Technical Report No. ENV-2025-020

Chewuch River Reach Assessment – Geomorphology and Hydraulics

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

U.S. Department of the Interior September 2025

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

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Prepared by:

Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Columbia-Pacific Northwest Region

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Peer Review Certification

This section has been reviewed and is believed to be in accordance with the service agreement and standards of the profession.

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Acronyms and Abbreviations

2D	two-dimensional
CI	confidence interval
DEM	digital elevation model
FS	Forest Service
ft	feet
ft^3/s	cubic feet per second
GIS	Geographic Information System
HAWS	height above water surface
IDW	inverse distance weighted
LW	large wood
mi^2	square mile(s)
MSRF	Methow Salmon Recovery Foundation
NAIP	National Agriculture Imagery Program
Reclamation	Bureau of Reclamation
RA	reach assessment
REM	relative elevation model
RM	river mile
SMS	Surface-water Modeling System
SRH	Sedimentation and River Hydraulics
TSC	Technical Service Center
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
yr	year

Symbols

ρ	density of water
d	depth of water
g	gravitational constant
%	percent
S	slope of river
ω	unit stream power
V	velocity of water

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1.0 Introduction

1.1 Background

The Bureau of Reclamation's (Reclamation) Technical Service Center (TSC) was tasked with informing the geomorphic and hydraulic characteristics of the Chewuch River in support of Methow Salmon Recovery Foundation's (MSRF) reach assessment (RA). The focus of the RA was the lower twenty river miles (RMs), or from the Chewuch River confluence with Twentymile Creek to the confluence of the Chewuch River with the larger Methow River (figure 1). As part of this effort, the TSC completed the following tasks: 1) a geomorphic assessment of current and historical river conditions, 2) hydrologic assessment for hydraulic modeling input, 3) hydraulic modeling of existing conditions, and 4) a large wood risk assessment for RM 20 to 0. This report documents those efforts and also details the existing and historical river conditions for 17 prioritization reaches along the river: 6 Doe reaches and 11 Pearrygin reaches (section 9.0). The Doe and Pearrygin reaches are upstream and downstream, respectively, of Eightmile Creek (at approximately RM 12; figure 1). These reaches were defined as part of a Columbia River Basin assessment (UCRTT 2021). The breaks between reaches are often based on geomorphic characteristics, distances downstream, or two dam locations within the reach (Chewuch Dam at RM 8.6 and Fulton Dam at RM 1.1).

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 upper portion of the basin near RM 30 (USDA 2001). This fire removed most of the evergreen (Lodgepole pine, spruce, and Douglas fir) 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 in 2021, affecting the RM 20 to 0 reach (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 River.

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) on the Methow River (Beck 1973). The largest flood of record in the Methow basin occurred in 1948 at the Pateros, WA, U.S. 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.

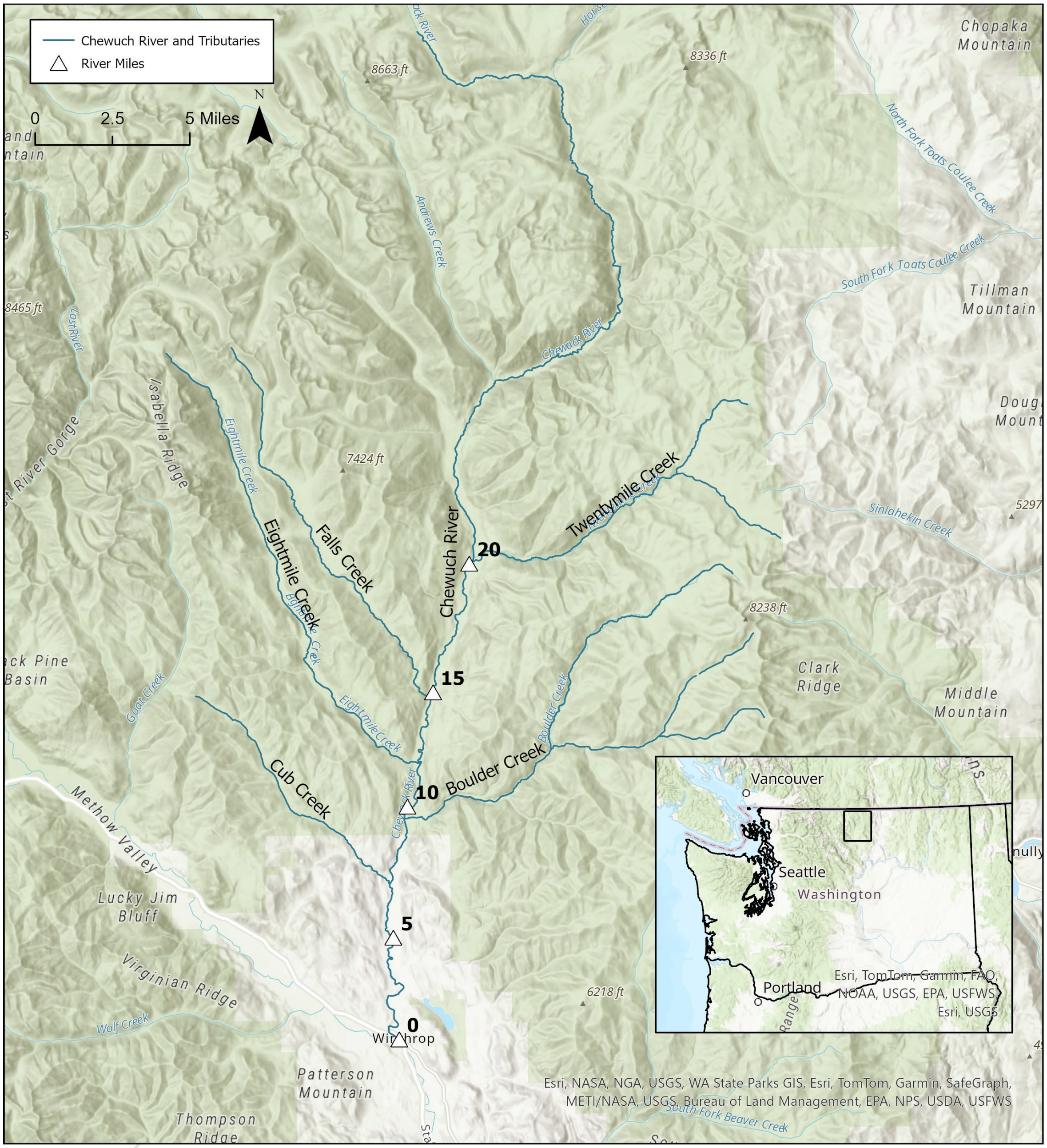

Figure 1.—Overview of the Chewuch River. RM 0 is at the confluence with the Methow River and river miles increase in the upstream direction.

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 U.S. 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). Besides the predicted flow, 5 percent (%) and 95% flows are also predicted to depict the bounds of uncertainty associated with peak flow calculation. The predicted flows in table 1 were used for modeling within this study. 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% CI Flow (ft^3/s)	95.0% CI 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
0.667	1.5	3087	2516	3716
0.5	2	3977	3308	4720
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
August Mean	126
March Mean	142
July Mean	412
April Mean	596

2.2 River Mile 20 to 0 Modeled Hydrology

Because the gage is located at approximately RM 0 and several significant tributaries are located between RM 20 and 0, flows at RM 20 and at each significant tributary from RM 20 to 0 were weighted by drainage area to calculate an approximate recurrence interval flow. Five tributaries between RM 20 to 0, in addition to the mainstem Chewuch River upstream of RM 20, were identified as significant: Twentymile Creek, Falls Creek, Eightmile Creek (at approximately RM 11.8), Boulder Creek, and Cub Creek (figure 1). Drainage areas of the Chewuch River and major tributaries are shown in table 3. Contributing areas of minor drainages also needed to be included to sum to the appropriate total Chewuch River drainage area (524 square miles [mi^2]) at the confluence with the Methow River (table 3). Table 4 shows the area-weighted flows for these creeks derived from the Chewuch River gage. Table 4 also shows the accumulation of area-weighted flows to the USGS gage total.

Table 3.—Contributing areas of the Chewuch River, major tributaries, minor tributaries, and accumulated totals for each reach

Drainage Basin	Approximate River Mile	Contributing Area of Specific Drainage (mi^2)	Contributing Area of Minor Drainages From Tributary to Next Confluence (mi^2)	Total Contributing Area in Reach Downstream From Tributary to Next Confluence (mi^2)
Chewuch River upstream of Twentymile Creek confluence	20.3	241	--	241
Twentymile Creek	20.3	42	18	301
Falls Creek	14.8	27	6	334
Eightmile Creek	11.8	47	2	383
Boulder Creek	9.5	81	11	475
Cub Creek	7.1	24	25	524

Table 4.—Area-weighted contributing flows in the mainstem Chewuch River and select 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
Sept Mean	36	9	5	7	14	7	79
August Mean	58	14	8	12	22	12	126
March Mean	65	16	9	13	25	13	142
July Mean	189	47	26	39	72	39	412
April Mean	274	68	38	56	105	56	596
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

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)
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 green bathymetric 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 red terrestrial lidar (above water only) from 2018 (figure 2) (Atlantic 2018). Bathymetric returns were highly successful from RM 20 to 0. However, not all inundated side channel or water body bathymetry was appropriately mapped due to the limited floodplain coverage in the 2022 lidar. Some inundated side channel bottoms that exist between RM 20 to 0 were not mapped appropriately in the 2018 dataset since it was only terrestrial lidar. Therefore, to more accurately depict those side channel conditions, side channel bottoms were lowered by either interpolating from information available in the 2022 lidar or from other information such as design drawings of restoration projects (figure 2).

Several locations were lowered using the methodology described above and are depicted in figure 2. Between RM 16.5 and 16, the larger, western channel was captured by bathymetric lidar, but a previously existing side channel that has become the low flow channel through this reach was not. The side channel bottom was linearly interpolated from upstream and downstream elevations where the side channel crossed back into the 2022 bathymetric lidar. Downstream from Boulder Creek at approximately RM 9 an existing side channel not captured in the bathymetric lidar was lowered using the difference in elevation between the 2018 and 2022 lidar where the two datasets overlapped. The same approach was used at approximately RM 7, where both the channel of Cub Creek and a pond on the east side of the river were poorly represented by terrestrial lidar. A restored side channel at approximately RM 5 was lowered using design drawings from the restoration project. Finally, a pond on the floodplain near RM 3 was lowered using the difference in elevation between the 2018 and 2022 lidar at the intersection of those two datasets to allow for inundation depths to be more accurate at higher flows.

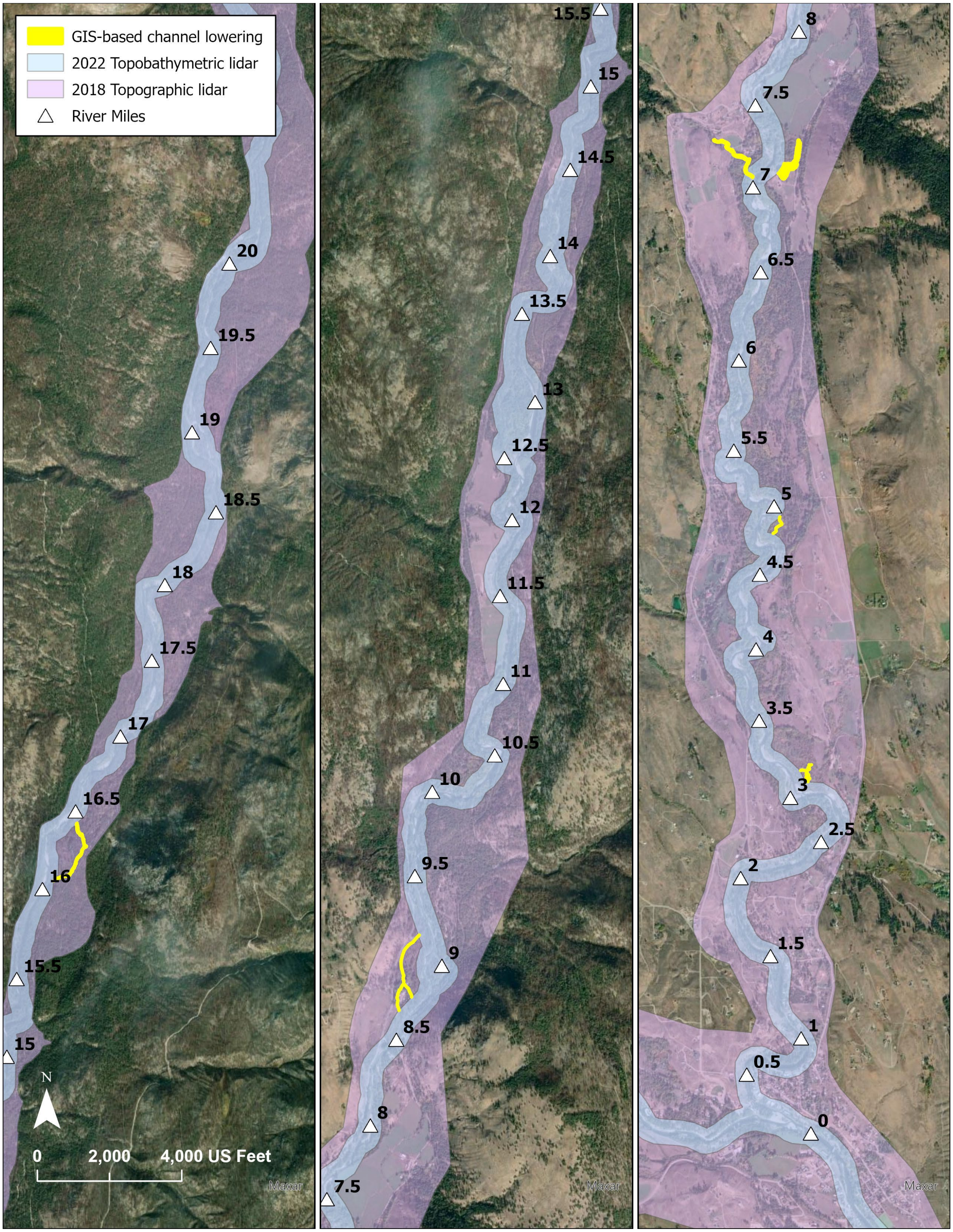

Figure 2.—Lidar and side channel lowering extents between RM 20 and 0.

4.0 Numerical Modeling Methodology

Reclamation's Sedimentation and River Hydraulics Two-Dimensional (2D) 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 2D hydraulics for a range of flow conditions and existing topobathymetric surfaces.

4.1 Models and Meshes

Three overlapping models were developed extending from approximately RM 20 to 15, RM 15 to 9, and RM 9 to 0. Model results were then stitched together to create a seamless prediction of existing conditions between the Chewuch River confluence with the Methow River at the downstream extent and the Chewuch River confluence with Twentymile Creek at the upstream extent. Modeled terrain was interpolated to the mesh from the topographic surfaces described in 3.0 Topographic Surface Development. The three models used an average channel element size of approximately 32 square feet and expanded to approximately 400 square feet at the outer floodplain margins.

4.2 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 from 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 three models are detailed in table 5. Channel roughness was decreased linearly from low flows (September mean) to the 2-year flow discharge from values of 0.045 to 0.03, respectively. This method was found to be helpful in nearby modeling on the Methow River (Reclamation 2019; Reclamation 2024).

Table 5.—Land cover type and associated Manning's roughness n-values for river miles 20 to 0

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

4.3 Model Boundary Conditions

Model boundaries were placed at locations upstream and downstream from 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.

The individual RM 20 to 15, RM 15 to 9, and RM 9 to 0 models were developed to overlap about 0.5 miles. Within overlapping areas, upstream and downstream boundary effects were examined by subtracting overlapping modeled depth results and looking for differences between the two models. Portions of the models where boundary effects propagated upstream or downstream and were not equal to the other model were removed. 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 approximately 0.6 miles downstream 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 the hydrology section of this report (2.0). We focused on the September mean, July mean, 2-yr, and 10-yr flows (table 4). The RM 20 to 15 models included an upstream Chewuch River inflow 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.

4.4 Model Performance and Limitations

Modeling for existing conditions 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. 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 the contribution of flows from tributaries and diversions along RM 20 to 0 and how these contributions accumulate to the USGS Chewuch River gauge.

As discussed in section 3.0, modeling was conducted using the most recent lidar data along each reach of the Chewuch River. The main issue identified in the lidar data was that the 2018 lidar failed to accurately measure bathymetry of side channels. The side channels were adjusted using Geographic Information System (GIS) methodologies. Modeling would be improved by field surveys in these areas.

Large wood (LW) jams and previously engineered LW structures were represented by the 2022 lidar. There is not a perfect way to represent LW within a 2D hydraulic model (Addy and Wilkinson 2019; Sixta and Ubing 2019) because LW structures are porous. Within SRH-2D, there is currently no method in which a computational cell can be represented with a porosity instead of a fully porous or fully obstructed cell. Therefore, elevations from the first return of the lidar hitting the LW jam or structure likely represents the top of the wood and omits any conveyance that may be found under the LW. Roughness was increased for these LW features if the center of the computational cell was within the LW 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.

5.0 Geomorphic Mapping Methods

5.1 Aerial imagery mapping

5.1.1 Imagery Sources

We mapped eight geomorphic features (see section 5.1.2) along the Chewuch River on aerial and satellite imagery datasets using Esri ArcGIS Pro®. Mapping of RM 20 to 0 utilized 7 years of imagery. The sources for the mapping were a combination of historical imagery downloaded from USGS EarthExplorer (1947, 1957, and 1975), historical imagery from a previous mapping effort in the Methow basin (1988; Reclamation 2008), U.S. 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, 1975, 1988, 2006, 2013, and 2023 (table 6).

Table 6.—Aerial imagery years and sources for geomorphic mapping of RM 20-0

Year	Source
1947	USGS EarthExplorer
1957	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. The control points were chosen as easily identifiable points that were visible within both sets of imagery, such as buildings or road bends. Pixels at a distance from the control points are not guaranteed to be accurate.

5.1.2 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, identification as a side channel serves as a higher confidence rating than identification as 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 low-frequency inundation 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 relative elevation model (REM) described below was used to help identify fans and channels in all years.

5.2 Relative Elevation Models

We created an REM for the Chewuch River (figure 3). The 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 generated points along that line that are spaced at approximately the channel width of 50 ft. The ‘Extract Values to Points’ tool is used to extract elevation values from the DEM raster. The IDW (Inverse Distance Weighted) 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. The full REM for the river is included in a supplementary geodatabase.

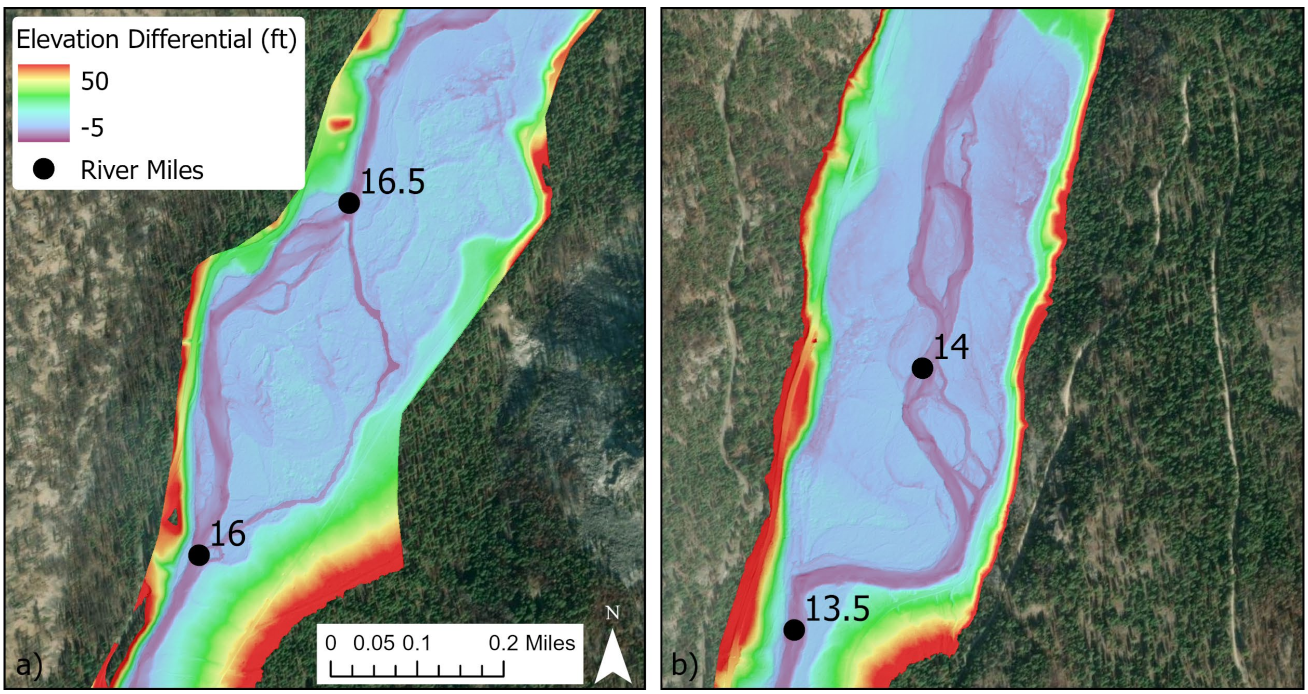

Figure 3.—Example relative elevation models (REMs) along the Chewuch River. Elevations are colored relative to the bed elevation along the channel centerline. Positive values are higher than the elevation of the channel, and negative values are lower. Anywhere with a lower elevation (purple colors) is either already connected to the main channel or would be a low effort to reconnect.

5.3 Height Above Water Surface Models

We created height above water surface (HAWS) models for the Chewuch River to highlight inundation extents and elevations of the land surface relative to the water surface elevation for different magnitude flow events from section 2.0 (Jones 2006). The methodology for this is similar to the REM method, but instead of using the elevations along the centerline extracted from the channel bed, the elevations are extracted from the water surface elevation raster developed from the SRH model output for different flow events. To accurately represent the water surface across the floodplain, a cross-sectional approach was used to extract water surface elevation at the channel and extrapolate that elevation to appropriate lateral locations. Cross-sections were spaced at 250 feet (ft) and the topobathymetric DEM used is the same as that used for the REM. Anywhere that the HAWS model is negative, that indicates an area of the channel or floodplain that would be inundated if it were connected to the main channel. Anywhere that is positive has a higher land elevation than the water surface elevation for that flow. The HAWS maps are included in an associated geodatabase.

5.4 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. Areas where we stepped out of the river are noted below. 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 4). We did not map wood in the field but did note locations of observed beaver dams (figure 5).

Figure 4.—Boulder-sized bed material in the vicinity of River Mile 9 (Reclamation/Aaron Hurst).

Figure 5.—A small beaver dam at a side channel outlet near River Mile 12.5. Photo taken looking upstream (Reclamation/Aaron Hurst).

In the RM 20 to 0 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. These locations are noted in the field mapping shapefile.

We used the field map and notes to validate the 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.

6.0 Chewuch River Hydraulics

As described in section 4.0, two-dimensional hydraulic modeling was conducted for the entire 20-mile Chewuch River assessment area. These models provide estimated flow conditions under existing conditions along the river using the hydrology, modeling methodology, and assumptions described above. Model results were then processed using ArcGIS Pro® and converted to 3-foot rasters of depth, velocity, and water surface elevation. In addition, inundation boundaries of each flow were produced. Examples of depth and velocity outputs are shown in figure 6 for a 1.5-year recurrence interval flow event. Inundation boundaries for select flows are plotted for each of the prioritization reaches described in section 9.0. All post-processed hydraulic model outputs are included in a supplementary geodatabase.

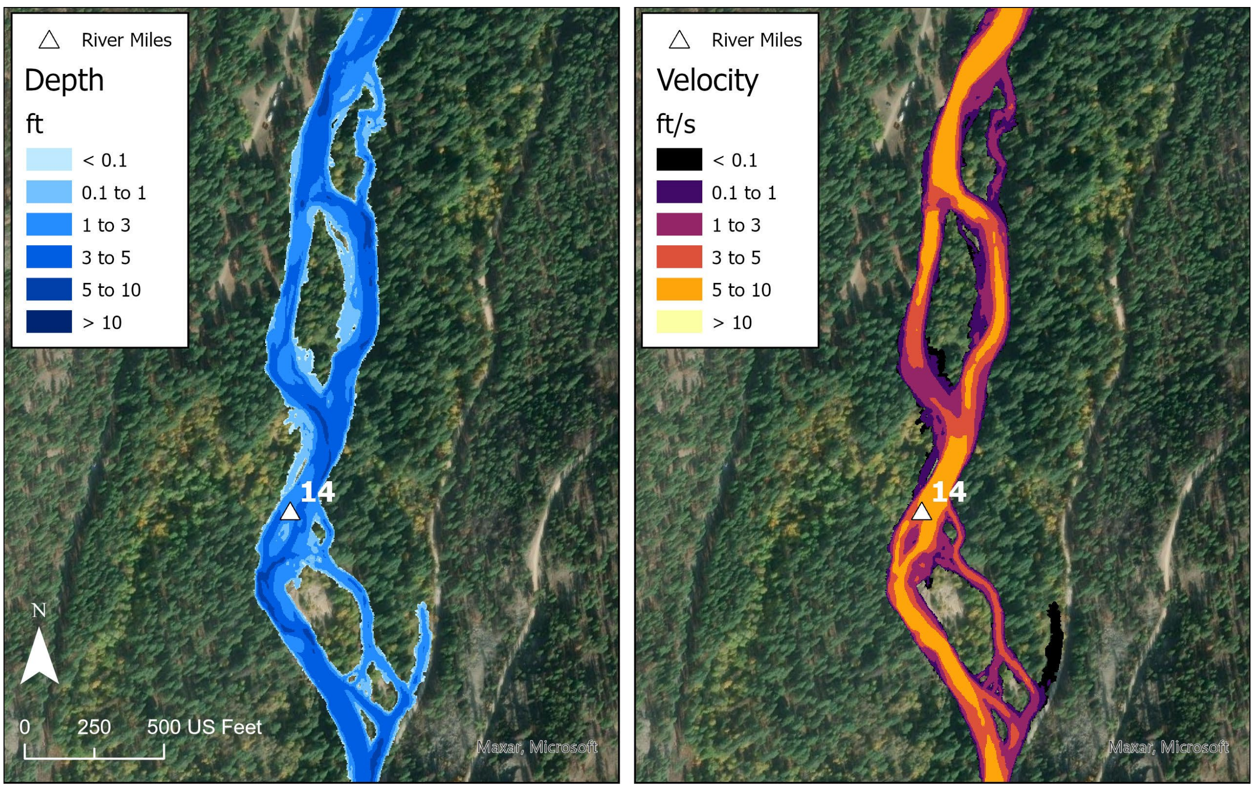

Figure 6.—Example of depth and velocities predicted by hydraulic modeling of the Chewuch River near RM 14. These results are shown for the predicted 1.5-year recurrence interval flow event.

Hydraulic conditions were summarized by calculating the area associated with different depth and velocity combinations at a range of discharges. Different reaches exhibit different patterns of depth and velocity (figure 7 and figure 8), which can have implications for the habitat suitability of the reach under different flow conditions. At low flows, many of the reaches have similar patterns with the largest areas having low depths and velocities in the main channel (figure 7). As flows increase, the differences in reaches become more apparent (figure 8). For example, at the 2-yr recurrence interval event Pearrygin 3 and 4 have large areas of low depth and velocity as they have more connected floodplains and have more widely distributed depth and velocity pairings. In comparison, the Pearrygin 8 reach has a much more narrowly distributed depth and velocity pairings with velocity increasing greatly at relatively low depths at the 2-year recurrence flow. In general, those reaches with more floodplain connectivity have less defined relationships between depth and velocity and more distributed areas across the spectrum of depth and velocity combinations. Reaches with less floodplain connectivity have more narrowly distributed depth and velocity pairings.

Profiles of modeled water surface elevations at selected flows are displayed in figure 9 and figure 10. Low water surface profiles (i.e., mean low and July mean) show smaller hydraulic controls like riffles where flat water surface profiles are repeatedly created by the riverbed. An example of this is within the Pearrygin 3 reach between RMs 3 and 4 (figure 10). Steeper sections of river do not display this same river form nor the impact on longitudinal water surface profiles (e.g., Doe 3 reach; figure 9). Other hydraulic controls can be observed in all flows. Folsom Dam at approximately RM 1.2 creates a backwater at low discharges and creates raised water surface elevations at higher flows as well (figure 10). The hydraulic control of tributaries is most clearly observed at high flows (i.e., 2-year and 10-year flows) where the tributary fans create a flow constriction, which in turn creates higher water surface elevations upstream of the confluence. Boulder Creek provides the best example of this at RM 10 (figure 9).

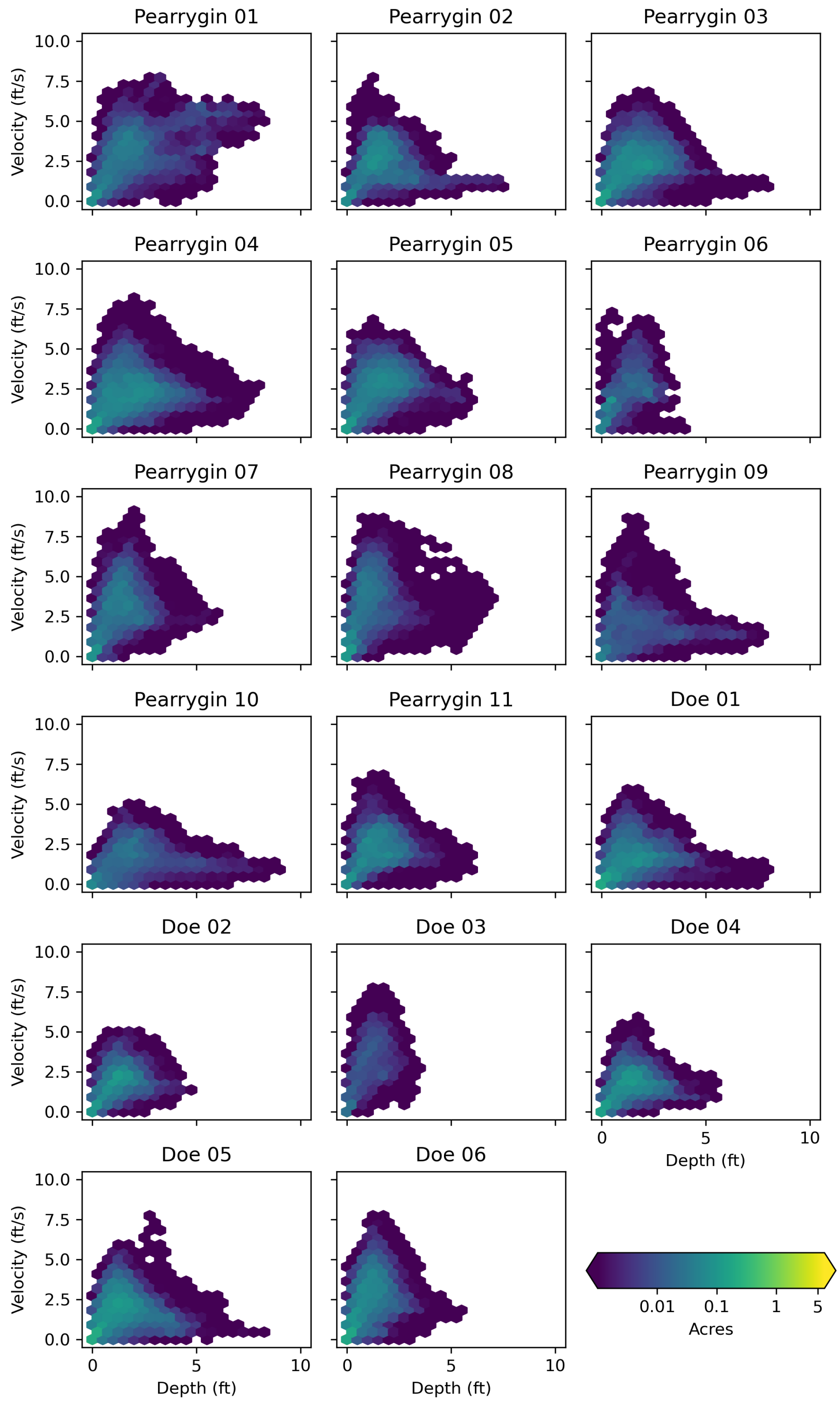

Figure 7.—Total area within reach with given depth and velocity combinations under the July mean flow conditions. Lighter colors indicate more inundated area with the associate width-depth pairing.

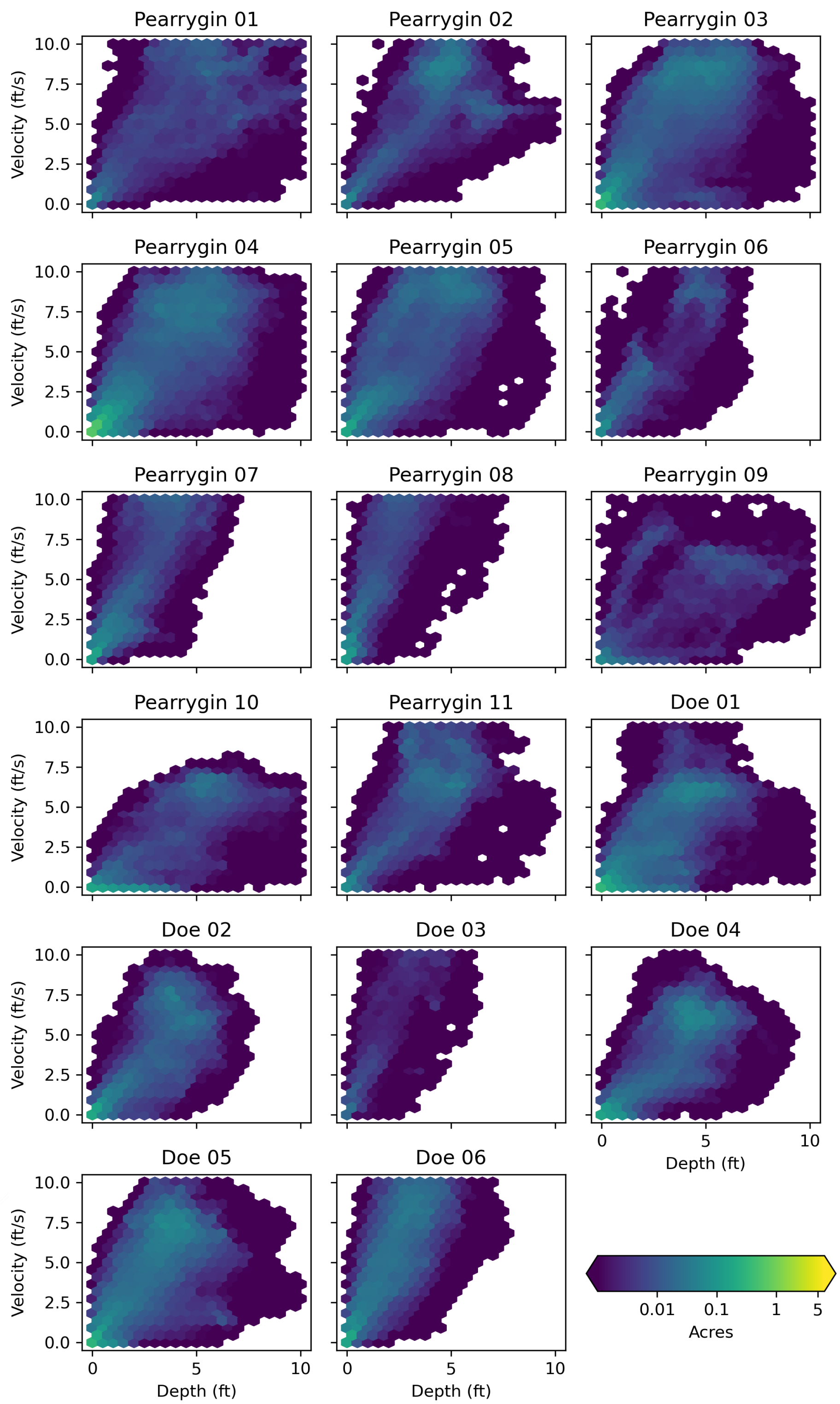

Figure 8.—Total area within reach with given depth and velocity combinations under the 2-year flow conditions. Lighter colors indicate more inundated area with the associate width-depth pairing.

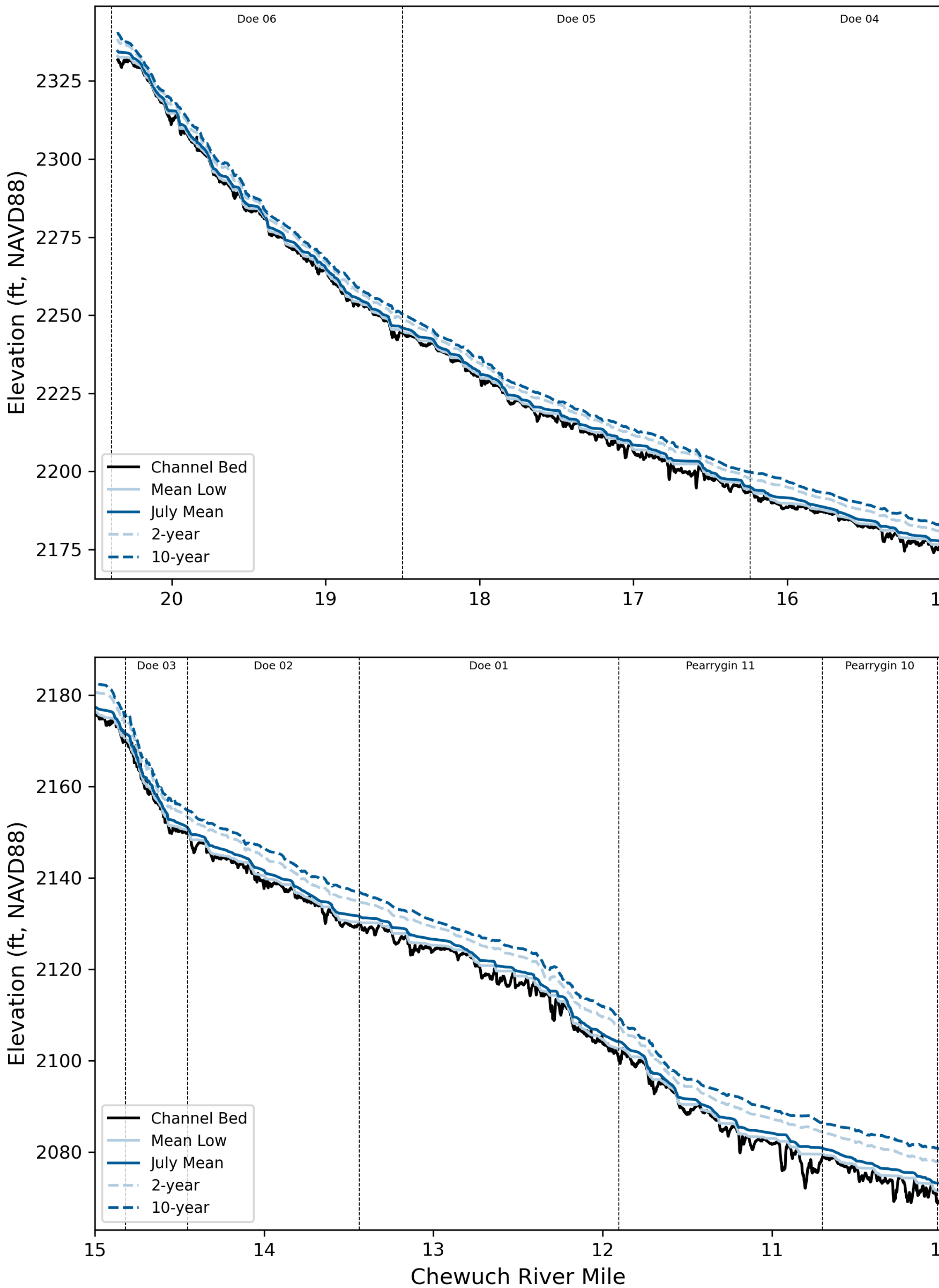

Figure 9.—Longitudinal profile of river bed and water surface elevations for select flows between river miles 20 and 10 along the Chewuch River.

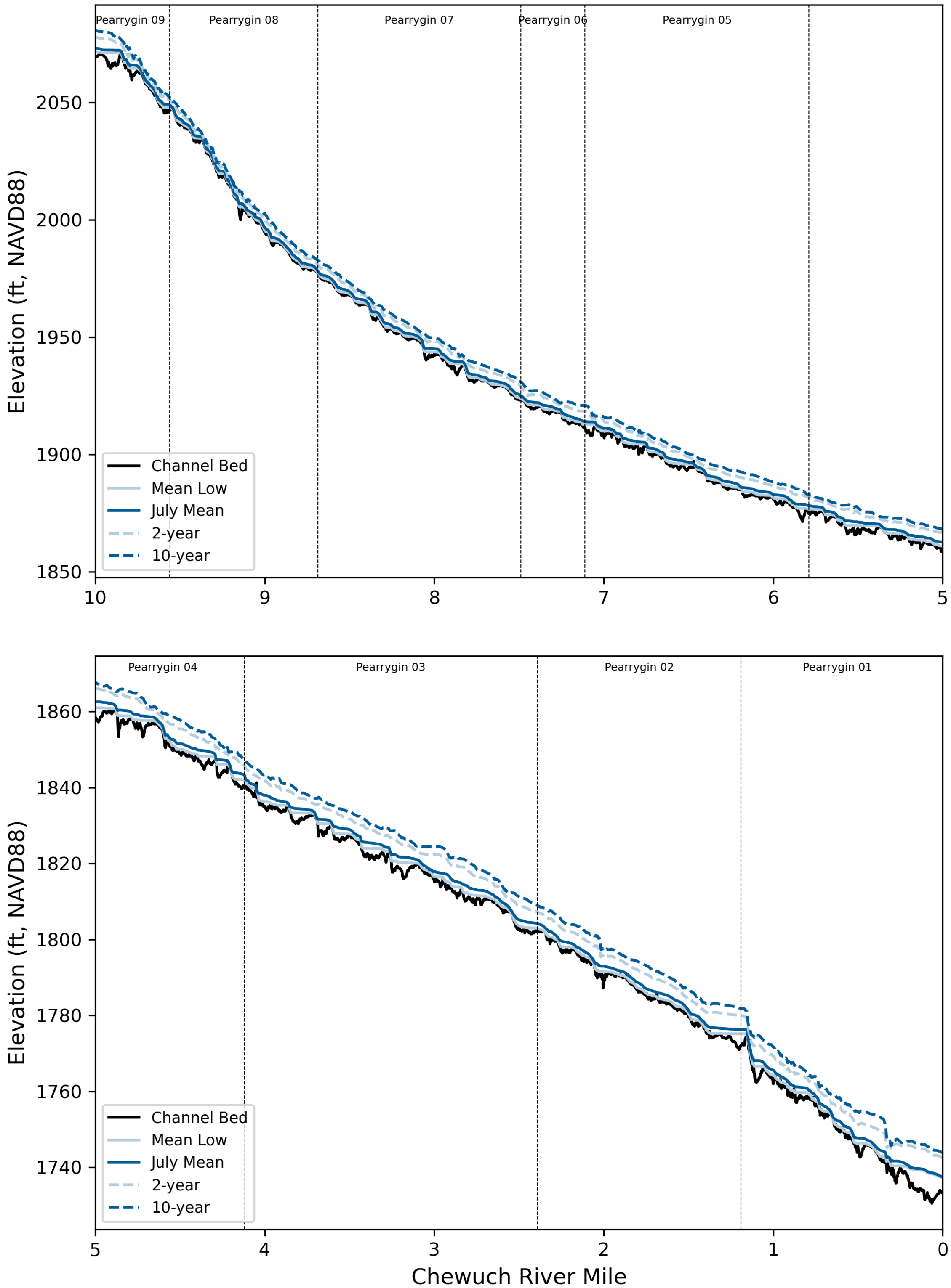

Figure 10.—Longitudinal profile of river bed and water surface elevations for select flows between river miles 10 and 0 along the Chewuch River.

7.0 Chewuch River Large Wood Risk Assessment

7.1 Background

The addition of 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 between RM 20 and 0. The risk assessment was developed based on Reclamation's Property Damage Risk Matrix (Reclamation 2014; figure 11). Instead of the qualitative approach in the 2014 Reclamation guidelines, TSC applied the hydraulic 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.

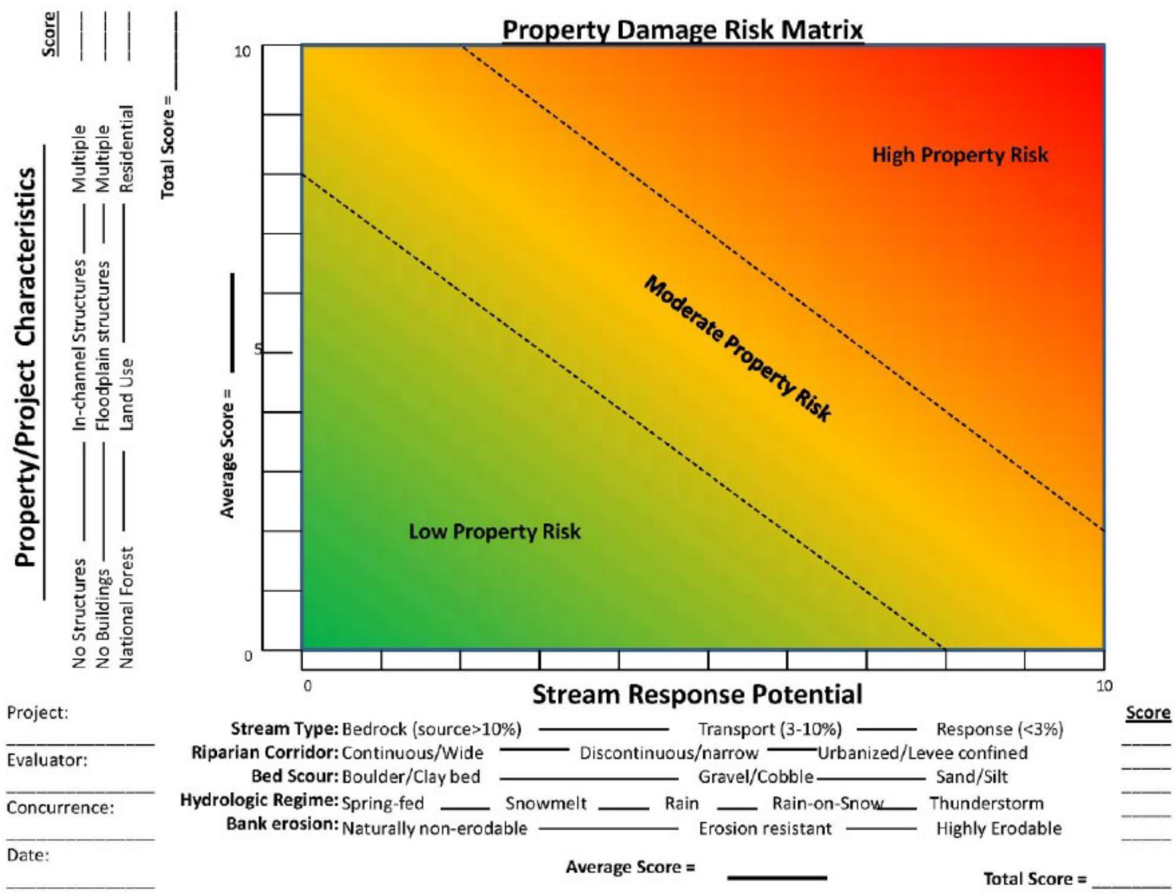

Figure 11.—The Property Damage Risk Matrix developed by Reclamation (2014).

7.2 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 5 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.

7.2.1 Stream Response Potential

7.2.1.1 *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 foot per second), ρ is the density of the water (slugs per cubic foot), g is the gravitational constant (feet per second squared), d is water depth (ft), V is velocity magnitude (feet per second), and S is the slope of the river (ft/ft). Water depth and velocity were extracted from model results on a 3-foot grid, which determined the resolution of the unit stream power calculations. In ArcGIS Pro, slope was calculated at 250-foot 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-foot 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.

7.2.2 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.

7.2.2.1 *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 12).

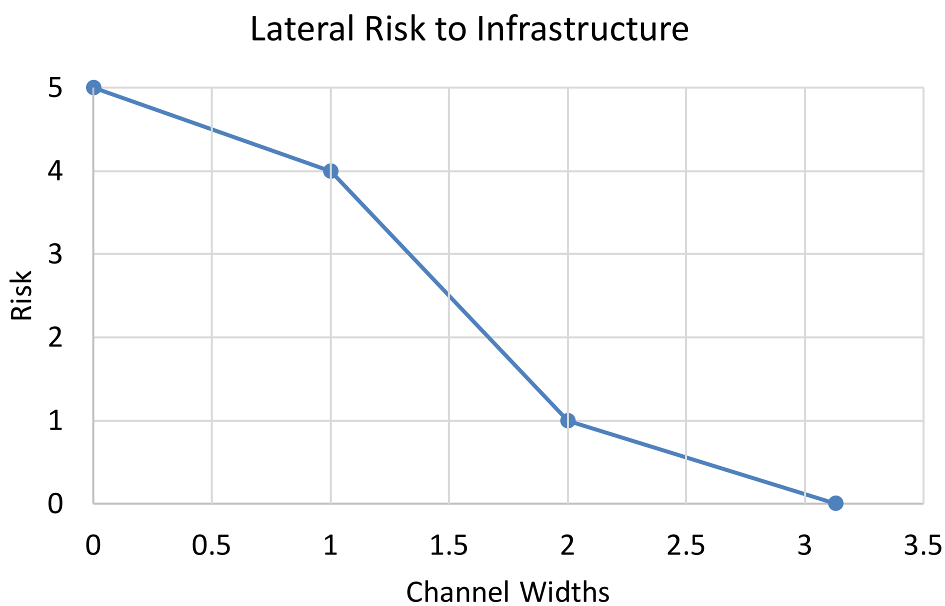

Figure 12.—Piecewise linear function used to calculate lateral risk to infrastructure.

7.2.2.2 *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-Forest Service (FS) 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 13). 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. Therefore, a piece of mobile wood that travels 100 channel widths downstream is likely to encounter at least 10 riffles, or depositional zones, where it may come to rest.

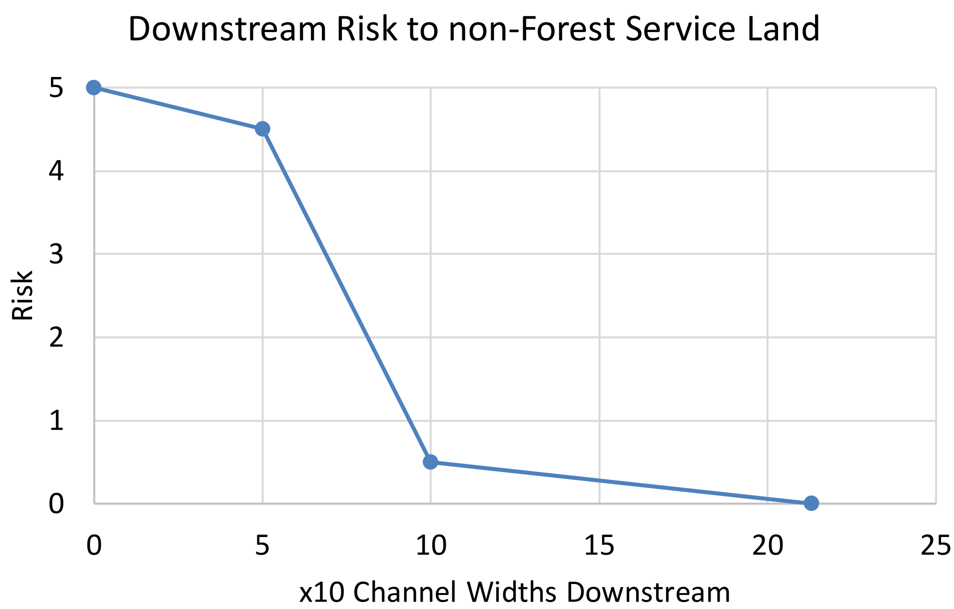

Figure 13.—Piecewise linear function used to calculate downstream risk to non-federal properties.

7.2.2.3 ***Total Property Risk***

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

7.3 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 14.

Because the upper five miles of the Chewuch River between RMs 20 and 15 is federally owned, LW risk generally increases from RM 20 downstream to RM 0 as downstream distance to non-FS land decreases (figure 15). 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 from RM 10 drives large increases in unit stream power making that portion of the river relatively high risk as compared to other locations. Figure 16 plots the risk scores, delineated by RM location, in a similar style chart as that developed by Reclamation (2014).

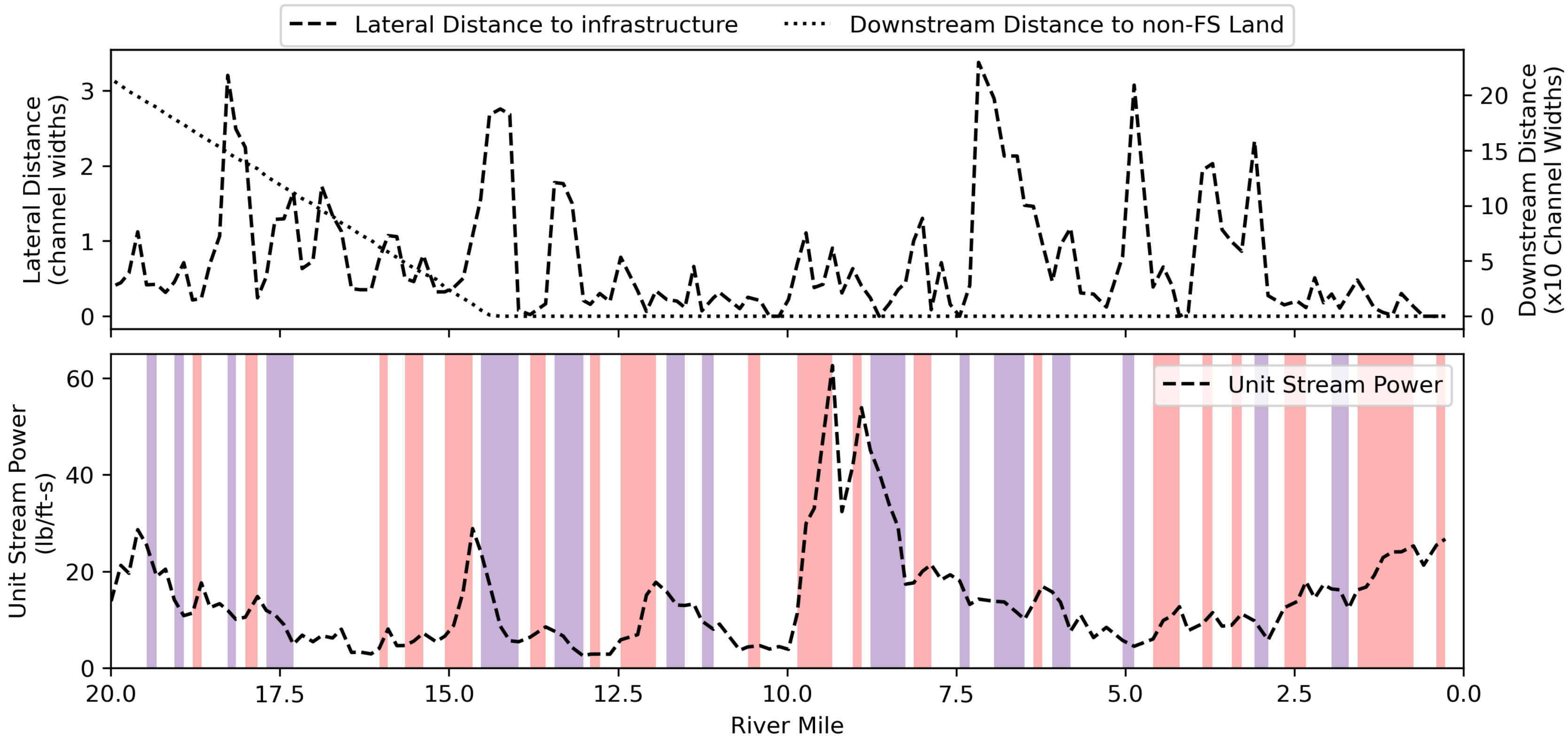

Figure 14.—Upper most plot shows lateral and downstream distances to infrastructure and non-federal property. The lower plot shows unit stream power values and change in unit stream power. Lengths of river where unit stream power is either increasing or decreasing for at least two 1/8th-mile risk segments are represented by red and purple shading, respectively.

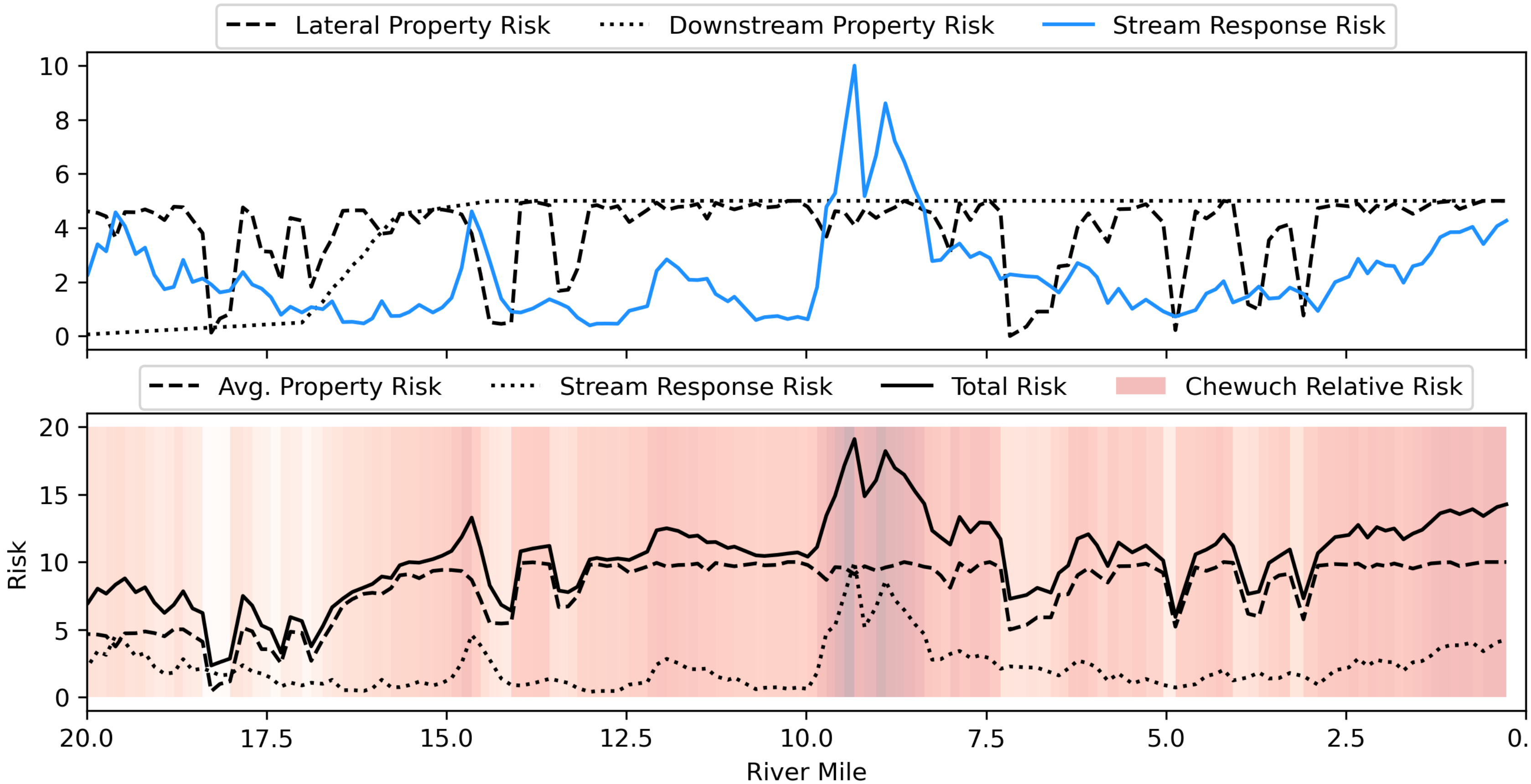

Figure 15.—Components of risk computation and overall risk score calculated at each 1/8-mile segment. The top plot shows the individual risk scores for lateral and downstream property risk as well as stream response risk. The bottom plot shows property risk and stream response risk, which are combined to estimate total risk. Darker shades of red represent more risk.

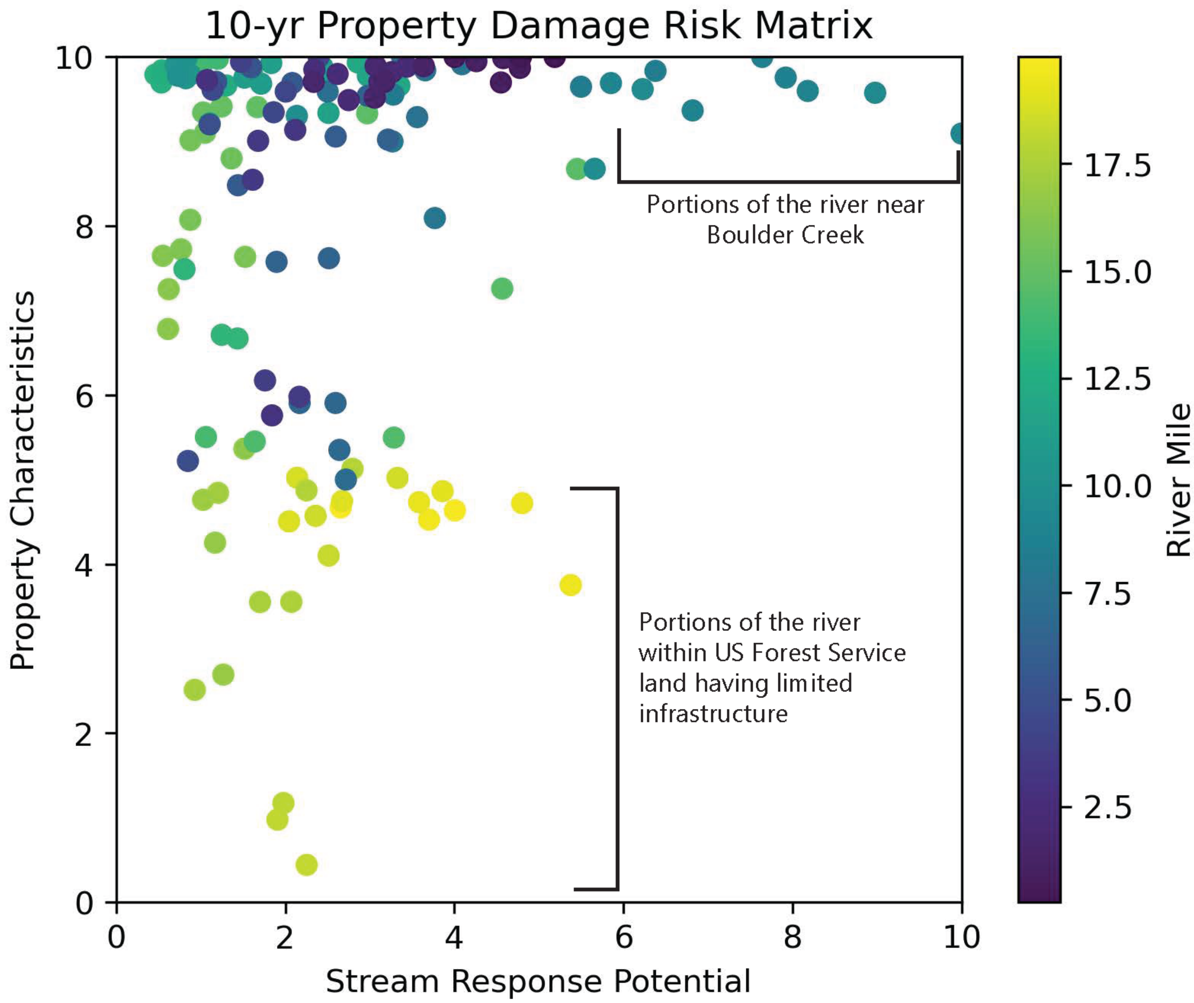

Figure 16.—Quantitative property risk matrix for Chewuch River for RM 20 to 0.

8.0 Chewuch River Geomorphic Setting

The Chewuch River between RM 20 and 0 can be characterized by stretches of pool-riffle morphology interspersed with stretches of more uniform width and depth. Those river morphologies are created due to the contributing hydrologic and geologic characteristics. While the hydrology of the Chewuch River was described in section 2.0, geologic conditions include river slope, valley width, and riverbed sediment grain size and are described in the following section. In combination with hydrology, each contributes to the form and hydraulics of the Chewuch River.

8.1 River Slope

River slope is a driver of flow energy with steeper slopes contributing to higher river energy and greater sediment and wood transport as discussed in section 6.0. Between RM 20 and 0, the Chewuch River has an average slope of 0.0056. However, individual prioritization reaches range in slope from 0.018 to 0.001 (figure 17). Channel slope in the lower 20 miles of the Chewuch River is often controlled by tributary confluences with slopes immediately upstream of the confluence shallower and slopes downstream from confluences steeper. For example, the lowest average reach slope is in Pearrygin 10 immediately upstream of the Boulder Creek confluence at approximately RM 10, while the steepest reach is Pearrygin 8 downstream from the same confluence (figure 17).

8.2 Valley Confinement

Valley confinement also plays a large role in floodplain development and channel form. Along the Chewuch River, alluvial fans and valley walls are generally the two types of confining features. We calculated confinement using numerical model results as the ratio of bankfull channel width (e.g., 1.5-year lateral inundation width) to floodplain width (100-year inundation width). Although not a direct measurement of valley width, the 100-year discharge fills the Chewuch River valley, thus approximating the lateral width of the alluvial surface between confining geological features. Generally, the Chewuch River can be considered a confined or partly-confined river, with all floodplain development occurring between valley walls (figure 18). Any meandering of the channel will ultimately hit a valley wall or be forced away from a valley wall by an alluvial fan. Even the most unconfined stretch of the river, the Pearrygin 3 reach, ends at a valley wall and the river becomes confined. The valley wall exerts a geologic control on the downstream end of the reach, which will ultimately impact upstream conditions. In addition to natural controls, rip-rapped banks along the river can act as anthropogenic confining features. The Doe reaches have variable lateral confinement, with longer pockets of broader floodplain in Doe reaches 2 and 5. The Pearrygin reaches generally decrease in confinement with Pearrygin 3 and 4 being the least confined reaches in the Pearrygin segment. The lower couple of miles that make up Pearrygin 1 and 2 are confined between valley walls until the confluence of the Chewuch and Methow Rivers.

8.3 Floodplain Connectivity

As an often partly confined system, floodplain connectivity along the Chewuch River can help provide geomorphic complexity in the form of multi-thread channels, side channels, lateral erosion allowing channel meandering processes, and riparian ecosystems. We measured floodplain connectivity along the Chewuch River as inundation width at a range of flows using numerical model outputs (figure 19). As expected, inundation width increases with increasing discharge. However, the analysis shows that some reaches of the Chewuch River are more highly connected at lower flows than other reaches. For example, if we compare inundation widths of the 10-year flow (10% probability flow) to a lower flow like the July mean flow, a highly connected portion of the river would have a similar value. Doe 1 and Pearrygin 8 have lengths of river that show a highly connected river. In contrast, Pearrygin 3 shows the most extensive 10-year floodplain width, but relatively little connectivity at lower flows. This may present an opportunity for restoration to enhance connectivity to some of these floodplain surfaces.

8.4 Riverbed Grain Mobility

The type and size of river sediments are the result of the climate and geology of a river basin. It is generally thought that the grain size of sediment within a river channel corresponds to the size that the river can transport at flood flows. We calculated predicted transport capacity based on hydraulic model outputs at four flows. For each flow, depth-averaged bed shear stress values calculated within SRH-2D were classified by size fractions that are likely to be mobile under the modeled flow conditions. The relationship between shear stress and grain size was based on the Shield's equation:

$$\theta = \frac{\tau_c}{g(\rho_s - \rho_w)D}$$

where θ is dimensionless critical shear stress, τ_c is critical bed shear stress needed to move a grain with diameter, D, g is the gravitational constant, ρ_s is the density of the sediment assumed to be 2.65 grams per cubic centimeter, and ρ_w is the density of water.

Often an assumption is made that the dimensionless critical shear stress approximates 0.045 (Knighton 1998). In combination with calculated bed shear stress from model results, an estimate of grain size that are at the threshold of motion was derived. The mobile grain size was calculated using the following re-arranged version of the Shield's equation:

$$D = \frac{\tau_c}{\theta g(\rho_s - \rho_w)}$$

Grain size values were calculated along the entire 20 miles of the reach assessment and plotted in comparison with measured grain sizes along the reach (figure 20). We found that predicted grain size mobility largely matched measured bed grain size well throughout the Chewuch River. Transport capacity often decreases upstream of the major tributaries as slopes decrease. With the increased discharge and greater slopes downstream from tributary confluences, transport capacity and predicted mobile sediment size increases. This is observed most clearly at Falls Creek (approximately [approx.] RM 14.8), Eightmile Creek (approx. RM 12), and Boulder Creek (approx. RM 9.5). Model results predict that flood flows (2- and 10-year flows) predominantly transport gravels and cobbles upstream of Boulder Creek. Downstream from Boulder Creek flood flows are predicted to transport cobbles. Boulders are predicted to be mobile immediately downstream from Boulder Creek. Throughout the river, flows higher than the 10-year event would be expected to move larger grain sizes.

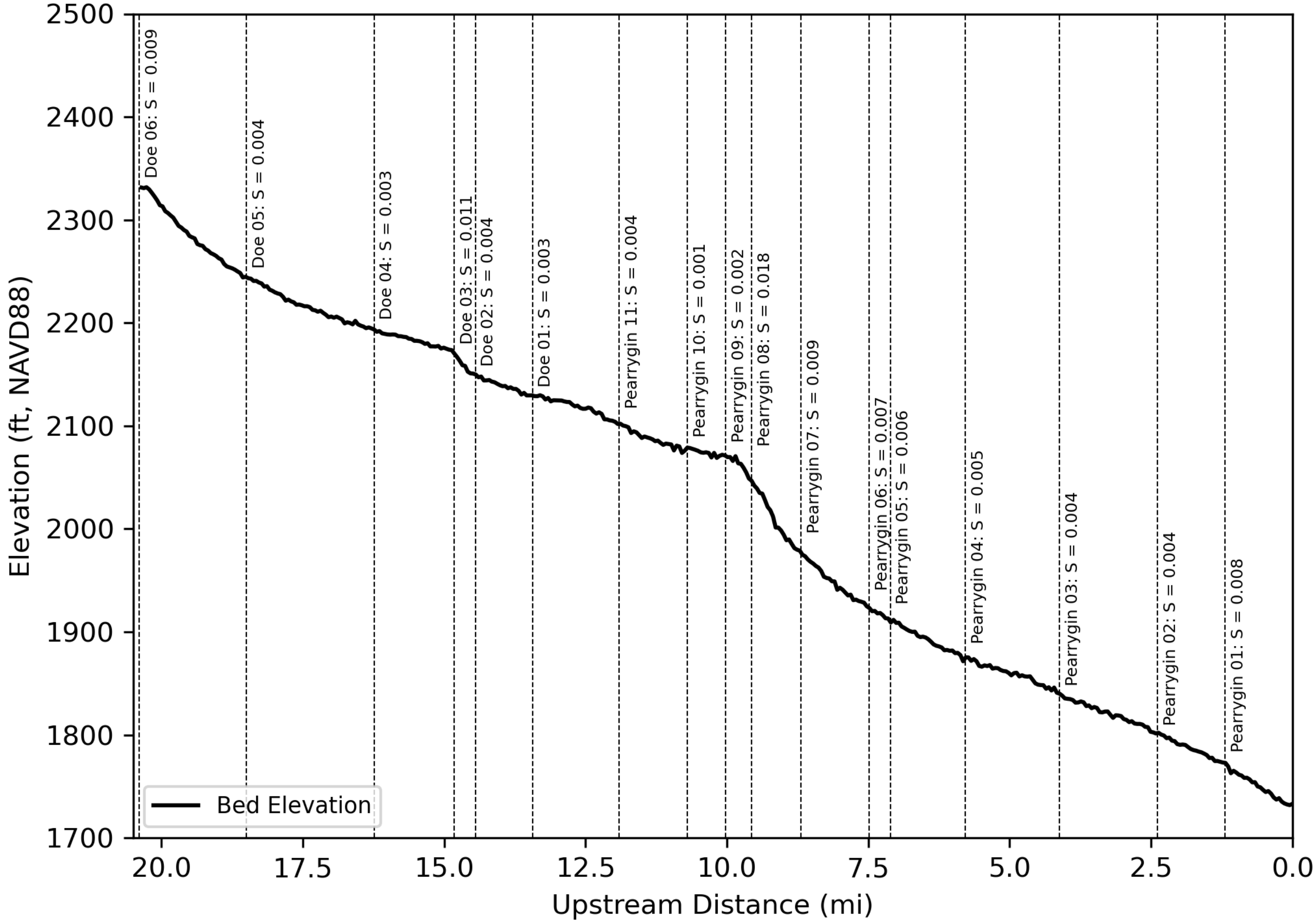

Figure 17.—Longitudinal profile of the Chewuch River from RM 0 to 20. Individual reach slopes are documented alone the dashed line demarcating the upstream extend of the labeled reach.

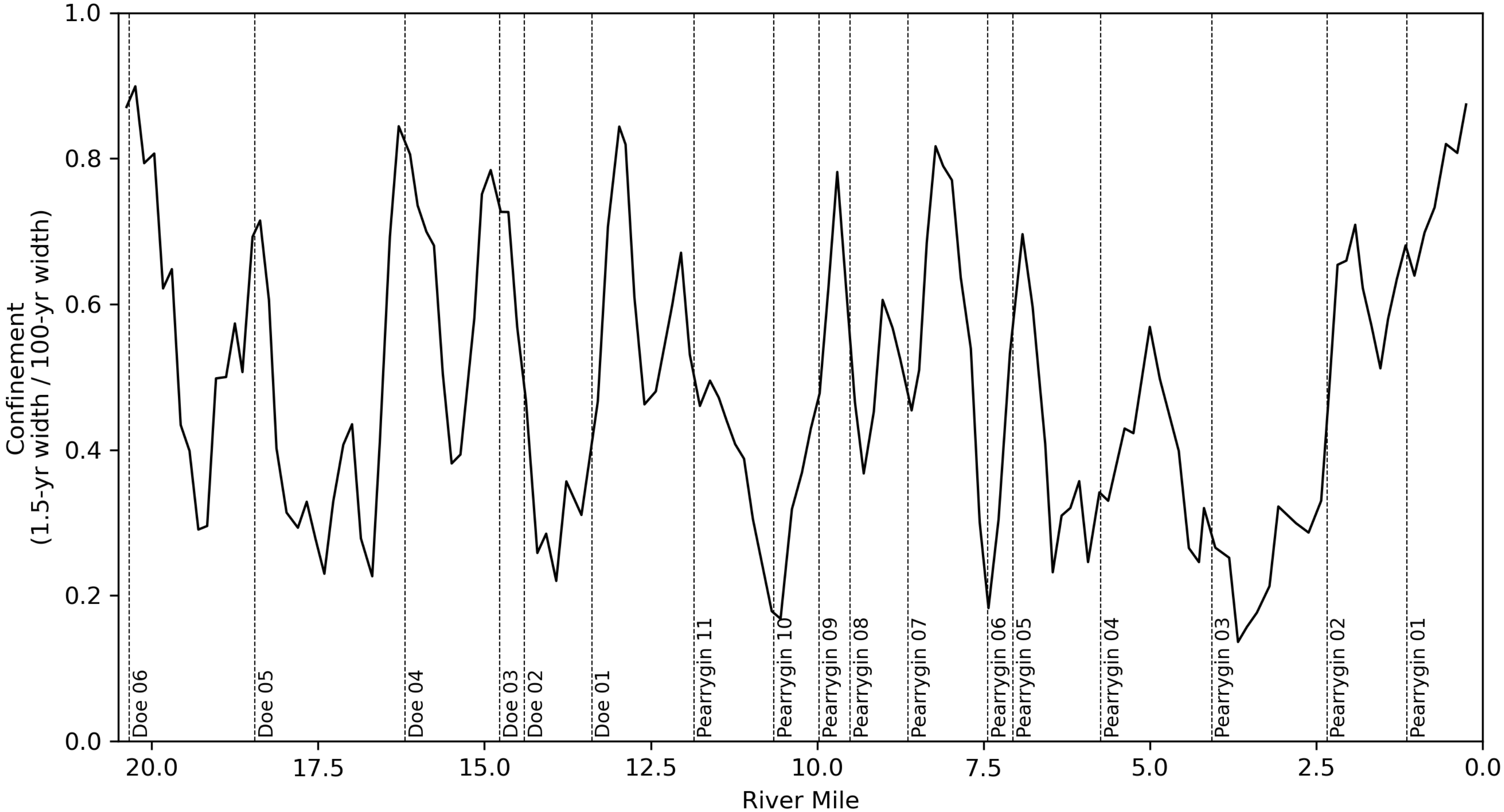

Figure 18.—Valley confinement, calculated as the ratio between the inundated width of a 1.5-year flow and a 100-year flow, along the Chewuch River. Here valley confinement is presented as a moving average across 1800 ft of downstream valley length.

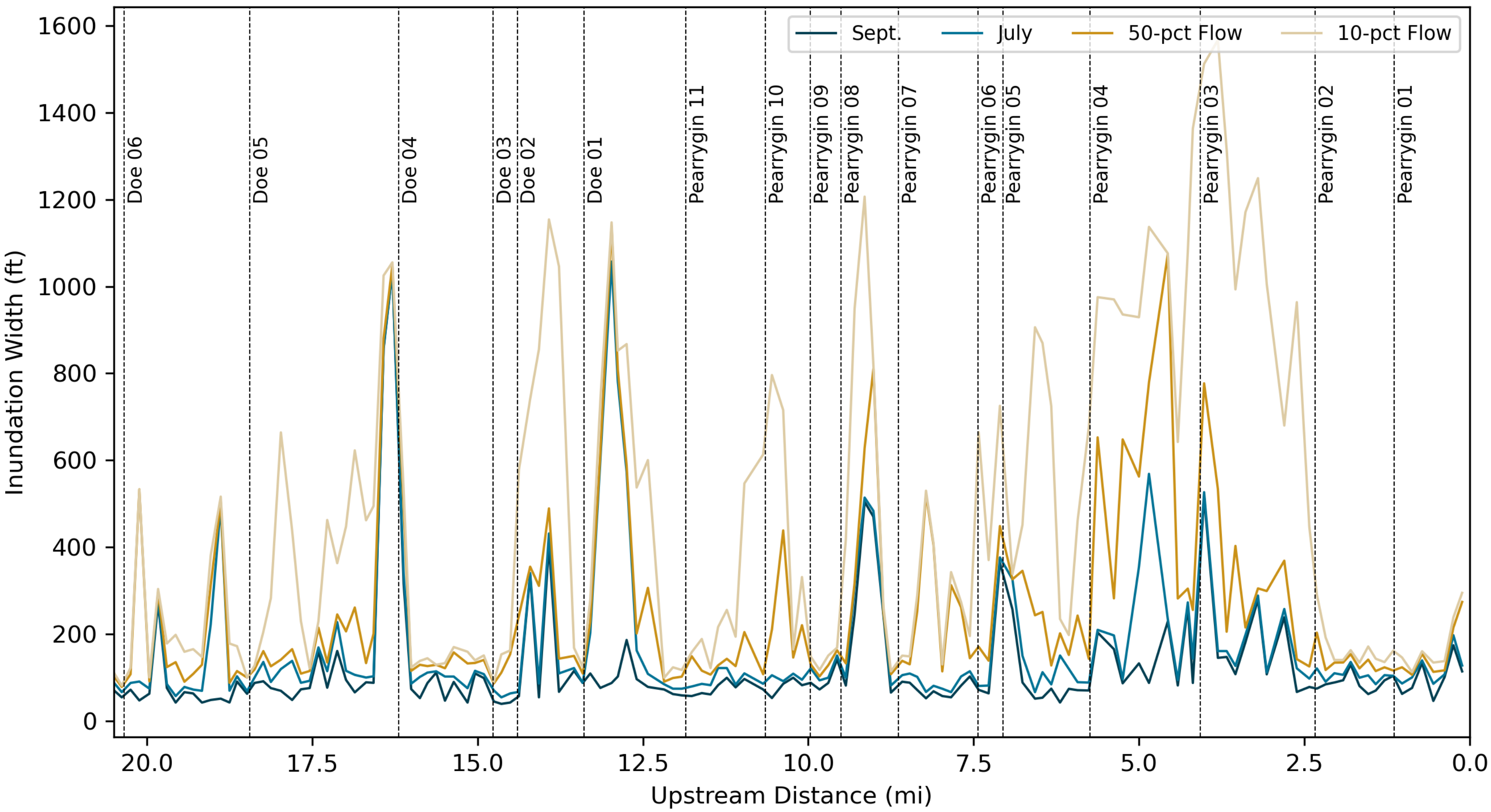

Figure 19.—Modeled inundation width along the Chewuch River.

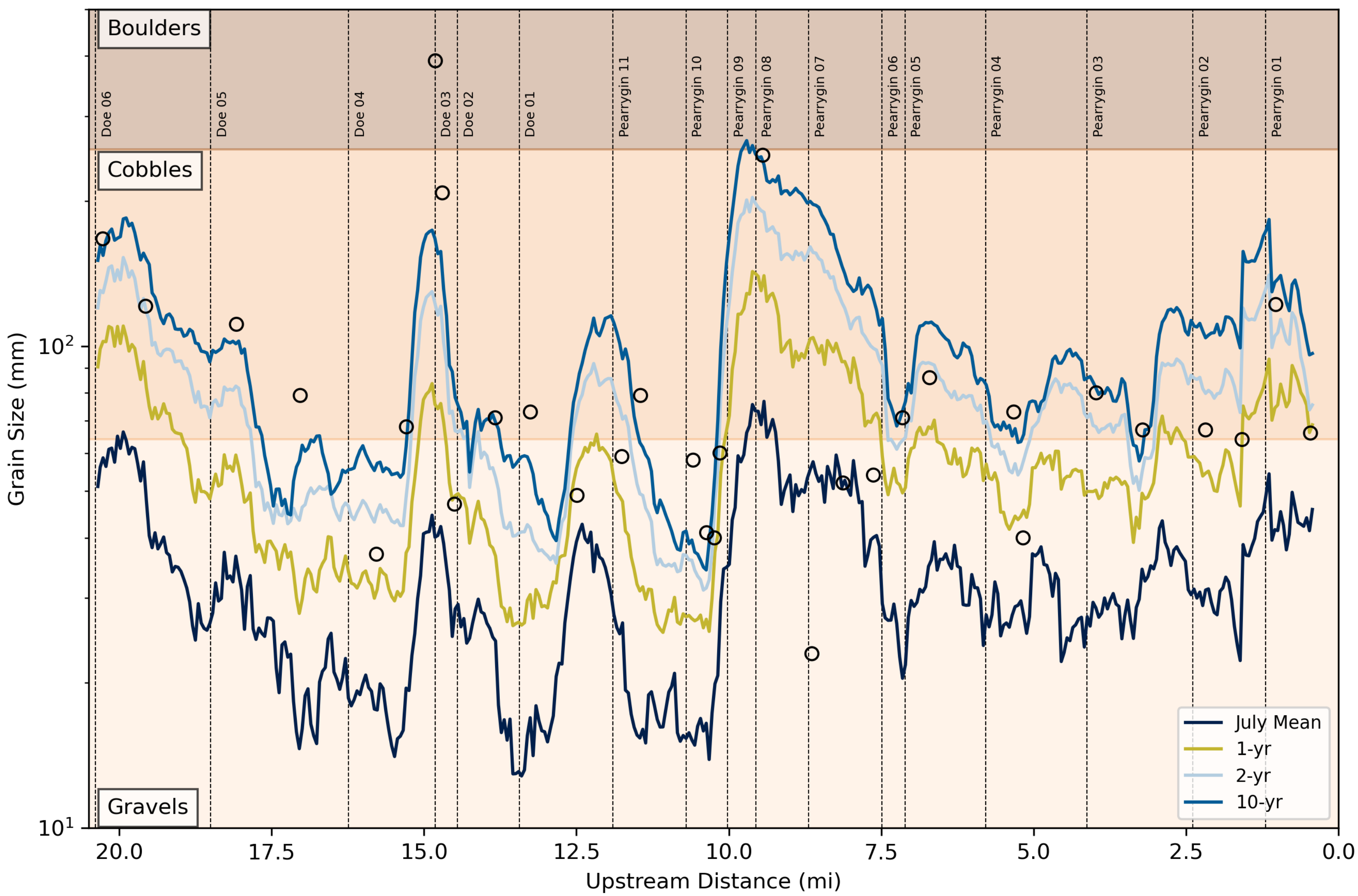

Figure 20.—Predicted grain sizes transported at four flows compared with field measured 50th-percentile grain size (black circles). Shading indicates gravel, cobble, and boulder size classes.

9.0 Prioritization Reach Characteristics

There are 17 named reaches between Twentymile Creek and the Chewuch River confluence with the Methow River: Doe reaches 1 through 6 and Pearrygin reaches 1 through 11. Here we describe geomorphic and hydraulic characteristics throughout each of the reaches from upstream to downstream based on the analyses described earlier in the report.

9.1 Doe 6

The Doe 6 reach extends from approximately RM 20.3 to 18.4. The confluence of Twentymile Creek with the Chewuch River at the upstream end of the Doe 6 reach creates a steep slope and high stream power throughout the reach in comparison to other areas of the Chewuch River (figure 14). The reach is relatively confined with few floodplain surfaces (figure 21). Flow complexity is mainly dependent on split flow channels. Several of these split flow channels are connected at lower flows (July mean) while other side channels need higher flows to connect (2-year). Due to the high stream power and confined nature of the reach, the riverbed is composed mainly of cobble-sized material, which are likely transported annually. Moving away from the Twentymile confluence, slope and stream power decline as Doe 6 transitions to Doe 5.

The upstream and downstream ends of this reach are bounded by two large alluvial fans that restrict lateral migration of the channel at those points (figure 22). The upstream fan is associated with Twentymile Creek, which contributes large material to the mainstem Chewuch River (figure 23). There is a slight expansion in valley width between the fans between RM 19.25 and 18.75. The Doe 6 reach experienced an increase in the area of the active geomorphic corridor from 1947 to 1957, consistent channel geometry from 1957 to 1988, and then a decrease in the active geomorphic corridor area from 1988 through 2013 (figure 24). The channel has been relatively stable since 2013.

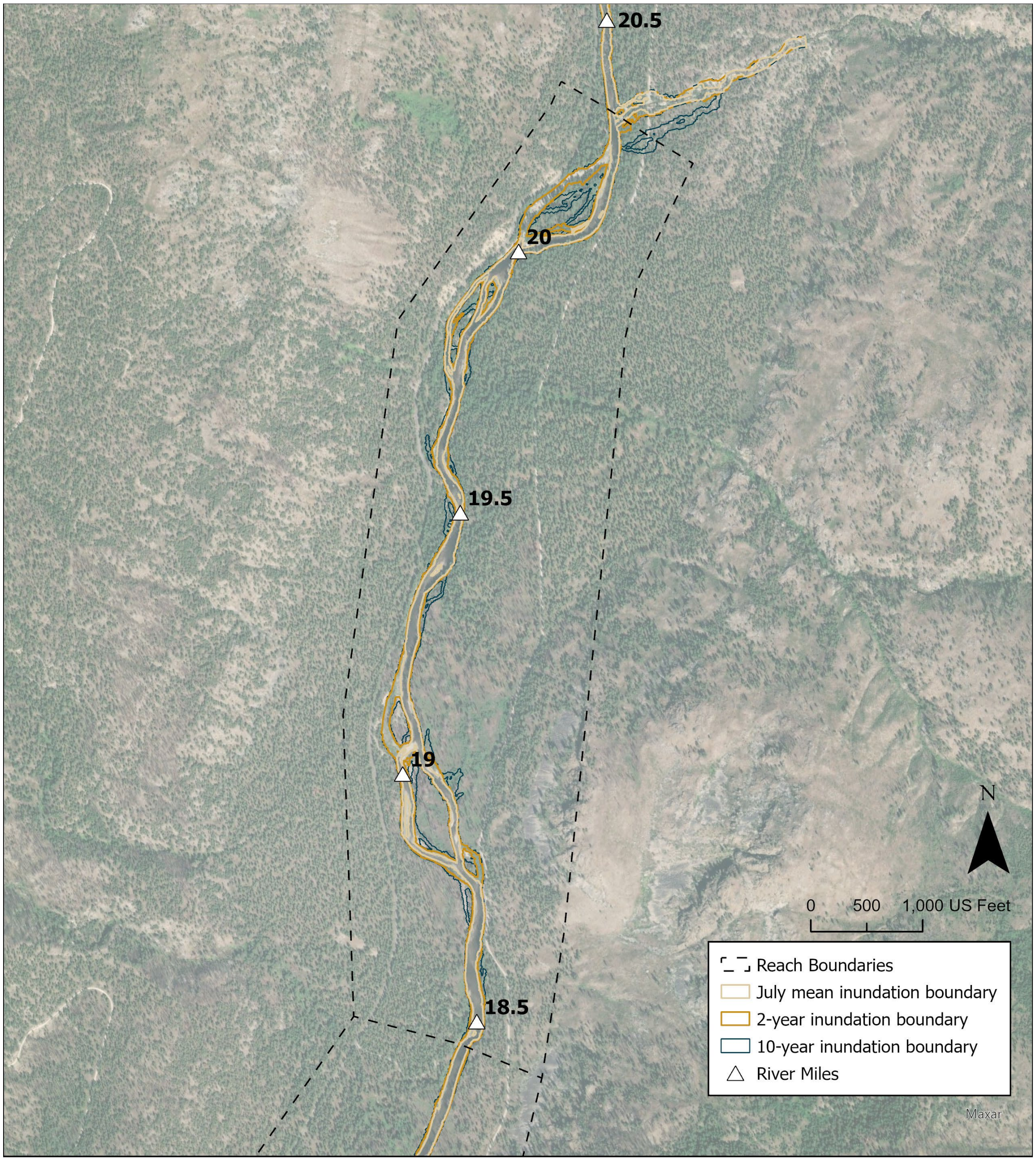

Figure 21.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Doe 6.

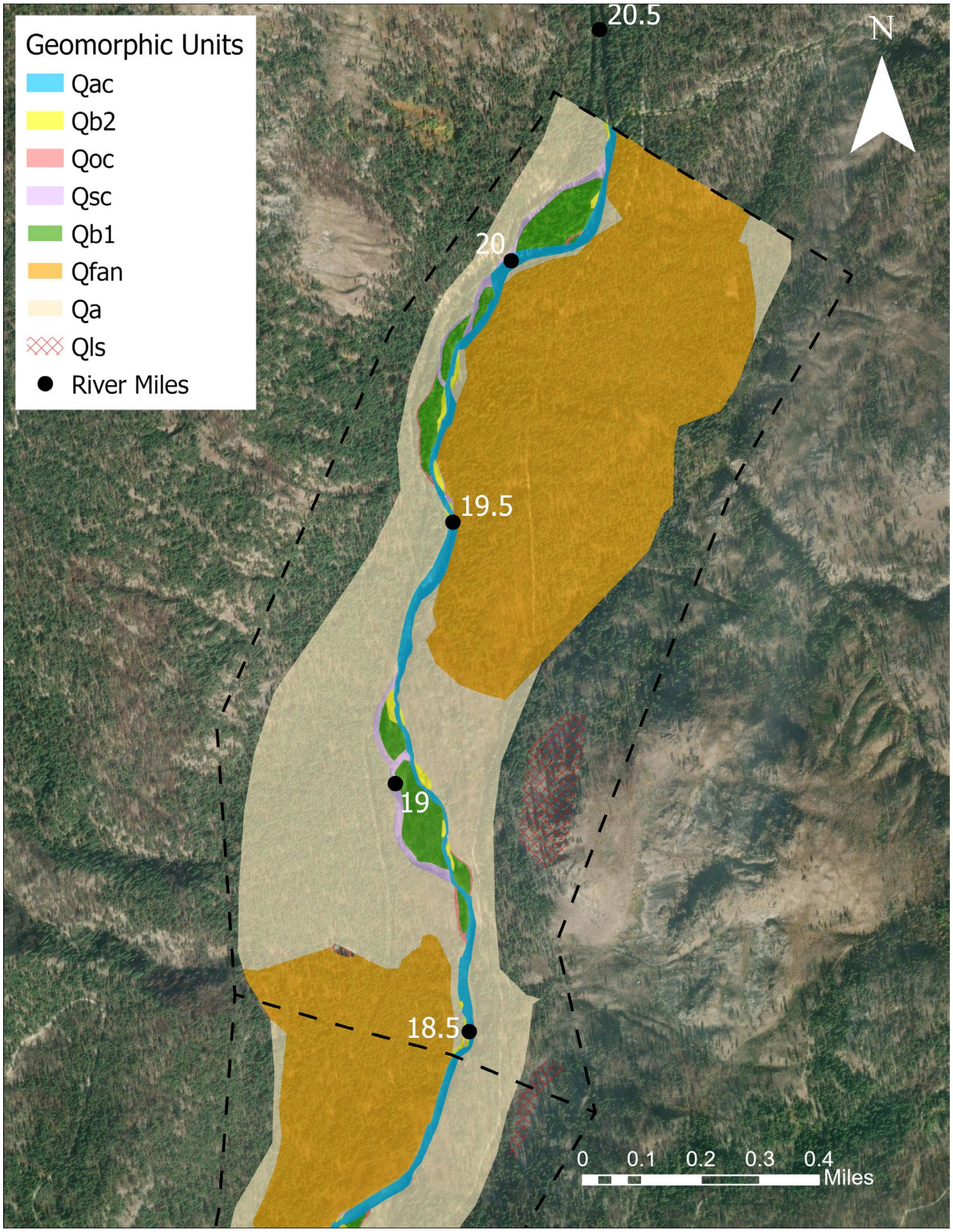

Figure 22.—Geomorphic mapping for 2023 for the Doe 6 reach (RM 20.3 to 18.4). The up- and downstream ends of the reach are bound by large alluvial fans. Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

Figure 23.—Looking upstream within Twentymile Creek from the mainstem Chewuch River. Backpack in the background for scale (Reclamation/Aaron Hurst).

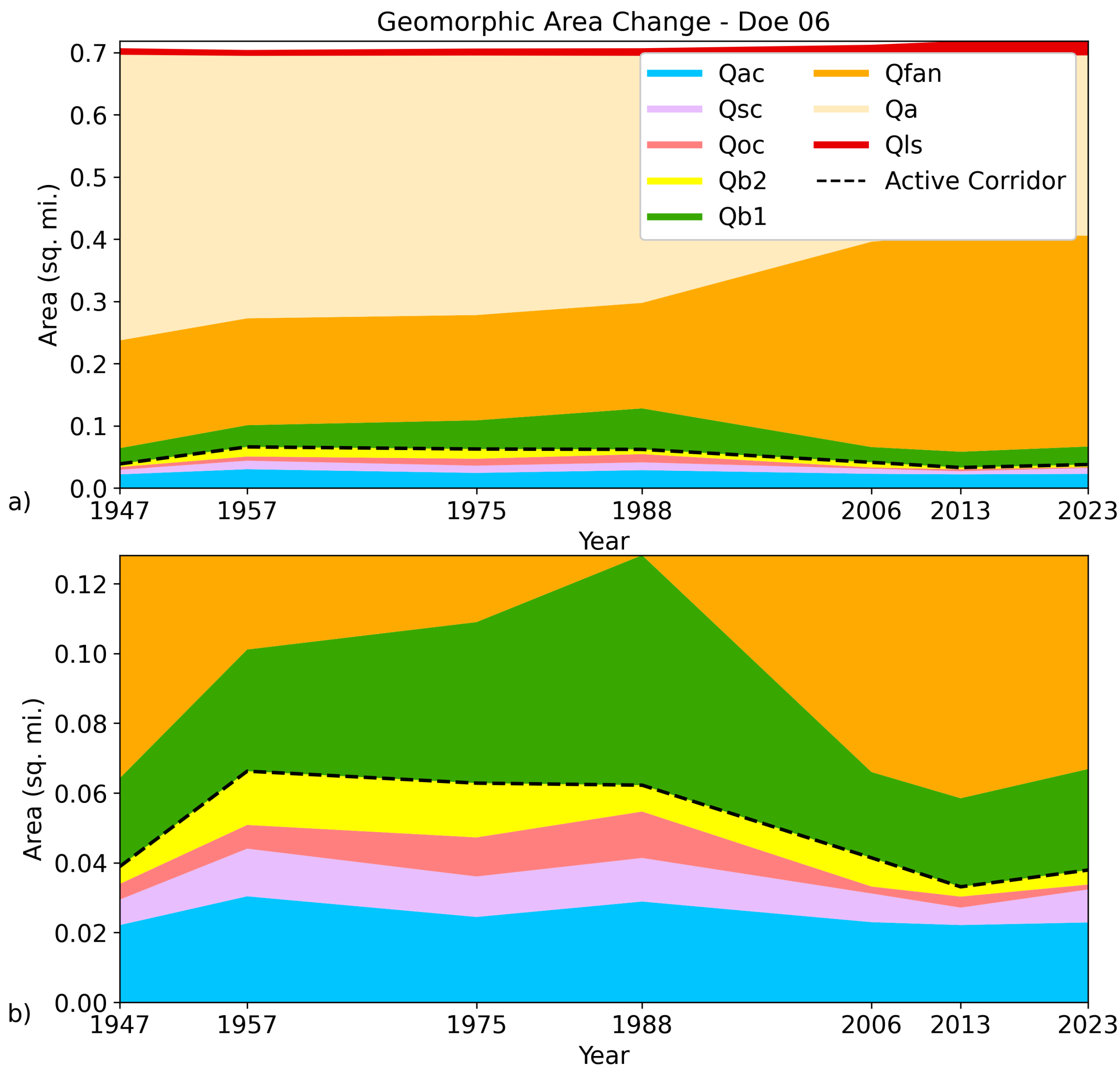

Figure 24.—Geomorphic area change for the Doe 6 reach (RM 20.3 to 18.4) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.2 Doe 5

The Doe 5 reach extends from approximately RM 18.4 to 16.2. River flow is contained within the main channel of the upper portion of Doe 5 as the river is confined (figure 18). At approximately RM 18, confinement lessens with lower floodplain surfaces available, however, those surfaces in much of the reach are not predicted to connect until the 10-year recurrence flow (figure 25). Stream power continues to decrease in Doe 5 from upstream to downstream (figure 14), which also means smaller grain sizes are predicted to be entrained in comparison to Doe 6. The river begins to show more complexity in river form with point bar development and pool-riffle morphology before the channel splits at RM 16.5 with a large island having more connectivity at the 2-year recurrence flow (figure 25). Although the valley is wider in this location, much of the floodplain remains relatively high compared to low flows.

At the RM 16.5 channel split, the lowest flows travel through a small side channel, but the larger main channel is also active at most flows. The apex of this split flow is influenced by a river restoration project with large wood structures and additional wood racking (figure 26). Small alluvial fans exist throughout the reach, but the large fan at the upstream boundary and the fan at RM 17 are probably the only ones that impact channel mobility (figure 27). The Doe 5 reach experienced an almost steady narrowing of the active geomorphic corridor from 1975 to 2023 (figure 28). This is largely due to abandonment of overflow channels and an accompanying decrease in the vegetated bar area. This reach is less confined than the upstream reach and historically had an extensive overflow channel network that was likely connected to the main channel at higher flows.

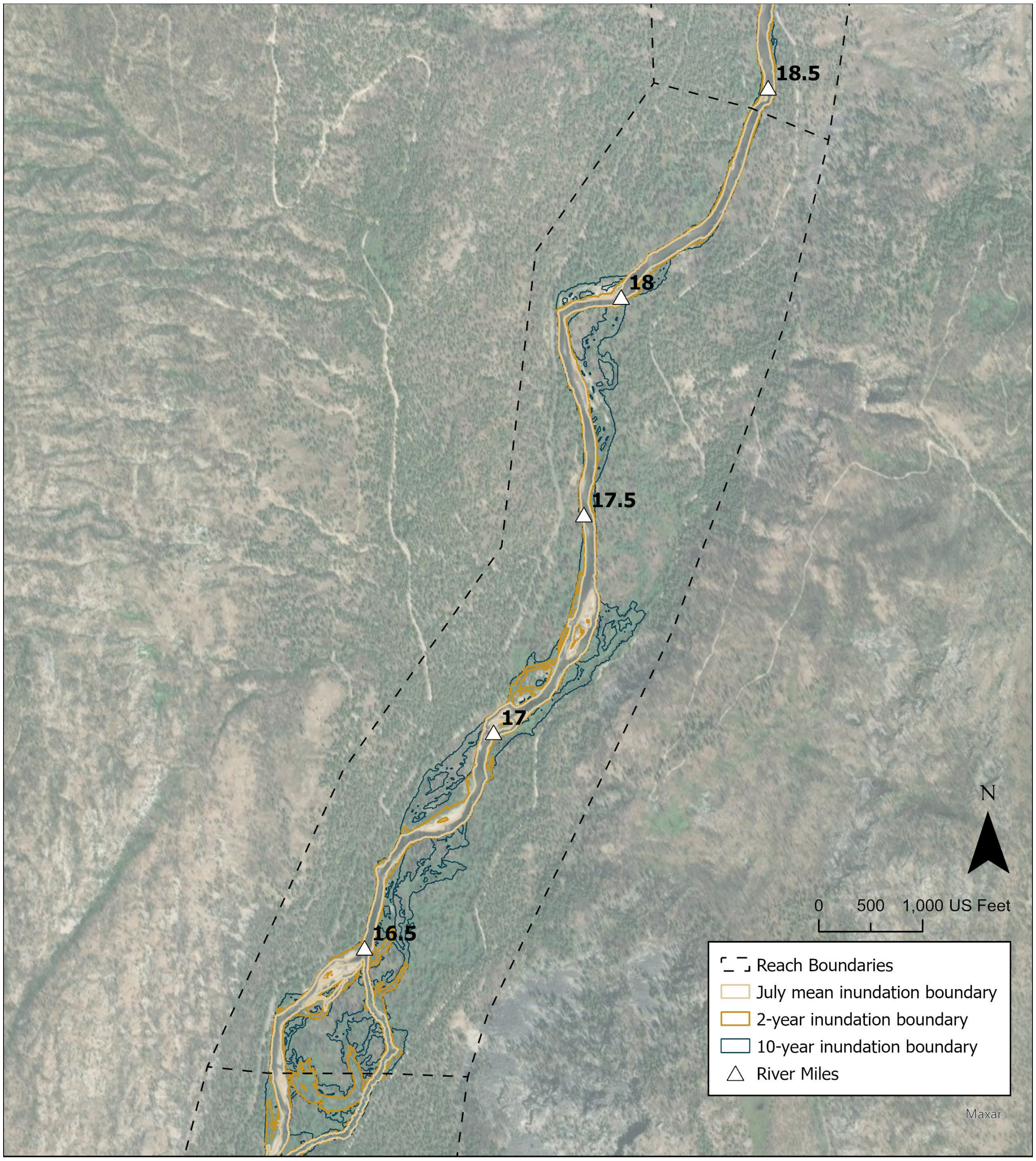

Figure 25.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Doe 5.

Figure 26.—Image is taken near River Mile 16.3 looking downstream within a side channel that carries low flows, while the mainstem, larger channel (not pictured) connects at most flows as well (Reclamation/Melissa Foster).

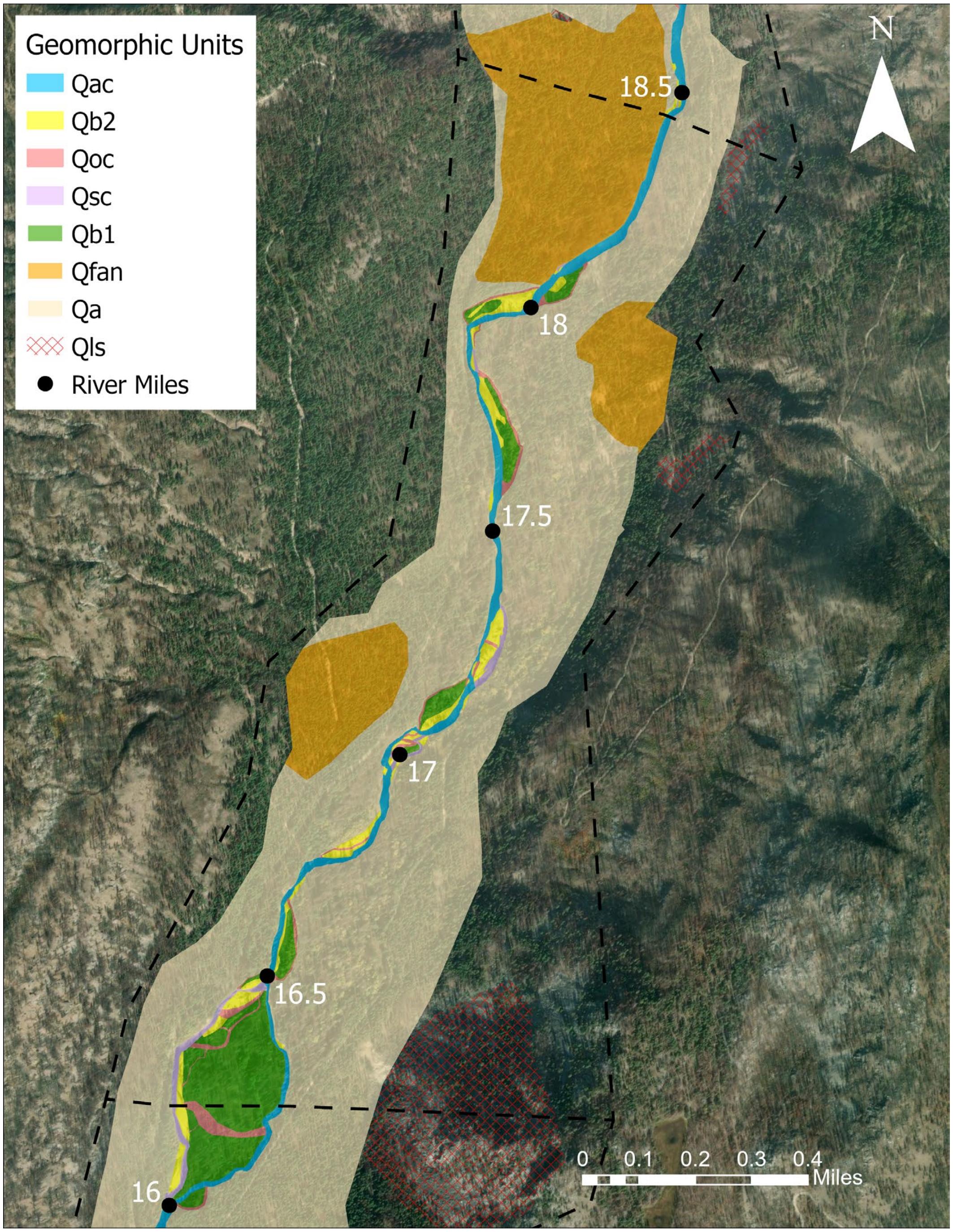

Figure 27.—Geomorphic mapping for 2023 for the Doe 5 reach (RM 18.4 to 16.2). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

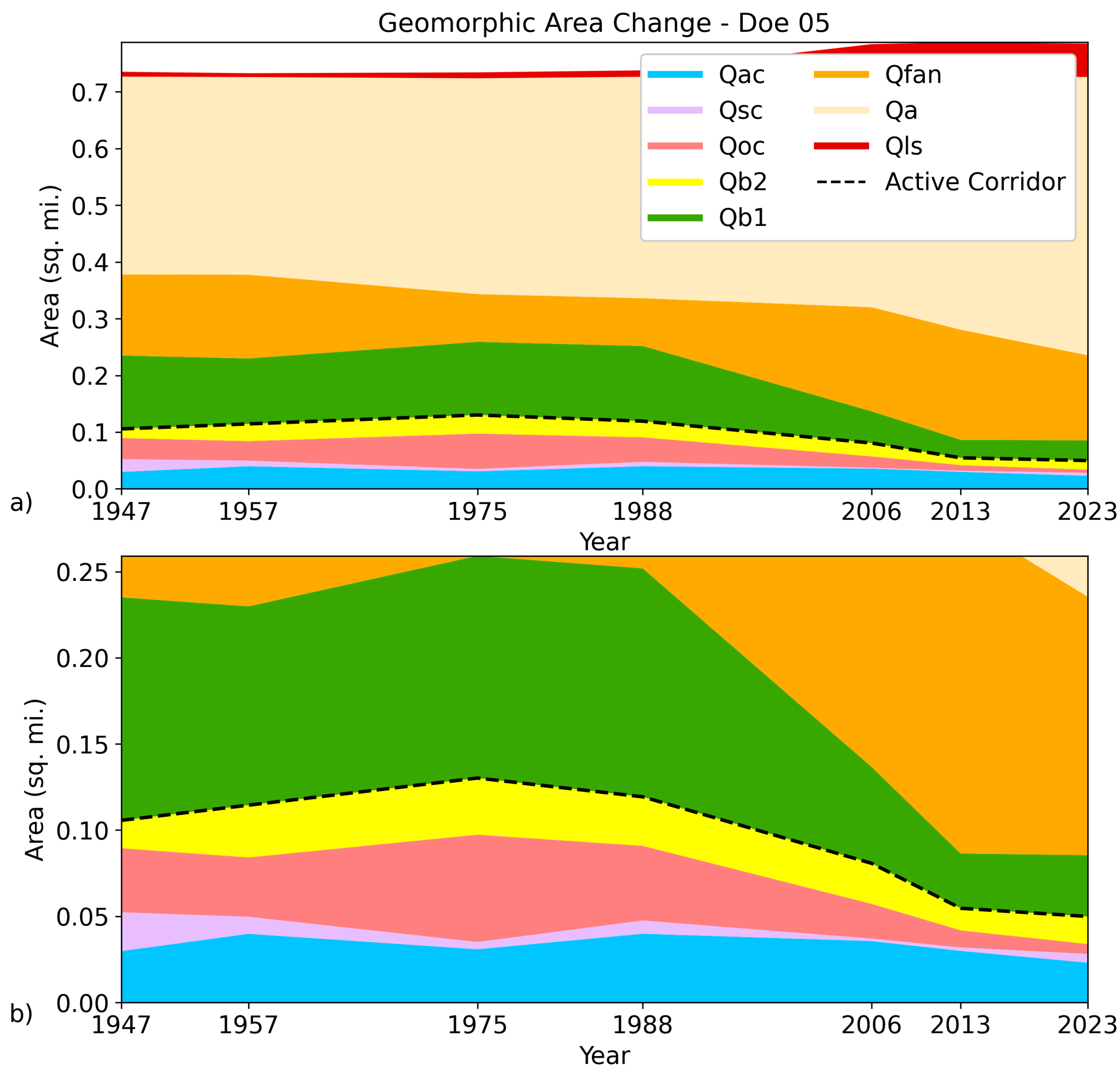

Figure 28.—Geomorphic area change for the Doe 5 reach (RM 18.4 to 16.2) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.3 Doe 4

The Doe 4 reach extends from approximately RM 16.2 to 14.8. Hydraulics in Doe 4 are defined by a constricting valley at the upstream end as flow through a split channel converges to a predominantly confined reach (figure 29). Between RM 15.5 and 15, there is a small amount of floodplain connectivity at higher discharges, but compared to other reaches, the river corridor is narrow (figure 18; figure 29). While the river is confined, stream power remains relatively low in this reach due to low slope. Slope is low due to the confluence of Falls Creek with the Chewuch River at the downstream end. The tributary creates a depositional fan and provides a geological control on the hydraulics in the river, thus impacting transport capacities and keeping predicted mobile grain sizes in the gravel and cobble range depending on discharge (figure 17; figure 20).

The channel through this reach is relatively straight through the confined valley (figure 30). The Falls Creek alluvial fan at the downstream end restricts channel mobility at that point. The Doe 4 reach has had a relatively stable geomorphic corridor through time (figure 31). The area of overflow channels increased from 1957 to 1975 due to activation of an overflow channel complex that was disconnected again by 1988.

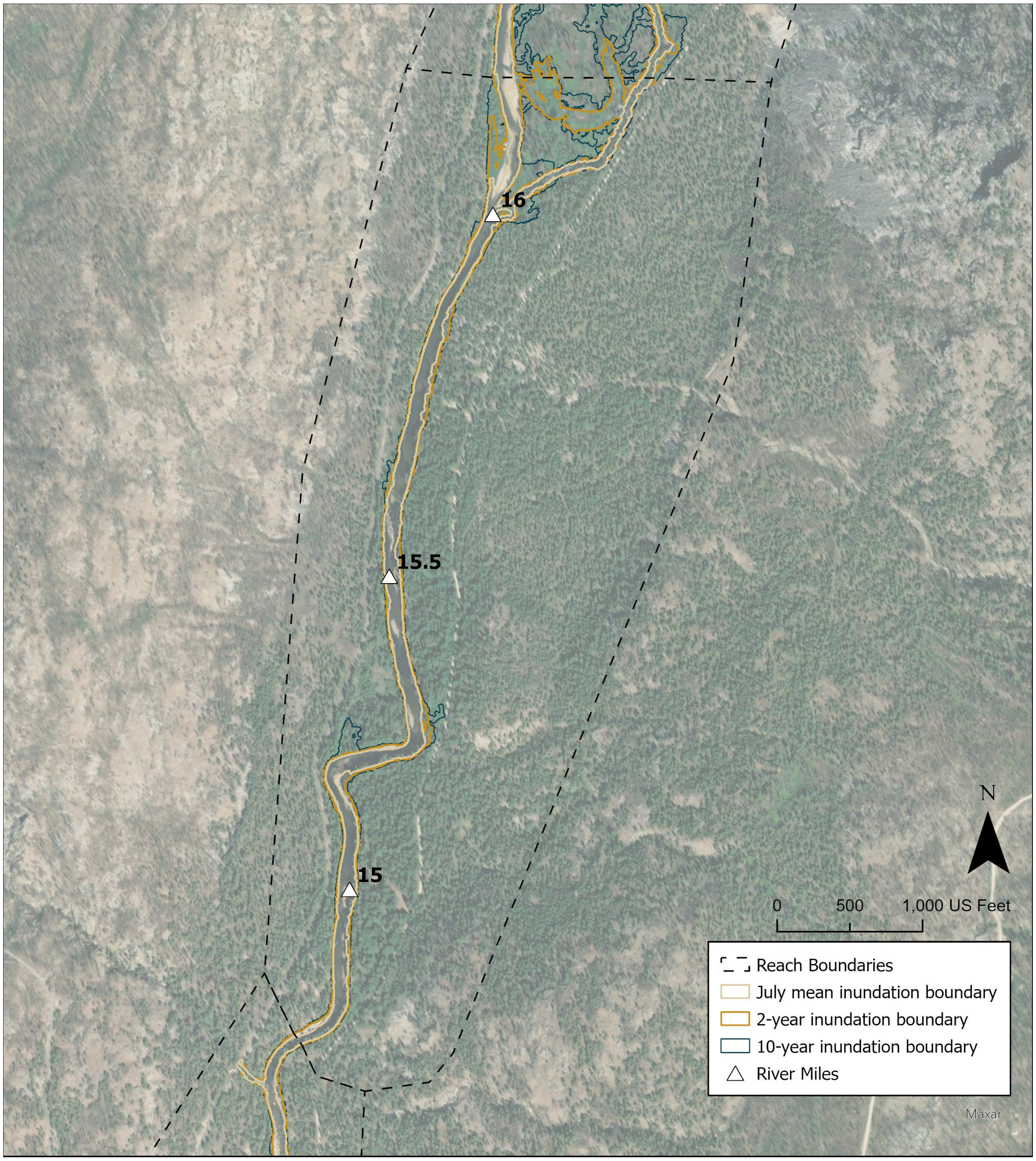

Figure 29.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Doe 4.

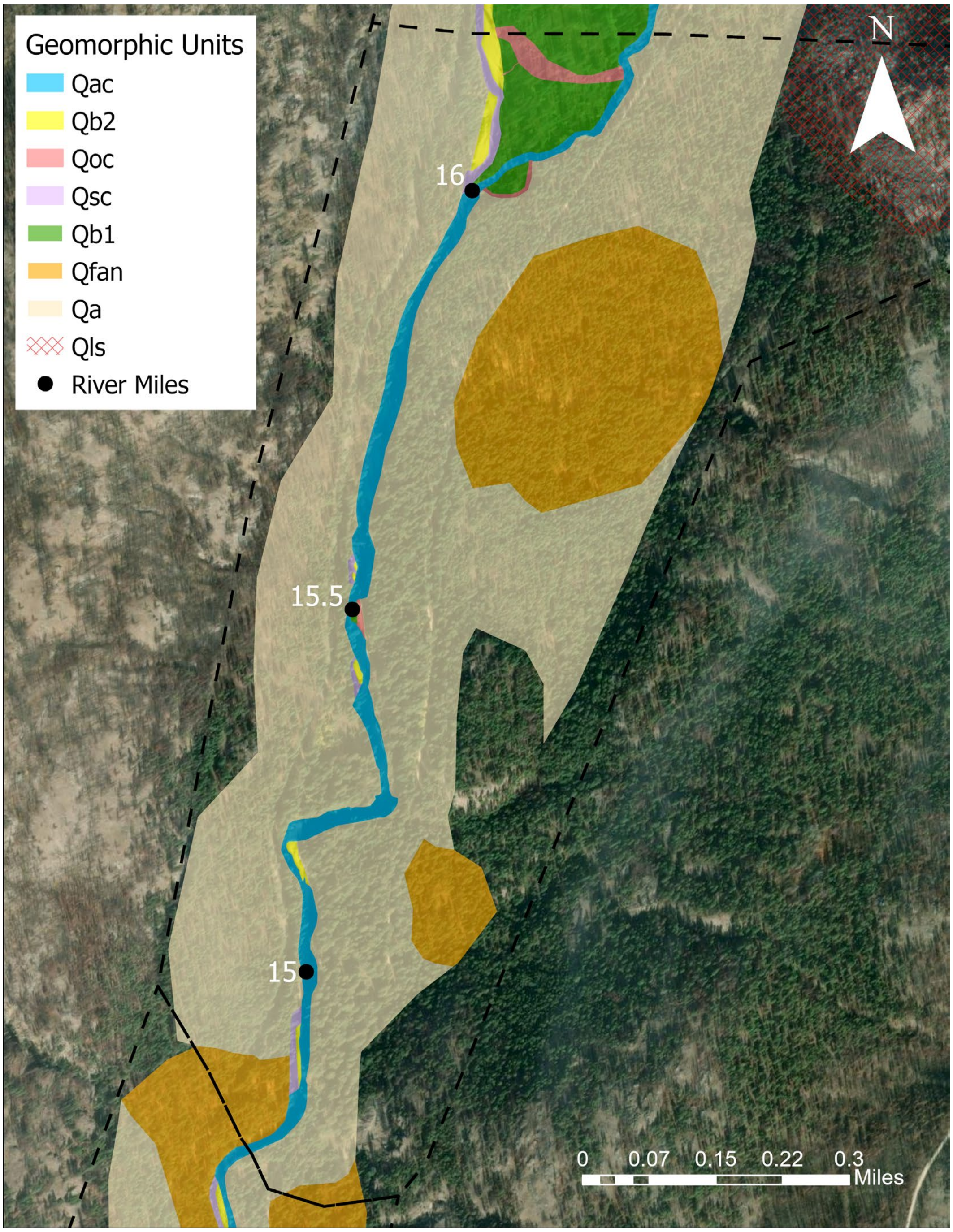

Figure 30.—Geomorphic mapping for 2023 for the Doe 4 reach (RM 16.2 to 14.8). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

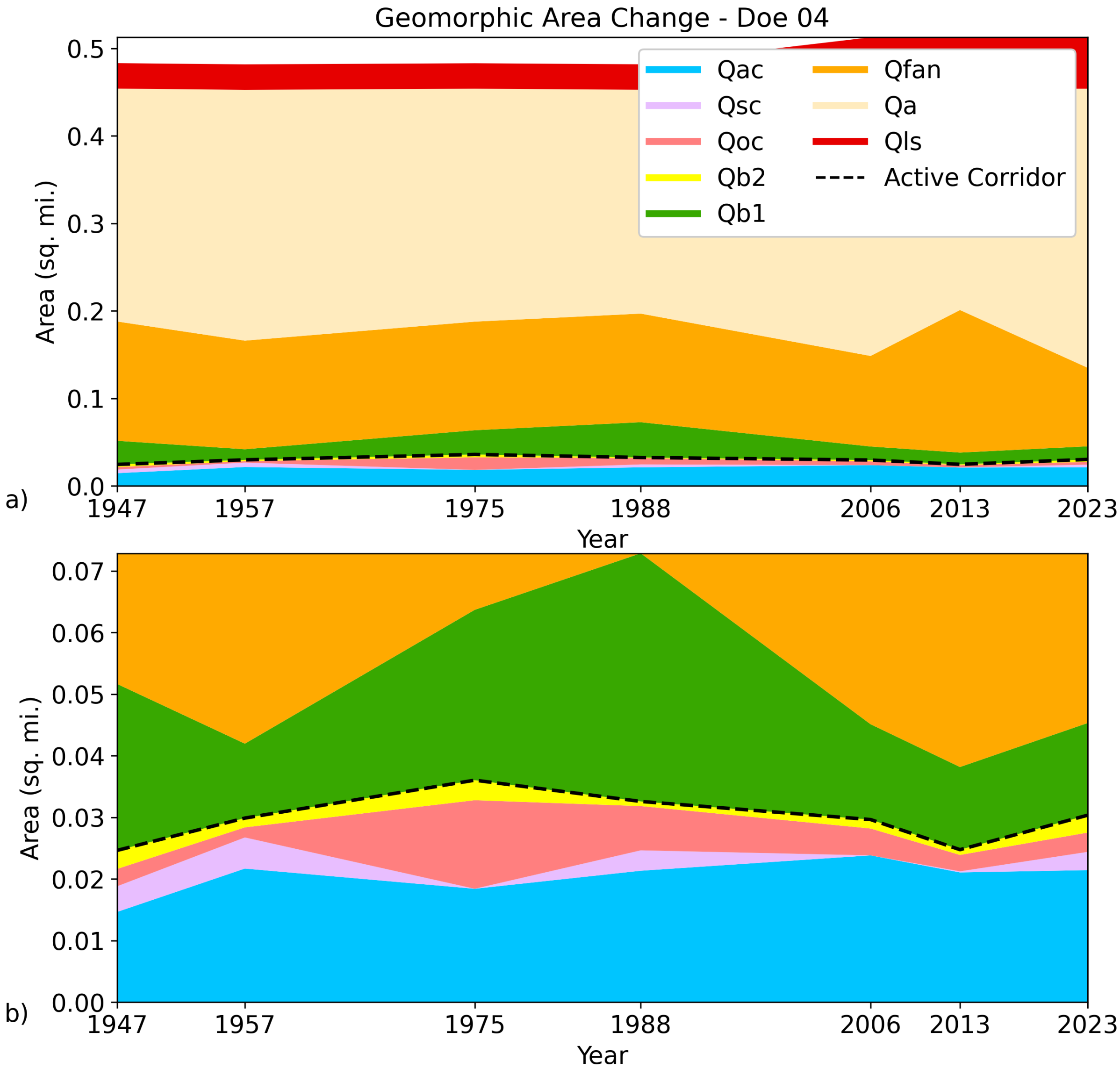

Figure 31.—Geomorphic area change for the Doe 4 reach (RM 16.2 to 14.8) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.4 Doe 3

The Doe 3 reach extends from approximately RM 14.8 to 14.4. Downstream from river confluences, slopes typically increase and this is the case for the Doe 3 reach, which begins near the confluence of Falls Creek with the Chewuch River (figure 17). The steep slope and increased discharge contributed from Falls Creek drive a sharp rise in stream power and predicted mobile grain size (figure 14; figure 20). The reach is short in length compared to other Chewuch River prioritization reaches and is generally confined, though that confinement decreases as the river flows into the Doe 2 reach (figure 18).

The river in Doe 3 is confined by alluvial fans along the entire reach, resulting in a straight and simple planform (figure 33). The result of this confinement is little change in the active geomorphic corridor through time (figure 34). The side channel at the upstream end of the reach activated between 2013 and 2023. There has generally been a decrease in overflow channels through time. Between 1957 and 1975, and overflow channel complex formed around RM 14.5. By 1988 the island between the overflow channel and the active channel vegetated, corresponding with the spike in vegetated bar area in 1988, and then by 2006 the entire overflow channel complex was disconnected from the main channel (figure 34).

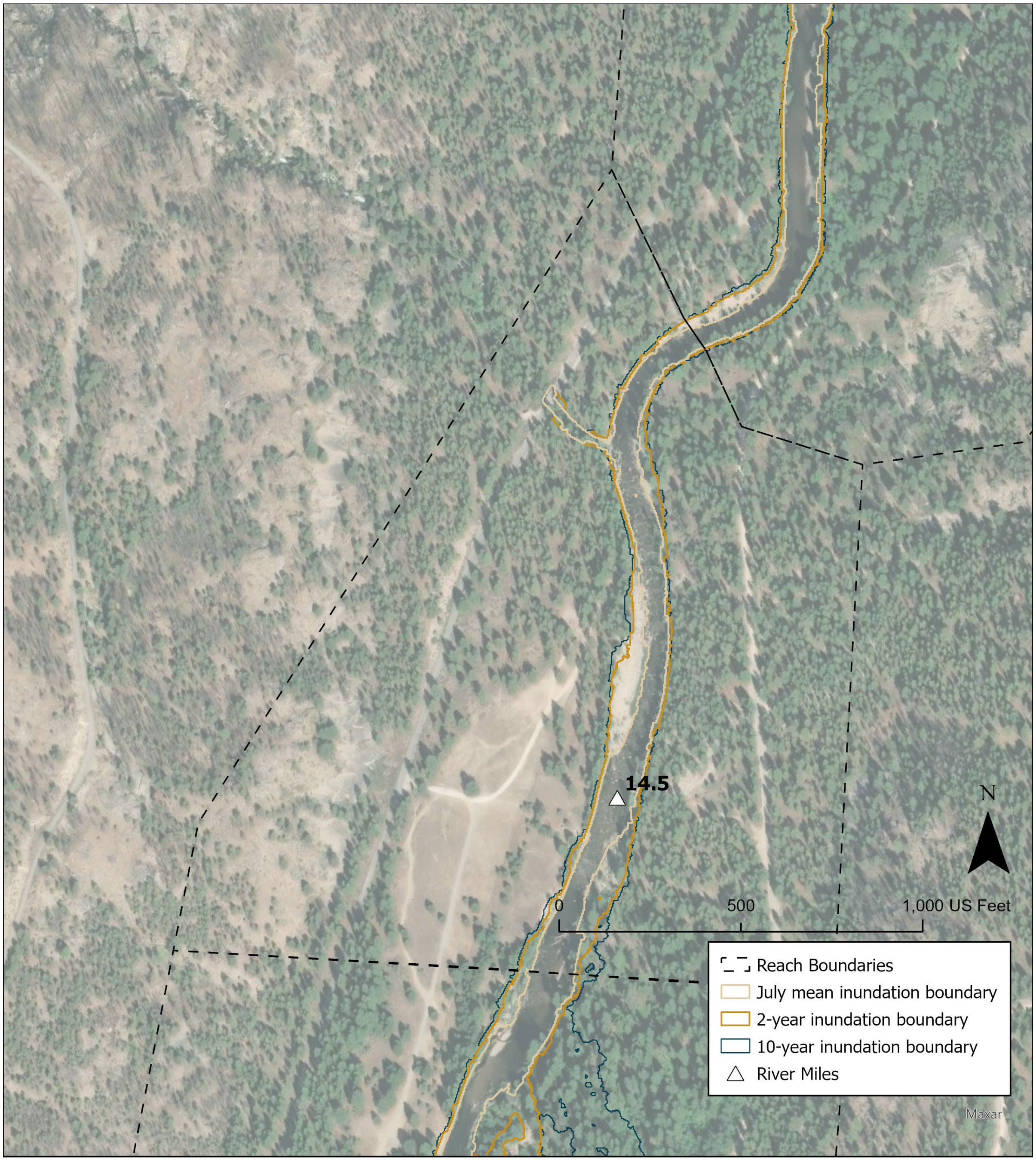

Figure 32.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Doe 3.

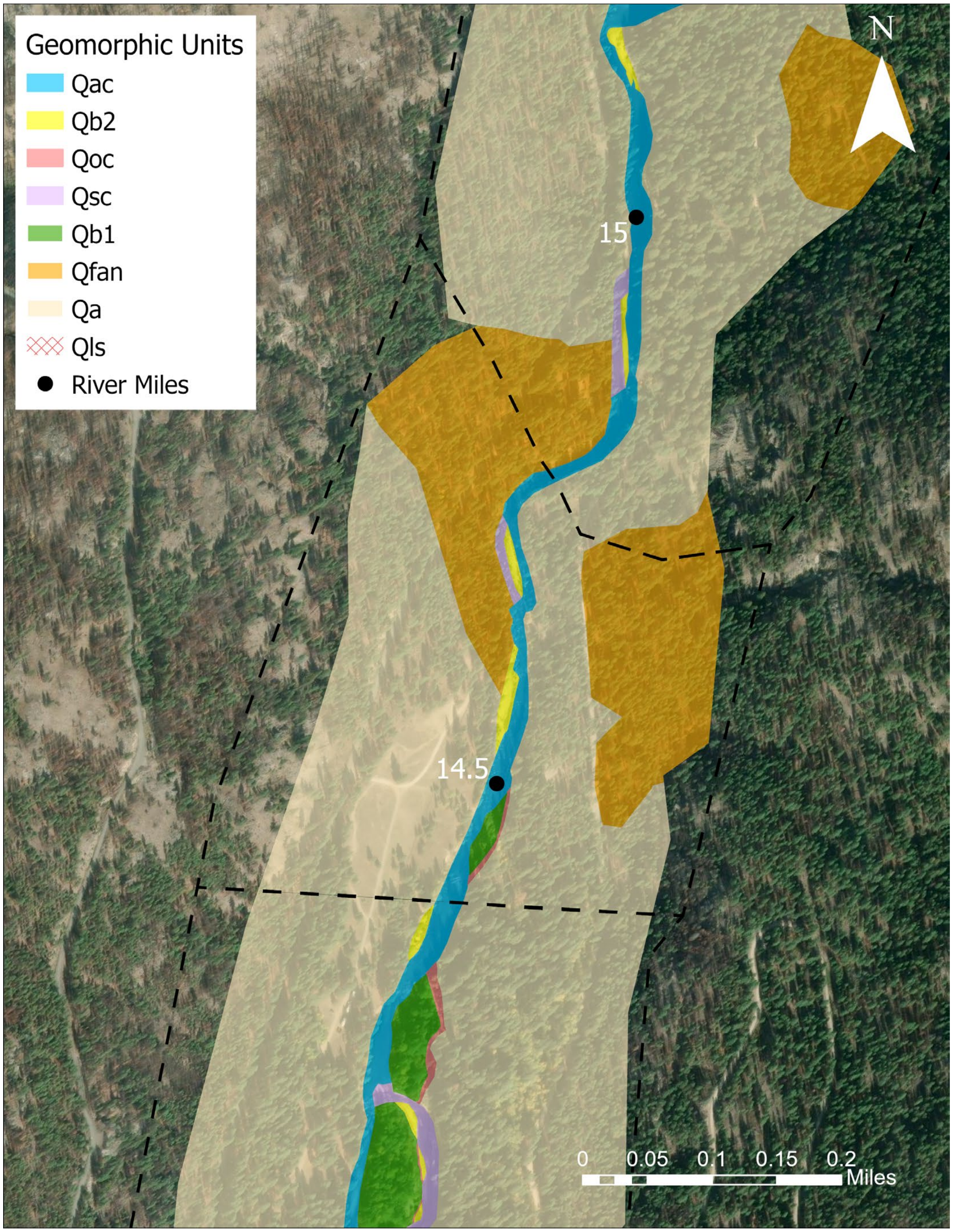

Figure 33.—Geomorphic mapping for 2023 for the Doe 3 reach (RM 14.8 to 14.4). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

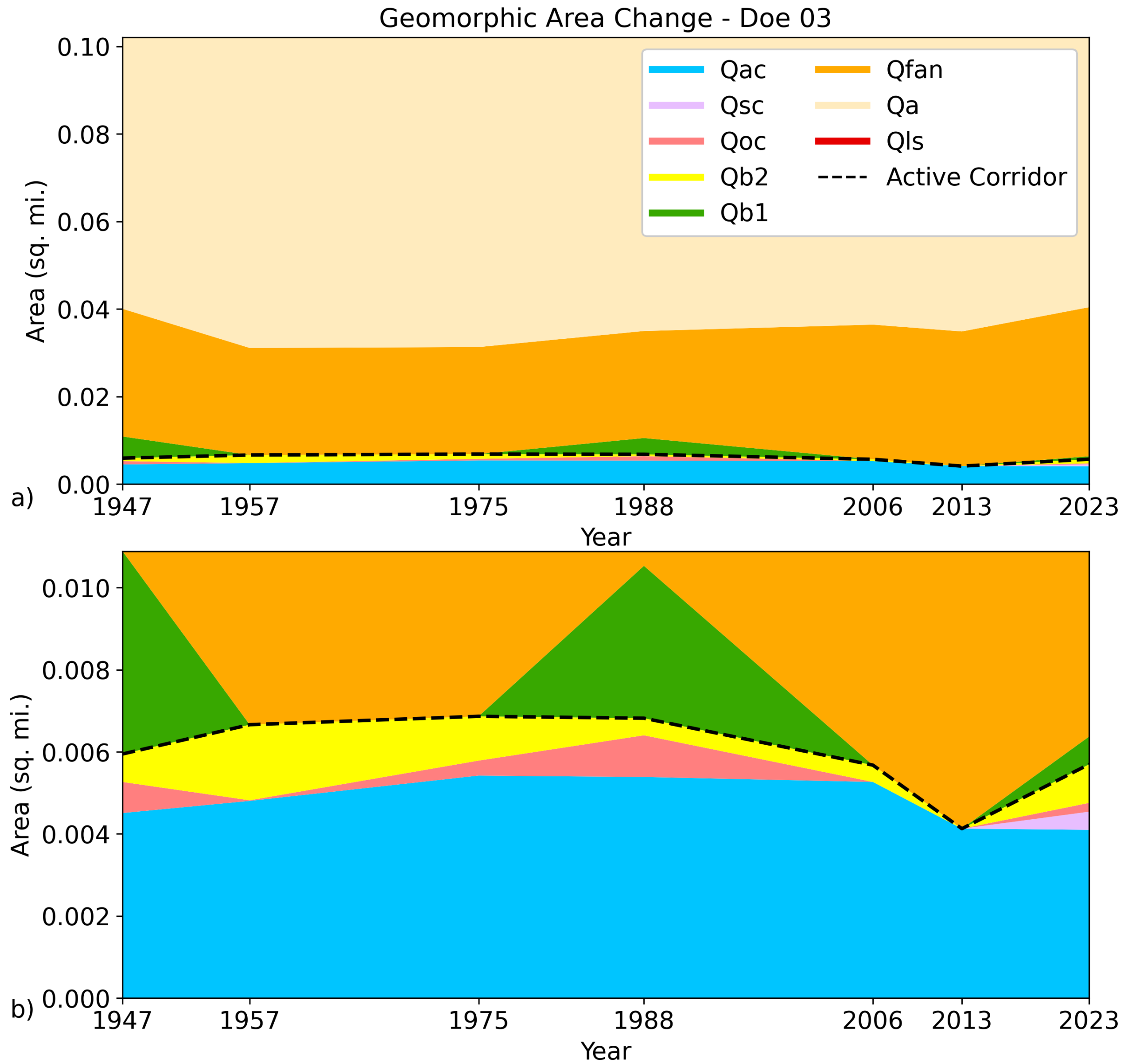

Figure 34.—Geomorphic area change for the Doe 3 reach (RM 14.8 to 14.4) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.5 Doe 2

The Doe 2 reach extends from approximately RM 14.4 to 13.4. Doe 2 transitions from the confined Doe 3 reach to the least confined reach of the Doe prioritization reaches of the Chewuch River (figure 18). With the decrease in confinement, main channel complexity increases with multiple split flow channels throughout the reach (figure 35). The split flow leads to complexity in river hydraulics, which drives more complex river form. Although the channel is more complex, much of the floodplain only connects between the 2- and 10-year recurrence flow (figure 35). Slopes within the reach are substantially lower than the Doe 3 reach (figure 17). With split flow and decreased slope, stream power decreases to relatively low levels as compared to other reaches along the Chewuch River (figure 14). Due to the lower stream power predicted mobile grain size decreases quickly from the spike associated with the Falls Creek confluence in Doe 3. At the downstream end of the reach, the river becomes confined again by valley geometry.

This reach exhibits complex channel networks within the floodplain, and the area of side channels has remained relatively constant through time (figure 36). The Doe 2 reach experienced a general decrease in the active corridor through time, largely due to a decrease in overflow channel and unvegetated bar area (figure 37). A large decrease in vegetated bar area occurred between 1988 and 2006. This is in large part due to disconnection of a large overflow channel complex between RM 14 and 13.5 and RM 14.25 to 14. However, several side channel and overflow channel complexes still exist, just over a smaller area. Around RM 13.75, the valley becomes more confined again where a fan pushes the river against the western valley wall.

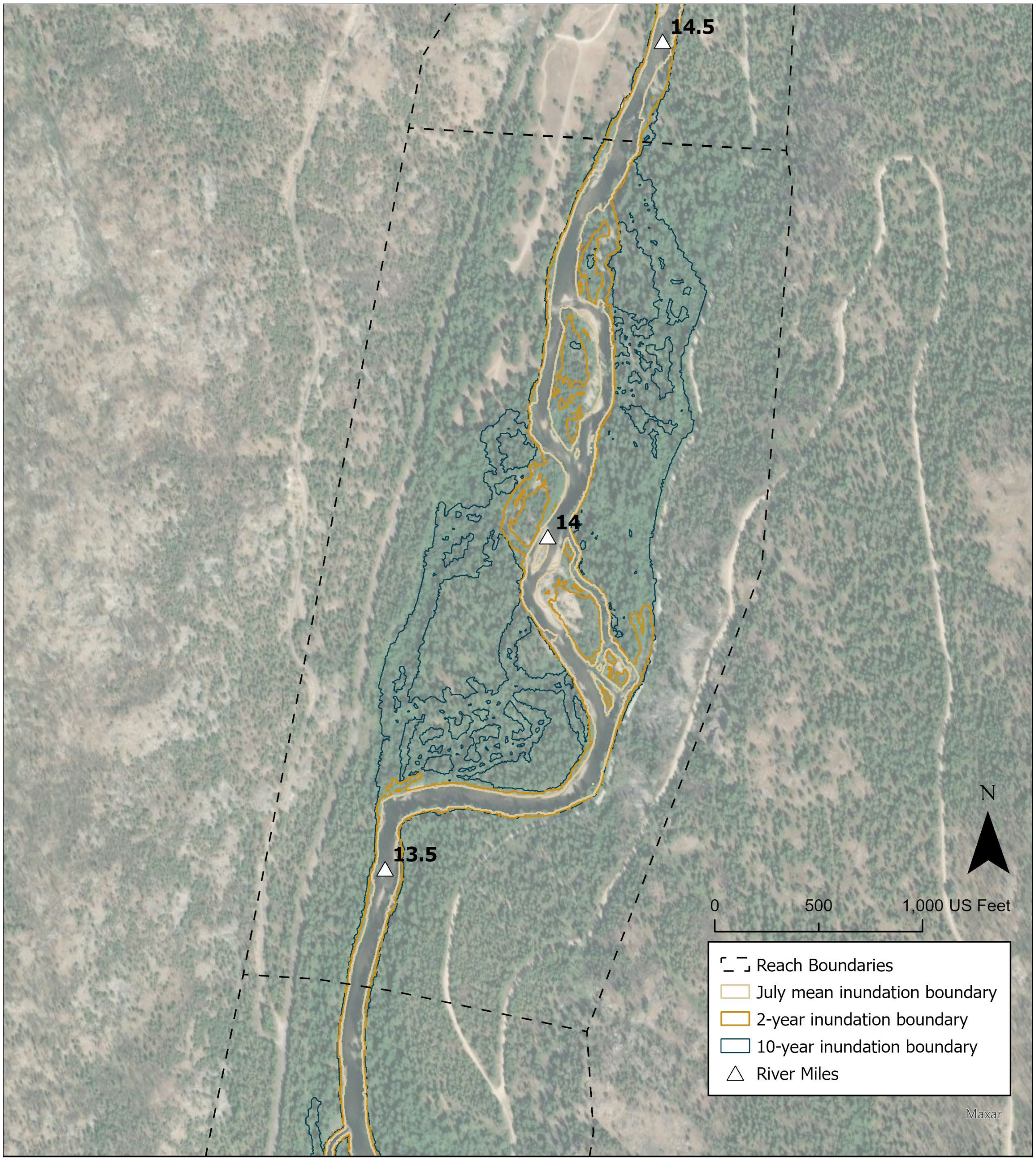

Figure 35.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Doe 2.

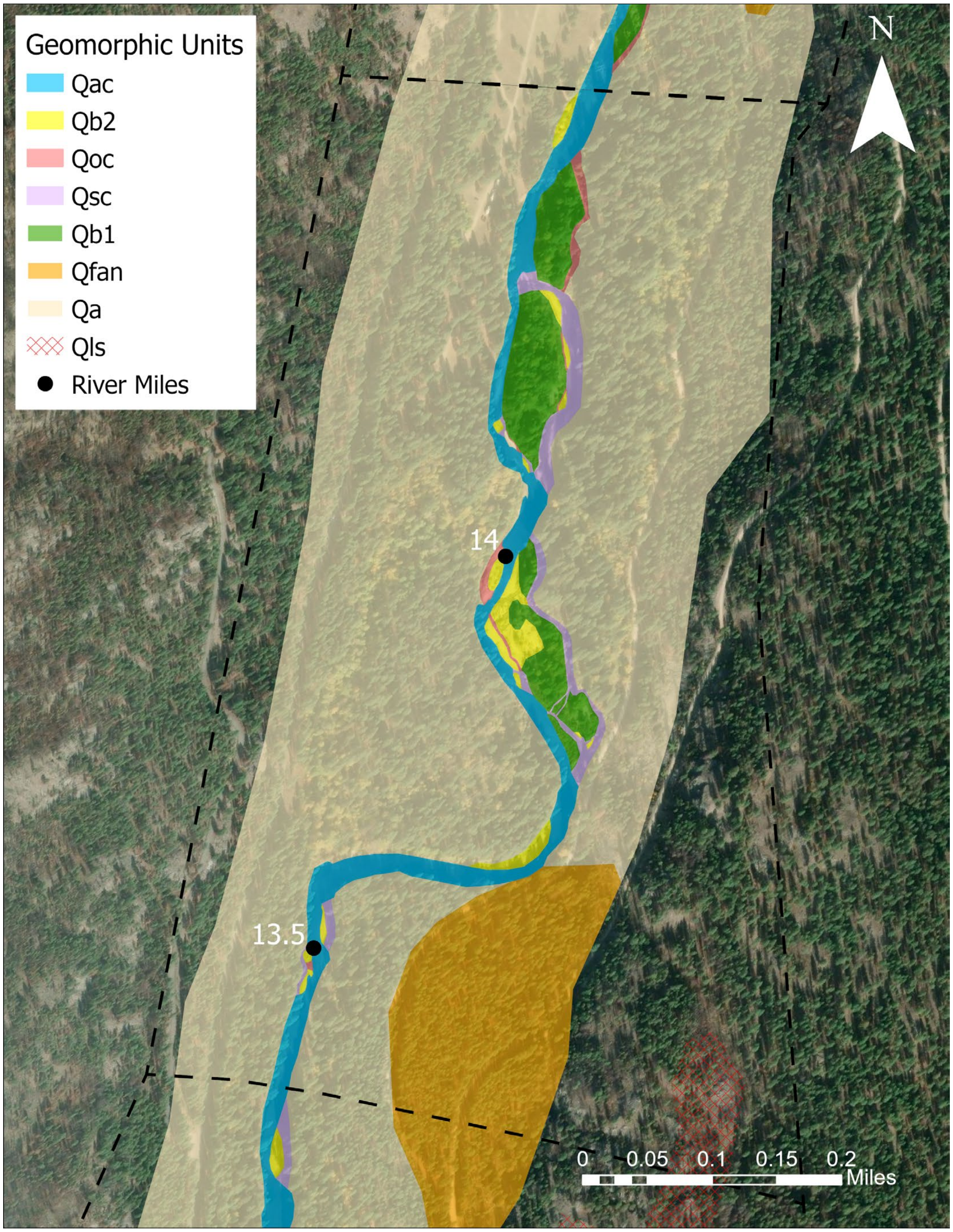

Figure 36.—Geomorphic mapping for 2023 for the Doe 2 reach (RM 14.4 to 13.4). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

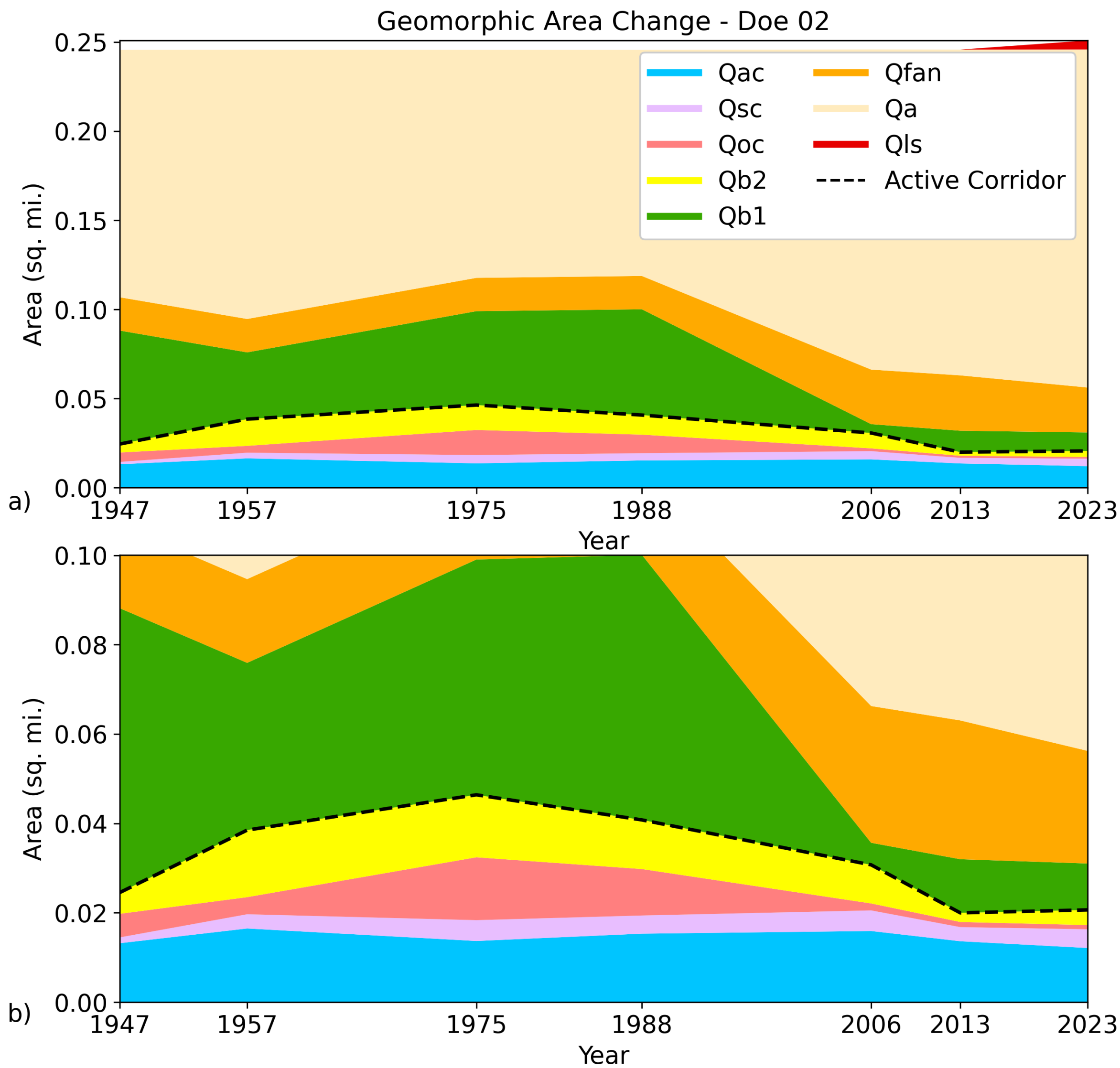

Figure 37.—Geomorphic area change for the Doe 2 reach (RM 14.4 to 13.4) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.6 Doe 1

The Doe 1 reach extends from approximately RM 13.4 to 11.9. Doe 1 transitions from a confined reach to a wider valley bottom with a split flow channel from approximately RM 13.2 to 12.5 (figure 38). Pool-riffle channel forms dominate the reach and more of the floodplain within Doe 1 connects under 2-year recurrence flow conditions than in the upstream Doe 2 reach (figure 19). Similar to Doe 2, slope and stream power are low in Doe 1 as another geologic and hydraulic control exists in the Eightmile Creek confluence at the downstream end of this reach (figure 14; figure 17). Upstream of Eightmile Creek, predicted mobile grain sizes are in the gravel to cobble range (figure 20).

The Doe 1 reach is confined at both the upstream and downstream ends by alluvial fans (figure 39). Between the upstream end of the reach and RM 12.5, several side channel and overflow channels occupy a large portion of the western floodplain. At the downstream end of the reach, the Eightmile Creek alluvial fan pushes the channel against the left valley wall. The area of the active geomorphic corridor has changed little through time. There was a slight increase in area through 1988 due to new side channels and overflow channels activating, and then a slight decrease through 2023 due to abandonment of some of the overflow channels (figure 40). This reach, however, has generally maintained complexity through time and has an active floodplain, which is exhibited in figure 41. The large channel complex between RM 13.4 and 12.5 reduced in complexity in 2006. In 2023, the westernmost overflow channel activated as a side channel (figure 39). The downstream channel complex began narrowing and losing complexity between 1988 and 2006.

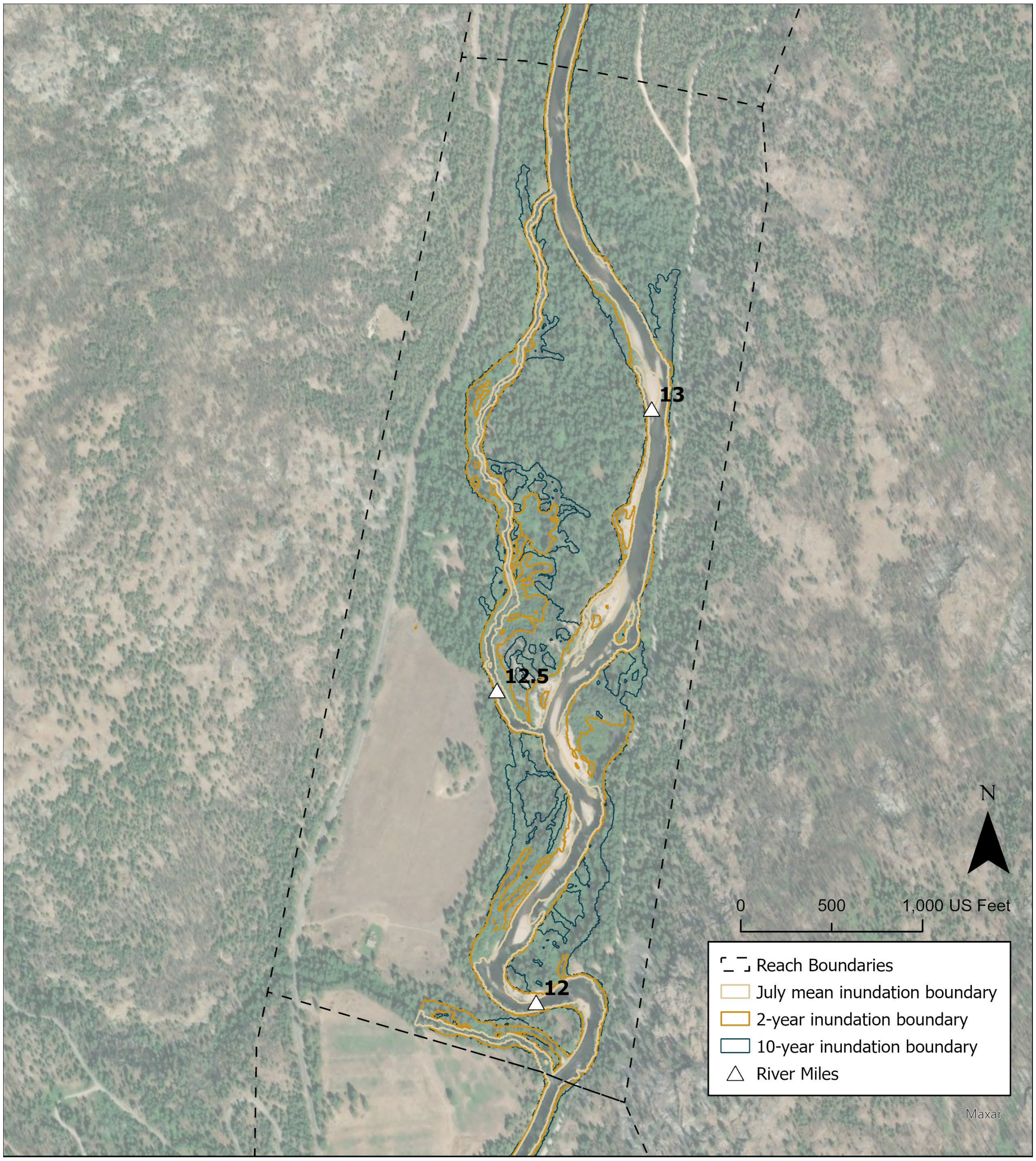

Figure 38.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Doe 1.

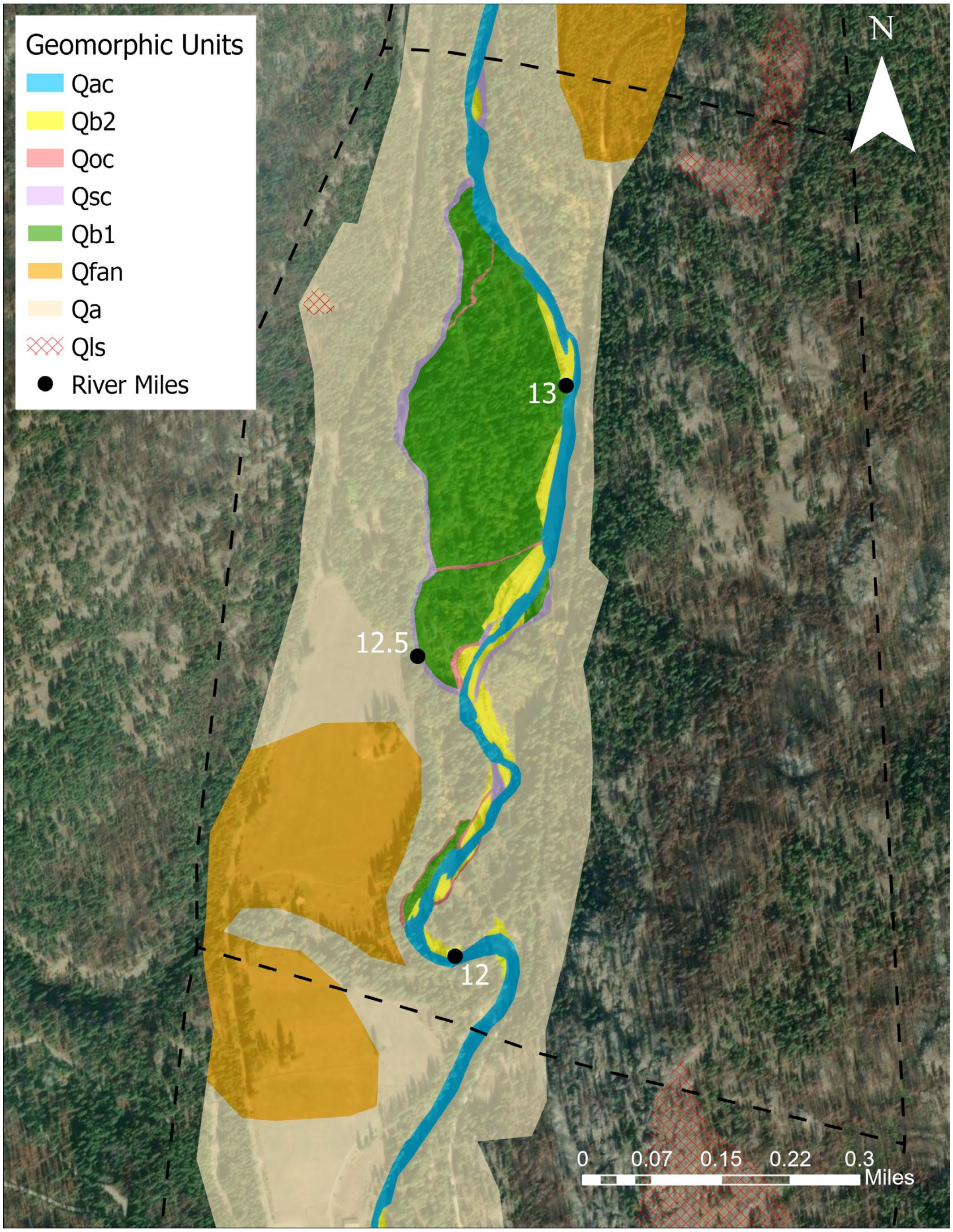

Figure 39.—Geomorphic mapping for 2023 for the Doe 1 reach (RM 13.4 to 11.9). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

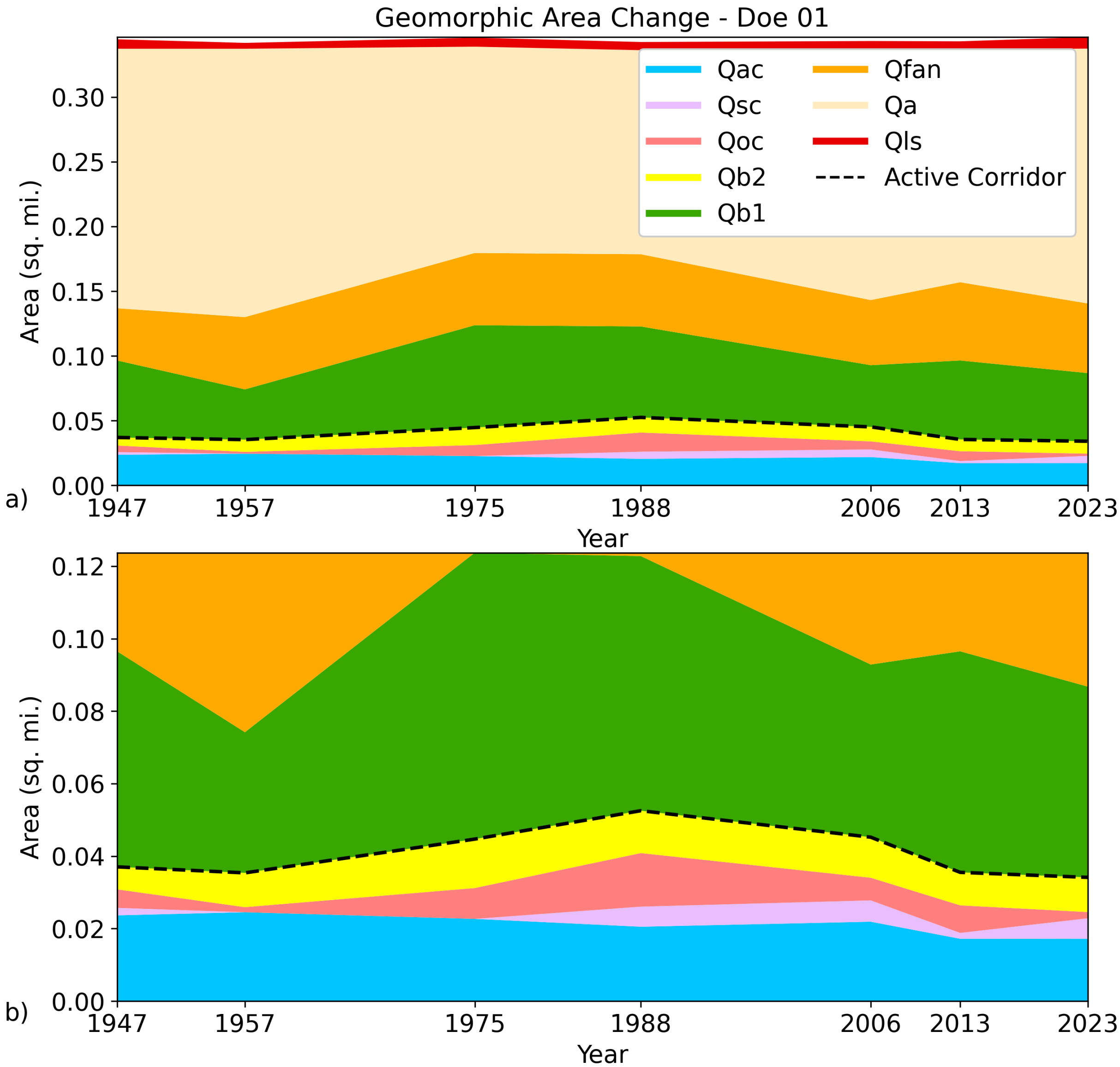

Figure 40.—Geomorphic area change for the Doe 1 reach (RM 13.4 to 11.9) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

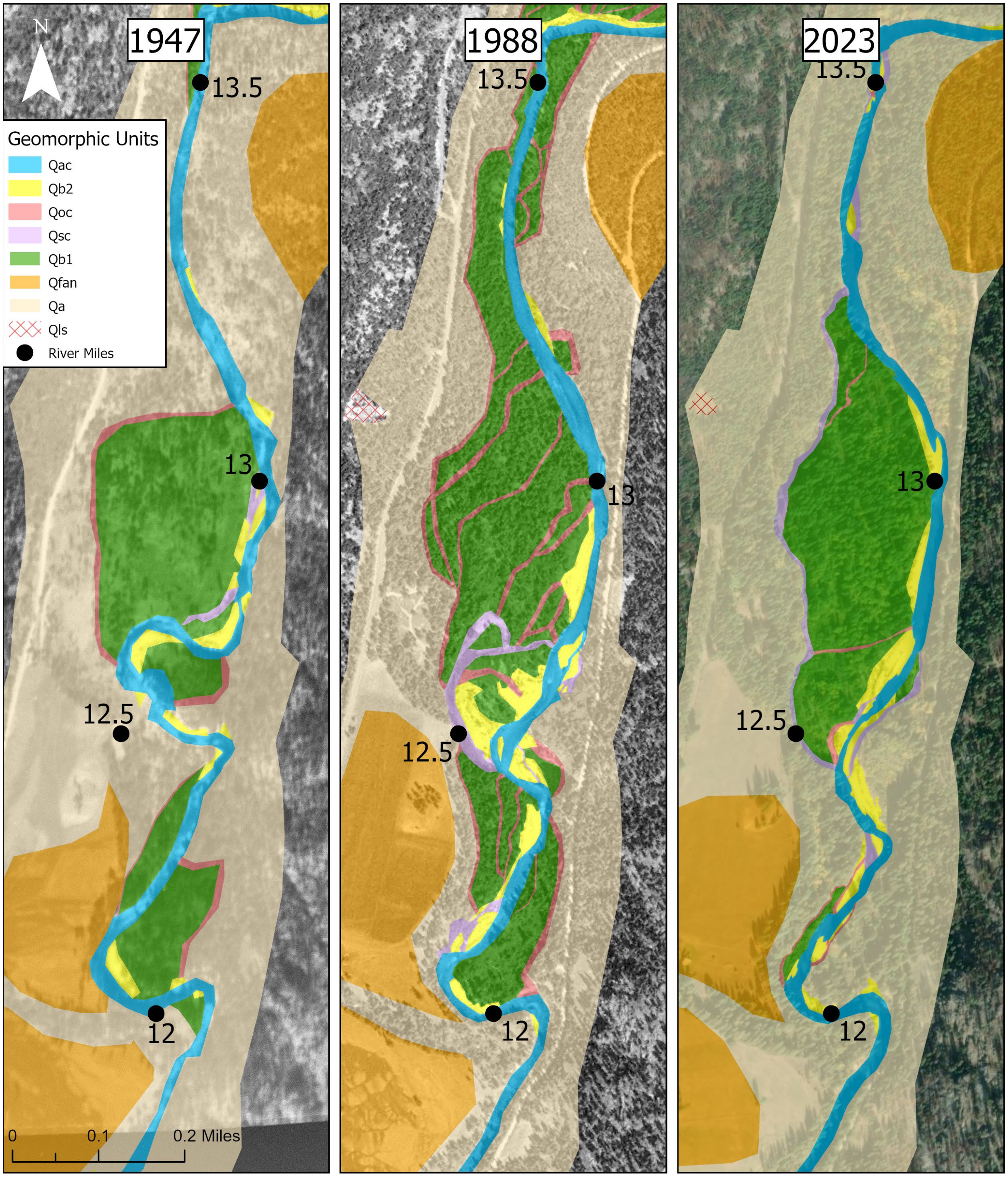

Figure 41.—Geomorphic map comparing the overflow channel and side channel complexes between 1947, 1988, and 2023. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.7 Pearrygin 11

The Pearrygin 11 reach extends from approximately RM 11.9 to 10.6. Like other confluences in the Lower Chewuch River, the confluence of Eightmile Creek increases river flows and the river slightly steepens downstream from the confluence (figure 17). This creates an increase in stream power, though the Eightmile Creek increase in stream power is more muted than the Twentymile, Falls, and Boulder Creek increases (figure 14). The river is relatively confined for the first mile of the Pearrygin 11 reach before a more expansive floodplain becomes available to larger recurrence interval discharges (figure 18; figure 42). The channel is generally straight and uniform in terms of dimensionality. At the few bends within the reach depositional bars and split low flows exist, which creates more hydraulic complexity (figure 42). Flows in the reach are likely to transport cobbles at the upstream end and decreasing in size to more gravels in the lower portion of the reach (figure 20).

The Eightmile Creek alluvial fan on the western side pushes the river to the eastern side of the valley and confines the reach for the first half mile. A moderately large landslide exists on the eastern valley wall but is offset from the channel and probably does not influence channel dynamics significantly (figure 43). The landslide occurred between 1975 and 1988 and has probably stabilized by now. Through time, the area of the active geomorphic corridor has decreased, largely due to decreasing overflow channels (figure 44). The present channel is relatively straight and has very few side and overflow channels. This simplification began in 1988 and is a significant decrease in floodplain activation since 1947. However, image quality in this reach was poor in 1947 and 1957, and so it is difficult to untangle causality.

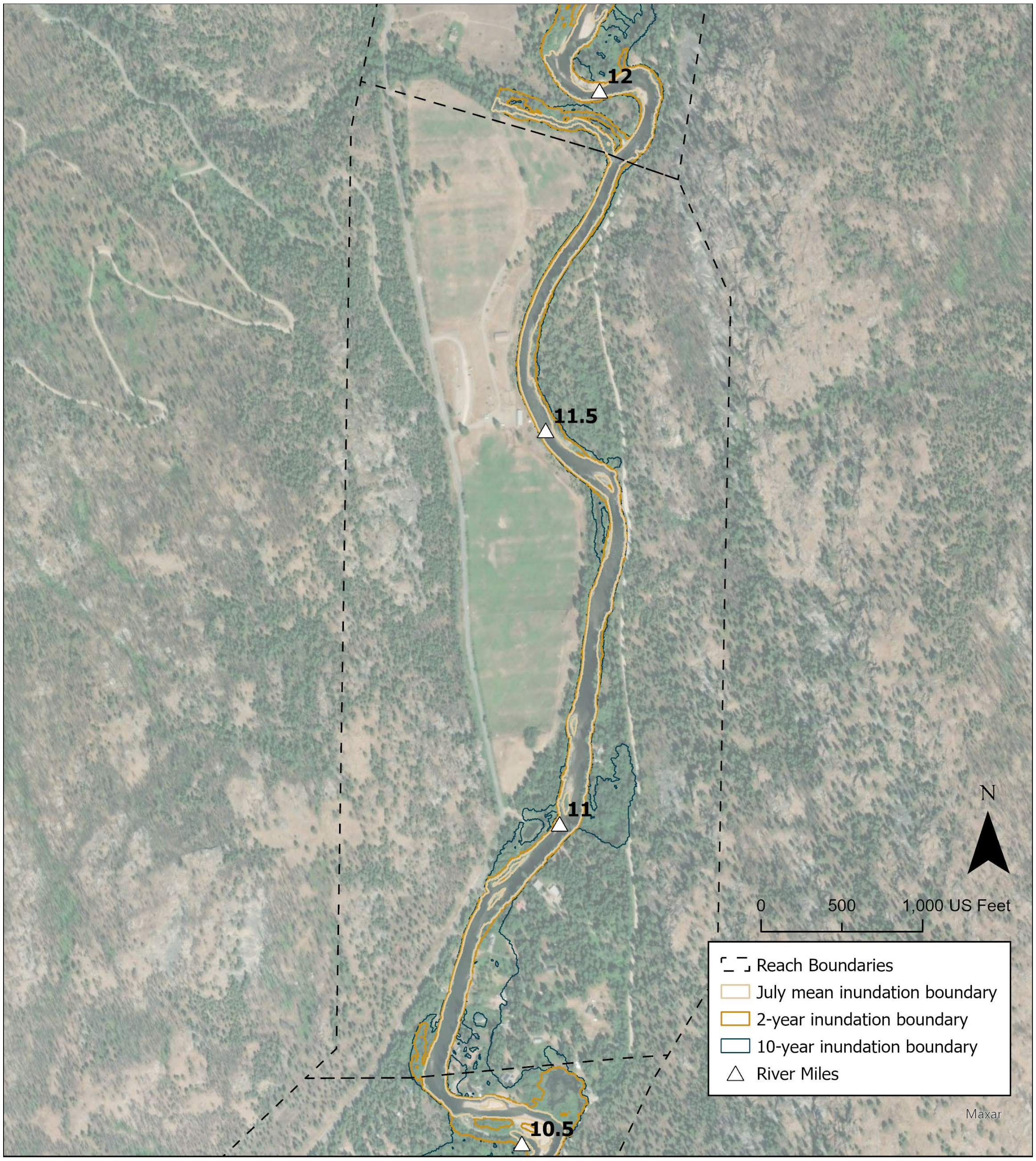

Figure 42.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 11.

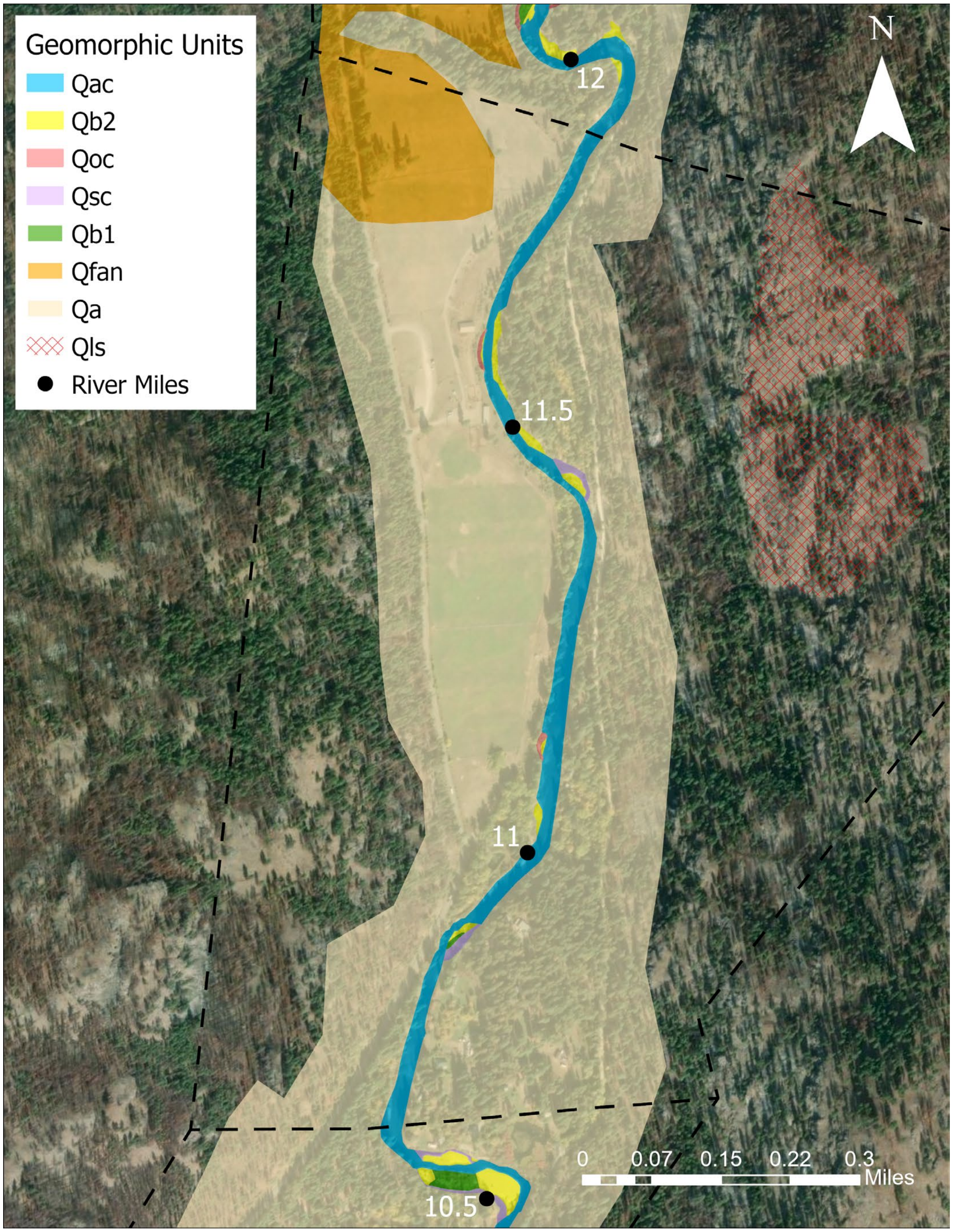

Figure 43.—Geomorphic mapping for 2023 for the Pearrygin 11 reach (RM 11.9 to 10.6). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

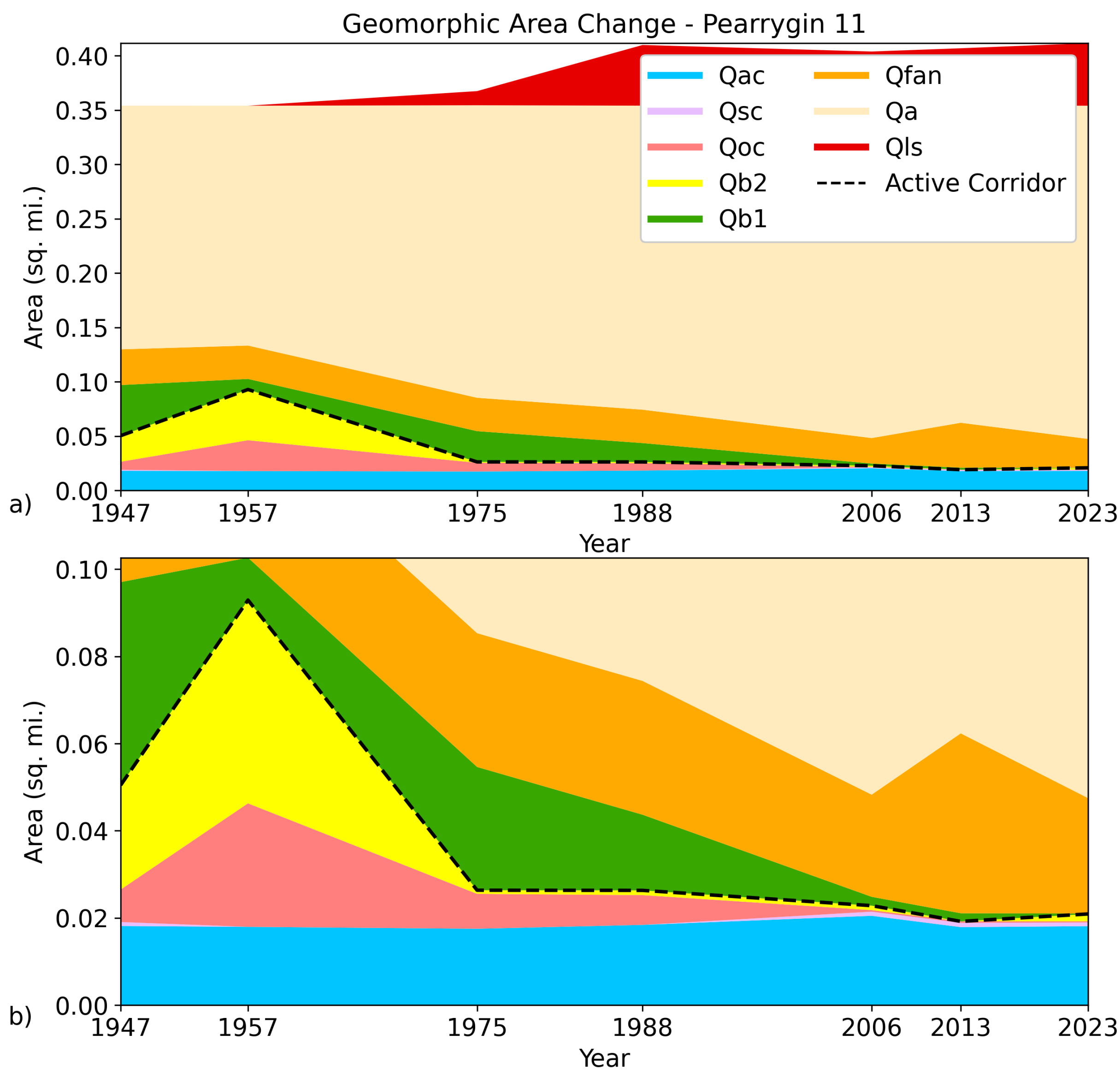

Figure 44.—Geomorphic area change for the Pearrygin 11 reach (RM 11.9 to 10.6) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.8 Pearrygin 10

The Pearrygin 10 reach extends from approximately RM 10.6 to 10. Pearrygin 10 is considerably more complex than the relatively straight Pearrygin 11. The river meanders from the western side of the valley to the eastern side before meandering back to the western side due to the Boulder Creek fan at the downstream end of the reach (figure 45). The large river bends create multiple point bars and an especially complex set of bars and split flows at approximately RM 10.5. The reach has the lowest slope in all the Lower Chewuch River and low stream power (figure 14; figure 17). These conditions are due to the large hydraulic control that the Boulder Creek confluence exerts on this reach, which does not flow into the Chewuch River until Pearrygin 8, but is clear to see in the longitudinal profile of the river (figure 17). Predicted mobile grain sizes are likely to be gravel material upstream of Boulder Creek (figure 20).

As described above, the active channel in the Pearrygin 10 reach meanders from the west to the east side of the valley and then back to the west over the length of the reach (figure 46). Beginning in 1975, the Pearrygin 10 reach experienced a significant decrease in vegetated bar area, decreasing by about 70% from 1988 to 2006 (figure 47). This is largely due to long-term reduction in complexity and disconnection of several overflow channel complexes. In 1947, the entire floodplain within the valley was occupied by a large and complex overflow channel network. This network decreased in complexity through 1975, but still occupied a large portion of the floodplain. Several of the channels reactivated in 1988, and then the complex was completely disconnected from the active channel by 2006, resulting in the current small, localized side channels and overflow channels. The valley through this reach is relatively unconfined except for at the downstream end where the Boulder Creek alluvial fan pushes the river to the western valley wall.

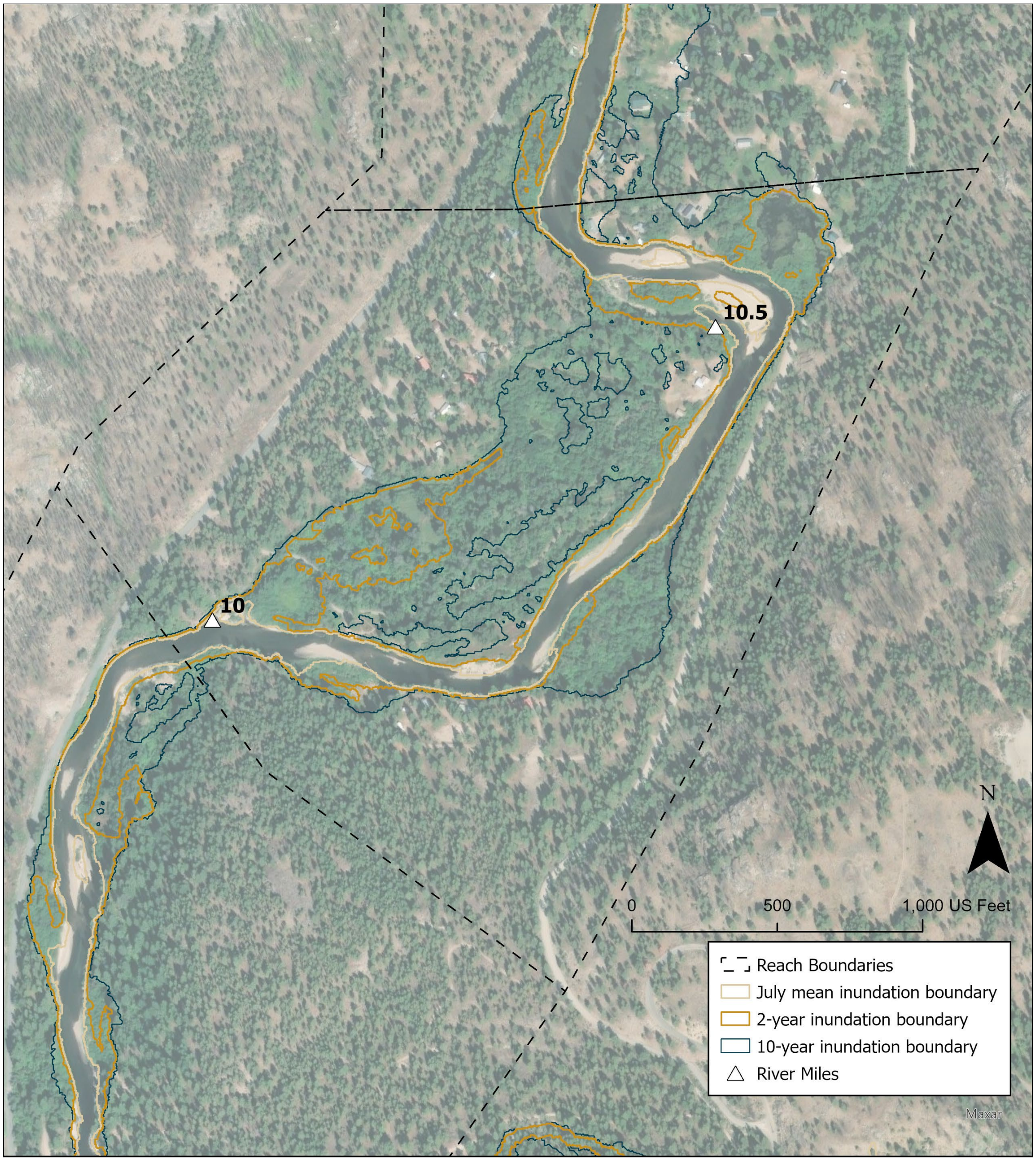

Figure 45.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 10.

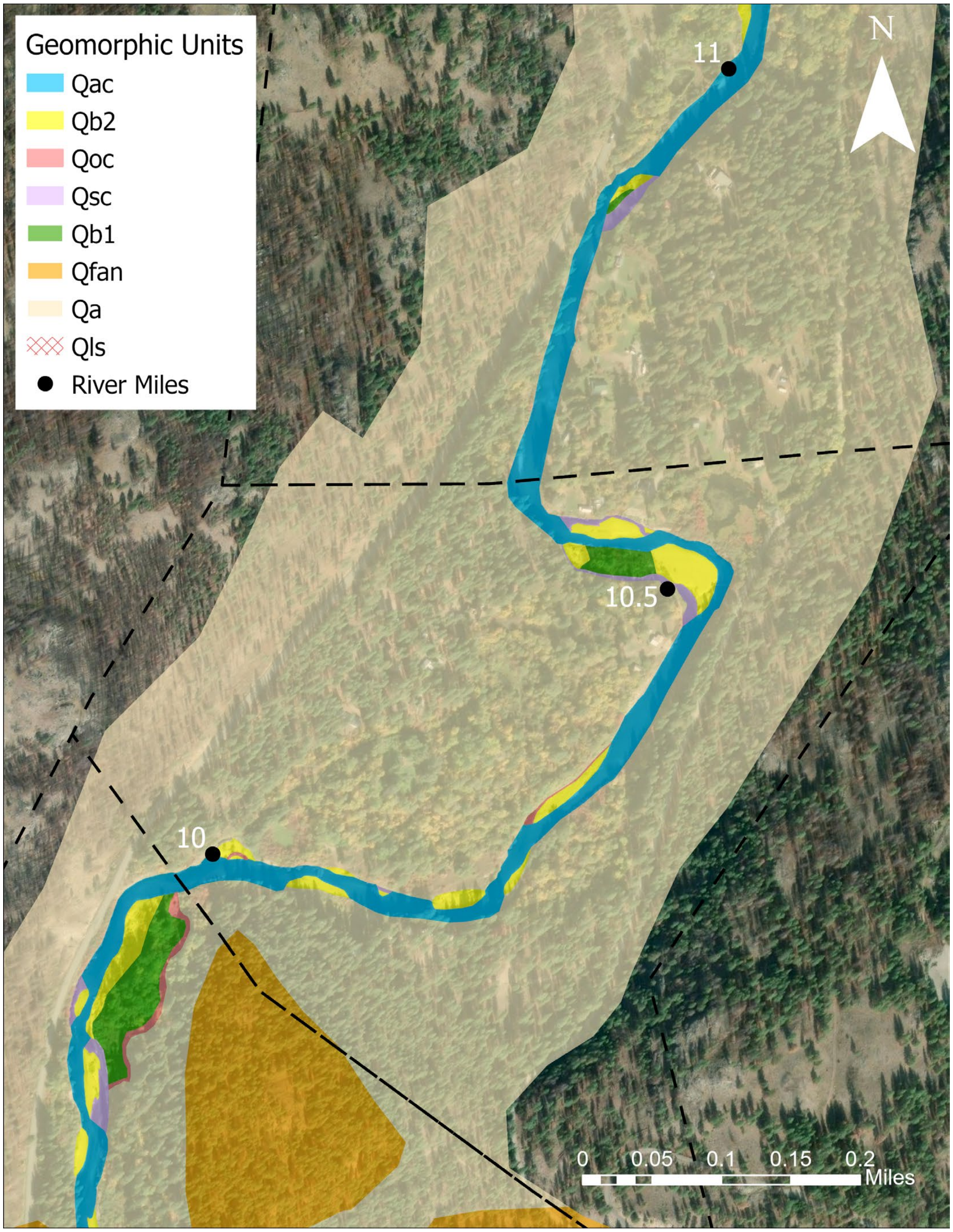

Figure 46.—Geomorphic mapping for 2023 for the Pearrygin 10 reach (RM 10.6 to 10). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

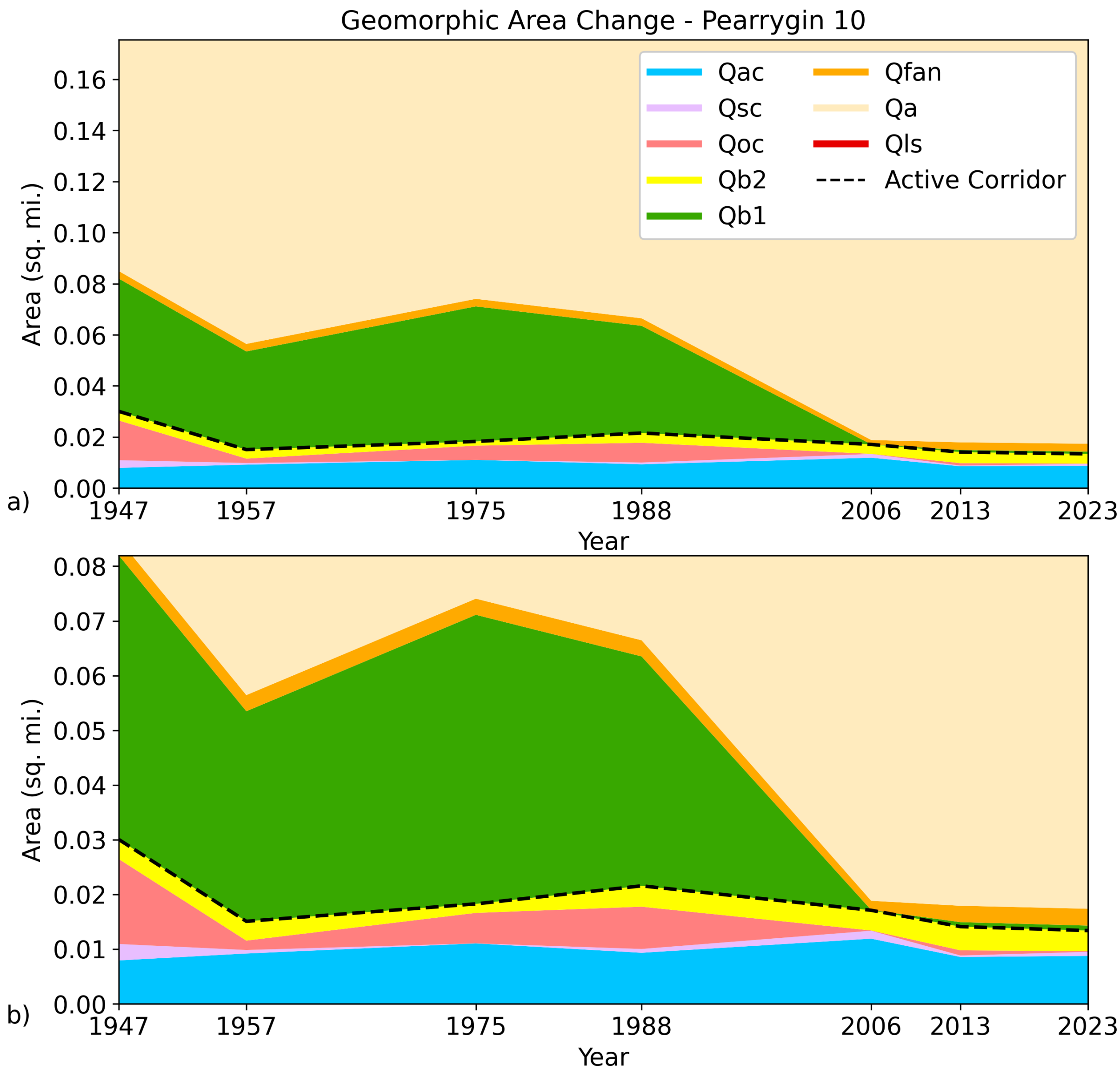

Figure 47.—Geomorphic area change for the Pearrygin 10 reach (RM 10.6 to 10) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.9 Pearrygin 9

The Pearrygin 9 reach extends from approximately RM 10 to 9.5. Pearrygin 9 is a short, straight reach in which the channel is confined between a valley wall and the Boulder Creek fan and ends just downstream from the confluence of the Chewuch River and Boulder Creek. Although the river is straight, small depositional point bars exist as the river has very low slope and stream power before the river bed begins to drop off at the Boulder Creek confluence (figure 14; figure 17; figure 48). This creates some small pockets of relatively well-connected floodplain in the short reach (figure 48). Predicted mobile grain sizes increases greatly from upstream, where gravel is likely mobile, to boulder size material downstream from the Boulder Creek confluence (figure 20).

The Pearrygin 9 reach is a short reach that is confined between the Boulder Creek alluvial fan and the valley wall for the entirety of the reach (figure 49). Due to limited channel mobility within this confined corridor, the channel has remained relatively straight with a consistent active geomorphic corridor area through time (figure 50). The fluctuating vegetated bar area corresponds to activation and deactivation of various overflow channels. From 1947 to 1957, the bar and overflow channel complex at the northern end of this reach disconnected due to westward channel migration. The side and overflow channel complexes in this are generally small and localized to the channel. From 1975 to 1988 some of the overflow channel complexes grew slightly, disconnected from 1988 to 2006, and then reactivated between 2013 and 2023.

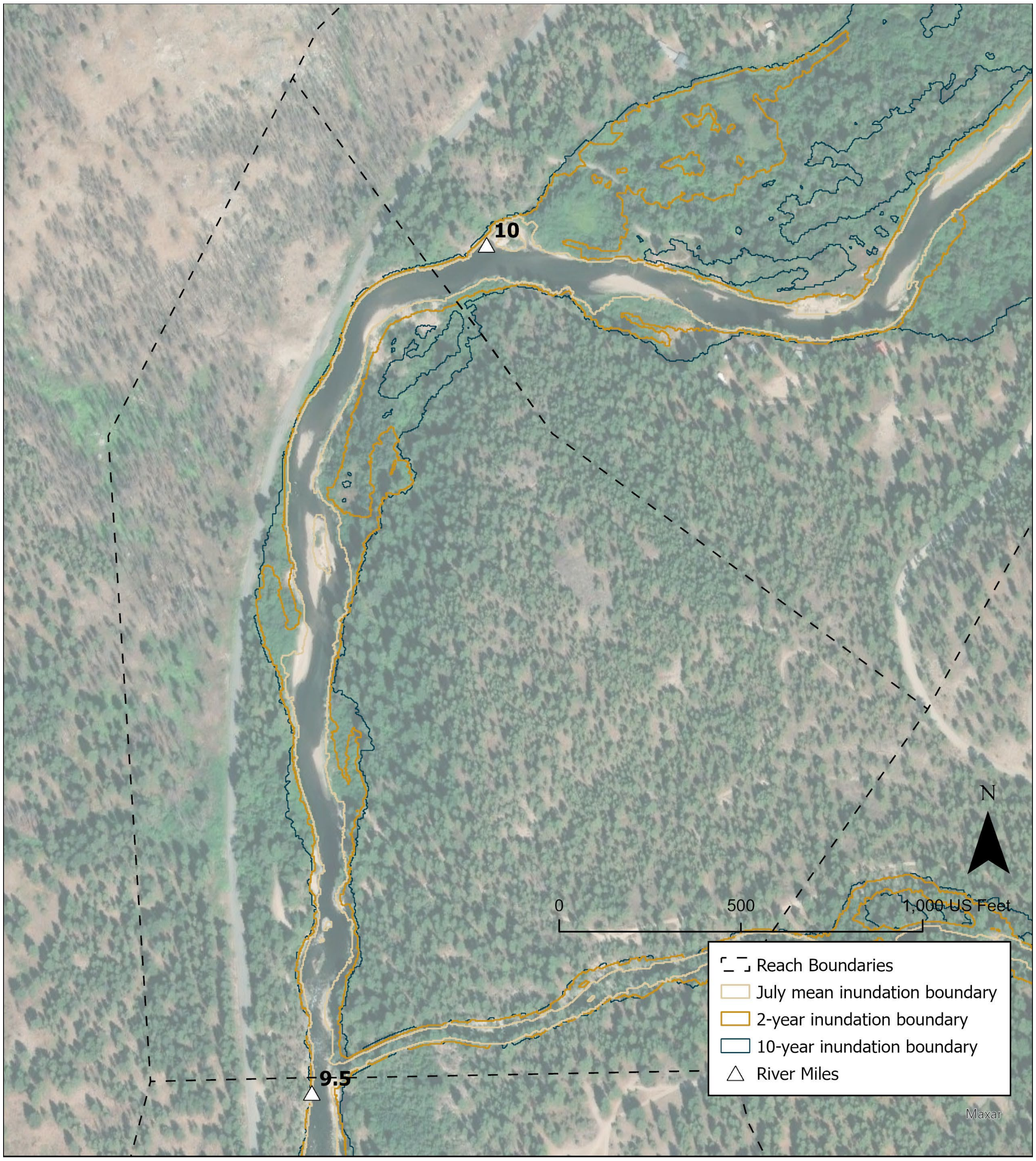

Figure 48.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 9.

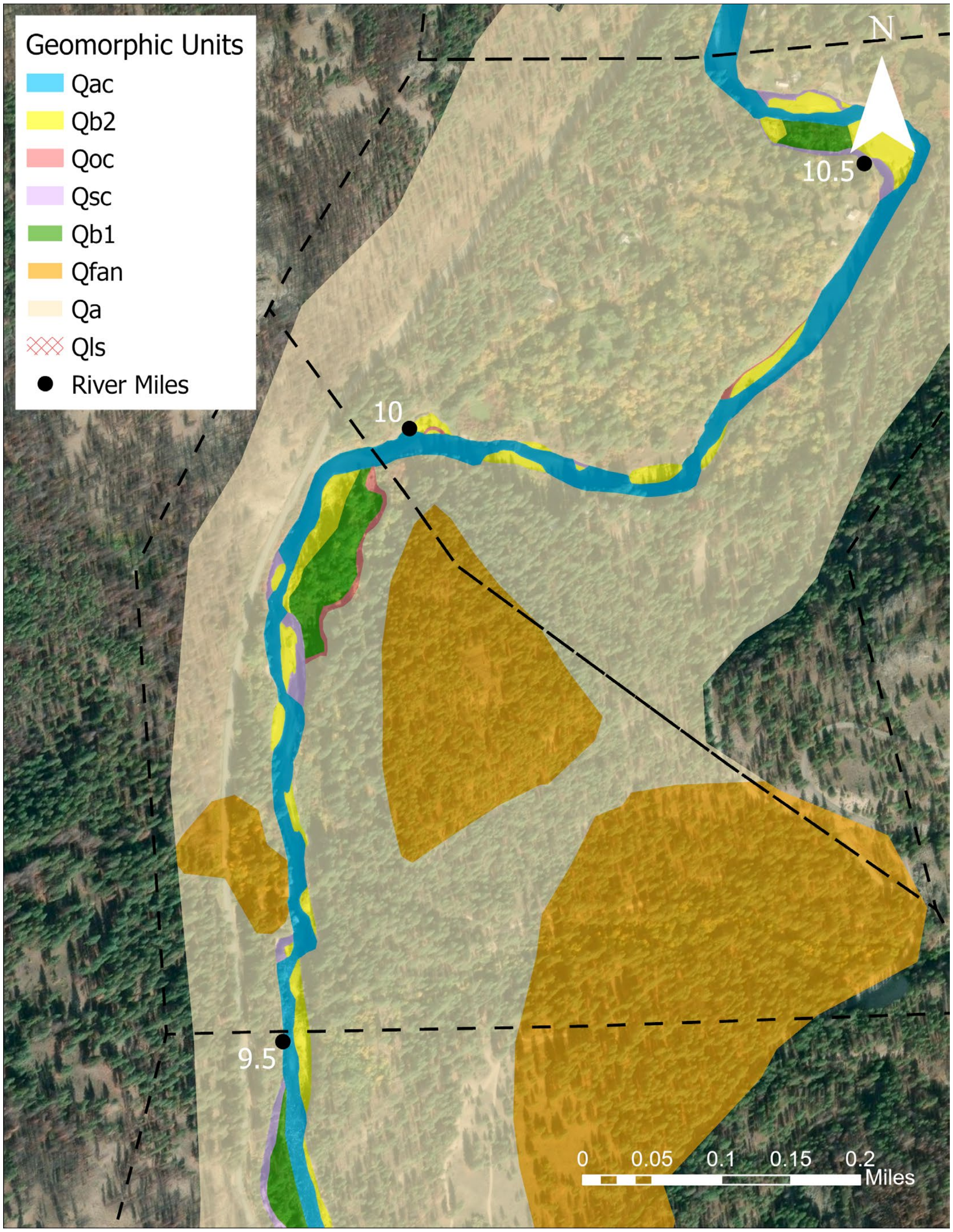

Figure 49.—Geomorphic mapping for 2023 for the Pearrygin 9 reach (RM 10 to 9.5). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

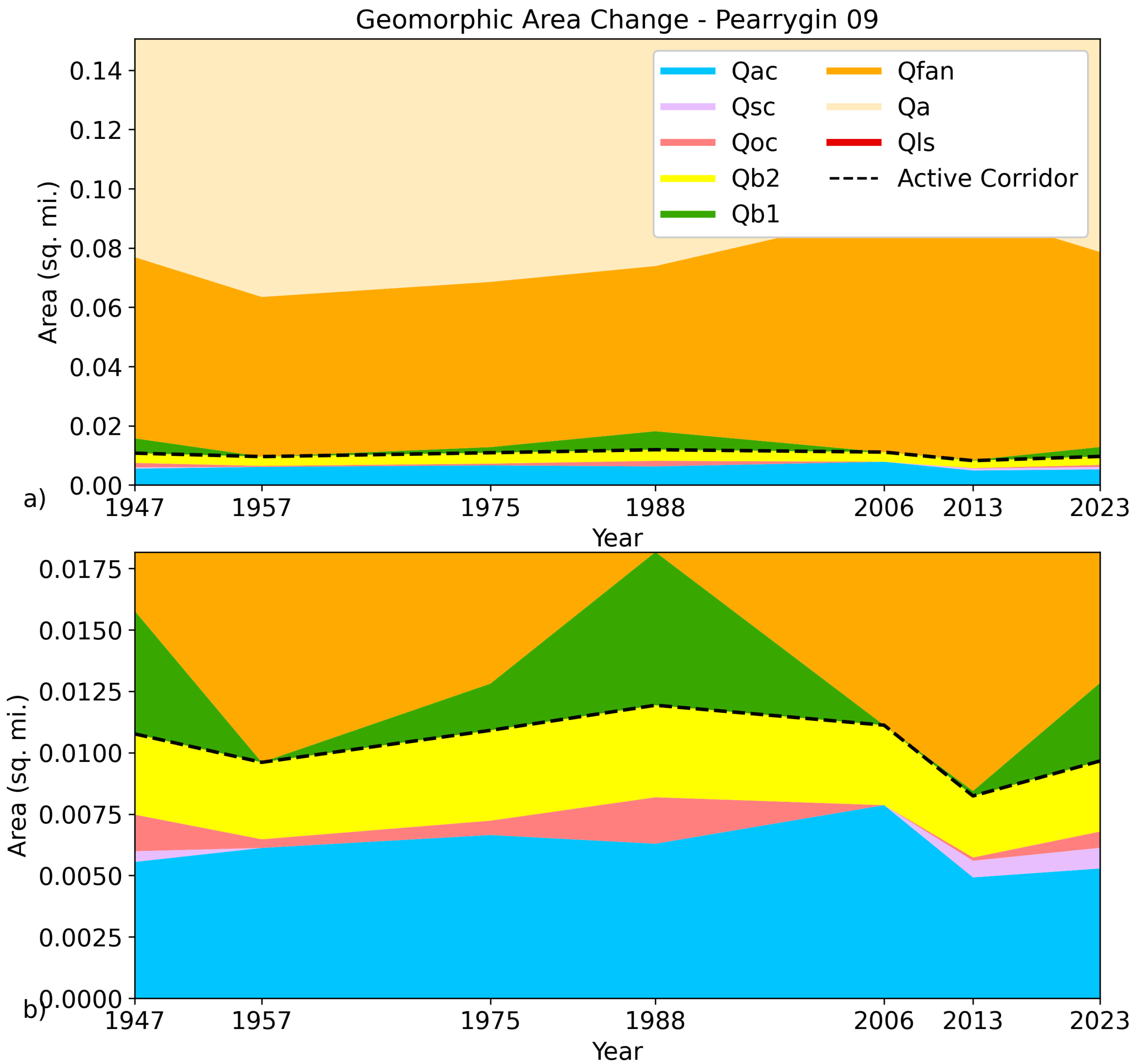

Figure 50.—Geomorphic area change for the Pearrygin 9 reach (RM 10 to 9.5) from 1947 to 2023. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.10 Pearrygin 8

The Pearrygin 8 reach extends from approximately RM 9.5 to 8.6. Pearrygin 8 is the steepest reach in the Lower Chewuch River with extremely high stream power and the ability to move large grain sizes even at the 10-year recurrence flow (figure 14; figure 17; figure 20). Although the river is steep and the main channel is likely to have high velocities, confinement in reduced in the reach and side channels activate at various flows (figure 18; figure 51). In addition, there is a diversion within the reach that connects a side channel on the western floodplain at low flows (figure 51). This side channel is perennial, so a nice habitat feature. However, it does not show up in the geomorphic assessment below because of the engineered flow through the feature. While the main channel splits twice within the reach, the channel is uniform in terms of dimensionality with large bed material throughout.

The upstream end of this reach is confined between the Boulder Creek alluvial fan and the valley wall, but the valley widens downstream from around RM 9.25 (figure 52). Vegetated bar area decreased steadily from 1947 to 2013, but by 2023 was back to pre-1988 levels due to reconnecting the western overflow channel (figure 53). This same complex was active through 1988 and then disconnected. This reach has seen a slight decrease in the active corridor area through time but has been relatively stable overall. Some narrowing and disconnecting of overflow channels occurred through 2013, but these complexes reconnected between 2013 and 2023.

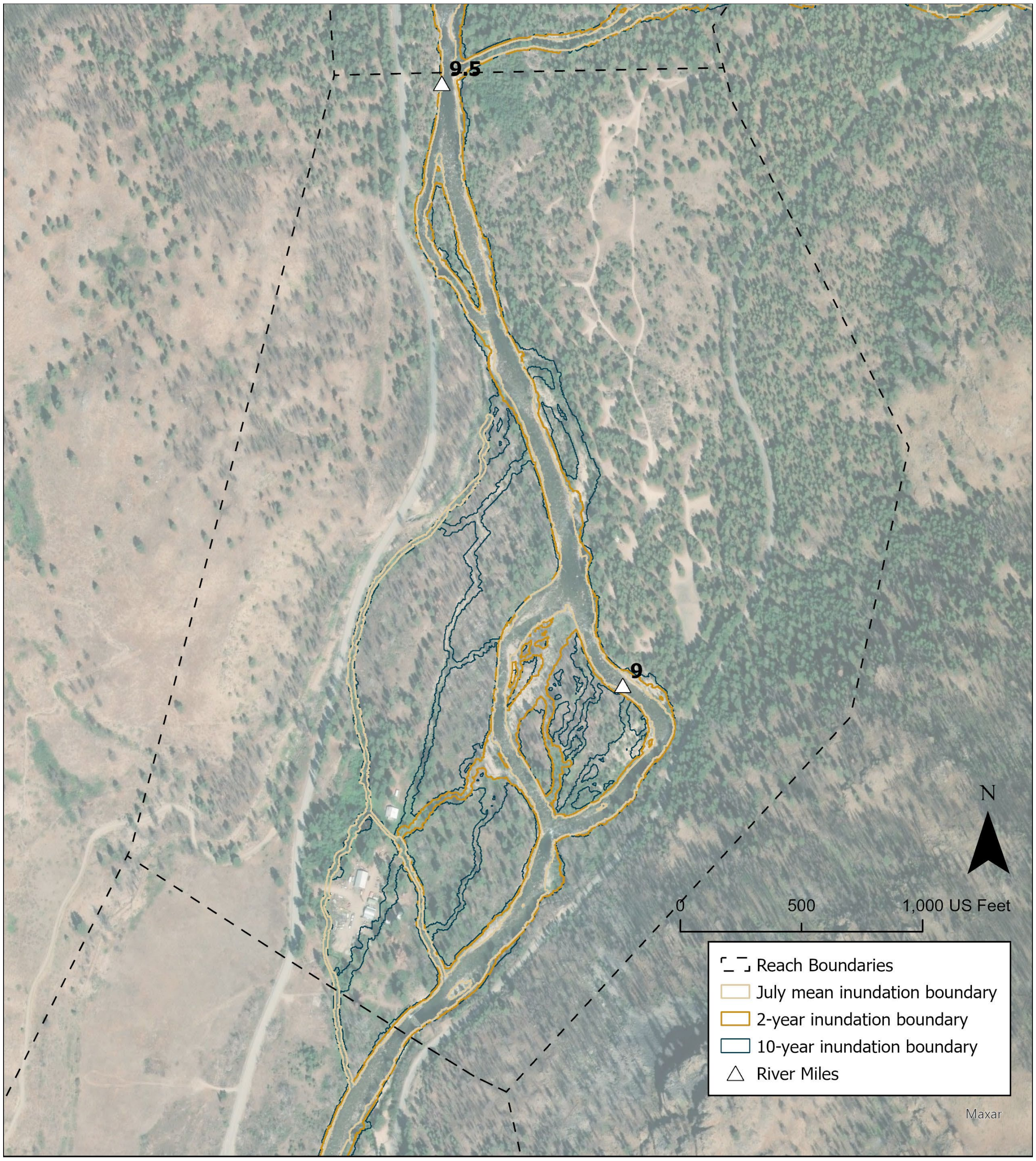

Figure 51.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 8.

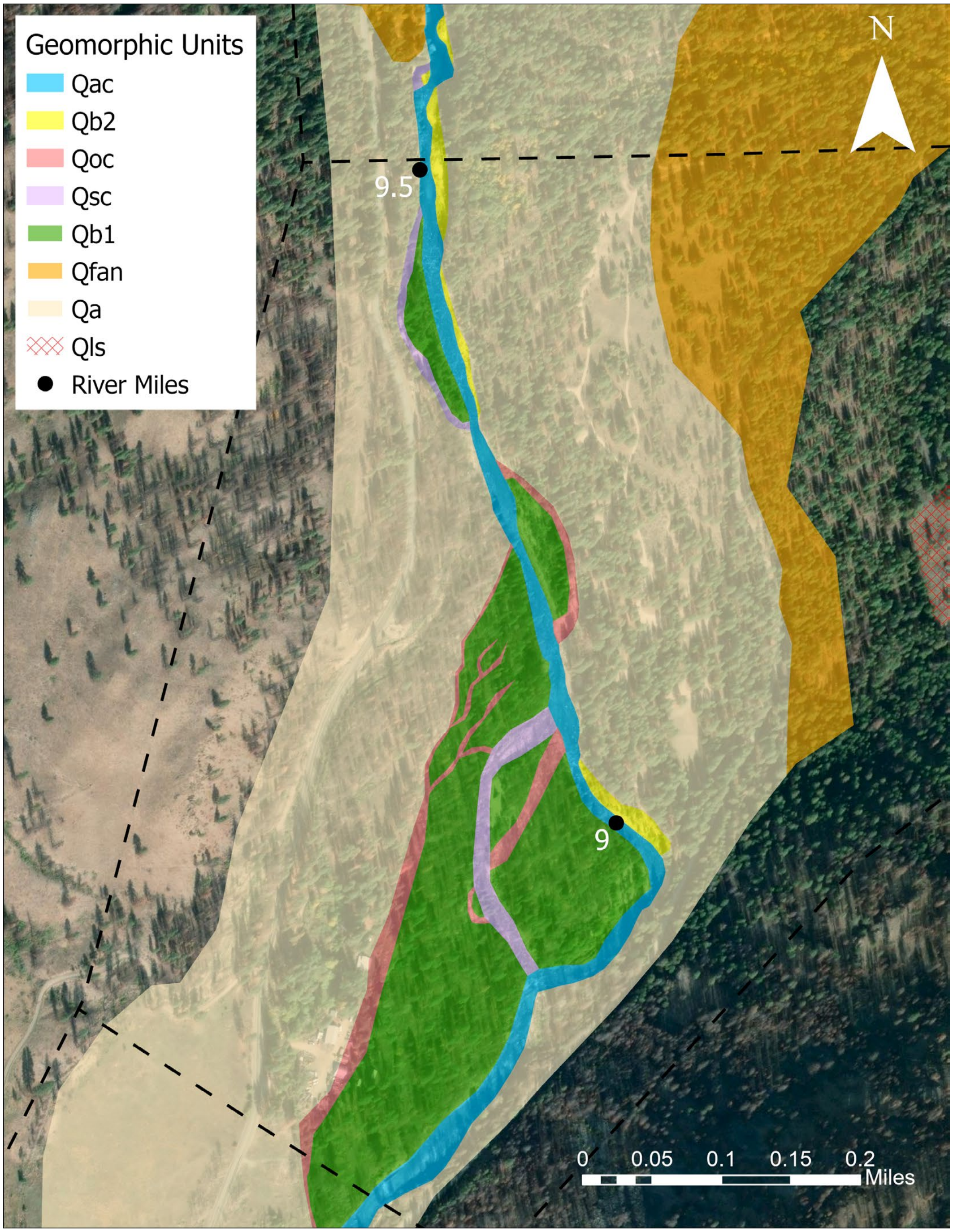

Figure 52.—Geomorphic mapping for 2023 for the Pearrygin 8 reach (RM 9.5 to 8.6). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

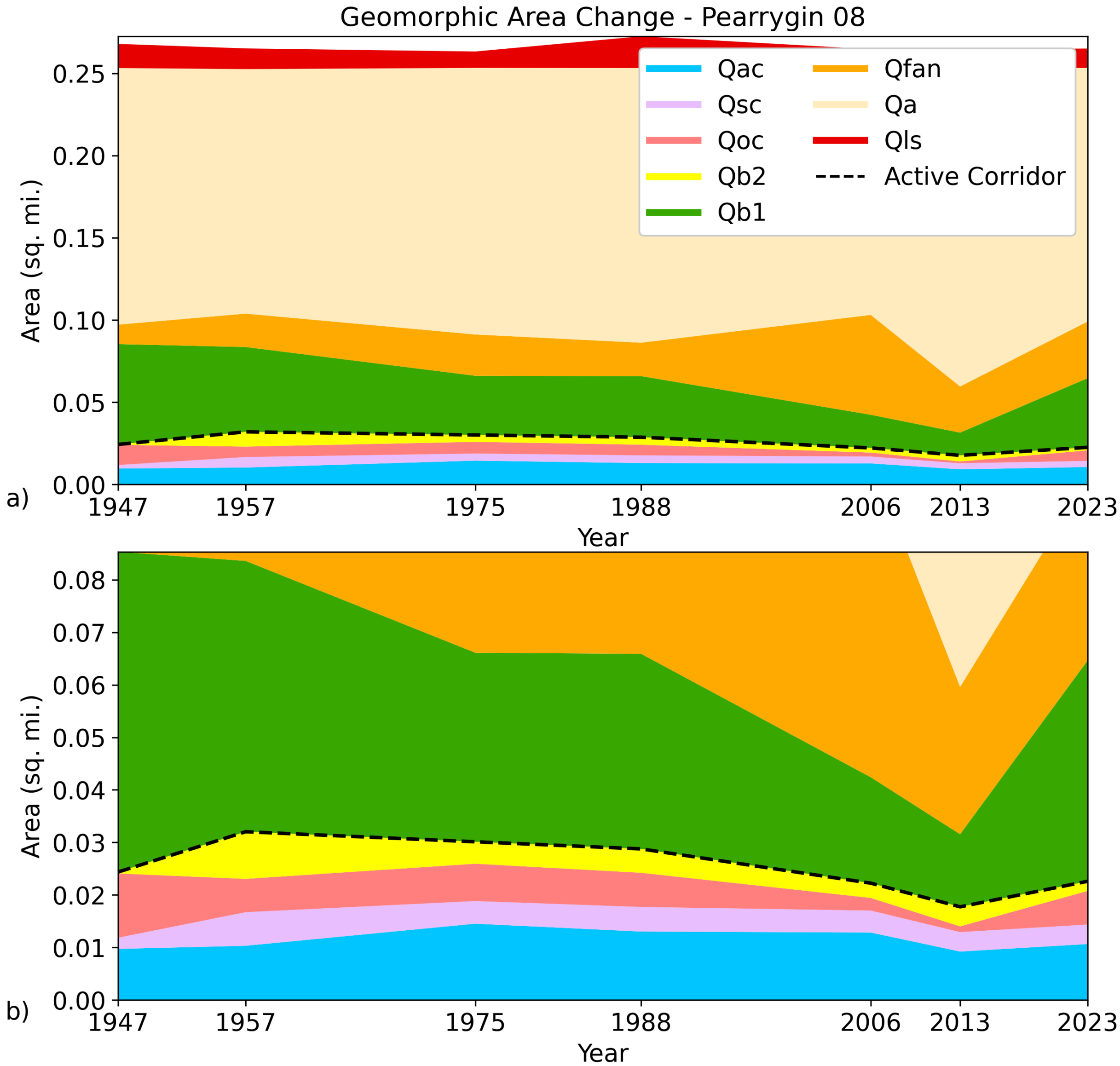

Figure 53.—Geomorphic area change for the Pearrygin 8 reach (RM 9.5 to 8.6) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.11 Pearrygin 7

The Pearrygin 7 reach extends from approximately RM 8.6 to 7.4. The upstream portion of Pearrygin 7 is relatively constricted, and the main channel is uniform with large bed material. The constriction is partially anthropogenically created at approximately RM 8.5 at a bridge crossing, although valley width is relatively narrow in this stretch as well. Downstream from the bridge, valley width increases, but the channel remains uniform until multiple well-connected side channels activate between the July mean and 2-year recurrence flow (figure 54). As the river is pushed west by a large alluvial fan, it is pushed up against the western valley wall and a large bedrock-forced pool is created by the still relatively high stream powers throughout the reach (figure 14; figure 55). Large cobbles are likely transported through the reach at the 10-year recurrence flow which in combination with steep slopes creates the relatively uniform main channel (figure 17; figure 20).

The Pearrygin 7 reach experienced a relatively stable active geomorphic corridor from 1957 to 2023 except for a slight decrease from 1957 to 1988 due to channel shortening (figure 56). From 1947 to 1957, the active channel widened slightly and vegetation clearing increased the area of the active geomorphic corridor. After 2006, fewer side channels were present. This is in part because the active channel switched locations and occupied a prior side channel. The abandoned active channel became an overflow channel. The valley is relatively confined in this reach due to development on the east bank.

Figure 54.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 7.

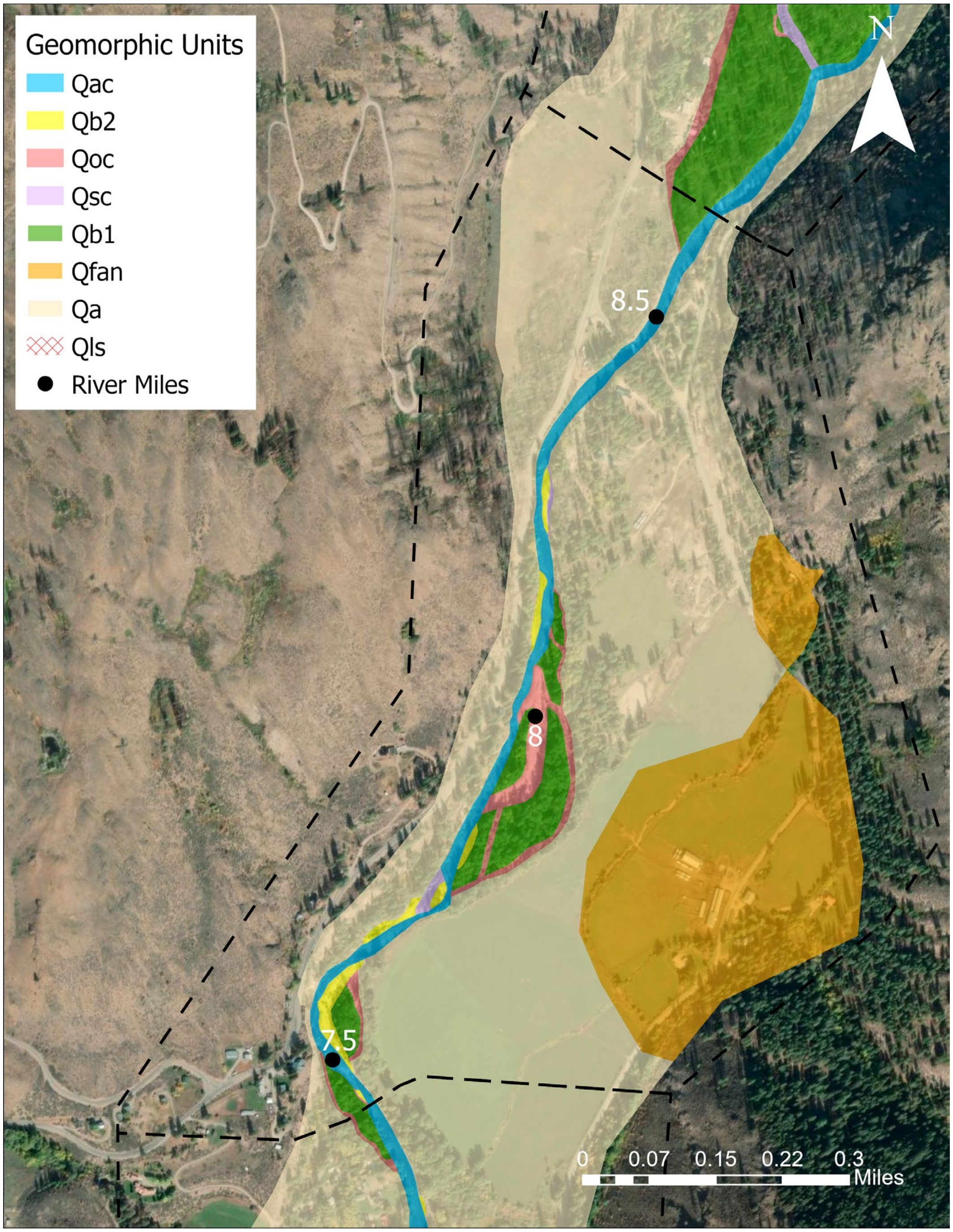

Figure 55.—Geomorphic mapping for 2023 for the Pearrygin 7 reach (RM 8.6 to 7.4). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

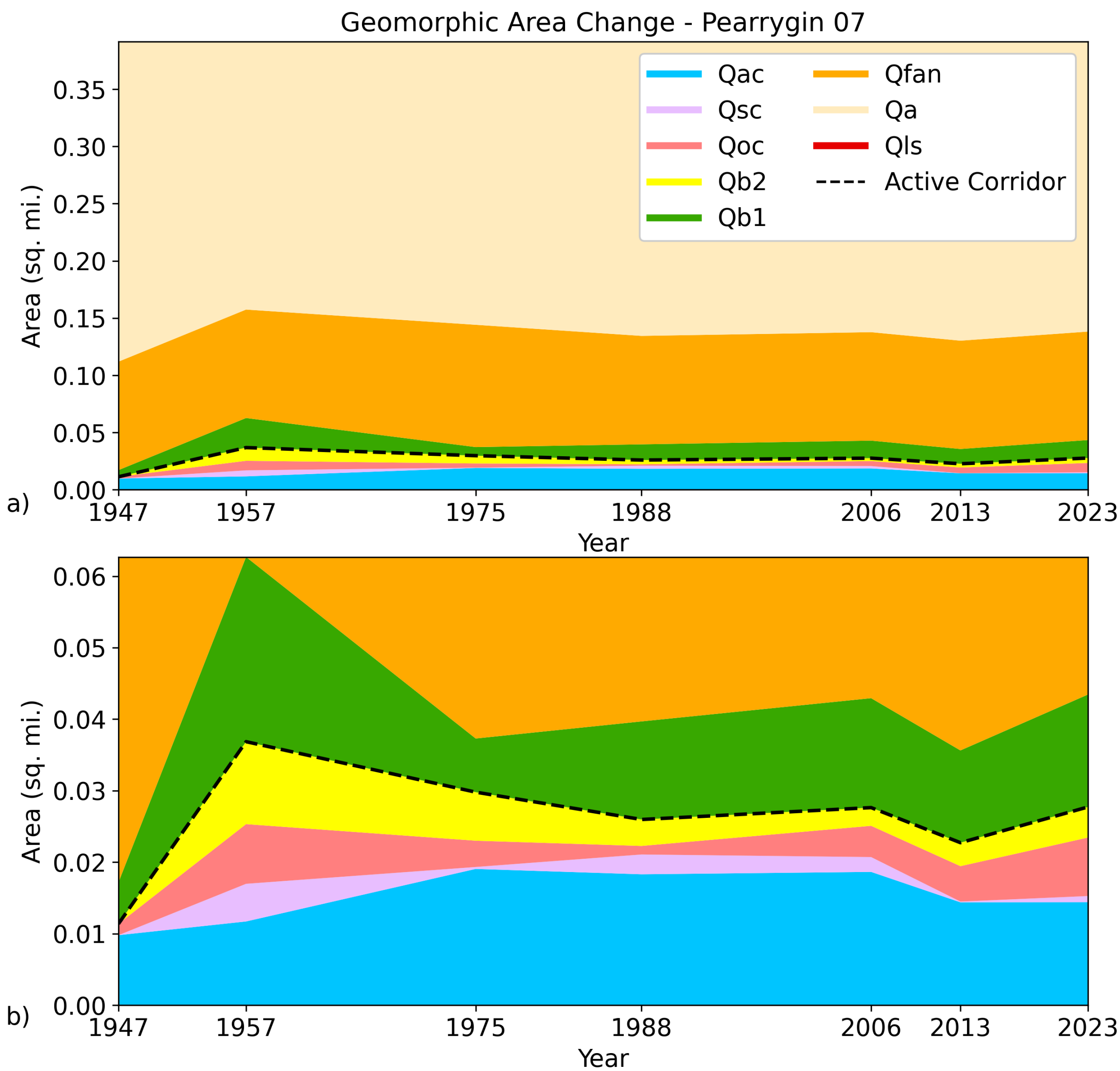

Figure 56.—Geomorphic area change for the Pearrygin 7 reach (RM 8.6 to 7.4) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.12 Pearrygin 6

The Pearrygin 6 reach extends from approximately RM 7.4 to 7.1. The short Pearrygin 6 reach encompasses a broadening river valley and ends with the confluence of Cub Creek. The channel is anthropogenically constricted along a large portion of the reach on the eastern side of the river by a rip-rapped bank, which disconnects a large portion of low floodplain with a wetland and pond (figure 57). Because the river is constricted, the channel is artificially uniform in nature. The west floodplain also has a large amount of infrastructure, but portions do inundate at larger flows like the 10-year recurrence flow. Pearrygin 6 begins an approximate 5 mile stretch of river with similar grain size mobility in the range of large gravels and small to moderate cobbles (figure 20). Slope and stream power decrease through this reach, though Cub Creek has a minimal impact on the long profile of the Chewuch River (figure 14; figure 17).

The current channel planform of Pearrygin 6 is very simplistic with one small overflow channel due to the anthropogenic constriction (figure 58). Naturally, the valley here is generally wide. The Pearrygin 6 reach experienced a large decrease in active geomorphic corridor area from 1957 to 1988 (an approximately 70% decrease; figure 59). The large increase from 1947 to 1957 is due to channel straightening and vegetation clearing that resulted in the previous main channel becoming a side channel. After the cleared vegetation regrew by 1988, the area of the active geomorphic corridor has remained stable. However, the area of side channels and overflow channels has also decreased in this time, greatly reducing the complexity of this reach. The area of vegetated bars has also decreased as channels are disconnected from the active channel.

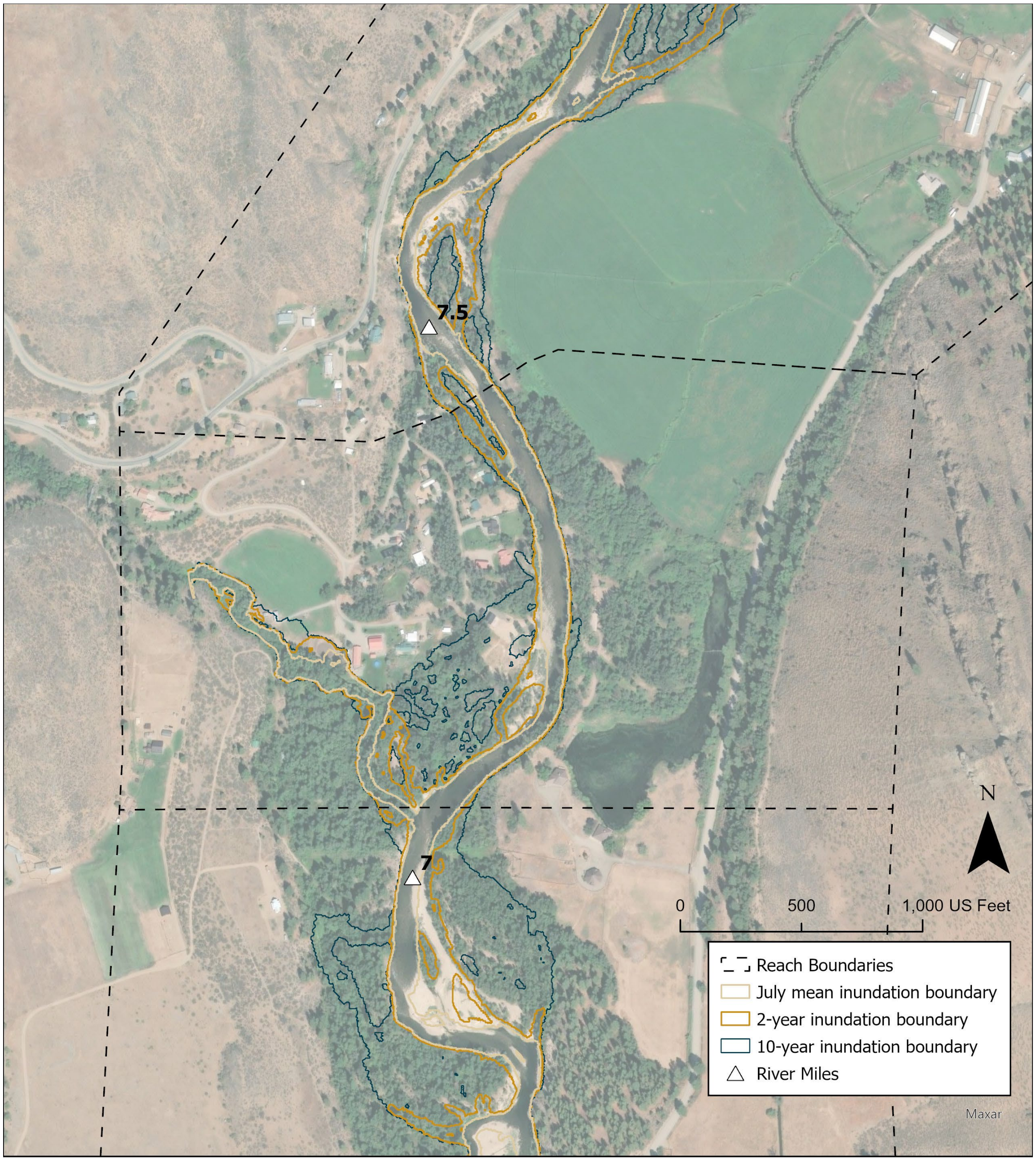

Figure 57.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 6.

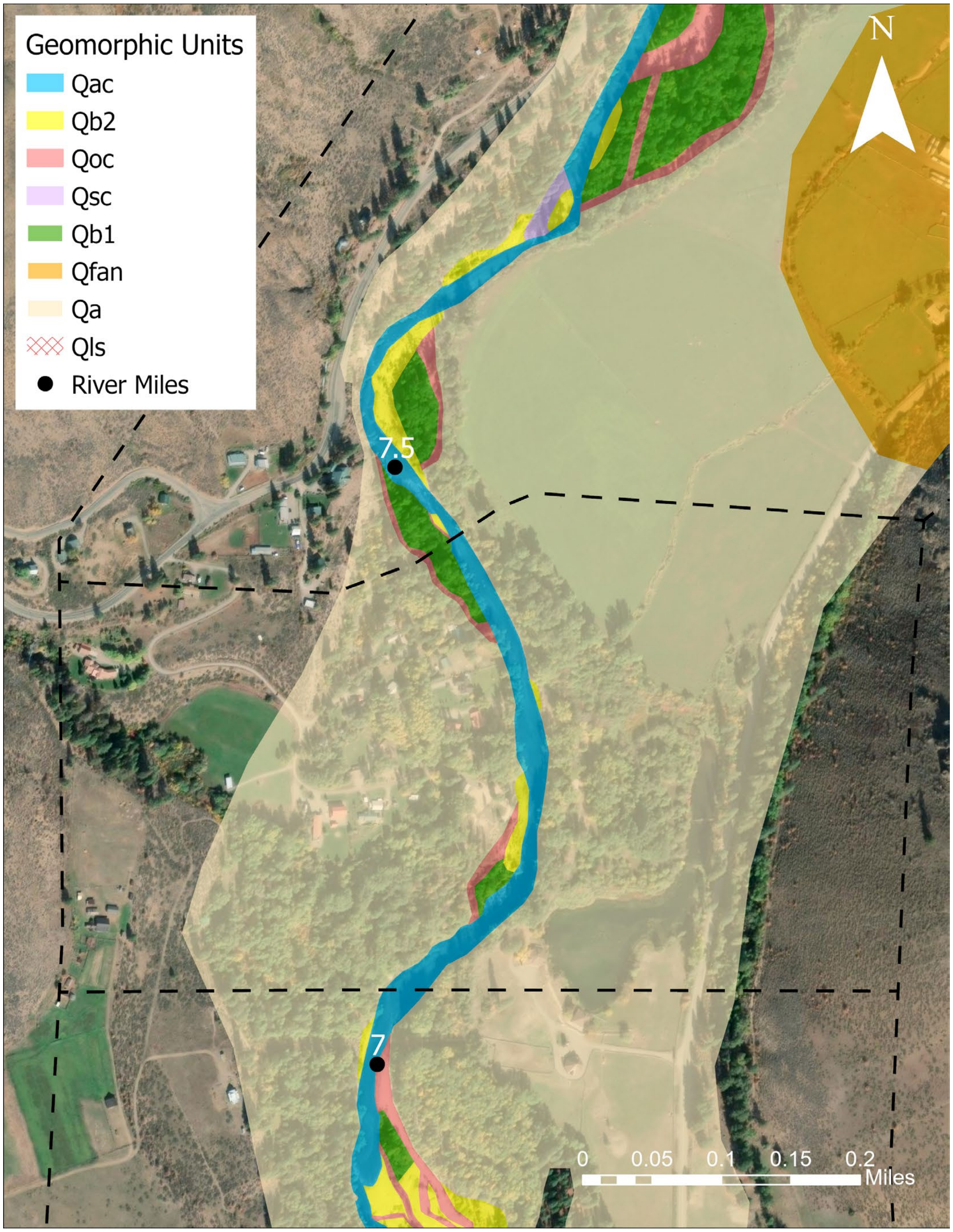

Figure 58.—Geomorphic mapping for 2023 for the Pearrygin 6 reach (RM 7.4 to 7.1). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

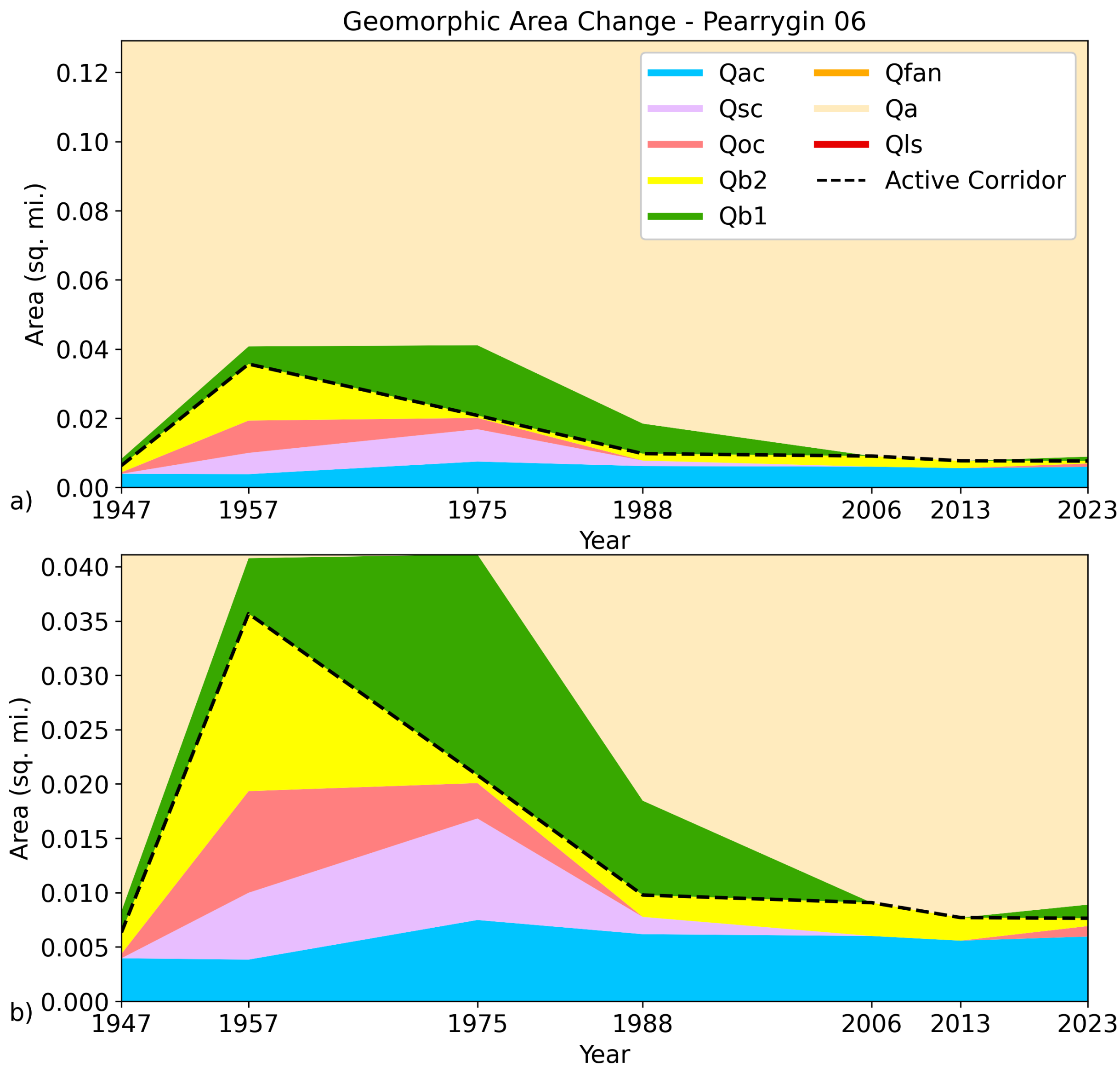

Figure 59.—Geomorphic area change for the Pearrygin 6 reach (RM 7.4 to 7.1) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.13 Pearrygin 5

The Pearrygin 5 reach extends from approximately RM 7.1 to 5.7. Downstream from the confluence of Cub Creek with the Chewuch River, the Chewuch River can be more consistently described as a pool-riffle system for the next 4.5 miles. The Pearrygin 5 reach is the most confined of this stretch, however, large point and mid-channel bars are present throughout the reach. The floodplain begins to inundate between the 2- and 10-year recurrence flow with flows at the 2-year recurrence flow mainly inundating the active channel bars or backwatering onto the downstream end of river meanders (figure 60). Slope and stream power decrease from Pearrygin 6 and mobile grain sizes remain in the large gravel to medium cobble range (figure 14; figure 17; figure 20).

The confluence with Cub Creek sets the upstream boundary of the Pearrygin 5 reach and channel complexity immediately increases (figure 61). This reach experienced a fluctuating active geomorphic corridor through time (figure 62). The sharp increase in active geomorphic corridor area from 1947 to 1957 is due to channel straightening in the vicinity of RM 6.5 to 7 that left overflow and side channel areas connected to the main channel from vegetation clearing (figure 63). The abandoned channel became two very wide side channels. From 1957 to 1988 the area of side channels consistently decreased as the cleared channels vegetated and side channels converted to overflow channels. Side channel area has remained stable since then. The vegetated bar area has decreased very slightly through time, and the area of overflow channels and the active channel have increased slightly. Compared to downstream reaches Pearrygin 3 and 4, this reach is narrower and more confined. In 1988 several channel complexes disconnected from the main channel, and the configuration has remained stable through the present with minor rearrangements.

Figure 60.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 5.

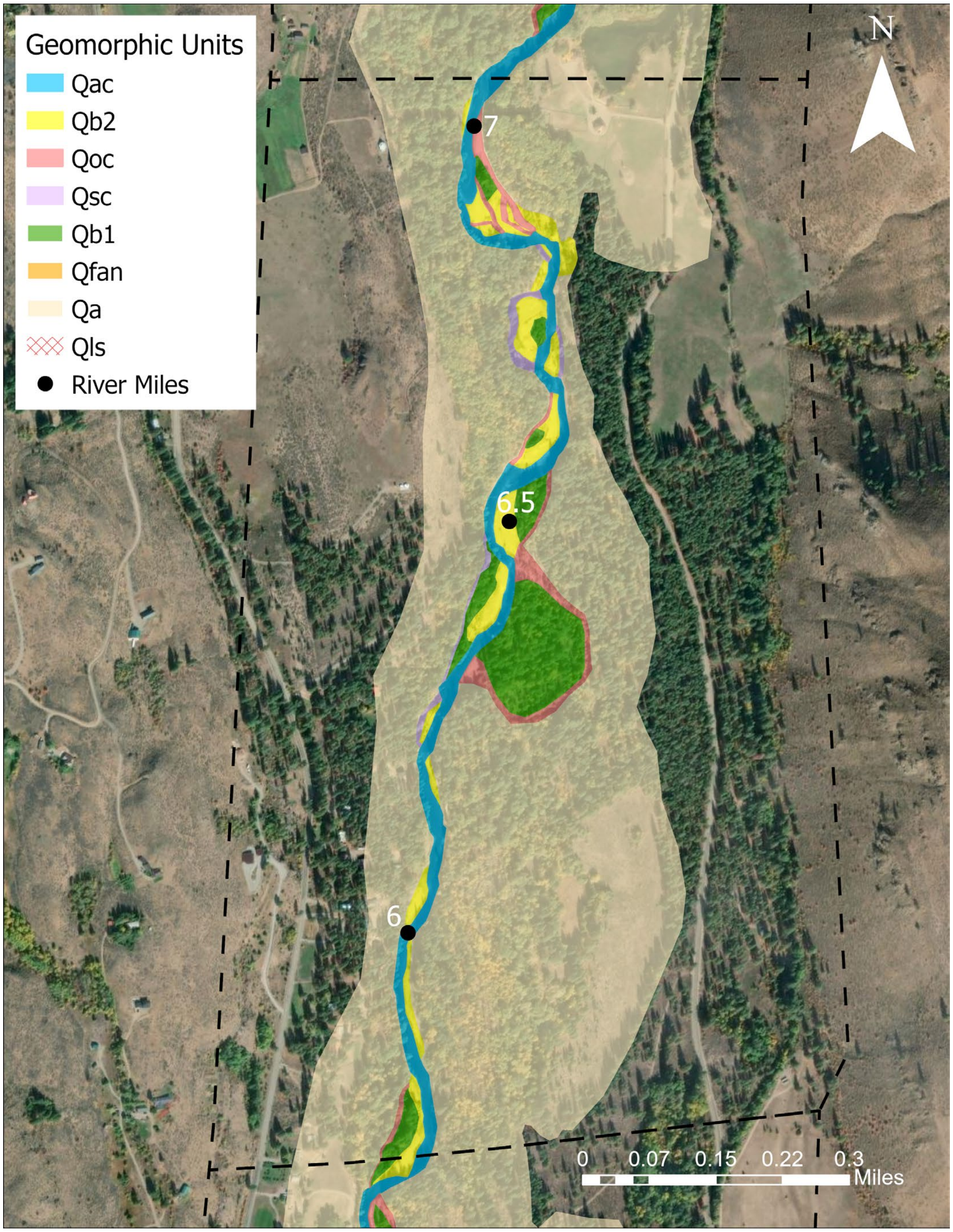

Figure 61.—Geomorphic mapping for 2023 for the Pearrygin 5 reach (RM 7.1 to 5.7). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

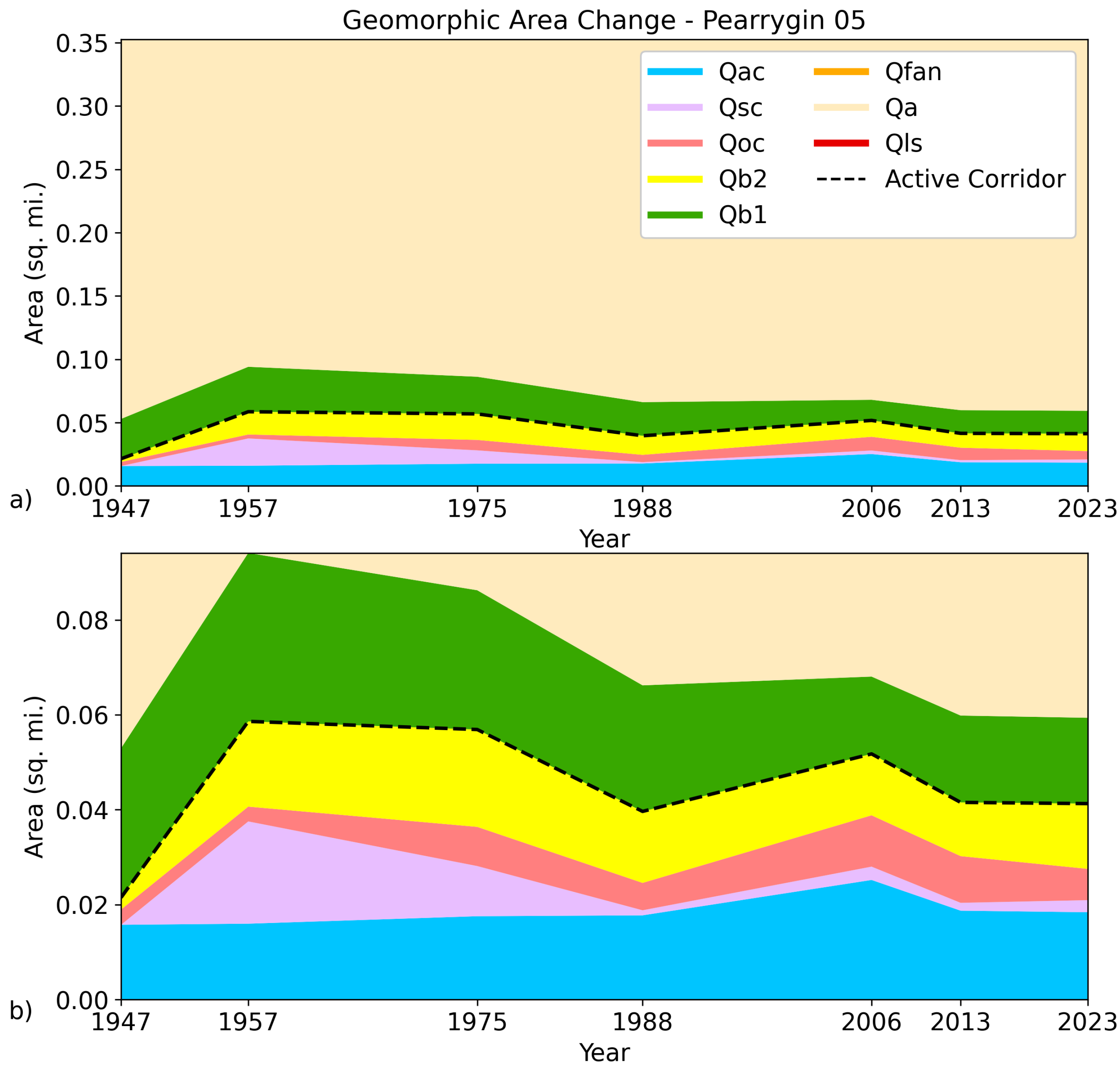

Figure 62.—Geomorphic area change for the Pearrygin 5 reach (RM 7.1 to 5.7) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

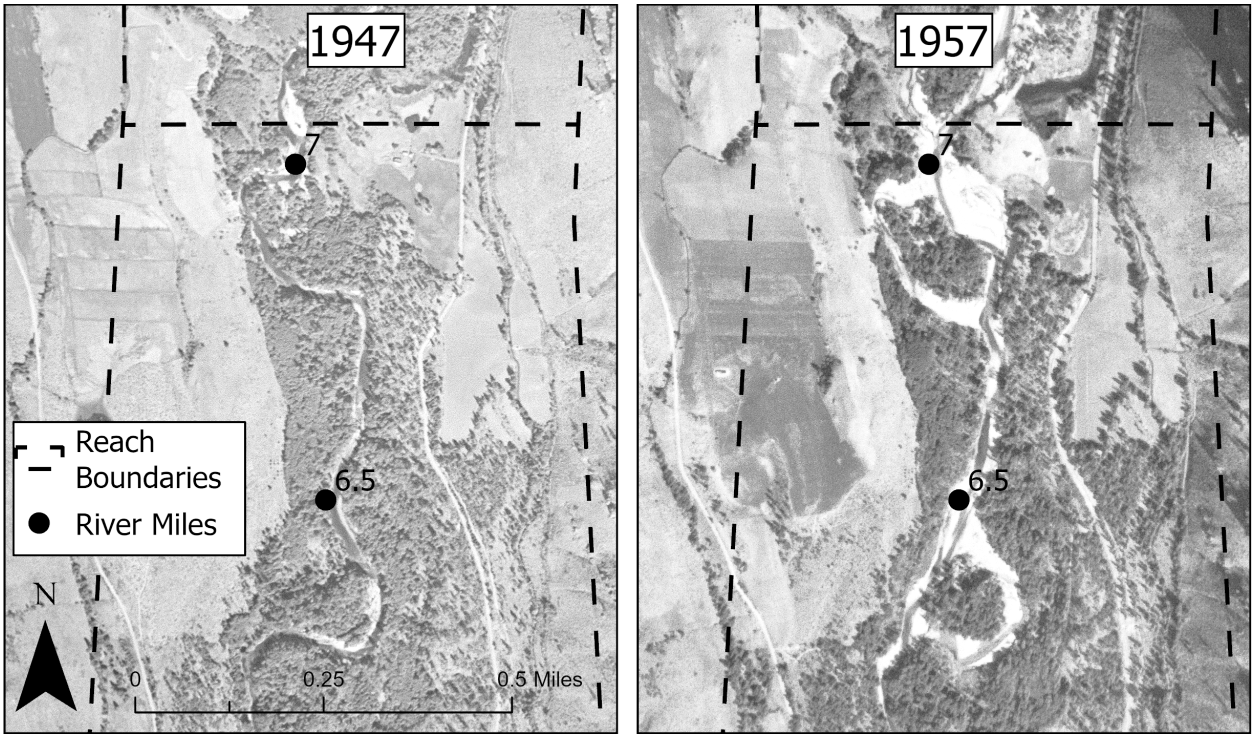

Figure 63.—Channel straightening from 1947 (left) to 1957 (right) increased the active geomorphic corridor area due to vegetation clearing.

9.14 Pearrygin 4

The Pearrygin 4 reach extends from approximately RM 5.7 to 4.1. The Chewuch River within Pearrygin 4 continues to exhibit the characteristics of a partly-confined, meandering river with pool-riffle form. The floodplain within the reach is more highly connected than other Pearrygin prioritization reaches with many surfaces connecting by the 2-year recurrence flow (figure 19; figure 64). There are several side channels and split flow patterns within the reach, which help support differences in hydraulics and sediment sorting. Slopes continue to decrease from upstream reaches with the lowest stream powers downstream from Boulder Creek occurring within the reach (figure 14; figure 17). Large gravels to moderate cobbles are likely mobile at higher flows (figure 20).

This reach is moderately confined with multiple side channel and overflow channel systems of moderate complexity (figure 65).The Pearrygin 4 reach experienced an increase in the area of the active geomorphic corridor from 1988, with the change in area between 1947 and 1957 again due to vegetation clearing. This coincided with an increase in vegetated and unvegetated bar and active channel area. The active channel area continued to increase until 2006 and then declined from 2006 to 2013. It has remained stable since then (figure 66). The increase in vegetated bar area from 1975 to 1988 coincides with overall increased side channel and overflow channel area.

From 1988 to the present, the area of overflow and side channels has stayed relatively constant. The decrease in unvegetated bar area over that timeframe is due to point bar vegetation as the river meandered.

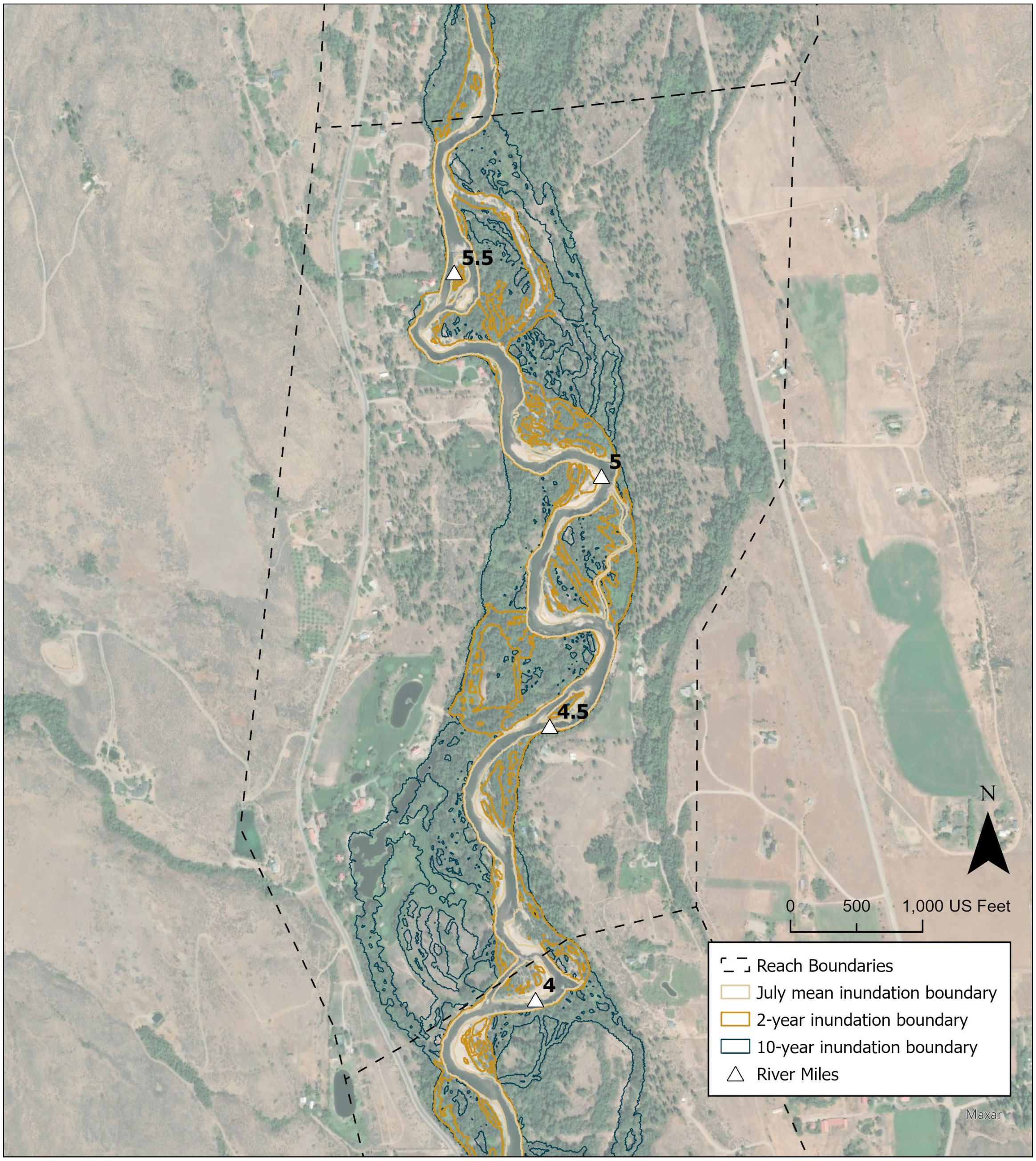

Figure 64.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 4.

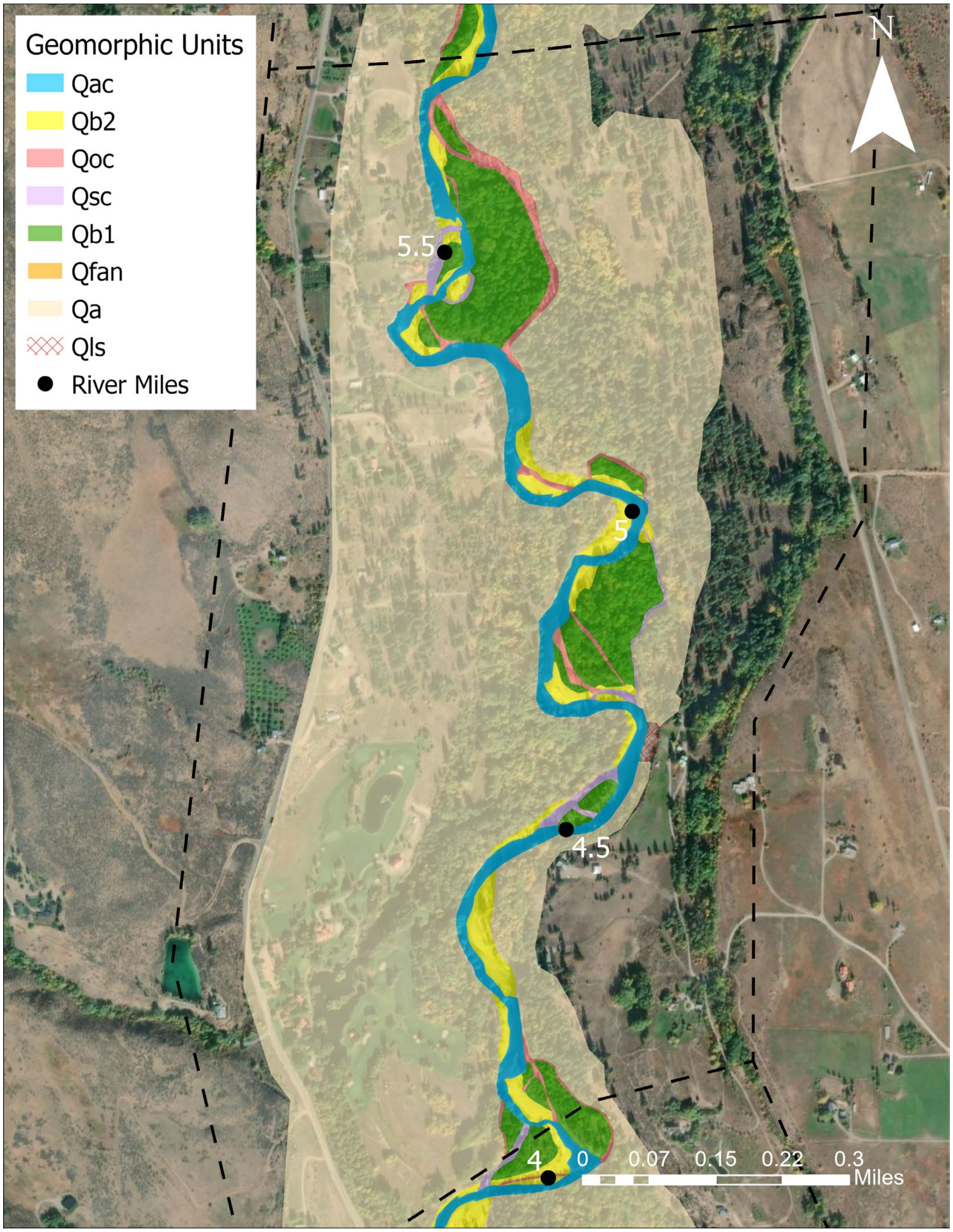

Figure 65.—Geomorphic mapping for 2023 for the Pearrygin 4 reach (RM 5.7 to 4.1). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

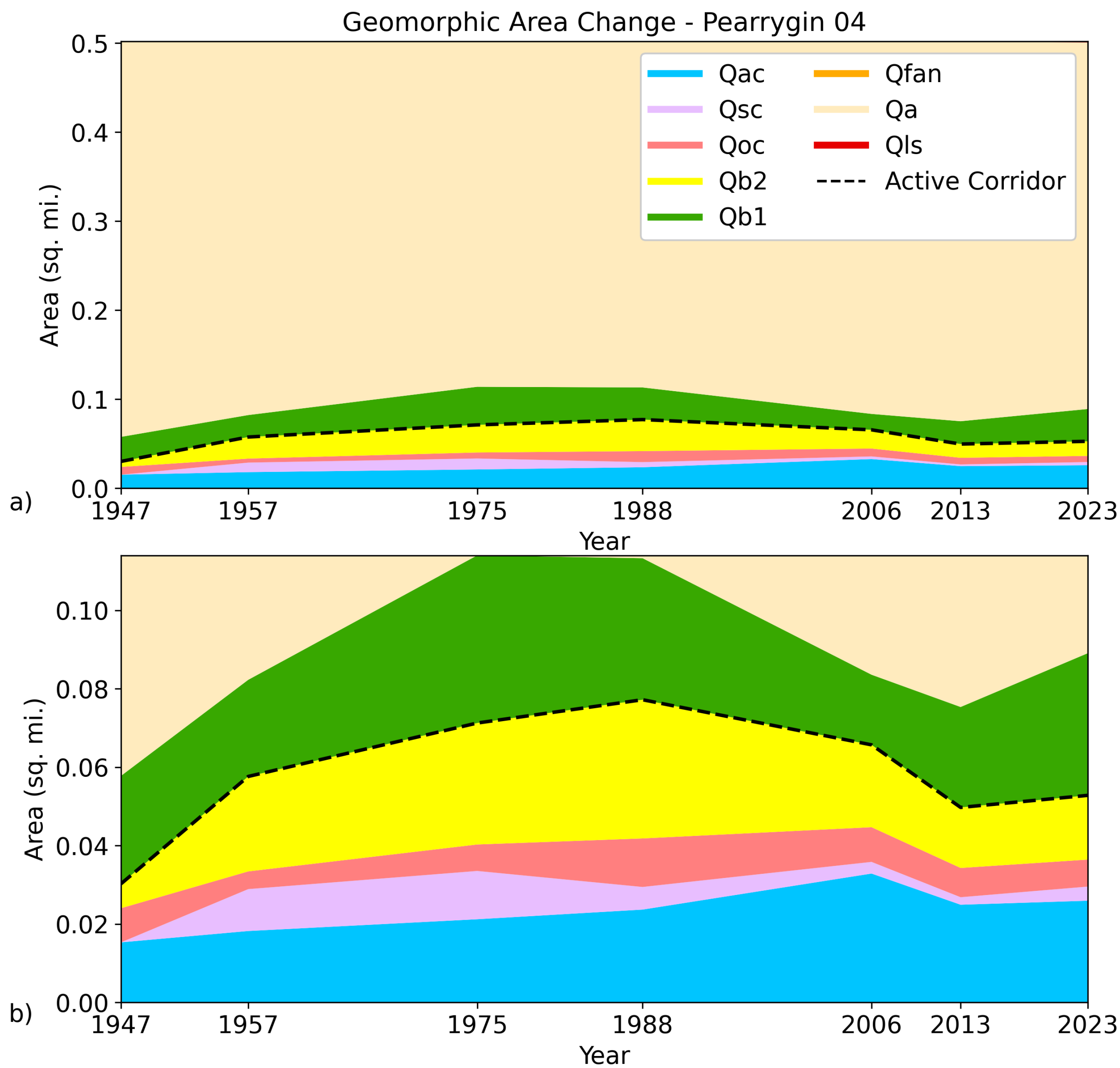

Figure 66.—Geomorphic area change for the Pearrygin 4 reach (RM 5.7 to 4.1) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.15 Pearrygin 3

The Pearrygin 3 reach extends from approximately RM 4.1 to 2.3. The Pearrygin 3 reach has the most expansive floodplain, however, much of the floodplain is less connected than the Pearrygin 4 reach (figure 19; figure 67). The availability of floodplain is driven by the least amount of valley confinement along the entire twenty miles of the Lower Chewuch River (figure 18). Slopes and stream power remain relatively low throughout the reach which continues to drive pool-riffle river form and associated hydraulics (figure 14; figure 17). At approximately RM 3, a rip-rapped channel bank drives a sharp meander to the east, which creates an upstream depositional area with multiple flow paths. The river then confines at the lower end of the reach ending the least confined stretch of the Lower Chewuch River (figure 68). Mobile grain sizes are predicted to remain in the large gravel to moderate cobble range (figure 20).

The Pearrygin 3 reach experienced a relatively active geomorphic corridor with minor fluctuations through time (figure 69). The large increase from 1947 to 1957 is likely due to increased channel mobility in this reach resulting in sediment deposition on banks. Vegetation clearing is also a possibility here. The overflow channels in this reach increased from 1957 to 1975 and then decreased again post 1975 due to an overflow channel complex between RM 4 and 3.5 that was not active in any other year. This channel complex activation is mirrored by the increase in vegetated bar area in 1975. Aside from 1975, 2023 has the largest area of side channels and overflow channels that are largely concentrated between RM 3 and 4. Vegetated bar area is high again in 2023 due to several smaller overflow and side channel complexes that are active along the entirety of the reach (figure 68).

Figure 67.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 3.

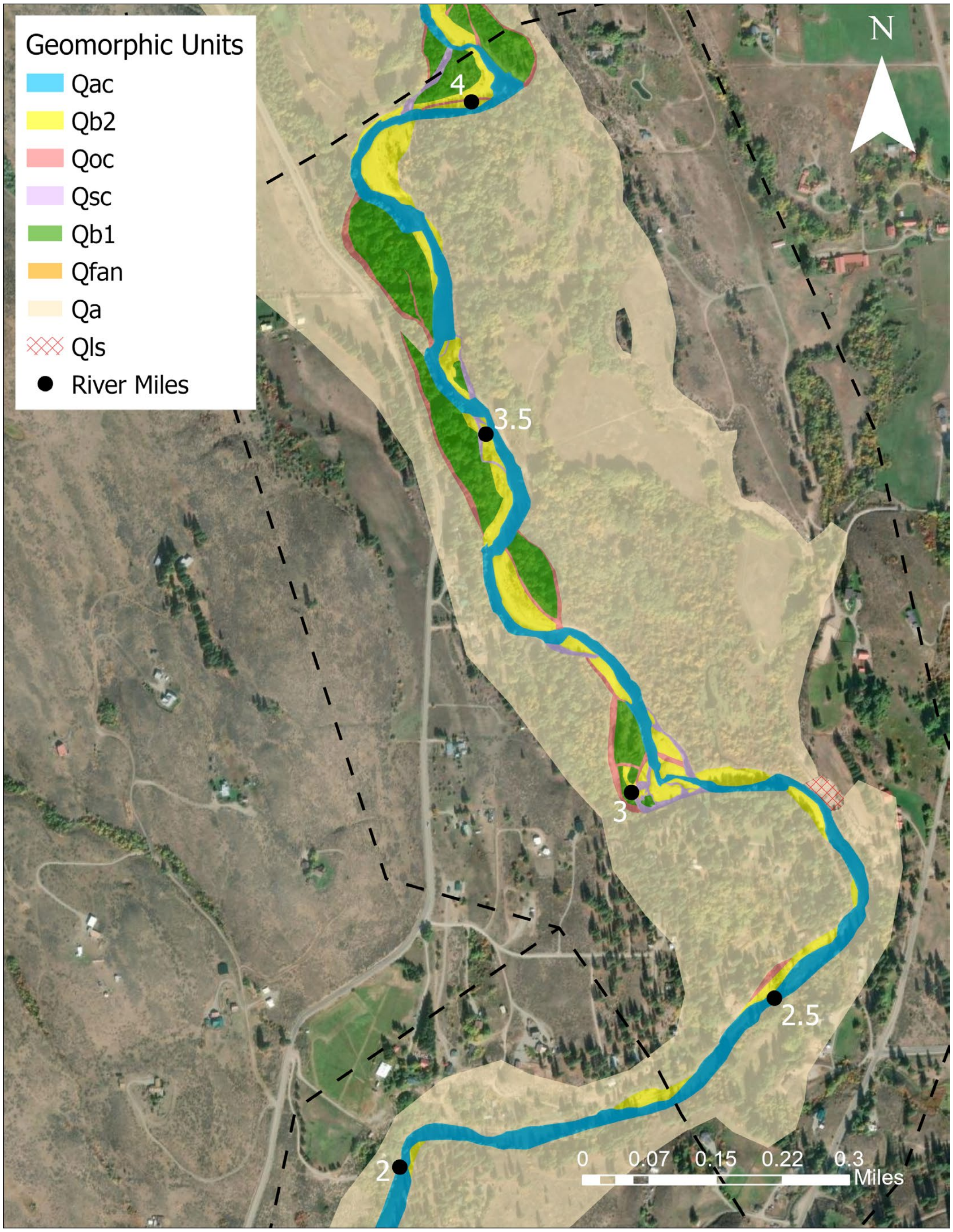

Figure 68.—Geomorphic mapping for 2023 for the Pearrygin 3 reach (RM 4.1 to 2.3). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

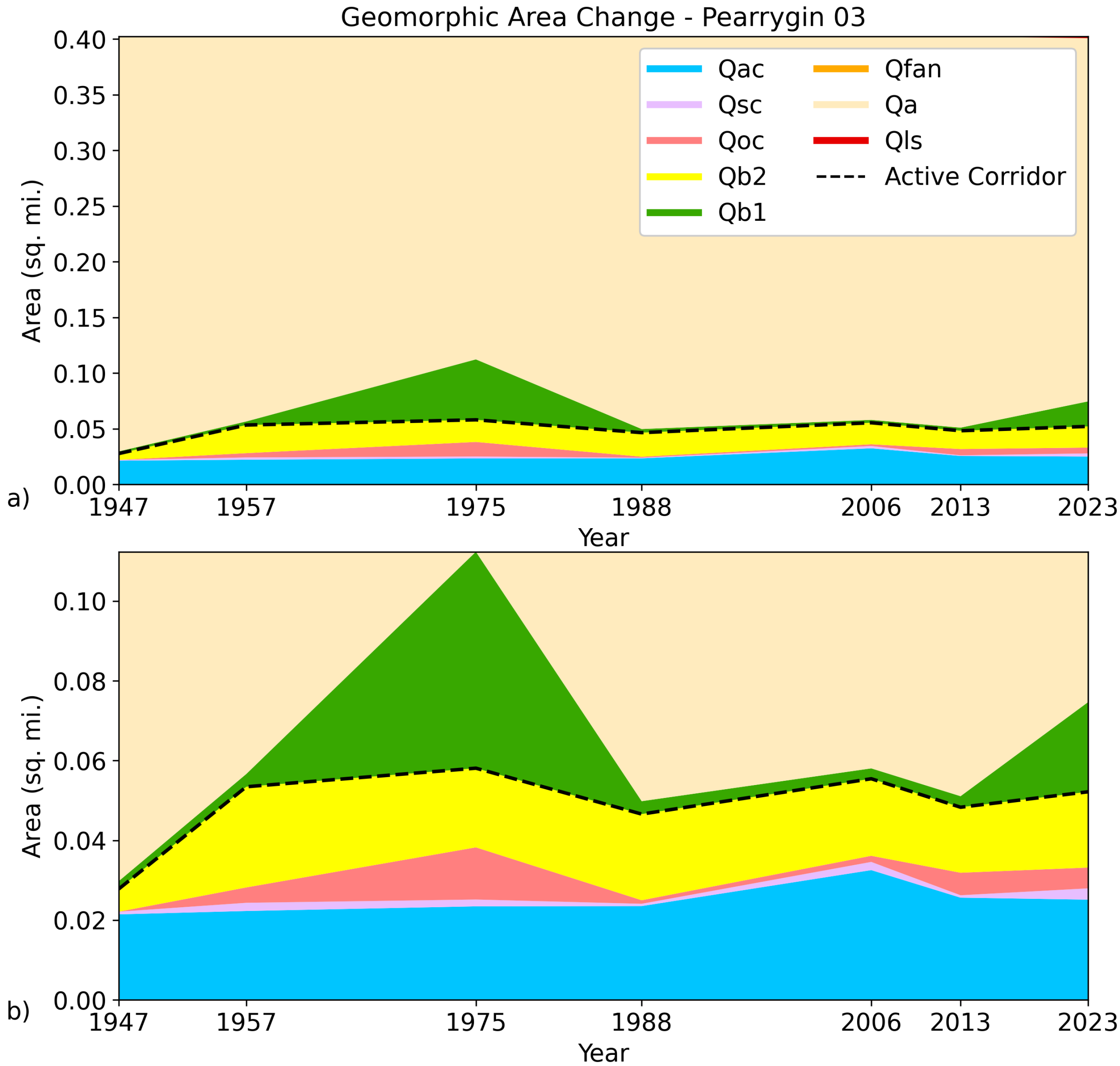

Figure 69.—Geomorphic area change for the Pearrygin 3 reach (RM 4.1 to 2.3) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.16 Pearrygin 2

The Pearrygin 2 reach extends from approximately RM 2.3 to 1.1. The Pearrygin 2 reach is predominantly confined with little to no floodplain (figure 18; figure 19), which creates relatively uniform channel geometry and hydraulics in the upstream portion of the reach (figure 70). Small bars and side channels do exist in select locations but are not defining features of the reach (figure 71). Hydraulics are anthropogenically influenced at the downstream end of the reach by Fulton Dam, though the dam does allow for fish passage. The dam creates a backwater for approximately a quarter-mile upstream, especially at low flows. There is also a forced pool upstream of the dam. Due to the more confined nature of the channel, stream power does increase with slightly larger mobile grain sizes than were more commonly transported in Pearrygin 3 (figure 14; figure 20).

The Pearrygin 2 reach experienced a slight increase in the area of the active geomorphic corridor through time (figure 72). This reach is characterized by limited complexity and a narrow valley due to geologic confinements (figure 71). No bars in this reach have ever vegetated. The side channels in this length are few in number and short in length. The banks of this reach are dominated by unvegetated bars.

Figure 70.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 2.

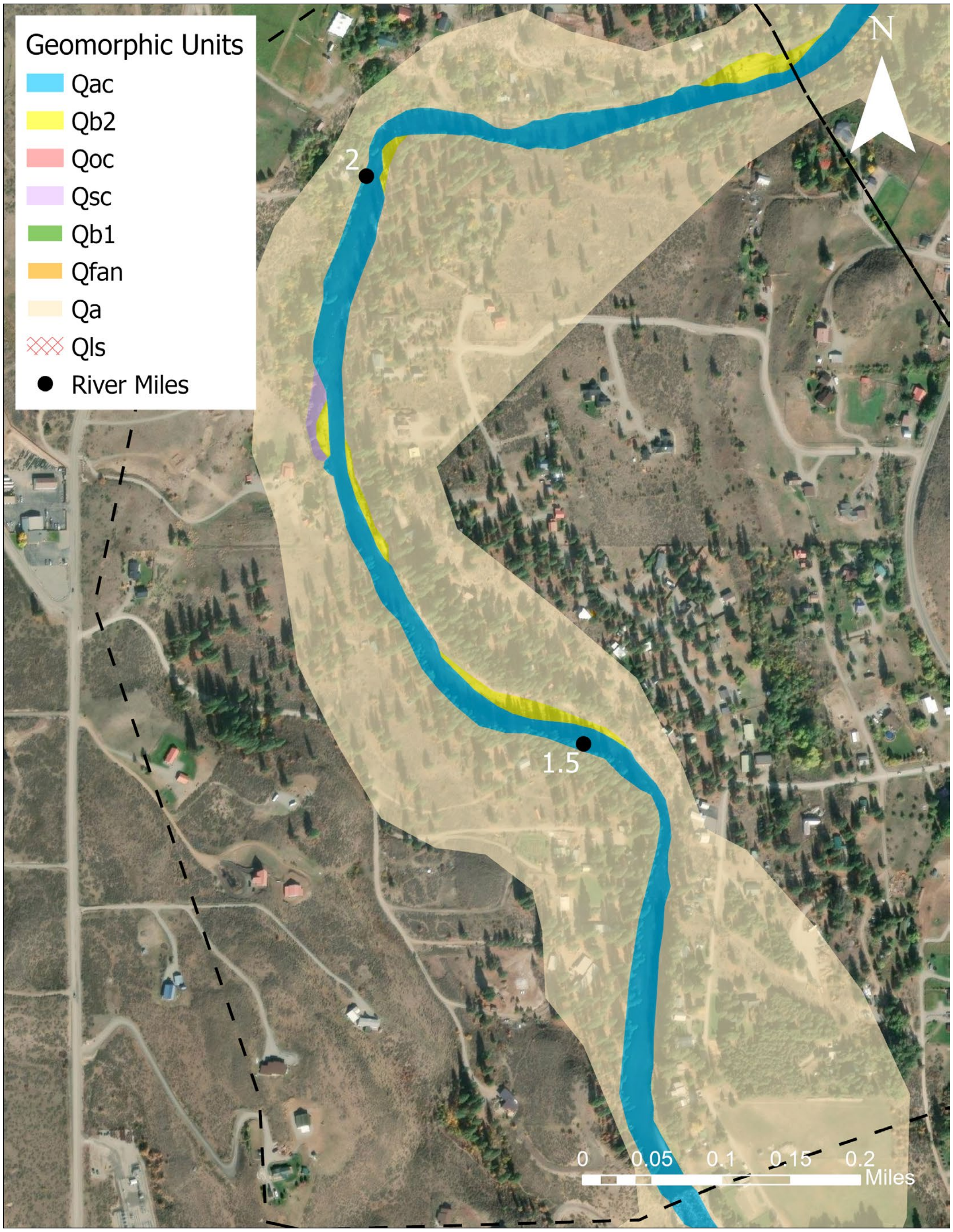

Figure 71.—Geomorphic mapping for 2023 for the Pearrygin 2 reach (RM 2.3 to 1.1). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

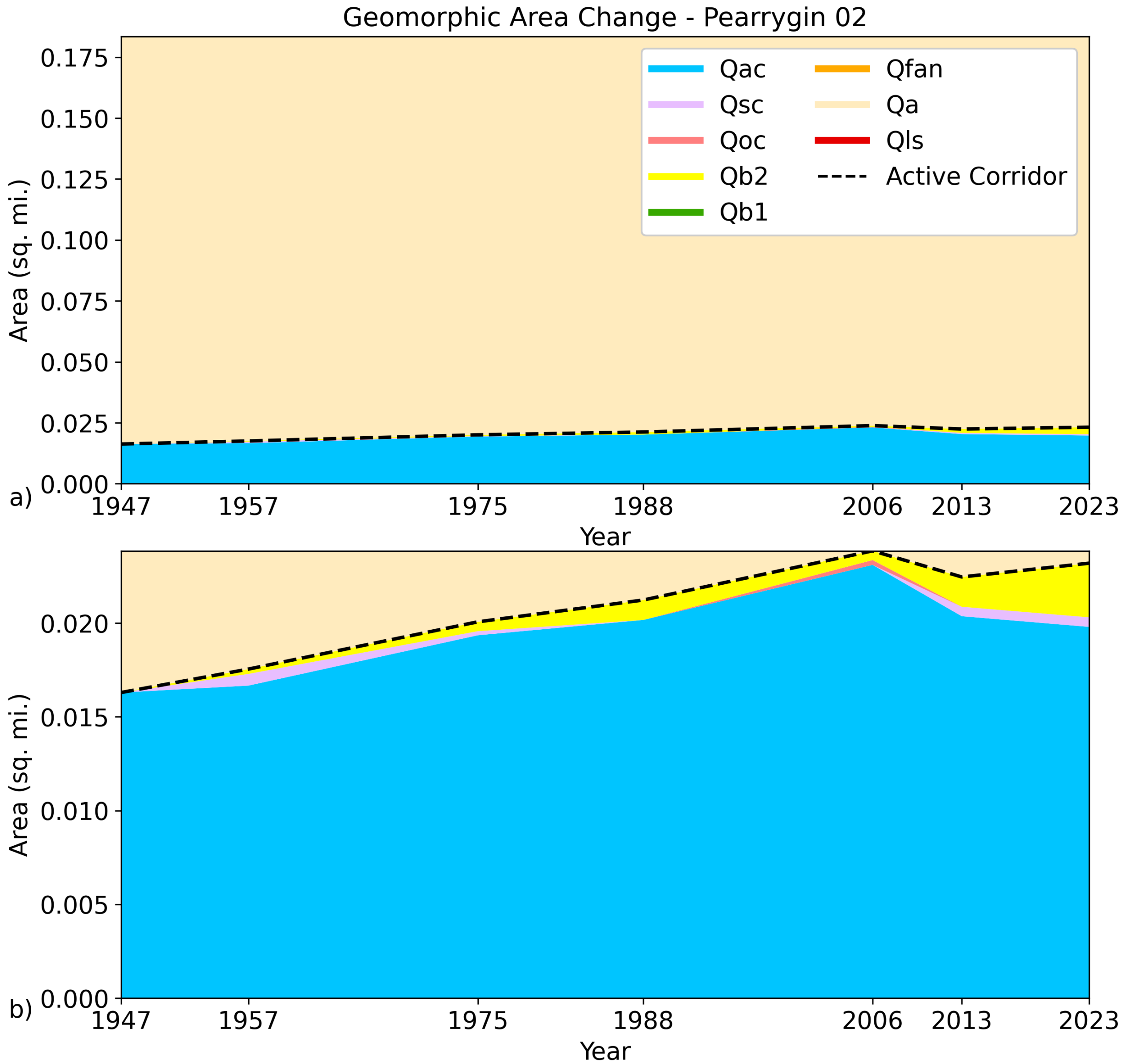

Figure 72.—Geomorphic area change for the Pearrygin 2 reach (RM 2.3 to 1.1) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

9.17 Pearrygin 1

The Pearrygin 1 reach extends from approximately RM 1.1 to 0. Pearrygin 1 is defined on the upstream end by Fulton Dam and on the downstream end by the confluence with the Methow River. Fulton Dam and the constructed downstream roughened channel creates an artificially steep and fast section of the river, but in general the channel through the reach is steeper and defined by uniform channel dimensionality (figure 17; figure 19). Similar to Pearrygin 2, there are small bars and pockets of floodplain where more lateral space exists, however the inundation width differences between low and high flows is minimal throughout most of the reach (figure 19; figure 73). The increased gradient and confinement from Pearrygin 2 are likely the cause for increased stream power and mobile grain size within the reach (figure 14; figure 20).

Pearrygin 1 is characterized by minimal geomorphic complexity and a narrow valley with human infrastructure on the elevated terraces (figure 74). The Pearrygin 1 reach experienced very little change in the active geomorphic corridor through time (figure 75). No vegetated bars were present from 1957 to the present. The few side channels that existed in the past were short in length and exhibited a simple planform. The modern channel does not exhibit any active side channels within this reach.

Figure 73.—Inundation boundaries for the July mean, 2-year, and 10-year flows in Pearrygin 1.

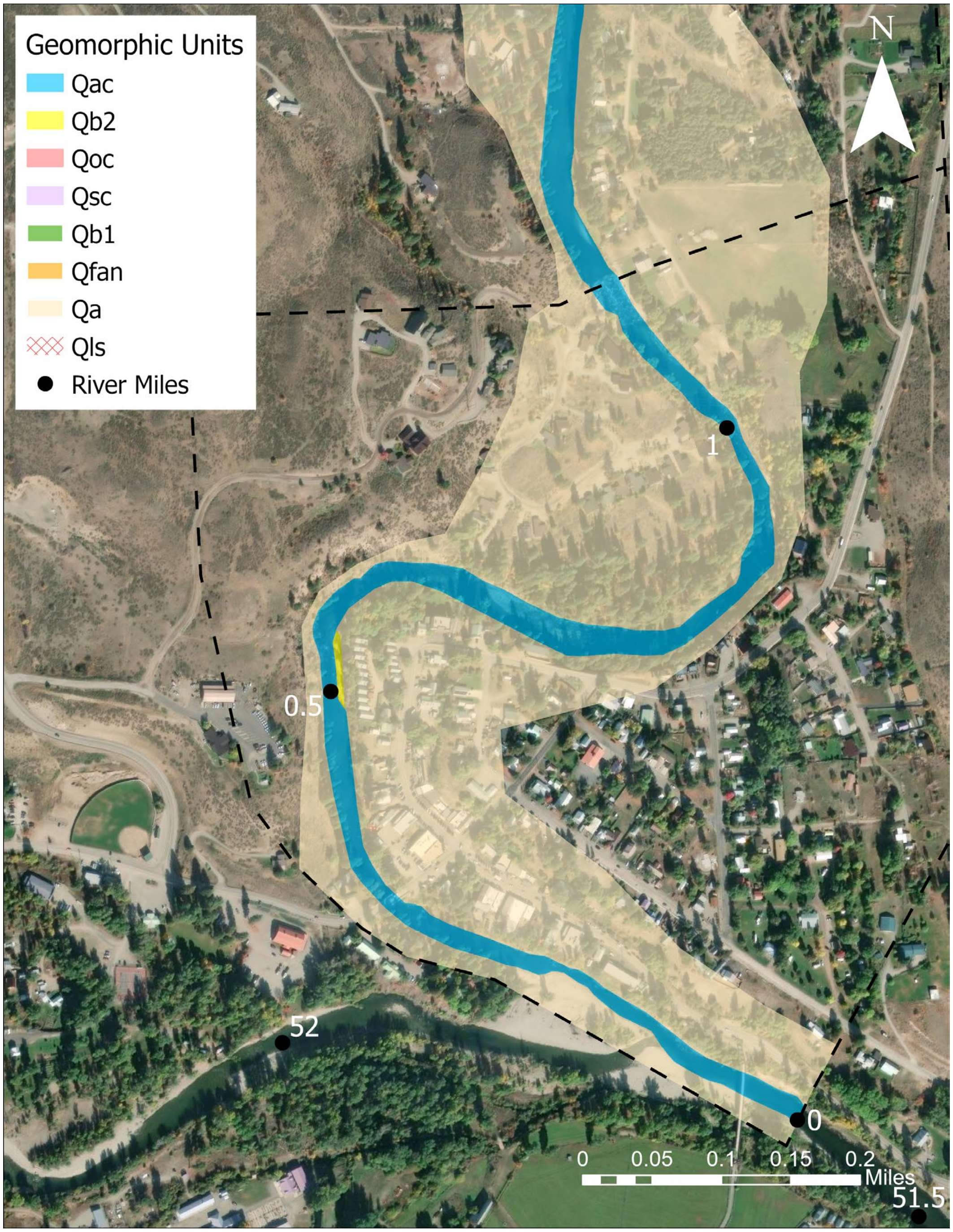

Figure 74.—Geomorphic mapping for 2023 for the Pearrygin 1 reach (RM 1.1 to 0). Dashed black lines indicate reach boundaries. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide. Background imagery is from the ESRI World Imagery Database for 2023.

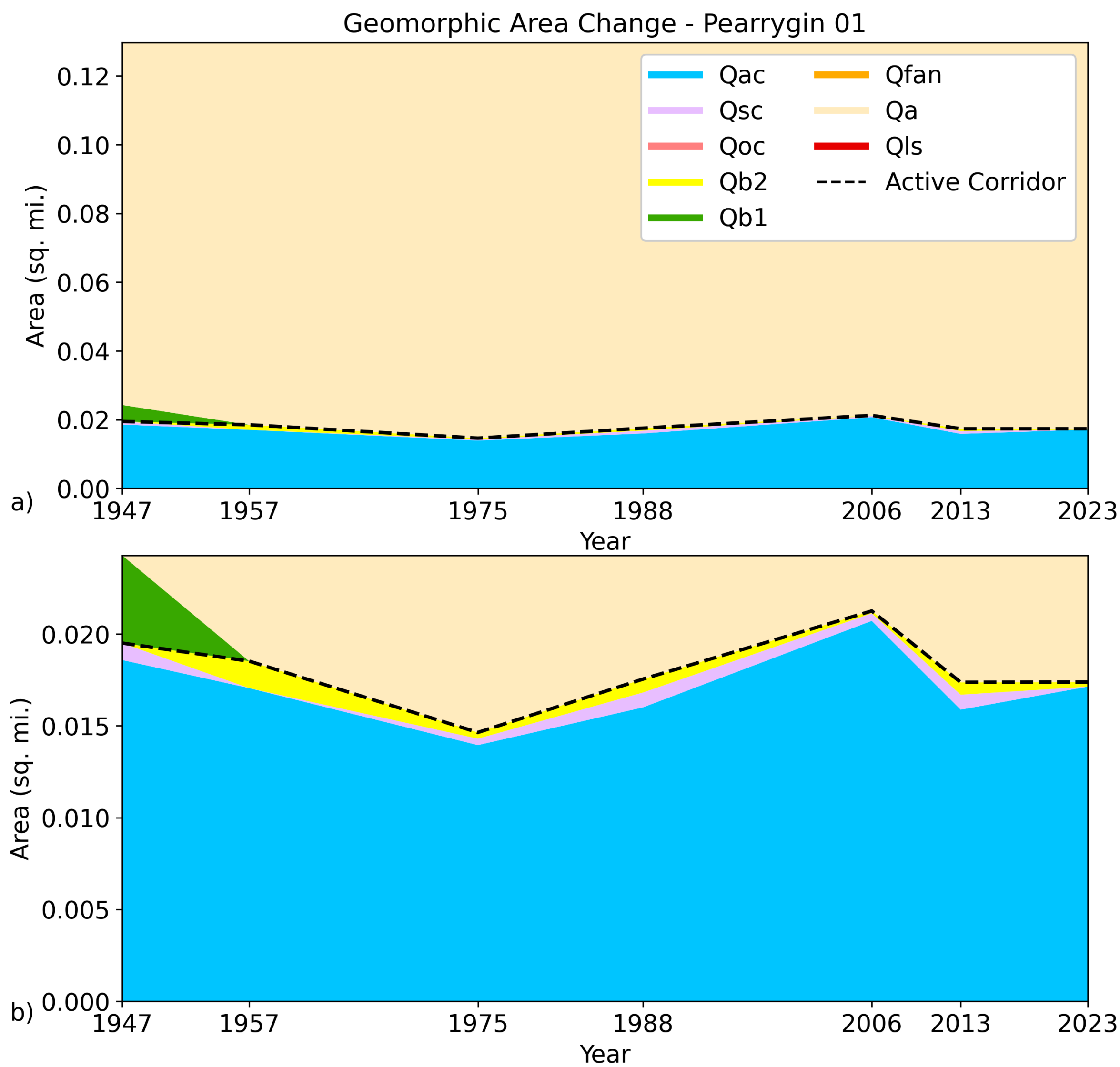

Figure 75.—Geomorphic area change for the Pearrygin 1 reach (RM 1.1 to 0) from 1947 to 2023. The bottom figure is zoomed in to look more closely at features with smaller areas. Qac = active channel, Qsc = side channel, Qoc = overflow channel, Qb1 = vegetated bar, Qb2 = unvegetated bar, Qfan = alluvial fan, Qa = Quaternary alluvium, and Qls = landslide.

10.0 Conclusions

A geomorphic assessment and hydraulic modeling for the lower twenty miles of the Chewuch River were conducted to support a larger Lower Chewuch River reach assessment. The geomorphic and hydraulic analyses utilized field-collected information about geomorphology and river characteristics in combination with available lidar datasets and hydrology. Geomorphic products include relative elevation maps, geomorphic mapping using historical and current aerial photography, and calculation of geomorphic changes in area of geomorphic surfaces. Hydraulic modeling products include depth, velocity, and water surface elevation rasters of 2022 conditions (e.g., when lidar was flown) as well as inundation boundaries at a range of discharges. All products are available in a supplementary digital geodatabase.

Channel mobility and complexity along the Chewuch River between RM 20 and 0 is controlled by the confinement of the valley. The valley confinement is set by alluvial fans deposited at tributary confluences, narrow valleys at bedrock constrictions, and anthropogenic modifications that restrict the movement of the channel. Vegetation clearing and channel straightening between 1947 and 1957 affected the morphology between RM 8.6 and 2.3 (Pearrygin 7 to Pearrygin 3). Almost all reaches have generally decreased in complexity, indicated by a decrease in the active geomorphic corridor area and a decrease in the area of overflow and side channels. The Pearrygin 11 and Pearrygin 10 reaches saw the most drastic increases in complexity due to disconnection of large channel complexes from the active channel. The Pearrygin 4 reach is the only reach that had a net overall increase in complexity, but the complexity has still declined since 1988. Pearrygin 2 is the only other reach with a net increase in the active geomorphic corridor area, but this is due to active channel widening rather than an increase in complexity. Several of the reaches are very confined and did not change much through time: Doe 4, Doe 3, Pearrygin 9, Pearrygin 2, and Pearrygin 1. The Pearrygin 5 reach is intermediately confined compared to other reaches and has fluctuations in complexity through time but little net change. The Doe 1 and Pearrygin 8 reaches have at least portions of reduced valley confinement and generally maintained complexity through time.

Hydraulic modeling along the Chewuch River shows large differences in hydraulic conditions between different prioritization reaches. Those differences are driven largely by the defining geology of the river corridor and influences of major tributaries throughout the twenty miles. Confinement, slope, and hydrology drive differences in hydraulics and river form. The more confined reaches generally have more uniform hydraulics and channel form, while less confined reaches allow for more alluvial process, pool-riffle formation, and more heterogenous water depths and velocities. While the defining geology often is an influence on river form and hydraulics, anthropogenic influences are also present in selected locations where rip-rap or dams can contribute to a decrease in dynamic river processes. Contrary to many rivers where river bed sediments fine in the downstream direction, the mountainous characteristics of the Chewuch River and its tributaries contribute to coarser bed material in the lower nine miles than much of the upstream 11 miles.

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