GEOMORPHIC REACH ANALYSIS OF THE HOH RIVER
Interim Report for River Miles 20.8 to 25.5 (Morgans Crossing Reach 7)

PREPARED FOR:

JEFFERSON COUNTY DEPARTMENT OF PUBLIC WORKS
PORT TOWNSEND, WASHINGTON

REPORT PREPARED BY:
TECHNICAL SERVICE CENTER
BUREAU OF RECLAMATION
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U.S. Department of the Interior
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Geomorphic Reach Analysis of the Hoh River, Washington

Interim Report for River Miles 20.8 to 25.5 (Reach 7)

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EXECUTIVE SUMMARY

Background

Management of infrastructure along the Hoh River has provided a challenge to resource managers due to the dynamic nature of the river and the increasing requirements to limit impacts to aquatic habitat. This report was prepared by the Bureau of Reclamation at the request of Jefferson County to assist in an upcoming bank protection project along the County Road at Mile Post (MP) 6.7 (road miles measured from the Highway 101 junction). The study reach is known as the Morgans Crossing Reach of the Hoh River, river miles 20.8 to 25.5 (measured from the river mouth). The objective of this geomorphic analysis is to provide information and tools that can be utilized for habitat restoration projects and management of infrastructure along the river.

Historical Channel Migration Zone

The historical channel migration zone (HCMZ) boundary is defined for the Morgans Crossing Reach by the extent of the existing active channel and flood plain. The active channel represents the low flow river channel and gravel bars that are frequently reworked during floods. The active flood plain includes areas adjacent to the active channel that contain side channels, secondary or flood-flow channels, and low elevation vegetated surfaces that are frequently inundated by floods such as the 1.5- up to possibly the 10-year flood (range of 22,000 to 42,800 ft^3/s). The area outside of the HCMZ boundary can still be inundated, but it takes larger floods to overtop the banks that form the HCMZ boundary, such as the 25-year up to the 100-year flood (range of 50,600 to 61,700 ft^3/s). The area within the HCMZ is dynamic and continually changing form during floods. It represents the area where the majority of coarse sediment (sand, gravel, and cobble) and woody debris is either currently being transported (active channel) or has been transported (historical active channel paths) since at least 1939.

Risk of Future Expansion along Historical Channel Migration Zone

The HCMZ boundary has the potential to expand in the future where the boundary is composed of erodible material and subjected to lateral erosion from the river during floods. In addition to delineating the HCMZ, the potential risk of lateral expansion along the HCMZ boundary was identified to provide a tool for understanding which areas along the HCMZ boundary are most likely to erode in the near future. The near future is defined as the next several years to decades, depending on the magnitude, duration, and frequency of future flood events. For sections of the HCMZ boundary at risk for erosion, the extent and rate of lateral erosion are affected by the characteristics of the bank along the boundary of the HCMZ, the amount of time the active channel is adjacent to the boundary, geologic features in the valley that may limit expansion or active channel paths, river discharge (number of floods), river slope, sediment and large woody debris deposition, bank vegetation, and land use within and along the boundaries of the HCMZ. The absolute limit of potential lateral expansion can be represented by the toe of the valley walls, but in many areas it is unlikely that the expansion would continue that far within the next several decades given the existing discharge, slope, and sediment load of the river.

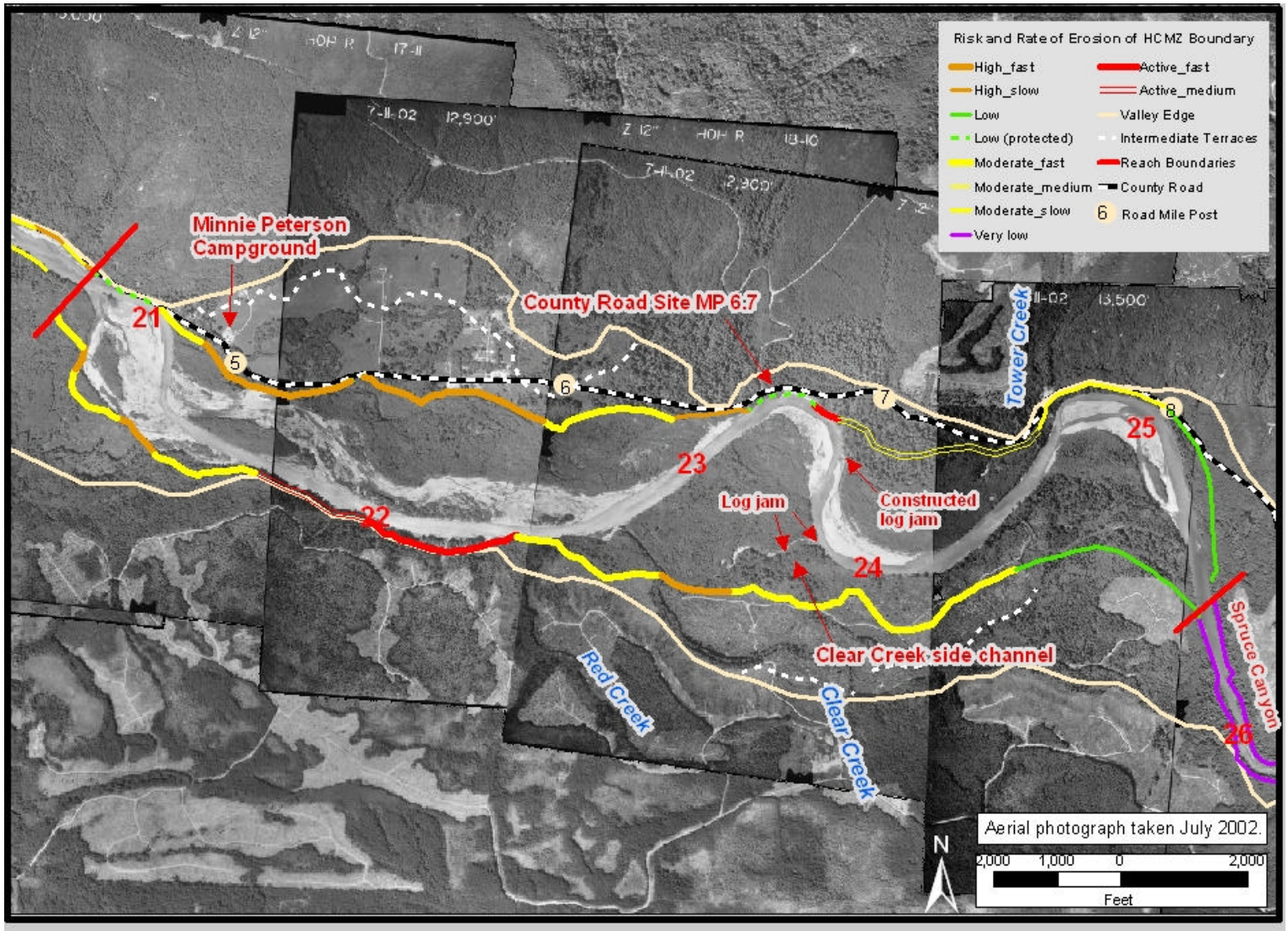
Management Considerations

In areas such as the Morgans Crossing Reach, clearing of the vegetation adjacent to the HCMZ can accelerate the rate at which the HCMZ boundary expands where the boundary is composed of erodible material such as alluvium or glacial outwash. Also, logging of the riparian flood plain within the HCMZ can accelerate the rate of channel migration and erosion, because bars have less of the vegetation that would normally dissipate energy (and water velocities) between the main channel and the boundaries of the HCMZ. Potential management strategies to limit human impacts and minimize future erosion where infrastructure or property needs to be protected could include deflecting the river away from the bank, setting back the infrastructure farther away from the HCMZ boundary, placing engineered bank protection, or a combination of these options. Because logging and development result in the highest potential future rates of lateral erosion, strategies to limit erosion may also include long-term land use alternatives such as re-vegetating the terrace surface and preventing development within or adjacent to the HCMZ.

Summary of Future Erosion Risk for Morgans Crossing Reach

A summary of the erosion risk for Morgans Crossing Reach is shown in Figure 1 on a 2002 aerial photograph for the right and left HCMZ boundaries. Each category represents the likelihood of erosion (active, high, moderate, low or very low) followed by the potential lateral rate of erosion (fast, medium, or slow) that could occur in the next several years to decades. The erosion risks were based on the characteristics of the HCMZ boundary and adjacent surface, and on the existing or potential future location of the active channel. For instance, “active_fast” represents an area that is actively eroding at a fast rate; “high_slow” is an area where the main channel is most likely to move against the HCMZ boundary as a result of a future flood, but when this occurs the rate of lateral erosion would be slow. The following discussion summarizes areas along the HCMZ boundary near the County Road that are actively eroding or have a high potential to erode. A more detailed discussion for the entire boundary is provided in the main report.

The areas at a high risk for erosion at a fast rate are where terraces along the HCMZ boundary have been cleared of vegetation. The longest section is along the right HCMZ boundary between RM 21 and 22.5. If the main channel cuts off its current path as predicted, it is likely that the new flow path may be against portions of this right HCMZ boundary. Currently, several side channels flow at or near the boundary and in one location bank protection has had to be placed to protect the County Road. Because the HCMZ boundary is very near the County Road between Road Miles 4.5 to 5.5, the road embankment should be closely monitored for stability if the channel does change course. If protection of this section of road was a priority, management options could include setting the road back to the next terrace surface or installing bank protection or river deflection structures now (in the dry) before the river changes course. This could provide a challenge by not knowing the exact alignment the river may take, but would provide some insurance if the river does avulse to this location. Engineered log jams or traditional rock structures could be considered. Either way, removal of vegetation within or adjacent to the HCMZ should be limited even if no proactive protection is placed, because an absence of vegetation would increase the potential for accelerated lateral erosion toward the road.



Assessment of the risk and rate of erosion of the HCMZ boundary in the Morgans Crossing Reach.

County Road MP 6.7

Regarding the County Road MP 6.7 site, the conclusions from the reach analysis indicate that the current meander bend at MP 6.7 will likely be cutoff and the active channel will be located further to the south. The development of a meander cutoff would mean that the present active channel would become a side channel along the County Road MP 6.7. However, as long as the river continues to run against this bank as it does now, it is likely that failure of the bank material will continue, particularly at the upstream end where it has already failed in the past. If nothing is done, there is a high risk that the meander bend will continue progressing downstream (until it cuts off) and cause additional erosion of the bank and riprap. Additionally, the river is dynamic and it is likely the river will flow against this bank again in the future, even if it temporarily cuts off. Therefore, in order to prevent any additional erosion of the existing road embankment, stabilization of the existing bank would need to be accomplished.

Engineered Log Jams at County Road MP 6.7

At the request of the County, GeoEngineers has proposed a series of three log jams along the right bank that would be located between the existing constructed log jam and the upstream end of the existing bank protection (see Figure 11 in main report). The purpose of the log jams would be to deflect the river thalweg and high velocities away from the right bank and prevent the bank upstream of the riprap, and the riprap itself, from failing. If properly designed and tied into the bank so that the log jams remain stable, the proposed engineered log jams will help to deflect the river away from the bank, and would provide some insurance that the bank will continue to be protected in the future. A small amount of erosion may temporarily occur upstream and downstream of each log jam, but because they are spaced less than a channel width apart, each log jam should create a depositional zone on its downstream side that would limit the potential for the channel to flow against the bank and cause further lateral erosion toward the County Road. The rate of future channel changes will depend on the magnitude and frequency of future floods and on the sediment loads on the Hoh River. Once the current main channel becomes a side channel, the existing log jam, and any additional log jams that are added in the future, will help create fish habitat within the active flood plain.

Road Setback Option at County Road MP 6.7

The existing road is at or very near the HCMZ boundary. Another management option for the County Road MP 6.7 would be to set back the road closer to the edge (toe) of the valley. If the road is setback, it would need to be determined how far to set the road back, whether to continue with the proposed engineered log jam project, and how to manage the existing bank protection and road embankment.

It is difficult to determine the exact timeframe at which the river might continue eroding the bank and reach the new road location if it were setback. Although the river is likely to cut off and abandon its current location in the near future, the farther the road is setback toward the valley wall, the less risk there would be for potential future erosion of the road embankment. The existing road is approximately 300 to 400 feet away from the valley edge in most locations. Based on historical lateral erosion measurements, the road

should be setback far enough to allow a buffer zone of large-diameter trees between the river bank and the road setback location to help minimize future lateral bank erosion. A minimum buffer zone that could be considered is at least an active channel width, about 200 feet. Given this assumption, if a road setback was the desired option, then it would be appropriate to set back the road all the way to the valley edge (see Figure 13 in main report) to allow for an additional factor of safety beyond the minimal 200 feet. However, the road should not be set so close to the valley wall that it has the potential to cause a landslide, particularly in the area mapped as a landslide on rock in Figure 13 (Gerstel, 1999).

Because the vegetation has been cleared where the road is currently located, the rate of lateral erosion could be accelerated if the road was set back and the existing bank protection failed or was removed. However, the rate of lateral erosion would likely slow once the river encountered the buffer zone area with significant-sized trees between the setback location and the HCMZ boundary. While it is not practical to assume the existing riprap would be maintained if the road is setback to the valley edge, in order to minimize accelerating the erosion, the riprap should be left in place. Further, the abandoned road embankment could be stockpiled with large-diameter trees cleared for the road setback location. The trees could be placed perpendicular to the river alignment so that if the abandoned road embankment began eroding, the trees might have a better chance of not being floated away by the river. If enough trees fell in and lined the eroding bank either from those stockpiled on the abandoned road or from the buffer zone, this would minimize lateral erosion rates.

If the County Road is setback to the valley edge, the proposed engineered log jams would not be needed to protect the road because lateral erosion would not be expected to reach the setback location over the next several decades. However, the engineered log jams would help deflect the river away from the current road location limiting future erosion, and would provide valuable aquatic habitat in this reach.

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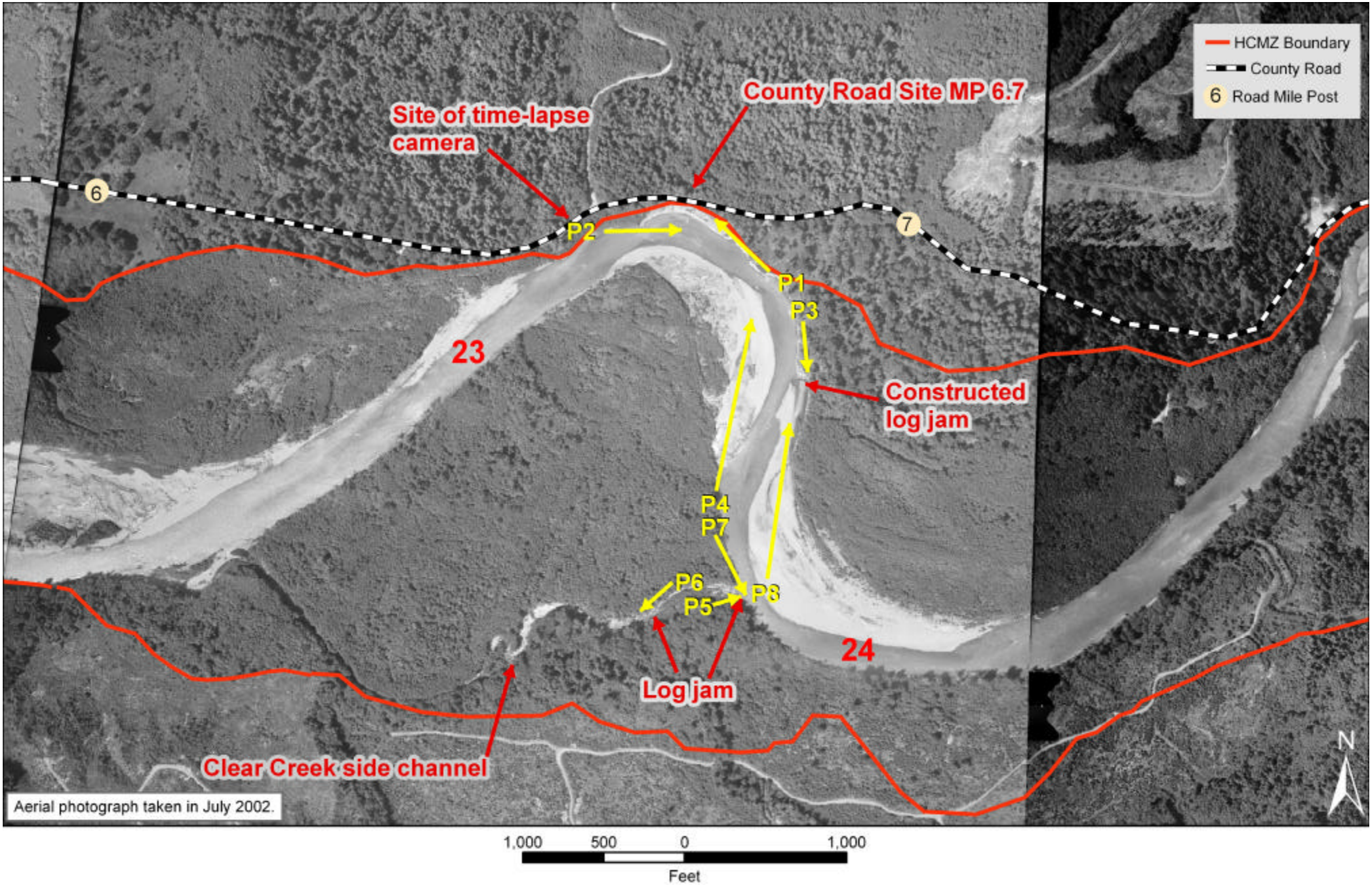
Photographic Overview: Reach 7

This section provides a photographic overview of Reach 7. Locations of each of the photographs are shown on the location map immediately following this page.



The locations and directions of the photographs in the Photographic Overview. The red numbers are river miles measured from the mouth of the Hoh River. The yellow letters and numbers indicate the positions from which the photographs were taken. The yellow arrows show the direction in which the photographs were taken.

Photographic Overview: Reach 7

PHOTO 1. Looking northwest at County Road (MP6.7). This site is located on the outside of a meander bend where velocities are high and have the capacity to erode the bank. In Dec. 1997-Jan. 1998, riprap was placed along 500 feet of the right bank to protect the road from further erosion. The upstream end of the riprap is near river mile 23.45 (river miles upstream from the mouth). Photo taken March 14, 2002.

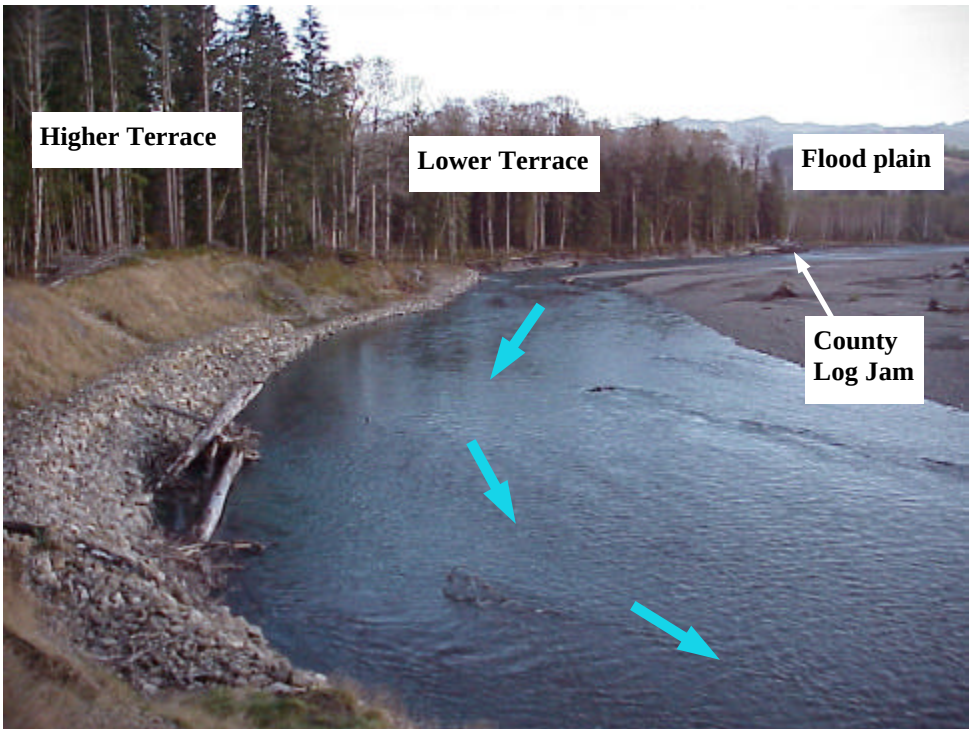


PHOTO 2. Looking upstream at County Road MP6.7 (see figure 2 in main report for location). There is a significant break in elevation between the higher terrace where the road is located, and the lower terrace upstream of the placed riprap. The lower terrace can get inundated by infrequent flooding, but the higher terrace does not. Therefore, neither of these terraces have functioned as flood plain in recent history. The outer edges of the terraces form the boundary of the channel migration zone. The active flood plain can be seen in this photo upstream of the lower terrace and is included in the historic channel migration zone.

In the winter of 2000-2001, a time-lapse camera was placed with this view. Although it was a fairly dry winter with few floods, it was observed that it took a flood of near 16,000 cfs (USGS Gage 12041200) to begin overtopping the gravel bars in the active channel. A larger flood would be needed to completely inundate the gravel bars and transport woody debris, as occurred in December 2001 and January 2002. Photo taken October 31, 2000.

Photographic Overview: Reach 7

PHOTO 3. Looking upstream of County Road MP6.7 where a log jam was constructed by Jefferson County (October 1998) to provide additional fish habitat in the river while also providing bank protection on the upstream end of the meander bend at this location. Photo taken May 3, 2001.

PHOTO 4. Looking north at upstream end of County Road MP6.7. Recent flooding during the 2001-2002 winter has resulted in additional erosion at the upstream end of the existing riprap and the area between the riprap and the constructed log jam. However, upstream of the log jam, deposition has occurred and a large gravel bar has formed. In September of 2002 (after this photo was taken), the area of failed riprap was reconstructed. Photo taken March 14, 2002.

Photographic Overview: Reach 7

PHOTO 5. Looking upstream at log jam located at the entrance to the side channel on the left bank, south of the main channel and the County Road MP6.7 site. Recent flooding has deposited a large amount of woody debris and sediment on this log jam and effectively blocked a surface water connection from the river. Photo taken March 14, 2002.

PHOTO 6. Looking downstream along the side channel directly to the south of the main channel and the County Road MP6.7 site. This log jam is approximately 650 feet downstream of the side channel entrance. Currently, tributaries (to the south) and groundwater are the only source of water into this channel during low flows. Evidence of recent flooding in the side channel and flood plain from the January 7, 2002 event was observed. Photo taken March 14, 2002.

Photographic Overview: Reach 7

PHOTO 7. Looking upstream from the log jam at the entrance to side channel across the river from the County Road MP6.7 site. The river is actively eroding the south river bank (right side of photo) because it is located on the outside of a meander bend. The bank is currently vertical due to the active erosion and trees gradually fall in and line the bank as their roots are undercut. This process slows the rate of bank erosion, but does not stop it, particularly during high flows when the smaller trees can be easily floated away. Photo taken March 14, 2002.

PHOTO 8. Looking downstream from the log jam at the entrance to side channel across from the County Road MP6.7 site. The river has deposited a large amount of woody debris along the outside of the meander bend. Photo taken March 14, 2002.

1.0 PROJECT BACKGROUND AND OBJECTIVE

The Hoh River is a gravel- and cobble-bed stream located on the Olympic Peninsula of northwestern Washington State (Figure 1). The river flows westward about 58 miles from the base of Mount Olympus to the Pacific Ocean near the town of Forks, Washington. The watershed has a drainage area of nearly 300 square miles, a large portion of which is located within the boundaries of Olympic National Park (ONP). The river is steep, falling about 5,000 feet in 58 miles for an average slope of 0.016.

Management of infrastructure along the Hoh River has provided a challenge to resource managers due to the dynamic nature of the river and the increasing requirements to limit impacts to aquatic habitat. In particular, there is a concern about the potential loss in salmonid productivity due to human impacts (Hatten, 1991). Although the river is naturally dynamic, human impacts may have altered and, in some areas, accelerated the physical river processes having an adverse affect on fisheries. Historically, roads and development adjacent to the Hoh River have been armored with riprap where the river is in contact with the road to prevent erosion and loss of the road. Recent documentation of riprap from the ONP Rainforest Campground downstream to the mouth indicates that approximately 5.8% of the right bank and 1.7% of the left bank of the Hoh River are hardened with riprap (Morris, 2001). Additionally, clearing of vegetation in the flood plain and adjacent terraces has also had an impact on channel processes.

A multi-year study is being undertaken by the Bureau of Reclamation (Reclamation) to develop a geomorphic interpretation of physical processes on the Hoh River for the lower 40 river miles from Mount Tom Creek in ONP downstream to the mouth, where the majority of human impacts have occurred. The major focus of the study is within the river reach between Mount Tom and the Oxbow Canyon, as shown in Figure 1. The objective of the geomorphic analysis is to provide a comprehensive understanding of natural physical processes that can be utilized for habitat restoration projects and management of infrastructure along the river. By understanding the natural processes and tendencies of the river, a comprehensive risk assessment of existing infrastructure along the Hoh River can be accomplished. The risk assessment provides a documentation of areas that are currently at risk from the river and areas that have a high potential to be at risk in the near future. By understanding the geomorphic characteristics and level of risk at each location, better decisions can be made as to the extent and degree of bank protection needed, particularly those incorporating aquatic habitat goals.

This interim report was prepared at the request of Jefferson County to assist in an upcoming engineered log jam project along the County Road at Mile Post 6.7 (road miles measured from the Highway 101 junction). This interim report focuses on the geomorphic interpretation needed for the planned projects at County Road MP 6.7. The multi-year study will build on this information in order to address the remaining reaches of river.

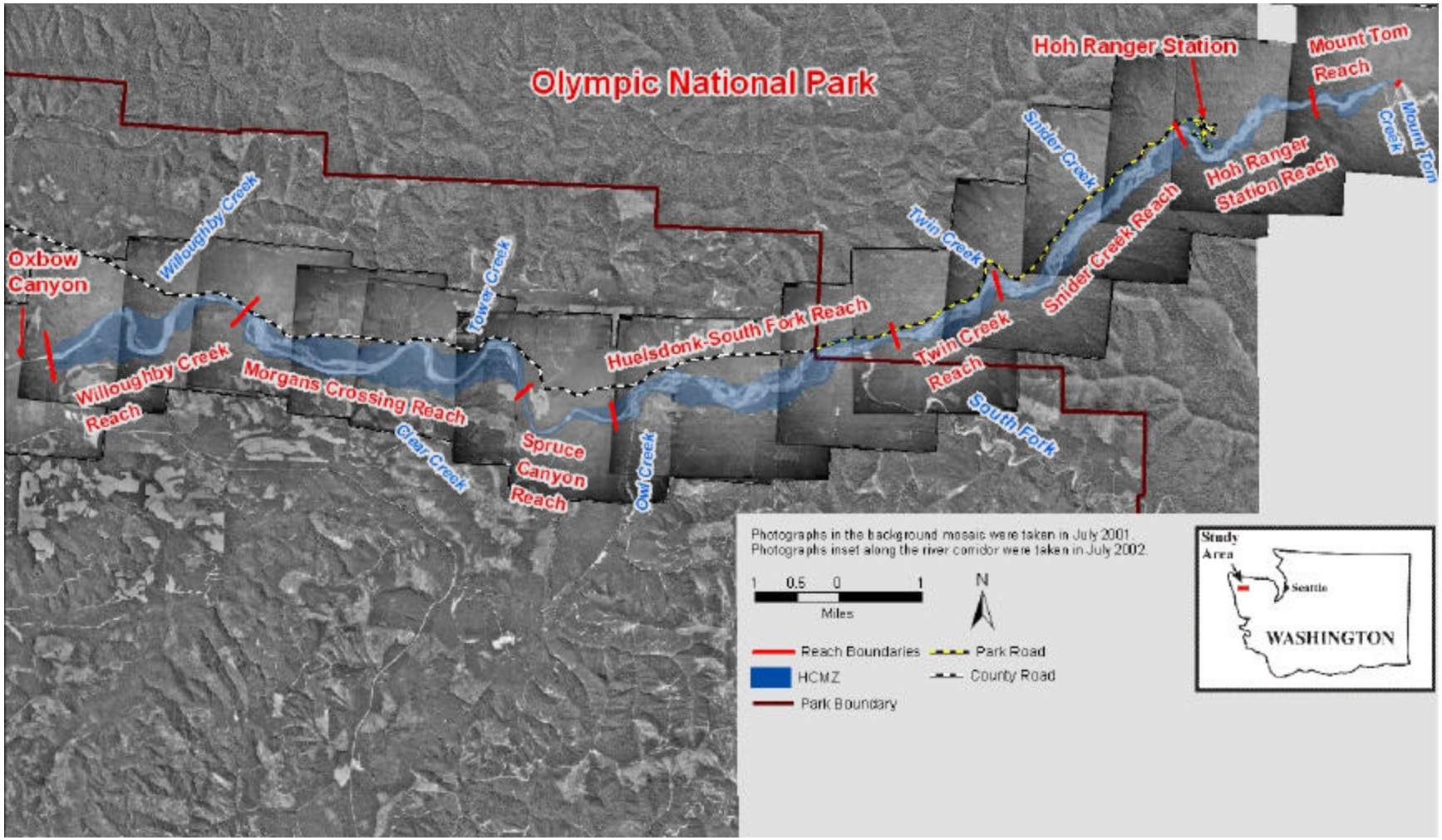


Figure 1. The location of the eight study reaches along the Hoh River between Mount Tom Creek and the Oxbow Canyon.

2.0 HOH RIVER HYDROLOGY

A hydrologic analysis was accomplished that summarizes peak flood frequency estimates, mean daily flow-duration and precipitation estimates for the Hoh River at Highway 101 (river mile 14.8) near Forks, Washington (England, 2003). The primary basis for the flood frequency and flow duration estimates are U.S. Geological Survey peak discharge and mean daily flow records. National Weather Service records were used to compute precipitation statistics.

2.1 Peak Discharge Frequency Estimates

The frequency and magnitude of floods on the Hoh River have a direct tie to the dynamics of the river channel and flood plain. In addition, bank stabilization and restoration projects should be designed to withstand a certain magnitude flood, for example the 100-year event. The log-Pearson Type III distribution was fit to annual peak discharge estimates using the Expected Moments Algorithm. Table 1 provides peak flood frequency estimates based on two historical gages on the Hoh River (England, 2003). The model estimates listed in Table 1 can be used to represent the discharge for the corresponding exceedance probability, but the associated 5% to 95% confidence limits should also be considered in any analysis based on these discharge estimates. The most recent floods on the Hoh River occurred on November 19, 2002, which had a peak of 33,300 ft^3/s (provisional data) and January 7, 2002, which had a peak of 43,300 ft^3/s. These floods are near the 5-year and 10-year return periods, respectively. The highest peak flow recorded at the U.S. Highway 101 gage was 54,500 ft^3/s on November 24, 1990, and the lowest mean-daily flow recorded was 252 ft^3/s.

Table 1. Peak discharge frequency estimates for the Hoh River at U.S. Highway 101 near Forks, WA

Annual Exceedance Probability (%)	Return Period (years)	Peak Discharge (ft^3/s)		
		LP-III Model Estimate	**5% Confidence Limit**	**95% Confidence Limit**
75	1.33	19,900	18,100	21,700
66.7	1.5	22,000	20,200	23,900
50	2	26,200	24,200	28,400
20	5	36,400	33,700	39,300
10	10	42,800	39,500	46,700
4	25	50,600	46,300	57,200
2	50	56,200	50,600	65,600
1	100	61,700	54,400	74,300
0.5	200	67,000	57,700	83,500

2.2 Mean-daily Flow Duration Curve

Flow-duration curves can be used to infer median river flow in a "typical" or "hypothetical" year. A series of flow-duration curves (annual, seasonal, and monthly) were developed using the mean-daily flows for the period of record. The annual flow duration curve (Figure 2) shows that mean daily flows are greater than about 1,260 ft3/s 75 percent of the time. The annual median flow (50 percent) is 1,810 ft3/s.

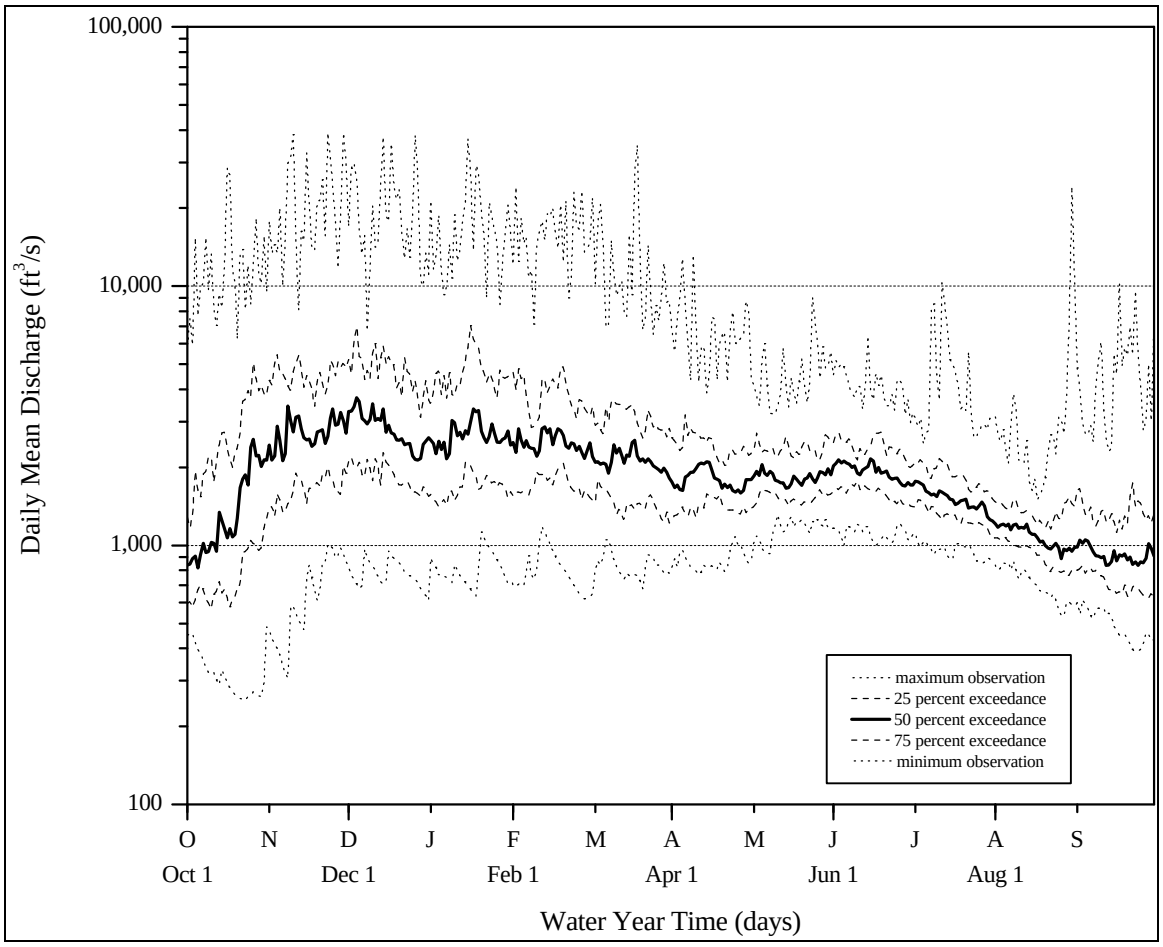


Figure 2. Period of record annual flow duration curve for Hoh River.

2.3 Precipitation Analysis

Annual mean precipitation ranged from 93.5 to 125.4 inches at three locations. The majority of precipitation occurs in the November through April period, which contributes to the occurrence of winter floods on the Hoh River. The driest period is during the spring, when snowmelt runoff is the dominant source of water for the Hoh River.

3.0 DESCRIPTION OF STUDY REACH

Between the confluence with Mount Tom Creek (located at RM 40, 3 miles upstream of the Hoh Rainforest Campground) and the entrance to the bedrock-controlled Oxbow Canyon (RM 17), eight reaches were defined for the Reclamation geomorphic reach analysis (see Figure 1; Table 2). The upstream and downstream boundaries of these reaches are formed by geologic controls that have remained stable since at least 1939. In other words, the river-bed elevation and alignment (path) remain constant at the upstream and downstream end of each reach. Each of these reaches has a distinct geomorphology that results from existing channel morphology and natural geologic controls on the river. The types of river planform in these eight reaches vary between meandering to more braided, multiple channel sections, along with including a section where bedrock confine the river to a narrow canyon. Table 2 lists some of the characteristics for each of the eight reaches, including river miles as measured from the mouth of the Hoh River, length, average slope (from 2000 channel survey data where available or USGS quadrangle maps), and sinuosity of the active channel measured from 1939 and 2002 aerial photographs.

Table 2. Reach descriptions for entire study area (RM 40 to RM 17)

Reach	Landmark	River Mile Range		Total Length (river miles)	Average Channel Slope	Active Channel Sinuosity	
						1939	2002
1	Mount Tom Creek	40.00	38.86	1.14	.0063	1.3	1.2
2	Hoh Ranger Station	38.86	36.57	2.29	.0063	1.2	1.3
3	Snider Creek (ONP Road Miles 3.0 to 6.0)	36.57	33.66	2.91	.0051	1.1	1.2
4	Twin Creek (ONP Road Miles 1.0 to 3.0)	33.66	31.56	2.10	.0047	1.0	1.0
5	Huelsdonk Ranch & South Fork confluence (County Road Miles 9.5 to 12.0 & ONP Road Miles 0.0 to 1.0)	31.56	27.18	4.38	.0034	1.1	1.1
6	Spruce Canyon (County Road Miles 8.5 to 9.5)	27.18	25.48	1.70	.0033	1.0	1.0
7	Morgans Crossing (County Road Miles 4.5 to 8.5)	25.48	20.77	4.71	.0026	1.1	1.3
8	Willoughby Creek (County Road Miles 2.0 to 4.5)	20.77	17.29	3.48	.0025	1.2	1.4

NOTE: Active channel sinuosity was measured from 1939 and 2002 aerial photographs that have been rectified to the same scale in a GIS system.

County Road MP 6.7 (Upper Hoh Road) is located along the right (north) river bank in Reach 7, also referred to as Morgans Crossing Reach, at approximately River Mile (RM) 23.5 (Figure 1). The upstream boundary for Reach 7 is formed by bedrock as the river exits Spruce Canyon. The downstream boundary for this reach is formed by a persistent geologic control on the river, which has remained in place since at least 1939.

Erosion of the road embankment at County Road MP 6.7 resulted in Jefferson County adding riprap to the bank between December 22, 1997, and January 22, 1998 (see photographs 1 and 2). During the period October 5-15, 1998, the County constructed a log jam approximately 1,000 feet upstream from the riprap where the terrace bank, flood plain, and river channel all intersect (see photograph 3). The log jam was designed to provide additional woody debris for fish habitat in the main channel, while preventing further erosion of the terrace bank. A section of the rock riprap failed at the upstream end of the bank protection (approximately 250 feet in length) during the winter of 2001-2002, and was reconstructed in September 2002.

A profile of the measured channel bottom and water surface was generated for Reach 7 from the 2000 river survey (Figure 3). Reach 7 has an average slope of 0.0026. Locally within the reach, the upstream-most section exiting Spruce Canyon has the steepest slope of 0.0034 for about one mile of river. A short section in the middle of Reach 7 (RM 23.77 to 24.41) has a gentler slope of 0.0020 where the river is currently meandering. The river resumes a steeper slope just downstream from where the meander bend reverses curvature to the left, near the log jam constructed by the County. This steeper slope continues downstream, past the County Road MP 6.7 site, to the end of Reach 7. This downstream steep section includes the portion of river running straight (rather than meandering) against a terrace along the left (south) side of the valley.

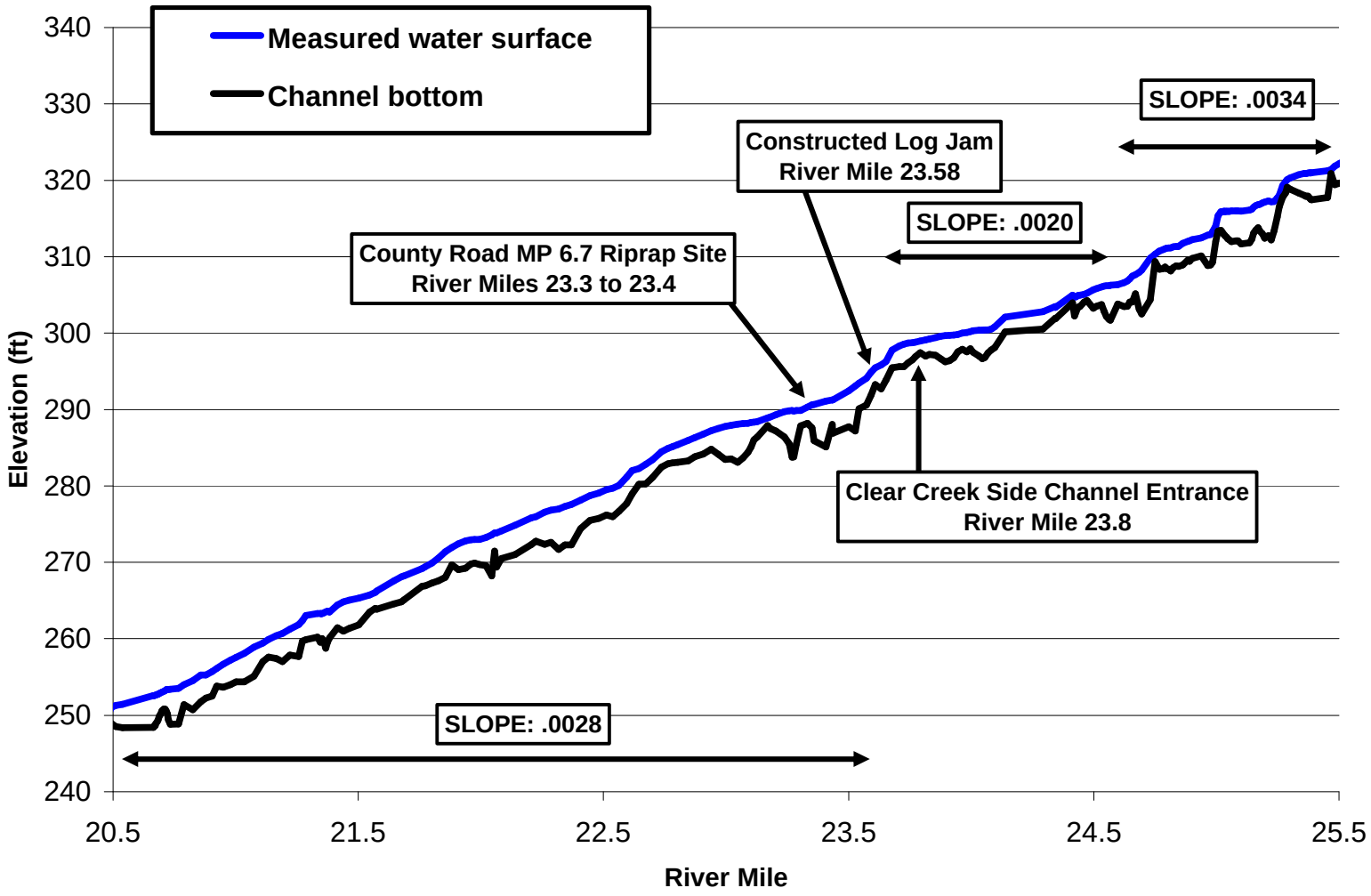


Figure 3. Longitudinal profile of channel bottom and measured water surface elevation in Reach 7.

4.0 DATA COLLECTION IN STUDY REACH

4.1 Survey Data

Survey data of the channel bottom, water surface, and exposed, un-vegetated gravel bars were collected during April 27 to May 3, 2000, using global positioning system (GPS) survey equipment combined with a depth sounder (transducer) on a cataraft (Washington North State Plane Coordinates, North American Datum 1983, National Geodetic Vertical Datum 1988, English Units, feet). The average river flow during the survey was 2,415 ft^3/s, and nearly 9000 data points were collected from the ONP boundary (RM 31) to the mouth of the Hoh River. The data were tied to a permanent control network established by a Reclamation survey crew from Ephrata, WA (see attachment A). This control network was based upon three permanent monuments set by the Washington State Department of Transportation. Each of these monuments was set using Global Positioning System (GPS) equipment and each has a published horizontal accuracy of 2 cm and vertical accuracy of 5 cm (ellipsoid height).

4.2 Aerial Photography

A series of aerial photographs and maps was acquired to document historical change along the river in the study area (Table 3). The most recent aerial photography available at the time of this report was acquired on July 10, 2002. The oldest available aerial photography was from 1939. Historical and recent 2002 aerial photographs were matched to the horizontal scale of an ortho-rectified 2001 photo mosaic created by the Washington Department of Natural Resources (WDNR). This process allows all the photographs to be viewed at the same scale and projection so that historical river channel paths can be compared to each other and to existing conditions. All photography and maps were projected in the same datum as the survey data, Washington North State Plane Coordinates, North American Datum 1983, English Units (feet).

4.3 Time-Lapse Photography

Three cameras were installed to take time-lapsed photography of the Hoh River during the 2000 - 2001 winter flood season at sites where bank erosion has threatened the Upper Hoh Road. The goal of the time-lapsed photography was to better understand the process linkages of flooding, bank erosion, and the transport and deposition of large woody debris. The three sites provided a comparison of an eroding bank without protection, a bank protected by riprap, and a bank protected by a combination of riprap and a constructed log jam which is the County Road 6.7 Site. Photos from the County Road 6.7 camera are included in Attachment B of this report. During the first two floods with peak flows recorded at the USGS gage of 7,750 ft^3/s (December 2, 2000) and 9,410 ft^3/s (December 16, 2000) a large point bar (gravel bar on the inside of a meander bend) along the active channel opposite the County Road 6.7 was not inundated and little change in river stage was evident in the photos. During the largest flood recorded during the 2000-2001 winter season of 15,900 ft^3/s (January 5, 2001), small secondary channels began conveying water through the point bar. The majority of the woody debris located on the

Table 3. Aerial Photography and Maps Acquired for Geomorphic Study.

Year	Scale	Study Area Covered from mouth (RM 0) to Mount Tom Creek (RM 40)	Type	Source	Project	Reach Rectified in GIS
10-12-1939	1"=2 miles	Mouth to RM 40	Black & white	USGS National Archives (Wallace Aerial Surveys)	GS-J	RM 0 to 40
1950-51	1:12,000	Mouth to RM 38	Black & white	BERRY	M49-13	RM 17 to 38
1960	1:12,000	Mouth to RM 35	Black & white	WDNR	WWJC6000	RM 17 to 35
8-9-1971	1:12,000	Mouth to RM 27	Black & white	WDNR	OLY-71	RM 17 to 27
7-22-1977	1:12,000	Mouth to RM 38	Black & white	WDNR	OL-77	RM 17 to 38
7-4-1981 & 9-14-1981 (at mouth)	1:12,000	Mouth to RM 38	Black & white	WDNR	OL-81	RM 17 to 38
1987	1:24,000	Mouth to RM 40	Quad Map (DRG)	USGS	-	RM 0 to 40
1994	1:24,000	Mouth to RM 40	Black & white	USGS	-	RM 0 to 40
7-28-1998	1:12,000	Mouth to RM 31	Color	Hoh Tribe	Quillaute-Hoh	Photos Not Rectified
7-8-2001	1:32,000	Mouth to RM 40	Black & white	DNR	OLQT00	RM 0 to 40
7-10 to 7-12, 2002	1:12,500	Mouth to RM 40	Color	Sound Aerial Survey	HOH R	RM 17 to 40

*ONP Boundary located at RM 31

gravel bar was not inundated and, therefore, no transport was observed. Following the flood, the gravel bars in the river looked very similar to pre-flood conditions. This indicates that it takes a discharge of at least 16,000 ft^3/s to increase river stage enough that gravel bars in the active channel begin to be inundated (at this location). A larger flood, possibly closer to the 1.5 (22,000 ft^3/s) or 2-year flood (26,200 ft^3/s), would be needed to completely inundate the active flood plain. This information was utilized in the determination of the historical channel migration zone boundary as discussed in Section 6 of this report.

4.4 Bank Descriptions

Banks along the HCMZ boundary were described at 17 localities where the bank is actively eroding or could be an area for future lateral erosion. At each description locality, the following characteristics were noted: sediment composition, bank height, slope, vegetation on bank and associated surface, root size and depth, evidence for active landslides and active erosion, bank protection, and human activities along the bank and associated surface (Attachment D).

5.0 CONCEPTUAL MODEL OF CHANNEL PROCESSES

In a natural river system, the active channel, flood plain, terraces, and adjacent slopes are formed primarily as streamflow alternately erodes, transports, and deposits sediment and woody debris (Figure 4). Because the relative amounts of water, sediment, and woody debris are continually changing, the channels and flood plain are continually adjusting to the variable supplies of these three components. Response to the changes may be different and may occur at different times and in different places along the river depending upon local conditions and the frequency of flooding. Water, sediment, and woody debris may move longitudinally down the valley, but alteration in these components may also result in vertical downcutting or aggradation, or in lateral erosion or deposition. In this way, natural river channels are dynamic and are subject to change over time, especially as bankfull and higher flows pass through the channel and rework sediment and woody debris.

The active channel includes the low-flow channels and intervening and adjacent gravel bars (Figure 4). The bars are often unvegetated, but may by sparsely covered with low alders, grasses, and shrubs. The higher bars are often covered with sand. In many areas of the Hoh River, the active channel includes multiple channels that can convey water, but often there is one dominant channel that carries the majority of flow. This main channel may be straight or meandering in planform. The channel alignment and width depends on the rate of river flow and sediment supplied from upstream. In an alluvial river reach the channel bed and banks are composed of sand, gravel, and cobble-sized sediments and not constrained by bedrock. In these alluvial river reaches, the channel width, depth, and longitudinal alignment will adjust over time so that the upstream supply rate of water and sediment can be conveyed through the reach without long-term erosion or deposition. The hydraulic capacity of the river to transport sediment increases primarily with the longitudinal slope of the river, flow velocity, and depth. The longitudinal slope of the river is limited by the valley slope (straight channel), but can be less if the river meanders back and forth across the river valley.

If the upstream sediment supply rate is greater than the hydraulic transport capacity, then sediment can deposit in the river channel and the resulting alignment will tend to follow a straighter pattern. If the river channel alignment is already straight, additional sediment deposits will result in a braided river with multiple channels. If the upstream sediment supply rate is less than the sediment transport capacity, then the channel bed and banks can erode and the resulting alignment will tend to follow a more meandering pattern. If coarse particles remain on the riverbed while finer particles erode, then eventually a coarse layer of particles will armor the riverbed and limit channel bed incision. However, a subsequent flood can later erode the armor layer if there is enough sediment transport capacity to move the larger sized particles.

When straight, the channel may have the potential to undercut and erode banks on either side of the river, and will often deposit sediment during high flows in the form of mid-channel or longitudinal bars that run parallel with the river channel. When meandering, the river will typically erode the outside bank of the meander bend while maintaining

enough channel width to convey high flows by depositing sediment along the inside of the bend (point bar). This continual process of erosion along the outside bank of a meander bend and deposition along the inside bank allows the river channel to migrate laterally across the valley and build and rework the flood plain. The deposit of woody debris on gravel bars and subsequent formation of log jams also play an integral role in the occurrence of channel changes by creating multiple channel paths and either causing or mediating avulsions (Collins and Montgomery, 2002).

In most wide valleys with a flat floor, one can expect that the river has been in many positions across the valley floor at some point in the past. Terraces within the valley are remnants of old flood plains and consist of old channel deposits of gravel and sand. A change in the relative proportion of water and sediment resulted in incision into these channel deposits, which left them exposed above the new active channel and flood plain (Figure 4). The old channel bed and flood plain, now a terrace, may still receive some water during higher flows and the old channel deposits are often covered by fine sand and silt. If incision continues, the terrace may eventually be high enough above the level of the channel so that flood flows no longer reach its surface. In this way, the terrace surfaces slowly stabilize, vegetation establishes, and soils begin to form. Progressively higher terraces are often progressively older. Terraces outside of the active channel on the Hoh River are probably at least 100 years old and higher terraces are a few hundred years old (Figure 4; Fonda, 1974; Swanson and Lienkaemper, 1982).

The major cause of variations in discharge over time scales of a few hundred to a few thousand years is climate change. Climate change affects rivers by altering the proportions of river flow and sediment load from the upstream watershed in response to a changed relationship among vegetation, soil, precipitation, and erosion. Ice extended down the Hoh River valley to near the South Fork or the Pacific Ocean at least five times between about 55,000 years ago and about 14,000 year ago (Thackray, 1996). As the ice retreated, water and sediment loads in the Hoh River were likely much larger than today. As the glaciers ceased to melt and the climate changed to a relatively more arid condition, the Hoh River channel incised the flood plain because there was a greater proportion of river flow to the sediment load supplied from the upstream watershed.

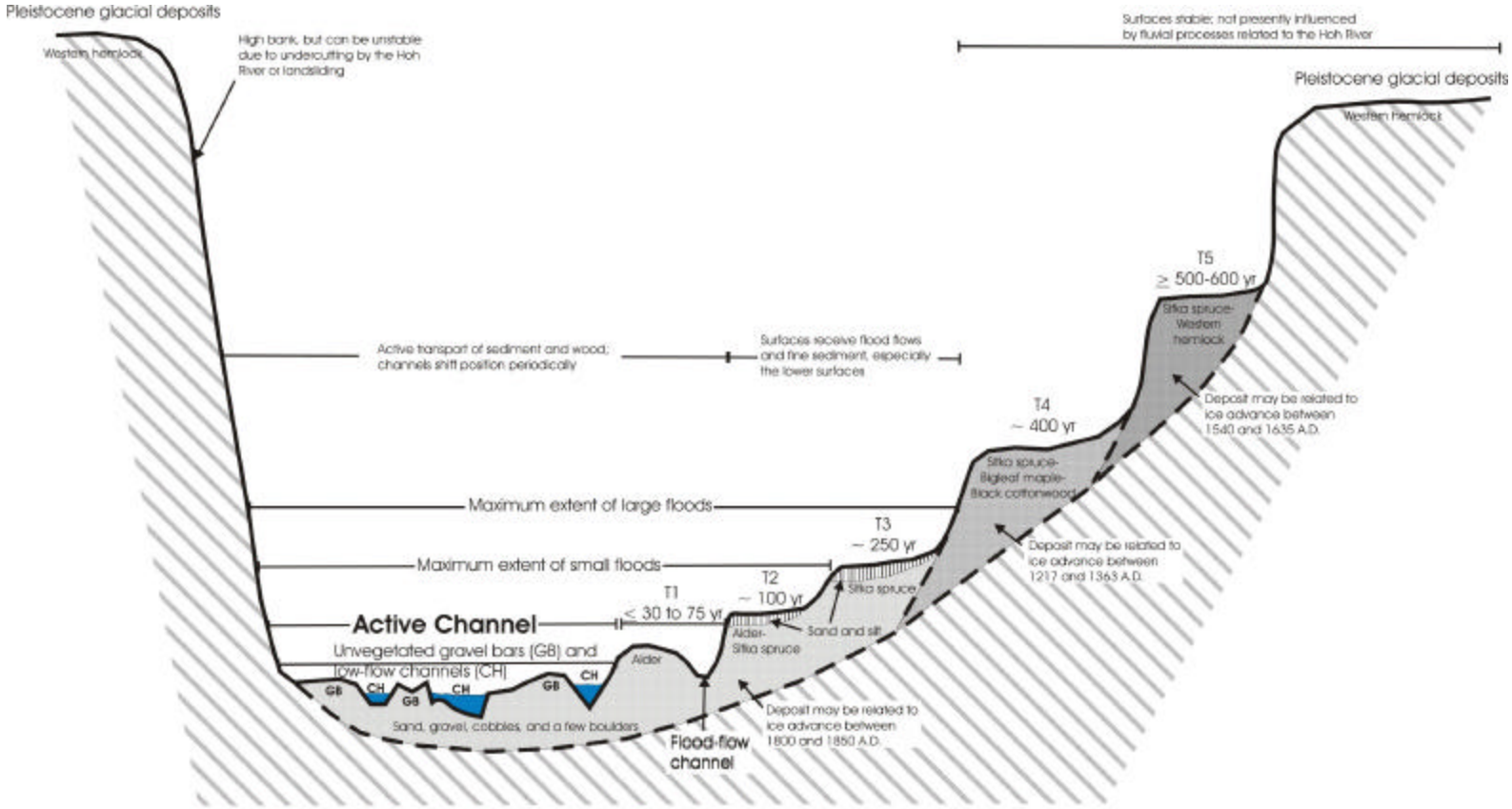


Figure 4. Generalized schematic cross section across the Hoh River valley showing the relationships among the active channel, extent of floods, and terraces. The terraces are numbered from T1 to T5 on the basis of their relative positions above the active channel. This sketch is a composite of many sites along the river, so that a single locality may have fewer or more terraces. The estimated ages shown for the terraces are from Fonda (1974) and Swanson and Lienkaemper (1982). The ages are based primarily on the ages of trees growing on the terraces and reflect the time when the terraces became stable enough to support trees. They could receive flood flows that do not substantially disrupt vegetation since that time. The subsurface geometry of the deposits is hypothetical. Fonda (1974) suggested that the alluvium beneath the lowest terraces are related to Neoglacial ice advances as shown.

6.0 IDENTIFICATION OF HISTORICAL CHANNEL MIGRATION ZONE

The discussion in this chapter explains how the historical channel migration zone (HCMZ) was defined and determined for the Hoh River. Identification of the risk for future expansion of the HCMZ is discussed in the following Section 7.

6.1 Definition

The HCMZ boundary is defined for this study by the extent of the existing active channel and flood plain. The active channel represents the low flow river channel and gravel bars that are frequently reworked during floods. The active flood plain includes areas adjacent to the active channel that contain side channels, secondary or flood-flow channels, and low elevation vegetated surfaces that are frequently inundated by floods such as the 1.5- up to possibly the 10-year flood (range of 22,000 to 42,800 ft^3/s). The area outside of the HCMZ boundary can still be inundated, but it takes larger floods to overtop the banks that form the HCMZ boundary, such as the 25-year up to the 100-year flood (range of 50,600 to 61,700 ft^3/s). The area within the HCMZ is dynamic and continually changing form during floods. It represents the area where the majority of coarse sediment (sand, gravel, and cobble) and woody debris is either currently being transported (active channel) or has been transported (historical active channel paths) since at least 1939.

The HCMZ can be bounded by terraces, glacial deposits (till, outwash, lacustrine sediments), alluvial fans, bedrock, or engineered bank protection (riprap, engineered log jam, bridge abutment, levees, road embankment). In some locations, future channel changes will expand the HCMZ boundary where the boundary consists of erodible material. This process is expected to continue for at least the next several decades, possibly centuries depending on whether climatic conditions remain relatively stable or change enough to cause major aggradation or incision within the HCMZ.

The HCMZ includes historical CMZs since at least 1939, but likely includes a longer period of record. The differences between the 1939 and historical CMZ boundaries represent areas of terrace bank erosion along the boundary since 1939. It is has been documented that terraces along the HCMZ boundary in the Hoh River valley range in age between a few to several hundreds of years (Fonda, 1974; Swanson and Lienkaemper, 1982). This would indicate that the HCMZ likely encompasses a longer time interval than since the 1939 channel, but the exact time interval is unknown.

6.2 Methodology for Determination of Historical Channel Migration Zone

For the Hoh River, the HCMZ was determined by examining historical and existing river processes using geologic evidence and aerial photography and maps. This method is described below:

- Analysis of historical aerial photographs and maps to depict historical main channel paths and active flood plain areas. Historical channel paths show areas where the active channels have been in the recent past, which helps define the HCMZ. Historical channel paths are often still visible in the existing active flood plain as side and overflow channels. In other cases, development or logging activities have reworked the historical channel paths and flood plain making them undetectable in the existing river system. For the Hoh River, historical aerial photographs ranging from 1939 to 2002 were used, along with a historical map from 1987 (see Table 3). The channel position in 1987 was taken from 1:24,000-scale topographic maps that were based on aerial photographs taken in 1987.

- Stereo analysis of 1998 aerial photographs to verify the boundary of the HCMZ. These aerial photographs, our only set with stereo coverage, were used to identify terraces and low surfaces that show evidence of old channels, such as narrow zones of lower or sparse vegetation on an otherwise densely vegetated surface. These surfaces would be included in the HCMZ even if the historical photo and map analysis revealed no active channels at these locations. On the other hand, high surfaces that appear to be smooth and uncut by channels would be excluded from the HCMZ. Stereo analysis was also used to identify intermediate surfaces between the HCMZ and the valley wall where the surfaces could be seen through the vegetation. However, in many areas the vegetation was too dense, and surfaces could only be observed and mapped in the field.

- Field inspections to verify delineated terrace banks and confirm the location of the HCMZ boundary. Terrace banks were identified in the field to verify mapping done from aerial photography and maps. Where multiple banks exist and the location of the HCMZ boundary was questionable, terrace surfaces were investigated to determine if they contained evidence of being within the active flood plain. As defined for this study, the active flood plain contains lower magnitude floods such as the 1.5- to 10-year annual flood peaks (22,000 to 42,800 ft^3/s). Therefore, it would take a larger magnitude flood, such as the 25- or 100-year flood, to overtop terrace surfaces outside the active flood plain and outside the HCMZ. During January 2002, a 43,300 ft^3/s flood occurred, which is near the 10-year return interval. This flood would be expected to have inundated a significant portion, if not all, of the HCMZ and evidence of fine sediment deposition and debris on questionable terrace surfaces was investigated.

6.3 Methodology for Defining the 1939 Historical Channel Migration Zone

Unlike the determination of the historical channel migration zone, which integrates extensive field work, the 1939 CMZ was estimated solely on the basis of aerial photography. Using the 1939 aerial photographs, an interpretation was made of the 1939 CMZ based on the distinction between vegetation in the active channel and flood plain (1939 CMZ) and on terraces that bound the 1939 CMZ. In general, the vegetation within the 1939 CMZ is dense, small, appears relatively smooth, and is often discontinuous because of recently active side channels that have removed vegetation or have kept it from growing. The vegetation on the terraces that bound the HCMZ is less dense and appears irregular, because individual trees are large enough to be visible and the trees are of differing species and heights.

Because field verification could not be accomplished for the 1939 HCMZ, some verification is needed to determine if the differences in the HCMZ boundaries in 1939 and 2002 are real or are an artifact of our methods in identifying the boundaries or of rubber-sheeting the photographs. To provide verification, the relative amounts of change in the 1939 and 2002 HCMZ boundaries were compared for the study area.

In ONP, very little change between the 1939 and 2002 boundaries has occurred, which would be expected because the channel is often confined by steep alluvial fans along the valley wall. Where alluvial terraces do exist, the river flows are less than downstream of the confluence with the South Fork, which likely reduces the magnitude of velocities against terrace banks. Finally, susceptibility to accelerated erosion from human impacts is limited within ONP because development and logging in the active flood plain and on terraces that bound the HCMZ have been minimal. However, downstream of ONP, the valley is wider, more erodible glacial bank are present, fewer alluvial fans exist, development and logging are common, and subsequently more erosion has occurred. In addition, historical channels on the 1950 and 1960 aerial photography flowed along areas of the 1939 CMZ boundary that can be seen on subsequent years of photographs to have been eroded. The position of the channel supports the interpretation that these sections were indeed eroded and that the discrepancies between the boundaries in 1939 and 2002 are not an artifact of identifying the boundaries or of errors associated with the rubber-sheeting of the 1939 aerial photography to the same scale as the 2002 photography. Although some minor error does occur when rubber-sheeting photographs, the relative locations and amounts of change in the HCMZ since 1939 are still more than the possible error.

7.0 METHODS USED TO ASSESS THE RISK OF CHANNEL MIGRATION ZONE EXPANSION

Expansion of the HCMZ is a natural process that results from a continually changing, dynamic river channel. In addition to delineating the HCMZ, the potential risk of lateral expansion along the HCMZ boundary was identified to provide a tool for understanding which areas along the HCMZ boundary are most likely to erode in the near future. The near future is defined as the next several years to decades, depending on the magnitude, duration, and frequency of future flood events. For sections of the HCMZ boundary at risk for erosion, the extent and rate of lateral erosion are affected by the characteristics of the bank along the boundary of the HCMZ, the amount of time the active channel runs against the boundary, geologic features in the valley that may limit expansion or active channel paths, river discharge (number of floods), river slope, sediment and large woody debris deposition, bank vegetation, and land use within and along the boundaries of the HCMZ. The absolute limit of potential lateral expansion in the future can be represented by the toe of the valley walls, but in many areas it is unlikely that the expansion would continue that far within the next several decades given the existing discharge, slope, and sediment load of the river.

The following discussion provides an overview of the methodology used to assign the risk of erosion to the HCMZ boundary. A more detailed discussion with additional documentation is provided in Attachment C. The risk of HCMZ expansion was developed using the following three steps:

STEP 1: Assess the likelihood that bank erosion will occur in the future along reaches of the HCMZ boundary (Figure 5). Likelihood categories include: very low, low, moderate, high, and actively eroding.

STEP 2: For reaches actively eroding or likely to erode, estimate the potential rates at which bank erosion could progress (Figure 6). Potential erosion rate categories include slow, medium, or fast.

STEP 3: Combine the likelihood of erosion and the potential erosion rates to determine the relative risk for expanding the HCMZ boundary (Table 4).

7.1 Likelihood of Future Bank Erosion

The likelihood of bank erosion along the HCMZ boundary (STEP 1) is primarily dependent upon two main factors: (1) the properties of the material in the bank, and (2) the bank's location relative to existing or potential mainstem and side channel locations of the Hoh River. Bank material properties were subdivided into five categories of erosion likelihood ranging from very little potential to erode, such as bedrock, to a high potential to erode, such as fine-grained glacial outwash.

The general categories of bank material and their associated erosion potential are listed below (see Attachment C for more details on characterization of bank materials):

- Bedrock – Erodibility: VERY LOW
- Human-placed bank protection – Erodibility: LOW
- Alluvial fan deposits – Erodibility: LOW to MODERATE
  Type 1: Steep, alluvial fans located at toe of valley wall with large sized-material (cobble and boulder) – Erodibility: LOW
  Type 2: Alluvial-fan deposits present on terrace surfaces with sand to cobble-sized material – Erodibility: MODERATE
- Alluvial and glacial deposits – Erodibility: MODERATE TO HIGH

Likelihood of erosion is also dependent on whether the main channel or a primary side channel of the Hoh River is currently or has the potential to flow adjacent to the bank. The greater the erodibility of the bank material and the greater the chance the river will run against the bank, the higher the likelihood of erosion. For example, if the material in a bank is loose, glacial outwash (fine sediment that has the potential to be easily eroded), then the bank would have a high potential for erosion. However, the likelihood of erosion would only remain high if the river had a high likelihood of running against the bank in the near future. Historical channel paths and features that may limit channel changes (bedrock, geologic controls, log jams, alluvial fans, etc) were used to estimate the likelihood of potential future channel paths along a given terrace bank.

7.2 Potential Rate of Bank Erosion

The potential rate of bank erosion (STEP 2) was determined to assess the relative rate at which a bank might laterally erode. Rates were broken into three categories including slow, medium, and fast. The potential erosion rate is dependent on two main factors: (1) the characteristics of the bank along the HCMZ boundary, and (2) the vegetation and land use within and on the surface adjacent to the HCMZ. Estimated rates were checked to see if they were reasonable by comparing them to observed historical rates of lateral erosion in areas with similar conditions.

Certain features along the HCMZ boundary may not completely prevent lateral erosion, but at the same time have significant capability to limit the rate at which it occurs. For instance, surfaces along the boundary with old growth forest or large-diameter trees can slow expansion of the HCMZ by providing protection to the eroding bank when the vegetation is at the water surface-bank interface (Beeson and Doyle, 1995). Alluvial fans with recurrent additions of sediment can also limit the expansion of the HCMZ boundary, particularly when the sediment is composed of large material (cobble and boulder). The height of banks along the HCMZ boundary can also limit the rate of lateral expansion because as banks get taller, the rate of expansion often slows due to the increase in bank material per unit width (Beeson and Doyle, 1995).

7.3 Influence from Human Activities

Human activities can increase or decrease the potential and rate of erosion along the boundaries of the HCMZ. For example, clearing of vegetation within the active flood plain can increase the rate of channel changes, result in higher velocities due to decreased roughness, and ultimately increase the potential for lateral erosion. Clearing of vegetation along terrace surfaces can increase the potential rate of erosion often resulting in rapid expansion of the HCMZ during floods. Beeson and Doyle (1995) documented that of 748 meander bends studied on four stream reaches in British Columbia, bends without riparian vegetation were nearly five times as likely as vegetated bends to undergo detectable erosion during flood events. For example, the largest amount of lateral bank erosion observed between 1939 and 2002 on the Hoh River was 1500 feet along a bank just upstream of the entrance to the Oxbow Canyon where the adjacent surface had been logged and developed in 1939. On the other hand, the majority of ONP has not been subjected to logging or development, and lateral terrace bank erosion has not been significant. The present vegetation and logging and development history were interpreted for this assessment from aerial photographs ranging from 1939 to 2002 (see Table 3). Human activities can also decrease the potential for lateral erosion, and restrict the boundaries of the HCMZ such as where stable, engineered bank protection has been placed along terrace banks.

7.4 Assigning a Risk of Future Erosion

The likelihood of future erosion and the potential rate of that erosion along the HCMZ boundary are combined to create “risk categories”. The risk categories are summarized in Table 4. The categories are intended to provide a tool for resource decision makers to assess and compare the risk of erosion in various reaches of river. For instance, consider a section of river with a HCMZ boundary assigned a high risk of erosion, but at a slow rate. If some critical infrastructure is located very close to the HCMZ boundary, even a slow rate may become a potential management concern if the likelihood of lateral erosion is high. However, if the infrastructure was located far enough away, even though the likelihood of erosion is high, the fact that the rate is slow may lower the priority of managing for potential erosion.

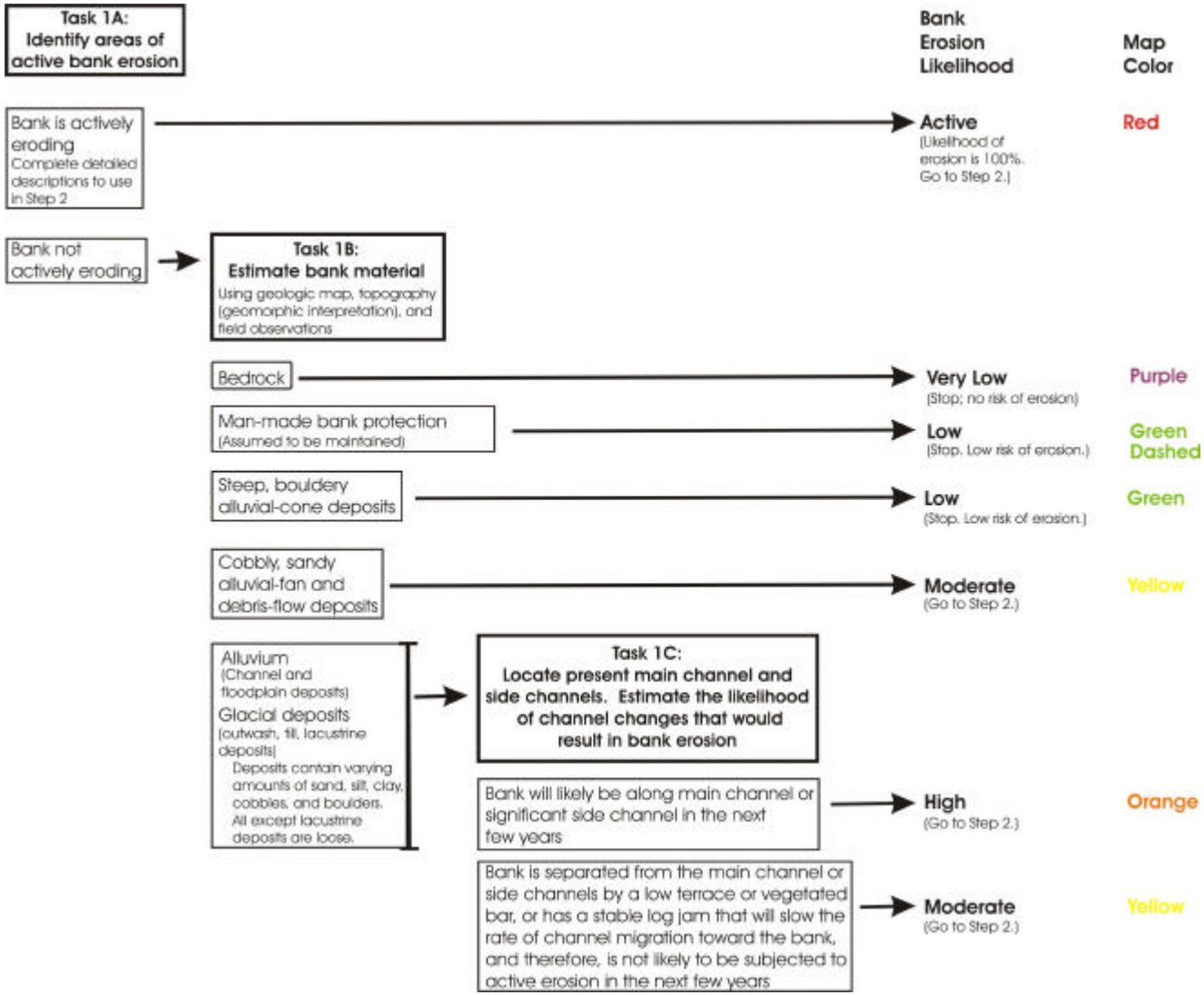


Figure 5. Step 1: Assessment of the likelihood of bank erosion along the HCMZ boundary

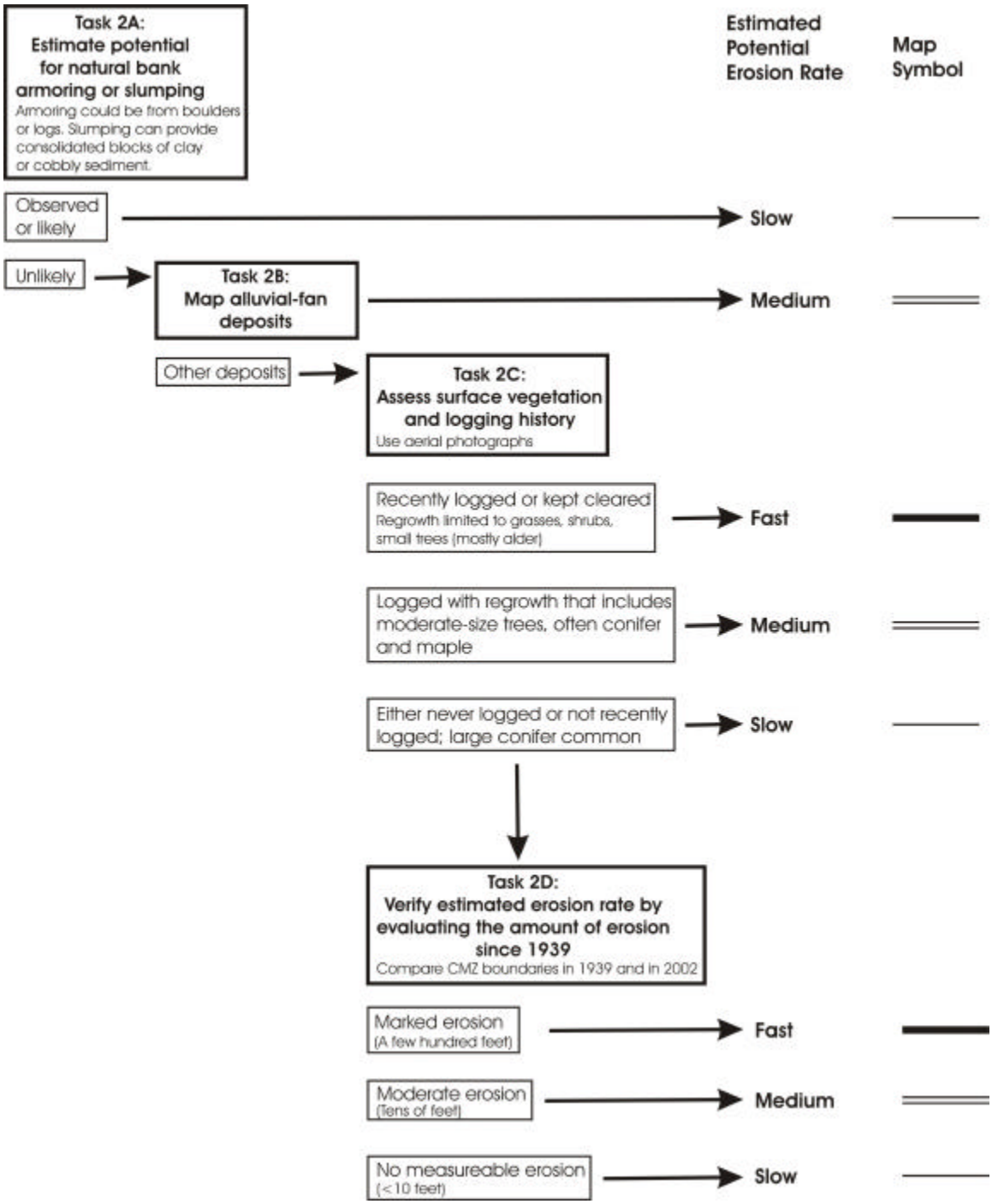


Figure 6. Step 2: Estimation of the potential rates of bank erosion along the HCMZ boundary

Table 4. HCMZ Boundary Risk Categories Developed From Combining Likelihood for and Potential Rates of Future Erosion[1]

Potential Erosion Rate[2]	Likelihood of Erosion with Present Conditions		
	Active Erosion	**High Likelihood of Future Erosion**	**Moderate Likelihood of Future Erosion**
Fast Rate	**Active_fast:** Evidence for recent lateral erosion[3]; bank has potential to erode several hundred feet over the next several floods	**High_fast:** Terrace bank consists of erodible material and is presently along a main channel, or in an area where a change in channel pattern is likely and would result in the bank being adjacent to a channel; bank has potential to erode several hundred feet over the next several floods	**Moderate_fast:** Terrace bank is composed of erodible material and is in an area where a change in channel pattern is possible, but not likely in the near future; bank has potential to erode several hundred feet over the next several floods
Medium Rate	**Active_medium:** Evidence for recent lateral erosion[3]; bank has potential to erode several tens to a few hundred feet over the next several floods	**High_medium:** Terrace bank consists of erodible material and is presently along a main channel, or in an area where a change in channel pattern is likely and would result in the bank being adjacent to a channel; bank has potential to erode several tens to a few hundred feet over the next several floods	**Moderate_medium:** Terrace bank is composed of erodible material and is in an area where a change in channel pattern is possible, but not likely in the near future; bank has potential to erode several tens to a few hundred feet over the next several floods
Slow Rate	**Active_slow:** Evidence for recent lateral erosion[3]; bank is not likely to erode more than a few tens of feet over the next several floods;	**High_slow:** Terrace bank consists of erodible material and is presently along a main channel, or in an area where a change in channel pattern is likely and would result in the bank being adjacent to a channel; bank is not likely to erode more than a few tens of feet over the next several floods;	**Moderate_slow:** Terrace bank is composed of erodible material and is in an area where a change in channel pattern is possible, but not likely in the near future; bank is not likely to erode more than a few tens of feet over the next several floods;

[1]Terrace bank material for active, high, and moderate erosion likelihood is chiefly unconsolidated and loose sandy, silty, or cobbly sediments. Boulders composition is variable. These sediments are alluvium (channel and flood plain deposits), glacial deposits (outwash and till), and finer sized alluvial-fan deposits. Where glacial deposits include lacustrine silt and clay, sediment can be consolidated and resistant to erosion. However, banks with this material where seepage is present often fail by slumping and so are unstable.

[2]This is the estimated potential erosion rate assuming that the main channel or a primary side channel, one that carries substantial flow, is adjacent to the terrace bank.

[3] Evidence of recent erosion includes a vertical or overhanging (undercut) bank, exposed roots, lack of vegetation, toppled or disturbed trees (usually alder) or shrubs, slumps, or water issuing from bank, usually just above a clayey silty bed.

8.0 REACH ANALYSIS AND RISK ASSESSMENT FOR REACH 7

This section provides a discussion on the geomorphic characteristics and risk assessment specific to Reach 7, which includes County Road MP 6.7. The HCMZ boundary and risk of future erosion along the boundary were determined using the methodology described in Section 6.0 and Section 7.0 of this report. For discussion purposes, river right and left are defined as if looking downstream from within the active flood plain.

8.1 Historical and Potential Future Channel Positions

The existing and historical river channel planforms are shown in Figures 7 and 8, along with the HCMZ boundary (shown in red). At the upstream and downstream ends of Reach 7, the river has passed through the same path since 1939. Between these boundaries, the river path is largely determined by what happens at the upstream end of the reach as it exits Spruce Canyon. As the river exits the canyon it forms a meander bend to the left as a result of the valley alignment also shifting to the left. As the channel meander bend migrates outward (becomes more elongated) through the end of Spruce Canyon, the river slope and sediment transport capacity are reduced. Consequently, the channel fills with sediment and migrates back toward the inside of the bend to the south. Gradually, the outward migration begins again and the process repeats itself. This process is also affected by recurrent sediment deposits from Tower Creek, with the latest one visible on 2002 aerial photography. However, no evidence of a recent sediment deposit is present on the 1994 aerial photography. It appears that when a sediment wave is transported down Tower Creek, the main channel cannot immediately transport all of the sediment delivered and is pushed to the south (away from Tower Creek). However, if subsequent floods occur before an additional sediment wave, the river will eventually transport the sediment and move farther north. The Tower Creek sediment deposits and valley alignment limit the potential for the channel to flow against and subsequently limit the amount of erosion that can occur on the right HCMZ boundary between the mouth of Spruce Canyon and the confluence with Tower Creek.

Downstream of the bend at Tower Creek, the river has been meandering in the upper portion of Reach 7 since 1950. Near RM 24, the meander bend present in 1960 has gradually progressed downstream and outward toward the HCMZ boundary. Since 1994, the meander bend near RM 23.5 has been locked into place against the protected bank at County Road MP 6.7. The protected bank limits the natural downstream progression of the meander bend. However, even without bank protection, natural erosion at this location is limited for two reasons. First, the boundary here is a high terrace with cobbly material that slows the rate of erosion, but will not completely stop it. Second, the alignment of the meander near RM 24 is approaching a planform that is perpendicular to the valley. When a meander bend reaches this point, the slope becomes flatter making it harder for the river to transport sediment. This usually leads to what is known as a cutoff, where the main channel will take an alternate, straighter and shorter path that results in a steeper slope.

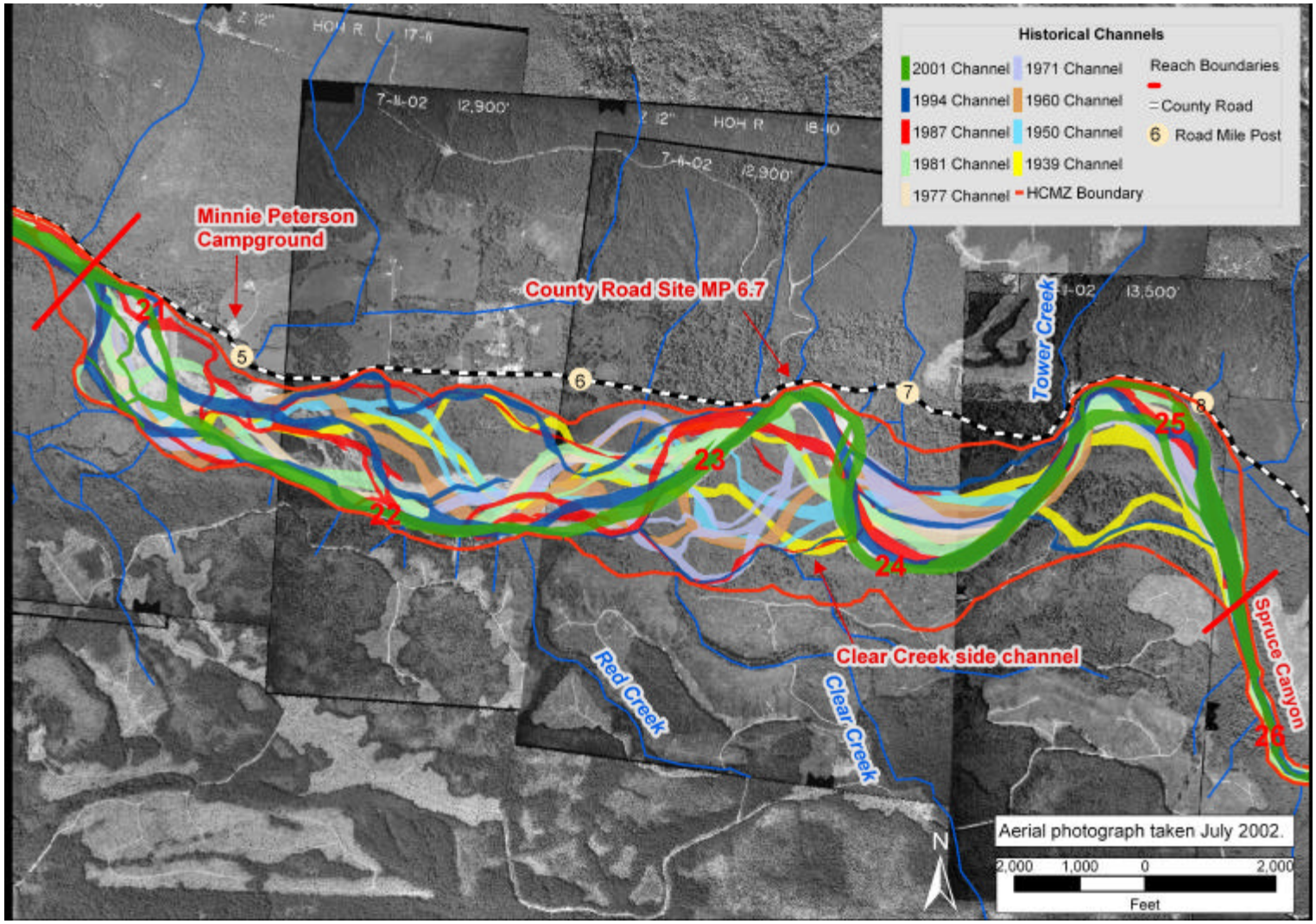


Figure 7. Historical channel alignments in the Morgans Crossing Reach 7.

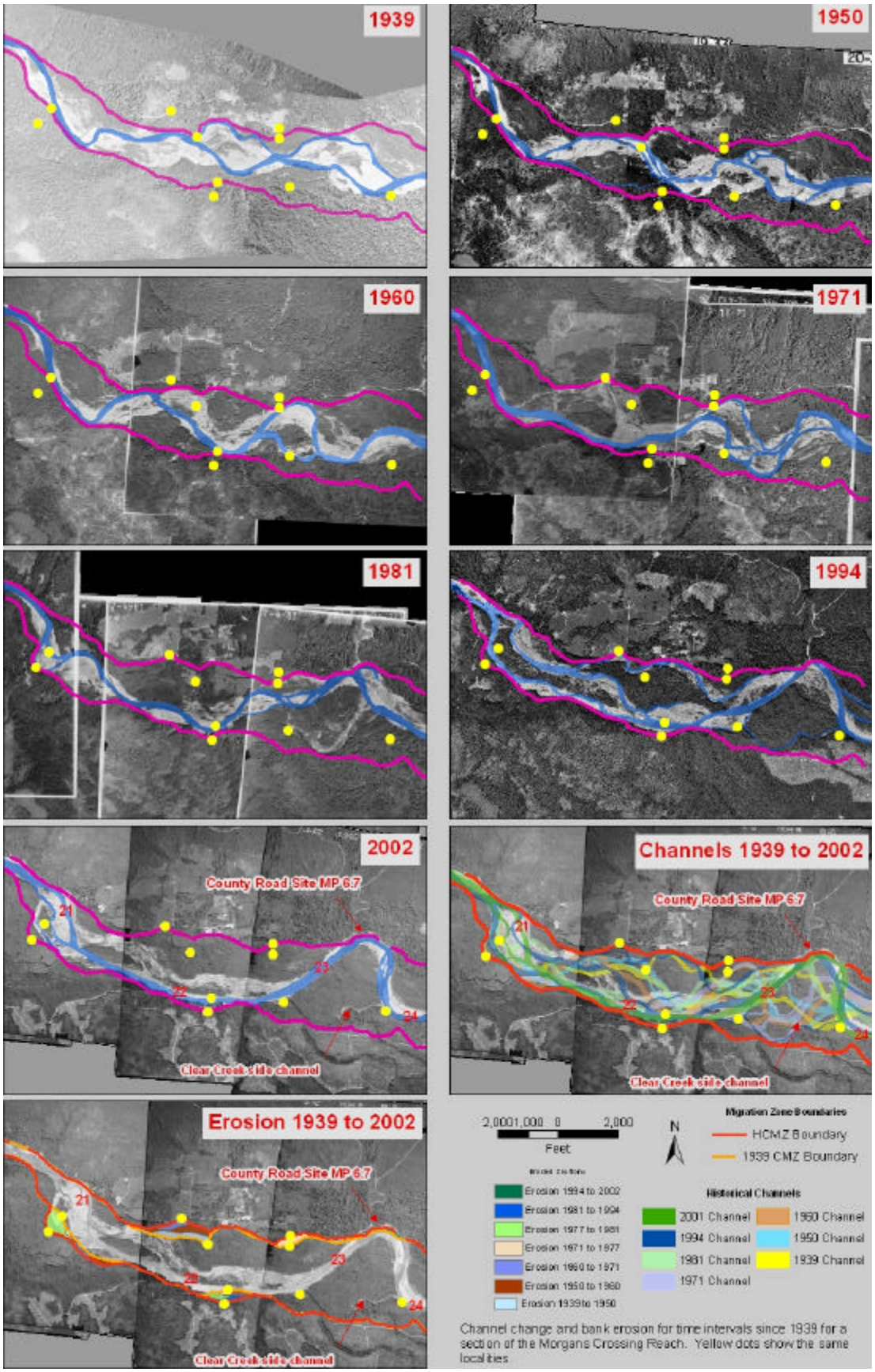


Figure 8. Historical photo sequence for Morgans Crossing Reach showing progression of HCMZ boundary since 1939.

If a large sediment wave were to enter the Hoh River and be transported through Spruce Canyon, the sediment deposition could accelerate the potential for a cutoff and cause the channel to migrate back toward the inside of the river bend and follow a straighter alignment similar to the path in 1939. This would mean that the river channel would cutoff the next downstream meander bend and bypass the County Road MP 6.7. Existing side channels offer potential paths for the river to cutoff during a flood. In this area, the Clear Creek Side Channel is a likely cutoff location, because the 1939 historical channel passed through this area. A natural log jam has formed at the entrance to this side channel, and currently limits the amount of flow and sediment that can enter the side channel. However, if a large enough flood were to occur, portions or the entire log jam could be blown out, and the main channel may completely avulse into this channel. Such a new channel position would likely result in an alignment near RM 24 similar to that of the 1939, 1950, or 1960 channels, and the main river channel would no longer be adjacent to County Road MP 6.7.

The alignment of the river channel through the downstream half of Reach 7 is dependent on the approach from the upstream half. Since the meander at the County Site has been locked into place, the river has been directed straight at the far left HCMZ boundary near RM 22.5. This results in the river being trapped against the left boundary all the way to the end of the reach. However, if a cutoff near RM 24 were to occur, the river would likely take an alternate path through the lower reach. Historical channels have passed through almost every location in the active flood plain in the lower half of the reach.

8.2 Bank Material Composition along HCMZ Boundary

An interpretation of the bank material along the HCMZ boundary for Reach 7 is shown in Figure 9 and discussed below. A summary of the bank material composition is listed in Table 5. The majority of the banks along the HCMZ is composed of alluvium and glacial deposits, which are the most erodible type of bank material.

Table 5. HCMZ Bank Material Composition in Reach 7.

Bank Material Category	Right Bank Composition	Left Bank Composition
Glacial	5%	19%
Alluvium	80%	77%
Alluvial Fan/Debris Flow	2%	4%
Bank Protection	12%	0%
Bedrock	1%	0%

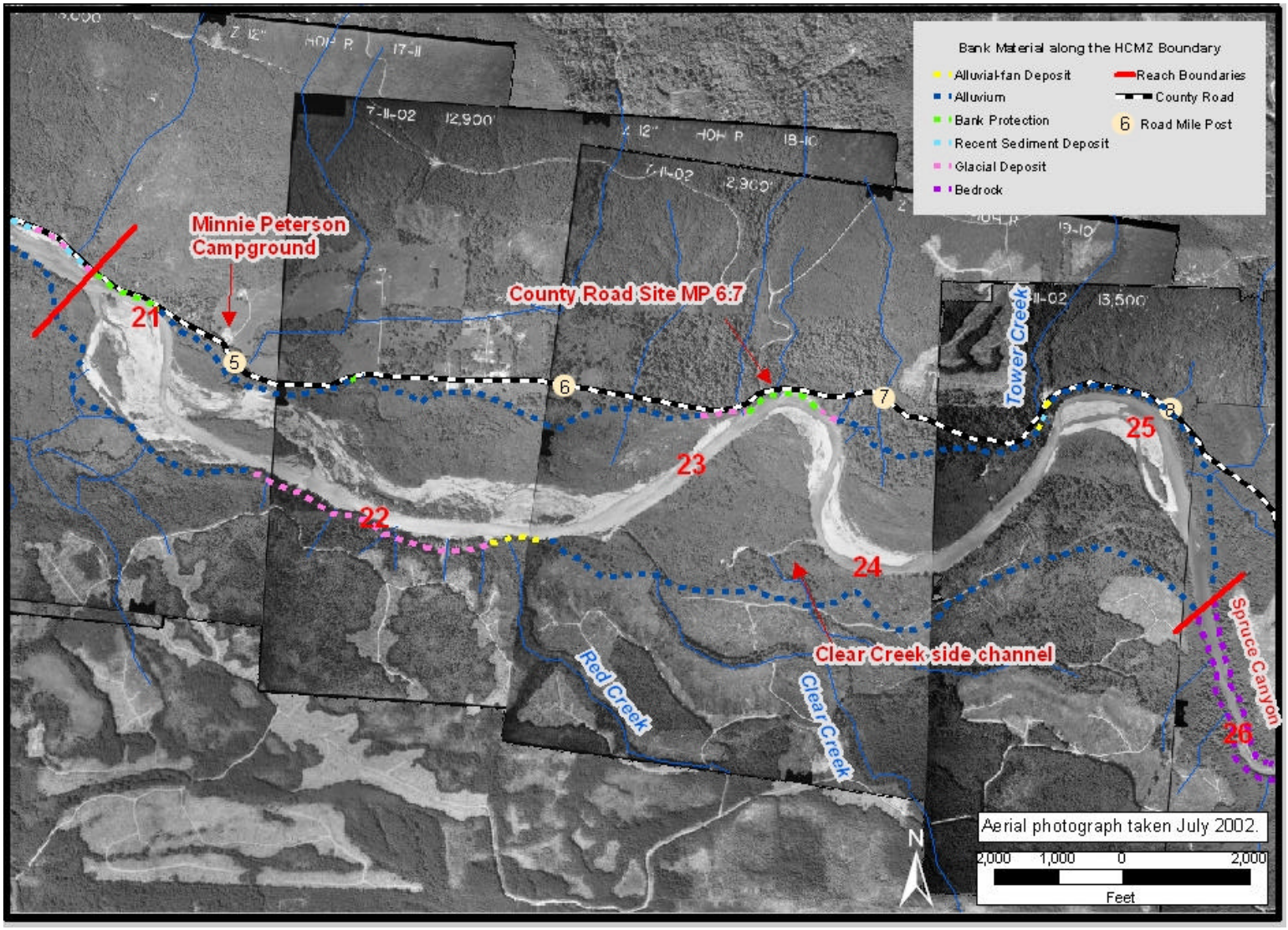


Figure 9. Bank material along the HCMZ boundary in Morgans Crossing Reach.

Erodible Glacial Sections

A section of the left HCMZ boundary near RM 22 is composed of a combination of glacial outwash, lacustrine, and till deposits, which at this locality consist of a sequence of four types of sediment: sand, silt, and clay over cobbly gravel over sand over silt and clay (see attachment D for description). The silt and clay are compact; the other sediments are unconsolidated and very loose. The lower silt and clay force water to flow laterally, where it exits the bank and causes bank failures in the overlying loose sediment. Because of the bank failures, this section of the HCMZ boundary is very unstable now and will continue to be unstable in the future.

Erodible Alluvial Sections

In Reach 7, the HCMZ boundary is composed primarily of alluvium, often with fine-grained flood plain deposits a few feet thick over cobbly channel deposits. Both of these materials are unconsolidated and loose, and, as a result, are very erodible.

Moderately Erodible Alluvial Fan Deposits

Two short sections of the HCMZ boundary in Reach 7 are composed of alluvial-fan deposits. One section is on the left side of the Hoh River near RM 22.5 at the mouth of Red Creek; the other section is on the right side near RM 25 at the mouth of Tower Creek. These deposits are composed of slightly coarser material than the adjacent alluvial banks, and are likely to be somewhat less erodible. Recent sediment deposits observed at Tower Creek indicate that sediment is recurrently supplied to the river and limits the potential lateral erosion of the adjacent HCMZ boundary at this location.

Areas with Human-Placed Bank Protection

Three sections of the right HCMZ boundary are stabilized by human-placed rock bank protection. The longest of these sections is along the County Road at MP 6.7. The natural HCMZ boundary at this locality is composed of glacial deposits, which are sand and silt over cobbly gravel over sand. These sediments are loose, primarily, and are very erodible. The rock bank protection failed at the most upstream section of this site, but the County reconstructed it in September 2002. A very short section on the right near RM 22 is also protected with rock, where the natural bank is composed of loose alluvial deposits. This section is presently along a small side channel of the Hoh River. A third protected section is at the downstream end of Reach 7, near RM 21, where the low-flow channel of the Hoh River presently abuts the right HCMZ boundary, which is composed of erodible glacial deposits. In addition to rock protection, a log jam was constructed in 1998 slightly upstream of the County Road MP 6.7. The log jam is tied into the HCMZ boundary, and has remained in place since construction.

8.3 Comparison of 1939 and 2002 HCMZ Boundaries

In Reach 7, the HCMZ boundary is generally composed of easily erodible alluvium terraces and ranges in width from 1200 to 3000 feet. Several areas of the HCMZ boundary have eroded since 1939 as evident in Figures 8 and 10. The total HCMZ area has increased by 7% since 1939 as a result of 68 acres of erosion along the boundary. Approximately 40 acres was lost from the terraces on the right side of the river, and 28 acres was lost from the left side. However, this erosion was site specific and did not occur along the entire 1939 HCMZ boundary length. Approximately 41% of the right boundary has experienced erosion since 1939, and 25% of the left boundary has experienced erosion. The majority of erosion has occurred along alluvial and glacial banks of the HCMZ boundary in areas where the channel has flowed and the adjacent terrace surfaces have been cleared of trees for development or logging. Specifically, 75% of the 1939 right HCMZ boundary that eroded was composed of alluvium and the remaining 25% was composed of glacial material. For the left bank, 63% of the eroded 1939 boundary was composed of alluvium, 28% of glacial material, and the remaining 8% is located at the transition between a glacial deposit and the edge of an alluvial fan.

In 1939, the river had a relatively straighter course in the upper half of Reach 7 than the channel paths documented since 1950 (see Figures 8 and 10). This straighter river course was 0.5 mile shorter than the existing 2002 channel. Because the upstream and downstream bed elevations of Reach 7 are fixed at the boundaries, the elevation drop through the reach must remain constant. This means that in 1939 the straighter channel had a shorter path that would have had a steeper average slope than the meandering channel measured in the upper half of Reach 7 in 2002. The active, unvegetated channel in 1939 was also wider than the current channel. The straighter and wider active channel in 1939 may be an indication that the river carried a higher sediment load than presently possibly due to a series of large floods in a relatively short timeframe, or due to higher sediment input from upstream sources. When sediment loads significantly increase, the active river channel tends to run straighter (rather than meander) in order to increase the river slope and sediment transport. The 1939 channel may also have resulted from a higher density of stable woody debris and gravel bars in the active channel resulting in multiple channels rather than a single meandering channel path. This process has been documented to occur on the Nisqually River, also located in northwest Washington state (Collins and Montgomery, 2002).

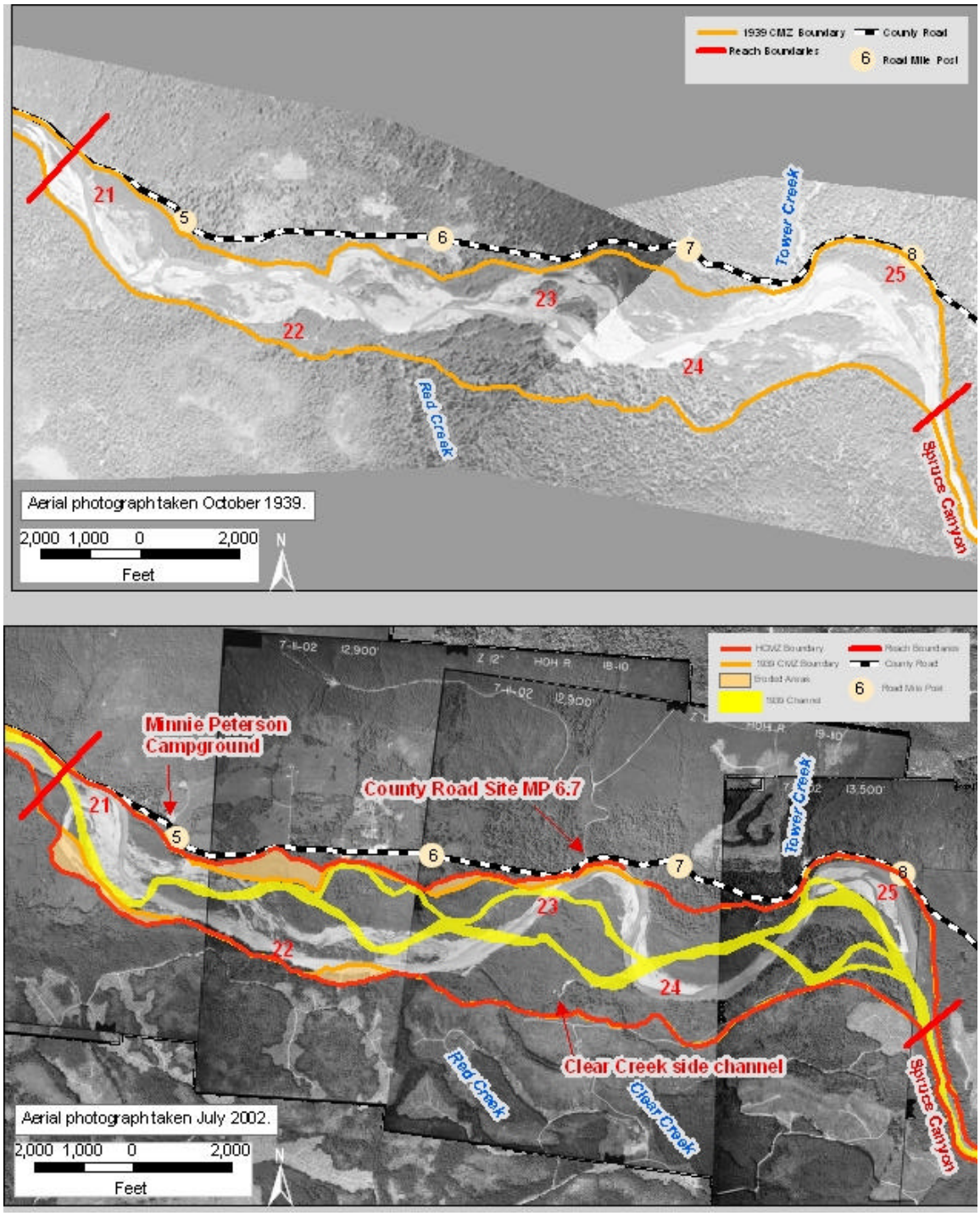


Figure 10. Comparison of the 1939 and 2002 channel migration zones for the Morgans Crossing Reach.

8.4 Erosion Risk along HCMZ Boundary

The risk of erosion along the HCMZ boundary was determined based on the composition of the bank material that composes the boundary, the likelihood that the river will flow against the bank causing erosion, and the potential rate at which that erosion might occur. The following discussion addresses the erosion risk along the HCMZ boundary in Reach 7 from the upstream end of the reach to the downstream end as shown in Figure 11.

Upstream of Reach 7, the river is confined in Spruce Canyon by bedrock, which will always force the flow to the north (right) side of the valley as it exits the canyon. This geologic control results in a low erosion risk (thin green line) for the left HCMZ boundary at the upstream end of Reach 7, and a short portion of the right HCMZ boundary. Between RM 25 and Tower Creek, the erosion of the right HCMZ boundary is limited to a moderate risk because the valley bends to the left (west), which results in the channel also bending to the left as it exits the canyon. Further, recurrent sediment waves transported down Tower Creek provide additional sediment to the river that limits the rate at which the river can erode the outside of the bend at RM 25. The potential rate of erosion at this location on the right boundary is slow because the terrace bank is high and very near the edge of the valley.

The section of the right HCMZ boundary just downstream of Tower Creek has a moderate risk of erosion with a medium rate. Although debris flows from Tower Creek do limit potential river alignments that would erode the boundary, historical alignments suggest that this section has some potential to be eroded. On the opposite (left) side, the HCMZ boundary has only a moderate risk of being eroded because the current meander bend that begins at RM 24 is likely to be cutoff in the next few years. If the channel cuts off and blows out the log jam at the entrance of Clear Creek Side Channel, then the areas of the HCMZ boundary along the edge of this side channel would be quickly eroded. The terrace bank would erode at a fast rate because it has been cleared of vegetation and is composed of alluvium.

At the County Road MP 6.7, the bank is currently protected by rock riprap, but there is a short section near the upstream end where the protection has failed and had to be rebuilt. The high bank composed of glacial deposits upstream of the riprap is currently eroding at a fast rate (shown as thick red line in Figure 11). As long as the channel is against this bank, it will continue to be subject to erosion. However, if a channel cutoff occurs, further erosion would be limited until the channel is once again flowing along this bank. The log jam placed by the County provides some protection to the HCMZ boundary for a short distance upstream and downstream of the jam. Even though a small amount of erosion of the HCMZ boundary has occurred downstream of the log jam, unless the river were to completely blow out the log jam, the structure will limit the extent of future erosion at this location.

Downstream of Clear Creek Side Channel on the left side, there is a short section of alluvial fan that limits erosion, and then a 0.8-mile-long stretch of actively eroding glacial bank. As the river meander at the County Road MP 6.7 has translated downstream and

outward since the 1980's, it has reached a point where it is locked into place because it can no longer move outward or downstream due to the protected bank. The river is now forced across the valley directly at the left HCMZ boundary at about RM 22.5. Once against this left bank, the river follows it all the way to the end of Reach 7. The upstream half of this bank has eroded laterally up to 400 feet since 1939, whereas the downstream half has hardly eroded since 1939 (see Figure 10). A possible explanation is that as the river elevation decreases in the downstream direction, the bank height increases, so that there is a greater volume of material to erode as the river attempts to migrate laterally to the left. Also, the greater the bank height, the greater the volume of boulders and logs that may fall out of the eroding bank and line the toe at the bottom along the river. Additionally, logging on the surface of this left boundary has accelerated the rate at which this bank can erode by destabilizing the bank. However, in a relative sense logging does not have as great as an impact on accelerating lateral erosion on the high glacial banks as it does on lower alluvial banks because the root depth is high above the water surface-bank interface.

On the opposite, right, side between RM 21 and 23, the river has eroded several hundred feet of terrace bank since 1939 (see Figure 10). The majority of erosion has occurred between RM 21 and 22, where the HCMZ boundary is now directly adjacent to the County Road. Clearing of vegetation on the terrace that forms the HCMZ boundary is evident starting in the 1939, and the area cleared increases with time. It appears that the areas where the river meander bends eroded the most amount of bank are areas that were cleared up to the boundary of the HCMZ. Near County Road Mile 6, the risk for erosion is mapped as moderate because there is a large vegetated bar between the river and the HCMZ boundary. However, if the river channel does flow against this boundary, then the rate would be fast because the terrace surface has been cleared of vegetation. Between County Road Mile 5 and 6, the HCMZ boundary has a high risk of erosion at a fast rate. This is because several side channels that currently convey water during floods run near the boundary, and the terrace surface has been cleared of vegetation. One small area near Road Mile 5.5 has already required bank protection to prevent the river from eroding the road embankment (see Figure 9).

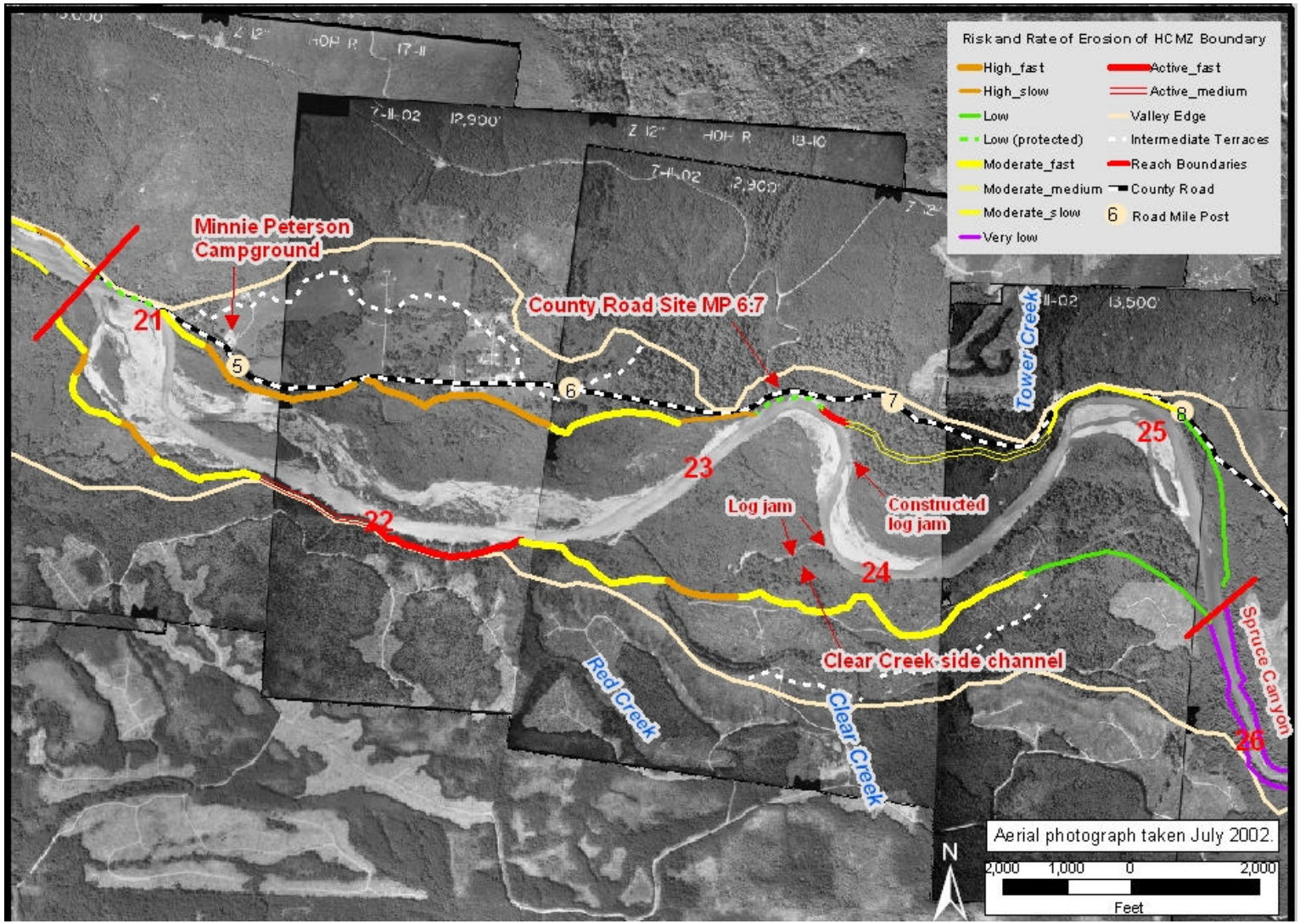


Figure 11. Assessment of the risk of future erosion along the HCMZ boundary in Morgans Crossing Reach.

9.0 MANAGEMENT CONSIDERATIONS FOR MORGANS CROSSING REACH 7

The HCMZ boundary defined in this study has the potential to expand in the future where the boundary is composed of erodible material and subjected to lateral erosion from the river during floods. In undeveloped areas, such as ONP, the rate of this expansion is limited by old growth trees on terrace surfaces that protect the bank. In areas such as Reach 7, clearing of the vegetation adjacent to the HCMZ can accelerate the rate at which the HCMZ boundary expands if the boundary is composed of erodible material such as alluvium or glacial outwash. Also, logging of the riparian flood plain within the HCMZ can accelerate the rate of channel migration and erosion, because bars have less of the vegetation that normally dissipates energy (and water velocities) between the main channel and the boundaries of the HCMZ. Potential management strategies to limit human impacts and to minimize future erosion where infrastructure or property needs to be protected could include setting back the infrastructure farther away from the HCMZ boundary, deflecting the river away from the bank, placing engineered bank protection, or a combination of these options. Because the clearing of riparian forest along the terrace banks or other disturbance (e.g., logging and development) result in the highest potential future rates of lateral erosion, strategies to limit erosion may also include long term land use alternatives such as re-vegetating the terrace surface and preventing development within or adjacent to the HCMZ.

A summary of the erosion risk for Reach 7 is shown in Figure 11 on a 2002 aerial photograph for the right and left HCMZ boundaries. Each category represents the likelihood of erosion (active, high, moderate, low or very low) followed by the potential lateral rate of erosion (fast, medium, or slow) that could occur in the next several years to decades. The erosion risks were based on the characteristics of the HCMZ boundary and adjacent surface, and the existing or potential future location of the active channel. For instance, “active_fast” represents an area that is actively eroding at a fast rate; “high_slow” is an area where the main channel is most likely to move against the HCMZ boundary as a result of a future flood, but when this occurs the rate of lateral erosion would be slow. The following section addresses areas of the HCMZ boundary in Reach 7 already actively eroding, or categorized at a high or moderate risk for eroding in the near future. An additional discussion of management considerations at County Road MP 6.7 is also included.

9.1 Active Erosion Areas

The longest portion of actively eroding bank is along the left HCMZ boundary near RM 22 (see Figure 11). The upstream half of this bank is laterally eroding at a medium rate relative to the downstream half that is eroding at a slow rate, and is currently unstable due to the glacial material that composes the high bank. The river has run against this bank several times since 1939, but detectable erosion was not observed until 1960 when the outside of a meander bend flowed against this bank. The total estimated erosion of approximately 9.9 acres has gradually occurred since that time. The complete failure of

the hillslope that can be observed today appears to have begun in the 1970's based on the aerial photography.

The cause of erosion and eventual hillslope failure at this location may be related to a combination of factors. Several drainages were mapped across this surface in the Middle Hoh Watershed Analysis (Parks, 1999). Seepage from these drainages and undercutting of the toe of the slope by the river are likely major contributors to the erosion and failure of the hillslope. Logging on the terrace surface was first observed in the 1950 aerial photography, but a buffer zone of trees has typically existed between the edge of the logging and the top of the bank. Although logging may not be the dominant factor for hillslope failure, it may have contributed by allowing more surface flow to runoff the top of the bank initiating failure, or by allowing more precipitation to reach the ground (no interception by tree canopy) and thus increase seepage rates to the hillslope. As long as the river remains against this bank, the boundary will continue to be unstable in the future and erosion will also continue.

9.2 Areas with High Risk for Future Erosion

The areas at a high risk for erosion in the next few years in this reach are where terraces along the HCMZ boundary have been cleared of vegetation for either development or logging and the channel is likely to flow against them. The longest section mapped as a high likelihood of erosion at a fast rate is along the right HCMZ boundary between RM 21 and 22.5. If the main channel cuts off its current path as predicted, it is likely that the new flow path may be against portions of this right HCMZ boundary. Currently, several side channels flow at or near the boundary and in one location bank protection has had to be placed to protect the County Road. Because the HCMZ boundary is very near the County Road between Road Miles 4.5 to 5.5, the road embankment should be closely monitored for stability if the channel does change course. If protection of this section of road is a priority, management options could include setting the road back to the next terrace surface or installing bank protection or river deflection structures now (in the dry) before the river changes course. Although it is difficult to predict the exact future alignment of the river, the County could proactively decide now what future alignment to defend. Engineered log jams or traditional rock structures also could be considered. Either way, removal of vegetation within or adjacent to the HCMZ should be limited even if no proactive protection is placed because an absence of vegetation would increase the potential for accelerated lateral erosion toward the road.

On the left boundary, there are two small sections at a high risk of being eroded also at a fast rate, but at the present time there is no infrastructure at these locations. The first section is where Clear Creek side channel runs against the HCMZ boundary and the second is at the downstream end of the reach near RM 21.

9.3 Areas with Moderate Risk for Future Erosion

The moderate risk implies these sections are predicted to be at risk over the next several years to decades, but not as soon as areas categorized at a high risk. There are several

segments on the left HCMZ boundary mapped as a moderate risk but are predicted to erode quickly if the river does run against this boundary. These sections would be eroded at a fast rate because the surface vegetation has been cleared of all old growth trees that would naturally slow the rate of erosion. Near the upstream end of the reach, the County Road between Road Miles 7.5 to 8 is categorized as a moderate risk because the channel often runs against it, but the rate is slow. Although the river often runs along this boundary, the potential for future erosion is limited because of sediment deposits in the main river from Tower Creek and the change in alignment of the valley as the river exits Spruce Canyon.

9.4 County Road MP 6.7 Site

The conclusions from the reach analysis indicate that the current meander bend at MP 6.7 will likely be cutoff and the active channel will be located further to the south. The development of a meander cutoff would mean that the present active channel would become a side channel along the County Road MP 6.7. However, as long as the river continues to run against this bank as it does now, it is likely the failure of the bank material will continue, particularly at the upstream end where it has already failed in the past. If nothing is done, there is a high risk that the meander bend will continue progressing downstream (until it is cut off) and cause additional erosion of the bank and riprap. Additionally, the river is dynamic and it is likely the river will flow against this bank again in the future, even if it is temporarily cut off. Therefore, in order to prevent any additional erosion of the existing road embankment, stabilization of the existing bank would be needed.

At the request of the County, GeoEngineers has proposed a series of three log jams along the right bank that would be located between the existing constructed log jam and the upstream end of the existing bank protection (Figure 12, Jefferson County, 2003). The purpose of the log jams would be to deflect the river thalweg and high velocities away from the right bank and prevent the bank upstream of the riprap, and the riprap itself, from failing. If properly designed and tied into the bank so that the log jams remain stable, the proposed engineered log jams will help to deflect the river away from the bank, and would provide some insurance that the bank will continue to be protected in the future. A small amount of erosion may temporarily occur upstream and downstream of each log jam, but because they are spaced less than a channel width apart, each log jam should create a depositional zone on its downstream side that would limit the potential for the channel to flow against the bank and cause further lateral erosion toward the County Road. The rate of future channel changes will depend on the magnitude and frequency of future floods and sediment loads on the Hoh River. The existing log jam, and any additional log jams that are added in the future, will help create fish habitat along the right bank of the existing active channel. After a future cutoff of the upstream meander bend, these log jams would continue to provide fish habitat as a side channel forms in the flood plain.

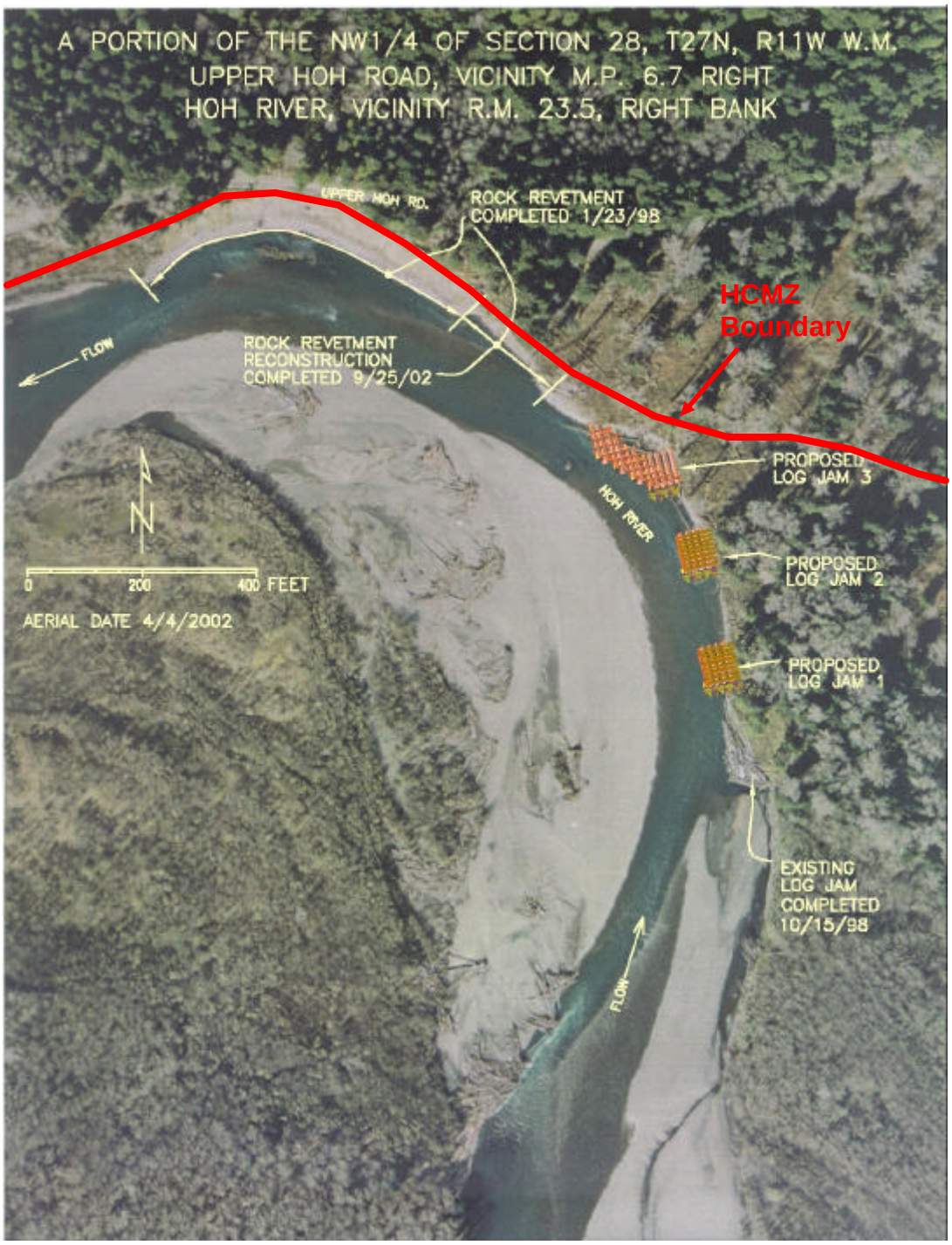


Figure 12. Schematic of proposed engineering log jams and superimposed HCMZ boundary on right bank (schematic provided by Jefferson County, 2003).

The existing road is at or very near the HCMZ boundary. Another management option for the County Road MP 6.7 would be to set back the road closer to the edge (toe) of the valley. If the road is setback, it would need to be determined how far to set the road back, whether to continue with the proposed engineered log jam project, and how to manage the existing bank protection and road embankment.

If the road were setback, it is difficult to determine if future bank erosion would ever reach the setback road or the exact timeframe at which this might occur. Although the river is likely to cut off and abandon its current location in the near future, the farther the road is setback toward the valley wall, the less risk there would be for potential future erosion of the road embankment. The existing road is approximately 300 to 400 feet away from the valley edge in most locations. Based on historical lateral erosion measurements, the road should be setback far enough to allow a buffer zone of large diameter trees between the river bank and the road setback location to help minimize future lateral bank erosion. A minimum buffer zone that could be considered is at least an active channel width, about 200 feet. Given this assumption, if a road setback was the desired option, then it would be appropriate to set back the road all the way to the valley edge as shown in Figure 13 to allow for an additional factor of safety beyond the minimal 200 feet. However, the road should not be set so close to the valley wall that it has the potential to cause a landslide, particularly in the area mapped as a landslide on rock in Figure 13 (Gerstel, 1999).

Because the vegetation has been cleared where the road is currently located, the rate of lateral erosion could be accelerated if the road were set back and the existing bank protection failed or were removed. However, the rate of lateral erosion would likely slow once the river encountered the buffer zone area with significant sized trees between the setback location and the HCMZ boundary. While it is not practical to assume the existing riprap would be maintained if the road is setback to the valley edge, The existing riprap should be left in place (even if it is not maintained) in order to avoid accelerating the erosion of the terrace bank. Further, the abandoned road embankment could be stockpiled with large-diameter trees cleared for the road setback location. The trees should be placed perpendicular to the river alignment so that if the abandoned road embankment began eroding, the trees would have a better chance of reaching the river edge together and form a jam rather than being floated away one at a time. If enough trees fell in and lined the eroding bank either from those stockpiled on the abandoned road or from the buffer zone, this would minimize lateral erosion rates.

If the County Road is setback to the valley edge, the proposed engineered log jams would not be needed to protect the road because lateral erosion would not be expected to reach the setback location over the next several decades. However, the engineered log jams would help deflect the river away from the current road location limiting future erosion, and might provide valuable aquatic habitat in this reach.

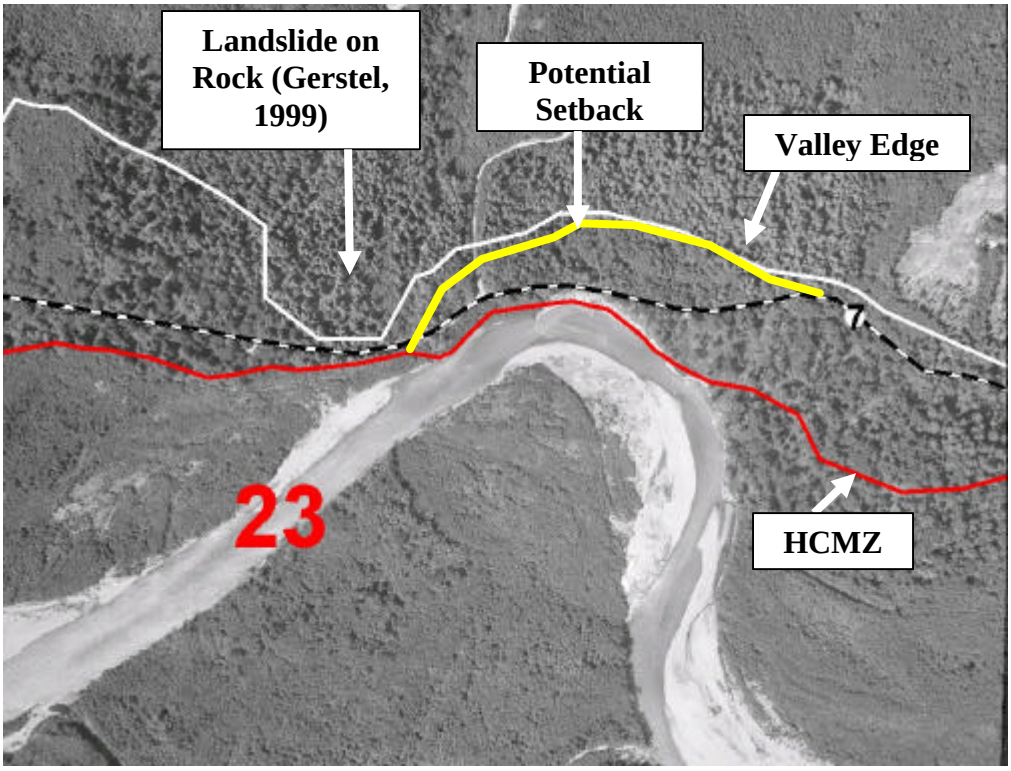


Figure 13. Potential road setback option at County Road MP 6.7.

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ATTACHMENT A

Reclamation Control Network for Hoh River Established April 2000

The control network data was established by a Reclamation licensed survey crew from Ephrata, WA, for river channel survey work in April 2000. This control network was based upon three permanent monuments set by the Washington State Department of Transportation (RUBY, GP16101-10, and NOLAN). Each of these monuments was set using Global Positioning System (GPS) equipment and have a published horizontal accuracy of 2 cm and vertical accuracy of 5 cm (ellipsoid height). The datum for the network is Washington North State Plane Coordinates, North American Datum 1983, and National Geodetic Vertical Datum 1988 and was computed with GEOID99. Listed below are the coordinates of the network base stations, descriptions and directions to each base station, and figures showing the general location of each point along the river channel.

Reclamation Point Number	Easting (NAD 83 ft)	Northing (NAD 83 ft)	Elevation (NADV 88 ft)	Point Description
10	783074.56	295493.44	125.25	Permanent WDOT Monument "NOLAN"
11	860210.11	308639.22	737.53	5/8 REBAR
21	759110.17	278762.82	117.73	Permanent WDOT Monument "RUBY"
22	799036.38	303753.95	163.47	Permanent WDOT Monument "GP 16101-10"
23	834054.48	305204.17	595.94	5/8 REBAR
30	788712.00	303540.03	265.83	ALUM CAP
31	765563.87	293468.08	36.75	ALUM CAP
32	800534.45	313495.27	321.23	ALUM CAP
33	824583.94	321467.58	2096.86	5/8 Rebar
34	859109.99	315647.18	442.11	5/8 REBAR
38	864468.82	317658.08	468.40	SET SPK
40	877869.26	329023.50	581.74	SET SPK
41	877804.47	328990.94	576.98	SET SPK

Reclamation Control Network Point Descriptions

Point 10
This point is also known as NOLAN ID #4412 in the WADOT monument database. This point can be found on their Web site at www.wsdot.wa.gov/monument/report.cfm

Point 11
From the intersection of Hwy. 101 and Clear Creek Rd.(H1000), take Clear Creek Rd. for 6.9 miles to an intersection. Take the road to the left (H1000). Continue on road H1000 for another 6.85 miles to a gravel road on the right. Take the gravel road for 0.3 miles to a fork and to the point. The point is on the right side of the fork. Point is a 5/8" Rebar with a center punch mark. The point is 13.0' south of a steel witness post. The point is 9.4' north of the upstream end of CMP. The intersection of H1000 and the gravel road to the point is 0.65 miles past the intersection of road H1000 and road H1065.

Point 21
This point is also known as RUBY ID #1585 in the WADOT monument database. This point can be found on their Web site at www.wsdot.wa.gov/monument/report.cfm

Point 22
This point is also known as GP16101-10 ID #1961 in the WADOT monument database. This point can be found on their Web site at www.wsdot.wa.gov/monument/report.cfm

Point 23
From the intersection of Hwy. 101 and Clear Creek Rd.(H1000), take Clear Creek Rd. for 5.35 miles to a gravel road on the left (H1040). Take road H1040 for 1.2 miles to a fork. At the fork take road H1043 to the left. Proceed on road H1043 for 0.4 miles to the point on the left. The point is in the middle of a small turn out. The point is a 5/8" Rebar with a center punch mark. From the point to the WNW 15.4' is a steel witness post. The point is 22' left of the CL of road H1043. Ownership of land unknown.

Point 30
From the intersection of Hwy. 101 & Oil City Rd., take Oil City Rd. for 3.05 miles to a gravel road on the left with a cable across the road. Go through the cable gate and go 0.18 miles to the end of gravel road and end of truck travel. Then pack East along grown over road for 300'+/- to the point. Point #30 is an Aluminum cap on 5/8" Rebar stamped "30". There is a wood guard stake along side. The point is 7' South of a stump painted pink and 4' north of an unpainted stump. The point is 25' Northeast of a slash pile. Point is on WA DNR land.

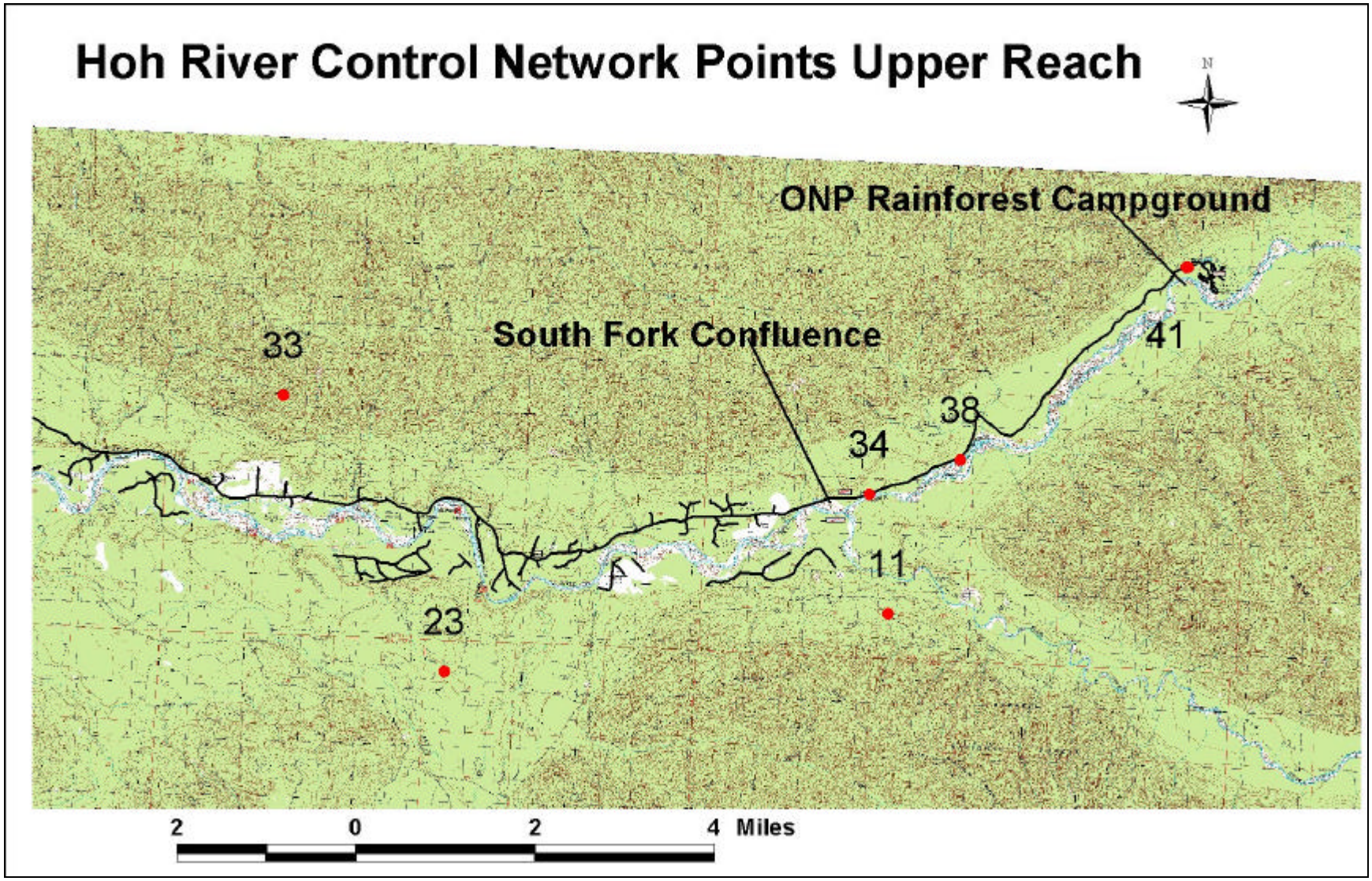
Point 31
From the intersection of Hwy. 101 & Oil City Rd., take Oil City Rd. for 9.05 miles to the point on the left. The point is an Aluminum cap on a 5/8" Rebar stamped "31". The pin is 35' south of the CL of gravel road. The pin is 5' north of top of river bank. The point is 105' SSW of power pole "2613 213801". The pin is 52' south of a metal T post and

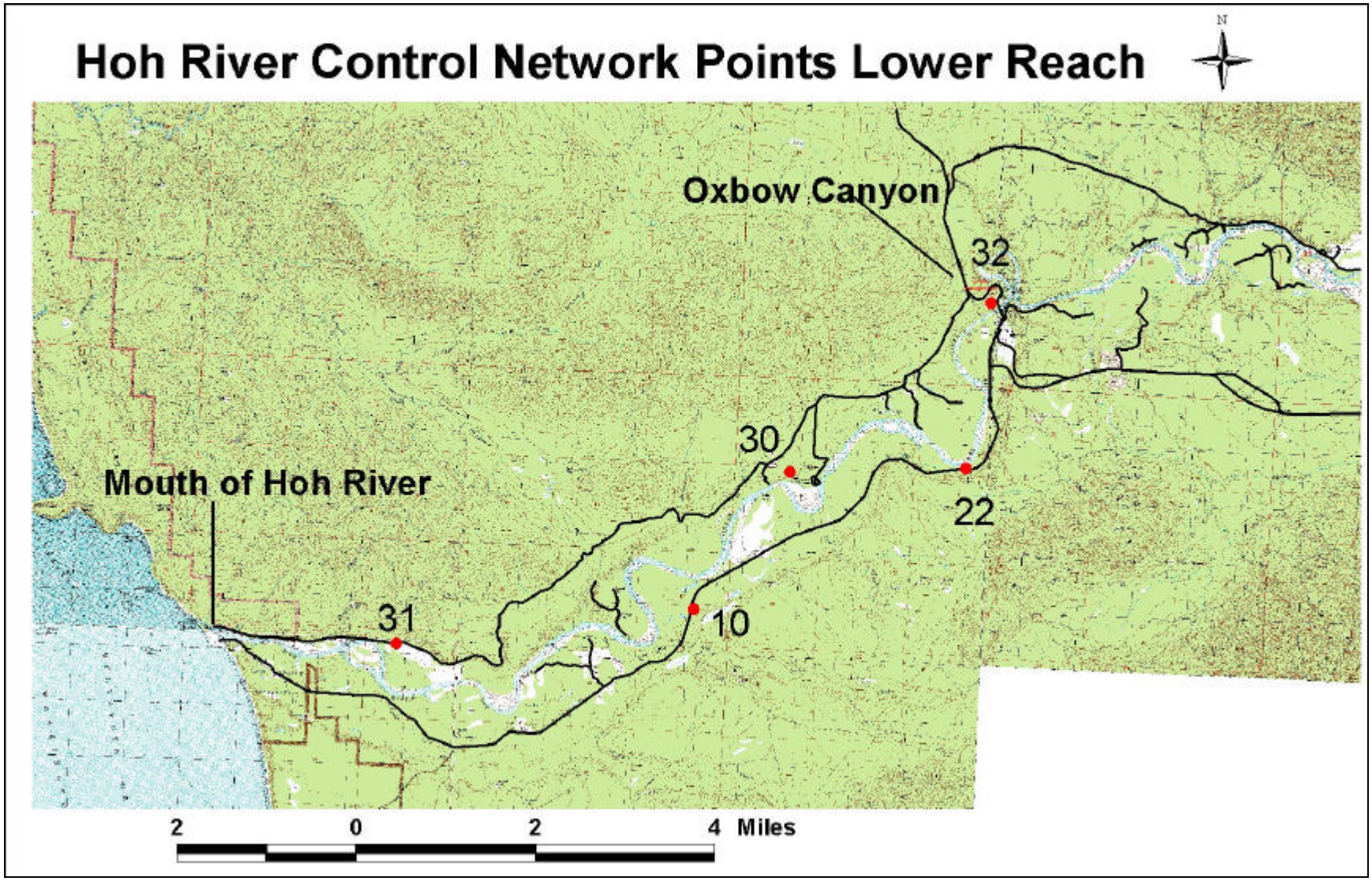
115' east of a metal T post. The point is in the middle of curve to the left. The pin is on private land. Contact land owner before using point.

Point 32
From the intersection of Hwy. 101 & Oil City Rd., take Oil City Rd. for 0.2 miles to a gravel road on the left. Take the gravel road. On the gravel road take the forks that go to the left, from the pavement to the point is 0.35 miles. The point is an Aluminum cap on a 5/8' Rebar stamped "32". The point is set on the south side of the gravel road. The point is 10' north of a slash pile and 3.2' north of a steel witness post. Ownership of land is not known.

Point 33
From the intersection of Hwy. 101 and Upper Hoh Rd., take the Upper Hoh Rd. for 6.5 miles to a gravel road on the left (H3700). Take road H3700 for 0.35 miles to a fork. Take the left fork road H3100. On road H3100 go 1.4 miles to a gravel road on the right (H3160). Take road H3160 for 2.1 +/- miles to a sharp turn to the left. The point is to the right of this sharp turn to the left. There is a pull out that a vehicle can be parked in. From the turn out proceed to the SSW approx. 60' and to the point. The point is in a small clearing on the side of the hill. The point is an Aluminum cap on 5/8" Rebar. The Land is owned by WA DNR.

Point 34
From the intersection of Hwy. 101 and Upper Hoh Rd., take the Upper Hoh Rd. for 12.95 miles to the point on the right. The point is an Aluminum cap on 5/8" Rebar, stamped "34". The point is 20' south of the CL of the pavement and 4' north of the top of Rip Rapped bank. The point is 130' west of Plastic cap marked "99003" set by the Federal Highway Department. This point is on NPS land.


Hoh River Control Network Points Upper Reach
N
ONP Rainforest Campground
South Fork Confluence
33
41
38
34
11
23
2
0
2
4 Miles


Hoh River Control Network Points Lower Reach
N
Oxbow Canyon
32
30
22
Mouth of Hoh River
31
10
2
0
2
4 Miles

Attachment B: Time-lapse Photography at County Road MP 6.7

Figure B-1: View from camera 3 on November 11, 2000, at 12:15 pm (USGS Gage: 1,185 cfs).

Figure B-2: View from camera 3 on January 5, 2001, at 8:15 (USGS Gage: 14,300 cfs).

Figure B-3: View from camera 3 on February 25, 2001, at 12:15 pm (USGS Gage: 1,000 cfs).

ATTACHMENT C: METHODS USED TO ASSESS THE RISK OF CHANNEL MIGRATION ZONE EXPANSION

Expansion of the HCMZ is a natural process that results from a continually changing, dynamic river channel. In addition to delineating the HCMZ, the risk of expansion along the HCMZ boundary was identified to help provide a useful tool for understanding which areas along the HCMZ boundary are most likely to erode and how quickly. While expansion of the HCMZ is natural, the rates of expansion can be drastically different in areas where development has occurred. Areas where human impacts may be accelerating the rate of expansion were also incorporated into the risk assessment. The risk of HCMZ expansion was developed using the following three steps:

<u>STEP 1:</u> Assess the likelihood that bank erosion will occur along reaches of the HCMZ boundary (categorized from no potential to erode to actively eroding)

<u>STEP 2:</u> For reaches actively eroding or likely to erode, estimate the potential rates at which bank erosion could progress (slow, medium, or fast)

<u>STEP 3:</u> Combine the likelihood of erosion and the potential erosion rates to determine the relative risk for expanding the HCMZ boundary

The likelihood of bank erosion (STEP 1) is primarily dependent upon two main factors: (1) the properties of the material in the bank, and (2) the bank's location relative to existing or potential mainstem or side channel locations of the Hoh River. Bank material properties were subdivided into five categories of erosion likelihood ranging from very little potential to erode, such as a bedrock outcrop, to a high potential to erode, such as fine-grained glacial material. Likelihood of erosion is also dependent on whether the main channel or a primary side channel of the Hoh River is currently or has the potential to flow adjacent to the bank. The greater the erodibility of the bank material and the greater the chance the river will run against the bank, the higher the likelihood of erosion. For example, if the material in a bank were loose (fine sediment that has the potential to be easily eroded) then it would have a high potential for erosion. However, the likelihood of erosion would only remain high if the river had a high likelihood of running against the bank in the near future. Historical channel paths and features that limit channel changes (bedrock, log jams, debris flows, etc) were used to estimate the likelihood of potential future channel paths along a given terrace bank.

The potential rate of bank erosion (STEP 2) was determined to assess the relative speed at which a bank might erode if erosion was initiated from the Hoh River flowing adjacent to the bank. Rates were broken into three categories including slow, medium, and fast. The potential erosion rate is dependent on two main factors: (1) the properties of the material in the bank, and (2) the vegetation and land use on the surface within and adjacent to the HCMZ. In some cases, bank height also affects the potential rate of lateral erosion assigned because there is more material to erode when the bank is higher.

1.1 STEP 1: Assess the Likelihood of Erosion of the HCMZ Boundary

Assessment of the likelihood of bank erosion along the HCMZ boundary was accomplished through four basic tasks (Figure C-1).

TASK 1A: Identify areas of active bank erosion along the HCMZ boundary
For remaining banks along the HCMZ boundary that are not actively eroding, the following tasks were completed.

TASK 1B: Estimate the erodibility of bank material

TASK 1C: Estimate the potential for main or side channels to flow against the HCMZ boundary

TASK 1D: Assign a likelihood of erosion based on results from Tasks 1B and 1C

1.1.1 TASK 1A: Map Actively Eroding Terrace Banks

The first task was to identify banks along the HCMZ that are actively eroding. Because actively eroding terrace banks pose the most immediate risk for expansion of the HCMZ, they were mapped in a separate category and have the most detailed information. Actively eroding terrace banks were initially identified in the office using aerial photography and subsequently verified during a field trip in August 2002. The characteristics of the actively eroding banks were described and are included for Reach 7 in Attachment D. Evidence for active erosion includes an adjacent river channel, a vertical or overhanging (undercut) slope, exposed roots, a lack of vegetation, toppled or disturbed trees (usually small alder) or shrubs, slumps, or water seeping from the bank (often just above silty clay beds).

Many of the actively eroding banks are located on the outside of present meander bends of the main Hoh River channel. Most of these banks are composed of loosely consolidated alluvial deposits or glacial deposits. The most unstable active banks are predominantly loose sand. Other actively eroding banks include some clay and silt beds, along which sediment is recurrently slumping.

1.1.2 TASK 1B: Estimate Terrace Bank Material Erodibility

For the remaining terrace banks along the HCMZ boundary without obvious evidence for active erosion, the second task was to estimate the bank material to help determine the potential erodibility. Bank material was estimated using field observations, a published geologic 1:125,000-scale map (Tabor and Cady, 1978), and 1:24,000-scale topographic maps to interpret geologic deposits and related geomorphic features such as alluvial fans (Figure C-2).

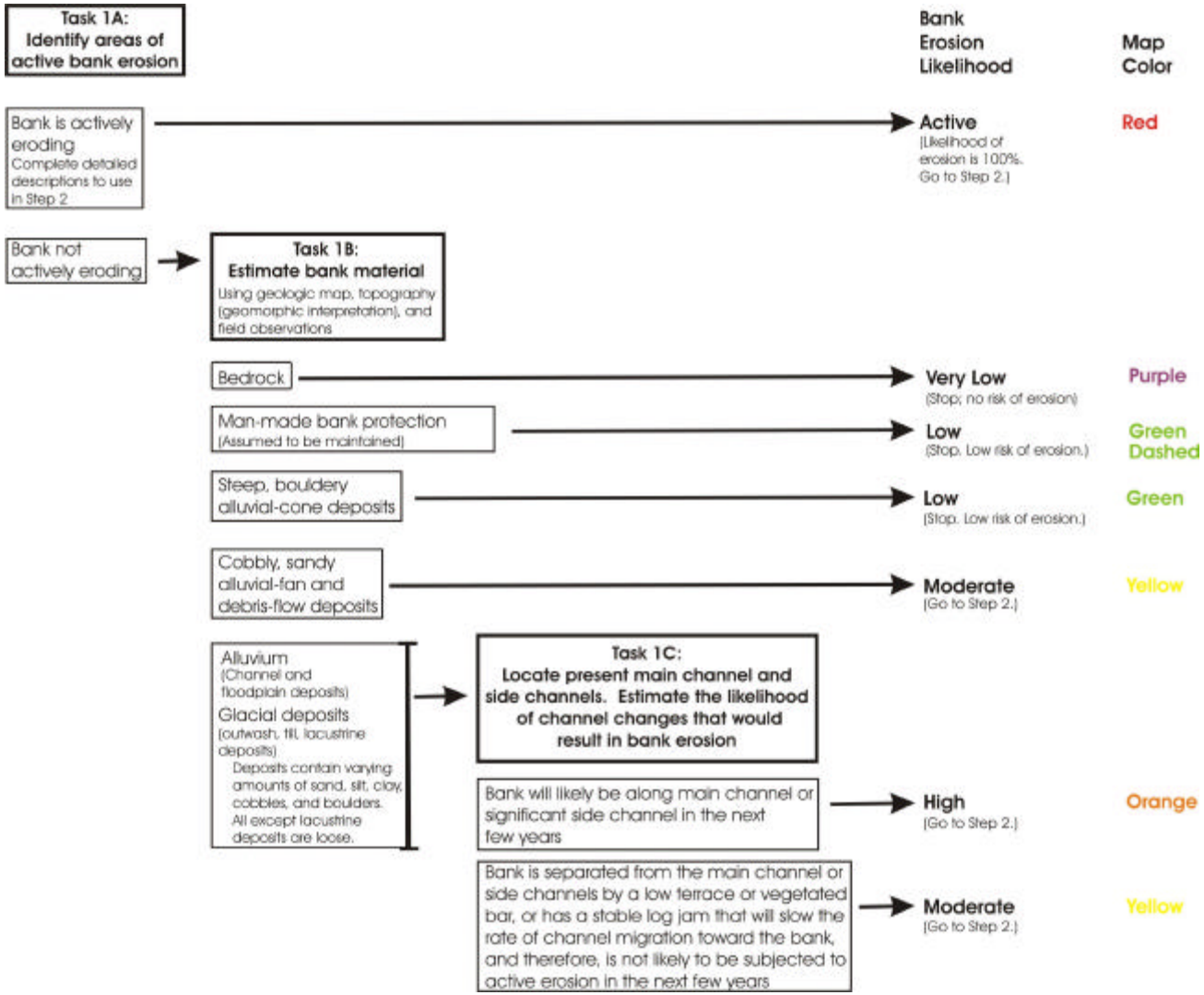


Figure C-1. Step 1: Assessment of the likelihood of bank erosion along the HCMZ boundary

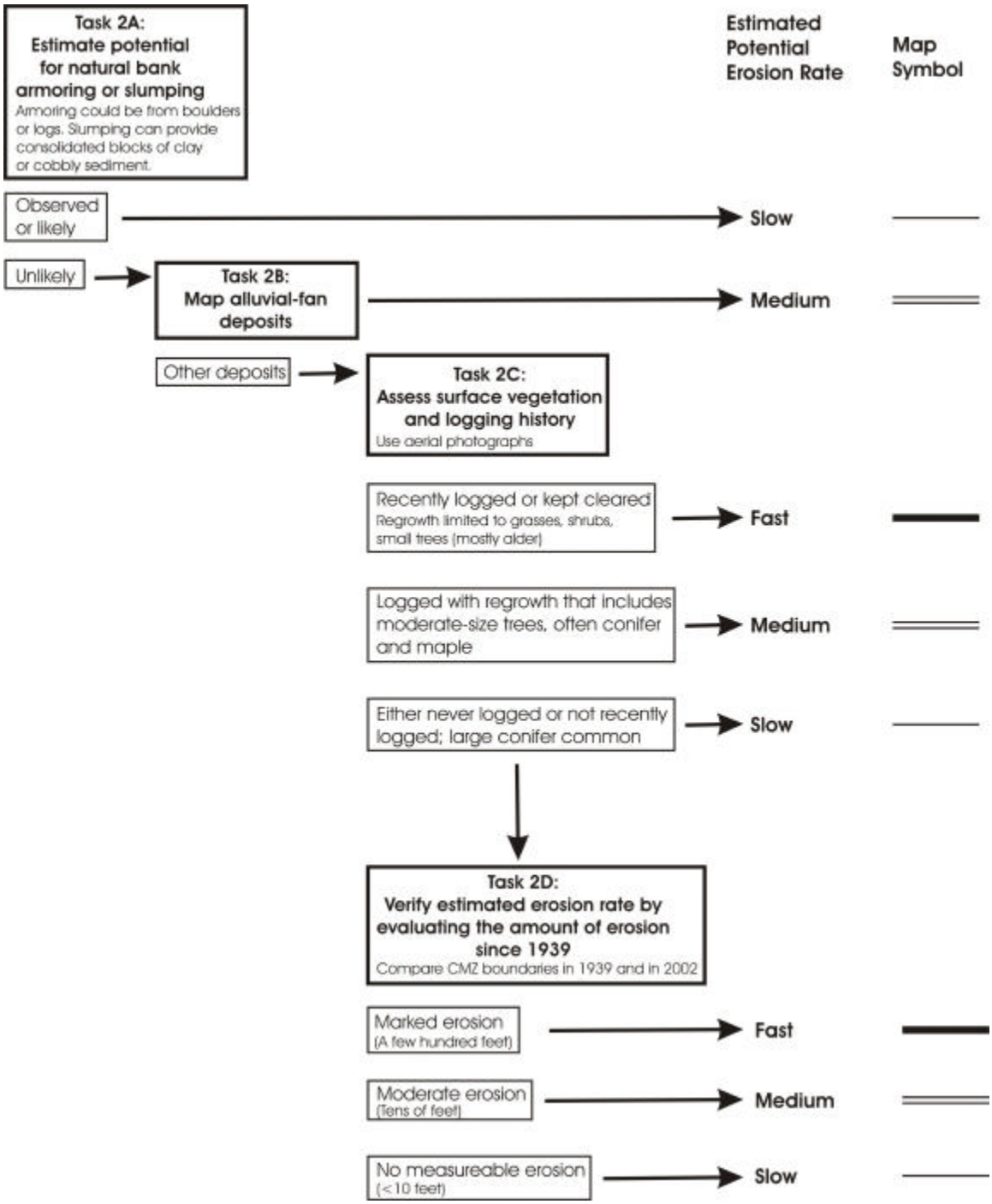


Figure C-2. Step 2: Estimation of the potential rates of bank erosion along the HCMZ boundary

Because the Hoh River has downcut through bedrock, Pleistocene glacial deposits, and Pleistocene and Holocene alluvial deposits, sediment in the banks is quite variable, both vertically and laterally. We have tried to assess the dominant characteristics for the terrace banks in these deposits that would serve as the best indicator of erodibility. The bank material was broken up into the following categories described below.

Bedrock – Erodibility: VERY LOW
Banks that are composed of naturally formed bedrock. Along the entire study area, two areas of bedrock are present: one in Spruce Canyon in Reach 6 and one in Oxbow Canyon, just downstream of Reach 8. Banks composed of bedrock are generally stable, limit channel migration, and have essentially very little chance for measurable erosion during the next several decades.

Human-placed protection – Erodibility: LOW
Terrace banks along the HCMZ that are protected through man-made activities, including riprap, engineered or placed logs, and road embankments. We assume that the protection will be maintained, so that the likelihood for erosion of these banks is very low, regardless of the natural underlying bank composition. In a few locations, banks have been protected that are within the HCMZ rather than on the boundary. In these cases, the bank protection was identified along with the natural boundary of the HCMZ and the material that composes it.

Alluvial fan deposits – Erodibility: LOW to MODERATE
Two types of alluvial fan deposits were observed in the study reach (Harvey, 1997). The two types were not distinguished for mapping of bank categorization, but were incorporated when determining the potential for future lateral erosion. For each alluvial fan deposit, recent sediment deposits that reached the Hoh River channel were mapped where observed during field investigations. Sediment deposits that reach the river channel can limit lateral erosion of the HCMZ depending on the size of material, the frequency of occurrence, and the process initiating the sediment transport. Estimating the frequency of occurrence and characterizing the origin of the sediment deposit were beyond the scope of this study, but could include a range of processes from debris flows to reworking of bed-material during flood events. Generally speaking, debris flows have the capacity to carry larger sized sediment due to slurry type transport as opposed to capacity limited transport of flood events (limited by slope and discharge).

> **Type 1: Steep, alluvial fans located at toe of valley wall with large sized-material (cobble and boulder) – Erodibility: LOW**
> Alluvial deposits that are associated with steep alluvial fans, contain cobble and boulder-sized material, and generally drop right into the active channel or flood plain without crossing any terrace surfaces. They are present at the mouths of tributaries that drain steep rock slopes immediately adjacent to the Hoh valley. Steep alluvial fans were observed along the HCMZ boundary upstream of the South Fork in Reaches 1 through 4.

These steep alluvial fans are not very likely to be eroded by the Hoh River, and are categorized to have a low likelihood of erosion. Although unconsolidated, the large cobbles and boulders in the fans are difficult for the river to transport, especially with the reduced flow upstream of the confluence with the South Fork of the Hoh River.

Type 2: Alluvial-fan deposits present on terrace surfaces with sand to cobble-sized material – Erodibility: MODERATE

Other alluvial-fan deposits develop as tributaries along the Hoh River drop off the steep valley wall onto terrace surfaces before reaching the active flood plain of the Hoh River. The alluvial fans are formed from sediment transported down the tributary channel and deposited where the tributary slopes flatten. As one channel fills with sediment, the tributary channel will shift to another location. Over long periods of time, the various channel positions and sediment deposits form the "alluvial fan", with the widest portion of the fan at the confluence with the Hoh River. These deposits are often found at the mouths of larger tributaries downstream of the South Fork, where the valley is relatively wide, primarily in Reaches 5, 7, and 8. Alluvial-fan deposits located on terrace surfaces are generally composed of finer-sized material (sand, gravel, and cobble) and have flatter slopes than the steep alluvial-fan deposits.

Because of the finer-sized sediment and flatter slopes in the Type 2 alluvial-fan deposits relative to those of the Type 1 steep alluvial-fan deposits, these deposits are assumed to be more easily eroded by the Hoh River and are assigned a moderate (instead of low) likelihood of erosion (Figure 5). These areas are not assigned a high likelihood of erosion because pulses of sediment periodically transported down the channels limit the likelihood of lateral erosion, even if the sediment sizes are small relative to the steep alluvial fans found in the upper watershed.

Alluvial and glacial deposits – Erodibility: MODERATE TO HIGH

The remaining banks are composed of alluvial and glacial deposits. Most of the alluvial deposits are associated with terraces of the Hoh River and its major tributaries. Alluvial deposits associated with terraces consist of both fine-grained (silty and sandy) flood plain deposits and cobbly channel deposits. Often both are present in one bank, with flood plain deposits a few feet thick overlying cobbly channel deposits.

The glacial deposits are present throughout the valley and are associated with high surfaces and ridges. The glacial deposits include outwash and till deposits that are composed of loosely consolidated sand, silt, cobbles, and boulders, as well as lacustrine deposits, which are thin to thick beds of compact silt and clay. The lacustrine beds act as a barrier to downward water movement, so that water is forced to flow laterally along these beds until it reaches the bank. The outward-flowing water contributes to slumping of the sediment in the bank.

Except for the fine-grained glacial lacustrine sediments, the alluvial and glacial outwash deposits are primarily loosely consolidated, relatively fine-grained, and are easily transported by the Hoh River. Thus, the potential for erodibility of these banks is high. For banks that include a substantial amount of lacustrine sediment, the potential for erosion is dependent upon the exact composition of the deposits and the amount of and location of seepage from the bank. These banks often fail by slumping and the disturbed sediment, especially if silt-sized, may be easily removed by the Hoh River. If the slumped sediments are primarily clay, then they may remain in consolidated blocks that can armor the bank and limit the rate of further erosion.

1.1.3 TASK 1C: Identify Potential Future Channel Positions

Although terrace bank material is important in assessing the likelihood that a bank could erode, banks that are composed of loose, easily eroded sediment may be stable if the Hoh River channel is not in contact with the bank. Thus, the likelihood of erosion must also include estimating the potential for future channel locations to be against the HCMZ boundary. The greater the potential for the channel to flow against a bank composed of erodible material, the higher the likelihood the bank will be eroded.

Future positions of the main channel were evaluated based on existing and historical channel positions. Existing channel positions give an indication of which direction the channel is headed. For instance, if an existing channel contains a meander bend, the channel is likely to continue eroding the outside of the meander bend while gradually shifting the meander in the downstream direction. Eventually, the meander planform will become perpendicular to the valley and a sudden change in channel position (avulsion) will be likely. Historical channel positions suggest potential locations for the channel avulsions. Often an existing unvegetated overflow or a vegetated side channel that already contains water during high flows is a likely candidate for the channel to avulse to since a flow path is already established. Side channels that have large stable log jams at their entrances have some protection from the main channel avulsing into them, but eventually may be subjected to the log jam being blown out. A few banks may never be subjected to the river running against them even if they are composed of highly erodible materials. This is because in certain reaches geologic features such as bedrock canyons or debris flows limit potential channel paths as the river transitions from one area to the next.

1.1.4 TASK 1D: Assign the Likelihood of Erosion

Likelihood of erosion categories include very low, low, moderate, high, and areas that are already actively eroding. For the very low potential category, boundaries were composed of bedrock and were not dependent on whether the channel runs against the bank. For low, moderate, and high likelihood of erosion categories, the rating was assigned based on a combination of the potential for bank erosion and the potential for the channel to run against the bank in the next several years to decades. Terrace banks that are currently along the present main channel, or an active side channel, were typically observed as

actively eroding unless the bank material was composed of bedrock or stable human-placed protection.

Terrace banks along the active flood plain where the main channel is progressing toward them were rated as having a high likelihood of being subjected to erosion. Terrace banks along smaller side channels that are beginning to convey flow or areas where historical channels have existed are also interpreted as having a high likelihood of the channel running against them in the near future. Banks that are protected from present channels by vegetated bars or surfaces that include only small, discontinuous flood channels of limited extent are the less likely to be adjacent to the main channel or a primary side channel during the next few years. Thus, banks in these locations are thought to have a moderate likelihood of erodibility because it may be a longer time before the river flows against them. Terrace banks that have not had flow against them for very long time periods due to geologic features that limit potential channel paths are rated as having a low likelihood of erosion.

1.2 STEP 2: Estimation of Potential Lateral Erosion Rates

Once the likelihood for erosion of the terrace banks bounding the HCMZ was determined, the potential rates of lateral bank erosion were estimated for those banks in the active, high, and moderate likelihood to erode categories. For terrace bank erosion in the low and very low categories, erosion rates were not estimated. Lateral erosion rates were identified as slow, medium, or fast using four tasks:

TASK 2A: Estimate the potential for natural bank armoring or slumping
TASK 2B: Map alluvial-fan deposits
TASK 2C: Assess the vegetation and logging history for the surfaces above the banks
TASK 2D: Compare the present HCMZ boundary with the HCMZ boundary in 1939

1.2.1 TASK 2A: Estimate the Potential for Natural Terrace Bank Armoring or Slumping

The first task was to determine which terrace banks in the moderate, high, and active likelihood categories had natural bank armoring that would result in a slow rate of erosion. The tendency for a bank to become naturally armored is primarily a function of bank material. On the basis of field observations, three main types of material seem to provide natural armoring: boulders, blocks of consolidated clay, and large logs. The large logs are chiefly those that have fallen onto the bank from the surface above the bank. The availability of large logs is a function of the vegetation on the surface above the bank, which is discussed in Section 1.2.3 (Step 2C).

If the content of boulders in an alluvial or glacial deposit is high enough, then periodic undercutting of the finer sediment by the Hoh River as it flows along the terrace bank will leave boulders on the bank that are too large for the Hoh River to transport. The

boulders often become concentrated along the toe of the bank, where they protect the bank from additional erosion. Similarly, if a significant number of large blocks of compacted clay are present on the bank, usually from slumping, then the blocks can act as armoring and also limit the rate of erosion.

1.2.2 TASK 2B: Map Alluvial-fan and Recent Sediment Deposits

Most terrace banks composed of alluvial-fan deposits contain enough large rocks to slow the rate of potential erosion by the Hoh River. Further, recurrently active sediment waves that reach the main channel (through either debris flow or bedload transport processes) also slow erosion of the adjacent banks, because the sediment deposit provides additional material that must be eroded. A contributing factor is the slope of the alluvial fan away from the valley wall. The steeper the slope the more expansion of the HCMZ boundary is limited due to increasingly larger volumes of material that reach the main river channel.

1.2.3 TASK 2C: Assess the Vegetation and Logging History for the Surfaces above the Banks

Of the terrace banks that do not have a tendency to become armored, the surface vegetation is an important factor in determining the potential erosion rate. Surfaces that have large diameter trees tend to have a slower rate of erosion because as the banks become undercut by the river, the larger trees have substantial roots that protect the bank and limit erosion, or the tree may fall against the bank providing natural armoring. Beeson and Doyle (1995) documented that of 748 meander bends studied on four stream reaches in British Columbia, bends without riparian vegetation were nearly five times as likely as vegetated bends to undergo detectable erosion during flood events. For example, the largest amount of lateral bank erosion observed between 1939 and 2002 on the Hoh River was 1500 feet along a bank just upstream of the entrance to the Oxbow Canyon that had been logged and developed in 1939. On the other hand, the majority of ONP has not been subjected to logging or development, and lateral terrace bank erosion has not been significant. The present vegetation and logging and development history were interpreted from aerial photographs ranging from 1939 to 2002 (see Table 3).

Surfaces that have been recently logged or are kept clear (e.g., by development, for pasture) were categorized as fast potential erosion rates. The grasses, shrubs, and scattered trees provide few roots to stabilize sediment in the terraces, and do not provide large enough logs to armor the banks.

Banks along terraces that have been logged, but have at least moderate-size trees at this time are estimated to have a medium erosion rate. The exception is terrace banks that are composed of loose sand and are a few tens of feet high. These high banks may not receive much benefit from the tree roots or the potential effects of log armoring. Thus, these banks are estimated to have fast, rather than medium, erosion rates.

Banks along terraces that are covered with thick stands of large trees are estimated to have slow erosion rates. These are surfaces that have never been logged, mostly in ONP, or surfaces that were logged so long ago that the large trees have reestablished. The trees on these surfaces are large enough and prevalent enough that their roots can provide some stability to the bank sediments and any trees that fall onto the bank will be large enough to provide armoring.

Even in areas of large-diameter trees (where erosion rates are otherwise slow), terrace banks composed primarily of loose silt and that are a few tens of feet high are thought to have a medium potential erosion rate. This is because of the high erodibility of the sediment and the height of the bank, which limits the effectiveness of roots and logs for slowing erosion.

1.2.4 TASK 2D: Verify Rates by Comparing the Historic and 1939 CMZ Boundaries

Verification of the assigned potential erosion rates was accomplished by comparing the locations of the HCMZ boundary in 1939 and in 2002. For terrace banks that have eroded during the last 63 years, the amount and average yearly rate of erosion were approximated. In general, terrace banks assigned a fast erosion rate should have on the order of hundreds of feet of erosion. Terrace banks with a medium erosion rate should have on the order of several tens of feet of erosion. Finally, terrace banks with a slow erosion rate should have on the order of less than10 feet of erosion. Potential erosion rates were adjusted where significant evidence suggested a different rate than previously assigned.

A few exceptions existed where historical erosion did not tell the whole story. For instance, in some areas the HCMZ terrace bank has only just recently been exposed to the river flow and has not been subjected to erosion in the past. These areas must rely on the bank properties and potential channel path assessments to assign potential rates of erosion. Comparison of more recent aerial photography from 1994, 2001, and 2002 provides some indication of the potential rates of erosion for these banks that are actively eroding. In other cases, areas along the HCMZ that had once been cleared of vegetation have already eroded at a fast rate, but remaining large diameter trees on the edge of the logged area may limit the rate of any additional erosion now that the logged area has eroded.

1.3 STEP 3: Assign a Risk of Terrace Bank Erosion Based on Likelihood and Rate Categories

For the banks bounding the HCMZ with at least a moderate likelihood of erosion, the likelihood for erosion and the potential rate of that erosion are combined into risk categories (Table C-1). The purpose of integrating the categories is to not only see which areas are most likely to erode over the next several years to decades, but also to estimate at what rate they might erode relative to other areas along the HCMZ boundary. For instance, a given reach may have several areas of high likelihood or actively eroding

banks, but knowing which banks might erode the fastest helps prioritize the risk. On the other hand, a reach in ONP may have all banks categorized as slow rates of erosion due to large diameter trees, but knowing which areas have the highest likelihood to erode next is important in understanding the risk of erosion. The risk of erosion is of particular concern in areas where it is desired to protect and manage property and infrastructure. The categories are mapped with a combination of colors and line patterns along the HCMZ boundary on aerial photography.

Terrace banks bounding the HCMZ with Likelihood-Rate categories of Active-fast, Active-medium, High-fast, and High-medium are the areas that we think are the most likely to be eroded at the fastest rate during the next few years. These banks are shown on figures by red (Actively Eroding) and orange (High Likelihood), thick (Fast Rate) and double (Medium Rate) lines. These terrace banks often are composed of loose alluvial or glacial deposits and are bounding terraces that have been logged recently or are kept clear of trees. These banks are primarily in Reaches 5, 7, and 8, where channel changes between 1939 and 2002 are the greatest.

Terrace banks in these same reaches that are composed of alluvial-fan deposits are interpreted to have only a moderate likelihood of erosion and potential slow rates if erosion does occur. This is because of the coarser, cobble-sized material in these deposits and the continuing additions of sediment being transported down the tributary during runoff events.

Steep alluvial fans with large sized-material (cobble and boulder) are thought to have a low risk of erosion during the next several years. These banks are located primarily within ONP (Reaches 1, 2, 3, and 4). Where the banks bounding the HCMZ are bedrock, as in Spruce Canyon (Reach 6) and downstream of Reach 8 in Oxbow Canyon, the likelihood of erosion during the next few years to decades is assumed to be very low.

Table C-1. HCMZ Boundary Risk Categories Developed From Combining Likelihood for and Potential Rates of Erosion[1]

Potential Erosion Rate[2]	Likelihood of Erosion with Present Conditions		
	Active Erosion	**High Likelihood of Future Erosion**	**Moderate Likelihood of Future Erosion**
Fast Rate	**Active_fast:** Evidence for recent lateral erosion[3]; bank has potential to erode several hundred feet over the next several floods	**High_fast:** Terrace bank consists of erodible material and is presently along a main channel, or in an area where a change in channel pattern is likely and would result in the bank being adjacent to a channel; bank has potential to erode several hundred feet over the next several floods	**Moderate_fast:** Terrace bank is composed of erodible material and is in an area where a change in channel pattern is possible, but not likely in the near future; bank has potential to erode several hundred feet over the next several floods
Medium Rate	**Active_medium:** Evidence for recent lateral erosion[3]; bank has potential to erode several tens to a few hundred feet over the next several floods	**High_medium:** Terrace bank consists of erodible material and is presently along a main channel, or in an area where a change in channel pattern is likely and would result in the bank being adjacent to a channel; bank has potential to erode several tens to a few hundred feet over the next several floods	**Moderate_medium:** Terrace bank is composed of erodible material and is in an area where a change in channel pattern is possible, but not likely in the near future; bank has potential to erode several tens to a few hundred feet over the next several floods
Slow Rate	**Active_slow:** Evidence for recent lateral erosion[3]; bank is not likely to erode more than a few tens of feet over the next several floods;	**High_slow:** Terrace bank consists of erodible material and is presently along a main channel, or in an area where a change in channel pattern is likely and would result in the bank being adjacent to a channel; bank is not likely to erode more than a few tens of feet over the next several floods;	**Moderate_slow:** Terrace bank is composed of erodible material and is in an area where a change in channel pattern is possible, but not likely in the near future; bank is not likely to erode more than a few tens of feet over the next several floods;

[1]Terrace bank material for active, high, and moderate erosion likelihood is chiefly unconsolidated and loose sandy, silty, or cobbly sediments. Boulders composition is variable. These sediments are alluvium (channel and flood plain deposits), glacial deposits (outwash and till), and finer sized alluvial-fan deposits. Where glacial deposits include lacustrine silt and clay, sediment can be consolidated and resistant to erosion. However, banks with this material where seepage is present often fail by slumping and so are unstable.

[2]This is the estimated potential erosion rate assuming that the main channel or a primary side channel, one that carries substantial flow, is adjacent to the terrace bank.

[3] Evidence of recent erosion includes a vertical or overhanging (undercut) bank, exposed roots, lack of vegetation, toppled or disturbed trees (usually alder) or shrubs, slumps, or water issuing from bank, usually just above a clayey silty bed.

Attachment D: Bank Descriptions for Reach 7, Hoh River

GPS Location (NAD 1983 ft)	Easting: 829,849.5 Northing: 314,946.2	Easting: 830,128.6 Northing: 314,744.4	Easting: 823,714.7 Northing: 313,034.4
Location	Bank where riprap along Upper Hoh Road has been eroded; downstream of locality #22B	Bank just upstream of bank described at WP13	Bank just downstream of Red Creek
Erodibility	High to moderate	High to moderate	High
Relationship to HCMZ or geologic boundaries	HCMZ boundary	HCMZ boundary	HCMZ boundary
Date described	8/2/02	8/2/02	8/2/02
Bank	Right	Right	Left
Landform	Remnant of glacial deposits	Terrace defining HCMZ boundary	Remnant of glacial deposits
Relationship to channel	Along outside of meander bend of main channel	Along outside of meander bend of main channel	Along straight section of main channel
Bank height (ft; m)	31; 9.5	10.5; 3	142; 43
Bank material	Sand and silt over channel-fill cobble gravel cut into "blue" channel or delta cross-bedded sands	Overbank sand and silt about 3 ft (1 m) thick over channel-fill cobble gravel	Tan and gray sand/silt/clay over cobble gravel inter-fingered with gray sand/silt/clay over gray cross-bedded, coarse and medium sand
Consolidation	Consolidated for silt and clay; loose for cobble gravel and sand and silt	Loose	Consolidated for clay and silt; loose for sand/silt/clay and cobble gravel
Slope (degrees)	90 for most of bank	90 for the sand and silt (upper part); 25 to 45 for the cobble gravel (lower part)	90; 25-45 at base of bank or at drainages
Dominant vegetation	Mixed: Spruce, hemlock, shore pine; 2 ft (0.5 m) max dm	Mixed: Large alder, hemlock, spruce	Conifer
Human features and activities	Probably clear cut because trees seem to be too small for a surface this high; Upper Hoh Road and riprap	Upper Hoh Road on surface	None
Roots	Fine and medium roots cover <5% of bank	Fine roots cover <5% of bank	Medium roots cover <5% of bank; grass and shrubs growing in part of bank
Protection	Riprap on bank just upstream of this locality	LWD along about 50% of bank; just downstream of JeffCo's constructed log jam	None
Evidence of active landslide	None	None	Yes, at drainages; none along vertical portions of bank; water exiting from bank
Evidence of active erosion	Bank is undercut, and roots are exposed; known erosion from aerial photographs	Bank is undercut, and roots are exposed	None
Other notes	Bank has eroded about 120 ft (36.5 m) since 1939. Horizontal distance to bank from observation site is 219 ft	Bank here is all alluvium in contrast to its continuation downstream (see WP13)	Colluvial cones cover base of slope; some "blue" silt and clay near base of slope; bank has benches that are capped by fine-grained deposits (silt); bank has a high risk for continued landslides