State of Oregon
Oregon Department of Geology and Mineral Industries
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OPEN-FILE REPORT O-25-10

CHANNEL MIGRATION ZONE MAPS FOR UMATILLA RIVER AND LOWER MCKAY CREEK, UMATILLA COUNTY, OREGON

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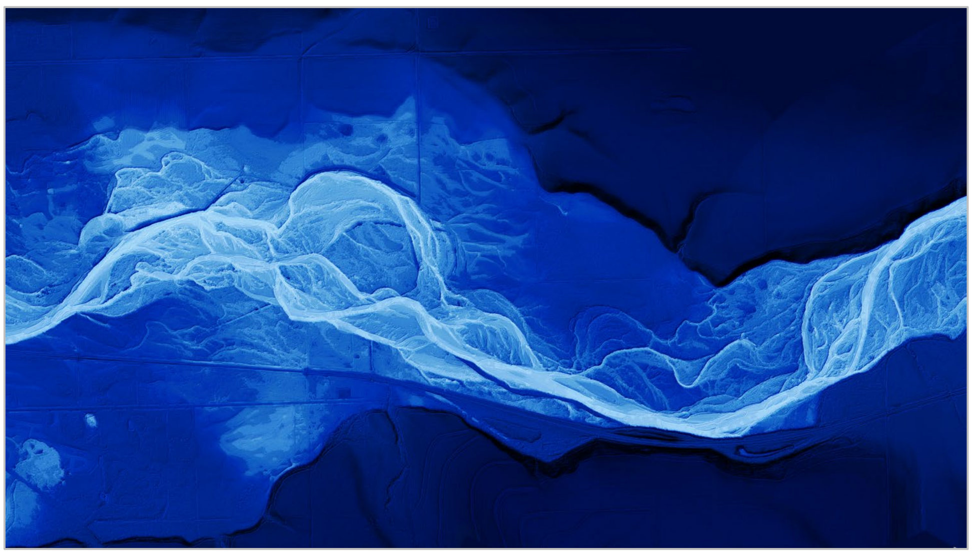

2025

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WHAT'S IN THIS REPORT?

This report describes the methods and results of channel migration zone mapping for Umatilla County, Oregon. This information can help communities plan and prepare for natural disasters.

Cover image: An artistic display of a relative elevation model (REM) based on lidar collected in 2020 for the Umatilla River near Mission, Oregon. An REM shows the height of the land above the water's surface. Here, white represents the river's surface height and the darker shades of blue represent higher land surfaces above the water. (45.6712, -118.6447 WGS geographic coordinates). Image credit: Christina Appleby, 2025.

Expires:6/30/2026

Oregon Department of Geology and Mineral Industries Open-File Report O-25-10
Published in conformance with ORS 516.030

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Geodatabase is Esri® version 10.7 format. Metadata is embedded in the geodatabase and is also provided as separate.xml format files.

Umatilla_Co_CMZ.gdb

Feature dataset: Umatilla_River_CMZ

Feature classes:

Umatilla_River_AC; Umatilla_River_AHA; Umatilla_River_CMZ; Umatilla_River_EHA_Low; Umatilla_River_EHA_Medium; Umatilla_River_EHA_High; Umatilla_River Flag; Umatilla_River HMA; Umatilla_River_Study_Area

Feature dataset: McKay_Creek_CMZ

Feature classes:

McKay_Creek_AC; McKay_Creek_AHA; McKay_Creek_CMZ; McKay_Creek_EHA_Low; McKay_Creek_EHA_Medium; McKay_Creek_EHA_High; McKay_Creek_Flag; McKay_Creek_HMA; McKay_Creek_Study_Area

SPREADSHEETS

Umatilla County CMZ Excel Tables:

Umatilla River - CMZ Summary.xsls
McKay Creek - CMZ Summary.xsls

UNITS OF MEASUREMENT

The intended audience for this report includes both the general public, scientists, planners, emergency managers, public safety agencies, and decision makers at the community, county, tribal, state, and federal levels. Therefore, we selected U.S. Customary units as the primary units; SI (International System) Metric units are included in parentheses. A conversion table for U.S. Customary units to SI (International System) Metric units is included for easier conversion where needed.

U.S. Customary Units to SI (International System) Metric

	Original Units	Conversion Equation	To Obtain
length:	inch (in)	in × 2.54	centimeter (cm)
	foot (ft)	ft × 0.305	meter (m)
	mile (mi)	mi × 1.609	kilometer (km)
area:	square mile (mi^2)	mi^2 × 2.590	square kilometer (km^2)
	acre (ac)	ac × 0.004	square kilometer (km^2)
discharge:	cubic feet per second (ft^3/s)	ft^3/s × 0.028	cubic meters per second (m^3/s)
temperature:	degrees Celsius (°C)	(°C × 9/5) + 32	degrees Fahrenheit (°F)

SI (International System) Metric to U.S. Customary Units

	Original Units	Conversion Equation	To Obtain
length:	centimeter (cm)	cm × 0.394	inch (in)
	meter (m)	m × 3.281	foot (ft)
	kilometer (km)	km × 0.621	mile (mi)
area:	square kilometer (km^2)	km^2 × 0.386	square mile (mi^2)
discharge:	cubic meters per second (m^3/s)	m^3/s × 35.310	cubic feet per second (ft^3/s)
temperature:	degrees Celsius (°C)	(°C × 9/5) + 32	degrees Fahrenheit (°F)

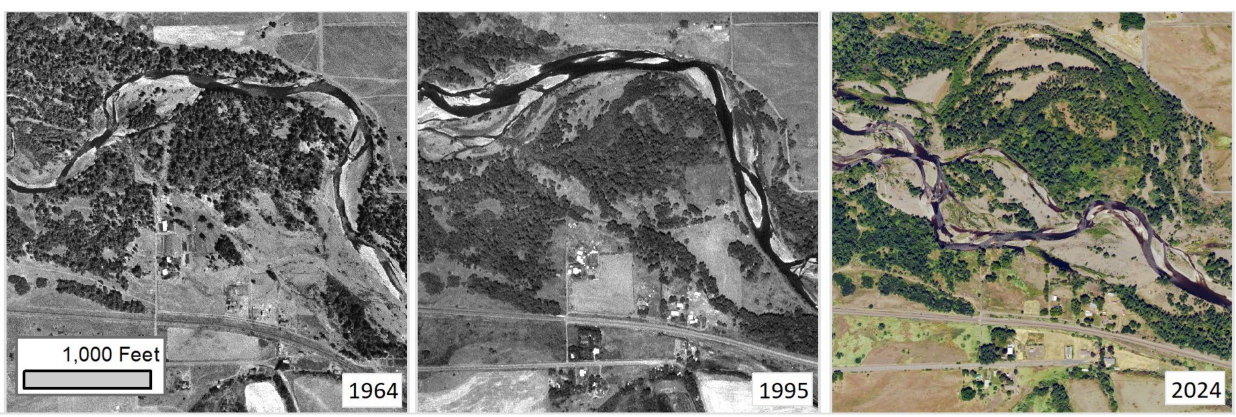
EXECUTIVE SUMMARY

This study provides Oregon communities with new information about the natural hazards from channel migration. During 2024 and 2025, the Oregon Department of Geology and Mineral Industries (DOGAMI) produced channel migration zone (CMZ) maps for the Umatilla River and lower McKay Creek in Umatilla County. At the same time, the Department of Land Conservation and Development (DLCD) identified community-driven strategies for reducing risk associated with future channel migration.

CMZ maps define the area in which a given stream is likely to move laterally and change its channel course within the next 30 and 100 years. In this study, CMZs were mapped along nearly 83 river miles (133 km) of the mainstem of the Umatilla River and 6 river miles (10 km) of lower McKay Creek (below the McKay Dam). The components that comprise these CMZ maps are the active channel (AC); historical migration area (HMA); 30-year high, 30-year medium, and 100-year low erosion hazard areas (EHAs); avulsion hazard area (AHA); and flagged streambanks. The method used derived primarily from the interpretation of historical aerial photographs, high-resolution lidar topography, geologic maps, and flood inundation maps.

The CMZ maps produced for this study of the Umatilla River and lower McKay Creek show that despite the modifications to the land and river by humans since the 1800s, nearly all the river segments (RS) along the Umatilla River and lower McKay Creek have experienced some degree of lateral migration during the last 72 years. An example of channel migration on the Umatilla River during this time is shown in **Figure E-1**, below. Historical channelization; infrastructure such as levees, roads, railroads, dams, and bridges; and bedrock confine the channel and restrict movement. However, in areas where movement is not limited, the banks of the Umatilla River have eroded by hundreds of feet and the banks of lower McKay Creek have moved dozens of feet. Avulsions are common along the Umatilla River in the reaches upstream of the City of Pendleton, causing the river to rapidly move large distances across the floodplain. If the trend of river erosion and avulsions continues, people and infrastructure may be at risk.

Figure E-1. An example of channel migration from 1964 (U.S. Geological Survey, 1964), 1995 (U.S. Department of Agriculture, 1995), and 2024 (Oregon Geospatial Enterprise Office, 2025) along the Umatilla River near Mission, upstream of Pendleton, in Umatilla County, Oregon.



CMZ maps are designed to aid in community planning, raise awareness of riverine flood and erosional hazards, and to inform decisions about environmental and emergency management and land use. The maps may be used to identify which buildings, critical facilities, transportation infrastructure, and utility lines are potentially at risk from channel migration and to prioritize areas for pre-disaster risk reduction. The strategies identified by DLCD to reduce risk and their recommendation for enhanced coordination may be found in the **Appendix**. The maps in this study do not replace a site-specific analysis by a land surveyor, geologist, engineer, or some combination thereof. These hazard maps will provide a timely and valuable resource for Tribal, county, and community planning efforts, including during the development of emergency plans and updates to Natural Hazard Mitigation Plans (NHMPs).

1.0 INTRODUCTION

1.1 Purpose and Study Area

The purpose of this project is to help communities better understand channel migration hazards and to provide data that will aid in the identification of areas at greatest risk so that communities may plan for, prepare for, and mitigate riverine hazards. This is accomplished by providing the best available information about potential channel migration.

The study areas examined in this report were determined by the need for mapping of channel migration. Rivers were selected based on proximity to population centers, transportation corridors, and requests from Confederated Tribes of the Umatilla Indian Reservation (CTUIR), county staff, and community stakeholders. Additionally, this study utilized the statewide channel migration screening established by Roberts and Anthony (2017) to identify priority areas for CMZ mapping. These hazard maps will provide a timely and valuable resource for county and community planning efforts, including the NHMP updates that occur every five years in the county and communities studied here.

The main objectives of this study are to produce CMZ maps for the Umatilla River and lower McKay Creek in Umatilla County. These maps can be used to perform detailed risk assessments that demonstrate how many people and which buildings and infrastructure are at risk from channel migration hazards. They are designed to be shared with local, Tribal, and state emergency managers, planners, elected officials, community leaders, watershed councils, residents, and other stakeholders to inform land use and environmental planning, develop building ordinances and codes, and identify, prioritize, and implement hazard mitigation actions.

1.2 Overview of the Hazards of Channel Migration

Channel migration is a geomorphic process by which a stream shifts its course laterally across its floodplain over time. This process includes bed and bank erosion, sediment deposition, and channel avulsion, a process in which the stream abruptly moves to an entirely new location on the floodplain (Slingerland and Smith, 2004). Channel migration can undermine buildings, roads, levees, and other infrastructure. It can rapidly redirect flooding to new areas, erode land, cut off evacuation routes during floods, and, in rare cases, endanger lives (Olson and others, 2014).

Channels migrate and change as a function of sediment supply, discharge, channel bed and bank geology, climate, riparian vegetation, basin physiography, and human modifications (Knighton, 1998). While bedrock-controlled channels migrate very gradually across centuries, alluvial channels with braided, meandering, and anastomosing forms commonly migrate across the landscape over years or decades (Rapp and Abbe, 2003). Channel geometry may change in both the horizontal and vertical plane. Horizontal movement is often observed as lateral migration, avulsions, widening, or narrowing. Vertical movement includes channel bed incision and sediment aggradation, both of which can trigger lateral migration.

CMZ mapping seeks to identify the area the channel is most likely to occupy in the future based on historical channel behavior and current geomorphic conditions. CMZ maps include the areas on the floodplain previously occupied by the channel, as these areas create a high potential for channel reoccupation. They also include the areas susceptible to future erosion that can be identified by establishing a historical rate of bank erosion using aerial photographs and geologic maps (Rapp and Abbe, 2003). Potential avulsion areas are shown in CMZ maps and are mapped based on interpretations of lidar topography, with a focus on low-lying areas near the AC.

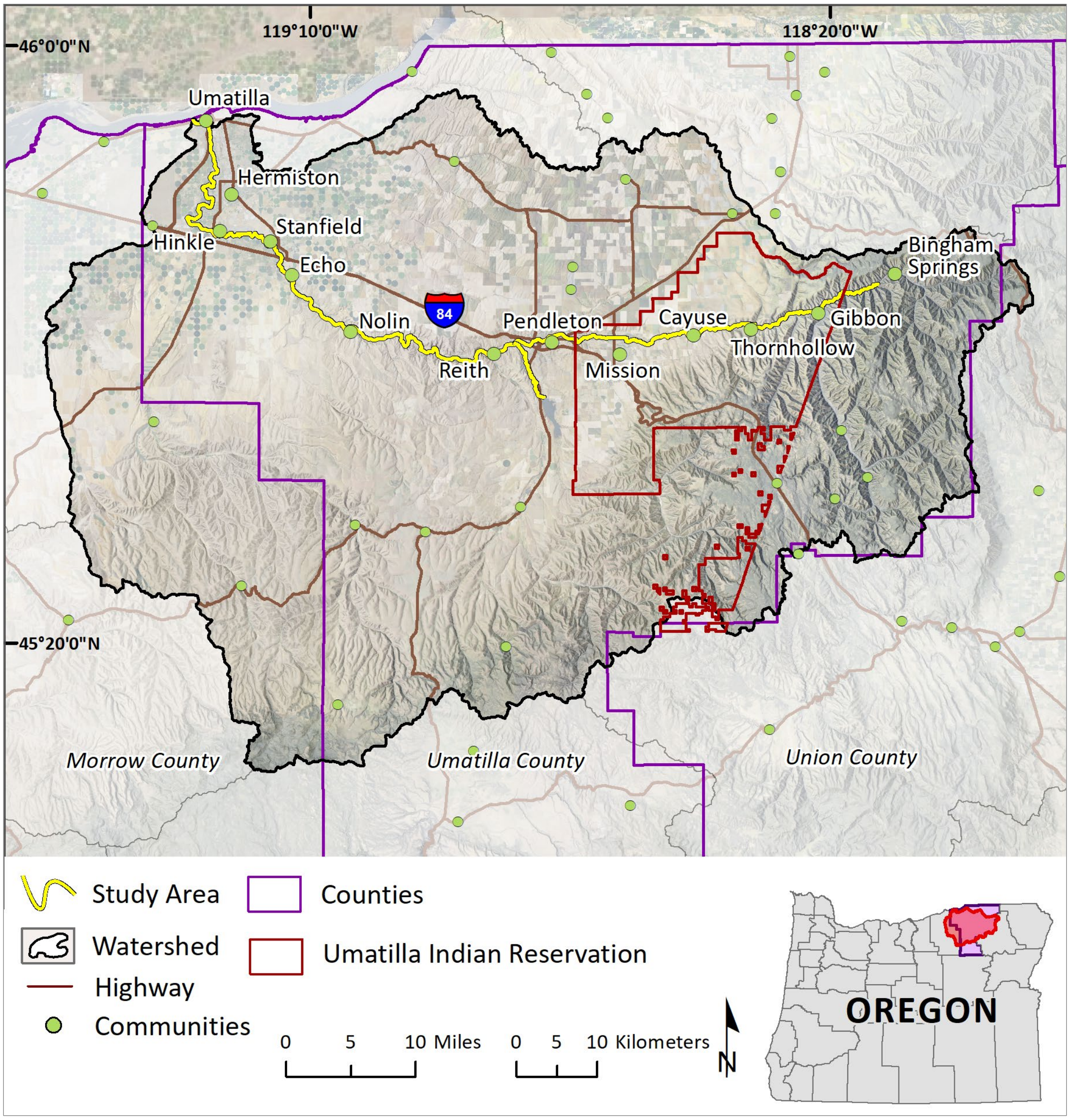
Channel migration is a very poorly understood natural hazard in Oregon for several reasons:

- CMZs have not been mapped along most of Oregon's rivers. Although Roberts and Anthony (2017) produced a statewide screening to help prioritize mapping, it did not directly answer primary questions about CMZ, such as which rivers have experienced the greatest channel migration or which reaches are most vulnerable to future migration.
- Conventional flood hazard maps like the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps (FIRMs) only examine hazards posed by standing floodwaters modeled on a static floodplain. However, channels commonly migrate during flood events, creating the potential for new areas to be impacted by erosion and flooding beyond the area mapped in the FIRMs.
- Past damage from channel migration has not been documented separately from general flood damage. The direct and indirect impact of channel migration on the people, buildings, roads, and other infrastructure in Oregon remains unknown.

1.3 Umatilla County

Umatilla County is in northeastern Oregon in the middle of the Columbia River Plateau. As shown in **Figure 1-1**, the Columbia River flows along the north edge of the county, dividing Oregon from Washington, and the southeastern side of the county includes a large swath of the Blue Mountains range. It shares its borders with Walla Walla, Benton, and Columbia counties in Washington to the north; Grant County to the south; Union and Wallowa counties to the east; and Morrow County to the west. Umatilla County encompasses 3,231 mi^2 (8,370 km^2), which includes 16 mi^2 (41 km^2) of water. Of the 36 counties in Oregon, Umatilla County is the 14^{th} most populous, with just over 81,000 residents as of 2024 (Oregon Blue Book, 2025a). The largest population centers include Hermiston, Milton-Freewater, Pendleton, and Umatilla, all located in the north and central portions of the county. Beyond these urbanized areas, there are dozens of small cities and unincorporated communities spread across the county. It also includes the land of the CTUIR. Following the naming convention used by CTUIR publications, the land is hereafter referred to as the Umatilla Indian Reservation.

Figure 1-1. Study areas (highlighted in yellow) within Umatilla County, Oregon. The context map shows the location of Umatilla County and adjacent count boundaries (in purple), the Umatilla River watershed (in black), and the Umatilla Indian Reservation boundary (in red) in northeastern Oregon.



Before contact with Europeans, the Cayuse, Umatilla, and Walla Walla people lived throughout the Columbia River basin for more than 10,000 years (CTUIR, 2020a). In 1855, these Tribes signed a treaty with the United States Government that reduced their lands from more than 6 million acres (24,281 km^2) to 250,000 acres (1,012 km^2); subsequent federal legislation further reduced the Umatilla Indian Reservation to 172,000 acres (696 km^2) in the area just east of Pendleton and smaller parcels southeast of Pilot Rock (CTUIR, 2020a). An increasing number of Euro-American settlers came to Umatilla County spurred on by the Gold Rush in 1862, the railroad construction in 1881, and the development of dryland wheat farming (Oregon Blue Book, 2025b). Water diverted from the Umatilla River provided far more agricultural opportunities; however, diversion dams limited fish passage and the summer and fall river levels were so low between the mid-1920s and early 1990s that the native salmon and steelhead were extirpated (Harrison, 2023). This had severe negative consequences for the indigenous economy, culture, and nutrition. After extensive efforts, salmonids were reintroduced to the Umatilla River basin. More information on the history of Cayuse, Umatilla, and Walla Walla can be found on the CTUIR website (CTUIR, 2020b). Today, the Hermiston area is known for its production of watermelon; this, in combination with food processing, forest products, manufacturing, recreation and tourism, aggregate production, and wind power generation have fueled economic growth for the region (Oregon Blue Book, 2025b).

The climate is semi-arid with warm, dry summers and cool, moist winters. The National Weather Service (NWS, 2025) recorded an average of 12.2 in (31 cm) of total precipitation in Pendleton, including 17 in (43 cm) of snowfall, with 80 percent of precipitation falling between October and May. NWS noted that the nearby Blue Mountains experience far greater precipitation with 30–70 in (76–178 cm) recorded annually. The snow accumulation in the Blue Mountains is susceptible to rapid melting due to warm, westerly winds (called Chinook winds), which regularly affect the area (NWS, 2025).

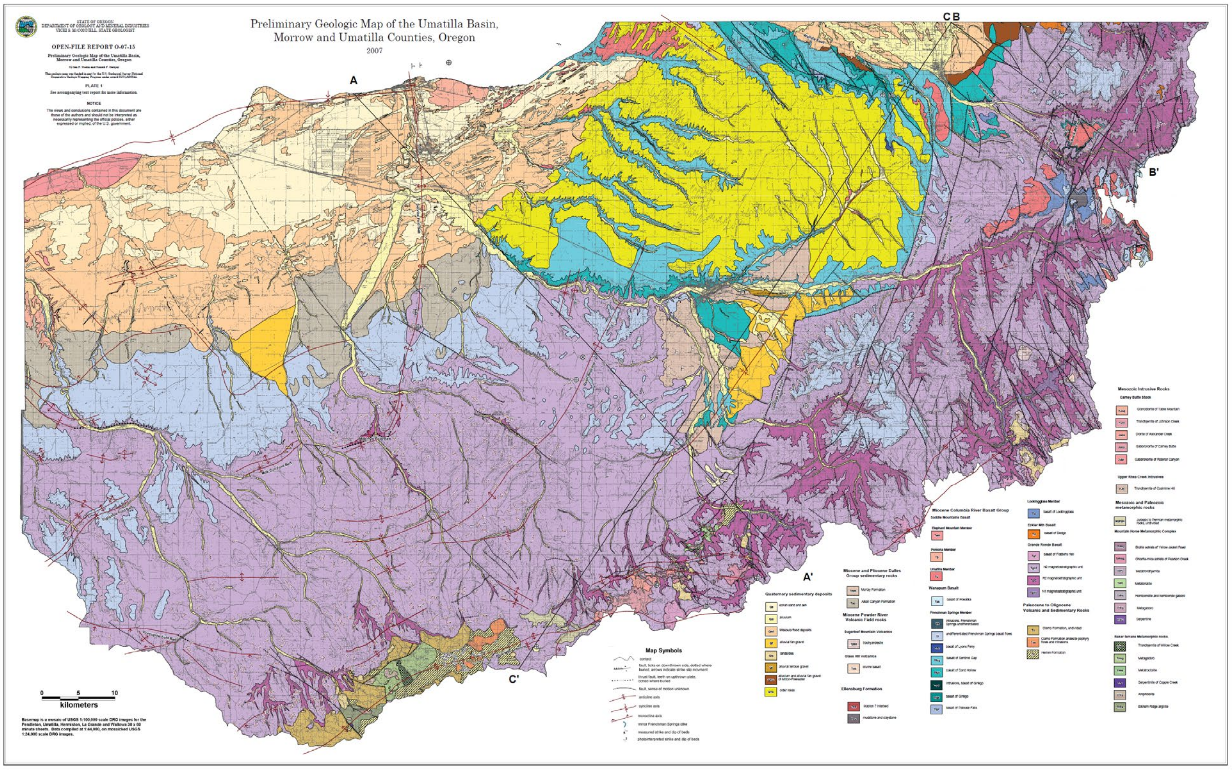
1.4 Umatilla River and Lower McKay Creek

The Umatilla River watershed covers approximately 1,340 mi^2 (3,471 km^2) (**Figure 1-1**). The Umatilla River flows from the eastern edge of the county to northwest, ending at the confluence with the Columbia River. This study area spans nearly 83 river miles (133 km) of the mainstem of the Umatilla River, beginning upstream of Gibbon at the confluence with Bobsled Creek and ending at the confluence with the Columbia River. It also includes 6 river miles (10 km) of lower McKay Creek, which flows from south to north, beginning at the outlet of the McKay Reservoir and ending at the confluence with the Umatilla River. McKay Creek is one of numerous tributaries to the mainstem Umatilla River; the other largest tributaries include the North Fork Umatilla River, South Fork Umatilla River and Meacham, Isqúulktpe (also referred to as Iskullpa), Wildhorse, McKay, Birch, and Butter creeks. The Umatilla River flows through CTUIR Reservation land and through the communities of Gibbon, Mission, Pendleton, Stanfield, Echo, Hermiston, and Umatilla. Lower McKay Creek flows through the community of Green Meadows and the Glendale neighborhood of Pendleton.

1.4.1 Geology

The bedrock that underlies the vast majority of the Umatilla River watershed is composed of different members of the Columbia River Basalt Group (CRBG). These lava flows are ~14 million to 16 million years old (Madin and Geitgey, 2007). The flows were produced by a period of extensive eruptions from vast fissures in eastern Oregon and Washington. In some locations, these ancient lava flows are thousands of feet thick; they may be exposed at the surface, just beneath a thin layer of soil and alluvium, or under other Quaternary deposits. **Figure 1-2** is a reproduction of the Madin and Geitgey (2007) map plate showing the generalized watershed geology. In this figure, two members of the Miocene CRBG are shown: the Frenchman Springs Member basalts (~361–623 ft (~110–190 m) thick, shown in shades of blue and teal) and the Grande Ronde basalt (shown in shades of purple). These units make up the valley walls for much of the Umatilla River upstream of Echo and dominate the southeastern half of the watershed. By contrast, McKay Creek flows through a valley made up of the McKay Formation that is a sedimentary bedrock of cobble conglomerate, pebbly sandstone, and tuffaceous siltstone (Madin and Geitgey, 2007) that is less resistant to erosion when compared to the surrounding CRBG.

Figure 1-2. Reproduction of the Preliminary Geologic Map of the Umatilla Basin, Morrow and Umatilla Counties map plate from Madin and Geitgey (2007). The Frenchman Springs member basalts are shown in shades of blue and teal, the Grande Ronde basalts are shown in shades of purple, Quaternary loess is shown in bright yellow, Missoula Flood deposits are shown in light orange, and recent eolian sand and ash, which postdates the Missoula Flood is shown in light yellow-tan.



Bedrock between Echo and the town of Umatilla is also composed of CRBG, but it is overlain by thick packages of younger, Quaternary sedimentary deposits. In the northern center of the watershed, wind-deposited silt (loess) that pre-dates the Missoula Floods (commonly 33–49 ft (10–15 m) thick, shown in bright yellow) is found directly above the CRBG and McKay Formation (Madin and Geitgey, 2007). The area to the northwest, between the town of Umatilla and Echo, was repeatedly impacted by the large glacial outburst floods, including the Missoula Floods. As a result, there is a thick package of Missoula Flood deposits (commonly 16–49 ft (5–15 m) thick, shown in light orange) and recent eolian sand and ash, which postdates the Missoula Flood (no thickness described; shown in light yellow-tan) in this area (Madin and Geitgey, 2007).

The valley bottoms of the Umatilla River and lower McKay Creek are primarily composed of recent, Quaternary alluvium from hillslope erosion and reworking of floodplain sediments. The alluvium has been estimated by Jones and others (2007) to be ~9 ft (~3 m) thick and Gonthier and Harris (1997) estimated that it averages about 12 ft (4 m) thick. Jones and others (2007) described the alluvium “basalt gravel, cobbles, and boulders intermixed with silt and sand lenses.” The U.S. Geological Survey (USGS) produced a detailed geomorphic map of surficial units in the Umatilla River corridor that subdivides the valley into 25 units, including water, AC, paleochannels, flood basin, multiple valley bottom surfaces, modified land, hillslopes, terraces, and bedrock (Yuh and others, 2024). They note that surfaces below 1,115 ft (340 m) above sea level, the approximate elevation of Pendleton, were repeatedly impacted by the large glacial outburst floods.

There are a series of active, Quaternary faults within the basin, including the Thorn Hollow and Saddle Hollow faults that intersect the Umatilla River and a limb of the Cabbage Hill fault that lies very near the channel (Madin and Geitgey, 2007). These features, and other recent tectonic activity, may influence surface-groundwater interactions, long-term channel migration, and valley geometry, but an investigation of this relationship is beyond the scope of this study.

To learn more about the regional geology, please review the reports, maps, and field trip guide produced by Madin and Geitgey (2007), Ferns and others (2004), Ferns (2006a), Ferns (2006b), Ferns and Ely (2006), Ferns and McConnell (2006a), Ferns and McConnell (2006b), McClaughry and Azzopardi (2023), Madin and others (2023), and Darin and others (2025).

1.4.2 Hydrology

Uncontrolled flow in the Umatilla River basin follows a distinct seasonal pattern that is common in the Pacific Northwest; the cool, wet winter and spring snowmelt produces the highest discharge, and the warm, dry summer and early fall results in lower discharge, as shown in **Figure 1-3**. This pattern is modified in the basin by surface and groundwater interactions within the alluvial aquifer, extraction of water for domestic purposes, the water stored and released by McKay Creek Reservoir, and other irrigation practices, including diversion of water at dams along canals managed by the U.S. Bureau of Reclamation (USBR, (USBR, 2025)). The average daily discharge between 1995–2024 along the mainstem of the Umatilla River near Pendleton was ~540 ft^3/s (15 m^3/s) with late summer, low flows typically <100 ft^3/s (3 m^3/s) (July–September) (USGS, 2025a). During the winter and spring, peak flows ranged between 1,770 ft^3/s (50 m^3/s) to 25,000 ft^3/s (708 m^3/s), which included several major floods, as shown in **Figure 1-4** (USGS, 2025a).

Figure 1-3. Graph of monthly average discharge for 2020–2024 water years along the Umatilla River near Pendleton and near the town of Umatilla (USGS, 2025a). These gages are in RS 28 and RS 2, respectively.

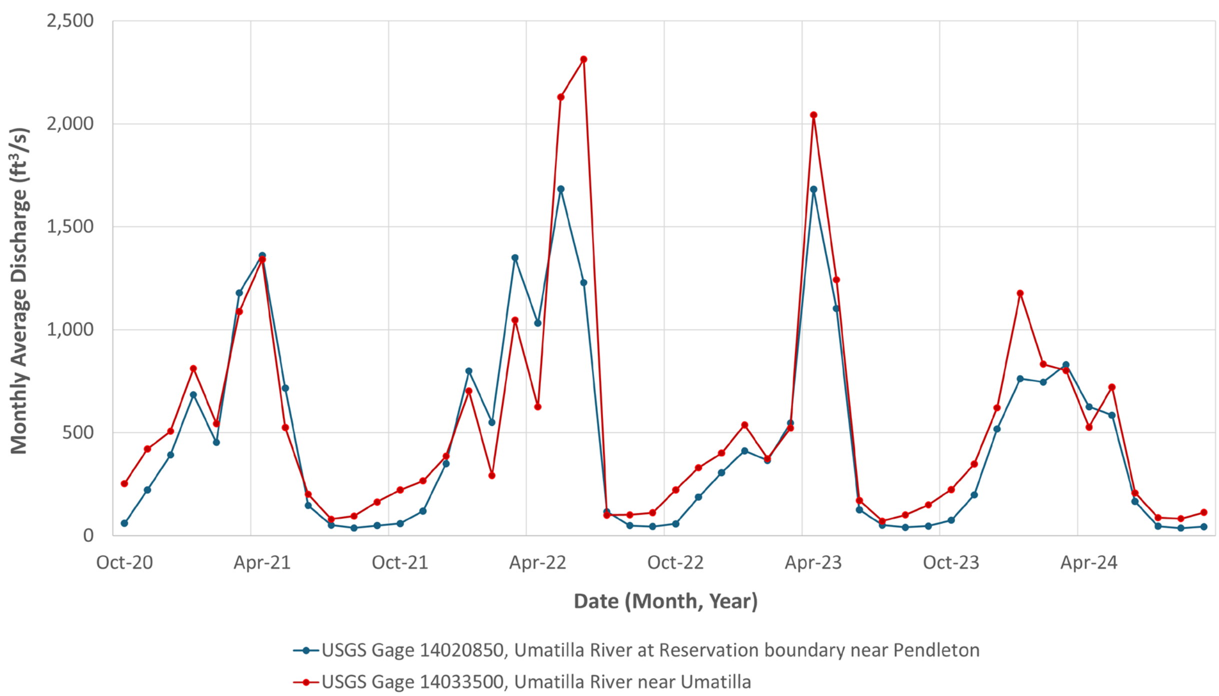
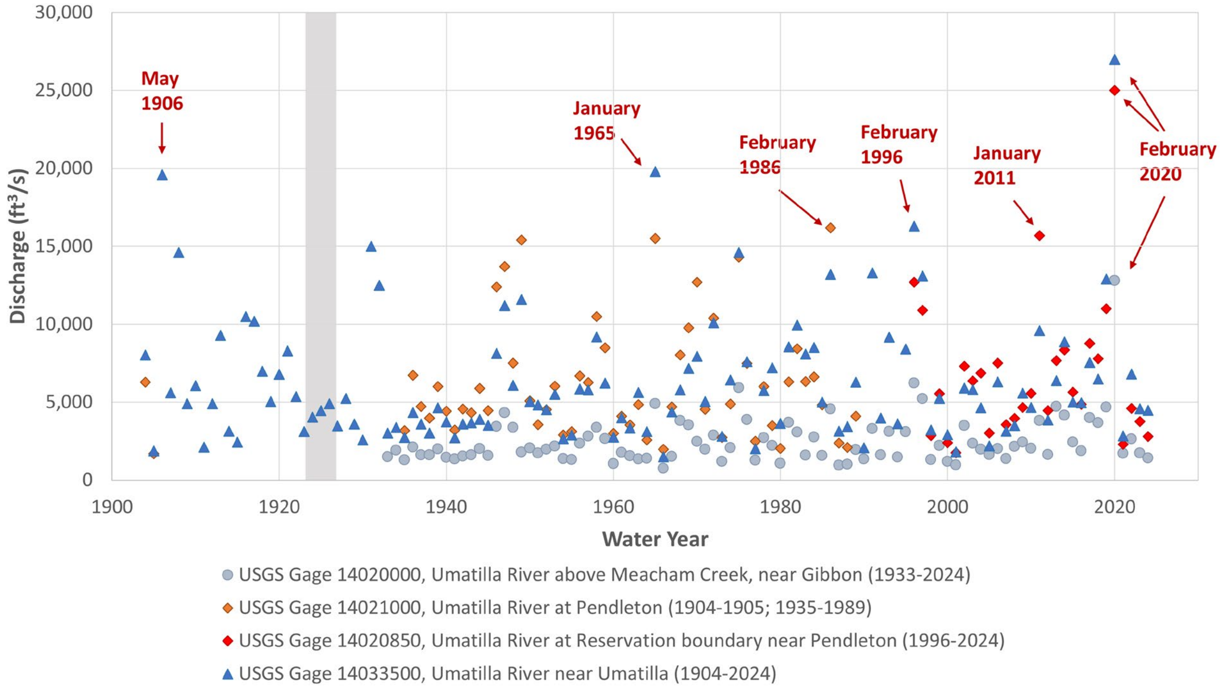
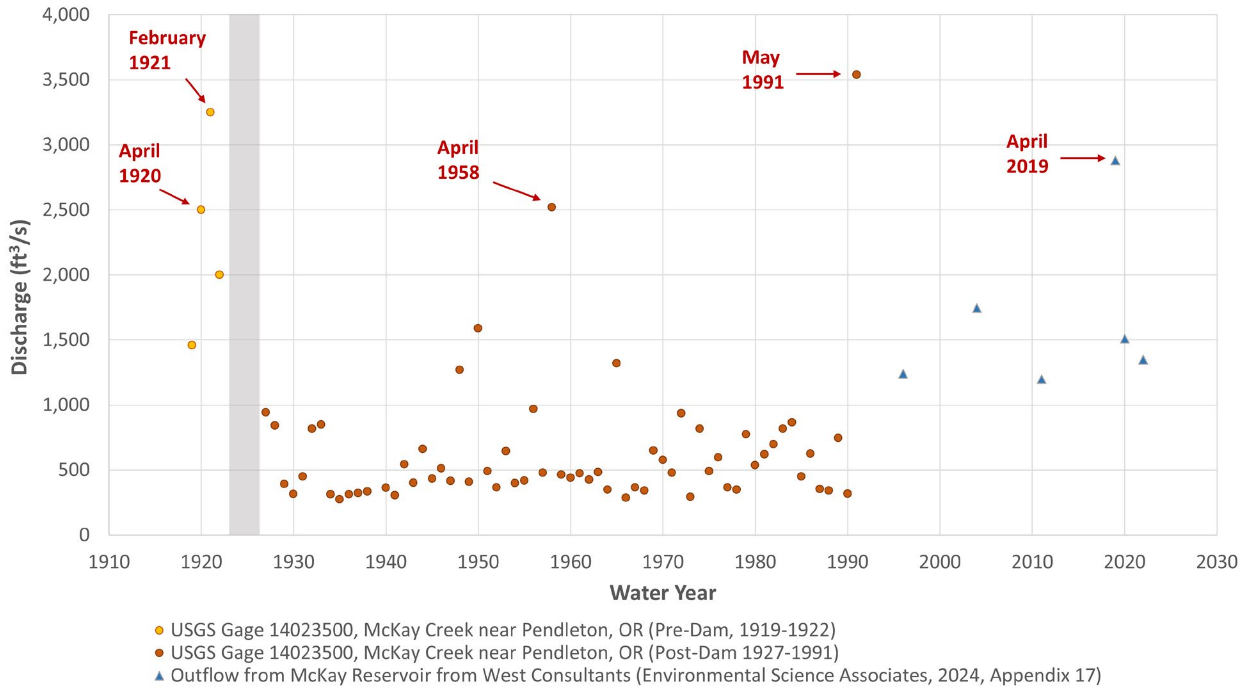


Figure 1-4. Peak streamflow at four USGS streamgages located near Gibbon in RS 38 in gray circles (USGS, 2025b), Pendleton in RS 26 in orange diamonds (USGS, 2025c), Pendleton near the Umatilla Indian Reservation boundary in RS 28 in red diamonds (USGS, 2025a), and Umatilla in RS 2 in blue triangles (USGS, 2025d). A gray bar indicates the years during which the McKay Reservoir was constructed (1923–1927).



Since the construction of the McKay Reservoir in 1923–1927, the USBR has controlled the quantity and timing of flow in lower McKay Creek. Prior to the dam's construction, McKay Creek's average daily discharge between 1918–1922 was ~160 ft^3/s (~4.5 m^3/s), including no flow recorded for many summer months (July–September), and as shown in **Figure 1-5**, the annual winter or spring peak flow ranged from 1,460 ft^3/s (41 m^3/s) to 3,250 ft^3/s (92 m^3/s) each year (USGS, 2025e). After the dam's construction, the controlled flows of the McKay Creek no longer follow this pattern; there are less frequent large floods and much lower average daily flows. Flows above 1,500 ft^3/s (42 m^3/s) were recorded only three times between 1927 and 1991, after which time the USGS station records have not been published (2025e). Between 1986–1990, the USGS gage recorded an average daily discharge of 85 ft^3/s (2.4 m^3/s). Furthermore, during the winter and spring, flows were frequently less than 10 ft^3/s (0.3 m^3/s), but unlike in the past, water flowed through McKay Creek consistently in July and August (USGS, 2025e).

Figure 1-5. Peak streamflow along lower McKay Creek below the reservoir in RS 5 (USGS, 2025e; Environmental Science Associates, 2024). Gray highlight indicates the years during which the McKay Reservoir was constructed.



As previously mentioned, the surface-groundwater interactions, irrigation practices, and use of domestic wells also modify flow in the Umatilla River. Large parts of the basin have been designated as critical groundwater areas by the Oregon Water Resources Department (OWRD) due to concerns about falling groundwater levels, over-allocated groundwater resources, and nitrate contamination (OWRD 2003, Oregon Department of Environmental Quality [DEQ], 2025a). These topics are complex and beyond the scope of this study. However, there are many resources available that describe the history and current condition of these issues. These include but are not limited to: USGS's early study of geology and groundwater (Hogenson, 1964) and hydrogeologic study and groundwater budget (Herrera and others, 2017), USBR's website (2025) and study for CTUIR (USBR, 2012), DEQ's website on nitrate contamination (2025a) and report (2025b), the Lower Umatilla Basin Groundwater Management Area website (2025), and the Umatilla County detailed timeline of water and irrigation changes in their 2021 NHMP, Table DR-2.

In terms of understanding channel migration patterns, it is worth observing that the discharge in the Umatilla River mainstem does not consistently increase as the river flows downstream and drainage area increases, as is common in western Oregon. In arid regions, it is not uncommon for reaches or entire rivers to be described seasonally as "losing streams" when the floodplain water table is lower than the stream level and water infiltrates into the ground. In the case of the Umatilla River, the river is losing water not only to the ground but also because of extraction by people. To compare, the drainage area upstream of the gage station at Pendleton is 441 mi^2 (1,142 km^2) (USGS, 2025a), and the drainage area upstream of the gage in the town of Umatilla is 2,290 mi^2 (5,931 km^2) (USGS, 2025d). However, **Figure 1-3** shows that the two gages have relatively similar monthly average discharges even though one location has a drainage area five times larger than the other.

This pattern is also observable in the annual peak discharges shown in **Figure 1-4,** where the flood flows at Pendleton are similar to, and sometimes exceed, the flows in the town of Umatilla. It can also be seen in the FEMA effective Flood Insurance Study (FIS) discharges. According to the FEMA hydraulic models, the 1-percent annual chance flood (i.e., the 100-year flood) discharge at Pendleton is 22,200 ft^3/s (629 m^3/s); at the confluence with Butter Creek, it is 28,000 ft^3/s (793 m^3/s); and in the town of Umatilla, it is 21,600 ft^3/s (612 m^3/s) (2010). Although stream power is directly proportional to discharge and discharge in Oregon typically increases with drainage area, this is not the case in the mainstem of the Umatilla River as discharge is extracted for irrigation, evaporates, and is lost to groundwater recharge in alluvium. A study by Jones and others (2007) provides a more detailed examination of the seasonal hyporheic flow patterns in the Umatilla River floodplain, which also indicate groundwater flow direction varies seasonally.

1.4.2.1 Recent Flooding

The Umatilla River watershed is prone to riverine flooding and damaging river erosion. A flood planning document prepared in 2000 for Umatilla County described the risk of flooding as “widespread” in many of the communities along the Umatilla River (Gardenhire, 2000). The 2021 Umatilla County NHMP ranked floods as the greatest risk to the county, highlighting the February 2020 flood that caused major damage and was a federally declared disaster. This, and other large, damaging floods, are labeled in **Figure 1-4**. On February 4th and 5th, 2020, heavy rain produced by an atmospheric river melted a deep snowpack in the Blue Mountains; this triggered rapid runoff and flooding throughout the Umatilla River watershed that peaked on February 6th and remained at flood stage in many places until February 8th or 9th. The peak discharge of 25,000 ft^3/s (708 m^3s) estimated by the USGS (2025a) during the 2020 flood exceeded the threshold for a 1-percent annual chance flood in Pendleton and the town of Umatilla, calculated by FEMA (2010). In many areas without infrastructure to protect from flooding, water flooded nearly all of the valley bottom, which is consistent with the FEMA FIS maps that depict the 100-year floodplain.

This event resulted in one fatality; stranded residents; forced widespread evacuation; impacted hundreds of homes; damaged roads, utility lines, irrigation systems, bridges, and levees; and closed Interstate 84 and the railroads (Oregon Department of Emergency Management (ODEM), 2025). The local governments and non-profits requested ~$26.7 million in public assistance for debris removal, emergency protective measures, roads and bridges, water control facilities, public buildings, utilities, and more (ODEM, 2025; FEMA, 2020). The Oregon Department of Transportation (ODOT) requested an additional ~$17.4 million in funds from the Federal Highway Administration for damages to major transportation networks (ODEM, 2025). In total, the repair and replacement costs for the disaster was at least ~$48 million, but this estimate does not include indirect impacts, such as the loss of income from closed businesses.

The cost of the damage from floodwaters inundating land and structures is not typically described separately from the damage from channel migration and erosion. Beyond the removal of debris, the physical damage to, and undermining of, roads, railroads, levees, and bridge abutments, can be caused primarily by erosion and not from water inundation. Based on the type of costs described above, we suggest that channel migration was a major driver of damage during the 2020 floods.

1.4.2.2 Climate Change

Across the Pacific Northwest and in Umatilla County, warmer temperatures due to climate change are expected to result in greater winter runoff and streamflow. As more precipitation falls as rain and less as snow, the snowmelt is expected to begin earlier in the year, and summer flows are predicted to be lower because of less seasonal precipitation (Dalton, 2020). According to Fleishman and the Oregon Climate Change Research Institute (OCCRI) (2023), thus far, Oregon's annual average temperature has increased by approximately 2.2°F (1.1°C) per century since 1895, and, without significant reductions in greenhouse gas emissions, the annual temperature is projected to increase by 5°F (1.8°C) by the 2050s and 8.2°F (4.5°C) by the 2080s.

Although Oregon has experienced a statistically significant increase in temperature, there is currently no evidence of a change in total precipitation across the state (Fleishman and OCCRI, 2023). However, this may be explained by substantial natural variability and relatively short periods of observation. A literature review by the U.S. Army Corps of Engineers (USACE) completed in 2015 (USACE, 2022) found strong evidence of decreasing trends in the Pacific Northwest region's annual streamflow, particularly in the spring and summer flows, and a decrease in the region's April 1 snow-water equivalent for the latter half of the 20th century. They attributed these patterns to increasing temperature trends.

The Umatilla River watershed is also vulnerable to droughts. The Umatilla County NHMP (2021) recognized 25 drought events between 1894 and 2020 that impacted the county; some of these events spanned multiple years and included a federally declared disaster. Work by Dalton (2020) suggests that by the end of the 21st century, some of the subbasins within the Umatilla River watershed will be at greater risk of a water shortage during the summer because low flows are projected to decrease compared to historical conditions. This change may further complicate the competing water needs for aquatic species, irrigation, and groundwater management.

1.4.3 Geomorphology

The Umatilla River can be divided into three distinct sections that have differing underlying geologic and geomorphic conditions and have been modified by Euro-Americans in different ways since the mid-1800s. Each of the four following subsections provides a generalized description of these parts of the basin within the study area, including McKay Creek. We have indicated the corresponding RS numbers that are shown on the maps in the results section.

1.4.3.1 Upper Umatilla River

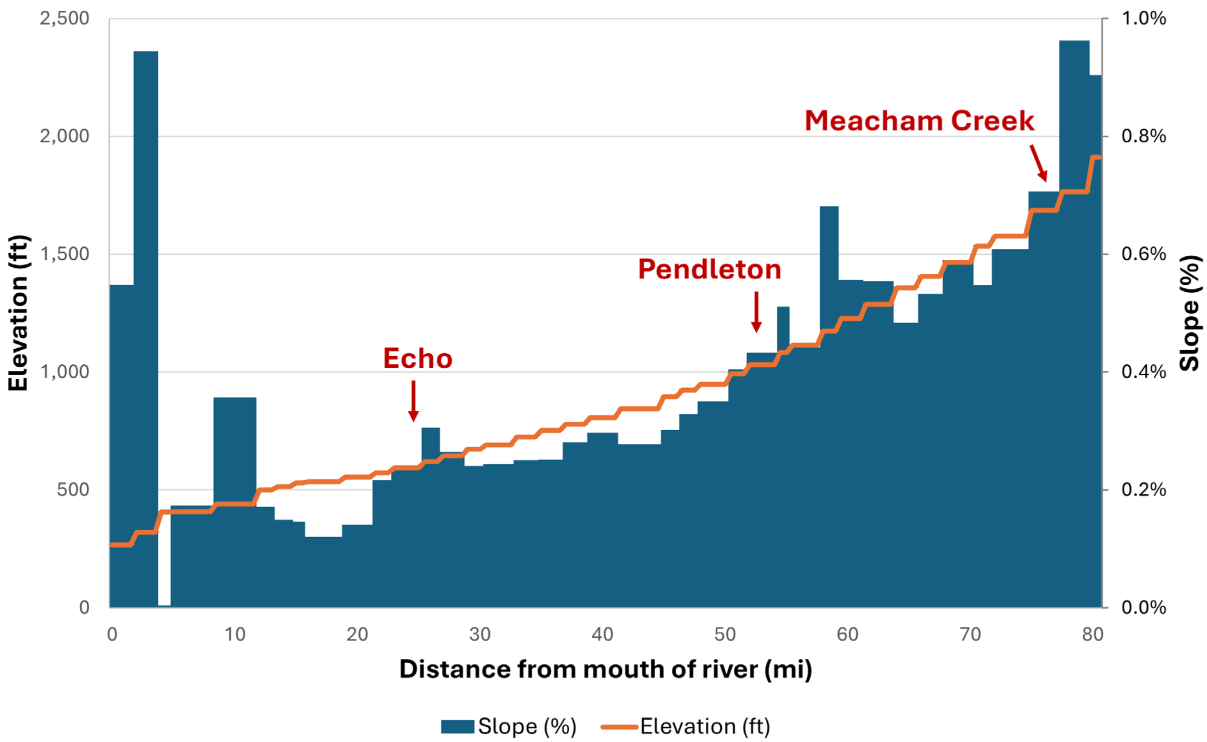
The upper Umatilla River begins at the upstream edge of this study area, at the confluence with Bobsled Creek; it flows across the Umatilla Indian Reservation, adjacent to or through the towns of Gibbon, Cayuse, Mission, and Riverside and ends at the western edge of Pendleton (RS 28–39). This is the most geomorphically diverse and complex section of the mainstem, as shown in **Figure 1-6**. It has experienced widespread channel migration, has many large woody debris (LWD) log jams and mid-channel forested islands, a history of avulsions, and includes both single and multi-thread (braided and anastomosing) channels.

Figure 1-6. Photographs taken by the authors in 2024 and 2025, and OSIP 2024 aerial imagery along the upper Umatilla River. WGS geographic coordinates. A (45.7309, -118.2695); B (45.6839, -118.4983); C (45.6713, -118.6504); D (45.6781, -118.5780); E (45.6845, -118.5069); F (45.6751, -118.5647)

The valley walls are composed of CRBG volcanics, and the valley bottom is composed of Holocene fluvial deposits, small alluvial fans, and artificial fill (i.e., levees, berms, roads, and railroad embankments). Although the valley bottom was not directly impacted by the Missoula Floods, the upper hillslopes along the north side of the valley are covered in loess deposits. The channel bed is primarily composed of gravels and cobbles with intermittent bedrock outcrops; Hughes (2008) reported the 50th percentile (i.e., median) grain size is ~2.4 inches (~6 cm) and the 84th percentile grain size is ~6 inches (~15 cm). The larger tributaries, including Meacham and Isqúulktpe creeks are significant sources of new sediment to the mainstem and aggrade with large packages of sediment each winter in the tributary channels.

As shown in **Figure 1-7**, the upstream reaches are slightly steeper than the reaches approaching Pendleton. In the farthest upstream reaches, above the confluence with Meacham Creek (RS 38–39), the valley is very narrow, typically between ~350–500 ft (~107–152 m) wide and the water surface slope is relatively steep (0.90-0.96 percent). As a result, there is very little space for human infrastructure. For example, Binghamton Road was constructed directly adjacent to the channel in many locations. The river is confined by both the bedrock valley walls and the road's shoulder in these reaches.

Figure 1-7. Umatilla River study area's early fall water surface elevation and slope for each RS. To provide perspective, a 0.2 percent slope is the same as a ~11 ft (~3.2 m) change in elevation across 1.0 mi (1.6 km) and a 1.0 percent slope is the same as a ~53 ft (~16 m) change in elevation across 1.0 mi (1.6 km).



Below the confluence with Meacham Creek, the Umatilla River valley begins to widen and the water surface flattens. The flow in Meacham Creek often exceeds the flow in the mainstem, and the drainage area for Meacham Creek is larger than the mainstem above the confluence. Between this point and the eastern edge of the town of Mission (RS 31–37), the valley is typically ~1,000–2,000 ft (~305–610 m) wide, and the slopes range from 0.48–0.71 percent. Within the town of Mission, and to the edge of Pendleton (RS 28–30), the valley widens further to ~2,500–5,500 ft (~762–1,676 m) and the slope is 0.44–0.68 percent. River movement is limited in some areas where levees and the railroad have been constructed, cutting off the river from large swaths of the valley bottom. The channel is most obviously straightened and channelized near the town of Mission where the channel was repeatedly dredged in the 1940s–1960s (Jones and others, 2008). Levees and bedrock hold the channel in its current location.

As previously mentioned, the upper Umatilla River reaches are bisected by Quaternary fault lines and fold axes. Some of the changes in valley widths may be due to these tectonic features, but further investigation is required to understand the relationship between these features, river location, and underlying geology. For more information, please review the reports by McClaughry and Azzopardi

(2023) and Madin and others (2023), which include recently published geologic maps that show mapped faults and folds.

1.4.3.2 Middle Umatilla River

The middle reaches of the Umatilla River flow from the western edge of Pendleton, through the city, along the narrow canyon that Reith Road parallels, and ends just upstream of Echo (RS 15 to 27). The river is a single-thread channel, shown in **Figure 1-8**, with low sinuosity that has been artificially straightened and channelized by levees, berms, roads, and railroad embankments. As shown in **Figure 1-7**, these reaches have a gentle water surface slope, which decreases near Pendleton (~0.4–0.5 percent) and then remains relatively consistent throughout the canyon at ~0.25–0.35 percent The valley walls are hundreds of feet tall and made up of CRBG volcanics, which also naturally confine the channel. In the City of Pendleton, the channelization is easily observed as the river has been relocated and straightened, flowing between the bedrock of the valley wall and the levees. There is one diversion dam and many bridges that span the channel. The middle Umatilla River flows through the valley bottom, which is composed of Holocene fluvial deposits, small alluvial fans, and artificial fill. The valley is typically 900–2,000 ft (274–610 m) wide. The bed of the channel is primarily composed of gravels and cobbles.

Figure 1-8. Photographs taken by the authors in 2024 and 2025, and OSIP 2024 aerial imagery along the middle Umatilla River. WGS geographic coordinates. A (45.6766, -118.7774); B (45.6708, -118.8384); C (45.6561, -118.8789); D (45.6786, -119.0244); E (45.6854, -119.0940); F (45.6744, -119.0712).

A notable geographic feature, Horseshoe Curve (RS 20), was the former location of the Furnish (Coe) irrigation dam. The dam was breached in 1934, only 25 years after it was constructed, because the valley behind the dam filled with fine-grained sediment that triggered localized flooding of the adjacent railroad tunnel. This created an anomaly in the surficial geologic deposits. After the dam breach, the Umatilla River eroded through the layers of accumulated silt that now make up the banks of the river for ~3 river miles (~4.8 km).

1.4.3.3 Lower Umatilla River

The lower Umatilla River flows from the reaches just upstream of Echo to the confluence with the Columbia River (RS 1 to 14). As shown in **Figure 1-9**, this is a single-thread channel that flows through land that was shaped by the late Pleistocene outburst floods (i.e., the Missoula Floods). There are many miles of ditches and multiple diversion dams that extract water from the channel, which reduces the stream power along these reaches.

Figure 1-9. Photographs taken by the authors in 2024 and 2025, and OSIP 2024 aerial imagery along the lower Umatilla River. WGS geographic coordinates. A (45.7420, -119.1993); B (45.7420, -119.1993); C (45.7851, -119.2410); C (45.7896, -119.2857); E (45.8068, -119.3551); F (45.9140, -119.3468).

The upstream half of this section flows through a wide valley, from around 2,600 ft (800 km) to more than 5,000 ft (1,600 km) wide, called the Umatilla Meadows (RS 9–14). The channel is moderately to highly sinuous and, as shown in **Figure 1-7**, has a very low slope (<0.2 percent). It meanders through modern floodplain sediments, ~0–10 ft (~0–3 m) above the early fall water surface elevation, which are surrounded by dunes and a low-lying, possibly seasonally inundated, floodplain with an indistinct boundary mapped by Yuh and others (2024) as a "flood basin," ~6–14 ft (~2–3.5 m) above the channel. Limited field work by the authors indicated the surface of the bed of the channel was primarily composed of gravels and cobbles. The channel flows at the toe of the valley wall, which is ~60–100 ft (~18–30 m) above the channel.

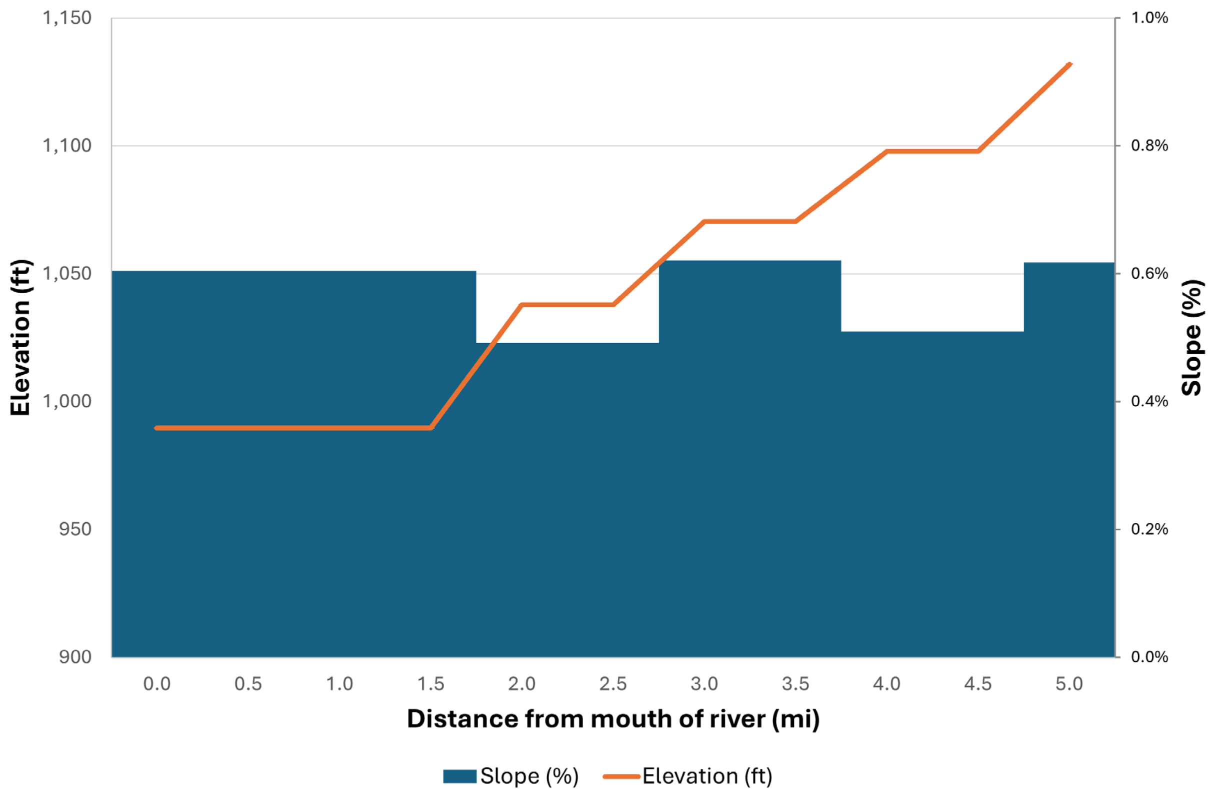
Below the confluence with Butter Creek, the valley turns abruptly north and narrows. From the confluence and downstream, the Umatilla River flows intermittently confined through the canyon-like valley that cuts through the CRBG bedrock, Missoula Flood deposits, Umatilla terrace deposits, and aeolian sands that make up the valley walls (RS 1–8). The walls stand ~20–40 ft (~6–12 m) above the channel in the upstream reaches closer to Butter Creek and the town of Hinkle. The channel becomes progressively more incised as it flows toward the confluence with the Columbia River, such that the valley walls are ~30 ft to more than 150 ft (~9 m to more than 46 m) above the channel surface near the town of Umatilla. Additionally, the channel becomes much steeper (0.6–1.0 percent, see **Figure 1-7**) below the Three Mile Falls Diversion Dam where the bed of the channel has downcut to meet basalt bedrock (OWRD, 2003). The valley bottom is typically 350–1,100 ft (107–335 m) wide and is composed of modern Umatilla River floodplain deposits. Limited field work by the authors indicated the surface of the bed of the channel was primarily composed of bedrock, gravels, and cobbles.

1.4.3.4 Lower McKay Creek

The lower McKay Creek flows out of McKay Reservoir and into the Umatilla River at the confluence near Pendleton (RS 1 to 5). It is primarily a single-thread channel with modern, gravel and cobble alluvium composing the bed and banks of the channel (as shown in **Figure 1-10**). Pebble counts collected at five sites along the lower McKay Creek had an average median grain size of 1.5 in (3.9 cm) (Environmental Science Associates, 2024). The valley bottom is typically only ~2–8 ft (0.6–2.4 m) above the early fall water surface elevation. The channel flows through a narrow valley of sedimentary McKay Formation bedrock that is typically ~1,000–3,000 ft (~305–914 m) wide and more than 200 ft (61 m) above the channel. As shown in **Figure 1-11**, the channel has a consistent, modest slope of ~0.5–0.6 percent across all the reaches. Some of the reaches have been artificially straighten and most currently have a fairly straight form, except RS 4, which takes a meandering form.

Figure 1-10. Photographs taken by the authors in 2025, and OSIP 2024 aerial imagery along lower McKay Creek. WGS geographic coordinates. A (45.5972, -118.7983); B (45.6252, -118.8111); C (45.6456, -118.8227); D (45.6478, -118.8234); E (45.6524, -118.8250); F (45.6664, -118.8354).

Figure 1-11. Lower McKay Creek's water surface elevation and slope for each RS.



Flow in lower McKay Creek is controlled by releases from the USBR-operated dam that was constructed in 1923–1927; the channel has no major tributaries. The dam also prevents sediment from moving from the upper watershed down into lower McKay Creek. As a result, sediment in the channel is sourced from the bed, banks, and valley walls below the dam. As shown in **Figure 1-5**, large peak flood flows along McKay Creek that used to occur annually are now rare events, which limits the stream power and capacity of the river to move bedload sediment.

After the dam was built, the local communities regularly dredged and occasionally straightened the channel to increase flood capacity. Concurrently, many homes and structures were constructed in low-lying areas, adjacent to the channel. In 1990, channel dredging stopped regularly occurring on McKay Creek due to the Endangered Species Act protection of salmonid habitat. A study by Environmental Science Associates (2024) found that, without sediment removal by humans or by the river during large flood flows, sediment has accumulated, and the bed of the channel has aggraded. However, during the 2019 flood, larger flows were released from the dam that had sufficient energy to cause bank erosion in the upper reaches and transport accumulated bedload sediment. In addition, emergency conditions allowed the local government to temporarily dredge the channel in 2020. Environmental Science Associates (2024) reports that the 2019 flood introduced more sediment from bank erosion (>18,000 yd^3 (>13,762 m^3)) than was removed by dredging (8,029 yd^3 (6,137 m^3)). They suggest this created a state of disequilibrium in the channel that they predict will take up to a decade to naturally stabilize and that flows greater than 800 ft^3/s (23 m^3/s) to 1,000 ft^3/s (28 m^3/s) would likely induce further channel migration. According to the Environmental Science Associate study, the FEMA FIRMs were produced using channel profiles collected during the period when the channel was being regularly dredged. As a result, the FIRMs underestimate the current risk now that the channel has aggraded and flood conveyance capacity has diminished. Much more information can be found in the Environmental Science Associates report available on the Umatilla County website.

1.4.4 Historical Changes

In the areas unconfined by bedrock, the Umatilla River has historically been a highly geomorphically dynamic river. However, the changes made by Euro-Americans beginning in the mid-1800s, including dredging; straightening; construction of levees, roads, and railroads; and water extraction for irrigation and domestic use, have collectively constrained the river, reducing channel complexity and mobility. According to the CTUIR 2025 Action Plan, 48 river miles (96 km), or 44 percent of the total river length, are constrained by infrastructure like levees, roads, and railroads. These structures limit flood inundation to less than half of the historical floodplain (CTUIR, 2025b). They also report that the channel complexity decreased by 55 percent between 1952–2025, which is associated with a substantial loss of off-channel habitat, LWD, and dense, woody riparian vegetation.

Despite these changes and constraints, the Umatilla River channel has continued to migrate in many reaches through gradual change and during major flood events. There have been two, relatively recent geomorphic studies of the Umatilla River that focused on channel migration. Hughes' (2008) dissertation studied the geomorphic response of the Umatilla River to flood events in 1965 and 1975. Merrill's (2024) thesis examined flood events in 1996–1997 and 2020. Both studies found that, as expected, the Umatilla River responds to floods in many ways including by widening the AC; large-scale, rapid lateral migration; channel straightening; bar formation and scour; and removal of riparian vegetation. They also found that the areas that experienced the least channel change during floods were those that were already straightened and had a reduced floodplain (i.e., where bedrock, terraces, or infrastructure confined the channel). Additionally, Hughes studied the river's behavior in the years after the floods. He observed that after the 1965 flood, the channel narrowed, sinuosity increased, and erosion returned to a slower rate with smaller bars and areas of scour. After the 1975 flood, he further noted that vegetation returned to the floodplain, which narrowed the AC width and size of bars, returning the AC to a condition similar to its state prior to the 1965 flood.

CTUIR has completed river and floodplain restoration efforts across the Umatilla River basin to rebuild riparian and instream habitat for wildlife, including salmon, steelhead, and other native fish species. Their goal is to steward a "healthy river capable of providing First Foods that sustain the continuity of the Tribe's culture" and they recognize the importance of river dynamism (Jones and others, 2008). Their strategies include reconnecting floodplains to streams, removing fish passage barriers and levees, re-meandering channels, installing large wood structures, and restoring native vegetation to improve juvenile rearing and adult spawning habitat.

Although CTUIR projects focus on ecological and cultural restoration, they also can have an impact on channel migration and flood conditions. Reconnecting rivers to their floodplains by removing levees and reestablishing a meandering river channel can reduce peak flood levels, as shown by an estuary restoration project in Tillamook, Oregon (NOAA, 2019). By reestablishing natural functions of floodplains, these changes may also allow the erosive energy of the river to dissipate as water flows across a reconnected floodplain, which leads to less erosion in downstream reaches (Loose and Shader, 2016). In addition, efforts to restore native beaver populations by CTUIR may also reduce flooding by slowing the speed of water and retaining water behind beaver-built dams, increasing bank stabilization and sediment deposition, and promoting floodplain connection (Pollock and others, 2023). More information about the ongoing work by CTUIR is available on their websites: https://ctuir.org/ (CTUIR, 2020c), https://fisherieshabitat.ctuir.org/our-work/ (CTUIR, 2025a), and https://umatillariver.org/projects/ (CTUIR Fisheries Habitat Program, 2025a).

2.0 METHODS

2.1 Overview

The goal of this CMZ evaluation is to define the area in which a given stream is most likely to move laterally within the next 30 and 100 years. The CMZ boundary is designed to aid in planning, raise awareness of hazards, and to inform decisions about environmental and emergency management. These maps may be used to identify which buildings, critical facilities, infrastructure, and transportation lines are potentially at risk from channel migration and to prioritize areas for pre-disaster risk reduction.

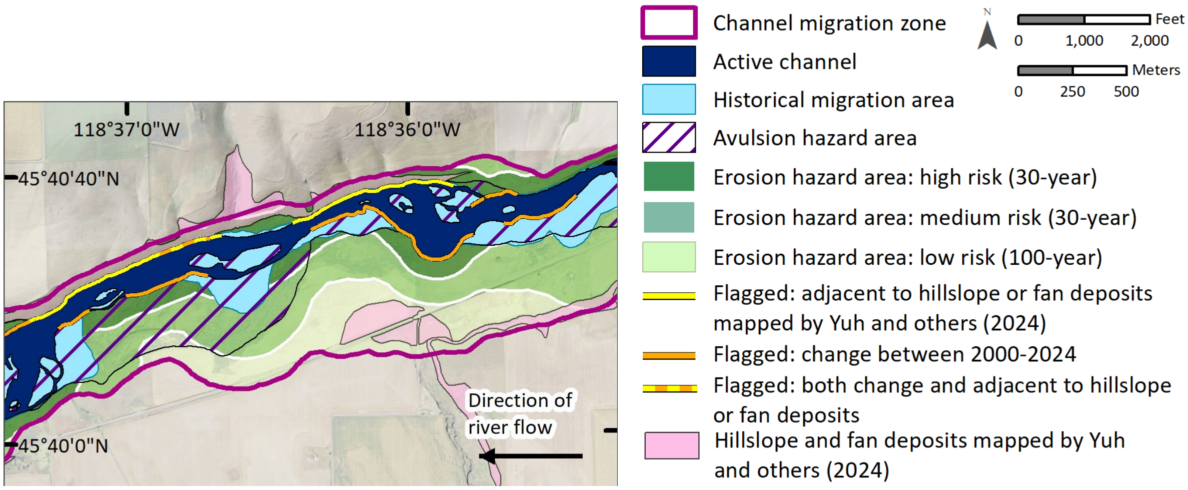
This study produced CMZ maps for two rivers located in Umatilla County following the methods outlined in this section. The methods integrated techniques and mapping units from prior studies conducted in Oregon, Washington, and Colorado, including English and Coe (2011), Lagasse and others (2004), Olson and others (2014), Rapp and Abbe (2003), and multiple studies by the King County Department of Natural Resources and Parks from 1991–2020 (e.g., King County, 2019). The terminology and definitions of mapping units differ somewhat among these previous studies. The terms used in this study are defined below. In addition, the terms river, stream, and creek are used interchangeably.

- **Active channel (AC):** the area within the floodplain that regularly conveys water, including the exposed, unvegetated sediment deposits both within, and adjacent to, the river; it is inundated at times of high discharge (Montgomery and MacDonald, 2002).
- **Historical migration area (HMA):** the combined areas that the channel has occupied in historical record, including the AC (labeled historical migration zone by Rapp and Abbe, 2003)
- **Erosion hazard area (EHA):** the area most likely to be impacted by lateral migration and channel widening over a specified period, based on historical erosion rates (similar to the erosion hazard zone by Rapp and Abbe, 2003).
- **Avulsion hazard area (AHA):** the area most likely to be impacted by rapid channel diversion and occupation (similar to the avulsion hazard zone by Rapp and Abbe, 2003).
- **Flagged**: channel banks that have been identified for further geotechnical inspection due to signs of recent migration or proximity to landslides.
- **Modern valley bottom (MVB):** the relatively flat area adjacent to the stream, including the current and potentially historical floodplains, bounded by steeper valley walls that resist erosion (Rapp and Abbe, 2003; Kline and others, 2007).
- **Lidar-derived digital elevation model (DEM):** highly accurate and detailed, ~3 ft (~1 m), topographic datasets collected using a laser scanner that can display the ground surface elevations relative to NAVD88 without structures or vegetation.
- **Relative elevation model (REM):** a visualization used to identify floodplain features with raster values that represent height above water surface; created from a DEM that has been normalized to the elevation of the water surface (Olson and others, 2014).
- **River segment (RS):** a section of river that displays relatively similar hydrologic and geomorphic characteristics, composed of multiple reaches (similar to channel reach in Rapp and Abbe, 2003); in this study, typically ~8,000–14,000 ft (~2,440–4,270 m) in length.
- **Stream stations:** evenly spaced points along the river centerline.

- **Channel confinement:** a characteristic of rivers that are limited in their ability to laterally migrate due to bed and bank materials that resist erosion. Channels that flow within narrow valleys are said to be confined and those that migrate freely through erodible sediment in open valleys are described as unconfined (Montgomery and Buffington, 1997).
- **Incision:** the process by which a river erodes downward into its bed. If a channel erodes deeply into its bed, the banks of the channel become very steep and the adjacent floodplain is less frequently flooded (see Simon and Hupp's 1986 conceptual model for modified channel evolution).
- **Single-thread and multi-thread:** a description of channel form. Channels with a single AC are described having a single-thread form. Channels with multiple ACs flowing through the floodplain are described as multi-threaded (Buffington and Montgomery, 2013).
- **Anabranching and braided streams:** a description of channel form. Stable, multi-thread channels with relatively large, often vegetated islands between channels are described as anabranching. Unstable, multi-thread channels with temporary sediment bars and islands separating the channels are described as braided (Knighton, 1998).
- **Sinuosity:** a description of channel curved form relative to a straight path. It is quantified as an index by dividing the channel length by the relatively straight valley length; the lower the index value the straighter the channel. For the purposes of this study, very low sinuosity (straight) channels have an index of <1.05, low to moderate sinuosity channels are 1.05–1.30, highly sinuous channels are 1.3–3.0, and very highly sinuous channels are >3.0 (Fryirs and Brierley, 2013).

The CMZ is composed of the AC, HMA, EHA high hazard (30-year median rate), EHA medium hazard (30-year maximum rate), EHA low hazard (100-year maximum rate), AHA, and Flagged. These units are produced using the approaches described in the following section. **Figure 2-1** is an example of an image that can be used to visualize how the channel units are combined. This study mapped the high-, medium-, and low-hazard EHA to show potential movement across the next 30 and 100 years at different levels of confidence. The high-hazard area represents the zone directly adjacent to the AC that is most likely to be impacted by channel migration. The medium- and low-hazard areas represent locations beyond the HMA and have a lower likelihood of being impacted by channel migration within the next 30 and 100 years. A more detailed explanation of each of the components is provided in **Section 2.3.**

Figure 2-1. Conceptual diagram of the components of a CMZ map, including the AC, HMA, AHA, EHAs, flagged streambanks, and CMZ. Example from the Umatilla River, Umatilla County.



2.2 Data Sources

The methods used by this study to define the CMZ components were primarily based on the interpretation of remotely sensed datasets to accommodate the large size of the study areas. Several days of field observations were performed to help with the interpretation of the remotely sensed data and to identify processes only visible in-person. To guide the mapping of the CMZ, this study utilized or created the datasets listed below.

2.2.1 Topographic Data

This study used ~3 ft (~1 m) lidar DEMs to delineate modern channel and valley features, to estimate water surface slopes, and to create longitudinal profiles. We used DOGAMI ([n.d.a]) lidar datasets collected in 2000, 2011, and 2020.

REMs for both rivers in this study were generated to aid in the identification of floodplain features. A REM shows topography relative to the channel's water surface elevation, such as the floodplain or drainage ditch height above or below the channel. These visualizations were produced by normalizing or 'detrending' the lidar DEMs to the river's water surface elevation using GIS tools and following the method detailed in Olson and others (2014, Appendix E). Using this method, water surface elevations were extracted from the DEM along the channel as points to create an interpolated raster surface that represented the water surface over a large area (spanning the valley bottom if possible). The original DEM was subtracted from the water surface raster to produce the final REM.

The lidar DEMs were often visualized as slopeshades in combination with other semitransparent datasets such as the REMs, imagery, or geologic maps.

2.2.2 Aerial Imagery

This study used the 2024 high-resolution 1 ft (0.3 m) Oregon Statewide Imagery Program data (OSIP, Oregon Geospatial Enterprise Office, 2025), which was the most recent aerial imagery available at the time of mapping. This dataset was used to digitize the AC, characterize channel form and features, and document current land use, land cover, infrastructure, and presence of LWD.

Historical orthoimagery was used to delineate the HMA and digitize the historical streambank lines that were used to determine erosion rates. Orthorectified historical images were captured by the USGS during the 1950s–1980s era. National Agriculture Imagery Program (NAIP) statewide imagery was also available for 1990s–2020s for each of the full study areas. The following imagery was used in the analysis for Umatilla River and McKay Creek:

- Orthorectified USGS single-frame images: 1952, 1964 (partial), 1965 (partial), 1974 (partial), 1976 (partial), 1977 (partial), 1981
- Orthorectified NAIP and OSIP mosaicked images: Orthorectified NAIP 1995, 2000, 2005, 2009, 2011, 2012, 2014, 2016; OSIP 2017, 2022, 2024

2.2.3 Geology

This study used the best available geologic GIS data to understand the underlying geology of the streambed, streambanks, valley bottom, and valley walls. This included the geologic maps by Yuh and others (2024), Madin and Geitgey (2007), Ferns and others (2004), Ferns (2006a), Ferns (2006b), Ferns and Ely (2006), Ferns and McConnell (2006a), Ferns and McConnell (2006b), McClaughry and Azzopardi (2023), Madin and others (2023), and the Oregon Geologic Data Compilation (release 8) by Darin and others (2025). Published literature, including journal articles, reports, and white papers from county and federal agencies, academia, researchers, and CTUIR were also evaluated for relevant geologic and geomorphic information.

2.2.4 Infrastructure

Infrastructure GIS datasets, accessed through the Oregon Geospatial Enterprise Office, Google Maps, and the USGS by Yuh and others (2024), were used to identify the location of levees, roads, railroads, dams, and bridges that may impact channel migration. Maps produced by and for CTUIR and Umatilla County were also used.

2.2.5 Local Geomorphic and Channel Migration History

Study of the region's fluvial geomorphology has been included as a subsection within many previous studies by or for CTUIR and Umatilla County, including those cited in **Section 1.3**. These documents provided additional context and information about historical changes within the watershed, including human modifications to the channel, major floods, past observed channel migration, and geologic units susceptible to erosion. We also reviewed the thesis by Merrill (2024), dissertation by Hughes (2008), McKay Creek study by ESA (2024), Umatilla River Assessment by Tetra Tech (2023), CTUIR River Vision (Jones and others, 2008), and the CTUIR Action Plan (2025).

2.2.6 Flood History

The USGS stream gages provided the most detailed record of peak flood flows during the 20th and 21st centuries (USGS, 2025a–2025e); on McKay Creek this was augmented with peak flood values reported by ESA (2024). We also reviewed the Umatilla County NHMP (2021), Gardenhire assessment of flood fighting potential (2000), a story map by ODEM (2025), and the CTUIR River Vision (Jones and others, 2008). FEMA (2010) FIS maps were reviewed to understand the potential areas impacted by floods.

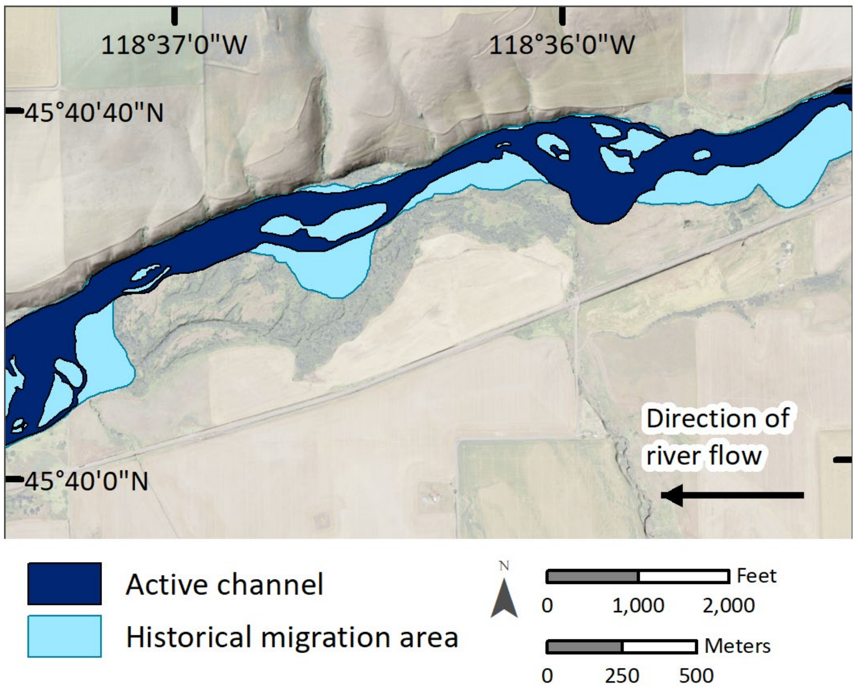
2.3 Channel Migration Zone Mapping

Using the previously described datasets, contextual information, and basemaps, the AC, HMA, and MVB were delineated; the study area was divided into RS; and the EHAs, AHAs, and flagged banks were mapped to identify the final CMZ boundary. The process used to produce these, and several intermediary datasets, is documented in the following eight subsections. The CMZ map components were produced using Esri ArcGIS software version 10.7. Unless otherwise stated, all new map components were digitized at a scale of 1:4,000 or finer, detail.

2.3.1 Active Channel (AC)

The AC is composed of the river's wetted perimeter and the exposed, unvegetated sediment deposits that are adjacent to the river. As shown in **Figure 2-2**, it is limited to the areas that are likely to have conveyed flows in the recent past and where woody vegetation is unable to be maintained (Montgomery and MacDonald, 2002).

Figure 2-2. Example of the 2024 AC and 1952–2024 HMA mapped along the Umatilla River, Umatilla County.



In this study, the 2024 AC boundary was delineated based on the most recent available aerial photography at the time of mapping (Oregon Geospatial Enterprise Office, 2025). Also, the lidar slope map and REM were used as references to identify banks and boundaries obscured in the imagery by vegetation. In areas where the channel has migrated in the time since the lidar collection, the digitization was aligned to match the most recent aerial imagery.

After mapping the AC boundary, the stream centerline was digitized and stream station points were generated every 100 ft (30.5 m) along the middle line of the AC, parallel to the AC bank edges. These intermediary datasets were used to characterize RS length and sinuosity and produce longitudinal profiles. The average AC width was measured by generating cross-sectional transects that were clipped to the AC boundary.

2.3.2 Historical Migration Area (HMA)

The HMA is composed of the combined areas occupied by current and past ACs visible in historical aerial imagery. These areas are most commonly adjacent to the AC. HMAs are formed by fluvial processes and could experience future migration. **Figure 2-2** provides an example of an HMA surrounding an AC.

This study mapped the HMA for both rivers using historical aerial photographs at a scale of 1:4,000 or finer. As discussed in **Section 2.2**, these included orthorectified aerial photographs from the late 1950s to the present day. The lidar DEMs and REMs were also used to verify the location of the historic channel in areas where imagery was difficult to accurately interpret due to vegetation obscuring channel banks or because of errors produced during orthorectification.

2.3.3 Modern Valley Bottom (MVB)

The MVB is composed of the relatively flat area adjacent to the stream, including the current, and potentially, historical, floodplains. It is bounded by steeper valley walls and is typically composed of erodible, Quaternary alluvial sediments.

This study mapped the MVB boundaries for both rivers using the lidar DEM, REM, and surficial geologic maps. The valley margin was identified by an abrupt change in slope; this margin is often readily apparent in small-scale maps as the valley bottom is commonly <2 percent slope when measured across wide areas and the valley wall is commonly >5 percent slope. Bedrock and older pre-Holocene terraces that did not show signs of recent fluvial erosion were considered to be outside of the MVB. The MVB is used to constrain the EHA. Additionally, the MVB centerline was mapped as an intermediary dataset by digitizing a line that runs along the valley, parallel to the valley walls, following the method of Kline and others (2007).

2.3.4 River Segments (RS)

Each stream is divided into RS that display relatively similar hydrologic and geomorphic characteristics. These valley-scale segments are typically ~8,000–14,000 ft (~2,438–4,267 m) in length, which is longer than the "geomorphic reaches" that are commonly used in site-specific studies with much smaller scopes.

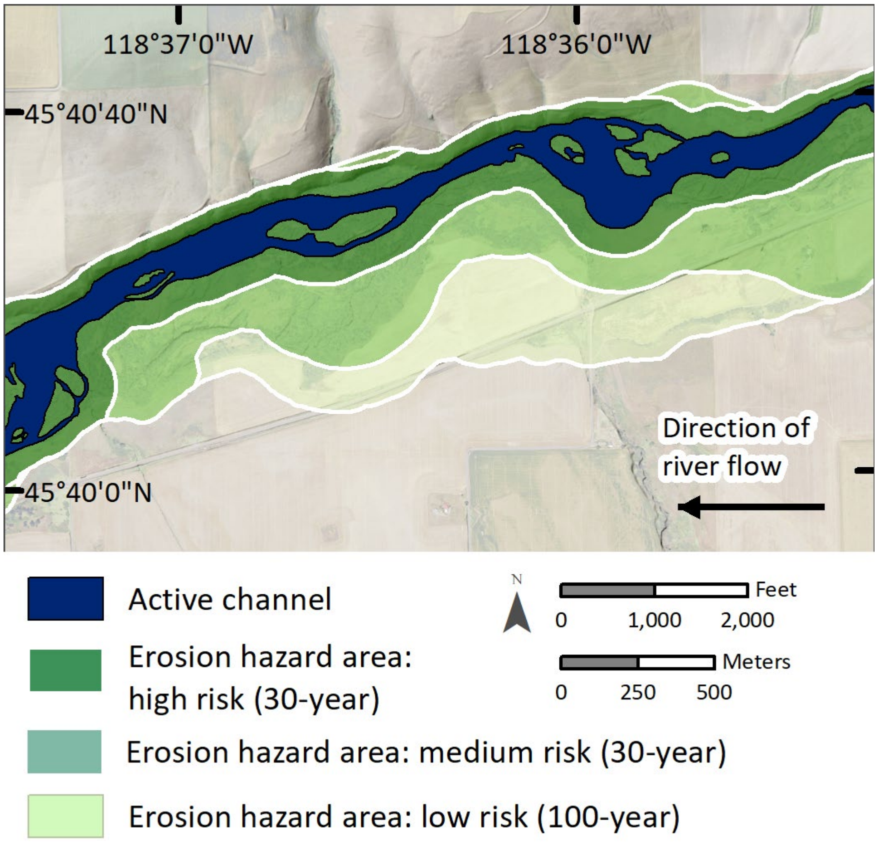
This study divided the streams in this study into different segments characterized by changes in channel slope, valley width, channel confinement, channel pattern, discharge (i.e., at confluences with large tributaries), infrastructure, geology, land use, and HMA width. This list of characteristics is similar to those used in the method applied by Olson and others (2014). These segments are used to organize the CMZ components and as a part of the EHA mapping process. This study also reviewed, and was influenced by, the reach divides used in the CTUIR Umatilla River Action Plan (2025).

Once the RS were established, several intermediary datasets were produced that characterized the river geomorphology, including the segment length, average channel width within each segment, and the segment sinuosity (channel length/valley length). These characteristics are summarized in the spreadsheets that accompany this report.

2.3.5 Erosion Hazard Area (EHA)

The EHA identifies the area most likely to be impacted by lateral erosion and to which the channel is most likely to move over a specified period of time. For this study, the high-, medium-, and low-hazard EHA were mapped to show potential movement over 30 and 100 years. **Figure 2-3** provides an example of the EHA zones. As explained below, this study follows the method by Appleby (2024), which categorizes the EHA components by hazard level.

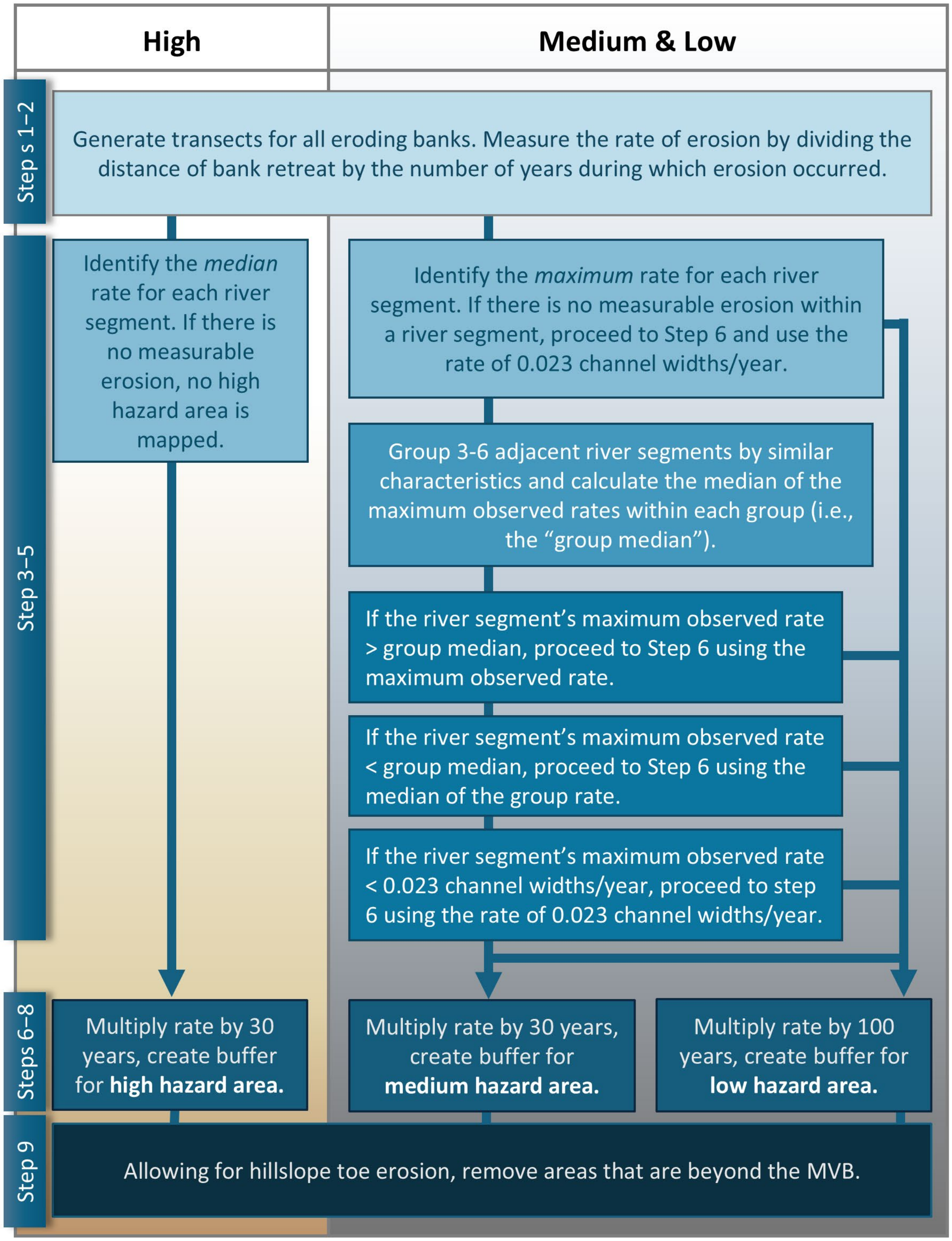
Figure 2-3. Example of EHAs: high hazard (median erosion rate projected 30 years into the future), medium hazard (maximum erosion rate project 30 years into future), and low hazard (maximum erosion rate project 100 years into future) along the Umatilla River, Umatilla County.



As summarized in **Figure 2-4**, the process this study used to map the EHA included three steps: 1) measuring and selecting historical erosion rates, 2) projecting the erosion rates 30 and 100 years into the future, and 3) removing areas from the EHA that extend beyond the MVB or are constrained by other geologic controls (e.g., basalt). For the segments that did not have measurable migration during the period of observation (1950s–2020s), an erosion rate established by Lagasse and others (2004) was used that conservatively includes the area of erosion for streams that are static for long periods of time (see Step 6, below, for more detail). The EHA methodology was designed to include the median- and maximum-possible extent of lateral erosion for an RS based on the observed historical erosion patterns.

This study mapped the high-, medium-, and low-hazard EHA to show potential movement within 30 and 100 years at different levels of confidence. The high-hazard area represents the locations directly adjacent to the AC that are most likely to be imminently impacted by channel migration. The erosion rates for these areas reflect the median rate of erosion within each RS and thus may underestimate the full extent of channel migration within the next 30 years. The medium- and low-hazard areas are the locations beyond the HMA that represent the furthest extent of channel migration within the next 30 and 100 years. These areas are based on the maximum observed erosion rate for the RS or the adjacent RS. In terms of risk to people and infrastructure, this could be considered the worst-case scenario. The timeframes of 30 and 100 years were selected to aid individuals and communities who need to make short- and long-term decisions and plans. In addition, the 30-year timeframe is familiar to most people, as it is a standard length of a mortgage and is often used by FEMA to describe the chance of flooding for a given property.

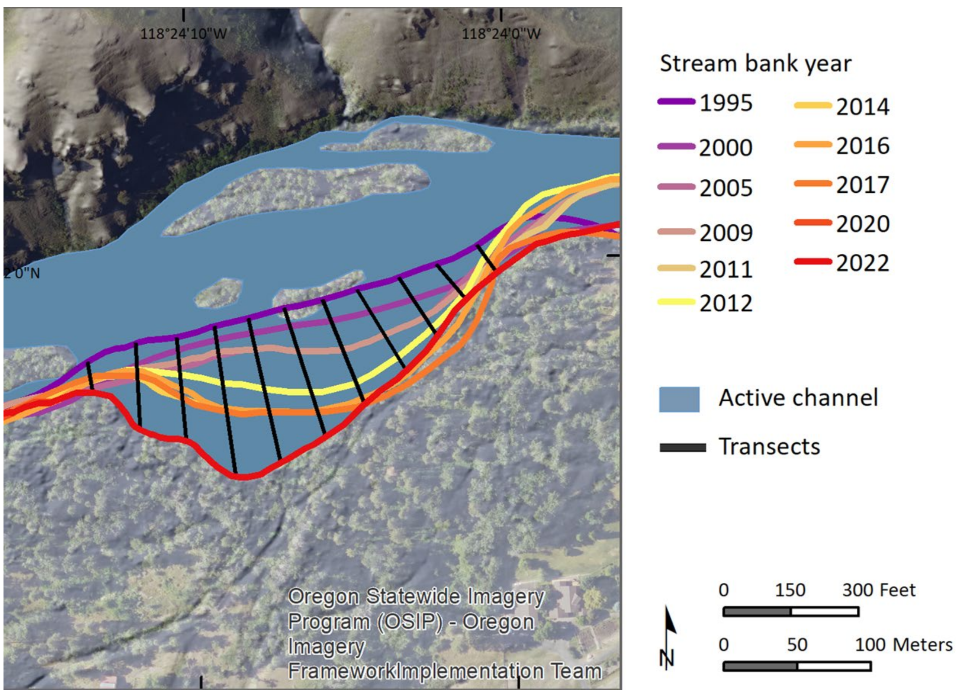
Figure 2-4. Conceptual model for EHA mapping method, divided into high-, medium-, and low-hazard components.



The following steps describe the methodology used to map the EHA zones according to hazard level.

1. Measuring and selecting the historical erosion rate
    a. This study converted the HMAs from polygons into right and left bank lines and removed the bank lines where little to no movement was detected. As shown in **Figure 2-5**, transects were generated that crossed these successively eroding bank lines. The production of these transects was expedited by using the USGS's ArcGIS tool Digital Shoreline Analysis System (DSAS) v.5, but the same effect can also be achieved solely using Esri's ArcGIS. In a limited number of areas, where the sequential eroding banks had very different curvatures, the transects were divided into several segments to allow for better delineation of bank retreat. At minimum, the transects had to span at least 10 years of movement.

Figure 2-5. Example of streambank lines from 1980–2022 and transects along the Umatilla River, Umatilla County.



    b. Bank erosion rates were measured along these transects and identified both the median and maximum erosion rate (ft/yr [m/yr]) within each RS.
2. Selecting and modifying erosion rates
    a. The median erosion rates were selected to represent the high hazard for each RS. These rates were not modified. The median value was selected to represent the central tendency of the rates, because there are often outlier maximum values that skew the mean value. Steps 4 and 5 are required to map the medium- and low-hazard area, and the method for mapping the high-hazard area resumes in Step 6.
    b. For single-thread channels that did not appear to experience bank erosion during the period of observation, did not have sediment bars, showed low variability in channel width, or that had an erosion rate of <0.023 channel widths per year, an erosion rate of 0.023 channel widths per year was used. This erosion rate was established by Lagasse and others (2004), who observed that 90 percent of single-thread channels tend to exhibit a migration rate ≤0.023

channel widths per year. These values were used to map the medium and low-hazard EHA components; no area was mapped as high hazard.

   c. The maximum erosion rates were selected or modified in one of the following steps. All erosion rates were converted into channel widths/year (i.e., the feet per year divided by the RS average channel width). In areas where human modifications caused individual RS to migrate at a much slower rate than the RS directly up and downstream of that segment, this study examined the rate for the six adjacent RS (i.e., RS 14–19) that share similar characteristics (e.g.., channel width, slope, bank geology, sinuosity, valley confinement) and calculated the group median of the maximum observed erosion rates. This group median rate was established because this analysis does not assume structures built along the channel, like levees, were designed or are consistently maintained to withstand river erosion. As a result, when these structures fail, the rate of erosion will be more similar to the adjacent reaches without infrastructure. This study followed the erosion rate selection process listed below and shown in **Figure 2-4**:
      i. In areas where the measured maximum erosion rate was less than 0.023 channel widths/year, this greater erosion rate, established by Lagasse and others (2004), was selected to represent the medium- and low-hazard for each RS.
      ii. In areas where the measured maximum erosion rate was greater than the group median erosion rate, the greater measured rate was selected to represent the medium- and low-hazard for each RS. Similarly, in areas where the measured maximum erosion rate was lower than the group median erosion rate, the greater group median rate was selected to represent the medium- and low-hazard for each RS. By using the greater of the two values for maximum erosion rate, unrealistic, abrupt changes in erosion rates were avoided in adjacent RS. Cumulatively, these choices will lead to an overestimation of the area of the medium and low EHA, but this decision is intentional, given the goal to identify all areas at potential risk from erosion hazards in the near and distant future. The selected rates are hereafter described as the "modified maximum rate." The original, group, and final erosion rates are provided in the accompanying Excel spreadsheets.
3. Projecting erosion rate
   a. To create the high-hazard EHA, this study multiplied the median erosion rate (ft/yr (m/yr)) for each RS by 30 years. The AC was buffered by this value to identify the areas most likely to be impacted by erosion in the near future. This method is similar to that described by Rapp and Abbe's (2003) approach to establishing an erosion setback with a design life of 30 years.
   b. To create the medium- and low-hazard EHA, this study multiplied the selected maximum erosion rate (ft/yr (m/yr)) for each RS by 30 and 100 years. The HMA was buffered by this value to identify the widest area potentially at risk from erosion.
   c. The high-, medium-, and low-hazard EHAs were examined and any erroneous buffer artifacts, such as small gaps and sharp cusps, were removed. The transition between river sections was smoothed in areas where there were differences in buffer widths.
4. Removing areas beyond the MVB
   a. Based on the assumption that the stream will not erode the areas outside of the MVB, this study removed much of the area outside of the MVB from the high-, medium-, and low-hazard EHA. A small geotechnical setback area was included that extended one-half of the AC width

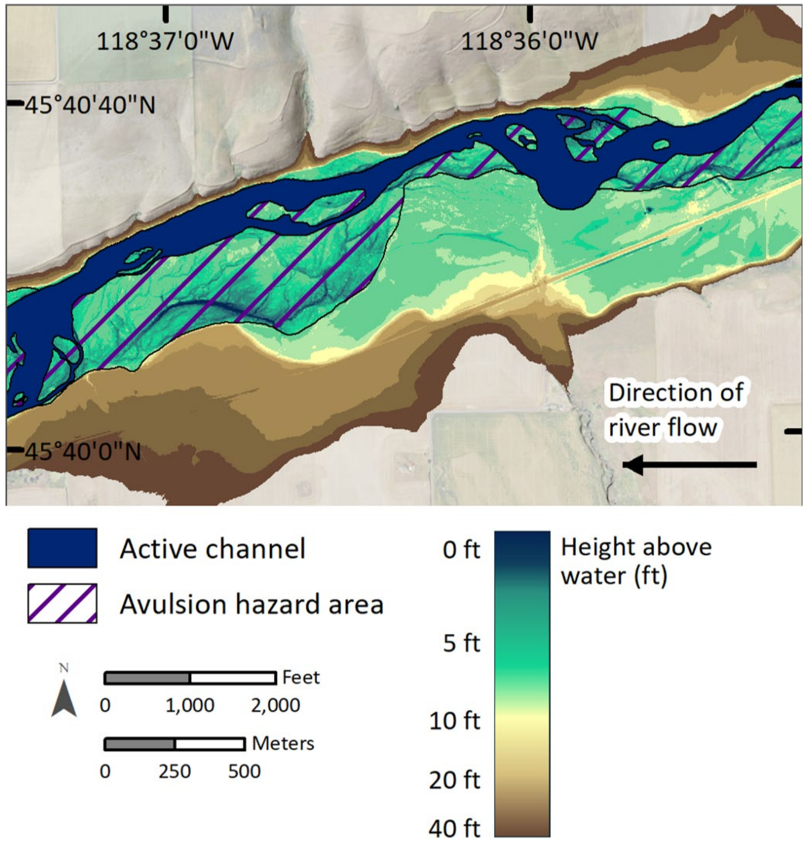
outside of the MVB as a part of the EHAs to account for a small amount of valley wall erosion. This is similar to the geotechnical setback used by Olson and others (2014).

2.3.6 Avulsion Hazard Area (AHA)

The AHA includes the land adjacent to the AC and HMA that the channel has the potential to occupy or reoccupy. Avulsions occur when the channel is abruptly diverted from its main course and flow is redirected along a different path. Avulsions may take place on a very local, reach scale, or at a large, valley-scale depending on the conditions of the channel and valley, and are typically caused by aggradation of the sediment, which triggers the stream to find a more efficient, steeper gradient path within the floodplain (Slingerland and Smith, 2004).

To map the AHA, this study used the DEMs, REMs, geology, and aerial imagery to digitize the areas within each RS where avulsions may occur. Areas in the AHA have a width equal to or greater than the average channel width for the segment. This study focused on low-lying areas on the floodplain that had unconfined channels and potential avulsion paths that had steeper gradients than the existing channel. Secondary and relic channels, swales, meander-neck cut offs, and channels with an absence of dense and woody riparian vegetation along the banks, were all included in the AHA. Areas with human-made ponds or drainage ditches, and streams with channel-spanning logs and LWD jams were also examined for potential avulsions. **Figure 2-6** provides an example of the AHA, where low-lying areas adjacent to the channel, shown in the REM, are included in this component, along with a diversion canal. The number of avulsions observed from the historical imagery or described in prior studies was noted and included in the tables that accompany this publication. Highly localized conditions, such as a migrating head cut or new or growing accumulation of LWD, may trigger an avulsion, but these conditions are very difficult to predict. As a result, this study was intentionally overinclusive in the areas mapped within the AHA.

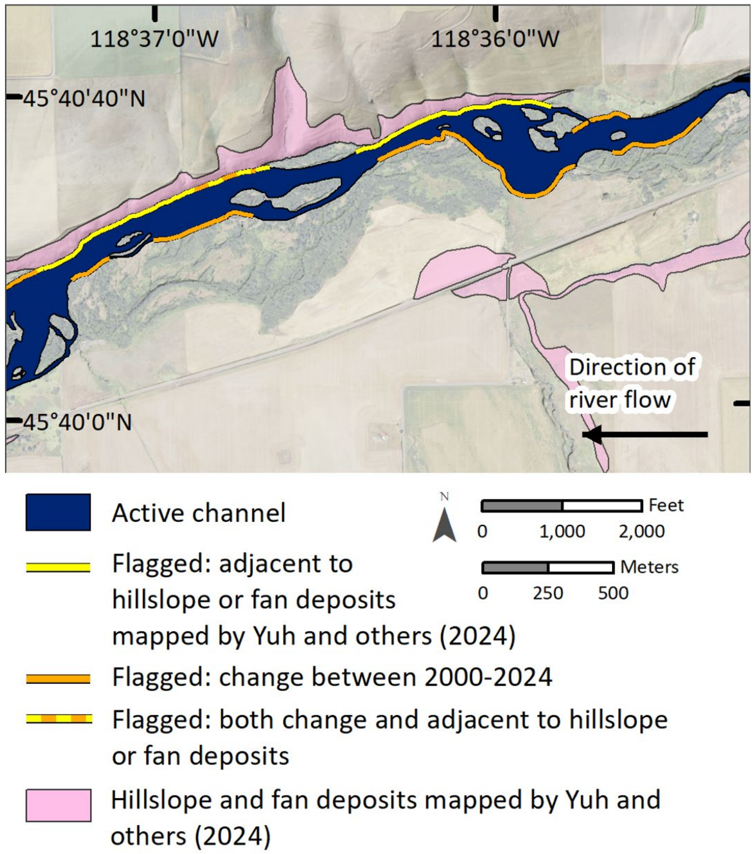
Figure 2-6. Example of the AHA mapped along the Umatilla River, Umatilla County with the REM basemap.



2.3.7 Flagged

Flagged streambanks highlight areas with a higher likelihood for lateral migration or bank instability in the immediate future. In this study, streambanks were flagged based on two characteristics: recent lateral migration or location directly adjacent to hillslope or fan deposits. These conditions may indicate potentially unstable channel conditions, increased sources of sediment supply, or the possibility of future landslides or debris flows that could confine or block channel flow, all of which could result in channel migration or avulsion. **Figure 2-7** provides an example of flagged banks.

Figure 2-7. Example of flagged banks along the Umatilla River, Umatilla County.



This study flagged stream banks where channel migration and stream bank erosion were observed between 2000 and the most recent aerial image. Aerial images available from the last 24 years were used to define the recent erosion flagged banks because this period of time has relatively similar hydrologic and land-use conditions as the present day and includes the impacts of several large flood events in Oregon.

This study also flagged AC streambanks that were located directly adjacent to hillslope alluvium or fan deposits mapped by Yuh and others (2024). They described hillslope deposits as, "steep (commonly 20–35 deg.) surfaces that appear to be formed by creep, debris flow, shallow landsliding, and other mass-movement processes," and the fan deposits as, "Mostly moderately sloping (2–5 deg.), cone-shaped surfaces; formed where stream issues from narrow valley into broad valley, or where tributary stream is near or at junction with main stream." In areas outside of the area mapped by Yuh and others (2024), banks were flagged where the channel flowed along valley walls that may include unmapped landslides. The flagged streambanks were annotated where one or both conditions were met. As the streams will continue to change with time, this study recognizes the need to monitor, and potentially update, the flagged areas every five years and/or after major disturbances, such as large floods.

2.3.8 Channel Migration Zone (CMZ)

The CMZ is composed of all areas within the AC, HMA, EHA (high-, medium-, and low-hazard), and AHA. Because the low-hazard EHA encompasses all areas within the AC, HMA, and high- and medium-hazard EHA, the CMZ was created by merging the low-hazard EHA and the AHA.

Potential future changes, such as alterations in hydrology due to climate change, sediment supply, land use, riparian vegetation, and human modifications to the river and watershed, could lead to migration beyond the mapped CMZ. As a result, this study recognizes the need to monitor and update the CMZ every 30 years and after major disturbances like flood events and dam removals.

3.0 RESULTS

This study mapped CMZs along nearly 83 river miles (133 km) of the mainstem of the Umatilla River and 6 river miles (10 km) of lower McKay Creek (**Figure 3-1**–**Figure 3-14**). Across the two rivers, there was a wide variety of channel forms, human modifications, and degrees of geomorphic dynamism. In the accompanying Excel spreadsheets, a summary of each RS stream characteristics is provided, including channel length, average width, water surface slope, sinuosity, and channel pattern. These spreadsheets also document recent migration, the presence of LWD, and the channel bank and valley geology and include information about the EHA, AHA, and flagged banks for each RS. Here, the main study findings are provided. For unfamiliar terminology, please review the definitions provided in **Section 2.1**. To more easily describe the patterns observed in the lengthy Umatilla River study area, the results and discussion use the terms upper, middle, and lower to geographically divide the river based on large changes in valley confinement and human modifications to the river channel and floodplain. The report presents the river segments from highest to lowest for ease of following the influence of upstream effects on downstream sections.

3.1 Umatilla River

3.1.1 Upper Umatilla River

The upper Umatilla River, from the confluence with Bobsled Creek to the eastern edge of Pendleton (RS 28–39; **Figure 3-1**–**Figure 3-5**), is a single and multi-thread channel with intermittent reaches taking on a braided form. The upper Umatilla River has the highest rates of erosion, a higher frequency of historical avulsions, and a wider HMA than the middle and lower reaches. While bedrock naturally confines the channel in some areas, levees and road and railroad embankments also limit channel movement in some sections. There are several large tributaries, most notably the North and South Fork Umatilla River and Meacham and Isqúulktpe creeks.

This study revealed the following notable changes and features in upper Umatilla River:

- All of RS in this area exhibit lateral migration that can be measured between the early 1950s and 2020s. This indicates that, despite many anthropogenic disturbances that have affected river discharge and floodplain dynamism such as levees, straightening, and confinement due to road and railroad embankments, many of the reaches in the upper Umatilla River still experience lateral instability.
- Within the upper basin, all RS have moved >100 ft (>30 m) laterally since the 1950s. RS 28, 30–34, 36, and 37 have all moved > 400 ft (>122 m)to occupy new areas on the floodplain between the 1950s and 2020s, as can be seen from the dark blue AC and light blue HMA in **Figure 3-1**–**Figure 3-5**. The greatest movement occurred in RS 30 and RS 31.
- Some of the RS in this section include reaches that were relocated prior to the 1950s to accommodate road or railroad construction. One of the RS with the least channel migration in this area is RS 29. RS 29 was straightened, channelized, and repeatedly dredged in the 1940s to 1960s (Jones and others, 2008). Although levees and bedrock hold the channel in its current location,

the channel has expanded and contracted through time between the levees, which is a common response to floods and post-flood stabilization (Hughes, 2008; Merrill, 2024). Mapping by Yuh and others (2024) and the historical floodplains visible in the REM suggest that the previous CMZ and area of inundation within RS 29 was similar to RS 28 and 30.

- In descending order, RS 32, 31, 30, 33, and 28 have the highest median erosion rates that range from ~9–13 ft/yr (~2.7 –4.0 m/yr). RS 32, 33, 28, 34, and 35 have the highest maximum erosion rates, that range from ~31–43 ft/yr (~9 –13 m/yr).
- Many areas within the upper Umatilla River show evidence of past avulsions (see AHA tab in the Umatilla summary Excel table), and there is a strong potential for future avulsions based on current floodplain conditions. Historical imagery and observations made by Hughes (2008) and Merrill (2024) indicate that all RS except 29 and 32 have likely experienced one or more avulsions since the 1950s, often occurring during a major flood event. We observed the greatest concentration of avulsions in RS 30, 31, 34, 36, and 37. The abundance of sediment from tributaries and the floodplain, LWD jams, riparian vegetation, and topography, including the common presence of swales and secondary channels, are all conducive to future avulsions in these areas. The AHA extends beyond the EHA in some areas, because the low-lying topography and areas with small overflow or relic channels prone to avulsion may exist great distances from the AC or HMA.
- All RS, except 29, 30, and 39, include locations where the AC flows adjacent to the toe of hillslope alluvium or fan deposit, as mapped by Yuh and others (2024) and as shown in the flagged banks in **Figure 3-1**–**Figure 3-5**. Additionally, RS 38 and 39 include areas where the AC flows adjacent to the toe of the valley wall, which may include unmapped landslide deposits.
- When compared to the current effective FEMA FIRMs (2010), the 2024 AC flows beyond the floodway boundary in all RS except 29 (and 39 where FEMA has not performed an FIS). In RS 28, 30, 33, 34, and 36–38, these differences are due to channel migration, and the 2024 AC lies at least 100 ft (30 m) beyond the floodway and, in some cases, more than 100 ft (30 m) beyond the mapped 500-year floodplain boundary (e.g., RS 28, 30, and 36). Minor differences seen in some areas are likely due to the use of low spatial accuracy, pre-lidar topographic maps in flood studies.

3.1.2 Middle Umatilla River

The middle Umatilla River, from the eastern edge of Pendleton to the area just upstream of Echo (RS 15 to 27, **Figure 3-5**–**Figure 3-10**), is a single-thread channel. It flows within a narrow bedrock canyon and has been artificially straightened and confined by levees and the City of Pendleton, Reith Road, and railroad embankments. Consequently, the mid-basin has many stabilized banks with few areas of channel migration since the 1950s. There are several large tributaries, including Wild Horse, McKay, and Birch creeks.

This study revealed the following notable changes and features in middle Umatilla River:

- All of the 13 RS in the mid-basin exhibited measurable channel movement between the 1950s–2020s. Although movement is most pronounced in areas that have been less impacted by bank hardening, straightening, and levees, these reaches of the Umatilla River continue to experience lateral instability.
- Within the middle basin, approximately half of the RS experienced ~200–500 ft (~61–152 m) of movement in limited areas between the 1950s and 2024. As shown in the difference between the dark blue AC and light blue HMA in **Figure 3-5**–**Figure 3-10,** the greatest movement occurred in RS 16, 20, and 21.

- Approximately half of RS in this area experienced <200 ft (<61 m) of lateral movement. The smallest amount of lateral movement occurred in RS 17, 18, and 24–27. The restricted movement in those RS is a product of levees, such as those in Pendleton, which often trap the river between bedrock walls and hardened banks. All of the RS in this section include reaches that have been relocated prior to the 1950s to accommodate road or railroad construction. Additionally, RS 22 and 25 appear to have been relocated again between the 1950s and present.
- The fastest median erosion rates were observed in RS 24, 19, and 20; these rates ranged from ~10–12 ft/yr (~3–4 m/yr). The fastest maximum erosion rates were observed in RS 19, 20, 24, and 23; these rates ranged from ~19–34 ft/yr (~6–10 m/yr).
- Historically, there was widespread potential for avulsions, but the modern levees, road, and railroad embankments limit the channel's movement. If these structures are not maintained and the channel erodes through or overtops them, the potential for an avulsion will increase. We observed two avulsions along RS 20 in the area where sediments were previously impounded by the removed Furnish Dam.
- All RS, except 18 and 27, include locations where the AC flows adjacent to the toe of hillslope alluvium or fan deposits mapped by Yuh and others (2024), as shown in the flagged banks in **Figure 3-5–Figure 3-10.**
- When compared to the current effective FEMA FIRMs (2010), the 2024 AC flows beyond the floodway boundary in all RS. The difference is minor in most cases and likely due to the use of low spatial accuracy, prelidar topographic maps in flood studies. However, in RS 16 and 20, this difference reflects channel migration, and the AC is ~100–300 ft (~30–91 m) beyond the edge of the FEMA-mapped 100-year floodplain in each case, respectively.

3.1.3 Lower Umatilla River

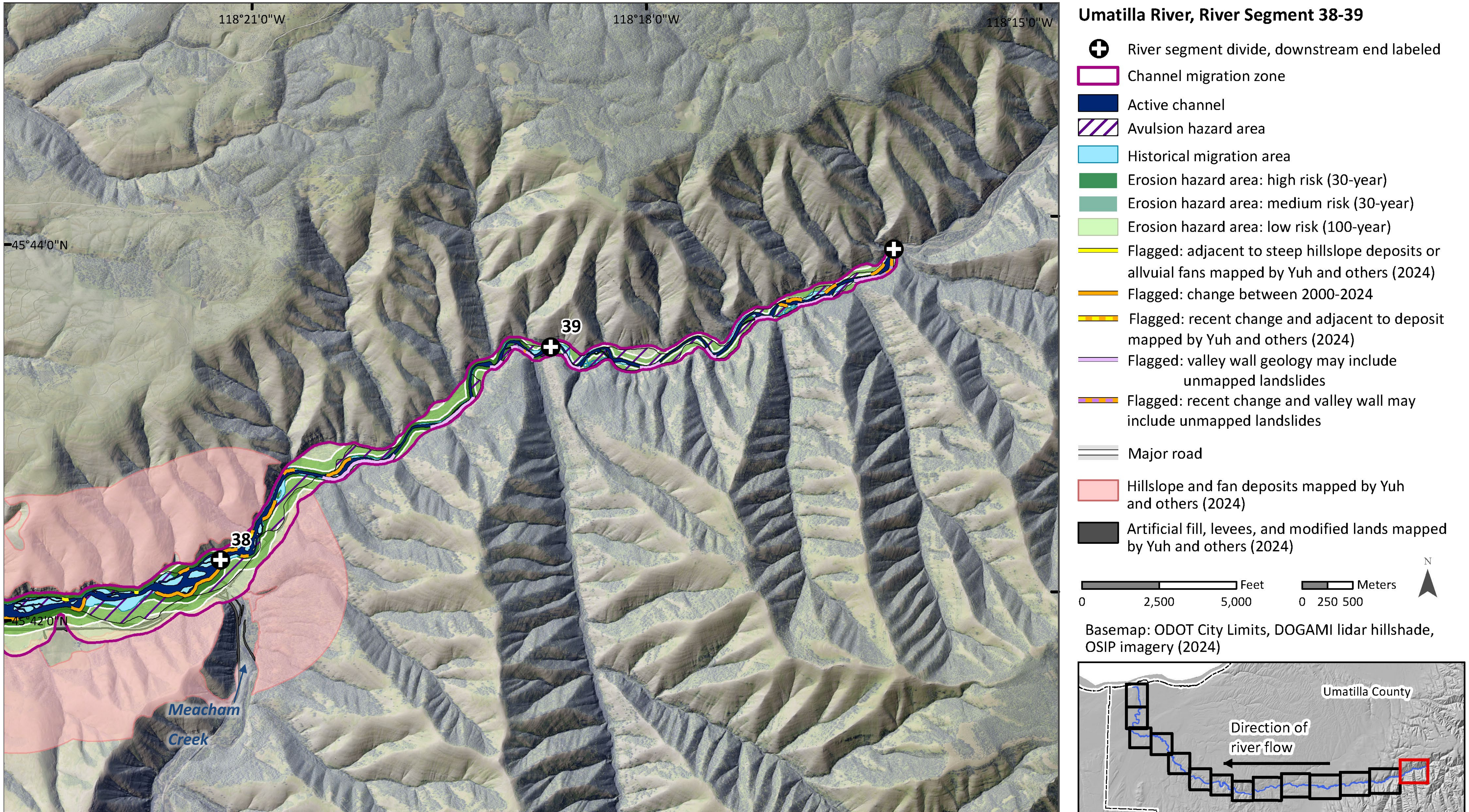
The lower Umatilla River flows from the reaches just upstream of Echo to the confluence with the Columbia River (RS 1–14; **Figure 3-10–Figure 3-14**). It is a single-thread channel that meanders across wide valley, known as the Umatilla Meadows, and then flows, confined, through a valley cut through late Pleistocene outburst floods deposits. There are many miles of ditches and multiple diversion dams that extract water from the channel and only one large tributary, Butter Creek.

This study revealed the following notable changes and features in lower Umatilla River:

- Overall, the lower section of the Umatilla River has a wider range of erosion rates than the middle or upper sections. While the greatest median and maximum erosion rates are similar in this section to the others, the RS with the slowest erosion are slower here than in other sections.
- As shown in **Figure 3-10–Figure 3-14**, within the lower basin, approximately half the RS in this area experienced <200 ft (<61 m) of lateral movement, including RS 1, 2, and 4–8. Approximately half the RS experienced ~200–500 ft (~61–152 m) of movement in limited areas between 1950s and the present, including RS 9–14. No lateral movement was observed along RS 3.
- In descending order, RS 12, 13, 14, and 11 have the highest median erosion rates, ranging from ~9–13 ft/yr (~2.7–4 m/yr). RS 13, 12, 11, 14, and 9 have the highest maximum erosion rates, ranging from 27–41 ft/yr (8–13 m/yr).
- Several RS within the lower Umatilla River show evidence of past avulsions (see AHA tab in the Umatilla summary Excel table), and there is strong potential for future avulsions based on current floodplain conditions. Historical aerial imagery indicates that RS9, 12, and 13 have likely experienced one or more avulsions since the 1950s.

- All RS except 8, 11, and 13, include locations where the AC flow adjacent to the toe of hillslope alluvium or fan deposits mapped by Yuh and others (2024), as shown in the flagged banks in **Figure 3-10**–**Figure 3-14.**
- When compared to the current effective FEMA FIRMs (2010), the 2024 AC flows beyond the floodway boundary in some RS, but in most cases, the difference is minor and likely reflects the use of low spatial accuracy, prelidar topographic maps in flood studies. There is a larger difference in RS 9, 11, 13, and 14, in which the AC flows 50–300 ft (15–92 m) outside the floodway.

Figure 3-1. Umatilla River CMZ map, RS 38–39, Umatilla County, Oregon.



Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-2. Umatilla River CMZ map, RS 35–37, Umatilla County, Oregon.

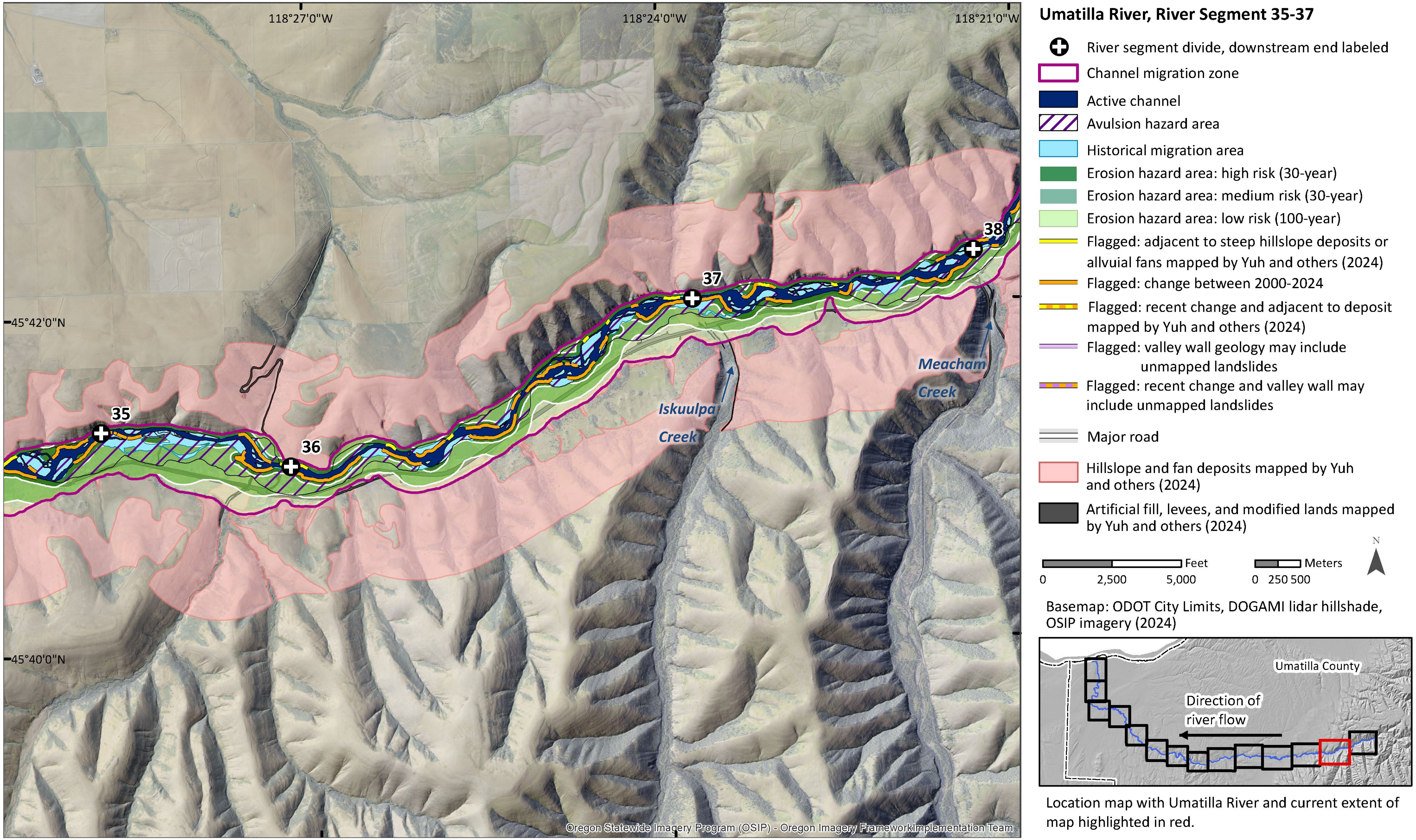
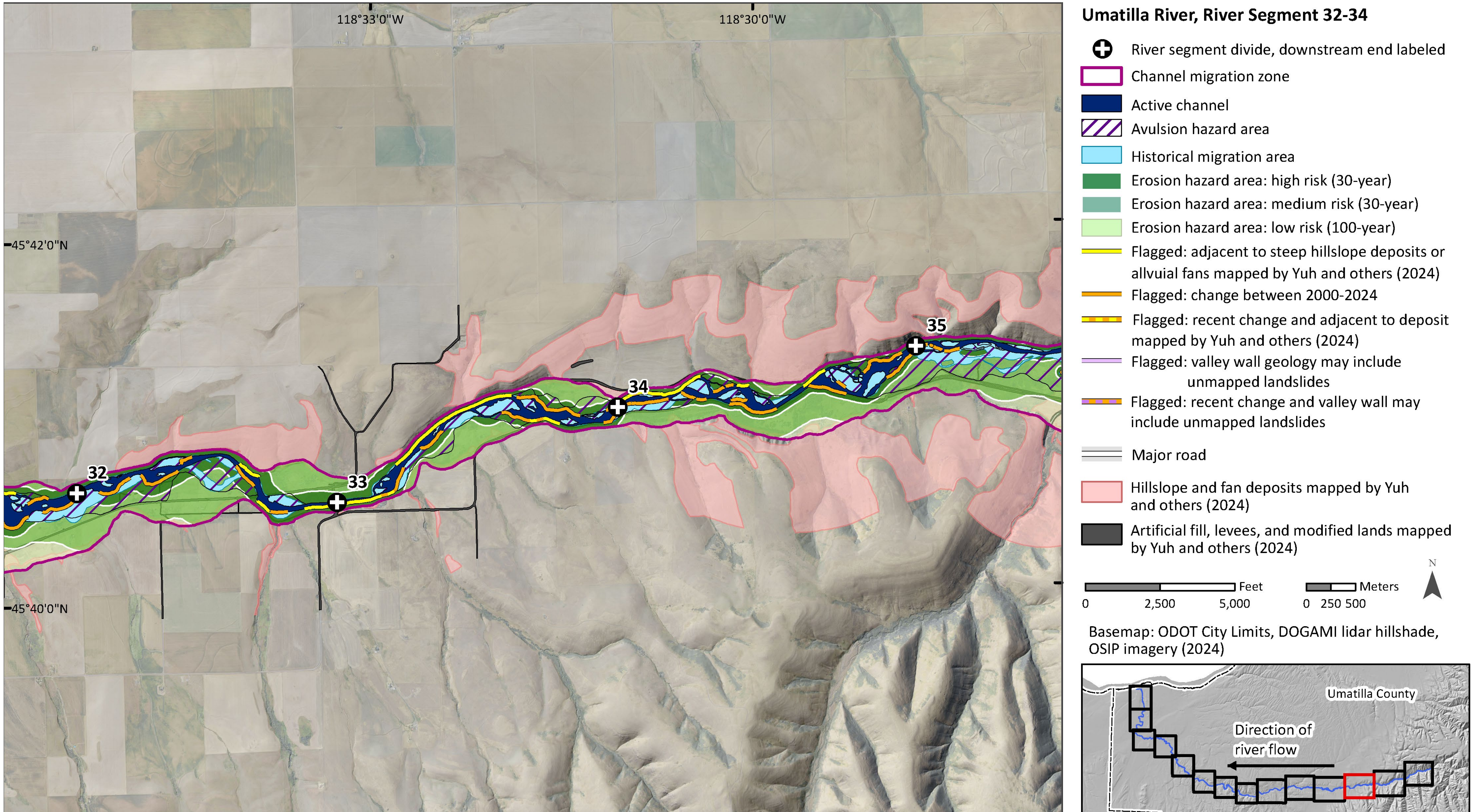
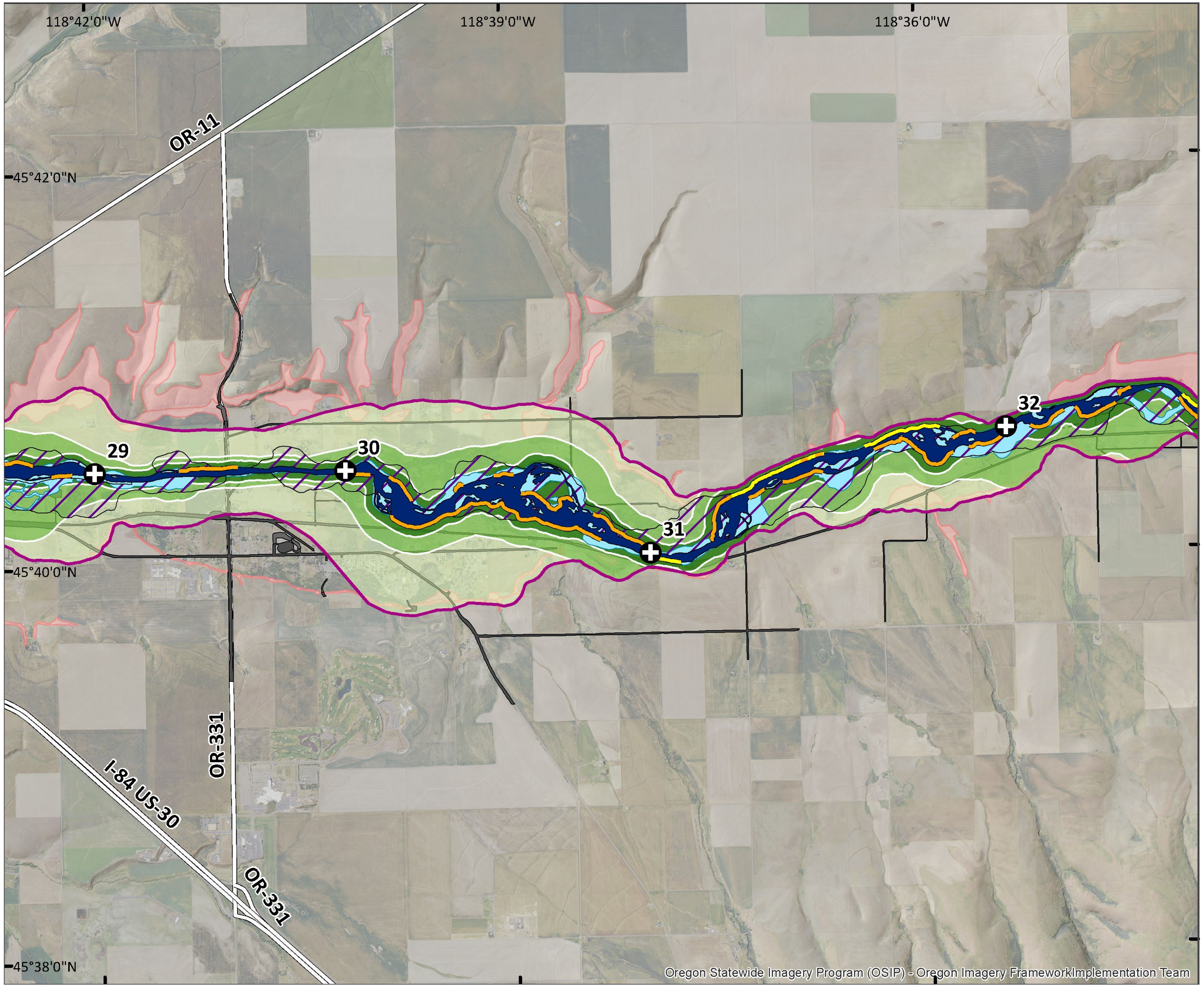


Figure 3-3. Umatilla River CMZ map, RS 32–34, Umatilla County, Oregon.



Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-4. Umatilla River CMZ map, RS 29–31, Umatilla County, Oregon.

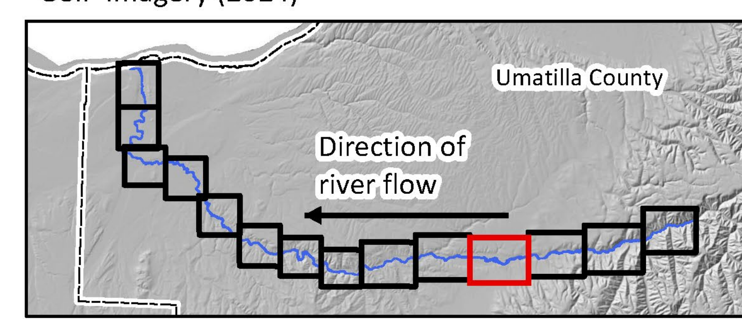


Umatilla River, River Segment 29-31

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: adjacent to steep hillslope deposits or allvuial fans mapped by Yuh and others (2024)
- Flagged: change between 2000-2024
- Flagged: recent change and adjacent to deposit mapped by Yuh and others (2024)
- Flagged: valley wall geology may include unmapped landslides
- Flagged: recent change and valley wall may include unmapped landslides
- Major road
- Hillslope and fan deposits mapped by Yuh and others (2024)
- Artificial fill, levees, and modified lands mapped by Yuh and others (2024)

Feet: 0, 2,500, 5,000 — Meters: 0, 250, 500 — N

Basemap: ODOT City Limits, DOGAMI lidar hillshade, OSIP imagery (2024)



Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-5. Umatilla River CMZ map, RS 26–28, Umatilla County, Oregon.

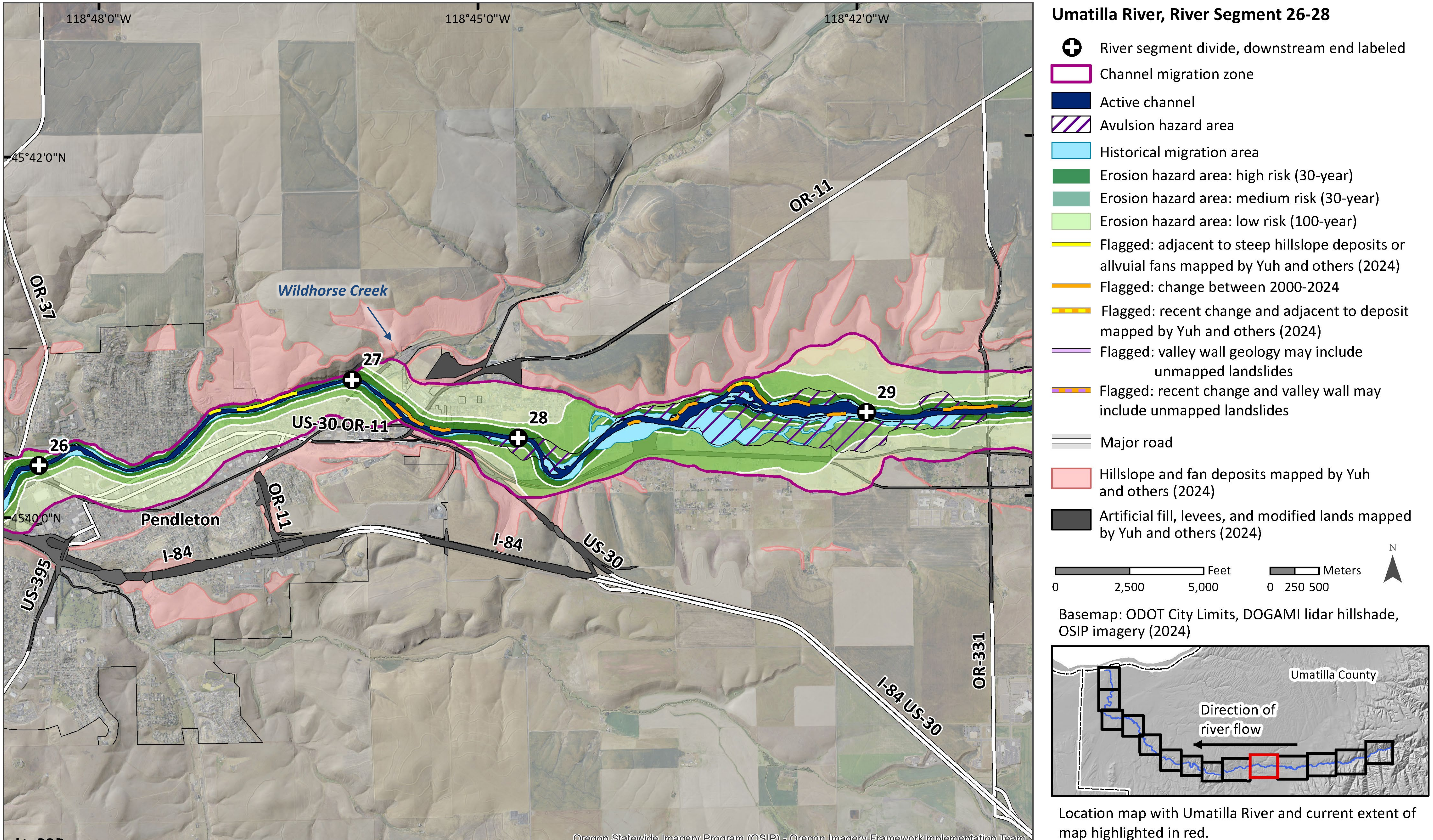
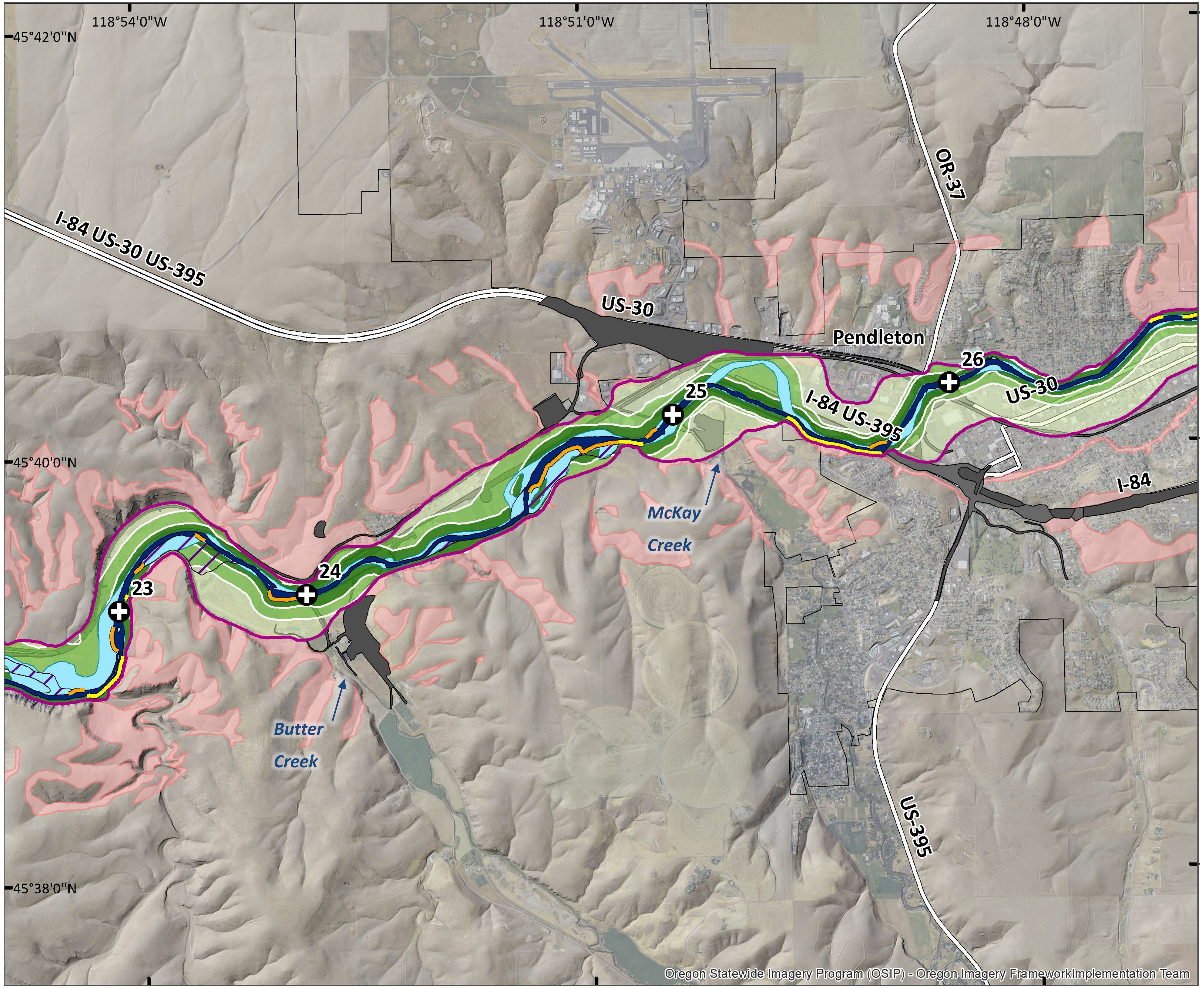


Figure 3-6. Umatilla River CMZ map, RS 23–25, Umatilla County, Oregon.

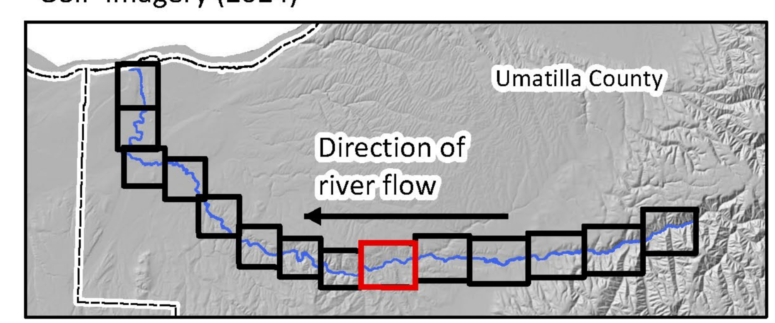


Umatilla River, River Segment 23-25

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: adjacent to steep hillslope deposits or alluvial fans mapped by Yuh and others (2024)
- Flagged: change between 2000-2024
- Flagged: recent change and adjacent to deposit mapped by Yuh and others (2024)
- Flagged: valley wall geology may include unmapped landslides
- Flagged: recent change and valley wall may include unmapped landslides
- Major road
- Hillslope and fan deposits mapped by Yuh and others (2024)
- Artificial fill, levees, and modified lands mapped by Yuh and others (2024)

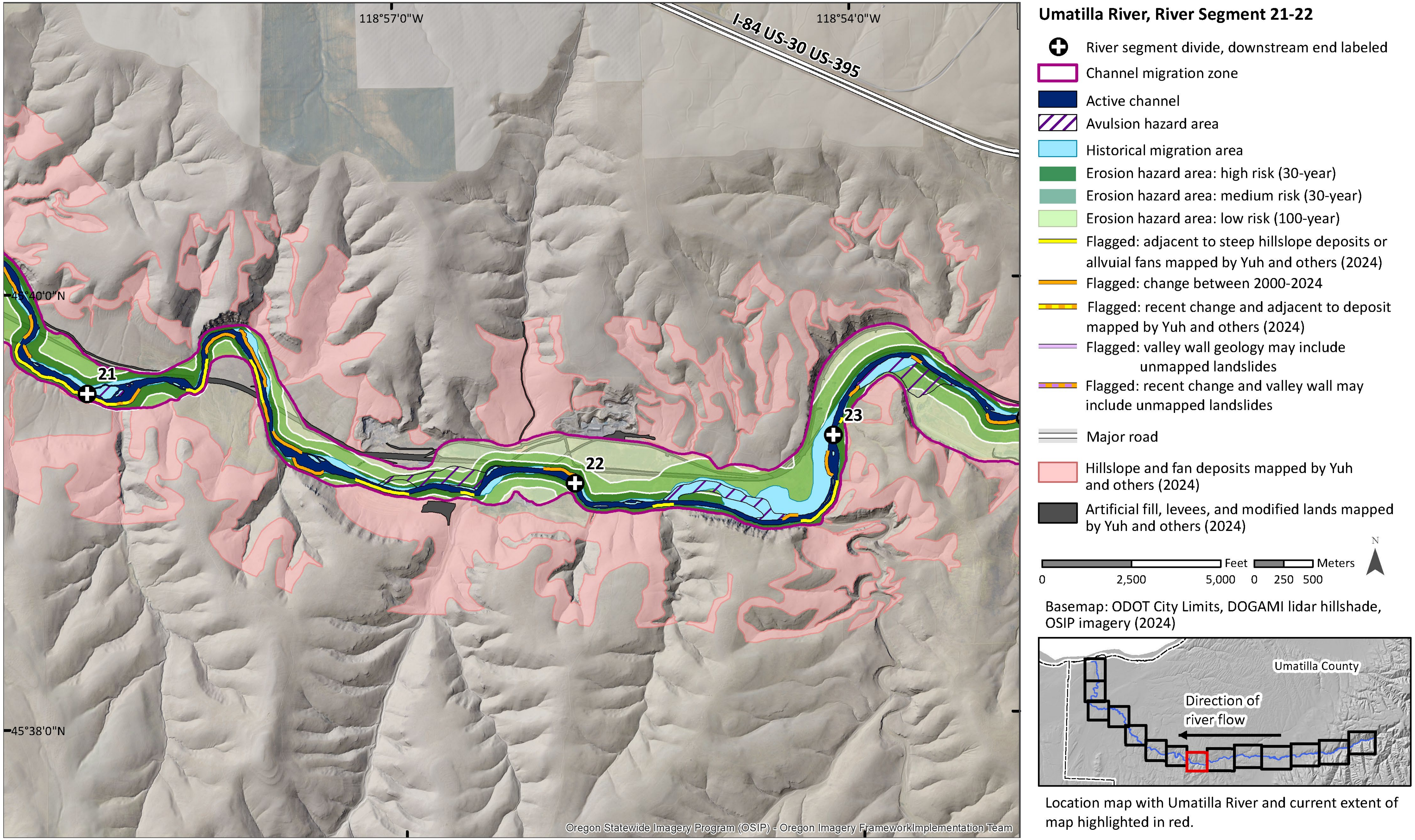
Feet: 0 2,500 5,000
Meters: 0 250 500
N

Basemap: ODOT City Limits, DOGAMI lidar hillshade, OSIP imagery (2024)



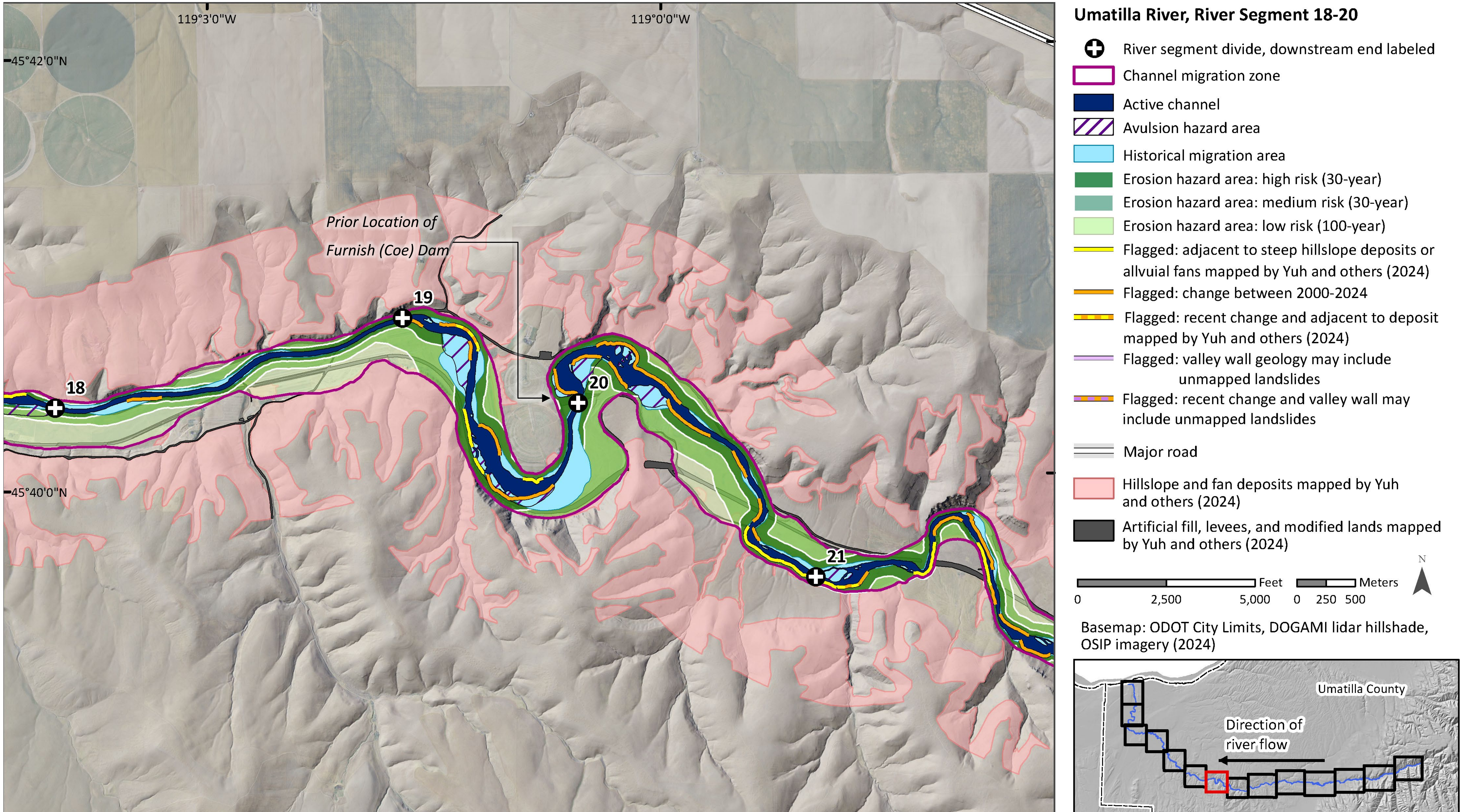
Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-7. Umatilla River CMZ map, RS 21–22, Umatilla County, Oregon.



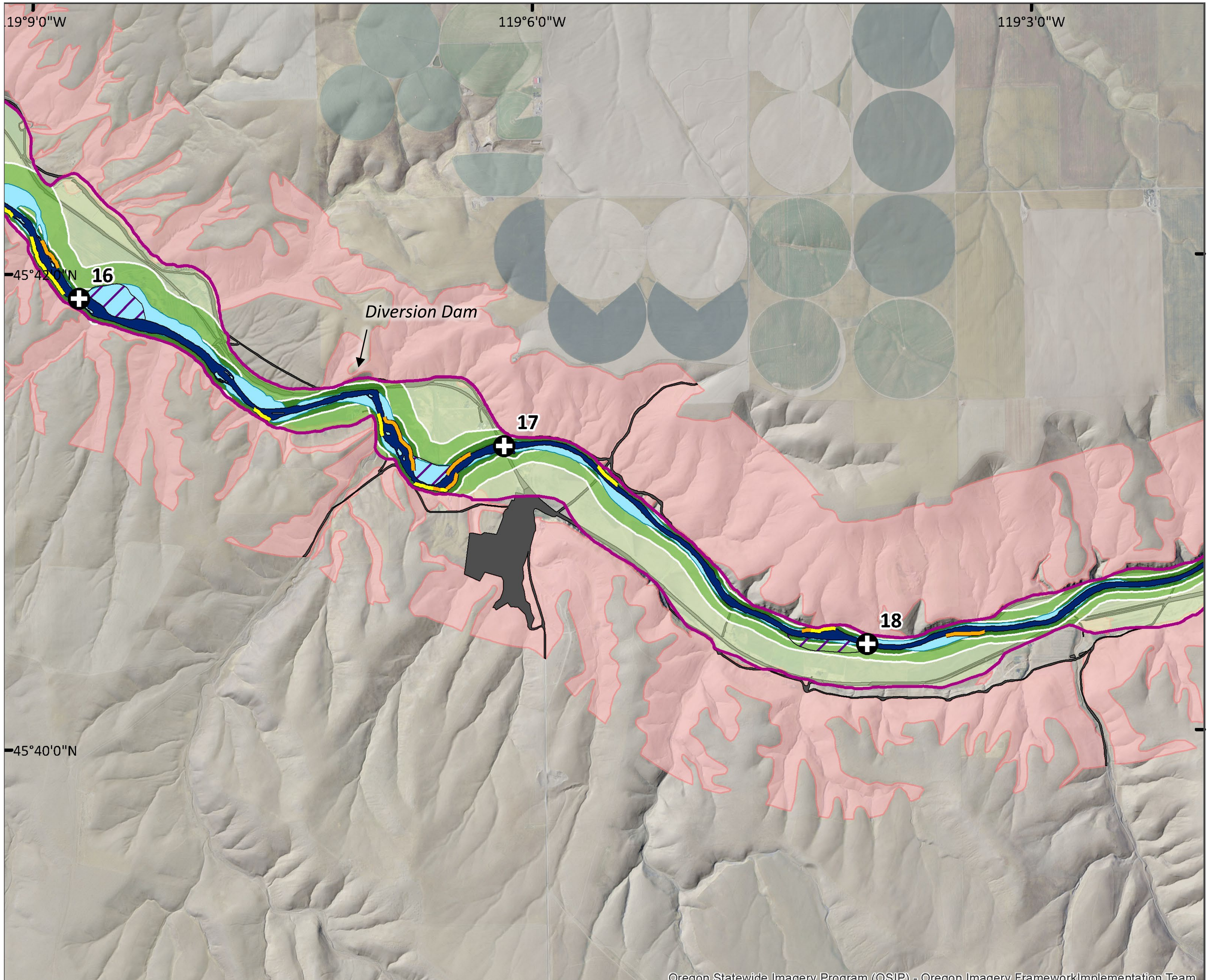
Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-8. Umatilla River CMZ map, RS 18–20, Umatilla County, Oregon.



Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-9. Umatilla River CMZ map, RS 16–17, Umatilla County, Oregon.

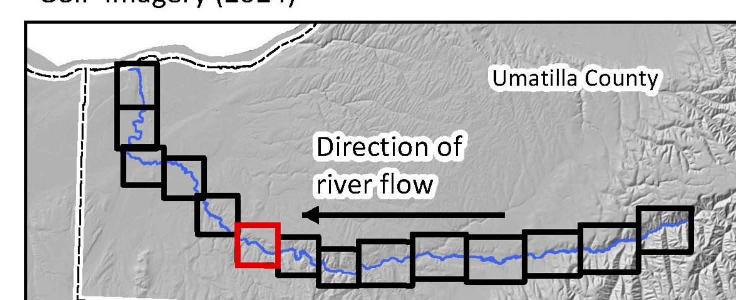


Umatilla River, River Segment 16-17

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: adjacent to steep hillslope deposits or allvuial fans mapped by Yuh and others (2024)
- Flagged: change between 2000-2024
- Flagged: recent change and adjacent to deposit mapped by Yuh and others (2024)
- Flagged: valley wall geology may include unmapped landslides
- Flagged: recent change and valley wall may include unmapped landslides
- Major road
- Hillslope and fan deposits mapped by Yuh and others (2024)
- Artificial fill, levees, and modified lands mapped by Yuh and others (2024)

Feet: 0, 2,500, 5,000 — Meters: 0, 250, 500 — N

Basemap: ODOT City Limits, DOGAMI lidar hillshade, OSIP imagery (2024)



Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-10. Umatilla River CMZ map, RS 13–15, Umatilla County, Oregon.

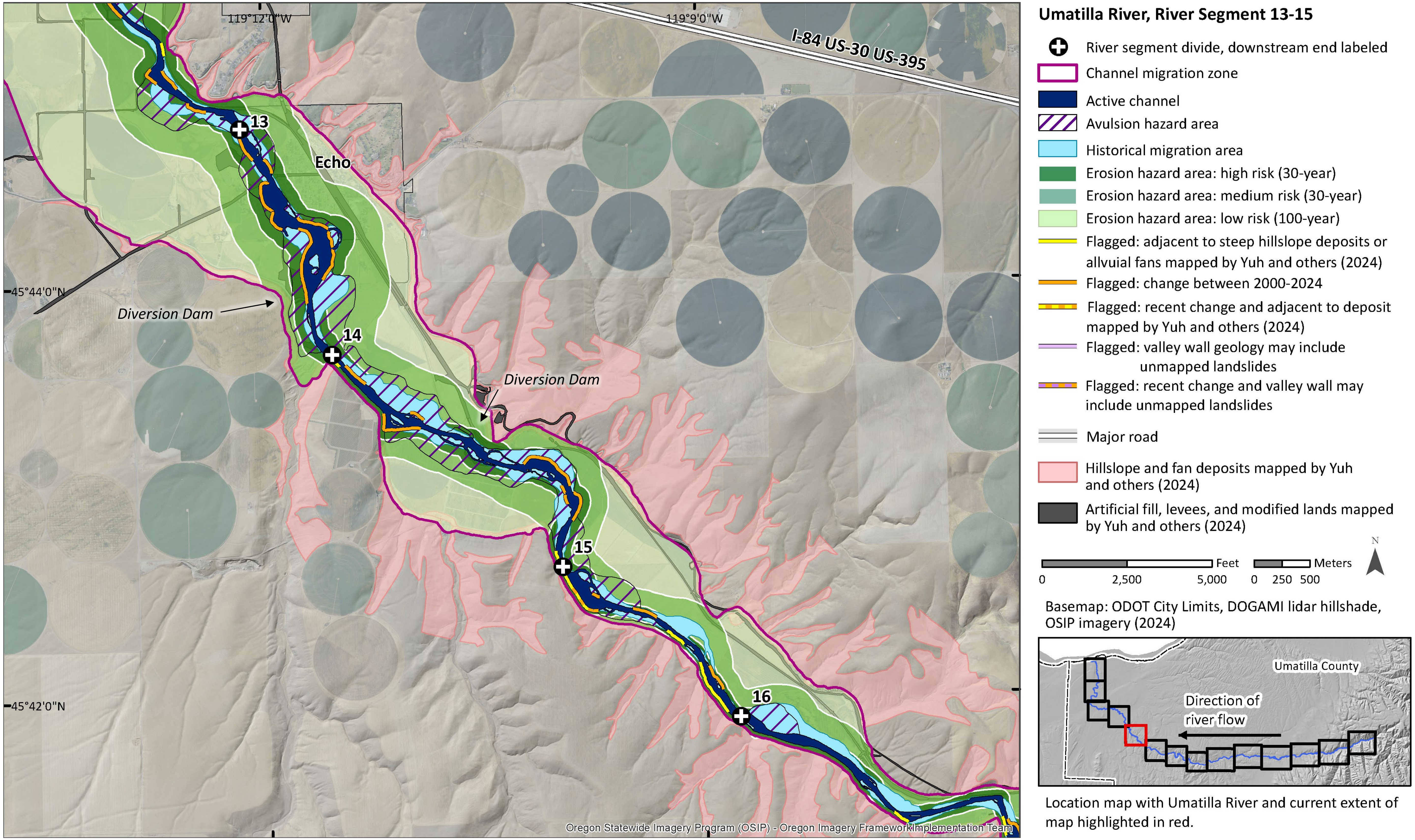
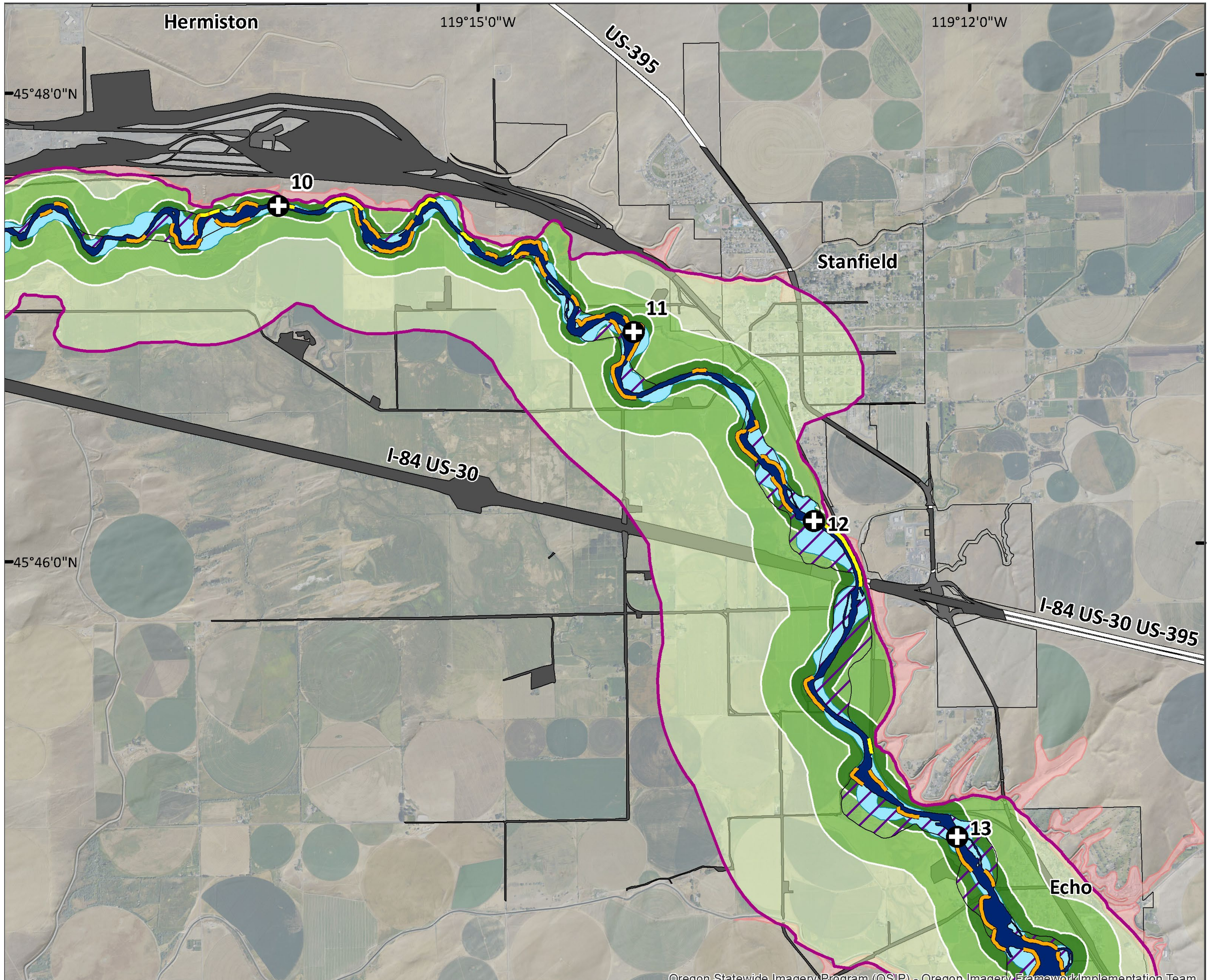


Figure 3-11. Umatilla River CMZ map, RS 10–12, Umatilla County, Oregon.

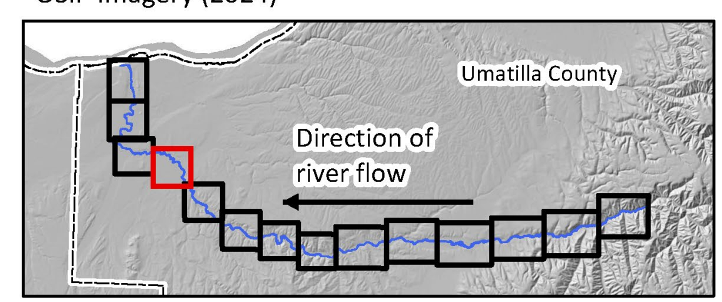


Umatilla River, River Segment 10-12

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: adjacent to steep hillslope deposits or allvuial fans mapped by Yuh and others (2024)
- Flagged: change between 2000-2024
- Flagged: recent change and adjacent to deposit mapped by Yuh and others (2024)
- Flagged: valley wall geology may include unmapped landslides
- Flagged: recent change and valley wall may include unmapped landslides
- Major road
- Hillslope and fan deposits mapped by Yuh and others (2024)
- Artificial fill, levees, and modified lands mapped by Yuh and others (2024)

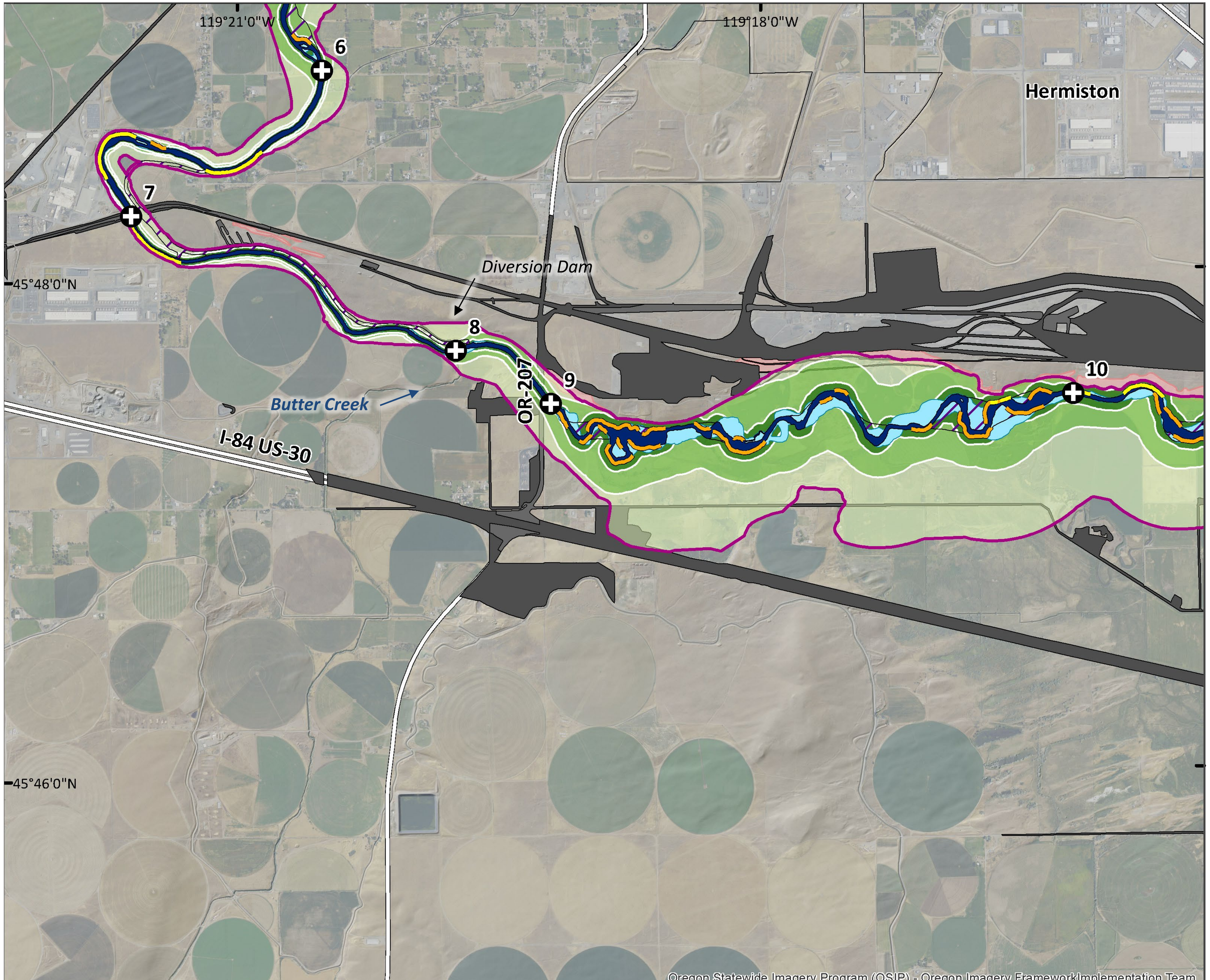
Feet: 0, 2,500, 5,000 — Meters: 0, 250, 500 — N

Basemap: ODOT City Limits, DOGAMI lidar hillshade, OSIP imagery (2024)



Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-12. Umatilla River CMZ map, RS 7–9, Umatilla County, Oregon.

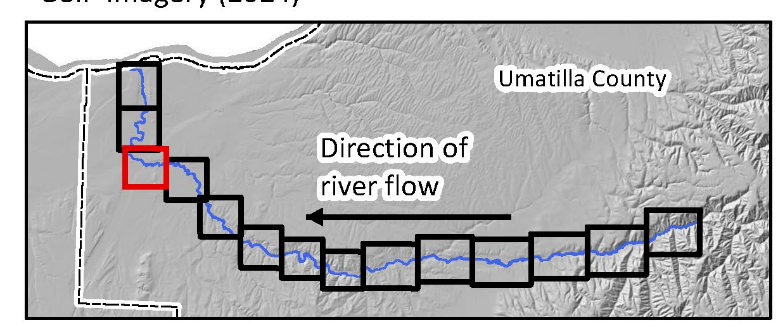


Umatilla River, River Segment 7-9

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: adjacent to steep hillslope deposits or allvuial fans mapped by Yuh and others (2024)
- Flagged: change between 2000-2024
- Flagged: recent change and adjacent to deposit mapped by Yuh and others (2024)
- Flagged: valley wall geology may include unmapped landslides
- Flagged: recent change and valley wall may include unmapped landslides
- Major road
- Hillslope and fan deposits mapped by Yuh and others (2024)
- Artificial fill, levees, and modified lands mapped by Yuh and others (2024)

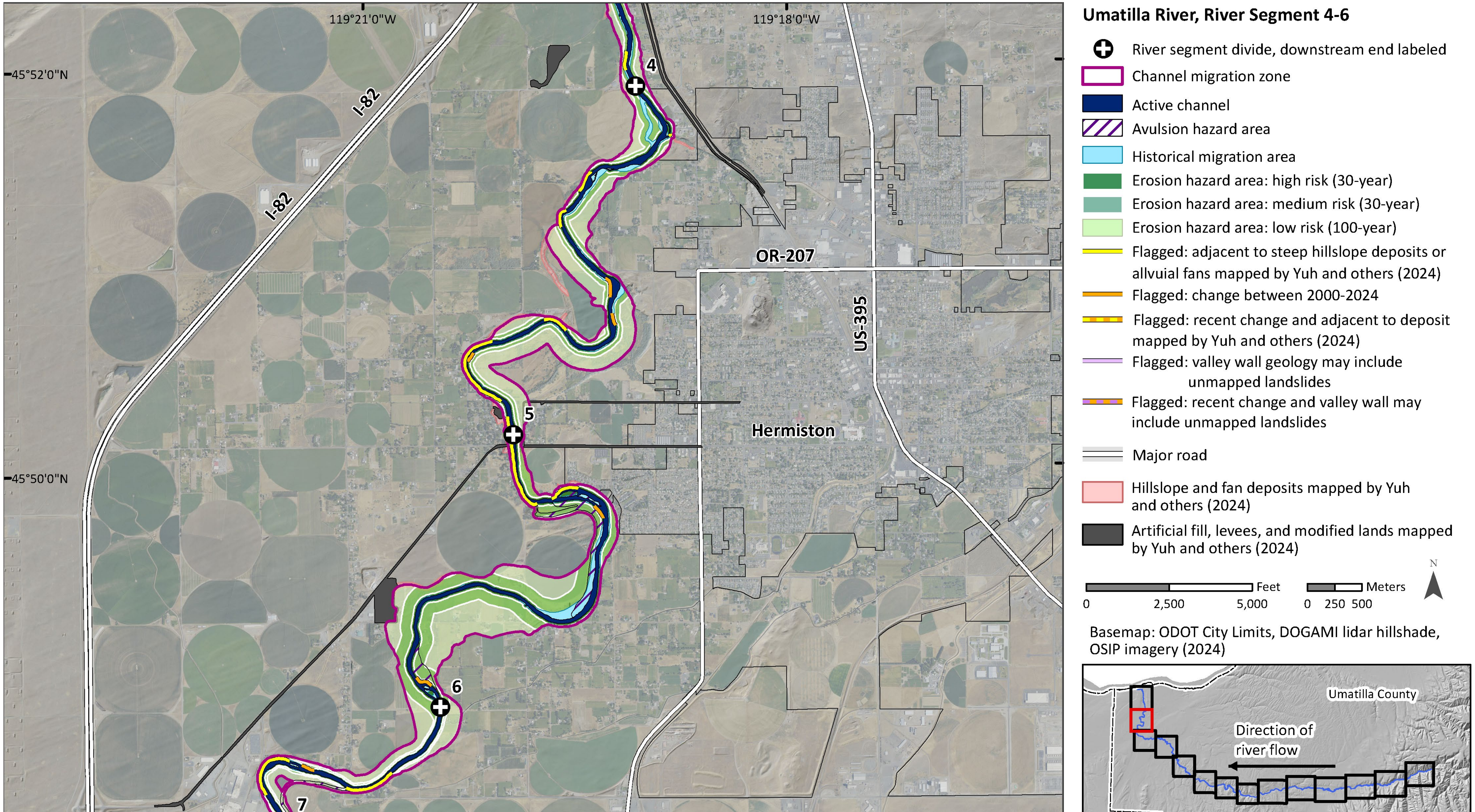
Feet: 0, 2,500, 5,000 — Meters: 0, 250, 500 — N

Basemap: ODOT City Limits, DOGAMI lidar hillshade, OSIP imagery (2024)



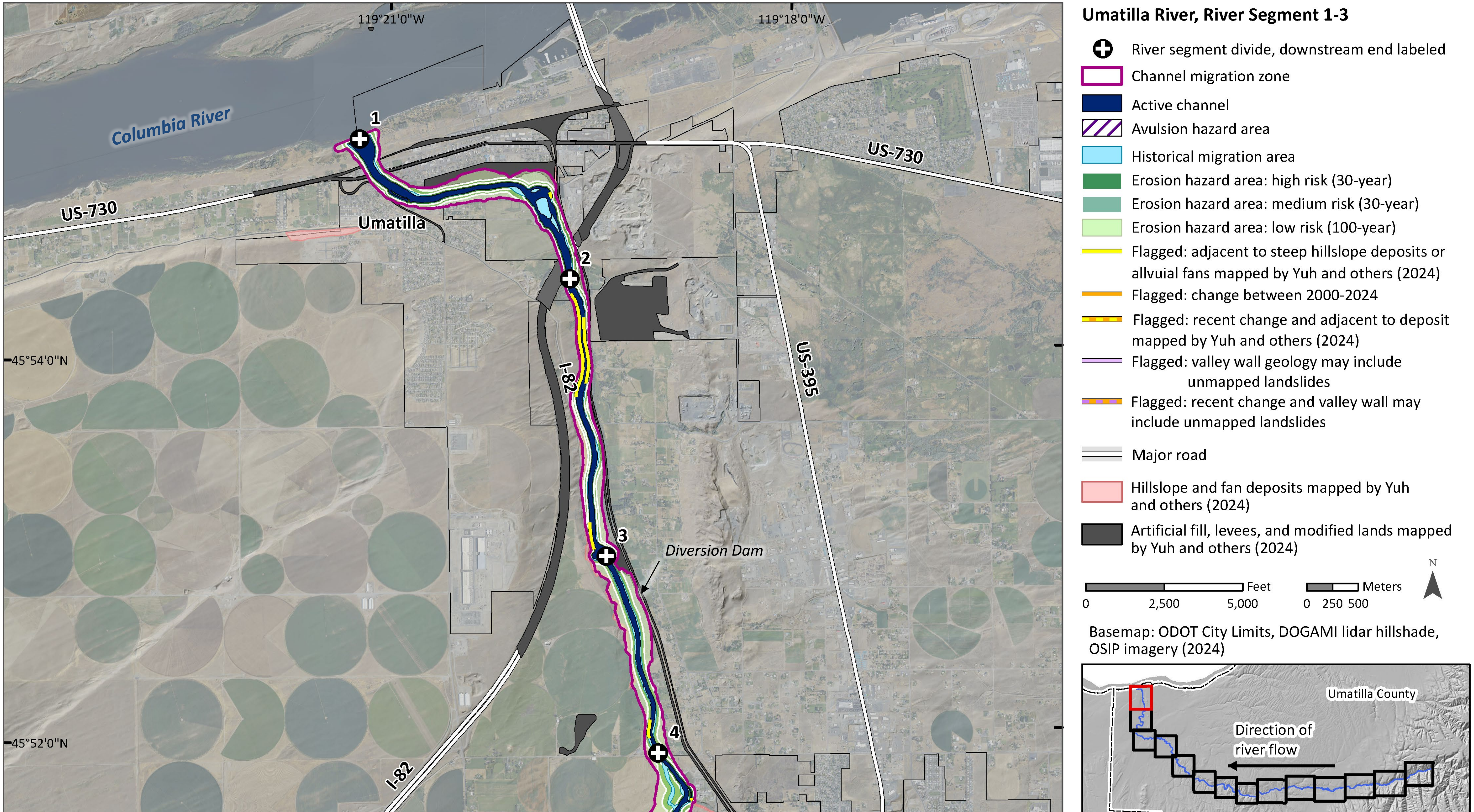
Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-13. **Umatilla River CMZ map, RS 4–6, Umatilla County, Oregon.**



Location map with Umatilla River and current extent of map highlighted in red.

Figure 3-14. Umatilla River CMZ map, RS 1–3, Umatilla County, Oregon.



Location map with Umatilla River and current extent of map highlighted in red.

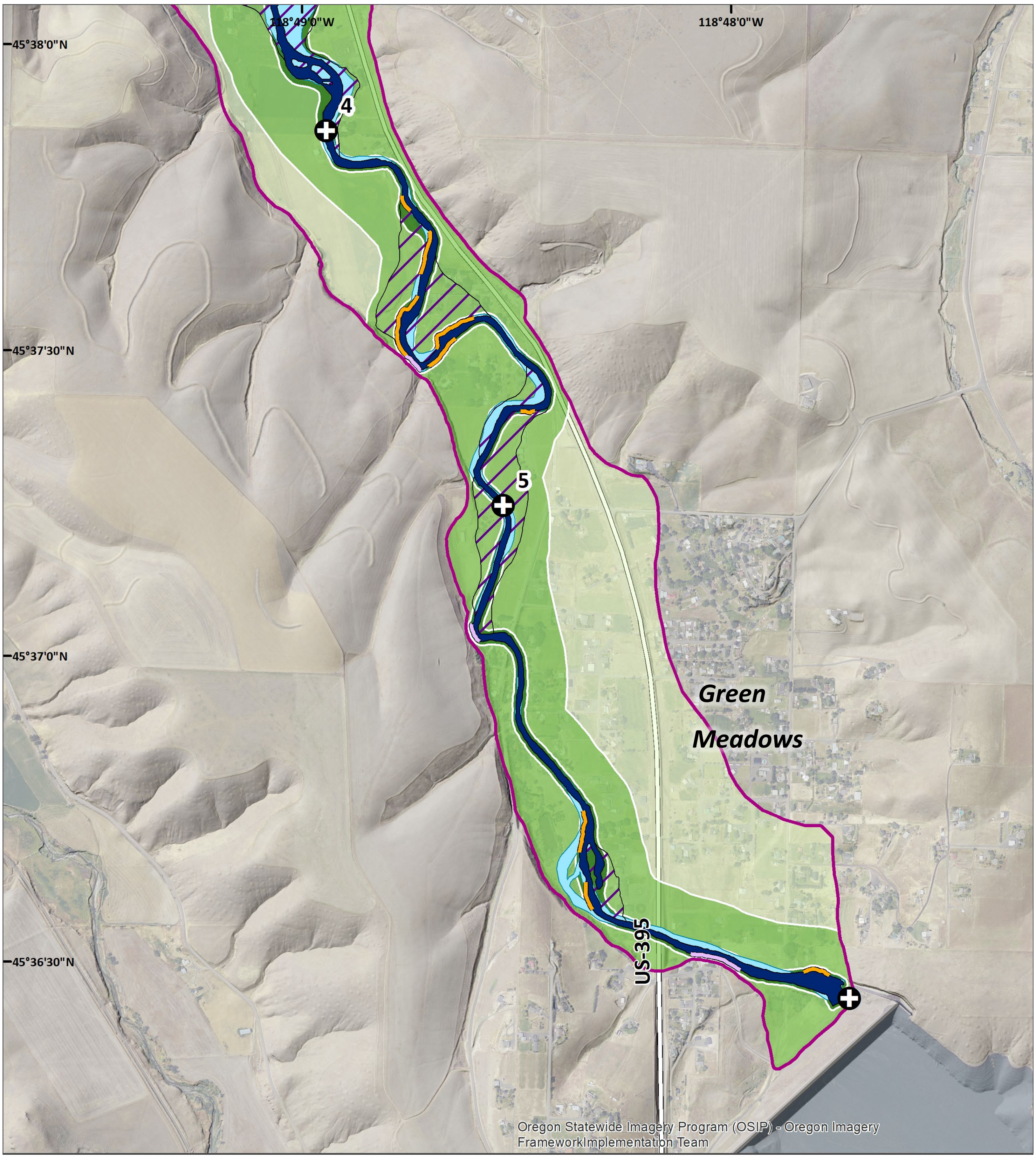
3.2 Lower McKay Creek

Lower McKay Creek flows from McKay Reservoir to the confluence with the Umatilla River (RS 1–5; **Figure 3-15**–**Figure 3-17**). It is primarily a single-thread channel flowing in a narrow valley bottom with discharge controlled by the USBR-operated dam. Overall, there has been limited channel migration along lower McKay Creek between the 1950s and 2020s. However, this is partly due to active community and landowner management, dredging, and straightening of the channel between the dam's construction and the 1990 salmonid habitat protections. Based on the REM, it appears there are several sections that were straightened before the 1950s imagery was collected: the reaches adjacent to the Pendleton Wastewater Treatment Facility and an agricultural field in RS 1, much of the channel in RS 2 and part of RS 3 in the Glendale neighborhood, and several parts of RS 5 at the dam outlet and near the roads. Between the 1950s and 1980s, aerial imagery shows the channel in RS 1 was straightened in two additional locations. The channel movement after 1990 is concentrated along just a few reaches and is associated with larger flood events.

This study revealed the following notable changes and features in lower McKay Creek:

- All RS in this area exhibit small amounts of lateral migration that can be measured as having occurred between the early 1950s and 2020s (as can be seen from the dark blue AC and light blue HMA in **Figure 3-15**–**Figure 3-17)**. Of the banks and meander bends that laterally migrated, movement of ~50–80 ft (~15–25 m) was typical in RS 1, 4, and 5. In RS 3, there was movement of ~100–180 ft (~30–55 m) along banks at the upstream end of the RS, which represents the largest lateral movement in lower McKay Creek. In RS 5, there was an additional change in which the creek split into two channels that eventually avulse into the new channel (discussed below).
  - RS 1 and 3 have the highest median erosion rates: ~2 ft/yr (~0.6 m/yr). These RS also have the highest maximum erosion rates, ranging from 16–18 ft/yr (4.9–5.5 m/yr).
  - We observed one possible avulsion in the imagery from 1952 and 1964 in RS 5 in which the river was relocated ~230 ft (~70 m) from its original location. However, our level of certainty about these being true avulsions was moderate. Interpreting the 1952 imagery was challenging because the river's width is fairly narrow, and the resolution of the 1952 imagery was fairly low (6.5 ft (1.9 m)). However, the topography, vegetation, and geology of the floodplain are conducive to avulsions in limited areas. If the AC reconnects with one of the low-lying historical channels or swales on the floodplain, there is an increased chance of avulsion within the CMZ.
  - There are no detailed landslide or surficial geological maps available for McKay Creek. However, the valley wall geology is composed of McKay Formation, which is a sedimentary bedrock of cobble conglomerate, pebbly sandstone, and tuffaceous siltstone (Madin and Geitgey, 2007). Although there are steep drainages along the valley walls, there are also two broad features along the valley floor: one that appears on topographic maps to be alluvial fan under Glendale and a second that may be a historical terrace under Green Meadows. Either feature could serve as another source of sediment for the channel. Thus, we have flagged banks where the AC interacts with the valley wall in RS 1, 4, and 5.
  - When compared to the current effective FEMA FIRMs (2010), the 2024 AC flows beyond the floodway boundary in all RS. In RS 4, this difference is due to channel migration. However, in RS 1–3 and 5 this discrepancy is minor, likely due the use of low spatial accuracy, pre-lidar topographic maps in flood studies.

Figure 3-15. Lower McKay Creek CMZ map, RS 4–5, Umatilla County, Oregon.



Basemap: DOGAMI lidar hillshade, Oregon State Imagery Program (2024)

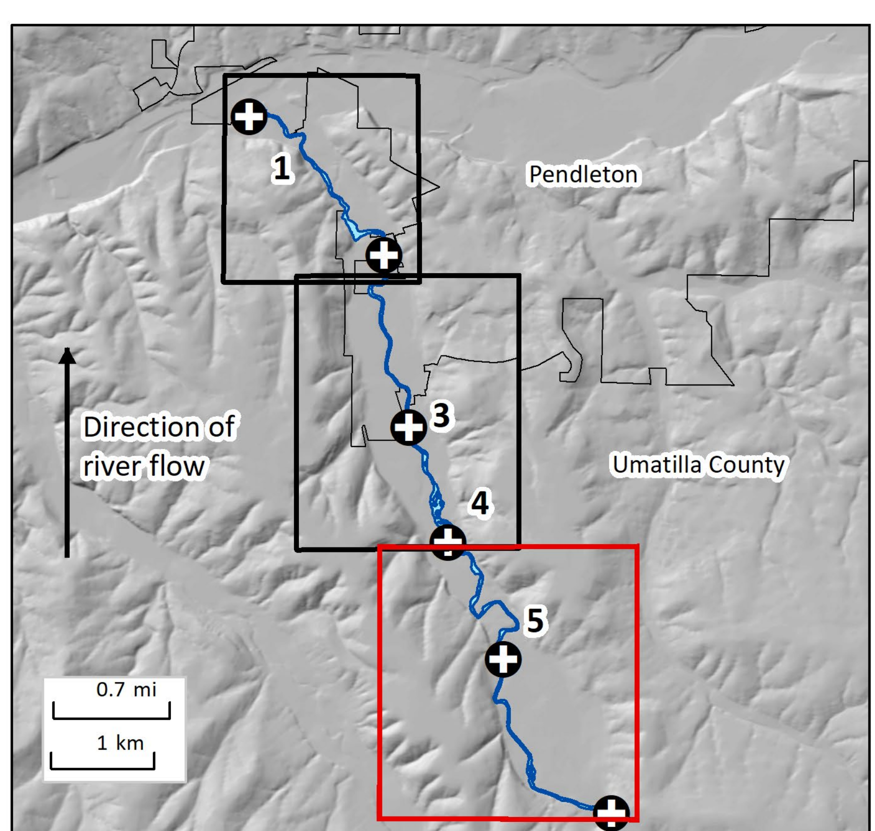
McKay Creek, River Segment 4-5

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: change between 2000-2024
- Flagged: valley wall geology may include unmapped landslides
- Major Roads

Feet: 0 1,000 2,000

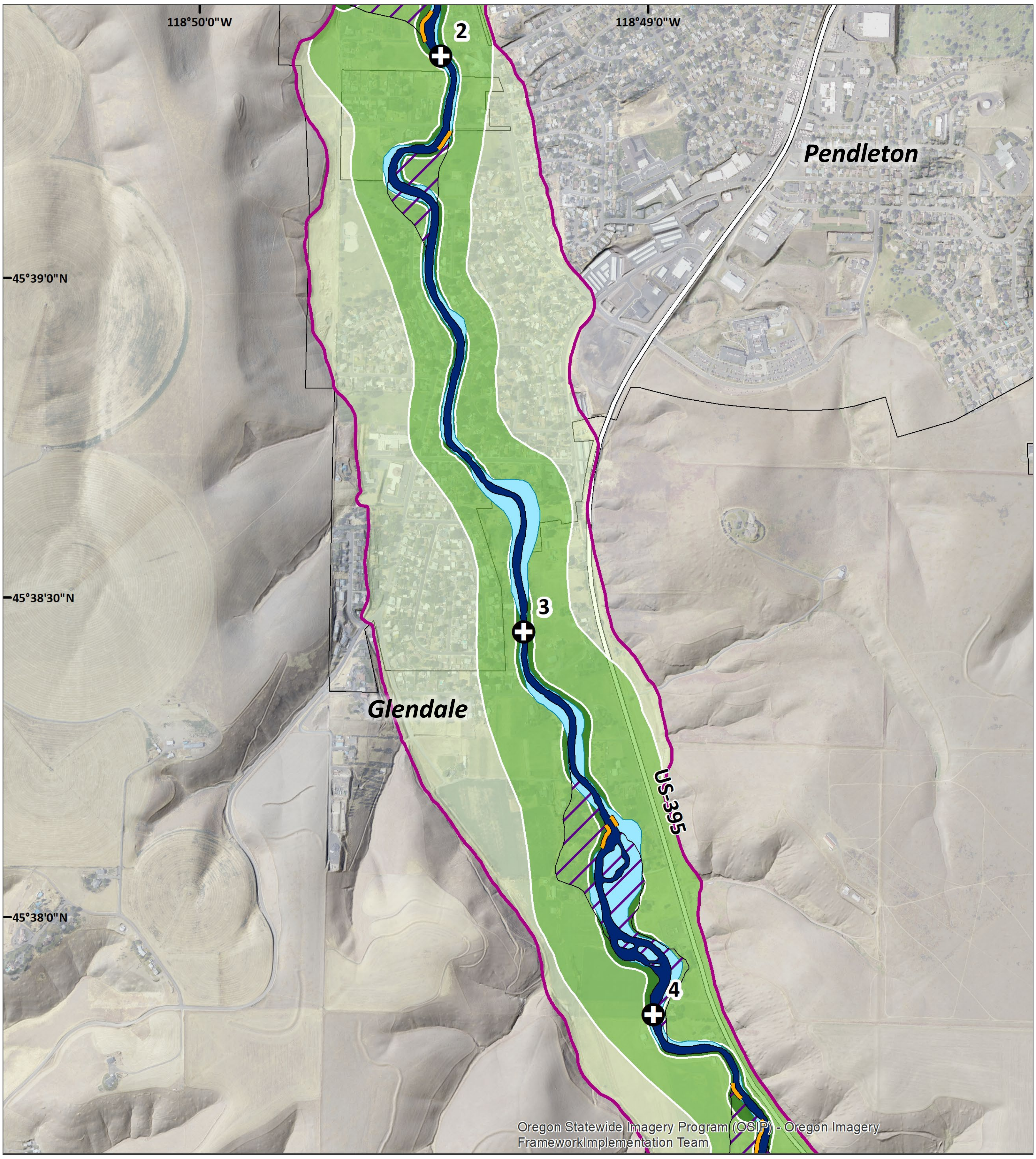
Meters: 0 100 200

N



Location map of McKay Creek in Umatilla County with current extent of map highlighted in red.

Figure 3-16. Lower McKay Creek CMZ map, RS 2–3, Umatilla County, Oregon.



Basemap: DOGAMI lidar hillshade, Oregon State Imagery Program (2024)

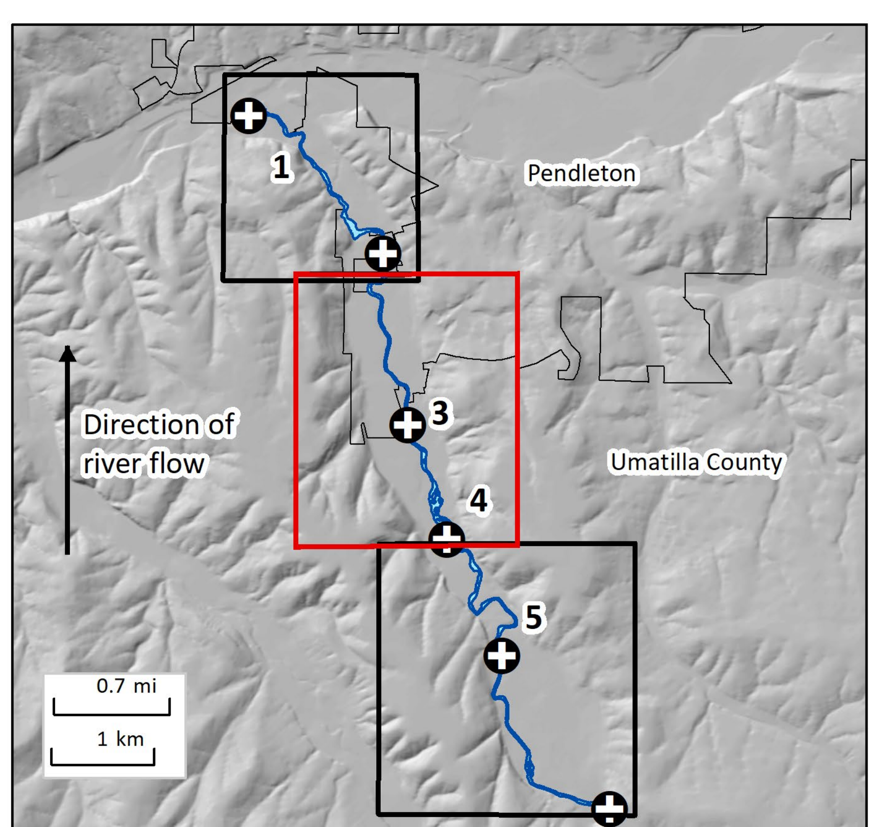
McKay Creek, River Segment 2-3

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: change between 2000-2024
- Flagged: valley wall geology may include unmapped landslides
- Major Roads

Feet: 0, 1,000, 2,000

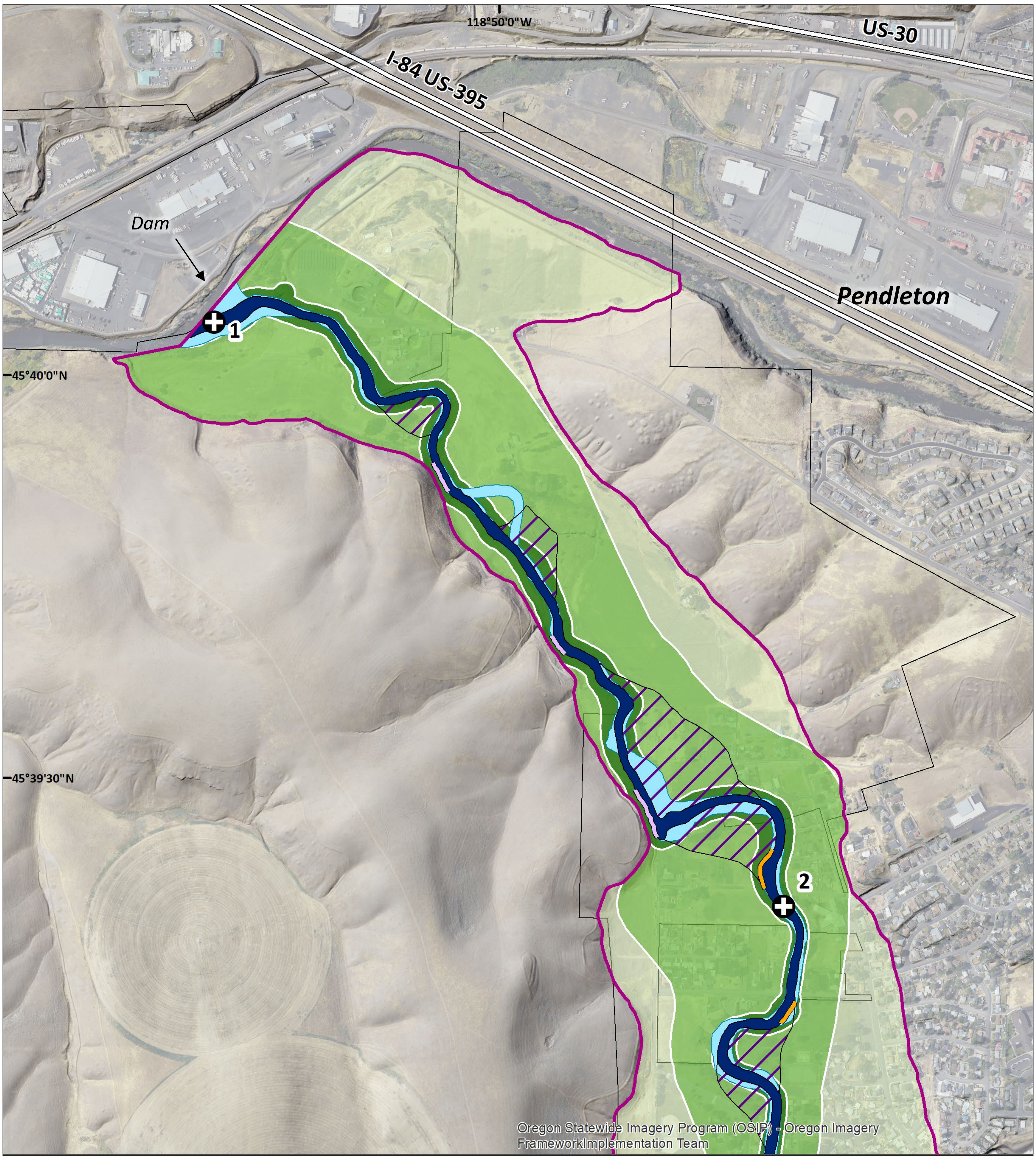
Meters: 0, 100, 200

N



Location map of McKay Creek in Umatilla County with current extent of map highlighted in red.

Figure 3-17. Lower McKay Creek CMZ map, RS 1, Umatilla County, Oregon.



Basemap: DOGAMI lidar hillshade, Oregon State Imagery Program (2024)

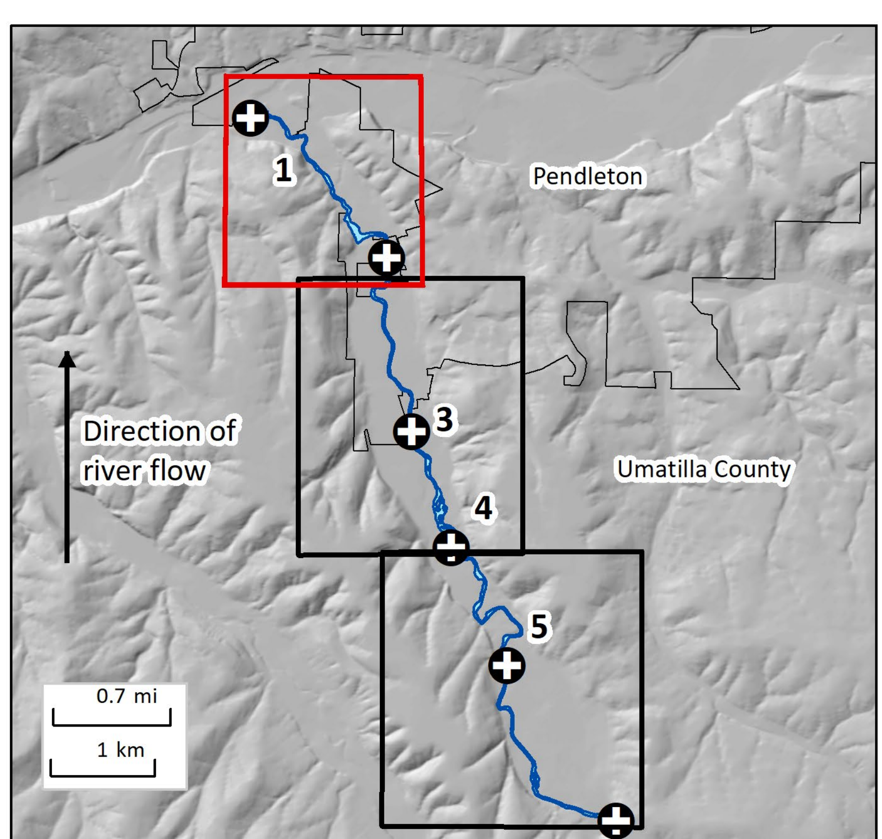
McKay Creek, River Segment 1

- River segment divide, downstream end labeled
- Channel migration zone
- Active channel
- Avulsion hazard area
- Historical migration area
- Erosion hazard area: high risk (30-year)
- Erosion hazard area: medium risk (30-year)
- Erosion hazard area: low risk (100-year)
- Flagged: change between 2000-2024
- Flagged: valley wall geology may include unmapped landslides
- Major Roads

0 1,000 2,000 Feet

0 100 200 Meters

N



Location map of McKay Creek in Umatilla County with current extent of map highlighted in red.

4.0 DISCUSSION AND RECOMMENDATIONS

The CMZ maps produced for this study of the Umatilla River and lower McKay Creek identify the areas that are most likely to be occupied by each stream in the future due to lateral movement. The maps demonstrate that, despite anthropogenic controlling factors (e.g., channelization and infrastructure such as levees, roads, railroads, dams, and bridges), almost all the RS along the Umatilla River and lower McKay Creek have experienced some degree of lateral migration in the last 70 years and some reaches have moved hundreds of feet.

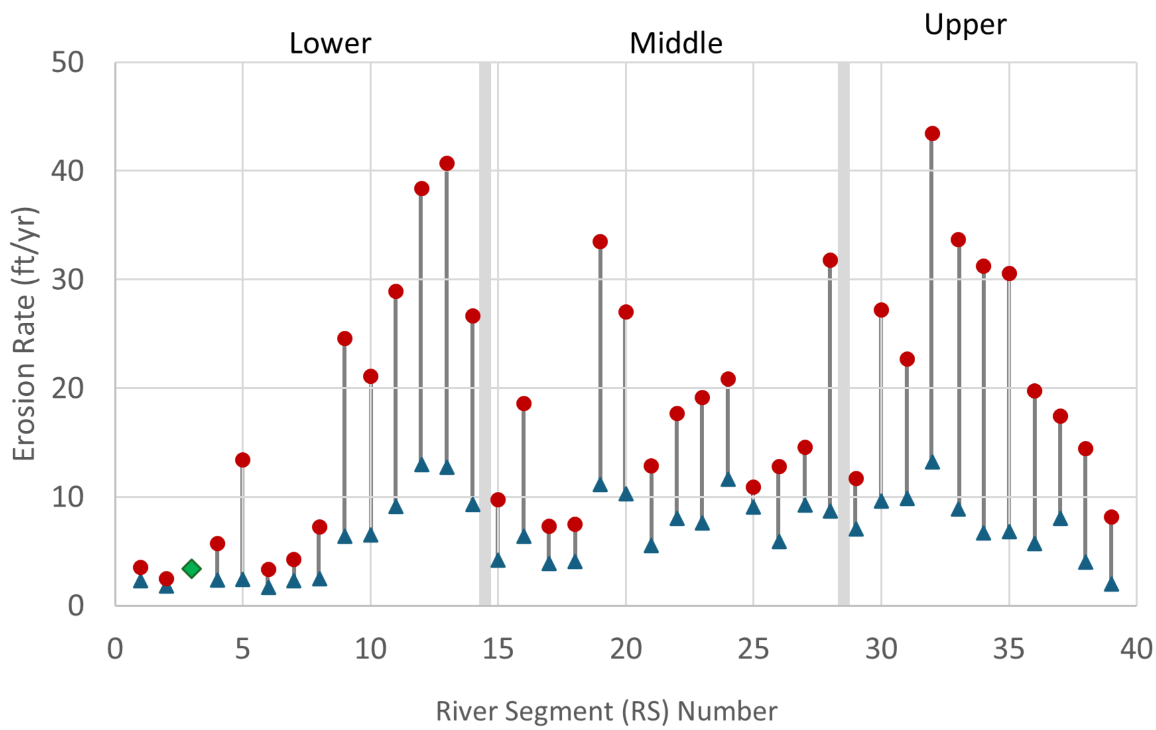
If patterns of erosion from the 1950s to present day continue, both the Umatilla River and lower McKay Creek have the potential to migrate laterally, placing people and infrastructure at significant risk. The continued instability of these streams is a product of stream flow, energy, sediment supply, geology, vegetation, and human modifications. It is important to understand, monitor, and prepare for potential future channel migration. The following sections discuss the findings for each channel, outline the application of the CMZ maps, limitations of the methods and datasets used, and opportunities for future work that will provide new insights into channel migration hazards.

4.1 Umatilla River

As shown in **Figure 4-1**, the maximum observed erosion rates are highest in upper Umatilla River basin, the areas adjacent to the former location of the Furnish Dam, and in the Umatilla Meadows section of the lower Umatilla River near Echo and Stanfield. These rates commonly range from 27–44 ft/yr (8.2–13.4 m/yr). These values often reflect the rapid changes that occurred during major floods, such as those in 1996 and 2020, in areas with fewer confining manmade and natural features.

All the reaches in this study area have been impacted by Euro-American land and river modifications that collectively reduce channel migration and dynamism. Under modern conditions, the slowest maximum rates along the mainstem of the Umatilla River are along the reaches downstream of Butter Creek that flow through Missoula Flood deposits and bedrock which naturally confine channel movement. These reaches have maximum erosion rates of <6 ft/year (<2 m/yr). There are three other areas with low maximum erosion rates: RS 29 adjacent to Mission, RS 25–27 along Pendleton, and RS 17 and 18 in the canyon adjacent to Reith Road. These areas have been heavily modified, straightened, and have levees constructed adjacent to the channel that restrict movement. It is likely that, prior to modern modifications, the erosion rates were more similar to the reaches that have fewer modifications and are directly adjacent to these reaches. For example, RS 29’s maximum observed erosion rate was ~12 ft/yr (~4 m/yr), but it may have the stream power to move 30 ft/yr (9 m/yr) if it is restored to an unconfined, meandering state.

Figure 4-1. The observed, unmodified maximum (red circles) and median (blue triangles) rates of erosion within each RS observed along the Umatilla River, Umatilla County. Rates are based on the period 1950s to 2020s. RS 3 had no measurable erosion rate and was assigned a value using the method described in Section 2.3.5 (green diamond).



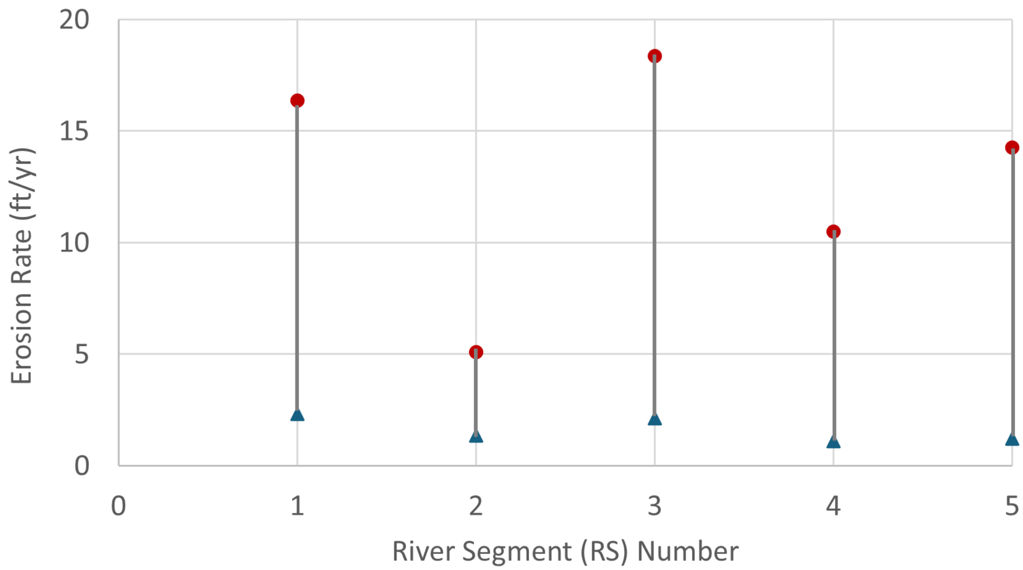
4.2 Lower McKay Creek

Along lower McKay Creek, there has been relatively little channel migration, which is likely due to a combination of factors including the dam controlling flow and preventing sediment from entering the stream; the history of dredging and straightening throughout the 20th century; and the modern urbanization, including hardening of the floodplain and the removal of riparian vegetation and large wood. As shown in **Figure 4-2**, most of the median rates of erosion are 1–2 ft/yr (0.3–0.6 m/yr) and the maximum rates are between 5–18 ft/yr (1.5–5.5 m/yr).

Because we are aware channel management practices changed significantly after 1990 and much attention has been paid to the erosion that occurred during the 2019 flood, we compared the change in channel location across four periods of time: 1952–1974, 1974–1995, 1995–2012, and 2012–2024. Although these time periods are not equal, they each include one of the four largest peak flows between 1952 and the present day (see **Figure 1-5**). If we measure the amount of new area occupied by the channel between each of these periods (excluding the areas of anthropogenic straightening in RS 1 and small slivers <10 ft wide that are likely an artifact of digitization and not channel migration), we find that in 1952–1974, the channel occupied ~9.3 new acres (37,640 m^2); in 1974–1995, the channel occupied 3.2 new acres (12,950 m^2); in 1995–2012, the channel occupied 4.5 new acres (18,210 m^2); and in 2012–2024, the channel occupied 3.2 new acres (12,950 m^2). These are approximate figures and the uncertainty in the mapping from the older imagery, particularly 1952, is the greatest due to lower imagery resolution.

However, we can broadly compare these values and observe that channel migration has been persistent throughout the last 72 years. The channel migration did not abruptly increase after dredging ceased.

Figure 4-2. The observed, unmodified maximum (red circles) and median (blue triangles) rates of erosion within each RS observed along lower McKay Creek.



4.3 Comparison to Other Studies

During the mapping process, we observed several geomorphic responses to the 2020 floods. First, in close alignment with the studies by Hughes (2008) and Merrill (2024), the channel widened; there was large-scale, rapid lateral migration in the upper reaches; large sections of the floodplain were scoured, including dense patches of forested floodplain that became incorporated into the AC; and many avulsions occurred. Second, not discussed by Hughes (2008) and Merrill (2024), there was widespread impact to infrastructure. The stream power was great enough during this event to damage miles of road, including eroding through both lanes of Bingham Road. The flooding also caused the Thorn Hollow Bridge to fail (although it was recognized to be in poor structural condition before the flood); undercut buildings on CTUIR land, eroded through several existing levees; and undercut the edge of Interstate 84. These impacts highlight that many types of infrastructure, including levees and roads, were not constructed to withstand the erosive force of the river and do not act as effective revetment during major floods. If these structures are not maintained, replaced when they degrade or are removed, the channel will be less confined, and, over time, may reoccupy historical sections of the floodplain.

The maps produced in this study are generally consistent with, but more detailed than, those produced by Tetra Tech for CTUIR in 2023 (Appendix 5). The Tetra Tech maps followed a slightly different method based on the Washington Department of Natural Resources' planning-level maps, which measure erosion rates from channel centerline movement. Tetra Tech's mapping indicated that the entire MVB, and some areas beyond the MVB, were vulnerable to channel migration. This extent is consistent with the area identified as the low-hazard EHA by this study. We have added key information to these maps by subdividing the CMZ into each of the components (AC; HMA; low-, medium-, high-hazard EHA; AHA; and flagged), which can be used to understand relative risk and target areas of more immediate concern. The

Tetra Tech study also produced separate avulsion pathway maps. These are also similar to the AHA zones mapped by this study, but there are some differences in interpretations.

4.4 Applications for Data and Maps

The results of this study can be used for the following purposes:

- **Risk assessments and risk reduction**: The CMZ maps produced in this study are designed to be used to perform risk assessments, including the identification of buildings, critical facilities, transportation infrastructure, and utility systems that are potentially in harm's way. This information can be used to estimate the potential financial impact of future channel migration, the number of people who may be at risk or displaced due to this hazard, and economic losses due to building damage and business closure. The results of these risk assessments can then be used to identify specific, targeted mitigation actions that may be implemented to reduce risk and increase community resilience (e.g., establishing CMZ setbacks, restoring riparian vegetation, buyouts for properties at risk, stabilizing banks, etc.). The local, state, Tribal, and federal highway managers may find these maps useful for prioritizing location for monitoring and repairs.
- **Education and awareness**: CMZ maps are tools for sharing information with local, Tribal, and state emergency managers, planners, elected officials, community leaders, residents, and other stakeholders. They can be used for public awareness campaigns, educational presentations, and other outreach products to demonstrate the extent and severity of these natural hazards. To that end, such products may be used to show the need for insurance.
- **FEMA FIS updates**: CMZ maps can quickly highlight areas where the modern AC has moved beyond the original area used in FEMA FIRMs. This study highlights areas where the 2024 Umatilla River AC flows beyond the FEMA floodway boundary and, in some areas, beyond the 100-year and 500-year mapped floodplain. The smaller differences are likely due to the use of nonlidar topographic maps that have lower spatial accuracy in FEMA flood studies, but, in areas with large differences, it is likely due to lateral migration. This indicates the FEMA FIRMs should be updated to reflect current conditions.
- **Planning and decision making**: The CMZ maps may be used to inform land-use planning, develop building ordinances and codes, and identify, prioritize, and implement needed hazard mitigation actions. They can be used in planning documents such as NHMPs and Comprehensive Plans and can also help stakeholders decide which locations have the greatest need for mitigation actions. By including CMZ maps in the land-use and development planning process, communities will also increase their resilience to climate change.
- **Environmental conservation and restoration**: This work can also be applied for uses beyond immediate hazard mitigation. CMZ maps are especially useful for identifying areas best suited for riparian habitat conservation and potential ecological restoration. The CMZ contains ecologically valuable river habitat and can be used to establish an erodible river corridor (Kondolf, 2011). CTUIR, along with the county and state parks in the area, may find these data useful for planning new partnerships, prioritizing future restoration opportunities, and performing outreach with landowners.

4.5 Limitations of Data and Maps

Users of this report should consider the following constraints:

- **Changing conditions:** Although it is common practice, predicting future channel migration from historical patterns may not be possible if key conditions change. For example, changes in dam regulation, sediment supply, precipitation patterns, or land use may result in modern bank erosion rates that differ from those calculated from historical images. Climate change, wildfires, human channel modifications, and changes in riparian vegetation, sediment supply, land use, landslides, and infrastructure can lead to unprecedented patterns in channel migration. The maps produced by DOGAMI represent predictions based on the last 70 years of history. As key conditions evolve, these maps are expected to change as well, reflecting shifts in climate and other external drivers. For example, recent or ongoing river and floodplain restoration work could result in greater uncertainty in these CMZ maps, particularly along the Umatilla River. The goal of such projects varies based on the site and the organization leading the effort, but they often aim to improve the ecological health and restore the physical features of the rivers and their floodplains to offer benefits to riparian and aquatic species. Depending on the site-specific conditions and the goals of the restoration designs, these projects have the potential to reestablish more geomorphically dynamic and unstable bank and bed conditions. This increases uncertainty regarding the CMZ maps produced for this study, and they may need to be updated to include future changes. The recent channel modifications may create unprecedented conditions that could result in channel migration hazards impacting nearby properties and infrastructure. However, these projects also provide a unique opportunity to learn about the modern river dynamics and response to these interventions. To learn more about ongoing restoration projects, please review the information available at https://umatillariver.org/projects/ (CTUIR Fisheries Habitat Program, 2025a).
- **Period of historical observation:** There is strong geomorphic evidence that the channel migration patterns along the Umatilla River changed beginning in the 1800s with the major modifications made by Euro-Americans. To predict future channel changes more accurately, the window of observation was limited to modern conditions in this study. For most of the study area, this meant the CMZ mapping was based on aerial photographs that span the period from the 1950s to the present day. One of the disadvantages of using a limited, approximately 70-year window, of observation is that this method may miss long-term trends, the impacts of infrequent storm events, and other natural variability of the river's behavior. This is a tradeoff that may result in incomplete observations of changes and errors in the measured rates of erosion.
- **Method validation:** The CMZ mapping method used in this study has not been rigorously validated based on multiple decades of data; unfortunately, this lack of validation is common for CMZ maps in Oregon and other states. This study's aim was to produce maps that are both reasonable based on current channel conditions and past migration patterns and that give a range of future conditions, including the maximum extent of possible bank retreat. In this study, CMZ mapping uncertainty was not quantified, however, one potential source of error was minimized. We orthorectified historical images that were georeferenced with a root mean square error of less than two pixels (0.5–7.0 ft (0.15–2.1 m)) and digitize features at a scale of 1:4,000 or finer. Higher accuracy orthorectification produces more accurate bank digitization and erosion rates. In the future, the method used in this study should be compared to future observed migration to reassess its accuracy and utility.

- **Study area extent:** This study mapped CMZs for the mainstem Umatilla River and one of its major tributaries, but it did not include other key tributaries. Channel migration along unstudied rivers may impact communities within each county and should be considered in future studies.
- **Local conditions and site-specific analysis**: This study does not replace the need for site-specific analyses. For any point along a mapped RS, there may be local conditions that change the migration pattern at that location, such as unmapped bedrock outcrops, revetments, LWD accumulations, or bridge abutments. Due to a lack of site-specific analysis, detailed hydraulic modeling, and geotechnical knowledge of existing infrastructure, this study did not assume study area infrastructure was designed and constructed to resist erosion and migration stresses. In areas where the CMZ extends beyond bank-stabilizing structures, landowners or managers may need to evaluate the geotechnical strength of existing structures, monitor, and potentially maintain these structures if they wish to continue limiting bank erosion.

4.6 Recommendations and Future Studies

This study advances knowledge of both channel migration processes and the methods

- **Perform risk assessments**: As discussed in **Section 4.4**, these CMZ maps are designed to be used in risk assessments. Risk assessments that utilize the CMZ maps can provide estimates of the costs of building damage due to different flood risk scenarios and exposure analysis to determine which structures may be at risk from channel migration during the next 30 and 100 years.
- **Develop Umatilla River Corridor landslide maps**: Although the maps by Yuh and others (2024) include hillslope and fan deposits, there are no lidar-based, landslide-specific maps for valley walls of the Umatilla River watershed. The streambanks of RS 38 and 39 were flagged in areas where the channel flows at the toe of the hillslope, but, due to the lack of landslide or detailed surficial geologic maps, this study cannot say with certainty if the AC does or does not flow at the toe of a landslide deposit. It is important to identify these intersecting hazards because they indicate areas where there are potentially unstable channel and hillslope conditions, increased sources of sediment supply, or the potential for future mass movements. Such a scenario could result in a landslide blocking the river channel and subsequent rapid channel migration, avulsion, and threat to human lives and infrastructure. This study recommends that detailed landslide maps are produced in this area to better understand these hazards and risks.
- **Investigate active fault and channel interactions:** There are a series of active, Quaternary faults within the basin, which may influence surface-groundwater interactions, long-term channel migration, and valley geometry. Additional investigation is needed to define this relationship. This area has a recent history of tectonic events, including the 1936 State Line earthquake, also known as the Milton-Freewater earthquake, which struck along the Oregon-Washington border on July 15, 1936. With an estimated magnitude of 5.0 to 5.5 (Eastern Oregon, 2015) and a maximum Modified Mercalli Intensity of VII (Very Strong [Neumann, 1938]), it was one of the most powerful earthquakes to be recorded in northeastern Oregon and southeastern Washington.
- **Update CMZ maps**: CMZ maps will become out of date over time and will require periodic updates. This study recommends that all elements of the CMZ maps are remapped every 20 to 30 years (when sufficient time has passed to develop new erosion rates) and/or after a significant flood event. In addition, this study recommends that the flagged map components be reviewed every five years, or more frequently, to determine if new areas need to be included.

- **Map CMZs in additional study areas**: This study recommends performing CMZ mapping across Oregon. Within Umatilla County, additional tributaries of the Umatilla River mainstem as well as the Walla Walla River mainstem and its tributaries may also impact people and infrastructure in the county.
- **Advance the CMZ Method**: As discussed in **Section 4.5**, multidecadal validation of the CMZ mapping methods is needed, particularly as it relates to quantifying the uncertainty in the mapping approach. It would be useful to compare the CMZ method used here to mapping techniques that are being developed elsewhere, such as those utilized in Colorado or Washington.
- **Expand knowledge of channel migration processes**: There are many unanswered questions about channel migration patterns for rivers in Oregon. Future studies will need to answer questions such as:
    - Which RS and what overall proportion of rivers in Oregon experience channel migration over interannual to interdecadal time periods?
    - What are the key characteristics that can be used to identify river reaches that are highly susceptible to channel migration in Oregon? Are these characteristics consistent statewide, regionally, or locally? Characteristics may include, but are not limited to, sediment supply, discharge, slope, riparian vegetation, LWD, bed and bank geology, and human modifications to the stream channel and adjacent land.
    - What impact is climate change having on channel migration and erosion rates in Oregon and how will this impact change in the future?

The CMZ maps produced for this study of the Umatilla River and lower McKay Creek are designed to aid in community planning, raise awareness of riverine flood and erosional hazards, and to inform decisions about environmental and emergency management and land use. The maps show that, despite changes made by humans such as channelization and infrastructure construction, channel migration is a persistent factor for the communities adjacent to these rivers. The strategies identified by DLCD to reduce risk and their recommendation for enhanced coordination may be found in the **Appendix**.

5.0 ACKNOWLEDGMENTS

The authors would like to acknowledge and thank everyone who made this project happen. This work was funded by FEMA Grant No. EMS-2021-CA-00011. Support from FEMA Region X, particularly that of Rynn Lamb, is sincerely appreciated. The authors would also like to acknowledge the partnership and information from the staff of the Confederated Tribes of the Umatilla Indian Reservation, Umatilla County Soil and Water Conservation District, Umatilla County, Pendleton, and Echo. The authors are also grateful for the help and support from DOGAMI staff, including Lalo Guerrero, Fletcher O'Brien, Alexander Lopez, and Jason McClaughry and DLCD staff, including Marian Lahav and Susan Millhauser.

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