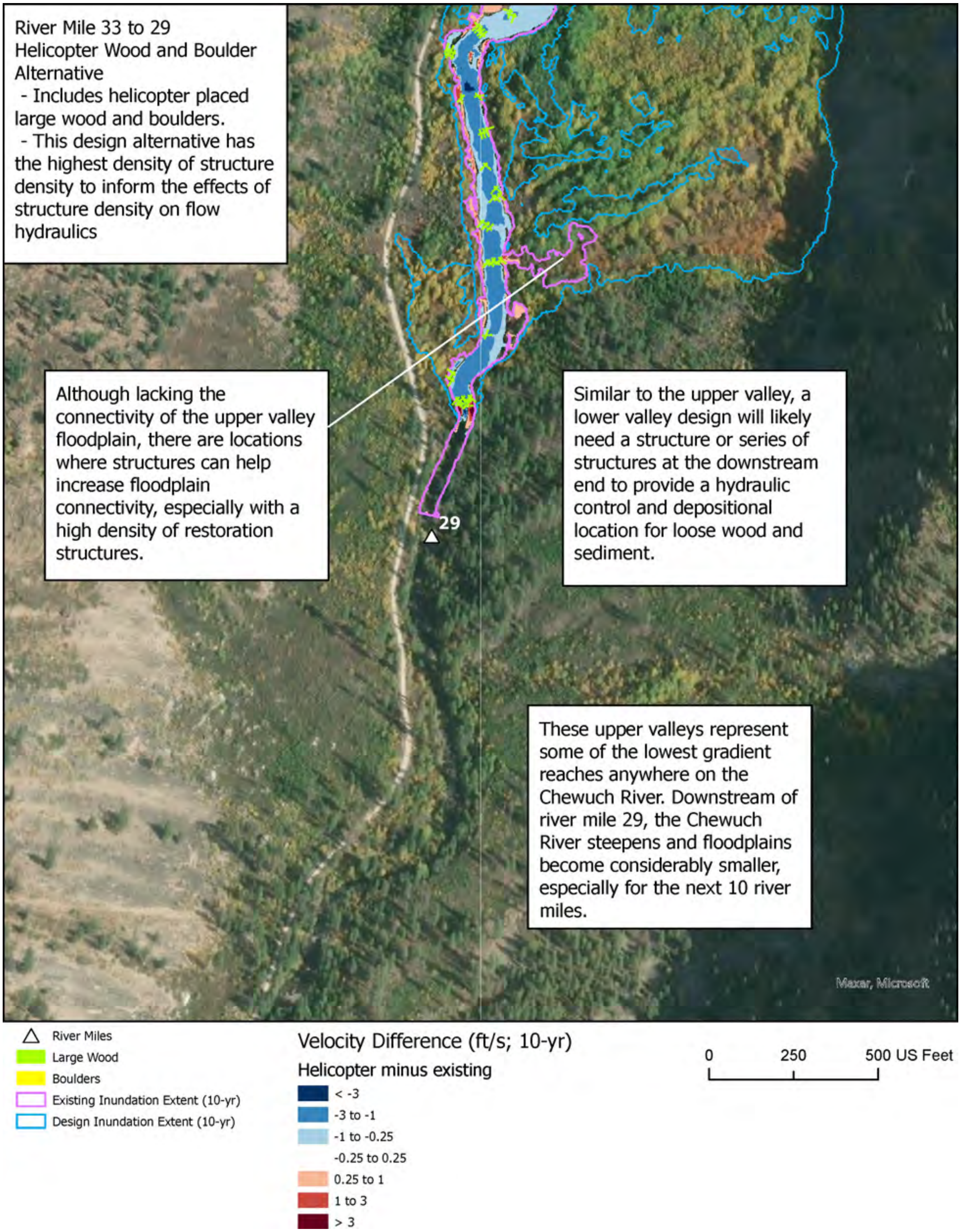
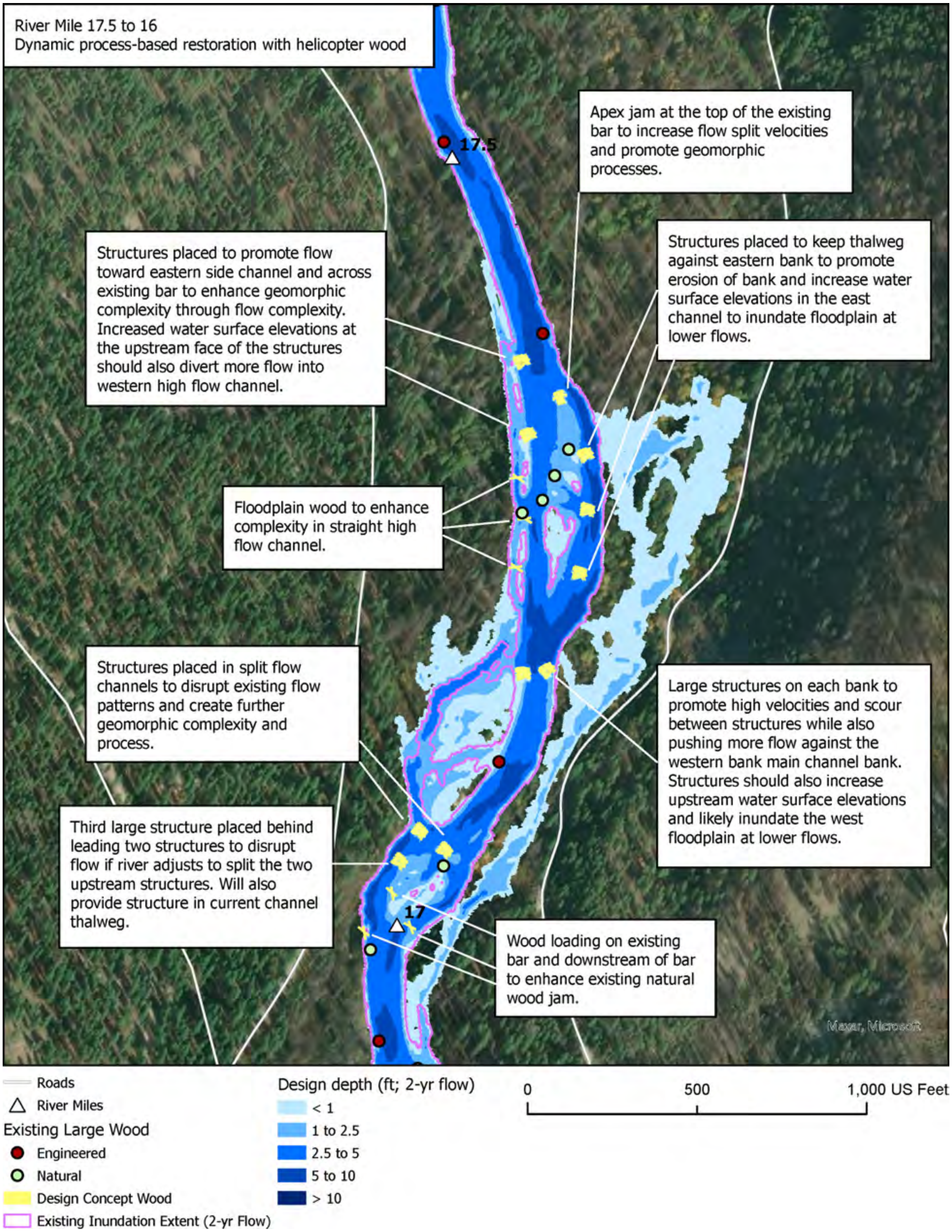
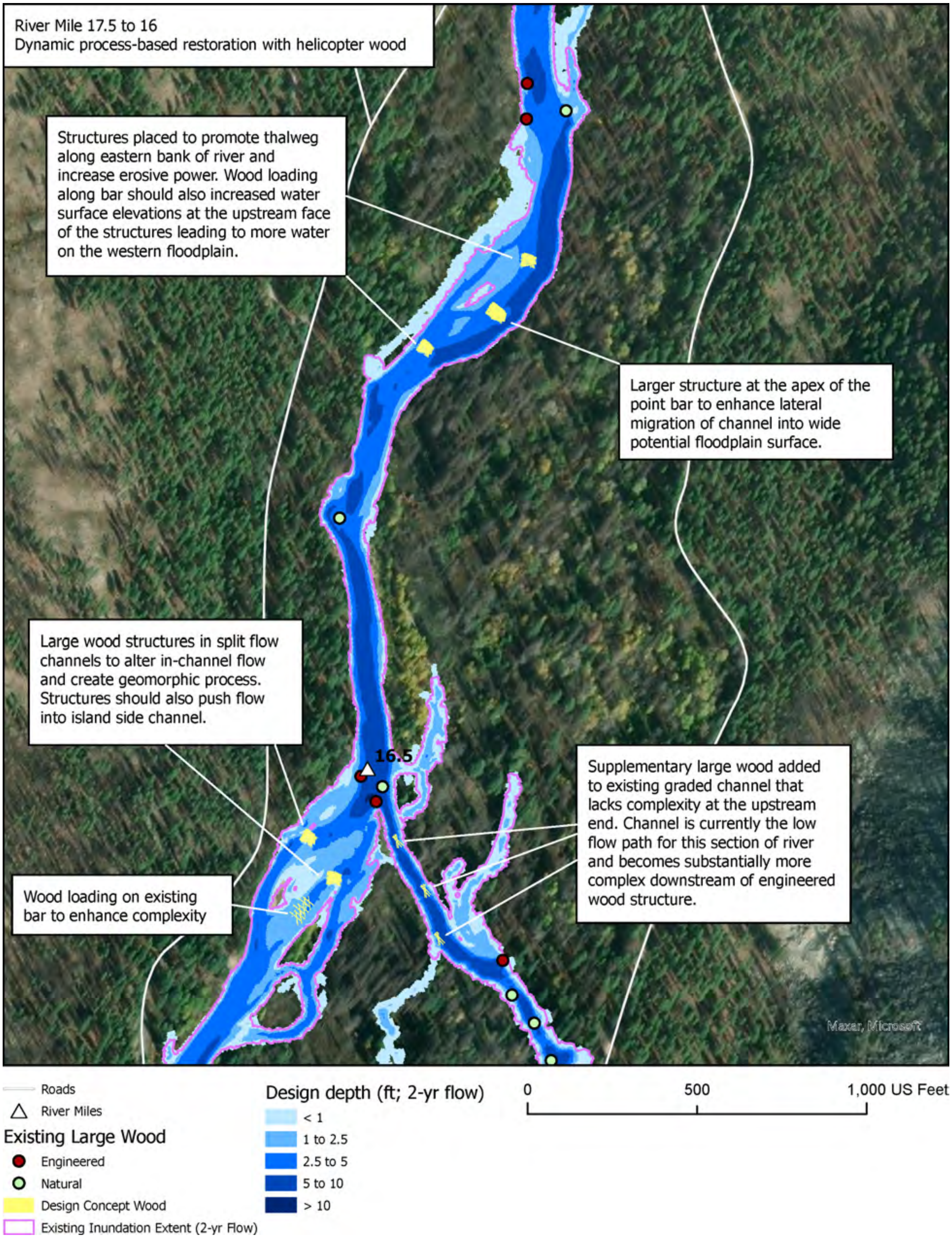
Helicopter Wood and Boulder Alternative
- Includes helicopter placed large wood and boulders.
- This design alternative has the highest density of structure density to inform the effects of structure density on flow hydraulics
Low-tech PALS, large wood, or boulders placed to both alter flow patterns and provide road protection along the outer bank of a meander.
29.5
Structures placed at the upstream and downstream end of side channels can help to increase inundated at lower flows and ideally create a more geomorphically active side channel
River Miles
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Helicopter minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet

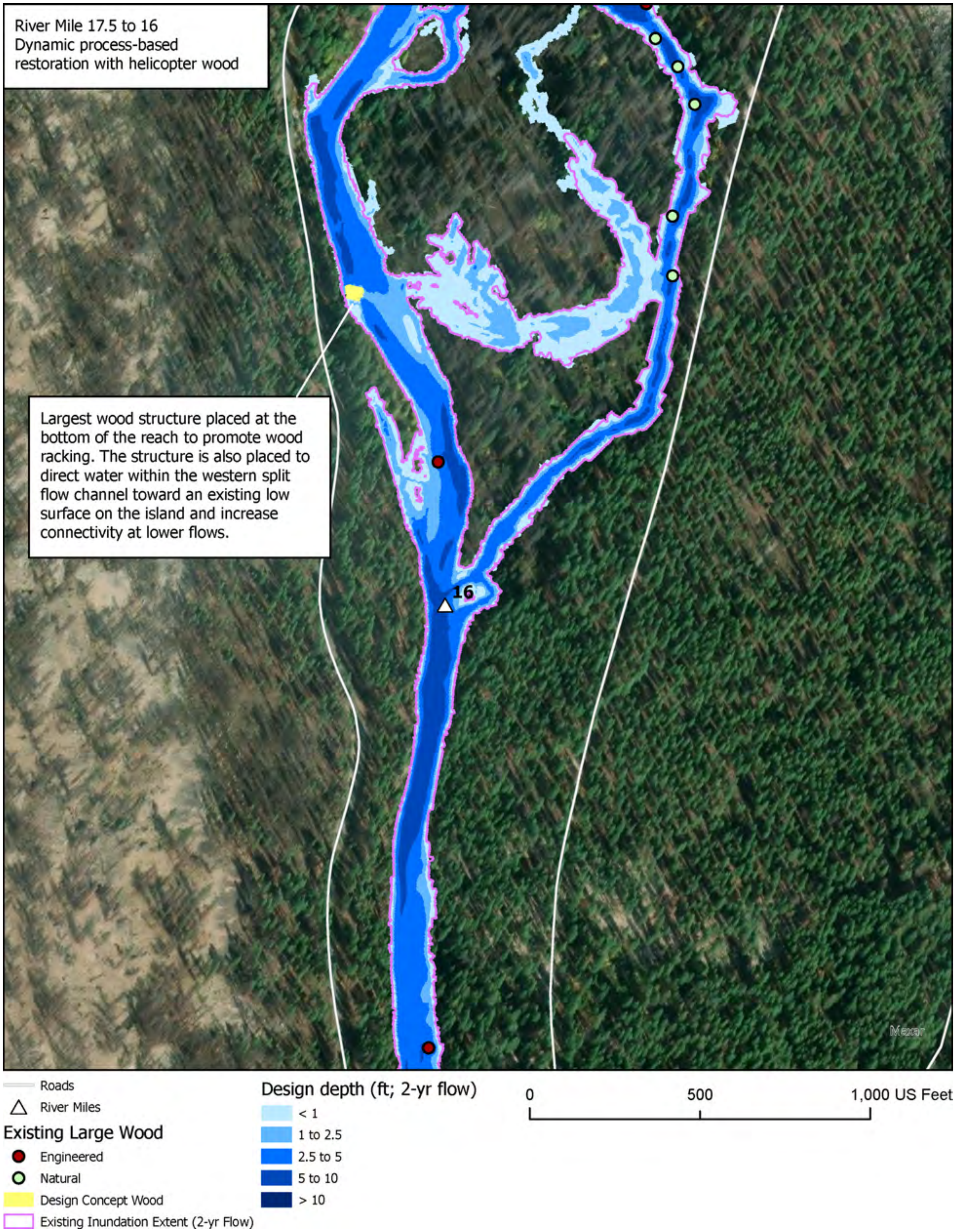

River Mile 33 to 29
Helicopter Wood and Boulder Alternative
- Includes helicopter placed large wood and boulders.
- This design alternative has the highest density of structure density to inform the effects of structure density on flow hydraulics
Although lacking the connectivity of the upper valley floodplain, there are locations where structures can help increase floodplain connectivity, especially with a high density of restoration structures.
Similar to the upper valley, a lower valley design will likely need a structure or series of structures at the downstream end to provide a hydraulic control and depositional location for loose wood and sediment.
29
These upper valleys represent some of the lowest gradient reaches anywhere on the Chewuch River. Downstream of river mile 29, the Chewuch River steepens and floodplains become considerably smaller, especially for the next 10 river miles.
Maxar, Microsoft
River Miles
Large Wood
Boulders
Existing Inundation Extent (10-yr)
Design Inundation Extent (10-yr)
Velocity Difference (ft/s; 10-yr)
Helicopter minus existing
< -3
-3 to -1
-1 to -0.25
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
250
500 US Feet

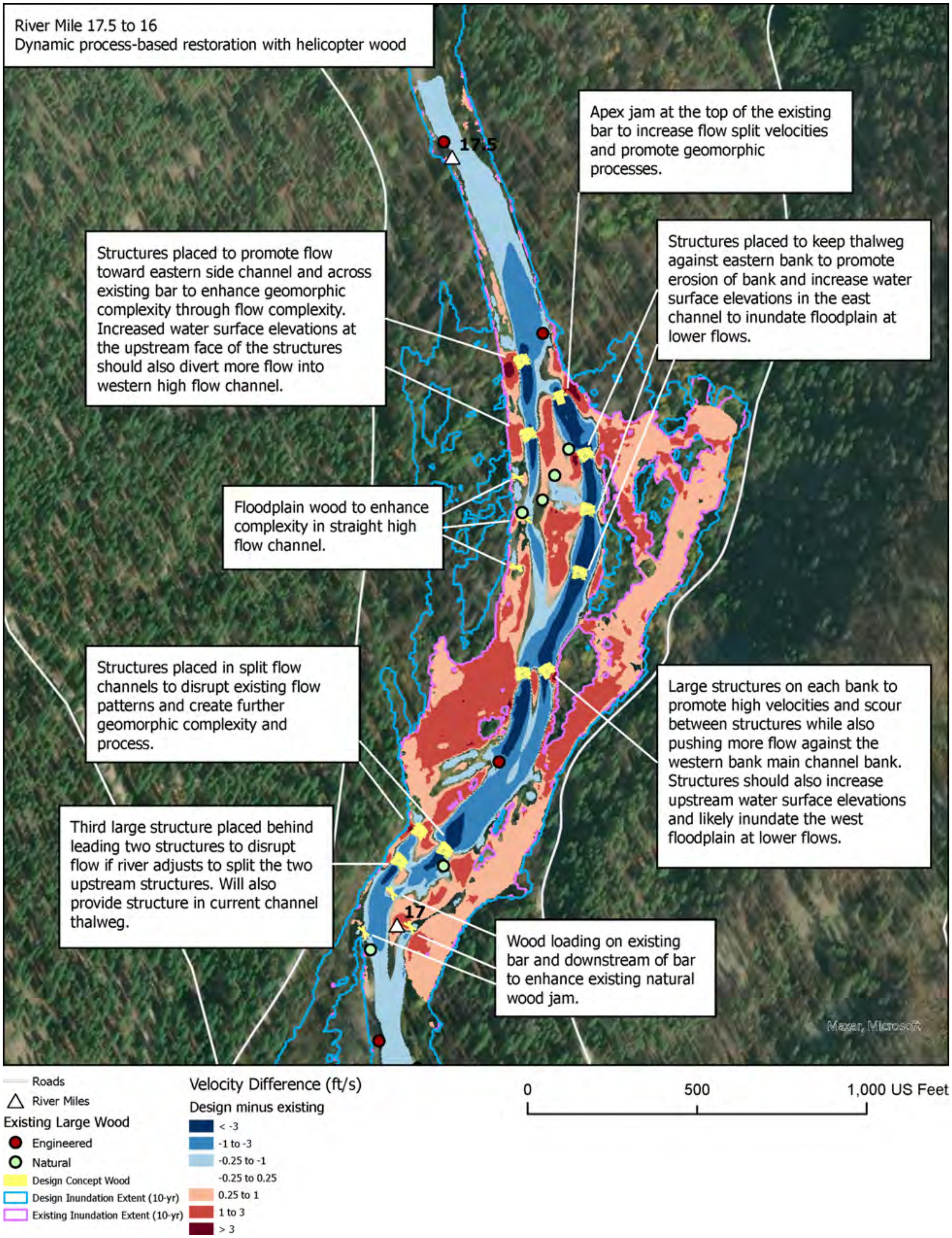
Appendix E

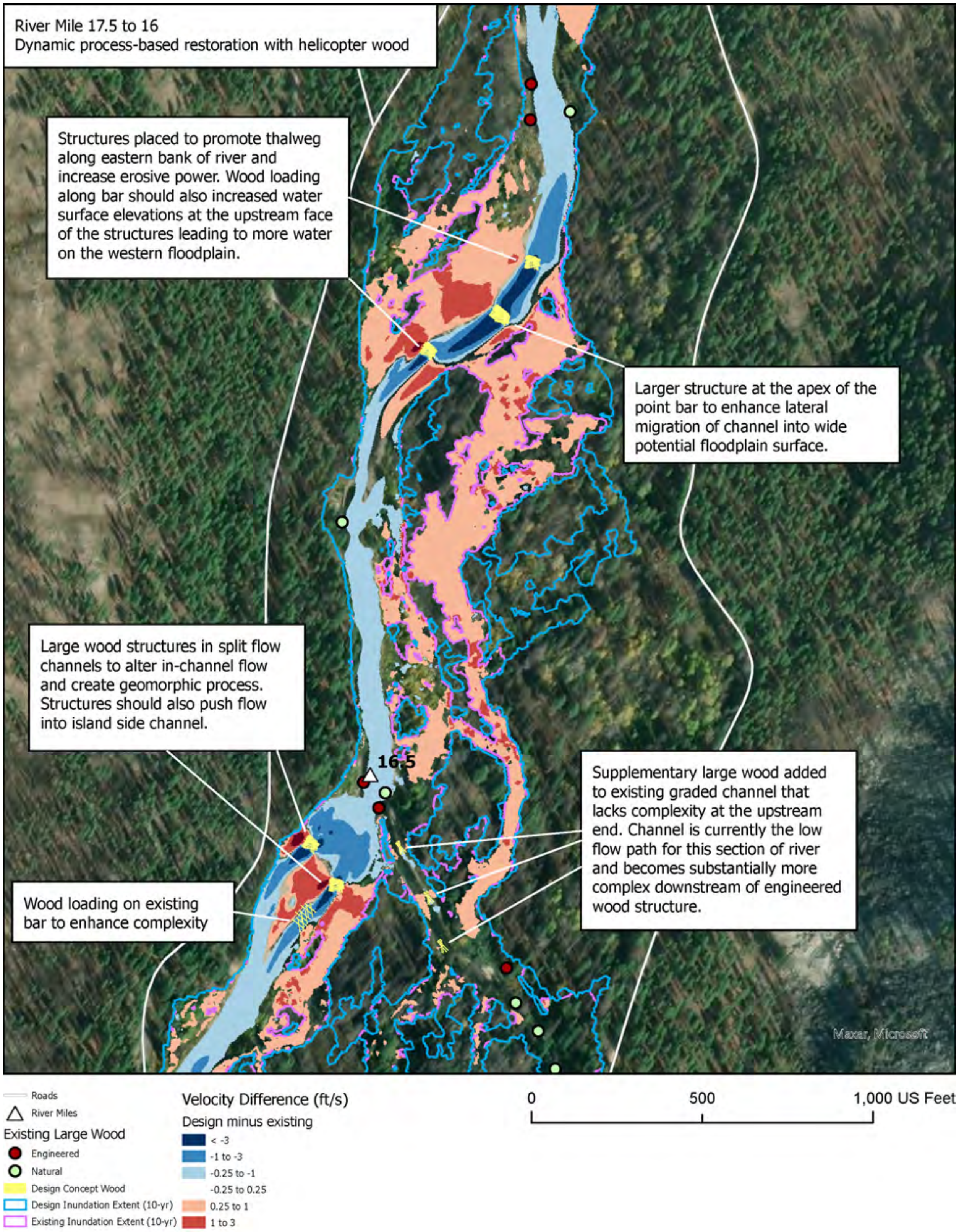
Design Concept 1 and Model Results for River Miles 33 to 29

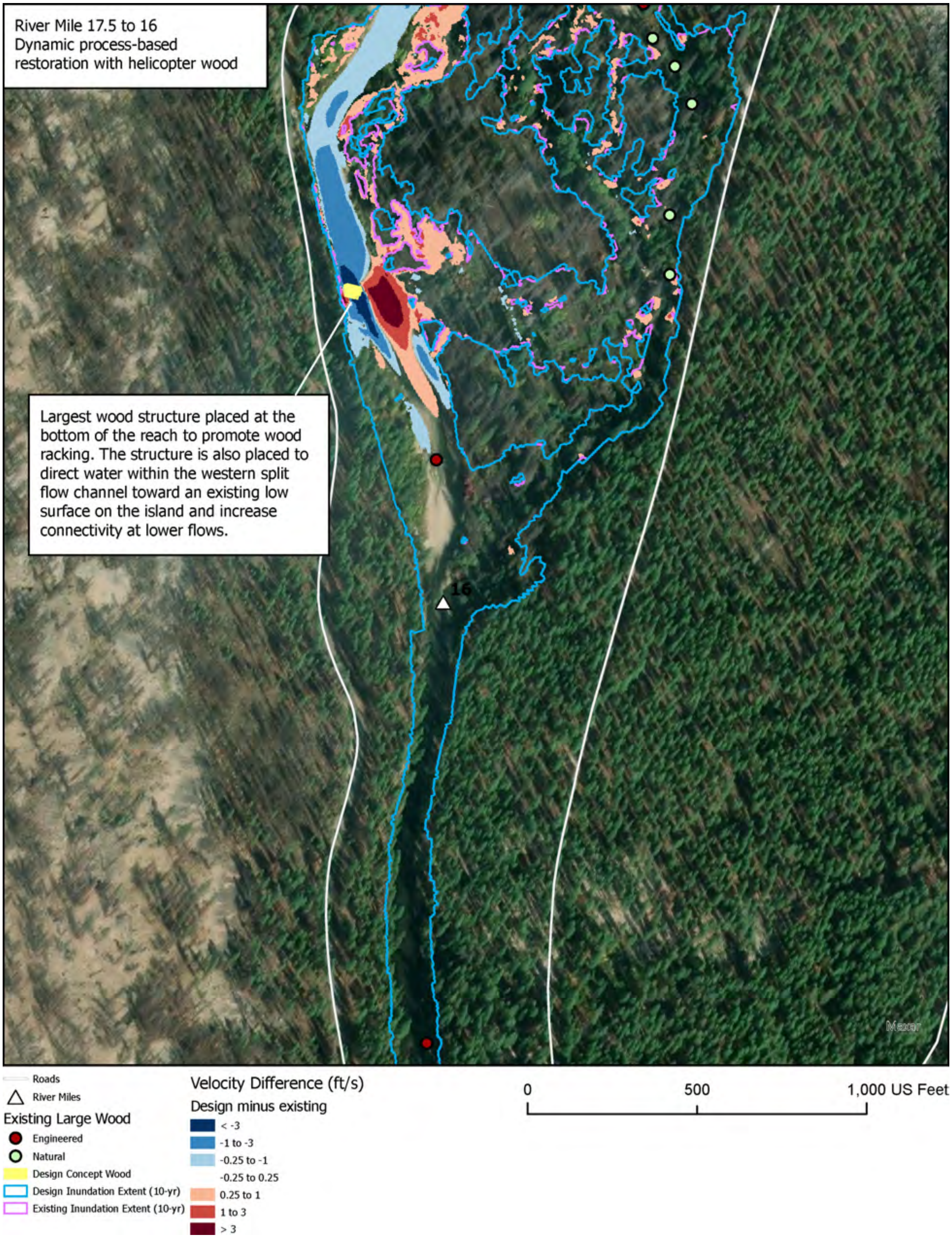

River Mile 17.5 to 16
Dynamic process-based restoration with helicopter wood
17.5
Apex jam at the top of the existing bar to increase flow split velocities and promote geomorphic processes.
Structures placed to promote flow toward eastern side channel and across existing bar to enhance geomorphic complexity through flow complexity. Increased water surface elevations at the upstream face of the structures should also divert more flow into western high flow channel.
Structures placed to keep thalweg against eastern bank to promote erosion of bank and increase water surface elevations in the east channel to inundate floodplain at lower flows.
Floodplain wood to enhance complexity in straight high flow channel.
Structures placed in split flow channels to disrupt existing flow patterns and create further geomorphic complexity and process.
Large structures on each bank to promote high velocities and scour between structures while also pushing more flow against the western bank main channel bank. Structures should also increase upstream water surface elevations and likely inundate the west floodplain at lower flows.
Third large structure placed behind leading two structures to disrupt flow if river adjusts to split the two upstream structures. Will also provide structure in current channel thalweg.
17
Wood loading on existing bar and downstream of bar to enhance existing natural wood jam.
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Existing Inundation Extent (2-yr Flow)
Design depth (ft; 2-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet

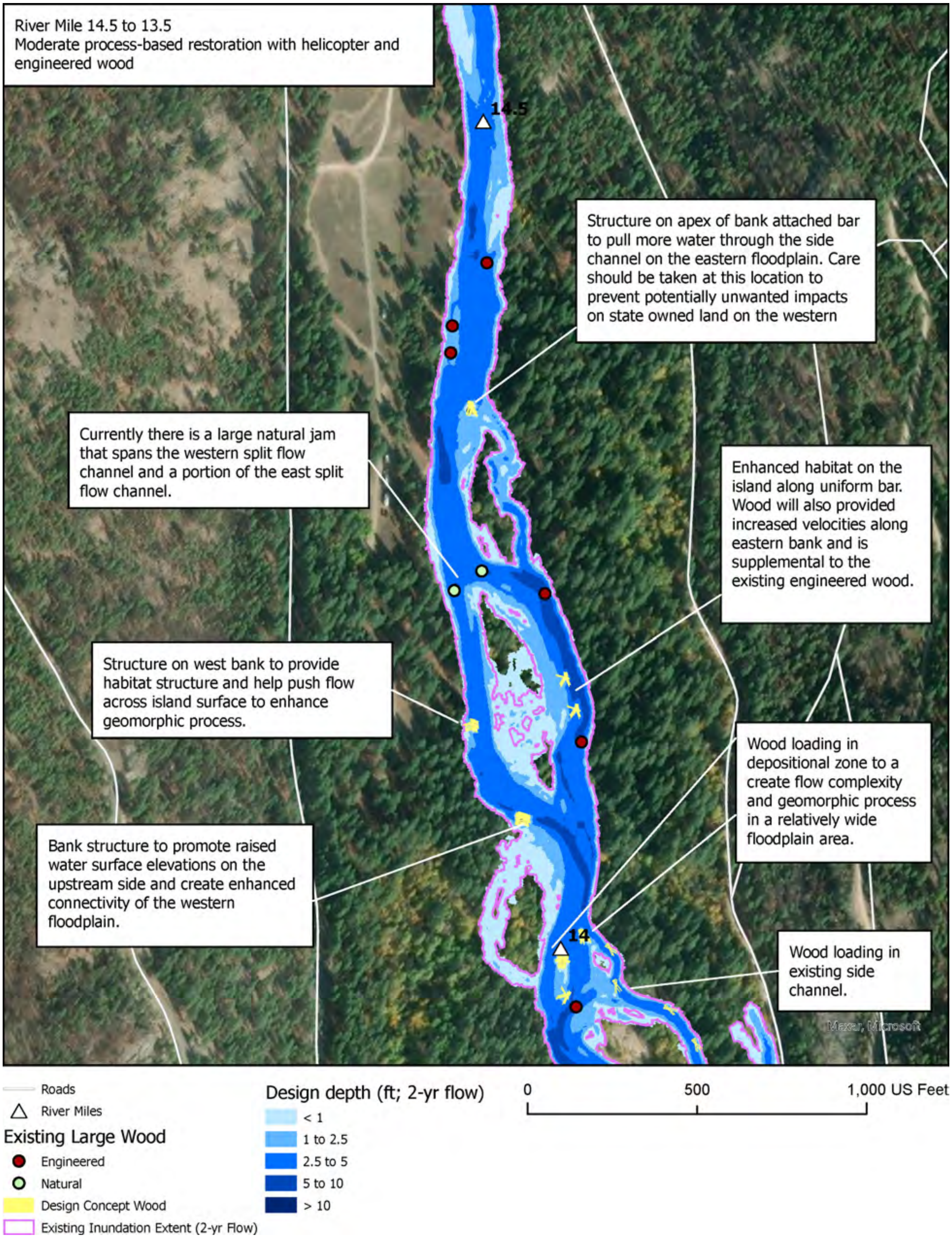

River Mile 17.5 to 16
Dynamic process-based restoration with helicopter wood
Structures placed to promote thalweg along eastern bank of river and increase erosive power. Wood loading along bar should also increased water surface elevations at the upstream face of the structures leading to more water on the western floodplain.
Larger structure at the apex of the point bar to enhance lateral migration of channel into wide potential floodplain surface.
Large wood structures in split flow channels to alter in-channel flow and create geomorphic process. Structures should also push flow into island side channel.
16.5
Supplementary large wood added to existing graded channel that lacks complexity at the upstream end. Channel is currently the low flow path for this section of river and becomes substantially more complex downstream of engineered wood structure.
Wood loading on existing bar to enhance complexity
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Existing Inundation Extent (2-yr Flow)
Design depth (ft; 2-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet

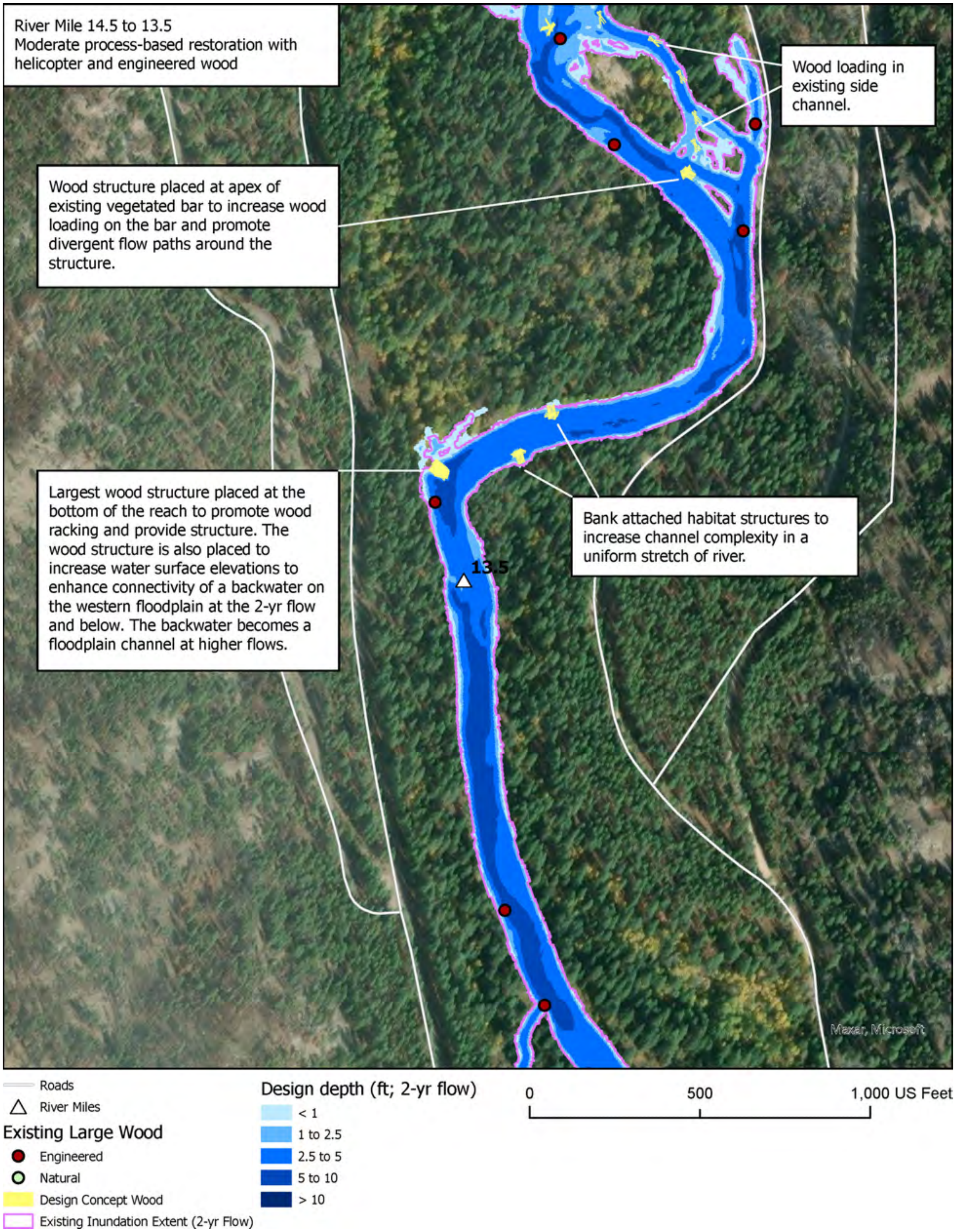

River Mile 17.5 to 16
Dynamic process-based restoration with helicopter wood
Largest wood structure placed at the bottom of the reach to promote wood racking. The structure is also placed to direct water within the western split flow channel toward an existing low surface on the island and increase connectivity at lower flows.
16
Mexar
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Existing Inundation Extent (2-yr Flow)
Design depth (ft; 2-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet

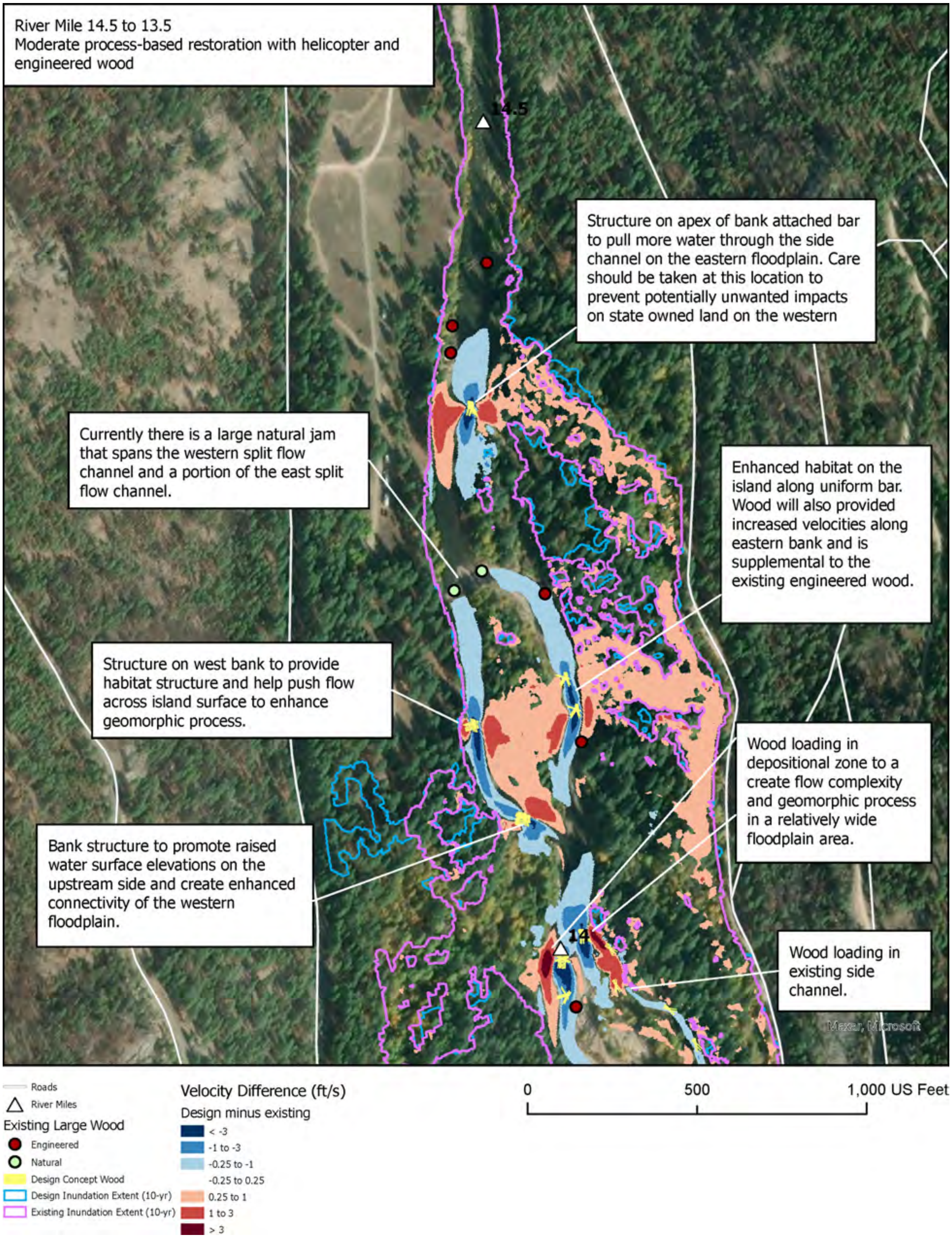

River Mile 17.5 to 16
Dynamic process-based restoration with helicopter wood
17.5
Apex jam at the top of the existing bar to increase flow split velocities and promote geomorphic processes.
Structures placed to promote flow toward eastern side channel and across existing bar to enhance geomorphic complexity through flow complexity. Increased water surface elevations at the upstream face of the structures should also divert more flow into western high flow channel.
Structures placed to keep thalweg against eastern bank to promote erosion of bank and increase water surface elevations in the east channel to inundate floodplain at lower flows.
Floodplain wood to enhance complexity in straight high flow channel.
Structures placed in split flow channels to disrupt existing flow patterns and create further geomorphic complexity and process.
Large structures on each bank to promote high velocities and scour between structures while also pushing more flow against the western bank main channel bank. Structures should also increase upstream water surface elevations and likely inundate the west floodplain at lower flows.
Third large structure placed behind leading two structures to disrupt flow if river adjusts to split the two upstream structures. Will also provide structure in current channel thalweg.
17
Wood loading on existing bar and downstream of bar to enhance existing natural wood jam.
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Design Inundation Extent (10-yr)
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s)
Design minus existing
< -3
-1 to -3
-0.25 to -1
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
500
1,000 US Feet

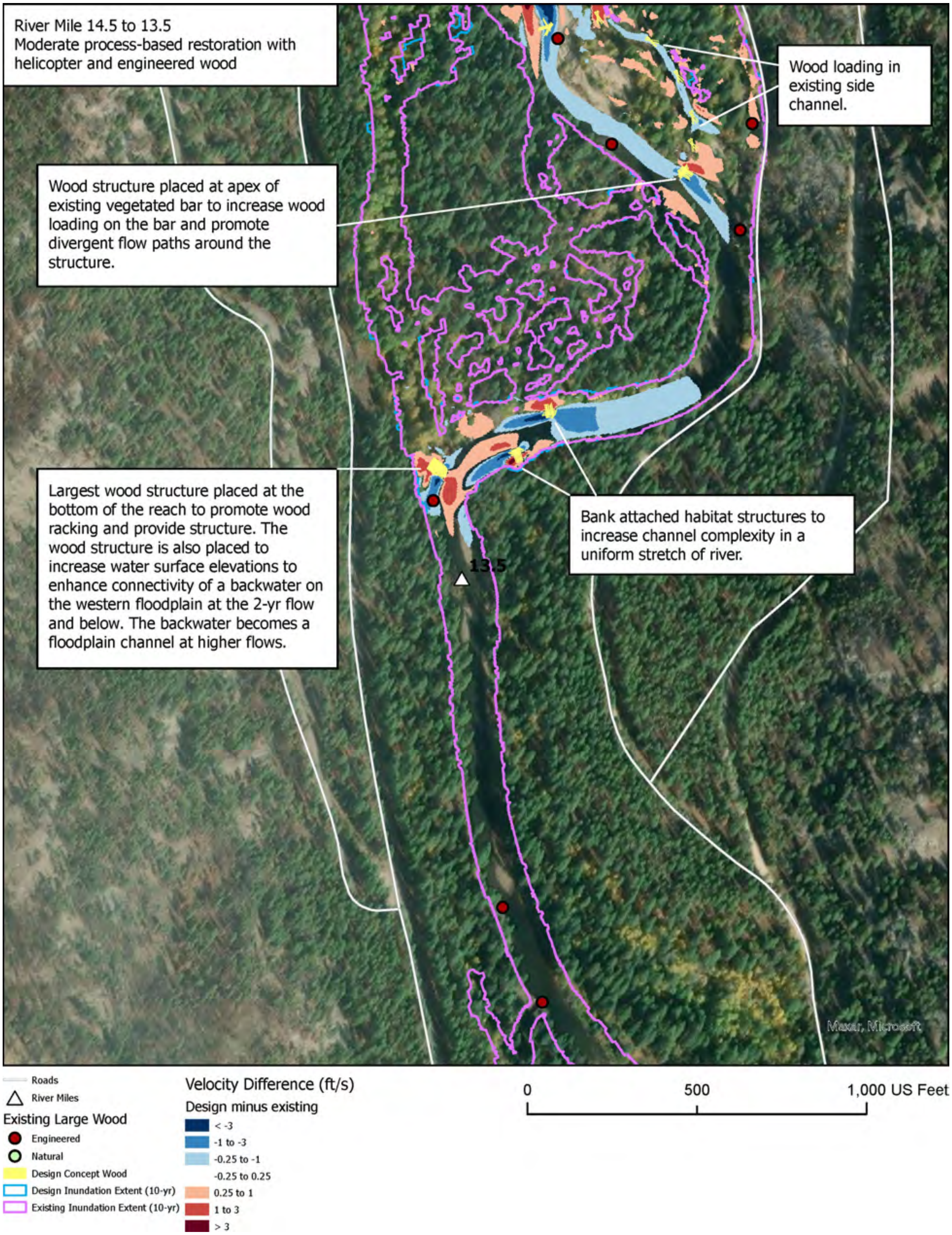

River Mile 17.5 to 16
Dynamic process-based restoration with helicopter wood
Structures placed to promote thalweg along eastern bank of river and increase erosive power. Wood loading along bar should also increased water surface elevations at the upstream face of the structures leading to more water on the western floodplain.
Larger structure at the apex of the point bar to enhance lateral migration of channel into wide potential floodplain surface.
Large wood structures in split flow channels to alter in-channel flow and create geomorphic process. Structures should also push flow into island side channel.
16.5
Supplementary large wood added to existing graded channel that lacks complexity at the upstream end. Channel is currently the low flow path for this section of river and becomes substantially more complex downstream of engineered wood structure.
Wood loading on existing bar to enhance complexity
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Design Inundation Extent (10-yr)
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s)
Design minus existing
< -3
-1 to -3
-0.25 to -1
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
500
1,000 US Feet

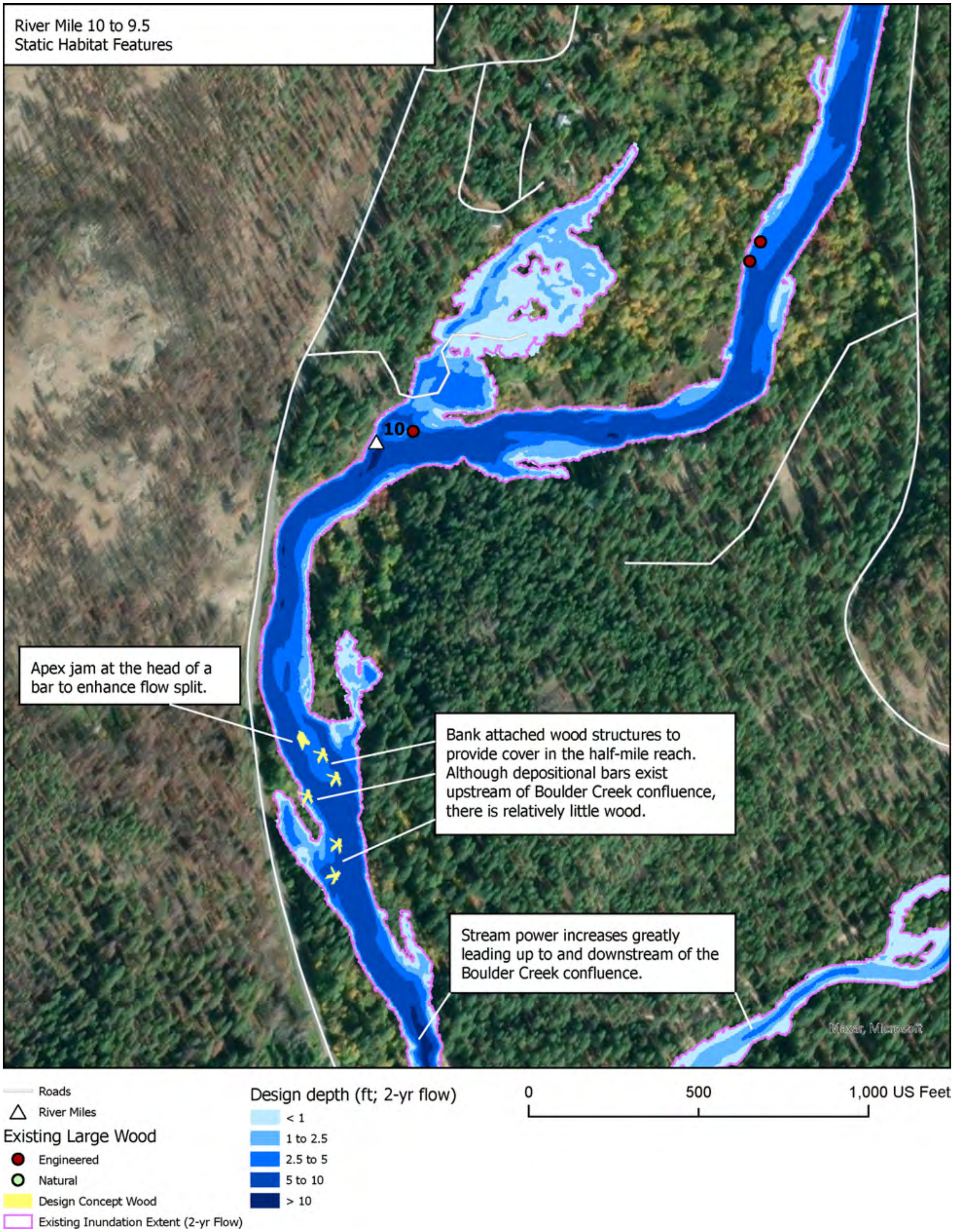

River Mile 17.5 to 16
Dynamic process-based restoration with helicopter wood
Largest wood structure placed at the bottom of the reach to promote wood racking. The structure is also placed to direct water within the western split flow channel toward an existing low surface on the island and increase connectivity at lower flows.
16
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Design Inundation Extent (10-yr)
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s)
Design minus existing
< -3
-1 to -3
-0.25 to -1
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
500
1,000 US Feet

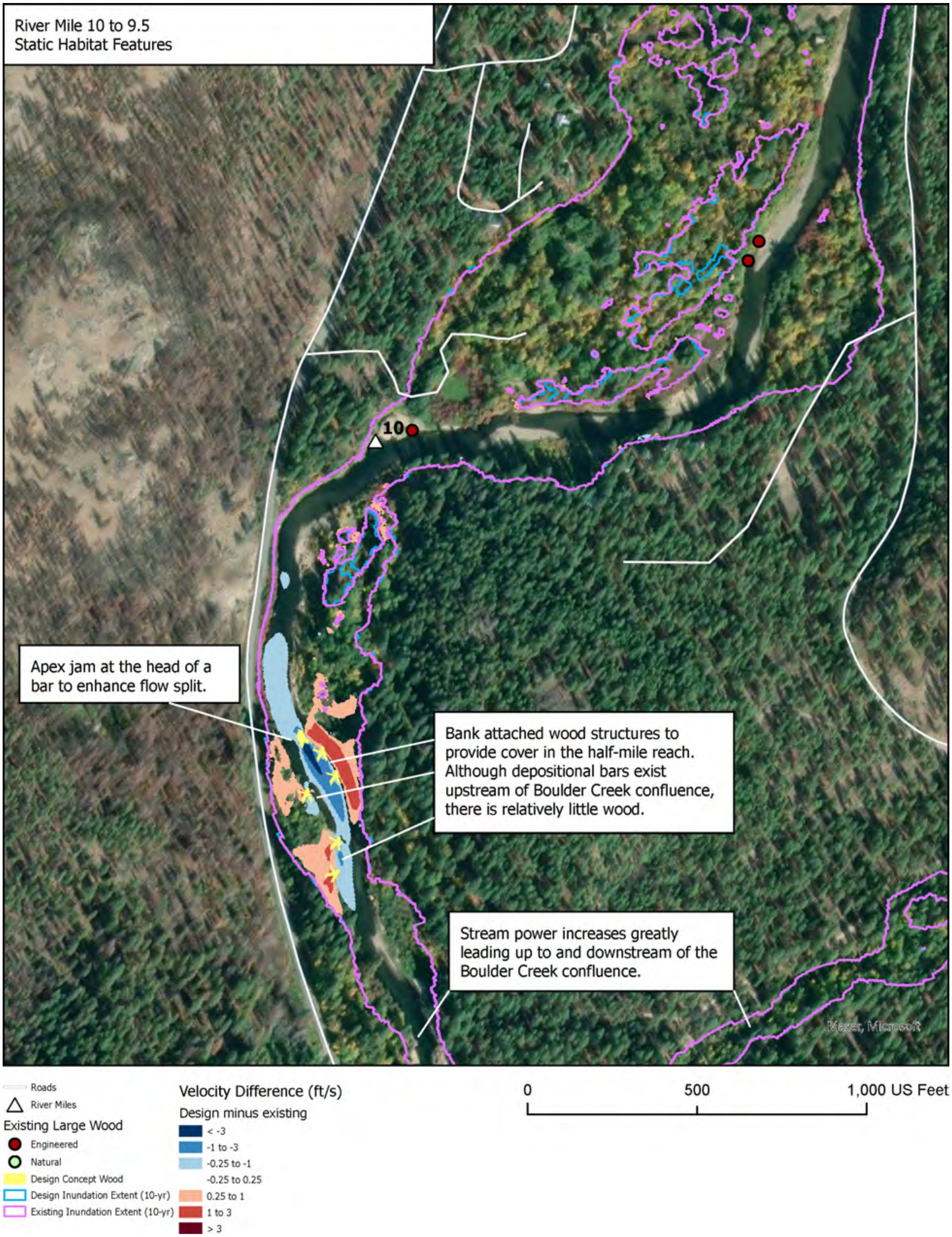

River Mile 14.5 to 13.5
Moderate process-based restoration with helicopter and engineered wood
14.5
Structure on apex of bank attached bar to pull more water through the side channel on the eastern floodplain. Care should be taken at this location to prevent potentially unwanted impacts on state owned land on the western
Currently there is a large natural jam that spans the western split flow channel and a portion of the east split flow channel.
Enhanced habitat on the island along uniform bar. Wood will also provided increased velocities along eastern bank and is supplemental to the existing engineered wood.
Structure on west bank to provide habitat structure and help push flow across island surface to enhance geomorphic process.
Wood loading in depositional zone to a create flow complexity and geomorphic process in a relatively wide floodplain area.
Bank structure to promote raised water surface elevations on the upstream side and create enhanced connectivity of the western floodplain.
14
Wood loading in existing side channel.
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Existing Inundation Extent (2-yr Flow)
Design depth (ft; 2-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet


River Mile 14.5 to 13.5
Moderate process-based restoration with helicopter and engineered wood
Wood loading in existing side channel.
Wood structure placed at apex of existing vegetated bar to increase wood loading on the bar and promote divergent flow paths around the structure.
Largest wood structure placed at the bottom of the reach to promote wood racking and provide structure. The wood structure is also placed to increase water surface elevations to enhance connectivity of a backwater on the western floodplain at the 2-yr flow and below. The backwater becomes a floodplain channel at higher flows.
Bank attached habitat structures to increase channel complexity in a uniform stretch of river.
13.5
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Existing Inundation Extent (2-yr Flow)
Design depth (ft; 2-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet


River Mile 14.5 to 13.5
Moderate process-based restoration with helicopter and engineered wood
14.5
Structure on apex of bank attached bar to pull more water through the side channel on the eastern floodplain. Care should be taken at this location to prevent potentially unwanted impacts on state owned land on the western
Currently there is a large natural jam that spans the western split flow channel and a portion of the east split flow channel.
Enhanced habitat on the island along uniform bar. Wood will also provided increased velocities along eastern bank and is supplemental to the existing engineered wood.
Structure on west bank to provide habitat structure and help push flow across island surface to enhance geomorphic process.
Wood loading in depositional zone to a create flow complexity and geomorphic process in a relatively wide floodplain area.
Bank structure to promote raised water surface elevations on the upstream side and create enhanced connectivity of the western floodplain.
14
Wood loading in existing side channel.
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Design Inundation Extent (10-yr)
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s)
Design minus existing
< -3
-1 to -3
-0.25 to -1
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
500
1,000 US Feet

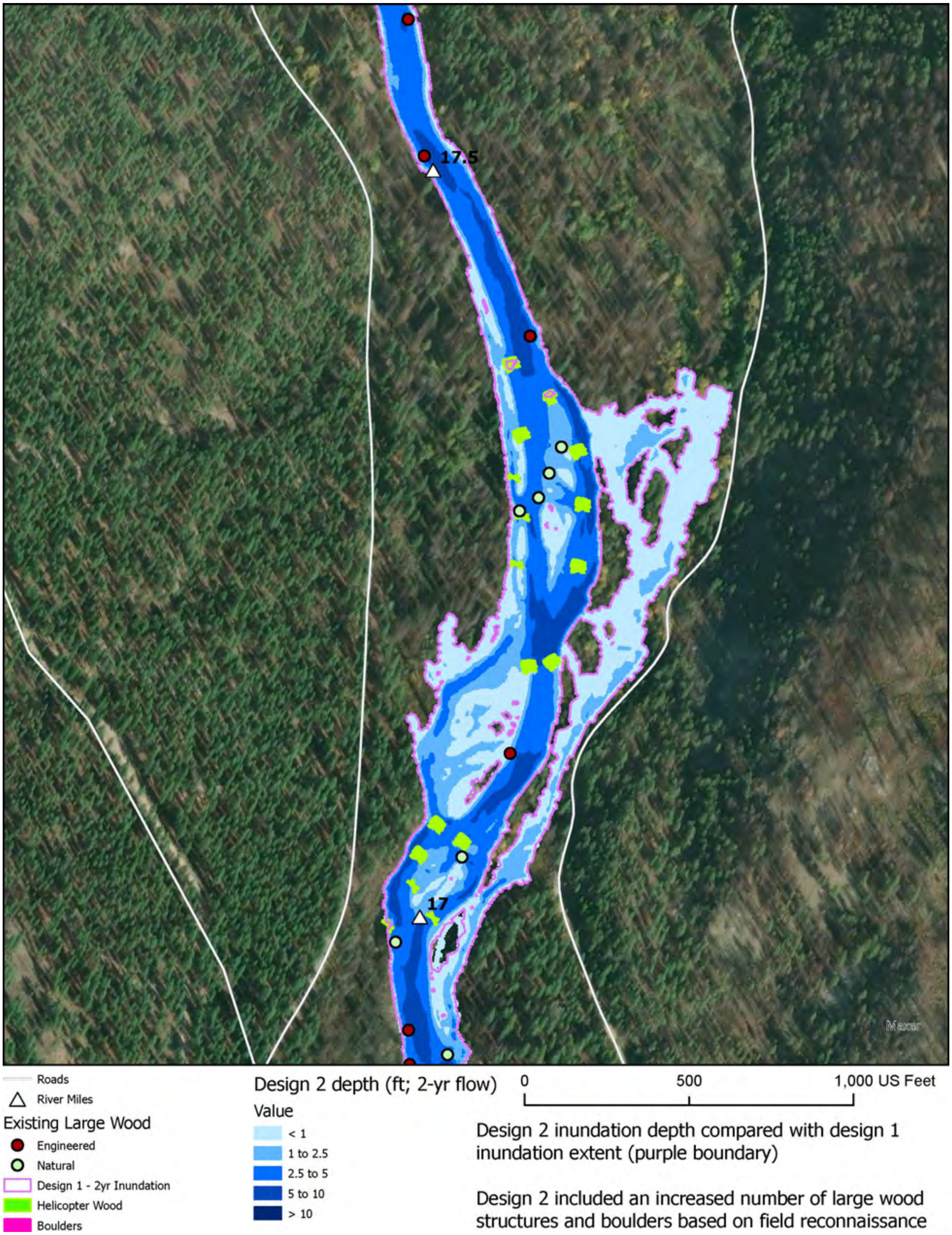

River Mile 14.5 to 13.5
Moderate process-based restoration with helicopter and engineered wood
Wood loading in existing side channel.
Wood structure placed at apex of existing vegetated bar to increase wood loading on the bar and promote divergent flow paths around the structure.
Largest wood structure placed at the bottom of the reach to promote wood racking and provide structure. The wood structure is also placed to increase water surface elevations to enhance connectivity of a backwater on the western floodplain at the 2-yr flow and below. The backwater becomes a floodplain channel at higher flows.
Bank attached habitat structures to increase channel complexity in a uniform stretch of river.
13.5
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Design Inundation Extent (10-yr)
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s)
Design minus existing
< -3
-1 to -3
-0.25 to -1
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
500
1,000 US Feet


River Mile 10 to 9.5
Static Habitat Features
10
Apex jam at the head of a bar to enhance flow split.
Bank attached wood structures to provide cover in the half-mile reach. Although depositional bars exist upstream of Boulder Creek confluence, there is relatively little wood.
Stream power increases greatly leading up to and downstream of the Boulder Creek confluence.
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Existing Inundation Extent (2-yr Flow)
Design depth (ft; 2-yr flow)
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet


River Mile 10 to 9.5
Static Habitat Features
10
Apex jam at the head of a bar to enhance flow split.
Bank attached wood structures to provide cover in the half-mile reach. Although depositional bars exist upstream of Boulder Creek confluence, there is relatively little wood.
Stream power increases greatly leading up to and downstream of the Boulder Creek confluence.
Maxar, Microsoft
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design Concept Wood
Design Inundation Extent (10-yr)
Existing Inundation Extent (10-yr)
Velocity Difference (ft/s)
Design minus existing
< -3
-1 to -3
-0.25 to -1
-0.25 to 0.25
0.25 to 1
1 to 3
> 3
0
500
1,000 US Feet

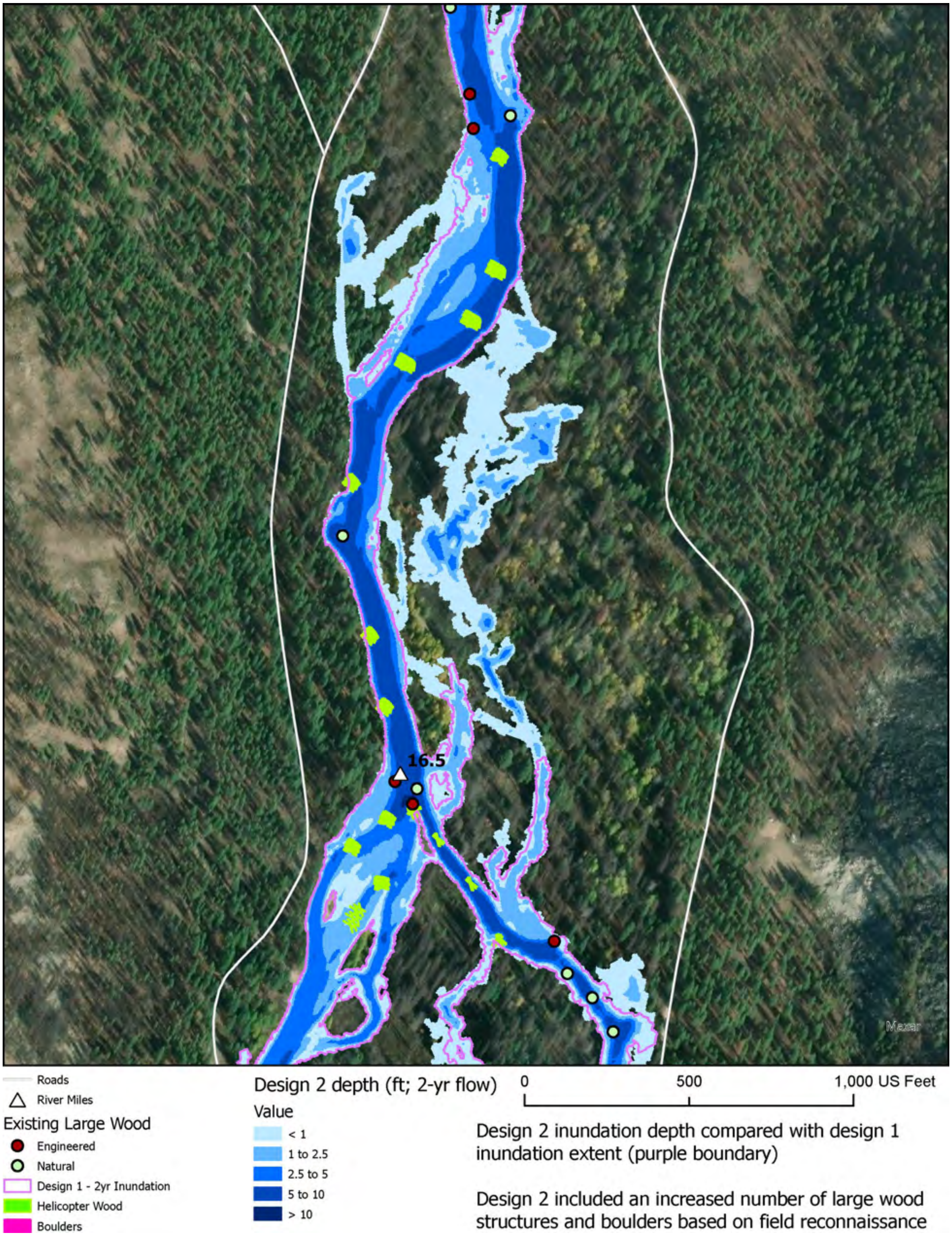
Appendix F

Design Concept 2 and Model Results for River Miles 33 to 29



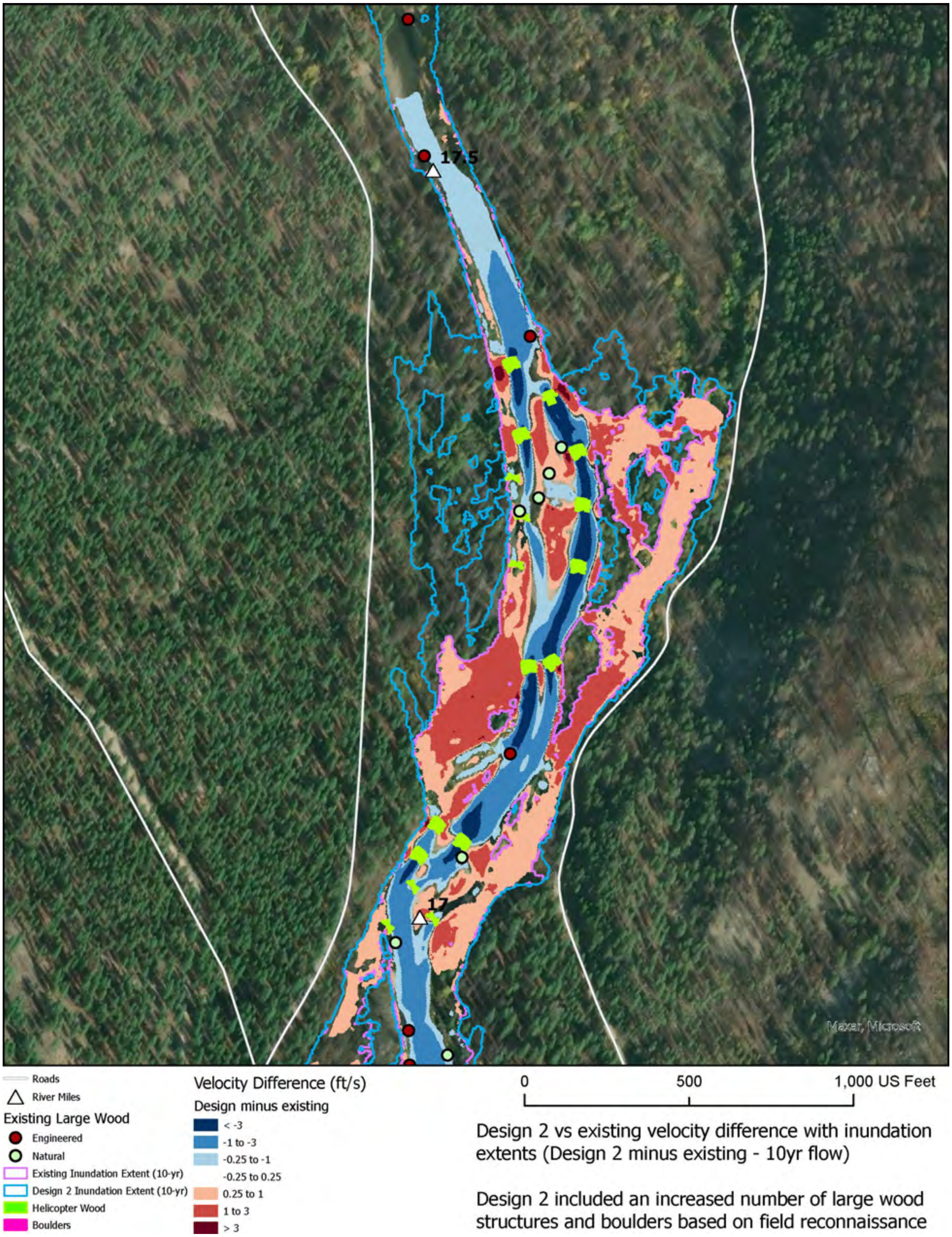
Design 2 inundation depth compared with design 1 inundation extent (purple boundary)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance


16.5
Roads
River Miles
Existing Large Wood
Engineered
Natural
Design 1 - 2yr Inundation
Helicopter Wood
Boulders
Design 2 depth (ft; 2-yr flow)
Value
< 1
1 to 2.5
2.5 to 5
5 to 10
> 10
0
500
1,000 US Feet
Design 2 inundation depth compared with design 1 inundation extent (purple boundary)
Design 2 included an increased number of large wood structures and boulders based on field reconnaissance

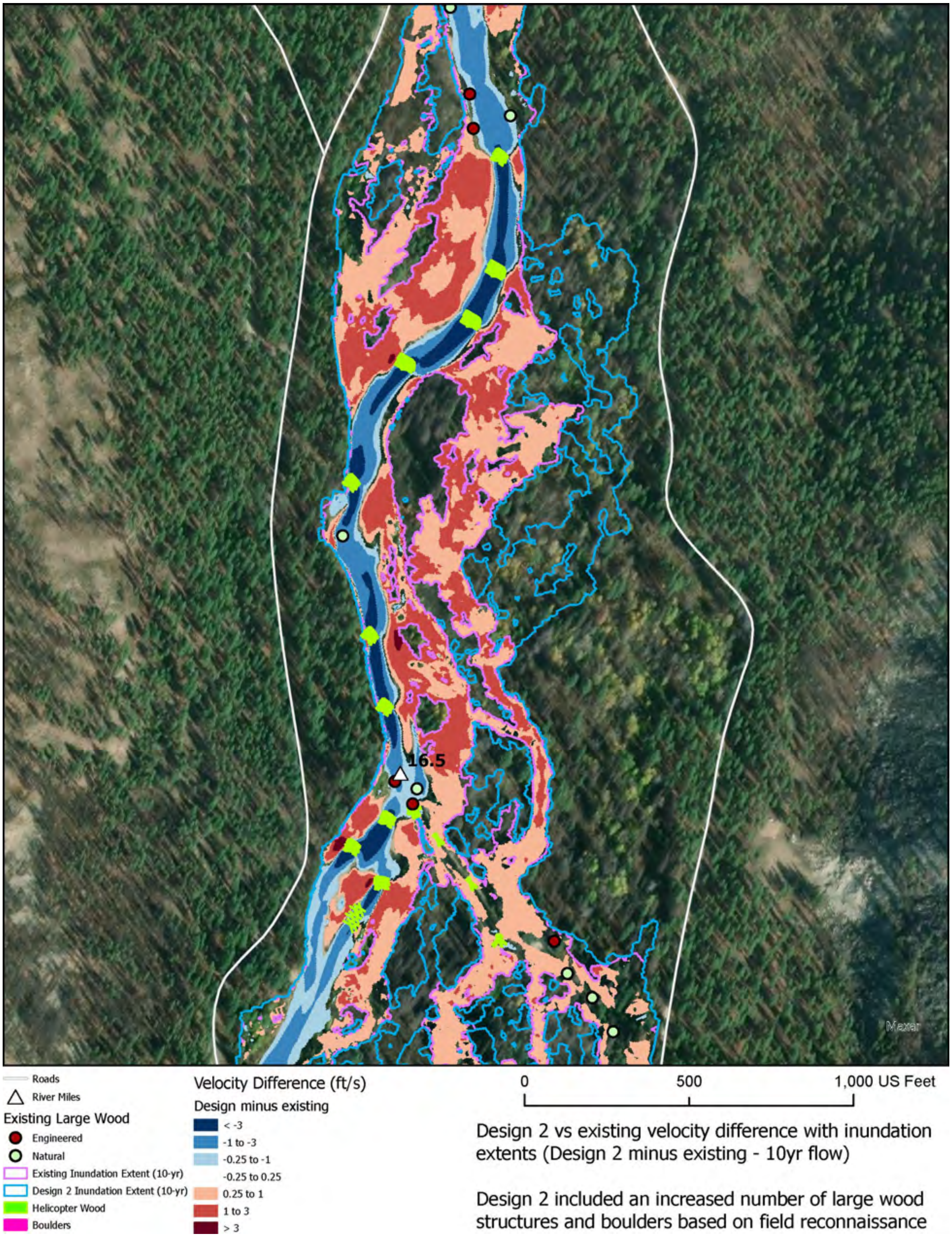
Design 2 inundation depth compared with design 1 inundation extent (purple boundary)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



Design 2 vs existing velocity difference with inundation extents (Design 2 minus existing - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance

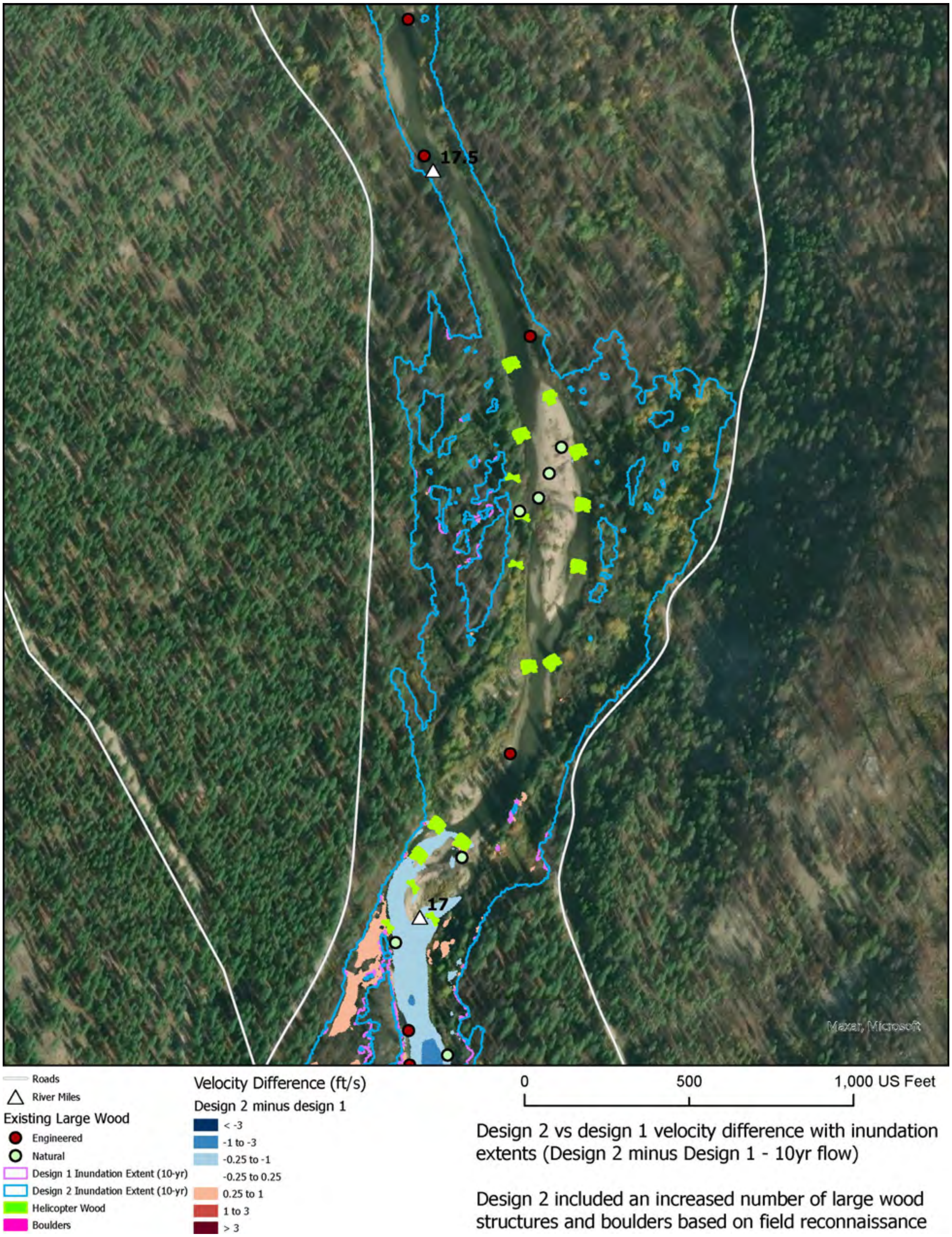


Design 2 vs existing velocity difference with inundation extents (Design 2 minus existing - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance

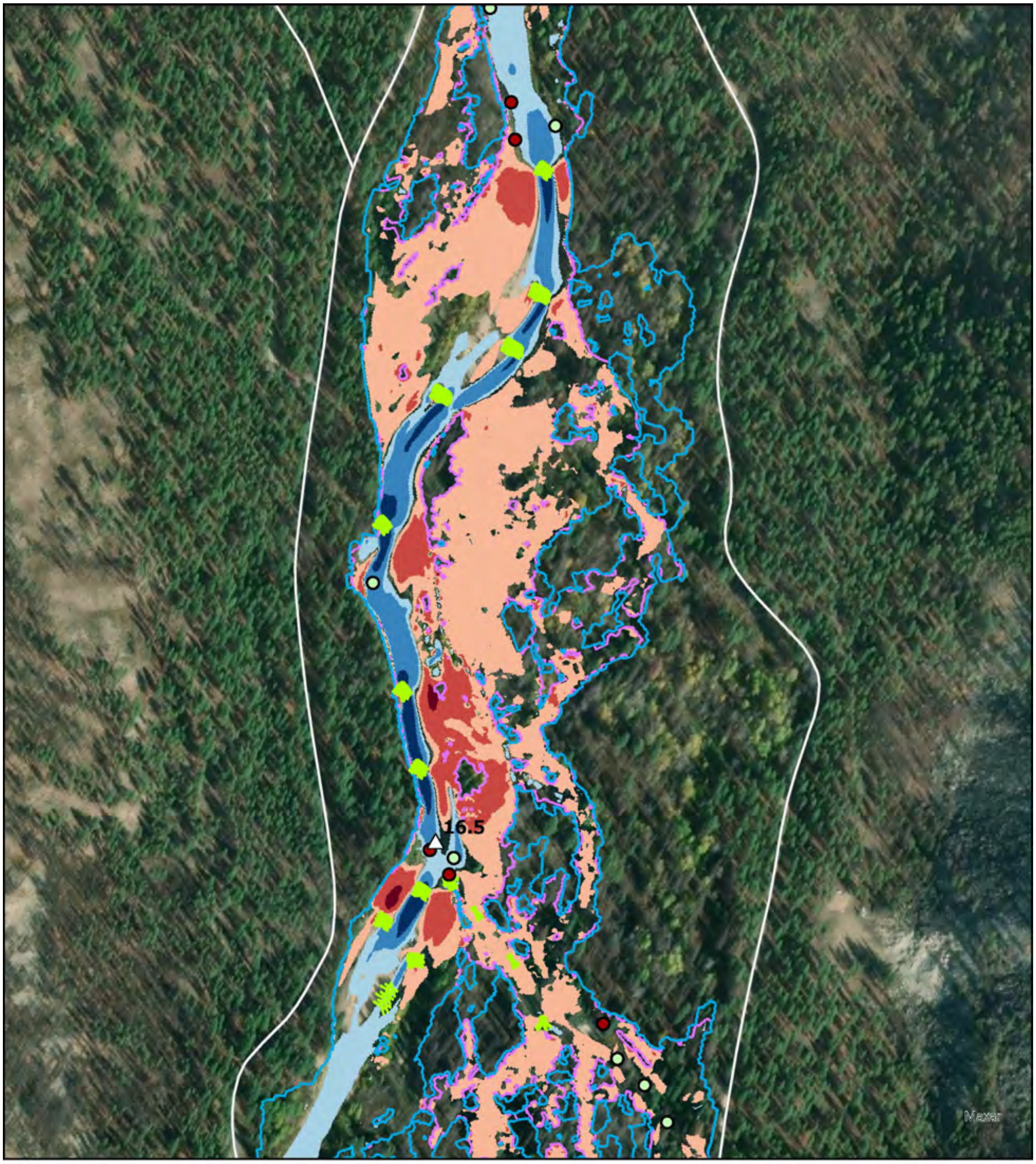
Design 2 vs existing velocity difference with inundation extents (Design 2 minus existing - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



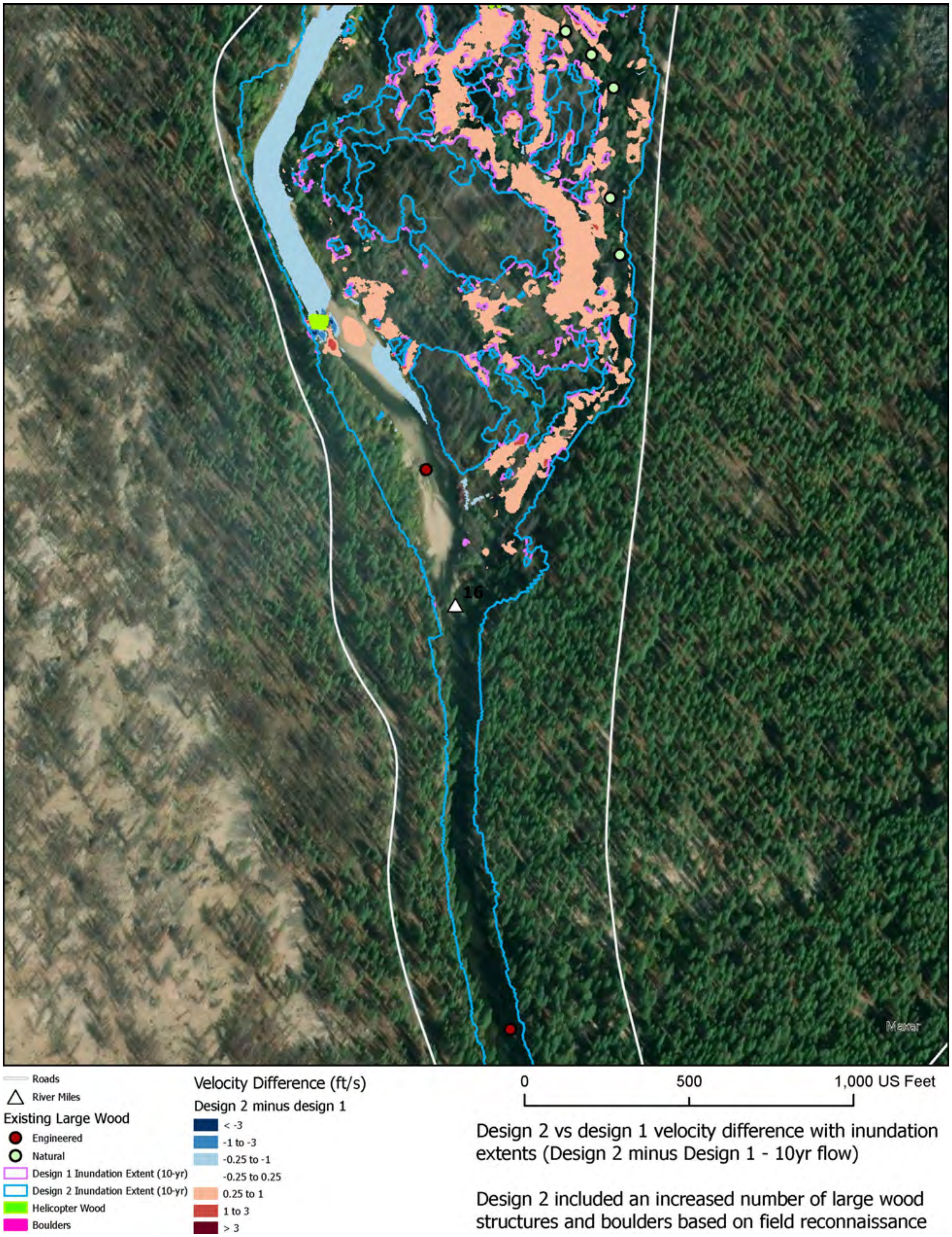
Design 2 vs design 1 velocity difference with inundation extents (Design 2 minus Design 1 - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



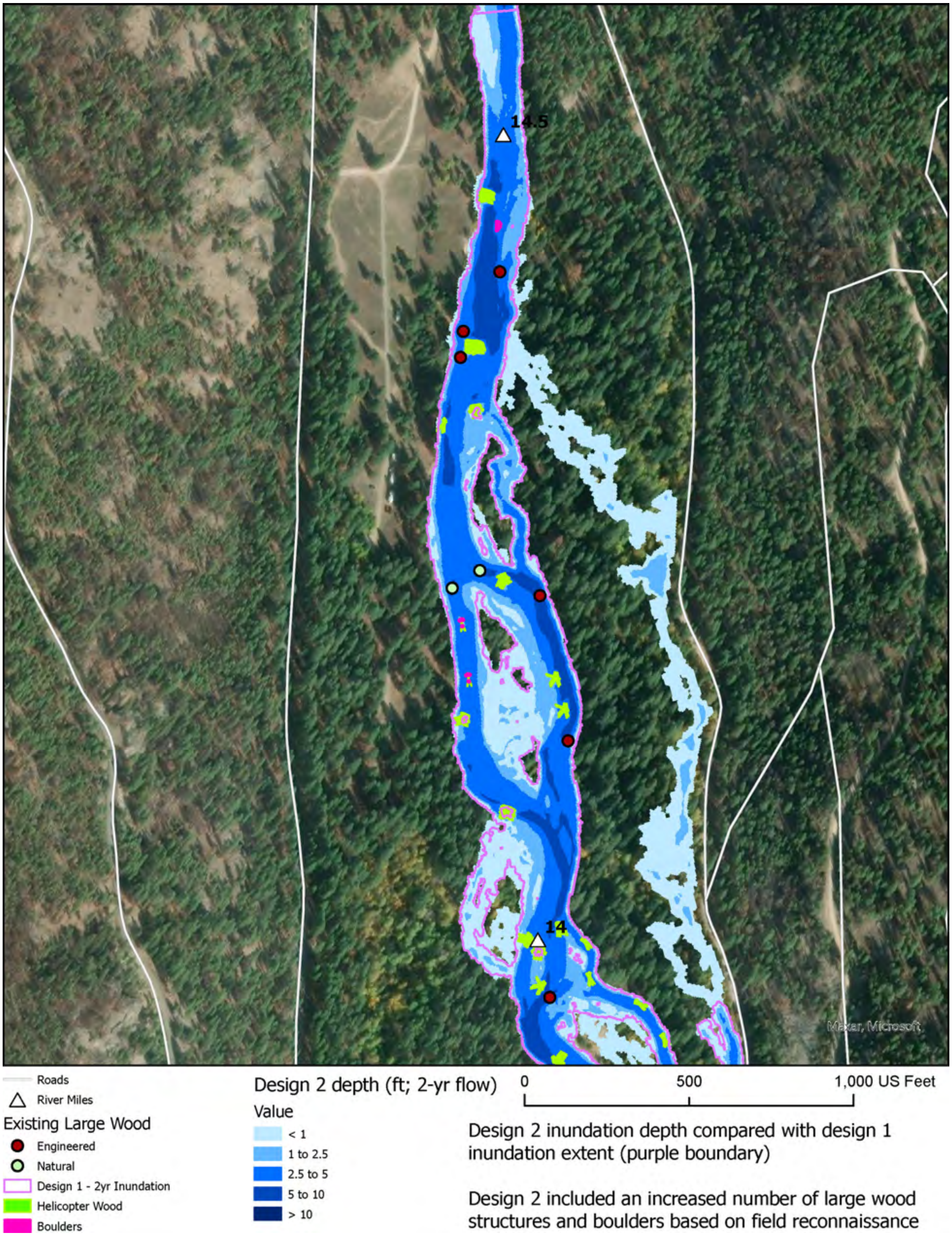
Design 2 vs design 1 velocity difference with inundation extents (Design 2 minus Design 1 - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



Design 2 vs design 1 velocity difference with inundation extents (Design 2 minus Design 1 - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance

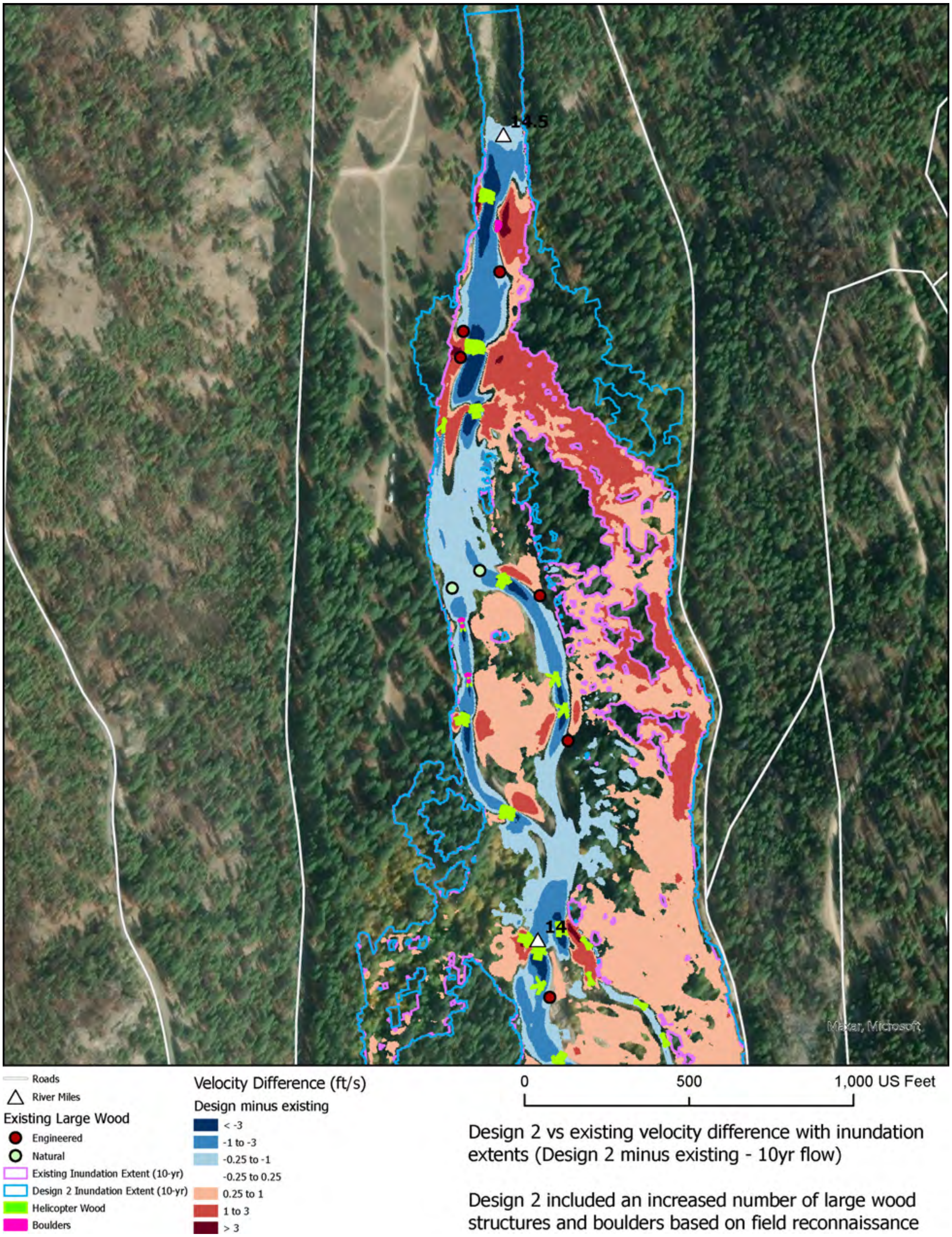


Design 2 inundation depth compared with design 1 inundation extent (purple boundary)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance

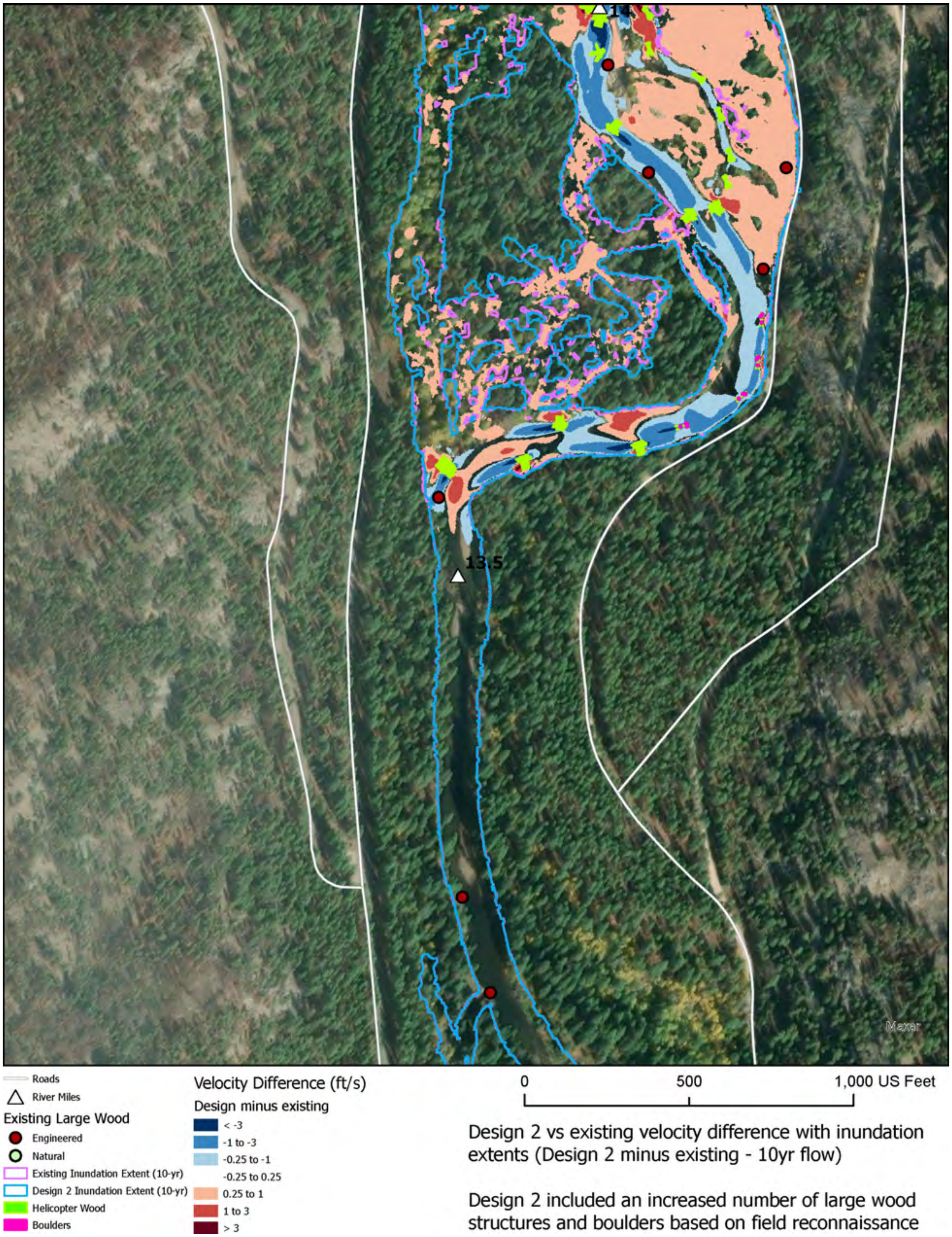
Design 2 inundation depth compared with design 1 inundation extent (purple boundary)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



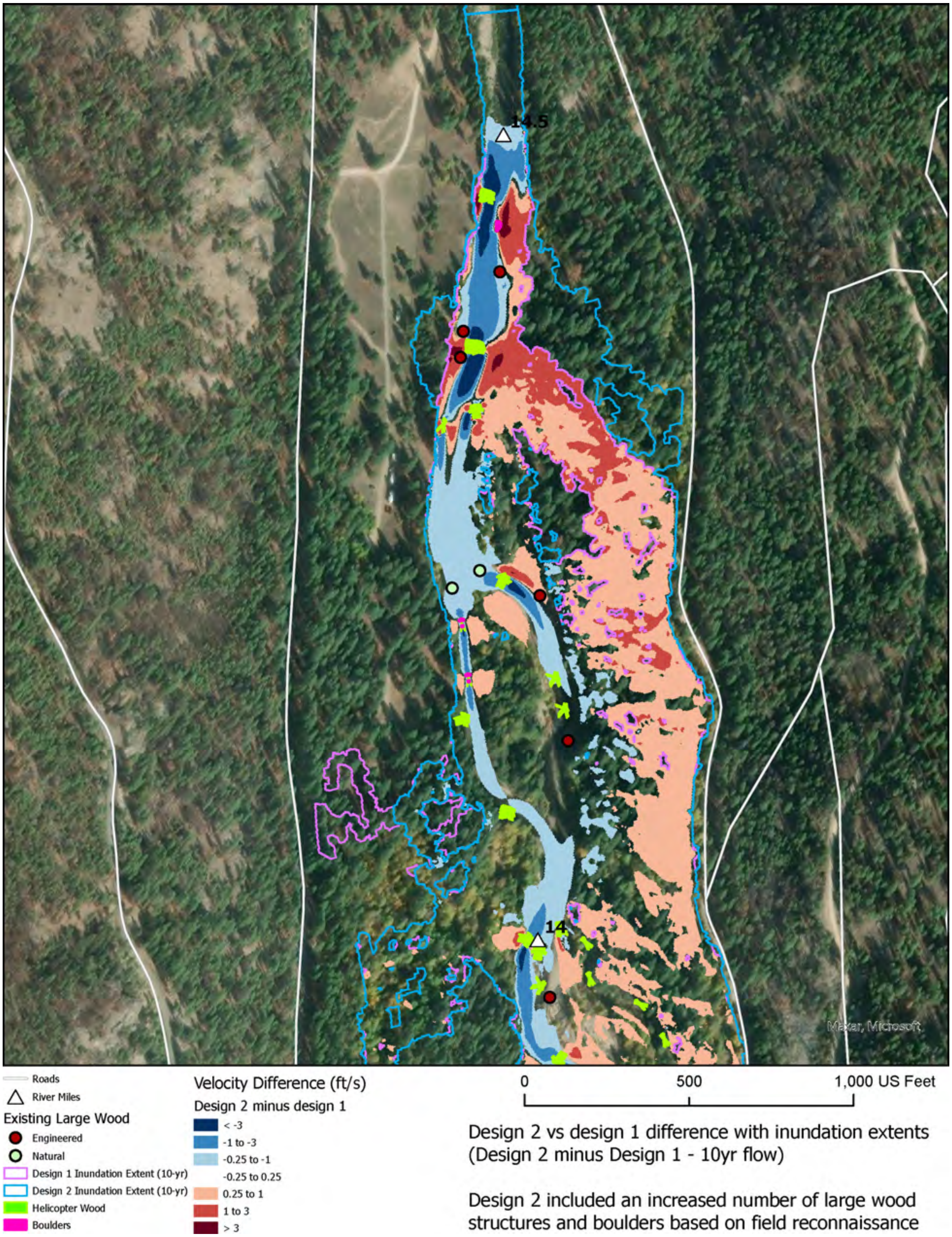
Design 2 vs existing velocity difference with inundation extents (Design 2 minus existing - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



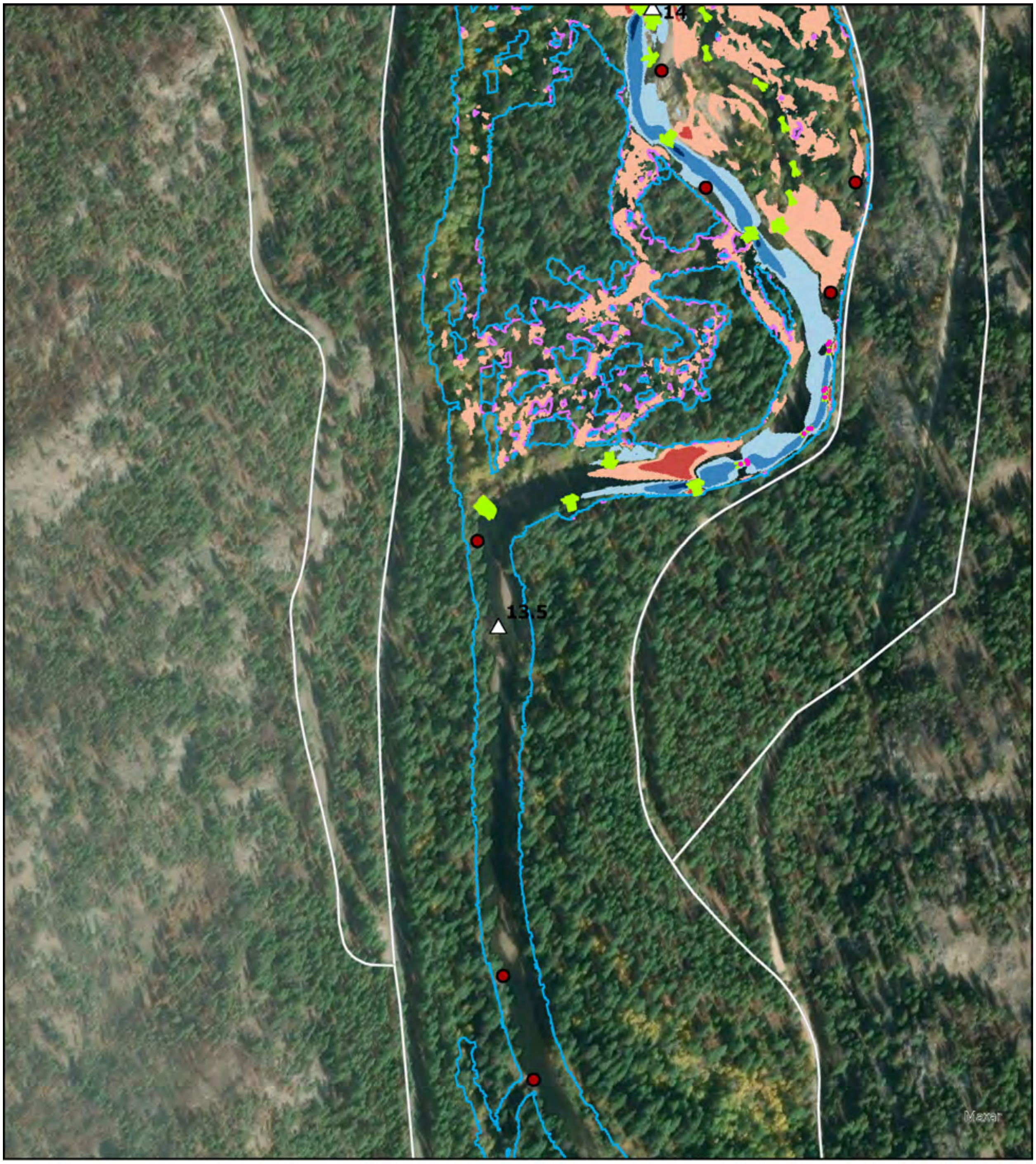
Design 2 vs existing velocity difference with inundation extents (Design 2 minus existing - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



Design 2 vs design 1 difference with inundation extents (Design 2 minus Design 1 - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance

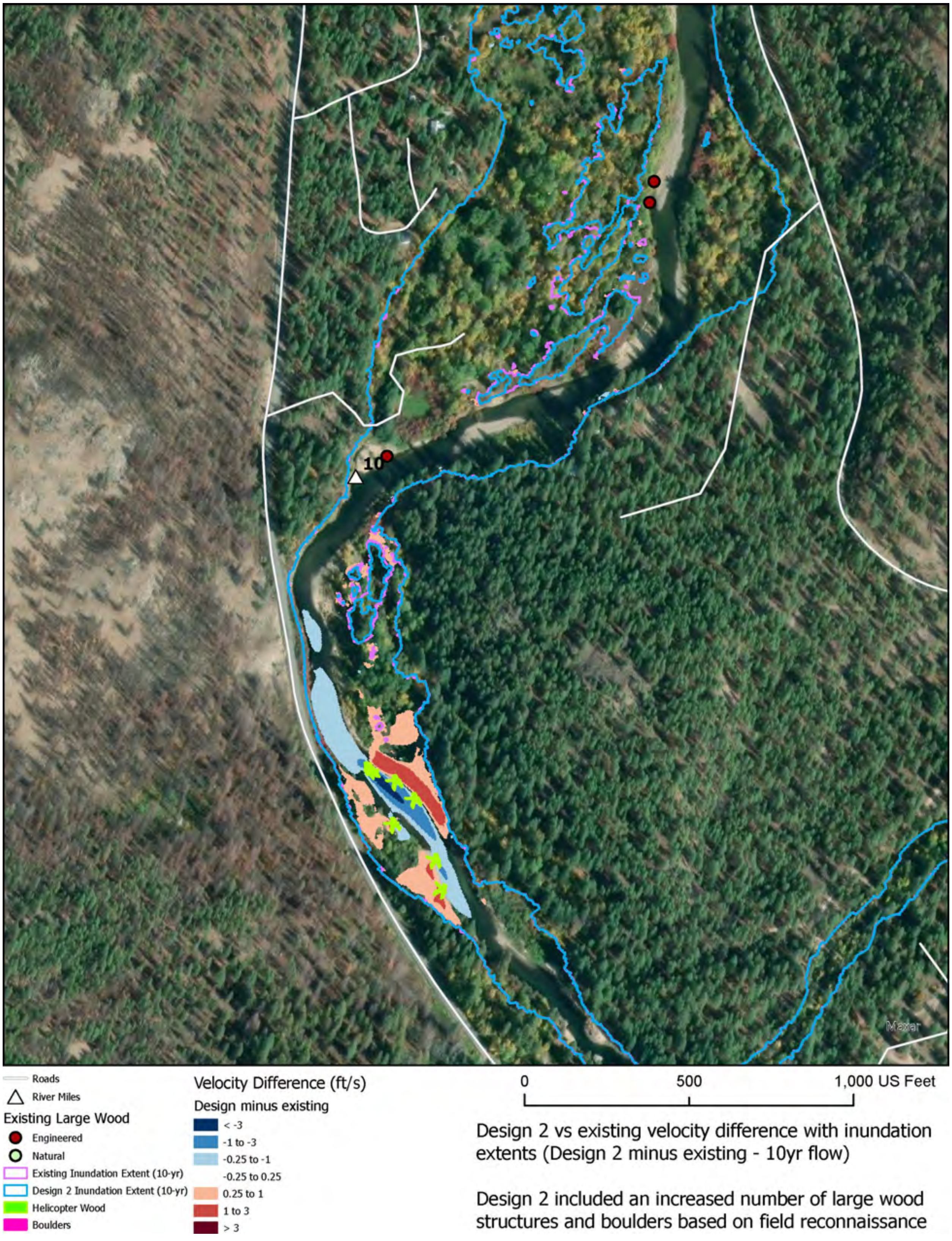


Design 2 vs design 1 difference with inundation extents (Design 2 minus Design 1 - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance

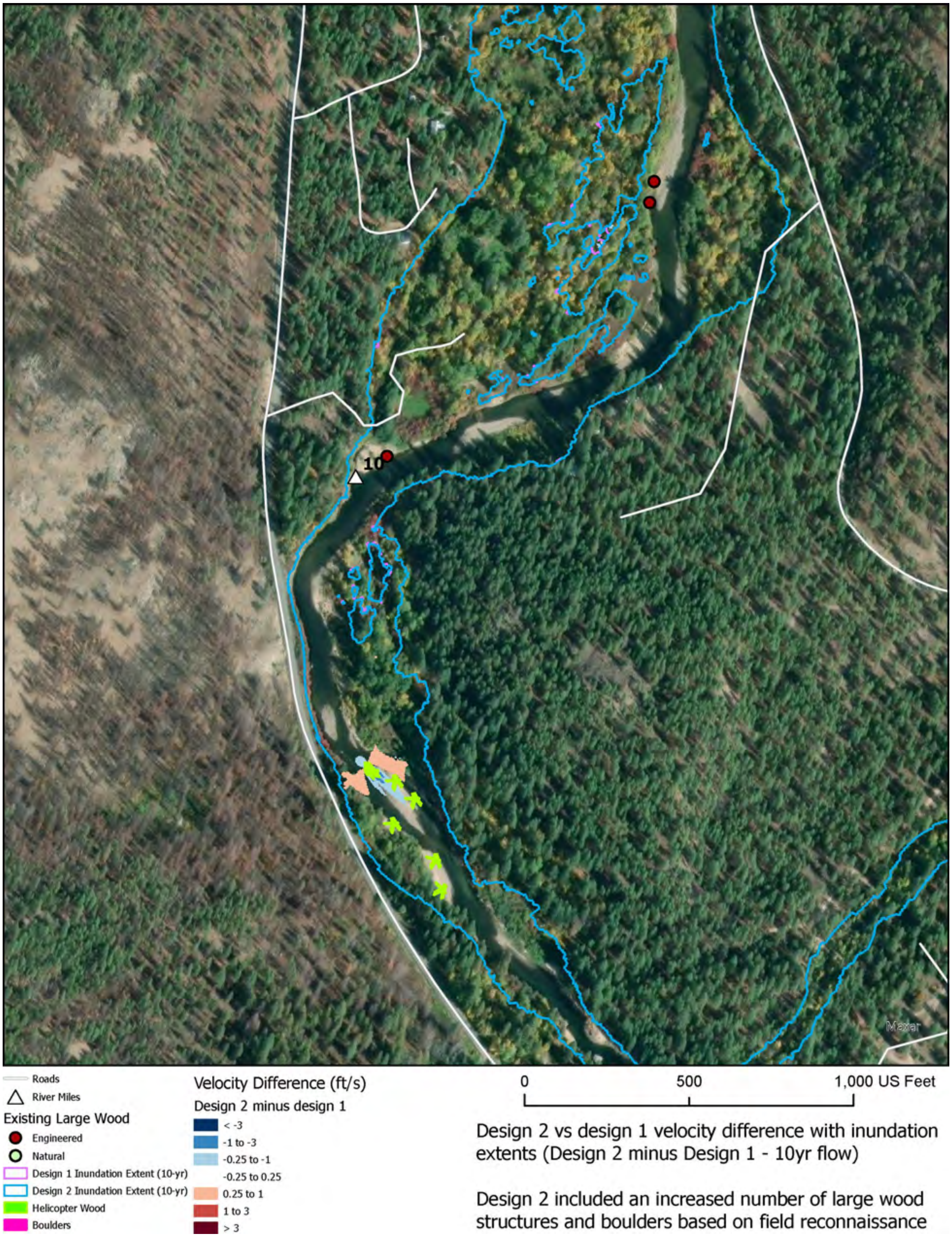
Design 2 inundation depth compared with design 1 inundation extent (purple boundary)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



Design 2 vs existing velocity difference with inundation extents (Design 2 minus existing - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance



Design 2 vs design 1 velocity difference with inundation extents (Design 2 minus Design 1 - 10yr flow)

Design 2 included an increased number of large wood structures and boulders based on field reconnaissance