LOWER ELWHA RIVER CHANNEL MIGRATION ZONE DELINEATION

Elwha River, Little River, Indian Creek

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PREPARED FOR:

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Department of Community Development

June 20, 2025

This project was funded in part by a Washington Department of Ecology Shoreline Planning Competitive Grant (SEASPC-2325-ClCoCD-00006)

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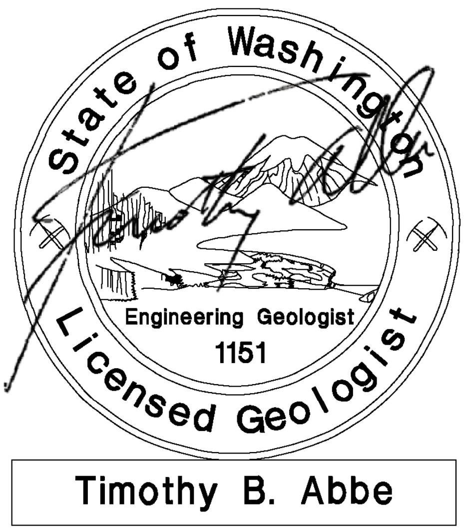

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Channel Migration Zone Terminology

Active channel	Unvegetated area occupied by a river channel, including gravel bars.
Aggradation	The accumulation of sediment in a river channel.
Alluvial fan	A sediment deposit that accumulates where a relatively steep stream flows onto a flatter valley floor.
Alluvium	The accumulation of sediment in a river channel.
Angle of repose	The angle at which loose material will stand stable without sliding over the long term.
Avulsion	Sudden change of river or channel location, generally during a flooding event.
Avulsion hazard zone (AHZ)	Area mapped as having a likelihood of avulsion during the lifespan of the CMZ. Determined using REM, hydraulic modeling, and LiDAR hillshade.
Bedrock	Solid rock assumed to have no erosion potential over the lifetime of the CMZ.
Braided	A type of river planform characterized by multiple rapidly migrating channels separated by unvegetated gravel bars.
Channel gradient	The steepness of a river channel, expressed as the amount of elevation change over a specified distance.
Channel migration zone (CMZ)	A delineated area which a river may be expected to occupy over a given period of time, based on historical migration rates and patterns.
Channel trace	A polygonal representation of a river's active channel, derived from historical imagery.
Confined	When the movement and floodplain of a river is limited by adjacent topography.
Disconnected CMZ	The portion of a delineated CMZ which sits landward of critical infrastructure such as federally certified levees as well as federal and state highways.
Erosion hazard area (EHA)	Combination of the erosion setback and geotechnical setback.
Erosion rate	Calculated for each reach using the change in area between historical photos.
Erosion setback (ES)	Calculated erosion rates multiplied by the lifespan of the CMZ delineation.
Floodplain	Area inundated by a 100-year recurrence peak flow
Geotechnical setback (GS)	An area delineated beyond the erosion setback to account for freshly eroded, unstable banks adjusting to their angle of repose.
Historical migration zone (HMZ)	The area occupied by a river's active channel through time. Delineated primarily using historical imagery, supplemented with maps and LiDAR.
Holocene	A geologic time period representing the present and the relatively recent past, since the last ice age (12,000 years ago).
Incision	The erosion of a river into its bed, limiting the connection to its floodplain – often occurring as a result of land use changes.
Legitimate structure	Human-made structures that require a public commitment to keep them intact, such as certified federal levees and State Highways.
Levee	A structure built to prevent the flooding of a river.

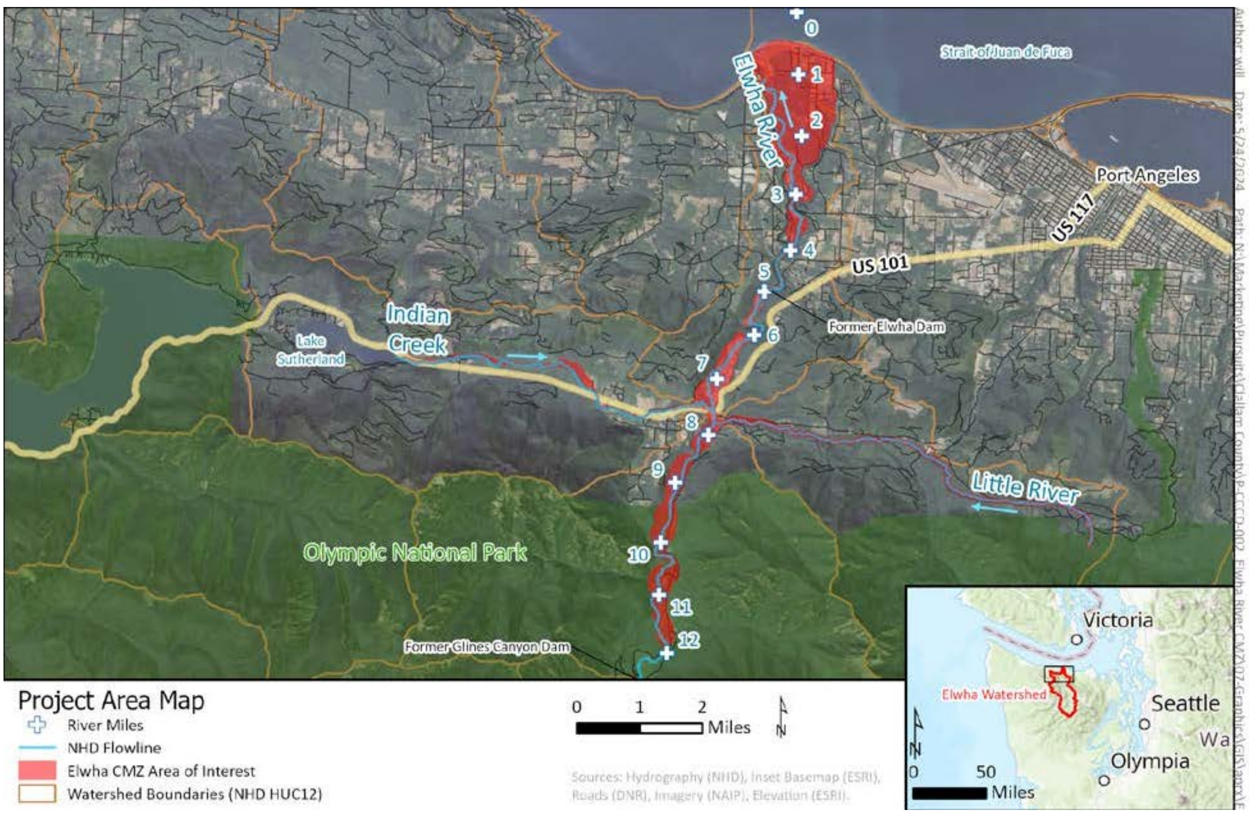
LiDAR	Light detection and ranging – a remote sensing system where a laser is used to measure the height of objects relative to each other, usually mounted to an airplane.
LiDAR hillshade	A product of LiDAR data showing landscape features in high resolution
Reach	A section of a river defined by similar geomorphology and river processes.
Relative elevation model (REM)	A GIS derived product of LiDAR data which shows topographic elevations relative to a river's surface.
Riparian area	The area near a river which is strongly influenced by river processes, either in the present or in the past.
Terrace	Flat alluvial surface representing a former floodplain, higher in elevation than the current floodplain.

1. INTRODUCTION

This report describes the methods, analyses, results, and limitations of the detailed channel migration zone (CMZ) delineation for the lower Elwha River watershed. At the request of the Clallam County Department of Community Development (County), Natural Systems Design, Inc. (NSD) conducted a CMZ delineation under the State of Washington Department of Ecology (ECY) Shoreline Planning Competitive Grant agreement SEASPC-2325-ClCoCD-00006.

This study includes the Elwha River downstream from the Altair Campground (approximately RM 11.8) to the Strait of Juan de Fuca, the Little River from the Olympic National Park (ONP) boundary (approximate RM 7) to Elwha River, and Indian Creek from the outlet of Lake Sutherland (approximate RM 6) to Elwha River (Figure 1-1). The portions of the study area located outside of ONP are the primary focus of this shoreline planning technical work and NSD was able to also include portions of the study area inside of ONP to provide a more robust analysis for a broader geography.

Figure 1-1. Overview of the lower Elwha watershed and study area.



1.1 Study Goals and Objectives

The primary goal is to delineate the CMZ for the Elwha River, Little River, and Indian Creek. This study builds on a previous planning-level delineation of Clallam County Rivers (Olson et al., 2014), as well as scientific literature on channel response from dam removal. The detailed CMZ delineation provides planners and resource managers with the information necessary for establishing reach-scale jurisdictional boundaries to support the County in implementing and updating the Shoreline Master Program (SMP) and Critical Areas Ordinance (CAO). The detailed CMZ will help the County better understand current and future patterns of erosion and flood risk along the Lower Elwha River watershed to incorporate risk-informed decisions into various planning processes to benefit public safety, infrastructure, and aquatic and riparian ecology.

The Elwha River is a shoreline of statewide significance under the Shoreline Management Act (SMA) (RCW 90.68.020), Indian Creek and Little River are jurisdictional shorelines, and collectively these water bodies are valued and managed as shorelines of the state. Shoreline use and development activities are regulated locally by the Clallam County SMP, which establishes limitations and requirements specific to CMZs. As an early part of the recent SMP Update, the inventory of shoreline conditions occurred during the active phase of removing both Elwha River dams (2011 to 2014) and did not include CMZ mapping for the Elwha system. Dam removal has dramatically affected the river environment downstream and at the delta. A growing collection of newer data and technical information documents the river's response to the release of impounded sediment and wood, the draining of two reservoirs, and the return of natural sediment and wood transport processes.

The Clallam County SMP establishes jurisdictional limits (§1.8 or CCC 35.05.080) to include the full extent of the 100-year floodplain and all lands necessary for critical area buffers. Critical areas such as geologically hazardous areas and frequently flooded areas that are in shoreline jurisdiction are regulated by the SMP, while critical areas located outside shoreline jurisdiction are regulated by the Clallam County CAO. Accurate CMZ mapping will help better implement both the SMA and CAO locally on a project-specific basis.

Under the SMA, Flood Hazard Reduction Principles under WAC 173-26-221(3)(b) limit the allowance for excluding "areas separated from the active river channel by legally existing artificial channel constraints that limit channel movement" from the CMZ to locations that are "within municipalities and urban growth areas." Excluding these areas under the SMA is not applicable in the unincorporated areas of the County. The WAC requires scientific and technical demonstration for structures built below the 100-year flood elevation to be considered a CMZ restriction (disconnected migration area).

Areas outside of County jurisdiction, in the National Park Service (NPS) boundary, are not subject to Clallam County Code. The purpose of including the Elwha River in the NPS is to strengthen the understanding of geomorphic and hydraulic processes into the upper watershed.

Study Approach and Scope

CMZ delineation of the Elwha River, Indian Creek, and Little River (study reaches) follows an established methodology by Rapp and Abbe (2003) along with the latest scientific literature on river corridors. Project tasks as outlined follow the methodology described in the ECY framework (Washington Department of Ecology, 2025) and were sequenced to incorporate feedback from the local community and co-managers.

- A **Quality Assurance Project Plan (QAPP)** was developed to outline data collection and use protocol to ensure accuracy is maintained.
- **Data collection** includes historical data and field observations.
- **Public Outreach** to community and co-managers to share project updates and results through various media.
- **CMZ delineation** includes geomorphic reach delineation, hydraulic modeling, and detailed mapping of the channel migration zone.

1.2 Limitations

This report has been prepared for Clallam County for the Lower Elwha River, Lower Little River, and Lower Indian Creek Channel Migration Zone Delineation. Methods used to delineate the CMZ were adopted from the Washington State Department of Ecology (Rapp and Abbe, 2003) with the following limitations:

- Hazards that exist but were not mapped for this assessment; the hazards mapped for this analysis were limited to lateral erosion and avulsion potential on the Elwha, Little River, and Indian Creek. Other natural hazards in the valley exist, including but not limited to flooding, landslides, seismic and/or liquefaction hazards, and tsunamis.
- Erosion risk levels (moderate, high, severe) or probabilities of occurrence were not determined or included in this study.
- Temporal changes, disturbances, or recovering conditions, such as riparian development or wood jams, are variables that will impact channel response. Predicting the local response and impacts over the time scale of this study is not considered feasible because of the unpredictable nature, time scale, and extent of the change. For example, predicting the location of the channel, size and duration of a wood jam, and riparian conditions at a site even in 5 years is felt to have a low degree of assurance. Analysis looking at a smaller timeframe context and a more site-specific or sub-reach perspective should include such conditions and potential channel response.
- All mapping was completed at a reach scale and may not capture all local features.
- Bank armoring is not considered a "legitimate structure" or barrier that would prevent channel migration, in this CMZ, unless it has owner committed to maintenance (federal levees and state highways). All banks are considered potentially erodible except for bedrock outcrops.
- Poorly registered or blurry historical images can lead to misaligned channel traces used to define the historical migration zone, and to calculate channel migration rates. The size of the historical migration zone is based on the cumulative channel traces over time, so any misaligned images would falsely indicate channel migration and result in an over-sized HMZ.
- The detailed CMZ delineation is based on average erosion rates over the period of record. This could bias movement in some locations that have been static under with-dam conditions, or underestimate future channel movement due to the relatively limited time of recorded no-dam conditions. Site-specific investigations should be conducted where near-term migration rates and/or site geology create anomalies in the reach-averaging approach, and that mapping be revisited in the event controlling factors change dramatically.
- The historic record for post-dam removal information is short relative to pre-dam removal, thus higher uncertainty exists in the former reservoir reaches. Future channel changes should be monitored and CMZ updated if deemed necessary.
- Vegetation commonly obscures the top of bank in air photos, making slow migration difficult to capture. If the channel is sufficiently narrow, vegetation canopy can obscure the entire channel from view, making it difficult to impossible to observe and quantify channel migration. Full canopy obstruction is characteristic of most of Indian Creek and Little River.
- Field reconnaissance was conducted at representative locations, not for the entire study area. Data were then extrapolated elsewhere as deemed relevant.

- No geotechnical studies were conducted, 1:24,000 surficial geologic maps were used to interpret bank composition, bedrock locations, and rock type. Thus, the limitations of these mapped data translate to this study.
- Hydraulic model calibration was not performed in this study. This may require full topo-bathymetric channel data, measurements of water surface elevation, and adjustment of model computation parameters for further analysis.
- Future shifts in system hydrology, climate, sediment transport, riparian conditions, land use, or channel stability would also affect the accuracy of the mapping. Site-specific investigations should be conducted where near-term migration rates and/or site geology creates anomalies in the reach-averaging approach, and that mapping be revisited in the event controlling factors change dramatically.
- Improvements in technology, new information, and evolving geologic interpretations may allow for more accurate mapping or a reinterpretation of mapped hazards in the future. Mapping should be updated as new information and technology becomes available.

2. BACKGROUND

The Elwha River is one of the largest rivers in Clallam County, located on the Olympic Peninsula of northwest Washington state. It has a steep gradient, large sediment supply and an actively migrating channel within alluvial valley reaches. The Elwha River watershed is approximately 321 square miles, flows through a mountainous landscape with a high level of relief, with 83 percent of the watershed within the Olympic National Park (ONP) boundary. The study area extends from the outlet at the Strait of Juan to Fuca to River Mile (RM) 13.3 upstream of the Altair Campground in ONP. The Elwha shows a typical seasonal flow regime for large rivers in western Washington, with high flows being driven by winter rain events and spring freshets, and with low flows from mid-summer into early-fall.

The lower Elwha River has two major tributaries, Indian Creek and Little River. Indian Creek originates at Lake Sutherland and flows east to the Elwha. Much of the Indian Creek valley is private land. Indian Creek enters the Elwha just downstream of the U.S. Highway 101 bridge at River Mile (RM) 7.7. Little River originates within ONP, flowing north into state land and then turns to the west, flowing through private property before joining the Elwha River immediately upstream of the U.S. Highway 101 bridge. Infrastructure and human development are present in varying degrees throughout floodplains in the Elwha, Little River and Indian Creek systems, notably the City of Port Angeles water supply facilities at RM 3.0. The Lower Elwha Klallam Tribe Reservation is located along the delta of the Elwha River and is protected by a certified U.S. Army Corps of Engineers (USACE) federal levee. Near the upstream extent of the study area is the National Park boundary, where recent channel migration has affected access after the Hot Springs Road washout in 2016.

The Elwha had two large dams, the Elwha Dam at RM 4.9 built in 1912 and the Glines Canyon Dam built in 1927 at RM 13.4. Both dams were removed as part of the Elwha Restoration Act, the Elwha in 2012 and Glines Canyon in 2014. The two dams stored about 21 million cubic meters of sediment (~16 in Lake Mills and ~5 in Lake Aldwell). Randle et al. (2015) reported that over 7 million cubic meters had been released from the reservoirs two years after the Elwha Dam removal was completed and only three-quarters of Glines Canyon Dam had been removed. The peak sediment pulse, and associated channel change, occurred within the first five months (East et al., 2018). By 2016, approximately 65 percent of the initial sediment had been exported from the two reservoirs (Ritchie et al., 2018). Dam removal restored fish passage and the river's natural flow, sediment, and wood transport regimes.

Shortly after dam removal the lower Elwha River experienced significant riverbed aggradation due to the artificially high sediment sourced from the reservoir areas. This resulted in more rapid channel migration in some areas. Channel incision and migration was particularly evident in the reservoir areas (previous Lake Aldwell and Lake Mills). Ritchie et al (2018) estimate that in the five years following the removal of the Elwha Dam, ~10 percent of the eroded reservoir sediment was deposited in the river channel and floodplain, ~26 percent deposited in and around the delta, and the remaining ~64 percent was transported offshore. However, adjustment of the lower Elwha River is ongoing, driven by the response to high-flow events (East et al., 2018).

The river is also expected to change as a result of the warming climate. Climate change predictions for the region indicate more extreme weather patterns in the near future which will increase the dynamic nature of the Elwha River in the form of channel migration, avulsion, planform evolution, and floodplain inundation. These processes are essential for forming critical salmonid habitat but also pose risks to infrastructure and property.

3. DATA SOURCES

This study relies on digital and spatially referenced data to perform the desktop analyses, particularly light detection and ranging (LiDAR) derived digital elevation models (DEM) and aerial imagery. Historical topographic maps and imagery were available for years between 1873 and 2023 and were selected to create a representative record of channel evolution over time. Select parameters of interest for the CMZ delineation include the following:

- Topographic surface elevations derived from LiDAR digital elevation models (DEMs).
- Historical channel locations delineated from historical imagery analysis.
- Location of stream channel alignments verified in the field.
- Location and characteristics of eroding streambanks verified in the field.
- Hydraulic and hydrologic conditions (e.g., peak flow, depth, velocity, and inundation extent) derived from stream gages, elevation data, hydraulic modeling, and verified in the field.

A targeted field reconnaissance was conducted at specific locations within the study area to verify findings of desktop analyses and mapped CMZ components.

3.1 Quality Assurance Project Plan (QAPP)

NSD prepared the QAPP detailing data collection methods, sources, and limitations (NSD, 2024). The QAPP was approved by ECY on June 25, 2024. Refer to Appendix E for the approved QAPP document.

3.2 Existing Data Sources

The information required to achieve the project goals and objectives has been assembled from existing public sources where available. Refer to Table 3-1 below for an inventory of external data gathered and intended purpose for CMZ delineation.

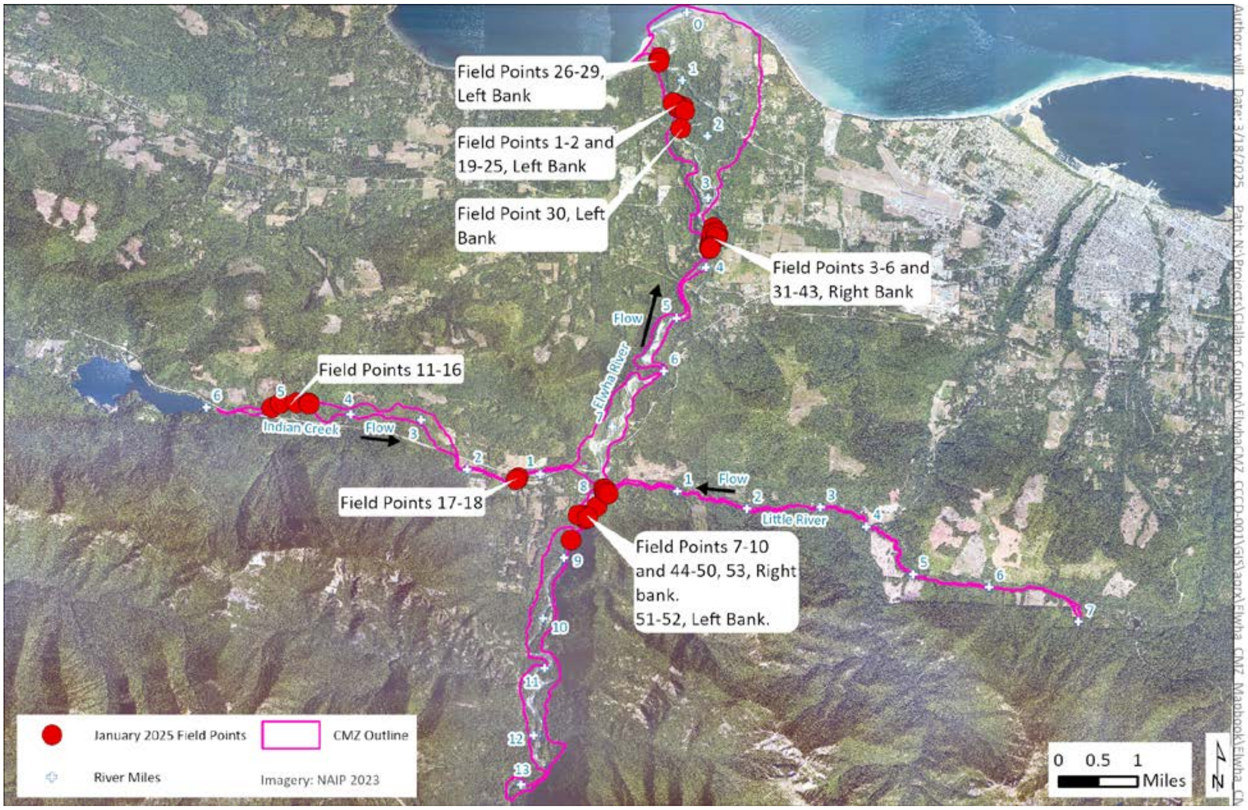
Table 3-1. Summary of data used in the CMZ delineation study.

DATASET	REASON	SOURCE
Digital elevation model	Develop topo-surface	Olympics North 2018 lidar, Elwha River 2014 lidar, hosted by WDNR. Mosaiced into a single dataset by NSD, summer 2024.
Historic digital elevation model	Comparison of current and historical (pre-dam removal) conditions	Clallam 2002 lidar, hosted by WDNR.
Historic General Land Office Maps for 1873, 1880, and 1894	Identify regions of channel migration	General Land Office, hosted by BLM
USGS topo map for 1918 and 1919	Identify regions of channel migration	USGS
Aerial imagery for 1939, 1956, 1976, 1981, and 1994	Identify regions of channel migration	USGS
Aerial imagery for 1971	Identify regions of channel migration	Clallam County
Aerial Imagery for 2002 and 2016	Identify regions of channel migration	National Park Service
Aerial imagery for 2006, 2009, 2011, 2013, 2015, 2017, 2019, 2021, 2023	Identify regions of channel migration	National Agriculture Imagery Program, hosted by USDA.
Existing hydrologic conditions	Inform hydraulic modeling	USGS Gage: Elwha River 12045500.
FEMA Flood Insurance Study (FIS) and Federal Insurance Rate Maps (FIRM)	Inform hydraulic modeling	FEMA map service center, revised study for Clallam County (2001) based on 1979 detailed analysis.
FEMA 2019 Preliminary DFIRM database	Inform hydraulic modeling	FEMA map service center
Geologic maps	Inform assessment of erosion and channel migration risks, including active landslides	1:24k Surface Geology and 1:100k Surface Geology, both hosted by WDNR
Federal levees	Inform disconnected CMZ designation	US Army Corps of Engineers
Elwha River Miles	Background mapping	USGS (NHD)
Indian Creek and Little River Miles	Background mapping	USGS (NHD) flow lines and NSD river mile point creation
Roads	Background mapping	Clallam County
Buildings	Background mapping	Microsoft online database

3.3 Field Reconnaissance

NSD staff conducted a targeted field reconnaissance with Clallam County project manager on January 10, 2025 throughout the study reaches. The purpose of the site visits was to verify mapping of components of the CMZ during the delineation process. Field activities included visual observations of channel alignment and planform, bank composition and condition, presence of secondary channels, floodplain condition, riparian vegetation, and inspection of bank hardening or armoring. Data was recorded in alignment with QAPP protocol (Appendix E). Refer to Appendix D for the full set of field photos their locations, and Attachment 3 for geodatabase.

Figure 3-1. Field reconnaissance observation point locations by NSD and Clallam County (January 10, 2025).



4. HYDRAULIC ANALYSIS

U.S. Army Corps of Engineers, Hydrologic Engineering Center software HEC-RAS (version 6.50) was used to develop a two-dimensional (2D) coarse basin-scale flood model of the study area, which includes the Elwha River, Indian Creek, and Little River. The 100-year flood was simulated under quasi-steady flow conditions using the full momentum equation set. The 2-year peak flow was modeled to help inform avulsion potential. Model results are based on the best available data, including the digital elevation model referenced in Table . Refer to Attachment 4 and 5 for hydraulic model input and output files.

The study area includes effective mapped FEMA floodplain zones (FEMA, 2001) and preliminary map updates (2019). Note that the effective flood maps were based on 1979 detailed analysis and include the influence of former Elwha and Glines Canyon dams. The 2D hydraulic model used in this CMZ delineation utilizes the best available data for post-dam removal conditions. The main purpose of the model was to approximate the contemporary floodplain extents. A detailed model calibration analysis was not performed as part of this study.

The study area was split into two model domains due to LiDAR DEM coverage. The upper model domain (2014 LiDAR) covers the Elwha River between RM 8 and 13.3. The lower model domain (2018 LiDAR) covers the Elwha River from RM 9.8 to 0.0 and includes Little River and Indian Creek. Note that hydraulic results maps blend the two output datasets at RM 8.5 where computed water surface and velocity values converge. Refer to Appendix C for hydraulic results maps.

Hydrology

The upstream boundary conditions are defined by inflows for the 100-year and 2-year events. A flood frequency analysis was performed using U.S. Army Corps of Engineers, Hydrologic Engineering Center software HEC-SSP, Bulletin 17C EMA analysis for the USGS Elwha River streamgage 12045500 (1898-2023) with Regional Skew = -0.07, Regional Skew MSE = 0.4243, based on Mastin et al. (2017). Regional regression estimates, using USGS StreamStats application, were used to derive peak flows for Indian Creek at its confluence with the Elwha River. A flood frequency analysis was performed for the Little River using the Bulletin 17C EMA analysis for the WA Department of Ecology Little River streamgage 18N050 (2003-2012), which was located near the confluence with the Elwha River. It is acknowledged that the Little River gage has a relatively short period of record and may have limited field-measured peak discharge, however a comparison with USGS StreamStats estimates yield similar peak flow estimates. Therefore, peak flows for Little River preferentially use historical data.

Modeled Elwha River inflows do not include additional tributaries or local drainages beyond Little River and Indian Creek. The Elwha River inflow at the hydraulic model boundary was scaled to its outlet by a drainage ratio from the streamgage location and subtract contributing flows from Indian Creek and Little River. Little River includes the South Branch as a discrete inflow, as scaled from the gage location. There are no modeled tributary inputs to Indian Creek.

Peak flows are adjusted for average conditions during LiDAR flights, since the model terrain includes water surface. The 2018 LiDAR flight was flown between 2/10/2018 and 2/12/2018 (1,950 cfs), and the 2014 LiDAR flight was flown between 11/7/2014 and 11/11/2014 (2,830 cfs). Inflows are developed for each of the two sets of LiDAR-based terrain, and two separate model domains (Table 4-1 and Table 4-2).

Table 4-1. Summary of 2-yr peak flow for model inflow boundary conditions.

MODEL	ELWHA R	INDIAN CR	LITTLE R	S. BRANCH LITTLE R	TOTAL
2018 Model Domain	13,398	487	248	461	14,593
2014 Model Domain	12,675	-	-	-	12,675

Table 4-2. Summary of 100-yr peak flow for model inflow boundary conditions.

MODEL	ELWHA R	INDIAN CR	LITTLE R	S. BRANCH LITTLE R	TOTAL
2018 Model Domain	43,520	1,821	1,110	1,544	47,734
2014 Model Domain	42,650	-	-	-	42,650

The downstream boundary is defined by normal depth slope in the 2014 model, while the downstream boundary in the 2018 model is defined by known water surface elevation. The water surface elevation at the Strait of Juan de Fuca for the 100-year recurrence interval event, as the Mean Higher-High Water tidal datum (10.77 feet NAVD88), was obtained from the effective FEMA FIS (2001).

Mesh

The 2D model mesh is constituted by an irregular grid of cells that vary in size. Cell width varies in the mainstem channels: the Elwha River main channel uses 30-, Indian Creek has 15-, and Little River has 10-foot-wide cells. The surrounding floodplain areas use 60-foot-wide cells with added breaklines to refine the mesh with additional detail between 5- to 60-foot-wide cells added throughout the model to capture secondary flow paths and high ground that affect reach-scale flood inundation patterns. The model computation parameters include the SWE-ELM (full momentum) equation set, Courant number between 0.5-2, with no hydraulic structures (bridges or culverts) explicitly defined.

Hydraulic Roughness

Roughness polygons were delineated using a combination of the REM and 2023 NAIP ortho imagery. Engineered logjams constructed in 2024 near US-101 (RM 7.5) as well as the Ranney Reach (RM 3.0) further downstream were included in the roughness coverage. Manning’s n-values were estimated using field observations, previous model calibration (NSD, 2022), and literature references such as Chow (1959).

Table 4-3. Manning's roughness coefficients (n-value) defined in the 2D hydraulic model based on land cover categories.

ROUGHNESS CATEGORY	MANNING'S N-VALUE
Beach Berm	0.026
Bedrock	0.020
Building	1.000
Elwha River	0.037
Elwha River - Canyon	0.050
Estuary	0.040
Forest	0.120
Gravel Bar	0.045
Indian Creek	0.045
Little River	0.035
Little River - Canyon	0.050
Little River - Headwaters	0.050
Log Jam	0.150
Manmade Channel	0.025
Pasture	0.030
Paved Road	0.015
Rip Rap	0.055
Sand	0.026
Side Channel	0.055

4.1 Hydraulic Model Results

Outputs from the coarse reach-scale 2D hydraulic flood model were used to inform CMZ delineation. The inundation extent for the 100-year discharge represents the contemporary floodplain under existing conditions, which is consistent with FEMA standards. The 100-year floodplain is an indicator of areas susceptible to fluvial erosion processes. The 2-year discharge was considered as a representative flow to identify potential avulsion pathways based on connectivity between the main and side channels, as well as low-lying overflow pathways through floodplain. Refer to Appendix C for maps of hydraulic model output within the study area.

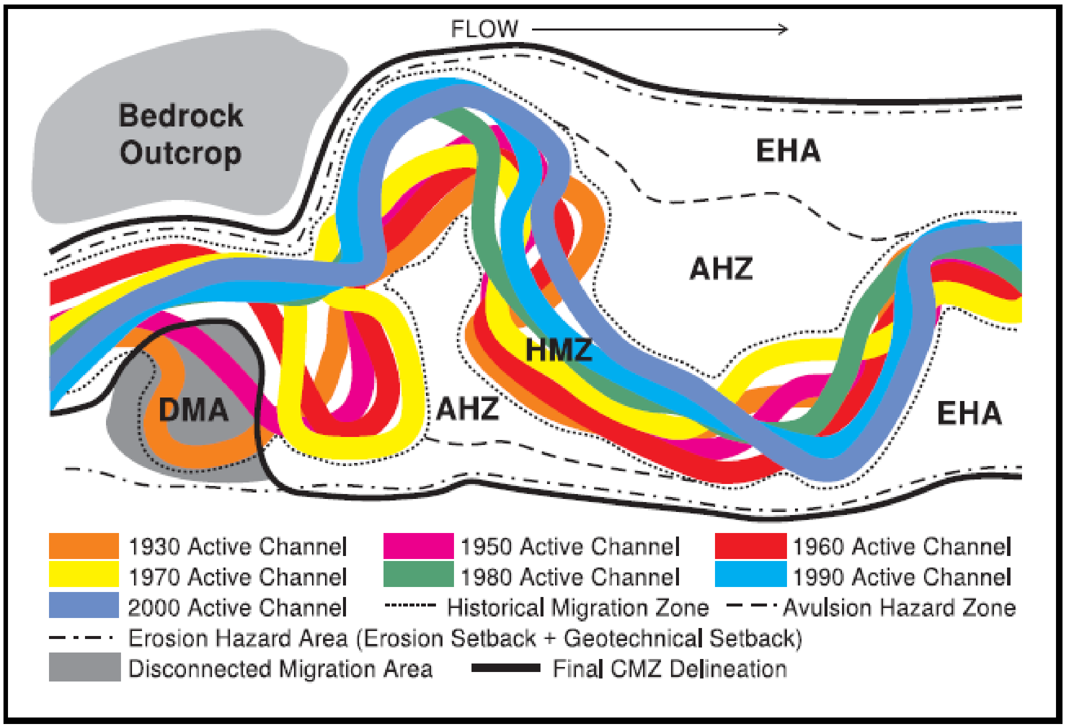
The 2D hydraulic model shows that the 100-year floodplain occupies most of the alluvial valley bottom throughout the Elwha River. The computed floodplain extents for Little River and Indian Creek follow general patterns in reach topography, where Little River is highly confined throughout, and Indian Creek has a broad floodplain north of US-101 and is confined south of US-101.

Differences in the Elwha River floodplain boundaries between the 2D model in this study and the effective FEMA 100-year floodplain are primarily expressed in former Lake Aldwell, where the 2D model output has a narrower floodplain in the former reservoirs. The effective FEMA floodplain is based on hydraulic analyses performed in 1979, which included the former reservoir and channel topography with the dams in place (FEMA, 2001). The 2D model shows expanded pockets of floodplain extents in Elwha reaches 1 and 2, compared to effective boundaries, that may be related to channel aggradation following dam removal or updated terrain data sources since 1979.

5. CHANNEL MIGRATION ZONE DELINEATION

This section describes the methods, results, and assumptions used to perform a detailed delineation of the CMZ for the study reaches in the lower Elwha River watershed. The delineation protocol follows established guidelines from Rapp and Abbe (2003) for a 100-year CMZ lifespan. Figure 5-1 depicts the detailed CMZ and its components. The outer edge of the CMZ is the jurisdictional boundary: CMZ = HMZ + AHZ + EHA – DMA

Figure 5-1. Conceptual depiction of a CMZ and its components, from Rapp and Abbe (2003).



Analyses that informed detailed CMZ delineation primarily utilized Geospatial Information Systems software, ESRI ArcPro. The horizontal spatial reference coordinate system is NAD 1983 State Plane Washington North (US Feet), and the vertical datum is NAVD88 (US Feet).

5.1 Geomorphic Reaches

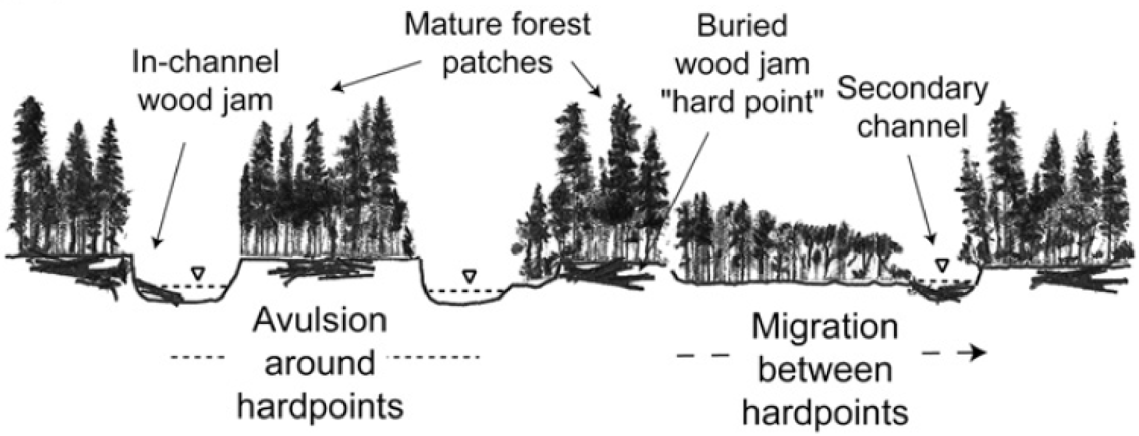
The lower Elwha River (RM 0 to 13.3) was divided into geomorphic reaches to identify distinct river segments with similar characteristics, based on valley confinement, channel gradient and planform, geomorphic controls, and anthropogenic constraints (Figure 5-3). The primary purpose of the reach delineation is to compute channel migration rates that are representative of each reach based on its unique characteristics. Table 5-1 provides metrics characterizing all 14 Elwha River reaches delineated for this study.

Reach breaks occur predominately at locations where the valley margins constrict the channel, like at the Elwha River Road, State Highway 112, and US Highway 101 crossings of the Elwha River. Other bedrock constrictions of the valley represent the reach breaks upstream of these crossings. Channel gradient in general increases in the upstream direction, however there is a more general trend of steeper reaches in the confined canyons and less steep reaches where there is a wide alluvial valley bottom. The lowest calculated slope was 0.26 percent near the river's outlet to the Strait of Juan de Fuca in Reach 1. Reach 11 is the steepest reach at 1.31 percent, the former site of the Olympic Hot Springs Road bridge. The sediment regime of the Elwha River was disturbed for over a century after installation of the Glines Canyon and Elwha dams, isolating reaches from upstream sediment supply below the dams, while burying other reaches upstream of the dams. The Elwha Dam was built in 1912 at RM 4.9 and stored about 5 million cubic meters of sediment at time of removal in 2012. The Glines Canyon Dam was built in 1927 at RM 13 and stored about 16 million cubic meters of sediment at time of removal in 2014. After removal of the dams the river has begun to rework and transport the stored sediment to the downstream reaches starved of sediment. This redistribution of sediment along the river corridor has influenced channel migration rates and initiated vertical adjustments in the channel and floodplains.

The lithology and character of the valley bottom and margins vary reach to reach and are largely responsible for reach geometry and where reach breaks occur. Holocene alluvium mantles the valley floor in the widest (1,600) reach near the river's outlet, with Pleistocene alpine glacial outwash (Olympic alluvium) forming the valley walls (WGS, 2023). As the valley margins begin to constrict, outcroppings of Tertiary sedimentary and volcanic rocks become more prevalent that limit channel migration, often mantled with mass wasting deposits. The sedimentary Hoko and Lyre Formations constrict the valley to 300 feet wide below the Little River and Indian Creek confluences, upstream of the confluences the volcanic Crescent Formation and valley spanning landslides have formed similar 200 to 300 feet wide valley constrictions that serve as reach breaks. Three valley constrictions are at or adjacent to thrust faults crossing the valley, the Lower Elwha (Elwha River Road crossing, RM 3.3), Lake Creek – Boundary Creek (Highway 101 crossing, RM 8), and Crescent (Elwha Ranger Station, RM 12) faults.

The channel planform varies as the slope and valley width change from reach to reach, with single thread channels in the confined reaches, transitioning to an anabranch planform as the valley widens and slope decreases. An outlier is the former Lake Aldwell lakebed reaches (6 and 8, Table 5-1, where the channel has a wandering planform as it exhumes the excess sediment deposited across the valley bottom. Channel migration potential in the bedrock-controlled reaches is very limited to negligible on the timescale of this study. Once the channel is flowing over alluvium, geomorphic processes will begin to dictate the channel form and geometry. Where large trees cover the alluvial valley bottom they play a role in the channel form and geometry and can elicit rapid local changes once recruited (e.g., Abbe and Montgomery 1996, 2003). Historically large trees lined the channel banks of the Elwha, and provided resistance to channel migration from root cohesion, strengthening the channel banks, as well as deflecting flow away from the eroding bank once recruited into the channel. The largest of the large trees, those the river cannot readily move, create hard points in the valley that split flow creating multiple channels, while protecting the floodplain in the lee from the migrating river to allow another generation of large trees to grow (Collins et al. 2012). Channel avulsions are more common on anabranch channels as the main stem alternates from channel to channel across the valley bottom (). Single thread channels are dominated by lateral channel migration, with avulsions occurring as new channels form cutting off meander bends, resulting in a straighter channel. If channel migration continues to the valley margin, there is a risk of oversteepening and destabilizing the slope.

Figure 5-2. Conceptual model of floodplain landforms in an anastomosing (anabranch) river, from Collins et al. (2012). Forests and logjams stabilize alluvial patches to form multiple channels that persist for hundreds of years.



Due to a lack of defining features or abrupt changes in channel or valley geometry, Little River was treated as a single reach for this study. Little River is a steep mountain river with a mean channel gradient of 4.68 percent through the study area. Local slopes range from 1.7 percent for the half mile immediately above the Olympic Hot Springs Rd bridge to 34.7 percent in the headwater bedrock gully at the upper end of the study area, immediately adjacent to Olympic National Park. However, this gully represents only 3 percent of the length of Little River within the study area. For the remainder of the stream, a maximum slope of 6.1 percent occurs in a canyon extending from RM 4 to RM 5.5. Channel planform ranges from straight, step-pool and plane bed segments in steeper (>2 percent) confined areas to meandering pool-riffle channels in the lower gradient segments. Little River is confined to a narrow canyon by outcrops of basalt bedrock on either side upstream of RM 1.1. The valley bottom within the study area ranges in width from 70 feet in bedrock canyon areas to more than 600 feet in the lower reaches, where landslide deposits and alluvium mantle the valley bottom. Recent landslides (last 30 years) have occurred at several locations along the steep slopes within the study reach, initiating in older mass wasting material, glacial deposits, and parent bedrock. Since 2009, the right bank of the Elwha at the confluence with Little River has migrated eastward by over 100 feet, effectively reducing the overall length of Little River by eroding into its alluvial delta. Since removal of the Elwha Dam in 2012, the Elwha River has also incised through bed material deposited at the upstream end of Lake Aldwell by 8 to 10 feet, which in turn increased gradient in lower Little River through an ongoing episode of incision as a response to headcut propagation (NSD, 2016). The historic Little River delta extends approximately 0.2 RM upstream of the Elwha River confluence with a complex of relic distributary channels on the left floodplain surface.

Similar to Little River, Indian Creek was assessed as a single reach, though it is a very different valley. Indian Creek originates from the outlet of Lake Sutherland. The basin is dominated by sedimentary and volcanic rocks overlain by Quaternary deposits, including several landslides and alluvial fans mapped on valley margins (Brown et al., 1960). From RM 6 to 4.3, Indian Creek meanders along the northern margin of the valley at an approximate slope of 1.1 percent. Within its alluvial valley bottom (300 to 900 feet wide), there are multiple active channels that flow through vegetated islands and beaver dam complexes. Flow is metered by the outlet of Lake Sutherland which is presumed to attenuate peak flows to some degree. From RM 4.3 to 2.2, Indian Creek has a reduced slope of approximately 0.25 percent.

Downstream of US-101 at RM 2.2, the active channel corridor narrows to approximately 100 feet with a single-threaded channel. Indian Creek steepens to 2.8 percent due to an apparent knickpoint (Bountry et al., 2018) and continues through its confined valley to the historic delta (RM 0.5) with plane-bed and forced pool-riffle morphologies. Indian Creek is influenced by the removal of Aldwell Dam, with similar effects to Little River with channel incision and steepening of the reach to the outlet.

Figure 5-3. Vicinity map of the study area, as outlined in pink. Mapped Elwha River geomorphic reaches are divided by dashed black lines.

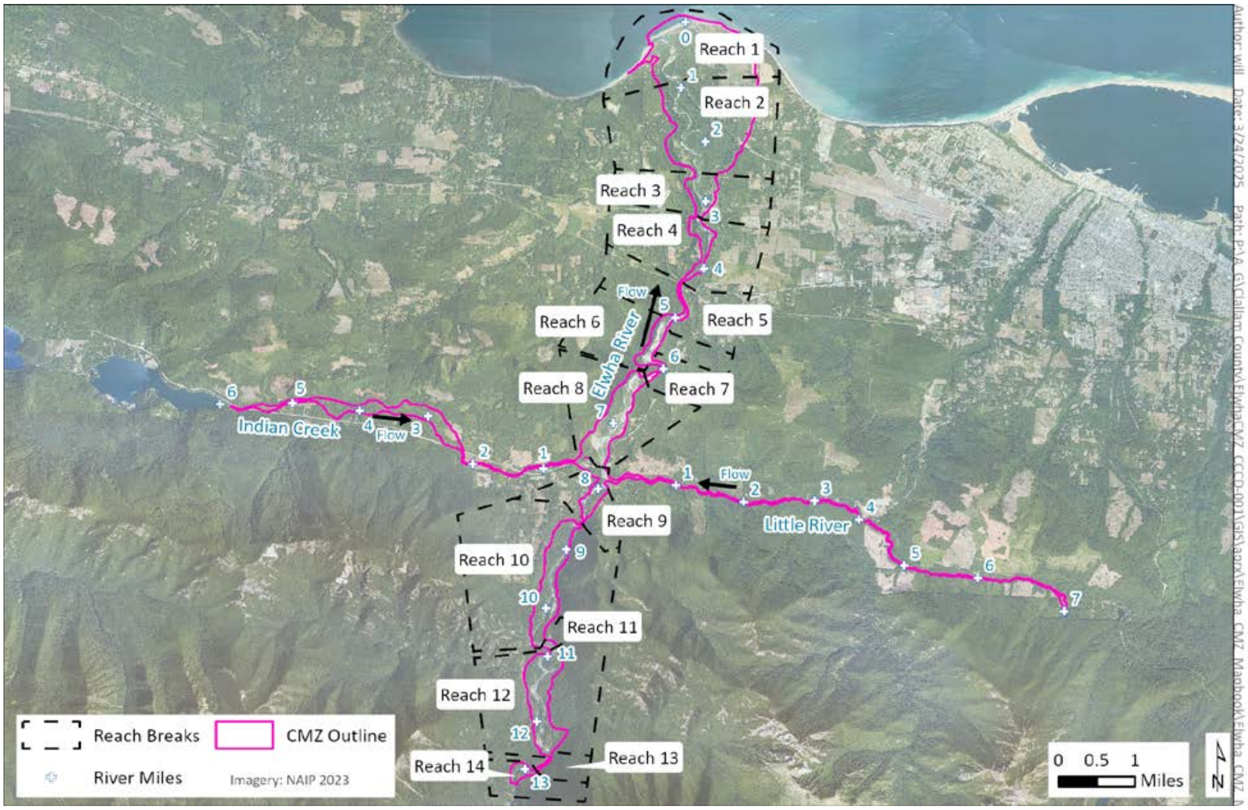


Table 5-1. Description of geomorphic reaches delineated in the Elwha River study area.

REACH	DESCRIPTION	RM	AVG CHANNEL GRADIENT (FT/FT)*	AVG VALLEY BOTTOM WIDTH (FT)**	COMMENTS
1	Outlet to Fox Pt. Bluff	0.0 - 0.9	0.0026	6,200	Elwha River delta and outlet at Strait of Juan de Fuca, USACE levee on right floodplain, Place Rd levee on left bank, limit of tidal influence.
2	Fox Pt. Bluff to Sisson Rd.	0.9 - 2.6	0.0035	4,500	Hunt Rd side channel, USACE levee on right floodplain.
3	Sisson Rd. to Elwha River Rd Bridge	2.6 - 3.3	0.0036	1,600	Anabranch planform, City EWTP and municipal water intake.
4	Elwha River Rd Bridge to former Aldwell Dam	3.3 - 4.4	0.0042	900	Single-thread channel, constructed riffle and City industrial surface water intake.
5	Aldwell Dam Canyon	4.4 - 5.2	0.0082	300	Former Aldwell Dam site, bedrock canyon.
6	Former North Aldwell Reservoir	5.2 - 5.8	0.0038	800	Lower reservoir reach, anabranch planform.
7	Aldwell Reservoir Canyon	5.8 - 6.3	0.0027	300	Bedrock canyon
8	Former South Aldwell Reservoir	6.3 - 7.8	0.0057	1,400	Upper reservoir reach downstream of US-101, broad alluvial valley, Indian Creek delta on left bank.
9	MacDonald Streamgage to US-101	7.8 - 8.6	0.0047	900	Single-threaded channel, active side channel downstream of spur dike on right bank, Little River delta on right bank.
10	ONP entrance	8.6 - 10.8	0.0072	1,400	Broad alluvial valley, anabranch planform with relatively smaller secondary channels, County road on right edge of valley.
11	Olympic Hot Springs Rd washout meander	10.8 - 10.9	0.0131	500	Tortuous meander bend, former location of Olympic Hot Springs Rd bridge.
12	ONP Ranger Station	10.9 - 12.6	0.0078	1,400	Broad alluvial valley, anabranch planform with relatively smaller secondary channels, active landslide on left and right hillslopes
13	Altair Canyon	12.6 - 12.9	0.0058	200	Canyon segment with bedrock on right valley wall.
14	DS of former Glines Canyon Dam	12.9 - 13.3	0.0111	900	Wide single-threaded channel along meander bend, mapped landslides on left and right valley margins.

*Channel gradient is approximated from LiDAR DEM's, which include water surface elevation returns.
**Average valley bottom width is measured from LiDAR DEM at approximately 20 feet above the main channel water surface.

5.2 CMZ Delineation Methods

CMZ delineation follows the GIS-based mapping approach outlined in the Rapp and Abbe (2003) protocol. The delineation took an iterative approach, beginning with historical imagery analysis to identify the historical migration zone (HMZ). Building upon this, the avulsion hazard zone (AHZ) was identified using a combination of hydraulic modeling results and evaluation of a relative elevation model (REM) (Figure 5-4). A REM is a digital elevation model that expresses elevation relative to the water surface (expressed as 0-ft elevation), providing the elevation of floodplain features relative to the channel elevation. The erosion hazard area (EHA) extends beyond the HMZ and AHZ, representing the area of potential erosion during the 100-year lifespan of the CMZ. For the Elwha River, valley bottom erosion rates were calculated using historical channel alignments, and bluff erosion rates were established by directly measuring bank loss at known bluff erosion sites, using historical imagery and sequential LiDAR elevation models. These erosion rates were combined and used to calculate the EHA. In areas where the EHA shows erosion into high banks or bluffs, a geotechnical setback (GS) was defined which represents the limit of instability caused by unstable eroded banks adjusting to their angle of repose (39 degrees). The angle of repose was taken from nearby slopes, lacking measurable historic erosion.

Geologic features previously mapped by the Washington Geologic Survey such as bedrock outcrops and landslides were referenced throughout the CMZ mapping process (WGS, 2023). Where bedrock outcrops occur, no GS was mapped. Where the CMZ borders or extends into mapped landslides, the landslide areas may be thought of as a continuation of hazard areas outside the scope of the CMZ.

Figure 5-4. An example of the relative elevation model (REM) along the lower Elwha River based on height above water surface, in feet. Refer to Appendix B for the complete set of REM maps of the study area.

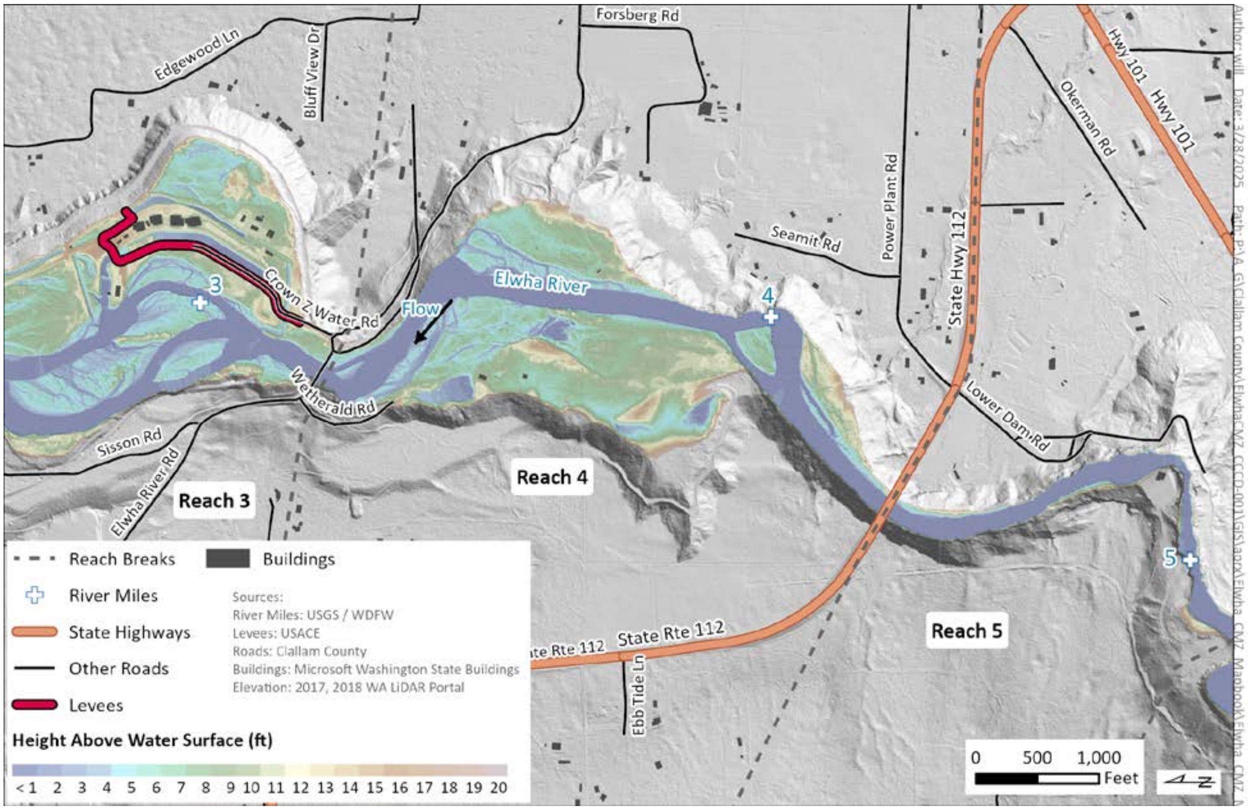


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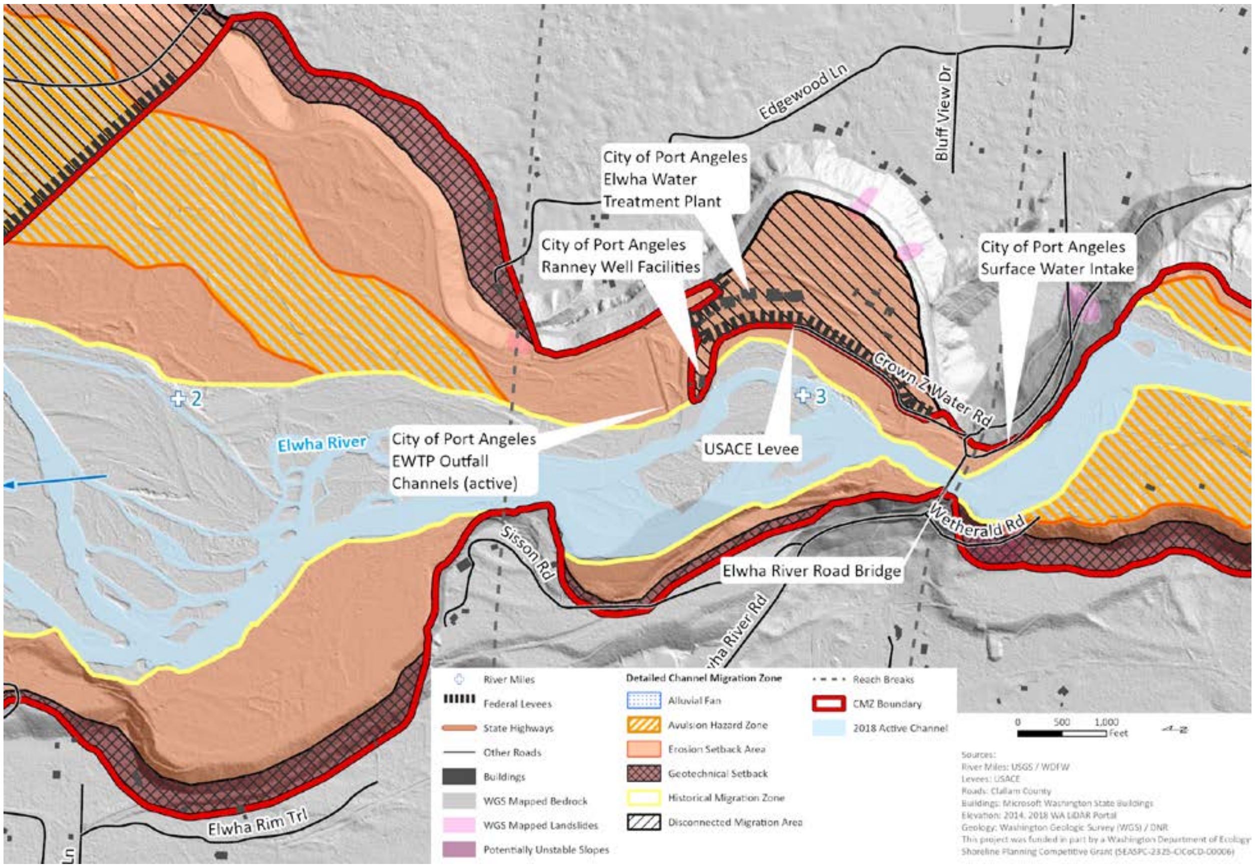
Figure 5-5. An example of CMZ mapping along the lower Elwha River. Bedrock and landslides were mapped by the Washington Geological Survey, updated in 2023. Refer to Appendix A for the complete set of CMZ delineation maps.



Mapping Refinement Summary

Following initial mapping efforts, topographic data and hydraulic analysis results were used selectively to further refine mapped elements. During and after the CMZ drafting process, multiple public meetings were held to conduct outreach and solicit local stakeholder input, which was then used to further inform and adjust the position of the CMZ map elements. These meetings were co-managed by Clallam County Department of Community Development and NSD (Section 6).

A field reconnaissance effort occurred on January 10, 2025 to investigate representative areas throughout each stream (Section 3.3). Geology , presence of bedrock, and evidence of hydraulic connectivity to assess avulsion potential were all used as indicators for field verification. Adjustments in the mapping were then made after field efforts.

Under Washington State ECY Minimum Standards of Practice (Washington Department of Ecology, 2025), the Elwha River would likely be within the level of detail of 5 to 6. The CMZ delineation methods outlined in this study are consistent with both Rapp and Abbe (2003) and the ECY Minimum Standards of Practice.

Historical Migration Zone (HMZ)

Rapp and Abbe (2003) define the Historical Migration Zone (HMZ) as the area the channel has occupied over the course of the historical record (to earliest available map or aerial photograph); it is delineated by the outermost extent of channel locations plotted over that time.

Delineation Approach

To delineate the HMZ, the active channel alignment was manually digitized across a series of historical aerial imagery (Table 3-1). The unvegetated width was used to identify active channels in spatially referenced, historical aerial images. Secondary channels were included if unvegetated segments were visible in aerial imagery. These channel alignments were then merged (with holes representing islands removed) to develop the HMZ.

Mapping of active channels was informed by the best-available LiDAR data, particularly for secondary or side channels for areas with a high density of forest canopy. Historical survey plats and topographic maps were additional data sources to verify the presence of historically active channels. Finally, active channels were verified by observations from field reconnaissance.

For each image or map dataset used in the analysis, a channel polygon was delineated for the active channel(s) for the corresponding year. The total area is calculated for each year of channel polygon. The final HMZ is defined by the outermost left and right edges of the entire set of channel polygons.

Considerations

The lower Elwha River is characterized predominantly by an anabranch planform, which distinctly has multiple active channels that weave in and around vegetated islands on the valley floor. Vegetated islands surrounded by active channels are considered part of the active channel corridor.

Little River has a more confined stream corridor compared to the Elwha River and with a largely forested floodplain. Active channel areas are not visible in historical imagery, so the HMZ was delineated primarily based on the REM. Field observations were used to inform active channel margins from representative elevation contours in the LiDAR.

Indian Creek is buffered by a forested floodplain with dense canopy cover, so active channels are not visible in historical imagery. Unlike Little River, the REM of Indian Creek often does not show distinct channel depressions due to the nature of the shallow channel mosaics in the area. Therefore, the Indian Creek HMZ was digitized based on a combination of the most active channel alignment (where visible in modern aerial imagery) and the REM. Delineations were then refined based on field observations.

Avulsion Hazard Zone (AHZ)

Rapp and Abbe (2003) defines the Avulsion Hazard Zone (AHZ) as the areas of the river landscape, such as secondary channels, relic channels, and swales, that are at risk of channel occupation outside of the HMZ. For anabranch planforms, avulsions typically occur rapidly during a high-flow event when the main channel redirects course through a secondary channel, or forms a new channel through an erodible floodplain surface.

The most common mechanism of avulsion expected in the lower Elwha River is an island forming type, described by a sudden redirection of the main channel around an obstruction in which multiple channels create a mid-channel bar (Legg and Olson, 2014). Stable “hard points” in the valley bottom, such as logjams, help sustain multiple channels. In the Elwha River, island forming avulsions can occur at the reach scale and can persist for decades. Examples in the study area include Olympic Hot Springs Rd in the ONP and the Hunt Rd side channel.

Delineation Approach

Some criteria for potential avulsion pathways include channel features that have apparent upstream and downstream connections to the mainstem channel and pathways that would shorten the total channel length. These preferential flow paths were primarily identified using LiDAR, and field verified where possible. Hydraulic model results were used to inform connectivity of flow paths to the mainstem channel and their potential ability to capture the majority of flow. The AHZ was mapped by applying a representative width of the unvegetated contemporary active channel corridor, or meander belt width, to the identified avulsion pathway which typically follows the lowest elevation contour through the floodplain surface. High ground between the edge of the mapped AHZ and the HMZ was included in the AHZ. A combination of LiDAR, hydraulic model results, and field observations were used to inform mapped AHZ extents.

Considerations

Variables that influence channel avulsions in anabranch planforms include the potential range of vertical bed instability, erodibility of streambanks or floodplain surfaces, vegetation, and the influence of large wood. Considering the restored connectivity of sediment and large woody debris transport from the upper basin following dam removal, floodplain surfaces up to 2 meters above the main channel bed could be susceptible to avulsion in the Elwha River due to aggradation associated with logjam formation (Abbe and Montgomery, 2003).

Little River avulsion pathways were detected by channel features visible in the LiDAR DEM, REM, and hydraulic model results.

Indian Creek avulsion pathways were primarily detected by the computed 2-year inundation extent from the hydraulic model since prominent channel features are often too shallow to be captured definitively by the LiDAR DEM and REM.

Erosion Hazard Area (EHA)

Rapp and Abbe (2003) define the EHA as the area outside of the HMZ and AHZ which may be susceptible to bank erosion from (1) stream flow and/or (2) mass wasting that has been initiated by current fluvial processes and/or may be initiated in the future. Bank erosion is often a result of flow recruiting sediment directly from stream banks, but failure of steep or high terraces can also occur when flow undermines the slope toe, which does not require inundation of the terrace surface.

Delineation Approach

The EHA is composed of two main components: erosion setback (ES) and geotechnical setback (GS). The ES is the area that is susceptible to erosion, based on the rates of erosion that will occur over the 100-year design life of the CMZ. The ES is the area covering the erosion rate multiplied by 100 years that is applied to the outermost edge of the HMZ or AHZ. This approach accounts for erosion risk independent of the current channel position, which is especially important when considering the Elwha River can unpredictably shift locations.

Erosion rates in the valley bottom were determined by differencing the active channel area (square feet) between the start and end years of image dates and dividing by the length of reach (feet) along the valley centerline. The result is an average length (feet) of lateral erosion within a reach over the period of record. Erosion rates were then annualized for the period of analysis, which is 84 years (1939 to 2023) for the Elwha River, and extrapolated to cover the predicted erosion over the 100-year CMZ lifespan. The ES accounts for the proportion of time where fluvial processes erode the valley bottom versus eroding into the valley wall (hillslope) over the 100-year CMZ lifespan. Table 5-2 provides a summary of annualized valley bottom erosion rates for the Elwha River.

A separate rate for bluff erosion (3 feet/year) was estimated using the transect method (Rapp and Abbe, 2003) at Fox Point Bluff (reaches 1 and 2) for the period between 1919 and 2023, with erosion becoming more obvious in the 1956 imagery dataset. A second rate for bluff erosion (1.1 feet/year) was estimated using the transect method (Rapp and Abbe, 2003) at an actively eroding bluff at approximately RM 2.9, along the left bank (reaches 3 and 4). Erosion at this bluff was measured by differencing LiDAR datasets acquired in 2002 and 2018 and also informed by imagery acquired throughout that period. Measured bluff erosion rates are only valid for reaches 1 to 4, where similar lithology, bluff height, vegetation, and channel morphology characteristics apply.

The GS accounts for mass wasting that may occur at the ES boundary as the hillslope works to achieve a more stable configuration (Rapp and Abbe, 2003). The GS is projected outward from the boundary of the ES, and predicted using the height of the embankment, *H*, estimated stable slope, S_h, from the relationship:

$$\frac{\tan(90 - S_h)}{H} = GS$$

Estimating S_h considered embankment characteristics such as lithology, height, vegetation cover, and location in the watershed for identifying analog stable slope sites. The GS was not estimated where slopes have mapped bedrock lithology units or existing landslide hazard areas (WGS 2023).

Note that areas west of Place Rd. levee, including the coastal bluffs, did not incorporate detailed mapping of the EHA or AHZ as these areas are influenced by coastal erosion processes in addition to that of the Elwha River, which was outside the scope of this CMZ delineation.

Considerations

The 1939-2023 average erosion rates were used to determine the valley bottom ES in the Elwha River, which compare well with a previous study of the lower Elwha River that computed 6.6 to 8.5 feet/year between 1939 and 2006 using the transect method (Draut, 2008). For comparison, maximum erosion rates over the 84-year historical imagery record are shown with post-dam removal rates (2014 to 2023). Refer to Table for computed erosion rates. Maximum rates were also computed for comparison purposes using the transect method at the location of maximum change within a reach. The average rate for the post-dam removal period used area-change method from 2014 to 2023. Older topography maps date back to 1873 but were not considered to have a spatial resolution adequate to inform erosion rates.

Table 5-2. Annualized valley bottom erosion rates (feet per year) by reach for the average over the entire period of record, post-dam removal, and the maximum rate over the entire period of record.

REACH	1939-2023 AVG (FT/YR)	1939-2023 MAX (FT/YR)	2014-2023 AVG (FT/YR)
1	9.7	13.7	18.2
2	9.6	15.1	5.4
3	3.3	6.4	8.7
4	0.9	3.4	0.4
5*	0.0	0.3	0.1
6	0.0	0.0	11.0
7*	0.0	0.0	0.3
8	0.5	0.0	36.7
9	1.4	3.1	7.5
10	1.4	4.4	4.1
11*	0.4	1.1	0.1
12	4.7	6.2	21.3
13*	0.1	0.9	0.0
14	1.0	1.9	3.4

Note *: reach located within confined bedrock canyon.

Dam removal in the early to mid-2010s resulted in a sudden influx of sediment into the lower Elwha River that had been stored in the reservoirs: approximately 5 million cubic meters stored in Lake Aldwell (Elwha Dam) and 16 million cubic meters stored in Lake Mills (Glines Canyon Dam). In most reaches this has resulted in much higher average erosion rates since dam removal than the overall historical period average (Table 5-2). The recent elevated erosion rates (both max rates and post-dam removal) represent a short-term response from dam removal where rapid adjustment of the channel bed occurred. The average calculated erosion rates over the historical period represent a probable erosion projection over the lifespan of the CMZ. While the average erosion rates incorporate past avulsions into the calculation, the CMZ delineates avulsion hazard area separately, which provides a conservative buffer considering the possibility of ongoing instability as the Elwha River continues to adjust from dam removal.

Calculated erosion rates within the former Lake Aldwell Reservoir are relatively high for the post-dam removal period compared to neighboring reach, which matches observations and the expected trend given the exposure of highly erodible material to unregulated flow of the Elwha River. Extrapolating the available post-dam removal rates would lead to an improbable ES into mountainous upland areas.

Bluff or hillslope erosion rates were not quantified upstream of Reach 4 on the Elwha River due to a lack of supporting evidence in the topographic and imagery datasets. Where the EHA or AHZ projects into an erodible valley hillslope, mapped extents active landslides (WGS, 2023) should be considered as a setback for erosion risk beyond the delineated CMZ.

Change in active channel position was not detectable on Little River or Indian Creek due to dense canopy cover in the historical aerial imagery. The EHA was based on the modeled 100-year inundation extents for both tributaries and supported by field observations. In both tributaries, for areas where no EHA was delineated and there was no mapped bedrock present, a 10-foot EHA buffer was applied to account for local erosion that could occur from bank recruited treefall. Ten feet was selected as the buffer width as it represents the maximum rootwad diameter of such an expected tree and therefore is approximately the width of expected localized erosion in these areas.

Alluvial Fans

Alluvial fans occur where steep, confined channels emerge into unconfined, low-gradient channels, or broad flat areas (Rapp and Abbe, 2003). Alluvial fans have distinct arcuate, or cone- or fan-shaped, landforms that have formed by repeated episodes of channel aggradation and abandonment to seek lower grade. As such, alluvial fans are composed of highly erodible bed material and are prone to sudden change from the tributary itself or erosion due to its adjoining stream.

Delineation Approach

Unless the channel is no longer active within the hydrologic, climatic, and tectonic regime, the CMZ encompasses the entire area of the alluvial fan (Rapp and Abbe, 2003). Alluvial fans are mapped from their apex and around the base to the junction where the tributary enters the valley. Note that Indian Creek and Little River have alluvial fans at their respective outlet.

Disconnected Migration Areas (DMA)

Rapp and Abbe (2003) define disconnected migration areas (DMA) as areas of the CMZ with federally certified structures (such as highways or levees) that prevent channel migration. DMAs are located within an area of erosion risk (historical, active, or projected future conditions) mapped by the CMZ, but protected behind a certified structure that prevents channel migration during large flood events and are thus excluded from the final CMZ boundary.

Only structures that constitute a legitimate barrier to channel migration were used to delineate DMAs. Legitimate barriers are human-made structures that resist erosion and channel migration, while requiring a public commitment to keep them intact, such as certified Federal levees and State Highways. Legitimate structures require commitments for long-term maintenance to fulfill their critical need to the public. Examples of human-made structures not deemed legitimate barriers to channel migration include riprap bank armoring, push-up or sugar dikes, or non-State highways that could fail under a large flood event and would not necessarily be replaced or repaired after a failure event and do not have long-term maintenance plans.

Other human-made structures or shoreline modifications, as legally existing artificial channel constraints, that prevent channel movement may qualify for a DMA if there is a public commitment to keep them intact beyond the 100-year lifespan of the CMZ. Examples in the Elwha River watershed include the City of Port Angeles Ranney Well Facilities.

Delineation Approach

The CMZ is delineated prior to mapping any DMAs. After legitimate structures were identified, the associated disconnected floodplain areas are superimposed on the CMZ. This can occur anywhere flow is potentially obstructed by a legitimate structure, regardless of the direction of flow relative to the structure. For example, where a certified levee is perpendicular to flow, floodplain surfaces behind the levee may be in the DMA. Another example is that when a creek crosses a legitimate structure (such as the US-101 Indian Creek crossing), floodplain areas downstream of the structure that may be obstructed by upstream flow may be in the DMA. The hatched area mapped as DMA represents protected development or human encroachment within the CMZ. The final CMZ does not include the DMA. Delineation of the DMA simply indicates those areas would be in the CMZ if not for a Federal levee or state highway.

5.3 Discussion

This section describes the CMZ delineation results by respective river and/or reach. Refer to Appendix A for the complete set of detailed CMZ maps.

5.3.1 Elwha River

Reach 1 to 2 (RM 0 to 2.6)

The valley bottom is approximately 1,500 feet wide at the upstream extent of reach 2 and widens to 6,000 feet at the Strait of Juan de Fuca. The average slope gradually flattens from 0.0035 to 0.0026 (feet/feet). The HMZ encompasses roughly half the valley bottom in these reach segments. Evidence in the LiDAR, through relic channel scars and meander bends in the valley margins, indicates that the Elwha River has historically occupied its entire valley bottom. The HMZ encompasses all floodplain areas between historic active channel positions, such as the Hunt Rd side channel avulsion (Reach 2), and incorporates this total area into the reach averaged erosion rates. A major avulsion pathway was mapped along the right floodplain through the Lower Elwha Klallam Tribe Reservation. The Federal levee prevents flooding and erosion east of its position, so the AHZ and EHA are within a DMA.

Fox Point bluff is a notable location of active erosion. The erosion rate based on measurements from aerial imagery is approximately 3 feet/year from 1919 (topographic map) to 2023. Anecdotal accounts collected during the field reconnaissance suggest rates up to 10 feet/year, which may be biased towards the episodes of mass wasting of the bluff in recent years. Geotechnical setbacks are mapped in the areas where erosion is predicted within the 100-year CMZ lifespan. Average bluff heights range between 100 to 140 feet with an approximate angle of repose of 39 degrees.

Place Road levee extends approximately 1,000 feet from the northern terminus of Fox Point bluff that separates a historic distributary channel from the active floodplain on the left bank. Since it is not certified, the low-lying terrain west of Place Rd levee is mapped as HMZ. The remaining beach or coastal bluffs are not included in the CMZ delineation.

Reach 3 to 4 (RM 2.6 to 4.4)

The alluvial valley in reach 3 ranges from 1,500 to 2,000 feet wide, where the Elwha River valley transitions to the delta. There are currently three active channels. A Federally certified levee on the right bank of the eastern channel, Ranney Reach, protects City-owned infrastructure (EWTP) from flooding and erosion. CMZ areas landward of the Ranney levee are mapped as DMA. The Ranney well facility is located within a mapped EHA. The well laterals extend into the Ranney Reach channel approximately 40 feet below the existing bed (Hunt, 2013), which are also within the regulatory FEMA special flood hazard area and floodway (FEMA, 2001). Though this bank is armored with riprap, it is assumed that the Ranney well facilities have a public commitment to maintain operation at its current location as the primary source of municipal water intake for the City of Port Angeles and is mapped as a DMA. The EHA designation indicates that the well facility is in an area of high erosion risk.

The valley wall on the left bank includes mapped bedrock units. However, westward channel migration is measured within the bedrock extents through both aerial images and LiDAR DEM. Previous field observations confirm unstable hillslopes along the left bank of the western channel but do indicate an erosion resistant lithology (marine sedimentary rock).

Reach 4 is characterized by a single-threaded channel with a relatively straight alignment and plane-bed channel. Immediately upstream of the Elwha River Rd bridge is the City-operated industrial surface water intake, which includes a constructed riffle. This reach has shown relatively little channel migration over the period of available imagery, likely due to the combination of being immediately downstream of the former Elwha Dam and stabilization of the channel from the constructed riffle. As a result, computed erosion rates are relatively low so portions of the alluvial valley are not included in the CMZ. Anecdotal accounts gathered from the field reconnaissance indicate that the Elwha River has aggraded in this reach since dam removal.

Reach 5 to 8 (RM 4.4 to 7.8)

The former Elwha Dam is located in the middle of reach 5. This bedrock canyon reach was separated from adjacent reaches to reduce bias of little to no lateral channel migration on computed erosion rates. The same was done for reach 7 as another bedrock canyon that is located between the former upper and lower Lake Aldwell reservoir reaches.

Reach 6 bounds the former North Aldwell Reservoir. The HMZ includes the boundaries of active channel positions between 2011 and 2023. The EHA is taken as the boundary of the reservoir pool where highly erodible lakebed deposits are found. There is no AHZ mapped in reach 6 since erosion is expected to occur by lateral migration through reservoir deposits. The North Aldwell Reservoir has a mapped CMZ width ranging between 600 to 900 feet wide. At the upstream extent of reach 6 on the left bank is a forested terrace that sits within the former reservoir pool footprint and at the base of a mapped landslide, assumed within the EHA. The valley walls are otherwise mapped as bedrock.

Reach 8 includes the former South Aldwell Reservoir up to US-101. The alluvial valley bottom expands from approximately 1,100 feet wide at the downstream extent to 1,700 feet wide near Indian Creek. Similar to reach 6, the HMZ includes the boundaries of active channel positions between 2011 and 2023 and the EHA is taken as the boundary of the reservoir pool. Terraces formed by remnant reservoir deposits are vegetated but have been eroding at elevated rates following dam removal (Table 5-2). The western terrace in reach 8 has maximum widths of 600 to 1,000 feet, and heights of 20 to 30 feet above the 2023 channel bed. It is highly unlikely that erosion of the western terrace would occur through avulsion given its height. Therefore, it is mapped as EHA. The Indian Creek delta is located on the southern portion of the remnant reservoir deposit terrace and has numerous channels that the outlet could avulse through and is thus mapped as AHZ. Reach 8 is bounded by bedrock on the right valley wall where reservoir deposits have largely been eroded already. The left valley wall is nearly all mapped with active landslides (WGS, 2023).

Reach 9 (RM 7.8 to 8.6)

The Elwha River expands downstream from the valley constriction, at the Elwha River USGS streamgage at MacDonald Bridge, and abruptly turns northwest towards the left bank. A ~400-foot-long spur dike on the right bank extends from Olympic Hot Springs Rd and has limited the Elwha River from migrating towards the right side of the valley. An active side channel begins at the waterward edge of the spur dike and flows parallel with Olympic Hot Springs Rd. The area between the side channel and the left valley margin are mapped as HMZ. The spur dike has likely reduced erosion on the right bank but is not certified. Therefore, the dike is included within the CMZ.

The EHA buffers the HMZ according to average erosion rates in reach 9 which includes a portion of Olympic Hot Springs Rd. Exposed bedrock was identified in the field along the right bank, downstream of RM 8 towards the outlet of Little River, which prevents lateral migration. At the downstream end of reach 9 on the left bank mapped EHA is within the apparent historical alluvial fan of Indian Creek. A portion of the fan area is mapped as DMA due to the presence of US-101.

Reach 10 to 11 (RM 8.6 to 10.9)

The Elwha River in reach 10 is bounded by valley constrictions at its upstream and downstream limits. The 2023 channel is primarily single-threaded but has numerous secondary channels on the left floodplain surface. The main channel in 2023 is positioned along the right valley margin along Olympic Hot Springs Rd. There are two AHZ units within reach 10; one through the ONP mule paddock and pasture area near RM 10 and the second on the left floodplain surface near RM 9. Both AHZ units are within the 2 m margin of vertical bed instability and have relic channel features expressed in the topography. The EHA includes most of the Olympic Hot Springs Rd within the ONP boundary.

Reach 11 encompasses the meander bend at the location of the Olympic Hot Springs Rd washout (avulsion). The CMZ spans the width of this confined valley segment.

Reach 12 (RM 10.9 to 12.5)

The Elwha River in reach 12 has the steepest gradient of all segments not within a canyon (0.0072 feet/feet). The mapped CMZ generally ranges between 1,200 to 1,500 feet wide between RM 12.5 and 11.5. In its downstream portion below RM 11.5, the CMZ widens to ~2,000 feet wide, which includes the Olympic Hot Springs Rd washout and channel avulsion. Two AHZ units are mapped in the right floodplain that include additional Olympic Hot Springs Rd sections and the historic ranger station. Several large landslide units are mapped along the valley walls which could be activated if the main channel erodes into the toe of the hillslope.

Reach 13 to 14 (RM 12.5 to 13.3)

Reach 13 is a confined segment bounded by bedrock on the right valley wall and mapped landslide on the left. The CMZ in this reach is mapped entirely as HMZ.

Reach 14 is located immediately downstream of the former Glines Canyon dam. The CMZ has a maximum width of ~1,000 feet measured at the apex of the meander bend. An AHZ is mapped in the point bar on the right bank. Both left and right valley hillslopes are mapped as landslide units.

5.3.2 Little River

Little River differs from the Elwha in that its channel is largely confined within a narrow valley or bedrock canyon. There is relatively little space in the valley bottom for Little River to significantly change its horizontal position, though sections of Little River Rd are at risk where the road is runs adjacent to the active stream corridor. The Little River delta is mapped as HMZ, bounded by the 2023 main channel position along the right valley margin and left edge of a distributary channel and former outlet location. There is no EHA where bedrock is presumed to border the right bank of the Elwha River (downstream of RM 8).

Upstream of the Olympic Hot Springs Rd bridge to RM 1 includes the widest segments of alluvial valley in lower Little River, at approximately 300 feet. The EHA is guided by hydraulic model results under the 100-year recurrence interval flow, which includes portions of Little River Rd on the right bank. At the upstream extent of Little River, near RM 7, at the foothills is a low-gradient channel complex that has a wider CMZ boundary due to broader inundation at the 100-year event. Several bedrock canyon segments confine Little River near RM 1, 3, 5, and 6. No GS were mapped in the CMZ, though numerous landslide units are mapped within the study area that could be activated due to undermining from Little River.

5.3.3 Indian Creek

Indian Creek has a broad, flat, and densely vegetated alluvial valley bottom upstream of Highway US-101 and lacks the competency for significant bank erosion upstream of RM 2.2 based on field reconnaissance. The HMZ is based on low-lying terrain in the LiDAR and guided by 2-year inundation extents from the hydraulic model results. Near RM 5, an alluvial fan on the southern valley margin has confined the valley bottom and Indian Creek active channel corridor. This feature was not mapped in the CMZ, since the risk of erosion is considered low given the relatively flat channel gradient and metered flow from Lake Sutherland. The AHZ is guided by modeled 100-year inundation extents. An apparent human-constructed pond/pit near RM 3 on the left bank falls within the AHZ and is therefore included in the CMZ.

Downstream of RM 1.6 at US-101, Indian Creek and transitions to a steeper and more confined reach downstream to the Elwha River – the CMZ is primarily composed of the HMZ from this point to RM 0.5. The historic delta is mapped as an alluvial fan, which is bisected by US-101 as a DMA. The 2023 outlet channel is mapped as HMZ. A portion of the left bank Elwha floodplain is mapped as AHZ since Indian Creek could avulse in a multitude of potential directions through the terrace formed by remnant reservoir deposits. Note that this area is also prone to lateral migration of the Elwha River.

6. COMMUNITY OUTREACH AND CO-MANAGER ENGAGEMENT

NSD supported County-led initiatives for robust outreach to public landowners, co-managers, and stakeholders within the study area on the goals and objectives, technical methods, and results of the detailed CMZ delineation. The goal of the outreach campaign was to inform the public about existing and future risks associated with flooding and erosion in the lower Elwha River watershed, with the objective to share progress updates of the project. The primary components in the outreach campaign included:

- Website hosted by Clallam County with project information, regular updates and optional sign-up for an email listserv,
- Postcard mailers to private landowners in the study area vicinity,
- Community questionnaire sent with options for online or paper format,
- Meetings and presentations hosted by Clallam County with informational poster displays.

Community Outreach

Mailers were sent on 10/14/2024 to 128 landowners identified as bordering the Elwha River, Little River, or Indian Creek shoreline within the study area vicinity to inform the public about the project goals and objectives, to distribute the landowner questionnaire and notify people about the public meeting. Flyers were posted on the County website, Laird's corner store, and at other public locations where County notices were posted.

The questionnaire gathered input on past experiences with flooding and erosion, and to solicit questions about the CMZ delineation process. Questionnaire responses and related personal information were not shared publicly. A total of 13 responses were collected between October 1 and November 8, 2024, including online and in-person responses from landowners who received mailers and the general public. Approximately 90% of respondents who answered the question indicated that flooding or erosion has occurred on their property.

The previously advertised public meeting hosted by Clallam County was held on October 29, 2024 to share information on the project background and proposed study methods, followed by an open floor session for participants to ask questions or voice concerns. Time for open discussion for participants was allotted to share experiences of channel migration and express concerns. Printed tabletop maps (36" x 48", aerial imagery) of the project vicinity and additional Questionnaire forms were made available. Sticky notes and pens accompanied the printed maps to allow participants to add notes to specific locations in the study area. At the request of landowners at the community presentation, the NSD field team added two specific sites on the Elwha River to investigate channel conditions and intake information from landowners in-person. Most participants acknowledged that the Elwha and Little River systems are highly dynamic and that while there are impacts from flooding and erosion, the health of its ecosystem relies on the variable nature of channel evolution.

A second public meeting was hosted by Clallam County at the courthouse building to present the draft results of the CMZ delineation on May 13, 2025. Approximately 15 people participated in-person. Mailers were sent to 123 landowners to notify people of the public meeting. This meeting centered on a PowerPoint presentation of the draft CMZ boundaries, which was digitally recorded. Questions and general discussions from public participants occurred throughout and after the presentation that involved the County project manager and NSD staff. Some of the questions asked for more clarity on the methods of CMZ delineation. Most of the questions and concerns raised by in-person participants were related to the application of the CMZ by County planners.

Input from the participating community members generally consisted of sharing knowledge and experience of flooding and erosion at their respective properties, questions about the technical methods, and validation that the Elwha River system is highly dynamic and unpredictable in nature. Appreciation for the Elwha River and its tributaries was apparent. Concerns were voiced about the long-term safety from erosion at several properties along the lower Elwha River.

Hosting separate meetings for the community was useful to focus the topic at hand. The first meeting provided background information of the watershed and an introduction to CMZ delineation methods. This allowed the audience to gain the same base of understanding that the technical team used to delineate CMZ boundaries. The second meeting centered on the draft delineation and walked through each of the project reaches individually. This allowed a facilitated discussion of site-specific concerns and considerations, and how the CMZ delineation addressed them. In retrospect, the first community meeting could have been advertised or hosted through the local library or community college to boost attendance of the event more broadly beyond landowners in the immediate project vicinity.

Co-manager Engagement

A presentation hosted by Clallam County was held on November 21, 2024 to share information on the project background and proposed study methods. Representatives from the Lower Elwha Klallam Tribe and Olympic National Park were in attendance. The project team acknowledges these co-managers for sharing spatial data and sharing local histories of channel evolution throughout the study area. A second presentation to present the draft results of the CMZ delineation was hosted by Clallam County on April 23, 2025 for the North Olympic Peninsula Lead Entity meeting. A question and discussion session was held for meeting participants following the presentation. The NPS and LEKT representatives were interested in the results of the modeling and mapping analyses to add to their understanding of the river systems and near-term projected trends of channel movement. LEKT provided comments on the draft maps to help inform current active channels in the floodplain that were not identifiable through remote sensing. No other specific CMZ mapping comments were provided as outcomes from these presentations.

Final Presentation

A presentation hosted by Clallam County occurred on May 5, 2025 to share information on the project background, study methods, and draft results to the Board of County Commissioners. Questions from the Commissioners were raised about technical methods and how specifically dam removal affects the CMZ delineation results.

Outcomes

A summary of the repeated themes from Community and Co-Manager engagement:

- Appreciation of the Elwha River, Little River, and Indian Creek was expressed in all meetings for the ecosystem and societal benefits these landscapes offer. Coupled with this was an understanding that erosion is a natural process that is expected, albeit unpredictably.
- An understanding was gained about what composes a CMZ and what the technical protocols consider in the delineation process.
- Questions were raised by several private landowners about how the CMZ would affect them in practice.
- Several private landowners requested that the technical team include their properties in the field reconnaissance to gather observations for the draft delineation.

- Input, written or otherwise, collected from community members, NPS and LEKT representatives informed map callouts for specific features of interest in the lower Elwha River watershed.
- Of all five outreach presentations conducted to public landowners and co-managers, only LEKT provided written comments on the draft CMZ for revisions; these comments were discussed and incorporated into the final CMZ mapping as appropriate.

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