RECLAMATION
Managing Water in the West

Methow Subbasin Geomorphic Assessment Okanogan County, Washington

Bureau of Reclamation
Technical Service Center, Denver, CO
Pacific Northwest Regional Office, Boise, ID
Methow Field Station, Winthrop, WA

February 2008

MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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

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BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER, DENVER, CO,
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AND
METHOW FIELD STATION, WINTHROP, WA.

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SUMMARY

Reclamation completed a geomorphic assessment of physical river processes and associated habitat for ESA-listed Upper Columbia River spring Chinook salmon and steelhead for nearly 80 river miles (RM)[1] of the Methow Subbasin, located in Okanogan County, Washington. U.S. Forest Service fishery scientists assisted Reclamation with habitat evaluations. The assessment area includes a 46.9-mile-long section of the Methow River (river miles 28.1 to 75), the downstream-most 18.1 river miles of the Twisp River (tributary to Methow) and the downstream-most 14.3 river miles of the Chewuch River (tributary to Methow).

The purpose of this report is to describe technical results from a geomorphic assessment of part of the Methow River subbasin and describe a strategy that resource managers can use to sequence and prioritize opportunities for protecting or restoring channel and floodplain connectivity and complexity in the Methow subbasin.

This report describes a tributary reach-based approach to conduct geomorphic assessments and how this approach provides a platform that can be integrated with monitoring and adaptive management activities. The tributary reach-based approach employs a sequence of steps to focus funding and technical resources at telescoping geographic scales and to provide insight on the identification of project areas with potential to implement projects with the greatest biological benefits. This systematic, reproducible, and scientific approach includes stakeholder involvement to guide progress. Definition of discrete geographic areas (reaches) and the use of the "Matrix of Pathways and Indicators" (MPI) provides an objective basis to integrate project implementation with implementation, status and trend, and effectiveness monitoring, and adaptive management at comparable geographic scales. Connection between project implementation, monitoring, and adaptive management can be potentially "rolled up" from smaller to larger scales to measure progress toward Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) and recovery plan goals.

Identification of potential habitat restoration actions is based on a geomorphic assessment that evaluated trends in physical processes and habitat over the last century. Prioritization of reaches is based on the current habitat quality, potential habitat improvements, and how well proposed restoration actions meet established objectives from the *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (Upper Columbia Salmon Recovery Board, 2007) and other biological guidance documents.

The strategy described in this report also identifies spatial linkages within the assessment area so that potential restoration activities can be conducted to expand and

[1] Actual stream distance based on 2004 aerial photography is 79.3 river miles; in most instances the stream distance has been rounded up and is referred to as an 80-mile distance.

reconnect areas that are already functioning. Attention to spatial linkage ensures there are no other critical limiting factors that need to be addressed before newly improved habitat can be accessed and utilized (e.g., barriers, flow limitations). In addition, unanticipated impacts to presently functioning habitat, other potential restoration projects, infrastructure, and property can be minimized, and effectiveness and sustainability can be maximized by understanding the physical processes that affect potential restoration projects.

Twenty-three reaches were delineated and characterized into three general types: unconfined, moderately unconfined, and confined, based on differences in geomorphic conditions and the potential to provide habitat features associated with multiple life stages and species use, particularly complexity habitat for ESA-listed spring Chinook salmon and steelhead. Because one of the primary habitat objectives from the *Upper Columbia Recovery Plan* (UCSRB, 2007) is protecting and improving connectivity between the channel and floodplain, reaches with measurable off-channel and floodplain areas were separated from naturally confined, single-thread channel reaches for purposes of discussing restoration opportunities.

The lengths of river reaches that have vegetated floodplain are listed below based on 2004 aerial photography:

- 15.2 miles of the middle Methow River (70 percent of main channel length)
- 21.4 miles of the upper Methow River (86 percent of main channel length)
- 15.5 mile of the Twisp River (85 percent of main channel length)
- 9.5 miles of the Chewuch River (60 percent of main channel length)

The primary limiting factors to habitat function in confined reaches is historical conversion of the riparian buffer zone to riprap levees or embankments along the boundary of the floodplain. By river segment, 32% (4 miles) of the floodplain boundary in confined reaches of the Middle Methow are armored with riprap, 30% (2 miles) of the Upper Methow, 20% (about 1 mile) of the Twisp River, and 4% (about 0.4 mile) of the Chewuch River.

The primary limiting factor to habitat function in moderately confined and unconfined reaches are human features and historical activities that have limited the connectivity of the channel and floodplain, channel migration and reworking processes, and the availability of habitat complexity features. Human features and activities most commonly observed in this assessment are levees, roads, riprap, bridges, historic filling of channels, and removal of riparian vegetation and large woody debris (LWD).

Despite impacts from human activities and features, the channel planform and bed elevations appear consistent in most locations with no detectable trends of channel bed incision or aggradation on a decadal scale. The river hydraulics and sediment sizes present along the channel bed within the study area are most notably dominated by geologic features that control the river bed slope and the lateral extent of the active channel and floodplain (width). The average sediment particle sizes measured in the bar and channel surface are gravel to cobble (40 to 140 mm) for all three rivers, with the larger sizes present in the reaches with steeper slopes. Except for a few steep, confined reaches, the bars and channels can be reworked at the more frequent 2- and 5-year flood peaks. This is one indicator that the energy in most reaches is not exceeding sediment supply, which combined with findings from historical channel analysis and field observations suggests there is limited tendency for continued incision.

LWD levels are highest in unconfined reaches, but are believed to be lower than natural conditions due to historic removal of woody debris and log drives on the mainstem Methow River. The total percent of floodplain area where vegetation has been noticeably cleared is 19.9% for the Methow River (Middle and Upper), 14.8 % for the Chewuch River, and 24.1% for the Twisp River.

The effects of human features and activities have not been detected on hydraulics and sediment characteristics at the reach scale. At a more localized scale, human features and activities have impacted hydraulics, availability of LWD and riparian vegetation, and spawning-sized sediment availability that are critical to habitat quantity and quality. Hydraulic conditions have been most impacted by reducing flow access to off-channel areas at the entrance to side channels, and to some degree altering access to overbank flooding.

Habitat action classes and their associated viable salmonid population (VSP) parameters were identified for each reach as referenced from Table 5.9 in the *Upper Columbia Recovery Plan* (UCSRB, 2007). A combination of geomorphic analysis tools including trend analysis of channel planform, position, and elevation over time along with field observations were used to determine the degree of departure from the natural setting, and the potential to recover natural function with proposed restoration strategies. Removal or modification of human features has a good chance of success for achieving long-term restoration of floodplain access and complexity that is now absent in many locations without risking impacting the baseline morphology of the channel. Short-term actions such as LWD placement or riparian planting may be needed to supplement long-term strategies that will take longer timeframes for physical processes and habitat features to recover. In some areas, restoration may not be fully achieved if impacts can only be partially addressed (e.g., a partial breach in a levee versus a full removal) or if future infrastructure development worsens the present setting.

Within the reaches with vegetated floodplain, 27% (1,446 acres) were identified for protection and monitoring where there were limited or no human features and physical processes were in a properly functioning condition. In the remaining 73% (3,827 acres), 56 potential floodplain restoration areas were identified on the mainstem Methow River, 49 areas on the Twisp River, and 27 on the Chewuch River. A combination of protection and restoration strategies could cumulatively yield up to 3,600 acres on the Methow River, 1,100 acres on the Twisp River, and 600 acres on the Chewuch River of functioning habitat for spring Chinook and steelhead (Table 1). Within the restoration areas, various types of physical settings are present that offer potential to improve habitat function for ESA-listed spring Chinook and steelhead (Table 2).

Table 1. Summary of protection and restoration areas identified for the four valley segments.

Valley Segment	Total Main Channel Length (river miles)	Total Floodplain Area (acres)	Floodplain Protection Area		Floodplain Restoration Area	
			(acres)	(% of total)	(acres)	(% of total)
Upper Methow	RM 50 to 75	1391	126	9%	1265	91%
Middle Methow	RM 28 to 50	2196	748	34%	1447	66%
Twisp	RM 0 to 18	1084	381	35%	703	65%
Chewuch	RM 0 to 14	603	192	32%	411	68%
Total Area		5274	1446	27%	3827	73%

Table 2. Summary of restoration areas by process type for the four valley segments.

	Complexity Habitat Area (acres)[1]	Overbank Floodplain Area (acres)[2]	Areas with Heavy Development (acres)	Complexity Habitat Area (% of total)	Overbank Floodplain (% of total)	Heavy Development (% of total)
Upper Methow	1150	56	241	79%	4%	17%
Middle Methow	1041	90	135	82%	7%	11%
Twisp	587	107	10	83%	15%	1%
Chewuch	354	30	26	86%	7%	6%

[1] contains off-channel areas and frequently inundated floodplain acres
[2] inundated at infrequent floods

Products available from this work were processed into a geographic information system (GIS) database to allow the information to be spatially related and readily transferred to other design engineers, cooperators, and stakeholders (Appendix Q). The 23 geomorphic reaches identified in this assessment report will be prioritized by a local Methow Subbasin coordination group. Once a reach is prioritized, a more detailed technical analysis including a modified “Matrix of Diagnostics/Pathways and Indicators” (NOAA, 1996; USFWS, 1998) and relevant data collection effort (referred to as a “reach assessment”) may be conducted to refine restoration project possibilities. This stage is a cooperative process with project sponsors, stakeholders, regulatory and permitting entities, and technical groups involved in recovery planning and implementation in the Upper Columbia Basin.

1. INTRODUCTION

The Methow Subbasin is located on the east side of the Cascade Range in north-central Washington (Figure 1). The watershed drains about 1,890 square miles, and the Methow River flows about 86 river miles from the crest of the Cascades (elevation 8950 feet) to its confluence with the Columbia River at river mile (RM) 524 (elevation 775 feet). It is part of the Upper Columbia River Basin, which includes the Columbia River between the Yakima River (RM 335) and Chief Joseph Dam (RM 545) and all its tributaries along this reach.

Over the years, there have been substantial changes in habitat due to human factors and natural events, and several important fish species have been listed under the Endangered Species Act (ESA). Protection of existing aquatic habitat and restoration of altered habitat are generally accepted methods that benefit listed fish.

In order to make good decisions about where and how to implement projects aimed at protecting and restoring physical processes that provide suitable aquatic habitat, a strong scientific foundation is necessary. This *Geomorphic Assessment* includes state-of-the-art science and introduces preliminary project implementation opportunities.

This report contains terms from a number of technical disciplines, so it includes a glossary. On first reference, such terms are emphasized in ***bold italic.***

1.1 Background and Need

In the Methow Subbasin, human activities have altered the natural environment resulting in simplifying habitat complexity, loss of connectivity and riparian functions in the channel corridor. Simplified habitat has included a reduction in the abundance of large woody debris (LWD), limited side-channel access, and limited floodplain connectivity. The simplified habitat and reduced floodplain connectivity have, in turn, reduced rearing habitat for spring Chinook salmon, steelhead, and bull trout in the Methow River and tributaries. Reduced function of these “limiting factors” have affected the abundance, productivity, spatial structure, and diversity of Upper Columbia River (UCR) spring Chinook salmon, UCR steelhead trout, and bull trout populations to such a degree that they were listed under the ESA. The UCR spring Chinook salmon was listed as ***endangered*** in 1999 (NOAA Fisheries Service, 1999). The UCR steelhead trout was listed as endangered in 1997; its status was upgraded to ***threatened*** in January 2006, and then it was reinstated to endangered in June 2007 (NOAA Fisheries Service, 2007b); this was in accordance with a U.S. District Court decision. Bull trout was listed as threatened in 1999 (USFWS, 1998).

Recovery of the listed salmonid species to viable populations requires reducing or eliminating threats to the long-term persistence of fish populations, maintaining widely distributed and connected fish populations across diverse habitats within their native ranges, and preserving genetic diversity and life-history characteristics. Successful recovery of listed species means that populations have met certain measurable criteria (i.e., abundance, productivity, spatial structure, and diversity), referred to as viable salmonid population (VSP) parameters (ICBTRT, 2005; UCSRB, 2007b).

To achieve recovery, four sectors need to be addressed: harvest, hatchery, hydropower, and habitat (ICBTRT, 2005; UCSRB, 2007b). The following biological guidance documents include recommendations for the Methow Subbasin on developing implementation frameworks, and types and prioritization of restoration activities needed to achieve recovery in these four sectors:

- *Viability Criteria for Application to Interior Columbia Basin Salmonid evolutionarily significant units* (ESUs) (Interior Columbia Basin Technical Recovery Team (ICTRT), 2007)
- *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (Upper Columbia Salmon Recovery Board (UCSRB), 2007); referred to as *Upper Columbia Recovery Plan* (UCSRB ,2007) in this document
- *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region (Draft)* (Upper Columbia Regional Technical Team (UCRTT), 2007); referred to as *Upper Columbia Biological Strategy* (UCRTT, 2007) in this document
- *Salmon, Steelhead and Bull Trout Habitat Limiting Factors (LFA), Water Resource Inventory Area (WRIA) 48, Washington State Conservation Commission Final Report* (Andonaegui, 2000)
- *Methow Subbasin Plan*, prepared for the Northwest Power and Conservation Council (NPCC) (KWA, et al., 2004)

The documents listed above identify potential protection and restoration strategies that were based on available information and the professional judgment of a panel of scientists. Further technical investigation was recommended to refine protection and restoration strategies to the level of detail needed to implement projects, and to determine if the recommendations are sustainable and compatible with the geomorphic conditions in the river. Regarding physical processes associated with the habitat sector, the *Upper Columbia Recovery Plan* (UCSRB, 2007) recommends conducting additional assessments to identify priority locations for protection and restoration actions, and to examine fluvial geomorphic processes in order to assess how these processes affect habitat creation and loss. The *Upper Columbia Recovery Plan* (UCSRB, 2007) was formally adopted by the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries Service) (NOAA Fisheries Services, 2007b) as the Federal recovery plan for the Methow Subbasin.

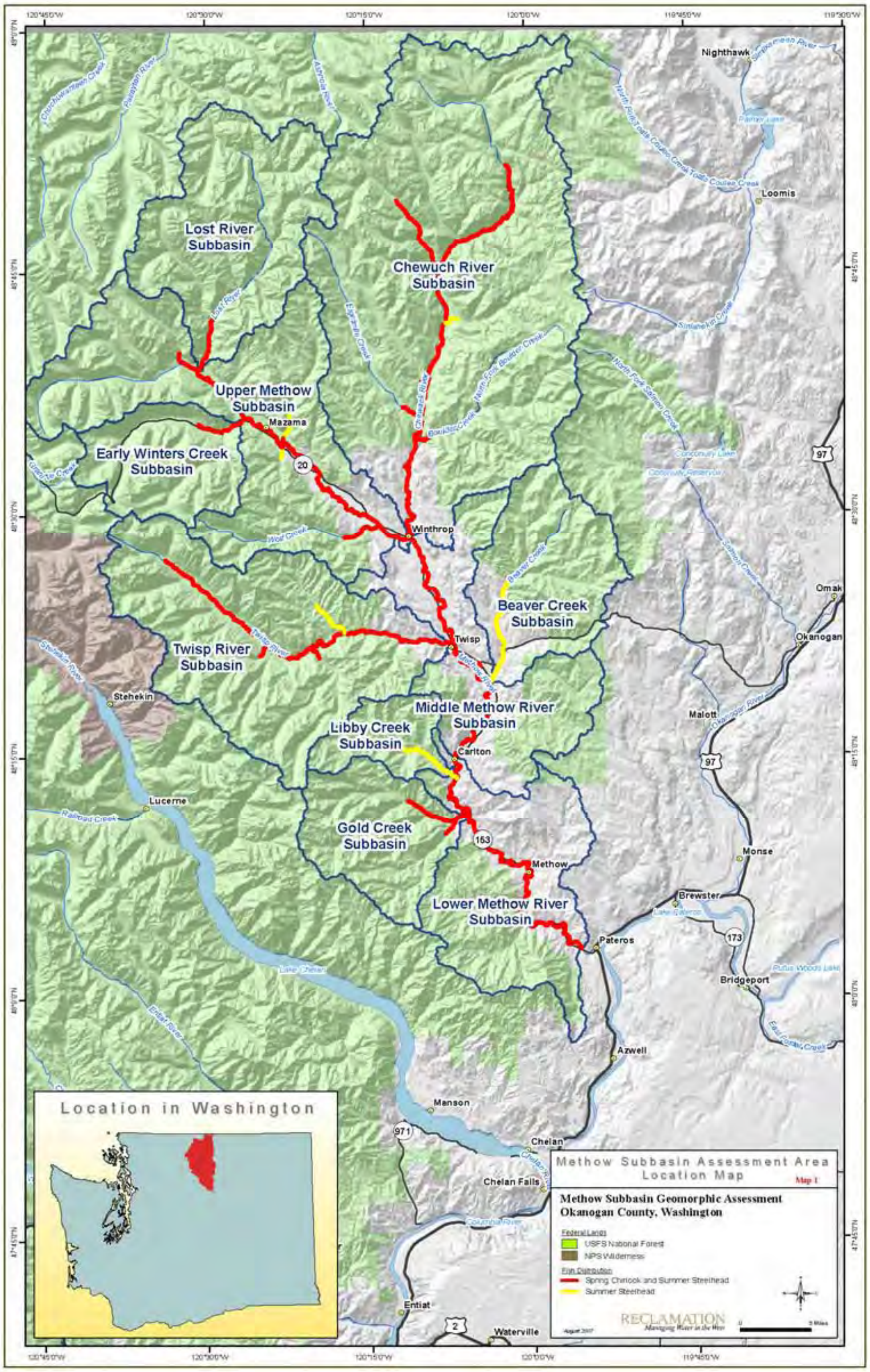

Figure 1. Location map of assessment area in the Methow Subbasin, located in Okanogan County, Washington. (Map generated by Kurt Wille at Reclamation for Methow Atlas)

Biological Opinions (BiOps) on the operation and maintenance of the Federal Columbia River Power System[2] (FCRPS) issued by NOAA Fisheries Service to the Bonneville Power Administration (BPA), U.S. Army Corps of Engineers (Corps), and Bureau of Reclamation (Reclamation), collectively referred to as the "Action Agencies," include measures to improve tributary habitat for salmon and steelhead listed under the Endangered Species Act (ESA). These measures are addressed by the Action Agencies consistent with subbasin plans developed through the NPCC and State recovery plans approved by NOAA Fisheries Service.

1.2 PURPOSE AND SCOPE

The purpose of this report is to describe technical results from a geomorphic assessment of nearly 80 river miles of the Methow River Subbasin and describe a strategy that resource managers can use to sequence and prioritize opportunities for protecting and restoring channel and floodplain connectivity and complexity in the Methow Subbasin. The report addresses ***Category 2*** river valley segments in the Methow Subbasin, located in Okanogan County, Washington (see Figure 1 and Table 3). Category 2 watersheds support important aquatic resources, and are strongholds for one or more listed fish species (UCRTT, 2007). Compared to Category 1 watersheds, Category 2 watersheds have a higher level of fragmentation resulting from habitat disturbance or loss.

The Middle Methow, Upper Methow, Twisp, and Chewuch River valley segments were investigated concurrently to compare and prioritize potential habitat protection and restoration areas within the historic channel migration zone and floodplain of 23 delineated geomorphic reaches. Protection areas are sections of river and floodplain that do not have any known human features or impacts that need to be addressed in order to restore channel migration and floodplain connectivity processes. The purpose of identifying protection areas is to assist in prioritization of restoration areas if it is desired to build upon currently functioning areas, and also to help stakeholders identify areas that could be protected from future development and impacts as seen in other areas that now need restoration. Restoration areas have known human features or impacts that could be addressed as part of a restoration project (e.g., removal of a levee, placement of LWD, etc.). Note that in many report sections the middle and upper Methow segments are combined for discussion purposes. The assessment was carried out by Reclamation with the technical assistance on fish habitat from the USFS through an interagency agreement funded by Reclamation.

[2] The FCRPS comprises 14 mainstem Federal hydroelectric dams in the Columbia River Basin. The Army Corps of Engineers and Reclamation operate and maintain the dams, and the Bonneville Power Administration markets the power.

Table 3. Assessment area within Methow Subbasin.

Valley/Stream Segment	Downstream Boundary	Upstream Boundary	River Mile (RM) Length
Upper Methow River	RM 51.5 (confluence with Chewuch River)	RM 75 (Lost River confluence)	23.5
Middle Methow River	RM 28.1 (near Carlton, WA)	RM 51.5 (confluence with Chewuch River)	23.4
Twisp River	RM 0	RM 18.1 (boundary of Forest Service Land and confluence with Eagle Creek)	18.1
Chewuch River	RM 0	RM 14.3 (boundary of Forest Service Land and confluence with Falls Creek)	14.3
TOTAL LENGTH			**79.3**

1.3 AUTHORITY

Reclamation established a Tributary Habitat Program to address tributary habitat improvement commitments for the FCRPS BiOps. Objectives of the Tributary Habitat Program are to improve the survival of Columbia River Basin salmon and steelhead listed under the ESA. This will be accomplished by helping ensure fish screens that meet current criteria are in place, artificial fish passage barriers are replaced or removed to provide access to spawning and rearing areas, and instream flow and spawning and rearing habitat are improved in selected Columbia River tributary subbasins including the Methow. Working closely with local partners and willing private landowners, Reclamation provides engineering and related technical assistance to meet mutual tributary habitat improvement objectives. Reclamation conducts the Tributary Habitat Program under authorities contained in the ESA, Fish and Wildlife Coordination Act, and Fish and Wildlife Act as delegated from the Secretary of the Interior in Secretarial Order No. 3274 dated September 11, 2007.

1.4 FCRPS BIOP

Reclamation's commitment to tributary habitat improvement for the draft FCRPS BiOp (NOAA Fisheries Service 2004) began in 2000 and has operated in nine Interior Columbia River tributary subbasins with over 50 ongoing project activities in various stages of development, implementation, or completion at any one time. Considering the necessary interactions among partners for any given project—including local, State, Federal, and tribal resources; oversight, regulating, and funding entities and private landowners—this program is a challenging endeavor for Reclamation and the many partners with whom it works. While there are scores of people with these partners throughout the Columbia River Basin that see habitat projects through to completion, there are also dozens of Reclamation people that participate in a wide assortment of technical, administrative, and management capacities needed to deliver the services and products provided by Reclamation.

The "tributary reach-based approach" was piloted in this geomorphic assessment even though the scope of the assessment covered several tributaries within one subbasin. It is a mechanism that can improve the delivery of services and products within schedule and budget for our partners and for Reclamation. In addition to features described in more detail later in this report, this approach provides:

- A planning tool that can be used collectively by all partners within a subbasin to focus their resources in a systematic and scientifically reproducible way to identify and prioritize floodplain connectivity and channel complexity restoration/protection projects.
- A method that will help Reclamation managers anticipate upcoming near-term and long-term workloads, assign people and allocate funding for that workload, and keep partners informed on the extent of available Reclamation near- and long-term resources for their planning purposes.

1.5 Report Organization and Methodology

Section 2 of this report summarizes the generalized approach that developed as this assessment took place. Section 3 documents the protection and restoration strategy developed in this assessment. This section includes identification of reaches based on processes and habitat function, and prioritization of these reaches in terms of potential habitat recovery. Section 4 summarizes technical findings on the geomorphic conditions of the 80 river miles analyzed in this assessment report consistent with the strategies presented in Section 3. Section 5 describes conclusions followed by a list of references for the main report only. All references are provided in Appendix S along with contributing authors and reviewers, list of abbreviations, and glossary.

Existing and new information were synthesized into a GIS database, so that the information can be viewed spatially and readily transferred to other design engineers, cooperators, and stakeholders. Detailed methods and findings of the work described are contained in nineteen appendices, which are provided on a DVD at the back of this report. An atlas that includes a series of maps showing the spatial relationships of the data compiled for this assessment accompanies this report, and is also provided on the attached DVD.

Work described in this report was accomplished by a multidisciplinary team from Reclamation consisting of expertise in hydraulic and sedimentation engineering, geology, and geomorphology, and biological expertise from the USFS for the Methow Subbasin.

The scope, analyses, and protection and restoration strategies described in this geomorphic assessment were guided by those developed by Upper Columbia Basin fisheries scientists.[3] Variations in channel and floodplain processes were used to delineate and evaluate potential project areas in 23 Methow Subbasin reaches where habitat for ESA-listed fish might be protected, enhanced, or restored. Prioritization of project areas were made based on the current habitat quality, potential habitat improvements, and how well proposed restoration actions meet established habitat objectives from Upper Columbia recovery plan documents (see Section 1.1). At key milestones in this geomorphic assessment, presentations of completed and ongoing work were made to the technical staff of local Reclamation partners so they could provide suggestions and other input to this process.

The information from this assessment report also provides a current description of river processes operating within the 80 river miles in the assessment area, so that subsequent, more detailed assessments for smaller river sections can build upon and refine this information to successfully implement proposed actions. Restoration projects implemented with a clear understanding of the associated physical processes have a greater potential for sustainable short-term and long-term habitat benefits for spring Chinook and steelhead.

Methodology used to produce this report and the accompanying map atlas is described in detail in Appendix D. A brief summary of this methodology is presented below.

- Delineate and characterize river valley segments and channel reaches on the basis of their geomorphic characteristics (Appendix C) and biological opportunities (Appendix F), and develop potential restoration strategies organized by a reach-based approach (Appendix A)
- Identify a technical sequencing of the reaches that can be used to prioritize the potential habitat protection and restoration areas within the assessment area based on linkage to primary limiting factors for salmon recovery (Appendix B)
- Identify the recurrence intervals of natural disturbances, identify human-induced disturbances, and how they affect channel processes and planform within the assessment area (Appendices E, G, H, K, O, P, R)
- Identify the natural physical processes and disturbance regimes that affect habitat at the subbasin and reach scales from both historical and contemporary context (Appendices H, I, J, K, L, M)

[3] The Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan (UCSRB, 2007) and the A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia (UCRTT, 2007) serve as final guidance.

For this assessment, methods included a mixture of quantitative and qualitative analysis to provide an acceptable level of certainty consistent with assessment objectives. Quantitative methods provide more certainty to results than qualitative methods, but cannot be used in all areas because they are more costly and time consuming to employ. Qualitative methods are faster and less costly, but can be difficult to repeat in a scientific manner and therefore, have less certainty. The approach taken was to meld several independent-analysis tools that could be overlaid and compared to determine conclusions regarding channel processes within the scope of the objectives of the broad assessment described in this report. Quantitative data were collected to characterize and compare reach-level trends within the four valley segments of the 80-mile assessment area. Refinement of this information with additional data and analysis can then occur at a smaller scale of the channel reach selected by stakeholders and project partners in which to implement restoration actions.

2. LINKING TO IMPLEMENTATION AND MONITORING

The scope of this assessment originated in 2004 based on input from local stakeholders and documents that provided both technical guidance on recovery strategies and legal authority to accomplish this work. Many of the guidance documents have been revised concurrent with this Methow Subbasin assessment. The approach taken in the assessment, in particular the identification and preliminary prioritization of restoration and protection opportunities, evolved to incorporate new information as it became available. This report documents one stage of the tributary reach-based approach, a scaled assessment approach being utilized by Reclamation. The entire approach is described in a general sense in Section 2.1, to provide the reader a background of how this report fits within a larger process. Section 2.2 proposes how the tributary reach-based approach sets up the potential for bridging implementation and monitoring activities within an adaptive management setting.

2.1 TRIBUTARY REACH-BASED APPROACH

The tributary reach-based approach developed from discussions among participating scientists, managers, and local recovery planners who recognized a process-based geomorphic assessment would align well with the objectives and guidance expressed in NPCC subbasin plans and recent recovery planning documents including the *Upper Columbia Recovery Plan* (UCSRB, 2007), *Upper Columbia Biological Strategy* (UCRTT, 2007), and the draft *Upper Columbia Monitoring and Evaluation Plan* (October, 2007).[4]

The tributary reach-based approach includes the following stages:

- A "tributary assessment" of a valley segment is made at a relatively coarse scale. A tributary assessment focuses on a length of river up to a few tens of miles long. The purpose of the tributary assessment is to identify major geologic and hydraulic processes active within the valley segment, explore whether geomorphic and hydraulic conditions upstream and downstream from the valley segment affect conditions, and identify "geomorphic reaches" within the segment that share common geologic and hydraulic attributes.
- Near the conclusion of the tributary assessment: stakeholders review results and include relevant social, political, and biological information; and prioritize which of the geomorphic reaches possess the greatest potential to implement projects that will obtain successful, sustainable, biological benefits

[4] The draft *Upper Columbia Monitoring and Evaluation Plan* is currently being developed for the Upper Columbia salmon and steelhead ESA recovery plan (http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/Upper-Col-Plans.cfm)

and warrant a more detailed “reach assessment.” A few project locations and concepts may be identified at the tributary scale that do not require a reach assessment, particularly when the processes associated with the project are fairly localized and isolated.

- A reach assessment focuses on an individual reach identified in a tributary assessment, which is preferably less than 10 miles in length. The purpose of the reach assessment is to further refine understanding of the predominant processes that affect the reach, to establish baseline environmental habitat conditions, and provides technical recommendation of sequenced habitat actions. Analysis obtained previously from the tributary assessment provides information on upstream and downstream geomorphic and hydraulic conditions that could affect those physical conditions within the assessed reach. A reach assessment identifies “project areas” that are based on limiting factors (i.e., the effects of human disturbances) and establishes a baseline of environmental habitat conditions using a modified “Matrix of Diagnostics/Pathways and Indicators” (NOAA Fisheries Service, 1996). Relevance of the modified NOAA Matrix to monitoring and adaptive management is discussed in the next section of this report.
- At the conclusion of a reach assessment: stakeholders review results, include more detailed social, political, and biological information, and prioritize project areas and specific projects with the greatest potential to obtain successful, sustainable, biological benefits. After projects are identified and prioritized, partners typically take the next steps to design and implement alternatives, including landowner discussions, and secure funding for construction.

The tributary reach-based approach described above is used to identify potential habitat protection and restoration opportunities. The purpose of nesting reach assessments within a tributary assessment is to ensure the appropriate geomorphic and hydraulic information is obtained at the appropriate scale and timeframe for answering relevant questions or problems being investigated. In turn, this supports a decision process with others to seek ways to prioritize funding and resources as effectively as possible. The decision process further allows partners to systematically identify and prioritize areas with the greatest potential to implement protection or restoration projects that obtain successful, sustainable biological benefits, postpone investment in areas with less potential, and avoid investing in areas with little potential. This is a flexible approach and can be modified to accommodate smaller areas or the availability of pre-existing information.

Use of the tributary reach-based approach could contribute to obtaining funds for project implementation. Funding proposals that conform to a systematic scientifically-based approach to identify and prioritize channel-complexity and floodplain-reconnection protection and restoration projects potentially could be more open to consideration for grants from entities that require sound justification for the proposals they choose to fund.

2.2 Potential for Linking the Tributary Reach-Based Approach with Monitoring and Adaptive Management

Within the Upper Columbia River Basin, many different organizations—including Federal, state, tribal, local, and private entities—implement tributary actions and have drafted integrated monitoring strategies that are intended to assess the effectiveness of restoration projects and management actions on tributary habitat and fish populations (Hillman, 2006). Because of all the activities occurring within the Upper Columbia Basin, the *Monitoring Strategy for the Upper Columbia Basin* (Hillman, 2006) recommends a monitoring plan that captures the needs of all entities, avoids duplication of sampling efforts, increases monitoring efficiency, and reduces overall monitoring costs.

The plan described in the *Monitoring Strategy* (Hillman, 2006) is aimed at answering the following basic questions:

1. Status monitoring—What are the current habitat conditions and abundance, distribution, life-stage survival, and age-composition of fish in the Upper Columbia Basin?
2. Trend monitoring—How do these conditions change over time?
3. Effectiveness monitoring—What effects do tributary habitat actions have on fish populations and habitat conditions?

In the *Upper Columbia Biological Strategy* (UCRTT, 2007), further guidance is provided on implementing monitoring activities specific to habitat restoration actions. Monitoring strategies are generally described in three categories:

1. Implementation monitoring,
2. Level 1 effectiveness monitoring, and
3. Levels 2 and 3 effectiveness monitoring.

Implementation monitoring simply provides proof that the action was carried out as planned (UCRTT, 2007). Level 1 (extensive methods) is the next step up from implementation monitoring; it involves fast and easy methods that can be completed at multiple sites. Levels 2 and 3 (intensive methods) include additional methods beyond Level 1 that increase accuracy and precision but require more sampling time (Hillman, 2006). Further descriptions of the monitoring categories are provided in Appendix A.

The tributary reach-based approach described above is designed to focus on the geomorphic and hydraulic physical conditions that influence identification, prioritization, and development of projects for implementation. This approach provides a systematic, reproducible, and scientific platform that can be telescoped from relatively coarse to progressively finer scales at specifically defined geographic locations. Also, the approach incorporates the modified "Matrix of Diagnostics/Pathways and Indicators" (MPI). A modified MPI provides a common frame of reference from which to define baseline environmental habitat conditions that can be used in the future to evaluate changes in those conditions resulting from human disturbances (such as land development or habitat project implementation) or natural events (such as landslides, floods, or droughts). Consequently, this approach provides a viable platform with the potential to link project implementation at a defined geographic scale with monitoring and adaptive management activities at the same geographic scale.

A framework that links project implementation to the three types of monitoring at a common geographic scale —implementation, status and trend, and effectiveness— could conceivably support the role of adaptive management. Within this context, adaptive management better serves the selection and implementation of habitat actions with the greatest potential biological benefits. This kind of framework is consistent with the "adaptive management framework" contained in the *Upper Columbia Recovery Plan* (UCSRB, 2007) which, in turn, is based on guidance provided in *Adaptive Management for ESA-Listed Salmon and Steelhead Recovery: Decision Framework and Monitoring Guidance* (NOAA Fisheries Service, 2007a).

The modular nature of the tributary reach-based approach lends itself well to scaling up and down depending on the nature of inquiry. Organizing implementation, monitoring, and adaptive management at a common geographic scale, such as the reach, thus provides a "building block" structure that could be explored for meeting concurrently FCRPS BiOp and recovery goals at the population, Major Population Group (MPG), and Evolutionarily Significant Unit (ESU), and Discrete Population Segment (DPS) levels.

Monitoring efforts are critical for scientists, managers, and stakeholders in order to apply "lessons learned" and improve upon restoration activities and practices in the future. Monitoring informs entities involved in restoration on how individual projects are performing immediately after construction and over time. Additionally, monitoring will help to determine changes compared to baseline conditions in project areas and reaches. Information presented in this geomorphic assessment report is intended to complement the monitoring protocols described above by providing baseline information on channel and floodplain function. Subsequent reach assessments (at more detailed spatial scales) will provide additional information on present biological use and habitat conditions. Reclamation, their partners, and project sponsors are conducting implementation monitoring to document restoration actions accomplished in the Methow Subbasin. This information provides environmental baseline conditions for future monitoring efforts that can be utilized by entities working on status, trend, and effectiveness monitoring plans to test whether the river and habitat function responded as anticipated to implemented projects. Additionally, each restoration project implemented will have documented predictions based on hypotheses as to how processes and complexity are to improve (restore) as an outcome of the project(s).

3. REACH-BASED PROTECTION AND RESTORATION OPPORTUNITIES

Section 3.1 describes the overarching strategy for assessments as it relates to the concept of adaptive management. Section 3.2 describes how the four river valley segments were broken into 23 geomorphic reaches based on physical processes and habitat complexity components. Section 3.3 provides a list of restoration actions that could be considered to restore natural processes and available habitat complexity, and identifies which actions are appropriate for each reach. Section 3.4 provides a technical prioritization of the reaches based on strategies outlined by recovery plan documents. Section 3.5 provides a preliminary identification of the opportunities for restoration and protection throughout each reach

3.1 SCIENTIFIC ASSESSMENT AND ADAPTIVE MANAGEMENT NEXUS

The *Upper Columbia Recovery Plan* (UCSRB, 2007) recognizes that there are inherent uncertainties in habitat restoration actions that are implemented on dynamic river systems. Therefore, authors of the *Upper Columbia Recovery Plan* incorporated an adaptive management framework into the plan's implementation strategy. The adaptive management framework recommended by the *Upper Columbia Recovery Plan* is based on guidance provided in *Adaptive Management for ESA-Listed Salmon and Steelhead Recovery: Decision Framework and Monitoring Guidance* (NOAA Fisheries Service, 2007a). At the core of adaptive management is implementing to monitor the effect of habitat restoration actions on recovering salmonid populations based on VSP parameters.

Adaptive management is widely applied to natural resource restoration since it builds a strong foundation through learning from the outcomes of implementation and new science, while adjusting decisions and direction accordingly to maintain and improve the certainty of achieving habitat action goals. Careful and continued monitoring of these outcomes is essential to both advance scientific understanding and to substantiate the purpose and need for further adjustments. However, groundwork investigation is necessary to set up an adaptive management framework. Reclamation telescopes its investigations in two stages, initially from a coarse resolution at the watershed or tributary then to a finer resolution of the individual reach. The first stage described in this report for the Methow Subbasin focuses on characterizing geomorphic parameters and conditions of the ecosystem, delineating reaches, and identifying preliminary project areas.

An adaptive management process offers a systematic and rigorous approach to habitat restoration when tied into the scaling relationships of a nested hierarchical framework. A hierarchy is a graded organizational structure and essentially adaptive management is structured decision-making during implementation. The *Upper Columbia Biological Strategy* recognizes the role that climatic, vegetation, and physiographic factors play in assessing and developing tributary habitat actions within dynamic landscapes and riverscapes. Within river ecosystems, physical processes and these controlling factors operate and interact simultaneously across a range of spatial and temporal scales. Habitat restoration typically fails when physical processes and corresponding controlling factors are not well understood or considered (UCRTT, 2007). The recognition of the nested hierarchical nature of rivers is essential in understanding the effects of human disturbances on physical processes.

The hierarchical nature of rivers was first introduced by Frissell et al. (1986), who emphasized levels of nested connectivity between a watershed and its many microhabitats. Frissell et al. (1986) and Montgomery and Buffington (1998) proposed multiple spatial levels within the hierarchical structure of dynamic river ecosystems, including the geomorphic province, watershed (also termed subbasin), valley segment, reach, and habitat unit. O'Neill et al. (1986) established common ground among the two schools of thought, biotic and physical/process, by recognizing that ecosystems organize due from the differences in process rates among several discrete levels. Ecosystems thrive as result of a dual hierarchical structure (Figure 2). Hillman (2006) further recognizes the significance of how one level within a hierarchical structure influences others and that this understanding is greatly informed by the levels above and below it. Thus, hierarchy theory not only provides a useful approach for interpreting the complex nature of rivers (Dollar et al., 2007), but establishes a systematic framework through telescoped assessments for identifying and prioritizing habitat protection and restoration actions.

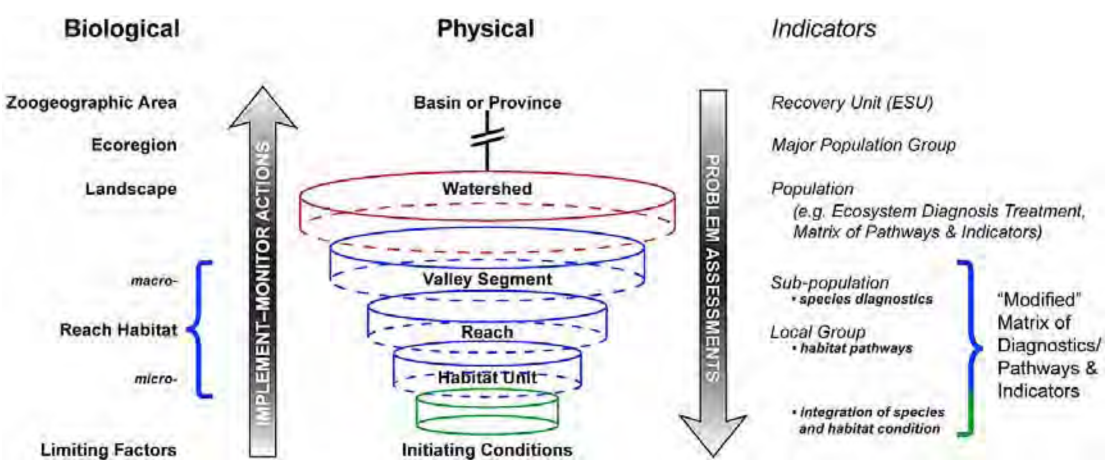

Figure 2. Biophysical levels of spatial organization typical of a nested hierarchical framework demonstrating in a cross-walk, the relationship of biotic (left) and physical (center) scaling relationships with that of relevant biotic and ecosystem indicators on the right.

Figure 2 represents a dual hierarchical structure of ecosystems illustrating that processes and functions are capable of operating on multiple levels, ultimately forming nested, interdependent systems (or adaptive cycles) where a lower level of organization influences upper levels. Hence, many small habitat actions conceivably have lasting cumulative effects and benefits to the river ecosystem. In the figure, bio-physical attributes are shown empirically operating over multiple levels of organization. For example, corresponding scaling relationships are represented on the left by the biological realm (land cover and vegetation) and on the right by the physiography realm (geology, geomorphology, and topography). The third realm, climate is unrepresented. Habitat complexes and their corresponding interrelationships within dynamic river systems are driven in two directions by both ultimate and proximate controlling factors; habitat quality emerges at the reach scale through time at the intersection represented by the third dimension.

Nested relationships are particularly affected by ultimate control factors such as climate, vegetation, and physiography, which operate over large areas, provide stability over long time frames, and enable a shaping of overall characteristics and conditions of a geomorphic province (basin) and respective watersheds. In the instance of this assessment, four valley segments (Upper and Middle Methow, Twisp, and Chewuch) were examined and further delineated into 23 geomorphic reaches within the focal area of the Methow Subbasin. At intermediate scales of the reach hydrologic and geomorphic processes shape channel characteristics, which in turn shape and constrain smaller-scale habitat features (Allen and Starr, 1982; Frissell et al., 1986; Poff, 1997; Allan, 2004; Dollar et al., 2007).

The 23 reaches in the four Methow Subbasin segments were characterized based on differences in geomorphic conditions and potential to provide habitat features associated with multiple life stages and species use, particularly complex habitat for ESA-listed spring Chinook and steelhead. One of the primary habitat objectives from the *Upper Columbia Recovery Plan* (UCSRB, 2007) is protecting and improving connectivity between the channel and floodplain and hence habitat units. Therefore, for purposes of discussing preliminary restoration opportunities unconfined and moderately confined reaches with wide floodplain areas were identified separately from naturally confined, single-thread channel reaches.

Habitat-forming processes such as sediment, hydrologic, and wood regimes emerge from functional landscape or watershed conditions, creating and re-creating habitat complexes and individual habitat units such as pools, riffles, and bars. In turn, biodiversity emerges in the form of species assemblages, reflected by the biological indicators: recovery unit (ESU), population, sub-population, and local group, which are affected by causal limiting factors and threats.

The geomorphic reach represents the organizational level of focal interplay between ultimate and proximate controlling factors. Proximate factors are constrained by ultimate controls and characterized by local conditions of geology, landscape, and biological processes operating at a smaller area over a shorter time frame typical of active habitat units. The most common human features and activities observed in this geomorphic assessment were levees, roads, riprap, bridges, historical filling of channels, and removal of riparian vegetation and LWD.

The dueling relationship between ultimate and proximate controls unfolds everyday as worldviews of differing scientific disciplines engage each other in attempting to formulate multi- and inter-disciplinary approaches to implement and thereafter monitor habitat actions. A spatial hierarchical structure was used to set the context for process-based restoration and protection opportunities at the reach scale. Findings described in the remainder of this report represent a scaled, systematic approach intended to identify, develop, implement, and sustain successful habitat restoration projects that can minimize risk of adverse impacts to existing property development and currently functioning habitat.

Where the watershed or tributary assessment investigates the relevancy of ultimate control factors, the reach assessment focuses on local proximate control factors. The eventual goal of habitat restoration actions is to reestablish the ability of a river ecosystem to maintain habitat function and connectivity without continued human influence. Connectivity in this sense is viewed in three physical dimensions: longitudinal, along the river channel critical for salmon migration; lateral, critical for access and viability of off-channel habitat; and vertical, critical for water quality and water quantity in habitat areas. Human features and historical activities can act as primary and causal limiting factors to channel and floodplain connectivity, channel migration and reworking processes, and the availability of habitat complexity features.

The goal for habitat protection and restoration actions is to maximize habitat complexity consisting of rearing areas, over-wintering areas, and spawning habitat by addressing the impacts that have occurred. The greatest impacts to river and floodplain processes along the Methow, Twisp, and Chewuch Rivers are generally attributed to levees, roads, riprap, bridges, historical filling of channels, and removal of riparian vegetation and LWD. The modification or removal of such features and actions does offer opportunity to improve channel and floodplain connectivity, channel migration and reworking processes, and the availability of habitat complexity features. However, before this can be determined, establishing baseline environmental conditions is a necessary prerequisite. The baseline is optimally accomplished at the reach scale during a reach assessment through the use of a modified “Matrix of Diagnostics/Pathways and Indicators” (NOAA Fisheries Service, 1996; USFWS, 1998) that includes an enhanced set of indicators for the pathways: habitat elements, channel dynamics, and riparian vegetation conditions. The Matrix or MPI serves not only as a basis for establishing baseline conditions, but also a platform for identifying and refining project areas and in turn, providing a context for recommending a technical prioritization of habitat actions.

The most commonly associated ultimate controls at the regional level manifest through the goals and objectives represented by the *Upper Columbia Recovery Plan*, the FCRPS BiOp, monitoring protocols, and viability criteria. In contrast, tributary habitat management actions manifest through implementation activities at the local level through an operationalization of recovery planning efforts and “project-based” strategies. Time is as critical as the three physical dimensions of river connectivity. Regional recovery plans include recommendations that proposed habitat actions be completed over the short- and long-term basis. A sequence of actions is recommended in the *Upper Columbia Recovery Plan* because there are insufficient resources available to implement all recovery actions. Therefore, the UCSRB identified a tiering or priority-setting methodology organized by four types of tiers. The UCSRB encourages work on the highest Tier I habitat actions with presumably the greatest biological benefits. Tiering in this context is based on the consideration and interrelationships of biological benefit, cost, and feasibility for implementation.

Where cumulative habitat actions can be linked at the reach through the intersection of lower and higher order physical-habitat-forming processes, quality habitat structure should emerge through the fourth dimension of time. Given that most restoration occurs at the reach scale (Fausch et al., 2002; UCRTT, 2007), implementation and hence a spectrum of monitoring strategies need to be geared accordingly within an adaptive management framework. In this way, the cumulative effect of habitat improvements on VSP parameters at the reach level directly indicate benefits to abundance and productivity; as several critical reaches are restored in several valley segments through time, continued cumulative actions ultimately address the spatial structure and diversity of the ESU.

3.2 DELINEATION OF GEOMORPHIC REACHES

Twenty-three geomorphic reaches were delineated primarily on the basis of changes in physical characteristics that dominate channel function and the formation and sustainability of habitat features. (See Appendix C for more detailed information of each reach). Examples of physical characteristics include geologic controls, valley slope, sediment input and transport capacity, riparian vegetation, role of LWD, and water temperature. Geomorphic processes and habitat conditions that result from the physical characteristics of the river were then evaluated to further define reach characteristics. Examples of geomorphic processes used to evaluate reaches are channel form and rate and extent of change in channel position.

The longitudinal (along the river length) boundaries of the 23 reaches are generally located at natural constriction points – such as bedrock or large alluvial-fan deposits – that provide lateral, and often vertical, limits to channel change (Appendices G and M). The lateral boundary of the reaches is defined by the extent of the floodplain, often referred to as the “low surface” in this assessment (Appendix M). The low surface is composed of the active channel (unvegetated main channel and sediment bars), secondary or side channels, vegetated islands, and the adjacent floodplain, which may include overflow channels and surfaces less frequently inundated (Appendix G). The boundary of the floodplain consists of bedrock, alluvial fans, and glacial deposits that are difficult to erode on a decadal time scale and limit (or at least slow) lateral expansion (Figure 3 and Figure 4; also see Appendices E and G). Glacial deposits are the most common geologic unit along the boundary of the low surface in all four river valley segments (Appendix E). The second-most common geologic unit (by percentage) is alluvial fans in the Methow and Twisp, and bedrock in the Chewuch. Landslides compose less than 5% of the total boundary length on either side of the river for all four river valley segments.

	
Figure 3. View of glacial bank along Methow River upstream of Winthrop.	**Figure 4. View of the Methow River between Carlton and Twisp River confluence, where bedrock composes the boundary of the low surface.**

As a result of geologic influences, the floodplain within the assessment area ranges from reaches that are naturally confined and relatively narrow to floodplain areas that are unconfined with more dynamic lateral channel migration over a wider floodplain. Because one of the primary habitat objectives is improving connectivity between the channel and floodplain, reaches with measurable floodplain were separated from reaches with very little floodplain for purposes of discussing restoration opportunities. Three floodplain types were identified that help group the 23 reaches based on the natural potential of channel habitat complexity:

- High complexity, with wide, unconfined floodplain
- Medium complexity, with narrower, moderately confined floodplain
- Low complexity, with narrow, confined floodplain

Although the level of complexity may vary, each of the three floodplain types has valuable habitat components that are essential to sustaining the variety of aquatic life stages and species within the Methow Subbasin ecosystem. Areas with higher rates of floodplain reworking and interaction between the channel, side channels, and riparian vegetation offer the most opportunity for providing habitat complexity.

Approximately 78% of the 80-mile assessment area is composed of moderately confined and unconfined reaches. These reaches have measurable floodplain areas adjacent to the main channel that consist of islands, overbank flooding areas, side, and overflow channels. These floodplain areas contain opportunities for protecting and restoring habitat complexity in unconfined and moderately confined reach types (Figure 5 and Figure 6).

The lengths of river reaches that have vegetated floodplain are listed below based on 2004 aerial photography:

- 15.2 miles of the middle Methow River (70 percent of main channel length)
- 21.4 miles of the upper Methow River (86 percent of main channel length)
- 15.5 mile of the Twisp River (85 percent of main channel length)
- 9.5 miles of the Chewuch River (60 percent of main channel length)

The following three sub-sections provide more detailed explanations of each of the floodplain types.

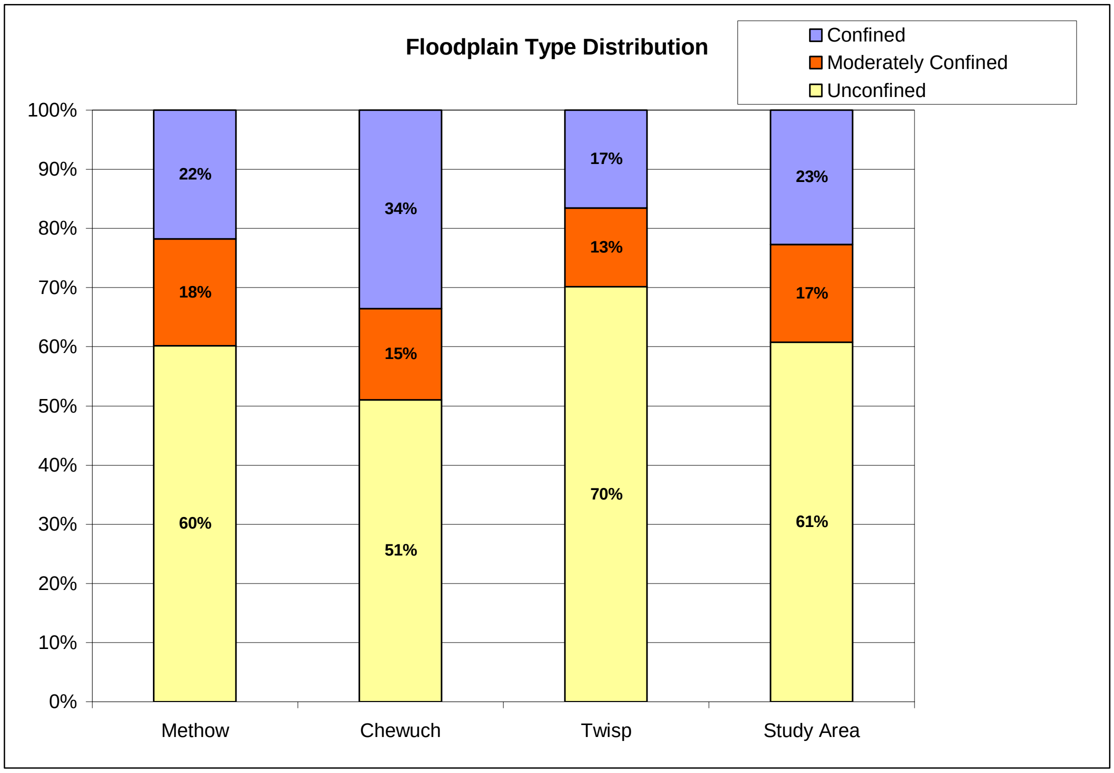

Figure 5. Distribution of reach types and floodplain availability within assessment area.

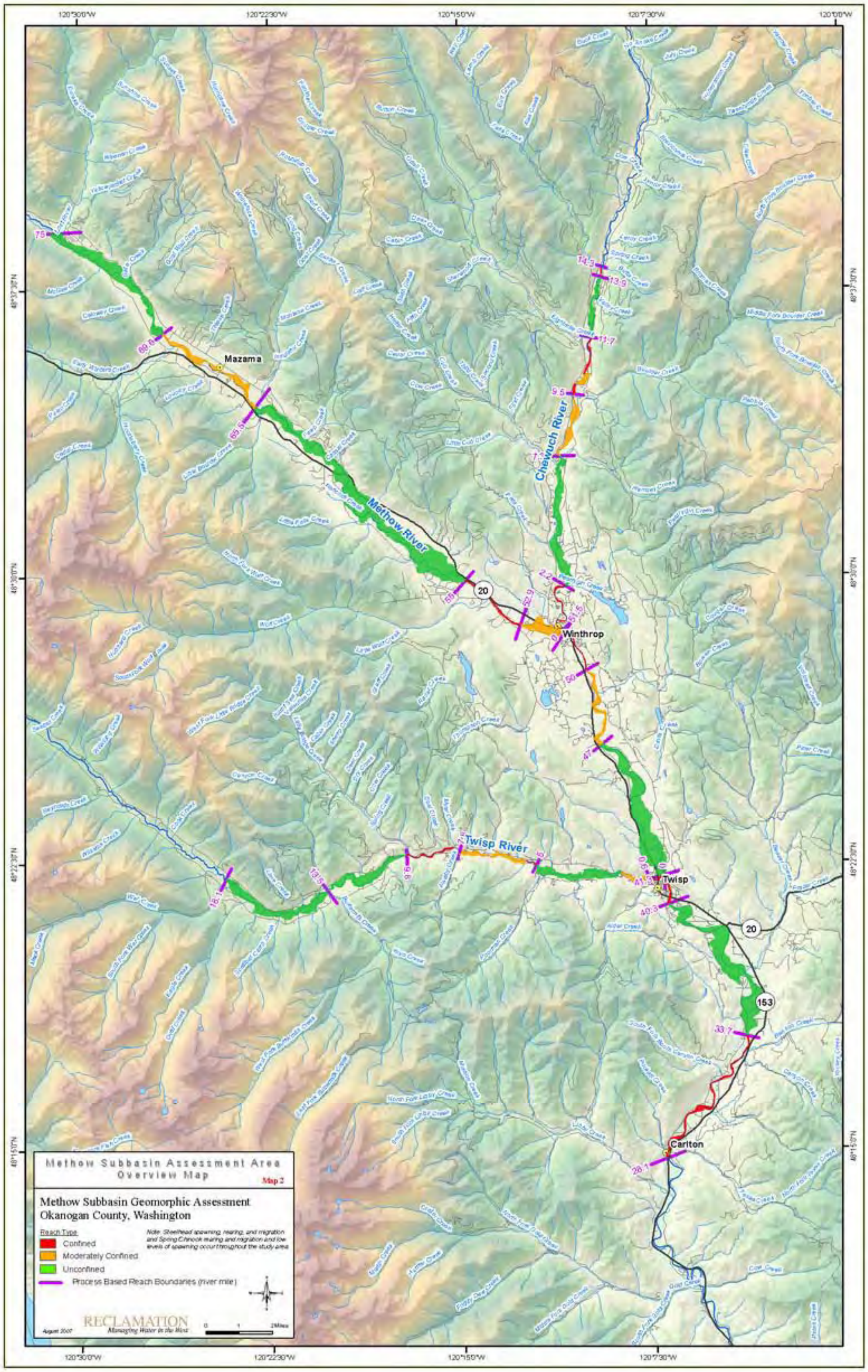

Figure 6. Geomorphic reach locations categorized by floodplain type.

3.2.1 High Complexity with Wide, Unconfined Floodplain

The unconfined floodplain reaches typically have a high degree of channel and floodplain interaction from year to year with a dynamic cycle of conversion from river to floodplain and vice versa (Figure 7and Figure 8). In a natural system, this dynamic process is what helps these reaches maintain a healthy riparian forest that provides ample shade and complexity while still being dynamic enough to build new habitat areas as others are eroded. Erosion and deposition are common as the channel migrates across the floodplain. During a single flood, one channel may fill with sediment. As this occurs, the channel can be abandoned and another channel enlarged (eroded) to become the new main channel. However the average channel bed elevations within the reach may not change over time, so that there is no temporal trend change in the total volume of sediment stored in the reach beyond a natural range of fluctuation.

The interaction between water in the river and the groundwater table is highly dynamic and an important part of the aquatic habitat. Complex channels often have smaller sediment sizes in bars and in the channel bed than steeper, single-thread channel reaches. The smaller sediment, complexity of channels, and presence of LWD creates and maintains more spawning and rearing habitat for spring Chinook than other types of reaches. Steelhead is also successful in these reaches, and there is ample holding and cover for migratory species passing through. This floodplain type typically contains deep levels of alluvium that allow a dynamic interaction between the river and groundwater. In areas that are subject to dewatering, local biologists have observed in the field that scour holes are often created by LWD which can potentially provide sustainable pools until river flows rise. Areas with cold water recharge, such as springs, are typically associated with a high concentration of spawning and rearing use.

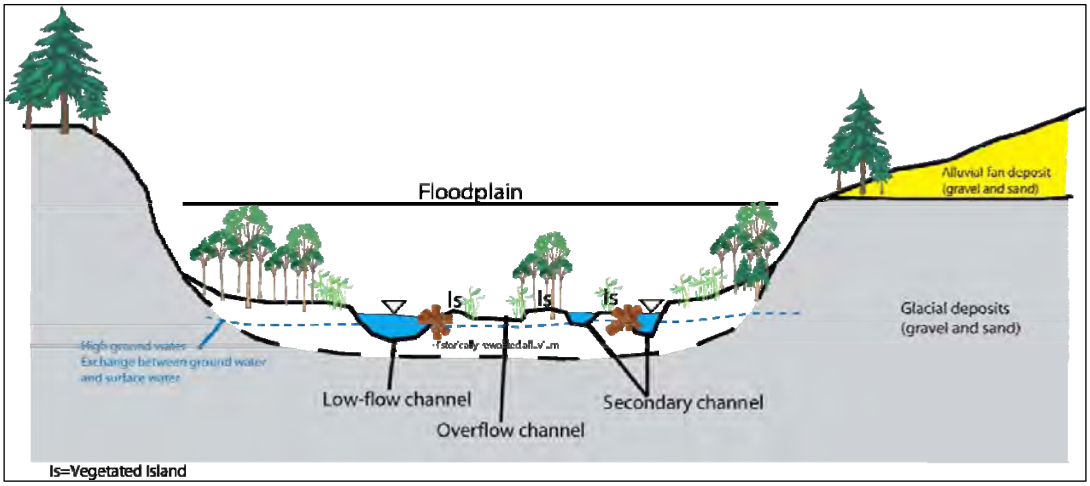

Figure 7. Schematic cross section of a wide, unconfined floodplain, such as the Methow River upstream of Wolf Creek.

Figure 8. Log jam formed at head of vegetated island at location of flow split in Methow River upstream of confluence with Chewuch River.

3.2.2 Medium Complexity, with Moderately Confined Floodplain

This moderately confined floodplain type contains a more defined main channel than the high-complexity reaches, and has only one or two well defined off-channel areas (Figure 9). Side channels offer valuable habitat, particularly when groundwater helps supply water to the channel during low-flow conditions (Figure 10). Older surfaces are often present within the floodplain, and these higher surfaces are more stable than the surfaces in the unconfined floodplain areas. The higher elevation surfaces are inundated during floods, but typically only suspended sediments are deposited on these surfaces. This results in less frequent lateral reworking of the floodplain. Changes in channel position typically occur within a few defined channels that transport the majority of coarse sediment rather than across the entire floodplain. The main channel remains in one place for several years to decades. A dense riparian buffer zone slows near-bank velocities, provides wood recruitment to the channel, and reduces the rate of bank erosion. LWD is most common in the slower velocity off-channel areas. Log jams often occur at the head of vegetated islands as in the unconfined floodplain types. Wetlands are occasionally present in the off-channel areas of these reaches, and beaver activity can be common.

Moderately confined reaches do not have as much complexity as the unconfined floodplain type, but they still contained a wide variety of habitat components and complexity, and support a range of fish species and life cycles. The off-channel areas support mainly spawning and rearing of spring Chinook and steelhead. Off-channel areas with cold springs commonly are inhabited by non-native brook trout. The main channel can support steelhead, spring Chinook, and summer Chinook spawning. Off-channel areas likely were heavily used by coho salmon before the extirpation of the species from the Methow River. (If current coho reintroduction efforts are successful, these areas would likely be dominated by them.) Fish usage in the natural setting is dynamic in order to take advantage of varying hydrologic conditions. In lower flow years, fish spawning in riffles and typically higher velocity areas are successful because high freshets do not wash out the redds. However, redds placed at the edge of the wetted channel may dry out and not be successful in dry years. In higher flow years, the redds in the riffles are washed out, but redds at the edges of the channel are successful. Local recharge areas also provide refuge during low-flow conditions in these reaches.

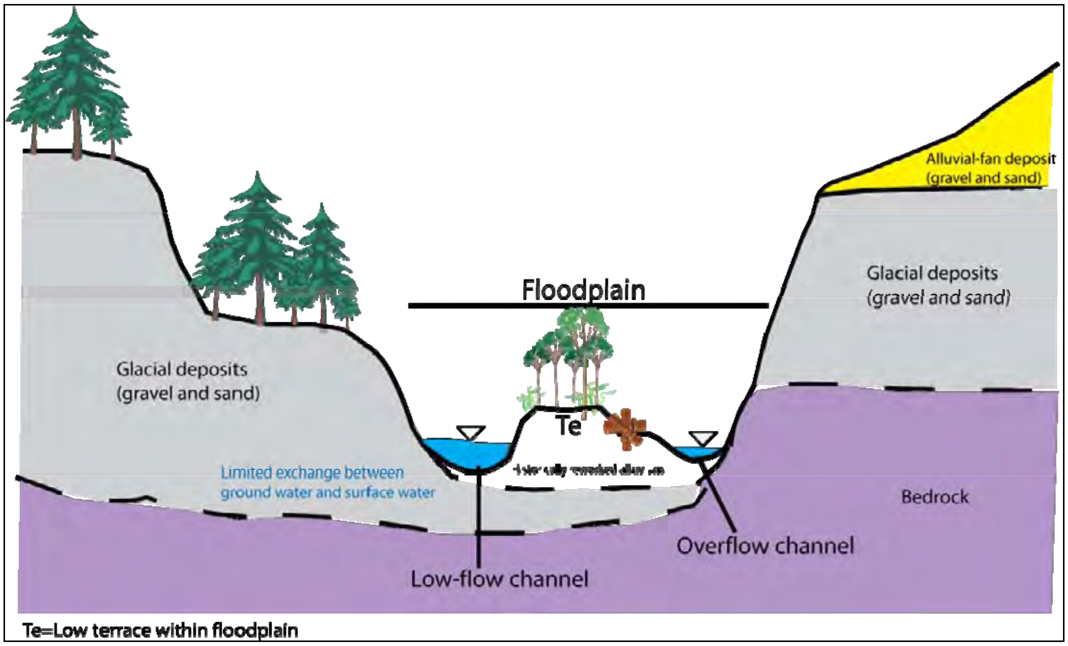

Figure 9. Schematic cross section of a narrower, moderately confined floodplain within the assessment reach, such as portions of the Methow River between Twisp and Winthrop.

Figure 10. Looking downstream at beaver lodge on side channel of Methow River downstream of confluence with Chewuch River.

3.2.3 Low Complexity, with Narrow, Confined Floodplain

The third floodplain type is confined, straight channel reaches that have little to no off-channel habitat (Figure 11). However, these reaches do have an important habitat function. Some species are successful in spawning in these reaches, but within the assessment area these reaches generally provide holding and migration corridors for fish trying to access upstream or downstream reaches. Riparian vegetation is present on narrow sediment bars and provides a limited recruitment source of LWD for downstream reaches (Figure 12). Pockets of slower-velocity flows behind occasional boulders provide resting areas. LWD in the channel is generally limited, but occasionally occurs on bars or on the upstream sides of exposed boulders in the bed. During floods, river stage increases faster than in other reaches, and the same area is consistently reworked during each flood. However, riparian vegetation requires fresh, bare soil to establish. Riparian vegetation cycles in these reaches as a function of the hydrologic regime. During a period of dryer years, the riparian vegetation establishes. Occasionally, a large flood erodes the vegetation and restarts the cycle by providing a fresh surface on which new vegetation can become established.

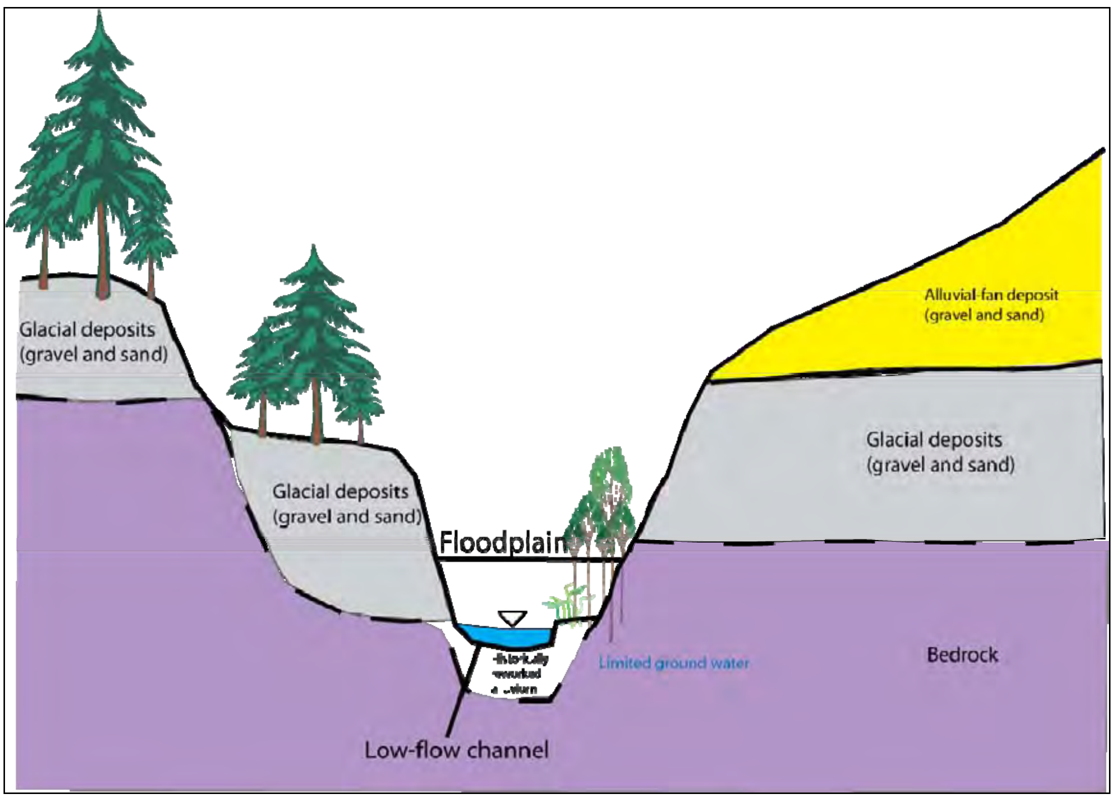

Figure 11. Schematic cross section of a narrow, confined floodplain within the assessment reach, such as portions of the Methow River downstream of Twisp.

Figure 12. Example of confined floodplain section on Methow River between Winthrop (RM 51) and Wolf Creek (RM 55).

3.3 HUMAN CAUSED IMPACTS TO PHYSICAL PROCESSES

Within the floodplain (low surface), there are a range of human features present, but generally these features are located sporadically throughout these sections rather than continuously along the channel. The majority of these features were observed on aerial photography as being constructed following the two largest documented floods in 1948 and 1972. An example location is provided in Figure 13, Figure 14, and Figure 15 where a levee was observed on the post-flood 1948 aerial photograph (post-flood 1948 photo not shown). A list of all human features and activities documented to noticeably impact river processes include the following:

- highway or road bridges
- footbridges
- levees (fill is generally stable and resistant to erosion)
- push-up levees (often formed using floodplain sediment and can be easily eroded by the river during high flows)
- filling of historic channels (difficult to document with certainty, but interpreted based on presumed setting of certain areas compared with current condition)
- clearing of vegetation within the floodplain

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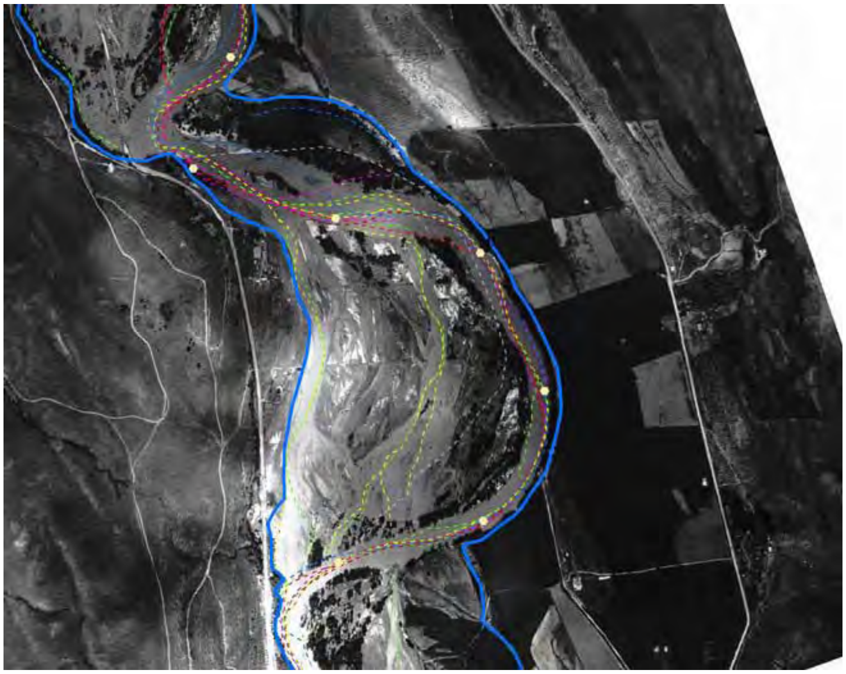

Figure 13. 1948 aerial photograph of Middle Methow River during the 1948 flood. Relative to the picture, the river is flowing from top to bottom. Beige dots show the alignment along the 2006 main channel in 1/10 mile increments. Dashed lines represent historical channels based on 1948 to 2004 aerial photography. The solid blue line represents the boundary of the floodplain (low surface) as of 2004.

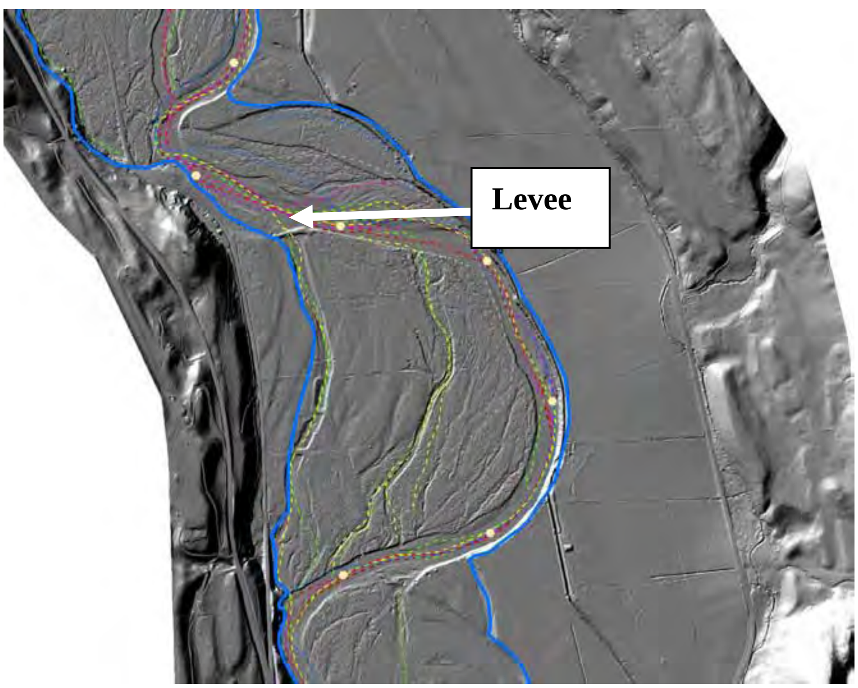

Figure 14. Same location as previous figure showing levee that was placed following the 1948 flood. Figure background is 2006 Light Detection and Ranging (LiDAR) hillshade.

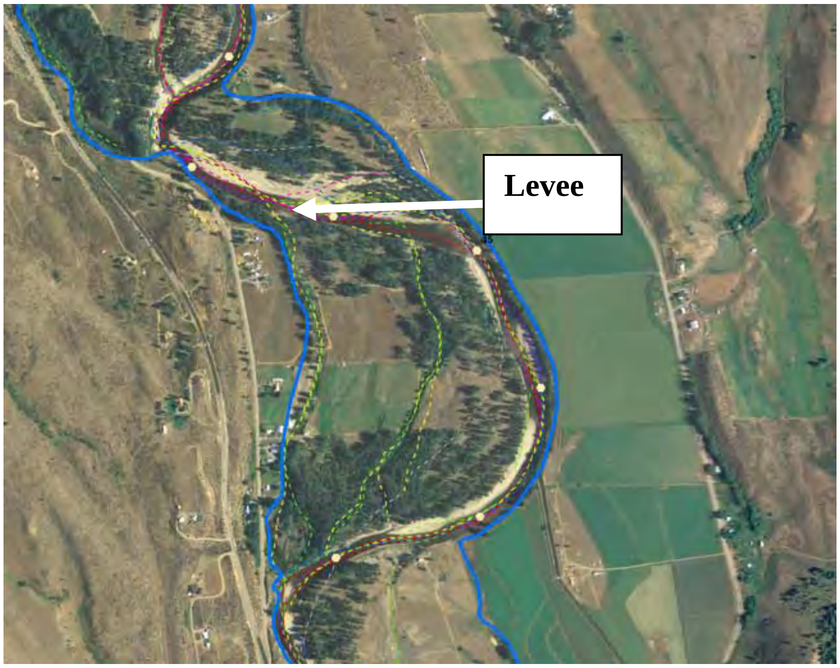

Figure 15. Same location as previous two figures with 2006 aerial photograph as background showing clearing of vegetation and present development.

- removal of LWD pieces and log jams from the channel
- roads
- rock riprap
- "Detroit" riprap (old vehicles placed on bank)
- cabled logs (several logs placed along bank for protection against erosion) or log structures (cabled log or log-jam-type structures)
- diversion dams
- diversion locations
- headgates
- water pipes

The shade and cover from the few log structures constructed actually provide some fish habitat. Bank armoring, levees, bridges, and other features located within the floodplain prevent channel migration and restrict access to overbank floodplain areas and side and overflow channels. This in turn impacts access by fish and the formation of habitat complexity features that depend on channel migration, recruitment of LWD, and reworking of the streambed. Many of the features block off only the upstream entrance of a side channel, or only a portion of the floodplain rather than running parallel to the main channel for long distances (see Figure 14 and Figure 15). In many cases, the downstream entrance to a side channel is still accessible, and portions of the floodplain are still active due to lateral overtopping of flow from the river downstream of a human feature.

Where bank protection is located along the main channel, the river may have formed an adjacent deep scour hole due to higher velocities that sweep against the bank. These deeper areas pull streamflow away from the opposite side of the river, reducing habitat complexity and access to off-channel areas opposite the armored (protected) area. As a benefit, this process may provide a pool for aquatic habitat. However, such pools lack shade, hiding cover, and structure to capture nutrients and form pockets of slower velocity flows (refugia) that would be created by vegetation and roots present along a natural bank. In areas where the bank would naturally have had vegetative cover, the adjacent sections of the river are devoid of shade and any potential for LWD recruitment. The reduction in shade has the greatest impact on smaller stream sections where the overhanging vegetation affects a significant portion of the wetted channel width. Protection along banks that were naturally limited in vegetation or that are fairly high above the channel has much less impact on channel processes.

3.4 Description of 23 Geomorphic Reaches

Table 4 presents a summary of characteristics for the 23 geomorphic reaches, including whether the reaches are confined, moderately confined, or unconfined as defined in Section 3.2. Each reach is designated by a letter and number (M = Methow; C = Chewuch; T = Twisp). Numbering starts at the downstream end of the reach.

The “floodplain protection area” (column 5) documents the percent of the total floodplain and off-channel area that has no human features so there is no restoration action needed. These areas are for the most part presently functioning in terms of physical processes and vegetation, but in some cases are indirectly impacted by nearby human features in other floodplain restoration areas.

Columns 6 and 7 document the length of well-defined side channels (from 2004 aerial photographs and 2006 LiDAR) that could provide off-channel habitat (see Methow Atlas for channel mapping). The table is separated into channels with no human features blocking them off (protection areas) and channels that are presently cut off at either the upstream or downstream ends (or both) by levees, bridges, etc. (restoration areas). In some unconfined and moderately confined reaches, historical channels may have been filled or altered and this measurement does not capture the full length of potential channels. Therefore, this number of channels represents a minimum number of potential channels that could provide off-channel habitat. More refined mapping at the reach analysis or project level stage with additional field verification should be done to validate the channel mapping.

Column 9 documents the boundary of the floodplain on terraces or high elevation glacial banks. The ratio was computed by dividing the total length of human features along the floodplain boundary (typically bank protection) by the total floodplain boundary length for each reach (see map atlas for human feature mapping). The higher the number computed, the greater the boundary length impacted. The amount of floodplain boundaries protected ranges from none in some reaches to 61% in Reach M3. Generally the confined reaches have more bank protection, which is interesting because these are generally bound by glacial terraces that would be expected to have minimal lateral bank erosion. It is believed that the majority of bank protection went in after the 1948 and 1972 floods, during which accelerated bank erosion may have occurred due to most of these areas being cleared of native vegetation. Glacial banks in this system contain large cobbles that often line the toe of the bank during erosion helping to protect from extensive lateral expansion due to river erosion. Although the lateral extent of bank erosion that could occur during floods is likely small, many houses and infrastructure are located in close proximity to the edge of the bank and cannot tolerate even localized bank erosion without incurring damage. This may explain the large amount of bank protection present on glacial banks. Lateral bank erosion of these glacial banks has only been detected in a few sections of the 80-mile assessment area where no bank protection has been placed. The limited erosion measured from 1948 to 2004 also may result from the fact that the majority of banks with the potential to be eroded have already been armored with riprap.

As a rough indicator of disruption to channel migration and floodplain access (column 8), a second ratio was computed by dividing the total length of human features that disconnect the main channel from side channels or floodplain, or prevent lateral migration by the reach length. Reaches with higher values have more reduction in floodplain connectivity than reaches with lower values, which indicates the reaches with higher values may have more opportunity for improving habitat function.

The amount of floodplain area where vegetation has been cleared under the present setting (2006) is also documented in column 10 (see map atlas for vegetation mapping). Reaches with larger values of vegetation clearing generally have more development potentially posing more challenging restoration strategies than areas with limited or no development. Areas of historic vegetation clearing are not well documented and were not incorporated into this computation. Therefore, this number represents a minimum area of floodplain clearing and does not include areas that were cleared in the past and currently in a regeneration stage.

Combining results from all columns in Table 4 gives a quick look at the current condition of each reach and restoration opportunities. Reaches that are unconfined and moderately confined generally have more disruption to channel and floodplain connectivity and habitat access than confined reaches. Reaches with a high percentage of protection areas (limited or no human impacts), good connectivity to side channels, healthy riparian buffer zones (little riprap), and limited vegetation clearing are the least impacted and vice versa for the most impacted. Reaches M2, M4, M7, M9, C2, and T2 have at least 1 mile of potential off-channel habitat that could be reconnected. Of these reaches, M9, M10 and C2 have at least 30% of the reach that is noted as a protection area that could be built upon to provide more connectivity of habitat availability at a reach scale. T6 has the highest percentage of functioning off-channel habitat presently available

Table 4. Summary of reach characteristics.

Reach Name	Floodplain Type	Down-stream River Mile	Up-stream River Mile	Floodplain Protection Area (properly functioning with no human impacts) (% of total reach)	Length of Side Channels (miles)		Indicator of Disruption to Processes		Minimum Cleared Vegetation (% of total reach)
					Presently Accessible[1]	Presently Cut Off by Human Features	Disruption to Channel Migration and Floodplain Access[2]	% of Floodplain Boundary (terraces and glacial banks) that is Armored [3]	
M1	Confined	28.1	33.7	NA	0	0	0.13	27	11.1
M2	Unconfined	33.7	40.3	7%	0.9	8.2	0.66	23	24.4
M3	Confined	40.3	41.3	NA	0	0	0.06	61	5.3
M4	Unconfined	41.3	47	9%	1.2	7.0	0.80	17	37.0
M5	Moderately confined	47	50	26%	0.2	1.1	0.38	14	26.6
M6	Confined	50	51.5	NA	0	0	0.00	12	0.0
M7	Moderately confined	51.5	52.9	0%	0	1.4	1.89	4	40.9
M8	Confined	52.9	55	NA	0	0	0.01	40	10.6
M9	Unconfined	55	65.5	34%	11.4	9.7	0.54	10	13.2
M10	Moderately confined	65.5	69.6	56%	1.2	1.2	0.05	7	11.6
M11	Unconfined	69.6	75	38%	3.2	2.8	0.40	7	7.8
C1	Confined	0	2.2	NA			0.04	2	8.8
C2	Unconfined	2.2	7.3	32%	2.9	3.7	0.16	0	16.8
C3	Moderately confined	7.3	9.5	45%	0.9	0.6	0.45	0	24.6

Reach Name	Floodplain Type	Down-stream River Mile	Up-stream River Mile	Floodplain Protection Area (properly functioning with no human impacts) (% of total reach)	Length of Side Channels (miles)		Indicator of Disruption to Processes		Minimum Cleared Vegetation (% of total reach)
					Presently Accessible[1]	Presently Cut Off by Human Features	Disruption to Channel Migration and Floodplain Access[2]	% of Floodplain Boundary (terraces and glacial banks) that is Armored [3]	
C4	Confined	9.5	11.7	18%			0.12	6	12.7
C5	Unconfined	11.7	13.9	29%	0.2	0.6	0.14	0	2.1
C6	Confined	13.9	14.3	NA			0.00	0	0.0
T1	Confined	0	0.6	0%		0.2	0.64	33	87.2
T2	Unconfined	0.6	5	9%	0.7	4.9	0.98	3	38.9
T3	Moderately confined	5	7.8	45%	1.0	0.7	0.29	9	21.9
T4	Confined	7.8	9.8	18%		0.2	0.28	16	15.4
T5	Unconfined	9.8	13.5	14%	0.8	1.3	0.44	8	31.7
T6	Unconfined	13.5	18.1	61%	3.9	1.8	0.26	0	8.3

1/ Although presently accessible, the natural frequency of inundation may still be disrupted in some cases due to past human activities such as filling of channel entrances or altering the land surface for housing, infrastructure, or agriculture.
2/ Computed by taking the total length of human features located within the floodplain (low surface) divided by the total reach length.
3/ Computed by taking the total length of riprap and bank armoring located along the floodplain (low surface) boundary divided by the total length of the boundary.

3.5 Reach-Based Protection and Restoration Strategy

The goal for habitat protection and restoration strategies is to maximize availability and connectivity of complexity habitat consisting of rearing areas, over-wintering areas, and spawning habitat. Identification of floodplain protection areas as part of an overall restoration strategy is important for enhancing the beneficial effects of restoration projects in adjacent areas. If restoration is approached at the geomorphic reach scale, protection areas within the reach can provide a connection among two restoration areas being addressed and effectively increase the habitat area that is restored.

The primary restoration concept recommended to recover long-term habitat function and complexity based on this analysis would be setback or removal of features that impact connectivity of the channel and floodplain, channel migration and reworking processes, and the availability of off-channel and main-channel complexity features such as side channels and LWD formed pools. This strategy is concentrated in moderately confined and unconfined reaches.

In naturally confined reaches, the largest impact has been conversion of the natural riparian zone along the high-elevation glacial banks to riprap. Modification or removal of these features in conjunction with riparian planting offers the best opportunity for improving long-term habitat viability in these reaches. However, addressing riparian boundaries of confined reaches is considered a lower priority because the banks are high in elevation and offer limited opportunity for cover and LWD recruitment. In addition, the potential for terrace bank erosion would have to be determined, and possibly mitigated, prior to the removal of any terrace bank protection. Rapid rates of terrace bank erosion would not achieve river restoration objectives.

A complete list of strategies that could be utilized to increase habitat function and complexity is listed as follows:

- Protection of existing riparian zones and functioning channel and floodplain areas that provide shade, large woody debris, and root mass to the river system;
- Continued improvement of fish passage where not yet addressed;
- Removal, setback, or modification of levees and roads, and lengthening of bridge spans to restore access to the natural floodplain, thus increasing lateral connectivity of river processes resulting in more productive off-channel rearing and over-wintering habitat areas, and groundwater recharge to maintain base flows in the river;
- Reconnection of off-channel ponds that could provide rearing habitat by removing artificial blockages, by providing passage around dams, by removing riprap, by modifying road embankments, and by enlarging culverts;

- Protection and restoration of hyporheic function between the river and the groundwater aquifer through reconnection of the floodplain where artificially blocked off to improve water temperatures;
- Reforestation of cleared floodplains and river banks, along with placement of LWD or engineered log jams, prioritizing areas with the most potential for interaction with the river to improve water temperature and habitat quality;
- Reestablishment of beaver populations where feasible with adjacent land use; and
- Reduction of the number and distribution of exotic plant and animal species where they pose a threat to native species.

For each reach, floodplain areas were broken out based on whether they were generally functioning from a process and riparian vegetation perspective, or whether they were in need of some type of restoration action due to human features or past activities. This is summarized by valley segment in Table 5 (amount of protection area was documented by reach in Table 4). Restoration opportunities exist in all four river valley segments, with the most need (or least amount of functioning area) in the Middle Methow, and relatively equal need in Upper Methow, Twisp, and Chewuch.

Table 5. Percent of functioning (protection) versus non-functioning (restoration) floodplain area for the four river valley segments.

River Valley Segment	River Miles	Total Floodplain Area (acres)	Floodplain Protection Area		Floodplain Restoration Area	
			(acres)	(% of total)	(acres)	(% of total)
Upper Methow	RM 50 to 75	2,196	748	34%	1,447	66%
Middle Methow	RM 28 to 50	1,391	126	9%	1,265	91%
Twisp	RM 0 to 18	1,084	381	35%	703	65%
Chewuch	RM 0 to 14	603	192	32%	411	68%
Total Area		**5,274**	**1,446**	**27%**	**3,827**	**73%**

The next step was to determine which restoration actions were needed to improve habitat complexity and physical processes that have been disrupted from historical human activities (such as logging, filling of channels, clearing of riparian vegetation and LWD, etc.) and present human features (roads, bridges, levees, riprap, etc.). Restoration concepts are documented in Appendix A (“Restoration Opportunities”) at a reach scale and for individual potential floodplain areas within each reach.

The findings of the geomorphic assessment were then translated into habitat action classes and the associated VSP parameters that would be addressed as referenced from Table 5.9 in the *Upper Columbia Recovery Plan* (Table 6). All of the habitat action classes in the *Upper Columbia Recovery Plan* were considered except for water quality and quantity restoration, nutrient restoration, and in-stream structures (rock weirs, boulder placement, etc.). Water quality and quantity and nutrient restoration are being addressed as primary goals in separate efforts. However, restoration of floodplain processes will serve to improve water quality and quantity in some reaches. Currently there are ample opportunities for restoration of processes without using in-stream structures so they were not considered at this scale. Although tributaries were not assessed in detail, locations are listed where known issues exist that have some interdependency with processes in the mainstem stream segment. Additional assessment will be needed to validate and refine these potential actions in tributary areas.

Only one obstruction to main channel passage was present on the mainstem Methow River (at MVID East near RM 46), although passage is available along an adjacent side channel. The approximately 3-foot-high portion of the diversion dam above the river bed was recently removed to eliminate this barrier. Two other small diversion dams on the Chewuch River are also in the process of being modified to eliminate passage barriers that had existed at some, but not all, flows.

A generalized restoration strategy for each of the 23 reaches is provided in Appendix A, along with a detailed list of floodplain protection areas and restoration concepts for 73 sites. These restoration concepts will need to be refined as additional analyses are completed at more detailed scales. The study results described in this report are being used to work with local stakeholders and biologists to help prioritize protection and restoration strategies as discussed in the next section.

Table 6. Reach-based habitat action classes associated VSP parameters for the study reaches and selected tributaries.
An "X" represents a proposed habitat action or VSP parameter based on direct findings of this assessment. An "O" represents a possible action based on local knowledge and qualitative observations during the course of the 80-mile assessment.

Reach Name	Floodplain Type	Habitat Action Class [1/]						VSP Parameters Addressed [2/]	
		Riparian restoration on terraces (floodplain boundary)	Riparian restoration along channels and floodplain surfaces	Side-channel reconnection	Road Maintenance (e.g., removal, setback, or culvert replacement)	Floodplain Restoration	LWD Restoration	A/P	D/SS
M1	Confined	O	X					X	
M2	Unconfined	O	X	X	X	X	X	X	X
M3	Confined	O						X	
M4	Unconfined	O	X	X	X	X	X	X	X
M5	Moderately confined	O	X	X	X	X	X	X	X
M6	Confined	O						X	
M7	Moderately confined	O	X	X	X	X	X	X	X
M8	Confined	O						X	
M9	Unconfined	O	X	X	X	X	X	X	X
M10	Moderately confined	O	X	X		X	X	X	X
M11	Unconfined	O	X	X	X	X	X	X	X
C1	Confined	O						X	
C2	Unconfined		X	X		X	X	X	X
C3	Moderately confined		X	X	X	X	X	X	X
C4	Confined	O	X			X	X	X	X

Table 6. Reach-based habitat action classes associated VSP parameters for the study reaches and selected tributaries.
An "X" represents a proposed habitat action or VSP parameter based on direct findings of this assessment. An "O" represents a possible action based on local knowledge and qualitative observations during the course of the 80-mile assessment.

Reach Name	Floodplain Type	Habitat Action Class [1/]						VSP Parameters Addressed [2/]	
		Riparian restoration on terraces (floodplain boundary)	Riparian restoration along channels and floodplain surfaces	Side-channel reconnection	Road Maintenance (e.g., removal, setback, or culvert replacement)	Floodplain Restoration	LWD Restoration	A/P	D/SS
C5	Unconfined		X	X		X	X	X	X
C6	Confined								
T1	Confined	O	X		X	X		X	X
T2	Unconfined	O	X	X	X	X	X	X	X
T3	Moderately confined	O	X	X		X	X	X	X
T4	Confined	O	X					X	
T5	Unconfined	O	X	X		X	X	X	X
T6	Unconfined		X	X	X	X	X	X	X
Early Winters; Methow RM 67.3		O	O		O	O	O	X	
Wolf Ck, Methow RM 52.8		O	O		O	O	O	X	X
Goat Ck, Methow RM 64		O	O		O	O	O	X	X
Eightmile Ck, Chewuch RM 11.7		O	X		O	O	O	X	X

[1/] Habitat action classes and associated VSP parameters addressed referenced from Table 5.9 in Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan (UCSRB, 2007)
[2/] A/P = abundance and productivity; D/SS = diversity and spatial structure as described in Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs (ICTRT, 2007)

3.6 Technical Prioritization of Restoration for 23 Geomorphic Reaches

One question faced by resource managers looking at large potential project areas is whether to fix areas that are least broken first or to start with areas where there is the most opportunity for improvement. The *Upper Columbia Recovery Plan* recommends prioritizing areas that are currently properly functioning (protect and monitor), looking next at areas in which processes that benefit habitat can be restored (restoration or rehabilitation), and finally investigating options such as in-stream structures where present constraints do not allow restoration of channel and floodplain processes (not all stream conditions are suitable for in-stream structures).

In following recommendations established by the *Upper Columbia Recovery Plan*, geomorphic reaches were technically ranked with a method that gives more weight to areas with a higher degree of functioning complexity habitat than to reaches with a lower degree of functioning complexity habitat (a greater departure from the natural setting) (see Appendix B for more details on ranking methods).

Step 1 of the ranking was to categorize the 23 geomorphic reaches by general floodplain type (that is, confined, moderately confined, and unconfined) and the degree of human feature impacts in each reach (see Table 4)All three floodplain types have some degree of presently functioning habitat and potential for improvement of habitat quantity and quality. However, the unconfined and moderately confined reaches generally offer the most opportunity for providing channel and floodplain processes associated with habitat "complexity." In Step 2, general habitat actions were identified for each of the 23 reaches based on their geomorphic setting and historical impacts to physical processes and habitat function (see Table 6).

In Step 3, six of the nine confined reaches were dropped from consideration for developing a detailed restoration strategy. Confined reaches may offer restoration opportunities along the floodplain (low surface) boundary through the possible removal or modification of bank protection to incorporate riparian vegetation that promotes shade, large wood recruitment, and a reduction in sediment delivery. Confined reaches pose challenges for LWD and rock placement projects because they are naturally high energy reaches where it would be difficult to maintain these features. There are generally greater opportunities in the reaches with vegetated floodplain areas (moderately confined and unconfined) to identify complexity projects that can help restore the long-term function of the river. Therefore, project concepts were not developed in the confined reaches for this assessment. Nonetheless, human features in confined reaches were identified and could be further evaluated in future assessments.

The 17 remaining reaches were then ranked to allow relative comparison from the perspective of the ability to provide habitat complexity and extent of presently functioning areas (Table 7). The numeric ranking focuses on physical processes associated with lateral connectivity of the floodplain and channel, and with formation of habitat features associated with complexity. For example, the higher the total score, the better the opportunity for channel habitat complexity improvements. Score values should not be used literally, but rather to group potential reaches into tiers for discussion purposes (e.g., a value of 32 and 30 could be virtually the same for ranking purposes). Ranking is only a starting point, and should be used concurrently with detailed geomorphic mapping and analysis conclusions presented in the appendices of this report, and proposed restoration concepts for the 73 areas listed in Appendix A. A combination of these tools will hopefully provide local subbasin workgroups and resource managers enough information to make decisions on where to focus more detailed efforts and begin to develop more detailed implementation action plans. These plans may involve a combination of conservation and restoration actions, along with biological benefit, landowner and constructability considerations of proposed actions.

In Step 4, three additional parameters were included to provide additional decision making criteria that may ultimately increase or decrease the restoration value of a reach despite the process-based numeric ranking:

- Present spawning use
- Multiple life stage and species use
- Presence of cold water recharge sources

All reaches within the assessment area are used by spring Chinook and steelhead for spawning (*Methow Atlas;* also see Appendix F, "Biological Setting"). However, certain areas have been documented during historical redd surveys to be consistently used for spring Chinook spawning and are noted in Table 7 because of their high functionality. Steelhead spawn throughout the assessment area. River reaches with cold water recharge provide refuge in areas affected by temperature and dewatering. These recharge areas also are generally associated with high quality habitat in areas already properly functioning.

All of the reaches provide important habitat for a variety of life stages for spring Chinook, steelhead, and other species as noted in Appendix F. The need for protection and restoration in any given reach depends upon the natural resiliency of the river reach to human disturbance, the potential threats to natural function and processes in the reach, the current level of impairment in a reach, and the presence of one or more life stages or ESA-listed species. Reaches with multiple species and multiple life functions with a high risk of threat are a high priority for protection. Reaches with multiple species and multiple life functions that have some impairment of function should be a high priority for restoration and protection. Reaches where function is substantially impaired should be considered for restoration and protection once more functional areas have been secured.

In Step 5, additional data regarding the existing life stages and species use within the assessment area are presented for consideration when deciding between reaches with a similar ranking (Table 8; also see Appendix F). Presence of non-native species is also listed in Table 7 and may need to be considered at the reach scale assessment.

Based on physical processes, river reaches C2, M4, M9, and T6 are the top-ranked reaches for each of the four valley segments from a physical processes perspective. All reaches but M2 presently have a high density of spring Chinook spawning use. While the upper portions of the Chewuch did not score as high, they have been documented to have high quality habitat due to cold water recharge areas, which could bump this area to a higher priority to improve and build upon existing habitat. On the other hand, while M2 does not presently have high spawning use, there are two large off-channel areas in this reach that would provide a great opportunity to create new habitat in an area that is presently lacking.

With this in mind, the ranking results are meant to be only a starting point for discussion by local technical teams, and they can be modified in the future by incorporating new information as it becomes available. Once a reach has been prioritized for implementing restoration activities, there are several combinations and sequencing of project alternatives that may be undertaken. Reach assessments will develop an implementation strategy from a technical perspective at a more detailed scale. Additional factors, such as constructability of projects, cost, landowner willingness, funding availability, and permitting acceptance, will provide additional guidance as to the types, localities, and sequencing of projects within a given reach. An initial perspective on restoration concepts and degree of departure (effort needed to restore) for project level areas within each reach is provided in Appendix R (“Degree of Departure from Natural Setting”).

Table 7. Geomorphic ranking of 17 unconfined or moderately confined reaches and biological functionality.

Reach Designation [1/]	River Mile	Geomorphic Potential Score [2/]	Total Floodplain Area (acres)	Relative Floodplain Area (reach area/total area of segment)	Final Rank (geomorphic potential/ normalized area)	Spring Chinook Spawning Use [3/]	Multiple Life Stages and Species[4/]	High groundwater exchange and/or cold water recharge present
Middle Methow River								
M2	33.7 to 40.3	27	553	0.4	10.7		YES	
M4	41.3 to 47	26	768	0.6	14.4	Minor	YES	YES
M5	47 to 50	17	70	0.0	0.8		YES	YES
Upper Methow River								
M7	51.5 to 52.9	0	180	0.1	0.0	High	YES	
M9	55 to 65.5	88	1,318	0.6	52.8	High	YES	YES
M10	65.5 to 69.6	36	191	0.1	3.1	High	YES	
M11	69.6 to 75	25	508	0.2	5.8	High	YES	
Twisp River								
T1	0 to 0.6	0	6	0.0	0.0		YES	
T2	0.6 to 5	37	300	0.3	10.3	Minor	YES	
T3	5 to 7.8	36	110	0.1	3.7	Moderate	YES	
T4	7.8 to 9.8	11	20	0.0	0.2	Moderate	YES	YES
T5	9.8 to 13.5	34	203	0.2	6.4	High	YES	
T6	13.5 to 18.1	76	444	0.4	31.1	High	YES	YES
Chewuch River								
C2	2.2 to 7.3	32	380	0.6	20.2	High	YES	
C3	7.3 to 9.5	25	76	0.1	3.2	High	YES	YES
C4	9.5 to 11.7	32	50	0.1	2.7	High	YES	YES
C5	11.7 to 13.9	21	97	0.2	3.4	High	YES	YES

[1/] Reach Name M = Methow; C = Chewuch; T = Twisp ; [2/] See Appendix Section B–3 and Tables B–4 and B–5 for criteria and terminology used to develop geomorphic potential. [3/] Steelhead spawning occurs throughout the assessment area. Note that in some cases the biological use listed occurs in only a portion of the geomorphic reach boundary. [4/]For specific species and life stage use, see Table 5.

Table 8. Species and life stage usage for ESA and non-ESA listed fish within the assessment area.

Explanation: **F** = Foraging; **H** = Holding; **M** = Migration; **OW** = Over-wintering; **P** = Present; **R** = Rearing; **S** = Spawning;
Letters in parentheses: **(j)** = juvenile; **(a)** = adult;
Bold letter (**M, S, R)** show types and location of high density or abundant use. Non-bold letters show general use.

Biologic Reach	Spring Chinook (ESA listed)	Steelhead (ESA listed)	Bull trout	Summer Chinook	Coho	Pacific lamprey	Westslope cutthroat trout	Sockeye	Non-native brook trout
Methow River									
Carlton to Twisp (Twisp River) (RM 27 to RM 41)	M (j, a), OW, R	M, OW (j, a), R, S	F, M, OW	M, S	M, S	M, R, S	P	M, S	
Twisp River to Winthrop (Chewuch River) (RM 41 to RM 51)	H, M, R, OW, S	M, OW (j, a), R, S	F, M, OW	M, S	S	M, R, S	P		
Winthrop (Chewuch River) to Weeman Bridge (RM 51 to RM 61)	H, M, OW, R, **S**	M, OW (j, a), R, **S**	F, M, OW	M, S			P		P
Weeman Bridge to Mazama (RM 61 to RM 68)	M, OW, M, **S**	M, R, S	F, M, OW				P		P
Mazama to Lost River (RM 68 to RM 75)	M, R, S (when flows allow)	M, R, S	F, M, OW				P		
Chewuch River									
Winthrop to Falls Creek RM 0 to 14	**M, S, R**	**M, S, R**	F, M, OW			M,R, S	P		P
Twisp River									
Twisp to Buttermilk Creek RM 0 to 15	**M**, S, R	, S, R	F, M, OW				P		P

M

3.7 BREAKOUT OF POTENTIAL PROTECTION AND RESTORATION PROJECT AREAS

A total of 135 potential project areas were identified within the moderately confined or unconfined reaches based on findings from the geomorphic assessment (Figure 16). Project areas were broken into two categories: "Protection or Restoration." The term monitoring was also included in the protection areas name to recommend continued observation to document how these areas are functioning in the future. If the condition of these areas changed due to human impacts such as development, they would be switched from a protection category to an area in need of restoration. Restoration sites will also need monitoring to ensure actions taken meet both short-term and long-term project objectives (see Section 2.2). Locations of the protection and restoration areas are shown for each of the four valley segments in (Figures 17, 18, 19, and 20). Further evaluation to determine project benefits, feasibility, sustainability, and potential sequencing within each reach will be accomplished in subsequent assessments, and thus are not discussed in this report.

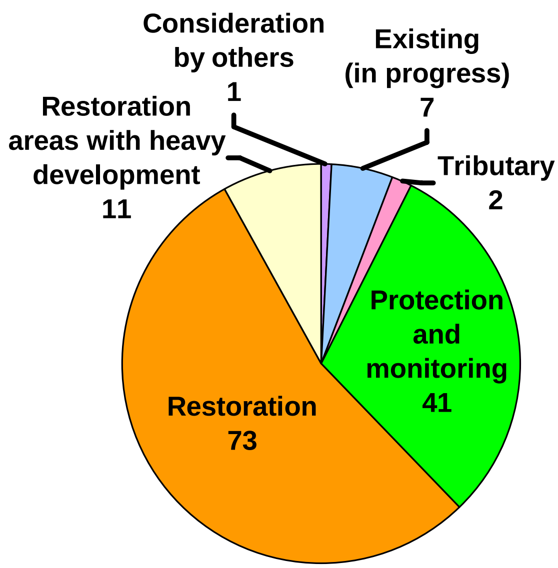

Figure 16. Distribution of potential project types in assessment area.

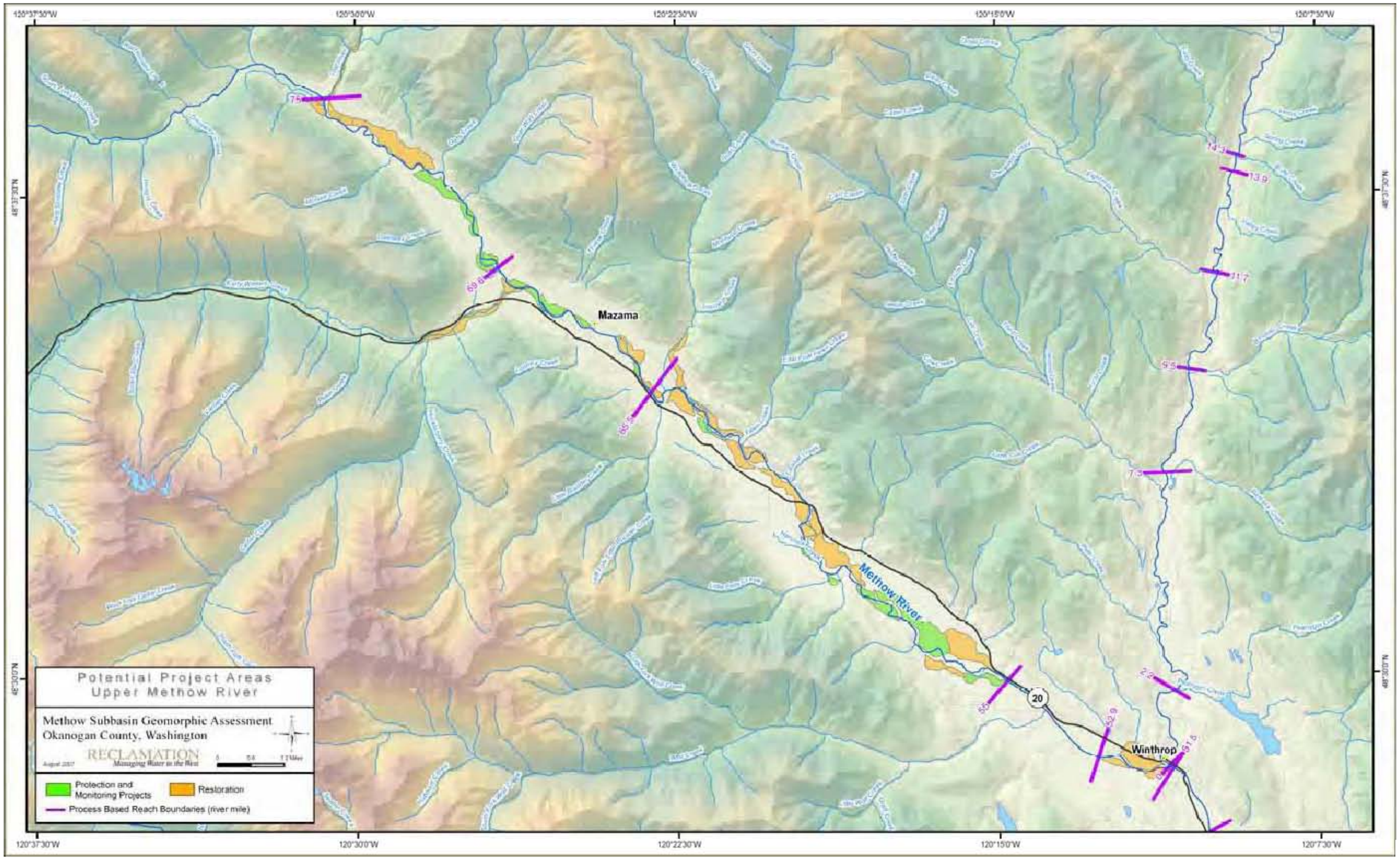

Figure 17. Location map for potential protection (green) and restoration (orange) areas within the Upper Methow River (RM 50 to 75) .

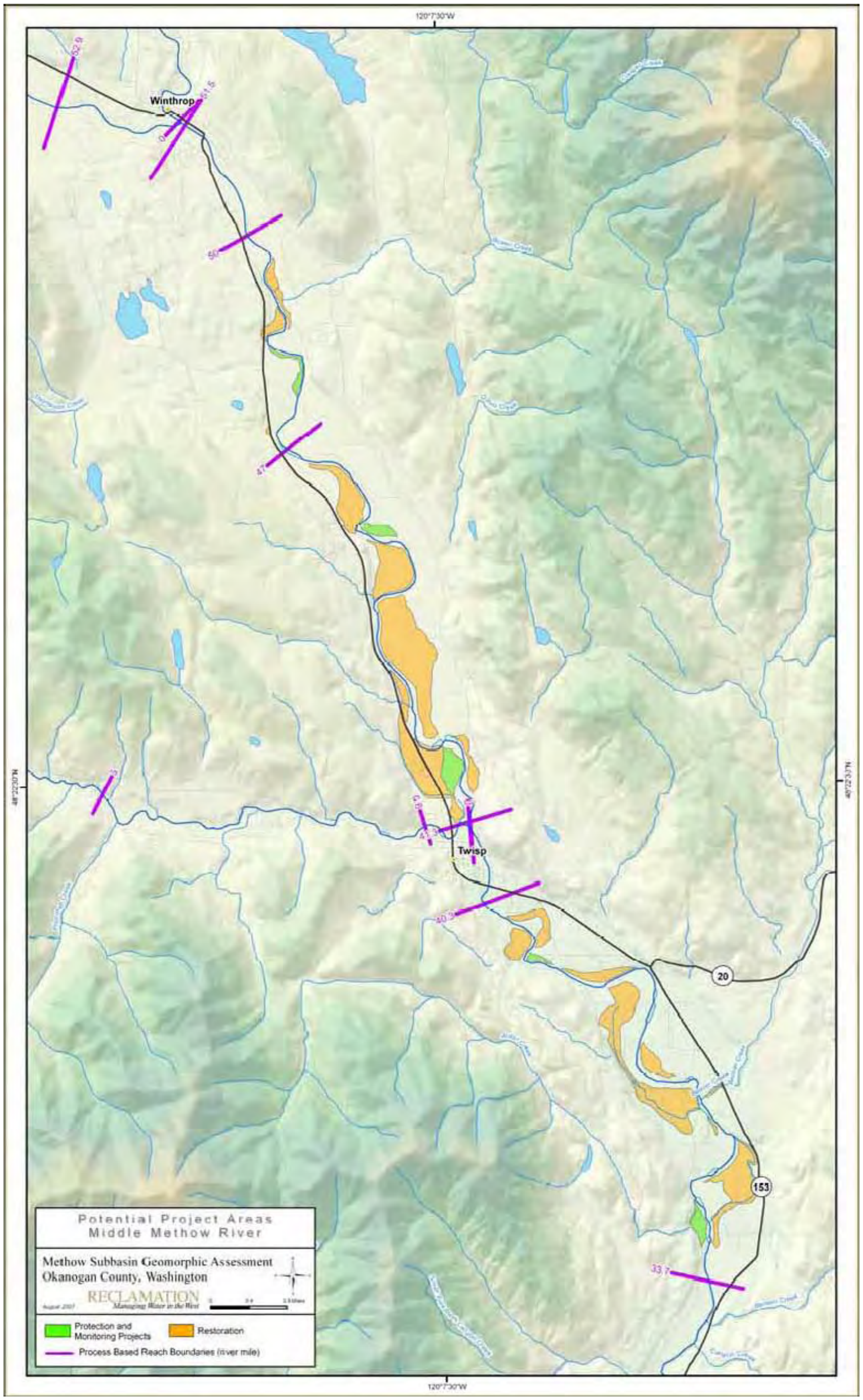

Figure 18. Location map for potential protection (green) and restoration (orange) areas within the Middle Methow River (RM 28 to 50).

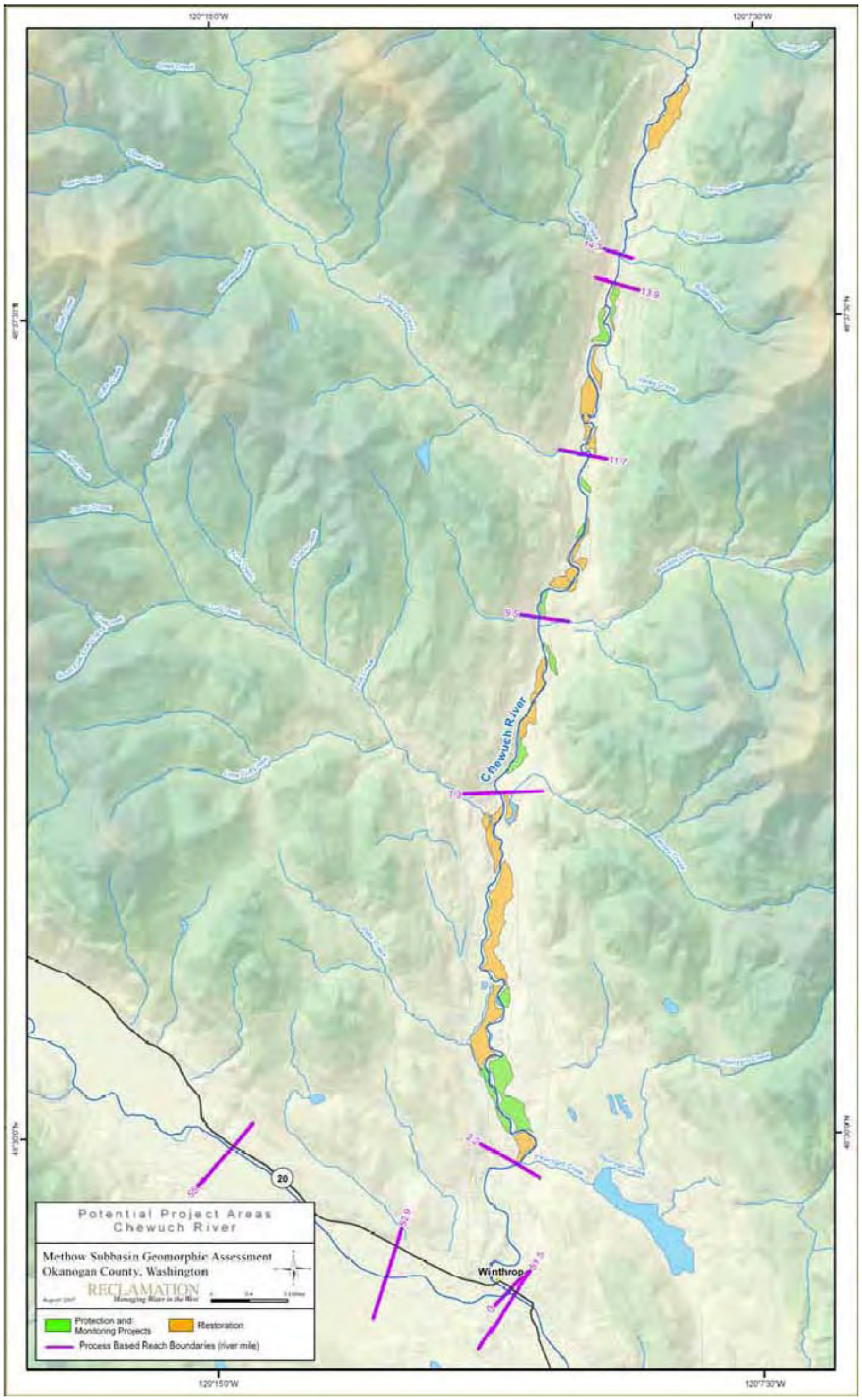

Figure 19. Location map for potential protection (green) and restoration (orange) areas within the Chewuch River (RM 0 to 14

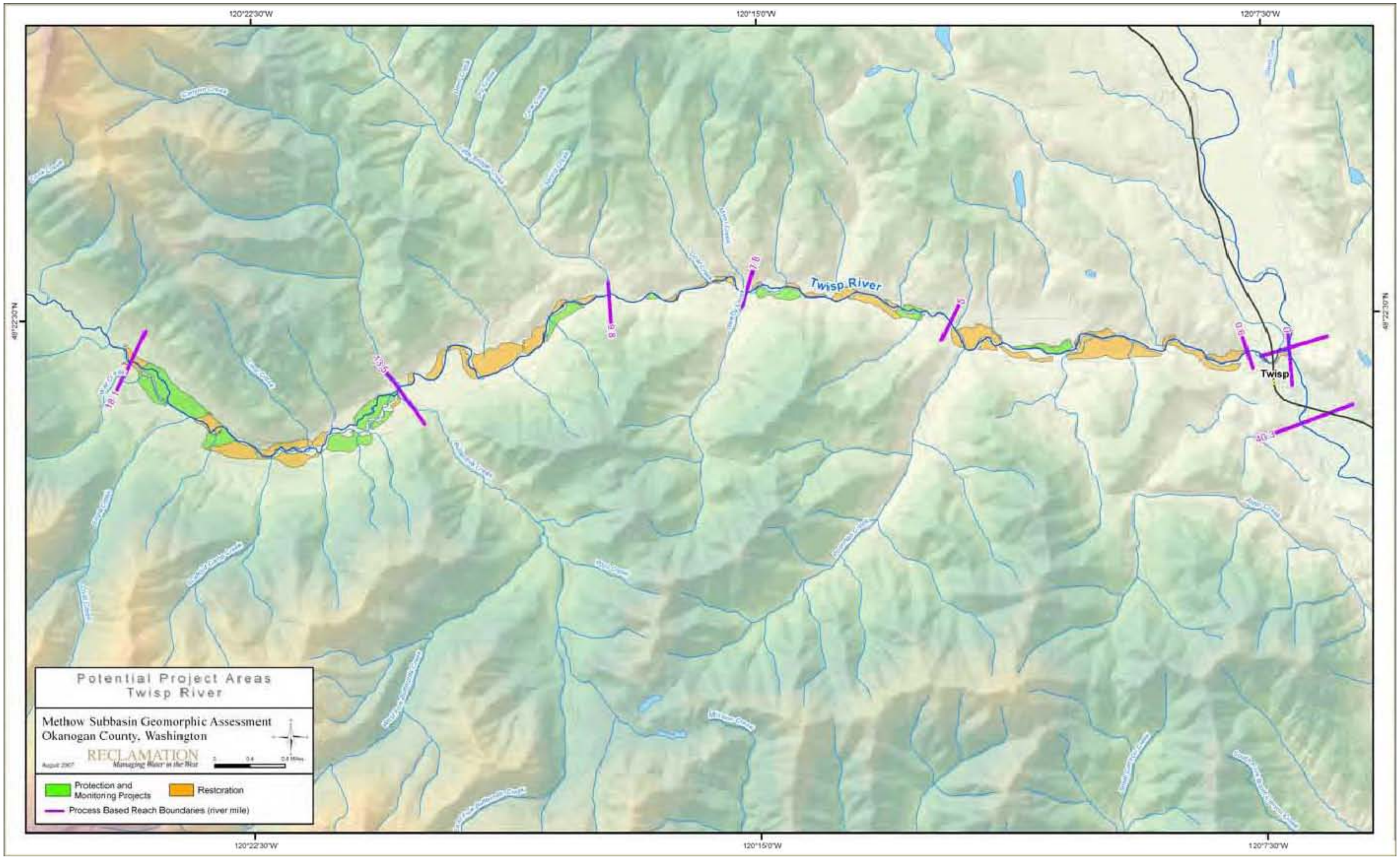

Figure 20. Location map for potential protection (green) and restoration (orange) areas within the Twisp River (RM 0 to 18)

The 41 sites within the protection and monitoring category are sites with no known human features that impact floodplain connectivity or complexity. A full list of these sites and accompanying map locations is provided in Appendix A. Additional field verification could find human features in these areas that were not known or located at the time of this assessment.

Each of the 73 potential restoration areas identified represents a section of floodplain that has been disconnected from the active channel by human features or human activities. Human features that disconnect the floodplain were not used as boundaries, but rather make up the components of possible project concepts within each floodplain area. Within this category, seven existing projects were included in the documentation to show how new projects link to areas already being treated. Of the restoration sites identified, 11 areas were separated out because they have substantial development currently in place that may require long-term planning to implement.

For the categories labeled as “tributary” and “consideration by others category,” three sites were identified that are located adjacent to the boundaries of this assessment. These sites were identified as potentially needing restoration based on local knowledge in the subbasin, subject to findings of subsequent analysis. Detailed information for these areas is not available from this report.

The protection and restoration sites were categorized and ranked based on their geomorphic setting, and thus the type of limiting factor and habitat improvement they would address (Table 9). Areas containing complex networks of channels and side channels provide the most direct benefit to increasing available habitat area and channel and floodplain connectivity. Terrace surfaces (higher elevations beyond the floodplain) provide some relief during floods by allowing flow to spill out onto the floodplain surface, thus reducing energy in the main channel. While these terrace surfaces are important to include in a reach-based restoration strategy, they are generally small relative to the entire reach, they do not contain any low elevation channels, and are infrequently inundated. Further ranking of the restoration sites to determine the degree of departure from the natural setting, and thus provide some indication of the level of restoration effort was also accomplished and is provided in Appendix R.

Table 9. Technical ranking criteria of geomorphic based habitat potential and occurrence by valley segment.

Biological Benefit	Project Type	Geomorphic Potential	Percentage 1/	Area by Valley Segment (acres)			
				Upper Methow	Middle Methow	Twisp	Chewuch
High	8 (Best)	Functioning wetland or channel network area	15	446	27	298	0
High	7	Functioning primary side or secondary side channel areas	8	112	98	80	136
Low	6	Functioning overflow channel or low surface (floodplain)	5	190	0	4	56
High	5	Full restoration of wetland or channel network area	10	305	0	187	15
High	4	Partial restoration of wetland or channel network area	23	627	321	234	16
High	3	Primary side or secondary side channel with floodplain reconnection	11	64	214	69	251
High	2	Primary side or secondary side channel with partial or little floodplain reconnection	16	155	505	97	73
Low	1	Overflow channel or low surface (floodplain)	5	56	90	107	30
NA	0 (Worst)	Project area has heavy development in present setting	8	241	135	10	26

1/ Percentage of 80-mile assessment area in which category occurs (does not include active channel)

In comparing potential project types among the four valley segments evaluated (Middle Methow, Upper Methow, Twisp, and Chewuch), most existing project work is presently being accomplished on the Twisp River. The highest amount of potential protection and restoration opportunities for future work is on the Methow River, because it is larger in size than the Chewuch and Twisp.

On the Methow River, protection areas dominate in unconfined reach M9 (RM 55 to 65.5) and moderately confined reach M10 (RM 65.5 to 69.6), where channel networks and wetlands are common (Figure 17). Some potential restoration areas also are proposed for these two reaches, where channels or floodplain have been artificially disconnected from the main channel. Potential restoration areas dominate in the downstream unconfined reaches M2 and M4 (RM 33.7 to 40.3 and 41.3 to 47.0), where primary side channels are common, but are often disconnected from the main channel by levees or diversion structures (Figure 18).

On the Twisp River, most potential restoration areas involve the reconnection of channel networks, primary side channels, and floodplain (Figure 19). Projects that would reconnect channel networks are dominant in reaches T5 and T6 (RM 9.8 to 13.5 and 13.5 to 18.1). Projects that would reconnect primary side channels dominate in reaches T2 and T3 (RM 0 to 0.6 and 0.6 to 5). Protection and monitoring areas are present along most of the river, but are primarily located in the upstream unconfined reach, T6.

On the Chewuch River, potential projects are a mix of sites recommended for protection and monitoring, and those recommended for restoration (Figure 20). Potential restoration areas include reconnection of channel networks and wetlands or reconnection of a primary side channel.

3.8 RESTORATION SUCCESS AND SUSTAINABILITY

It is important to consider whether proposed restoration actions will be successful and sustainable. Actions with the most potential to create habitat are those that work to restore river processes that generate complexity habitat, particularly in dynamic reaches that naturally have channel migration and floodplain interaction. The Methow Subbasin is fortunate in that natural geologic controls on the system have largely kept the overarching river morphology intact, despite human activities. Therefore, there is generally a good potential for recovering lateral connectivity between the river and floodplain by removing human features (riprap, levees, bridges, roads, etc.) that disconnect these areas. This connectivity is expected to be restored in a short timeframe following project implementation. Full restoration of floodplain processes will take longer periods of time, perhaps decades, dependent on the timing and magnitude of floods and vegetation growth following project implementation. Consideration was given as part of the assessment of the effects of removing all human features. If only a portion of the human features currently in place are removed, additional analysis would need to be done to understand the level of floodplain function that can be restored.

Once lateral connectivity is re-established, side channels, riparian vegetation, and LWD that provide off-channel habitat and habitat complexity will begin to re-establish. Complexity features will form fairly quickly in areas where the human features have not been in place for a long period of time, or where the human features are not in good condition and have already been breached by the river. Formation of complexity habitat is expected to take several years, or not occur at all in areas where the human features have been in place for a longer time period and currently are reasonably intact. In these areas, riparian planting and placement of LWD may be needed to jump start natural river processes.

Many of the off-channel areas have been cleared of vegetation for agriculture or urban development. Side and overflow channels are filled with sediment, in some cases due to a lack of flushing from the river. In these areas, it may take a significant flood to erode the surface and start the decadal-long process of building new surfaces and establishing riparian vegetation. Cottonwood trees require a bare and moist deposit of sand or gravel, ample exposure to the sun, and the absence of prolonged inundation or scour to become established. The lack of floodplain reworking to create bare substrate has caused a combination of limited cottonwood regeneration and a conversion of new growth to species such as shrubs, aspen, and conifers.

Given the age of present riparian vegetation stands, initial LWD recruitment could be high where floodplains are reconnected and older trees are accessed that have been unavailable for recruitment during the last 50 years or so. Recruited trees may contain more Douglas fir and aspen than cottonwoods in areas where these species have replaced cottonwood galleries. Areas that have been cleared of vegetation may require manual planting to re-establish riparian stands and bank stabilization until trees grow to maturity. Recruitment of LWD from these areas would be a long-term process that could be allowed to occur after the riparian vegetation has become established and matured. This could be 50 or more years out into the future. Engineered log jams could be added to protect these areas while trees are allowed to grow.

4. GEOMORPHIC CONDITIONS

The geomorphic assessment focused on physical processes that drive creation and sustainment of habitat features important to spring Chinook and steelhead. Evidence for changes to channel planform, channel bed elevation, riparian condition, and channel and floodplain connectivity were evaluated to infer potential changes to salmonid habitat quantity and quality. Habitat features that were considered include development of pools, quality of and access to side channel areas, LWD, spawning gravels, and refuge areas during high- and low-flow periods. Of particular focus are trends over the last century as a result of human activities and features which could impact the quantity and quality of habitat.

To evaluate geomorphic processes, a conceptual model was developed of the natural setting prior to disturbances, the present setting was documented, and predictions of river trends in the future were accomplished (see Appendix D for details on methodology and Appendix E for conceptual model). The natural setting is defined as the mid-to-late 1800s, the period just prior to significant human-induced disturbances to physical river processes. Hypotheses of the natural setting provide a conceptual model of the process-based opportunities for habitat improvement. Comparison of the present river setting to the conceptual model of the natural setting helps determine which processes have been altered and to what degree. Historical trends were evaluated to identify the rate and extent of changes (Appendix G). Project concepts must incorporate not only the present setting, but anticipate how river processes may or may not change in the future. Looking at historical trends of river processes on a decadal scale provides an understanding of the rate of change from the natural setting, how the changes relate to historical floods and human activities, and whether the changes have had a trend that will continue in the future.

Section 4.1 presents an overview of the present condition and impacts to physical processes for the 80 river miles evaluated, which provided the framework for establishing restoration strategies presented in the previous report Section 3. This is followed by a description of geomorphic conditions for Methow (Section 4.2), Twisp (Section 4.3), and Chewuch rivers (Section 4.4).

4.1 SUMMARY OF IMPACTS TO PHYSICAL PROCESSES

Based on the geomorphic conditions, a complete list of limiting factors that could be addressed to improve the availability and quality of spring Chinook and steelhead habitat are:

- Reduction in access to side channel and floodplain areas due to bridges, roads, levees, and push-up dikes that disconnect the channel from the historical channel migration zone and floodplain area

- In reaches confined by levees, flood depths and flow velocities are both greater than under natural conditions; the increased flow depth and velocity mobilize larger pieces of woody debris and larger bed-material particle sizes, resulting in less wood and a coarser streambed than under natural conditions
- Alteration of the composition of the riparian vegetation and changes in the rates of regeneration of the riparian vegetation caused by a lack of lateral reworking of the channel and floodplain
- Reduction in habitat cover, shading, and hydraulic diversity within the channel and floodplain caused by historical removal of large woody debris for flood control, historical log drives, bridge clearance, fishing and boater safety, and salvaging wood for domestic use
- Reduction in the complexity along the boundaries of the channel and floodplain caused by conversion of natural banks to man-made bank protection in the form of rock and in many cases old vehicles dumped along the banks of the mainstem Methow River
- Reduction in large trees available for recruitment to the river due to timber harvest and conversion of riparian forests to agricultural fields or residential development
- Reduction in populations of beaver, which create wetland riparian area;
- Reduction in populations of anadromous fish and reduced delivery of marine-derived nutrients to the river system in the form of post-spawning salmon carcasses
- Introduction of exotic species, such as brook trout, into previously barren streams and lakes, and invasive weeds within or adjacent to riparian areas
- Suppression of fires, possibly along with a changing climate, also plays a role in impacting processes and appears to be creating larger wildfires than in the recent past (Whitlock et al., 2003)

4.1.1 Stream Energy

Over time, streams attempt to move towards an equilibrium condition to balance energy available with energy needed to convey and transport the incoming sediment. Human features that alter the supply of water and sediment can change the ability of the stream to transport sediment, and thus result in incision, aggradation, or a change in channel planform (that is, meandering to straight or braided). Additionally, removal of LWD and vegetation combined with constriction of the channel and floodplain can also impact the balance in stream energy.

There are no man-made dams and reservoirs in the assessment area or upstream watershed that could have significantly reduced sediment loads or incoming water discharge (peak floods) over the last century (Appendix O). The only dams present have low heights (less than 10 feet) and likely filled in with sediment in the upstream reservoir during the first large flood.

The majority of sediment supplied to the channel is from storage areas within the floodplain (bars, islands, low-elevation surfaces, side channels, etc.). This can impact local channel position and geometry, but reworking processes are natural and have not been observed to have a detectable impact on channel planform (see Section 4.1.2). Logging has occurred in the upstream USFS-managed portion of the Methow Subbasin, but historically has been much less extensive than logging activities within the 80-mile assessment area. The exception is the Beaver Creek drainage, located downstream of Twisp, which has had extensive logging. Erosion along the floodplain (low surface) boundary, which results in expansion of the floodplain and sediment recruitment, has been minimal on all three drainages in the assessment reaches. Fires occur annually in the Methow Subbasin, and major fires that burn large areas are frequent. The burned areas have been documented since the 1700s (Appendix L). Recent fires in the Methow Subbasin are larger than in the past according to tree core mapping studies (Schellhaus et al., 2001). This could have a profound effect on sediment supply, wood supply, water chemistry, and water temperature, all of which influence habitat conditions (Bisson et al., 2003). However, fires at a natural frequency are part of the natural setting and contribute to the long-term sediment supply and habitat conditions.

Figure 21. Photograph of Chewuch River in the area of the 2001 Thirtymile Fire area showing a large debris flow from hillslope where fine sediment was stored on the alluvial fan as well as being delivered to the river. ***(July 2005)***

No obvious trends in the occurrence or magnitude of peak floods were detected from the U.S. Geological Survey (USGS) gaging station data that could imply a change to stream energy over time. A more robust analysis may be needed to further validate this conclusion in the future as a longer record of stream flow data become available. The longest gage record at any one location in the Methow Subbasin is only 52 years (Appendix J). Table 10 shows the range of discharge and slopes present in the Methow, Chewuch, and Twisp river valley segments analyzed.

Table 10. Range of discharges and channel slopes along each river within the assessment area.

River	2-Year Flood Peak (cfs)	100-Year Flood Peak (cfs)	Slope (%)
Methow	3,700–10,300	7,400–32,800	0.27–0.70
Chewuch	2,400–3,200	6,900–9,400	0.24–1.80
Twisp	1,100–2,300	3,200–6,800	0.16–1.40

There is a range of flow for each segment because of tributaries that enter along the river segment. Additional streamflow from tributaries provides more potential energy to transport sediment and LWD if hydraulic conditions are otherwise comparable. Increasing the slope can also increase the river's ability to transport sediment and LWD, while decreasing the slope can reduce the transport capacity. Overall, the bed material grain size of all three rivers show a very tight correlation to slope, indicating the natural geologic controls play the largest role in adjusting sediment transport capacity. On the Methow River, the slope gradually decreases from Lost River to Winthrop, and then is fairly steady downstream to Carlton. The decrease in slope tends to cause a reduction in sediment transport capacity, but this is balanced by the increase in tributary discharge with distance downstream (see Section 4.1). Significant increases in discharge to the Methow River occur at the Twisp and Chewuch confluences. The large influx of discharge at Winthrop from the Chewuch River appears to balance the reduced sediment transport capacity that occurs due to the reduction in slope. The Twisp and Chewuch rivers both have significant slope breaks that impact stream energy from one reach to the next (Section 4.2 and 4.3; Appendix K). An increase in discharge with distance downstream does not play a large role in stream energy on the Twisp or Chewuch rivers because the tributaries within the assessment area add only a small amount of flow relative to the mainstem river flow.

4.1.2 Channel Planform

Channel planform can be used as an indicator of the whether the sediment transport capacity of a given reach equals, exceeds, or is less than the incoming sediment load as discussed in the river dynamics section earlier in this chapter. Historical aerial photographs within the assessment area indicate there is no evidence of change in channel planform on a reach scale over a decadal time period. For example, reaches that are single-threaded main channels have remained single-threaded channels, and reaches with a complex network of multiple channels and vegetated floodplain also have maintained the same planform.

Laterally, many sections of the Methow, Chewuch and Twisp river floodplains are bounded by either glacial terraces, alluvial fans (deposited several hundreds to thousands of years ago), or bedrock that is not easily eroded (Appendix E). These features establish the boundary of the active floodplain and result in local pinch points where the floodplain narrows relative to upstream and downstream sections. Generally these features limit the rate of lateral erosion caused by river processes (see Appendix C for descriptions by reach).

Channel changes were also observed by comparing historical maps and aerial photography before and after large floods. The largest known floods were in 1894, 1948, and 1972 and channel changes would be expected as a result of these flows (Appendix J). The 1948 and 1894 floods are believed to be similar in magnitude, but the 1948 flood may have been slightly larger. The 1948 flood exceeded the 100-year flood frequency estimate and, based on historical photographs, this flood inundated the entire floodplain (low surface) (Figure 22). This flood is noted by locals to have "reset" the river, mobilizing large portions of LWD and changing channel position and geometry in many cases (Figure 23). When a flood of this magnitude occurs, the channel geometry often changes but still may be within the bounds of natural variation expected in the system. Aerial photographs of the Methow River before, during, and after the 1948 flood validate that no change to the over-arching channel planform was observed for the mainstem Methow River. Aerial photographs before and after the 1972 flood were examined to validate this hypothesis on the Chewuch and Twisp Rivers, because the 1948 photographs were sporadically available from during the flood, but not before and after.

Figure 22. Photograph during the 1948 flood

Figure 23. Photograph of "large woody debris" pile on the north side of the bridge across the Twisp River following the 1948 flood. The bridge shown is thought to have been located just upstream from a highway bridge.

Courtesy of the Shafer Museum, Winthrop, WA.

4.1.2 Channel and Floodplain Connectivity

The largest departure from the natural channel processes results from roads, bridges, levees and push-up dikes that disrupt the lateral connectivity between the active floodplain areas and the main channel, and historic removal of large woody debris (Figure 24 and Figure 25). Many of these features and large woody debris removal activities occurred following the large floods in 1948 and 1972 to limit bank erosion and property damage from future floods. In most cases, the majority of floodplain levees, push-up dikes, and roads and bridges cut off the floodplain at unique locations, but do not confine the river for a very great longitudinal distance as in some systems. This allows the river to still have some connectivity during flood flows when river water gets high enough to overtop banks laterally (downstream of the human feature) and result in inundation. More detectable impacts would be expected in the side and overflow channels downstream of where the levees or dikes are located. These channels are not flushed with water and replenished with new sediment and LWD as frequently as would occur in the natural setting where there is a connection with the river at the upstream entrance.

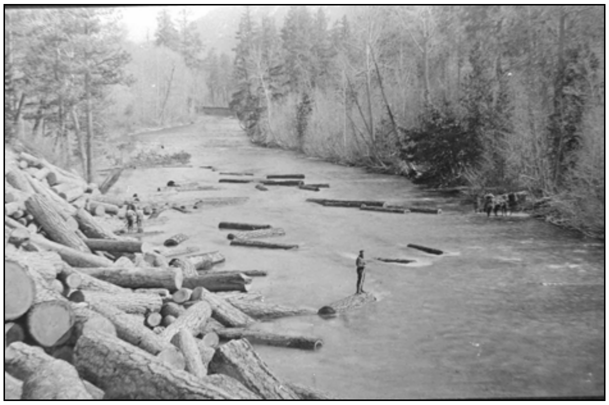

Figure 24. Ground photograph of log drive likely in the 1920s or 1930s on upper Methow River.

Location is believed to be above Winthrop (RM 55) because the most commonly referenced log mills during this period were between 4 to 6 miles upstream of Winthrop. Photograph copy courtesy of the Shafer Museum Collection, Winthrop, Washington.

Figure 25. Log jam in the Sheep Creek/Thirtymile Creek area in the upper Chewuch drainage basin in 1962 that was subsequently removed (by man) the same year.

Photograph copy courtesy USFS.

4.1.3 Bank Erosion and Floodplain Reworking

To get an indication of which reaches are experiencing channel migration and floodplain reworking, the position of the main channel was tracked over time using historical aerial photography (Appendix G). Unconfined reaches had the largest amount of channel bank erosion, and thus migration of the channel position (Table 11). Channel reworking within the existing floodplain was much more common than erosion along the low surface boundary. As would be expected, the bank erosion in confined reaches was minimal.

Erosion along the floodplain boundary into glacial deposits or alluvial fans, which results in expansion (widening) of the floodplain, has been minimal on all three drainages in the assessment area (Table 11). For the Methow River, about 3% of the low-surface boundary length eroded between 1948 and 2004 (14,100 feet eroded out of a total measured length of 485,300 feet). For the Chewuch River, about 0.5% of the low-surface boundary has eroded between 1954 and 2004 (340 feet eroded out of a total length of 68,400 feet). For the Twisp River, about 4% of the measured length of the low-surface boundary has eroded between 1954 and 2004 (3,200 feet eroded out of a total length of 86,100 feet). Note that not all river reaches in the Twisp and Chewuch rivers could be compared due to a lack of historical aerial photography (Appendix G).

Table 11. Comparison of channel bank erosion and migration within the floodplain and along the floodplain boundaries.

Reach	**Reach Type**	**Percent of 2004 Channel Banks that Eroded due to Channel Migration**	**Percent of Bank Erosion Along Low Surface Boundary** (Expansion)	**Percent of Bank Erosion Within Floodplain Sediments** (Floodplain Reworking)
M1	Confined	23.1	2.6	20.5
M2	Unconfined	62.5	17.5	45.0
M3	Confined	15.1	0.0	15.1
M4	Unconfined	60.0	2.5	57.5
M5	Moderately confined	51.9	9.1	42.8
M6	Confined	13.2	6.6	6.6
M7	Moderately confined	63.4	5.9	57.5
M8	Confined	18.8	0.0	18.8
M9	Unconfined	52.6	5.1	47.5
M10	Moderately confined	34.9	4.0	30.9
M11	Unconfined	30.9	0.0	30.9
C1	Confined	7.9	0.0	7.9
C2	Unconfined	65.8	1.3	64.5
C3	Moderately confined	12.7	0.0	12.7
C4	Confined	11.4	0.0	11.4
C5	Unconfined	NA	NA	NA
C6	Confined	NA	NA	NA
T1	Confined	46.4	0.0	46.4
T2	Unconfined	100.0	7.1	92.9
T3	Moderately confined	54.3	8.5	45.8
T4	Confined	NA	NA	NA
T5	Unconfined	NA	NA	NA
T6	Unconfined	NA	NA	NA
Methow		**44**	**6**	**38**
Chewuch		**29**	**0.5**	**28**
Twisp		**34**	**3**	**31**

4.1.4 Channel Hydraulics and Sediment Transport

As a result of floodplain confinement, water is restricted to a smaller area during floods. When this occurs, velocities in the main channel are higher than if the water is allowed to spill off into the floodplain. Because of the higher energy in the main channel, the channel could be expected to become more sinuous, incise, or widen. However, geologic controls in both the channel bed and along the channel margins limit the ability of the river to significantly adjust its geometry. Based on observations and hydraulic computations, the sediment transport capacity of the system appears to generally exceed the sediment supply available. Therefore, sediment delivered from the upstream watershed and tributaries is transported through the four river valley segments without significant deposition that would alter the channel planform, bed elevation, or longitudinal slope. Although locally bed elevations may change in response to a change in channel position, reach-scale trends in aggradation or incision were not detected.

Consequently, little change has occurred in the channel form or main channel bed elevation as a result of features that cut off the floodplain. As discussed earlier, the channel planform has not had any detectable changes. However, the presence of LWD in many areas is thought to be reduced as a result of historical clearing of large wood from the system (Appendix O).

To validate that only minimal, if any, change has occurred to the channel bed elevation, information on channel geometry and bed elevation changes was compared where historical survey data is available. Historical profile data were available for a large portion of the Methow River within the assessment reach and for a portion of the Chewuch River (see Appendix K for more details). Both data sets detected only minimal vertical change on a reach scale, which would indicate no aggradation or incision of the river bed of has occurred on a decadal timeframe.

Another indicator of whether the river's channel has been altered is sediment transport capacity. It would be expected that if the river's sediment transport capacity is in balance with the incoming supply, the river should be able to rework the bed and sediment bars on a frequent basis. Although 184 cross-sections were collected within the approximately 80-mile assessment reach, they were spaced too far apart to perform hydraulic modeling and sediment transport capacity computations. As an alternative, normal depth was assumed and incipient motion computations were used to look at the ability of the present river to mobilize the channel bed and bar features along the active channel (Appendix K). If the sizes of sediment that can be mobilized far exceed the sizes of sediment present along the channel bed, then the river may be tending toward incision. Because the sediment on the surface of the sediment bars must be mobilized first to get reworking along the bar, pebble count measurements of the surface sediment sizes can be compared to the incipient motion computations for this purpose.

The average sediment particle sizes measured in the bar and channel surface are gravel to cobble for all three rivers (Table 12; Appendix K). In most locations, the bars and channels can be reworked at the more frequent 2- and 5–year floods (Table 13). The frequent presence of alluvial bars along the river channel indicates that the channel is not degrading, which matches conclusions from historical channel analysis.

Table 12. Average sediment size in bar and channel and maximum sediment size mobilized by 2-year, 5-year, and 100-year floods.

Location		Measured sediment size		Sediment particle size (mm) mobilized by a certain flood.		
River	Reach	Bar D_{50} (mm)	Chan. D_{50} (mm)	2-year flood	5-year flood	100-year flood
Chewuch	RM 0 – 5.5	66	106	68	94	150
	RM 5.5 – 9.5	182	141	180	241	380
	RM 9.5 – 14	43	45	41	55	88
Twisp	RM 0 to 1.5	54	64	41	48	80
	RM 1.5 - 9.8	127	136	109	136	220
	RM 9.8 – 17	48	61	57	73	122
Methow	RM 28 – 50	80	85	70	93	152
	RM 50-70	78	80	75	93	128
	RM 70 – 76	93	83	92	114	160

Table 13. Minimum flood frequency at which typical bar and channel sediment sizes are mobilized.

River	Reach	Bar D_{50} (mm)	Chan. D_{50} (mm)
Chewuch	RM 0 – 5.5	2-year	10-year
	RM 5.5 – 9.5	2-year	2-year
	RM 9.5 – 14	2-year	2-year
Twisp	RM 0 – 1.5	10-year	25-year
	RM 1.5 – 9.8	5-year	5-year
	RM 9.8 – 17	2-year	2-year
Methow	RM 28 – 50	5-year	5-year
	RM 50 – 70	2-year	2-year
	RM 70 – 76	2-year	2-year

4.1.5 Riparian Vegetation

Riparian vegetation is a crucial component of the aquatic ecosystem and can be used as an indicator as to whether river and floodplain processes are functioning as would be expected in the natural setting. Cottonwoods are associated mainly with riparian areas that are frequently reworked, and thus are a good species to use to evaluate whether the floodplain is being accessed. Previous studies hypothesized that riparian processes are not properly functioning in the assessment area due to a combination of historical clearing, lack of access to water due to either river incision and/or drought, lack of floodplain reworking, disease, and wildlife browsing. This assessment found that historical clearing and the lack of floodplain reworking has had the largest impact on establishment of cottonwoods (Appendix H). Areas that traditionally would have supported cottonwood galleries have now converted to shrubs, aspen, and/or Douglas-fir (Appendix H). The total percent of floodplain area where vegetation has been noticeably cleared is 19.9% for the Methow River (Middle and Upper), 14.8% for the Chewuch River, and 24.1% for the Twisp River.

The cottonwood stands that are present are generally 50 to 100 years old with little evidence of regeneration in the last 50 years. It is hypothesized, from historical investigations in this assessment, that 50 to 100 years ago, cottonwoods were able to successfully regenerate when the river was allowed to more frequently inundate and rework the floodplain. Given this timing, it is plausible that the majority of human flood protection structures were established in the active floodplain after the 1948 flood and 1972 flood causing a subsequent decline in the ability of cottonwoods to regenerate. This is supported by the historical aerial photographs and historical accounts of flood protection structures. Existing cottonwood stand are generally healthy but vitality could be improved by increasing water connection to stand areas; in some areas tops of trees are dying off indicating lack of sufficient water. Trees do not appear to reach maturity in many places and die back at around 50 to 60 years of age.

The regeneration of black cottonwood throughout the riparian area is compromised and often non-existent, or is restricted to areas that receive periodic inundation (instream bars, active side channels, low banks). Cottonwood regeneration is believed to be unsuccessful in recent decades because seedlings cannot establish due to a lack of lateral channel migration and/or reworking of side and overflow channels during floods. This process is needed to expose mineral soil beds and to provide the baseline conditions for seed establishment. The groundwater connection still appears to be functioning in some areas, as indicated by the presence of wetlands and aspens or other vegetation growing in ditches and side channels. This suggests that main channel incision is not a significant cause of the decline in cottonwoods, but that the decline is more likely due to human features that cut off the floodplain (surface water connection) during spring runoff and subsequent growing months during flow recession. Because cottonwoods failed to re-establish, other more drought-tolerant species, such as ponderosa pine or Douglas-fir, appear to be thriving. Once these species establish they drain the gravelly areas, which results in even less water to be available to cottonwood regeneration, and also create a forest canopy (shade) that is too dense for cottonwood seeds to establish. It is not known how evapo-transpiration rates influence this relationship.

4.1.6 Large Woody Debris (LWD)

A properly functioning riparian corridor is essential for providing large trees for shade, LWD recruitment, bank stability, floodplain structure, and roughness. Leaf litter and insects falling into the river from riparian areas provide nutrients for aquatic food chains. Larger pieces of wood are important because they trap smaller pieces of wood, organic debris and fine sediment, creating bars, log complexes, deep pools, complex aquatic habitat, and a growing medium for riparian vegetation.

Accumulations of large wood also facilitate channel migration, forming new channels that often excavate new gravel for spawning and provide extremely productive habitat for salmonids (USFS, 2002). LWD helps to form nutrient reservoirs by creating slow water areas where organic litter can accumulate and by providing a medium for algae, zooplankton, and insects to grow on. LWD provides shade and can provide refuge in areas where water temperatures would otherwise be considered too warm.

Primary pieces of large wood are those that influence channel forming processes because they are not easily moved by the river. Based on local observations by biologists within the Methow Subbasin, very large logs (greater than 40 inch diameter at the large end), especially with attached root masses, form the foundation of large wood complexes that are more stable than complexes made of smaller wood. These large pieces of wood and resulting log jams help promote bar formation, influence channel migration, bedload sorting, and pool scour. These characteristics combine to define quality habitat for all life stages of native salmonids. The collection of organic debris and fine sediment around primary wood pieces helps vegetation establish and these areas can become future riparian forested areas.

The MPI (NOAA Fisheries Service, 1996) recommends that “a stream has at least 20 pieces per mile of wood greater than 35 feet long with a diameter greater than 12 inches, and that the stream has good potential for future recruitment.” These criteria were developed in general terms at a watershed scale. Comparison to local streams of similar size and characteristics was used by local biologists to validate where this criteria is appropriate. Quantitative evaluation of LWD has only been done in a portion of the 80-mile assessment area.

Instream wood levels are increasing dramatically in the Big Valley Reach of the Methow River (RM 55 to 65) due to recruitment from stream banks and channel migration into forested areas. Stream habitat assessments for the Chewuch, Twisp, and portions of the Upper Methow upstream of RM 75 (boundary for this Reclamation assessment) show that the large wood standard is not met in any of the downstream reaches of these streams except for the lower mile of the Twisp River. The upper, less-managed reaches of these rivers that are within the range of spring Chinook and steelhead spawning generally exceed the MPI wood standard. All of these reaches have had major wood removal projects in the past, as well as stream side selective logging; this indicates that although the MPI standard is exceeded, the wood levels were still probably below natural potential at the time of the surveys. In the Chewuch and West Fork Methow rivers, the in-channel wood levels are presently very high due to recruitment following the 2001 Thirtymile Fire and the 2003 Farewell and Needles fires. Future recruitment of conifer trees in these areas will not be available until the forests mature, at least 50 years or longer for more substantial sized wood.

Within the 80-mile assessment area, the areas with the most potential for LWD recruitment and sustainability are those with complex channel networks and areas that have had less forest clearing in recent decades. LWD would be expected to deposit within channel eddies, entrances to side channels, and at the heads of islands where it creates stable hard points that slow the rate of river migration and allow formation of vegetated islands. Extensive LWD would not be expected to occur in the main channel in confined sections (no vegetated floodplain) unless the wood became hung up on a boulder or other local obstruction. The presence of LWD has been documented by other studies and the available documentation is summarized below. Updated, local site conditions should be reassessed at the reach-assessment level in the future.

4.2 Middle and Upper Methow Geomorphic Conditions

This report section summarizes the physical processes specifically operating in the Middle and Upper Methow sections from RM 28 to 75, and the types of human feature impacts. The Upper Methow subwatershed contains 322,385 acres from its confluence with the Chewuch River (RM 50.1) to the Cascade crest near elevation 8500 feet. The Middle Methow River subwatershed extends between Winthrop (RM 50.1) downstream to Carlton (RM 26.8), covering about 15,600 acres.

Over 80% of all of the lands in the Methow Subbasin are owned by the Federal Government and managed by the USFS (according to the Methow Valley Water Pilot Planning Project Planning Committee, as cited in KWA, 2004). Most of the land along the mainstem Methow River downstream of the Lost River confluence is privately owned with some Washington Department of Fish and Wildlife (WDFW) and USFS holdings. Most of the land above the valley floor and in the tributaries is managed by the WDFW or the USFS. Precipitation in the upper Methow subwatershed is about 80 inches at the Cascade crest and about 10 inches near the mouth (Richardson, 1976).

4.2.1 Habitat Conditions

Both spring Chinook and steelhead utilize the mainstem Methow for migration, holding, foraging, spawning, rearing, and over-wintering (Appendix F). From 1987 to 1999, approximately 40% of spring Chinook spawning occurred in the upper Methow River subwatershed between the Lost River confluence (RM 75) and the Winthrop Bridge (RM 50) (USFS, 1998). Bull trout also utilize this reach for migration, foraging, and over-wintering.

Occasionally, portions of the river dewater between Robinson Creek (RM 74.0) and Weeman Bridge (RM 59.7), which impact habitat availability (Appendix F). Overall, the Methow River has a trend of increasing temperature in the downstream direction, with a large range of temperature fluctuation measured throughout the day (Appendix I). Natural spring locations tend to correlate with a localized decrease in temperature in the main channel.

4.2.2 Geologic Controls and Channel Slope

The longitudinal profile of the Methow River has a trend of decreasing slope in the downstream direction (Figure 26). Ice from the continental ice sheet and alpine (valley) glaciers periodically filled the Methow River valley along the entire length of the assessment area (RM 28 to 75). Glacial ice and melt water eroded into the sedimentary and volcanic rocks and deposited a relatively thick sequence of unconsolidated gravel and sand. The Methow River now flows through these unconsolidated deposits. The loose deposits within the floodplain can be reworked by the river, as opposed to the more consolidated glacial deposits that form the boundary of the floodplain. From Lost River (RM 75) to Weeman Bridge (RM 61) coalescing alpine glaciers from Early Winters Creek (confluence at RM 67.3) and the West Fork Methow River (confluence at RM 75) are believed to have carved a glacial trough (Figure 27). The trough was subsequently filled-in with glacial and fluvial deposits during the retreat of the alpine glaciers followed by the advance and deposits of the continental glacier. The thickness of the unconsolidated sediments along the trough is greater than 1,000 feet in some locations (Waitt, 1972). From Weeman Bridge downstream to Carlton, the thickness of unconsolidated sediments overlying bedrock varies considerably. In some areas, the thickness of the unconsolidated sediments is believed to be over 200 feet. However, there are several areas where bedrock is exposed along the riverbank and in the river channel, such as in the channel bed at RM 48.1 and at 48.8.

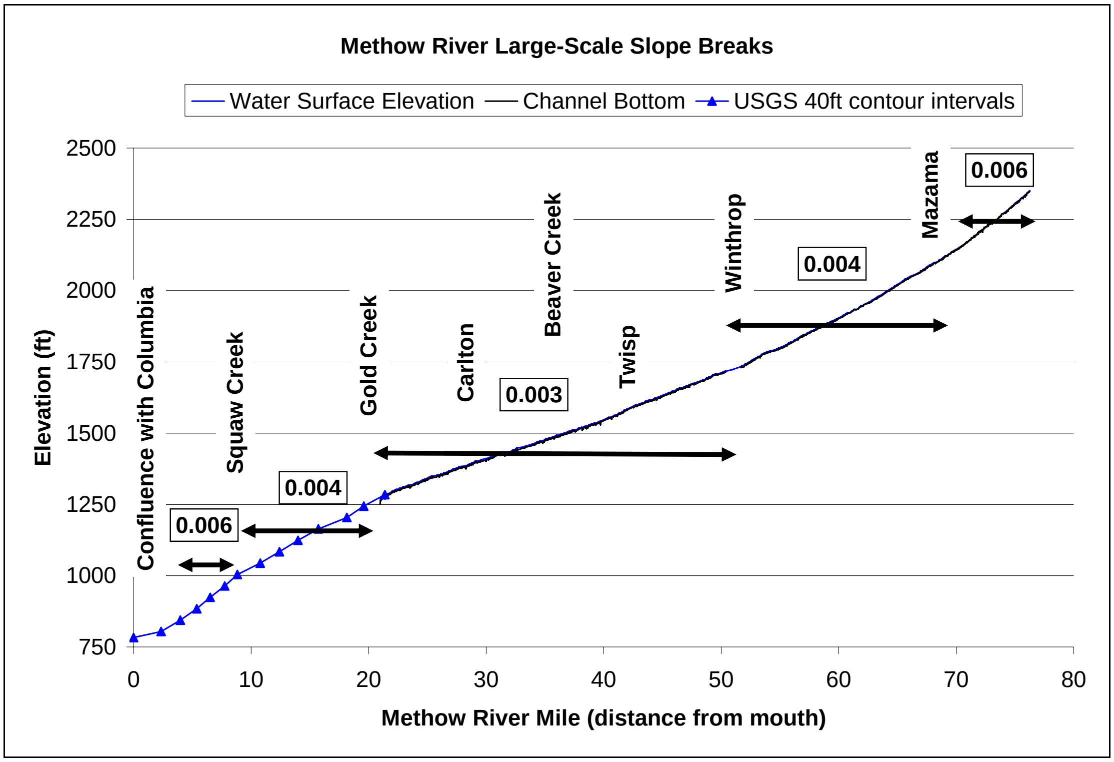

Figure 26. Major slope breaks along Methow River. From RM 28 to 75, elevation data is from a 2005 channel bottom survey.

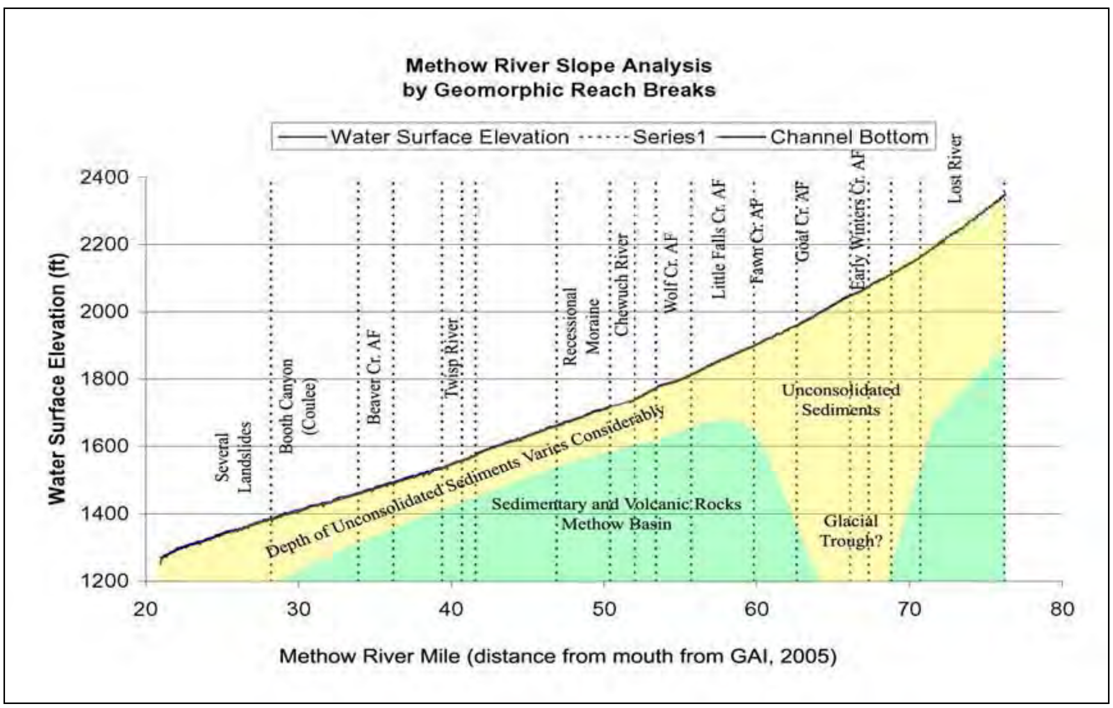

Figure 27. Longitudinal profile of the Methow River channel showing relative depth of Quaternary sediments and geomorphic reaches in the study area.

The active floodplain along the Methow River between RM 28 and 75 is bound by geologic features that limit lateral erosion consisting of bedrock, glacial deposits, alluvial fans, and landslides or debris flows. The dominant feature is glacial deposits, which composes 73 to 80% of the floodplain boundary (Table 14).

Table 14. Summary of geologic composition along boundary of Methow River assessment area.

Geologic surface description	Bank Length (miles)		Percentage of Bank in Each Type	
	Right	Left	Right	Left
1 = Bedrock	2.9	2.7	7%	6%
2 = Glacial deposits of varying age and heights above the river bed	32.7	36.1	73%	81%
3 = Alluvial-fan deposit	7.8	4.6	17%	10%
4 = Landslide/debris flow	1.3	1.5	3%	3%
Total	**44.7**	**44.9**	**100%**	**100%**

4.2.3 Floodplain Expansion and Reworking

Erosion of river banks can occur within the floodplain (low surface), indicating channel migration and lateral reworking is occurring. Bank erosion can also occur along the boundary of the floodplain, indicating expansion (enlarging) of the floodplain area. Along the Methow River low surface boundary, 22 areas of expansion were noted between 1948 and 2004. The total bank length of expanded areas along the boundary of the low surface is about 14,000 feet. This is about 6% of the entire bank line in the assessment section.

Amounts and rates of erosion were calculated for the floodplain boundary of the Methow River from 1945 – 1948, 1948 – 1954, 1954 – 1964, 1964 – 1974, and 1974 – 2004 (Appendix G). Few places along the low surface boundary in the assessment section have experienced measurable lateral expansion since the earliest aerial photograph available (1948 or 1954). Where expansion has occurred, the area eroded has been relatively small. Two areas have experienced relatively large areas of recurrent expansion of the low surface boundary: 1) near RM 36 on river left immediately upstream of the Beaver Creek confluence, and 2) near RM 60.5 on river right about 1,500 feet downstream of Weeman Bridge (Appendix G). Golder Associates accomplished a channel hazard analysis that provides extensive information on potential erosion areas along the boundary of the low surface (Golder, 2005).

Within the floodplain, the largest amount of reworking from channel migration has occurred in the upstream geomorphic reaches M9 through M11. In these reaches, changes have occurred in all of the years, often in the same locations (Appendix G and the *Methow Atlas*). Some changes have occurred in the downstream reaches, but M4 is the only other reach that has had significant historical change. Most of the erosion occurred along the low-surface banks of the unvegetated channel between 1948 and 2004. Glacial deposits are the next most eroded geologic unit along the banks of the unvegetated channel, which correspond to erosion along the boundary of the floodplain (low surface).

4.2.4 Impacts to Floodplain Width

The Methow River natural floodplain width ranges from a little less than 100 to 4,500 feet (Appendix E). The widest floodplain areas are between RM 55 and RM 65 and RM 34 and RM 46. The narrowest floodplain areas are between RM 28 and RM 34 and RM 65 and RM 70. The active channel in 2004 made up about 52% of the floodplain (low surface) and channel area in the confined reaches, about 16% of the floodplain and channel area in the unconfined reaches, and about 23% of the floodplain and channel area in the moderately confined reaches (Appendix C).

Human features have decreased the width of the natural floodplain (low surface) to some degree in all reaches, with more notable impacts in the following river reaches (Figure 28 and Figure 29):

- RM 34 to 38
- RM 42 to 47
- RM 51 to 53
- RM 60 to 64
- RM 71 to 75

Two of the five existing bridges present significantly constrict the natural floodplain width.

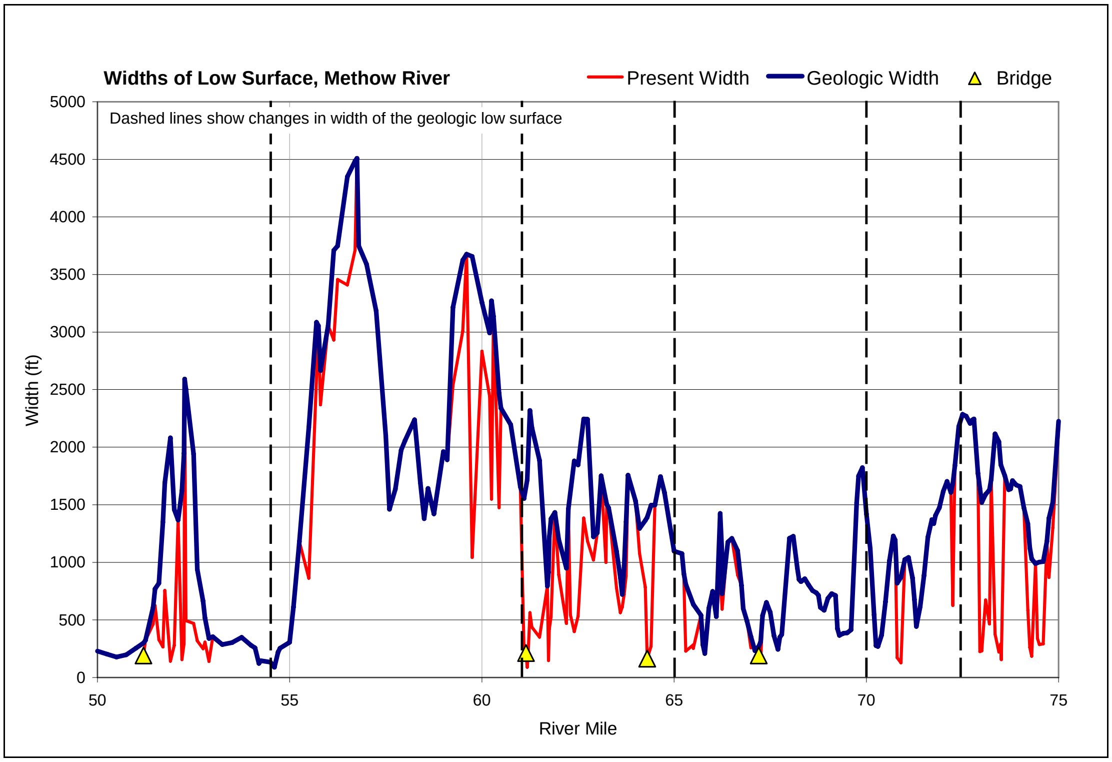

Figure 28. Reduction in Upper Methow floodplain widths due to human features (RM 50 to 75).

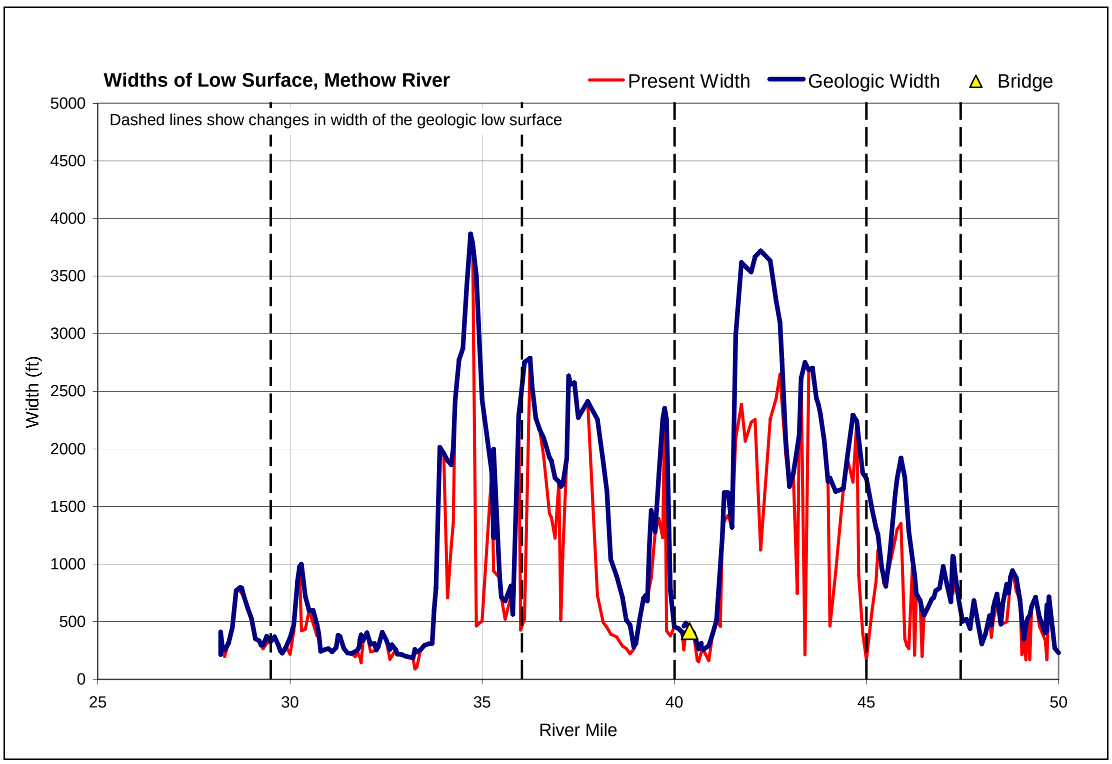

Figure 29. Reduction in Middle Methow floodplain widths due to human features (RM 50 to 75).

4.2.5 Vegetation and Large Woody Debris

The largest and most diverse riparian vegetation areas are located between Wolf Creek confluence (RM 55) to the Lost River confluence (RM 75). From RM 55 downstream to RM 28 (Carlton), there is increasingly less riparian extension and diversity with a few exceptions. The riparian corridor is naturally more confined by geologic surfaces so there is a narrower zone of riparian vegetation. The vegetation in this section of the river is described by Baesecke (2005) in Appendix H. "Often the riparian zone is merely a line of trees along the river; sometimes those trees are Ponderosa pine, or other species that are often non-native. A few instream bars support mostly shrubs and non-native forbs. In places black cottonwood trees are found along the sides of the river bank."

LWD mapping by Golder Associates on 2001 aerial photographs documents that most log jams presently occur upstream of RM 55 (near Wolf Creek) to RM 75 (Lost River) (Appendix E; Golder, 2005). This is due to the more extensive riparian vegetation zone and complex channel networks that persist in this reach and lower stream power of the channel.

4.2.6 Location and Types of Human Features

The types of human features present in the Methow were subdivided into features within the floodplain and features along the floodplain boundary (Figure 30 and Figure 31). Features within the floodplain generally consist of levees, riprap, roads, and bridges that limit lateral migration of the channel, access to side and overflow channels, and have had the largest impact in unconfined and moderately confined reaches. Additionally, historic clearing of vegetation and LWD in the channel has reduced the quality and density of habitat components formed by riparian vegetation and large woody debris.

Less than 30% of the boundary of the low surface has human features along it. The greatest length of human features occurs between RM 34 and RM 46, and the shortest length occurs between RM 70 and RM 75. The largest component along the low surface boundary is riprap that has been placed for bank protection. Five bridges are also present. Along the boundary of the low surface, there is more bank protection in the downstream half of the Methow River assessment area.

Reaches M2, M4, M5, M7, M9, and M11 have a greater length of human features within the low surface than along the boundary (Appendix P). Reaches M1, M3, M6, M8, and M10 have a greater length of human features along the boundary than within the low surface area. The reach with the longest length of human features within the low surface is M9 with nearly 6 miles of cumulative length. Reaches M4 and M2 also have long lengths of human features within the low surface with between about 4 and 4.5 miles of cumulative length (Figure 28). The longest lengths of human features along the low surface boundary, about 3 miles each, are in reach M2 and M1 (Figure 29).

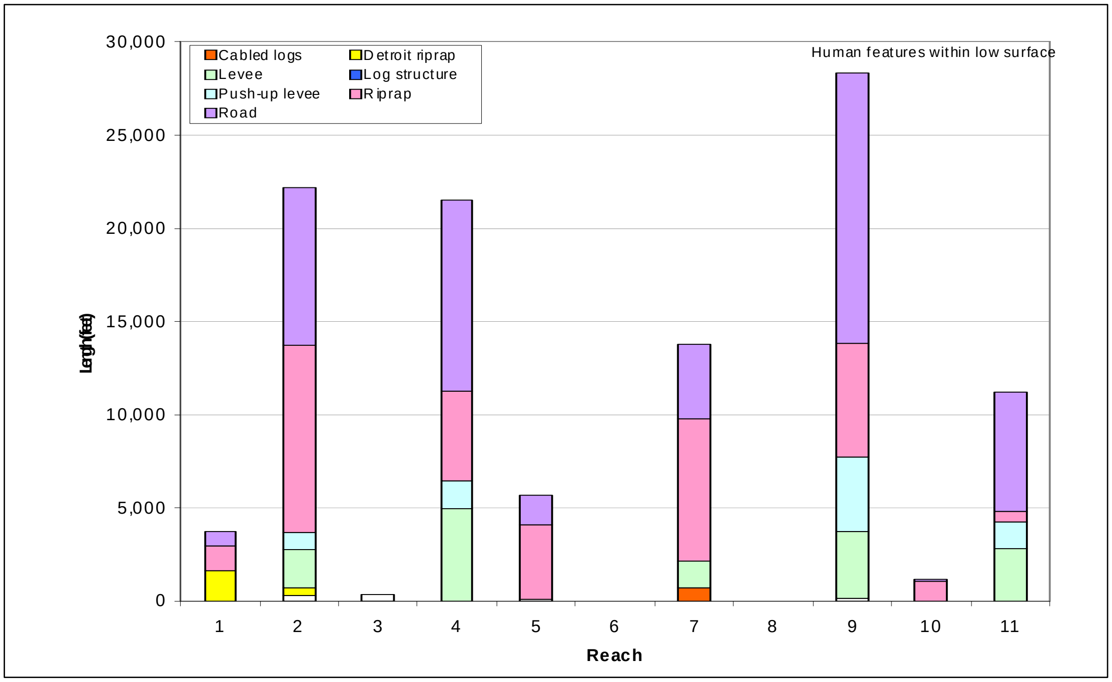

Figure 30. Methow River – Types of human features within the flood prone area (low surface) on the mainstem by reach.

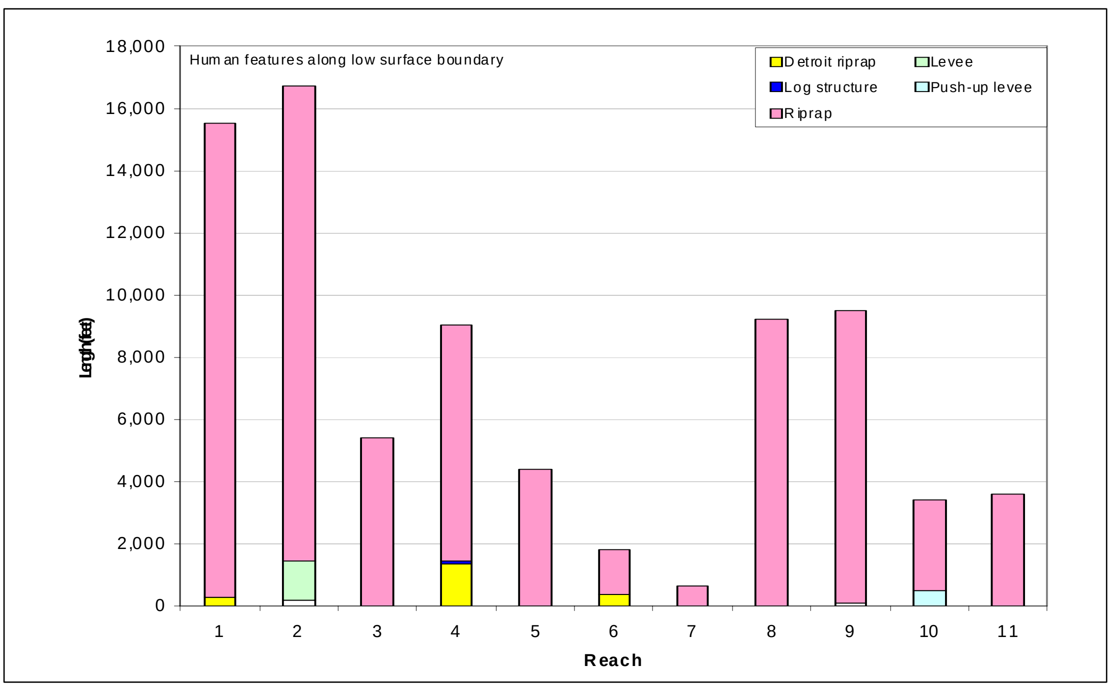

Figure 31. Methow River – Types of human features along the boundary of the floodplain (low surface) on the mainstem. See Table 3 for river mile boundaries of each reach. The floodplain is bound by a combination of terrace deposits, alluvial fans, bedrock, and glacial outwash (see Appendix G).

4.3 TWISP RIVER GEOMORPHIC CONDITIONS

The Twisp River subbasin is generally a west-to-east drainage containing about 157,000 acres. The stream is about 30 miles long and enters the Methow River at RM 40.2. Elevations range from 8500 feet in the headwaters to 1600 feet at the confluence. Annual precipitation ranges from 90 inches along the Cascade crest to 20 inches in Twisp (Andonaegui, 2000). About 90% of the land (about 145,000 acres) in the Twisp River subbasin is managed by the USFS, including nearly all of the land above the valley floor upstream of the confluence with Little Bridge Creek (RM 10) (USFS, 2001). About half of the USFS land (about 72,000 acres) lies within the Chelan-Sawtooth Wilderness and is administratively withdrawn from most management activities, including timber harvest and road construction. Most of the Twisp River valley bottom from the mouth to the confluence with Eagle Creek (at about RM 17) is privately owned. The USFS manages several small areas of land along the river or in the floodplain in the lower 17 miles of the river; these include parcels at Elbow Coulee (RM 6), Little Bridge Creek (RM 10), at the Gary Brown irrigation diversion (RM 12), and above the south shore in the Scaffold Creek area (RM 16) (USFS, 2001). All of the land along the river bottom upstream of the confluence with Eagle Creek is managed by the USFS. The State of Washington owns land near Elbow Coulee and near the Twisp Power and Light irrigation diversion at RM 7.5.

4.3.1 Habitat Conditions

Spring Chinook and steelhead utilize the Twisp River from RM 0 to 15 for migration, spawning, and juvenile rearing; bull trout utilize this reach for foraging, migration, and over-wintering (Appendix F). Most of the spring Chinook spawning and all of the bull trout spawning in the Twisp River presently takes place above RM 12 up to RM 27 (Appendix F).

The Twisp River shows an overall warming trend of temperature in the downstream direction within RM 18 to 0 (PWI, 2003; Appendix F). Water temperatures in the lower Twisp River have been documented to exceed minimum state and NOAA Fisheries Service standards during low flow periods in late summer (PWI, 2003; USFS, 2001). A few coldwater sources provide local refuge such as between RM 18 and 16 likely due to springs. There is a localized cooling trend between RM 9.6 to 7 but there is not a clear explanation on the cause at this time.

4.3.2 Geologic Controls and Channel Slope

The longitudinal profile on the Twisp River shows a sharp break at RM 10 near the Little Bridge Creek confluence (Figure 32 and Figure 33). Although minor variations in bedrock are present, the rock types are primarily the same longitudinally. The maximum extent of the alpine (valley) glacier that came down the Twisp River valley coincides with the approximate location of the slope change. Glacial erosion occurred upstream of this point resulting in deepening and widening of the valley and a flatter valley slope (trough). Fluvial erosion occurred downstream of the retreating glacier and the sediment-rich discharges incised through the glacial deposits and bedrock leaving a narrower and steeper valley slope. Exposed bedrock was noted in the channel bed at RM 5.1 to 5.3, 9.9, 11.1, 13.2, and at 16.2.

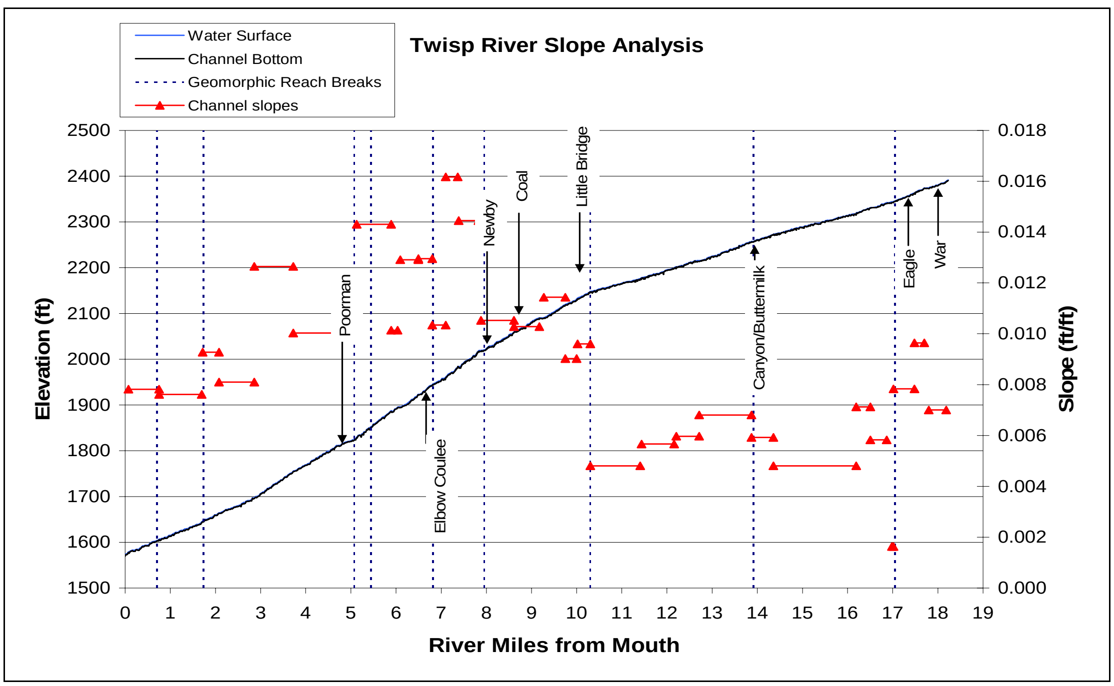

Figure 32. Twisp River assessment area. Longitudinal profile of elevations and slopes.

Figure 33. View of Twisp River just upstream of Little Bridge Creek near RM 10 (August 17, 2005).

4.3.3 Expansion and Reworking

The active floodplain along the Twisp River between RM 0 and 18 is bound by geologic features that limit lateral erosion consisting of bedrock, glacial deposits, alluvial fans, and landslides or debris flows. The dominant feature is glacial deposits, comprising 59 to 70% of the floodplain boundary, although alluvial fans are fairly common. Along the 6.7-mile-long assessment section of the Twisp River, six areas of expansion of the low surface boundary were noted between 1954 and 2004. The total length of expanded areas is about 2,900 feet. This is about 7% of the entire assessment section that was evaluated.

Table 15. Summary of geologic composition along boundary of Twisp River assessment area.

Geologic surface description	Bank Length (miles)		Percentage of Bank in Each Type	
	Right	Left	Right	Left
1 = Bedrock	0.4	1.6	3%	11%
2 = Glacial deposits of varying age and heights above the river bed	9.3	9.9	59%	70%
3 = Alluvial-fan deposit	5.2	2.3	33%	17%
4 = Landslide/debris flow	0.8	0.3	5%	2%
Total	**15.7**	**14.1**	**100%**	**100%**

The time intervals for which amounts and rates of erosion were calculated on the low surface boundary for the Twisp River are 1954 to 1964, 1964 to 1974, and 1974 to 2004. Of the 18.1-mile-long river section evaluated on the Twisp, only the downstream-most 6.7-miles had historical aerial photography available in a GIS rectified format. Bank erosion rates within the low surface are generally considered part of the natural process of lateral migration in this segment of river, unless locally exacerbated by human features that result in directing the river into a bank. Of the 6.7-mile-long channel of the Twisp River compared, 6 areas of expansion of the low surface boundary were noted between 1954 and 2004 (Appendix E). The total length of expanded areas is about 2,900 feet. This is about 7% of the low surface banks in the Twisp River section evaluated (RM 0 to 6.7). Low-flow channel changes have occurred historically along the Twisp River primarily in geomorphic reaches T2, T3, and T6 (Appendix G).

4.3.4 Impacts to Floodplain Width

The Twisp River natural (geologic) floodplain widths range from 100 to just under 1,900 feet (Figure 34). The widest floodplain area occurs between RM 11 and 12 and RM 14 to 18. The narrowest floodplain areas occur between RM 0 and 1, RM 5 and 6, RM 8 to 10, and RM 13 and 14. The floodplain widths have been reduced in several locations. There are presently 10 bridges, most of which result in constrictions to the floodplain.

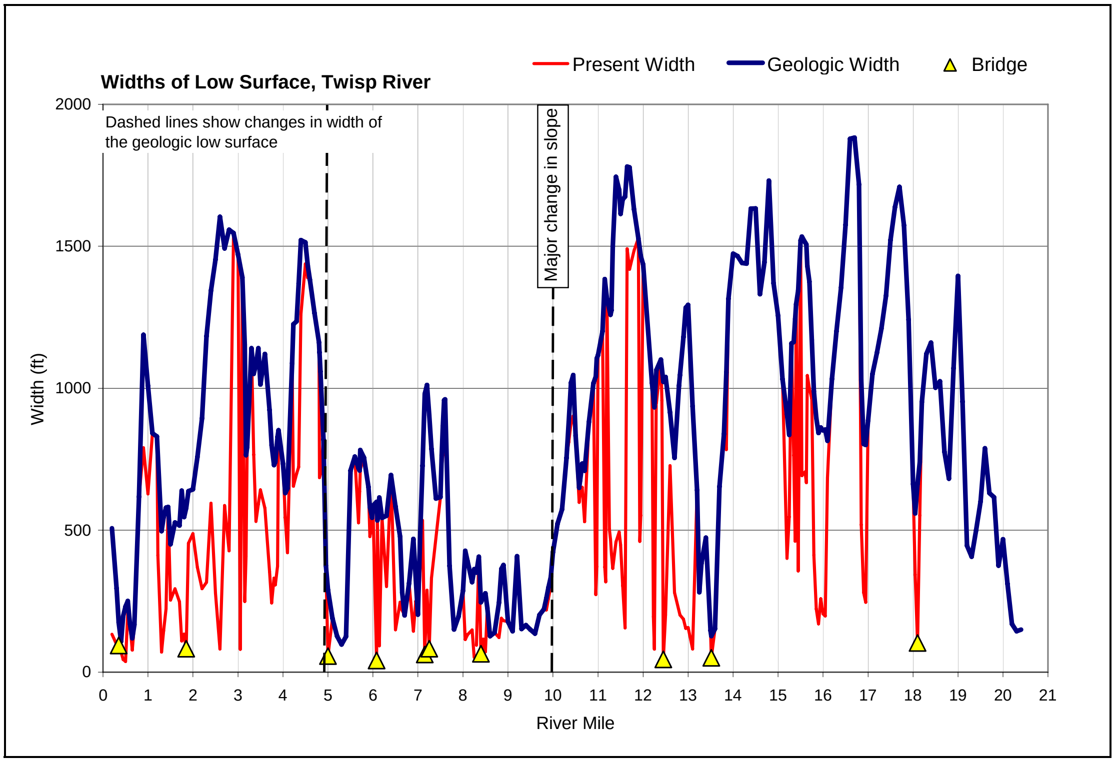

Figure 34. Reduction in Twisp River floodplain widths due to human features.

4.3.5 Vegetation and Large Woody Debris

During the riparian surveys in the Twisp River and its tributaries (PWI, 2003), the following observations were made. (Note that RM is from PWI assessment, and may be slightly different than the Reclamation RM used in this report.)

- Upper watershed (RM 22.65 and upstream) generally has healthier stands that are able to ward off pests, show vertical diversity (multiple canopy layers), and *Populus* species regeneration
- The mid-section (RM 13.7 to 22.65 at Reynolds Creek) has more diseased trees and mortality, smaller stands, only 1 or 2 canopies and less regeneration
- The *Populus* stands in the lower part of the watershed (RM 0 to 13.7 at Buttermilk Creek Road Crossing) are in very poor condition if at all present. Several stands that are located in this portion of the Twisp River have died out, witnessed by large remaining black cottonwood snags and LWD.

Large wood is scarce in the lower 13.7 miles of Twisp River due partly to past clearing of the channel and harvesting along the banks (USFS, 2001). Less than 8 pieces of wood per mile greater than 35 feet long and 12 inches in diameter were counted in the lower 13.7 river miles (USFS, 2001). Large wood in the channel was much more abundant in many stream reaches in the upper 16.7 miles of the Twisp River. An average of 42 pieces per mile greater than 35 feet long and 12 inches in diameter were counted along this upstream reach (USFS, 2001). About 30% of the wood counted in the channel had a diameter greater than 20 inches (about 12 pieces per mile). Fifty-three log jams, many creating deep pools, were found in the upper 16.7 miles of the Twisp River.

Woody debris jams were counted from the 1955, 1964, 1970 and 1973 aerial photographs between RM 0 to 20.5 at Cook Creek confluence (PWI, 2003); of the 17 woody debris jams that were mapped, only the jam above War Creek was found after the 1972 flood. No woody debris jams were observed downstream of RM 13.8 at Buttermilk Creek confluence. It is hypothesized that this is because LWD was removed by humans following the 1948 and 1972 floods.

4.3.6 Location and Type of Human Features

The types of human features present in the Twisp were subdivided into features within the floodplain and features along the floodplain boundary (Figure 35 and Figure 36). Features within the floodplain generally consist of levees, riprap, roads, and bridges that limit lateral migration of the channel, and limit access to side and overflow channels and have had the largest impact in unconfined and moderately confined reaches. Additionally, historical clearing of vegetation and large woody debris in the channel has reduced the quality and density of habitat components formed by riparian vegetation and large woody debris.

The most common feature along the boundary of the floodplain is riprap. Eight bridges were constructed across the channel and most of these significantly constrict the floodplain width. The highest percentage of the low surface boundary that is protected by human features on the Twisp River is 19%, which occurs in reaches T3b and T4. Ten percent of the low-surface boundary in Reach T1 is protected by human features. For other reaches where human features have been mapped along the low surface boundary, the human features compose only a few percent of the low surface length: 3% for Reach T5, 2% for Reach T2b, and 1% for Reach T3c.

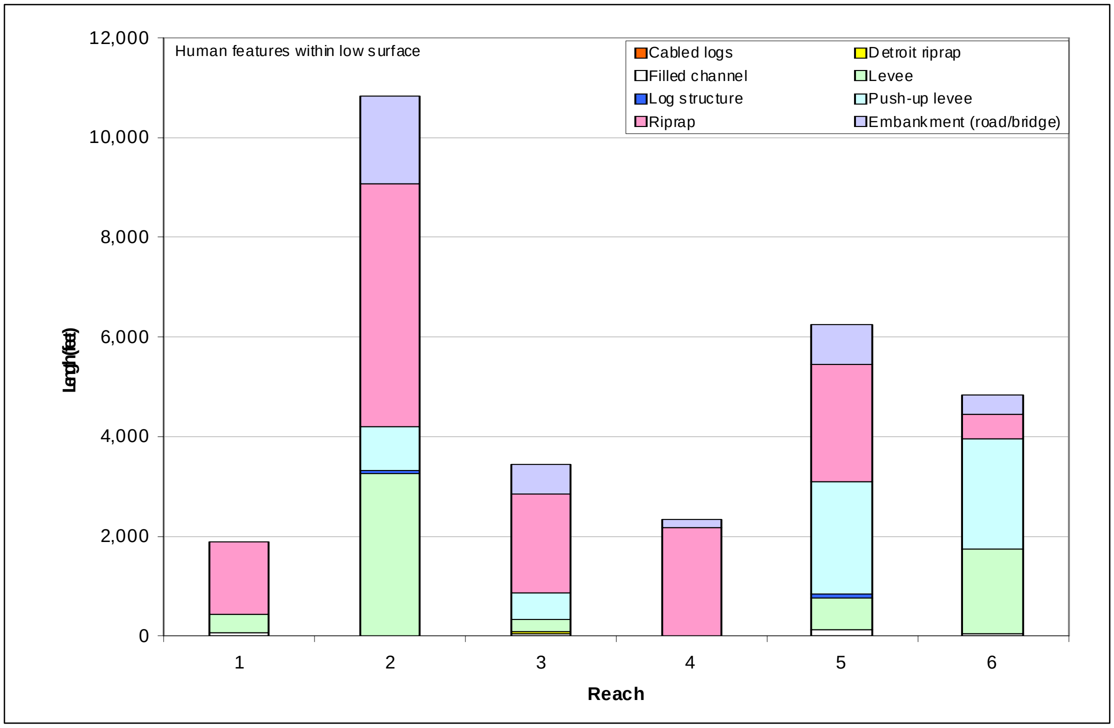

Figure 35. Twisp River – Types of human features within the flood prone area (low surface) by reach. See Table 3 for river mile boundaries of each reach.

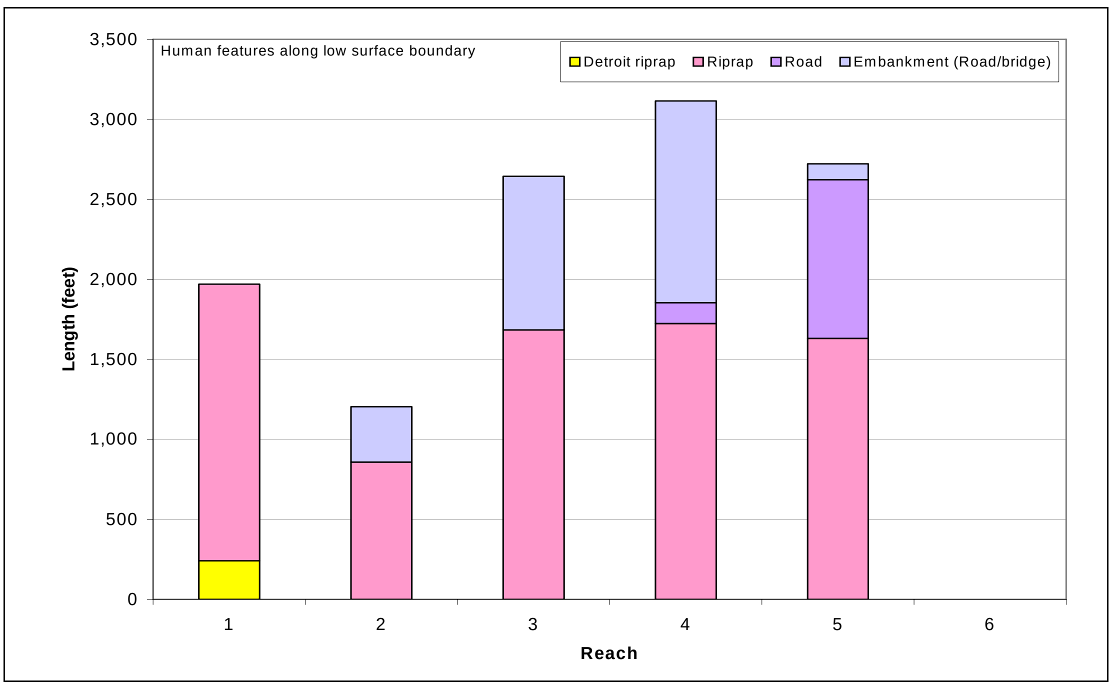

Figure 36. Twisp River – Types of human features along the boundary of the floodplain (low surface) by reach. The floodplain is bound by a combination of terrace deposits, alluvial fans, be bedrock, and glacial outwash (see Appendix G). See Table 3 for river mile boundaries of each reach.

4.4 CHEWUCH GEOMORPHIC CONDITIONS

The Chewuch River is generally a north-to-south drainage containing about 340,000 acres. The downstream-most 14 river miles were evaluated in this assessment. Elevation range in the drainage is about 8700 feet down to 1700 feet at the confluence with the Methow River at RM 44.8 (Andonaegui, 2000). Annual precipitation is approximately 35 inches in the upper subwatershed to about 15 inches at the mouth (Richardson, 1976, as referenced in Andonaegui, 2000). The USFS manage about 95% of the drainage (above RM 7) of which the 34% is located in the Pasayten Wilderness. Along the Chewuch River, the USFS boundary begins at RM 7.0 and includes a mixture of private and federal lands between RM 7.0 and 8.0. Lands downstream of RM 7.0 along the Chewuch River are all privately owned (Andonaegui, 2000). The majority of human-related impacts have occurred outside of the wilderness area and along the mainstem Chewuch River and its tributaries downstream of RM 25.0 (Andonaegui, 2000). The Chewuch River water temperature tends to warm in the downstream direction based on data collected by Pacific Watershed Institute (PWI, 2003; Appendix F). Cold-springs and subsurface processes appear to play a larger role than surface water in defining stream temperature patterns.

4.4.1 Habitat Conditions

The Chewuch River provides roughly a third of the spring Chinook production in the Methow Subbasin and is heavily used for both steelhead and spring Chinook for spawning, rearing, and migration (Appendix F). Spring Chinook and steelhead spawn from RM 0 up to Chewuch Falls at about RM 35 with the bulk of spawning occurring between RM 2 to RM 20. High-density spring Chinook spawning habitat can be found between the confluence of Boulder Creek and Eightmile Creek (RM 10 to 12). This area is upstream of all major irrigation diversions and has the greatest late summer streamflows and the coldest water. The lower Chewuch River is an important migration corridor for large migratory bull trout and for spawning and rearing lamprey. Bull trout also use the reach for foraging, especially in the cold water areas near Eightmile Creek.

The Chewuch River has a decreasing trend of water temperature from RM 14 downstream to Eightmile Creek (USFS, 2002; Appendix F). Cold-springs and sub-surface processes appear to play a larger role than surface water in defining stream temperature patterns. Within RM 0 to 14, the most substantial cold water source is Eightmile Creek. Downstream of Eight-mile Creek, water temperatures gradually increase, except for a slight decrease in the lower one to two miles of river (USFS, 2002).

4.4.2 Geologic Controls and Channel Slope

The longitudinal profile along the Chewuch River steepens between RM 9 and RM 10 relative to the upstream and downstream river reaches (Figure 37; Appendix K). One of the graben-bounding faults crosses the valley at an oblique angle near RM 9, and is relatively easy for the river to erode the bedrock (Appendix M). Upstream of RM 10, the bedrock is crystalline, and is relatively resistant to erosion. Downstream of RM 9 the bedrock is sedimentary and volcanic, which are generally more susceptible to erosion. The differences in rock types, which are juxtaposed (put side by side) by the graben-bounding fault, create a resistant "step" in the longitudinal profile of the Chewuch River. Very large boulders that have been deposited by glacial or debris-flow processes at the mouth of Boulder Creek, which is in this same area, enhance the resistant character of the near-surface crystalline rocks. Exposed bedrock was observed in the bed at RM 1.5 (Smith et al., 2000).

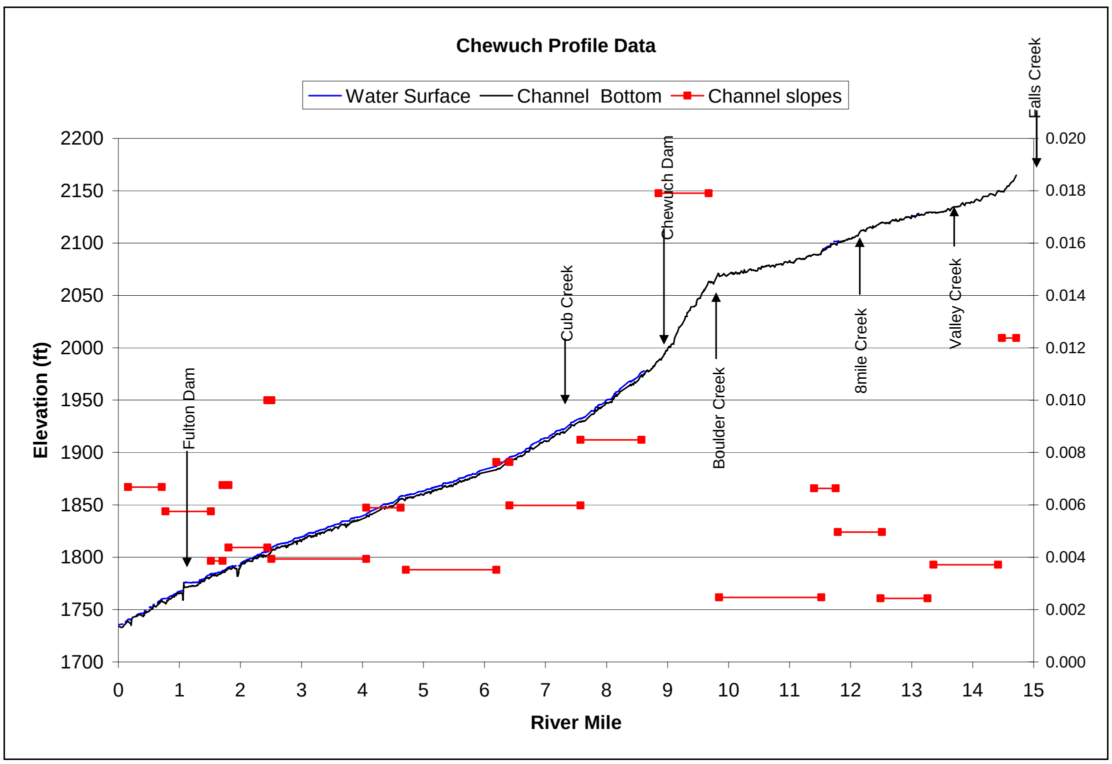

Figure 37. Chewuch River – Longitudinal profile of channel slope .from RM 0 to 15.

4.4.3 Floodplain Expansion and Reworking

The active floodplain along the Chewuch River between RM 0 and 14.3 is bound by geologic features that limit lateral erosion consisting of bedrock, glacial deposits, alluvial fans, and landslides or debris flows. The dominant feature is glacial deposits, composing 66% of the floodplain boundary, with bedrock being the second most common (Appendix G). Along the 11.7-mile-long assessment section of the Chewuch River with historical aerial photographs available, the unconfined reach C2 is the only area where expansion of the low surface boundary was noted between 1974 and 2004 (Appendices E and G). The total length of expanded area is about 1.3% of the low surface boundary in Reach C2 where expansion occurred, and about 0.6% of the entire assessment section that was evaluated (Appendix G).

The greatest number and longest length of reworked areas in the Chewuch River (RM 0 to 11.7) are in the unconfined Reach C2 (Appendix G). This reach has 24 areas of reworking along a length of about 18,000 feet. This is the only unconfined reach evaluated.

Table 16. Chewuch River – Summary of geologic composition along boundary of assessment area.

Bank Length (miles)		**Percentage of Bank in Each Type**		**Geologic surface descriptions**
Right	Left	Right	Left	
3.0	2.8	23%	22%	1=Bedrock
8.6	8.7	66%	66%	2=Glacial deposits of varying age and heights above the river bed
1.2	1.6	9%	12%	3=Alluvial-fan deposit
0.2	0.0	1%	0%	4=Landslide/debris flow
13.0	**13.1**	**99%**	**100%**	**Total Length**

4.4.4 Impacts to Floodplain Width

The Chewuch River floodplain ranges in width from just under 100 feet to just under 2,000 feet (Figure 38). The widest floodplain area occurs between RM 2 and RM 4, and between RM 5.5 and RM 9.5. The narrowest floodplain occurs between RM 0 and RM 2, and between RM 9.5 and RM 11.5. Human features have decreased the width of the floodplain throughout the assessment area. One of the two bridges in place causes a reduction in floodplain width.

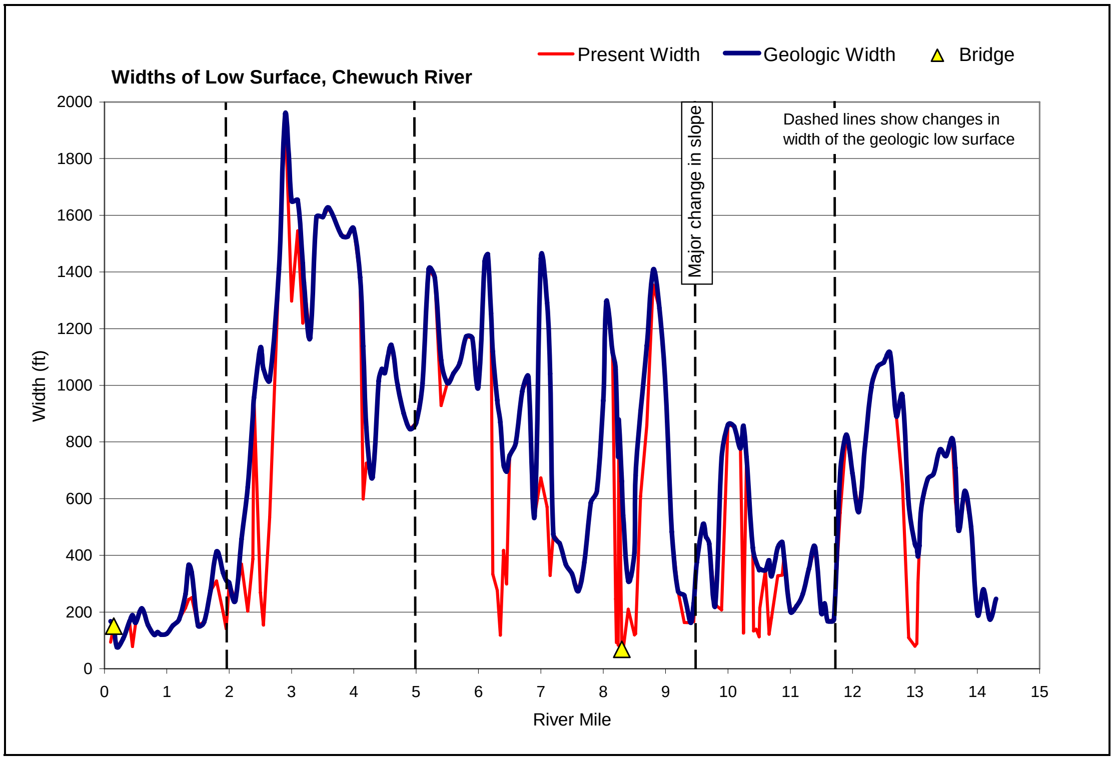

Figure 38. Chewuch River – Reduction in floodplain widths due to human features.

4.4.5 Vegetation and Large Woody Debris

The largest and most diverse riparian vegetation areas on the Chewuch River within the assessment area are located between RM 2.6 (near Pearrygin Creek) upstream to approximately RM 7 (near Cub Creek) (Appendix H). Several areas with ample ground moisture or backwaters support mixed riparian shrub stands but do not appear to allow the regeneration of cottonwoods. The vegetation along the Chewuch River was not field-checked and will need to have this step done at the reach-assessment level to better understand and validate these observations from aerial photography.

The Pacific Watershed Institute completed a stream survey from the mouth of the Chewuch River to Boulder Creek (RM 9.5) that included documentation of LWD (Smith et al. 2000). The survey found LWD greater than 35 feet long and 1 foot in diameter ranged from 8 to 18 per mile depending on the reach. The river length with the most LWD was from RM 2 to 5.4.

4.4.6 Location and Type of Human Features

The types of human features present in the Chewuch were subdivided into features within the floodplain and features along the floodplain boundary (Figure 39 and Figure 40). Features within the floodplain generally consist of levees, riprap, roads, and bridges that limit lateral migration of the channel, access to side and overflow channels, and have had the largest impact in unconfined and moderately confined reaches. Additionally, historic clearing of vegetation and large woody debris in the channel has reduced the quality and density of habitat components formed by riparian vegetation and LWD. The most common feature along the boundary of the floodplain is riprap.

Less than 5% of the boundary of the low surface has human features along it (Appendix P). Within the low surface, the largest component of human features is road embankment and riprap (Appendix P). The largest component along the low surface boundary is riprap that has been placed for bank protection. Two bridges are also present.

The total length of human features within the low surface is greater than the total length of human features along the boundary of the low surface in reaches C2, C3, and C5, but the values for both of these lengths are nearly the same in reaches C1 and C4 (Appendix P). In the reaches C2 and C3, all of the human features are within the low surface. The reach with the longest length of human features within the low surface is Reach C3 (nearly 1 mile). The reach with the longest length of human features along the low surface boundary is Reach C4 (about 0.3 mile).

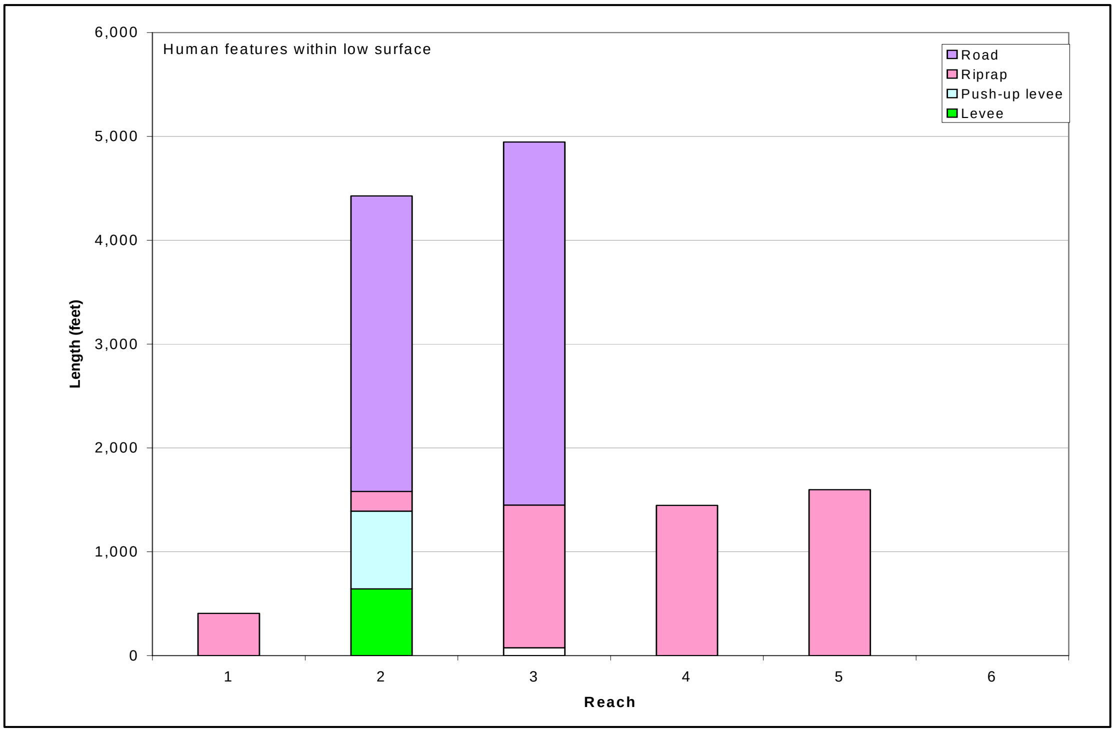

Figure 39. Chewuch River – Types of human features within the flood prone area (low surface) by reach. See Table 5 for river mile boundaries of each reach.

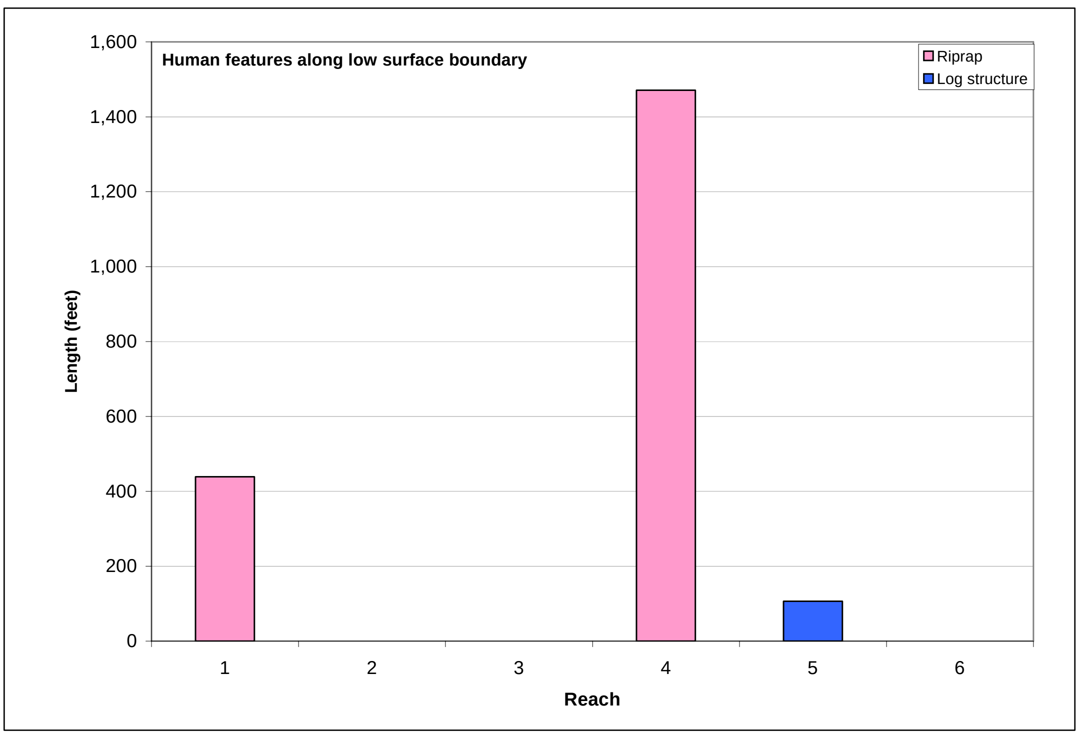

Figure 40. Chewuch River – Types of human features along the boundary of the floodplain (low surface) by reach. The floodplain is bound by a combination of terrace deposits, alluvial fans, bedrock, and glacial outwash (see Appendix G). See Table 5 for river mile boundaries of each reach.

4.5 REMAINING DATA GAPS

Processes were considered in this assessment at a valley segment and reach scale with available information from past studies. The exception is hydrologic analysis which was generated at the subbasin scale. The types, locations, and timing of human impacts to upland vegetation, sediment and water supply were investigated and qualitatively linked to processes evaluated within the assessment area. The upstream areas in the Methow Subbasin are largely administered by the USFS. These areas have limited human development, but are believed to have had significant impacts on the timing and severity of fires, which do affect sediment and LWD delivery to the rivers (Molesworth, 2007). Other cooperators may want to consider expanding the more detailed analysis done at a reach level farther upstream into the watershed beyond Reclamation's assessment area boundaries.

This report provides an important level of technical information for resource decision makers to evaluate where to begin potential restoration actions within the 80-mile-long Methow Subbasin assessment area. Broad-scale conclusions presented in this report provide generalized characteristics and physical river processes on a reach-scale level. On a project scale, characteristics and processes may have localized features that differ from the broad-scale descriptions. Additional data and analysis will be needed in most cases for the subsequent reach assessments (0.5 to 10.5 river miles in length) and project-scale evaluations prior to project implementation. The level of analysis needed will vary depending upon the complexity of the proposed project and adjacent land use and infrastructure. During this assessment, several ideas for additional assessment were developed. Answering some of these questions may be more in a research category, while others are more crucial to accomplishing future reach assessments or project designs:

- Habitat survey of baseline conditions and limiting factors to provide a more detailed diagnosis within the reach of biological conditions to guide treatment sequencing and prioritization.
- Linkage of biological conditions with an understanding of channel and floodplain function using the MPI (NOAA Fisheries Service, 1996).
- Photo documentation of human features within the reach to validate previous mapping and to look for new features that may have been missed or constructed since the completion of the assessment of the 80-mile-long assessment area.
- Refinement of geologic surface mapping in GIS using 2006 LiDAR data and field verification to validate the active floodplain and off-channel areas.
- Hydraulic model to validate the present and potential connectivity between the active floodplain and main channel, and identify any potential concerns for protection of infrastructure and property that will need to be addressed.

- Refinement of GIS mapping of present side and overflow channels using 2006 LiDAR data and field verification of the presence and definition (well defined, partially blocked at upstream or downstream entrance, filled in) of side and overflow channels, particularly in vegetated floodplain areas that could not be easily accessed in the 80-mile assessment stage.
- Assessment of the present connectivity (or lack there of) between side channels and the mainstem channel during a range of flows using a hydraulic model, ground photo documentation, helicopter video and/or survey of water elevations during high water, and evidence of high water marks following floods.
- Bed-material samples in the main or side channels to determine sediment transport capacity if there are questions about the ability of the river system to sustain off-channel areas once they are reconnected to the river.
- Collection of new temperature or flow data during critical, low flow, late-summer periods if there is concern about water quality as a limiting factor for success of proposed habitat actions.
- Refinement of or additional mapping of vegetation by classification, age, density, and health in order to determine if there are any riparian vegetation efforts needed to increase the likelihood success or to reduce the timeframe of when benefits are detectable to fish.
- Rectification of additional historical aerial photographs or maps if new information is found that will help provide refinement to the historical trend analysis.
- Integration of any monitoring information available to apply any lessons learned to restoration strategies being developed or implemented.

During the alternatives evaluation and construction design phases, additional ground survey data may be needed to refine numerical modeling used to evaluate alternatives and develop designs of project features.

5. CONCLUSIONS

This report provides results from a geomorphic assessment and reach-based restoration strategy for nearly 80 miles of Category 2 river segments in the Methow Subbasin, located in Okanogan County, Washington. These 80 miles represent four valley segments consisting of the Upper Methow (RM 50 to 75), Middle Methow (RM 28 to 50), Twisp (RM 0 to 18) and Chewuch Rivers (RM 0 to 14). The four river valley segments were evaluated concurrently to compare and prioritize potential protection and habitat restoration areas.

Variations in channel and floodplain conditions and the occurrence of natural floodplain constriction points were used to delineate 23 reaches where habitat for ESA-listed spring Chinook and steelhead might be protected, enhanced, or restored. The objective of this assessment was to provide resource managers with a way to identify, sequence, and prioritize opportunities for protecting or restoring channel and floodplain connectivity and channel complexity in the 23 reaches identified. Technical prioritization of reaches was made based on the current habitat quality, potential habitat improvements, and how well the proposed restoration actions meet established habitat objectives from local biologists, the *Upper Columbia Recovery Plan* (UCSRB, 2007), and other available documents that provide biological strategies for the Methow Subbasin. Additional steps will be needed by local groups to complete the reach prioritization of process.

The 23 reaches were characterized into three general types based on differences in geomorphic conditions and the potential to provide habitat features associated with multiple life stages and species use, particularly complexity habitat for ESA-listed spring Chinook and steelhead. One of the primary habitat objectives from the *Upper Columbia Recovery Plan* is protecting and improving connectivity between the channel and floodplain. Therefore, for purposes of discussing restoration opportunities, unconfined and moderately confined reaches with wide floodplain areas were identified separately from naturally confined, single-thread channel reaches. Three floodplain types were identified that help group the 23 reaches based on the natural potential of channel habitat complexity:

- High complexity, with wide, unconfined floodplain (61% of total area)
- Medium complexity, with narrower, moderately confined floodplain (17% of total area)
- Low complexity, with narrow, confined floodplain (23% of total area)

The primary human impact in naturally confined reaches is large amounts of riprap located along the boundary of the floodplain. The occurrence of channel migration and bank erosion would naturally be fairly small in these reaches, so the riprap has a minimal impact on physical river processes. The man-made bank protection also does not generally impact salmon migration access or spawning habitat that may occur in these reaches. Therefore, removal of the riprap along glacial terraces has limited benefits for improving habitat complexity relative to other channel and floodplain reconnection actions that could be done in reaches with active channel migration and substantial vegetated floodplain. If the riprap repeatedly fails and contributes non-native material to the river, it could impact bed-material composition but this type of historic documentation was not available.

The primary limiting factor to habitat function in moderately confined and unconfined reaches are human features and historical activities that have limited the connectivity of the channel and floodplain, channel migration and reworking processes, and the availability of habitat complexity features. Human features and activities most commonly observed in this assessment are levees, roads, riprap, bridges, historical filling of channels, and removal of riparian vegetation and large woody debris.

Historical accounts, maps from the early 1900s, aerial photographs from 1948 to 2004, survey data, and geomorphic observations and mapping were used to look for evidence of changes in geomorphic conditions over a decadal time period as a result of floodplain confinement and removal of riparian vegetation and large woody debris. The channel planform and bed elevations appear stable in most locations with no trends of channel bed incision or aggradation on a decadal scale. The percentage of floodplain area where vegetation is presently cleared is 19.9% for the Methow River (Middle and Upper), 14.8% for the Chewuch River, and 24.1% for the Twisp River. LWD levels are presently highest in unconfined reaches, but are believed to be lower than natural conditions due to historical removal of woody debris and log drives on the Methow River.

The river hydraulics and sediment sizes present along the channel bed are most notably dominated by geologic features that control the river bed slope and the lateral extent of the active channel and floodplain (width). Human features and historical human activities that have disrupted floodplain connectivity and altered the riparian zone do not appear to have altered channel slopes and bed sediment characteristics on a reach scale. Even though human impacts cannot be detected on reach-based hydraulics and sediment characteristics, they have impacted localized hydraulics, habitat features formed by LWD and riparian vegetation, and spawning-sized sediment availability that are critical to habitat quantity and quality. Hydraulic conditions have been most impacted by reducing flow access to off-channel areas at the entrance to side channels, and to some degree altering access to overbank flooding.

Habitat action classes and the associated VSP parameters that would be addressed were identified for each reach as referenced from Table 5.9 in the *Upper Columbia Recovery Plan*. Removal or modification of human features has a good chance of success for achieving long-term restoration of floodplain access and complexity that is now absent in many locations without risking impacting the baseline morphology of the channel. Short-term actions such as LWD placement or riparian planting may be needed to supplement long-term strategies that will take longer timeframes for physical processes and habitat features to recover.

This assessment report builds on the previous work of many others to help fill large information voids needed to establish a cohesive reference point to establish protection and restoration opportunities within the nearly 80-mile assessment area. Reclamation and local partners learned a great deal about physical river conditions in the Methow, Twisp, and Chewuch Rivers as this assessment effort unfolded. They also obtained insight about the assessment process, itself. During this process, Reclamation and local partners needed firm justification to advance candidate projects sooner than the scheduled report completion date. Reclamation responded by providing interim informational products that partners used to focus on areas that needed the most attention to produce the greatest biological benefits possible.

In summary, project partners and Reclamation learned that both river valley segment (tributary) and reach assessments are valuable to identify, develop, and implement instream habitat projects. Reclamation will continue to work with partners to scale, scope, and sequence the preparation of tributary and reach assessments they conduct within acceptable reporting times and available budgets, as guided by local priorities and needs. Evaluating the nearly 80 river miles concurrently allowed for prioritization of protection and restoration projects in terms of which areas provided the most habitat potential. However, taking on a large-scale assessment of nearly 80-miles is resource and budget intensive. Consequently, Reclamation plans to focus future tributary assessments for this program at an individual river-valley-segment scale rather than include multiple segments in a single assessment report. A tributary assessment conducted for an individual river segment is intended to advance local protection and restoration objectives at a scale that is more amenable for all involved parties to execute and manage. Boundaries of the river valley segments should consider whether there are any linkages of physical processes or human features (such as an upstream dam or significant logging) between reaches that need to be considered to fully understand restoration opportunities.

From the findings presented in this assessment, more detailed diagnostic evaluation of localized processes and habitat features can be conducted for the reaches with the greatest prospects for biological benefits based on interests among landowners, project sponsors, and other public and private stakeholders. The product from the reach assessment phase includes a technical implementation strategy of protection and restoration opportunities identified (sequencing), and further information on project habitat benefit, feasibility and sustainability based on refined analysis of habitat features and channel and floodplain connectivity. Project sites can then be prioritized and selected by local entities based on the technical findings and additional criteria developed such as biological benefit, public acceptance, and constructability. Assessments at the project site scale can then be conducted to implement individual projects that have landowner and local support. This nested process focuses objective discussions about project development and selection among local partners so that technical and oversight resources are directed where they will have the greatest benefit, and costly, extraneous efforts that do not conform to local objectives are eliminated or deferred.

6. REFERENCES

Parenthetical Reference	**Bibliographic Citation**
Allan 2004	Allan, J.D. 2004. "Landscapes and riverscapes: The influence of land use on stream ecosystems." Annual Review of Ecology, Evolution, and Systematics, 35: 257-284.
Allen and Star 1982	Allen, T.F.H., and T.B. Starr. 1982. *Hierarchy: Perspectives for Ecological Complexity*. Chicago, IL: University of Chicago Press, 310 pp.
Andonaegui 2000	Andonaegui, C. 2000. "Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48." Washington State Conservation Commission, Final Report, 232 p.
Benda et al. 1998	Benda, L.E., D.J. Miller, T. Dunne, G.H. Reeves, and J.K.Agee. 1998. "Dynamic Landscape Systems," In: Naiman, R.J., Bilby, R.E. (Eds.), River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer, Verlag.
Bisson et al. 2003	Bisson, P.A., B.E. Rieman, C. Luce, P.F Hessburg, D.C. Lee, J.L. Kershner, G.H Reeves, and R.E Gresswell. 2003. "Fire and aquatic ecosystems of the western USA: current knowledge and key questions." Forest ecology and Management 178 (2003) 213-229
Brookes et al. 1996	Brookes, A., S. Knight, and F.D. Shields, Jr. 1996. *River Channel Restoration, Guiding Principles for Sustainable Projects*. Wiley and Sons. p.103.
Dollar et al. 2006	Dollar, E.S.J., C.S. James, K.H. Rogers, and M.C. Thoms. 2006. "A framework for interdisciplinary understanding of rivers as ecosystems." Geomorphology v. 89, p. 147-162.
Frissell et al. 1986	Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. "A hierarchial framework for stream habitat classification: Viewing streams in a watershed context." Environmental Management 10:199-214.

Parenthetical Reference	Bibliographic Citation
Golder 2005	Golder Associates, Inc. 2005. *Methow River channel migration assessment – Channel Migration Zone Components and Channel Migration Hazard Zones*. Prepared for Okanogan County Department of Planning and Development, Okanogan, Washington by Golder Associates, Inc., Redmond, Washington. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Hillman 2006	Hillman, T.W. 2006. *Monitoring Strategy for the Upper Columbia Basin, Second Draft Report*. Prepared by BioAnalysts, Inc, Boise, Idaho; prepared for Upper Columbia Salmon Recovery Board, Bonneville Power Administration, and National Marine Fisheries Service.
ICBTRT 2007	Interior Columbia Basin Technical Recovery Team. July 2007. *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* ["current draft"], 49 pp. Website: http://www.nwfsc.noaa.gov/trt/col_docs/viabilityupdatememo.pdf
KWA et al. 2004	KWA Ecological Sciences, Inc., et al. 2004. *Methow Subbasin Plan.* Prepared for the Northwest Power and Conservation Council.
Montgomery and Buffington 1998	Montgomery, D.R., and J.M. Buffington. 1998. "Channel processes, classification, and response." In: Naiman, R.J., Bilby, R.E. (Eds.), River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer, Verlag.
Montgomery and Bolton 2003	Montgomery, D.R., and S.M. Bolton. 2003. *Hydrogeomorphic variability and river restoration, In Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems*, eds. Wissmar, R.C. and P.A. Bisson, American Fisheries Society, Bethseda, Maryland, pp 39-80.
Molesworth 2007	Molesworth, Jennifer. 2007. Methow Subbasin Liaison, Twisp, Washington. Bureau of Reclamation. Personal communication.
Neuendorf et al. 2005	Neuendorf, K., K.E., Mehl, Jr., J.P. and J.A. Jackson. 2005. *Glossary of Geology, 5th edition*, American Geological Institute, pp 779.
NOAA Fisheries Service 1996	NOAA National Marine Fisheries Service. 1996. "Matrix of Pathways and Indicators" in Making Endangered Species Act determinations of effect for individual or grouped actions at the watershed scale.

Parenthetical Reference	Bibliographic Citation
NOAA Fisheries Service 1999	NOAA National Marine Fisheries Service. 1999. *Endangered and threatened species, listing of several Evolutionarily Significant Units (ESUs) of West Coast steelhead. Final rule. Federal Register, Vol. 63, No. 111, Wednesday, June 19, 1998.*
NOAA Fisheries Service 2004	NOAA National Marine Fisheries Service. 2004. *Endangered Species Act – Section 7 Consultation Biological Opinion: Consultation on Remand for Operation of the Columbia River Power System and 19 Bureau of Reclamation Projects in the Columbia Basin (Revised and reissued to court order, NWF v. NMFS Civ. No. CV 01-640-RE (D. Oregon))*. Portland, Oregon, November 30.
NOAA Fisheries Service 2005	NOAA National Marine Fisheries Service. 2005. Decision Document *Biological Opinion Consultation on Remand for Operation of the Federal Columbia River Power System Including 19 Bureau of Reclamation Projects in the Columbia Basin signed on January 12, 2005*
NOAA Fisheries Service 2007a	NOAA National Marine Fisheries Service. 2007a. *Adaptive Management for ESA-Listed Salmon and Steelhead Recovery: Decision Framework and Monitoring Guidance*: 56 pp. NMFS Northwest Regional and Northwest Fisheris Science Center. Website: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/ESA-Recovery-Plans/upload/Adaptive_Mngmnt.pdf
NOAA Fisheries Service 2007b	NOAA National Marine Fisheries Service. 2007b. “Notice of Adoption of the Upper Columbia River Spring Chinook Salmon and Steelhead Recover Plan.” Federal Register Vol. 72, No. 194, October 9, 2007. Pages 57303-57307. This adopts UCSRB 2007 as the Federal recovery plan. Website: http://www.nwr.noaa.gov/Publications/FR-Notices/2007/upload/72FR57303.pdf . Linked at http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/Upper-Col-Plan.cfm
O’Neill et al. 1986	O’Neill, R.V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen., 1986. “A hierarchical concept of ecosystems.”
Owen and Chiras, 1995	Owen, S., and D. Chiras. 1995. *Natural resource conservation; management for a sustainable future.* Prentice Hall, Englewood Cliffs, New Jersey, 586 p.

Parenthetical Reference	Bibliographic Citation
Poff 1997	Poff, N.L. 1997. "Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology." Journal of the North American Benthological Society, 16: 391-409.
PWI 2003	Pacific Watershed Institute (PWI). 2003. *Twisp Watershed Assessment, Restoration Strategies and Action Plan.*
Reclamation 2008a	Bureau of Reclamation. 2008a. *Methow Subbasin Geomorphic Assessment.* February 2008. Prepared by Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, Colorado in cooperation with Pacific Northwest Regional Office, Boise, Idaho and Methow Field Station, Winthrop, Washington.
Reclamation 2008b	Bureau of Reclamation. 2008b. *Methow Subbasin Geomorphic Assessment, Technical Appendices.* February 2008. Prepared by Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, Colorado in cooperation with Pacific Northwest Regional Office, Boise, Idaho, and Methow Field Station, Winthrop, Washington.
Reclamation 2008c	Bureau of Reclamation. 2008c. *Methow Subbasin Geomorphic Assessment, Map Atlas.* February 2008. Prepared by Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, Colorado.
Richardson 1976	Richardson, D. 1976. "Natural monthly streamflow in the Methow Basin." Washington Department of Ecology, Olympia, Washington. Water Resources Analysis and Information Section, Office Report No. 46, 7 p.
Schellhaus et al. 2001	Schellhaus, R.; Spurbeck, D.; Ohlson, P. (et al.). 2001. "Fire disturbance effects in subalpine forests of North Central Washington." 30 p. Unpublished document. On file with U.S. Department of Agriculture, Forest Service, Methow valley Ranger District, Winthrop, Washington. 98862.
Smith et al. 2000	Smith, J.E., Fisher, B., and Farmer, S. 2000. *Lower Chewuch River fisheries habitat survey, final report.* Prepared for CI Johnson and Associates in cooperation with the Methow Basin Planning Unit by the Pacific Watershed Institute, Winthrop, Washington. December 2000. 58 p.

Parenthetical Reference	Bibliographic Citation
Spence et al. 1996	Spence, B.C.; G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki, December 1996. *An Ecosystem Approach to Salmonid Conservation.* TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, Oregon. Website: http://www.nwr.noaa.gov/Publications/Reference-Documents/ManTech-Report.cfm
UCRTT 2007	Upper Columbia Regional Technical Team. 2007. *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board.* August 2007. Wenatchee, Washington. Appendix H of UCSRB 2007. Website: http://www.ucsrb.com/plan.asp or http://www.ucsrb.com/appendices/UCSRP%20APDX%20H%20Biological%20Strategy.pdf
UCSRB 2007	Upper Columbia Salmon Recovery Board. 2007. *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan.* Wenatchee, Washington. 300 pp. Website: http://www.ucsrb.com/plan.asp
USFS 1998	U.S. Forest Service. 1998. *Upper Methow Watershed Analysis.* Okanogan National Forest, Methow Valley Ranger District, Winthrop, Washington.
USFS 2001	U.S. Forest Service. 2001. *Twisp River Stream Survey Summary.* Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, Washington.
USFS 2002	U.S. Forest Service. 2002. *Chewuch River Stream Survey Summar.* Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, Washington.
USFWS 1998	U.S. Fish and Wildlife Service. 1998. *Endangered and Threatened Wildlife species, Determination of Threatened Status for the Klamath River and Columbia River Delisting of several Evolutionarily Significant Units (ESUs) of West Coast steelhead. Final rule.* Federal Register, Vol. 63, No. 111, Wednesday, June 10, 1998. pp. 31647-31674.

Parenthetical Reference	Bibliographic Citation
Whitlock et al. 2003	Whitlock, C., S.L. Shafer, and J. Marlon. 2003. "The role of climate and vegetation change in shaping past and future fire regimes in the northwest US and the implications for ecosystem management." Forest ecology and management 178 (2003) 5 – 2.

7. ABBREVIATIONS

Abbreviation	Definition
BiOp	biological opinion (under the ***ESA***)
BLM	Bureau of Land Management of the U.S. Department of the Interior
cfs	cubic feet per second, a measure of flow volume
Corps	U.S. Army Corps of Engineers
D_{50}	The median particle-size diameter for a sediment sample, such that 50 percent of the sample is larger than this value.
DS	downstream
ESA	Endangered Species Act
ESUs	evolutionarily significant units
FCRPS	The FCRPS comprises the Bonneville Power, the Army Corps of Engineers, and the Bureau of Reclamation. ACOE and Reclamation operate Federal hydroelectric dams in the Columbia River Basin and BPA markets the power.
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GLO	Government Land Office, the predecessor of the Bureau of Land Management
GPS	global positioning system
HBET	Haub Brothers Enterprises Trust
ICBTRT	Interior Columbia Basin Technical Recovery Team
IFIM	Instream Flow Incremental Methodology
LFA	Limiting Factors Analysis
LiDAR	Light Detection and Ranging (LiDAR) is a remote sensing system used to collect topographic data.
LWD	large woody debris
MSFH	Methow State Fish Hatchery
MSRF	Methow Salmon Recovery Foundation
NAD 1983	The North American Datum of 1983 (NAD 83) is the horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980.
NAVD 1988	The North American Vertical Datum of 1988 (NAVD 88) is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations
NED	National Elevation Data
NMFS	National Marine Fisheries Service of ***NOAA***

Abbreviation	Definition
NOAA	National Oceanic and Atmospheric Administration of the U.S. Department of Commerce
NOAA Fisheries Service	NOAA National Marine Fisheries Service (**aka NMFS**)
PUD	public utility district
PWI	Pacific Watershed Institute
Reclamation	Bureau of Reclamation of the U.S. Department of the Interior
RM	river mile
RTK GPS system	real-time kinematic global positioning equipment utilizes a process where GPS signal corrections are transmitted in real time from a reference receiver at a known location to one or more remote rover receivers.
RTT	regional technical team
SIAM	Sediment Impact Analysis Methods; co-stars of “101 Dalmatians”
TIR	thermal-infrared photography
TRT	Technical Recovery Team
UCRTT	Upper Columbia Regional Technical Team
UCSRB	Upper Columbia Salmon Recovery Board
Upper Columbia Biological Strategy	*A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board* (UCRT 2007)
Upper Columbia Recovery Plan	*Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (UCSRB, 2007)
US	upstream
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service of the Department of Agriculture
USFWS	U.S. Fish and Wildlife Service of the Department of the Interior
USGS	U.S. Geological Survey of the Department of the Interior
VS	unit stream power
VSP	viable salmonid populations
WCRD	Wolf Creek Reclamation District
WDFW	Washington Department of Fish and Wildlife
WNFH	Winthrop National Fish Hatchery,
WRIA	Water Resource Inventory Area
zcAHZ	avulsion hazard zone
zcEHZ	extreme hazard zone

8. GLOSSARY

Some terms in this glossary appear in this *Technical Assessment*, many are in the various appendices.

Term	Definition
adaptive management	A management process that applies the concept of experimentation to design and implementation of natural resource plans and policies.
aggrading stream	A stream that is actively building up its channel or floodplain by being supplied with more bedload than it is capable of transporting.
alluvial fan	A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases; it is steepest near the mouth of the valley where its apex points upstream, and it slopes gently and convexly outward with a gradually decreasing gradient (Neuendorf et al., 2005).
alluvium	A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream, as a sorted or semi-sorted sediment on the river bed and floodplain (Neuendorf et al., 2005).
anadromous (fish)	A fish, such as the Pacific salmon, that spawns and spends its early life in freshwater but moves into the ocean where it attains sexual maturity and spends most of its life span (Owen and Chiras, 1995).
bar (in a river channel)	Accumulations of bed load (sand, gravel, and cobble) that are deposited along or adjacent to a river as flow velocity decreases. If the sediment is reworked frequently, the deposits will remain free of vegetation. If the surface of the bar becomes higher than the largest flows, vegetation stabilizes the surface making further movement of the sediment in the bar difficult.
bedload	The sediment that is transported intermittently along the bed of the river channel by creeping, rolling, sliding, or bouncing along the bed. Typically includes sizes of sediment ranging between coarse sand to boulders (the larger or heavier sediment).
bed-material	Sediment that is preserved along the channel bottom and in adjacent bars; it may originally have been material in the suspended load or in the bed load.

Term	Definition
bedrock	A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material (Neuendorf et al., 2005). The bedrock is generally resistant to fluvial erosion over a span of several decades, but may erode over longer time periods.
canopy cover (of a stream)	Vegetation projecting over a stream, including crown cover (generally more than 1 meter (3.3 feet) above the water surface) and overhang cover (less than 1 meter (.3 feet) above the water).
Category 2	Category 2 watersheds support important aquatic resources, and are strongholds for one or more listed fish species. Compared to Category 1 watersheds, Category 2 watersheds have a higher level of fragmentation resulting from habitat disturbance or loss. These watersheds have a substantial number of subwatersheds where native populations have been lost or are at risk for a variety of reasons. Connectivity among subwatersheds may still exist or could be restored within the watershed so that it is possible to maintain or rehabilitate life history patterns and dispersal. Restoring and protecting ecosystem functions and connectivity within these watersheds are priorities. Adapted from UCRTT (2007).
centerline	A line drawn along the center of the active or unvegetated channel; visually placed to be at the center of all channel paths.
channel morphology	The physical dimension, shape, form, pattern, profile, and structure of a stream channel.
channel planform	Characteristics of the river channel that determine its two-dimensional pattern as viewed on the ground surface, aerial photograph, or map.
channel remnant (wet)	Same as an ***old channel*** (wet) for channels on the ***USGS*** topographic maps from the middle 1980s. Mapped as a channel remnant (wet), because this is how they appear on the topographic maps.
channel sinuosity	The ratio of length of the channel or thalweg to down-valley distance. Channel with a sinuosity value of 1.5 or more are typically referenced as meandering channels (Neuendorf et al., 2005).
channel stability	The ability of a stream, over time and under the present climatic conditions, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern, and profile without either aggrading or degrading.
channelization	The straightening and deepening of a stream channel to permit the water to move faster, to reduce flooding, or to drain wetlands.

Term	Definition
core habitat	Habitat that encompasses spawning and rearing habitat (resident populations), with the addition of foraging, migrating, and overwintering habitat if the population includes migratory fish. Core habitat is defined as habitat that contains, or if restored would contain, all of the essential physical elements to provide for the security of allow for the full expression of life history forms of one or more local populations of salmonids.
Cretaceous	The final period of the Mesozoic era that covered the span of time between 135 and 65 million years ago.
depositional areas (stream)	Local zones within a stream where the energy of flowing water is reduced and sediment settles out, accumulating on the streambed.
Detroit riprap	Consists of car bodies along a river bank historically placed in many river systems to armor the bank in an attempt to limit future erosion.
discharge (stream)	With reference to stream flow, the quantity of water that passes a given point in a measured unit of time, such as cubic meters per second or, often, cubic feet per second (cfs).
diversity	All the genetic and phenotypic (life history traits, behavior, and morphology) variation within a population.
ecosystem	A unit in ecology consisting of the environment with its living elements, plus the non-living factors, which exist in and affect it (Neuendorf et al., 2005).
embeddedness	The degree to which large particles (boulders, gravel) are surrounded or covered by fine sediment, usually measured in classes according to percentage covered.
fine sediment (fines)	Sediment with particle sizes of 2.0 mm (0.08 inch) or less, including medium to fine sand, silt, and clay.
floodplain	The surface or strip of relatively smooth land adjacent to a river channel constructed by the present river in its existing regimen and covered with water when the river overflows its banks. It is built on alluvium, carried by the river during floods and deposited in the sluggish water beyond the influence of the swiftest current. A river has one floodplain and may have one or more terraces representing abandoned floodplains (Neuendorf et al., 2005).
flow regime	The quantity, frequency, and seasonal nature of water flow.
fluvial bull trout	Bull trout that migrate from tributary streams to larger rivers to mature (one of three bull trout life histories). Fluvial bull trout migrate to tributaries to spawn.
fluviolacustrine	Pertaining to sedimentation, partly in lake water and partly in streams, and to sediment deposited in alternating and overlapping lacustrine and fluvial conditions (Neuendorf et al., 2005).

Term	Definition
Fraser glaciation	Equivalent to the Late Wisconsin Glaciation from about 30,000 to 9,500 years B.P.
geometric mean	A measure of central tendency that is applied to multiplicative processes (e.g., population growth). It is calculated as the antilogarithm of the arithmetic mean of the logarithms of the data.
geomorphic province	A geomorphic province is comprised of similar land forms that exhibit comparable hydrologic, erosional, and tectonic processes (Montgomery and Bolton, 2003); any large area or region considered as a whole, all parts of which are characterized by similar features or by a history differing significantly from that of adjacent areas (Neuendorf et al., 2005); also referred to as a basin. An example would be the Upper Columbia Basin.
geomorphic reach	A geomorphic reach, represents an area containing the active channel and its floodplain bounded by vertical and/or lateral geologic controls, such as alluvial fans or bedrock outcrops, and frequently separated from other reaches by abrupt changes in channel slope and valley confinement. Within a geomorphic reach, similar fluvial processes govern channel planform and geometry through driving variables of flow and sediment. A geomorphic reach is comprised of a relatively consistent floodplain type and degree of valley confinement. Geomorphic reaches may vary in length from 100 meters in small, headwater streams to several miles in larger systems (Frissell et al.., 1986). An example in this assessment would be geomorphic reach M10 (river miles 55 to 65) on the Upper Methow River valley segment, locally known as the Big Valley reach.
geomorphology	The study of the classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes caused by the actions of flowing water.
GIS	Geographical information system. An organized collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.
glacial deposits (undifferentiated)	Consists primarily of glaciofluvial deposits of sand, gravel, cobbles and boulders deposited by retreat and melting of the Okanogan Lobe of the Cordilleran Ice Sheet and most likely glacial deposits from alpine glacial advances post-dating and/or contemporaneous with the retreat of the Okanogan Ice Sheet. Unit also includes glacial outburst flood, lacustrine, delta, till and moraine deposits. The materials are generally unconsolidated and susceptible to fluvial erosion.
glaciofluvial	Pertaining to the melt water streams flowing from wasting glacier ice and especially to the deposits produced by such streams; relating to the combined actions of glaciers and streams (Neuendorf et al., 2005).

Term	Definition
glaciolacustrine	Pertaining to, derived from, or deposited in glacial lakes, especially a set of deposits and land forms composed of suspended material brought by melt water streams flowing into lakes bordering the glacier (Neuendorf et al., 2005)
habitat action	Proposed restoration or protection strategy to improve the potential for sustainable habitat upon which endangered species act (ESA) listed salmonids depend on. Examples of habitat actions include the removal or alteration of project features to restore floodplain connectivity to the channel, reconnection of historic side channels, placement of large woody debris, reforestation of the low surface, or implementation of management techniques.
habitat connectivity (stream)	Suitable stream conditions that allow fish and other aquatic organisms to access habitat areas needed to fulfill all life stages.
habitat unit	A habitat unit is defined as a morphologically distinct area within a geomorphic reach comprising floodplain and channel areas; typically less than several channel widths in length (Montgomery and Bolton, 2003). Individual habitat units may include pools, riffles, bars, steps, cascades, rapids, floodplain features, and transitional zones characterized by relatively homogeneous substrate, water depth, and cross-sectional averaged velocities.
headwaters	The source of a river. Headwaters are typically the upland areas where there are small swales, creeks, and streams that are the origin of most rivers. These small streams join together to form larger streams and rivers or run directly into larger streams and lakes.
Holocene	The geologic time interval between about 10,000 years ago and the present.
human features	Man-made features that are constructed in the river and/or floodplain areas (e.g., levees, bridges, riprap).
hydrologic response	The response of a watershed to precipitation; usually refers to stream flow resulting from precipitation.
hyporheic zone	In streams, the region adjacent to and below the active channel where water movement is primarily in the downstream direction and the interstitial water is exchanged with the water in the main channel. The boundary of this zone is where 10% of the water has recently been in the stream (Neuendorf et al., 2005).
ICBTRT	Interior Columbia Basin Technical Recovery Team. Expert panel formed by ***NMFS*** (NOAA Fisheries) to work with local interests and experts and ensure that ICBTRT recommendations for delisting criteria are based on the most current and accurate technical information available.

Term	Definition
igneous rocks	Rocks that form from the cooling and solidification of molten or partly molten material (magma) either below the surface as an intrusive (plutonic) rock or on the surface as an extrusive (volcanic) rock.
incipient motion	The initiation of mobilizing a single sediment particle on the stream bed once threshold conditions are met.
incision	The process where by a downward-eroding stream deepens its channel or produces a relatively narrow, steep-walled valley (Neuendorf et al., 2005).
intermediate surface	Comprised of glaciofluvial deposits that form a series of terrace risers and terrace treads that are elevated between 3 to 10 meters above normal water surface in the active channel. These surfaces are intermittent throughout the major drainages, but were only locally mapped where they have an influence on the morphology of the rivers. This surface is rarely flooded by the river under the current climatic regime. The intermediate surface is considered stable on a decadal time scale. These materials are unconsolidated and susceptible to fluvial erosion.
kame terrace	A terrace-like ridge consisting of stratified sand and gravel formed by a glaciofluvial or glaciolacustrine deposit between a melting glacier or a stagnant ice lobe and a higher valley wall or lateral moraine, and left standing after the disappearance of the ice (Neuendorf et al., 2005).
kettle	A depression in glacial drift formed by the melting of a detached block of stagnant ice that was buried in the drift.
landslide	Consists of a heterogeneous mixture of silt, sand, gravel, cobbles and boulders. Occur predominantly along glacial terrace deposits and valley walls. Mass wasting along the active river channels typically result in a "self-armoring" bank in that the finer materials are transported by the fluvial system and the larger materials are retained along the toe of the slope protecting the slope except during flood events.
large woody debris (LWD)	Large downed trees that are transported by the river during high flows and are often deposited on gravel bars or at the heads of side channels as flow velocity decreases. The trees can be downed through river erosion, wind, fire, or human-induced activities. Generally refers to the woody material in the river channel and floodplain whose smallest diameter is at least 12 in and has a length greater than 35 ft in eastern Cascade streams.
levee	A natural or artificial embankment that is built along a river channel margin; often a man-made structure constructed to protect an area from flooding or confine water to a channel. Also referred to as a dike.

Term	Definition
limiting factor	Alternate definition: Any factor in the environment of an organism, such as radiation, excessive heat, floods, drought, disease, or lack of micronutrients, that tends to reduce the population of that organism (Owen and Chiras, 1995).
low surface	Generally represents an area encompassing historic channel migration and floodplain. Consists of a mixture of reworked glacial deposits and fluviolacustrine deposits comprised of silt- to boulder-size material, but is predominantly sand, gravel, and cobbles. These deposits occur along stream channels and their active floodplains. These materials are unconsolidated and highly susceptible to fluvial erosion.
low-flow channel	A channel that carries flow during base flow conditions.
mass wasting	General term for the dislodgement and downslope transport of soil and rock under the influence of gravitational stress (mass movement). Often referred to as shallow-rapid landslide, deep-seated failure, or debris flow.
Mesozoic	An era of geologic time from about 225 to about 65 million years ago that includes the Triassic, Jurassic and Cretaceous periods.
metamorphic rocks	Rocks derived from pre-existing rocks (sedimentary or igneous) in response to marked changes in temperature, pressure, shearing stress and chemical environment.
moraine	A mound or ridge of unstratified glacial drift deposited by direct action of glacial ice.
nonnative species	Species not indigenous to an area, such as brook trout in the western United States. Sometimes referred to as an exotic species.
Oligocene	An epoch of the Tertiary period than began about 34 million years ago and extended to about 23 million years ago.
orthorectified photograph	An aerial photograph that has been corrected for the geometries and tilt angles of the camera when the image was taken and for topographic relief using a digital elevation model, flight information, and surveyed control points on the ground.
overbank deposits	Fine sediment (medium to fine sand, silt, and clay) that is deposited outside of the channel on the floodplain or terrace by floods.
overflow channel	A channel that is expressed by no or little vegetation through a vegetated area. There is no evidence for water at low stream discharges. The channel appears to have carried water recently during flood event. The upstream and/or downstream ends of the overflow channel usually connect to the main channel.
peak flow	Greatest stream discharge recorded over a specified period of time, usually a year, but often a season.

Term	Definition
planform	The shape of a feature, such as a channel alignment, as seen in two dimensions, horizontally, as on an aerial photograph or map.
Pleistocene	The geologic time interval between 1.6 million years ago and 10,000 years ago.
project area	A project area is a distinct geographic location with potential implementation opportunities for habitat restoration and protection actions. Project areas are at a comparable level of organization as a habitat unit within a geomorphic reach and typically bounded by geomorphic features (e.g. river channel, floodplain, or terrace).
project feature	A project feature is an individual structure or component of an active floodplain of a project area; examples include levees, roadway embankments, bridges, or culverts.
Quaternary	The geologic time interval between 1.6 million years ago and the present. It includes both the Pleistocene and the Holocene.
redd	A nest constructed by salmonid species in the streambed where eggs are deposited and fertilized. Redds can usually be distinguished in the streambed by a cleared depression and associated mound of gravel directly downstream.
riparian area	An area with distinctive soils and vegetation community/composition adjacent to a stream, wetland, or other body of water.
riprap	Large angular rocks that are placed along a river bank to prevent or slow erosion.
salmonid	Fish of the family *salmonidae*, including trout, salmon, chars, grayling, and whitefish. In general usage, the term most often refers to salmon, trout, and chars.
scour	Concentrated erosive action by flowing water, as on the outside curve of a bend in a stream; also, a place in a streambed swept clear by a swift current.
side channel	A channel that is not part of the main channel, but appears to have water during low-flow conditions and has evidence for recent higher flow (e.g., may include unvegetated areas (bars) adjacent to the channel). At least the upstream end of the channel connects to, or nearly connects to, the main channel. The downstream end may connect to the main channel or to an overflow channel. Can also be referred to as a secondary channel.
slough	A sluggish channel of water, such as a side channel of a river, in which water flows slowly through, swampy ground, such as along the Columbia River, or a section of an abandoned river channel, containing stagnant water and occurring in a floodplain (Neuendorf et al., 2005).

Term	Definition
smolt	A juvenile salmon or steelhead migrating to the ocean and undergoing physiological and behavioral changes to adapt its body from a freshwater environment to a saltwater environment.
spawning and rearing habitat	Stream reaches and the associated watershed areas that provide all habitat components necessary for adult spawning and juvenile rearing for a local salmonid population. Spawning and rearing habitat generally supports multiple year classes of juveniles of resident and migratory fish, and may also support subadults and adults from local populations.
stade	A substage of a glacial stage marked by a glacial readvance.
subbasin	A subbasin represents the drainage area upslope of any point along a channel network (Montgomery and Bolton, 2003). Downstream boundaries of subbasins are typically defined in this assessment at the location of a confluence between a tributary and mainstem channel. An example would be the Twisp River Subbasin.
suspended load	The part of the total stream load that is carried for a considerable period of time in suspension, free from contact with the streambed, it consists mainly of silt, clay, and fine sand (Neuendorf et al., 2005).
suspended sediment	Solids, either organic or inorganic, found in the water column of a stream or lake. Sources of suspended sediment may be either human induced, natural, or both.
terrace	A relatively stable, planar surface formed when the river abandons the floodplain that it had previously deposited. It often parallels the river channel, but is high enough above the channel that it rarely, if ever, is covered by water and sediment. The deposits underlying the terrace surface are alluvial, either channel or overbank deposits, or both. Because a terrace represents a former floodplain, it can be used to interpret the history of the river.
terrane	A crustal block or fragment that preserves a distinctive geologic history that is different from the surrounding areas and that is usually bounded by faults.
Tertiary	The first period of the Cenozoic era thought to have covered the span of time between about 65 million and 2 million years ago. It is divided into five epochs: the Paleocene, Eocene, Oligocene, Miocene and Pliocene.
tributary	A stream feeding, joining, or flowing into a larger stream or lake (Neuendorf et al., 2005).

Term	Definition
valley segment	A valley segment is a section of river within a subbasin. Within a valley segment, multiple floodplain types exist and may range between wide, highly complex floodplains with frequently accessed side channels to narrow and minimally complex floodplains with no side channels. Typical scales of a valley segment are on the order of a few to tens of miles in longitudinal length. An example in this assessment would be the Middle and Upper Methow River valley segments.
watershed	The area of land from which rainfall (and/or snow melt) drains into a stream or other water body. Watersheds are also sometimes referred to as drainage basins. Ridges of higher ground form the boundaries between watersheds. At these boundaries, rain falling on one side flows toward the low point of one watershed, while rain falling on the other side of the boundary flows toward the low point of a different watershed.

Methow Subbasin Geomorphic Assessment
Okanogan County, Washington
Technical Appendices

Bureau of Reclamation
Technical Service Center, Denver, CO
Pacific Northwest Regional Office, Boise, ID
Methow Field Station, Winthrop, WA

February 2008

MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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

Appendix	Title
A	Complexity Habitat Protection and Restoration Opportunities
B	Technical Ranking of Geomorphic Reaches
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E	Conceptual Model of Physical Processes Important to Salmonid Habitat Formation
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S	All References

APPENDIX A –

COMPLEXITY HABITAT PROTECTION AND RESTORATION OPPORTUNITIES

This appendix documents objectives, strategies, and opportunities for habitat protection and restoration for the 80 river miles of the Methow Subbasin addressed in this geomorphic assessment. Sections 1, 2 and 3 provide general objectives, strategies, and spatial approaches to complexity habitat protection and restoration based on available habitat recovery guideline documents and this geomorphic assessment. Section 4 provides an overall restoration concept for each of the 23 geomorphic reaches identified in this assessment, with supporting text in Attachment 1. Section 5 provides a list of 41 potential floodplain protection areas (1,446 acres) where no human features were identified, and a list of 91 potential floodplain restoration areas (3,287 acres) where human features are present that impact channel and floodplain processes. These 132 areas represent individual floodplain areas located within the 23 reaches. Attachment 2 contains a table of initial concepts for each of the floodplain restoration areas that would improve availability and quality of complexity habitat.

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1. HABITAT PROTECTION AND RESTORATION OBJECTIVES

This section describes habitat protection and restoration objectives for the Upper Columbia Subbasins as documented in the *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (UCSRB, 2007) (for short, the *Upper Columbia Recovery Plan)*, the Upper Columbia Biological Strategy (UCRTR, 2006), VSP guidelines (ICBTRT, 2005, McElhany et al., 2000) and this geomorphic assessment in terms of components specific to habitat complexity.

Human activities acting in concert with “limiting factors” —natural occurrences such as drought, floods, landslides, fires, debris flows, and ocean cycles — have adversely affected the abundance, productivity, spatial structure, and diversity of Upper Columbia spring Chinook salmon, steelhead and bull trout populations, resulting in these species being listed under the ESA. The Upper Columbia spring Chinook salmon were listed as endangered on March 24, 1999), the Upper Columbia steelhead were listed as endangered on August 18, 1997 and reclassified as threatened on January 5, 2006, and bull trout were listed as threatened on June 10, 1998. In the Methow Subbasin spring Chinook salmon and steelhead populations are currently not viable and have a greater than 25% chance of extinction in 100 years (UCSRB, 2007).

In the *Upper Columbia Recovery Plan* (UCSRB, 2007), the terms protection and restoration are utilized to describe habitat objectives and strategies for ESA listed species in the Upper Columbia River, including the Methow Subbasin. Habitat restoration strategies are defined as a process that involves management decisions and actions that enhance the rate of recovery of habitat conditions (referenced in UCSRB, 2007 as after Davis et al. 26 1984).

1.1 UPPER COLUMBIA RECOVERY PLAN

The *Upper Columbia Recovery Plan* (UCSRB, 2007) considered two forms of protection: no-net-impact and passive restoration, defined as follows:

> “No-net impact protection means that (1) activities that can harm stream and riparian structure and function will not occur, or (2) activities that harm stream and riparian habitat are mitigated by restoring and protecting an “equal or greater” amount of habitat. This type of protection is generally applied to areas where increased development is likely to occur. The second type of protection, passive restoration, addresses areas that are already protected under state and federal ownership. This also includes landowners that voluntarily protect stream and riparian conditions on their properties. Under this form of protection, habitat conditions improve as management actions are designed to maintain or improve habitat forming processes.”

The *Upper Columbia Recovery Plan* states that the goal of habitat restoration activities is "…to reestablish the ability of an ecosystem to maintain its function and organization without continued human intervention." The plan does not mandate or even suggest returning to the historic condition (often identified as some arbitrary prior state) and said, "Restoration to a previous condition often is impossible."

Specific habitat restoration objectives by Subbasin are provided in the *Upper Columbia Recovery Plan* and are noted as being consistent with local watershed plans, the *Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board* (UCRTT, 2007) (for short, the *Upper Columbia Biological Strategy)*, Habitat Conservation Plans, and re-licensing agreements. The *Upper Columbia Recovery Plan* notes that habitat objectives are intended to accomplish reduction of threats to the habitat needs of the listed species, and may be modified in response to monitoring, research, and adaptive management.

As discussed in the next two sections, the *Upper Columbia Recovery Plan* habitat objectives are structured into short-term and long-term timeframes, and alternatives are provided for situations when land use or other constraints make full restoration of processes impossible.

1.1.1 SHORT-TERM OBJECTIVES

Eleven short-term habitat objectives have been identified by the *Upper Columbia Recovery Plan* (2007):

- Protect existing areas where high ecological integrity and natural ecosystem processes persist.
- Restore connectivity (access) throughout the historic range where feasible and practical for each listed species.
- Where appropriate, establish, restore, and protect stream flows (within the natural hydrologic regime and existing water rights) suitable for spawning, rearing, and migration (based on current research and modeling).
- Protect and restore water quality where feasible and practical within natural constraints.
- Increase habitat diversity in the short term by adding instream structures (such as LWD [large woody debris], rocks, etc.) where appropriate. These structures can be used while other actions are implemented to restore proper channel and riparian function (that is, natural watershed processes).
- Protect and restore riparian habitat along spawning and rearing streams and identify long-term opportunities for riparian habitat enhancement.

- Protect and restore floodplain function and reconnection, off-channel habitat, and channel migration processes where appropriate and identify long-term opportunities for enhancing these conditions.
- Restore natural sediment delivery processes by improving road network, restoring natural floodplain connectivity, riparian health, natural bank erosion, and wood recruitment.
- Replace nutrients in tributaries that formerly were provided by salmon returning from the sea.
- Reduce the abundance and distribution of exotic species that compete and interbreed with or prey on listed species in spawning, rearing, and migration areas.
- Protect and restore habitat that will maintain connectivity between populations within the mainstem Methow River and the upper Twisp River, upper Chewuch River, Lost River, Early Winters Creek, Goat Creek, Wolf Creek, and Beaver Creek.

1.1.2 LONG-TERM OBJECTIVES

Eight long-term habitat objectives have been identified by the *Upper Columbia Recovery Plan* (2007):

- Protect areas with high ecological integrity and natural ecosystem processes.
- Maintain connectivity through the range of the listed species where feasible and practical.
- Maintain suitable stream flows (within natural hydrologic regimes and existing water rights) for spawning, rearing, and migration.
- Protect and restore water quality where feasible and practical within natural constraints.
- Protect and restore off-channel and riparian habitat.
- Increase habitat diversity by rebuilding, maintaining, and adding instream structures (such as LWD, rocks, etc.) where long-term channel form and function efforts are not feasible.
- Reduce sediment recruitment where feasible and practical within natural constraints.
- Reduce the abundance and distribution of exotic species that compete and interbreed with or prey on listed species in spawning, rearing, and migration areas.

1.2 VIABLE SALMONID POPULATION GUIDELINES

Recovery of the listed salmonid species to viable populations requires reducing or eliminating threats to the long-term persistence of fish populations, maintaining widely distributed and connected fish populations across diverse habitats of their native ranges, and preserving genetic diversity and life-history characteristics. To achieve recovery there are four sectors (harvest, hatchery, hydropower and habitat) that must be addressed. Implementation of actions within a single sector (such as habitat) will not achieve recovery. Successful recovery of listed species means that populations have met certain measurable criteria (abundance, productivity, spatial structure, and diversity) known as the "viable salmonid population" (VSP) parameters (ICBTRT, 2005; UCSRB, 2007).

As explained in the *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* ["current draft"] (ICBTRT, 2007), the risk of extinction at the population level can be directly related to the combination of abundance and productivity of a particular population. The VSP guidelines for abundance has several recommendations for a viable population (McElhany et al., 2000):

- Be large enough to have a high probability of surviving environmental variation observed in the past and expected in the future;
- Be resilient to environmental and anthropogenic disturbances; maintain genetic diversity; and support/provide ecosystem functions;
- Demonstrate sufficient productivity to support a net replacement of 1:1 or higher at abundance levels established as long-term targets;
- Demonstrate productivity rates at relatively low numbers of spawners that, on the average, are sufficiently greater than 1.0 to allow the population to rapidly return to abundance target levels after perturbations. (ICBTRT, 2007, p. 22)

McElhany et al. (2000) provided a number of additional guidelines for the spatial structure and diversity of viable salmonid populations that consider these principles. Specifically, their guidelines suggest that for spatial structure:

- Habitat patches should not be destroyed faster than they are naturally created;
- Natural rates of straying among subpopulations should not be substantially increased or decreased by human actions;
- Some habitat patches should be maintained that appear to be suitable or marginally suitable, but currently contain no fish;
- Source populations should be maintained. (ICBTRT, 2007, p. 46)

For diversity, they indicate that the important principles include:

- Human-caused factors such as habitat changes, harvest pressures, artificial propagation, and exotic species introduction should not substantially alter variation in traits such as run timing, age structure, size, fecundity, morphology, behavior, and molecular genetic characteristics;
- Natural processes of dispersal should be maintained;

- Natural processes that cause ecological variation should be maintained. (ICBTRT, 2007, p. 46-47)

1.3 BIOLOGICAL STRATEGY

The *Upper Columbia Biological Strategy* (UCRTR, 2006) provides general habitat restoration concepts for four biological (valley) segments discussed in this Reclamation geomorphic assessment: (1) Middle Methow, (2) Upper Methow, (3) Chewuch River, and (4) Twisp River. These restoration concepts were based on available information and professional judgment of local biologists. Recommended habitat actions (in priority) from the *Upper Columbia Biological Strategy* are shown in the following four tables for all four of these valley segments (Table A-1, Table A-2, Table A-3, and Table A-4). Tier 1 are the highest priority actions recommended. The four tables include restoration of not only habitat complexity opportunities within and adjacent to the 80-mile assessment area discussed in this Reclamation report, but also water quality and quantity actions.

Table A-1. Middle Methow Notes from Biological Strategy.

Reach Description
- mainstem Methow from Texas Creek confluence upstream to Chewuch River Confluence
- Native species: Spring and summer Chinook salmon, steelhead, bull trout.
- Drainage area: 15,600 acres

Status
- Category 2, major spawning area for steelhead and spring Chinook (based on historic intrinsic potential)
- The mainstem Methow River is an important migration corridor for spring Chinook salmon, steelhead and bull trout. Spawning and rearing habitat for summer Chinook salmon and steelhead.

Significant Subwatersheds:

Tributaries within this reach: Alder Creek, Bear Creek, Beaver Creek and Benson Creek (see separate assessment and strategy summary for Beaver Creek)

Factors Affecting Habitat Conditions
- Residential development is affecting riparian and floodplain condition.
- The Methow Valley Irrigation District fish screens and diversion structures do not meet state and federal standards.
- Low flows in late summer and winter may affect juvenile survival.
- Structures in tributaries are passage barriers for adult and juvenile salmonids.
- The mainstem Methow is on the state 303(d) list for temperatures.

Level of Certainty / Data Gaps
- Habitat in the Middle Mainstem Methow River and lower reaches of its tributaries has not been surveyed. Some recommendations are based on professional judgment. Habitat in upper reaches of the tributaries has been assessed by USFS.
- The effects of irrigation water withdrawal on stream flows are not fully understood.
- Passage barriers have been inventoried, but not fully assessed.

Habitat Action Recommendations

Tier 1

Protect functioning floodplain, riparian habitat, and side channels in the middle Methow River.

Floodplain and Side Channel Restoration
- Restore access by the mainstem channel to floodplains and side channels disconnected by dikes.

Obstructions
- Correct and maintain the MVID screens and diversion.

Tier 2

Large Woody Debris Restoration
- Increase recruitment and retention of LWD within the mainstem Methow River.

Tier 3

Ecological Interaction
- Reduce or eliminate brook trout

Table A-2. Upper Methow River Notes from Biological Strategy.

Reach Description — confluence with Chewuch River upstream to headwaters
Native species: spring Chinook salmon, steelhead, bull trout.
Drainage area: 322,385 acres
Status: Category 2; Major spawning area for spring Chinook and steelhead, core area for bull trout.
Significant Subwatersheds
Upper Methow, Mainstem West Fork Methow, Upper Goat Creek, Lower Goat Creek, Little Boulder Creek, Hancock Creek
Tributaries within this reach Brush Creek, Trout Creek, Rattlesnake Creek, Robinson Creek, Gate Creek, Goat Creek, Little Boulder Creek, Fawn Creek, Hancock Creek, Little Falls Creek, and Wolf Creek.
Factors affecting habitat conditions:

- The mainstem Methow River between RM 59 and 74 goes dry in low flow years.
- All reaches of the mainstem upper Methow River have LWD levels below USFS standards. Timber harvest and stream cleaning have reduced LWD recruitment in Goat Creek.
- Several small dikes cut off important side channel habitats.

Residential construction in flood prone areas has resulted in clearing of riparian habitat.
Level of Certainty / Data Gaps
Watershed and stream analyses by USFS and USGS provide high level of certainty on habitat conditions. The effect of surface water and groundwater withdrawal on the dewatered reach is not fully understood. The role of riparian condition and channel morphology on stream flows in this reach is not understood.

- The contribution of tributaries and mainstem bank erosion to sediment levels in the mainstem Methow River is not understood.
- There is concern about the effect of snowmobiles in the main channel Methow River on habitat and water quality.

Habitat Actions Recommendations
Tier 1
Protect remaining floodplain and riparian habitat.
Water Quantity Restoration (*Tier 2 in Goat Creek*)

- Restore drained wetlands
- See floodplain restoration
- Increase stream flows

Floodplain Restoration *(in combination with side channel connection, riparian restoration, and LWD recruitment/retention).*

- Restore natural channel form and function (*remove constrictions and constraints within the channel migration zone*)

Habitat Diversity
Goat Creek strategies are combined and rated as Tier 1. If each strategy is implemented individually then they will have a lower biological benefit.

- Reactivate historic channel to split flow on alluvial fan and improve function
- Add LWD complexes to channel to match natural wood loads in functioning reaches of Goat Creek
- Riparian Restoration, 2-3 miles replanting and restoration
- LWD enhancement
- Re-establish alluvial fan function - bridge reconstruction

Tier 2
Ecological Interaction

- **Add nutrients using hatchery carcasses and/or carcass analogs**

(continued on next page)
Upper Methow Notes (continued)

Sediment
- Reduce stream bank erosion on mainstem Methow River from Goat Creek to Mazama.
- Roads analysis and reconstruction / obliterations on USFS lands in Upper Goat Creek
- Other tributaries that supply unnatural levels of sediment to the mainstem spawning reaches

Riparian Restoration
- Wolf and Hancock Creeks
- LWD restoration

Tier 3

Habitat Diversity
- Instream structures in Hancock Creek
- Off-channel livestock water facility in Hancock Creek

Obstructions
- Diversion in Goat Creek

Tier 4

Riparian Restoration
- Manage dispersed recreation use in riparian areas throughout the watershed.

Table A-3. Twisp River Notes from Biological Strategy.

Reach Description — from confluence with Methow River upstream to headwaters
Native species: Spring Chinook salmon, steelhead, bull trout, Westslope cutthroat trout.
Drainage area: 157,000 acres
Status Category 2, Major spawning area for spring Chinook and steelhead and a core area for bull trout.

- Designated as a key watershed in NWFP.

Significant Subwatersheds
Middle Twisp, Lower Twisp, North Creek, Buttermilk Creek
Factors Affecting Habitat Conditions:

- Low instream flows in the lower Twisp River affect several species at several life history stages.
- The Twisp River (from Buttermilk Creek to the mouth) has been cut off from its floodplain and side channels through dikes and riprap in places, resulting in a highly simplified channel.
- In the lower Twisp River (RM 0.0 – 16.5) LWD levels and recruitment potential are well below amounts expected.
- The MVID East Canal diversion on the Twisp River at RM 3.9 is a rock levee dam that must be pushed up each year, disturbing salmonid rearing and spawning habitat.
- The lower Twisp River is listed on the Washington State 303(d) list for inadequate instream flow and for temperature exceedence.
- Beaver activity is very limited in the lower Twisp River where the large cottonwood galleries and low gradients would once have supported beaver colonies.
- The road in Little Bridge Creek affects stream channel function.

Level of Certainty / Data Gaps:

- Field habitat analyses have been conducted on public lands, allowing a high confidence in assessment.
- Field analyses are incomplete on private lands, yet reviews of aerial photographs in combination with field reviews have allowed strong inferences on habitat needs.
- Some uncertainty exists on relation of instream flows and fish habitat.
- Increasing recreational demand in key salmonid production areas in the Upper Twisp River is a concern.

Habitat Action Recommendations
Tier 1
Protect remaining floodplain and riparian habitat.
Water Quantity (Lower Twisp)

- Improve irrigation efficiency and reduce withdrawals.

Floodplain Restoration

- Remove or modify levees and dike were appropriate
- Replace undersized culverts to restore alluvial fan function and delivery of LWD and gravel to Twisp River.
- Side channel reconnection and restoration
- Reestablish beaver populations (some additional benefits to water quantity and winter temperatures).

Sediment

- Road maintenance, road reconstruction, heavy maintenance and obliteration where appropriate

Riparian Restoration

- Fence wetlands and riparian areas on USFS to allow recovery from livestock grazing and beaver recolonization.
- Increase LWD recruitment and retention in the lower 11 miles of Twisp River.

(continued on next page)
Twisp River Notes (continued)

Tier 2

Ecological Interaction

- Add nutrients using hatchery carcasses and/or carcass analogs

Tier 3

Obstructions

- Improve passage (*any mainstem Twisp passage impediments would be Tier 1*)
- Remove War Creek Weirs
- Replace any culverts that impede anadromous fish passage (tributaries)

Riparian Restoration

- Manage recreation site impacts to floodplain (North Creek/Gilbert area, Reynolds Creek)

Ecological Interaction

- Reduce or eliminate brook trout

Tier 4

Riparian Restoration

- Continue to implement Respect the River program

Table A-4 Chewuch River Notes from Biological Strategy.

Reach Description — from confluence with Methow River upstream to headwaters
Native species: Spring Chinook salmon, steelhead, bull trout, Westslope cutthroat trout.
Drainage area: 340,000 acres
Status: Category 2; Designated as a Key Watershed in NWFP.
Significant Subwatersheds — Perrygin Creek, Lake Creek, Lower Chewuch River
Factors Affecting Habitat Condition:

- Channel clearing and LWD removal reduced channel complexity in the Chewuch River from RM 0 to 20.
- Road placement and bank hardening have isolated sections of the main channel from its floodplain and side channels in a few places from the mouth to Boulder Creek.
- Skid roads in riparian areas upstream of Boulder Creek increase dispersed recreation use impacts to the stream.
- Low flows in late summer through winter reduce quantity of rearing habitat in the lower Chewuch River.
- High water temperatures in the lower river may at times cause a migration barrier.
- Livestock grazing may have potential impacts on riparian areas of mainstem Chewuch and tributaries.
- High road densities in Cub, Eightmile, and Boulder creeks combined with highly erosive soils create sediment and bank erosion problems.

Level of Certainty / Data Gaps:

- Field habitat analyses have been conducted on both private and public lands, allowing a high confidence in assessment.
- The relation of instream flows and fish habitat in the lower Chewuch River are not fully understood, yet some studies provide a strong level of inference.
- Bull trout use of the Chewuch is not fully understood.

Habitat Action Recommendations:

Tier 1

Protect existing intact and functioning habitats

Water Quantity Restoration

- Improve natural water storage by allowing beaver recolonization
- Increase stream flow

Habitat Diversity

- Restore habitat-forming processes and channel complexity of the Chewuch River from RM 0 to 28.
- LWD restoration and recruitment
- Side-channel reconnection

Sediment

- Transportation planning, road reconstruction, road maintenance, undersized culvert replacement
- Reduce road densities

Tier 2

Riparian Restoration

- Fence riparian areas and wetlands; maintain existing fences

Ecological Interaction

- Reduce or eliminate brook trout
- Add nutrients using hatchery carcasses and/or carcass analogs

Tier 3 — Obstructions – Improve fish passage at Eight Mile Creek

Tier 4 — Riparian Restoration – Continue Respect the River and expand to Eightmile

1.4 HABITAT COMPLEXITY OBJECTIVES

This Reclamation assessment is focused on developing strategies for implementing *Upper Columbia Recovery Plan* habitat objectives associated with complexity in the Methow Subbasin assessment area. According to the FCRPS BiOp Remand (NMFS, 2005) channel complexity projects include actions that would improve stream connectivity with floodplains and side channels. This could encompass side channel connectivity, floodplain connectivity, channel reconfiguration, placement of in-stream structures, and LWD replacement to create off-channel habitat and deep pools formed by LWD or boulders.

For the purpose of this assessment, objectives are categorized in terms of a spatial component, a desired timeframe, and a desired response. Spatially, projects should improve the vertical and lateral connectivity of the river and floodplain in the location where an action is being done. Additionally, projects should benefit downstream and upstream reaches and tributaries by creating connectivity of processes between river reaches (longitudinally), which should provide biological refugia and connectivity within the assessment area and between tributary or upstream populations. For example, restoration of riparian vegetation in one reach could provide LWD recruitment such that the LWD may be transported into a downstream reach and form essential habitat. Projects may also benefit habitat upstream reaches by improving habitat function and availability for fish migrating to or from upstream areas. From a timing perspective, projects should re-establish geomorphic processes and function that provide both short- and long-term benefits. The response should be to maximize aquatic habitat diversity and use, specifically features associated with habitat complexity through increasing diversity in hydraulic processes.

2. HABITAT PROTECTION AND RESTORATION STRATEGY

The consensus of the Upper Columbia Regional Technical Team (UCRTT) is that protection and restoration strategies should focus first on maintaining the best remaining examples of biological integrity, connectivity, and diversity; this strategy will contribute to the improvement in abundance, productivity, spatial structure, and diversity over the long term (UCRTT, 2007). Therefore, the goal of protection and restoration concepts proposed by Reclamation in this appendix is to sustain and, where possible, improve habitat-forming physical processes. However, the river may never resemble the exact conditions that it had prior to documented human disturbance (defined as mid to late 1800s). Restoration activities must consider present land use within a subbasin, and the possibility that natural controls on the river may be changing, such as the hydrologic regime.

2.1 APPLICATION OF CONCEPTUAL MODEL OF PHYSICAL PROCESSES AND HABITAT CONDITIONS

A conceptual model of pre-disturbance conditions is essential for guiding development of protection and restoration concepts and an implementation strategy. Using the conceptual model of pre-disturbance conditions, the aquatic habitat “opportunity” for a given reach can be estimated. Opportunity refers to the types of processes that would be expected to be in place if human disturbances had not occurred. Using natural processes that would be in place as a guideline for habitat concepts is needed to ensure project objectives are sustainable in that they work with natural river processes rather than against them. This provides biologists and resource managers with a reasonable expectation of how a project will meet complexity objectives. In cases where projects are not designed with natural processes in mind, project objectives may not be achieved. Further, unanticipated risks to land use or even negative impacts to habitat can occur.

The conceptual model combined with geomorphic analysis also provides a framework for identifying where processes are currently functioning, where and how they have departed as a result of man-made activities and features, and whether processes can be returned to a functioning state that will benefit listed species in a sustainable manner. The *Upper Columbia Recovery Plan* notes that “… human activities have reduced habitat complexity, connectivity, water quantity and quality, and riparian function in many stream reaches in the Upper Columbia Basin; loss of large woody debris (LWD) and floodplain connectivity have reduced rearing habitat for Chinook, steelhead, and bull trout in larger rivers (such as the Wenatchee, Entiat, Methow, and Okanogan Rivers).”

2.2 RECOVERY OF HABITAT COMPLEXITY FOLLOWING IMPLEMENTATION OF RESTORATION CONCEPTS

This assessment found that the largest departures from the natural setting in terms of physical channel processes associated with habitat complexity features are the disruption to channel and floodplain connectivity, largely due to levees, riprap, bridges, road embankments, and removal of riparian vegetation and large woody debris. Many human features are located intermittently throughout the Methow Subbasin, which results in localized influences to processes. Additionally, natural geologic controls on the system (alluvial fans, bedrock, glacial terraces, cobbles in channel bed, etc) have largely kept the overarching river morphology intact at a reach scale, despite human activities. This has limited incision in areas where the channel has been confined and limited lateral expansion of the floodplain boundaries where banks are more susceptible to erosion. As a result, there is generally a good potential for recovering lateral connectivity and channel migration of the river and floodplain by removing human features that limit or prevent these processes from occurring.

2.2.1 SIDE CHANNEL DEVELOPMENT

Once lateral connectivity is re-established, side channels and channel migration will begin to re-establish, particularly during high flows. Many of the off-channel areas have been cleared of vegetation for agriculture or development. Side and overflow channels have been artificially filled with sediment in some cases or have filled with fine sediment due to a lack of flushing from the river. In these areas it may take a significant flood to erode the surface and start the decadal-long process of building new surfaces and establishing riparian vegetation.

2.2.2 RIPARIAN VEGETATION AND LWD

The lack of floodplain reworking has caused a combination of limited cottonwood regeneration and a conversion of new growth to vegetation such as shrubs, aspen and conifers. Because cottonwoods require a fresh soil and ample exposure to sun to establish, these areas will need to be completely reworked with a fresh and bare surface formed before cottonwoods can re-establish. On the positive side, these areas do contain fairly old trees that will provide a short-term source of LWD as the river is allowed to rework these sections. This will help jump start the replenishment of LWD in the system to compensate for the past removal of wood, which has resulted in a lack of recruitment areas.

One strategy could be to remove existing stands of vegetation and replace them with cottonwoods, but this may result in increased bank erosion rates until the cottonwoods are established that may not be acceptable depending on nearby land use. Other opportunities exist to establish cottonwood galleries, such as along ditches, edges of wetlands where shrubs now grow, along side channels, or where vegetation has been completely cleared and nothing has grown back. Sites prone to wildlife browsing may need fencing for a few years to enable cottonwoods to re-establish.

Not all surfaces within the assessment area naturally had cottonwoods and, therefore, may not be good candidates for replanting cottonwoods, but could benefit from planting other vegetation species. Unconfined and moderately confined river reaches would be expected to have the most extensive riparian vegetation (including cottonwood galleries) present along wetted channels, in off-channel habitat areas such as wetlands, and in other areas frequently reworked by the river. Riparian vegetation relies on vertical connectivity of the floodplain to the water table, and also lateral connectivity within the floodplain to allow reworking of the lower surfaces. Some floodplain areas are higher in elevation than others and are likely older in age. Although these higher surfaces are still overtopped in floods and are considered part of the active floodplain (low surface), they do not get reworked as frequently as the lower channels, bars, and floodplain areas and are farther from the water table. These higher elevation surfaces may require planting different vegetation species than lower elevation areas closer to the river.

In areas where LWD would have been expected to persist and form local pools and roughness components in the channel, LWD or log jams could be placed to provide short-term changes. This would help provide habitat in the near term until the lateral reworking processes have a chance to re-establish an ample supply of LWD.

2.2.3 BANK PROTECTION ON TERRACES ALONG BOUNDARY OF FLOODPLAIN

Bank protection on terraces along the boundaries of the floodplain impacts the natural function of these boundary areas, particularly where the river runs adjacent to them. However, many of these areas have infrastructure located near the top of bank that could be at risk from erosion if the riprap is removed. These represent hazard zones even though they are not actually located within the floodplain. On the Methow River, an analysis was accomplished by Golder Associates that helps identify terrace surfaces at risk for future erosion. There has not been an analysis of this type on the Chewuch and Twisp Rivers.

One restoration concept in riprapped terrace locations could be to modify the bank protection to incorporate LWD if it could be done without risking infrastructure damage. This would be of particular advantage for habitat features where the river runs against the bank in moderately confined and unconfined reach types. Another concept could be to create an intermediate floodplain surface (between the river and top of bank) that allows for riparian vegetation growth and provides a buffer between the riprapped terrace bank and the river. If the bank protection is located on the main channel, the river may have formed a deep scour hole adjacent to the bank protection due to higher velocities sweeping against the rock. On the positive side, this process may provide a pool for aquatic habitat. However, the pool lacks nutrients or pockets of slow velocity created by vegetation and root features that would be present on a natural bank. In areas where the bank would naturally have had vegetation cover, the river is devoid of shade and potential for LWD recruitment. The reduction in shade has the greatest impact on smaller stream sections where the overhanging vegetation affects a significant portion of the wetted channel width. Protected bank areas that were naturally limited in vegetation or that are fairly high above the channel would have less impact on channel processes.

2.3 SPATIAL BREAKDOWN OF RESTORATION STRATEGY FOR 80-MILE ASSESSMENT AREA

Because the key concept of complexity-based restoration is to allow lateral, vertical, and longitudinal connection of floodplain processes, it makes sense to think of a restoration strategy from a process-based spatial perspective. The strategy should incorporate enough detail at a project level to accommodate planning and prioritization of future restoration efforts, but also to allow users to step back and see how a given project fits within the subbasin habitat availability and function. In the long run, perhaps a decade or two from now, stakeholders and biologists need a way to document whether restoration efforts met the goal of protecting and improving habitat complexity within the Methow Subbasin. The strategy proposed in this appendix is aimed at meeting that need by showing how processes interact among different spatial scales to provide a cumulative, sustainable benefit to habitat Because channel and floodplain processes are highly interdependent at the reach scale, it is anticipated that more detailed analysis and restoration efforts may occur at the reach scale through a prioritized strategy as discussed in Appendix B.

The scales evaluated are a subbasin level (see Section 3 of this appendix), the 23 geomorphic reaches within four valley segments of the 80-mile assessment area (see Section 4 of this appendix), and from individual potential project areas within each geomorphic reach (see Section 5 of this appendix) (Figure A-1). Because channel and floodplain processes are highly interdependent at the reach scale, it is anticipated that more detailed analysis and restoration efforts may occur at the reach scale through a prioritized strategy as discussed in Appendix B.

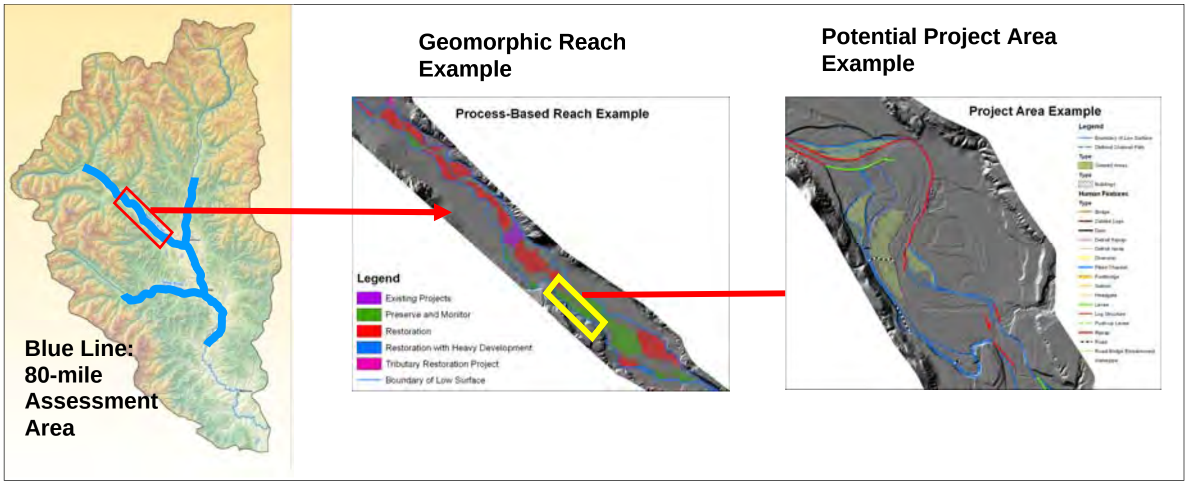

Figure A-1. Conceptual example of working from a subbasin scale downward to a project area scale when implementing habitat restoration concepts discussed in this assessment.

2.4 RESEARCH AND MONITORING GUIDANCE

The *Upper Columbia Biological Strategy* (UCRTT, 2007) and *Upper Columbia Recovery Plan* (UCSRB, 2007) say that there are critical uncertainties that need further research to better understand the fluvial processes. Critical uncertainty research targets specific issues that constrain effective recovery plan implementation. The Recovery Plan identifies research needs (monitoring objectives) for the four sectors (harvest, habitat, hydro, and hatcheries) affecting salmon, steelhead, and bull trout viability. Research needs in the habitat sector as identified in the Recovery Plan are as follows:

- Implement selected restoration projects as experiments.
- Increase understanding of estuarine ecology of Upper Columbia stocks.
- Increase genetic research to identify genotypic variations in habitat use.
- Increase understanding of linkages between physical and biological processes so managers can predict changes in survival and productivity in response to selected recovery actions.
- Examine relationships between habitat indicators and landscape variables.
- Examine fluvial geomorphic processes to better understand their effects on habitat creation and restoration.
- Examine water balance and surface/groundwater relations (in the sense of Konrad et al. 22 2003), especially the benefits of aquifer recharge during periods of high runoff in appropriate areas. Using the results inferred from these studies, evaluate the effects of aquifer recharge on late summer and winter instream flows and resultant habitat use. Implement and document an aquifer recharge demonstration project in the Methow Basin by diverting excess water during times of high spring runoff through selected unlined irrigation ditches. Evaluate the effect of this action (with selected irrigation

ditches to be designated as control) to enhance stream flows at critical times on spring Chinook salmon and steelhead habitat use.

- Test assumptions and sensitivity of EDT model runs.
- Evaluate nutrient enrichment benefits and risks using fish from hatcheries or suitable analogs.
- Assess population structure and size of bull trout in the Upper Columbia Basin.
- Assess the presence of bull trout in the Lake Chelan and Okanogan subbasins and upstream of Entiat Falls in the Entiat subbasin.
- Assess the effectiveness and feasibility of using fish transfers, range expansion, and artificia1 propagation in bull trout recovery.
- Examine migratory characteristics and reproductive success of bull trout.
- Describe the genetic makeup of bull trout in the Upper Columbia Basin.

In the *Upper Columbia Recovery Plan*, the UCRTT documents that it is planning to implement a detailed monitoring and evaluation program. The UCRTT plans to design and incorporate the plan into an adaptive management framework based on the principles and concepts laid out in *Adaptive Management for Salmon Recovery: Evaluation Framework and Monitoring Guidance* (the NMFS. 2007a). .

In the *Upper Columbia Biological Strategy*, further guidance is provided by the UCRTT on implementing monitoring activities specific to habitat restoration actions. Monitoring strategies are generally described in three categories:

1. Implementation monitoring
2. Level 1 effectiveness monitoring
3. Level 2 and 3 effectiveness monitoring

Implementation monitoring simply provides proof that the action was carried out as planned (UCRTT, 2007). Level 1 (extensive methods) involves fast and easy methods that can be completed at multiple sites, while Level 2 and 3 (intensive methods) includes methods that increase accuracy and precision but require more sampling time (Hillman 2006). Further descriptions of the monitoring categories are provided below.

Implementation monitoring is important to allow monitoring teams to go back and evaluate the effectiveness or longevity of a project implemented by project sponsors. To accomplish implementation monitoring, the *Upper Columbia Biological Strategy* recommends the following in addition to referencing Hillman (2006, formerly 2005) for examples of objectives for each project type:

- photo points with position descriptions that include both physical description and GPS coordinates
- written documentation describing if the objectives were met such as date of project completion and the quantity of each objective that was completed.

Level 1 effectiveness monitoring is used to demonstrate that the restoration action has at least affected the environmental parameters that were the target of restoration (Hillman 2006 as documented in UCRTT, 2007). To accomplish Level 1 effectiveness monitoring the *Upper Columbia Biological Strategy* recommends conducting photographs, counts, and presence/absence surveys at set intervals in order to evaluate effectiveness of the action. Level 1 effectiveness monitoring seeks to answer questions such as:

1) What was the survival of trees planted in a riparian project?
2) Is the restoration structure (i.e. fence, rock weir, culvert, etc.) still in place?
3) Is the restoration target (i.e. pools, wood, spawning gravel, side channel connection, etc.) still there after multiple high water events?
4) Are the terms of the easement being upheld through time?
5) Will target fish species / life stage be present in the side channel?

The *Upper Columbia Biological Strategy* recommends the following steps be included in a Level 1 effectiveness monitoring program:

- Define goals and objectives
- Define key questions and/or hypotheses
- Select appropriate monitoring design
- Select monitoring parameters
- Identify number of sites and years to monitor
- Determine sampling scheme (i.e. snorkeling surveys)
- Prepare appropriate reports

Level 2 and Level 3 effectiveness monitoring are generally beyond the scope and purview of most project sponsors. These levels of effectiveness monitoring require a much higher degree of monitoring expertise, in depth planning, experimental design, statistical design, data management, data analysis, and reporting (UCRTT, 2007). Level 2 and 3 effectiveness monitoring are extremely important and should be carried out on select projects and sub-watersheds in each of the Upper Columbia Subbasins, as funding allows (UCRTT, 2007).

3. RESTORATION NEEDS OUTSIDE OF 80-MILE ASSESSMENT AREA

Subbasin-level conditions were qualitatively evaluated to identify whether there were any critical issues that needed to be addressed that could impact restoration strategies proposed for the 80-mile assessment area. The 80-mile assessment area consists of four valley segments— Middle Methow (RM 28.1 to 51.5), Upper Methow (RM 51.5 to 75), Chewuch River (RM 0 to 14.3), and Twisp River (RM 0 to 18.1). Methods included field reconnaissance by the assessment team and literature review of available technical documents. There were no critical habitat complexity restoration needs identified outside of the 80-mile area, but restoration opportunities do exist as described below. Evaluating hatchery and harvest related components of salmonid migration into the Methow Subbasin was beyond the scope of this report.

3.1 DOWNSTREAM OF 80-MILE ASSESSMENT AREA (METHOW RM 28 TO 0)

Presently, no human or natural barriers exist downstream of the 80-mile assessment area (RM 28 on the mainstem Methow) that would prevent spring Chinook, steelhead, and bull trout from migrating into and accessing the assessment area. A dam did exist historically near the mouth of the Methow River and is noted in certain documents to have blocked fish passage into the Methow Subbasin (see Appendix O). However, based on photographs of the site it appears some fish, particularly spring and early summer migrating fish, may have been able to pass the dam but additional historical information on the dam is needed to validate this.

In terms of morphology, the downstream-most 28 river miles of the Methow Subbasin are fairly naturally confined by high elevation glacial terraces and bedrock. In a few localized places roads and bridges do constrict the floodplain, but human impacts are minimal relative to more developed areas in other sections of the subbasin. The downstream 28 miles functions as a migratory corridor for ESA-listed fish into the assessment area (see Appendix F “Biological Setting”). Steelhead and summer Chinook spawn in some places within this reach where water wells-up through the river bed through gravel accumulations to provide suitable habitat. Certain fish also use this section for spawning and rearing habitat, and ongoing work to further understand the habitat function in this area is being accomplished by Washington Department of Fish and Wildlife (WDFW).

3.2 TRIBUTARIES WITHIN ASSESSMENT AREA

Within the assessment area, several tributaries enter the Methow, Chewuch and Twisp Rivers. Many of these tributaries provide additional spawning, rearing, and holding habitat for ESA-listed fish. Extensive recent fish passage projects on Beaver Creek, Twisp River tributaries, Chewuch River and Libby and Gold Creek have restored connectivity of the assessment reach to most tributary habitats where man-made obstructions historically existed. Early winters, Goat Creek, and Wolf Creek on the Upper Methow, and Eight-mile Creek on the Twisp River were identified as having substantial man-made obstructions to channel migration and floodplain connectivity, particularly in the downstream-most sections near the confluence with the Methow or Twisp Rivers. Restoration strategies for these areas could be developed as part of a separate effort to build upon concepts presented in this report. Additional concepts are presented in Section 1.3 of this appendix.

3.3 UPSTREAM OF 80-MILE ASSESSMENT AREA

Upstream of the assessment area, additional spawning and rearing usage occurs in the Lost River, West Fork of the Methow, and upstream portions of the Chewuch and Twisp watersheds. The U.S. Forest Service manages many of these areas and separate restoration strategies could be developed to address localized areas of roads, camp sites, and development. No large-scale logging or water diversions occur that need to be addressed prior to implementing actions within the 80-mile assessment area. Improvement to habitat function within the assessment area will allow better longitudinal connectivity to fish migration into or out of tributaries and upstream river reaches. It will also increase the spatial and temporal variability of habitat available within the subbasin. Some tributaries and upstream areas also have human features that offer opportunities for restoration activities that could be further assessed if the assessment area is expanded in the future by Reclamation or another agency.

4. RESTORATION CONCEPTS AT REACH SCALE FOR 4 VALLEY SEGMENTS

The four valley segments were subdivided into 23 geomorphic reaches with similar floodplain and channel interaction processes that define unique opportunities for habitat restoration (see Appendix C). This resulted in five geomorphic reaches on the Middle Methow River, six on the Upper Methow River, six on the Chewuch River, and six on the Twisp River. Based on the geomorphic assessment findings, a summary of restoration strategies for each geomorphic reach is provided in **Table A-5** and in more detail in Attachment 1 of this appendix.

Table A-5summarizes primary and secondary restoration concepts for each reach. The primary concepts represent key actions that would have the most benefit to restoring off-channel, complexity habitat for ESA-listed salmonids. Secondary concepts are actions that also restore natural conditions and improve habitat, but either need to be done in conjunction with primary concepts or provide a lesser, more indirect benefit.

The table also documents a floodplain type for each reach. Three general floodplain types were established to categorize the 23 reaches based on their natural morphological setting and potential for preserving or restoring complexity habitat: high complexity (unconfined), medium complexity (moderately confined), and low complexity (confined) floodplains (see Appendix C for detailed descriptions). Unconfined and moderately confined reaches have measurable off-channel habitat and floodplain that can be easily discerned from the active channel area. The majority of habitat complexity restoration concepts are focused in these two reach types. In confined reaches, the active channel and floodplain are nearly the same and there is limited potential for off-channel habitat restoration areas, but spawning and migration habitat can be present.

Approximately 61 river miles of the 80-mile assessment reach are composed of “moderately confined” or “unconfined” floodplain (Figure A-2). Approximately one-tenth of the Methow River assessment area, one-third of the Chewuch River assessment area, and one-sixth of the Twisp River assessment area are classified as “confined” reaches.

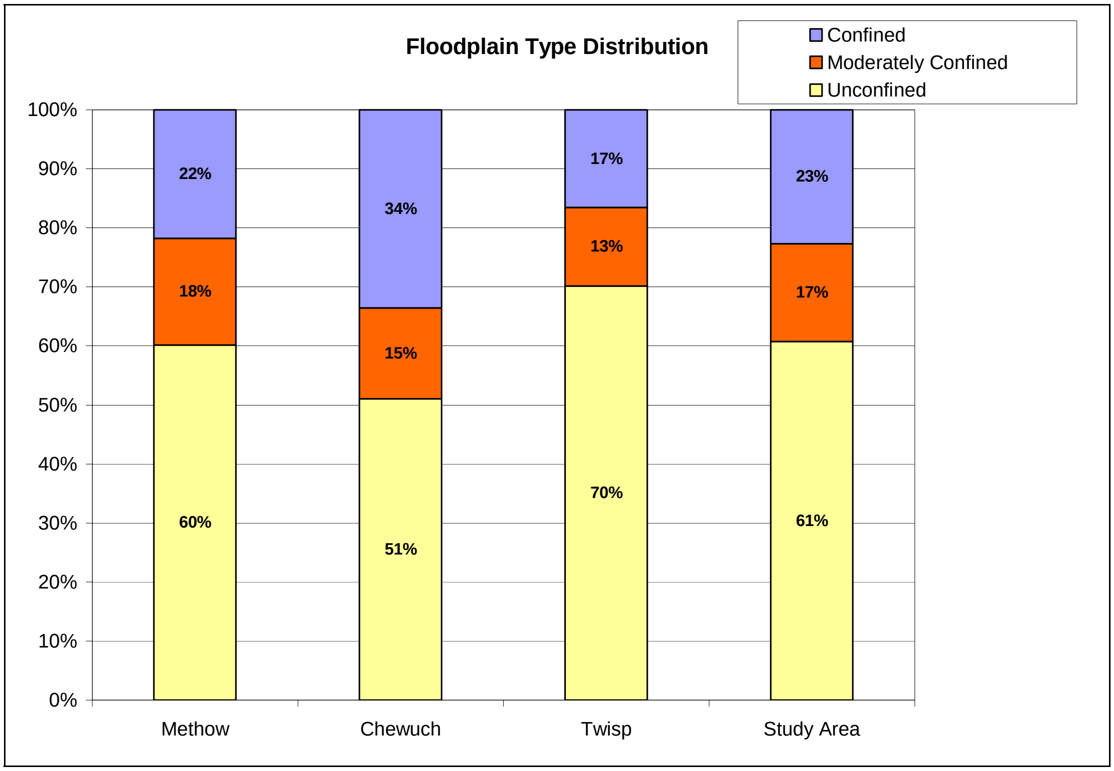

Figure A-2. Percentage of floodplain complexity type for Methow, Chewuch, and Twisp Rivers.

Within unconfined and moderately confined reaches with measurable floodplain areas beyond the active channel, potential protection (green polygons) and restoration floodplain areas (orange polygons) were delineated and labeled as shown in the location maps in Figure A-3, Figure A-4, Figure A-5, and Figure A-6. Protection areas represent sections with no known human features or vegetation clearing that impact channel and floodplain connectivity. Restoration areas have identified human features that could be addressed to restore channel and floodplain processes (see Appendix P). Consideration of the location of protection areas relative to non-functioning restoration areas offers an opportunity to provide cumulative benefits at a reach scale rather than piece-mealed sections of functioning habitat areas within the 80-mile assessment area. More discussion on protection and restoration concepts at the scale of individual floodplain areas within each reach is provided in Section 5. In discussing potential project areas, the nomenclature lists two letters of MR = Methow River, TR = Twisp River, or CR = Chewuch River followed by Prj which stands for project, and the river mile associated with the upstream most point of the polygon defining the boundary of the potential project area (e.g. MR_Prj-41 = Potential project on Methow River starting at river mile 41).

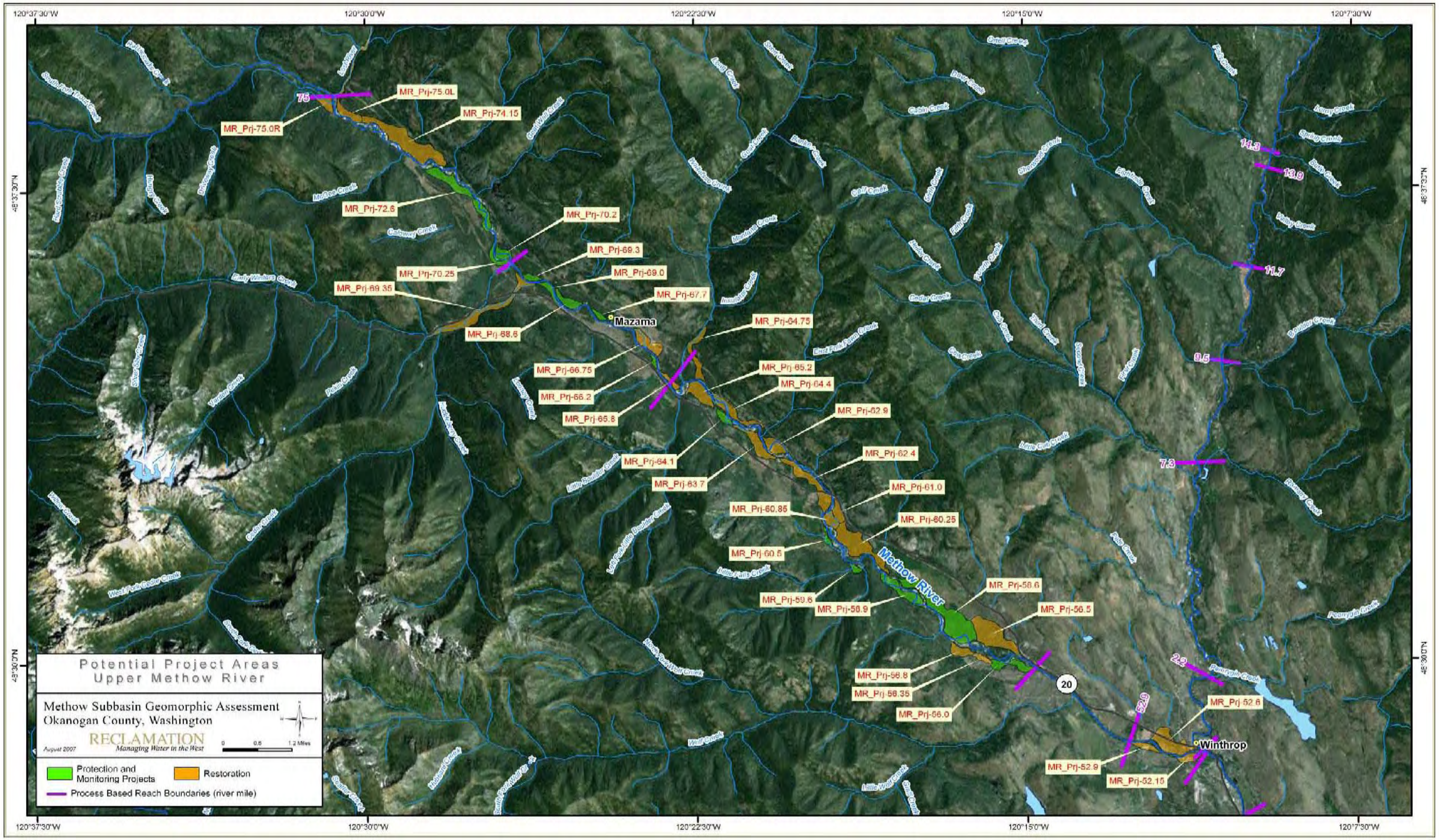

Figure A-3. Upper Methow River – Potential protection and restoration floodplain area locations, RM 50–75.

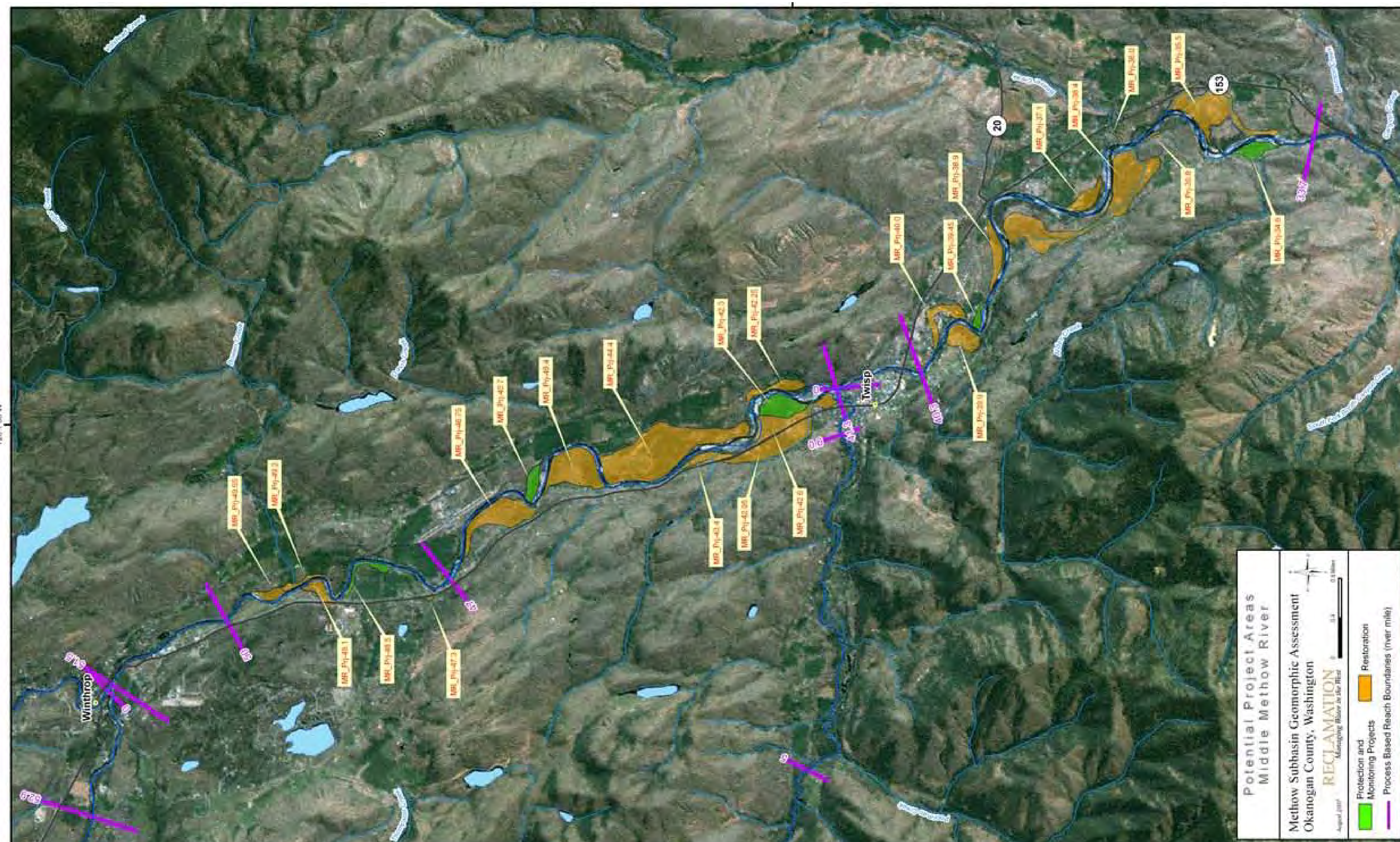

Figure A-4. Middle Methow River – Potential protection and restoration floodplain area locations, RM 28.1–50.

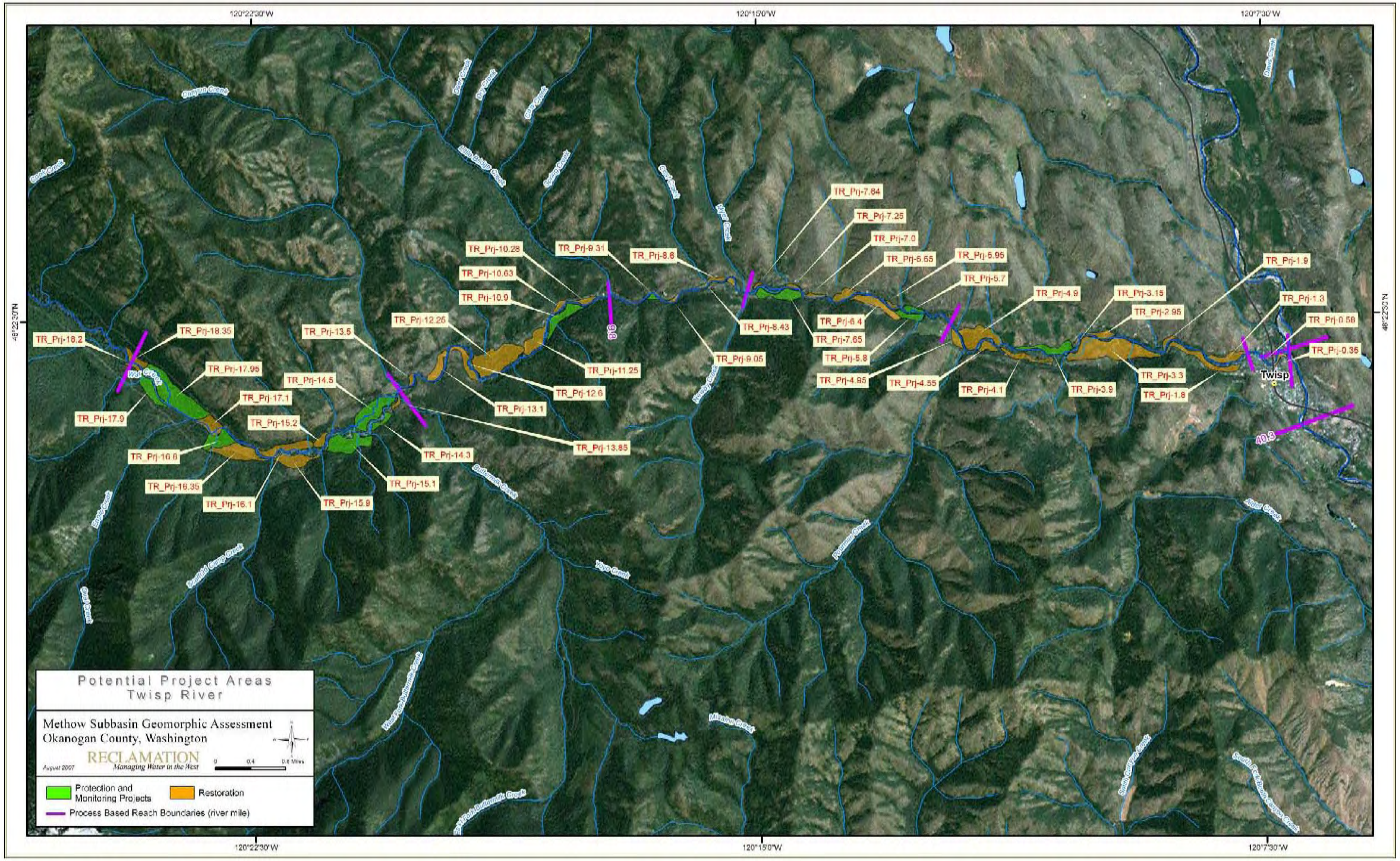

Figure A-5. Twisp River – Potential protection and restoration floodplain area locations, RM 0–18.

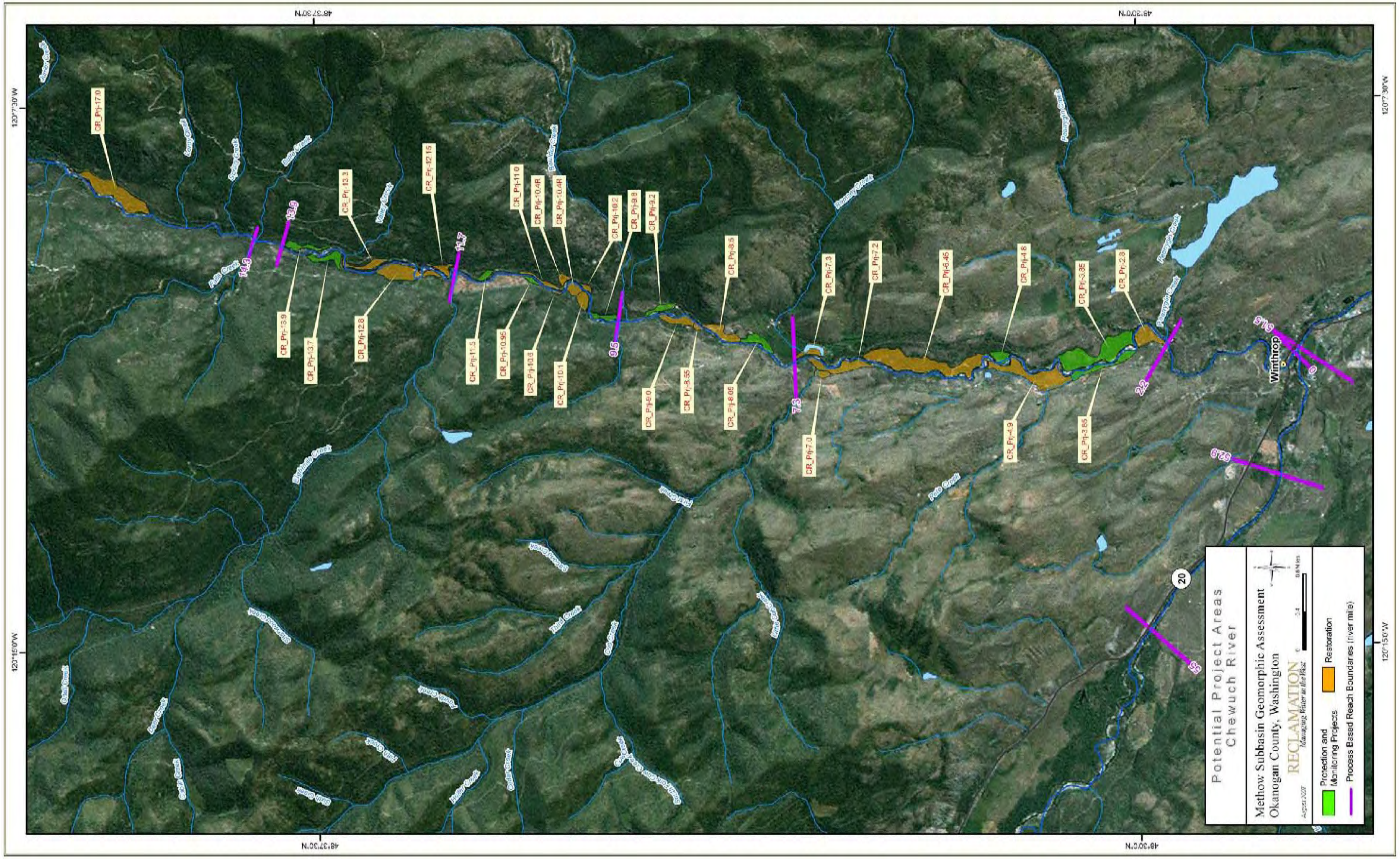

Figure A-6. Chewuch River – Potential protection and restoration floodplain area locations, RM 0–14.

Table A-5. Summary of restoration concepts at geomorphic reach scale for 23 reaches (see Attachment 1 for supplemental information).

Reach	Down-stream RM	Up-stream RM	Length (mile)	Type	Primary Restoration Concepts	Secondary Restoration Concepts
M1	28.1	33.7	5.6	Confined	None identified	None identified
M2	33.7	40.3	6.6	Unconfined	Restore access to 6.6 miles of off-channel habitat by removing or setting back levees, that block the side channels, and removing riprap that prevents lateral channel migration. An additional 1 mile of side channel possibly could be reconnected in the City of Twisp.	Further evaluate need for restoration strategies along 23% of terrace banks that have been riprapped; add LWD and possibly riparian planting to side channels if reconnected
M3	40.3	41.3	1.0	Confined	None identified	None identified
M4	41.3	47.0	5.7	Unconfined	Restore access to 5.3 miles of off-channel habitat by removing levees that block the side-channel entrances, removing riprap that prevents lateral migration, and improving road crossings that have no or undersized culverts; additional 1 mile of side channel could be reconnected that is blocked off by a highway; coldwater springs are present that may improve restoration benefit	Further evaluate need for restoration strategies along 17% of terrace banks that have been riprapped; monitor river response from removal of MVID East diversion dam
M5	47.0	50.0	3.0	Moderately confined	Enhance existing diversion channel (about 0.3 miles long) to provide complexity with LWD placement and riparian planting, and better connect to adjacent side channel; remove riprap at 2 other locations in reach that block off entrances to 0.6 miles of side channels; possibly address fill placed in historic channels once reaccessed	Further evaluate need for restoration strategies along 14% of terrace banks that have been riprapped
M6	50.0	51.5	1.5	Confined	None identified	None identified
M7	51.5	52.9	1.4	Moderately confined	Opportunity to reconnect 1.8 miles of side channel, but this reach poses a challenge to restoring natural processes because of heavy development in the town of Winthrop; field	Further evaluate need for restoration strategies along 4% of terrace banks that have been riprapped; possible LWD placement along side channels if reconnected; look for opportunities to protect any

Table A-5. Summary of restoration concepts at geomorphic reach scale for 23 reaches (see Attachment 1 for supplemental information).

Reach	Down-stream RM	Up-stream RM	Length (mile)	Type	Primary Restoration Concepts	Secondary Restoration Concepts
					assessment needed to evaluate current Winthrop hatchery to see if any opportunities for side channel enhancement;	existing eroding banks that are threatening infrastructure with methods that incorporate habitat features
M8	52.9	55.0	2.1	Confined	None identified	Additional geomorphic and habitat assessment work could be done to determine potential restoration opportunities by evaluating impacts of development post-1974 on Wolf Creek drainage that has confined the alluvial fan channels
M9	55.0	65.5	10.5	Unconfined	Enhance and reconnect more than 9 miles of side channels present in the floodplain by widening Weeman Bridge and addressing other small roads, riprap areas, levees, etc located along and in the channels; some channel excavation may be needed in areas where fill has been placed to improve inundation frequency and ability of channel to migrate; high density existing habitat use, springs, and healthy riparian zones offers good opportunity to build upon and focus in areas currently being utilized by salmonids;	Further evaluate need for restoration strategies along 10% of terrace banks that have been riprapped; possible LWD placement in side channels being reaccessed or enhanced; LWD placement in main channel upstream of Weeman Bridge to evaluate if effective in creating refuge scour pools during low flow periods when dewatering sometimes occurs;
M10	65.5	69.6	4.1	Moderately confined	Address artificial pond near RM 66.25 to improve function of the side channel presently being used as a road;	Restore access to floodplain area in Prj-65.8 by removing a levee; further evaluate need for restoration strategies along 7% of terrace banks that have been riprapped; consider evaluation of Early Winters and Goat Creek drainages for restoration possibilities where the alluvial fan channels have been artificially confined by human features near the confluence with the Methow River
M11	69.6	75.0	5.4	Unconfined	Lower half of reach is highly functioning habitat area identified for protection strategies; upper half has several small levees,	Further evaluate need for restoration strategies along 7% of terrace banks that have been riprapped

Table A-5. Summary of restoration concepts at geomorphic reach scale for 23 reaches (see Attachment 1 for supplemental information).

Reach	Down-stream RM	Up-stream RM	Length (mile)	Type	Primary Restoration Concepts	Secondary Restoration Concepts
					roads and housing built in recent years that is cutting off access to historic channels and limiting channel migration; growing housing developments in this areas poses challenges to restoration efforts; housing areas within the floodplain should be evaluated to look for restoration opportunities but to also ensure the safety of residents and evacuation routes during floods	
T1	0	0.6	0.6	Confined	None identified	None identified
T2	0.6	5	4.4	Unconfined	Continue to evaluate MVID West diversion and TR_Prj-4.1 for restoration opportunities; remove or set back levees, riprap and roads that parallel long sections of river and block off 2.3 miles of side channels and floodplain access in TR_Prj-3.3 and 3.15	Restore access to additional floodplain areas and secondary/overflow channels; LWD and riparian planting may be needed in conjunction with side channel reconnections; further evaluate need for restoration strategies along 3% of terrace banks that have been riprapped;
T3	5	7.8	2.8	Moderately confined	Complete TR_Prj-6.65 (Elbow Coulee) where possibly up to 0.3 miles of side channel will be reconnected; evaluate potential to work with heavy development in TR_Prj-7.25 to reconnect a 0.2 mile side channel that would provide off-channel habitat across from a protection and high density spawning are with springs; remove riprap and levees that block upstream and downstream ends of channels in smaller areas	Remove levees to reconnect floodplain areas; further evaluate need for restoration strategies along 9% of terrace banks that have been riprapped
T4	7.8	9.8	2.0	Confined	Evaluate if potential to reconnect 0.2 miles of channel in TR_Prj-8.6 where development exists	Reconnect small floodplain areas cut off by riprap;
T5	9.8	13.5	3.7	Unconfined	Remove, breach or setback small levees and riprap that block upstream and lateral	Further evaluate need for restoration strategies along 8% of terrace banks that have been riprapped,

Table A-5. Summary of restoration concepts at geomorphic reach scale for 23 reaches (see Attachment 1 for supplemental information).

Reach	Down-stream RM	Up-stream RM	Length (mile)	Type	Primary Restoration Concepts	Secondary Restoration Concepts
					connectivity with the main channel at two concurrent floodplain areas, which combined with a protection area would provide nearly 2 miles of functioning off-channel habitat; This reach would naturally have extensive channel migration and LWD recruitment, and additionally adding LWD could restore a large section of functioning habitat that has the potential to support a wide range of life stages. Nearly a third of the area of the floodplain vegetation has been cleared, mostly in the upstream end of the reach.	particularly near RM 12.5 and 10.5 on the outside of meander bends along the road; small amounts of side channel excavation and LWD placement may be needed to jump start connectivity with the main channel; remove riprap to restore floodplain access in small sections in the upstream portion of reach, where riparian planting may also be needed to slow bank erosion rates.
T6	13.5	18.1	4.6	Unconfined	Remove or set back levees and riprap between RM 15 to 17 to restore access to channel networks and wetlands, increasing off-channel habitat by at least 0.7 miles but estimated at many more; restoration would connect protection areas located just upstream and downstream; increasing development in this reach may pose challenges to restoring habitat	Remove small levees and riprap disconnecting floodplain areas that do not include side channels; riparian planting and LWD placement may be needed to enhance reconnected areas if levees and riprap are removed
C1	0	2.2	2.2	Confined	None identified	There are no restoration areas proposed in this reach, except for very minor areas with houses.
C2	2.2	7.3	5.1	Unconfined	Remove or set back small levees and riprap to reconnect at least 4.2 miles of off-channel habitat areas; this would extend existing protection areas additional 3 miles upstream; reconnection area at downstream end (below protection area) has heavy development	Possible riparian planting and LWD placement in conjunction with reconnection projects
C3	7.3	9.5	2.2	Moderately confined	Remove small area of riprap to restore access to 0.1 miles of side channel	Remove riprap or incorporate LWD features along main channel banks within floodplain to improve hydraulics in mainstem channel and add complexity

Table A-5. Summary of restoration concepts at geomorphic reach scale for 23 reaches (see Attachment 1 for supplemental information).

Reach	Down-stream RM	Up-stream RM	Length (mile)	Type	Primary Restoration Concepts	Secondary Restoration Concepts
C4	9.5	11.7	2.2	Confined	Small amounts of riprap could be removed near RM 10.4 to 10.5 with a possible need for excavating where fill has been placed; there is a small amount of clearing with possible fill placed, but remaining wetland and side channel area may be able to be a protection area if subsequent field work does not find any human features; some of the most heavily used spring Chinook spawning habitat can be found in the Chewuch River between the confluence of Boulder Creek and Eightmile Creek.	None identified
C5	11.7	13.9	2.2	Unconfined	Removal or enhancement with LWD of riprapped banks between RM 12.8 and 13 that block off at least 0.5 miles of side channels, and likely more once LiDAR is used to update channel mapping;	Possible LWD placement in conjunction with reconnection projects
C6	13.9	14.3	0.4	Confined	None identified	None identified

The types of human features located within the floodplain and along the boundary of the floodplain terrace banks are summarized by reach for the Methow (Figure A-7 and Figure A-8), Twisp (Figure A-9 and Figure A-10), and Chewuch Rivers (Figure A-11 and Figure A-12). The majority of human features along the boundary of the floodplain (terrace banks) consist of bank protection. The majority of human features within the floodplain area consist of a combination of levees, roads, bridges, and riprap that may be considered for setback, breaching, or removal to restore lateral migration, improve riparian areas and large woody debris recruitment, and restore access to side channels and floodplain areas.

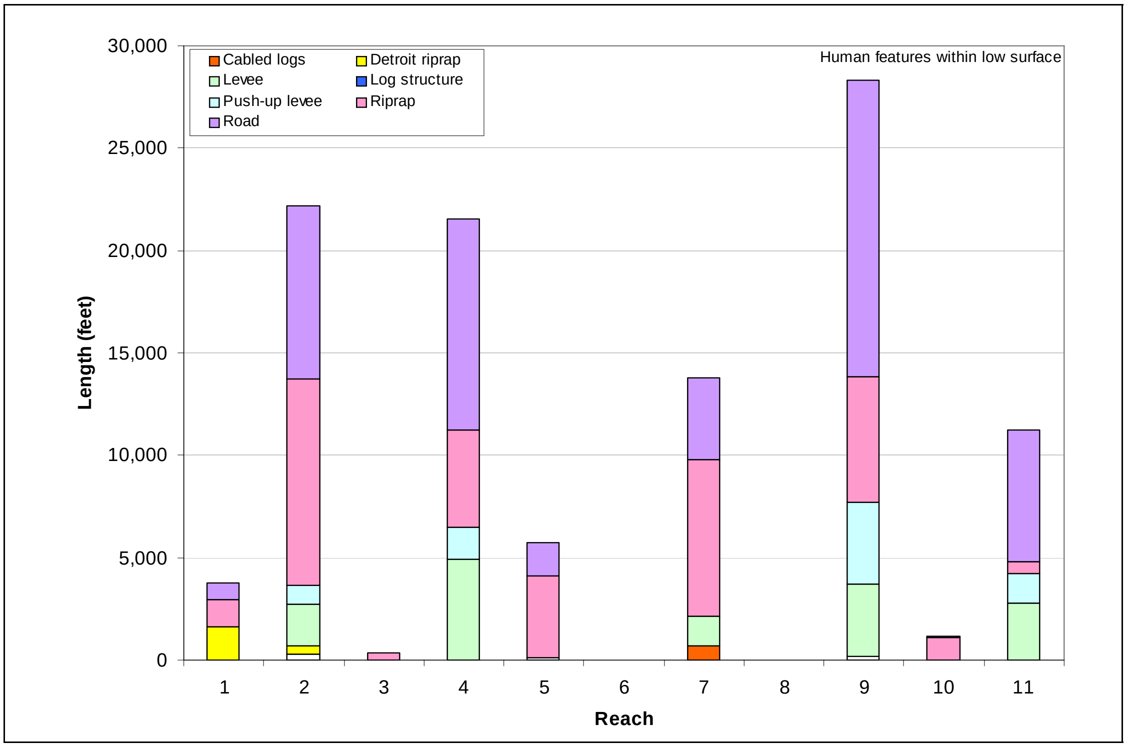

Figure A-7. Methow River – Types of human features within the low surface by reach.

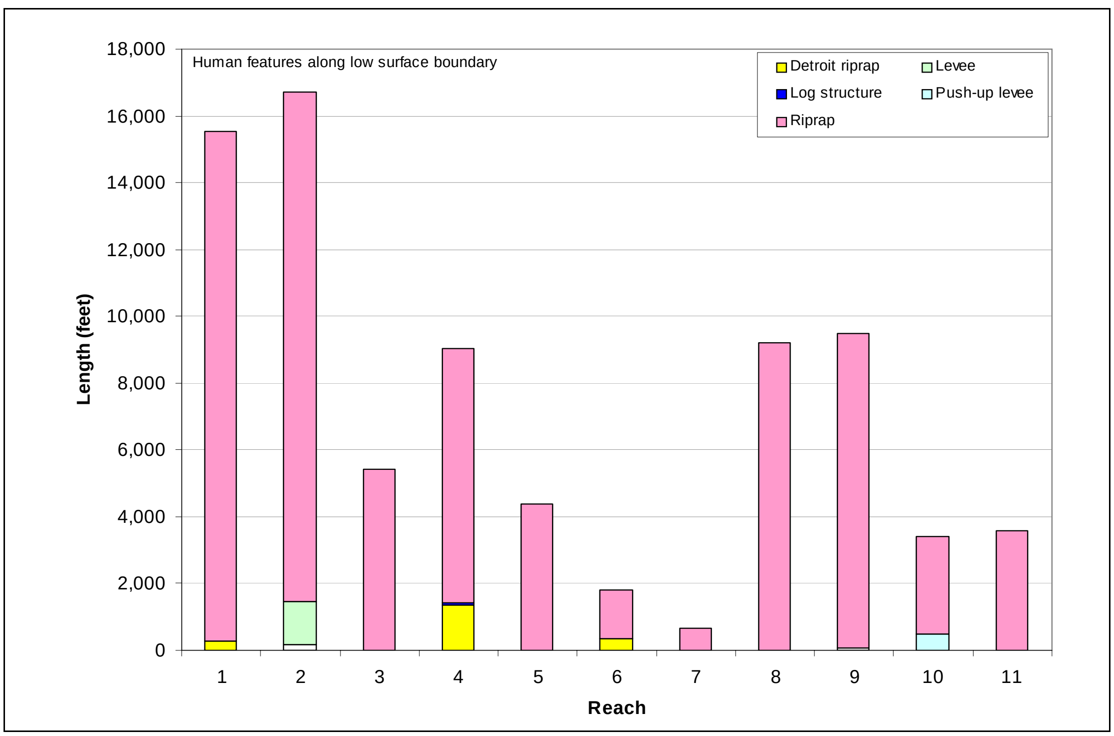

Figure A-8. Methow River – Types of human features along the boundary of the low surface by reach.

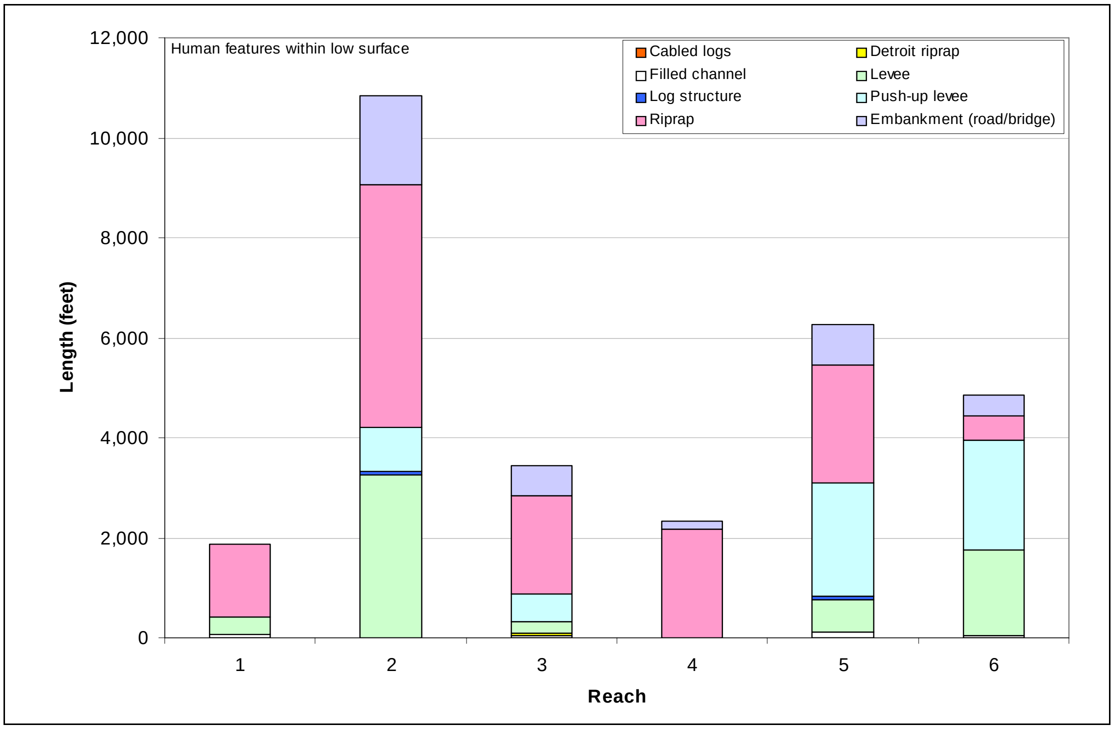

Figure A-9. Twisp River – Types of human features within the low surface by reach.

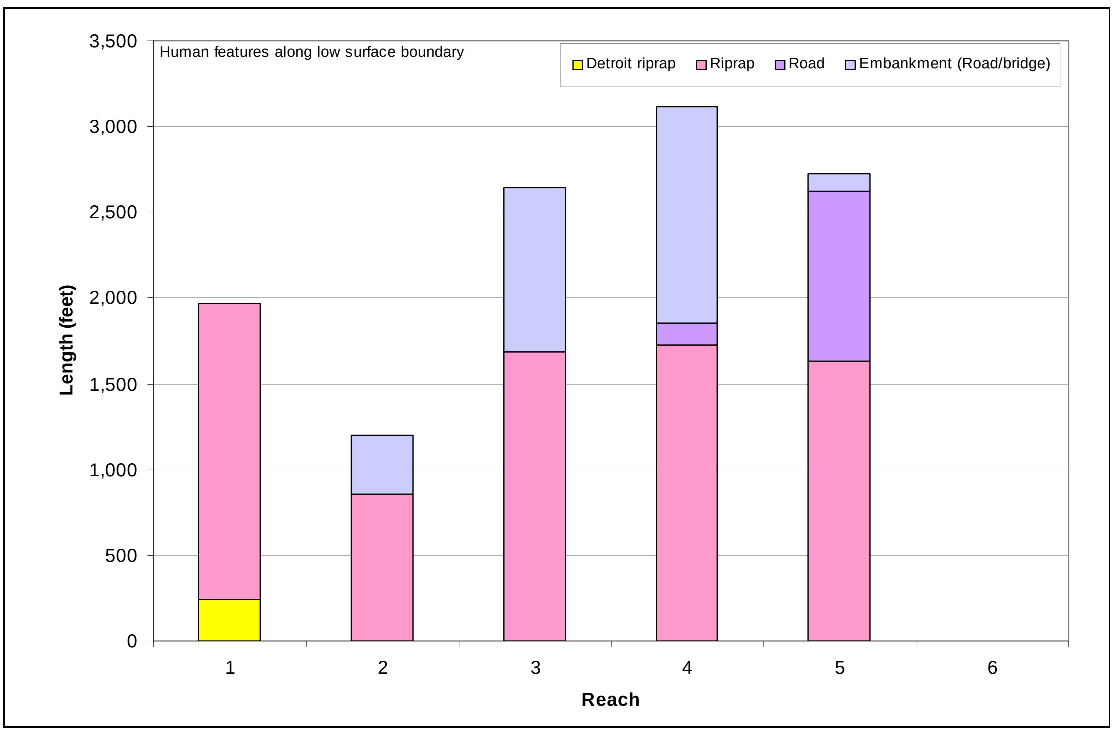

Figure A-10. Twisp River – Types of human features along the boundary of the low surface by reach.

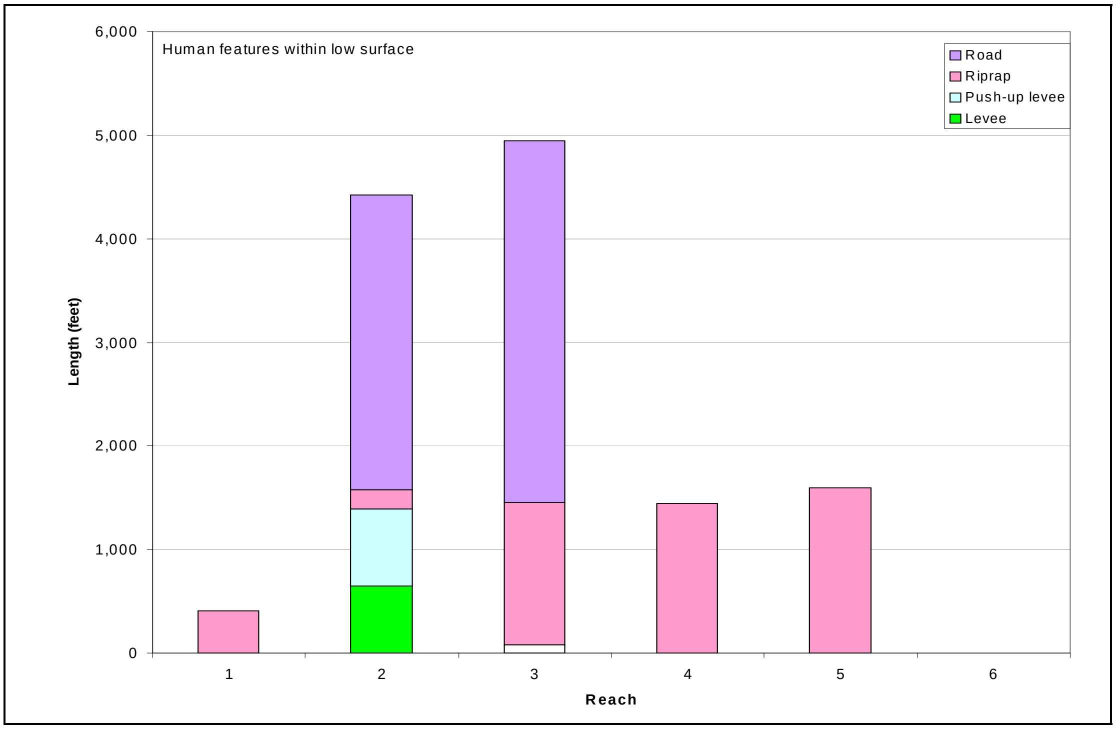

Figure A-11. Chewuch River – Types of human features within the low surface by reach.

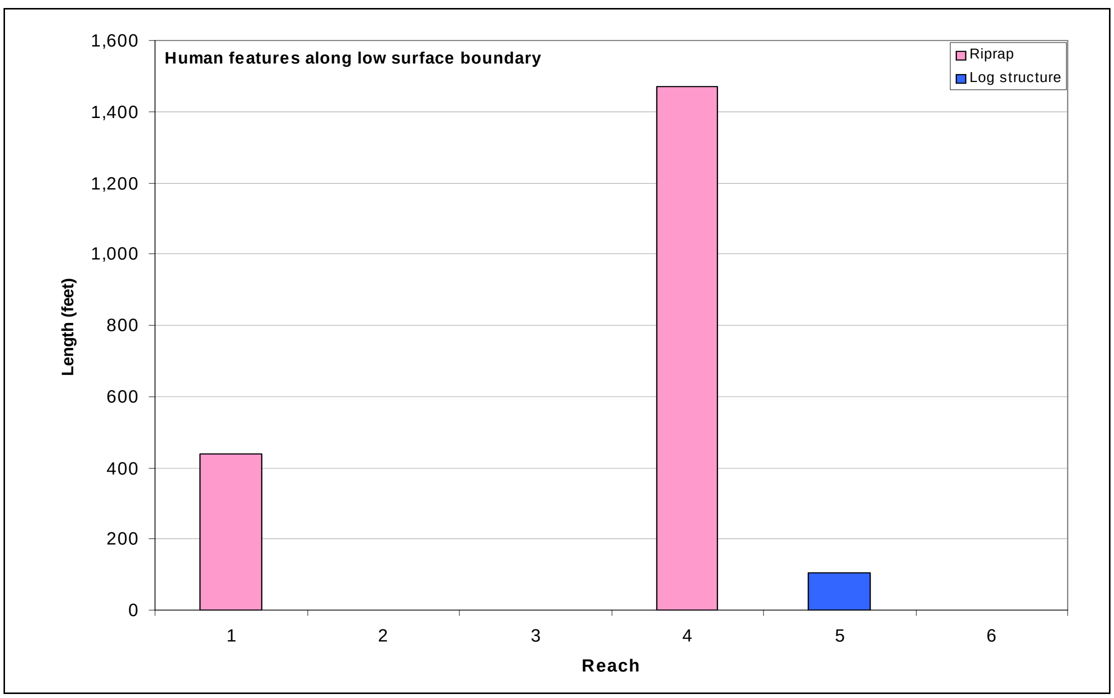

Figure A-12. Chewuch River – Types of human features along the boundary of the low surface by reach.

5. POTENTIAL PROTECTION AND RESTORATION PROJECT AREAS

Within the 61-miles of the assessment area with moderately confined to unconfined reach types, 132 individual floodplain areas were defined where there is opportunity to preserve or restore channel and floodplain processes. The boundary of each floodplain area was defined based on morphological features including terraces, alluvial fans, bedrock, and the main channel position in 2004 that separates one floodplain area from the next. Additional restoration may be needed in the main channel along the floodplain areas as part of a restoration strategy. For example, LWD may be added to the main channel. However, no obstructions or other features specifically in the main channel were identified that need to be addressed. The majority of restoration concepts involve addressing levees, riprap, bridges, and road embankments that prevent connectivity between the main channel and the floodplain.

The 132 floodplain areas were broken into 41 protection areas and 91 restoration areas (Figure A-13). Within the restoration category, 7 existing projects were included in the documentation to show how new projects link to areas already being treated. An additional 11 areas were separated out because they have substantial development currently in place that may require more long-term planning to implement. The tributary and consideration by others category includes 3 sites located adjacent to the boundaries of this assessment that were identified for potential restoration, subject to findings of subsequent analysis.

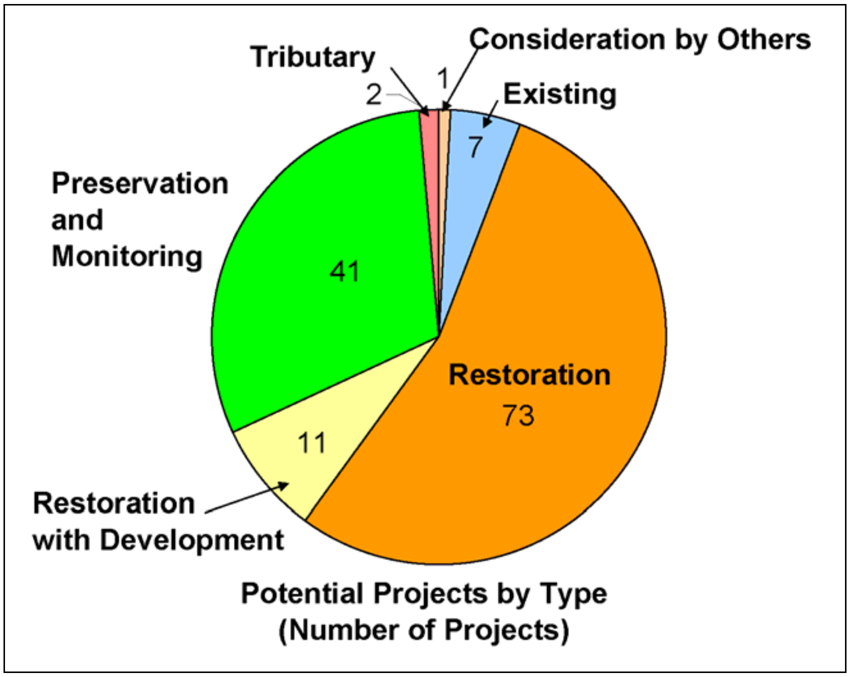

Figure A-13. Distribution of potential project types in assessment area.

5.1 LIST OF POTENTIAL PROTECTION AREA LOCATIONS AND TYPE

The 41 floodplain areas within the protection category are sites with no known human features or vegetation and LWD clearing that impact floodplain connectivity or complexity. These areas serve as opportunities for protection by local partners to prevent further development and vegetation clearing that would further impact habitat or cause a departure of channel and floodplain connectivity. These areas should be monitored in the future to ensure there are no human impacts that would transition this to a potential restoration area. Floodplain areas can vary in terms of benefit to restoring habitat and floodplain processes. Therefore, protection areas were categorized in terms of providing functioning wetland and/or channel network areas, providing a few well defined side channels, or providing an overbank flooding surface but no channels (Table A-6). The first two categories are considered to have a higher biological benefit in general terms of complexity habitat because they directly provide channels for off-channel habitat and channel migration. Overflow surfaces and channels are also important to reduce energy during floods in the main channel, but have a lower direct benefit for habitat compared to the other two types of floodplain areas. A full list of potential protection sites is provided in Table A-7, Table A-8, Table A-9, and Table A-10 and locations are shown in Figure A-3, Figure A-4, Figure A-5, and Figure A-6.

Table A-6. Classification of protection floodplain areas by geomorphic type.

Biological Benefit	Type	Category	
		Description	Percent of 80-mile assessment area [1/]
High	8	Functioning wetland or channel network area	15
High	7	Functioning side channels	8
Low	6	Functioning overflow channel or low surface (floodplain)	5

Note: Type 8 is "highest or best"; Numerical "type" value was also utilized in ranking of reaches (see Appx. B).
1/ does not include active channel

Table A-7. List of Middle Methow protection areas sorted by size of area.

River Segment	Reach	Protection Area Designation 1/	Type 2/	Floodplain Area (acres)	Cumulative Area Floodplain (acres)
Middle Methow	M4	MR_Prj-42.3	7	48	48
Middle Methow	M2	MR_Prj-34.6	6	27	75
Middle Methow	M4	MR_Prj-45.7	7	23	98
Middle Methow	M5	MR_Prj-48.5	7	18	116
Middle Methow	M2	MR_Prj-39.45	7	9	126

1/ MR = Methow River; Number represents upstream river mile of mainstem river channel adjacent to floodplain area;
2/ See Table A-6 for definitions of type.

Table A-8. List of Upper Methow protection areas sorted by size of area.

River Segment	Reach	Protection Area Designation 1/	Type 2/	Floodplain Area (acres)	Cumulative Area Floodplain (acres)
Upper Methow	M9	MR_Prj-58.6	8	263	263
Upper Methow	M11	MR_Prj-72.6	6	137	400
Upper Methow	M9	MR_Prj-58.9	8	79	479
Upper Methow	M9	MR_Prj-56.0	8	53	531
Upper Methow	M10	MR_Prj-68.6	7	40	571
Upper Methow	M11	MR_Prj-70.2	7	31	602
Upper Methow	M11	MR_Prj-70.25	7	26	628
Upper Methow	M10	MR_Prj-69.0	6	25	653
Upper Methow	M9	MR_Prj-64.1	8	23	676
Upper Methow	M10	MR_Prj-69.3	6	19	695
Upper Methow	M9	MR_Prj-60.5	8	15	710
Upper Methow	M10	MR_Prj-67.7	7	15	724
Upper Methow	M9	MR_Prj-59.6	8	14	739
Upper Methow	M10	MR_Prj-66.2	6	10	748

1/ MR = Methow River; Number represents upstream river mile of mainstem river channel adjacent to floodplain area;
2/ See Table A-6 for definitions of type.

Table A-9. List of Twisp protection areas sorted by size of area.

River Segment	Reach	Protection Area Designation [1/]	Type [2/]	Floodplain Area (acres)	Cumulative Area Floodplain (acres)
Twisp River	T6	TR_Prj-17.95	8	102	102
Twisp River	T6	TR_Prj-14.5	8	54	156
Twisp River	T6	TR_Prj-15.1	8	51	207
Twisp River	T6	TR_Prj-16.8	8	31	238
Twisp River	T5	TR_Prj-10.9	8	29	267
Twisp River	T3	TR_Prj-7.65	7	28	295
Twisp River	T2	TR_Prj-3.9	7	26	321
Twisp River	T6	TR_Prj-17.9	7	25	347
Twisp River	T3	TR_Prj-5.8	8	13	359
Twisp River	T6	TR_Prj-14.3	8	10	369
Twisp River	T3	TR_Prj-5.7	8	8	377
Twisp River	T4	TR_Prj-9.31	6	4	381

1/ TR = Twisp River; Number represents upstream river mile of mainstem river channel adjacent to floodplain area;

2/ See Table A-6 for definitions of type.

Table A-10. List of Chewuch protection areas sorted by size of area.

River Segment	Reach	Protection Area Designation [1/]	Type [2/]	Floodplain Area (acres)	Cumulative Area Floodplain (acres)
Chewuch River	C2	CR_Prj-3.85	7	85	85
Chewuch River	C2	CR_Prj-3.65	7	24	109
Chewuch River	C5	CR_Prj-13.7	6	16	125
Chewuch River	C3	CR_Prj-8.05	7	16	140
Chewuch River	C5	CR_Prj-13.9	6	12	153
Chewuch River	C2	CR_Prj-4.8	7	12	164
Chewuch River	C3	CR_Prj-9.2	6	10	174
Chewuch River	C3	CR_Prj-9.8	6	8	183
Chewuch River	C4	CR_Prj-11.5	6	6	189
Chewuch River	C4	CR_Prj-10.95	6	3	192

1/ CR = Chewuch River; Number represents upstream river mile of mainstem river channel adjacent to floodplain area;

2/ See Table A-6 for definitions of type.

5.2 LIST OF POTENTIAL RESTORATION AREAS AND CONCEPTS

Each of the 84 restoration areas represents a section of floodplain that has been disconnected from the active channel by human features or human activities. Human features that disconnect the floodplain were not used as boundaries of the restoration areas, but rather help define the potential restoration concepts within each floodplain restoration area. A list of 73 potential new restoration areas and initial restoration concepts for each area are provided in Attachment 2 to this appendix, with locations shown on Figure A-3, Figure A-4, Figure A-5, and Figure A-6.

Restoration concepts presented are only initial ideas based solely on the human features present and information available from this geomorphic assessment. Restoration areas should be viewed cumulatively with other potential project areas in a given reach to fully understand the potential benefits and issues that need to be addressed. For example, opening the floodplain on one side of the river will alter the energy and hydraulics on the opposite side. Additionally, opening up one section of floodplain may allow the river to be more fully connected with currently function areas (protection areas), creating a larger reach of viable habitat. These concepts also need to consider upstream and downstream processes, and integrated with biological evaluation of habitat complexity benefits and sustainability at each site.

Restoration areas with a type of "existing restoration site" have planning efforts already in place (not necessarily through the efforts of this assessment). Areas with a type of "restoration with development" have substantial infrastructure and restoration concepts were not identified at this scale of assessment, but could be further evaluated in future efforts.

5.3 SPATIAL DISTRIBUTION OF POTENTIAL PROJECT TYPES BY VALLEY SEGMENT

The distribution of protection and restoration sites by valley segment was compared, with the Middle and Upper Methow segments combined (Figure A-14). In comparing potential project types amongst the river segments (Middle and Upper Methow, Twisp, and Chewuch), most existing project work is presently being accomplished on the Twisp River. The highest amount of potential protection and restoration opportunities for future work are on the Methow River, because it is larger in size than the Chewuch and Twisp.

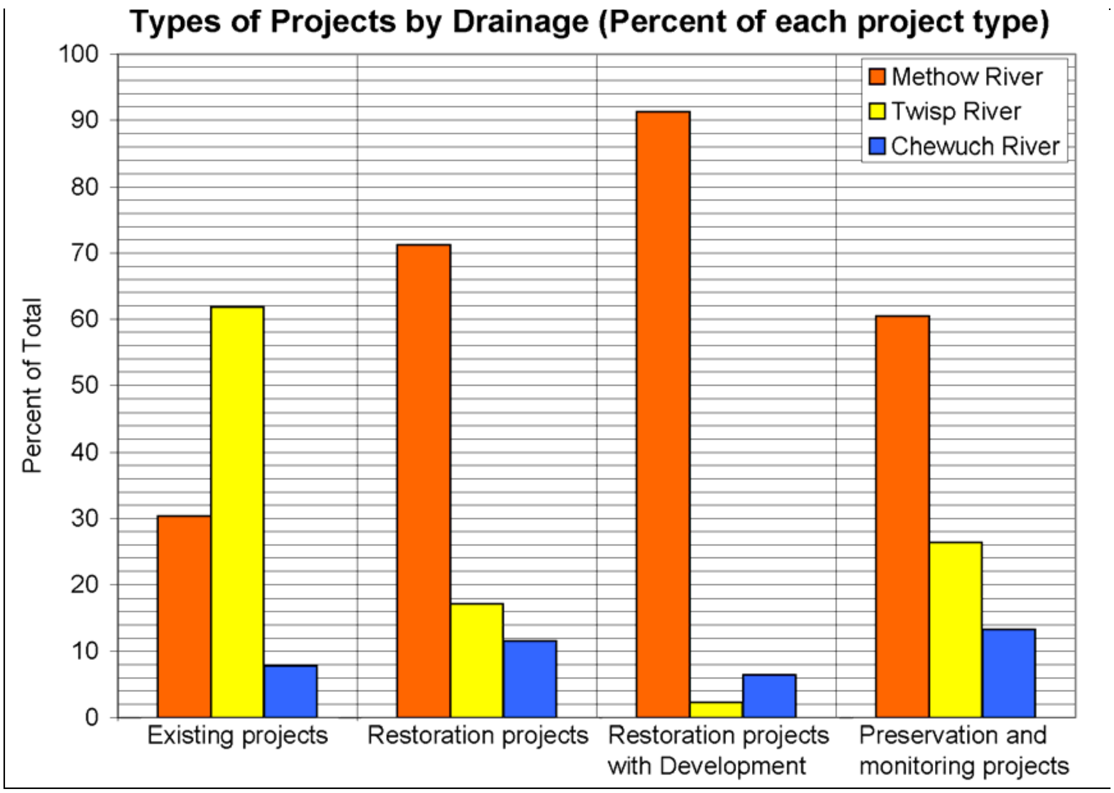

Figure A-14. Distribution of project type totals shown in previous figure by valley segment.

In Figure A-15, Figure A-16, and Figure A-17, symbols indicate the location and types of restoration and protection areas by river mile for each valley segment (Middle and Upper Methow are combined). For the restoration areas, where multiple symbols are shown, orange squares indicate potential projects that would reconnect channel networks and wetlands, blue squares indicate potential projects that would reconnect a primary side channel and adjacent floodplain, yellow squares indicate projects that would reconnect a primary side channel but not the adjacent floodplain, and green squares indicate projects that would reconnect overbank floodplain surfaces with no off-channel habitat.

On the Middle Methow and Upper Methow (Figure A-15), protection projects dominate in the upstream unconfined reach M9 and moderately confined reach M10, where channel networks and wetlands are common. Some restoration projects also are proposed for these two reaches, where channels or floodplain have been artificially cut off from the main channel. Restoration projects dominate in the downstream unconfined reaches M2 and M4, where primary side channels are common, and are often cut off from the main channel by a levee or diversion. Because of the higher surfaces that are present within the low surface in these two reaches, total floodplain reconnection may not be possible.

On the Twisp River (Figure A-16), most projects involve the reconnection of channel networks, primarily side channels, and floodplain. Projects that would reconnect channel networks are dominant in reaches T5 and T6. Projects that would reconnect primary side channels dominate in reaches T2 and T3. Protection and monitoring projects are present along most of the river, but are primarily located in the upstream unconfined reach, T6.

On the Chewuch River (Figure A-17), potential projects are a mix of sites recommended for protection and monitoring and those recommended for restoration. Restoration projects include reconnection of channel networks and wetlands or reconnection of a primary side channel.

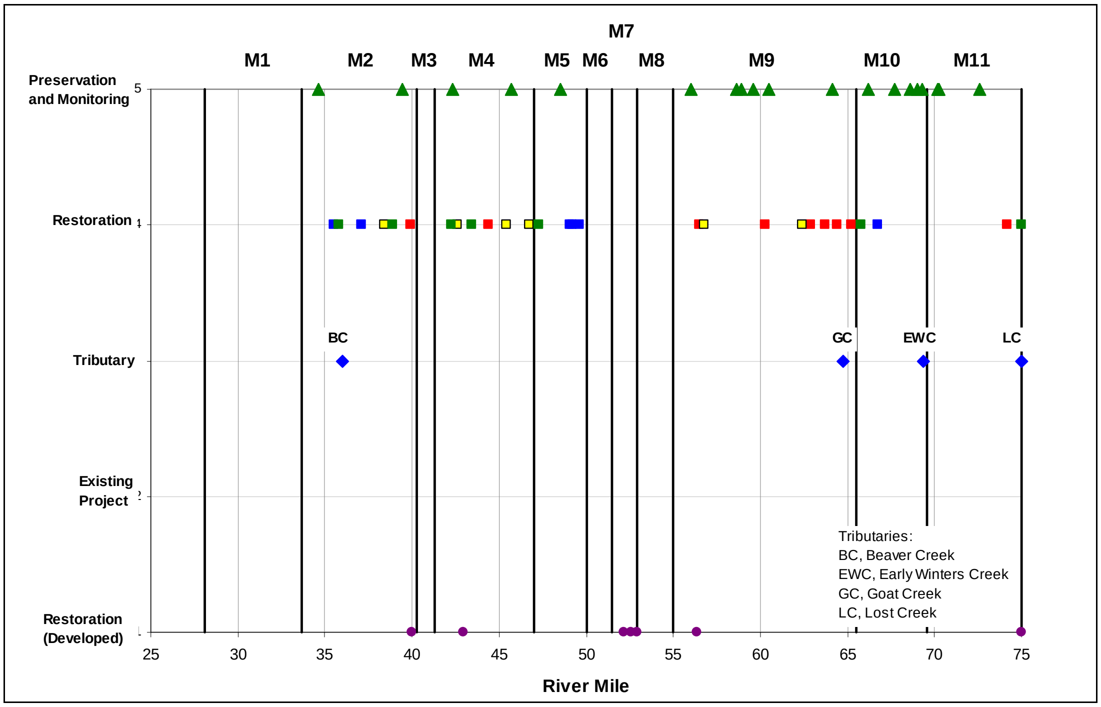

Figure A-15. Methow River – Types of proposed projects plotted by river mile, RM 28.1–75.

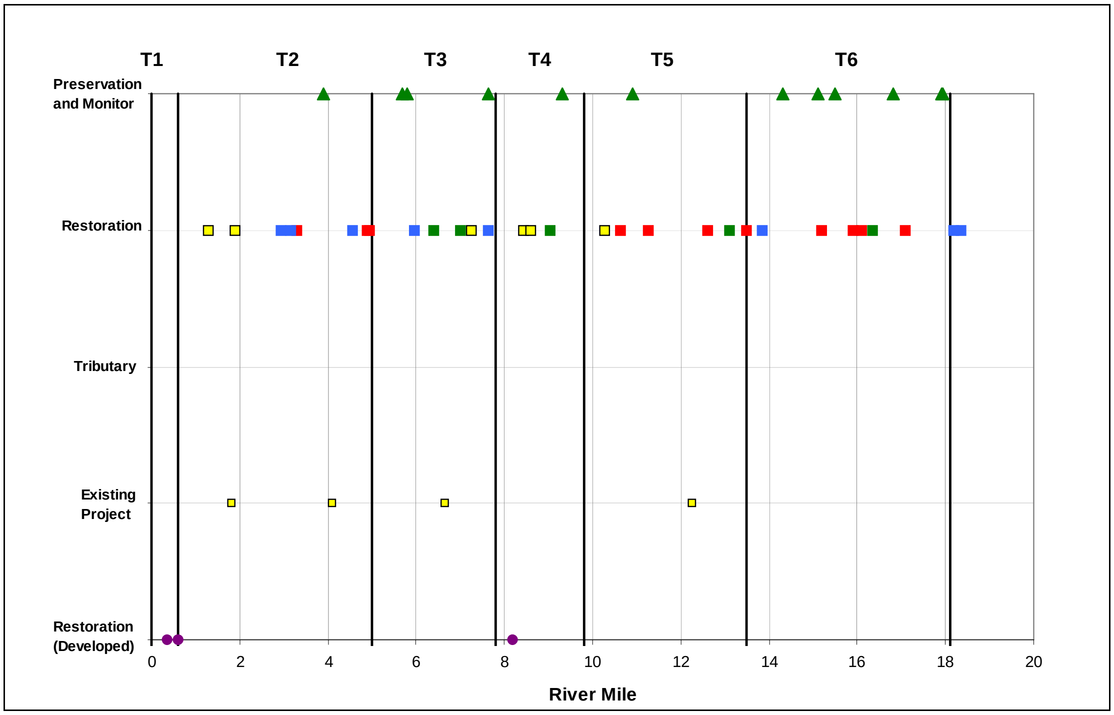

Figure A-16. Twisp River – Types of proposed projects plotted by river mile, RM 0–18.

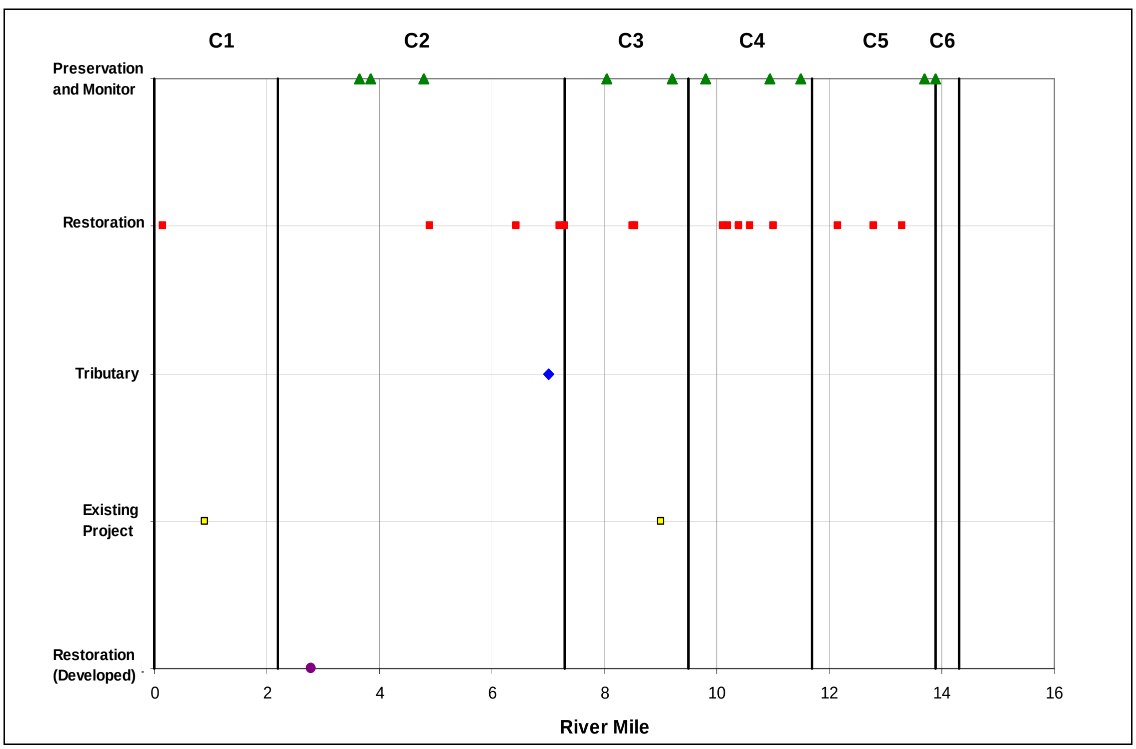

Figure A-17. Chewuch River – Types of proposed projects plotted by river mile, RM 0–14.

6. REFERENCES

IN TEXT	FULL CITATION
Hillman 2006	Hillman, T.W., 2006, *Monitoring strategy for the Upper Columbia Basin.*
ICBTRT 2007	Interior Columbia Basin Technical Recovery Team, July 2007, *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* [“current draft”], 49 pp.
McElhany et al. 2000	McElhany, P., Ruckelshaus, M.H., Ford, M.J., Wainwright, T.C., and Bjorkstedt, E.P., 2000, *Viable salmonid populations and recovery of evolutionary significant units, Technical Memorandum NMFS-NWFSC-42:* National Marine Fisheries Service, Seattle, WA.
NMFS 2007a	National Marine Fisheries Service, 2007a, *Adaptive Management for ESA-Listed Salmon and Steelhead Recovery: Decision Framework and Monitoring Guidance*: 56 pp. NMFS Northwest Regional and Northwest Fisheries Science Center.
Northwest Forest Plan 1994	US Forest Service and US Bureau of Land Management, April 1994 (and as amended) • *Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl,* • *Standards and Guidelines for Management of Habitat for Late-Succession and Old-Growth Forest Related Species with the Range of the Northern Spotted Owl,* See at http://www.fs.fed.us/r6/nwfp.htm (as 12/04/07)
UCRTT 2007	Upper Columbia Regional Technical Team, 2007, *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board.* August 2007. Wenatchee, WA. Appendix H of UCSRB 2007. See at http://www.ucsrb.com/plan.asp (as of 12/04/07).
UCSRB 2007	Upper Columbia Salmon Recovery Board, 2007, *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan.* Wenatchee, WA. 300 pp. See at http://www.ucsrb.com/plan.asp (as of 12/03/07).

ATTACHMENT 1 - LIST OF REACH–BASED RESTORATION STRATEGIES

Summary descriptions of restoration concepts for each of the 23 geomorphic reaches are provided below by valley segment (e.g. middle Methow, Upper Methow, Twisp, and Chewuch) for the 80-mile assessment area based on the findings of this geomorphic report.

MIDDLE METHOW REACHES (M1 to M6, RM 28 to 51.5)

Reach M1 is 5.6 miles long and located between RM 28.1 (near Carlton) and RM 33.7. The reach is a naturally confined with a single-thread channel located between glacial deposits, alluvial-fan deposits, or bedrock up to 200 ft high. Minimal channel migration has occurred between 1948 and 2004, and human activities are limited to riprap along the boundary of the floodplain on glacial terraces that have been cleared of vegetation. A few houses and associated roads also exist between RM 30 and RM 30.2. Only about 11% of the floodplain (low surface) has been cleared of vegetation, concentrated around RM 29 and 30. The need for restoring the 27% of terrace banks that have been riprapped could be further evaluated, but no channel or floodplain reconnection projects are proposed. However, the benefit of such activities to fish is expected to be small because these banks are generally high in elevation above the river and thus provide minimal potential LWD recruitment or shade and cover benefits relative to other reaches.

Reach M2 is 6.6 miles long and located between RM 33.7 and RM 40.3. This reach is the first unconfined floodplain with off-channel habitat encountered by fish migrating up the Methow. The majority of area downstream of M2 is naturally confined with single thread channels. Several sections in M2 contain well defined side and overflow channels and evidence of historic channel migration, but only 7% of the floodplain has not been affected by human features. The reach may have cold water recharge areas from groundwater seepage and a few ponded areas are present. Levee removal or setback at RM 35.5 would restore access to the upstream end of side channels providing off-channel habitat. Removal of riprap at RM 35.5, 35.8, and 37 would allowing for more natural rates of channel migration (assuming natural vegetation) and more river access to the floodplain.. Combined with two other smaller areas, levee and riprap setback could yield up to 7 miles of off-channel habitat, compared to about 1 mile currently available. The vegetation has been cleared in 24% of the floodplain. This limits the recruitment potential for LWD if side channels are re-accessed, suggesting additional LWD placement or riparian tree planting could be done to speed recovery in conjunction with off-channel reconnection projects. Other smaller opportunities also exist to restore access to overflow channels accessed during large floods, and to restore native vegetation along 23% of the terrace banks that have been riprapped. One project area MR_Prj-40.0 has substantial development that is part of the town of Twisp, but if restored could yield another 1 mile of side channel.

Reach M3 is a 1-mile long naturally confined reach through the town of Twisp that is bounded between RM 40.3 and RM 41.3. The Twisp River enters the Methow River at RM 41.1. The reach consists of a single main channel with limited floodplain bound by bedrock or high-elevation surfaces composed of glacial deposits. Only about 5% of the floodplain has been cleared of vegetation, but riprap has been placed along 61% of the terrace banks that border the floodplain. Potential restoration activities are limited to replacing the riprap on the terrace banks with native vegetation. Effects to water quality or runoff from the town of Twisp were not evaluated.

Reach M4 is 5.7 miles long and is located between RM 41.3, just upstream of the confluence with the Twisp River, and RM 47. The channel system in this reach is composed of side channels along with a network of secondary and overflow channels in some areas. Backwater ponding and beaver activity are present at the downstream ends of the side channels. At least 7 miles of side channels have been disconnected by levees, roads, and development, with only slightly more than 1 mile presently connected. Restoration of access to off-channel habitat could occur at MR_Prj-42.6, MR_Prj-44.4, MR_Prj-45.4, and MR_Prj-46.75. In the two project areas Prj-44.4 and Prj-45.5, levees block the upstream entrances to the channels and road crossings have been placed throughout the channels. An additional mile of well defined side channel in MR_Prj-42.95 is cut off by the highway and could possibly be reconnected with improved culverts or a highway setback could occur. Several springs enter the river in this reach, which appeared to have a cooling effect on water temperatures during base flow conditions that may boost habitat use if off-channel areas are restored (Appendix I). Nearly 40% of the floodplain vegetation has been cleared that could be replanted to improve roughness function of the floodplain during floods, and allow better recruitment potential for LWD if the channel is allowed to access the floodplain. About 17% of terrace banks along the boundary of the floodplain have been riprapped along the outside of meander bends. The Methow Valley Irrigation District (MVID) had a 3 ft diversion dam (MVID East) near RM 46 that was lowered in 2007 to eliminate any portion of the dam protruding above the river bed that could interfere with fish passage at low flows. Additional design work is being accomplished by Reclamation to improve the head works and flood protection of a recently added MVID East diversion structure that utilizes a small constructed channel on river left, parallel to the existing main channel.

Reach M5, which is 3 miles long, is located between RM 47 and RM 50. This reach is moderately confined by mostly glacial deposits and in some areas by bedrock. Side channels have been disconnected by levees, roads, and development. Only 0.2 miles of side channel are presently accessible. In MR_Prj-49.65 an existing diversion channel is present. Just adjacent to this diversion channel is a well developed side channel with good riparian vegetation and beaver activity. The diversion channel could be enhanced to provide more complexity and connectivity with the existing side channel using LWD and riparian planting if it does not impact diversion capabilities or is considered for replacement with wells. In MR_Prj-49.1 and 49.2 there are two 0.3-mile long side channels that could be reconnected by removing riprap that blocks the upstream entrance. Some excavation may be needed in Prj-49.1 to remove fill material. About 14% of the floodplain boundary has been riprapped, and 27% of the floodplain vegetation has been cleared that could also be addressed as a secondary effort.

Reach M6, which is 1.5 miles long, is located between RM 50 and RM 51.5, where the Chewuch River enters the Methow River and the town of Winthrop is located. This reach is naturally confined by high surfaces composed of glacial deposits, or bedrock, such as near RM 50 and just upstream of RM 51. The Chewuch River contributes almost as much flow as the Methow River at its confluence (Appendix J). In 2006, the Chewuch River caused a nearly 1º C rise in temperature in the mainstem Methow, possibly due to large fires occurring in the upper Chewuch watershed. Prior to the fires, temperature measurements did not show a warming effect. Because the floodplain is naturally confined, the impacts of human activities are limited to armoring along 12% of the glacial banks on river left at the upstream end. Less than 5% of the floodplain has been cleared of vegetation. There is one bridge, but it is located at a natural constriction. Effects to water quality or runoff from development at the town of Winthrop were not evaluated.

UPPER METHOW REACHES (M7 to M11, RM 51.5 to 75)

Reach M7, which is 1.4 miles long, is located between RM 51.5 (confluence of the Chewuch River), and RM 52.9 and includes part of the town of Winthrop. The reach is moderately confined, with a floodplain more than three times wider than the naturally confined reaches just downstream (M6) and upstream (M8). The floodplain is bounded by high surfaces composed of glacial deposits or bedrock. Channel migration has historically occurred, and side channels are evident. The reach has been documented to gain river flow from groundwater during low-flow periods (Konrad, 2003). There are no functioning floodplain areas in this reach due to houses, roads, and development that have decreased the floodplain width by nearly 900 ft and cut off 1.4 miles of side channels. MR_Prj-52.6 has significant development including houses and roads that pose a challenge to reconnection opportunities. The Winthrop hatchery is present in MR_Prj-52.15 and more detailed analysis is needed to see if there are any opportunities for enhancement to the connectivity and function of the side channel in this area. About 41% of the floodplain has been cleared of natural vegetation, but only 4% of the terrace banks have been riprapped. Due to the heavy development, it may be worth looking for opportunities to protect any banks that are currently eroding and threatening infrastructure with methods that incorporate habitat features such as LWD, rather than waiting until the next large flood occurs.

Reach M8, which is 2.1 miles long, is a naturally confined reach located between RM 52.9 and RM 55. The floodplain is bounded by high surfaces composed of glacial deposits and a large alluvial-fan deposit from Wolf Creek on river right near RM 54. Wolf Creek is the largest tributary in this reach, and was observed to have debris flows on the 1948 and 1974 aerial photographs. Since 1974, several areas of Wolf Creek have been developed and the alluvial fan has been channelized that could be evaluated in a separate effort for habitat restoration opportunities. A few LWD and pool formation restoration efforts were done in 2000 in lower 1.5 miles according to KWA, 2004). Water temperature measurements indicate Wolf Creek presently causes a warming effect on Methow River flows (Appendix I). About 11% of the floodplain has been cleared of vegetation and 40% of glacial banks have been riprapped. There are no off-channel habitat areas, so restoration opportunities in this reach are limited to evaluating if floodplain boundaries that have been riprapped could be improved to provide better habitat features and looking more closely at the Wolf Creek drainage.

Reach M9 is 10.5 miles long and is located between RM 55 and RM 65.5, near the mouth of Goat Creek. This is an unconfined reach, which has a wide and forested floodplain, extensive channel networks, and water-filled abandoned channels. Historically, channel migration has actively occurred in this reach creating a channel network of active, recently active, and abandoned main channels, secondary channels, and overflow channels. The mainstem flow gains groundwater during base-flow periods in late summer, and two seeps (Hancock Springs and Suspension Creek) provide cooling effects at RM 60 and RM 60.3. There are presently at least 11.4 miles of side channels not cut off by levees, roads, or other features and more than 9.7 miles of potential additional channels that could be reconnected and/or enhanced. The largest man-made confinement to the floodplain is from Weeman Bridge at RM 61.2, which if widened could increase channel migration and off-channel habitat availability both upstream and downstream of the bridge. Other smaller roads, embankment dams, and fill have occurred sporadically throughout the reach and impact the connectivity and inundation frequency of smaller channels within the floodplain. Notable constrictions are embankment dams near RM 56, a pedestrian tramway that contains bank armoring at RM 57, a suspension bridge near RM 65, and several small levees. About 13% of the floodplain vegetation has been cleared, which occurs mostly near Weeman Bridge. Historically, log drives and log mills were present in this reach which reduced LWD levels. The 1948 flood also notably washed out LWD in many areas and remaining LWD was removed following the flood. Although several small features disconnect the floodplain, this area also has diverse, healthy riparian vegetation with 34% of the reach identified for protection (Appendix H). Additionally, high density spawning use occurs in the vicinity of the spring outlets. This reach offers a great opportunity to enhance and expand existing habitat by fixing several smaller features that presently impact channel migration and floodplain connectivity. Upstream of Weeman Bridge, dewatering has been observed to occur in dry years during late fall and early winter periods. The longitudinal extent and duration of dewatering varies from year to year depending on flow conditions (wet or dry year). A spring at Suspension Creek at RM 64.5 helps mitigate for the dewatering and can keep pools wetted between the spring and the Weeman Bridge. Past studies suggest the dewatering is a natural occurrence, but local wells and diversions may cause dewatering to occur earlier than in natural conditions. If information is available, further research could be done to better evaluate this issue. Reach M9 is a naturally gaining reach, and downstream of Weeman Bridge flows were documented to gradually increase from groundwater sources (Appendix F). A pilot project could be placing additional LWD in the channel to form scour pools deep enough to hold water during the low-flow summer period and provide some localized refuge when the flow reduces.

Reach M10, which is 4.1 miles long, is located between RM 65.5 and RM 69.6, just upstream of Early Winters Creek. This reach is moderately confined with 1.2 miles of small side channels presently accessible and about 52% of the reach presently functioning. The large alluvial-fan deposits from Goat Creek, Little Boulder Creek, and Early Winters Creek naturally constrict the floodplain and naturally limit channel migration. The channel occasionally dewaters during the late summer and fall in very dry years (Konrad and others, 2003). An additional 1.2 miles of channels have been disconnected that would increase off-channel habitat availability. The main restoration effort in this section could be to modify an artificial pond near RM 66.25 to improve function of the side channel presently being used as a road. A smaller floodplain area in Prj-65.8 could also be restored by breaching, setting back, or removing a levee. Log drives also occurred historically in this reach, and some LWD placement may be appropriate to restore natural levels, although a fair amount of LWD is present in the channel as of 2006. About 12% of the floodplain vegetation has been cleared and 7% of the banks along the floodplain boundary are riprapped near the town of Mazama. The lower 2 miles of Early Winters has been channelized to accommodate Highway 20 (KWA, 2004) and could be evaluated in a separate effort for restoration opportunities. The Goat Creek drainage has 150 miles of roads (KWA, 2004) that may need to be further evaluated to determine if there is any impact on restoration projects proposed in this reach.

Reach M11, which is 5.4 miles long, is located between RM 69.6, at the Early Winters alluvial-fan deposit, and the confluence of Lost Creek and the West Fork Methow River near RM 75. This is an important spawning and rearing area for salmonids, and is also an important migration corridor for fish utilizing additional key habitat areas in the upstream West Fork and Lost River sections. This is an unconfined reach bounded by high banks composed of glacial deposits, alluvial-fan deposits, and bedrock. The large alluvial-fan deposit from Early Winters Creek at RM 69.6 naturally limits channel migration and the floodplain width. This reach naturally loses river flow to the groundwater aquifer and commonly dewaters during the late summer and fall (Konrad et al. 2003). Ponded areas, especially in abandoned channel paths, are common. The floodplain has extensive forest, channel networks, and LWD present, and the lower half (38%) of the floodplain is identified for protection strategies. About 3.2 miles of off-channel habitat are presently available, mostly in the lower half of the reach, but at least 2.8 miles are directly cut off by human features in the upper half of the reach (MR_Prj-74.15 is less developed and MR_Prj-75.01 is more developed). The floodplain has been narrowed significantly by roads, levees, houses, and development appears to be expanding in the upper half of the reach. Because many of these developments are in the floodplain, the long-term potential for impacting channel and floodplain processes is likely high assuming many of these areas will be protected following the next large flood. Overall floodplain vegetation has been cleared in only 8% of the reach, but in localized areas of development clearing is becoming more prevalent. About 7% of the terrace banks have been armored with riprap.

Due to the residential development, restoration strategies will need careful consideration to determine if there are opportunities to work with existing land use to reconnect off-channel habitat without endangering residents.

TWISP REACHES (T1 to T6, RM 0 to 18.1)

Reach T1 is naturally confined reach 0.6 miles long and located between RM 0 (confluence with Methow) and RM 0.6. The town of Twisp is on surfaces bounding both sides of the reach. The floodplain is bounded by bedrock or high banks that are composed of glacial deposits and only a few high flow channels are naturally present. Although the floodplain is naturally confined, it has been further narrowed by levees, roads, and houses. About 33% of the terrace banks that bounded the floodplain are riprapped. Restoration opportunities may be limited due to land use and no channel or floodplain reconnections are proposed.

Reach T2, which is 4.4 miles long, is an unconfined reach located between RM 0.6 and RM 5, near the mouth of Poorman Creek. The floodplain is naturally narrower downstream of RM 1.7 than in the upstream part of the reach. Downstream of RM 1.7, the floodplain is bounded by bedrock and high surfaces that are composed of glacial deposits. Upstream of RM 1.7, the floodplain is bounded by mostly glacial deposits, and small alluvial-fan deposits and landslide/debris flow deposits. There is one seep identified in this reach, near RM 2.8, and ponded areas, mostly in abandoned channels, are present near RM 1.5 and between RM 3.5 and RM 4. Only 9% of the reach is functioning with less than 1 mile of side channels presently accessible. Unlike other areas where levees and riprap mainly block off entrances to side channels, reach T2 has long distances of riprap and levees that run parallel to the main channel. These human features cut off access to nearly 5 miles of side channels and floodplain areas and prevent channel migration, particularly between RM 1.7 and RM 5. Irrigation withdrawals occur at two locations: MVID West at RM 3.9, and Brown/Gillihan Ditch at RM 4.6. MVID West is located in TR_Prj-4.1 where a series of ponds were constructed between 1954 and 1964 based on historical aerial photography from these years. It is unclear based on aerial photography if the ponds were dug along the path of a historic side channel or in a higher elevation floodplain surface. The MVID West diversion and ponds and side channels in TR_Prj-4.1 are presently being evaluated by Reclamation and local partners to update the diversion infrastructure and identify floodplain restoration opportunities. Restoration projects TR_Prj-4.9, TR_Prj-3.3, TR_Prj-3.15, and TR_Prj-1.8 offers an opportunity to restore nearly 4 miles of side channel habitat by addressing riprap, levees, and push-up levees that prevent channel migration and block access to the floodplain. TR_Prj-1.8 appears to have more disturbances to the historic channels including a series of man-made ponds that may require additional steps to identify restoration opportunities. Remaining project areas offer opportunities to restore access to secondary and overflow channels (less frequently inundated), and floodplain areas. About 39% of the floodplain has been cleared of vegetation, but only 3 % of the floodplain boundary has been riprapped. Historically, LWD removal occurred in the 1960s and 1970s along several sections of Twisp River including Reach T2, which may justify adding LWD back in the channel in appropriate locations.

Reach T3 is 2.8 miles long and located between RM 5, near the mouth of Poorman Creek, and RM 7.8, where Myer and Newby creeks join the Twisp River and their alluvial-fan deposits create a confined section. Reach T3 is a moderately confined reach bounded by mostly glacial deposits and a few small alluvial-fan deposits, with a narrow section naturally confined by bedrock at the downstream end (RM 5 to 5.4). One seepage area is present near RM 7.4 that may offer cold water recharge and a high density of spawning has been noted to occur at this location. About 45% of this reach is functioning and 1 mile of channels are presently accessible, but many key areas are disconnected by levees, roads, and other features. TR_Prj-6.65 (Elbow Coulee) is an existing project site where possibly up to 0.3 miles of side channel reconnections are being considered. There is an additional 0.4 miles of side and overflow channels that could be reconnected. TR_Prj-7.25 has a 0.2-mile long side channel that would provide off-channel habitat across from a protection area where a lot of spawning presently occurs. However, roads, bridges and development are present in addition to riprap along most of the channel length where floodplain side channel are blocked. The remaining potential project areas contain small amounts of riprap and levees that block upstream and downstream ends of channels. About 22% of the floodplain vegetation has been cleared, and 9% of the floodplain boundary has been riprapped. Irrigation withdrawals occur at two locations: Hottel Diversion at RM 6 and Twisp River Power and Irrigation Ditch at RM 6.9.

Reach T4 is a naturally confined 2-mile long reach located between RM 7.8, at the confluence of Newby and Myer creeks, and RM 9.8, near the confluence of Little Bridge Creek. This reach has a fairly steep slope relative to a flatter channel slope that occurs upstream of this reach. Although mostly confined by glacial surfaces and bedrock, there are a few floodplain areas that offer opportunities to restore floodplain access by addressing bridges, roads, and riprap located in the floodplain. However, development and infrastructure are present in 2 of the 3 potential areas. About 16% of the floodplain boundary has been riprapped that could be addressed. About 15% of the floodplain vegetation has been cleared for agriculture, grazing, and development.

Reach T5, which is 3.7 miles long, is located between RM 9.8, near the confluence of Little Bridge Creek, and RM 13.5. It is an unconfined reach with several wetland and channel networks areas, except for a 0.2-mile-long section between RM 13.3 and RM 13.5 confined by opposing alluvial-fan deposits from Buttermilk and Canyon creeks. The floodplain is bounded by bedrock, glacial deposits, alluvial-fan deposits (especially the large one from Buttermilk Creek), and short sections of landslide/debris-flow deposits. Only 14% of the reach is presently functioning that is composed of a fairly large floodplain area containing a 0.5-mile long side channel. Two additional large floodplain areas (TR_Prj-11.25 and 12.25) upstream of the protection site (TR_Prj-10.9) could be restored by removing small levees that block upstream and lateral connectivity with the main channel, and riprap that prevents channel migration. These three areas would provide a large cumulative area of functioning habitat. Both areas have good riparian vegetation and evidence of numerous side channels that would provide good off-channel habitat. Small amounts of side channel excavation at the upstream ends may be needed to jump start connectivity with the main channel. This reach would naturally have extensive channel migration and LWD recruitment, and additionally adding LWD could restore a large section of functioning habitat that has the potential to support a wide range of life stages. Nearly one-third of the floodplain vegetation has been cleared, mostly in the upstream end of the reach. Smaller floodplain areas at the upstream end where vegetation has been cleared could also be restored by removing riprap along the main channel and replanting vegetation. Because riparian vegetation may take decades to establish, riprap or other temporary stabilization measures may be needed to prevent accelerated rates of bank erosion until vegetation re-establishes. One diversion occurs at RM 11.1 (Elmer Johnson/ Libby/Culbertson Ditch) but there is no known need for rehabilitation of this infrastructure. About 8% of floodplain banks have been armored with riprap along the outside of meander bends, which could be evaluated to see if there is a need for addressing the riprap in terms of habitat function.

Reach T6 is 4.6 miles long and located between RM 13.5, near the confluence of Buttermilk and Canyon creeks, and RM 18.1, just upstream of the confluences of Eagle and War creeks. It is an unconfined reach with multiple channel networks, springs, and wetlands. The floodplain is bounded by primarily alluvial-fan deposits and some glacial deposits with no riprap. About 60% of this reach has functioning floodplain areas with at least 1.8 miles of side channels and a generally healthy riparian vegetation zone. However, in the middle of the reach between RM 15 and the USFS boundary at RM 17 development has recently increased. This area poses opportunities to reconnect at least 0.7 mile of side channels, with several more not detected on 2004 aerial photography, but visible on 2006 LiDAR. This would provide a cumulative benefit of a large functioning habitat area since there are protection areas just downstream and upstream. There are several levees and a few areas of riprap that prevent connectivity with the main channel, and about 8% of the floodplain vegetation has been cleared mostly near RM 16.2.

CHEWUCH REACHES (C1 to C6, RM 0 to 14.3)

Reach C1 is a 2.2-miles long naturally confined reach located between the confluence with the Methow River at Winthrop (RM 0) and RM 2.2. The floodplain is bound by glacial deposits and bedrock at the downstream end. Two landslide/debris flow deposits are present along the low surface (near RM 0.4 and near RM 0.95). A few houses are present within the floodplain, but only 9% of floodplain vegetation has been cleared. Due to the large amount of bedrock, only 2% of the floodplain banks are riprapped. There are no restoration areas proposed in this reach, except for very minor areas with houses or riprap. The Fulton diversion dam is located at RM 0.9 and has been recently updated to improve fish passage.

Reach C2, which is 5.1 miles long, is located between RM 2.2 and RM 7.3, near the confluence of Cub Creek. This is an unconfined reach with 2.5 miles of existing side channels. About one-third of the reach that is presently functioning and identified for protection between RM 2.8 and 3.9. A fair amount of spawning presently occurs throughout this reach. Between RM 3.9 and 7.3 there are at least 3.4 miles of channels that could be reconnected to create off-channel habitat areas. The cumulative length of all channels mapped is the longest of the six Chewuch River reaches evaluated. There appears to be only a few small levees, dikes, and roads that need to be addressed to reconnect side channels and floodplain areas. These human features limit the present width of the low surface to between 130 ft and 230 ft less than the geologic width of the low surface. About 17% of the floodplain vegetation has been cleared, particularly between RM 3 and 4. No riprap was noted on terrace banks (floodplain boundary). Diversion of water by the Chewuch diversion dam and irrigation withdrawals decreases the flows in this reach, especially in late summer.

Reach C3, which is 2.2 miles long, is located between RM 7.3, near Cub Creek, and RM 9.5, near the middle of the large alluvial-fan deposit from Boulder Creek. This is a moderately confined reach bound by bedrock and glacial deposits, mostly, and by a large alluvial-fan deposit from Boulder Creek at the upstream reach boundary. In this reach, the slope progressively steepens to the confluence with Boulder Creek, and large boulders originating from Boulder Creek line the Chewuch River bed. There are 0.7 miles of side channels currently accessible, and only 0.1 miles that could be reconnected. The main human features are a few small areas of riprap, which could be removed to restore access to the side channel. In several areas the riprap is placed along the edge of a floodplain surface which does not limit access to the floodplain, but does alter channel hydraulics in the main river. These areas could be replaced with protection that incorporates LWD to break up the hydraulics along these banks, or remove the protection if no longer needed. The Chewuch diversion dam is located at RM 9.3, and has been recently updated to improve fish passage.

Reach C4, which is 2.2 miles long, is located between RM 9.5, where Boulder Creek joins the Chewuch River, and RM 11.7, where Eightmile Creek joins the Chewuch River. This reach is composed of two confined sections between RM 9.5 and RM 9.8 and RM 10.4 to 11.7, and a moderately confined section between RM 9.8 and RM 10.4. CR_Prj-10.1 and 10.4L are the main opportunities in this reach to restore access to side channel and wetland areas. Small amounts of riprap could be removed near RM 10.4 to 10.5 with a possible need for excavating fill material from side channels. In CR_Prj-10.1 there is a small amount of clearing with possible fill placed in side channels, but this reach may be a protection area if subsequent field work does not find any human features. Some of the most heavily used spring Chinook spawning habitat can be found in the Chewuch River between the confluence of Boulder Creek and Eightmile Creek. This reach is upstream of all major irrigation diversions and has the greatest late summer stream flows and the coldest water according to local USFS biologists. This is because of spring-fed water from Eightmile Creek (Appendix I). Bull trout also use the reach for foraging, especially in the cold water areas near Eightmile Creek. Eightmile Creek contributes finer-sized sediment to the Chewuch River, believed to originate from timber harvesting activities that may need to be considered as part of a separate analysis (Appendix N). A small amount of floodplain vegetation has been cleared in 13 % of the reach. In 1961, the USFS funded the removal of debris and logjams in portions of both the Chewuch River and Boulder Creek (Andonaegui, 2000). The Chewuch watershed analysis reports that large-scale, channel-clean-out efforts removed additional LWD and log jams following the 1948 and 1972 floods (Smith et al, 2000). LWD placement may be beneficial as part of a restoration strategy, particularly between RM 9.8 and 10.4

Reach C5, which is 2.2 miles long, is located between RM 11.7 (Eightmile Creek) and RM 13.9. This is an unconfined reach with several wetland and channel network areas on either side of the river. This area is also a high spawning use area. The main human features are a series of riprapped banks between RM 12.8 and 13 that block off at least 0.5 miles of side channels, and likely more once LiDAR is used to update channel mapping. Riparian vegetation is generally in good condition, but development does exist that will need to be considered in restoration plans. Only a small area of the floodplain vegetation has been cleared and there is no riprap on terrace banks.

Reach C6 is a 0.4-mile long, naturally confined reach located between RM 13.9 and RM 14.3, where Falls and Butte Creek join the Chewuch River at the USFS boundary. The floodplain, which is only about 300 ft wide, is confined by alluvial-fan deposits from Falls Creek on river right and from Butte Creek on river left. There are no known human features that need to be addressed. Springs are present at Falls Creek, near the upstream reach boundary. Upstream of this reach, the land is managed by the USFS. Major wildfires have burned with varying intensities in 70% of the upper Chewuch watershed in 2001, 2003, and again in 2006 (Methow Valley Ranger District, 2007). In the summer of 2004 major landslides and debris torrents (Andrews Creek and Lake Creek drainages) occurred in the upper watershed and had a dramatic effect on the watershed. There was concern at the time that ESA-listed fish species would be negatively affected by the 2001 and 2003 fires. However, bull trout and spring Chinook redd counts show that populations have been maintained at pre-disturbance levels and the distribution of redds has slightly expanded to take advantage of new habitat created by the landslides.

ATTACHMENT 2 - LIST OF POTENTIAL FLOODPLAIN RESTORATION PROJECTS AND CONCEPTS

Tables of initial restoration concepts are provided below for the Middle Methow, Upper Methow, Twisp River, and Chewuch River.

Attachment Table A– 1. List of Middle Methow floodplain areas in need of restoration and initial concepts for consideration in scoping the next phase of assessment.

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Middle Methow	M2	MR_Prj-35.5	Restoration	Reconnect primary side channel	Remove levee and riprap at the upstream end of the site between RM 35.5 and RM 35.35, remove push-up levee at the downstream end of the site between RM 34.25 and RM 34.1, and remove riprap between RM 35.3 and RM 34.8
Middle Methow	M2	MR_Prj-35.8	Restoration	Reconnect low surface (floodplain)	Remove riprap along river between RM 35.8 and RM 35.65
Middle Methow	M2	MR_Prj-37.1	Restoration	Reconnect secondary channels	Remove riprap and cabled logs between RM 37.1 and RM 36.9
Middle Methow	M2	MR_Prj-38.4	Restoration	Reconnect primary side channel with wetland	Redesign levee along the upstream end of the project area between RM 38.4 and RM 38.1, redesign or remove small dams and roads across channel in several places
Middle Methow	M2	MR_Prj-38.9	Restoration	Reconnect overflow channels	Remove riprap along the project site between RM 38.9 and RM 38.1
Middle Methow	M2	MR_Prj-39.9	Restoration	Reconnect secondary channels with wetland	Remove riprap between RM 39.9 and near RM 39.7, and add culverts at road (Twisp-Carlton highway)
Middle Methow	M2	MR_Prj-40.0	Restoration with Development		
Middle Methow	M4	MR_Prj-42.25	Restoration	Reconnect low surface (floodplain)	Remove riprap between RM 42.25 and RM 41.9
Middle Methow	M4	MR_Prj-42.6	Restoration	Reconnect overflow channels	Remove or redesign one or both levees between RM 42.6 and RM 42.3; could consider connecting the upstream end only and leaving the levee farther from the river
Middle Methow	M4	MR_Prj-42.95	Restoration with Development		
Middle Methow	M4	MR_Prj-43.4	Restoration	Reconnect low surface (floodplain)	Restore cleared areas; buildings
Middle Methow	M4	MR_Prj-44.4	Restoration	Reconnect secondary and overflow channels	Excavate entrances to channels and improve connectivity, remove riprap between RM 43.2 and RM 43.4, remove push-up levee between RM 44.3 and RM 44.1; restore cleared areas

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Middle Methow	M4	MR_Prj-45.4	Restoration	Reconnect primary side channel (located farther from river) with wetlands and secondary channel (closer to river)	Remove or setback levee, remove push-up levee, and remove riprap between RM 45.4 and RM 45, redesign or remove roads and small dams or footbridges at several locations
Middle Methow	M4	MR_Prj-46.75	Restoration	Reconnect secondary and overflow channels	MVID diversion dam is being considered for replacement with an upstream diversion structure; remove levee on right bank and push-up levee on right side channel between RM 46.25 and RM 46.0, add (or replace) culvert for a road (old highway) that cuts across the site between RM 46.1 and RM 45.6, provide backwater connection to downstream secondary channel, restore cleared areas
Middle Methow	M5	MR_Prj-47.3	Restoration	Reconnect low surface (floodplain)	Redesign or remove road, or add culverts
Middle Methow	M5	MR_Prj-49.1	Restoration	Reconnect primary side channel	Remove or redesign fill at the upstream end of the primary side channel near RM 49, redesign or remove road and riprap between RM 48.7 and RM 48.5
Middle Methow	M5	MR_Prj-49.2	Restoration	Reconnect primary side channel	Remove riprap between RM 49.2 and RM 49.0
Middle Methow	M5	MR_Prj-49.65	Restoration	Reconnect primary side channel	Diversion channel could be enhanced with LWD and riparian vegetation, possible conversion of water users to another source, remove riprap between RM 49.25 and RM 49; beaver activity present at site

Attachment Table A– 2. List of Upper Methow River floodplain areas in need of restoration and initial concepts for consideration in scoping the next phase of assessment.

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Upper Methow	M6	MR_Prj-52.15	Restoration with Development		
Upper Methow	M6	MR_Prj-52.6	Restoration with Development		
Upper Methow	M6	MR_Prj-52.9	Restoration with Development		
Upper Methow	M9	MR_Prj-56.35	Restoration with Development		
Upper Methow	M9	MR_Prj-56.5	Restoration	Restore wetland and channel network with springs	Remove three small dams near RM 56.25, RM 55.75, and RM 55.5, restore areas with minor roads, restore cleared areas; would provide continuous connection with upstream protection site
Upper Methow	M9	MR_Prj-56.8	Restoration	Reconnect low surface (floodplain)	Remove riprap at upstream end near RM 56.9, remove roads near RM 56.75 and near RM 56.6, restore cleared areas
Upper Methow	M9	MR_Prj-60.25	Restoration	Reconnect channel network	Restore flow to primary and secondary channels upstream (in Fender Mill project site), remove riprap between RM 60.3 and RM 60.25, restore cleared areas
Upper Methow	M9	MR_Prj-60.85	Existing Restoration Site		
Upper Methow	M9	MR_Prj-61.0	Existing Restoration Site		
Upper Methow	M9	MR_Prj-62.4	Restoration	Reconnect secondary and overflow channels	Remove riprap between RM 62.5 and RM 62.1, possible culvert opening through Weeman bridge near RM 61.2 to allow channel connectivity with controlled flow at upstream entrance, redesign roads and levees (and riprap) that cut across low surface between RM 61.5 and RM 61.2, remove riprap between RM 61.8 and RM 61.7, and restore cleared areas
Upper Methow	M9	MR_Prj-62.9	Restoration	Reconnect primary side channel and secondary channels	Remove push-up levee between RM 62.5 and RM 62.25 (downstream end), may need to address amount of flow and WDFW diversion structure in main channel near RM 62.65
Upper Methow	M9	MR_Prj-63.7	Restoration	Reconnect secondary channels	Remove riprap between RM 63.6 and RM 63.25, remove levee between RM 63.75 and RM 63.6, redesign or remove bridges and road across former secondary channel

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Upper Methow	M9	MR_Prj-64.4	Restoration	Reconnect primary side and secondary channels	Assess whether Suspension Bridge impacts channel connectivity near RM 64.35, remove riprap between RM 64.4 and RM 64.35 and between RM 63.2 and RM 63.1; area currently used by winter skiers
Upper Methow	M9	MR_Prj-65.2	Restoration	Reconnect primary side and overflow channels with springs	Assess whether Suspension Bridge impacts channel connectivity near RM 64.35, remove or redesign levee between RM 64.25 and RM 64.1, remove small bridge (footbridge?) near RM 64.4, restore cleared areas; area currently used by winter skiers; contains Suspension Creek and springs, which are used intensively for spawning
Upper Methow	M10	MR_Prj-65.8	Restoration	Reconnect low surface (floodplain)	Remove push-up levees between RM 65.5 and RM 65.1, restore cleared areas
Upper Methow	M10	MR_Prj-66.75	Restoration	Reconnect primary and overflow channels	Modify artificial pond near RM 66.25 to allow flow, eliminate use of channel path as a road, restore cleared areas
Upper Methow	M11	MR_Prj-74.15	Restoration	Reconnect channel network	Remove or redesign roads and other development throughout project area to provide more channel connectivity, remove push-up levee between RM 73.55 and RM 73.3, restore cleared areas;
Upper Methow	M11	MR_Prj-75.0R	Restoration	Reconnect low surface (floodplain)	Remove roads, restore cleared areas; would need to assess connectivity with confluence of Lost River
Upper Methow	M11	MR_Prj-75.0L	Restoration with Development		

Attachment Table A–3. List of Twisp River floodplain areas in need of restoration and initial concepts for consideration in scoping the next phase of assessment.

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Twisp River	T1	TR_Prj-0.35	Restoration with Development		
Twisp River	T1	TR_Prj-0.58	Restoration with Development		
Twisp River	T2	TR_Prj-1.3	Restoration	Reconnect secondary channels	Remove push-up levee between RM 1.3 and RM 1.2, and restore developed areas
Twisp River	T2	TR_Prj-1.8	Existing Restoration Site		
Twisp River	T2	TR_Prj-1.9	Restoration	Reconnect low surface (floodplain)	Remove riprap between RM 1.85 and RM 1.7; assess need to redesign road and bridge near RM 1.85 (Are they acting as a levee?)
Twisp River	T2	TR_Prj-2.95	Restoration	Reconnect overflow channels	Remove riprap between RM 2.65 and RM 2.55
Twisp River	T2	TR_Prj-3.15	Restoration	Reconnect primary side channel	Remove riprap between RM 3.03 to 3.08
Twisp River	T2	TR_Prj-3.3	Restoration	Restore channel network with springs	Remove levee between RM 3.2 and RM 3.05, remove road and riprap between RM 2.35 and RM 2.2 and between RM 2.1 and RM 1.95, remove riprap between RM 2.75 and RM 2.58, redesign or remove roads between RM 2.75 and RM 1.95, restore cleared areas; buildings; project could be subdivided so that only restore the upstream portion is restored and roads are left in place
Twisp River	T2	TR_Prj-4.1	Existing Restoration Site		
Twisp River	T2	TR_Prj-4.55	Restoration	Reconnect secondary channels	Remove levee between RM 4.55 and RM 4.4; need to assess MVID west diversion redesign project located at this site and connectivity with downstream Chain of Lakes project
Twisp River	T2	TR_Prj-4.9	Restoration	Restore channel network	Excavate entrance of north channel, redesign bridge, riprap, and road near RM 5.0, remove push-up levee and riprap between RM 4.15 and RM 4, and remove riprap between RM 4.4 and RM 4.25

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Twisp River	T2	TR_Prj-4.95	Restoration	Reconnect overflow and possible secondary channels	Channel excavation will be needed where fill has been placed
Twisp River	T3	TR_Prj-5.95	Restoration	Reconnect secondary and overflow channels	Remove riprap between RM 6.0 and RM 5.95 and near RM 5.7
Twisp River	T3	TR_Prj-6.4	Restoration	Reconnect overflow channels	Remove levee between RM 6.35 and RM 6.3, remove push-up levee between RM 6.15 and RM 6.1, restore cleared areas; assess need to redesign bridge near RM 6.08 in main channel (Bridge may have little impact)
Twisp River	T3	TR_Prj-6.65	Existing Restoration Site		
Twisp River	T3	TR_Prj-7.0	Restoration	Reconnect low surface (floodplain)	Restore cleared areas; buildings
Twisp River	T3	TR_Prj-7.25	Restoration	Reconnect primary side channel	Multiple human features at this site impact channel connectivity; assess need to redesign road between RM 7.25 and RM 7.15 and to redesign bridge near RM 7.15, remove riprap between RM 7.2 and 7.05, will need to address diversion near RM 7.25
Twisp River	T3	TR_Prj-7.64	Restoration	Reconnect secondary channel	Remove riprap at downstream end of channel between RM 7.6 and RM 7.55, may need to excavate channel entrance
Twisp River	T4	TR_Prj-8.2	Restoration with Development		
Twisp River	T4	TR_Prj-8.43	Restoration	Reconnect low surface (floodplain)	Assess need to redesign or remove bridge near RM 8.4, remove riprap between RM 8.43 and RM 8.25
Twisp River	T4	TR_Prj-8.6	Restoration	Reconnect secondary channel	Assess need to redesign bridge and road near RM 8.4 to allow flow into secondary channel, remove riprap between RM 8.55 and RM 8.4, restore cleared areas; buildings
Twisp River	T4	TR_Prj-9.05	Restoration	Reconnect low surface (floodplain)	Remove riprap between RM 8.8 and RM 8.75, restore cleared areas; buildings

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Twisp River	T5	TR_Prj-10.28	Restoration	Reconnect low surface (floodplain)	Restore cleared areas
Twisp River	T5	TR_Prj-10.63	Restoration	Reconnect low surface (floodplain)	Assess the presence of any old channel paths that could be restored; assess need to redesign or remove road between RM 10.5 and RM 10.35, remove riprap between RM 10.65 and RM 10.58, restore cleared areas; buildings
Twisp River	T5	TR_Prj-11.25	Restoration	Restore wetland and channel network	Remove riprap between RM 11.25 and RM 11.15, assess need to redesign or remove road near RM 10.95, restore cleared areas; buildings
Twisp River	T5	TR_Prj-12.25	Existing Restoration Site		
Twisp River	T5	TR_Prj-12.6	Restoration	Reconnect low surface (floodplain) and possible secondary channel	Possible wetland or channels at downstream end, assess need to redesign or remove bridge near RM 12.45, restore cleared areas
Twisp River	T5	TR_Prj-13.1	Restoration	Reconnect low surface (floodplain)	Remove push-up levee between RM 13.1 and 12.8, restore cleared areas; no historical aerial photographs to determine if old channels or wetlands were present
Twisp River	T5	TR_Prj-13.5	Restoration	Reconnect secondary channels	Assess need to redesign or remove bridge and riprap near RM 13.5, remove push-up levee between RM 13.5 and RM 13.45
Twisp River	T6	TR_Prj-13.85	Restoration	Reconnect secondary channels	Remove riprap and cabled logs between RM 13.87 and RM 13.85, restore cleared artificial paths
Twisp River	T6	TR_Prj-15.2	Restoration	Restore wetland and channel network	Remove riprap near RM 15.2, assess need to improve channel definition and connectivity
Twisp River	T6	TR_Prj-15.9	Restoration	Reconnect secondary channels and possible wetland area	Remove push-up levees between RM 15.6 and RM 15.5 and near RM 15.4, restore cleared areas, improve channel definition and connectivity

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Twisp River	T6	TR_Prj-16.1	Restoration	Restore channel network and possible wetland area	Remove push-up levee and levee between RM 16.1 and RM 15.65, restore cleared areas; buildings, improve channel definition and connectivity
Twisp River	T6	TR_Prj-16.35	Restoration	Restore channel network and possible wetland area	Remove riprap between RM 16.05 and RM 16, restore cleared areas; improve channel definition and connectivity
Twisp River	T6	TR_Prj-17.1	Restoration	Restore channel network and wetland area	Remove push-up levee between RM 16.95 and RM 16.85
Twisp River	T6	TR_Prj-18.2	Restoration	Reconnect secondary channels and low surface (floodplain)	Improve channel definition and connectivity, assess need to redesign or remove bridge near RM 18.1 and roads
Twisp River	T6	TR_Prj-18.35	Restoration	Reconnect secondary channels and low surface (floodplain)	Improve channel definition and connectivity, redesign or remove bridge near RM 18.1 and roads between RM 18.1 and RM 17.95

Attachment Table A–4. List of Chewuch River floodplain areas in need of restoration and initial concepts for consideration in scoping the next phase of assessment.

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Chewuch River	C2	CR_Prj-2.8	Restoration with Development		
Chewuch River	C2	CR_Prj-4.9	Restoration	Reconnect primary side and secondary channels with wetlands	Remove roads or provide openings across primary channel near RM 4.15 and RM 4.4; possibly restore cleared areas along channels, but may not be needed over entire golf course area to make channels functional
Chewuch River	C2	CR_Prj-6.45	Restoration	Reconnect primary side channel	Remove push-up levee between RM 6.45 and RM 6.2, restore cleared areas
Chewuch River	C2	CR_Prj-7.2	Restoration	Reconnect primary side and overflow channels	Excavate channel entrances and improve connectivity
Chewuch River	C2	CR_Prj-7.3	Restoration	Reconnect primary side channel with wetland area	Redesign or remove road between RM 7.15 and RM 7.0, remove push-up levee and riprap between RM 7.12 and RM 7.0, excavate upstream and downstream ends of channel
Chewuch River	C3	CR_Prj-8.5	Restoration	Reconnect low surface (floodplain)	Redesign or remove bridge and associated riprap between RM 8.35 and RM 8.23, redesign or remove roads between RM 8.4 and RM 8.2, restore cleared areas; buildings
Chewuch River	C3	CR_Prj-8.55	Restoration	Reconnect overflow channel	Remove riprap between RM 8.52 and RM 8.5, restore cleared areas
Chewuch River	C3	CR_Prj-9.0	Existing Restoration Site		
Chewuch River	C4	CR_Prj-10.1	Restoration	Restore wetland or network	Restore cleared areas, need to assess if any human impacts affect channel connectivity
Chewuch River	C4	CR_Prj-10.2	Restoration	Restore wetland or network	Restore cleared areas, need to assess if any human impacts affect channel connectivity
Chewuch River	C4	CR_Prj-10.4L	Restoration	Restore primary side channel and wetland	Excavate channel entrance, remove riprap between RM 10.5 and RM 10.4, lack historical aerial photographs here, but believe this channel is an old path of the main channel
Chewuch River	C4	CR_Prj-10.4R	Restoration	Reconnect low surface (floodplain)	Restore cleared areas; buildings

Drainage	Reach	Area Designation	Type	Primary Goal	Initial Concepts
Chewuch River	C4	CR_Prj-10.6	Restoration	Reconnect low surface (floodplain)	Remove riprap between RM 10.5 and RM 10.45
Chewuch River	C4	CR_Prj-11.0	Restoration	Reconnect low surface (floodplain)	Remove riprap between RM 10.85 and RM 10.8, between RM 10.5 and RM 10.4, and near RM 10.7, restore cleared areas; buildings
Chewuch River	C5	CR_Prj-12.15	Restoration	Reconnect low surface (floodplain)	Remove riprap between RM 11.8 and RM 11.7
Chewuch River	C5	CR_Prj-12.8	Restoration	Reconnect primary side channel	Remove riprap between RM 13.1 and RM 12.9, excavate channel entrances and improve connectivity
Chewuch River	C5	CR_Prj-13.3	Restoration	Reconnect low surface (floodplain)	Remove riprap between RM 13.1 and RM 12.9

APPENDIX B –

TECHNICAL RANKING OF GEOMORPHIC REACHES

This appendix provides a potential strategy for technically comparing the 23 reaches identified in this assessment based on geomorphic characteristics and habitat function, and the extent of functioning floodplain area. This ranking may be of assistance to resource managers and biologists determining which areas should be further evaluated to develop a more refined restoration and implementation strategy.

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LIST OF FIGURES

There are no Figures in this Appendix B.

LIST OF TABLES

1. INTRODUCTION

One question faced by resource managers looking at large areas for potential projects is whether to fix what is least broken first or to start where there is the most opportunity for improvement. The *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (UCSRP, 2007) and the *Biological Strategy to Project and Restore Salmonid Habitat in the Upper Columbia Region* (UCRTT, 2007) recommend prioritizing areas that are currently functioning (protection), followed by areas in which processes can be restored that improve habitat.

The 23 geomorphic reaches were characterized and ranked so they can be relatively compared to help resource managers sequence restoration efforts at a reach scale. To utilize the Upper Columbia *Recovery* Plan and *Biological Strategy* recommendation, the ranking method gives more weight to areas with a high degree of functioning complexity habitat than to reaches with a greater departure from the natural setting. The ranking focuses on those physical processes associated with lateral connectivity of the floodplain and channel that are directly linked to forming habitat features associated with complexity (Appendix C, “Geomorphic Reaches”).

The known areas of presently high biological benefit were then overlaid with the rankings to document habitat functionality (Appendix F, “Biological Setting”). These areas may result in a higher priority over other reaches that are functioning from a physical process perspective, but do not have as much abundance and productivity. Biological parameters that do not affect channel morphology, but do affect habitat availability and quality, were then noted in order to provide additional decision making criteria that may ultimately increase or decrease the restoration value of a reach (e.g. cold water recharge areas).

The resulting information is provided in Table B-1 (“Summary findings of reach characteristics”), Table B-2 (“Reach-based habitat action classes to address and associated VSP parameters”), and Table B-3 (“Reach-based habitat action classes to address and associated VSP parameters”) with the supporting methodology described in subsequent sections of these technical appendices. Table B-4 (“Species and life stage usage for ESA and non-ESA listed fish within the assessment area”) is reproduced from the biological overview for further consideration by resource managers.

The ranking results are meant to be only a starting point for discussion that can be modified in the future by incorporating new information as it becomes available. Once a reach has been prioritized for implementing restoration activities, there are several combinations and sequencing of project alternatives that may be undertaken. Additional factors, such as constructability of projects, cost, landowner willingness, funding availability, and permitting acceptance, will provide additional guidance as to the types, localities, and sequencing of projects within a given reach. Appendix A ("Complexity habitat preservation and restoration opportunities") provides an initial perspective on restoration concepts. Appendix R ("Technical ranking of restoration sites based on degree of departure from Natural Conditions") discusses the effort needed to restore areas within each reach. This information will likely be refined during subsequent reach assessments at more detailed spatial scales.

Table B-1. Summary findings of reach characteristics.

Reach Name	Floodplain Type	Down-stream RM	Up-stream RM	Protection area with no Human features (% of total reach)	Length of Side Channels (miles)		Indicator of Disruption to Processes		Cleared vegetation (percent of total reach)
					Presently accessible [3/]	Presently cut off by human features	Connectivity within floodplain [1/]	Percent of floodplain boundary armored [2/]	
M1	Confined	28.1	33.7	NA	0	0	0.13	27	11.1
M2	Unconfined	33.7	40.3	7%	0.9	8.2	0.66	23	24.4
M3	Confined	40.3	41.3	NA	0	0	0.06	61	5.3
M4	Unconfined	41.3	47	9%	1.2	7.0	0.80	17	37.0
M5	Moderately confined	47	50	26%	0.2	1.1	0.38	14	26.6
M6	Confined	50	51.5	NA	0	0	0.00	12	0.0
M7	Moderately confined	51.5	52.9	0%	0	1.4	1.89	04	40.9
M8	Confined	52.9	55	NA	0	0	0.01	40	10.6
M9	Unconfined	55	65.5	34%	11.4	9.7	0.54	10	13.2
M10	Moderately confined	65.5	69.6	56%	1.2	1.2	0.05	7	11.6
M11	Unconfined	69.6	75	38%	3.2	2.8	0.40	7	7.8
T1	Confined	0	0.6	0%			0.64	33	87.2
T2	Unconfined	0.6	5	9%	0.7	4.9	0.98	3	38.9
T3	Moderately confined	5	7.8	45%	1.0	0.7	0.29	9	21.9
T4	Confined	7.8	9.8	18%	—	0.2	0.28	16	15.4
T5	Unconfined	9.8	13.5	14%	0.8	1.3	0.44	8	31.7
T6	Unconfined	13.5	18.1	61%	3.9 0.2	1.8	0.26	0	8.3
C1	Confined	0	2.2	NA	—	—	0.04	2	8.8
C2	Unconfined	2.2	7.3	32%	2.9	3.7	0.16	0	16.8
C3	Moderately confined	7.3	9.5	45%	0.9	0.6	0.45	0	24.6
C4	Confined	9.5	11.7	18%	—	—	0.12	6	12.7
C5	Unconfined	11.7	13.9	29%	0.2	0.6	0.14	0	2.1
C6	Confined	13.9	14.3	NA	—	—	0.00	0	0.0

Note: Table 2 and Appendix Table B-1 are the same. **1/** Computed by taking the total length of human features located within the floodplain (low surface) divided by the total reach length.
2/ Computed by taking the total length of riprap and bank armoring located along the floodplain (low surface) boundary divided by the total length of the boundary.
3/ Although presently accessible, the natural frequency of inundation may still be disrupted in some cases due to channel incision from human activities or other human induced factors.

Table B-2. Reach-based habitat action classes to address and associated VSP parameters.

An “X” represents a proposed habitat action or VSP parameter based on direct findings of this assessment. An “O” represents a possible action based on local knowledge and qualitative observations during the course of the 80-mile assessment.

		VSP Parameters Addressed [2/]							
Floodplain Type	Reach Name	Riparian restoration on terraces (floodplain boundary)	Riparian restoration along channels and floodplain surfaces	Side-channel reconnection	Road Maintenance	Floodplain Restoration	LWD Restoration	A/P	D/SS
Confined	M1	O	X					X	
Unconfined	M2	O	X	X	X	X	X	X	X
Confined	M3	O						X	
Unconfined	M4	O	X	X	X	X	X	X	X
Moderately confined	M5	O	X	X	X	X	X	X	X
Confined	M6	O						X	
Moderately confined	M7	O	X	X	X	X	X	X	X
Confined	M8	O						X	
Unconfined	M9	O	X	X	X	X	X	X	X
Moderately confined	M10	O	X	X		X	X	X	X
Unconfined	M11	O	X	X	X	X	X	X	X
Confined	C1	O						X	
Unconfined	C2		X	X		X	X	X	X
Moderately confined	C3		X	X	X	X	X	X	X
Confined	C4	O	X			X	X	X	X
Unconfined	C5		X	X		X	X	X	X

Floodplain Type	Reach Name	VSP Parameters Addressed [2/]							
		Riparian restoration on terraces (floodplain boundary)	**Riparian restoration along channels and floodplain surfaces**	**Side-channel reconnection**	**Road Maintenance**	**Floodplain Restoration**	**LWD Restoration**	**A/P**	**D/SS**
Confined	C6								
Confined	T1	O	X		X	X		X	X
Unconfined	T2	O	X	X	X	X	X	X	X
Moderately confined	T3	O	X	X		X	X	X	X
Confined	T4	O	X					X	
Unconfined	T5	O	X	X		X	X	X	X
Unconfined	T6		X	X	X	X	X	X	X
Early Winters; Methow RM 67.3		O	O		O	O	O	X	X
Wolf Ck, Methow RM 52.8		O	O		O	O	O	X	X
Goat Ck, Methow RM 64		O	O		O	O	O	X	X
Eightmile Ck, Chewuch RM 11.7		O	X		O	O	O	X	X

Table B-3. Geomorphic ranking of unconfined or moderately confined reaches and biological functionality.

Reach [1/]	River Mile	Geomorphic Potential Score [2/]	Total Floodplain Area (acres)	Relative Floodplain Area (reach area/total area of segment)	Final Rank (geomorphic potential/ normalized area)	Spring Chinook Spawning Use [3/]	Multiple Life Stages and Species[4/]	High groundwater exchange and/or cold water recharge present
Middle Methow River								
M2	33.7 to 40.3	27	553	0.4	10.7		YES	
M4	41.3 to 47	26	768	0.6	14.4	Minor	YES	YES
M5	47 to 50	17	70	0.0	0.8		YES	YES
Upper Methow River								
M7	51.5 to 52.9	0	180	0.1	0.0	High	YES	
M9	55 to 65.5	88	1,318	0.6	52.8	High	YES	YES
M10	65.5 to 69.6	36	191	0.1	3.1	High	YES	
M11	69.6 to 75	25	508	0.2	5.8	High	YES	
Twisp River								
T1	0 to 0.6	0	6	0.0	0.0		YES	
T2	0.6 to 5	37	300	0.3	10.3	Minor	YES	
T3	5 to 7.8	36	110	0.1	3.7	Moderate	YES	
T4	7.8 to 9.8	11	20	0.0	0.2	Moderate	YES	YES
T5	9.8 to 13.5	34	203	0.2	6.4	High	YES	
T6	13.5 to 18.1	76	444	0.4	31.1	High	YES	YES
Chewuch River								
C2	2.2 to 7.3	32	380	0.6	20.2	High	YES	
C3	7.3 to 9.5	25	76	0.1	3.2	High	YES	YES
C4	9.5 to 11.7	32	50	0.1	2.7	High	YES	YES
C5	11.7 to 13.9	21	97	0.2	3.4	High	YES	YES

Note: Table 5 and Appendix Table B-3 are the same. **1/** Notations — **M** = Methow; **C** = Chewuch; **T** = Twisp;

2/ See Tables B–4 and B–5 for criteria and terminology used to develop geomorphic potential.

3/ Steelhead spawning occurs throughout the assessment area. Note that in some cases the biological use listed occurs in only a portion of the geomorphic reach boundary.

4/For specific species and life stage use, see Appendix Table B-4.

Table B-4. Species and life stage usage for ESA and non-ESA listed fish within the assessment area.

Biologic Reach	Spring Chinook salmon (ESA listed)	Steelhead (ESA listed)	Bull trout	Summer Chinook salmon	Coho salmon	Pacific lamprey	Westslope cutthroat trout	Sockeye salmon	Non-native brook trout
Methow River									
Carlton (RM 27) to Twisp (at Twisp R., RM 41)	M (j, a), OW, R	M, OW (j, a), R, S	F, M, OW	M, S	M, S	M, R, S	P	M, S	
Twisp River (RM 41) to Winthrop (at Chewuch R., RM 51)	H, M, R, OW, S	M, OW (j, a), R, S	F, M, OW	M, S	S	M, R, S	P		
Winthrop (at Chewuch R., RM 51) to Weeman Bridge (RM 61)	H, M, OW, R, **S**	M, OW (j, a), R, S	F, M, OW	M, S			P		P
Weeman Bridge (RM 61) to Mazama (RM 68)	M, OW, M, **S**	M, R, S	F, M, OW				P		P
Mazama (RM 68) to Lost River (RM 75)	M, R, **S** (when flows allow)	M, R, S	F, M, OW				P		
Twisp River									
Twisp (RM 0) to Buttermilk Creek (RM 15)	**M**, S, R	**M**, S, R	F, M, OW				P		P
Chewuch River									
Winthrop (RM 0) to Falls Creek (RM 14)	**M, S, R**	**M, S, R**	F, M, OW			M, R, S	P		P

Note: Table 6 and Appendix Table B-4 are the same.
F = Foraging; H = Holding; M = Migration; OW = Over-wintering; P = Present; R = Rearing; S = Spawning;
Letters in parentheses: (j) = juvenile; (a) = adult;
When bold, the abbreviations M, S, and R show types and location of high density or abundant use; non-bold letters show general use.

2. REACH CATEGORIZATION

The first step of the ranking was to categorize the 23 geomorphic reaches on the basis of the general floodplain type ("confined," "moderately confined," and "unconfined"), amount of functioning floodplain area ("protection area"), and the degree of disruption to floodplain connectivity and riparian buffer zones (see Table B-1).

All three floodplain types have some degree of presently functioning habitat and the potential for improvement of habitat quantity and quality. However, the unconfined and moderately confined reaches generally offer the most opportunity for providing channel and floodplain processes associated with habitat "complexity".

More detailed information on the definitions for reach types, specific types of human features, locations, and impacts to processes in each reach can be found in Appendix C and Appendix E ("Conceptual Model of River Settings").

There is a total floodplain area of 1,447 acres that does not have any known human features (protection category); this comprises 874 acres for the Middle Methow and Upper Methow; 192 acres for the Chewuch River, and 381 acres for the Twisp River.

The degree of impact to channel and floodplain connectivity within the floodplain area (low surface) has been most affected by levees, roads, riprap, and bridges within the unconfined and moderately confined reaches. These reaches also offer the greatest opportunity for restoration of off-channel habitat and habitat features such as LWD formed pools that create "complexity habitat". The total percent of floodplain area where vegetation has been noticeably cleared is 19.9% for the Methow River (Middle and Upper), 14.8% for the Chewuch River, and 24.1 for the Twisp River.

3. PROPOSED HABITAT ACTIONS AND LINKAGE TO VSP PARAMETERS

The second step was to determine which restoration actions were needed to improve habitat complexity and physical processes that have been disrupted from historical human activities (such as logging, roads, clearing of LWD, etc.) and present human features (such as roads, bridges, levees, riprap, etc). Restoration concepts are documented in Appendix A ("Restoration Opportunities") and reach levels in Appendix C ("Geomorphic Reaches).

The findings of the geomorphic assessment were then translated into habitat action classes and associated "viable salmonid population" (VSP) parameters (ICBTRT, 2005; UCSRB, 2007) that would be addressed as referenced from Table 5.9 in the *Upper Columbia Recovery Plan* (UCSRB, 2007) (see Table B-2). All of the habitat actions from the recovery plan were considered except for water quality and quantity restoration, nutrient restoration, and in-stream structures. Water quality and quantity and nutrient restoration are being addressed in separate efforts and were not considered as a primary habitat action in this assessment. However, restoration of floodplain processes will serve to also restore water quality and quantity where impacted from levees, roads, and bridges. Currently there are ample opportunities for restoration of processes without using in-stream structures so they were not considered at this time. Although tributaries were not assessed in detail, locations where known restoration needs exist that are closely linked to processes in the assessment area are also listed in Table B-2. Additional assessment will be needed to validate and refine these potential actions in tributary areas.

4. GEOMORPHIC RANKING OF REACHES WITH VEGETATED FLOODPLAIN

In Step 3, six of the confined reaches were separated out where there is generally a single thread main channel and a minimal amount of vegetated floodplain. The remaining reaches that are wide enough to have some floodplain connectivity opportunities were further compared for prioritization of implementing restoration actions. The six confined reaches still have opportunity for improvement to existing processes, but the amount of complexity habitat that could be gained from such efforts would not be as great as in the other areas due to their geomorphic setting. The seventeen remaining reaches were ranked to allow relative comparison from the perspective of the ability to provide habitat complexity and extent of presently functioning areas (see Table B-3).

To give each reach a rank, 73 floodplain areas within the reaches were delineated and individually ranked based on geomorphic potential and other indicators of the degree of departure from the “natural” (undisturbed) setting (see Appendix R, “Degree of Departure from Natural Setting”). The floodplain area rankings for geomorphic potential only were then summed to get a total “score” for each reach. The reach scores were weighted based on the restoration area available. This step gives higher weight to larger reaches that would have more continuous (longitudinal and/or lateral) connectivity of processes and habitat availability within one area.

For the geomorphic potential (Table B-5), floodplain areas could receive a rank of 8 (best potential) to 0 (worst). The ranking was structured such that the highest-ranked areas (6 to 8) are protection areas that have no known human features or past activities that have significantly altered processes. Within the category of a protection area (6 to 8) or a restoration area (0 to 5), the ranking gives more points to areas that provide habitat features associated with complexity. Areas that serve mainly as an overflow surface and are only inundated during higher magnitude flows were ranked lower than areas that could provide off-channel habitat. Overflow areas could still be beneficial in providing refuge and restoring floodplain function, but when compared to other sites they seem to fall into a noticeably lower category of habitat complexity potential.

For a given floodplain type (geomorphic potential), restoration areas that had significant development (such as houses and infrastructure) within the floodplain received one point lower than areas that only had features that disconnected or impacted the reworking ability of the floodplain (Appendix R). This step helps indicate the short-term feasibility of restoring the area given present land use. Eleven floodplain areas were noted as having extremely heavy development and received a ranking of 0 because it is unlikely restoration could be done in the near-term without significant effort (such as housing developments, towns, hatcheries, etc.).

Table B-5. Criteria used to rank the moderately confined and unconfined floodplain reaches.

Rank [1/]	Biological Benefit	Geomorphic Potential [2/]	Percent of 80-mile assessment area [3/]
8	High	Functioning wetland or channel network area	15
7	High	Functioning primary side or secondary side channel areas	8
6	Low	Functioning overflow channel or low surface (floodplain)	5
5	High	Full restoration of wetland or channel network area	10
4	High	Partial restoration of wetland or channel network area	23
3	High	Primary side or secondary side channel with floodplain reconnection	11
2	High	Primary side or secondary side channel with partial or little floodplain reconnection	16
1	Low	Overflow channel or low surface (floodplain)	5
0	N/A	Project area has heavy development in present setting	8

1/ Rank: 8 = "(Highest or Best)"; 0 = Lowest or Worst

2/ See Table B-6 for definitions of terms used in geomorphic potential column. Note the geomorphic potential ranking values are opposite of that presented in Appendix R; this is in order to include the value of Protection areas.

3/ . Does not include active channel

Table B-6. Description of channel definitions used in geomorphic potential category.

TERM	BRIEF DESCRIPTION
Channel network	A branching, complex network of channels, including primary side, secondary, and overflow channels; some of the channels may be connected to the present main channel; some are not connected; some may still convey flow, especially at higher flows; some may contain water, even at low flows, and the source of the water could be groundwater or tributary flow
Wetland	A channel or channel network that has standing water, even at low flows; beaver activity or small, human-constructed dams may enhance the ponding of water
Primary side channel	Well defined, relatively wide channel that is readily visible on aerial photographs; channel is or appears to have been naturally connected to the main channel; channel usually incised; it may contain water even at low flows; unvegetated bars may be present along the channel; channel usually was a historical main channel, which carried most of the flow at that time, but was later abandoned naturally or has been cut off artificially
Secondary channel	Channel that is less defined and narrower than a primary side channel, but is still visible on aerial photographs; channel may or may not be naturally connected to the main channel; it may contain water at low flows, but the source is likely groundwater or tributary flow; channel usually was a historical secondary channel, which carried only a portion of the total flow; may have been abandoned naturally or cut off artificially
Overflow channel	Channel that is poorly defined, except in areas where the vegetation has been removed; channel is usually visible on aerial photographs as darker (wetter) path across a surface with minimal vegetation; no or very little incision; channel is usually higher than primary or secondary channels, or on a higher surface than the presently active channel; channel usually was a historical overflow channel, which carried only a small portion of the total flow during the highest (flood) flows; channel dry most of the year, and may be dry for several years
Low surface (floodplain)	Low surface is the area adjacent to the main channel and includes side and overflow channels; it includes historical channels, and the area where future channels are likely to migrate; it also includes areas between channels that have been and are most likely to experience flood flow, although water may extend beyond the low surface during very high flows; low surface includes surfaces of several relative heights (and probably several different ages), where the channel has not been in quite some time

5. BIOLOGICAL PARAMETERS

The goal of the proposed restoration concepts is to improve habitat complexity associated with channel and floodplain processes. Sediment transport and channel migration generally occur during bankfull and higher flows. However, additional processes that occur during critical low flow periods can increase or decrease the habitat viability of a reach. The following biological parameters could be additionally considered by resource managers in developing a restoration implementation strategy for the Methow:

- Existing use by species and life stage
- Presence of non-native species
- Water temperature (potential limiting factor in late summer and early fall)
- Spawning gravel embeddedness (potential limiting factor downstream of burned areas or high road density areas)
- Dewatering (potential limiting factor in late summer through winter in areas where stream flow goes subsurface)
- Recharge areas (potential natural mitigation to areas affected by temperature and/or dewatering; also provides high quality habitat (hot spots) in areas already functioning properly)
- Large wood levels and future recruitment

The existing use within the assessment area by species and life stage is presented in Table B-4 and in Appendix F ("Biological Setting"). All reaches within the assessment area are used by spring Chinook and steelhead for migration, rearing, and spawning according to fish distribution maps (see *Methow Atlas*). However, certain areas have been documented during historical redd surveys to be consistent "hot spots" for spring Chinook salmon spawning and are noted in Table B-3 because of their high functionality. Presence of non-native species is also listed in Table B-4 and may need to be considered at the reach scale assessment. Reaches with high levels of spring Chinook spawning based on 2003 and 2004 WDFW (Washington Department of Fish and Wildlife) spawning data are:

- Chewuch River: from Perrygin Creek (~ RM 2.0) upstream to Buck Creek (~RM 22)
- Twisp River: from Little Bridge Creek (RM 9.8) upstream to Cook Creek (RM 20.6)
- Methow River: from Winthrop (RM 51.5) to Goat Creek (RM 65); from Mazama (RM 67.25) to Goat Wall Creek (RM 71.25);
- Early Winters Creek: from mouth to Cedar creek (RM 1.9)
- Lost River: from mouth to Weenan Creek (RM 2.4)

From a biological perspective, reaches with multiple species and multiple life functions are a high priority for protection and perhaps restoration if function is impaired. Areas where this is known by local biologists to occur are noted in Table B-3 and listed below:

- Methow River from Wolf Creek (RM 55) to RM 65 (just downstream of Goat Creek),
- Twisp River from Little Bridge Creek (RM 9) upstream to RM 17 and
- Chewuch River from RM 2.0 to RM 7.0 and between Boulder Creek (RM 10) and Eightmile Creek (RM 12).

Development of individual restoration projects in the Chewuch, Twisp, and mainstem Methow rivers should consider if the observed temperatures are functioning at natural capability and, if appropriate, what types of restoration activities may possibly improve temperature conditions. Areas strongly influenced by groundwater tend to have more favorable temperatures and higher fish usage, and could provide the core area from which restoration projects proceed. Recharge areas from cold water tributaries or springs are located throughout the assessment area (see Appendix F for full list of documented sites and references). Locations with a notable influence on temperature and/or high salmon productivity within the assessment reach are:

- Eightmile Creek on the Chewuch River at RM 12
- Falls Creek on the Chewuch River at RM 14.2
- Springs and side channel input at RM 7 to 9.6 on Twisp River
- Springs input at RM 14.5 on Twisp River
- Suspension Creek at RM 64.5 on the Methow River
- Hancock Springs at RM 60 on the Methow River
- Two locations on the Methow River between the confluence with the Chewuch River and the Twisp River (RM 44.5 and 50.1)

Projects that improve groundwater exchange and surface-water exchange, stream shade, and access to thermal refuge areas could be extremely beneficial in any of the areas where high temperatures are observed. Projects that provide shade to unshaded off-channel areas or tributaries could be beneficial to help maintain or improve thermal refuge areas in the Methow River and lower reaches of the Twisp and Chewuch Rivers.

Excessive amounts of fine sediment in spawning gravels can cause problems to fish redds and fry survival because the sediment prevents flowing water to supply oxygen. The percentages of fine sediment ("embeddedness levels") in spawning gravels located in riffles and in pools were measured by USFS in the Chewuch and Twisp Rivers, but have not been measured in the mainstem Methow River. Fine sediment levels were highest in the Chewuch River due to frequent occurrences of large fires in recent years that activated several landslides and debris flows (see Appendix N, "Tributary Sediment Sources"). Although levels were high, field observations by USFS personnel of fish response within the fire areas following the fires have been favorable. Spring Chinook spawning counts downstream of the fire areas in the lower Chewuch also seem initially to be unaffected, but not enough time has passed to assess adult returns and effects to overall productivity. The Methow River would not be expected to have embeddedness issues in the main channel due to higher flow volumes, but could have high levels of fine sediment in backwater areas, particularly in areas that have been artificially cut off from the river. The Twisp River has not had fires in recent years and may experience high levels of fines if fires occur in the future. Because fires are part of the natural dynamics in the subbasin and no embeddedness data are available for the Methow portion of the assessment area, fine sediment levels were not noted in Table B-3 as a factor for prioritization of reaches.

Dewatering periodically occurs within the assessment area on the mainstem Methow River between Lost River and the Weeman Bridge (RM 75 to 61) in late summer and into winter depending on if fall rains arrive to increase flow. The longitudinal extent and duration of dewatering vary from year to year depending upon flow conditions (wet or dry year). The Early Winters Creek confluence provides spring Chinook spawning and rearing habitat within the dewatered reach of the Methow. Springs or groundwater return areas also provide some refugia for fish through the dewatering period. Examples of important springs in this section are a location between the Lost River and Early Winters Creek (locally known as the Cedarosa area) and at Suspension Creek (near RM 64.5) downstream of Goat Creek. Although dewatering limits habitat availability in drought years, scour holes formed by LWD can provide refuge during the dry periods. However, predation is very high in these pools as they become isolated from surface connection to the river. Spring spawning fish such as steelhead are probably able to successfully spawn and juveniles are able to emerge in July prior to dewatering in favorable years; whether steelhead fry are able to out-migrate prior to dewatering is unknown. In some years spring Chinook may successfully spawn in the reach, but often redds dewater.

Spawning surveys show high productivity in Early Winters Creek, Lost River, and the West Fork Methow River for bull trout and for spring Chinook. Information on steelhead is just beginning to emerge as redds count data becomes available for multiple years. Timing of adult bull trout and spring Chinook migration through the dewatering reach to these excellent upstream spawning areas is critical. Protection of riparian areas, large woody debris accumulations, and streamside vegetation through the dewatering area is important to ensure that the onset of dewatering is not earlier than would naturally occur. As floodplain function is restored, additional LWD pools should become available.

6. ADDITIONAL CONSIDERATIONS FOR PROJECT IMPLEMENTATION

This report provides an important level of baseline information for resource decision making and future project alternative evaluations. Additional data and analysis will be needed at the reach and/or project area level prior to project implementation. The level of analysis needed will likely vary depending on the complexity of the project and adjacent land use. One additional step that will be needed as a minimum is field verification of information presented in this report. Much of the almost 80-mile assessment area was walked in the field, but not all areas could be verified due to land access constraints and the large size of the assessment area. If warranted, additional ground survey data, refinement of geomorphic and geologic mapping, and more detailed hydraulic and sedimentation modeling may also be needed to accomplish design stages. The degree of biological information available within the assessment area varies greatly. Once a reach or project area is selected, additional biological surveys may be needed to better understand the existing and potential future habitat use. The biological data will also help address the biological benefit that would be gained by implementing a project. Development of this type of information could be structured into an existing protocol, such as the matrix of pathways and indicators, with modifications to include geomorphic analysis presented in this assessment.

7. REFERENCES

IN TEXT	FULL CITATION
ICBTRT 2007	Interior Columbia Basin Technical Recovery Team, July 2007, *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* ["current draft"], 49 pp. See at http://www.nwfsc.noaa.gov/trt/col_docs/viabilityupdatememo.pdf (as of 12/04/07).
UCRTT 2007	Upper Columbia Regional Technical Team, 2007, *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board.* August 2007. Wenatchee, WA. Appendix H of UCSRB 2007. See at http://www.ucsrb.com/plan.asp (as of 12/14/07).
UCSRB 2007	Upper Columbia Salmon Recovery Board, 2007, *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan.* Wenatchee, WA. 300 pp. See at http://www.ucsrb.com/plan.asp (as of 12/03/07). Federally adopted by NMFS 2007b.

APPENDIX C – GEOMORPHIC REACHES

This appendix documents delineation and characterization of reaches within the assessment area based on physical processes important to the formation and sustainability of habitat features. Additionally presented is a summary description of physical processes operating in each reach. Information in this appendix is intended to provide guidance for the types of protection and restoration alternatives that would be most successful and beneficial to the system, based on their biologic and physical components.

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1. INTRODUCTION

The Methow Subbasin is classified as a "Category 2 watershed," which means that it has significant subwatersheds that support important aquatic resources for one or more ESA-listed fish species, and is considered to have medium habitat fragmentation (UCSRB, 2007). The objectives of defining geomorphic reaches in the Methow Subbasin assessment area are:

- to identify protection areas that provide opportunities to conserve areas with properly functioning processes and contain biological productivity and diversity,
- to identify restoration areas that are not functioning properly and provide restoration alternatives for these areas that offer opportunities to increase biological productivity by improving the complexity of the stream channel and floodplain, and
- to understand the spatial linkage between the protection and restoration areas to provide a strategy aimed at achieving a cumulative biological benefit to the ecosystem.

In order to define protection and restoration areas, characteristics related to biologic activity were combined with the characteristics of the physical processes that were used to define geomorphic reaches. Findings presented in this report for each reach provide guidance for the types of protection and restoration alternatives that would be most successful and beneficial to the system, based on their biologic and physical components.

In this appendix, the characteristics that were used to define the geomorphic reaches are summarized first. In the following sections, the main inferred natural characteristics of each geomorphic reach are described, along with the impacts of human features on the reach. Human features are further evaluated in Appendix N and Appendix P. Geomorphic conditions are further discussed in Appendix E and Appendix G.

2. DELINEATION OF GEOMORPHIC REACHES

The geomorphic reaches were defined primarily on the basis of physical characteristics that dominate channel function and the formation and sustainability of habitat features. Examples of physical characteristics include geologic controls, valley slope, sediment input and transport capacity, riparian vegetation, and water temperature (Table C-1). Geomorphic processes that result from the physical characteristics of the river were then evaluated to further define reach characteristics. Examples of geomorphic processes used to evaluate reaches are channel form and evidence for changes in channel position, elevation, and bank erosion (Table C-2).

Within some reaches, small sections are present that have different characteristics than those of the rest of the reach. However, these sections are not separated into a unique reach because they are small and do not affect the overall character of the longer reach. However, these short sections are significant locally, and could affect habitat and potential project alternatives in that area. The sections with differing geomorphic characteristics within a reach are referred to as geomorphic subdivisions within the reach, and are indicated by lower-case letters after the reach designation (that is, M2a, M2b, etc.).

Table C-1. Physical characteristics used to define and describe geomorphic reaches.

Characteristic	Measured or Observed Feature	Use	Available Information for River		
			Methow	Twisp	Chewuch
Confinement of Floodplain	Geologic characteristics of valley	Defined reaches	Yes	Yes	Yes
	Natural controls (e.g., bedrock, large alluvial-fan deposits) on the vertical and lateral movement of the channel[1/]	Define reaches (especially boundaries)	Yes	Yes	Yes
	Surface height	Define reaches	Yes	Down-stream end only	N/A
	Width of the geologic (or natural) low surface	Define reaches	Yes	Yes	Yes
Slope	Longitudinal profile	Define reaches	Yes	Yes	Yes
Sediment	Sediment size (pebble counts)	Describe reaches	Yes	Yes	Yes
	Potential sediment sources	Describe reaches	Yes	Yes	Yes
	Sediment transport capacity	Describe assessment sections	Yes	Yes	Yes
	Sediment storage	Describe reaches	Yes	Yes	Yes
Riparian Vegetation	Presence of riparian vegetation and large woody debris	Describe reaches	Yes	Yes	Yes
Water Characteristics	Groundwater-surface water exchange	Define reaches	Yes	Yes	N/A
	Recharge areas	Define reaches	Yes	N/A	N/A
	Tributary inputs	Describe reaches	Yes	Yes	Yes
	Water temperature	Describe reaches	Yes	Yes	Yes

N/A = not available

1/ The natural controls listed in this table are major features that have a marked influence on the river system, so that they are used to define reach boundaries.

Table C-2. Geomorphic processes that vary among geomorphic reaches because of differences in the physical characteristics.

Characteristic	Measured or Observed Feature	Use	Available Information for River		
			Methow	Twisp	Chewuch
Channel Form	Types of channels	Define reaches	Yes	Yes	Yes
	Lengths and definition of secondary, overflow, and abandoned channels	Describe reaches	Yes	Yes	Yes
Rate of Channel Change	Relative areas occupied by the unvegetated channel and low surface	Describe reaches	Yes	N/A	N/A
	Change in channel position over time	Describe reaches	Yes	Yes	Yes
Lateral and Vertical Stability	Natural controls (e.g., bedrock) on the vertical and lateral movement of the channel 1/	Define reaches (especially boundaries)	Yes	Yes	Yes
	Evidence for incision and (or) aggradation	Describe reaches	Yes	Yes	Yes
	Lateral bank erosion (locations and amounts)	Describe reaches	Yes	Yes	Yes

N/A = not available.

1/ The natural controls listed in this table differ from those shown in Table C–1, which are major features that were used to define reach boundaries. The ones in this table are relatively minor controls, but they do affect channel processes within a reach.

2.1 REACH BOUNDARIES

The longitudinal (along the river length) boundaries of the reaches are generally located at natural constriction points, such as bedrock or large alluvial-fan deposits that provide lateral, and often vertical, limits to channel change (Appendix G and Appendix M). The natural controls also provide limits on channel connectivity between adjacent reaches. For example, channel position in one reach would not necessarily impact channel position in the adjacent reaches, because the channel must always pass through the constriction point. However, other processes are not constricted at these points. For example, sediment that is introduced in one reach may be transported to downstream reaches, depending upon the size of the sediment and the transport capacity of the river.

The lateral boundary of the reaches is defined by the extent of the floodplain, often referred to as the "low surface" in this assessment. The low surface is composed of the active channel (unvegetated main channel and sediment bars), secondary or side channels, vegetated islands, and the adjacent floodplain, which may include channels less-frequently inundated (referred to as "overflow" channels).

2.2 REACH TYPES

Within the assessment area, the natural floodplain type ranges from naturally confined sections to areas with more dynamic channel reworking over a wider floodplain. Three types of reaches are identified in the conceptual model for this assessment, each with unique natural processes that define unique habitat feature availability and complexity components:

1. High complexity, with wide, unconfined floodplain
2. Medium complexity, with narrower, moderately confined floodplain
3. Low complexity, with narrow, confined floodplain

For the Methow River, the active channel in 2004 made up about 52% of the low surface in the confined reaches, about 16% of the low surface in the confined reaches, and about 23% of the low surface in the moderately unconfined reaches (Figure C-10c). Outside of the active channel, the floodplain areas are composed of surfaces of various heights above the main channel. Because of the variability in their heights and locations within the floodplain in relationship to the channels, some surfaces are overtopped more frequently than others. In detail, these surfaces vary in age.

The average widths of the low surfaces in confined reaches are about 310 feet for the Methow River, about 333 feet for the Chewuch River, and about 218 feet for the Twisp River. The average widths of the low surfaces in unconfined reaches are about 1,870 feet for the Methow River, about 900 feet for the Chewuch River, and about 1,130 feet for the Twisp River. The average widths of the low surface in the moderately confined reaches area about 913 feet for the Methow River, about 655 feet for the Chewuch River, and about 576 feet for the Twisp River. Each of these reach types is further described below.

2.2.1 HIGH COMPLEXITY WITH WIDE, UNCONFINED FLOODPLAIN

This floodplain type consists of wide, active floodplain reaches that have a large supply of sediment in storage within the floodplain (Figure C-1). These reaches generally have flatter slopes and a complex network of channels and LWD relative to other more confined floodplain reaches within the basin. This results in a high degree of floodplain interaction from year to year with a dynamic cycle of conversion from river to floodplain and vice versa. This dynamic process is what helps these reaches maintain a healthy riparian forest that provides ample shade and complexity while still being dynamic enough to build new habitat areas as others are eroded. In these reaches, some areas of the floodplain are older than others; however, these areas are only slightly higher than the active channel, and remain active through repeated flooding.

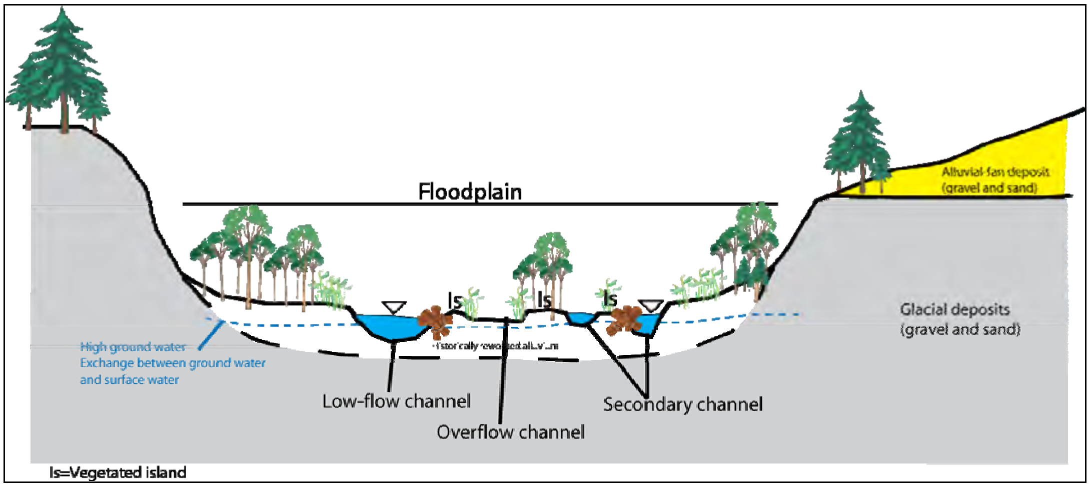

Figure C-1. Example of a schematic cross-section of a wide, unconfined floodplain (Reach M9; RM 55–65.5).

In these reaches, erosion of functioning habitat areas is as important as creation of new habitat areas. Riparian vegetation and LWD help the rate of floodplain reworking occur at a reasonable level, such that not all floodplain areas are eroded at once. LWD forms log jams in the channel areas and at the heads of bars (Figure C-2), which helps promote deposition downstream on the bar, which accumulates fine sediment, organic debris, seeds and pieces of living vegetation that provided a growing medium for future riparian forests. As sediment accumulates, riparian vegetation establishes. The LWD helps create stable hard points that allow vegetated islands to persist and slow the rate of channel migration across the floodplain. These stable hard points are important because they allow riparian vegetation to persist, so that the vegetation becomes large enough to slow channel migration and to contribute LWD to the river once it is eroded. The LWD provides complexity within the floodplain reach (Figure C-3), and also supplies LWD to downstream reaches.

Figure C-2. Log jam formed at head of vegetated island at location of flow split in Methow River upstream of confluence with Chewuch River.

Figure C-3. Methow River upstream of confluence with Chewuch River, where there is a diverse forest of riparian vegetation and frequent interaction of LWD with the river.

More than one channel is typically wetted during low-flow conditions. Erosion and deposition are common as the channel migrates across the floodplain; during a single flood one channel may fill with a sediment wave that moved down the reach and lost its conveyance capacity. As this occurs the channel can be abandoned and another channel enlarged (eroded) to become the new main channel. However the average channel bed elevations within the reach may not change over time, so that there is no net change in the total volume of sediment stored in the reach beyond a natural range of fluctuation. The area reaches a state of equilibrium until a stochastic event (fire, flood, drought, wet period, landslide, riprap, bridge, or house) changes the balance of wood, sediment, or stream flow. The interaction between water in the river and the groundwater table is highly dynamic and an important part of the aquatic habitat. These floodplain types often have smaller sediment in storage and in the bed than steeper, single-thread channel reaches.

The smaller sediment, complexity of channels, and presence of LWD create and maintain more spawning and rearing habitat for spring Chinook than other types of reaches. Steelhead is also successful in these reaches, and there is ample holding and cover for migratory species passing through. This floodplain type typically contains deep deposits of alluvium that allow a dynamic interaction between the river and groundwater. In areas that are subject to dewatering, scour holes created by LWD provide sustainable pools until river flows rise. Areas with cold water recharge, such as springs, provide "hot spots" of high spawning and rearing use. This is particularly important in river reaches where water quantity is low during drought years, which can result in higher-than-preferred temperatures during late summer conditions. The springs can help keep pools wetted and temperatures low for fish utilizing these areas.

2.2.2 MEDIUM COMPLEXITY, WITH MODERATELY CONFINED FLOODPLAIN

This moderately confined floodplain type contains a more-defined main channel than the high-complexity reaches, and has only one or two well-defined off-channel areas (Figure C-4). In this appendix, this is also sometimes referred to as "somewhat confined." The main channel conveys the majority of water and coarse sediment, but side channels have enough water to support habitat, particularly when groundwater helps supply the channel flow during low-flow conditions. Older surfaces are often present within the floodplain, and these higher surfaces are more stable than the surfaces in the unconfined floodplain areas. These surfaces are inundated during floods, but typically only suspended sediments are deposited on these surfaces. This results in less frequent lateral reworking of the floodplain. Channel avulsions typically occur within a few defined channels that transport the majority of coarse sediment rather than across the entire floodplain. The main channel remains in one place for several years to decades. A dense riparian buffer zone slows near-bank velocities, provides wood recruitment to the channel, and reduces the rate of bank erosion. LWD is most common in the slower velocity off-channel areas. Log jams often occur at the heads of vegetated islands as in the first unconfined floodplain types. Ponded water occasionally present in the off-channel areas of these reaches, and beaver activity can be common (Figure C-5).

Moderately confined reaches do not have as much complexity as the unconfined floodplain type, but they still contained a wide variety of habitat components and complexity, and support a range of fish species and life cycles. The off-channel areas support mainly spawning and rearing of spring Chinook and steelhead. Off-channel areas with cold springs commonly are inhabited by non-native brook trout. The main channel can support steelhead, spring Chinook salmon, and summer Chinook salmon spawning. Off-channel areas likely were heavily used by coho salmon before the extirpation of the species from the Methow River. (If current coho reintroduction efforts are successful, these areas would likely be dominated by them.) Fish usage in the natural setting is dynamic in order to take advantage of varying hydrologic conditions. In lower-flow years, fish spawning in riffles and typically higher velocity areas are successful because high freshets do not wash out the redds. However, redds placed at the edge of the wetted channel may dry out and not be successful in dry years. In higher flow years, the redds in the riffles are washed out, but redds at the edges of the channel are successful. Local recharge areas also provide refuge during low-flow conditions in these reaches.

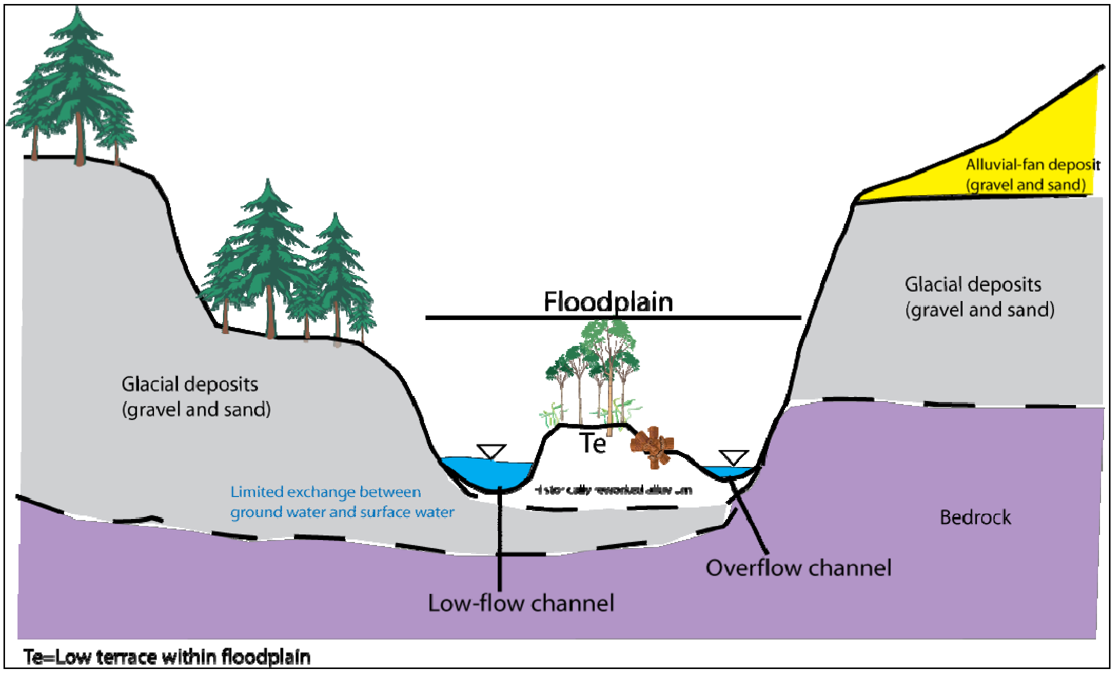

Figure C-4. Example of a schematic cross section of a narrower, moderately confined floodplain (portions of Reach M5, RM 47–50).

Figure C-5. Looking downstream at beaver lodge on side channel of Methow River downstream of confluence with Chewuch River.

2.2.3 LOW COMPLEXITY, WITH NARROW, CONFINED FLOODPLAIN

The third floodplain type is confined, straight channel reaches that have little to no off-channel habitat (Figure C-6). However, these reaches do have an important habitat function. Some species are successful in spawning in these reaches, but within the assessment area these reaches generally provide holding and migration corridors for fish trying to access upstream or downstream reaches. Riparian vegetation is present on narrow sediment bars and provides a limited recruitment source for downstream reaches (Figure C-7 and Figure C-8). Pockets of slower-velocity flows behind occasional boulders provide resting areas (Figure C-9). LWD in the channel is generally limited, but occasionally occurs on bars or on the upstream sides of exposed boulders in the bed. During floods, river stage increases faster than the wetted width, and the same area is consistently reworked during each flood. However, riparian vegetation requires fresh, bare soil to establish. Riparian vegetation cycles in these reaches as a function of the hydrologic regime. During a period of dryer years, the riparian vegetation establishes. Once in a while a rare, large flood occurs that erodes the vegetation and restarts the cycle by providing a fresh surface on which new vegetation can become established.

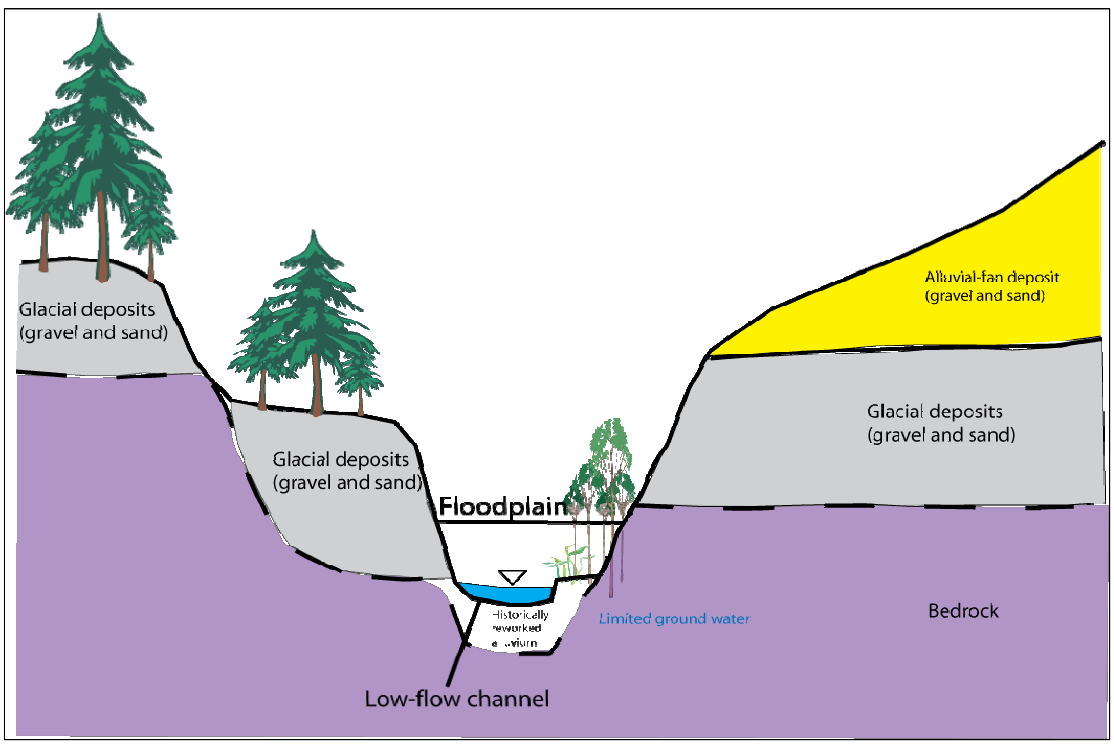

Figure C-6. Example of a schematic cross section of a narrow, confined floodplain section (portions of Reach M1, RM 28.1–33.7).

Figure C-7. Photo example of a confined floodplain section; Methow River between Winthrop (RM 51) and Wolf Creek (RM 55).

Figure C-8. Photo example of range in age and species of riparian vegetation on Middle Methow between Carlton and confluence with Twisp River.

Figure C-9. Photo example of boulders that occasionally are present in the river bed and provide localized pockets of deeper, slower velocity water for fish in confined river sections.

3. METHOW RIVER GEOMORPHIC REACHES

Eleven geomorphic reaches (M1 thru M11, downstream to upstream) are defined for the Methow River in the assessment area between RM 28.1 and RM 75 (Table C-3). Reaches M1 thru M5 are located in the Middle Methow and reaches M6 thru M11 are located in the Upper Methow. The Methow River in the assessment area alternates between confined reaches (M1, M3, M6, and M8) and unconfined reaches (M2, M4, M9, and M11). Reaches M5, M7, and M10 are moderately confined.

A major change in the physical characteristics and geomorphic processes occurs near RM 55, at the boundary between reaches M8 and M9. The river corridor downstream of this point is naturally confined, by high surfaces or by low terraces, in sections where the low surface is wider. Off-channel areas are mostly primary side channels. Channel migration is naturally limited by surfaces, so that reworking of the floodplain occurs only in the wider sections, and often only in a portion of the wider areas. The river corridor upstream of RM 55 is naturally unconfined, has a low gradient, and includes numerous secondary, overflow, and abandoned channels, some of which are now wetlands. Channel migration occurs, and reworking of the adjacent floodplain is common, and can be observed on historical aerial photographs during the last about 55 years.

In the confined reaches (M1, MR3, M6, and M8), the active channel is primarily a single channel that is not free to move due to the narrowness of the channel zone and the low surface between high banks. The average width of the low surface is about 310 feet for the confined reaches. The area of low surface outside of the active channel is limited. The active (unvegetated channel) makes up an average of about 52% of the low surface for the confined reaches. In one reach, the active channel is as much as 66% of the low surface area (Figure C-10c). For short sections of the confined reaches (less than 2 miles long), the active channel is nearly the entire low surface. Examples of these are the reaches at RM 29–30, RM 31.7–RM 33.7, RM 50–RM 51.5, and RM 54–55 (see Reclamation 2008c). Few surfaces are present within the low surface.

In the unconfined reaches (M2, M4, M9, and M11), the low surface is wider (average of about 1,870 feet), so that the active channel has been free to migrate. The main channel meanders, and a network of secondary and overflow channels may be present along with primary side channels. The active (unvegetated) channel makes up an average of about 23% of the low surface (Figure C-10c), so that the channel has plenty of room to migrate. Abandoned channels are common and can be converted into ponds through beaver activity or other processes. The unconfined reaches often have little topographic variation among surfaces within the low surface. The unconfined reaches tend to be gaining flow from the groundwater aquifer, although some sections are transitional or lose flow to the groundwater aquifer. Seeps or recharge areas may be present. Reach M11, along with the moderately confined reach M10, is a potentially losing reach, and the channel tends to be dry in the summer and early fall.

In the moderately-confined reaches (M5, M7, and M10), the low surface is wide enough that primary side channels are present, and floodplain extends beyond the unvegetated or active channel. The low surface usually includes several surfaces of varying heights above the active channel. These surfaces often separate the main channel from the side channels. These reaches may be either losing or gaining flow from the groundwater aquifer.

Table C-3. Methow River – Geomorphic reaches and geomorphic subdivisions.

Reach	Down-stream RM	Up-stream RM	Length (miles)	Geomorphic subdivisions[1/]	Down-stream RM	Up-stream RM	Length (miles)	Type
M1	28.1	33.7	5.6	M1	28.1	33.7	5.6	Confined
M2	33.7	40.3	6.6	M2a	33.7	35.8	2.1	Unconfined
				M2b	35.8	39.0	3.2	Confined
				M2c	39.0	40.3	1.3	Unconfined
M3	40.3	41.3	1.0	M3	40.3	41.3	1.0	Confined
M4	41.3	47.0	5.7	M4	41.3	47.0	5.7	Unconfined
M5	47.0	50.0	3.0	M5	47.0	50.0	3.0	Moderately confined
M6	50.0	51.5	1.5	M6	50.0	51.5	1.5	Confined
M7	51.5	52.9	1.4	M7	51.5	52.9	1.4	Moderately confined
M8	52.9	55.0	2.1	M8	52.9	55.0	2.1	Confined
M9	55.0	65.5	10.5	M9a	55.0	59.0	4.0	Unconfined
				M9b	59.0	61.7	2.7	Unconfined
				M9c	61.7	65.5	3.8	Unconfined
M10	65.5	69.6	4.1	M10	65.5	69.6	4.1	Moderately confined
M11	69.6	75.0	5.4	M11	69.6	75.0	5.4	Unconfined

1/ If no geomorphic subdivision is indicated, there are no additional lateral confinement points in the reach

The following pages present ten "subfigures," C-10a through C-10j. These show characteristics of the geomorphic reaches on the Methow River between RM 28 and RM 75. For all of these figures, the colored lines are values for the geomorphic reaches and the geomorphic subdivisions within them, and the vertical black lines show the boundaries of the geomorphic reaches.

Figure C-10. Methow River – Ten subfigures (on following pages) presenting characteristics of the geomorphic reaches between RM 28.1 and RM 75.

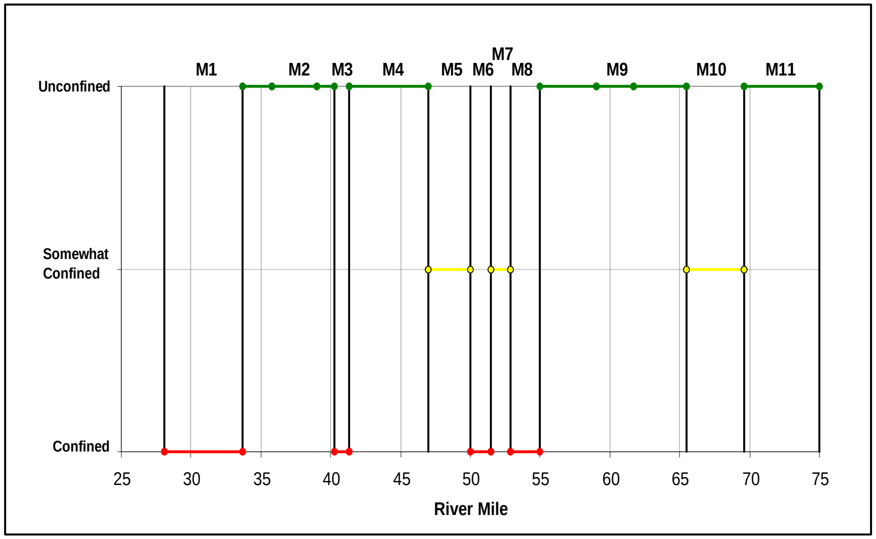

Figure C-10a. Variations in the geologic confinement of the low surface for each geomorphic reach and geomorphic subdivision within them plotted by river mile for the Methow River between RM 28.1 and RM 75. This section of the Methow River has four confined reaches (M1, M3, M6, and M8), four unconfined reaches (M2, M4, M9, and M11), and three somewhat confined reaches (M5, M7, and M10). Confinement is a subjective evaluation of the valley. See *Reclamation, 2008c* and accompanying maps for a comparison of the reaches.

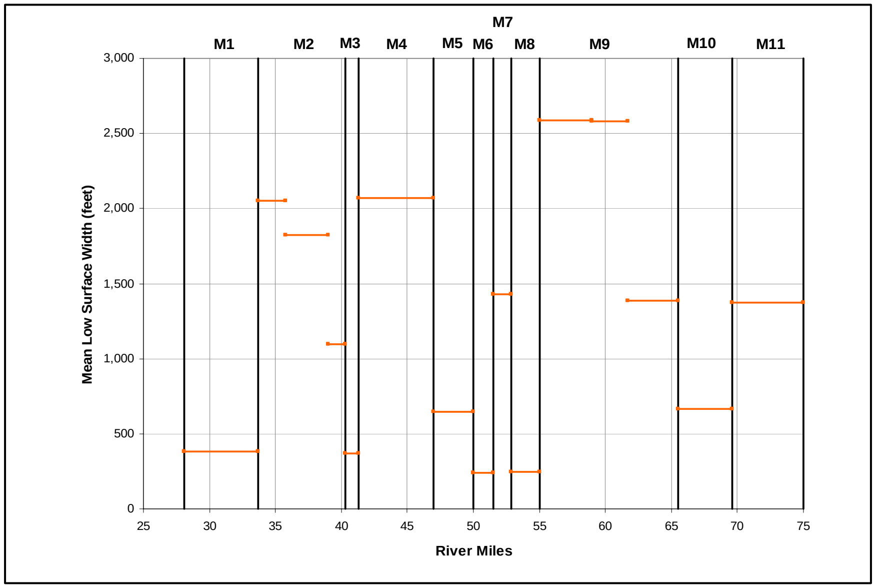

Figure C-10b. Mean widths of the low surface for each geomorphic reach and for geomorphic subdivision within the reaches plotted by river mile. The wider the low surface, the less confined the active channel. Although short sections are present where the low surface is more confined in reaches M2 and M9, the four unconfined reaches (M2, M4, M9, and M11) have wider low surfaces than those in the confined and somewhat confined reaches. This supports the subjective evaluation of confinement shown in Figure C-10a.

The low surface is bounded by alluvial-fan deposits, glacial deposits, landslides, or bedrock (Appendix G). Although these units other than the bedrock are erodible, the size of the sediment in the deposits and the heights of the banks mean that they confine the lateral movement of the active channel.

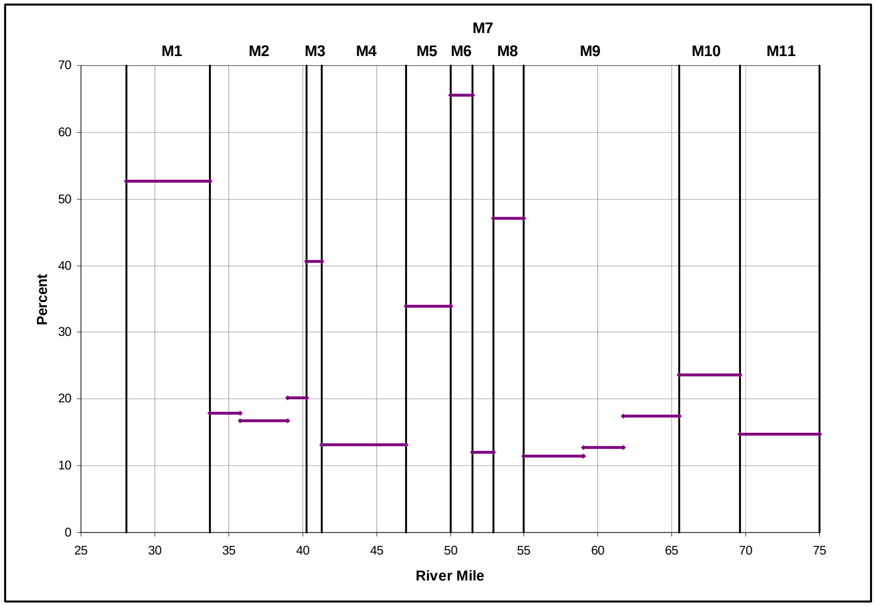

Figure C-10c. This shows the percentage of the geologic low surface that the unvegetated channel occupied in 2004 for each geomorphic reach and geomorphic subdivision within the reaches plotted by river mile. As percentages increase, the unvegetated channel comprises more of the area of the low surface, so that the reach is more confined. Reach M6 has the overall highest percentage of low surface as unvegetated channel (very confined). Reach M1 has the next highest percentage. The unconfined reaches have the lowest values.

The unvegetated channel was mapped on the 2004 aerial photographs in ARC. Areas of the unvegetated channel and low surface were calculated for each reach.

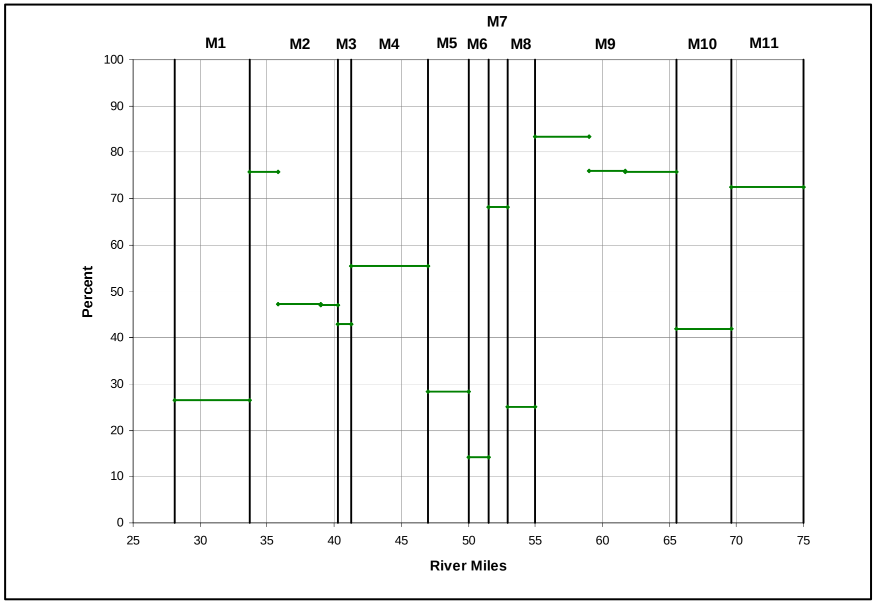

Figure C-10d. This shows the percentage of the 1948 and 2004 unvegetated channels that were in different areas in these two years for each geomorphic reach and geomorphic subdivision within the reaches plotted by river mile. The percent of the total area of the two unvegetated channels that was not unvegetated channel in both years is shown. In one of these years, the area was vegetated without evidence of being part of the active channel. Thus, a higher value indicates a larger area that was not unvegetated channel in both years, and suggests a greater amount of change in channel position. The unconfined reaches (M2, M4, M9, and M11) have higher values than the confined reaches (M1, M3, M6, and M8). The unvegetated channels were mapped in Arc on the 1948 and 2004 aerial photographs. The areas where the two channels intersect (areas that were unvegetated channel in both years) were subtracted from the total channel area. The remaining areas were calculated as a percent of the entire area of the two channels (Appendix G). This method compares channel positions in these two years only. Multiple changes in the positions of the channel paths in intervening years or reoccupation of a channel path are not recorded.

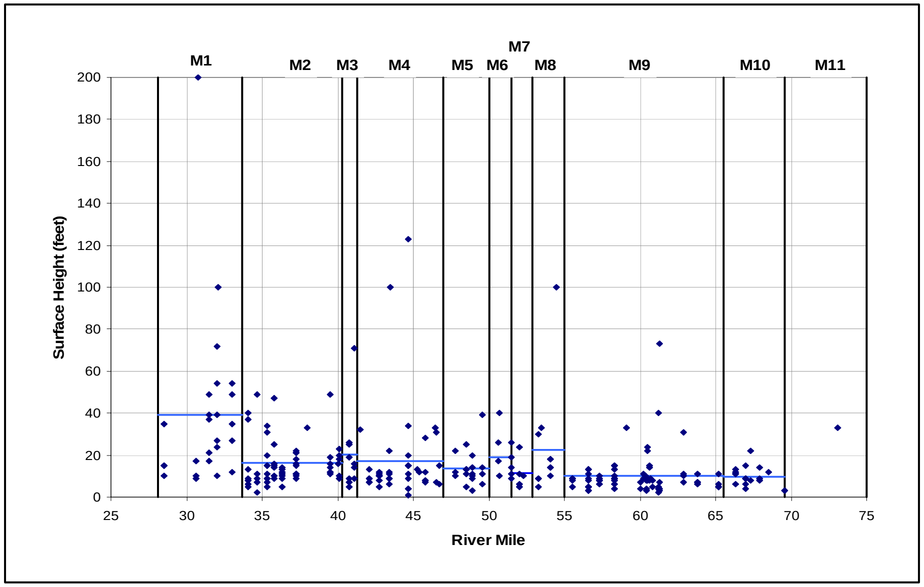

Figure C-10e. Measured and observed surface heights plotted by river mile along the Methow River between RM 28.1 and RM 75. The bright blue lines show the mean height for each geomorphic reach using all of the plotted points in that reach. The reach with the highest bounding surfaces is M1, which is confined by glacial deposits, primarily, and alluvial-fan deposits.

Most of the plotted heights are from survey cross sections, where the surface height was calculated by subtracting surface elevation from thalweg elevation along surveyed cross sections. Some of the heights are estimates from field observations. Although banks that are as high as the ones in reach M1 are present upstream, the banks adjacent to the active channel are lower, as indicated by the plot. Since the surveyed cross sections included only those surfaces near the active channel, the higher surfaces were not surveyed in the wider reaches. The higher banks in the upstream reaches are far enough from the active channel that they do not markedly constrict channel migration.

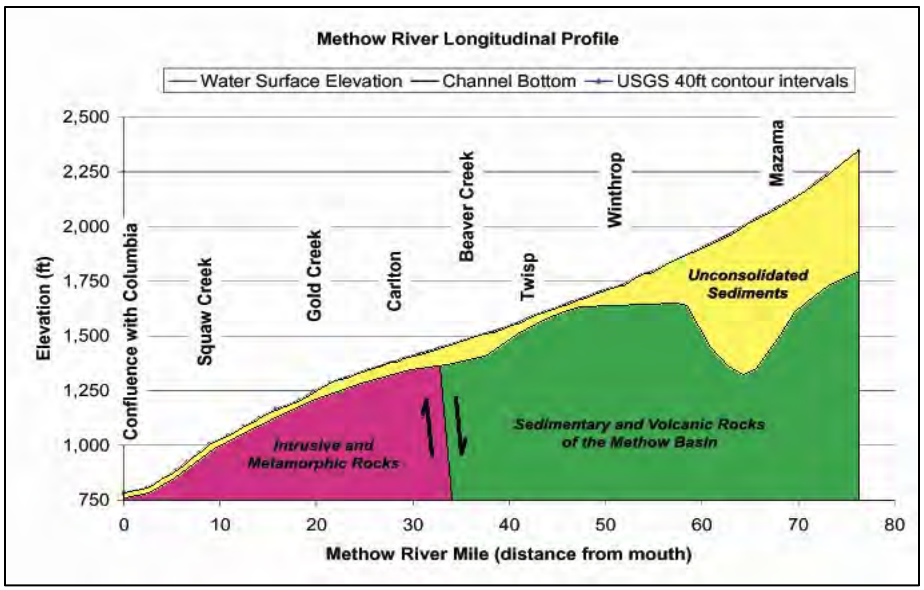

Figure C-10f. Slopes of the Methow River plotted by river mile between RM 28.1 and RM 75. Although the slope varies along this section of river, a marked change in slope is not present in the assessment area.

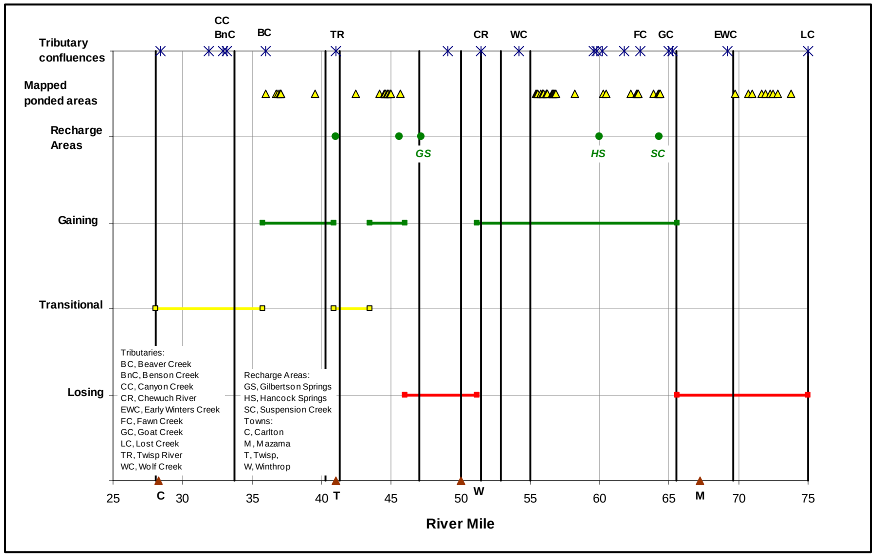

Figure C-10g. Water exchange between groundwater and surface water, groundwater recharge areas, mapped ponded areas, and major tributaries that contribute surface water to the Methow River plotted by river mile between RM 28.1 and RM 75.

The water exchange information is from the USGS (Konrad et al., 2003); the recharge areas are from the USFS.

Brown triangles indicate towns.

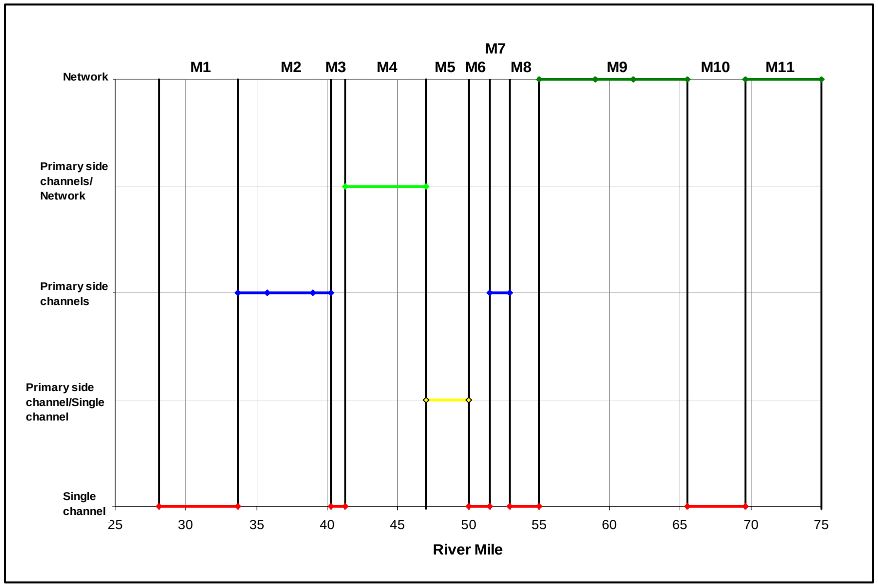

Figure C-10h. Channel characteristics for each geomorphic reach and geomorphic subdivision within the reaches plotted by river mile. Channel characteristics vary with the degree of confinement of the low surface, valley slope, and the amount of groundwater available.

The confined reaches (M1, M3, M6, and M8) are dominated by a single main channel path. Two of the unconfined reaches (M9 and M11) are dominated by channel networks. One unconfined reach (M4) has both primary side channels and channel networks. The fourth unconfined reach (M2) is dominated by primary side channels, often a single long channel that is separated from the main channel by alluvial surfaces. It also has some channel networks (*Reclamation, 2008c*). Channel characteristics were evaluated on the 2004 and historical aerial photographs. The primary form is shown here. Short sections in each reach have different forms (*Reclamation, 2008c*).

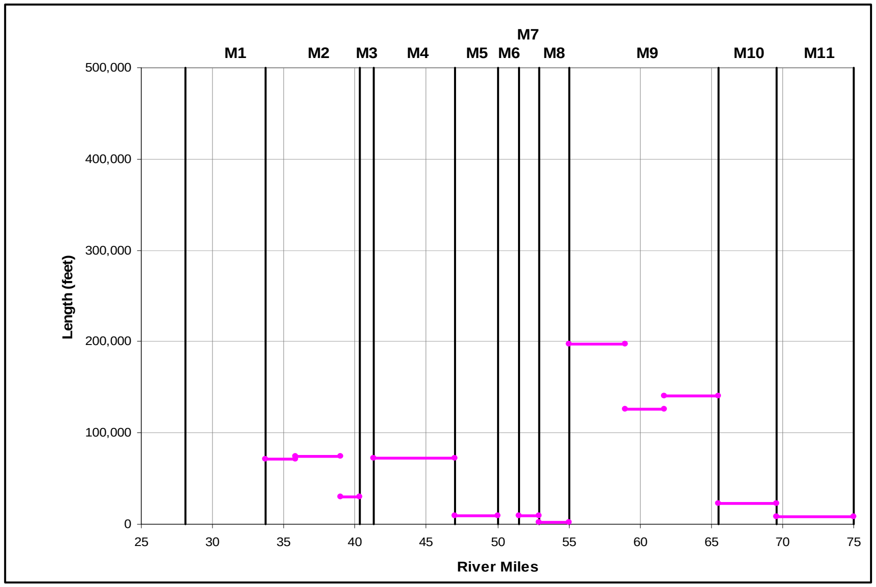

Figure C-10i. Cumulative lengths of secondary, overflow, and abandoned channels for each geomorphic reach and geomorphic subdivision plotted by river mile. The reaches with the longest total channel length have the most channels adjacent to the main channel. The longest lengths are in three of the unconfined reaches (M2, M4, and M9). The low value for reach M11 is likely the result of dense vegetation, which makes channels difficult to see. The confined reaches (M1, M3, M6, and M8) have few, if any, channels adjacent to the main channel.

The channels were mapped in Arc using the 2004 and historical aerial photographs (Appendix G; *Reclamation, 2008c*). The mapping is not consistent along the entire length of river, because of differences in the quality of the aerial photographs, in the density and types of vegetation near the channel, and in the time spent mapping each reach. Only easily observed, readily defined channels are included. Undoubtedly all of the reaches have considerably more channels than shown.

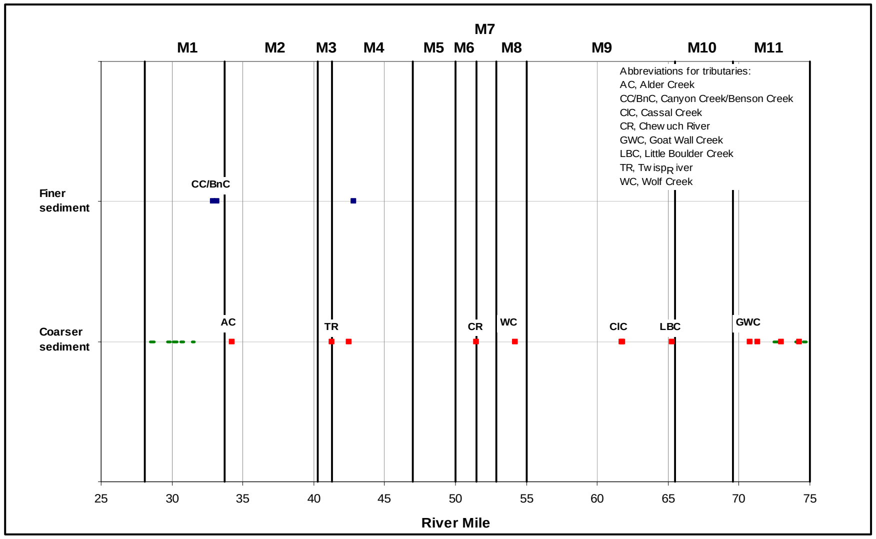

Figure C-10j. Major sources of coarse and fine sediment plotted by river mile for the Methow River RM 28.1–75. Tributary sources are shown by the squares. Orange squares show sources of coarse sediment (coarse gravel); and blue squares show sources of fine sediment (mostly sand, to fine gravel). Landslide/debris flow sources are shown by the green lines that indicate the extent of the landslide or debris flow. Sources of coarse sediment occur along the entire section of the river, but are more common in the upstream reaches, where slopes are steep and debris fans have formed (*Reclamation, 2008c*).

Sediment sources were mapped using the 2004 and historical aerial photographs and field observations.

3.1 REACH M1, RM 28.1–33.7

Reach M1 is 5.6 miles long and is located between Carlton (RM 28.1) and RM 33.7 (Table C-3). It is a confined reach, where the channel has a single path between banks that are up to about 200 feet high and that are composed of glacial deposits, alluvial-fan deposits, landslide deposits, or bedrock (Figures C-10a, C-10c, C-10e, C-10h, and Figure C-11). The low surface is narrow (Figure C-10b), and is barely wider than the unvegetated channel (Figure C-11). The unvegetated channel makes up more than 50% of the low surface area (Figure C-10c). The low surface extends beyond the unvegetated channel in only a couple of small areas, RM 28.5–29 and RM 30.75–31.2 (Figure C-11).

The incised, narrow low surface in Reach M1 does not allow for lateral migration of the active channel, and little movement of the channel has been occurred between 1948 and 2004 (Figure C-10d and Figure C-11). The channel flows in meanders that have incised into glacial deposits during the last 10,000 years or so. Consequently, the unvegetated channel cannot vary much from the path inscribed by the bounding high surfaces.

The main tributaries are Canyon Creek at RM 32.9 and Benson Creek at RM 33.2, which provide fine sediment to the reach (Figures C-10g, C-10j, and Figure C-11). Landslides/debris flows are sources of coarser sediment between RM 28.5 and RM 31.5 (Figure C-10j).

The reach is transitional (Figure C-10g). Seeps or ponded areas have not been mapped in the reach (Figure C-10g).

Because the low surface is naturally confined, the impacts of human activities are limited. A few houses and associated roads are present between RM 30 and RM 30.2 (see *Reclamation, 2008c*). Only about 10% of the low surface has been cleared of vegetation. The mean width of the geologic surface has not been markedly changed by human features.

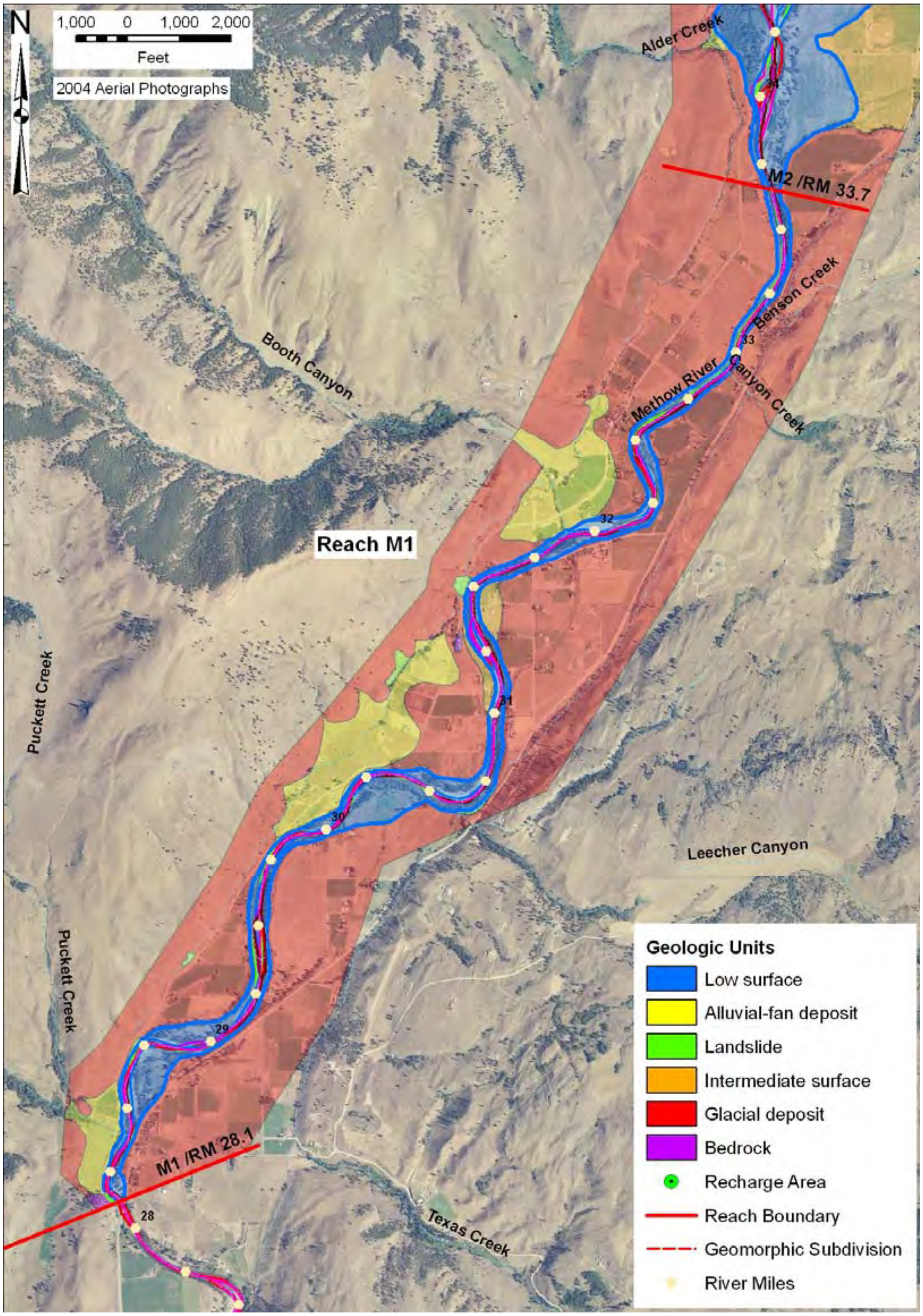

Figure C-11. Methow River – Geology and historical channels for confined geomorphic Reach M1 (RM 28.1–33.7).

The colored lines within the low surface are historical channel paths between 1945 and 2004 (see *Reclamation, 2008c*).

3.2 REACH M2, RM 33.7–40.3

Reach M2 is 6.6 miles long and is located between RM 33.7 and RM 40.3 (Table C-3). The reach is generally unconfined. However, the width of the low surface is variable, and the reach includes narrower sections that are 0.2 to 0.4 miles long and that separate wider sections of the reach (Figure C-12). The three wider sections are geomorphic subdivisions of the reach, and are indicated as M2a, M2b, and M2c (Table C-1 and Figure C-12).

For most of the reach, the channel meanders within a relatively wide low surface, and has secondary, overflow, and abandoned channels (Figures C-10a, C-10b, C-10i, and Figure C-12). The channel form includes primary side channels (Figure C-10h). In the narrower sections, a single main channel path is incised into bedrock or high surfaces composed of glacial or alluvial-fan deposits (Figure C-12). Bank heights are lower than they are in reach M1 (Figure C-10e).

The unvegetated channel occupies only 15 to 20% of the low surface area (Figure C-10c). However, widths of the low surface and degree of channel migration vary among the three geomorphic subdivisions of the reach (Figures C-10b and C-10d). The outsides of some meanders are bounded by bedrock, so that lateral migration is limited (Figure C-12).

The reach is primarily a gaining reach, and ponded areas have been mapped within the low surface (Figure C-10g). The downstream geomorphic subdivision (M2a), between RM 33.7 and RM 35.8, is a transitional reach (Figure C-10g).

The wider sections of this reach are the most impacted by anthropogenic features. Primary side channels have been disconnected by levees, roads, and development in at least three locations: near RM 35, near RM 38.5, and near RM 40. In the wider sections, the present low surface is about 420 to 463 feet narrower than it was naturally. The narrowing of the low surface has disconnected the channel from the adjacent floodplain. The impacts due to constraining the low surface with anthropogenic features are much less in the naturally narrower sections. In these sections the present low surface is about 55 to 285 feet narrower than it was naturally. Similarly, the impacts of vegetation clearing are much greater in the wider sections, where terraces within the low surface have been used for grazing, agriculture, and development. The area of the geologic low surface that has been cleared of natural vegetations is up to 38% in the wider sections. Cleared areas limit the recruitment potential for large woody debris (LWD).

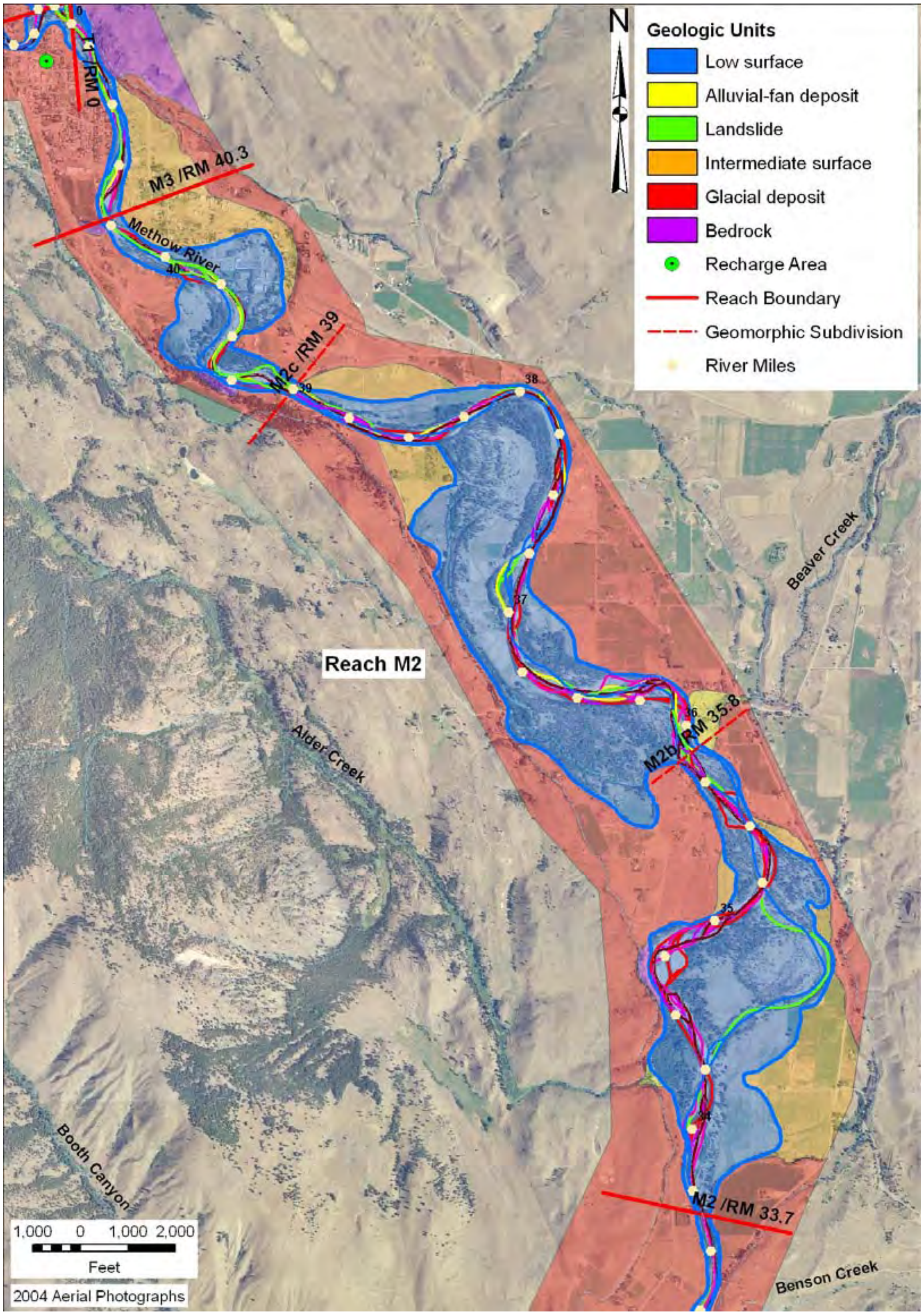

Figure C-12. Methow River – Geology and historical channels for unconfined geomorphic Reach M2 (RM 33.7–40.3).

The colored lines within the low surface are historical channel paths between 1945 and 2004.

3.3 REACH M3, RM 40.3–41.3

Reach M3 is 1 mile long and is a confined reach between RM 40.3 and RM 41.3, where the Twisp River enters the Methow River (Table C-3). It includes the town of Twisp near RM 41 (Figure C-13).

The channel form is a single main channel incised into bedrock or high surfaces composed of glacial deposits (Figure C-10h and Figure C-13). The low surface is very narrow, and the unvegetated channel occupies about 40% of the low surface (Figure C-10b and Figure C-10j). The channel path has migrated only a little since about 1948 (Figure C-13). Secondary, overflow, and abandoned channels have not been mapped in the reach (Figure C-10i).

Flow and sediment increase in this reach, because of the contributions from the Twisp River, a relatively large tributary (Figure C-10j and Figure C-13). The reach is a transitional reach upstream of the confluence with the Twisp River, and a gaining reach downstream of that point (Figure C-10g). A recharge area is present near the mouth of the Twisp River (Figure C-10g).

Because the low surface is naturally confined, the impacts of human activities are limited. Only about 5% of the low surface has been cleared of vegetation. The mean width of the geologic surface has only been decreased by an average of about 58 feet by human features.

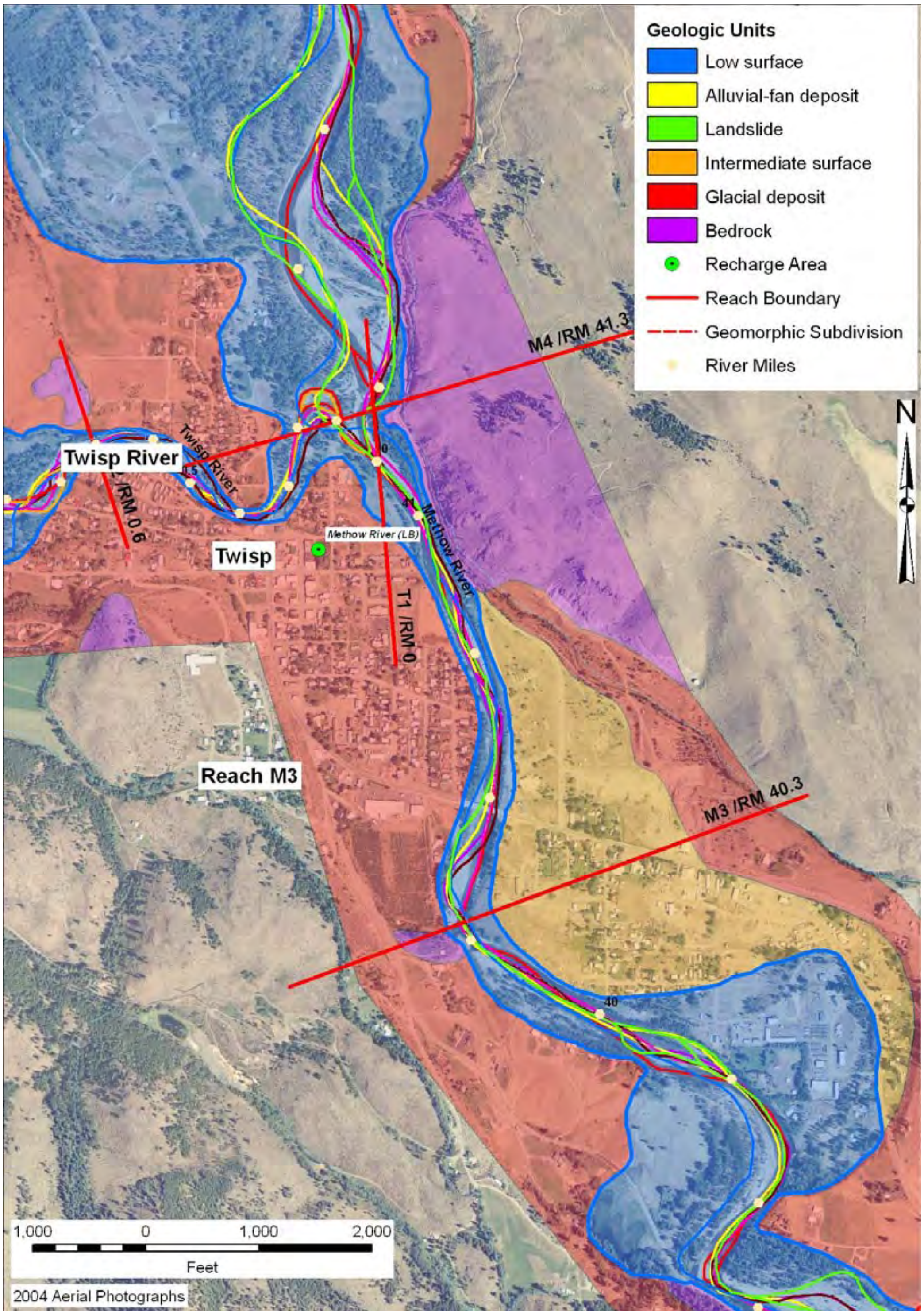

Figure C-13. Methow River – Geology and historical channels for confined geomorphic Reach M3 (RM 40.3–41.3), at the confluence of the Twisp River.

The colored lines within the low surface are historical channel paths between 1945 and 2004.

3.4 REACH M4, RM 41.3–47

Reach M4, which is 5.7 miles long, is located between RM 41.3, just upstream of the confluence with the Twisp River, and RM 47, where the low surface narrows (Table C-3; Figure C-14).

This reach is unconfined, but the low surface width progressively narrows in an upstream direction (Figure C-10a, Figure C-10b, and Figure C-14). The active channel makes up only about 12% of the low surface (Figure C-10c). The channel system in this reach is composed of primary side channels along with a network of secondary and overflow channels in some areas (Figure C-10h, Figure C-10i, and Figure C-14).

The reach is a transitional reach between RM 41.3 (downstream boundary) and RM 43.5, a gaining reach between RM 43.5 and RM 46, and a losing reach between RM 46 and RM 47 (upstream boundary) (Figure C-10g). Two recharge areas are present upstream of RM 45: one in the gaining section and one (Gilbertson Springs) at the upstream reach boundary (Figure C-10g). Ponded areas have been mapped in the gaining section (Figure C-10g). No large tributaries enter the reach. However, two unnamed tributaries (near RM 42 and RM 43) provide sediment to the reach (Figure C-10j).

Primary side channels have been disconnected by levees, roads, and development in at least two locations: near RM 43, and near RM 45.5. The present low surface is about 600 feet narrower than it was naturally. Nearly 40% of the low surface has been cleared. Cleared areas limit the recruitment potential for LWD.

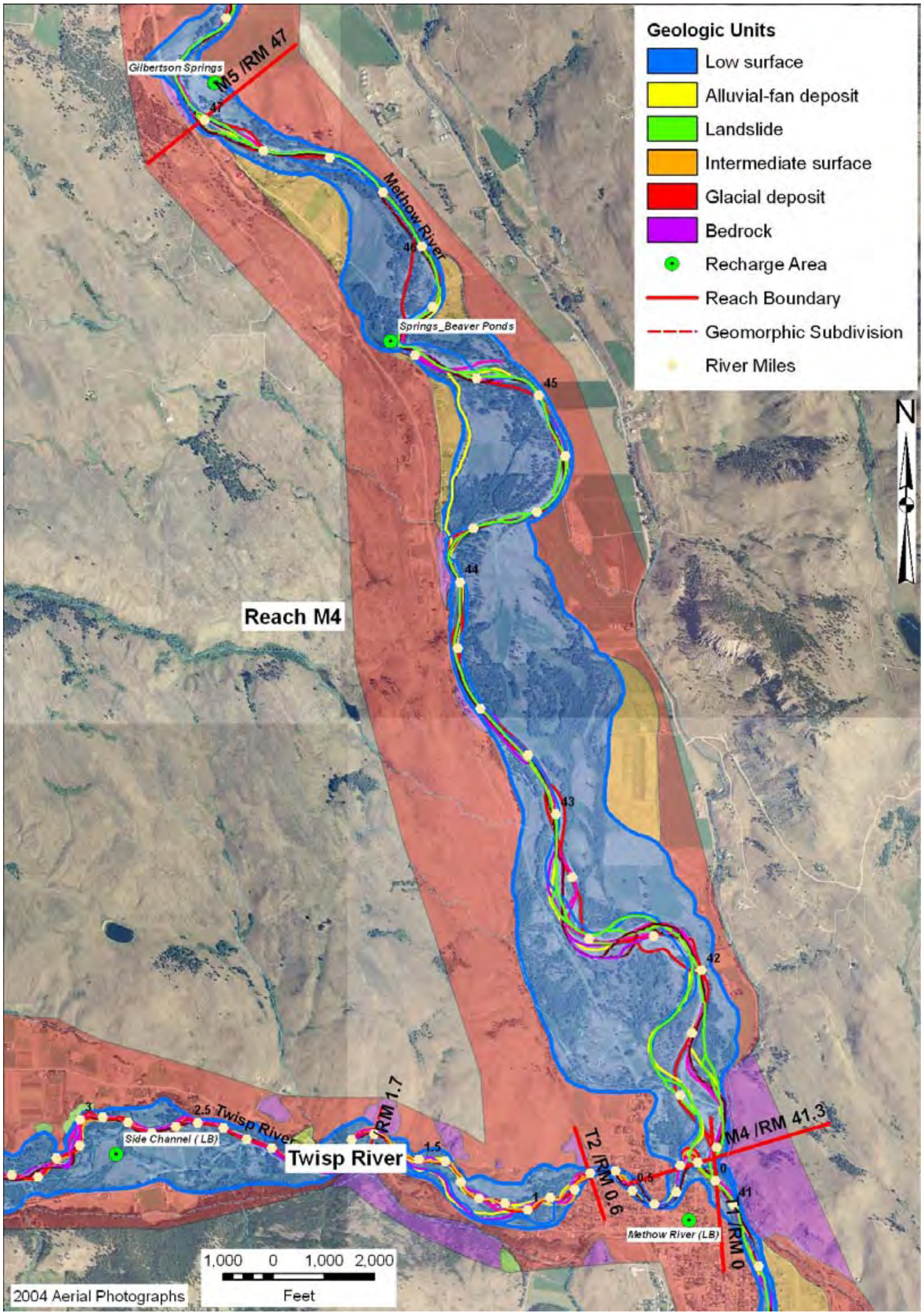

Figure C-14. Methow River – Geology and historical channels for unconfined geomorphic Reach M4 (RM 41.3–47), just upstream of the confluence with the Twisp River.

The colored lines within the low surface are historical channel paths between 1945 and 2004.

3.5 REACH M5, RM 47–50

Reach M5 is located between RM 47 and RM 50 and is 3 miles long (Table C-3; Figure C-15).

This reach is somewhat confined, and the low surface has a width that is intermediate between the wider reach (M4) downstream and the narrower reach (M6) upstream (Figures C-10a, C-10b, and Figure C-15). For most of the reach, the low surface is naturally confined by glacial deposits, primarily, and in some areas by bedrock (Figure C-15). The unvegetated channel occupies more than 30% of the low surface area (Figure C-10c).

The channel is primarily a single main channel; however, a primary side channel and some adjacent floodplain are present in some sections (Figure C-10h and Figure C-15). A few secondary, overflow, or abandoned channels are present (Figure C-10i and Figure C-15). The channel in this reach has more pronounced meanders than the reach upstream (M6; Figure C-15).

Reach MR5 is a losing reach, but a recharge area (Gilbertson Springs) is present at the downstream reach boundary (Figure C-10g). An unnamed tributary enters the reach on river left near RM 49 (Figure C-15).

In this somewhat confined reach, primary side channels have been disconnected by levees, roads, and development. The present low surface is about 80 feet narrower than it was naturally. The narrowing of the low surface has disconnected the channel from the adjacent floodplain. An average of about 22% of the area of the geologic low surface has been cleared of natural vegetations. Cleared areas limit the recruitment potential for large woody debris (LWD).

3.6 REACH M6, RM 50–51.5

Reach M6 is 1.5 miles long and is located between RM 50 and RM 51.5, where the Chewuch River enters the Methow River (Table C-3; Figure C-15). The reach includes part of the town of Winthrop.

This reach is very confined, and the unvegetated channel occupies about 65% of the low surface area (Figures C-10a, C-10b, C-10c, and Figure C-15). Very little floodplain exists outside of the unvegetated channel. The channel has a single channel path that has only broad meanders (Figure C-10h and Figure C-15). Secondary, overflow, or abandoned channels have not been mapped (Figure C-10i). The reach is confined by high surfaces composed of glacial deposits or bedrock, such as near the downstream reach boundary and upstream of RM 51 (Figure C-10e and Figure C-15).

Flow and sediment increase markedly in this reach, because of the contributions from the Chewuch River, a large tributary that enters the Methow River at the upstream boundary of this reach (Figure C-10j and Figure C-15). The reach is a losing reach (Figure C-10g).

Because the low surface is naturally confined, the impacts of human activities are limited. Less than 5% of the low surface has been cleared of vegetation. The mean width of the geologic surface has only been decreased by an average of slightly less than 20 feet by human features.

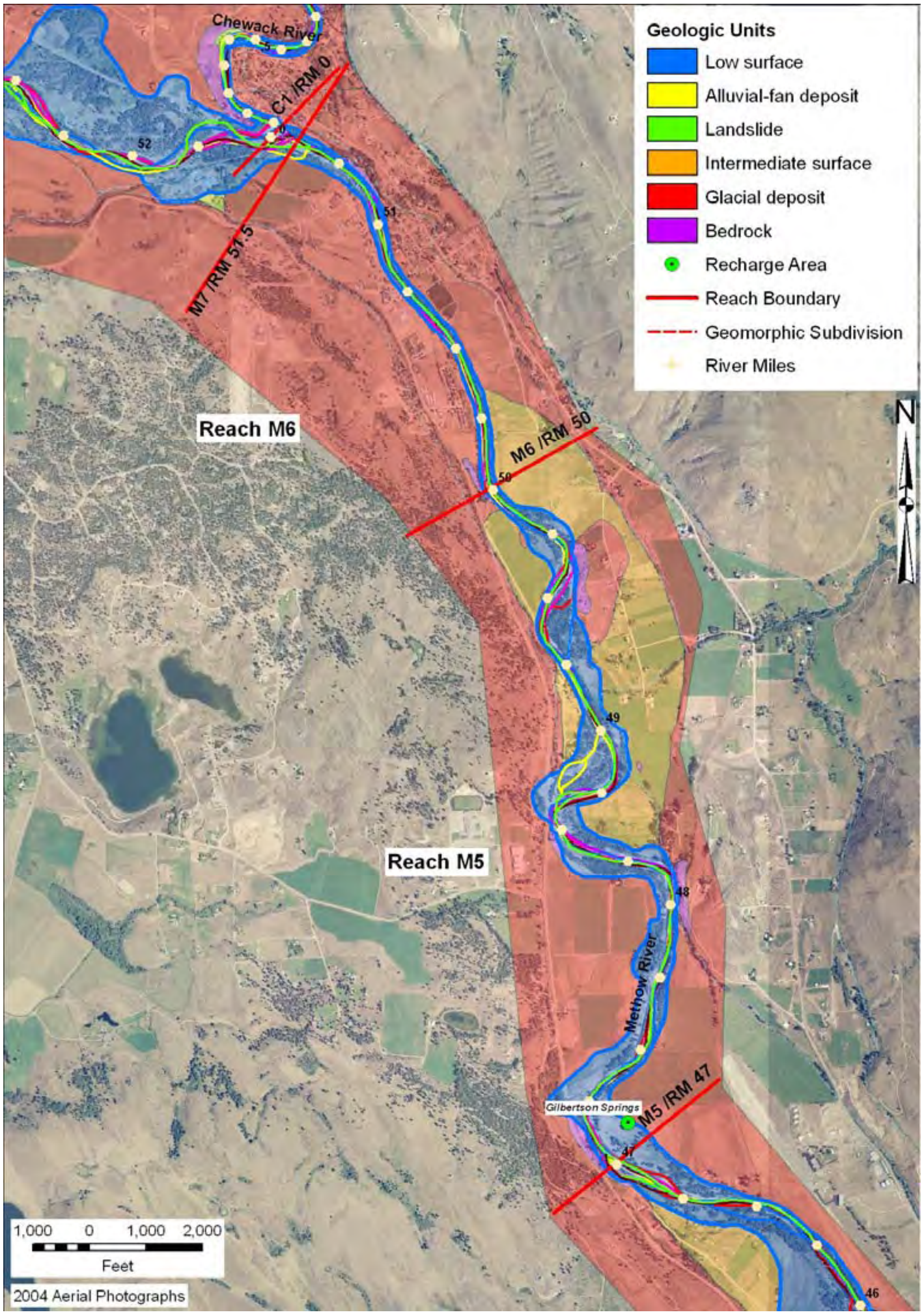

Figure C-15. Methow River – Geology and historical channels for moderately confined geomorphic Reach M5 (RM 47–50) and confined Reach M6 (RM 50–51.5), just downstream of the confluence with the Chewuch River.

The colored lines within the low surface are historical channel paths between 1945 and 2004.

3.7 REACH M7, RM 51.5–52.9

Reach M7 is 1.4 miles long and is located between RM 51.5 (at the confluence of the Chewuch River) and RM 52.9, where the low surface narrows (Table C-3; Figure C-16). It includes part of the town of Winthrop.

The reach is somewhat confined, and is more than three times wider than the reaches downstream (M6) and upstream (M8) (Figure C-10a, Figure C-10b, Figure C-16). The unvegetated channel occupies only a little more than 10% of the low surface, much less than in the adjacent reaches (Figure C-10c). A few secondary, overflow, or abandoned channels have been mapped in the reach (Figure C-10i). The low surface is confined by high surfaces composed of glacial deposits or bedrock, such as at the confluence of the Chewuch River (Figure C-16).

The channel consists of a main channel path and primary side channels (Figure C-10h and Figure C-16). The channel has shifted positions historically (Figure C-10d and Figure C-16).

The reach is a gaining reach, but the surface flow is much less than it is downstream of the confluence of the Chewuch River (Figure C-10g).

Impacts of human activities are more pronounced in this wider reach than in the adjacent upstream and downstream reaches. Houses, roads, and development have decreased the low surface average width by nearly 900 feet. Slightly less than 40% of the low surface has been cleared of natural vegetation.

3.8 REACH M8, RM 52.9–55

Reach M8, which is 2.1 miles long, is located between RM 52.9, where the low surface markedly narrows, and RM 55, where the low surface markedly widens (Table C-3; Figure C-10b and Figure C-17).

This reach is very confined, and the channel is nearly straight (Figure C-10a, Figure C-10b, and Figure C-16). The unvegetated channel occupies nearly 50% of the low surface area (Figure C-10c). The channel has migrated little historically (Figure C-10d; Figure C-16). The low surface is confined by high surfaces composed of glacial deposits and a large alluvial-fan deposit from Wolf Creek on river right (Figure C-17).

The reach is a gaining reach (Figure C-10g). Wolf Creek is the largest tributary, and contributes coarser sediment periodically to the reach (Figure C-10j; Figure C-16). Sediment plumes from Wolf Creek are visible in the Methow River on the 1948 and 1974 aerial photographs. Neither ponded areas nor recharge areas have been mapped in the reach (Figure C-10g).

Because the low surface is naturally confined, the impacts of human activities are limited. About 10% of the low surface has been cleared of vegetation. The mean width of the geologic surface has only been decreased by an average of about 10 feet by human features.

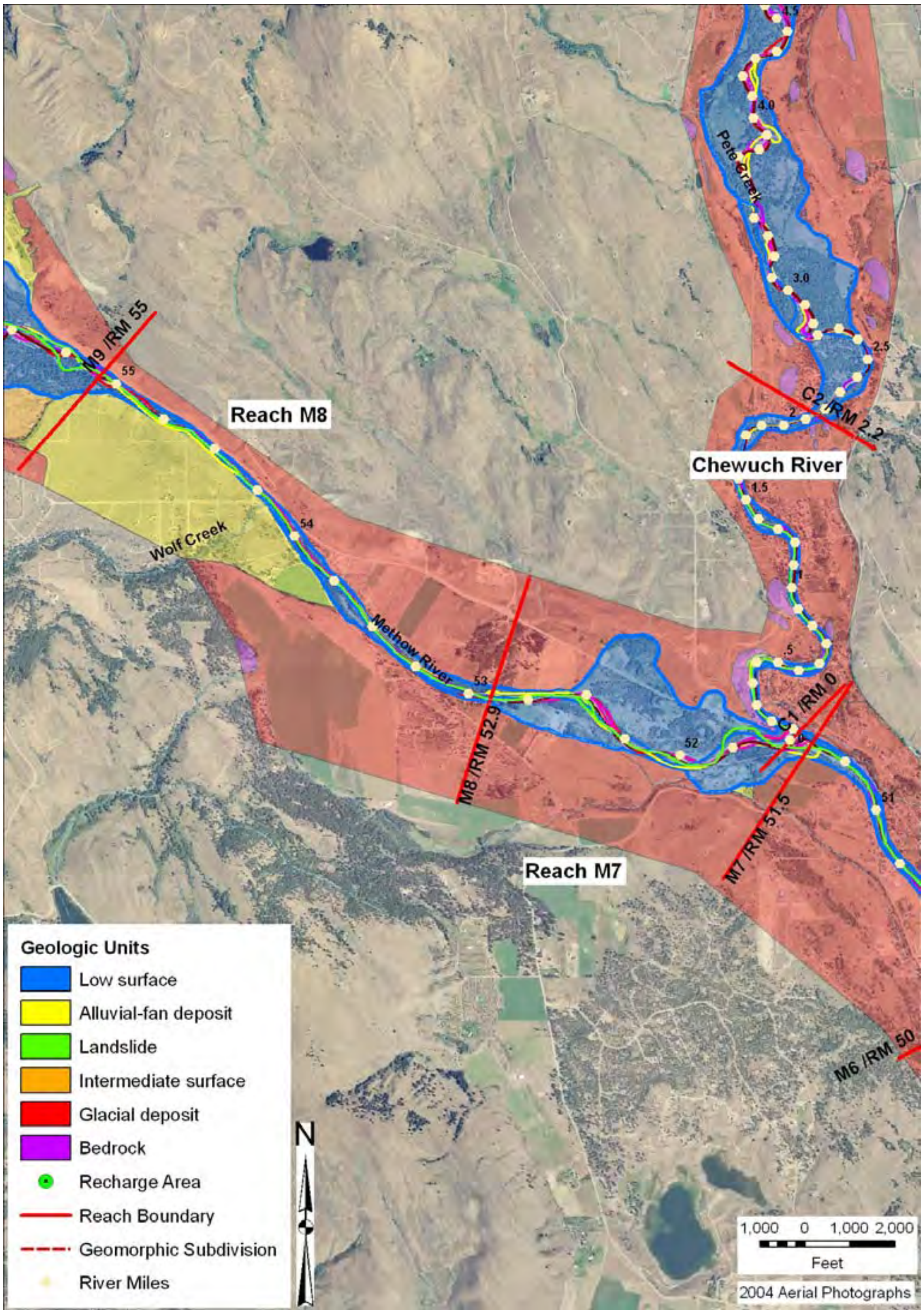

Figure C-16. Methow River – Geology and historical channels for moderately confined geomorphic Reach M7 (RM 51.5–52.9) and confined Reach M8 (RM 52.9–55), between the Chewuch River and Wolf Creek.

The colored lines within the low surface are historical channel paths between 1945 and 2004.

3.9 REACH M9, RM 55–65.5

Reach M9 is 10.5 miles long and is located between RM 55 (where the valley dramatically widens) and RM 65.5 (near the mouth of Goat Creek) (Table C-3; Figure C-17). A major change in physical characteristics and geomorphic processes occur at the downstream boundary of this reach (RM 55).

This is an unconfined reach, which has a wide low surface, extensive channel networks, and water-filled abandoned channels (Figures C-10a, C-10b, C-10g, C-10h; Figure C-17). Although the low surface is generally bounded by high banks composed of glacial deposits, alluvial-fan deposits, and bedrock, it is wide enough that these banks do not confine migration of the active channel. Only in a few places are the outsides of meanders bounded by bedrock (Figure C-17), so that lateral migration is limited. The exception is in the section between RM 61.7 and RM 65.5 (geomorphic subdivision M9c), which is somewhat narrower than downstream of this point, so that the meandering channel does seem to be naturally confined in places by the adjacent geologic deposits (Figure C-17), and the banks in this section are up to about 80 feet high (Figure C-10e).

Lower surfaces also are present within the low surface. The unvegetated channel occupies only between about 10 and 18% of the low surface area (Figure C-10c), which indicates the lack of confinement in the reach. Supporting this is the relatively long cumulative length of secondary and overflow channels (Figure C-10i), and the large area of channel change between 1948 and 2004 (about 80% of the channels were in different positions in these two years; Figure C-10d).

The channel system includes a network of active, recently active, and abandoned main channels, secondary channels, and overflow channels (Figure C-10h, Figure C-17). It is a gaining reach, and two seeps add groundwater to the river system, Hancock Springs at RM 60 and Suspension Creek at RM 64.3 (Figure C-10g). Many of the abandoned channels are filled with water that probably has a groundwater source, especially downstream of about RM 59 (Figure C-10g).

The main tributaries are Cassal Creek (RM 61.75), Fawn Creek (RM 62.9), Goat Creek (RM 65), and Little Boulder Creek (RM 65.3) (Figure C-10g). The last two are near the upstream reach boundary, and the constriction created by the two alluvial-fan deposits from these drainages is the reach boundary. Cassal and Little Boulder Creeks contribute coarser sediment to the reach (Figure C-10j).

The low surface has been most narrowed by human features in the middle section of the reach, between about RM 59 and RM 61.7, immediately upstream and downstream of Weeman Bridge at RM 61.2 (Figure C-17). This section of the reach has the most houses, roads, and development within the low surface. Other human features that create constrictions are embankment dams near RM 56, the "people mover" at RM 57, suspension bridge near RM 65, and several levees (such as McKinney levee). The maximum amount of clearing in this reach is about 18% of the low surface, which occurs in the middle section near Weeman Bridge. Additional activities in the future, especially those that disconnect the floodplain, could severely impact any presently working habitat.

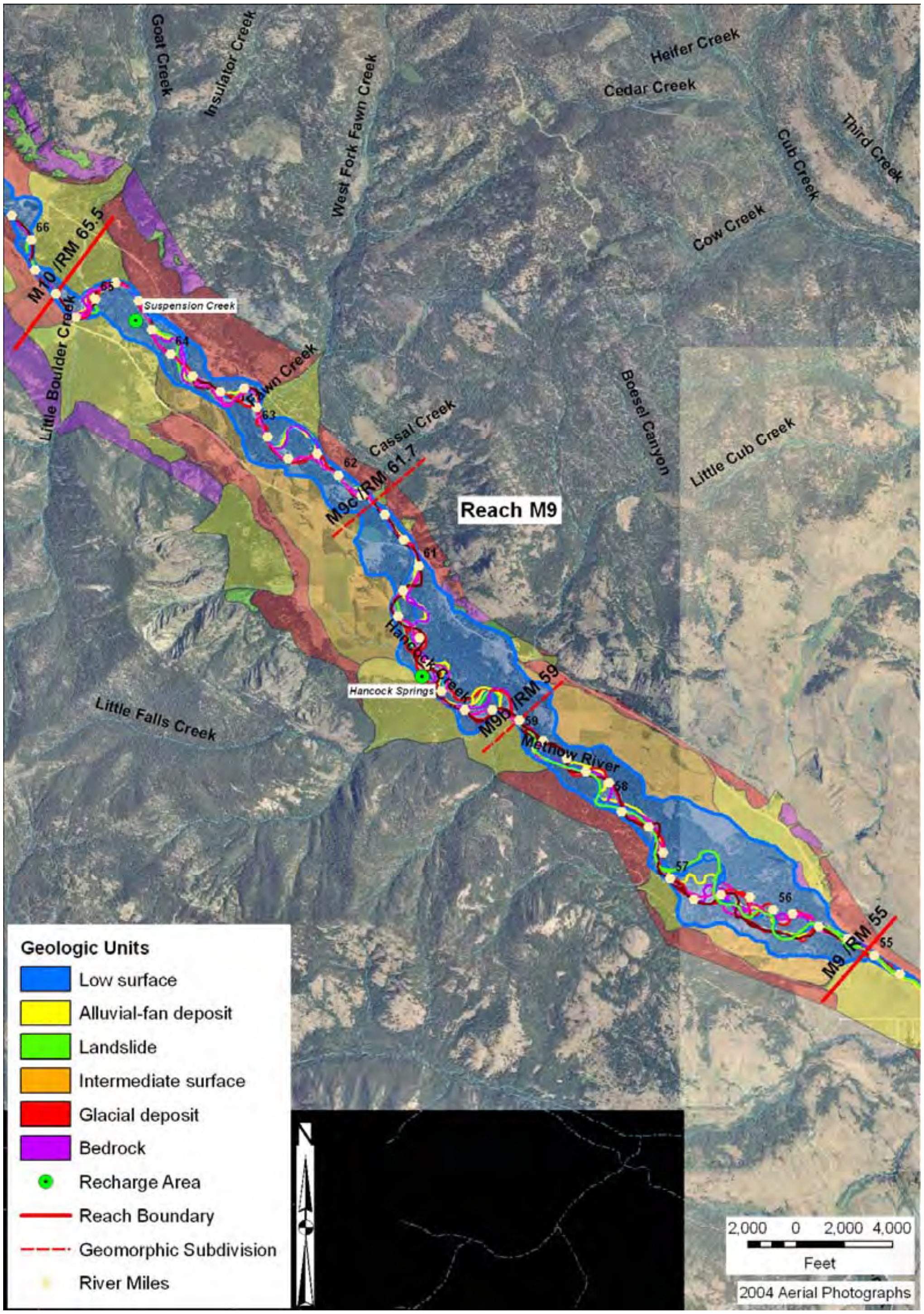

Figure C-17. Methow River – Geology and historical channels for unconfined geomorphic Reach M9 (RM 55–65.5), between Wolf Creek and Goat Creek/Little Boulder Creek.

The colored lines within the low surface are historical channel paths between 1945 and 2004.

3.10 REACH M10, RM 65.5–69.6

Reach M10 is 4.1 miles long and is located between RM 65.5 and RM 69.6, just upstream of Early Winters Creek (Table C-3; Figure C-18).

This reach is somewhat confined, and has mostly a single channel path, although short sections with a primary side channel do exist: near RM 66.5 and near RM 68.5 (Figures C-10a, C-10h, and Figure C-18). The width of the low surface is relatively narrow, but the reach includes some secondary, overflow, and abandoned channels (Figures C-10b and C-10i). The unvegetated channel occupies nearly 25% of the low surface (Figure C-10c). Historically, the channel has changed positions (about 40% of the channels were in different positions in 1948 and 2004; Figure C-10d).

The low surface is confined by high banks composed of glacial deposits, alluvial-fan deposits, and bedrock (Figure C-18). The large alluvial-fan deposits from Goat Creek, Little Boulder Creek, and Early Winters Creek naturally constrict the low surface. The downstream boundary at RM 65.3 is at the constriction created by alluvial-fan deposits from Goat Creek and Little Boulder Creek (Figure C-18). Several higher elevation surfaces are present within the low surface, and in places confine the unvegetated channel (Figure C-10e).

This reach is a losing reach where the channel dewaters during the late summer and fall in very dry years (Konrad et al., 2003). However, dewatering is more common upstream of Early Winters Creek at RM 69.6 in Reach M11. No seeps or springs have been mapped in this reach (Figure C-10g).

The main tributaries are Early Winters Creek at RM 69.2, and Goat Creek and Boulder Creek near RM 65.

The low surface in this reach has only been narrowed by human features by about 60 feet. The reach is naturally somewhat confined. Clearing in this reach is limited to about 10% of the total low surface area. Clearing decreases the potential of recruitment of LWD, which decreases channel roughness and bank stability.

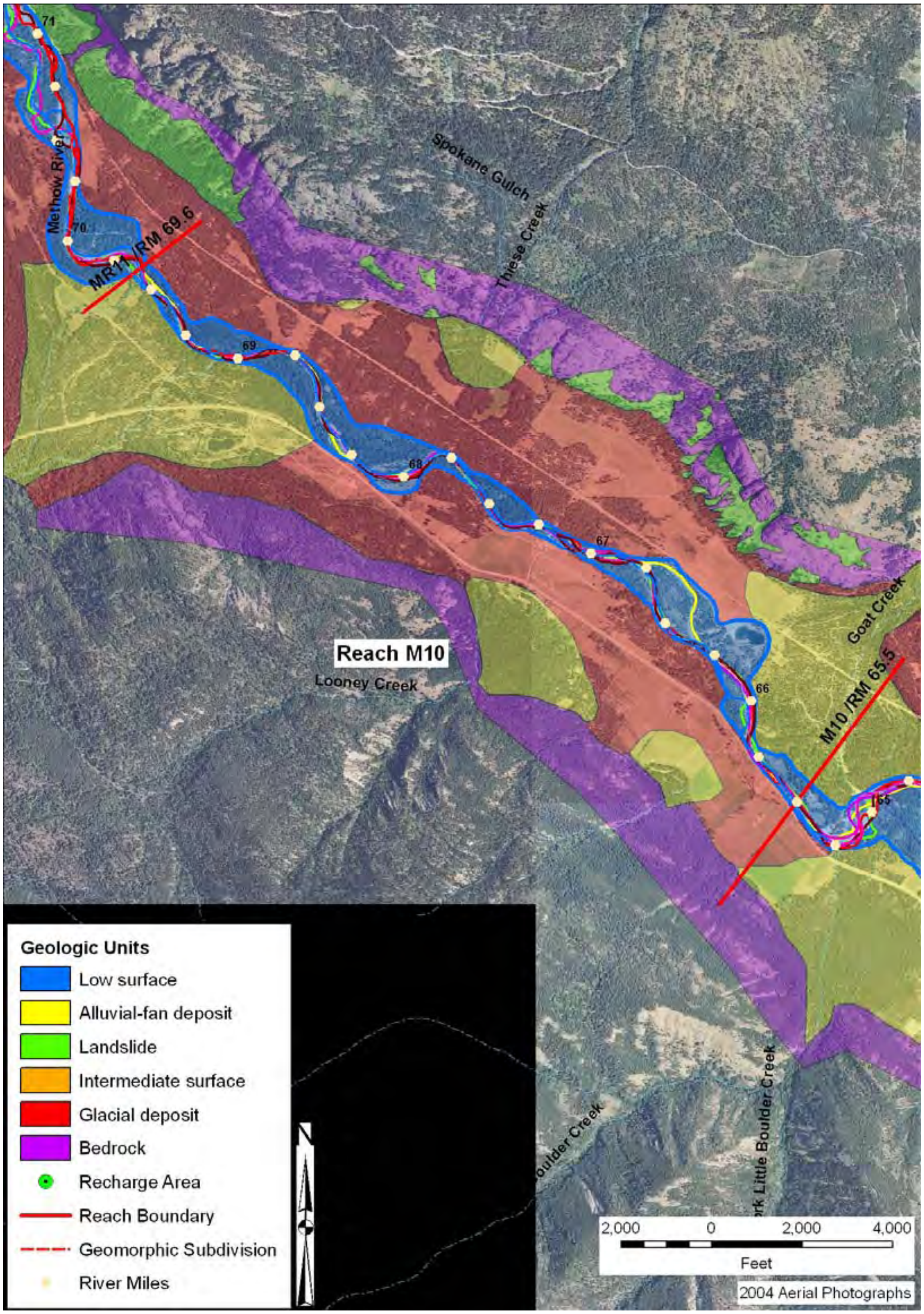

Figure C-18. Methow River – Geology and historical channels for moderately confined geomorphic Reach M10 (RM 65.5–69.6) between Goat Creek/Little Boulder Creek and Early Winters Creek.

The colored lines within the low surface are historical channel paths between 1945 and 2004.

3.11 REACH M11, RM 69.6–75

Reach M11 is 5.4 miles long and is located between RM 69.6, at the large alluvial-fan deposit from Early Winters Creek, and RM 75, near the mouth of Lost Creek (Table C-3; Figure C-19).

This is an unconfined reach, which consists of a moderately wide low-surface area (Figures C-10a, C-10b, and Figure C-19**)**. The unvegetated channel occupies only about 15% of the unvegetated channel (Figure C-10c). The low surface is bounded by high banks composed of glacial deposits, alluvial-fan deposits, landslide deposits, and bedrock (Figure C-19). The large alluvial-fan deposit from Early Winters Creek naturally constricts the low surface and defines the downstream boundary of the reach.

The low surface has extensive channel networks, especially upstream of RM 71.5, where the low surface is slightly wider than it is downstream. The section between RM 69.6 and RM 71.5 has long primary side channels. Primary side channels also are present upstream of RM 71.5 (Figure C-19).

The unvegetated channel has been able to migrate, which it has done between 1948 and 2004 (Figure C-10d and Figure C-19). Historically, the channel has changed positions (about 70% of the channels were in different positions in 1948 and 2004; Figure C-10d).

This reach is a losing reach where the channel commonly dewaters during the late summer and fall (Konrad et al. 2003). It is the reach that is most frequently dewatered on an annual basis. Ponded areas, especially in abandoned channel paths, are common (Figure C-10g). No seeps or springs have been mapped (Figure C-10g).

The main tributaries are Lost Creek (RM 75), Goat Wall Creek (RM 71.3), and McGee Creek (RM 73) (Figure C-10g). These tributaries contribute coarser sediment to the river system (Figure C-10j).

The low surface has been narrowed an average of about 280 feet by human features. The reach has been narrowed significantly by roads, levees, houses, and other development. Clearing in this reach is limited to <10% of the total low surface area, but clearing in some areas is substantial and is becoming more prevalent. Clearing decreases the potential of recruitment of LWD, which decreases channel roughness and bank stability.

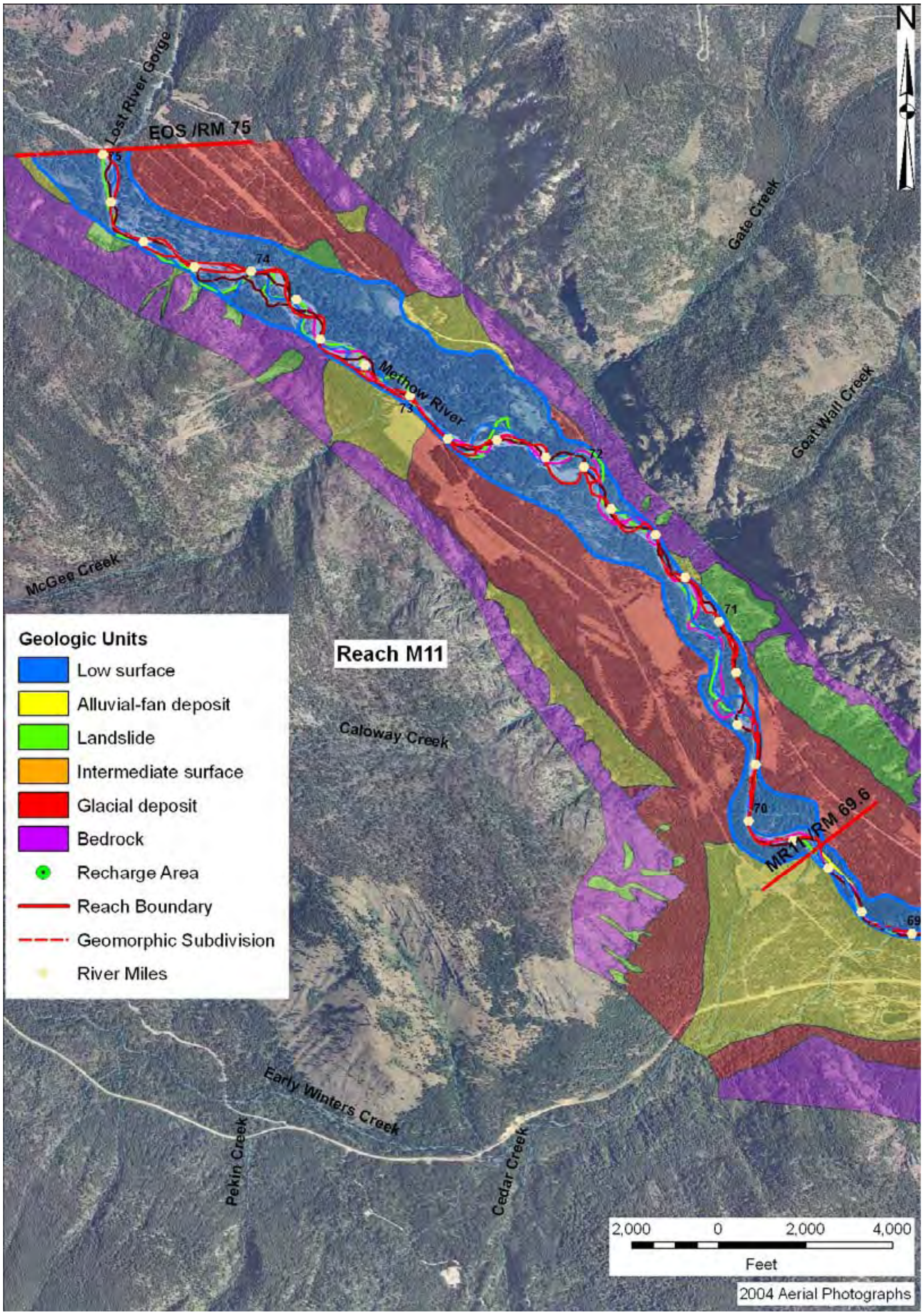

Figure C-19. Methow River – Geology and historical channels for unconfined geomorphic Reach M11 (RM 69.6–75), between Early Winters Creek and Lost Creek.

The colored lines within the low surface are historical channel paths between 1945 and 2004.

4. TWISP RIVER GEOMORPHIC REACHES

Six geomorphic reaches (T1 through T6, downstream to upstream) are identified for the Twisp River in the assessment section between the mouth (RM 0) and just upstream of War Creek (RM 18.1) (Table C-4). The Twisp River in the assessment section is primarily unconfined. The section includes two confined sections: between the mouth and RM 0.6 (Reach T1), and between RM 7.8 and RM 9.8 (included in Reach T4). The assessment section includes one moderately confined reach between RM 5 and RM 7.8 (reach T3) that has a 0.4-mile-long confined section at its downstream end (RM 5 to RM 4).

A change in channel slope occurs near RM 9.8, where Little Bridge Creek joins the Twisp River. This is at the upstream boundary of the confined Reach T4. The slope is much flatter upstream of this point in unconfined Reach T5, and is steeper downstream of this point in reaches T1, T2, and T3.

In the confined reaches (T1 and T4), the low surface is narrow and incised into bedrock and glacial deposits, primarily, or alluvial-fan deposits. The unvegetated channel cannot migrate freely within the narrow zone between high, confining banks. Few surfaces are present within the low surface.

In the unconfined reaches (T2, T5, and T6), the low surface is relatively wide, so that the unvegetated channel can migrate freely. The channel tends to meander, and the channel system includes primary side channels that are relatively well defined and long, and other short channels, either singly or in networks. A few ponded areas are present, mostly in abandoned channels, and a few springs have been noted.

In the moderately confined Reach T3, the low surface is wide enough that the unvegetated channel can migrate some but not freely. The downstream 0.4 mile of the reach is very confined, but this section is so short that is does not affect the overall character of the reach. The channel has broad meanders, and the channel system includes a primary side channel or a network of multiple paths. The channel system includes some secondary, overflow, or abandoned channels. The low surface is bounded by high banks composed of glacial deposits, mostly, and small alluvial-fan deposits that are limited to small tributaries that have incised through the glacial deposits. One ponded area and one spring have been mapped in the reach.

Table C-4. Twisp River – Geomorphic reaches and geomorphic subdivisions.

Reach[1/]	D/S RM	U/S RM	Length (miles)	Subdivision[1/]	D/S RM	U/S RM	Length (mile)	Type
T1	0	0.6	0.6	T1	0	0.6	0.6	Confined
T2	0.6	5.0	4.4	T2a	0.6	1.7	1.1	Unconfined
				T2b	1.7	5.0	3.3	Unconfined
T3	5.0	7.8	2.8	T3a	5.0	5.4	0.4	Moderately confined
				T3b	5.4	6.7	1.3	Moderately confined
				T3c	6.7	7.8	1.1	Moderately confined
T4	7.8	9.8	2.0	T4	7.8	9.8	2.0	Confined
T5	9.8	13.5	3.7	T5	9.8	13.5	3.7	Unconfined
T6	13.5	18.1	4.6	T6a	13.5	16.2	2.7	Unconfined
				T6b	16.2	18.1	1.9	Unconfined

1/ If no geomorphic subdivision is indicated, there are no additional lateral confinement points in the reach.

On the following pages, there are eight “subfigures,” C-26a through C-26h. These show characteristics of the processed-based reaches on the Chewuch River between RM 0 and RM 14.3. For all of these figures, the colored lines are values for the geomorphic reaches and the geomorphic subdivisions within them, and the vertical black lines show the boundaries of the geomorphic reaches.

Figure C-20. Twisp River – Eight subfigures (on following pages) presenting characteristics of the geomorphic reaches between RM 0 and RM 18.1.

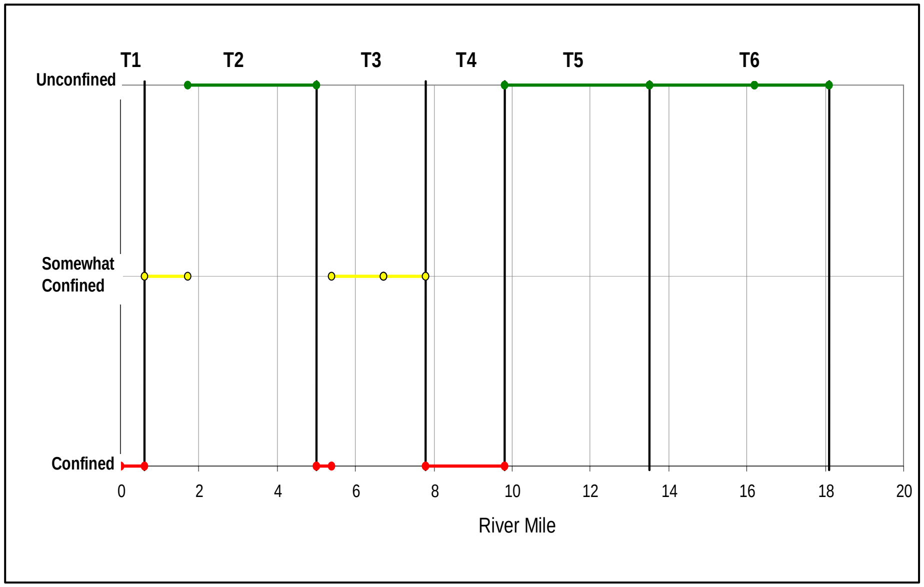

Figure C-20a. Variations in the geologic confinement of the low surface for each geomorphic reach and geomorphic subdivision within the reaches for the Twisp River plotted by river mile between RM 0 and RM 18.1. Each reach has a single value, except for short sections within reaches T2 and T3.

See the *Methow Atlas* (Reclamation, 2008c) for a comparison of the reaches.

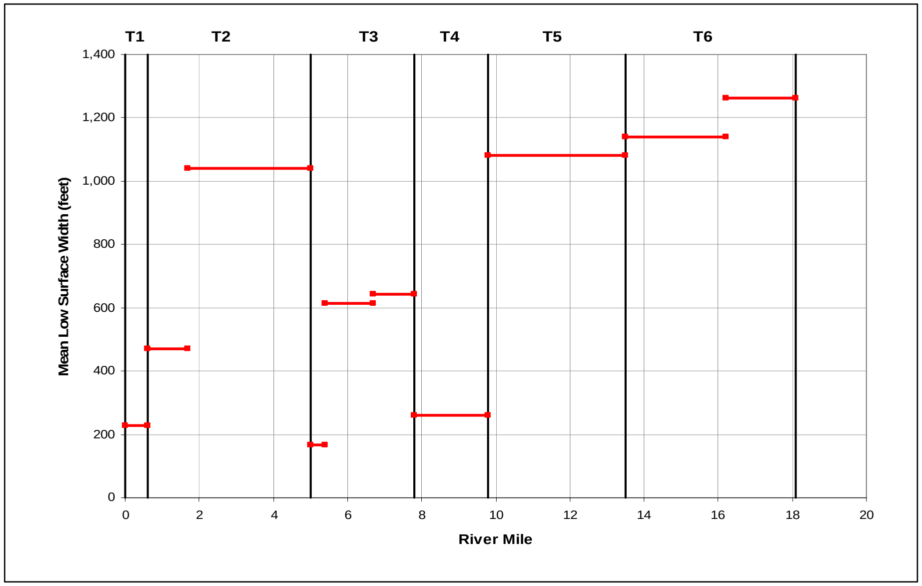

Figure C-20b. Mean widths of the low surface for each geomorphic and geomorphic subdivision within the reaches plotted by river mile. The wider the low surface, the less confined is the active channel. Although short sections are present where the low surface is more confined, the three unconfined reaches (T2, T5, and T6) have wider low surfaces than those in the two confined reaches (T1 and T4). This supports the subjective evaluation of confinement shown in Figure 20.

The low surface is bounded by alluvial-fan deposits, glacial deposits, landslides, or bedrock (Appendix G). Although these units other than the bedrock are erodible, the size of the sediment in the deposits and the heights of the banks mean that they confine the lateral movement of the active channel.

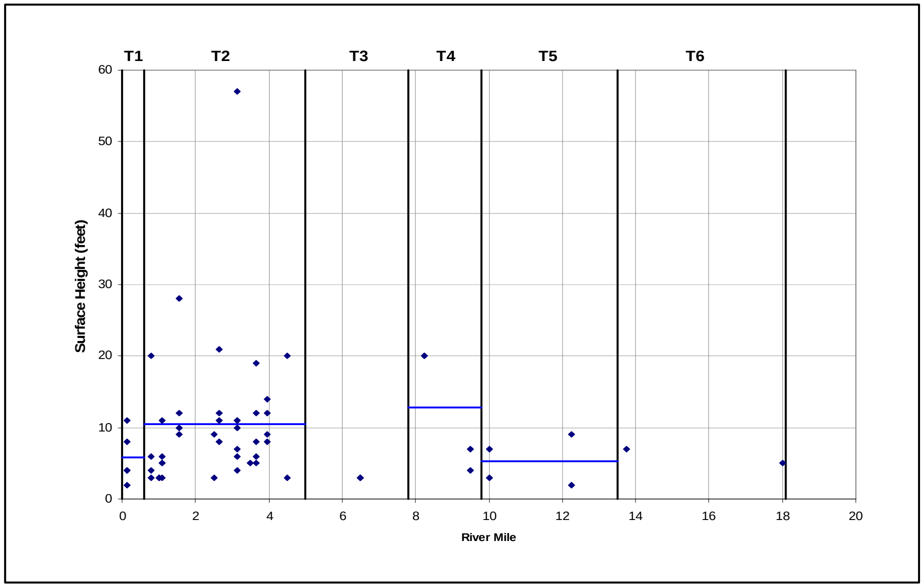

Figure C-20c. Measured surface heights plotted by river mile along the Twisp River between RM 0 and RM 18.1. The light blue, horizontal lines show the mean height for each reach, using all of the plotted points. The reach with the highest surfaces is T2, which is confined by glacial deposits, primarily, along with bedrock and alluvial-fan deposits.

Most of the heights downstream of RM 4 are from survey cross sections, where the surface elevations were subtracted from the thalweg elevations along the cross section. The heights upstream of RM 4 are from Golder Associates (2005).

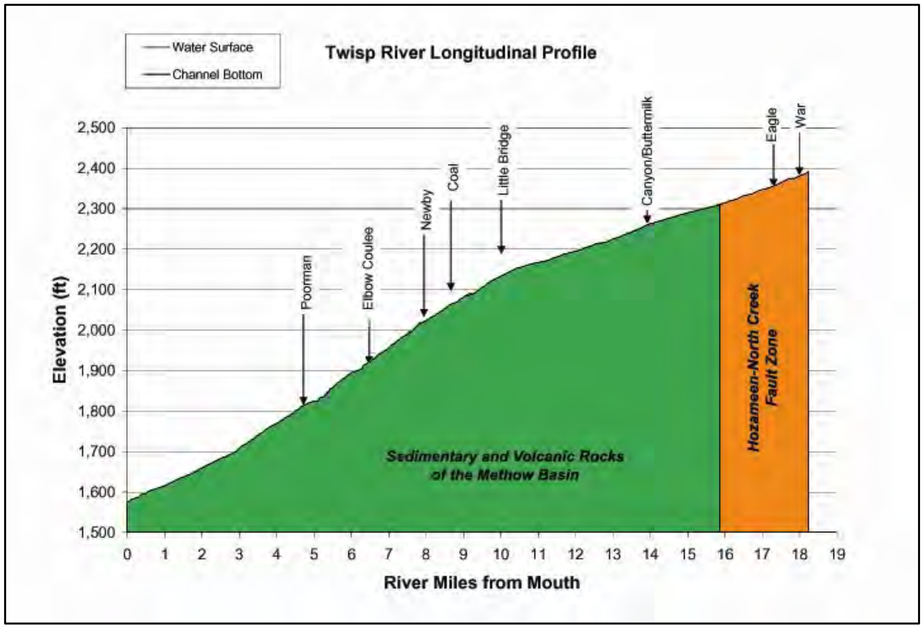

Figure C-20d. Slopes of the Twisp River plotted by river mile between RM 0 and RM 18.1. A marked change in slope occurs near RM 9.8 near the mouth of Little Bridge Creek. Slopes downstream of this point range between 0.010 and 0.014. Slopes upstream of this point are flatter and range between 0.002 and 0.010, but are mostly 0.006. The differences in the slopes result in a change in channel and floodplain processes that will need to be considered in the planning and implementation of any projects.

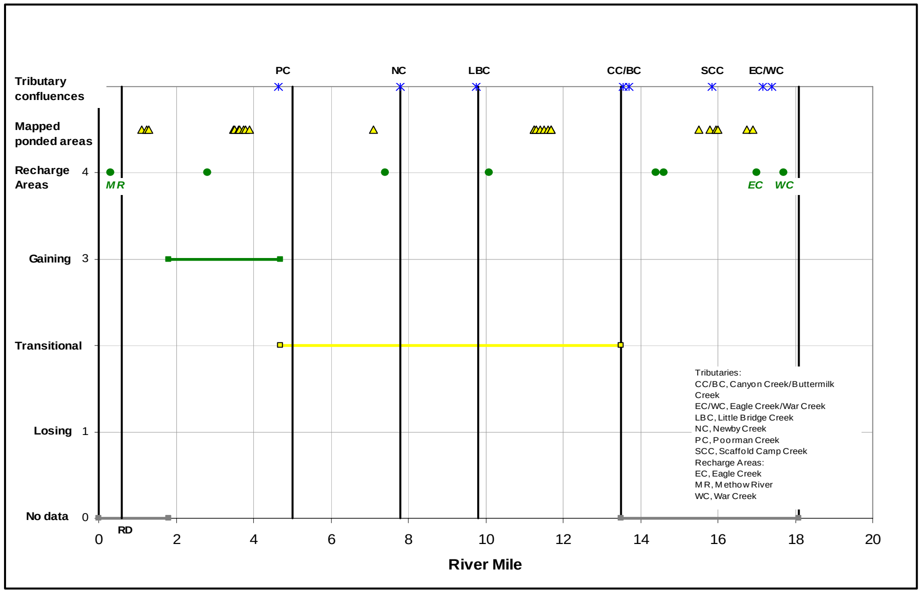

Figure C-20e. Water exchange between groundwater and surface water, groundwater recharge areas, mapped ponded areas, and major tributaries that contribute surface water to the Twisp River plotted by river mile between RM 0 and RM 18.1. Most of the assessment section where information is available is transitional. A gaining section is present in Reach T2 (RM 1.8–4.7).

The water exchange information is from the U.S. Geological Survey (Konrad and others, 2003). The recharge areas are from the U.S. Forest Service.

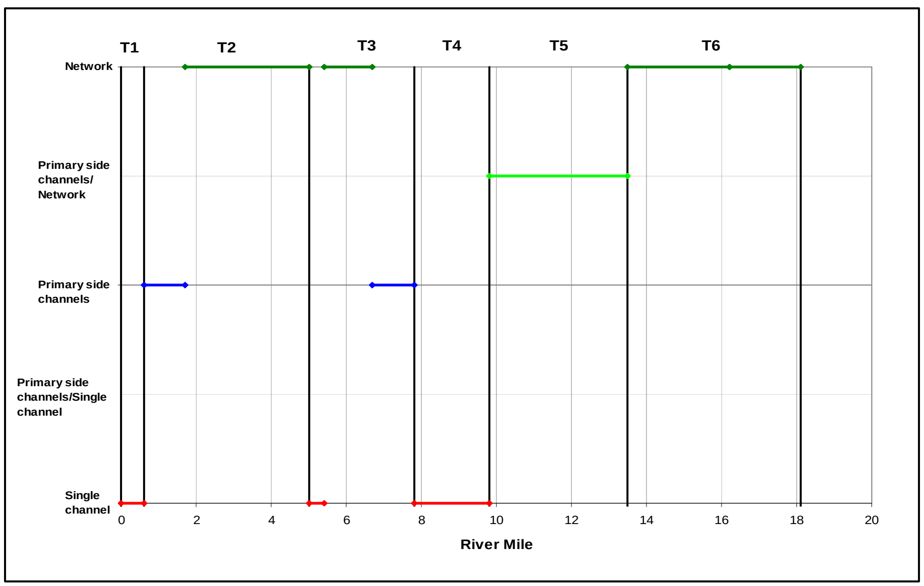

Figure C-20f. Channel characteristics for each process-based reach and geomorphic subdivision within the reaches plotted by river mile. Channel characteristics vary with confinement of the active channel and the amount of groundwater available.

The confined reaches (T1 and T4) are dominated by a single main channel path. Two of the unconfined reaches (T2 and T6) are dominated by channel networks. The other unconfined reach (T5) has both primary side channels and channel networks. The somewhat confined reach (T3) has variable characteristics: the section RM 5.4–6.7 has a channel network; the section RM 6.7–7.8 has primarily side channels; and the section RM 5–5.4 has a single channel.

Channel characteristics were evaluated on the 2004 and historical aerial photographs. The primary form is shown here. Short sections in each reach have different forms (*Reclamation, 2008c*).

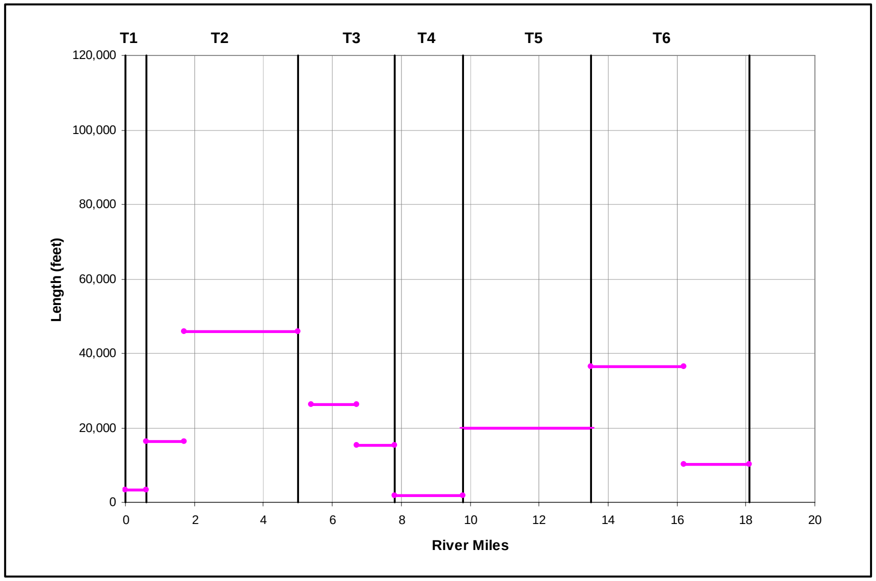

Figure C-20g. Cumulative lengths of secondary, overflow, and abandoned channels for each geomorphic reach and geomorphic subdivision within the reaches plotted by river mile. The reaches with the longest cumulative channel length have the most channels adjacent to the main channel. The longest cumulative lengths are in reaches T2 and T6, which are unconfined.

The channels were mapped in Arc using available aerial photographs (Appendix G; *Reclamation, 2008c*), so that the mapping is not consistent along the entire length of river. Only easily observed, readily mappable channels are included. Undoubtedly all of the reaches have considerably more channels than shown.

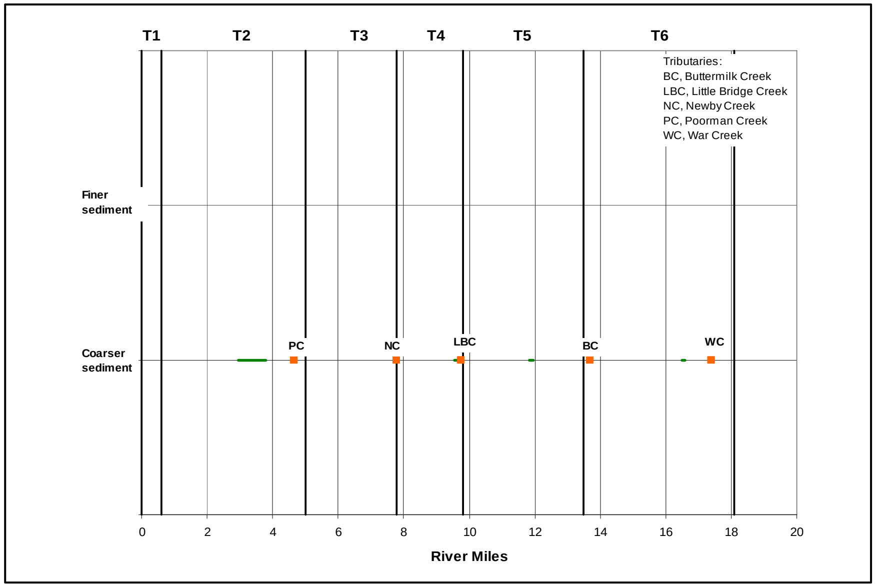

Figure C-20h. Major sources of coarser sediment plotted by river mile for the Twisp River between RM 0 and RM 18.1. Tributary sources of coarser sediment (coarse gravel) are shown by the orange squares. Landslides/debris flows, which are shown by the green lines, also contribute coarser sediment. The length of the green lines indicates the extent of the landslide/debris flow along the channel. The longest section with landslides is in reach T2, between RM 2.95 and RM 3.8.

Sediment sources were mapped using aerial photographs and field observations.

4.1 REACH T1, RM 0–0.6

Reach T1, which is 0.6 miles long, is located between the mouth of the Twisp River at Twisp (RM 0) and RM 0.6, where the low surface markedly widens (Table C-4; Figure C-21). The town of Twisp is on surfaces bounding both sides of the reach. It is a confined reach where the low surface is very narrow, and the channel has a single curving path (Figures C-20a, C-20c, C-20f, and Figure C-21). The low surface is bounded by bedrock or high banks that are composed of glacial deposits (Figure C-20c and Figure C-21). The low surface outside of the unvegetated channel is limited to the section just upstream of the mouth (the lower 0.3 miles of the reach).

The incised, narrow, low surface does not allow for much lateral migration of the unvegetated channel, and only limited migration of the channel has occurred between 1945 and 2004 (Figure C-21). Only a few secondary or overflow channels are present (Figure C-20g and Figure C-21).

No tributaries enter the Twisp River in this reach (Figure C-20e and Figure C-21). One spring near the Methow River is present (Figure C-20e and Figure C-21). No ponded areas have been mapped in this reach (Figure C-20e).

Extensive clearing of the low surface and adjacent bounding surfaces for residential development or agriculture limits the potential for recruitment of LWD within this reach. Although the low surface is naturally confined, the low surface has been confined even more by human features (e.g., levees, roads, houses). Development related to the town of Twisp has resulted in bank hardening (e.g., riprap).

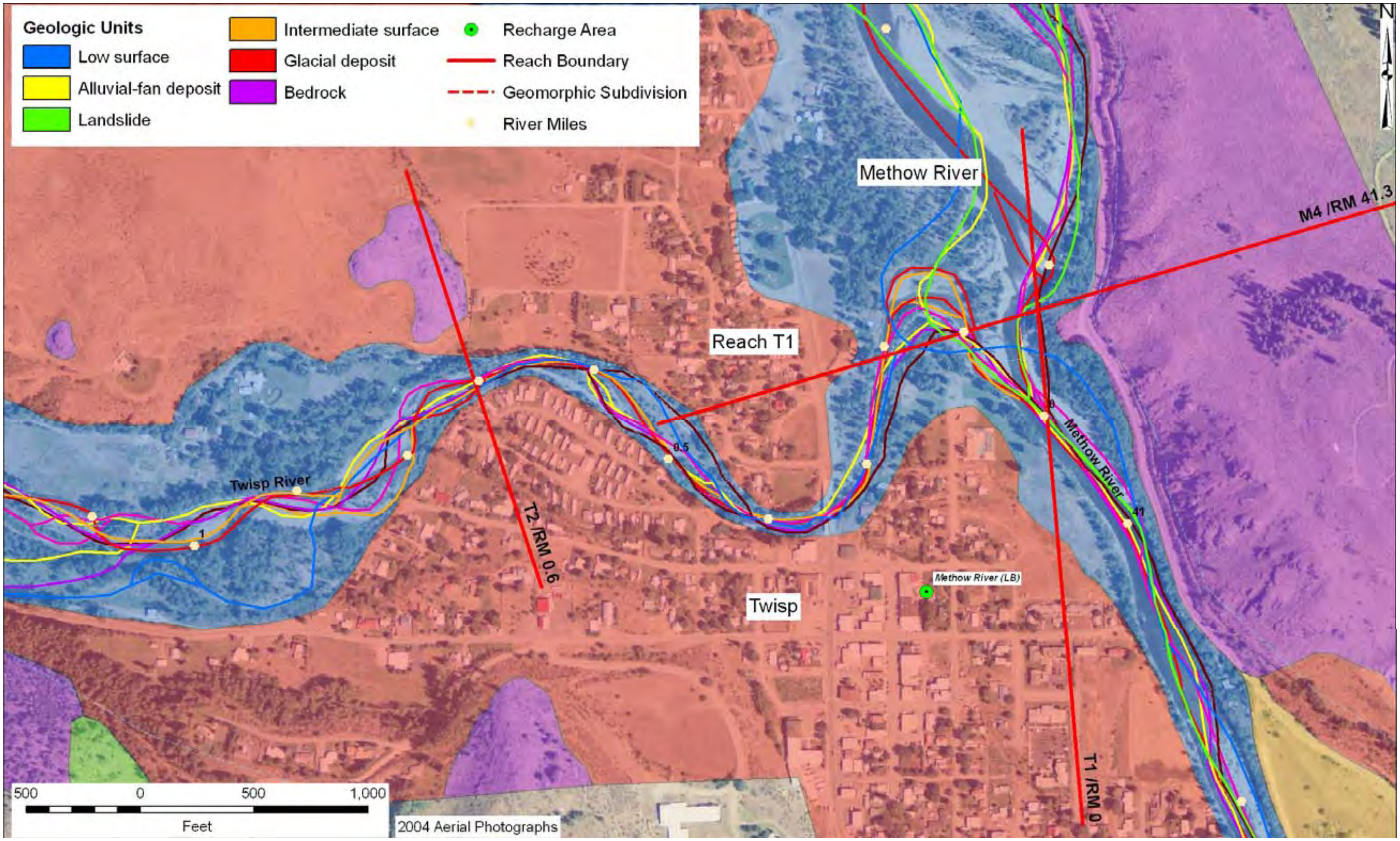

Figure C-21. Twisp River – Geology and historical channels for confined geomorphic Reach T1 (RM 0–0.6). Reach flows through the town of Twisp. The colored lines within the low surface are historical channel paths between 1945 and 2004.

4.2 REACH T2, RM 0.6–5

Reach T2, which is 4.4 miles long, is located between RM 0.6, where the low surface markedly widens, and RM 5, near the mouth of Poorman Creek (Table C-4, Figure C-22). It is primarily an unconfined reach, and the low surface is relatively wide (Figures C-20a, C-20g, and Figure C-22). It includes a geomorphic subdivision at RM 1.7. The low surface is narrower and somewhat or moderately confined downstream of this point. In the narrower section, the low surface is bounded by bedrock and high surfaces that are composed of glacial deposits (Figure C-20c and Figure C-22). In the wider section upstream of RM 1.7, the low surface is bounded by glacial deposits, mostly, and small areas of alluvial-fan deposits and landslide/debris flow deposits (Figure C-22).

The channel system is mostly a network of multiple channel paths. However, the narrower section between RM 0.6 and RM 1.7 has a main channel path with primary side channels (Figure C-20f and Figure C-22). Both sections include secondary, overflow, or abandoned channels (Figure C-20g). The channel has migrated in a few areas between 1954 and 2004: RM 0.8–1.6, RM 2.9–3.4, RM 4–4.2, and RM 4.3–4.5 (Figure C-22).

The main tributary entering this reach is Poorman Creek at RM 4.65 (Figure C-20e and Figure C-22). The section RM 1.7–4.7 is a gaining section (Figure C-20e). Between RM 4.7 and RM 5, the reach is transitional. (No data are available for the reach between RM 0.6 and RM 1.7.) Coarse sediment is contributed by Poorman Creek at RM 4.65 and by landslide/debris-flow deposits, especially between RM 2.95 and RM 3.1 and near RM 4.65 (Figure C-20h and Figure C-22).

There is one seep or spring identified in this reach, near RM 2.8 (Figure C-20e and Figure C-22). Ponded areas, mostly in abandoned channels, are present near RM 1.5 and between RM 3.5 and RM 4 (Figure C-20e).

Reach T2 has been impacted by human activities. Primary side channels and floodplain are cut off by levees, dikes, roads, and development. The greatest narrowing of the low surface by human features is the section between RM 1.7 and RM 5. The low surface has been artificially cleared of vegetation. Clearing of the surfaces, dikes, and bank protection adjacent to the active channel have reduced the LWD recruitment potential in the reach. Irrigation withdrawals occur at two locations: MVID West at RM 3.9, and Brown/Gillihan Ditch at RM 4.6.

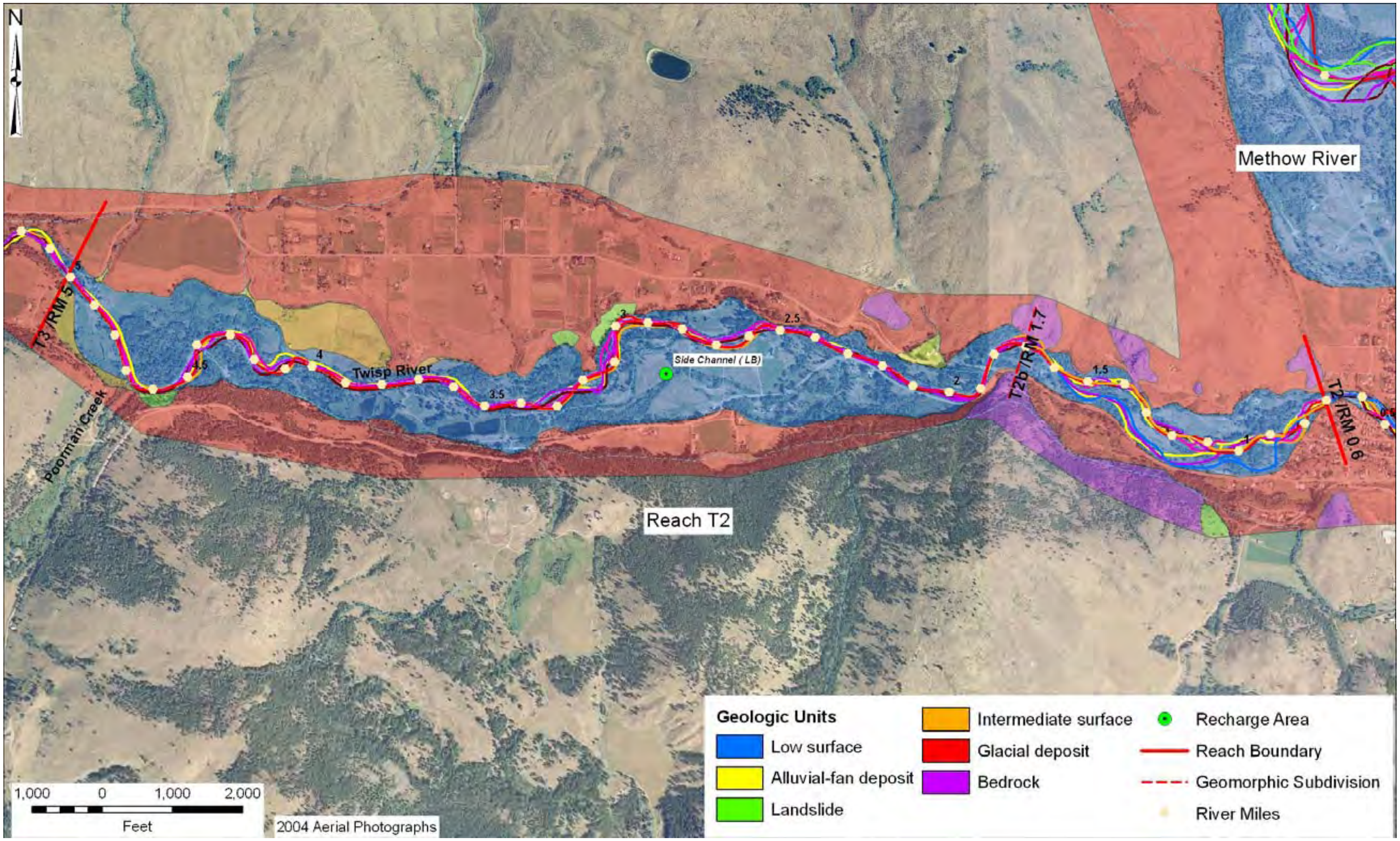

Figure C-22. Twisp River – Geology and historical channels for unconfined geomorphic Reach T2 (RM 0.6–5). Blue area is the low surface.

The colored lines within the low surface are historical channel paths between 1954 and 2004.

4.3 REACH T3, RM 5–7.8

Reach T3, which is 2.8 miles long, is located between RM 5, near the mouth of Poorman Creek, and RM 7.8, where Myer and Newby creeks join the Twisp River and their alluvial-fan deposits create a confined section (Table C-4, Figure C-23). It is primarily a somewhat, or moderately, confined reach (Figures C-20a, C-20b, and Figure C-23). The low surface is bounded by glacial deposits, mostly, and small alluvial-fan deposits (Figure C-23). The reach includes two geomorphic subdivisions, one at RM 5.4 and another at RM 6.7. The low surface is very confined in the 0.4-mile-long section between RM 5 and RM 5.4, where the low surface is bounded by bedrock (Figure C-20b and Figure C-23).

The channel system is either a channel network (between RM 5.4 and RM 6.7) or a main channel with primary side channels (between RM 6.7 and RM 7.8; Figure C-20f and Figure C-23). These two subdivisions of the reach include secondary, overflow, and abandoned channels (Figure C-20g). The channel migration in these sections is observable on aerial photographs taken between 1954 and 2004 (Figure C-23, *Reclamation, 2008c*). The channel through the very narrow subdivision (between RM 5 and RM 5.4) has a single flow path, which did not migrate between 1954 and 2004 (Figure C-20f and Figure C-23).

The main tributaries entering this reach are Newby and Myer Creeks near the reach boundary at RM 7.8 (Figure C-20e and Figure C-23). This reach is transitional (Figure C-20e). One seep or spring has been identified in this reach, near RM 7.4 (Figure C-20e and Figure C-23). A ponded area is present near RM 7 (Figure C-20e and Figure C-23). Coarse sediment is contributed by Newby Creek at RM 7.8 (Figure C-20h).

Reach T3 has been impacted by human activities. Primary side channels and floodplain are cut off by levees, dikes, roads, and development. The low surface has been artificially cleared of vegetation. Less clearing has occurred in the upstream section, between RM 6.7 and RM 7.8. Clearing of the surfaces, dikes, and bank protection adjacent to the active channel have reduced the LWD recruitment potential in the reach. Irrigation withdrawals occur at two locations: Hottel Diversion at RM 6 and Twisp River Power and Irrigation Ditch at RM 6.9.

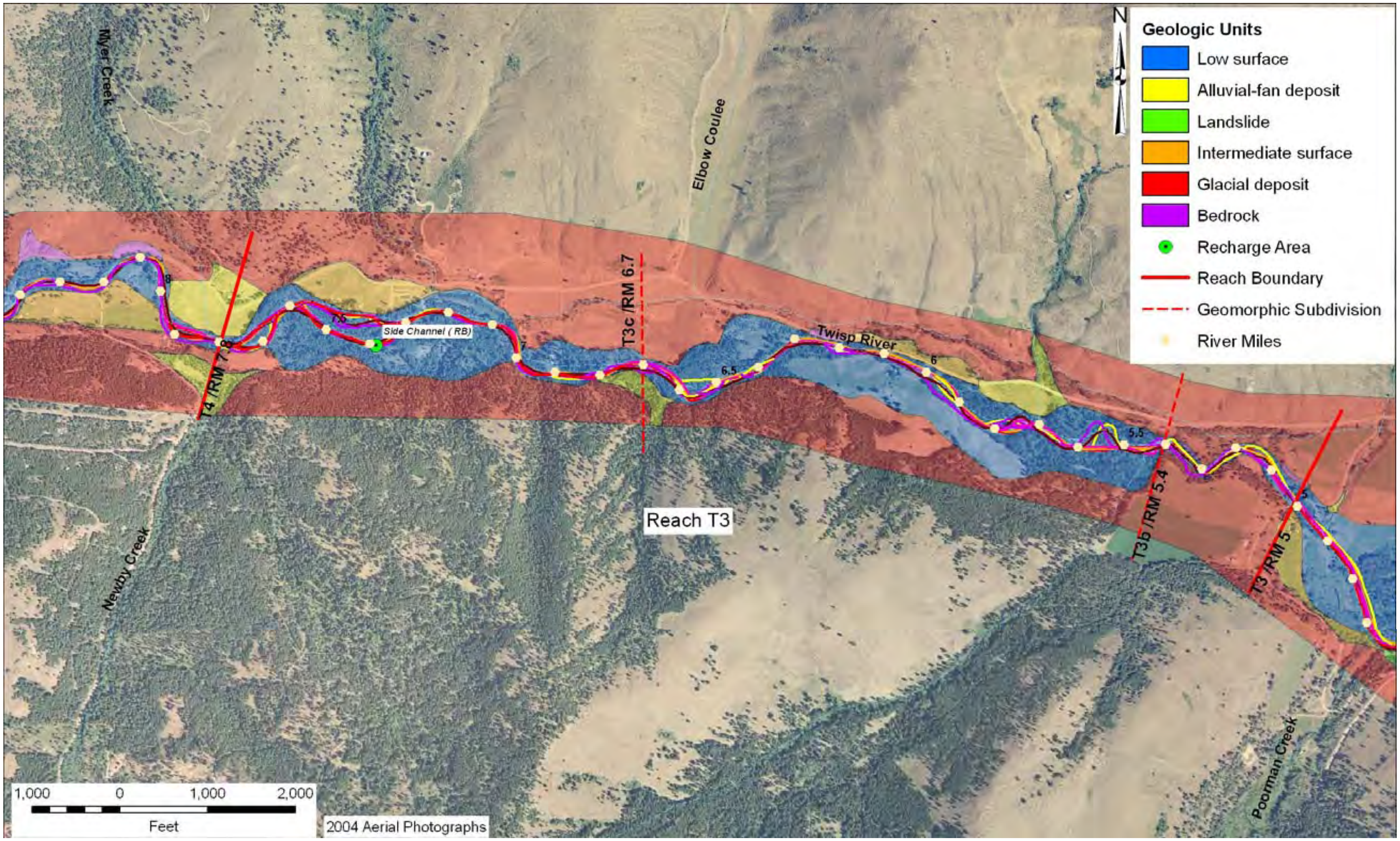

Figure C-23. Twisp River – Geology and historical channels for moderately confined geomorphic Reach T3 (RM 5–7.8 at Myer Creek). The colored lines within the low surface are historical channel paths between 1964 and 2004.

4.4 REACH T4, RM 7.8–9.8

Reach T4, which is 2 miles long, is located between RM 7.8, at the confluence of Newby and Myer creeks, and RM 9.8, near the confluence of Little Bridge Creek (Table C-4, Figure C-24). It is a confined reach with a relatively narrow low surface, which is bounded by bedrock and high surfaces composed of glacial deposits and alluvial-fan deposits at the upstream and downstream ends of the reach (Figures C-20a, C-20b, and Figure C-24). This reach extends to the change in slope near Little Bridge Creek (Figure C-20d).

The channel system is a single flow path, and only a few secondary, overflow, or abandoned channels have been mapped in the reach (Figures C-20f, C-20g, Figure C-24). The main channel has been nearly in the same position between 1964 and 2004 (Figure C-30; *Reclamation, 2008c*).

The only major tributary to enter this reach is Little Bridge Creek at the upstream boundary of the reach (Figure C-20e and Figure C-24). The reach is transitional (Figure C-20e). Coarse sediment is contributed by Little Bridge Creek and a landslide between RM 9.55 and RM 9.76 (Figure C-20h).

Reach T4 has been impacted by human activities. Only about 14% of the low surface in this reach has been cleared of vegetation for agriculture, grazing, and development, the clearing of the surfaces adjacent to the active channel has reduced the recruitment potential for LWD in the reach. Human features, such as levees, houses, and development, have decreased the width of the geologic low surface in this reach.

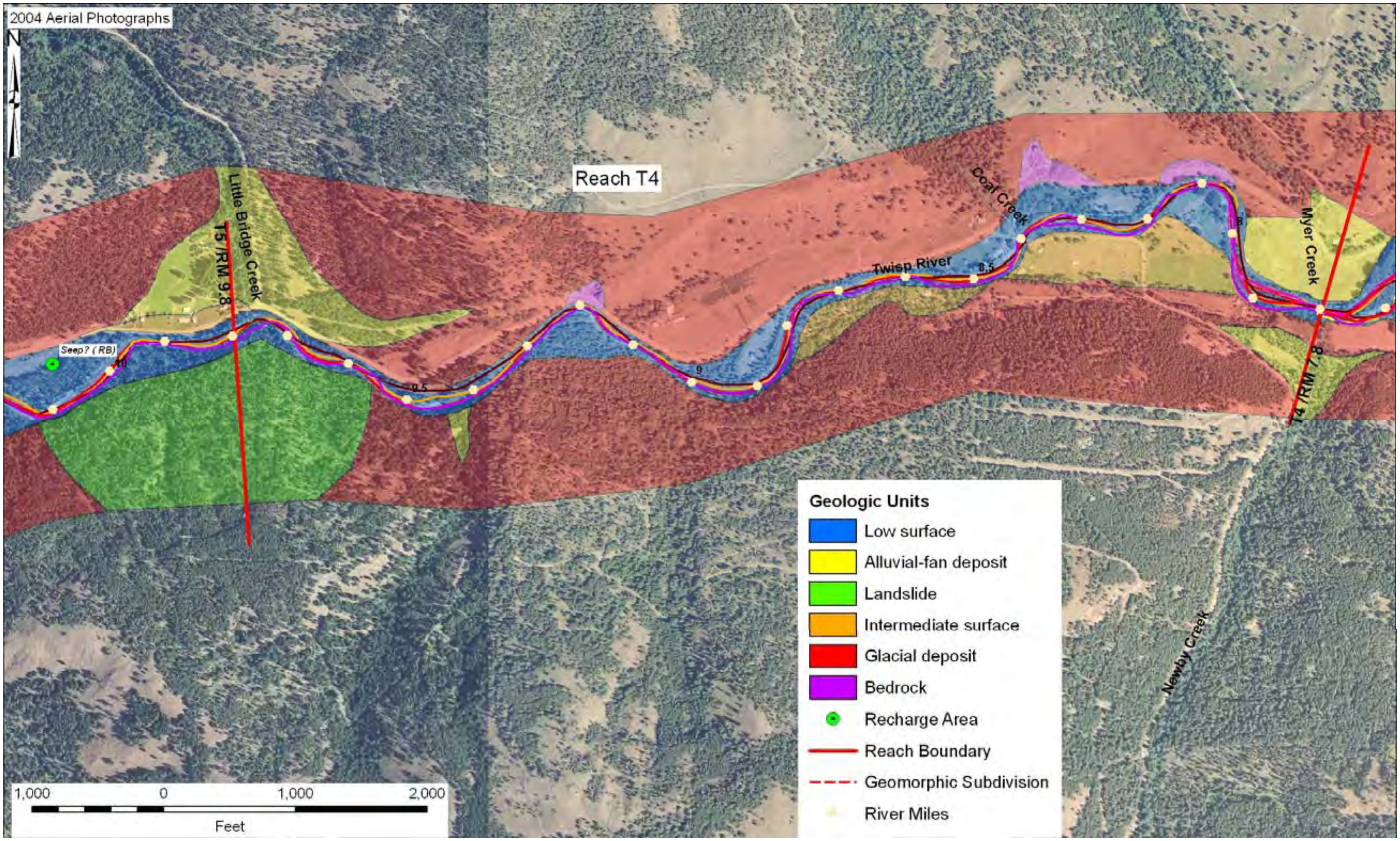

Figure C-24. Twisp River – Geology and historical channels for confined geomorphic Reach T4 (RM 7.8 at Myer Creek) to RM 9.8 (at Little Bridge Creek).

The colored lines within the low surface are historical channel paths between 1964 and 2004.

4.5 REACH T5, RM 9.8–13.5

Reach T5, which is 3.7 miles long, is located between RM 9.8, near the confluence of Little Bridge Creek, and RM 13.5, near the confluence of Buttermilk and Canyon creeks (Table C-4, Figure C-25). It is an unconfined reach, where the low surface is relatively wide (Figures C-20a, C-20b, and Figure C-25). The exception is a 0.2-mile-long section between RM 13.3 and RM 13.5, which is confined by opposing alluvial-fan deposits from Buttermilk and Canyon Creeks (Figure C-25). The low surface is bounded by bedrock, glacial deposits, alluvial-fan deposits (especially the large one from Buttermilk Creek), and short sections of landslide/debris-flow deposits (Figure C-25).

The channel system has a meandering main channel with primary side channels and a network of smaller channels (Figure C-20f and Figure C-25). Some channel migration is observable on aerial photographs taken between 1964/1985 and 2004 Figure C-25, *Reclamation*, *2008c*). Secondary, overflow, and abandoned channels are present (Figure C-20g).

Major tributaries are Little Bridge Creek, at the downstream reach boundary at RM 10, and Buttermilk and Canyon creeks at the upstream reach boundary at RM 13.5 (Figure C-20e and Figure C-25). The reach is transitional (Figure C-20e).

Buttermilk Creek (RM 13.7) has contributed coarse sediment to the reach (Figure C-20h). Landslide/debris-flow deposits supply coarse sediment to the Twisp River between RM 11.8 and RM 12 (Figure C-25). Ponded areas have been identified between RM 11.25 and RM 11.7 (Figure C-20e). One spring has been identified in the reach at RM 10 (Figure C-20e and Figure C-25).

Reach T5 has been impacted by human activities. Nearly a third of the area of the low surface has been cleared of natural vegetation. Clearing of the surfaces adjacent to the active channel has reduced the recruitment potential for LWD in the reach. The mean width of the geologic low surface has been decreased by human features, such as roads, houses, and other development. One diversion occurs at RM 11.1 (Elmer Johnson/ Libby/ Culbertson Ditch).

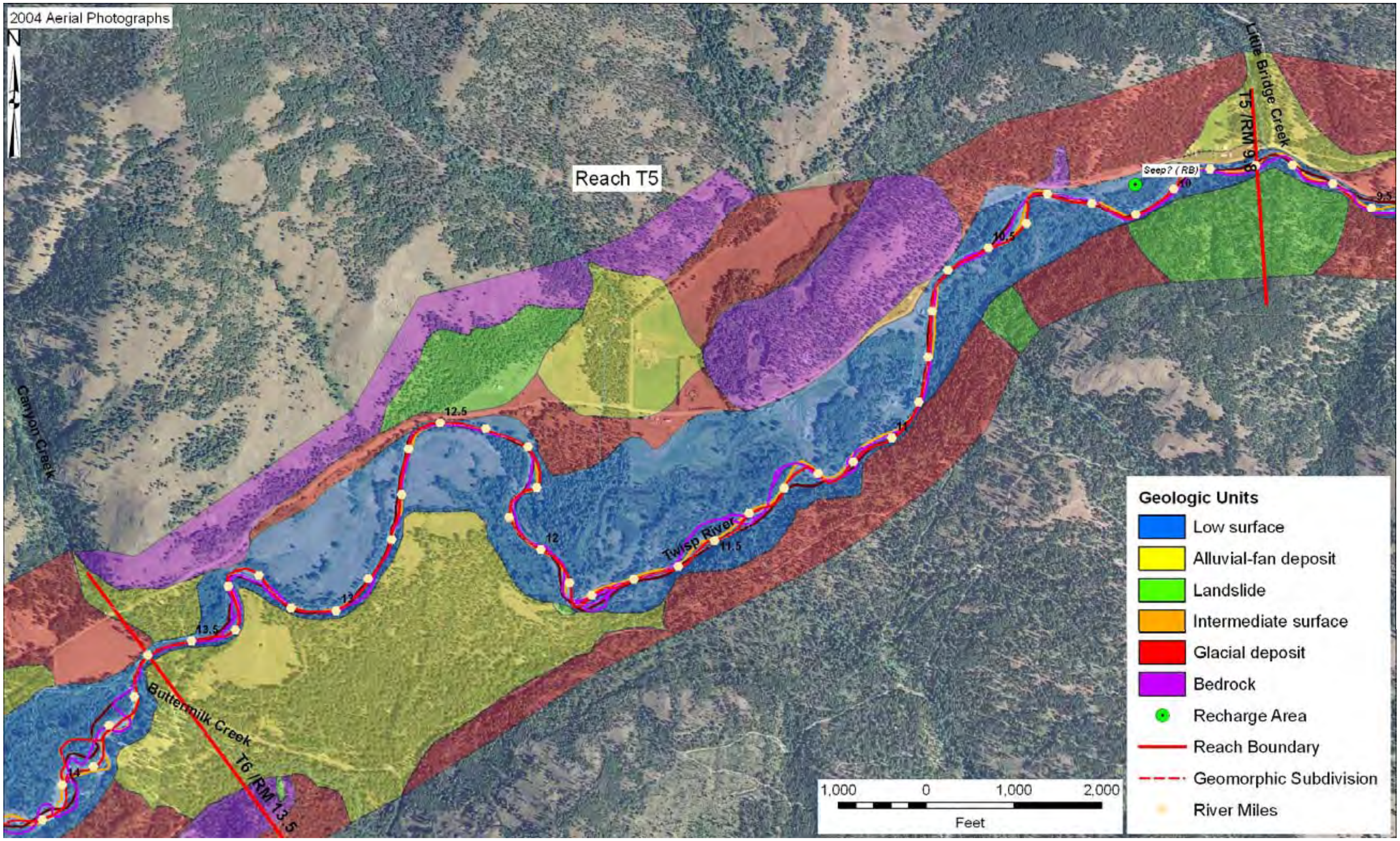

Figure C-25. Twisp River – Geology and historical channels for unconfined geomorphic Reach T5 (RM 9.8 at Little Bridge Creek) to RM 13.5 at Buttermilk Creek).

The colored lines within the low surface are historical channel paths between 1964 and 2004.

4.6 REACH T6, RM 13.5–18.1

Reach T6, which is 4.6 miles long, is located between RM 13.5, near the confluence of Buttermilk and Canyon creeks, and RM 18.1, just upstream of the confluences of Eagle and War creeks (Table C-4, Figure C-26). It is an unconfined reach, where the low surface is relatively wide (Figures C-20a, C-20b, and Figure C-32). The low surface is bounded by alluvial-fan deposits, primarily, and glacial deposits (Figure C-26). A geomorphic subdivision at RM 16.2 subdivides a slightly narrower downstream section from a slightly wider upstream section (Figure C-20b and Figure C-26).

The channel system is composed of a channel network; secondary, overflow, and abandoned channels are common (Figures C-20f, C-20g, and Figure C-26). Channel migration has occurred in several areas in this reach between 1964/1985 and 2004, especially in the downstream geomorphic section (RM 13.5 to RM 16.2), between RM 16.6 and RM 16.8, and between RM 17.4 and RM 18 (Figure C-26).

Major tributaries include Buttermilk and Canyon creeks near RM 13.5, Scaffold Camp Creek at RM 15.9, Eagle Creek at RM 17.2, and War Creek at RM 17.4 (Figure C-20e and Figure C-26). Ponded areas have been identified between RM 15.5 and 16.9 (Figure C-20e). Four springs have been identified in the reach at RM 14.4, RM 14.6, RM 17 (Eagle Creek), and RM 17.7 (War Creek) (Figure C-20e and Figure C-26).

War Creek (RM 17.4) contributes coarse sediment to the Twisp River (Figure C-20h). Landslide/debris-flow deposits also supply coarse sediment to the Twisp River between RM 16.5 and RM 16.6 (Figure C-20h).

One small log jam at RM 13.75 was noted by PWI (2003) in their mapping of LWD along the Twisp River. This logjam is upstream of the constriction that is created by the alluvial-fan deposits from Buttermilk and Canyon creeks near RM 13.5, at the downstream reach boundary.

Reach T6 has been impacted by human activities. Only 10% of the area of the low surface has been artificially cleared of vegetation. Clearing of the surfaces adjacent to the active channel has reduced the recruitment potential for LWD in the reach. Upstream of about RM 15 and downstream of the USFS boundary at RM 17, recent development has increased. The mean width of the geologic low surface has been decreased by human features, such as roads, houses, and other development.

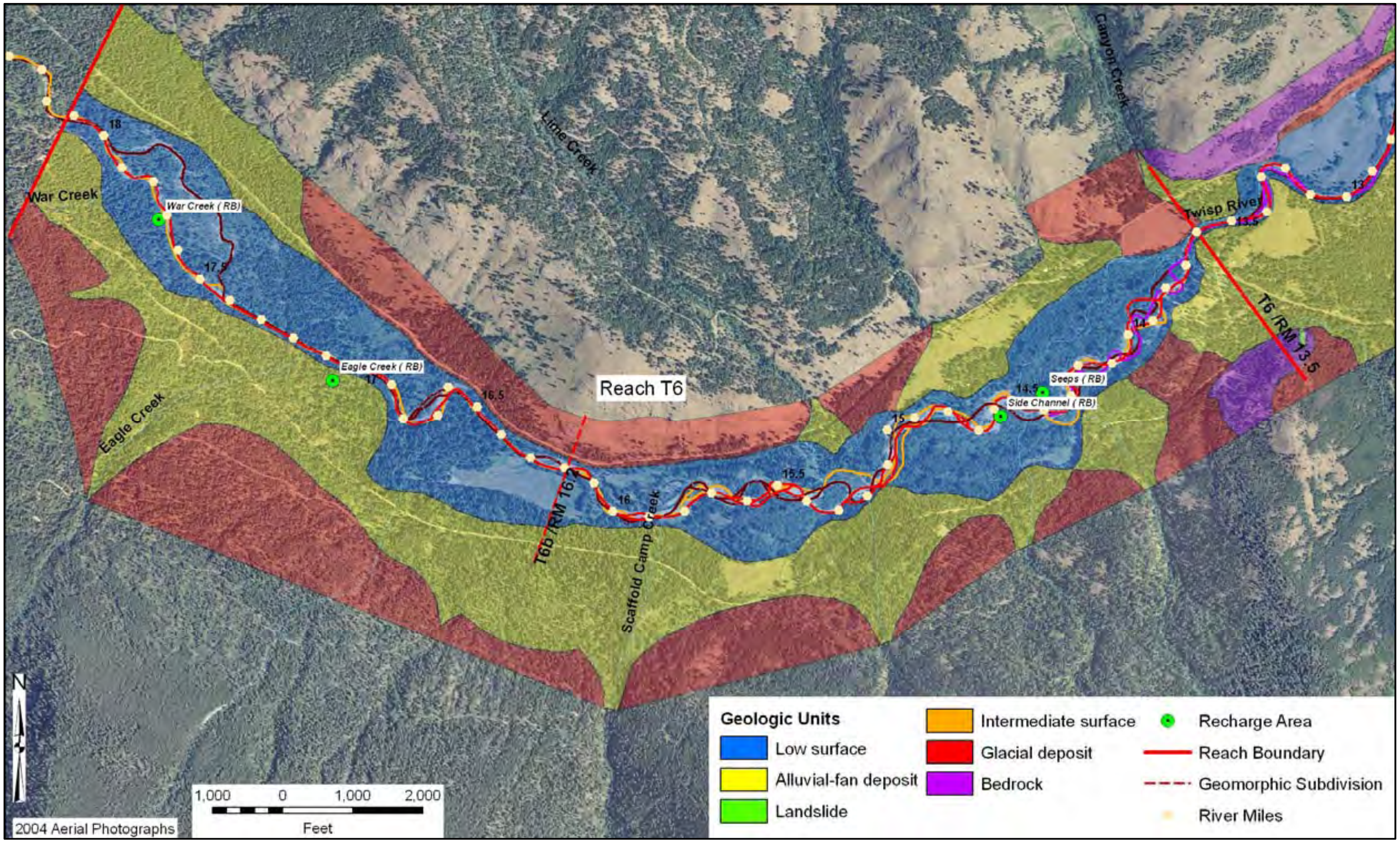

Figure C-26. Twisp River – Geology and historical channels for unconfined geomorphic Reach T6 (RM 13.5 at Buttermilk Creek to RM 18.1 at War Creek. The colored lines within the low surface are historical channel paths between 1964 and 2004.

5. CHEWUCH RIVER GEOMORPHIC REACHES

Six geomorphic reaches (C1 through C6, from downstream to upstream) are identified for the Chewuch River in the assessment section between the mouth (RM 0) and Falls Creek (RM 14.3) (Table C-5). The Chewuch River in the assessment section alternates between confined reaches (C1, C4, and C6) and unconfined reaches (C2 and C5). One reach (C3) is moderately confined.

The slope of the channel increases markedly between RM 9 and RM 9.8, and the slope is much flatter both upstream and downstream of this area. This change results in different valley and channel characteristics immediately upstream and downstream of the slope change.

In the confined reaches (C1, C4, and C6), the active channel is primarily a single channel that is not free to migrate due to the narrowness of the zone between bedrock or high banks, which are composed of glacial deposits and(or) alluvial-fan deposits. The area of low surface outside of the active channel is limited. Few surfaces are present within the low surface. A 0.6-mile-long section between RM 9.8 and RM 10.4 at the downstream end of reach C4 is wider than the rest of the reach and includes a relatively significant area of low surface outside of the unvegetated channel.

In the unconfined reaches (C2 and C5), the low surface is relatively wide, so that the unvegetated channel can migrate freely. The channel tends to meander. The channel system includes primary side channels that are relatively well defined and long, and other short channels, either singly or in networks. A few ponded areas, mostly in abandoned channels, are present, along with a large recharge area near Eightmile Creek at the downstream end of reach C4.

Recurrent wildfires have burned large portions of the Chewuch River watershed (see Appendix L). Subsequent debris flows have contributed large amounts of sediment periodically to the assessment reach. Most of the sediments that make it into the assessment reach are probably fines (sand and silt). The USFS is conducting ongoing monitoring of the sediment distribution that will provide additional data in the future on sediment levels deposited in downstream areas (Appendix K).

Table C-5. Chewuch River – Geomorphic reaches and geomorphic subdivisions.

Reach[1/]	Down-stream RM	Up-stream RM	Length (miles)	Subdivision[1/]	Down-stream RM	Up-stream RM	Length (miles)	Type
C1	0	2.2	2.2	C1	0	2.2	2.2	Confined
C2	2.2	7.3	5.1	C2a	2.2	5.6	3.4	Unconfined
				C2b	5.6	7.3	1.7	Unconfined
C3	7.3	9.5	2.2	C3a	7.3	8.5	1.2	Moderately confined
				C3b	8.5	9.5	1.0	Moderately confined
C4	9.5	11.7	2.2	C4a	9.5	9.8	0.3	Confined
				C4b	9.8	10.4	0.6	Confined
				C4c	10.4	11.7	1.3	Confined
C5	11.7	13.9	2.2	C5a	11.7	13.0	1.3	Unconfined
				C5b	13.0	13.9	0.9	Unconfined
C6	13.9	14.3	0.4	C6	13.9	14.3	0.4	Confined

1/ If no geomorphic subdivision is indicated, there are no additional lateral confinement points in the reach.

On the following pages, there are seven "subfigures," C-27a through C-27g. These show characteristics of the geomorphic reaches on the Chewuch River between RM 0 and RM 14.3. For all of these figures, the colored lines are values for the geomorphic reaches and the geomorphic subdivisions within them, and the vertical black lines show the boundaries of the geomorphic reaches.

Figure C-27. Chewuch River – Seven subfigures (on following pages) presenting characteristics of geomorphic reaches between RM 0 and RM 14.3.

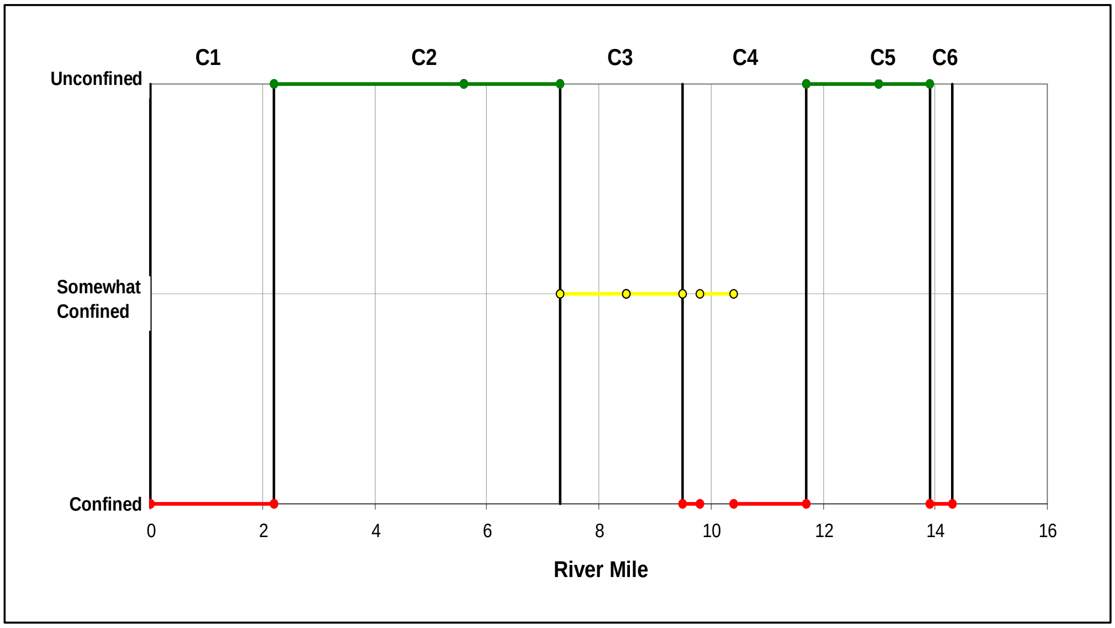

Figure C-27a. Variations in the geologic confinement of the low surface shown for each geomorphic reach and geomorphic subdivisions within the reaches plotted by river miles for the Chewuch River between RM 0 and RM 14.3. Although variation may be present within a single reach, all are dominated by one value. The assessment reach of the Chewuch River has three confined reaches (C1, C4, and C6), two unconfined reaches (C2 and C5), and one somewhat confined reach (C3).

See *Reclamation, 2008c* for a comparison of the reaches

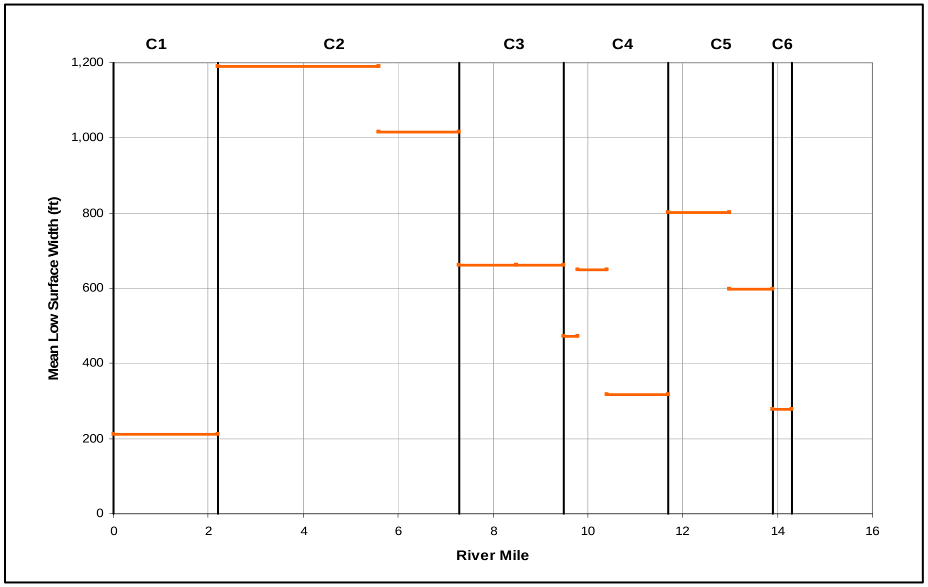

Figure C-27b. Mean widths of the low surface for each geomorphic reach and geomorphic subdivision within the reaches plotted by river mile. The wider the low surface, the less confined is the active channel. Although short sections are present where the low surface is more confined, the two unconfined reaches (C2 and C5) have wider low surfaces than those in the three confined reaches (C1, C4, and C6). This supports the subjective evaluation of confinement shown in Figure C-27a.

The low surface is bounded by alluvial-fan deposits, glacial deposits, landslides, or bedrock (Appendix G). Although these units other than the bedrock are erodible, the size of the sediment in the deposits and the heights of the banks mean that they confine the lateral movement of the active channel.

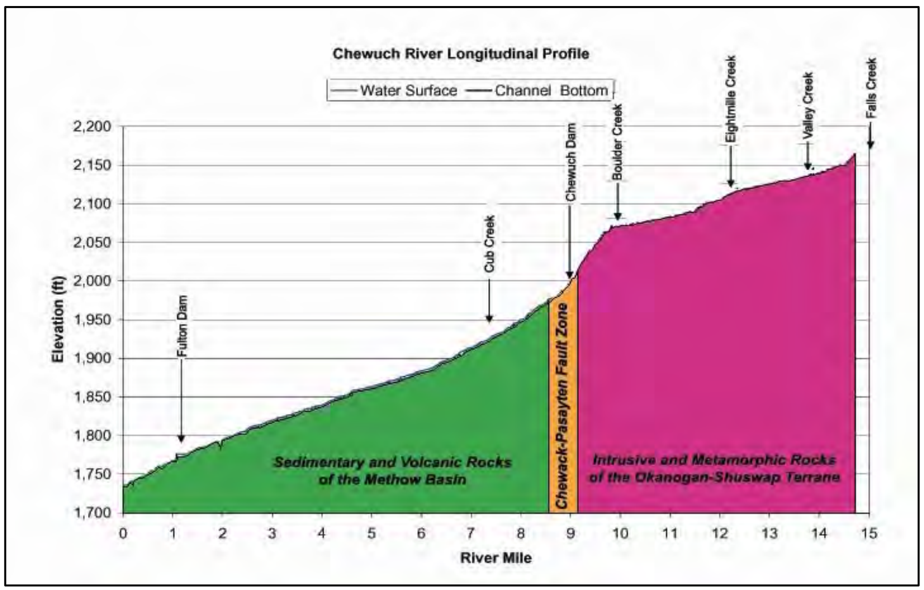

Figure C-27c. Slopes of the Chewuch River plotted by river mile between RM 0 and RM 14.3. A marked change occurs about RM 9–9.8, where the slope steepens. Flatter slopes are present both upstream and downstream. The steeper section may due to a fault, which crosses the valley here.

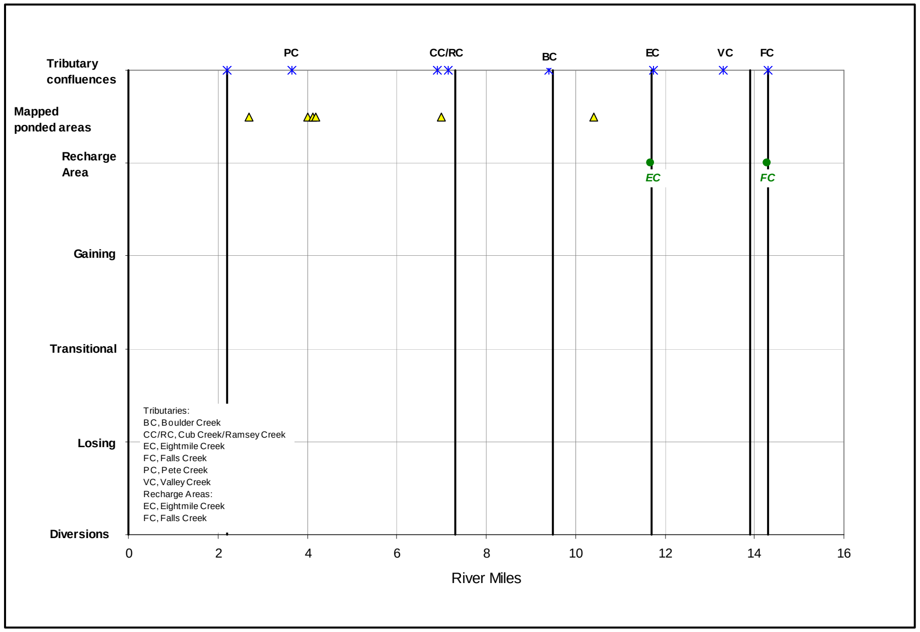

Figure C-27d. The locations of springs, mapped ponded areas, and major tributaries that contribute surface water to the Chewuch River plotted by river mile between RM 0 and RM 14.3. Groundwater-surface-water exchange information is not available for the Chewuch River. Springs have been noted only in the upstream portion of the assessment area, in Reach T5 and Reach T6.

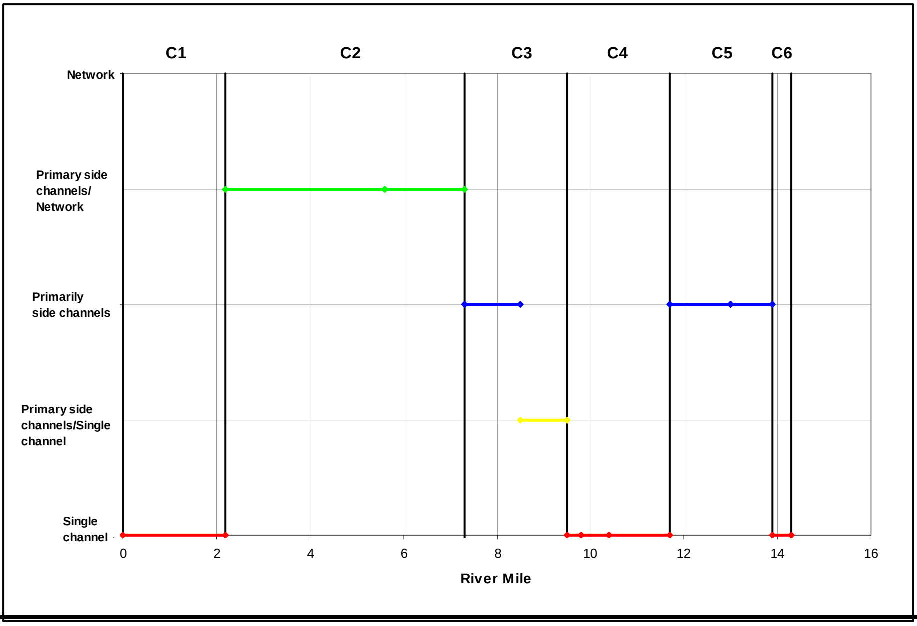

Figure C-27e. Channel characteristics for each geomorphic reach and geomorphic subdivision within the reaches for the Chewuch River between RM 0 and RM 14.3. Channel characteristics vary with confinement of the active channel and the amount of groundwater available.

The confined reaches (C1, C4, and C6) are dominated by a single main channel path. The downstream unconfined reach (C2) has channel networks. The upstream unconfined reach (C5) has primary side channels rather than networks. The somewhat confined reach (C3) has in different sections primary side channels and a single main channel.

Channel characteristics were evaluated on 2004 and historical aerial photographs. The primary form is shown here. Short sections in each reach have different forms (refer to *Reclamation, 2008c*).

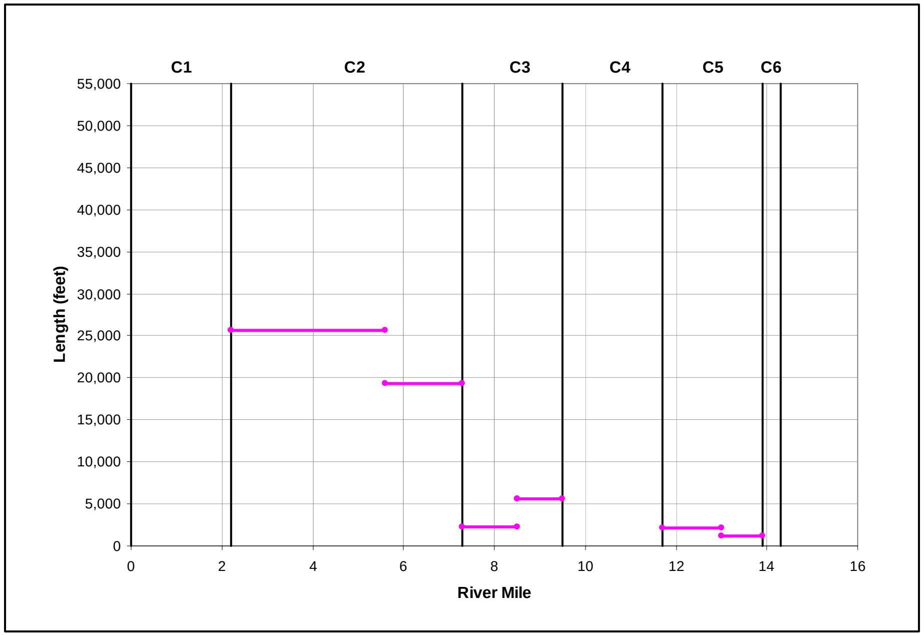

Figure C-27f. Cumulative lengths of secondary, overflow, and abandoned channels for each geomorphic reach and geomorphic subdivision within the reaches plotted by river mile. The reaches with the longest cumulative channel length have the most channels adjacent to the main channel. The longest cumulative length is in reach C2, an unconfined reach. The confined reaches (C1, C4, and C6) have few mapped channels adjacent to the main channel. The somewhat confined reach (C3) has some mapped channels. The low value the upstream unconfined reach, C5, is likely the result of the lack of historical aerial photographs and the dense vegetation that makes channels difficult to see.

The channels were mapped in Arc using available aerial photographs (Appendix G; *Reclamation, 2008c*), so that the mapping is not consistent along the entire length of river. Only easily observed, readily mapable channel are included. All of the reaches have considerably more channels than shown.

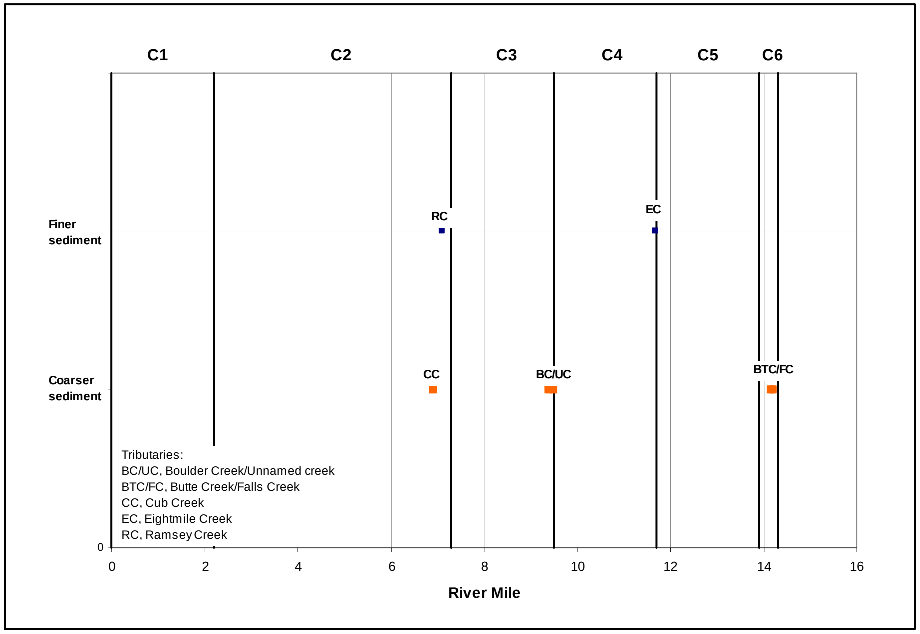

Figure C-27g. Major sources of coarser and finer sediment plotted by river mile for the Chewuch River between RM 0 and RM 14.3. Tributary sources are shown by the squares: orange for sources of coarser sediment (coarse gravel) and blue for finer sediment (sand, mostly, to fine gravel). Coarser sediment sources are tributaries where the slopes are steep and debris fans have formed at their confluence with the Chewuch River (*Reclamation, 2008c*).

Sediment sources were mapped using aerial photographs and field observations.

5.1 REACH C1, RM 0–2.2

Reach C1, which is 2.2 miles long, is located between the confluence with the Methow River at Winthrop (RM 0) and RM 2.2, where the low surface widens (Table C-5). This reach is confined, and has a narrow low surface that is bounded by high banks composed of glacial deposits or bedrock (Figures C-27a, C-27b, and Figure C-28). The low surface is somewhat wider upstream of about RM 1.2, and bedrock is more common downstream of this point than it is upstream (Figure C-28).

The channel system consists of a single path, and the narrow low surface does not allow for lateral migration of the active channel, and little movement of the channel has been noted between 1954 and 2004 (Figure C-27e and Figure C-28). The areas of low surface outside of the unvegetated channel are small (Figure C-28). Few secondary, overflow, or abandoned channels have been mapped in the low surface (Figure C-27f).

No major tributaries enter the reach (Figure C-27d and Figure C-28). Two landslide/debris flow deposits are present along the low surface (near RM 0.4 and near RM 0.95) and provide some sediment to the reach, but the landslide/debris flow areas are of limited extent (Figure C-28).

Because the low surface is naturally confined in Reach C1, the impacts of human activities are limited. A few houses are present within the low surface, for example, near RM 1.8. Only about 8% of the low surface has been cleared of vegetation. The mean width of the geologic low surface is only slightly narrower now than it was prehistorically because of human activities.

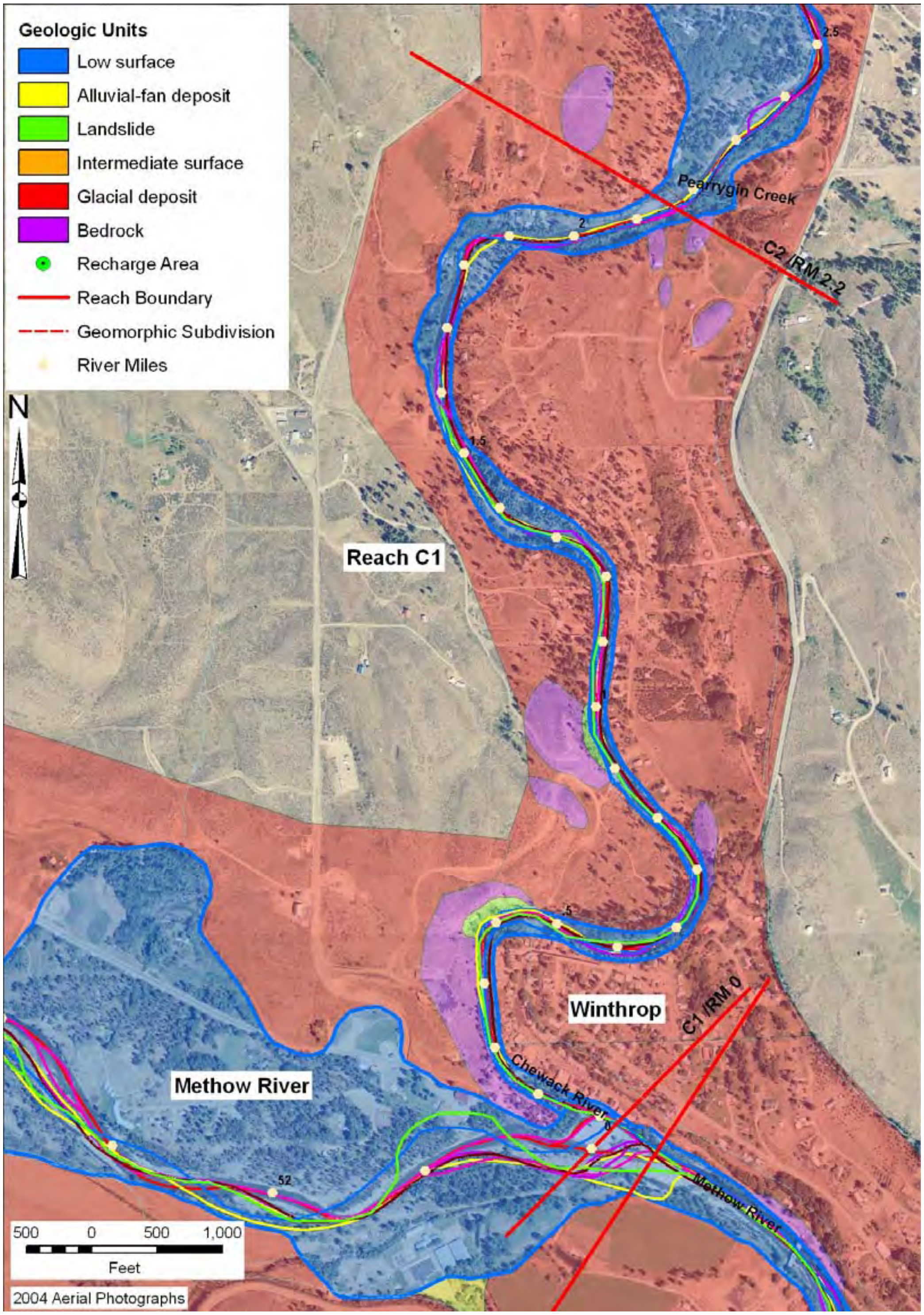

Figure C-28. Chewuch River – Geology and historical channels for confined geomorphic Reach C1 (RM 0–2.2).

The colored lines within the low surface are historical channel paths between 1954 and 2004.

5.2 REACH C2, RM 2.2–7.3

Reach C2, which is 5.1 miles long, is located between RM 2.2, where the low surface widens, and RM 7.3, which is near the confluence of Cub Creek (Table C-5; Figure C-29). This reach is unconfined, and the low surface is markedly wider (about six times as wide) than it is in reach C1 (Figures C-27a, C-27b, and Figure C-29). The low surface narrows slightly upstream of RM 5.6, which is a geomorphic subdivision (Figure C-27b and Figure C-29).

The channel system includes primary side channels and networks (Figure C-27e). The cumulative length of secondary, overflow, and abandoned channels is the longest of the Chewuch River assessment reaches. The cumulative length is slightly greater downstream of RM 5.6, where the low surface is wider than it is in the slightly narrower section upstream of this point (Figure C-27f and Figure C-29).

The main tributaries are Pete Creek near RM 4.0 and Cub and Ramsey Creeks near the upstream reach boundary at RM 7.3 (Figure C-27d and Figure C-29). Cub Creek provides coarser sediment to the reach, and Ramsey Creek provides finer sediment (Figure C-27g). A few ponded areas have been mapped in the reach (Figure C-27d).

Reach C2 is impacted by human activities. Primary side channels and floodplain are cut off by levees, dikes, roads, and development. These human features limit the present width of the low surface to between 130 feet and 230 feet less than the geologic width of the low surface. The human features block off-channel areas.

Between 3 and 25% of the low surface has been artificially cleared of vegetation. The largest area of clearing is RM 2.2–5.6. This is also the area where development has taken the largest area of the low surface. Clearing of the surfaces adjacent to the active channel has reduced the recruitment potential for LWD in the reach.

Diversion of water by the Chewuch diversion dam and irrigation withdrawals decreases the flows in this reach, especially in late summer.

Other human features that are present in this reach are the bridge on the Chewuch road and Skyline ditch.

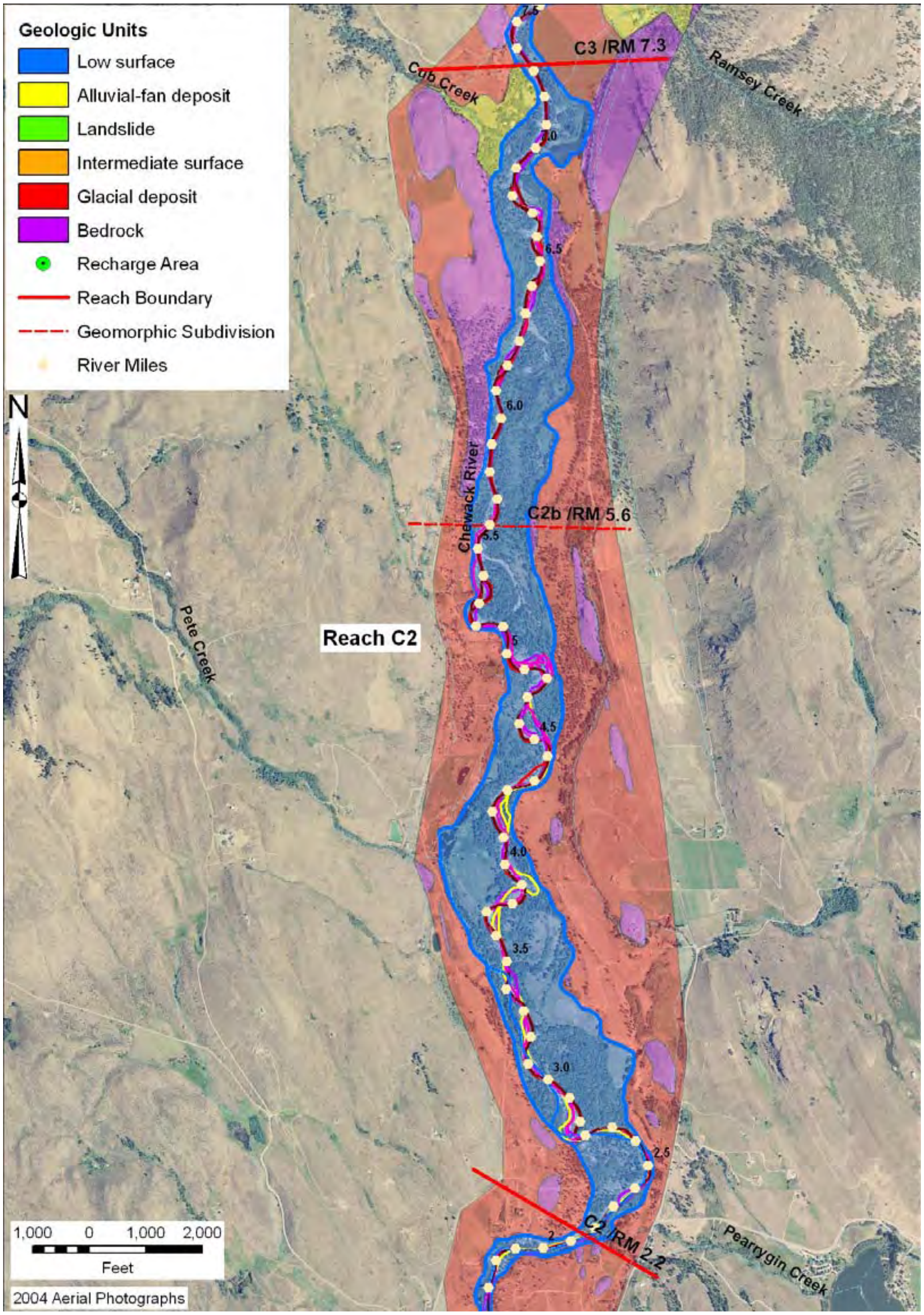

Figure C-29. Chewuch River – Geology and historical channels for unconfined geomorphic Reach C2 (RM 3.3–7.3 at Cub Creek).

The colored lines within the low surface are historical channel paths between 1954/1964 and 2004.

5.3 REACH C3, RM 7.3–9.5

Reach C3, which is 2.2 miles long, is located between RM 7.3, near Cub Creek, and RM 9.5, near the middle of the large alluvial-fan deposit from Boulder Creek (Table C-5; Figure C-30). This is a somewhat confined reach, which has a moderate average width that is nearly half of the width of the low surface in the adjacent downstream unconfined reach, C2 (Figures C-27a, C-27b, and Figure C-30). In this reach, the low surface is alternately narrower and wider (Figure C-30). The three narrower sections, which occur near the reach boundaries and at RM 8.5, are confined by bedrock and glacial deposits, mostly, and by a large alluvial-fan deposit from Boulder Creek at the upstream reach boundary. In these sections the low surface and channel migration have been constricted. In the two wider sections, the channel has been somewhat confined by slightly higher alluvial surfaces within the low surface, but has been able to migrate historically. The narrower section at RM 8.5 is a geomorphic subdivision within the reach.

In this reach, the slope progressively steepens to the confluence with Boulder Creek, which contributes large boulders to the Chewuch River (Figures C-27c, C-27g, and Figure C-30).

The channel system includes primary side channels in the wider sections and a single channel in the narrower sections (Figure C-27e and Figure C-30). A few secondary, overflow, and abandoned channels are present in the reach (Figure C-27f and Figure C-30).

The main tributaries are Boulder Creek on river left at RM 9.4 and an unnamed tributary on river right at RM 9.5. Both tributaries are near the upstream boundary of the reach (Figure C-27d and Figure C-30). Both tributaries contribute coarser sediment to the reach (Figure C-27g). No seeps or springs have been mapped in this reach (Figure C-27d).

Reach C3 is impacted by human activities. Primary side channels and floodplain are cut off by levees, dikes, roads, and development. These human features limit the present width of the low surface to between about 125 feet and 190 feet less than the geologic width of the low surface. The human features block off-channel areas.

Between 10 and 35% of the low surface has been artificially cleared of vegetation. The largest area of clearing is between RM 8.0 and RM 8.4. Clearing of the surfaces adjacent to the active channel has reduced the recruitment potential for LWD in the reach.

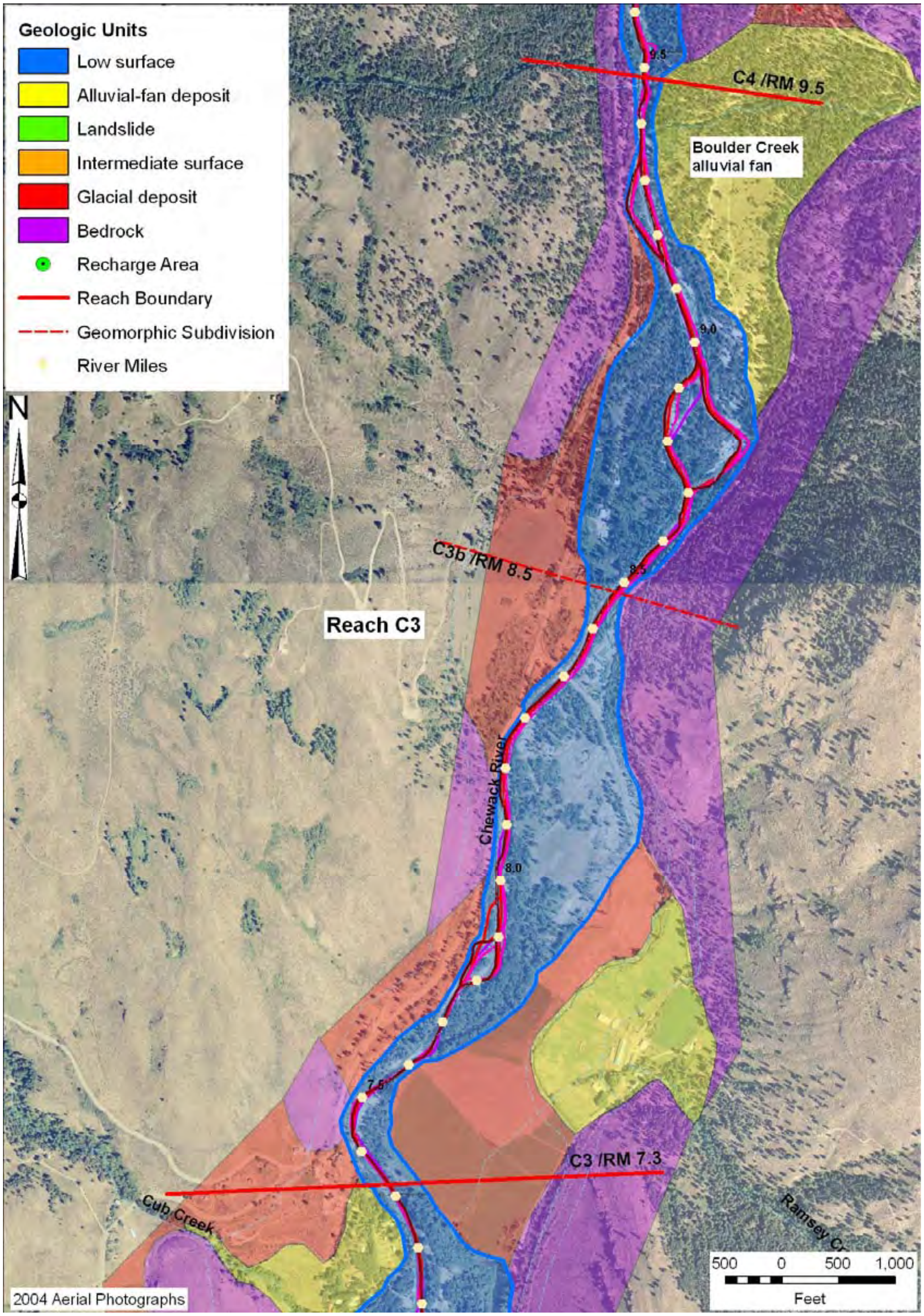

Figure C-30. Chewuch River – Geology and historical channels for moderately confined geomorphic Reach C3, between RM 7.3 (Cub Creek) and RM 9.5 (Boulder Creek).

The colored lines within the low surface are historical channel paths between 1974/1985 and 2004.

5.4 REACH C4, RM 9.5–11.7

Reach C4, which is 2.2 miles long, is located between RM 9.5, where Boulder Creek joins the Chewuch River, and RM 11.7, where Eightmile Creek joins the Chewuch River (Table C-5, Figure C-31). This reach is composed of three geomorphic subdivisions: a confined section between RM 9.5 and RM 9.8, a somewhat confined section between RM 9.8 and RM 10.4, and a confined section between RM 10.4 and RM 11.7 (Figure C-27a and Figure C-31). The low surface width varies among these subdivisions, and is the narrowest in the upstream geomorphic subdivision (Figure C-27b and Figure C-31). The low surface is bounded by bedrock, high glacial deposits, and alluvial-fan deposits near the upstream and downstream reach boundaries (Figure C-31). The slope is flatter in this reach than it is downstream in reach C3 (Figure C-27c).

The channel system throughout the reach has a single channel form, and few secondary, overflow, or abandoned channels have been mapped (Figures C-27e, C-27f, and Figure C-31). Between RM 9.8 and RM 10.4, the low surface is wide enough that the channel has split flow paths in two localities: near RM 9.7 and near RM 10.3. In reach C4, the main channel has been roughly in the same position between 1974/1985 and 2004 (Figure C-24; and *Reclamation, 2008c*). The channel meanders only slightly, except between RM 9.8 and RM 10.4, where single broad meander is present (Figure C-31).

There are no major tributaries that enter this reach, although Boulder Creek enters the Chewuch River at the downstream boundary at RM 9.5, and Eightmile Creek enters the Chewuch River at the upstream boundary at RM 11.7 (Figure C-27d, Figure C-31). One ponded area is present near RM 10.4 (Figure C-27d). One spring (Eightmile Creek) has been identified near RM 11.7, at the upstream boundary of the reach (Figure C-27d).

Because there are no major tributaries in this reach, little sediment enters the Chewuch River. Eightmile Creek, at the upstream reach boundary, contributes finer sediment to the Chewuch River (Figure C-27g and Appendix N). The source of this sediment is timber harvesting in the Eightmile Creek drainage (Appendix N). Sediment enters the Chewuch River by lateral erosion along the high glacial banks near Eightmile Ranch.

Upstream of RM 9.8, vegetation has been cleared from 13 to 17% of the low surface for agriculture, grazing, and development. The largest cleared area is in the section between RM 9.8 and RM 10.4, which has the widest low surface. Clearing of the surfaces adjacent to the active channel has reduced the recruitment potential for LWD in the reach.

Anthropogenic features, such as levees, houses, and development, have decreased the width of the low surface in this reach upstream of RM 9.8. The section where the low surface is widest, between RM 9.8 and RM 10.4, has been impacted the most. The low surface width has been decreased about 230 feet by human features. Between RM 10.4 and RM 11.7, the low surface width has been decreased by only about 50 feet.

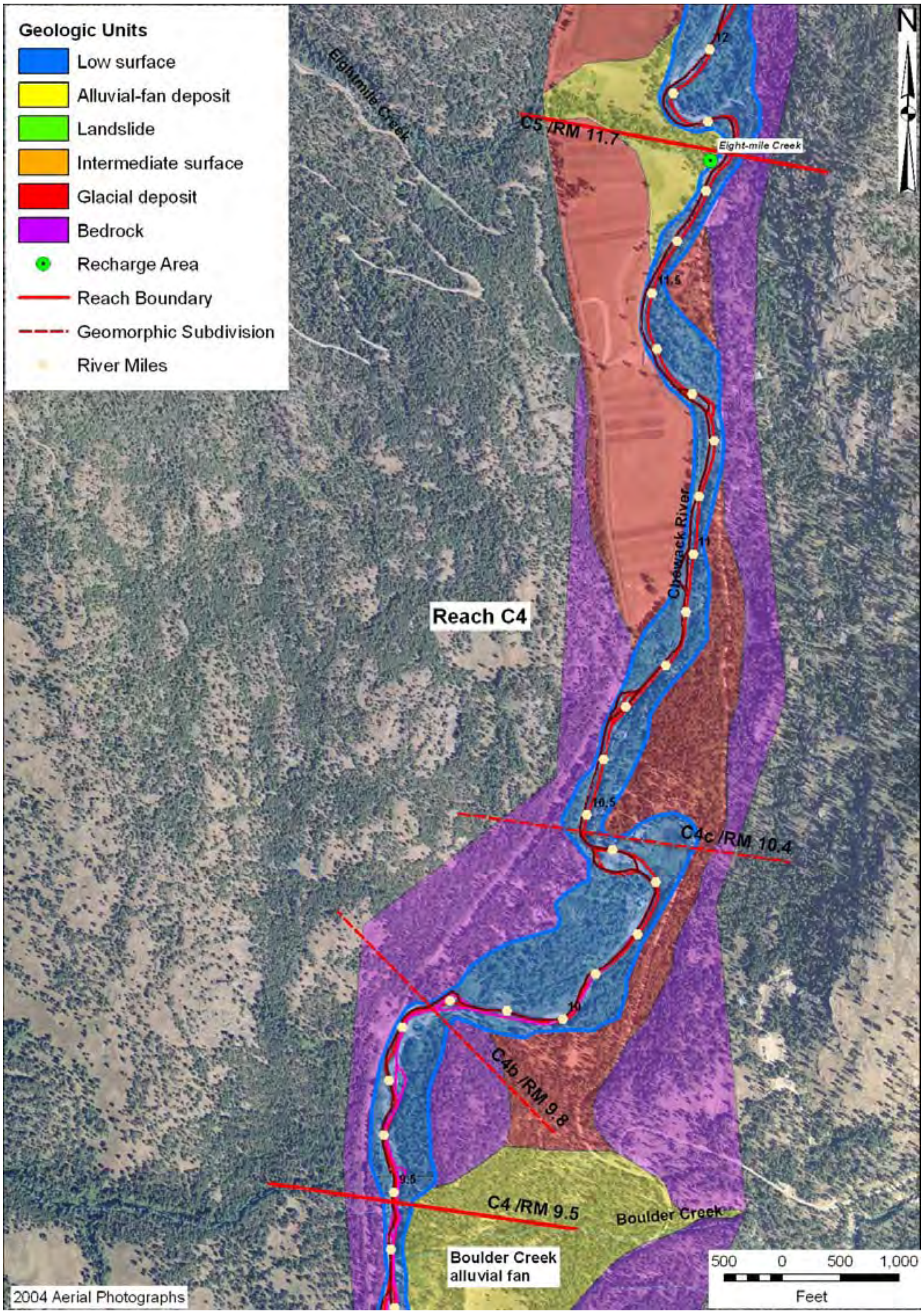

Figure C-31. Chewuch River – Geology and historical channels for confined geomorphic Reach C4 between RM 9.5 (Boulder Creek) and RM 11.7 (Eightmile Creek).

The colored lines within the low surface are historical channel paths between 1985 and 2004.

5.5 REACH C5, RM 11.7–13.9

Reach C5, which is 2.2 miles long, is located between RM 11.7, where Eightmile Creek joins the Chewuch River, and RM 13.9, where the low surface narrows (Table C-5, Figure C-32). This is an unconfined reach; however, the low surface is somewhat narrower upstream of RM 13 (at Valley Creek) than it is downstream of this point (Figures C-27a, C-27b, and Figure C-32). The change is low surface width is the boundary of a geomorphic subdivision.

The channel system consists mainly of a meandering main channel with primary side channels (Figure C-27e and Figure C-32). It includes a few secondary, overflow, or abandoned channels (Figure C-27f). The low number may be partially the result of limited available historical aerial photographs.

Major tributaries include Eightmile Creek, at the downstream reach boundary at RM 11.7, and Valley Creek at RM 13.3 (Figure C-27d, Figure C-32). No ponded areas have been mapped in this reach, but ponded areas are thought to exist near RM 12.4 (Figure C-27d).

Only a small area of the low surface has been artificially cleared of vegetation for development in Reach C5.

The width of the low surface has been decreased by human features, such as roads, houses, and other development. The presently active low surface is about 70 feet narrower than the geologic width of the low surface.

5.6 REACH C6, RM 13.9–14.3

Reach C6, which is 0.4 miles long, is located between RM 13.9 and RM 14.3, where Falls and Butte Creek join the Chewuch River (Table C-5; Figure C-32). It the downstream 0.4 miles of a confined section that continues upstream of the assessment area. The low surface, which is only about 300 feet wide, is confined by alluvial-fan deposits from Falls Creek on river right and from Butte Creek on river left (Figures C-27a, C-27b, and Figure C-32).

The channel system consists of a single channel (Figure C-27e). No secondary, overflow, or abandoned channels have been mapped (Figure C-27f). The unvegetated channel is nearly straight in this reach (Figure C-32).

The main tributaries are Falls Creek and Butte Creek, which join the Chewuch River near the upstream reach boundary (Figure C-27d and Figure C-32). Although no ponded areas were recognized in this reach during our assessment (Figure C-27d), some ponding exists on WDFW property on river right at RM 12.4. Springs are present at Falls Creek, near the upstream reach boundary (Figure C-27d).

Falls Creek and Butte Creek contribute coarse sediment (gravel) to the Chewuch River (Figure C-27g).

The width of the low surface in Reach C6 has not been affected by human activities. The low surface in this reach has not been cleared of much natural vegetation.

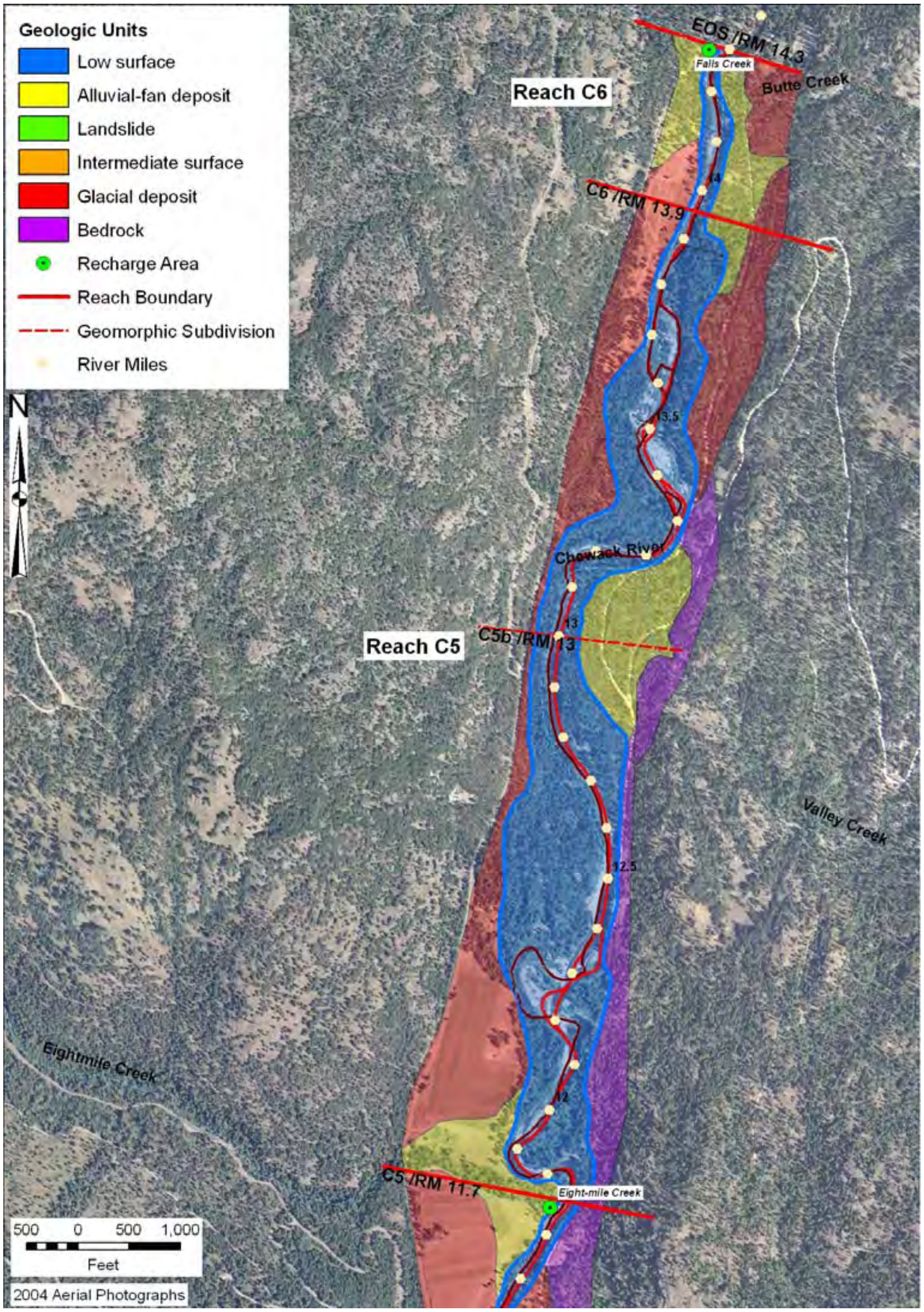

Figure C-32. Chewuch River – Geology and historical channels for unconfined geomorphic Reach C5, between RM 11.7 (Eightmile Creek) and RM 13.9 (where valley narrows).

The colored lines within the low surface are historical channel paths between 1985 and 2004.

6. REFERENCES

IN TEXT	COMPLETE CITATION
Golder 2005	Golder Associates, Inc., 2005, *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Konrad et al. 2003	Konrad, C.P.; Drost, B.W.; and Wagner, R.J. 2003, *Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington*. US Geological Survey Water-Resources Investigations Report 03-4244, 137 p.
Reclamation 2008c	Bureau of Reclamation. February 2008c. *Map Atlas for 80-Mile Study Area Reach, Geomorphic Assessment for Methow In-Channel Habitat Rehabilitation Plan, Methow River Subbasin, Okanogan County, Washington*, Technical Service Center, Remote Sensing and Geographic Information Group (M/S 86-68240), Denver, CO.
UCSRB 2007	Upper Columbia Salmon Recovery Board, 2007, *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan.* Wenatchee, WA. 300 pp. See at http://www.ucsrb.com/plan.asp (as of 12/03/07). Federally adopted by NMFS 2007b.

APPENDIX D –

ASSESSMENT APPROACH AND METHODS

This appendix documents the general approach used to accomplish the assessment objectives.

CONTENTS

LIST OF FIGURES

There are no Figures in this Appendix D.

LIST OF TABLES

There are no Tables in this Appendix D.

1. INTRODUCTION

This appendix documents the general approach used to accomplish the objectives of the *Geomorphic Assessment* (Reclamation, 2007e). Additional detail on methods can be found in Appendix H (vegetation), Appendix J (hydrology), Appendix K (hydraulics and sediment analysis), and Appendix M (geomorphology).

For this assessment, methods are based on a mixture of quantitative and qualitative analysis to provide an acceptable level of certainty given the assessment objectives. Quantitative data were collected with the intent to evaluate reach-level trends. Quantitative methods provide more certainty in results than qualitative methods, but in many cases were not collected at a project-site scale because of constraints of cost and time. Qualitative methods are faster and less costly, but can be difficult to repeat in a comparable manner and have less certainty. Where qualitative methods were used, several independent analysis tools were overlaid and compared to determine conclusions regarding channel processes.

The data and literature utilized are listed in Section 2 of this appendix. The spatial scale and rate of change of processes addressed in this assessment are documented in Sections 3 and 4, followed by a general list of the assessment tasks and types of data collected to support those tasks in Section 5. Assessment limitations are then discussed in Section 6 so that technical teams and project engineers utilizing this information in the future can assess what additional information may be needed. Finally, in Section 7 a more comprehensive list of methods are provided specifically for the biologic and geomorphic portions of this report.

The *Geomorphic Assessment* focuses on an 80-river-mile area within the Methow Subbasin; this area has been subdivided into geomorphic reaches in which similar physical river processes operate and thus similar habitat restoration opportunities exist. The overarching goal of this work is to identify project concepts at a reach scale that focus on the following objectives established by the *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (UCSRB, 2007) and *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region* (UCRTT, 2007):

- Improve and/or protect the lateral, vertical, and longitudinal connectivity of physical river processes and ecological interactions that provide complexity in the river and floodplain.
- Restore aquatic and riparian habitat through the re-establishment of floodplain, off-channel habitat, and channel migration processes that support salmonid habitat availability.
- Protect and restore habitat that will maintain connectivity between populations within the mainstem Methow River and tributaries utilized by salmonids.

- Where appropriate, enhance degraded areas in the short-term to improve habitat until natural processes can be restored in the long-term.

Projects implemented without a clear understanding of the physical processes in place will not have as much opportunity for short-term and long-term success, and can have unanticipated impacts to presently functioning habitat or nearby infrastructure and property. Therefore, project concepts are developed from a baseline understanding of the processes that are presently acting in the river system, how the current processes differ from those that operated before man's intervention (pre-historically), and a prediction of how current processes may continue to operate in the future.

The "natural setting" is defined as the mid-to-late 1800s; this period was just prior to significant human-induced disturbances to physical river processes. Hypotheses of the natural setting provide a conceptual model of the geomorphic opportunities for habitat improvement. For example, not all river reaches can support the same level of floodplain complexity due to variations in geologic controls, such as floodplain width, sediment sizes, channel slope, access to riparian vegetation zones, etc. Comparison of the present river setting to the conceptual model of the natural setting helps determine which processes have been altered and to what degree. Not all processes may be fully returned to the natural setting due to changes in vegetation, climate, or anthropogenic constraints, such as land use. Project concepts must incorporate not only the present setting, but anticipate how river processes may or may not change in the future. Looking at historical trends of river processes on a decadal scale provides an understanding of the rate of change from the natural setting, how the changes relate to historical floods and human activities, and whether the changes have had a continual trend in a certain direction or appear to have stabilized.

The assessment takes into account physical river processes that can change laterally (across), vertically, or longitudinally along the valley length. Connectivity within river system is an important consideration for habitat function because:

- Longitudinal connectivity (along river channel) is critical for salmon, steelhead and bull trout migration, genetic exchange between populations, re-founding of populations following major stochastic events.
- Lateral connectivity is critical for access and viability of off-stream habitat
- Vertical connectivity is critical for water quality and quantity in habitat areas (flow, water temperature)

2. DATA AND LITERATURE UTILIZED

Several analyses have been completed by other groups that were very beneficial. These reports were utilized wherever possible to avoid duplication of efforts and add to the information available to the assessment team.

2.1 AVAILABLE LITERATURE

Some of the key reports utilized include:

- Biological assessments including USFS stream survey reports
- *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. (Golder, 2005)
- *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. (PWI, 2003)
- *Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington*. US Geological Survey Water-Resources Investigations Report 03-4244. (Konrad et al., 2003)
- *Spring Chinook spawning ground surveys in the Methow River Basin in 2005.* Washington Department of Fish and Wildlife, Olympia, WA. Report prepared for Public utility District Number 1 of Douglas County. (Humling and Snow, 2006)
- Historical accounts of flooding and human activities located in journals and technical reports

The assessment team utilized the following documents to provide general guidance on development of the scope of work and products from this effort:

- *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* (ICBTRT, 2007)
- *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan* (UCSRB, 2007)
- *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board* (UCRTT, 2007)

- *Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48*: *Washington State Conservation Commission, Final Report* (Andonaegui, 2000)
- *Methow Subbasin Plan* (KWA, 2004)

Regarding physical processes associated with habitat, the *Recovery Plan* (UCSRB, 2007) recommends conducting additional studies to identify priority locations for protection and restoration, and to examine fluvial geomorphic processes in order to assess how these processes affect habitat creation and loss (note that an earlier version was available at the time of scope development).

The *Methow Subbasin Plan* recommended addressing the following questions, of which only the first item is addressed in this geomorphic assessment:

- Floodplain and off channel habitat impacts from levees, bank protection. Look at structural changes to river and floodplain and effect on geomorphic processes (channel migration) and aquatic habitats.
- Impact of diversions on duration and extent of stream dewatering tied to fish usage and passage (juveniles); look at wetted width and depth compared to Q [flow]
- Negative effects and benefits of converting open ditches to piped closed systems
- Agricultural uses including water rights, claims, certificates, and actual acreage of irrigated land, assess municipal, industrial, and domestic water uses versus rights.

Andonaegui (2000) documented “data gaps” (D-G) in the Methow Subbasin as follows:

D-G 1. Assessment of the extent of salmonid productivity is being limited by habitat conditions (human-induced or natural), correlated to species and life stage, and provided on a stream reach basis.

D-G 2. Watershed-wide fish passage barrier and screen safety inventory and assessment to include both private and public lands.

D-G 3. Assessment is needed to define current floodplains in the Methow watershed in terms of channel form and process.

D-G 4. Watershed-wide inventory and assessment of riparian habitat and conditions including change over time.

D-G 5. Hydrologic assessment to evaluate groundwater and surface water interactions, identify critical groundwater recharge areas, and locations and where groundwater contributes to surface water.

Human-induced impacts on a stream-reach basis (D-G 1) was addressed in this assessment for the 80-mile reach. A more refined correlation of this information to species and life stage could be done in future analysis of reaches chosen for further assessment where restoration actions are likely to be implemented. Floodplains in terms of physical processes and riparian habitat conditions are provided in this assessment for the 80-mile assessment area to address D-G 3 and D-G 4.

Reclamation has been working to address fish passage barrier and screen safety through a separate effort outside the scope of this assessment (D-G 2). The U.S. Geologic Survey (USGS) has been doing ongoing work to provide information to address the hydrologic data gap which was utilized in this 80-mile assessment (D-G 5).

2.2 AVAILABLE DATA

Materials used for reference include historical maps and aerial photographs to assess channel changes over time and included 1893, 1894, 1897, 1900, 1907, 1915, 1945, 1948, 1954, 1964, 1974, and 2004. Many of these photographs were provided by Okanogan County and the USFS. Photographs that were not already rectified[1/] were put in a known datum by Reclamation (Appendix Q). Coverage of each map and photo set varied (see Table G-7 in Appendix G for detailed spatial coverage). During the preparation of this report, additional photography was collected in 2005 and 2006 that is now available.

Survey data available in a known datum included historical water surface profiles from USGS maps on the Chewuch, and cross-section data from the 1970s on the mainstem Methow. New cross-section and longitudinal profiles of the channel bottom and water surface were collected by Reclamation in 2005. LiDAR ("light detection and ranging") data was collected in fall of 2006 during the completion of this report and is available for the entire 80-mile assessment area for future work.

Water temperature, thermo-profilers, and FLIR ("forward looking infrared") data is available for low-flow periods in 2001 for the Chewuch and Twisp Rivers. New data was collected for Reclamation by the USFS on the Methow River in 2005. Vegetation mapping was available for the Twisp River from a report by the Pacific Watershed Institute (PWI, 2003). New mapping was accomplished for the Methow and Chewuch portions of the *Geomorphic Assessment.*

1/ The process of "ortho-rectification" or placing an image over a known reference point or datum.

3. SPATIAL SCALE OF FINDINGS

Processes within the watershed upstream of the 80-mile assessment area were considered at a cursory scale with available information and field reconnaissance by the assessment team. The types, locations, and timing of human impact to upland vegetation, sediment, and water supply was investigated and linked from a qualitative perspective to processes evaluated within the approximately 80-mile assessment area. The exception is hydrologic analysis which was generated for non-gaged areas within the entire subbasin (Appendix J).

The upstream areas in the Methow Subbasin are largely administered by the USFS. These areas have limited human development, but have had significant impacts on fire management. Fire plays an important role in driving the processes and responses that shape habitat and have a large degree of influence on downstream channel processes within the Methow Subbasin. Fire in altered landscapes may need to be considered by resource managers as part of any restoration strategy. Fire exclusion for nearly 100 years in the headwaters and along the mainstem Methow River is believed by local USFS personnel to have reduced landscape scale disturbances and channel responses that create and maintain quality habitat. Although the timing and extent of fires has been altered, fire is considered part of the natural function within the subbasin.

Within the approximately 80-mile assessment area, conclusions are presented that provide generalized characteristics and physical river processes for 23 reaches identified. Within each reach, characteristics and processes may have localized features that differ from the broad-scale descriptions. Subsequent assessments at finer scales will typically be needed prior to implementing protection or restoration actions at project sites within a given reach.

4. RATE OF CHANGE

River systems are naturally dynamic. A geomorphic assessment must take into account the durations and rates of changes. Habitat use is often viewed over long time periods to account for this variability. The time scale of changes considered in this assessment vary from geologic processes that took thousands of years (or longer) to form the present river setting, to changes that occur within a single flood that drive channel form. However, the majority of focus for this assessment is focused on identifying long-term benefits from improving river processes that would be detected on a decadal scale or longer.

Channel change as a result of floods is a natural process. Floods that cause channel changes can occur on an annual basis or over longer time periods, based on variations in runoff and precipitation. Extreme floods occur infrequently at intervals of tens of years to 100 years or longer. These larger magnitude floods can result in "resetting" the river because they have more energy than the smaller floods (such as the 1948 flood of record).

Land-use changes brought about by human development have occurred in the Methow Subbasin since the late 1800s, but river response to these changes varies both in timescale and spatial extent. Some effects to river processes are only localized and temporary, where as others affect larger reaches and can take decades to fully see the effect.

Predictions of future river processes are based on current land use and management that may change. Additionally, many natural processes within the watershed, such as the frequency of fires and floods, will continue to fluctuate in future years. This assessment accounts for some level of variability by looking at decadal scale trends, but portions of the analysis should be repeated in the future to update findings and predictions. For example, future efforts could involve repeat topographic surveys and aerial photography to test whether parameters most affected by these controls have significantly changed (such as channel planform and geometry).

5. ASSESSMENT TASKS

A multi-disciplinary assessment team consisting of local biologists, fluvial engineers, geologists, geomorphologists, and botanists performed the following steps as part of the assessment of the 80-mile area.

5.1 DEVELOPED ASSESSMENT PLAN

a) Field Reconnaissance: the team toured the Methow Subbasin for a first-hand look at present river setting.

b) Scope Development: the team met with clients, local stakeholders and biologists to develop assessment area boundaries, objectives, timeline, and funding constraints.

c) Literature Review: the team gathered and reviewed available data and literature to determine data gaps in addressing physical processes.

d) Conceptual Model: the team developed hypotheses of river processes and trends to guide development of the assessment plan; hypotheses were based on existing literature, field reconnaissance, and local stakeholder observations.

e) Assessment Plan: the team identified new data collection and analyses that were needed in order to develop the geomorphic setting at a reach-level scale and to identify potential protection and restoration projects.

5.2 DEVELOPED NATURAL SETTING

f) Acquired historical ground photographs, journal accounts, books, and anecdotal information to document human activities in subbasin and river setting prior to earliest aerial photography (Appendix O)

g) Mapped historical river channels to document the natural (undisturbed) floodplain area (low surface) that defines the boundary of the interaction between channel and floodplain processes where habitat projects will be proposed (Appendix G and Q)

h) Mapped geologic units that bind the low surface and any geologic controls present in the channel bed (e.g. bedrock, large boulders) (Appendix M)

i) Identified natural lateral and vertical controls on river processes based on stereo-pair aerial photographs (2000), regional geology maps, geologic mapping, and field reconnaissance (2005 to 2006) (Appendix M)

j) Subdivided assessment area into reaches with unique geomorphic processes that offer unique habitat opportunities (Appendix C)

5.3 ASSESSED AND COMPARED PRESENT SETTING TO NATURAL SETTING

k) Assessed biologic information to understand present habitat use and opportunities for improvement (Appendix F)

l) Analyzed hydrologic data to develop a flood frequency for gaged and non-gaged locations (Appendix J)

m) Analyzed hydraulic and sediment data to provide additional information for evaluating the balance between water and sediment loads and how this impacts channel form; based on new channel survey and bed sediment data collected in 2005 (Appendix K)

n) Compared new survey data to historical survey data to look for signs of vertical channel change (Appendix K)

o) Mapped historical channel migration and bank erosion to look for signs of lateral channel change and to verify active floodplain reworking area; based on decadal-scale historical aerial photographs (1949 to 2004) and maps (late 1800s to early 1900s) that were acquired, rectified, and put into a GIS database (Appendix G)

p) Mapped human feature to identify locations and extent of areas within active floodplain that have been disconnected from the river channel and areas along boundary of active floodplain that have been altered (Appendix P)

q) Mapped vegetation in the riparian corridors of the Methow and Chewuch Rivers using recent aerial photography (already done on Twisp River) to look at the present condition of vegetation; these were also used to hypothesize how vegetation has been altered from historical conditions; a few areas on Methow and Twisp rivers were checked in the field to verify or disprove working hypotheses on vegetation processes (Appendix H)

r) Analyzed temperature and flow data on the Methow River using new data collected during low-flow period (late summer/early fall) in 2005 (available on Twisp and Chewuch Rivers from previous studies) to provide a better understanding of temperature conditions on Methow River during critical low-flow periods (Appendix I)

5.4 PREDICTED FUTURE SETTING

s) Integrated previous and new information to assess the natural setting of river, to determine how it has departed from natural conditions due to human features and actions, and to predict how it may or may not change in future (Appendix E)

t) Assumed that climate and land use in present setting do not change to a large-enough degree that they would impact river processes in the near future; sensitivity to this assumption was beyond the scope of this assessment. However, protecting and restoring physical and ecological processes may help ensure that listed fish populations have a strong habitat basis or refugia that will help the populations be resilient in the face of a changing climate or extensive environmental perturbations in the subbasin.

5.5 IDENTIFIED PROJECT CONCEPTS AND REACHES

u) Grouped assessment areas into geomorphic reaches, those sections of the river that have similar physical processes that offer unique habitat opportunities; this step separates areas of river that are naturally confined from areas with vegetated floodplain (off-channel habitat); this step also distinguishes the degree of complexity in reaches with vegetated floodplain based on the rate of lateral reworking and presence of large woody debris and wetland complexes (in the natural setting) (Appendix C)

v) Synthesized data and analyses from above tasks to determine reach-based restoration concepts based on the knowledge of natural setting, present condition, types of disturbances, and stability of river system (Appendix A)

w) Delineated unique floodplain areas within the low surface based on their present extent with boundaries defined by either the present active channel or the edge of the low surface (Appendix A)

x) Identified floodplain areas that are potential protection areas that do not have human features but need to be protected and monitored as part of a reach-based strategy (Appendix A)

y) Identified restoration project locations and concepts based on the presence of human features that disconnect the floodplain and/or impact physical processes (Appendix A)

z) Developed ranking criteria for project reaches and individual projects within the reaches that includes criteria based on results from the geomorphic assessment, biological benefit, constructability, and land-use perspectives. (Geomorphic and biological ranking presented in Appendix B and Appendix R; constructability and land-use are available upon request.)

5.6 DOCUMENTED ASSESSMENT FINDINGS

aa) Generated report

bb) Generated GIS databases

5.7 SHARED INFORMATION WITH LOCAL STAKEHOLDERS

cc) Presented information in workgroup settings and public forums to get feedback on assessment approach and technical findings.

6. ASSESSMENT LIMITATIONS

As mentioned earlier, the geomorphic assessment approach is a balance of quantitative and qualitative methods at a reach-scale perspective that looks at trends over time periods of years to decades. The present setting has the most certainty because it can be easily documented and investigated. The historical setting has less certainty than the present setting because of limited documentation, but it is based on knowledge of river processes and historical maps, journals, aerial photography, and other accounts. The predictions of the future river setting are developed from hypotheses based on knowledge of the historical and present setting and have the most uncertainty because there is less information available.

Future studies will need to incorporate additional field data and quantitative analyses to refine reach-level conclusions and to address local issues. Specific limitations relative to each discipline are listed below.

Geomorphic mapping was done on aerial photographs. Field checking was done along the main river channel in most areas, but could not be done in vegetated floodplains due to land access issues and budget and time constraints. Surfaces were mapped on the basis of relative elevation differences and composition of bank material. Surface ages were not determined, but could be done as part of future studies. In particular, there appears to be a range of surface ages within the low surface that could affect development of project concepts. Human features need to be verified at the project level, particularly following floods that can both remove human features or result in the construction of new features. LiDAR ("light detection and ranging") terrestrial data collected in November 2006 should be used to verify mapping at the reach and project scale.[2/]

Hydraulic computations used cross sections spaced about 2,000 feet apart on average so normal depth calculations were done based on local slopes (measured from a continuous profile) rather than a connected backwater model. This can result in errors in absolute water surface elevations when predicting hydraulics at higher flows (slopes approximate bankfull flow). Only limited cross-section data were available outside of the low surface or through the vegetated floodplain. The LiDAR data that was collected in November 2006 could be used in the future in conjunction with ground survey in wetted or densely vegetated areas where LiDAR does not provide quality data. Additional ground survey data may also be needed at a project-design scale in construction areas; the need for additional ground survey data depends on the

2/ The LiDAR data are maintained by Reclamation's Pacific Northwest GIS program in Boise, Idaho. Contact Kristin Swoboda at kswoboda@pn.usbr.gov or 208-378-5244.

certainty required for design and how much the channel areas have changed between the collection of LiDAR and the time at which a project is being constructed.

Sediment computations were limited to the ability of the river to rework the channel bed and bars. Sediment-transport-capacity and mobile-bed computations were not made, which limits the ability to predict amounts of incision or deposition within quantitative bounds. Fires in the subbasin are episodic and cause variability in sediment loads that were not addressed; these processes are thought to be part of the natural system and beneficial to recharging the ecosystem, but the effects of fires may need to be addressed for project areas directly within or downstream of fire areas.

The hydrology analysis utilized available long-term gages that accounts for major changes in flow. The focus was on high flows that cause channel change; low flows and groundwater interactions were not addressed. Future changes in climate were not addressed by this assessment. As more is learned about potential changes in climate, the effects of climate change on the basic input (such as precipitation and temperature) will need to be assessed specifically for the Methow Subbasin.

Vegetation mapping on the Methow and Chewuch Rivers was done using aerial photographs. Only limited field verification was done. No historical mapping of vegetation was completed on the two rivers.

Biological information for the mainstem Methow River is much more limited than for either the Chewuch or Twisp Rivers. Time and budget precluded an extensive habitat assessment. Detailed habitat data (such as wood levels, pool quality, depth and frequency, and spawning substrate) and fish-use data may be collected at the reach and/or project scale of assessment. New information on biological use is constantly being developed and future work should integrate new information as it becomes available. This *Geomorphic Assessment* fills a large gap in data that existed downstream of the area administered by the USFS, which is about 80 percent of the Methow Subbasin.

7. DETAILED LIST OF ASSESSMENT METHODS

This section provides a detailed outline of assessment methods utilized in this effort. The outline focuses on major tasks accomplished as part of this assessment. Additional tasks were accomplished at a more detailed scale.

7.1 BIOLOGY

7.1.1 Local biologic input

1. Reclamation teamed up with biologists from the USFS to integrate local knowledge of existing salmonid information into the assessment.
   a. Acquired available GIS data of redd locations
   b. Other data not available in GIS
2. The biologists participated in workgroups and field visits with the Reclamation assessment team to help understand where spawning, rearing, and over-wintering habitat areas were functioning and where they were not.
3. Biologists also provided hypotheses of why certain areas were not functioning.
4. Surveys of fish use by species and life cycle were not accomplished, but will be done for individual reaches and projects selected for the next phase of more detailed investigation.
5. Biologic input and review was also periodically provided by WDFW at key milestones in the assessment

7.1.2 Water temperature data

6. Temperature increases and consequent reductions in available oxygen tend to have deleterious effects on fish and other organisms by:
   a. Inhibiting their growth and disrupting their metabolism
   b. Amplifying the effects of toxic substance
   c. Increasing susceptibility to diseases and pathogens
   d. Encouraging an overgrowth of bacteria and algae which further consume available oxygen
   e. Creating thermal barrier to fish passage
7. Existing data on the Twisp and Chewuch Rivers and new water temperature data collected on the Methow River was compared to published thresholds to assess spawning, rearing, and migration viability

7.1.3 Recharge areas

8. Natural recharge areas (springs) and artificial recharge areas (irrigation) exist
9. Recharge areas are an important component for habitat function

   a. Recharge areas can help lower water temperatures in late summer to early fall, which is particularly important in areas that would otherwise be considered to have higher than preferred temperature for habitat use
   b. Recharge areas can also raise the temperature in winter months to prevent icing up in holding pools
   c. Recharge areas can help maintain a base flow in river areas that would otherwise go subsurface (dry) in late summer to early fall
10. Existing data on recharge locations in the Twisp and Chewuch Rivers and new location and flow data collected on the Methow River was integrated into the water temperature data to determine where high temperatures are naturally lowered due to springs

7.2 GEOMORPHIC ASSESSMENT

7.2.1 Objective

11. Geomorphic analysis was utilized to establish hypotheses of the natural river setting, present setting, and predicted future conditions.
12. The present setting has the most amount of certainty because it can be easily documented and investigated.
13. The historical setting has less certainty than the present setting because of limited documentation, but is based on knowledge of river processes and documentation that was available
14. The future setting is composed of hypotheses based on knowledge of the historical and present setting.

7.2.2 Identification of natural river and floodplain processes (setting)

15. Objectives
   a. To establish the baseline conditions prior to human development in the subbasin (mid- to late-1800s) for the purpose of evaluating where restoration needs to occur as a result of the effects of human actions on the system.
16. Approach
   a. To establish baseline conditions to evaluate working hypotheses through evaluation of the natural geologic controls on the system, historical documentation (journals, reports, etc), maps and decadal scale aerial photographs from early 1900s to 2005.
      i. Historical ground photographs were investigated through the help of the USFS
      ii. Journals and books documenting homesteader accounts of early river activities were reviewed
      iii. The most extensive historical documentation was available on the mainstem Methow River.
      iv. Some of the upper reaches on the Twisp and Chewuch rivers had fewer aerial photographs available than other assessment areas
      v. The first aerial photograph available is 1949; about 50 years after homesteading began. However, the largest floods occurred in

1894 and 1949 and 1972. It is thought that little flood protection was placed in the valley prior to 1949, and the majority of features present today were placed post-1949 flood.

vi. Older Government Land Office (GLO) maps pre-date majority of manipulation but provide limited detail on features.

b. Mapping of natural controls and identification of channel form identified various types of reaches (such as meandering; braided; and bedrock controlled)
c. The 80-mile assessment area was broken into unique geomorphic reaches with similar river process characteristics which could be used to implement habitat restoration concepts on a reach-based concept
d. Active floodplain (low surface) was identified to establish historical area of channel occupation. This is also the area of historical fish usage. Flooding can occur outside of this area onto adjacent (higher elevation) surfaces.
e. Lateral stability of the low surface was assessed by mapping surfaces that bind the active floodplain in GIS to assess the potential for erosion to see if they provide lateral stability or if the river was thought to naturally erode its banks and expand the low surface over time. Radiocarbon dating was not utilized in this coarse-scale assessment, but could be used to further verify this mapping in future efforts
f. Vertical stability (potential for long-term aggradation or incision) was assessed by mapping locations of geologic controls (bedrock, faults, slopes as observation), measuring sediment sizes in the channel bed, the ability of the river to mobilize these sediments, and trends in active channel widths over time
g. The longevity of off-channel habitat (side channels, wetlands) was assessed by looking at historical channel migration, channel slope, geologic controls, surface relative age (elevation, vegetation type)
h. Extent of natural channel roughness was evaluated by assessing presence of large woody debris sources on historical aerial photos and anecdotal accounts
i. Map alluvial fans, landslides, and tributaries to assess natural sediment sources that influence channel processes

7.2.3 Present Setting and Comparison to natural setting

17. Objective: To identify how natural channel and floodplain processes have been altered by human activities.
18. Approach
    a. Used historical accounts, aerial photographs, and maps to establish location and history of human activities in river area that could have altered channel processes
        i. Type of human activities
            1. Fire management
            2. removal of LWD within the river area
            3. flood protection/bank erosion
            4. logging and removal of riparian and upland forest

5. irrigation
6. construction of levees, bank protection, dams, diversions, roads, bridges, etc
7. development in tributaries

ii. Type of process impacted
1. Channel reworking
2. Floodplain connectivity
3. Low flow habitat availability
4. Roughness availability (velocities)
5. Lateral and vertical stability
6. Floodplain water storage (groundwater)

b. Evaluate how human activities have altered channel processes and whether the process was altered on a local or reach scale, over what timeframe, and quantify where possible

i. Surveyed cross-sections were used to look at relative elevations of main channel versus side channels in order to estimate the degree of incision or aggradation in the main channel

ii. Historical longitudinal profiles of the channel bed were compared to present bed elevations to estimate the degree of incision or aggradation over decadal time scales

iii. Widths of the natural low surface were compared with the present low surface to determine the extent of floodplain disconnected

iv. Incipient motion calculations were used to determine which reaches could mobilize the channel bed (rework) at a 2-year or greater flow and which reaches could not mobilize the bed at all indicating an armoring condition that would limit further incision

v. Utilized observations of flood deposits in combination with geomorphic surface mapping to assess whether there was signs of older surfaces not historically in the floodplain now having sediment deposited, hence showing signs of riverbed aggradation

vi. Bank heights of surfaces along the active floodplain were compared to see if the same surface was relatively higher or lower in some places when compared to the average channel bed elevations to see if signs of incision or aggradation; however, due to large assessment reach it was too time consuming and difficult to access enough areas to utilize this method; new LiDAR data collected in November 2006 could be used to implement this method at smaller scale assessments in the future

7.2.4 Future conditions

19. Objective: To predict future channel conditions within the next few decades to a hundred years relative to existing conditions
20. Approach

a. Anticipated land use changes within watershed

i. Assessed existing sediment sources to determine whether there is any anticipated change in sediment supply loads within the watershed from natural or human induced causes

ii. Assess whether any anticipated changes to channel forming discharges (annual flood an greater)

b. Areas that have incised relative to natural setting

i. Synthesized existing sediment incipient motion results with sediment bed measurements and geologic controls noted in the bed to predict whether further incision could occur, and if so to what extent and magnitude

c. Areas that have aggraded relative to natural setting

i. Assess whether there is any evidence of a change in channel planform that would suggest continued aggradation in the future.

ii. If there are areas where aggradation has occurred due to human features, has the river stabilized or is it likely to continue aggrading? This needs to be answered at a project level analysis with sediment transport capacity computations that were not done for this assessment due to lack of bed-material input data (only pebble counts were done)

d. Areas that have reduced in floodplain area

i. Use observations from 1949 flood photos and recent spring 2006 flood to predict how river might try and adjust in areas where floodplain has been cut off

7.3 REHABILITATION STRATEGIES AND PROJECT IDENTIFICATION

7.3.1 Objective

21. To identify projects that can restore or preserve natural processes and floodplain connectivity within the assessment area, and assess whether the geomorphic concepts are sustainable

7.3.2 Approach

22. Existing side channels within the low surface were mapped to assist with potential locations of floodplain reconnectivity projects
23. Size of side channel was estimated based on whether there was evidence on historical aerials of channel being a main channel or just an overflow channel
24. Potential project areas were mapped in GIS and overlaid with human features to develop a concept for each project that would mitigate for human actions and try to restore the site back to some degree of the baseline (natural) conditions
25. Synthesized information from the natural, existing, and future conditions were used to develop project concepts
26. Projects with no human features and minimal departure from the natural setting were broken out as sites where processes should be preserved (protected) and monitored
27. Projects were then grouped by geomorphic reaches to provide a summary and prioritization of where to begin restoration work based on how well a reach was currently functioning, the types and level of strategies that need

to be implemented to restore portions of the natural processes that have been disturbed, and what concepts were short- versus long-term

28. Project concepts were then qualitatively ranked based on construction feasibility by design engineers

8. REFERENCES

IN TEXT	FULL CITATION
Andonaegui 2000	Andonaegui, C. 2000. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48: Final Report.* Washington State Conservation Commission, 232 p.
Golder 2005	Golder Associates, Inc., 2005, *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Humling and Snow 2006	Humling, M. and Snow, C. 2006. *Spring Chinook spawning ground surveys in the Methow River Basin in 2005.* Washington Department of Fish and Wildlife, Olympia, WA. Report prepared for Public Utility District Number 1 of Douglas County.
ICBTRT 2007	Interior Columbia Basin Technical Recovery Team, July 2007, *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* ["current draft"], 49 pp. See at http://www.nwfsc.noaa.gov/trt/col_docs/viabilityupdatememo.pdf (as of 12/04/07).
Konrad et al. 2003	Konrad, C.P.; Drost, B.W.; and Wagner, R.J. 2003, *Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington.* US Geological Survey Water-Resources Investigations Report 03-4244, 137 p.
KWA 2004	KWA Ecological Sciences Ltd., 2004, *Methow Subbasin Plan.* Prepared under contract for Washington Department of Fish and Wildlife and funded by the Northwest Power and Conservation Council. April 23, 2004; 463 p.
PWI 2003	Pacific Watershed Institute, 2003, *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.

IN TEXT	FULL CITATION
UCRTT 2007	Upper Columbia Regional Technical Team, 2007, *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board.* August 2007. Wenatchee, WA. Appendix H of UCSRB 2007. See at http://www.ucsrb.com/plan.asp (as of 12/14/07).
UCSRB 2007	Upper Columbia Salmon Recovery Board, 2007, *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan.* Wenatchee, WA. 300 pp. See at http://www.ucsrb.com/plan.asp (as of 12/03/07). Federally adopted by NMFS 2007b.

APPENDIX E –

CONCEPTUAL MODEL OF PHYSICAL PROCESSES IMPORTANT TO SALMONID HABITAT FORMATION

Appendix E provides a baseline understanding of the physical processes that are presently acting in the river system, how the current processes differ from those that operated before man's intervention (pre-historically), and a prediction of how current processes may continue to operate in the future. Processes are focused on those that drive the creation and the sustainment of habitat features important to spring Chinook salmon and steelhead; these include development of pools, off-channel areas, side and overflow channels, large woody debris structures, spawning gravels, and refuge areas during high flows. Particular processes discussed are channel migration rates and planform, changes in channel bed elevation (incision or aggradation), riparian vegetation condition, and recruitment and presence of large woody debris (LWD). Information is analyzed to look for any changes or trends in these processes over the last century, as a result of human activities and features, which could impact the quantity and quality of habitat.

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1. OVERVIEW

This appendix provides a baseline understanding of the physical processes that are presently acting in the river system, how the current processes differ from those that operated before man's intervention (pre-historically), and a prediction of how current processes may continue to operate in the future. Processes are focused on those that drive creation and sustainment of habitat features important to spring Chinook and steelhead; these include the development of pools, off-channel areas, side and overflow channels, large woody debris structures, spawning gravels, and refuge areas during high flows. Particular processes discussed are channel migration rates and planform, changes in channel bed elevation (incision or aggradation), riparian vegetation condition, and recruitment and presence of large woody debris (LWD). Information is analyzed to look for any changes or trends in these processes over the last century, as a result of human activities and features, which could impact the quantity and quality of habitat. This analysis utilizes information provided in the accompanying technical appendices presented in this report.

The "natural setting" is defined as the mid-to-late 1800s, prior to significant human-induced disturbances to physical river processes. Hypotheses of the natural setting provide a conceptual model of the geomorphic opportunities for habitat improvement. For example, not all river reaches can support the same level of floodplain complexity; this is due to variations in geologic controls, such as floodplain width, sediment sizes, channel slope, access to riparian vegetation zones, etc.

Comparison of the present river setting to the conceptual model of the natural setting helps determine which processes have been altered and to what degree. Not all processes may be fully returned to the natural setting due to changes in vegetation, climate, or anthropogenic constraints, such as land use.

Project concepts must incorporate not only the present setting, but anticipate how river processes may or may not change in the future. Looking at historical trends of river processes on a decadal scale provides an understanding of the rate of change from the natural setting, how the changes relate to historical floods and human activities, and whether the changes have had a continual trend in a certain direction or appear to have stabilized. This information can be utilized to hypothesize whether any historical trends in physical processes will continue to change in the future.

2. METHODS

2.1 EVALUATION OF THE NATURAL SETTING

To evaluate the natural setting, the following steps were done:

a) Acquired historical ground photographs, journal accounts, books, and anecdotal information to document human activities in basin and river setting prior to earliest aerial photography (Appendix O)
b) Mapped historical river channels to document the natural (undisturbed) floodplain area (low surface) that defines the boundary of the interaction between channel and floodplain processes where habitat projects will be proposed (Appendix G and Q)
c) Mapped geologic units that bound the low surface and any geologic controls present in the channel bed (such as. bedrock or large boulders) (Appendix M)
d) Identified natural lateral and vertical controls on river processes based on stereo-pair aerial photographs (2000), regional geology maps, geologic mapping, and field reconnaissance (2005 to 2006) (Appendix M)
e) Subdivided assessment area into reaches with unique geomorphic processes that offer unique habitat opportunities (Appendix C)

2.2 EVALUATION OF THE PRESENT SETTING

To evaluate the present setting, the following tasks were accomplished:

a) Assessed biologic information to understand present habitat use and opportunities for improvement (Appendix F)
b) Analyzed hydrologic data to develop a flood frequency for gaged and non-gaged locations (Appendix J)
c) Analyzed hydraulic and sediment data to provide additional information for evaluating the balance between water and sediment loads and how this impacts channel form; based on new channel survey and bed sediment data collected in 2005 (Appendix K)
d) Compared new survey data to historical survey data to look for signs of vertical channel change (Appendix K)
e) Mapped historical channel migration and bank erosion to look for signs of lateral channel change and to verify active floodplain reworking area; based on decadal-scale historical aerial photographs (1949 to 2004) and maps (late 1800s to early 1900s) that were acquired, rectified, and put into a GIS data base (Appendix G)
f) Mapped human features to identify the locations and extent of areas within active floodplain that have been disconnected from the river channel and areas along boundary of active floodplain that have been altered (Appendix P)

g) Mapped vegetation in the riparian corridors of the Methow and Chewuch rivers using recent aerial photography (already done on Twisp River) to look at the present condition of vegetation; also hypothesized how vegetation has been altered from historical conditions; a few areas on Methow and Twisp rivers were checked in the field to verify or disprove working hypotheses on vegetation processes (Appendix H)

h) Analyzed temperature and flow data on the Methow River using new data collected during low-flow period (late summer/early fall) in 2005 (available on Twisp and Chewuch Rivers from previous studies) to provide a better understanding of temperature conditions on the Methow River during critical low-flow periods (Appendix I)

2.3 PREDICTION OF FUTURE CONDITIONS

To predict the future conditions of the river, the assessment team accomplished the following:

a) Integrated previous and new information to assess the natural setting of the river, to determine how it has departed from natural conditions due to human features and actions, and to predict how it may or may not change in future (Appendix E)

b) Assumed that climate and land use in the present setting do not change to a large enough degree that they would impact river processes in the near future; sensitivity to this assumption was beyond the scope of this assessment. However, protecting and restoring physical and ecological processes may help insure that listed fish populations have a strong habitat basis or refugia that will help the populations be resilient in the face of a changing climate or extensive environmental perturbations in the subbasin.

3. CONCEPTUAL MODEL OF NATURAL SETTING

The natural setting represents river conditions in the mid- to late-1800s, prior to European settlement in the basin (see Appendix P for further documentation). These are hypothetical conditions inferred from the available historical information and photographs, geomorphology, and hydraulics, because there is little documentation of the actual conditions of this time. The conceptual model of the natural setting was largely inferred from the present conditions, and then determining how human activities may have altered the river from historical accounts and the oldest available aerial photographs (1948 or 1954) and maps.

The following sections describe the geologic controls, sediment sources, channel dynamics, and vegetation components of the conceptual model of the natural setting developed by the assessment team. These features were utilized to develop unique geomorphic reach types and boundaries for the assessment area as described in Appendix C.

3.1 GEOLOGIC CONTROLS ON THE RIVERS IN THE ASSESSMENT AREA

The present morphology and alignment of the river are largely a result of natural geologic processes that still impose controls on the system. These geologic processes occurred over a timeframe of several thousands to tens of thousands of years. The valley shape was formed by glacial processes within which the river incised into the glacial sediments. Debris flows along tributaries resulted in large diameter material within the channel bed that is infrequently mobilized by the present hydrologic regime. Geologic controls consist of bedrock, alluvial fans, and glacial terraces that are difficult to erode on a decadal time scale and so limit vertical incision and lateral expansion over long reach lengths.

Rock type and structure control some characteristics of the drainages in the assessment reach by juxtaposing (placing side by side) rock types with different strength and erodibility. Within the assessment area, most of the Methow River and the lower parts of the Twisp and Chewuch Rivers flow within a northwest-trending, fault-bounded graben; this graben is filled with sedimentary and volcanic rocks that are folded and faulted. Rocks northeast and southwest of the graben, outside of the bounding faults, are igneous and metamorphic rock types (crystalline), which are generally harder and more resistant to erosion than the rock types that fill the graben. The graben-bounding faults, especially, as well as smaller faults, result in rock that is sheared and mixed. Sheared zones may be relatively weak and provide linear zones along which the rivers may erode more easily than the surrounding unsheared rocks.

Periodic glacial advances and retreats of the large Continental ice sheet and valley (alpine) glaciers have been superimposed on the older rocks. Ice and the large discharges that occurred during glacial/interglacial intervals sculpted valley topography that cannot be markedly altered by the much-smaller present discharges. Thus, these features reflect processes that do not occur today, and create controls for the river system. As a result, bedrock is very shallow in some places in the valleys, and thick sequences of unconsolidated deposits are preserved in other places. Variations occur longitudinally along the valleys and across the valleys.

3.1.1 LATERAL CONTROLS

Laterally, many sections of the Methow, Chewuch and Twisp river floodplains are bound by glacial terraces (Figure E-1), alluvial fans (deposited several hundreds to thousands of years ago), or bedrock that is not easily eroded (Figure E-2). These features establish the width of the active floodplain and result in local pinch points where the floodplain narrows relative to upstream and downstream sections. Generally these features limit the rate of lateral erosion caused by river processes (see Appendix C for additional descriptions).

The composition of the low surface for each of the three drainages was plotted by river mile and summarized in Table E-1, Table E-2, and Table E-3 to allow relative comparison of the geologic characteristics, which is shown in Figure E-3, Figure E-4, and Figure E-5. Glacial deposits are the most common geologic unit along the boundary of the low surface in all three sub-drainages. The second most common geologic units (by percentage) are either alluvial fans in the Methow and Twisp Rivers, bedrock in the Chewuch River. Landslides compose less than 5% of the total boundary length on either side of the river for all three sub-drainages.

Figure E-1. Glacial terrace – view of bank along Methow River upstream of Winthrop.

Figure E-2. Bedrock – view of Middle Methow between Carlton and Twisp River confluence, where bedrock composes the boundary of the low surface.

Table E-1. Methow River assessment area – summary of geologic composition along boundary.

Geologic surface description corresponding to figures	**Bank Length** (miles)		**Percentage of Bank in Each Type**	
	Right	Left	Right	Left
1 = Bedrock	2.9	2.7	7%	6%
2 = Glacial deposits of varying age and heights above the river bed	32.7	36.1	73%	81%
3 = Alluvial-fan deposit	7.8	4.6	17%	10%
4 = Landslide/debris flow	1.3	1.5	3%	3%
Total Length	**45**	**45**		

Table E-2. Twisp River assessment area – Summary of geologic composition along boundary.

Geologic surface description corresponding to figures	**Bank Length** (miles)		**Percentage of Bank in Each Type**	
	Right	Left	3%	11%
1 = Bedrock	0.4	1.6	59%	70%
2 = Glacial deposits of varying age and heights above the river bed	9.3	9.9	33%	17%
3 = Alluvial-fan deposit	5.2	2.3	5%	2%
4 = Landslide/debris flow	0.8	0.3		
Total Length	**16**	**14**		

Table E-3. Chewuch River assessment area – Summary of geologic composition along boundary.

Geologic surface description corresponding to figures	**Bank Length** (miles)		**Percentage of Bank in Each Type**	
	Right	Left	23%	22%
1 = Bedrock	3.0	2.8	66%	66%
2 = Glacial deposits of varying age and heights above the river bed	8.6	8.7	9%	12%
3 = Alluvial-fan deposit	1.2	1.6	1%	0%
4 = Landslide/debris flow	0.2	0.0		
Total Length	**13**	**13**		

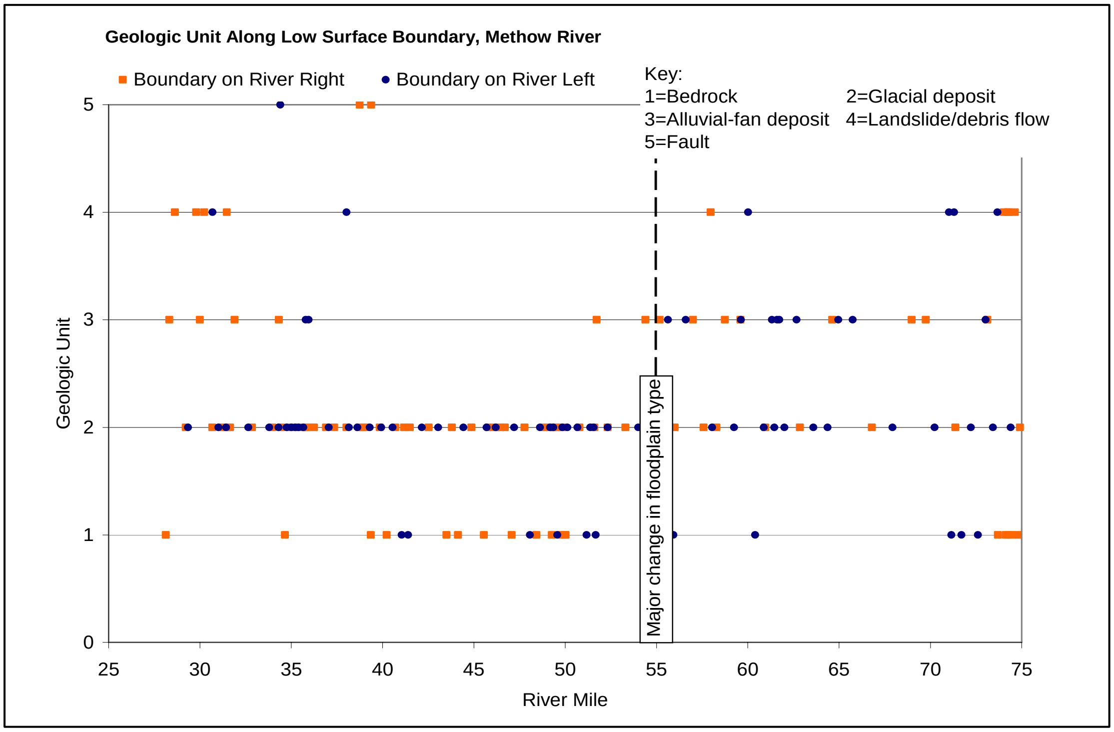

Figure E-3. Methow River assessment area – Geologic units present along the boundary of the low surface (floodplain).
The river mile plotted represents the mid-point of the feature.

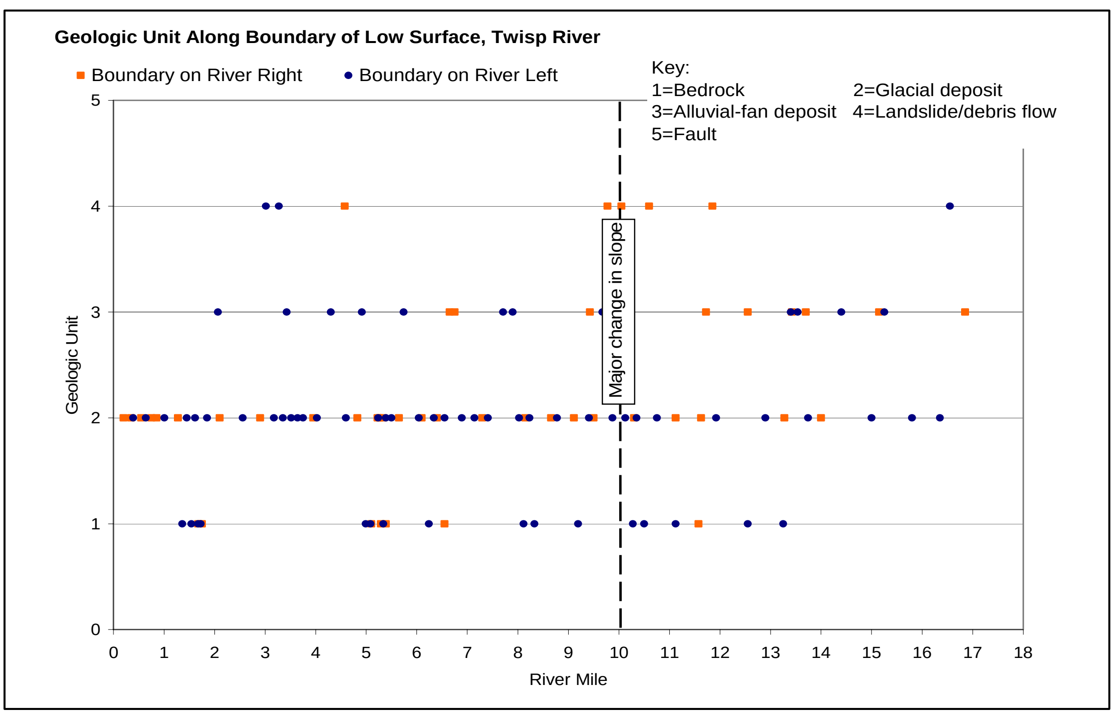

Figure E-4. Twisp River assessment area – Geologic units present along the boundary of the low surface (floodplain).
The river mile plotted represents the mid-point of the feature.

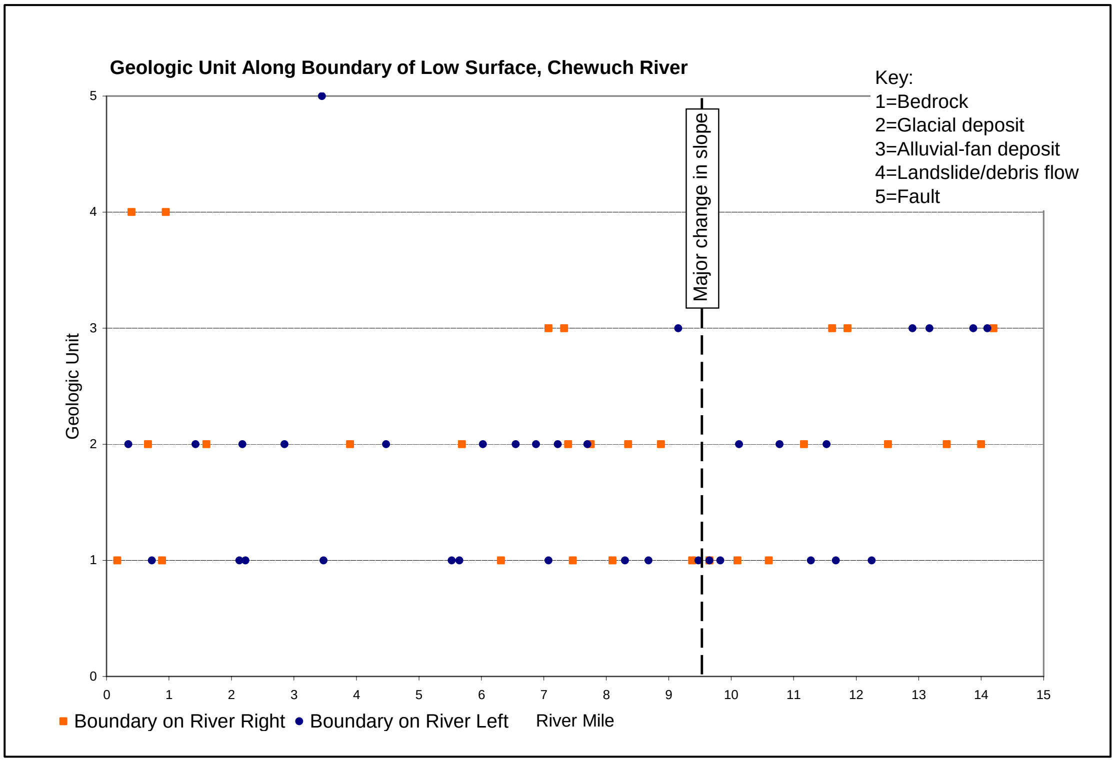

Figure E-5. Chewuch River assessment area – Geologic units present along the boundary of the low surface (floodplain).
The river mile plotted represents the mid-point of the feature.

3.1.2 VERTICAL CONTROLS

The geologic processes that have formed the valley largely control the slope of the presently active channel on a reach scale. The extent and type of glacial activity, faults, and the presence of bedrock all play a role in determining which reaches now have steeper versus flatter slopes. The geologic controls also limit the amount that the active channel can adjust within the context of the system as a whole.

The active channel may still adjust as a result of localized changes in available sediment or the occurrence of a flood. For instance, bank erosion or a debris flow could occur that causes the active channel to straighten in alignment, thus increasing its slope which increases the energy available to transport the new sediment input. A reach where the floodplain is artificially cut off would also be expected to have a straighter channel with an increased slope and energy potential. However, the cobble-sized sediment present in the channel bed in many reaches of the assessment area and periodic exposed bedrock outcrops also limit the potential for incision of the river bed when the energy is increased. Therefore, the relative comparison of slopes between reaches would not be expected to change over decades to a century of time as a result of natural or human induced changes (e.g., steeper reaches will continue to have higher slope values than flatter reaches and vice versa). Localized scour around riprap, LWD, and other features can still occur. Geologic influences on river slope for the Methow, Twisp, and Chewuch Rivers are described below.

The longitudinal profile of the Methow River has a trend of decreasing slope in the downstream direction, but a major slope break, such as those on the Chewuch and Twisp rivers, is not present (Figure E- 6). Ice from the continental ice sheet and alpine (valley) glaciers periodically filled the Methow River valley along the entire length of the assessment area (upstream of Lost Creek to about Carlton). Glacial ice and melt water eroded into the sedimentary and volcanic rocks (relatively easily eroded) and deposited a relatively thick sequence of unconsolidated gravel and sand. The Methow River now flows through these unconsolidated deposits, which can be relatively easily reworked by the river. A deep trough that was carved by the glacier from Early Winters Creek results in a very thick (several hundreds of feet) deposit of unconsolidated gravel and sand beneath this part of the valley (Konrad et al., 2003). Because the surface characteristics in the valley, though variable, are relatively similar along the length of the Methow River in the assessment reach, the presence of this trough does not affect the longitudinal valley profile. Exposed bedrock was noted in the channel bed at RM 48.1 and at RM 48.8.

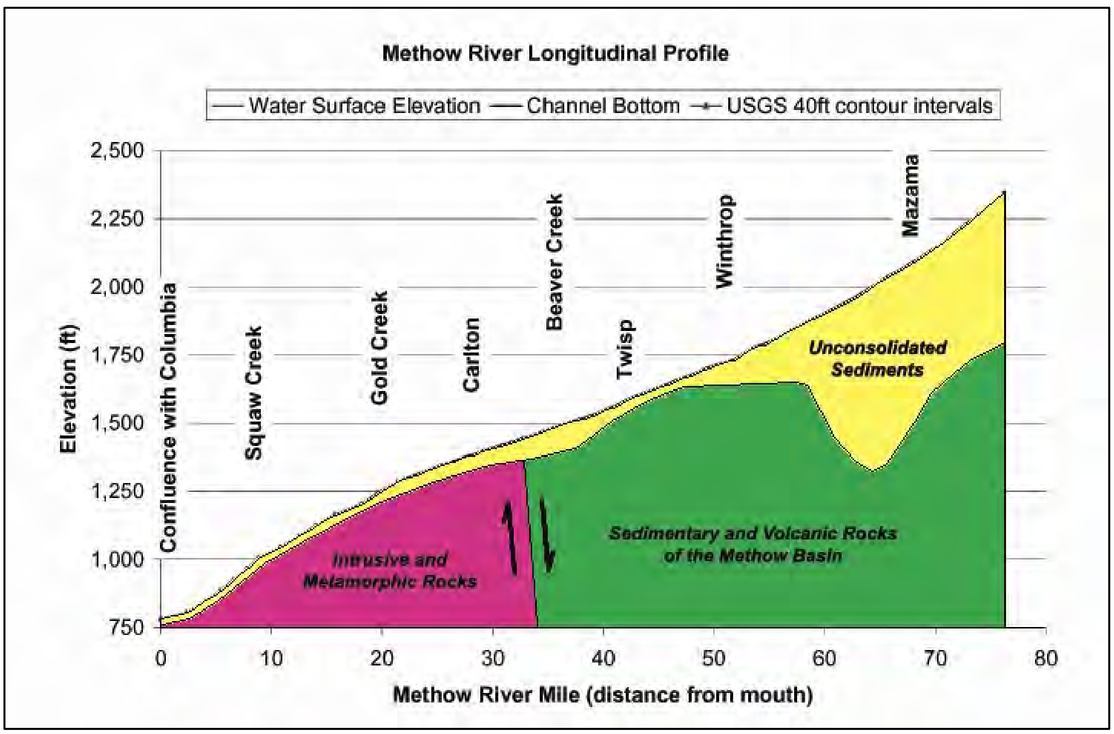

Figure E- 6. Methow River – Conceptual figure of geologic controls along longitudinal profile.

The longitudinal profile on the Twisp River shows a sharp break at RM 10 (Figure E-7 and Figure E-8). Although minor variations in bedrock are present, the rock types are primarily the same across the change in slope. However, the maximum extent of the alpine (valley) glacier that came down the Twisp River valley coincides with the approximate location of the slope change. Glacial erosion and deposition occurred upstream of this point, and is hypothesized to have resulted in a flatter slope. Fluvial erosion, which during times of glacier melting would be expected to be greater than present, occurred downstream of the ice, and has resulted in a steeper slope. Exposed bedrock was noted in the channel bed at RM 5.1–5.3, 9.9, 11.1, 13.2, and at 16.2.

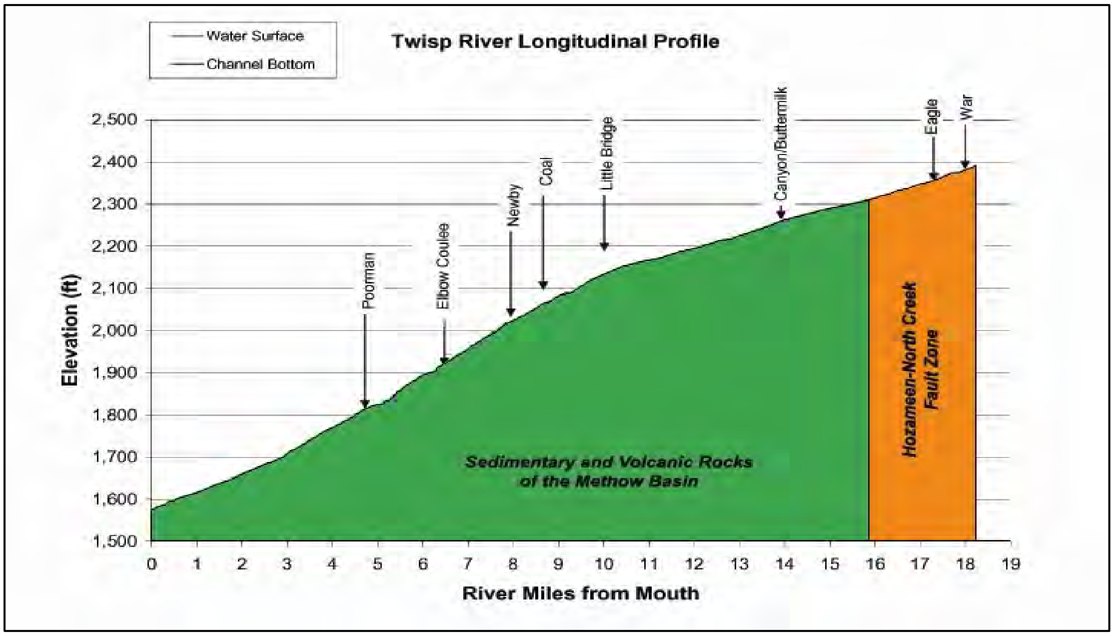

Figure E-7. Twisp River – Conceptual figure of geologic controls along longitudinal profile.

Figure E-8. View of Twisp River just upstream of Little Bridge Creek near RM 10 (August 17, 2005).

The longitudinal profile along the Chewuch River steepens between RM 9 and RM 10 relative to the upstream and downstream river reaches (Figure E-9). A graben-bounding fault crosses the valley at an oblique angle near RM 9, and is relatively easy for the river to erode. Upstream of RM 10, the bedrock is crystalline, and is relatively resistant to erosion. Downstream of RM 9, the bedrock is sedimentary and volcanic rocks, which are generally more susceptible to erosion. The differences in rock types, which are juxtaposed (put side by side) by the graben-bounding fault, create a resistant "step" in the longitudinal profile of the Chewuch River. Very large boulders that have been deposited by glacial or debris-flow processes at the mouth of Boulder Creek, which is in this same area, enhance the resistant character of the near-surface crystalline rocks. Exposed bedrock was observed at RM 1.5 (Smith et al., 2000).

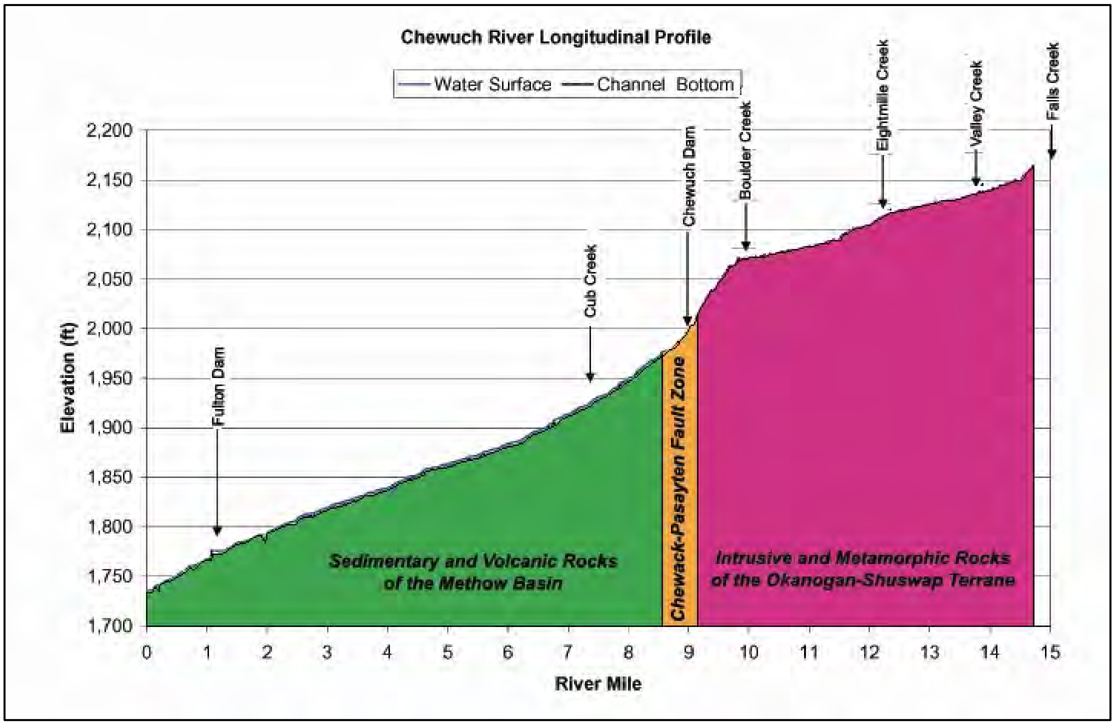

Figure E-9. Chewuch River – Conceptual figure of geologic controls along the longitudinal profile.

3.2 SEDIMENT SOURCES

Sources of sediment within the basin were qualitatively evaluated to determine the location and relative contribution of sediment sources to the river channel (see Appendix N for more detailed discussion). This information can be used as baseline data to determine if there are natural or human-induced alterations to sediment supply that could potentially impact channel processes. Potentially, a large reduction in sediment supply could lead to incision and/or narrowing of the channel; or, a large increase could lead to aggradation. By comparing sediment sources with the ability of the river to rework the sediment stored in the channel and adjacent bars, evaluation of the river's lateral and vertical stability can be assessed. Sediment sizes of interest at the reach scale are noted in this discussion as "coarse sediment" and range in size from coarse sand to cobbles.

The size classes of sediment referred to in this appendix are presented in Table E-4.

Table E-4. Sediment size class and particle diameter range.

Sediment Size Class	Particle Diameter Range (mm)
Clay	Less than 0.004
Silt	0.004 to 0.062
Sand	0.062 to 2
Gravel	2 to 64
Cobble	64 to 256
Boulder	256 to 4096
Sediment sizes are from Julien (1995).	

Sediment transported along the river system generally originates from four sources in the natural setting:

- Alluvium in storage (bars, floodplain) within the low surface (active floodplain)
- Unconsolidated deposits (glacial and alluvial-fan deposits) that underlie the surfaces that bound the low surface
- Landslides/debris flows from the slopes and banks adjacent to the river
- Sediment eroded and transported by the tributaries; this includes landslides/debris flows that occur within the tributaries and also fire-generated sediments. (Initially, mostly fine sediments are delivered to downstream reaches; at tributary junctions affected by fire, sediments are coarse and are significant sources of spawning gravels and habitat complexity, sediment fans perch water tables and influence surface water and ground water storage.)

Reworking of the alluvium within the low surface is the primary source of sediment to the rivers within the assessment reach. Sediment stored in the active channel bed and bars ranges from silt to boulders, but the average size is generally gravel- to cobble-sized sediment (Table E-4). Sediment stored within the floodplain is on average smaller than active channel sediment. Reworking occurs mostly during higher flows that are capable of inundating the floodplain and mobilizing sediment. Reworking can occur through the river migrating or avulsing to a new location within the floodplain, or by simply reworking the alluvial channel bed and adjacent gravel bars. The reaches within the approximately 80-mile assessment area that would be expected to supply the most sediment are the sections where the river laterally migrates across the floodplain at a frequent rate.

Bank erosion within the low surface provides additional sediment as the floodplain is reworked, particularly in areas with frequent channel migration. Erosion of the surfaces that only bound the low surface has been limited in lateral extent and has provided episodic, small amounts of sediment relative to the larger incoming sediment load.

Landslide and debris flows also deliver sediment to the river but these sources tend to be episodic in nature (Figure E-10 and Figure E-11). Types of sediment delivery include debris torrents, terrace-toe failures, deep-seated landslides, surface ravel, and soil creep. Generally these sources provide sand- to cobble-sized sediment. Episodic events generally occur during times of active freeze-thaw or during high rainfall events, especially if after an extensive fire (Figure E-10).

Figure E-10. Looking upstream at Andrews Creek, which has experienced periodic debris flows that deliver coarse sediment to the Chewuch River *(July 14, 2005)*.

Figure E-11. View of landslide along river right on Twisp River just upstream of Little Bridge Creek confluence (RM 10). *(August 17, 2005)*

Fires periodically occurred throughout the basin and provided additional sediment to the system and fresh, bare soil for riparian vegetation. Fires in unmanaged landscapes are thought by local biologists to be a natural part of replenishing organic debris, spawning substrates, and habitat complexity in affected stream reaches with only short-term impacts on habitat. In the natural setting, fires would occur at different places within the watershed at different times; if one drainage was impacted and temporarily depleted of habitat or fish populations were locally extirpated, the fish from neighboring watersheds would provide a source to bolster or re-establish fish populations in the impacted areas; this is provided there is physical passage available to the affected area and the population is robust enough to provide a surplus of individuals to stray into the affected habitat .

In the Chewuch watershed, the Thirtymile Fire (in 2001) burned approximately 9,324 acres and the Farewell Fire (2003) perimeter included approximately 79,000 acres. Both of these fires have resulted in a major alteration to the upper watershed that has provided new sediment and wood sources (Figure E-12, Figure E-13, and Figure E-14). High levels of organic debris and sediment fans have helped to capture fine sediments on adjacent floodplains and remove it from active channels. The fires resulted in both fine-sized sediment in the river and also debris flows that range in size from silt to boulders.

Following the 2003 Farewell Fire, fish usage recovery was nearly immediate and occurred the year following the fire. Redds and young salmonids were observed the year following the Farewell Fire and landslides. Bull trout redd counts have not dropped below pre-fire levels, and the distribution of bull trout spawning areas appears to have increased to include some of the new debris fans (spawning data from 1995 through 2006; personal observations, J. Molesworth). Long-term effects of the fires on spring Chinook and steelhead spawning habitat and water temperatures in the downstream reaches of the Chewuch River are unknown at this time. Fires are also thought to have been a natural control on vegetation that helped prevent the system from becoming too static. The fire helped remove vegetation and allow the river to rework surfaces, particularly in reaches with limited water available to result in channel and floodplain reworking. Fires also remove vegetation and expose soil to rainfall. High-intensity rainfall can then cause accelerated rates of debris flows, landslides, and bank erosion creating dramatic increases in coarse bedload, fine sediment and organic debris.

Figure E-12. View of Chewuch River in Thirtymile Fire area four years after the fire, in July 2005.

Figure E-13. View of debris flow entering Chewuch River in Thirtymile Fire area four years after the fire, in July 2005.

Figure E-14. View of Chewuch River in Thirtymile Fire area where a large debris flow from a hill slope where fine sediment was stored created an alluvial fan as well as being and delivered sediment to the river four years after the fire, in July 2005.

4. PRESENT RIVER SETTING

This section describes the present river setting and how current processes may have been altered from the conceptual model of the natural (pre-settlement) condition as described earlier (in Section 3). The discussion focuses on trends in physical river processes that are tied to channel morphology and habitat complexity.

Channel morphology can change over time as a result of natural or human-induced alteration to upstream parameters, or due to local parameters within a reach itself. Upstream conditions include the sediment and LWD that is recruited and transported into a reach, along with the hydrologic regime. Processes can also change due to local parameters within a reach (such as bridges, levees, riprap, etc.) that alter the hydraulic capacity (channel geometry and floodplain accessibility). A discussion is provided in this section on potential river responses to these types of changes, followed by an analysis of what changes have occurred and how they have or have not impacted channel morphology.

Over a decadal-to-century timeframe, incoming sediment loads are estimated to not have changed to a large enough degree to result in measurable changes to the river planform or floodplain reworking rate. Therefore, many processes within the assessment area are still functioning within the conceptual model of the natural setting. However, human activities have caused intermittent disruption to natural processes that vary in magnitude and impact. The documentation of human activities was analyzed to develop hypotheses as to which features could have affected physical channel processes. The effect on processes was then assessed using a combination of qualitative and quantitative methods, as summarized below.

4.1 RIVER DYNAMICS

Over time, streams attempt to move towards an equilibrium condition —balancing energy available with energy needed to transport the incoming sediment. “Dynamic equilibrium” is often referred to as the condition where the net incoming sediment supply approximately equals the sediment transported out of a reach over a given period of time. In this scenario, incoming discharge may alternate between wet and dry cycles, but there is no definitive trend in flow peaks or duration over a decadal time period. Additionally, short-term changes in the channel bed position and elevation can still occur, but net change in channel form or bed elevations for a given reach cannot be detected over years to decades. For example, a channel may migrate across its floodplain causing the existing channel to at least partially fill with sediment as the channel is abandoned. Concurrently, a new channel is eroded or converted from floodplain to channel area. At any one location in the floodplain during this process, an observer could note erosion or aggradation, but the overall sediment in storage within the reach would not have significantly changed.

A simplified version of this concept can be described using Lane's "Balance of Water and Sediment" (Figure E-15) (Lane, 1955). In Lane's illustration, the river's ability to remain in equilibrium is dependent on the river's ability to transport the incoming sediment supply given a quantity of water. Natural or man-induced changes in the incoming sediment load, water discharge, or sediment transport capacity can cause alterations to the balance. Channels can respond to changes in these parameters by adjusting laterally (widening or narrowing), adjusting vertically (incision or aggradation), or by altering the rate of channel migration, also referred to as floodplain reworking. In the Methow Subbasin, LWD also plays a role in forming the river's geometry and rate of floodplain reworking; this is particularly important in reaches with multiple channels and high interaction with the riparian corridor.

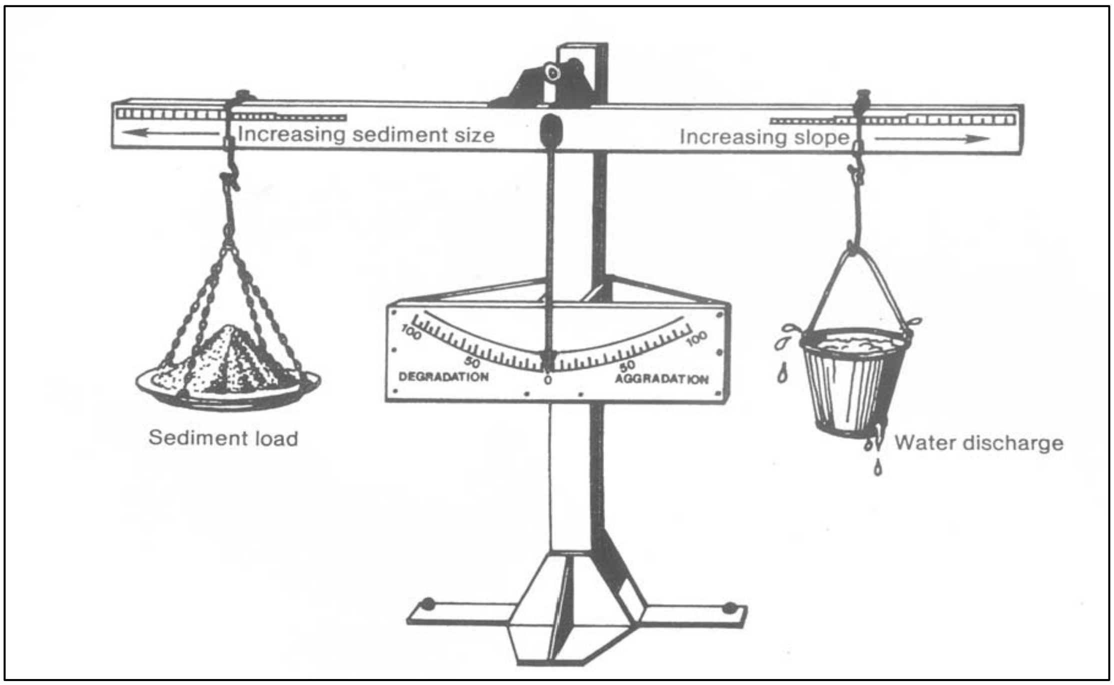

Figure E-15. Illustration of channel response to varying incoming sediment load and water based on sediment transport capacity within the reach (Lane, 1955).

If the energy available is not enough to transport the incoming sediment, the stream may straighten (increase its slope) and/or narrow to increase velocities. For example, a meandering channel may be observed to straighten (cut off). Sometimes cut offs are just part of the natural cycle of channel migration, and the river will begin meandering again shortly after the cutoff. However, a channel planform that adjusts to a straighter path for several years to decades may be an indication that the sediment load has increased, or the transport capacity has decreased. If the stream can not adjust enough to compensate for the incoming sediment supply, aggradation can occur.

If the energy available is higher than needed to transport the incoming sediment supply, the stream may widen or increase in sinuosity (which decreases slope) to try and dissipate energy. If the energy still exceeds that needed to transport the incoming sediment load, the stream may incise.

These channel responses may occur independently or concurrently, and can be limited in magnitude by geologic controls on the channel and floodplain. For example, the presence of bedrock may limit the ability of a channel to widen or incise. The upstream parameters of incoming sediment supply and water discharge are discussed next, followed by a discussion of changes to local parameters within the assessment area that may have impacted channel geometry and floodplain access.

4.2 INCOMING SEDIMENT SUPPLY AND WATER DISCHARGE

Total sediment volumes moved by the stream are subdivided for discussion into "wash load" (normally clays and silts that stay in suspension), "suspended bed material load" (particles such as fine sands found in the stream bed that are carried in the water column) and "bed load" (particles such as coarse sands, gravel, and cobble).

The bed load generally moves in contact with the streambed, but some may be carried in suspension at higher velocities. Bed load, also referred to "as coarse sediment load" in this assessment, is the focus of this discussion because this sediment is the driver of channel changes in rivers such as the Methow, Chewuch, and Twisp. Suspended sediment and wash loads can affect floodplain deposition processes and water quality (turbidity), but do not generally drive the channel morphology observed within the assessment area. They are an important part of riparian vegetation establishment, which will be discussed later in this section.

Incoming sediment loads and water discharge could be decreased from dams, either located upstream of or within the assessment area. There are no man-made dams and reservoirs in the assessment area or upstream watershed that could have significantly reduced sediment loads or incoming water discharge (peak floods) over the last century. The only dams present are small in height (less than 10 feet) and likely filled in with sediment in the upstream reservoir during the first flood. No obvious trends in the occurrence or magnitude of peak floods were detected from the USGS gaging station data, but a more robust analysis may be needed to further validate this conclusion. The longest gage record at any one location is 52 years.

Incoming sediment loads could be increased from accelerated bank erosion. Bank erosion is separated into two types: erosion along the boundary of the low surface (floodplain), and erosion within the low surface. Erosion along the boundary represents new sediment into the system that was not formerly available for transport. Erosion of banks within the low surface represents reworking of sediment that was already part of the sediment load, but temporarily in storage within the floodplain.

The residence time of the sediment in storage varies depending on the rate of reworking within a given reach type.

4.2.1 BANK EROSION ALONG THE LOW SURFACE BOUNDARY

Lateral erosion of the banks that bound the low surface has provided a limited amount of sediment overall to the rivers within the approximately 80-mile assessment reach. Bank erosion along the low surface has generally been in sections where unconsolidated glacial or alluvial-fan deposits are present in the bounding banks. In many areas the banks have been armored with riprap. In glacial banks without riprap protection, the deposits are thought to contain enough cobbles and boulders to cause the banks to be "self-armoring" (Figure E-16); finer-sized sediment is quickly transported downstream following erosion (assuming erosion occurs during high flows) and the coarser sediment remains at the toe of the bank acting as bank-protection until mobilized by large rare events.

Figure E-16. View from right bank looking upstream at self-armoring banks on Chewuch River (GPS location is N48º 35' 08.8: W120 º 09' 58.1). ***(August 26, 2005).***

Areas of expansion of the low surface (outward erosion of the low surface boundary) and areas of reworking within the low surface (eroded areas within the low surface) were mapped in ARC GIS for the Methow River between RM 28 and RM 75, for the Twisp River between RM 0 and RM 6.7, and for the Chewuch River between RM 0 and RM 11.7. The areas were mapped by comparing the channel position in the oldest available aerial photographs with the 2004 aerial photographs. The older photographs did not cover the entire lengths of the Twisp and Chewuch Rivers at the time that the eroded areas were mapped, so the entire lengths of the assessment reaches were not done. The date of the oldest available aerial photographs was 1948 for the Methow River, 1954 for the Twisp River, and 1974 for the Chewuch River.

The numbers, lengths, and percentages of the expanded and reworked areas are summarized below. The numbers of places where expansion and reworking have occurred are tabulated. The lengths of each area of erosion were measured along the 2004 low-flow channel for each reach. Lengths of expanded and reworked areas were calculated as a percentage of the length of each reach.

The areas where expansion (erosion) of the low surface occurred are discussed first, followed by areas where lateral reworking within the low surface was noted.

Expansion of the Low Surface for the Methow River RM 28–75

Along the 47-mile-long assessment section of the Methow River, twenty-two areas of expansion of the low surface boundary were noted between 1948 and 2004 (Table E-5 and Figure E-17,). The total bank length of expanded areas along the boundary of the low surface is about 14,000 feet. This is about 6% of the entire bank line in the assessment section.

Table E-5. Methow River (RM 28–75) – Number, lengths, and percentages of expanded and reworked areas.

		TOTAL					
Reach	Type	**Number of expand-ed areas**	**Number of re-worked areas**	**Bank length of expanded areas** (ft)	**Length reworked areas** (ft)	**Total expanded area as percent of reach length**	**Re-worked area as percent of reach length**
M2	Unconfined	5	21	6,225	21,071	17.9	60.5
M4	Unconfined	1	21	689	17,627	2.3	58.6
M9	Unconfined	7	55	2,832	57,797	5.1	104.3
M11	Unconfined	0	15	0	16,405	0.0	57.5
M5	Moderately confined	2	19	1,743	8,389	11.0	53.0
M7	Moderately confined	1	8	464	4,879	6.3	66.0
M10	Moderately confined	3	12	927	9,239	4.3	42.7
M1	Confined	2	6	748	6,023	2.5	20.4
M3	Confined	0	2	0	796	0.0	15.1
M6	Confined	1	2	496	639	6.3	8.1
M8	Confined	0	2	0	2,167	0.0	19.5
Total		22	163	14,123	145,033	5.7	58.6

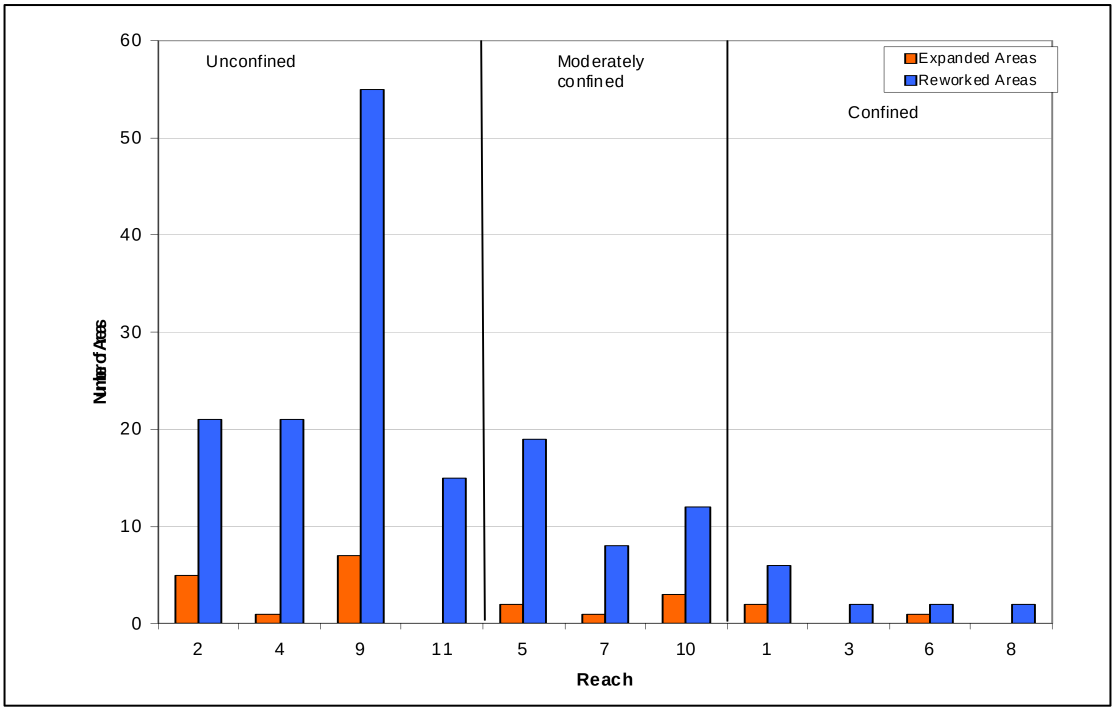

Figure E-17. Methow River (RM 28.1–75) – Numbers of places where expansion or reworking of the low surface was noted between 1948 and 2004.

Few places along the low-surface boundary in the assessment section have experienced expansion. Where expansion has occurred, the area eroded has been relatively small. Three areas in the assessment section have experienced relatively large amounts of recurrent expansion of the low surface boundary, and these are discussed in Appendix G. Two of these areas are on the Methow River: near RM 36 on river left immediately upstream of the Beaver Creek confluence and near RM 60.5 on river right about 1,500 feet downstream of Weeman Bridge.

The greatest number of expanded areas is in Reach M9, an unconfined reach. The longest cumulative length of expansion is in Reach M2 (Figure E-18). The other unconfined reaches have shorter cumulative sections of expansion. These cumulative lengths are only slightly longer than the cumulative lengths of expansion in the moderately confined reaches. The confined reaches have only short sections of expansion.

The percentage of each reach length that has expanded is the highest in Reach M2 (Figure E-19). Two of the moderately confined reaches, M5 and M7, have the next highest percentage of expansion. Confined Reach M6, has a relatively high percentage of expansion.

When expansion occurs, glacial deposits and intermediate surfaces are the two geologic units that are eroded (Figure E-20). Alluvial-fan deposits have been eroded in two reaches.

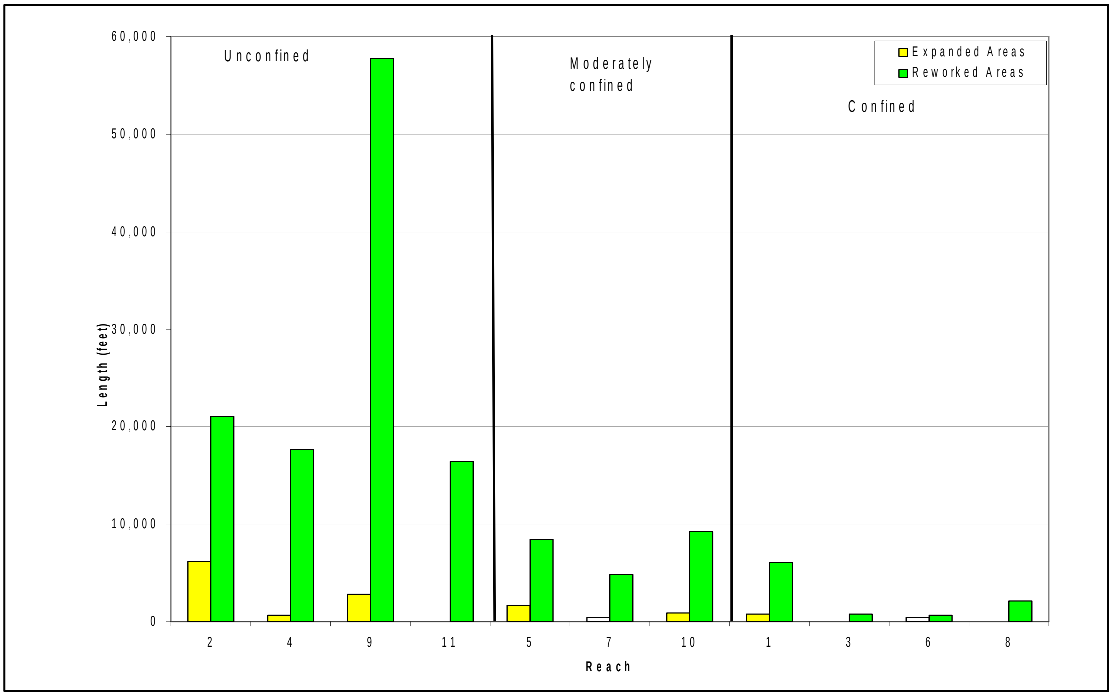

Figure E-18. Methow River (RM 28.1–75) – Cumulative length of sections with expansion or reworking of the low surface that were noted between 1948 and 2004.

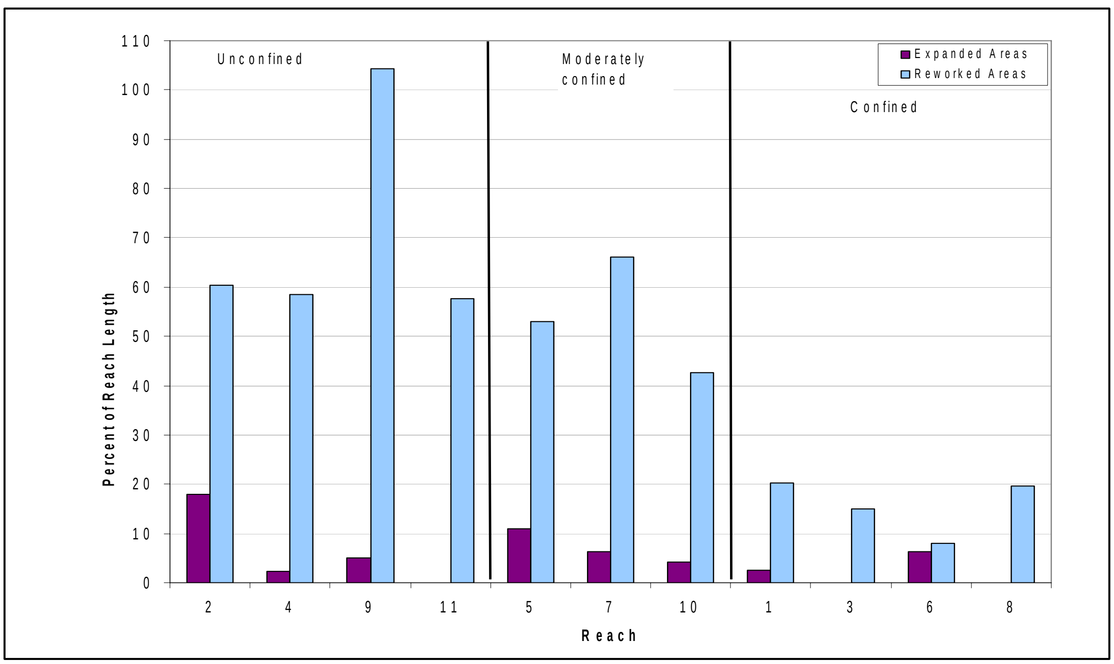

Figure E-19. Methow River (RM 28.1–75) – Percentage of the reach length that has experienced expansion or reworking of the low surface that were noted between 1948 and 2004.

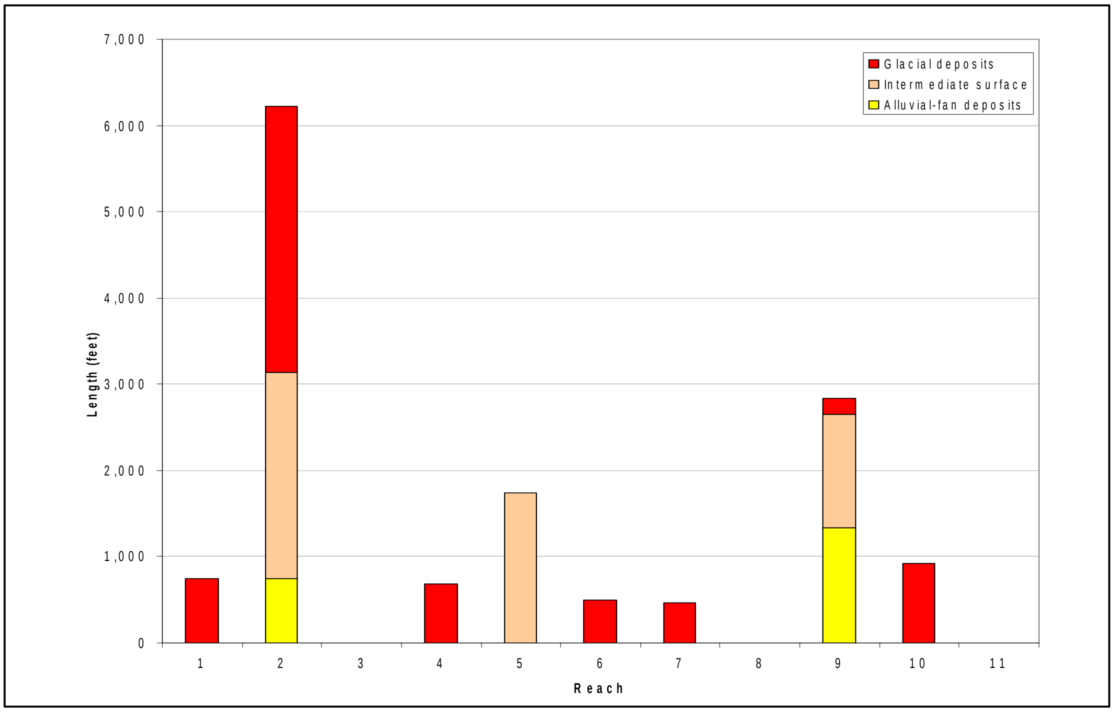

Figure E-20. Geologic units eroded in expansion of the low surface boundary for the Methow River.

Expansion of the Low Surface for the Twisp River RM 0 –RM 6.7

Along the 6.7-mile-long assessment section of the Twisp River, 6 areas of expansion of the low surface boundary were noted between 1954 and 2004 (Table E-6 and Figure E-21). The total length of expanded area is about 2,900 feet. This is about 7% of the entire assessment section that was evaluated.

Table E-6. Twisp River (RM 0–6.7) – Numbers, lengths, and percentages of expanded and reworked areas.

Reach	Type	TOTAL					
		Number		**Length (feet)**		**Percentage of reach length**	
		Expanded areas	**Reworked areas**	**Banks of expanded areas**	**Reworked areas**	**Total expanded area**	**Reworked area**
T1	Confined	0	5	1,639	1,752	51.7	55.3
T2	Unconfined	4	39	0	22,965	0.0	98.9
T3	Moderately confined	2	17	1,244	6,986	8.4	47.3
Total		**6**	**61**	**2,883**	**31,704**	**7.0**	**77.0**

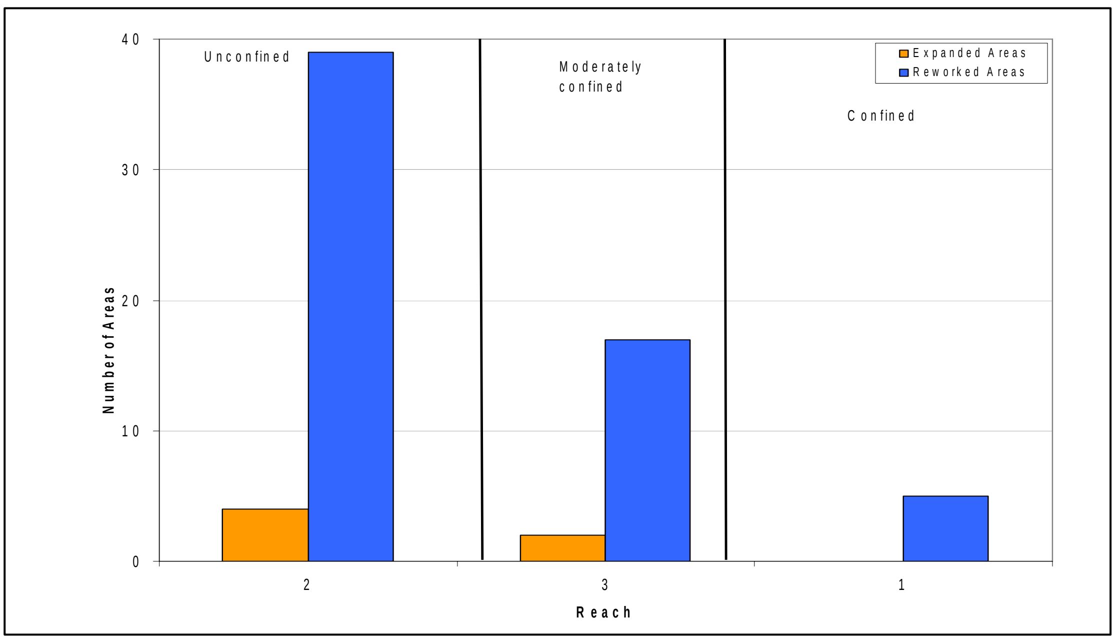

Figure E-21. Twisp River (RM 0–6.7) – Numbers of places where expansion or reworking of the low surface that were noted between 1954 and 2004.

Few places along the low surface boundary in the assessment section that was evaluated have experienced expansion. There are only four areas of expansion in the unconfined Reach T2 and two areas of expansion in the moderately confined Reach T3. Where expansion has occurred, the area eroded has been relatively small. The confined and moderately confined reaches have similar cumulative lengths of expansion (Figure E- 22). No expansion has occurred in the unconfined reach.

The percentage of each reach length that has expanded is the highest in the confined Reach T1 (Figure E- 23). When expansion occurs, glacial deposits primarily have been eroded (Figure E-24). Alluvial-fan deposits have been eroded in Reach T1.

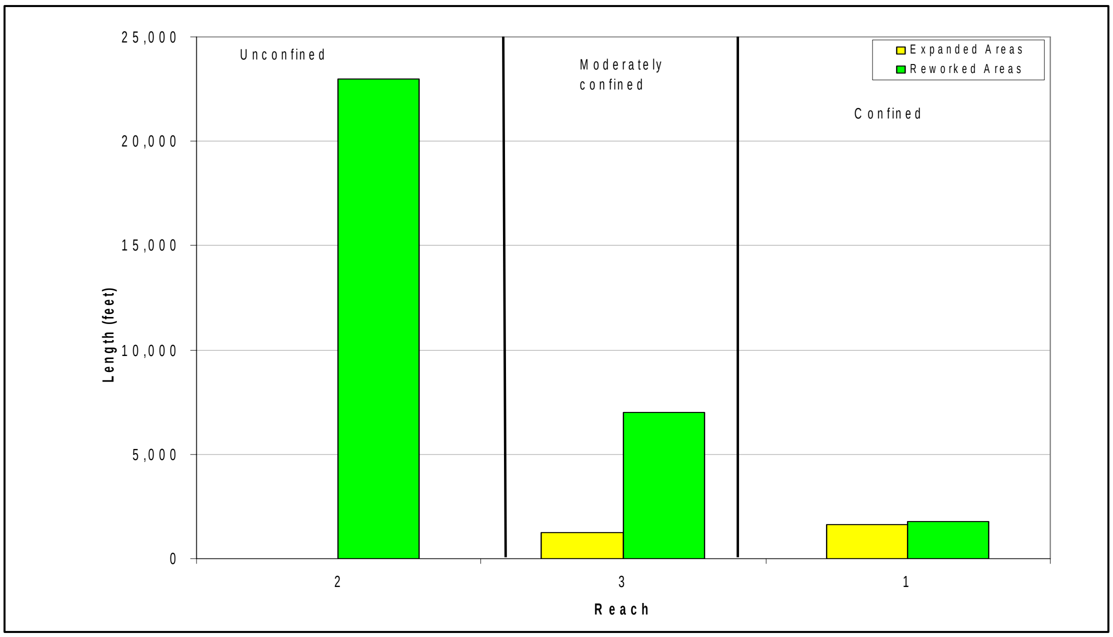

Figure E- 22. Twisp River (RM 0–6.7) – Cumulative length of sections with expansion or reworking of the low surface that were noted between 1954 and 2004.

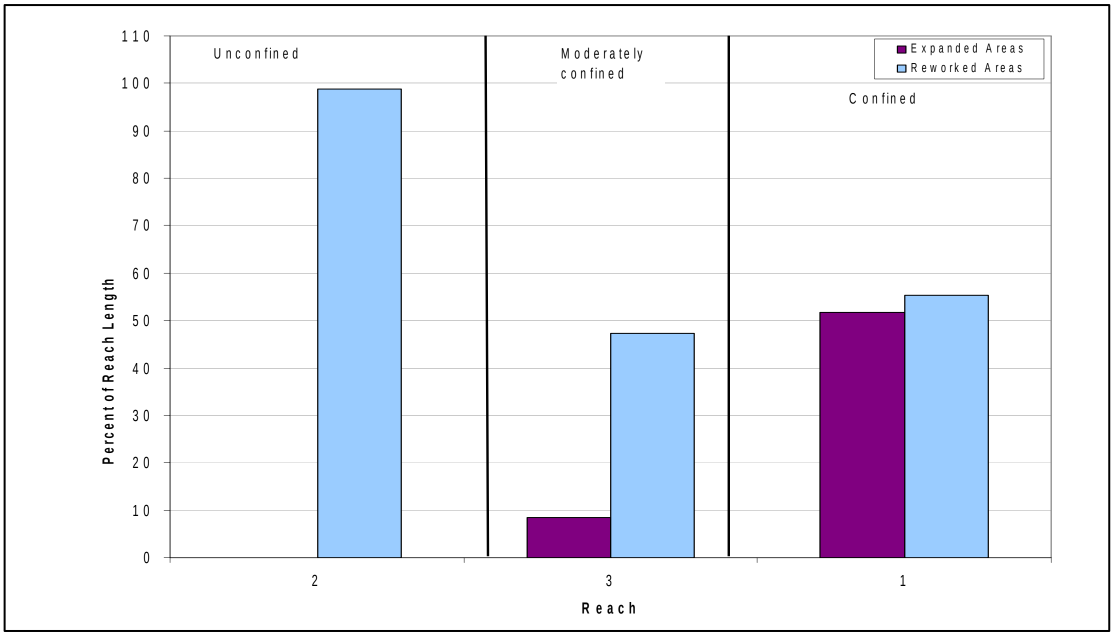

Figure E- 23. Twisp River (RM 0–6.7) – Percentage of the reach length that has experienced expansion or reworking of the low surface that were noted between 1954 and 2004.

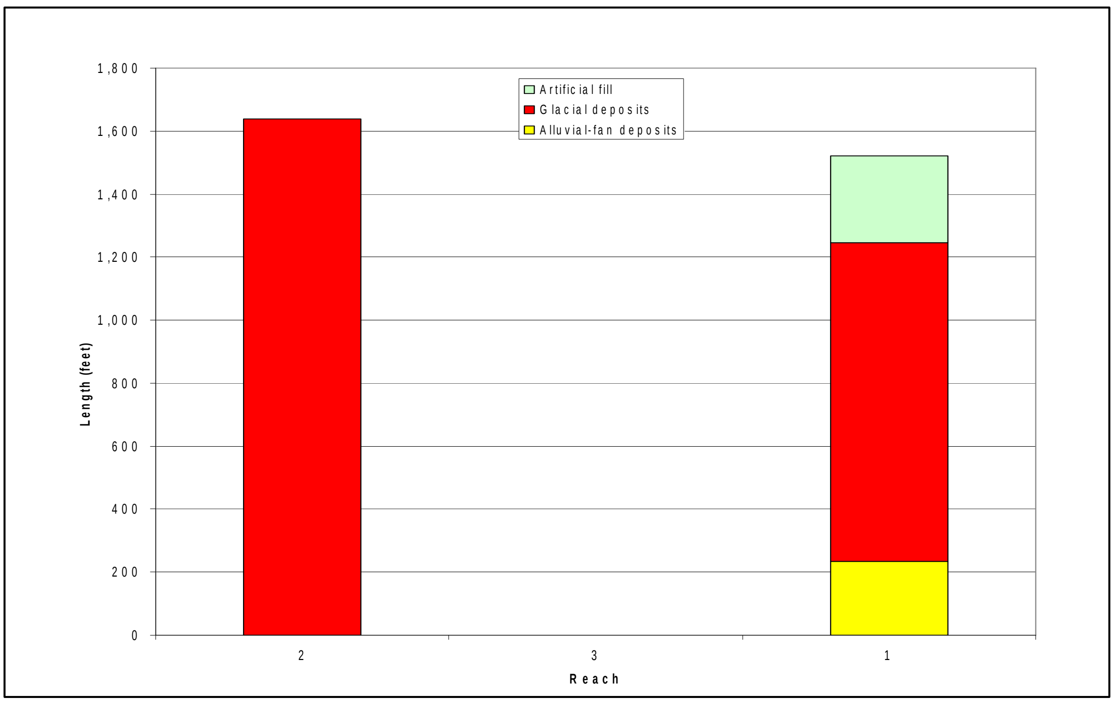

Figure E-24. Twisp River – Geologic units eroded in expansion of the low surface boundary.

Chewuch River (RM 0-11.7) – Expansion of the Low Surface

Along the 11.7-mile-long assessment section of the Chewuch River, one area of expansion of the low surface boundary was noted between 1974 and 2004 (Table E-7 and Figure E-25). The unconfined reach (C2) is the only reach where the low surface boundary has expanded. Total length of expanded area is about 340 feet, and glacial deposits were eroded at this site (Figure E-26). This is about 1.3% of the unconfined reach where expansion occurred and about 0.6% of the entire assessment section that was evaluated (Figure E-27).

Table E-7. Chewuch River – Numbers, lengths, and percentages of expanded and reworked areas (RM 0–11.7).

		TOTAL					
Reach	Type	**Number of expanded areas**	**Number of reworked areas**	**Bank length of expanded areas** (feet)	**Length reworked areas** (feet)	**Total expanded area as percent of reach length**	**Reworked area as percent of reach length**
C1	Confined	0	1	0	903	0.0	7.8
C2	Unconfined	1	24	340	18,273	1.3	67.9
C3	Moderately confined	0	2	0	1,474	0.0	12.7
C4	Confined	0	4	0	1,350	0.0	11.6
Total		1	31	340	21,999	0.6	35.6

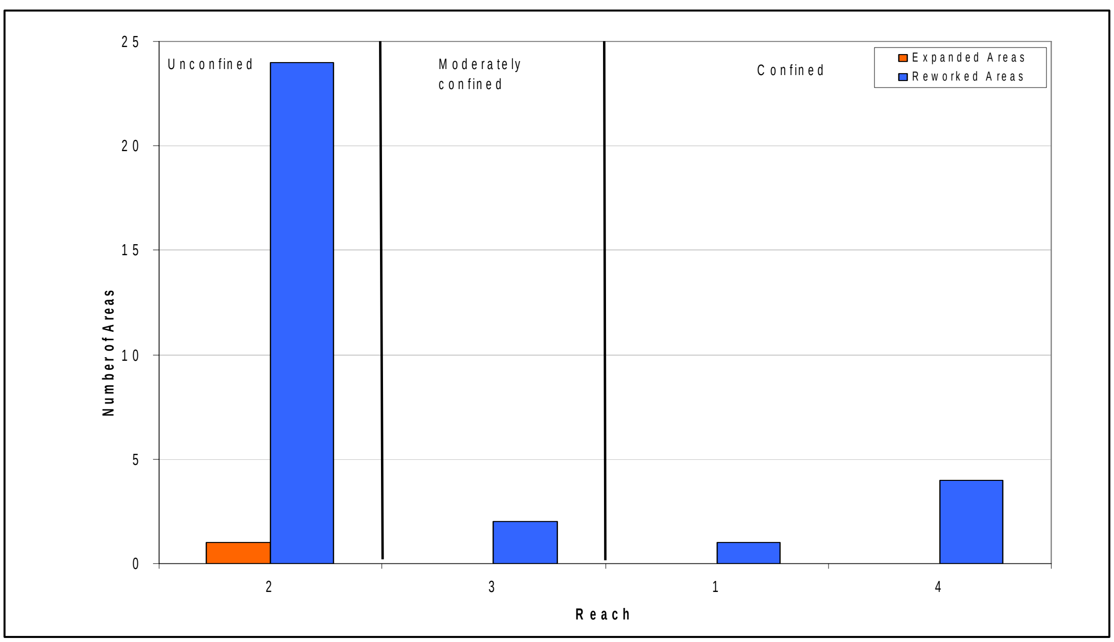

Figure E-25. Chewuch River (RM 0-11.7) – Numbers of places where expansion or reworking of the low surface that were noted between 1974 and 2004.

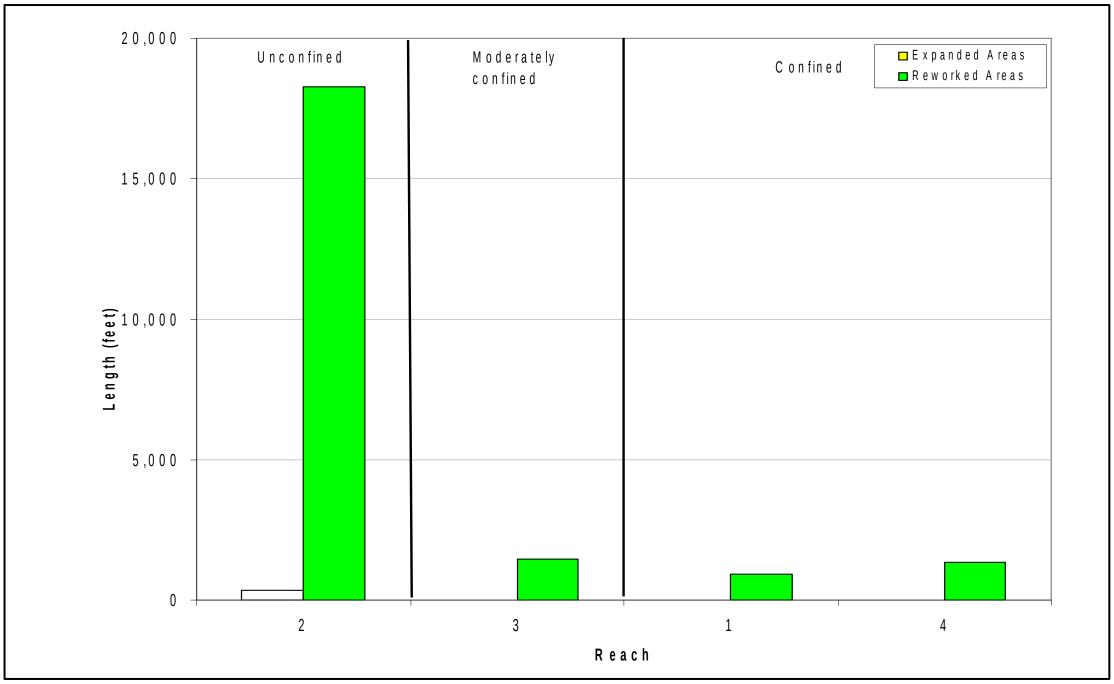

Figure E-26. Chewuch River (RM 0-11.7) – Cumulative length of sections with expansion or reworking of the low surface that were noted between 1974 and 2004.

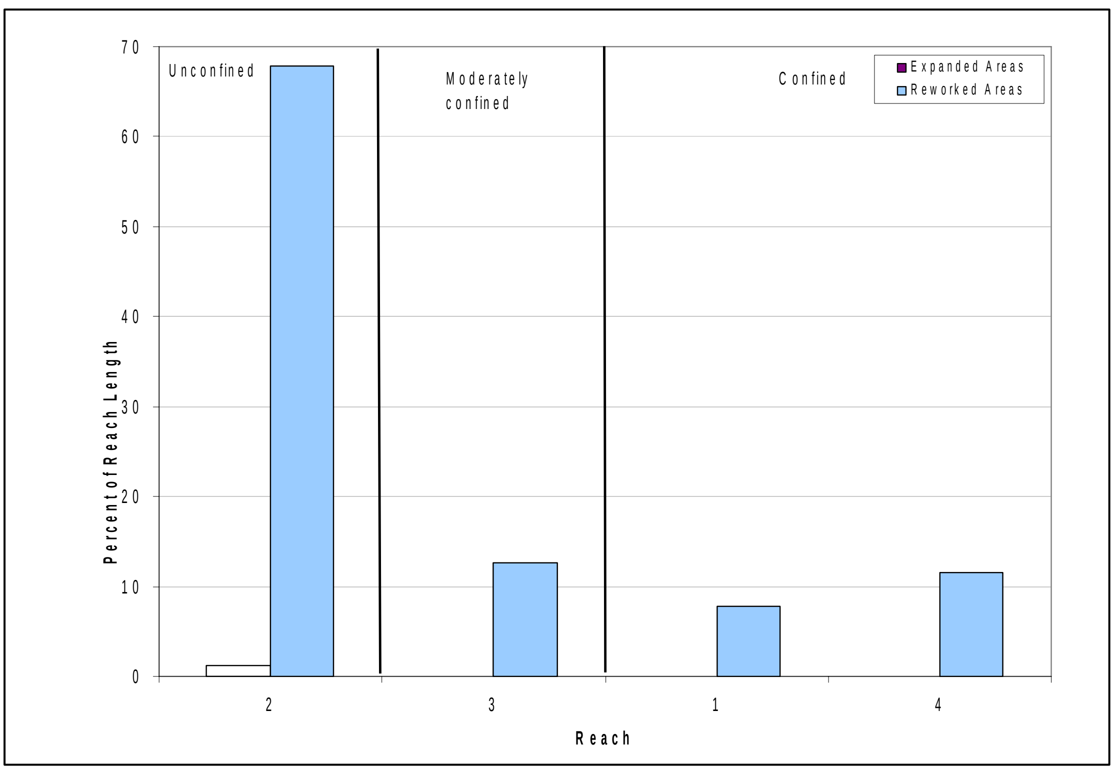

Figure E-27. Chewuch River (RM 0-11.7) – Percentage of the reach length that has experienced expansion or reworking of the low surface that were noted between 1974 and 2004.

4.2.2 FLOODPLAIN REWORKING

Conversion of floodplain to channel area within the low surface does release pulses of fine and coarse sediment into downstream reaches. However, this is part of the natural floodplain reworking process and an essential part of the natural sediment load. This process releases gravel-sized sediment that is critical in developing downstream spawning habitat.

Methow River (RM 28-75) – Reworking of the Floodplain

The greatest number of reworked areas in the Methow River (RM 28 to 75) is in Reach M9, an unconfined reach (Table E-5; Figure E-17). The other unconfined reaches have smaller number of reworked areas, which are similar to the number of reworked areas in the moderately confined reaches. The unconfined reaches have a few areas of reworking. The longest cumulative length of reworking is in Reach M9 (Figure E-18). The other unconfined reaches have shorter cumulative sections of reworking. These cumulative lengths are longer than the cumulative lengths of reworking in the moderately confined reaches. The cumulative lengths of reworking contrast with the relative short section that has experienced expansion during the same time interval. The percentage of each reach length that has been reworked is the highest in the unconfined Reach M9 (Figure E-19). The moderately confined reaches have the next highest percentage of reworking. Confined reaches have the lowest percentage of reworking, and Reach M1 and Reach M8 have the highest percentage of reworking within the group of confined reaches.

Twisp River (RM 0-6.7) – Reworking of the Floodplain

The greatest number of reworked areas in the Twisp River (RM 0 to 6.7) is in the unconfined reach, T2 (Table E-6**;** Figure E-21). The confined reach, T1, has the smallest number of reworked areas. The moderately confined reach, T3, has an intermediate number of reworked areas. The longest cumulative length of reworking is in confined Reach T1 (Table E-6). The confined Reach T1 has the shortest cumulative length of reworked areas. The moderately confined Reach T3 has an intermediate length. The percentage of each reach length that has floodplain reworking is the highest in the unconfined Reach T2 (Table E-6**;** Figure E-21). The moderately confined Reach T3 has the lowest percentage of reworking. The confined Reach T1 has a moderate percentage of reworking.

Chewuch River (RM 0-11.7) – Reworking of the Floodplain

The greatest number and longest length of reworked areas in the Chewuch River (RM 0 to 11.7) are in the unconfined Reach C2 (Table E-7; Figure E-25). This reach has 24 areas of reworking along a length of about 18,000 feet. This is the only unconfined reach evaluated. The moderately confined reach and the two confined reaches that were evaluated had one to four sites of reworking along lengths of about 1,000 to 1,500 feet. The unconfined reach has the highest percentage of the reach that has been reworked, about 68% of the reach length (Figure E-27). In the other reaches, only about 8% to 13% of the reach length shows reworking. About 36% of the entire reach that was evaluated has been reworked

4.2.3 SEDIMENT FROM BURN AREAS

At least 70% of the Chewuch watershed has burned since 2001, at varying intensities and over varying time periods. The fires have resulted in extensive debris flows that deliver fine- and coarse-sized sediment to the river. Debris flows are part of the natural system, but may be happening in the Chewuch drainage at a faster-than-average rate due to the high occurrence of fires in recent years. Fires also remove riparian vegetation allowing for easier mobilization of floodplain sediments into the downstream channel. A higher-than-normal spring run off in 2006 mobilized a large portion of sediment from the burn area and caused debris flows in the Andrews and Lake Creek drainages. These events are still considered within the natural setting, although their timing may have been altered due to fire repression efforts in the earlier part of the twentieth century. Other drainage areas within the assessment area are expected to have fire occurrences in the future.

4.2.4 ANTHROPOGENIC SEDIMENT SOURCES

Anthropogenic sources provide a limited amount of additional coarse-sized sediment overall, but may be locally significant. The types of sources include roads and embankments, levees, and bank protection (that is, riprap). There has been repeated logging in the basin within the assessment area and in the upstream watershed. Road densities from logging activities are highest in Buttermilk Creek and Little Bridge Creek in the Twisp watershed; in Cub, Eightmile, Falls, Doe, Boulder, and Ramsey Creeks in the Chewuch watershed; and in Beaver Creek which enters the Methow at RM 36 (written communication, J. Molesworth, 2007). Effects of fine sediment from logging activities were beyond the scope of this assessment, but generally would be expected to have the most impact on micro-habitat areas such as redds, backwater areas, ponds, etc. The fine sediment loads are not expected to have impacted channel form because these sediments are easily mobilized within the assessment area as evidenced by the channel bed surface sediment which is much coarser in composition.

4.3 STREAM POWER

To better understand if one reach is adjusting as a result of something occurring in an upstream reach, it is helpful to compare transport capacity among reaches.

Stream power is a surrogate for sediment transport capacity that provides a relative comparison of the river's energy between reaches. Both total and unit stream power computations were made to evaluate the influence of changing water discharge and slope on sediment transport capacity in the present river setting (see Appendix K). Increased discharge provides more potential energy to transport sediment and LWD if hydraulic conditions are otherwise comparable. Increased slope will also increase the river's ability to transport sediment and LWD, while decreased slope can reduce the transport capacity. The total stream power computation shows how the combination of discharge and slope vary along the river from a reach-based perspective. The "unit stream power" (velocity multiplied by slope) is often used as an indicator of the relative energy required to transport a given sediment load among various cross-sections.

Overall, all three rivers show a very tight correlation to slope, indicating the natural geologic controls play the largest role in adjusting sediment transport capacity. The Twisp and Chewuch Rivers both have slope breaks that are significantly steeper than slopes on the Methow River (Table E-8; Figure E-28, Figure E-29, , and Figure E-30). A change in discharge does not play a large role on the Twisp or Chewuch Rivers because the tributaries within the assessment area provide a small amount of flow relative to the mainstem river flow. On the Methow River, the slope gradually decreases from Lost River to Winthrop, and then is fairly consistent downstream to Carlton. Significant changes in discharge occur at the Twisp and Chewuch confluences. The large influx of discharge from the Chewuch River at Winthrop appears to balance out the declining sediment transport capacity.

Table E-8. Range of discharges and channel slopes along each river within the assessment area.

River	2-Year Flood Peak (ft^3/s)	100-Year Flood Peak (ft^3/s)	Slope (foot/foot)	Slope (%)
Methow	3,700-10,300	7,400-32,800	0.0027-0.0070	0.27-0.70
Twisp	1,100-2,300	3,200-6,800	0.0016-0.0140	0.16-1.40
Chewuch	2,400-3,200	6,900-9,400	0.0024-0.0180	0.24-1.80

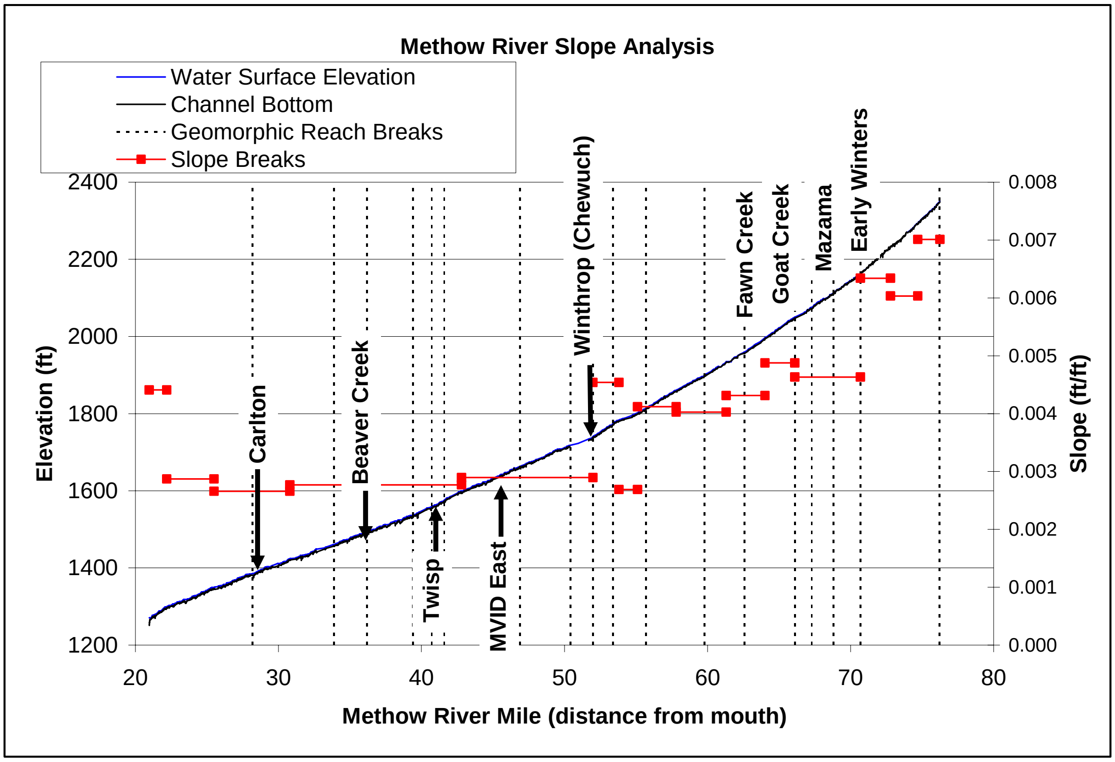

Figure E-28. Methow River – Longitudinal profile from measured survey data.

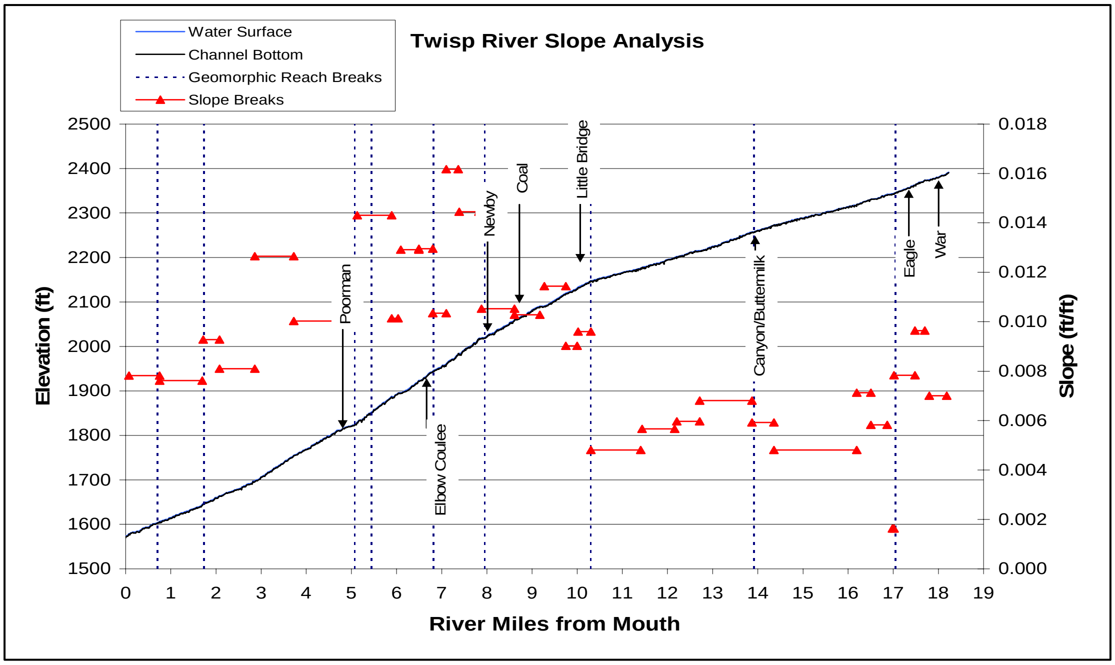

Figure E-29. Twisp River – Longitudinal profile from measured survey data.

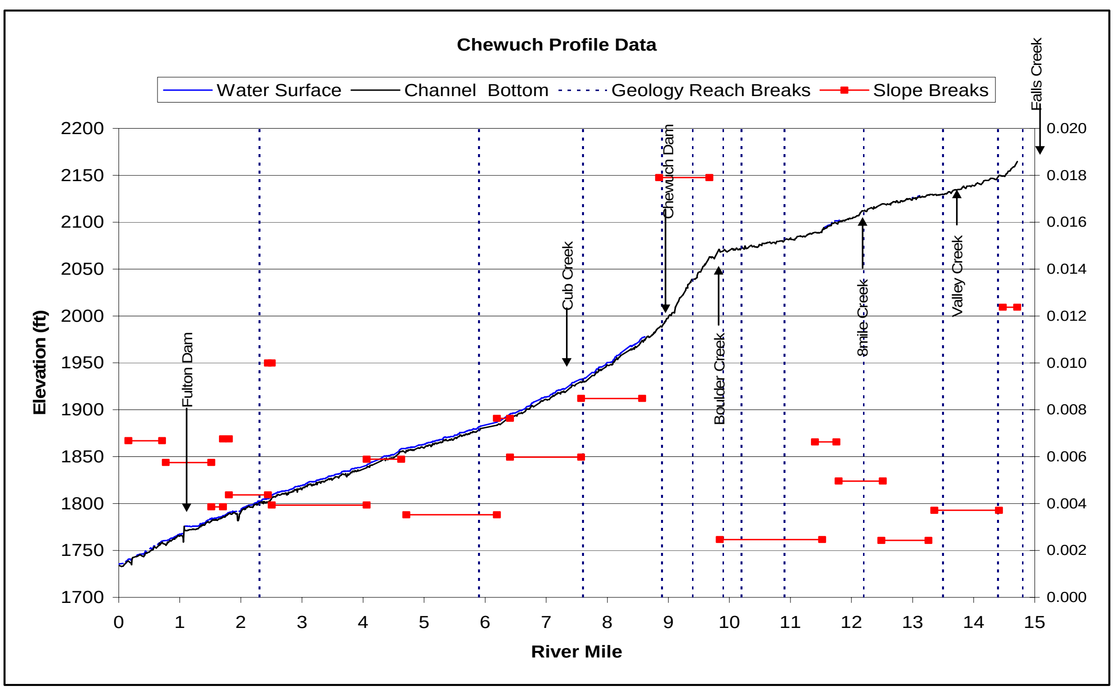

Figure E-30. Chewuch River – Longitudinal profile from measured survey data.

4.4 CHANNEL PLANFORM ANALYSIS

Channel planform can be used as an indicator of whether the sediment transport capacity of a given reach equals, exceeds, or is less than the incoming sediment load as discussed earlier in Section 4.1 "River Dynamics." It can also be used to indicate whether this balance has changed over time. Historical aerial photographs within the assessment area indicate no evidence of change in channel planform on a reach scale over a decadal time period. For example, reaches that are single-threaded main channels have remained so, and reaches with a multiple, complex network of channels and vegetated floodplain also have remained in the same planform type. Variability in the delivery of sediment loads can occur, particularly in areas subject to episodic fires and debris flows.

The largest floods on record were in 1894, 1948, and 1972, and channel changes would be expected as a result of these flows. The 1948 Flood and 1894 Flood are believed to be similar in magnitude, but the former may have been slightly larger. The 1948 Flood exceeded the 100-year flood frequency estimate and, based on historic photographs, inundated the entire floodplain. This flood is noted by locals to have "reset" the river, eroding the majority of LWD and changing channel position and geometry in many cases. When a flood of this magnitude occurs, the channel geometry often changes but still may be within the bounds of natural variation expected in the system.

Aerial photographs of the Methow River taken before, during, and after the 1948 flood validate that no change to the over-arching channel planform was observed for its mainstem. Aerial photographs taken before and after the 1972 flood were used on the Chewuch and Twisp Rivers to validate this hypothesis because 1948 photographs were sporadically available from the flood period, but not before and after.

4.5 FLOODPLAIN CONNECTIVITY

The largest departure from the natural channel processes results from roads, bridges, levees, and push-up dikes that disrupt the lateral connectivity between the active floodplain areas and the main channel. In order to propose restoration strategies, it is important to understand how these features have changed the geologic (natural) floodplain widths. To show the impact on lateral connectivity, the geologic floodplain widths were compared to present widths. The floodplain naturally expands and contracts as a result of a variation in the influence of geologic controls along the assessment area.

The mean and minimum floodplain widths have seen the most measurable reductions due to human feature that cut off the floodplain. In most cases, maximum floodplain widths have not been impacted by human features. This is because the majority of floodplain levees, push-up dikes, roads, and bridges cut off the floodplain at unique locations, but do not confine the river for a very great longitudinal distance. This allows the river to still have some connectivity during flood flows when river water gets high enough to overtop banks laterally (downstream of the human feature) and result in inundation. More detectable impacts would be expected in the side and overflow channels downstream from where the levees or dikes are located. These channels are not flushed with water and replenished with new sediment as frequently as in the natural setting where there is a connection with the river at the upstream end.

The Methow, Twisp, and Chewuch rivers were subdivided into geomorphic reaches having similar processes, as discussed earlier. Within each reach, the degree of artificial confinement of the floodplain was evaluated by looking at changes to the minimum, mean, and maximum floodplain widths.

4.5.1 METHOW RIVER

The Methow River natural floodplain width ranges from a little less than 100 to 4,500 feet (Figure E-31, Figure E-32, and Figure E-33). The widest floodplain areas occur between RM 55-65 and between RM 34-46. The narrowest floodplain areas occur between RM 28-34 and between RM 65-70. Human features have decreased the width of the natural floodplain to some degree in all reaches, and the mean width in these four reaches:

- RM 33 to 46
- RM 46 to 55
- RM 55 to 65
- RM 70 to 75

Two of the five bridges present significantly constrict the natural floodplain width. The maximum widths of the present low surface are the same as the maximum widths of the geologic low surface in all of the reaches except between RM 65 and RM 70. The minimum widths of the present low surface have decreased the minimum widths of the geologic low surface for nearly all reaches. The exception is the reach between RM 46 and RM 65. The minimum width is markedly decreased in the reach between RM 55 and RM 65.

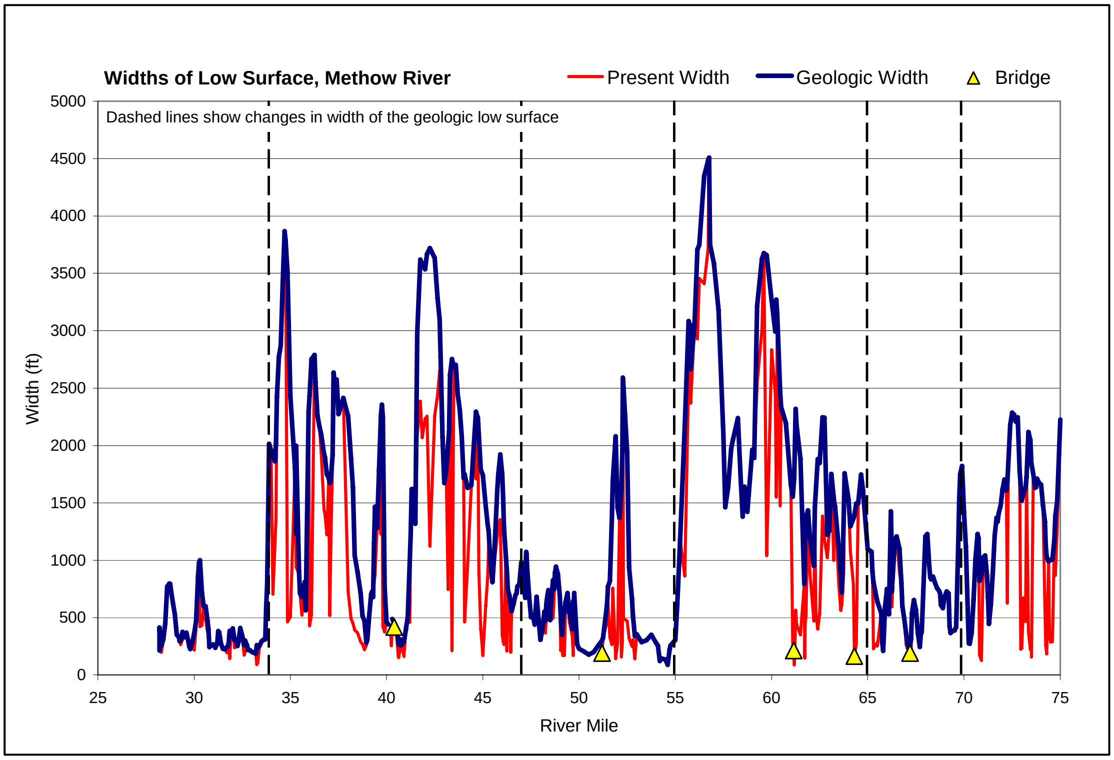

Figure E-31. Methow River (RM 28.1–75) – Floodplain widths.

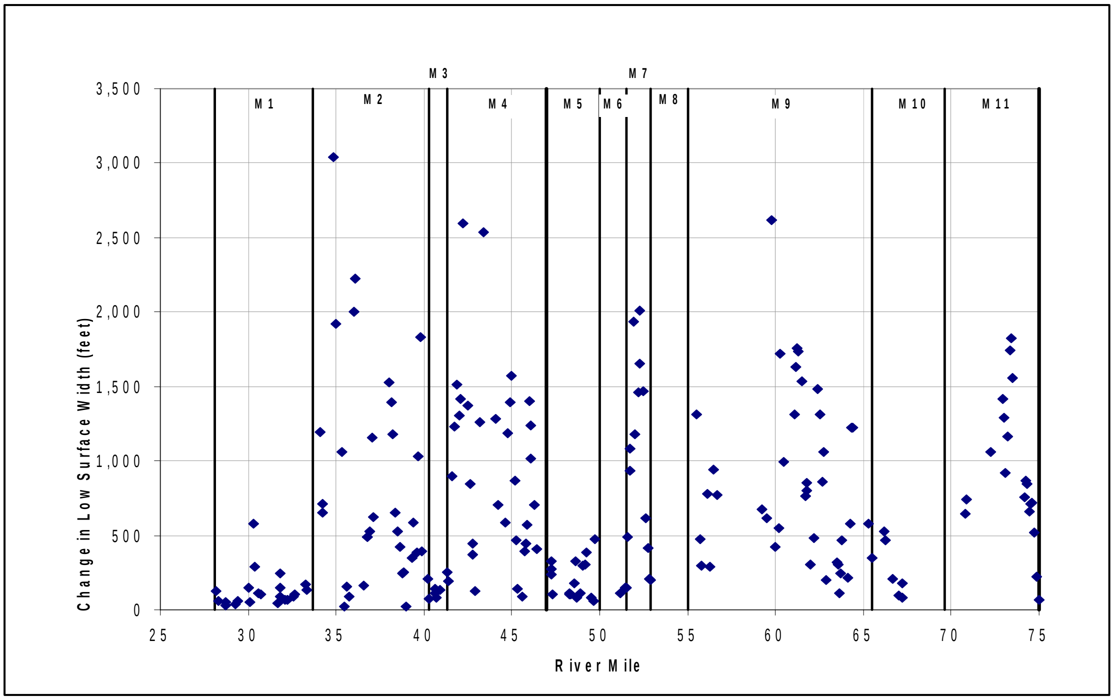

Figure E-32. Methow River (RM 28.1–75) – Decrease in low surface width caused by human features within the low surface plotted by river mile.

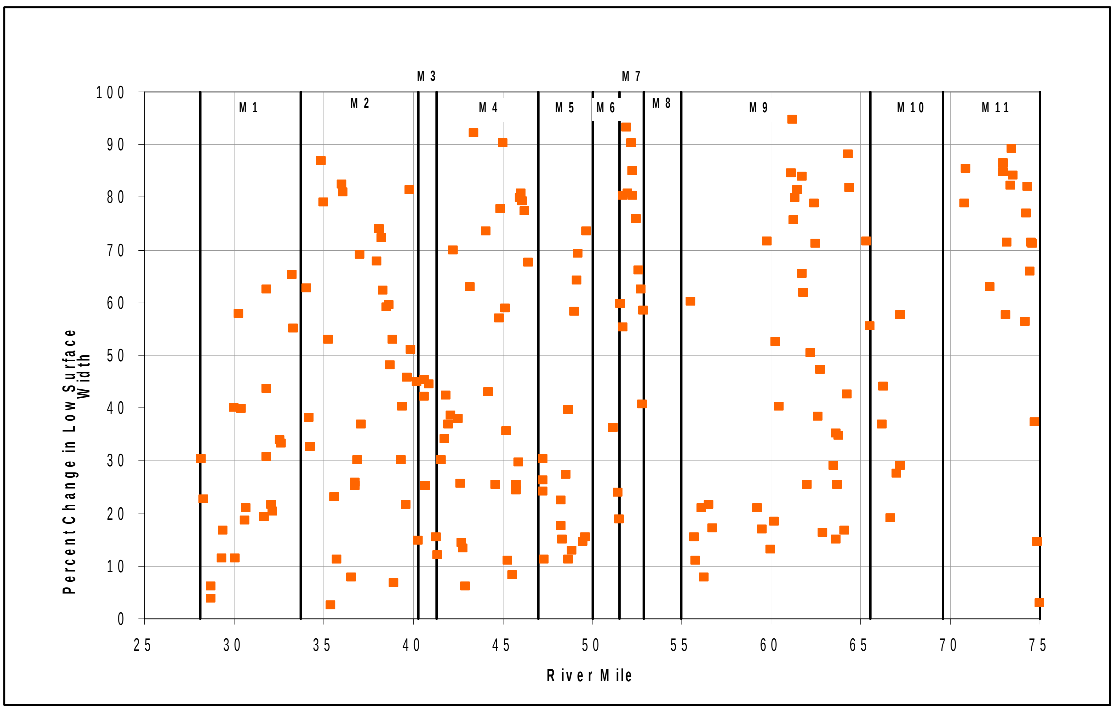

Figure E-33. Methow River (RM 28.1–75) – Percent decrease in the geologic width of the low surface caused by human features within the low surface plotted by river mile.

4.5.2 TWISP RIVER

In the natural setting, the Twisp River floodplain width ranged from a hundred to just under 1,900 feet (Figure E-34, Figure E-35, and Figure E-36). The widest floodplain area occurs between RM 10–18. The narrowest floodplain areas occur between RM 5-10. Human features have decreased the mean width of the geologic low surface markedly in two reaches, RM 0–5 and RM 10–18. Maximum widths of the present low surface are only slightly lower than the maximum widths of the geologic low surface in two reaches, and the same in the reach RM 10–18.

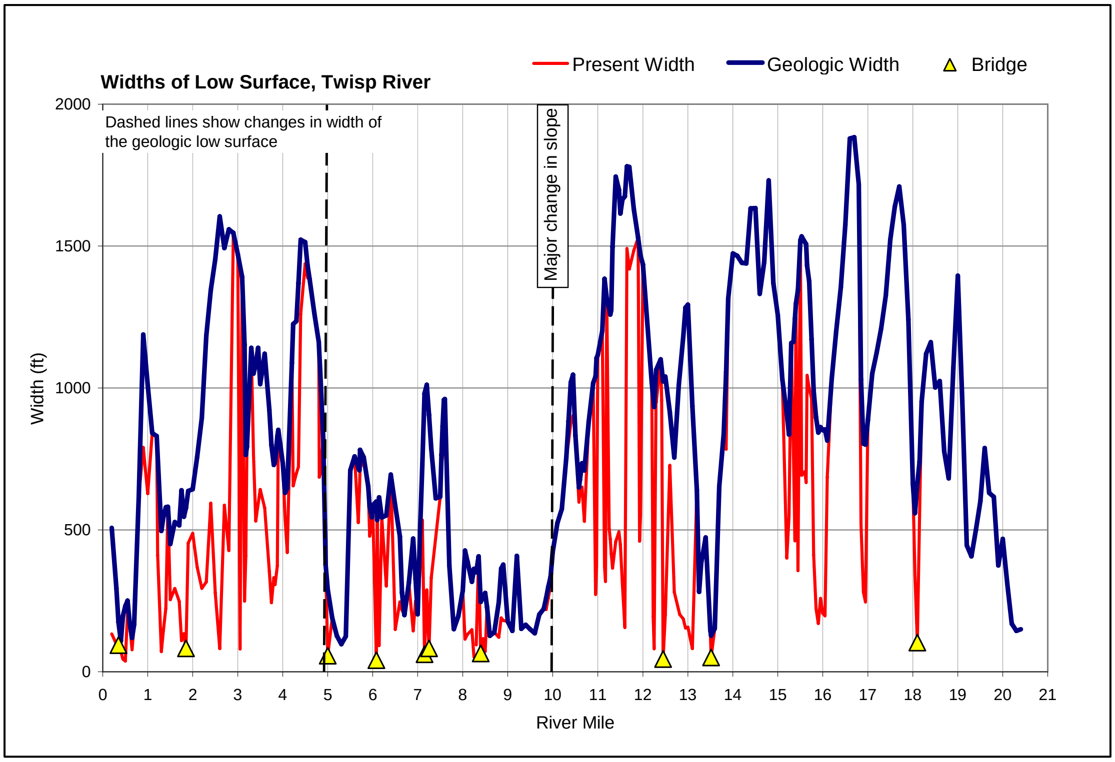

Figure E-34. Twisp River (RM 0-18) – Floodplain widths.

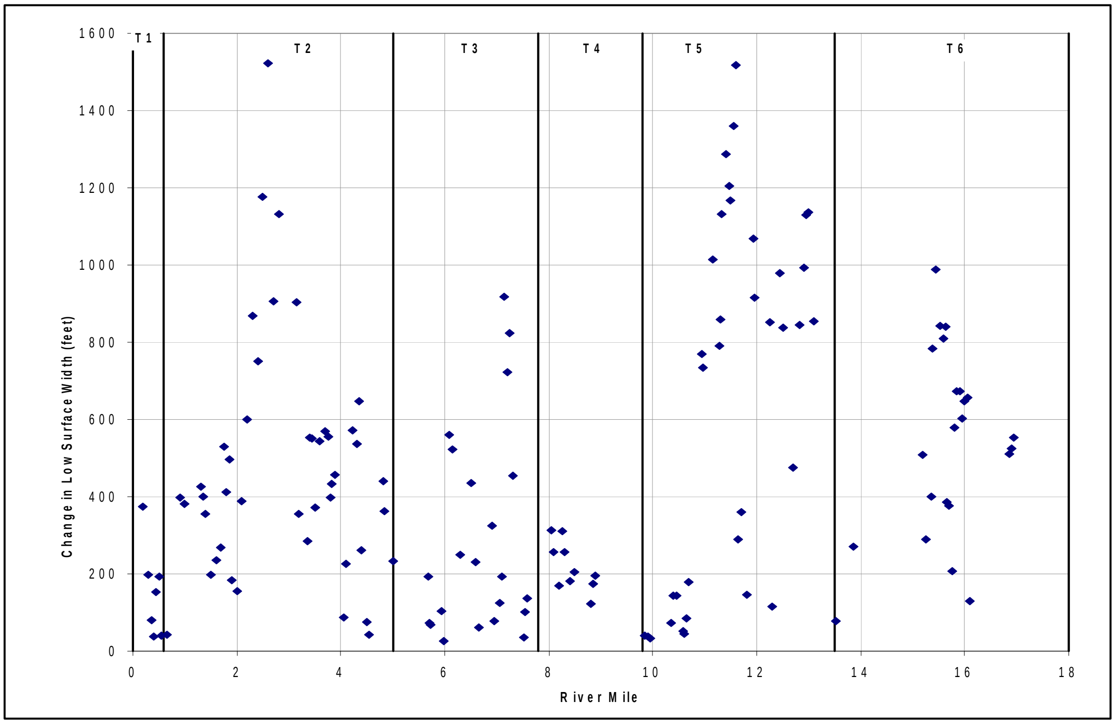

Figure E-35. Twisp River (RM 0-18) – Decrease in low surface width caused by human features within the low surface plotted by river mile.

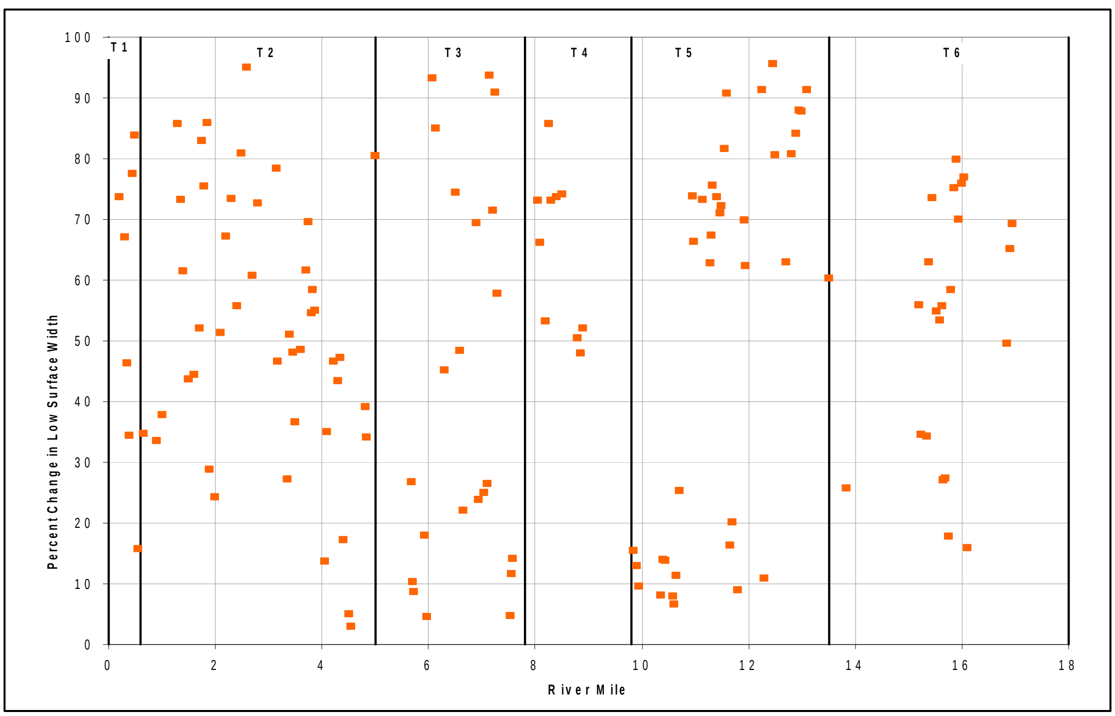

Figure E-36. Twisp River (RM 0-18) – Percent decrease in the geologic width of the low surface caused by human features within the low surface plotted by river mile.

4.5.3 CHEWUCH RIVER

The Chewuch River floodplain ranges in width from just under a hundred to just under 2000 ft (Figure E-37, Figure E-38, and Figure E-39). The widest floodplain area occurs between RM 2-5.5 and between RM 5.5-9.5. The narrowest floodplain occurs between RM 0-2 and between RM 9.5-11.5. Human features have decreased the mean width of the floodplain throughout the assessment area, but the maximum widths have not been affected, except for between RM 0-2. This is also the narrowest reach so the impact to the maximum width is minimal.

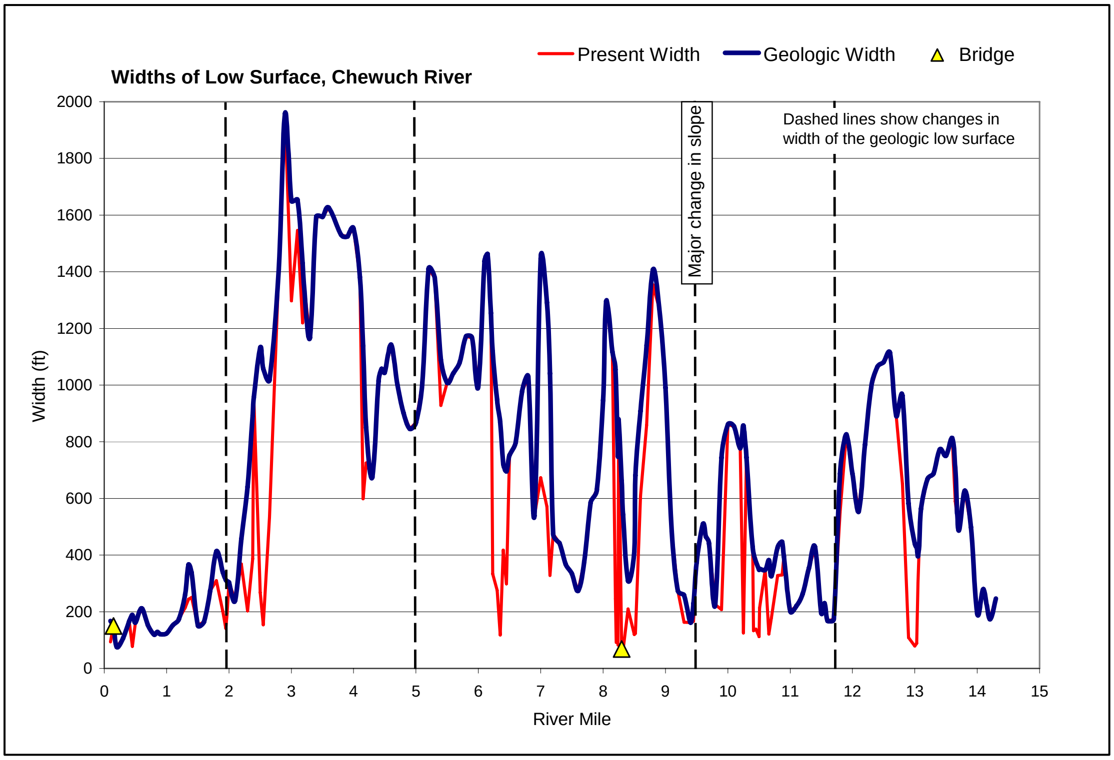

Figure E-37. Chewuch River (RM 0-14) – floodplain widths.

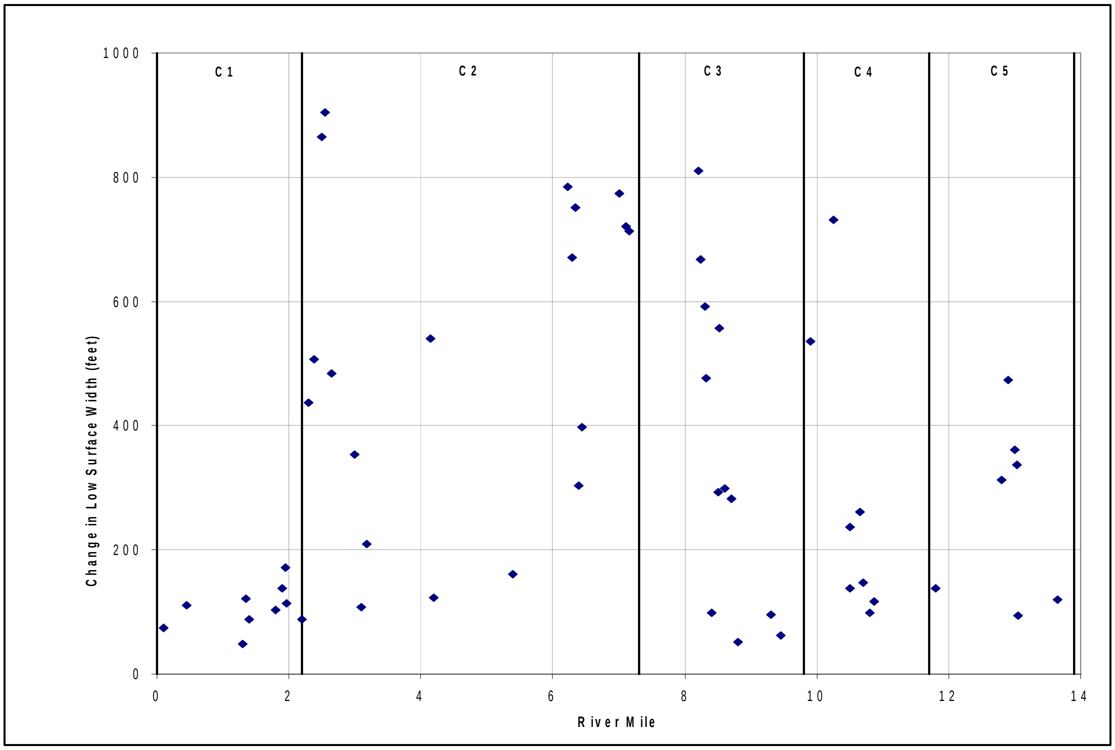

Figure E-38. Chewuch River (RM 0-14) – Decrease in low-surface width caused by human features within the low surface plotted by river mile.

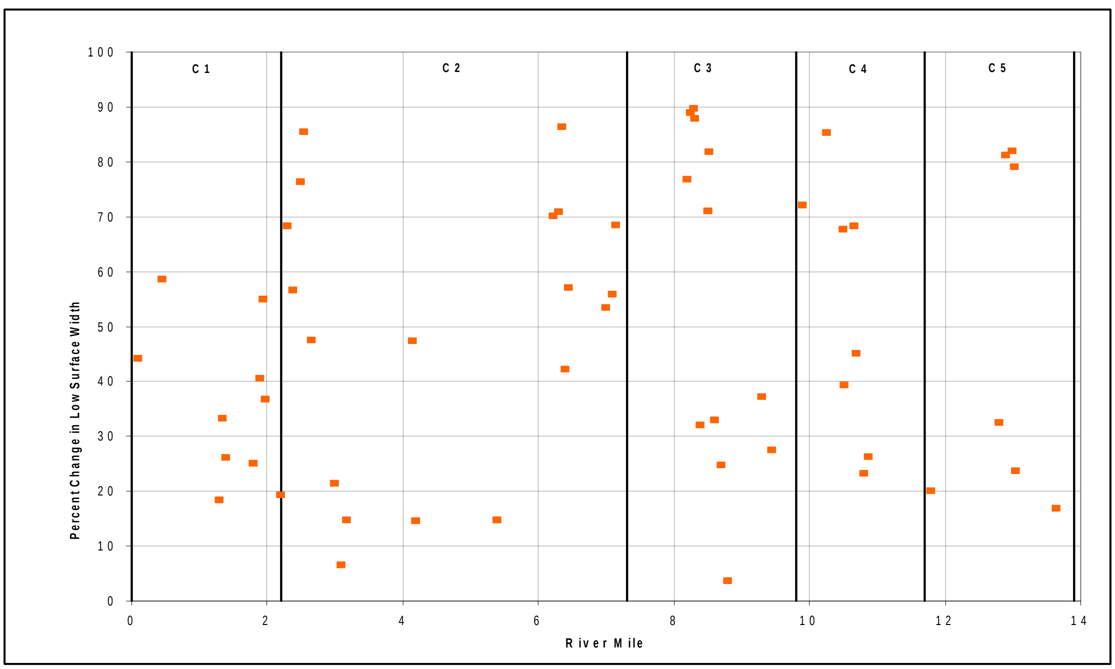

Figure E-39. Chewuch River (RM 0-14) – Percent decrease in the geologic width of the low surface caused by human features within the low-surface plotted by river mile.

4.6 CHANNEL RESPONSE

As a result of floodplain confinement, water is restricted to a smaller area during floods. When this occurs, velocities in the main channel are higher than if the water had been allowed to spill off into the floodplain. Because of the higher energy in the main channel, the channel could be expected to become more sinuous, incise or widen. However, geologic controls in both the channel bed and along the channel margins limit the ability of the river to significantly adjust its geometry. As a result, it would be anticipated that little change has occurred in the channel form or main channel bed elevation as a result of features that cut off the floodplain. As discussed earlier, the channel planform has not had any detectable changes. However, the presence of large woody debris in many areas is thought to be reduced as a result of historical clearing of large wood from the system (Appendix O). To validate that only minimal, if any, change has occurred to the channel bed elevation, information on channel geometry and bed elevation changes was compared where historical survey data are available.

Historical profile data were available for a large portion of the Methow River within the assessment reach and for a portion of the Chewuch River (see Appendix K for more details). Both data sets detected minimal vertical change on a reach scale that would indicate aggradation or incision of the river bed of more than a few feet on a decadal timeframe.

Another indicator of whether the river's channel has been altered is sediment transport capacity. It would be expected that if the river's sediment transport capacity is in balance with the incoming supply, then the river should be able to rework the bed and sediment bars on a frequent basis. Although 184 cross-sections were collected within the approximately 80-mile assessment reach, they were spaced too far apart to perform sediment transport capacity computations. As an alternative, incipient motion computations were used to look at the ability of the present river to mobilize the channel bed and bar features along the active channel. If the sizes of sediment that can be mobilized far exceed the sizes of sediment present in the bars, the river may be tending toward incision. Because the sediment on the surface of the sediment bars must be mobilized first to get reworking along the bar, pebble count measurements of the surface sediment sizes can be compared to the incipient motion computations for this purpose.

The average sediment particle sizes measured in the bar and channel surface are gravel (2 to 64 mm) to cobble (64 to 256 mm) for all three rivers (Table E-9). The mobilization results are presented in Table E-10. In many locations, the bars and channels can be reworked at the more frequent 2-year and 5–year floods.

Table E-9. Average measured sediment size in the bar and channel within reaches of similar slope.

River	Reach	Bar D50	Chan. D50
Methow	RM 28 – 50	80	85
	RM 50-70	78	79
	RM 70 – 76	93	83
Twisp	RM 0 to 1.5	54	64
	RM 1.5 - 9.8	127	136
	RM 9.8 – 17	48	61
Chewuch	RM 0 – 5.5	66	106
	RM 5.5- 9.5	182	141
	RM 9.5 – 14	43	45

Table E-10. Minimum flood frequency at which typical bar and channel sediment sizes are mobilized.

River	Reach	Bar D50	Chan. D50
Methow	RM 28 – 50	5-yr	5-yr
	RM 50-70	2-yr	2-yr
	RM 70 – 76	2-yr	2-yr
Twisp	RM 0 to 1.5	10-yr	25-yr
	RM 1.5 - 9.8	5-yr	5-yr
	RM 9.8 – 17	2-yr	2-yr
Chewuch	RM 0 – 5.5	2-yr	10-yr
	RM 5.5- 9.5	2-yr	2-yr
	RM 9.5 – 14	2-yr	2-yr

4.7 RIPARIAN VEGETATION

Riparian vegetation is a crucial component of the aquatic ecosystem and can be used as an indicator as to whether river and floodplain processes are functioning as would be expected in the natural setting. Cottonwood, in particular, was used in this assessment. Cottonwoods are associated mainly with riparian areas that are frequently reworked, and thus are a good species to use to evaluate whether the floodplain is being accessed. Previous studies hypothesized that riparian processes are not properly functioning in the assessment area due to a combination of historical clearing, lack of access to water due to either river incision and/or drought, lack of floodplain reworking, disease, and wildlife browsing. This assessment found that historical clearing and the lack of floodplain reworking has had the largest impact on establishment of cottonwoods. Areas that traditionally would have supported cottonwood galleries have now converted to shrubs, aspen, and/or Douglas-fir.

4.7.1 VEGETATION ANALYSIS

Previous mapping that was available on the Twisp River documented the types and extent of vegetation present along the corridor (PWI, 2003). This mapping was based on aerial photography and field surveys. New mapping was done on the Methow and Chewuch Rivers (Baesecke, 2005; report provided as Appendix H–1) (see Figure E-40). The new mapping was done using aerial photographs with limited field review; historical conditions were only qualitatively evaluated (no GIS mapping). Hadfield (2007) field-checked vegetation conditions at five sites within the assessment area; two sites were located on the Twisp River and three sites were located on the Methow River (Hadfiled, 2007; Appendix H–2). Key points from these efforts are summarized below. Additional field mapping should be accomplished for future projects to better understand localized conditions that can vary dramatically across the assessment area.

4.7.2 DESCRIPTION OF RIPARIAN VEGETATION

Information from Hadfield (2007) is summarized here, with additional details in Appendix H-2. Black cottonwood, *Populus trichocarpa*, is the largest hardwood tree species growing in the Pacific Northwest. It is the fastest growing hardwood species in this region. Individual black cottonwood stems can be 200 feet tall and 6 feet in diameter (DBH, "diameter at breast height"). It is common for the stems in northcentral Washington to be 60 feet to 120 feet tall and from 2 feet to 4 feet DBH. Large diameter branches develop in the upper crowns. The tall stems have excellent potential to provide ample shade over rivers because of their large crowns. Cottonwoods can produce large amounts of LWD as they die and break apart.

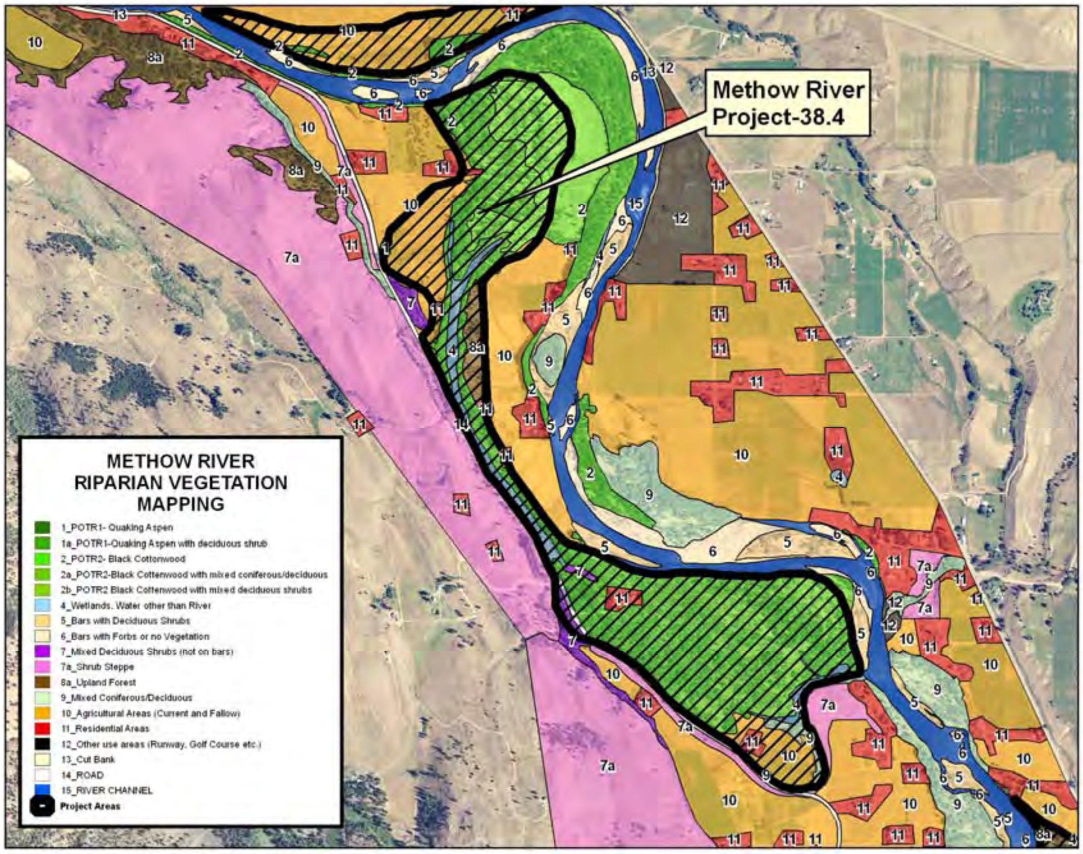

Figure E-40. Example of vegetation mapping (Methow River at RM 38.4).

Black cottonwood is a relatively short-lived tree species. In some locations, such as the Willamette Valley, it may reach maturity in 60 years. Typically, most cottonwood stems reach maturity around 70 to 90 years and then begin to decline and display progressively greater amount of crown dieback with time. Some black cottonwoods in British Columbia reportedly have grown well for up to 200 years, but that appears to be an exception to their relatively short life span in most portions of its range.

Aspen is also prevalent in the assessment area. Aspen stems can reach heights of 85 feet, but typically range from 50 to 75 feet. Aspen does not get as tall or big in diameter as cottonwoods. Individual aspen stems typically would produce less LWD than cottonwood because of the smaller stem and branch size. However, because aspen stems are much more abundant than cottonwood stems, the larger numbers of aspen stems could generate rather large amounts of LWD. Aspen trees can provide substantial amounts of shade, but not as much as cottonwood stems.

Density of vegetation also has an influence on the interaction between the river and riparian zone. Density of vegetation affects the rates of water provided below the canopy, bank stability, the amount of large woody debris that is available to the river to be recruited, and the ability of competing species to regenerate.

4.7.3 FACTORS AFFECTING RIPARIAN VEGETATION ESTABLISHMENT AND SURVIVAL

Typically cottonwood seeds are dispersed in the spring and are most "successful" (likely to continue growing) in unvegetated "fresh and bare" soil areas,where bars or floodplain have been reworked or contain a new layer of fine sediment. Cottonwood saplings continue to grow throughout the summer and early fall if there is adequate connectivity to the water table. A cottonwood sapling is usually considered successful if it reaches three years of age. At the sapling stage, a cottonwood can be desiccated if it does not have enough water, is exposed to frequent inundation (flooding), wildlife browsing, or disease. Additional details on the establishment of cottonwoods are provided in Appendix H-2 (Hadfield, 2007). "Black cottonwood is classed as very intolerant of shade. It grows best in full sunlight. On moist lowland sites, it makes rapid initial growth and thereby survives competition from slower-growing associated species" (DeBell, 1990). It "rapidly expires at all ages if shaded" (McLennan and Mamias, 1992).

Aspen grows best in moist, well-drained-but-not-wet soils. It will not grow well if the water table is within 2 feet of the soil surface. Aspen typically does not grow immediately adjacent to perennially flowing or standing water, unlike cottonwood. Aspen will not grow in droughty soils, but it will grow in drier soils than cottonwood. Aspen is a short-lived tree species, with a pathological rotation around 100 years, somewhat longer than cottonwood. Like cottonwood, aspen is very intolerant of shade and needs full sunlight to grow and survive. Aspen regenerates most commonly by sprouting from the roots following major disturbances to the above ground portions of the stands.

4.7.4 PRESENT CONDITION OF RIPARIAN VEGETATION

Historically, many of the terraces bounding the river were cleared of native vegetation through burning or logging activities. This process would have occurred gradually over the late 1800s and early 1900s. Within the low surface, the riparian vegetation may have largely been intact in several locations for many decades past the start of settlement (Figure E-41). However, certain areas were more subject to disturbance, particularly the upper Methow watershed where there were log drives and in areas where roads and bridges were placed. The aerial photographs show that over time there was additional clearing of vegetation on lower surfaces within the low surface. The large floods in 1894, 1948 and 1972 would have reworked or provided fresh soil on the majority of the active floodplain. These floods are noted by locals to have liberated large amounts of LWD, but channel-clearing activities likely removed a lot of the wood. The floods would have created ideal conditions for cottonwoods to re-establish.

Figure E-41. Photograph looking south (downstream) at the confluence of the Methow and Chewuch Rivers near Winthrop, WA in 1908. Photograph courtesy of Shafer Museum, Winthrop, WA.

Presently there are more aspen, Ponderosa pine, Douglas-fir, and deciduous shrubs than cottonwood abundance. The cottonwood stands that are present are generally 50 to 100 years in age with little evidence of regeneration in the last 50 years. It is hypothesized from historical investigations in this assessment that 50 to 100 years ago cottonwoods were able to successfully regenerate when the river was allowed to more frequently inundate and rework the floodplain. Given this timing, it is plausible that the majority of human flood protection structures established in the active floodplain after the 1948 and 1972 floods caused a subsequent decline in the ability of cottonwoods to regenerate. This is supported by the historical aerial photographs and historical accounts of flood-protection structures. Existing cottonwood stands are generally healthy, but vitality could be improved by increasing water connection to stand areas; in some areas tops of trees are dying off indicating lack of sufficient water. Trees do not appear to reach maturity in many places and die back at around 50 to 60 years of age.

The largest and most diverse riparian vegetation areas on the Methow River within the assessment area are located between Wolf Creek confluence (RM 55) to the Lost River confluence (RM 75). With a few exceptions, from RM 55 downstream to RM 28 (Carlton) there is increasingly less riparian extension and diversity. The riparian corridor is naturally more confined by geologic surfaces so there is a narrower zone of riparian vegetation. Baesecke (2005) describes the vegetation in this section of the river as follows: “Often the riparian zone is merely a line of trees along the river;

sometimes those trees are Ponderosa pine or other species that are often non-native. A few instream bars support mostly shrubs and non-native forbs. In places black cottonwood trees are found along the sides of the river bank."

The largest and most diverse riparian vegetation areas on the Chewuch River within the assessment area are located between RM 2.6 (near Pearrygin Creek) upstream to approximately RM 7 (near Cub Creek). Several regions with ground moisture or backwaters support mixed riparian shrub stands but don't appear to allow the regeneration of cottonwoods. The Chewuch River was not field-checked and will need to have this step done at the reach-assessment level to better understand and validate these observations from aerial photography.

During the riparian surveys in the Twisp River and its tributaries (PWI, 2003), the following observations were made (note that RM are from PWI assessment, and may be slightly different than the Reclamation RM used in this report).

- Upper watershed (RM 22.65 and upstream) generally has healthier stands that are able to ward off pests, show vertical diversity (multiple canopy layers), and Populus species regeneration
- The mid-section (RM 13.7–22.65 at Reynolds Creek) has more diseased trees and mortality, smaller stands, only one or two canopy layers less regeneration
- The Populus stands in the lower part of the watershed (RM 0–13.7 at Buttermilk Creek Road Crossing) are in very poor condition if at all present. Several stands that are located in this portion of the Twisp River have died out, witnessed by large remaining Black Cottonwood snags and LWD.

Using the vegetation mapping, documentation was done by RM of whether there is existing cottonwood along the active channel (Figure E-42, Figure E-43, and Figure E-44). The extent of black cottonwood was mapped in ARC GIS using the mapping of Heike Baesecke from 2005 for the Methow and Chewuch Rivers and from 2003 for the Twisp River (Appendix H-1). Only the areas of black cottonwood that are along or near the unvegetated channel (2004) were included.

On the Methow River, at least a narrow band of cottonwood is present along most of the river, but gaps are present in reaches M1, M9, M10, and M11. On the Twisp River, a gap in cottonwoods is present in the confined Reach T4 between RM 8.55–9.8. Upstream of RM 12.5, the presence of cottonwood within the low surface is discontinuous. On the Chewuch River, cottonwoods are present along the river in only a part of the downstream unconfined reach (C2), between about RM 2.2–7.3. Downstream of RM 3, primarily in Reach C1, mixed coniferous/deciduous vegetation and upland forest are present where the surfaces have not been cleared for residential development. Upstream of RM 8.5, upland forest, mixed deciduous shrubs, and mixed coniferous/deciduous vegetation are present.

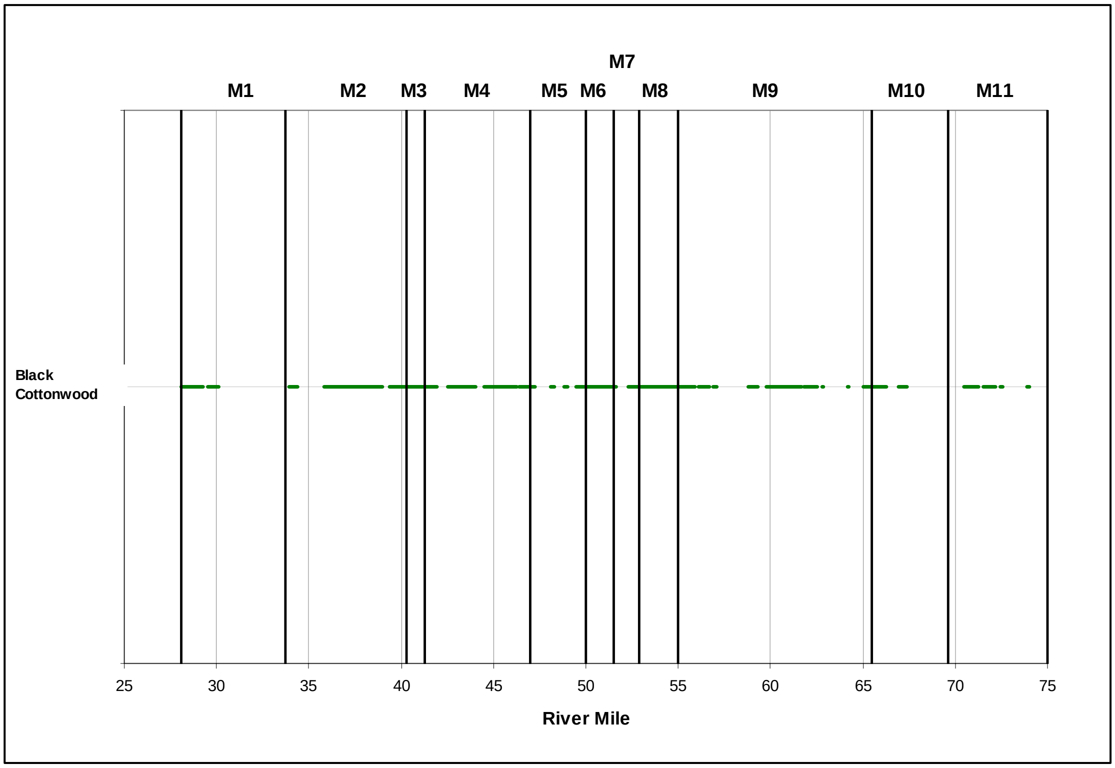

Figure E-42. Methow River (RM28–75) – The extent of black cottonwood mapped along the unvegetated channel and within the adjacent low surface plotted by river mile.

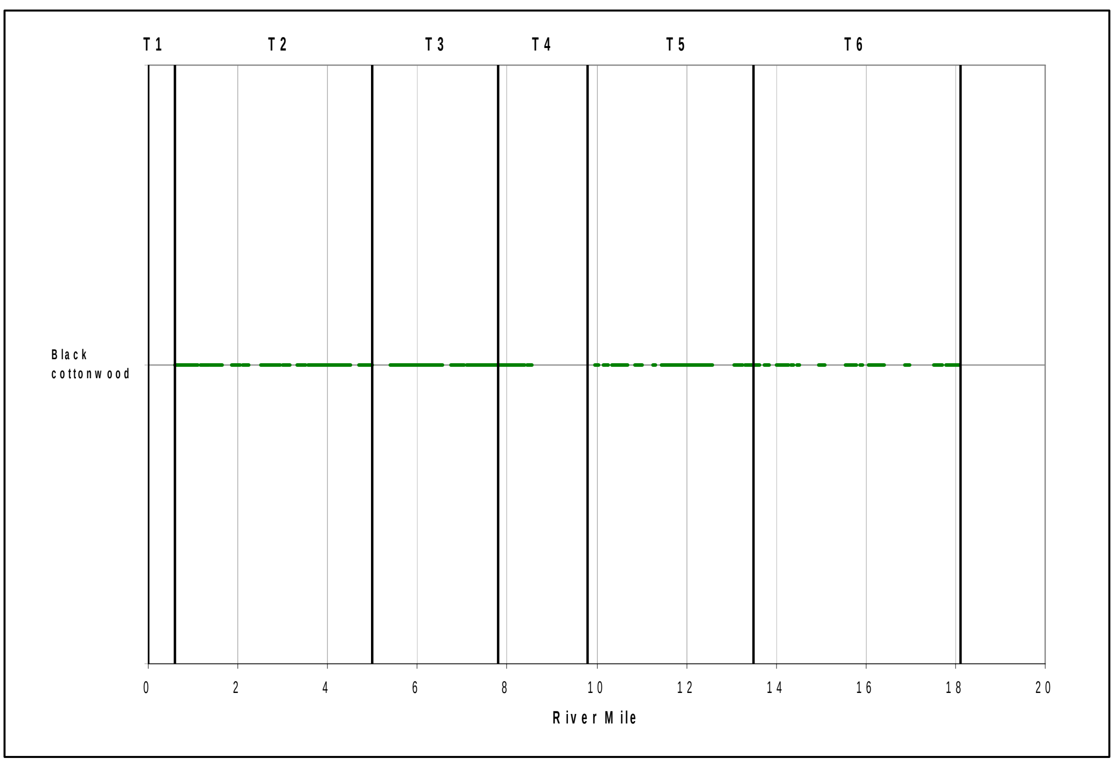

Figure E-43. Twisp River (RM 0–18) – The extent of black cottonwood mapped along the unvegetated channel and within the low plotted by river mile.

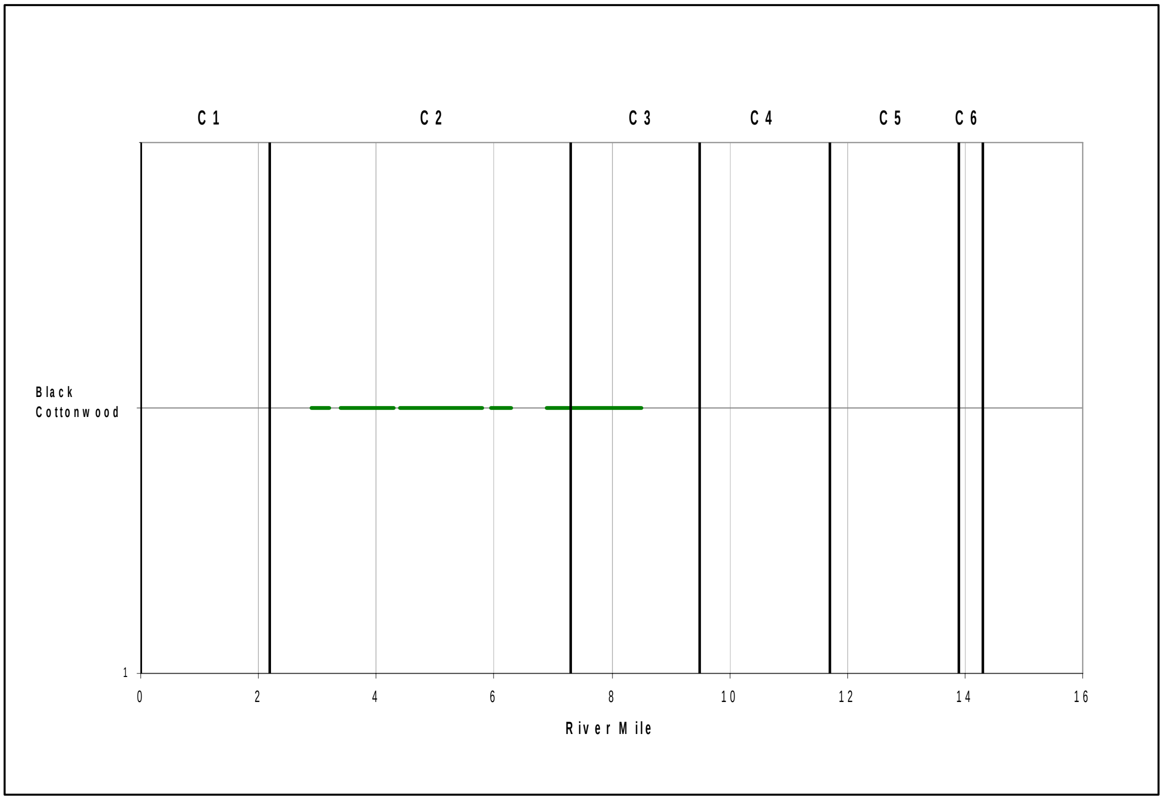

Figure E-44. Chewuch River (RM 0–14) – The extent of black cottonwood mapped along the unvegetated channel and within the low surface plotted by river mile.

4.7.5 PRESENT ABILITY OF COTTONWOODS TO REGENERATE

The regeneration of black cottonwood throughout the riparian area is compromised and often non-existent, or is restricted to areas that receive periodic inundation (instream bars, active side channels, low banks). Cottonwood regeneration is believed to not be successfully occurring in recent decades because seedlings cannot establish due to a lack of lateral channel migration and/or reworking of side and overflow channels during floods. This process is needed to expose mineral soil beds and to provide the baseline conditions for seed establishment. The groundwater connection still appears to be functioning in some areas observed by presence of ponded water and aspens or other vegetation growing in ditches and side channels. This suggests main channel incision is not a significant cause of decline in cottonwoods, but the decline is more likely due to human features that cut off the floodplain (surface water connection) during spring runoff and subsequent growing months during flow recession. Once cottonwoods fail to re-establish, other more drought-tolerant species, such as Ponderosa Pine or Douglas-fir, appear. Once these species establish, they drain the gravelly areas causing even less water to be available and also create a forest canopy (shade) that is too dense for cottonwood seeds to establish. It is not known how evapo-transpiration rates influence this relationship.

Disease in existing cottonwoods is part of the natural cycle and is not considered to be a significant cause of non-regeneration. Wildlife browsing is occurring at some sites that make it even more difficult for cottonwoods to establish. In the early 19th century fur traders mention deer, but ate a regular diet of horse meat; so, it is believed that deer were scarce, which may explain why browsing was not an issue for cottonwood at that time (Portman, 2002). The harsh winter of 1889–1890 was also noted to decimate Methow valley deer population and cause low populations for the next 40 years (Portman, 2002). Deer were noted to recover in the 1930s. Heavy domestic stock grazing killed grass but promoted bitterbrush, a favorite food of deer, which may have helped their numbers (Portman, 2002). Presently deer are in abundance in the Methow valley.

4.8 LARGE WOODY DEBRIS (LWD)

A properly functioning riparian corridor is essential for providing large trees for shade, LWD recruitment, bank stability, floodplain structure and roughness. Leaf litter and insects falling into the river from riparian areas provide nutrients for aquatic food chains. Larger pieces of wood are important because they trap smaller pieces of wood, organic debris and fine sediment, creating bars, log complexes, deep pools, complex aquatic habitat and a growing medium for riparian vegetation. Accumulations of large wood also facilitate channel migration, forming new channels that often excavate new gravel for spawning and provide extremely productive habitat for salmonids (USFS, 2002). LWD helps to form nutrient reservoirs by creating slow water areas where organic litter can accumulate and by providing a medium for algae, zooplankton and insects to grow on. LWD provides shade and can provide refuge in areas where water temperatures would otherwise be considered too warm.

The “Matrix of Pathways and Indicators” (MPI) (in NMFS, 1996) recommends that “a stream [with] at least 20 pieces per mile of wood greater than 35 feet long with a diameter greater than 12 inches” has good potential for future recruitment. Instream wood levels are increasing dramatically in the Big Valley Reach of the Methow River due to recruitment from stream banks and channel migration into forested areas. Stream habitat assessments for the Chewuch, Twisp, Upper Methow, and West Fork Methow Rivers show that the large wood standard is not met in any of the downstream reaches of these streams except for the lower mile of the Twisp River. The upper, less-managed reaches of these rivers that are within the range of spring Chinook and steelhead spawning generally exceed the MPI wood standard. All of these reaches have had major wood removal projects in the past, as well as stream side selective logging; this indicates that although the MPI standard is exceeded, the wood levels were still probably below natural potential at the time of the surveys. In the Chewuch and West Fork Methow rivers, the in-channel wood levels are presently very high due to recruitment following the 2001 Thirtymile Fire and the 2003 Farewell and Needles fires. Future recruitment in these areas will not be available until the forests mature in 100 to 150 years.

Within the approximately 80-mile assessment area, the areas with the most potential for LWD recruitment and sustainability are areas with complex channel networks and areas that have had less clearing in recent decades. LWD would be expected to occur within eddy areas of the main and side channels, and at the head of islands creating stable hard points that slow the rate of river migration and allow formation of vegetated islands. Extensive LWD would not be expected to occur in the main channel in confined sections (no vegetated floodplain) unless the wood became hung up on a boulder or other local obstruction. The presence of LWD has been documented by other studies and the available documentation is summarized below. Updated, local site conditions should be reassessed at the reach-assessment level in the future.

4.8.1 METHOW RIVER – LARGE WOODY DEBRIS

LWD mapping on 2001 aerial photographs documents that most log jams within the Methow River assessment area presently occur upstream of RM 55 (near Wolf Creek) to RM 75 (Lost River) (Figure E- 45; Golder, 2005). This is due to the more extensive riparian vegetation zone and complex channel networks that persist in this reach and lower stream power.

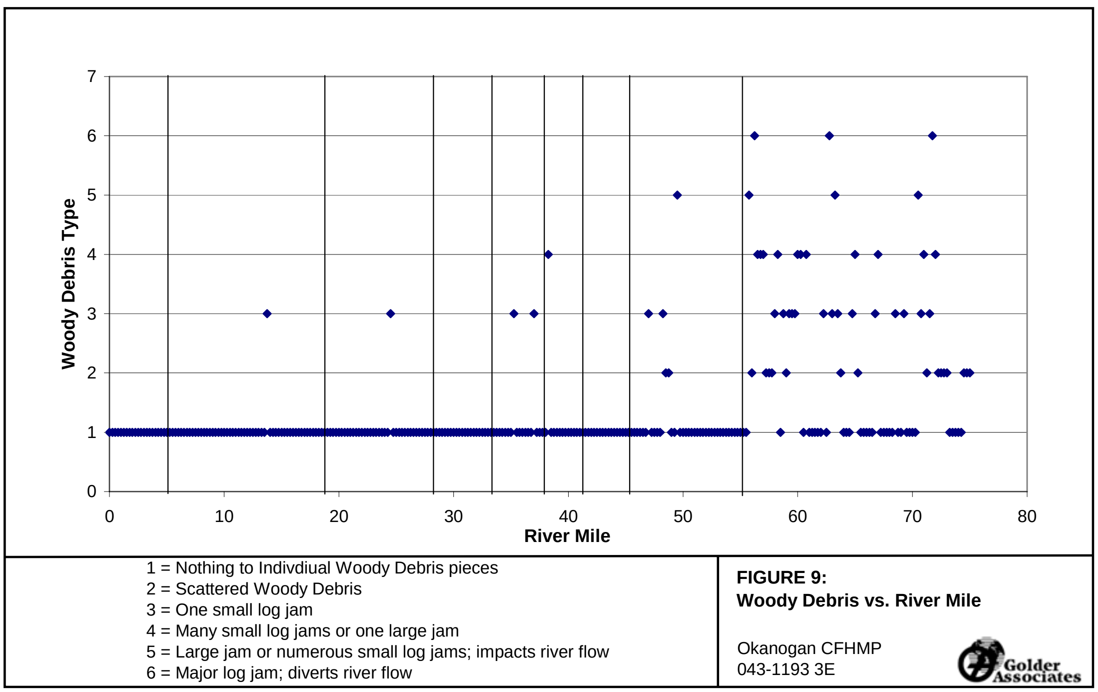

Figure E- 45. Methow River – LWD mapping (Golder, 2005).

4.8.2 TWISP RIVER – LARGE WOODY DEBRIS

Large wood is scarce in the lower 13.7 miles of Twisp River due partly to past clean-outs in the channel and harvesting along the banks (USFS, 2001). Less than 8 pieces of wood per mile greater than 35 feet long and 12 inches in diameter were counted in the lower 13.7 river miles (USFS, 2001). Large wood in the channel was much more abundant in many stream segments in the upper 16.7 miles of the Twisp River. An average of 42 pieces per mile greater than 35 feet long and 12 inches in diameter counted in the channel (USFS, 2001). About 30% of the wood counted in the channel had a diameter greater than 20 inches (about 12 pieces per mile). Fifty-three log jams, many creating deep pools, were found in the upper 16.7 miles of the Twisp River.

The present recruitment potential is poor in a two-mile stream segment above Buttermilk Creek (RM 13.7) due to the lack of conifers growing in the floodplain (USFS, 2001). The floodplain vegetation consists mainly of seedling-size and sapling-size deciduous trees, as frequent flooding does not allow for the establishment of conifers in this area. The present recruitment potential varies from fair to good between War Creek (RM 17.6) and Poplar Flats Campground (RM 24.2), and is excellent in the upper 6 miles of the river (USFS, 2001).

Debris jams counted from the 1955, 1964, 1970 and 1973 air photos for RM 0 to 20.5 at Cook Creek confluence shows that of the 17 log jams mapped only 1 was found after the 1972 flood (PWI, 2003). This jam was above War Creek. No log jams were observed downstream of RM 13.8 at Buttermilk Creek confluence. PWI (2003) hypothesized that this is because of the LWD removed by humans following the 1948 Flood.

4.8.3 CHEWUCH RIVER – LARGE WOODY DEBRIS

The Pacific Watershed Institute completed a stream survey from the mouth of the Chewuch River to Boulder Creek (RM 9.5) that included documentation of LWD (Smith et al., 2000). The survey found LWD that was greater than 35 feet long and 1 foot in diameter ranged from 8 to 18 per mile depending on the reach. The section with the most LWD was RM 2–5.4.

As part of a stream survey effort, the USFS documented the amount of LWD on the Chewuch River from RM 9.5 (Boulder Creek) to RM 36.2 (a natural barrier to fish). Surveys were done in 1993, 2002, and 2005 (Figure E-46). Future large wood recruitment is limited below the confluence with Lake Creek (RM 24.3) due to past selective logging along the stream banks, and above RM 29 by past fires (USFS, 2002). Between surveys in 1993 and 2002, large wood did not increase in the channel area surveyed, medium wood did increase by 50%, and small wood increased the most, largely due to wood recruited from areas burned in recent fires (USFS, 2002). Restoration work conducted in the mid to late 1990s by the USFS and Pacific Watershed Institute has increased the amount of large woody material in a few key areas of the channel.

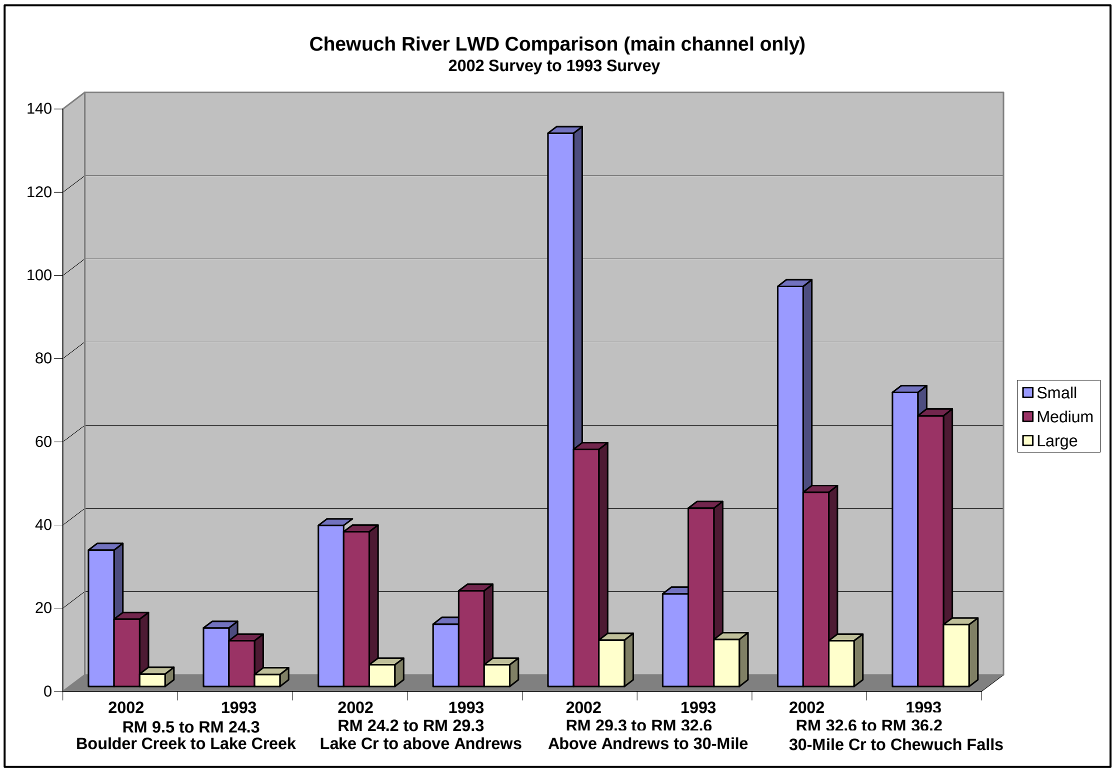

Figure E-46. Chewuch River (RM 9.5–24.3) USFS data on presence of LWD.
LWD categories are defined as "small" (less than 20' in length with a diameter of greater than 6"), "medium" (greater than 35' in length with a diameter of between 12" and 20"), and "large" (greater than 35' in length with a diameter of greater than 20"). *Duplicated from USFS, 2002*.

5. PREDICTION OF FUTURE PHYSICAL PROCESSES

This section provides predictions on how the physical river processes will function in the future given the human features and land use that are currently in place. The future is defined as several years to a few decades. This is because other factors, such as climate change or land use change, could significantly alter river processes beyond this timeframe, and these factors are difficult to predict.

Based on the historical and present settings, the river processes most impacted from the natural setting are lateral floodplain connectivity. This has resulted in an alteration of riparian vegetation and a reduction in the availability of off-channel habitat. Further reduction to channel complexity has occurred due to historical removal of LWD. Where the floodplain has been cut off, there is increased energy in the main channel which could result in channel changes. However, geologic controls and large sediment sizes in the bed provide a limit to the amount of incision that could occur. Lateral erosion is also limited due to the composition of the glacial terraces, alluvial fans, and bedrock that line the low surface (floodplain). If no action is done, these controls are expected to continue to limit vertical incision or lateral expansion of the floodplain in the future. If human features are removed to restore connectivity of the floodplain, it is expected that the active channel can effectively reconnect with the floodplain in most areas. Localized analysis should be done to confirm the frequency and degree of connectivity that will occur. If only a portion of the human features in place are removed, additional analysis would need to be done to better understand if floodplain function can be fully or only partly restored.

River processes within the low surface are still active in many areas and would be expected to continue in the future where currently functioning, or improve in the future where restored. Reworking of the channel bed and floodplain through sediment transport processes and channel migration are a healthy part of the fluvial system. These processes result in localized erosion and aggradation of the channel bed, but there is no evidence that would suggest a trend toward a long-term net change in the floodplain elevation.

The geomorphic assessment estimates minimal change in the lateral extent of the geologic floodplain (low surface) over the last century due to geologic controls that limit the potential for erosion (expansion). However, localized erosion has occurred and in some cases may be linked to human features within the low surface that redirect the river. This causes excess energy against the opposite bank and can result in erosion, particularly when the bank has been cleared of vegetation. If the human features are left in place, continued erosion of these localized areas may occur if the bank is not protected. If the human features are removed, bank erosion would be expected to decrease but localized analysis would be needed to further investigate each area. Bank areas cleared of vegetation may continue to see higher-than-natural erosion rates if the natural vegetation would have been expected to provide roughness and reduction in energy along the bank.

Golder Associates (2005) produced an avulsion hazard assessment that provides an estimate of erosion potential along the low surface boundary in the future for the mainstem Methow River (glacial terraces, alluvial fans, and bedrock areas). Many of the erosion hazard zones identified are within the low surface mapped by Reclamation. However, a few areas were identified that are susceptible to future erosion (expansion of low surface). Some banks that are prone to erosion that would result in lateral expansion of the river banks have been armored with rock and/or cars. These areas will continue to lack natural buffer zones that would have been present in natural setting. An analysis of future erosion potential has not been completed for the Chewuch and Twisp portions of the assessment area.

Cottonwood galleries may continue to decline if lateral channel reworking is not allowed to occur. In unvegetated areas the opportunity for cottonwoods to reestablish in the next several years is good if human features are removed and floodplains reconnected. Opportunity is poor for cottonwoods to re-establish in the next several years in areas that already have vegetation. Other species have overtaken cottonwood areas and provide too much shade; so that it will be difficult for cottonwood seedlings to establish given the present setting. Cottonwoods may establish in these areas if the river is allowed to erode them and create a fresh, bare surface. However, in some areas the new vegetation is fairly dense and may require a significant flood to erode the surface. There is a good potential to enhance existing cottonwood stands and increase abundance of cottonwood stands using existing technology and planting methods known to be successful. Riparian vegetation restoration is also subject to additional factors that affect the future success including non-native species and wildlife.

Given the present riparian vegetation age, initially LWD recruitment could be high once floodplains are reconnected and older trees are accessed that have been unavailable for recruitment for the last 50 or so years. Recruited trees may contain more Douglas-fir, ponderosa pine, and aspen than cottonwoods in areas where these species have replaced cottonwood galleries. However, many areas have less large fir than in the past as evidenced by very large fir and pine stumps on river terraces along the Twisp, Chewuch, and Methow rivers. Areas that have been cleared of vegetation may require manual planting to re-establish riparian stands and recruit LWD.

6. REFERENCES

IN TEXT	FULL CITATION
Baesecke 2005b	Baesecke, H. November 2005. "Vegetation in Methow Subbasin" in *Geomorphic Assessment Technical Appendices* as Appendix H, Section 1 (Reclamation 2008b).
DeBell 1990	DeBell, D.S. 1990. "*Populus trichocarpa"* p. 570–576, in *Silvics of North America, Volume 2, Hardwoods*: USDA Forest Service, Agriculture Handbook 654.
Golder 2005	Golder Associates, Inc., 2005, *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Hadfield 2007	Hadfield, J.S., 2007, "Biological Evaluation of Condition of Black Cottonwood in Bureau of Reclamation Potential Vegetation restoration project areas along the Twisp and Methow rivers, Okanogan County, Washington" in *Geomorphic Assessment Technical Appendices* as Appendix H, Section 2 (Reclamation 2008b).
Julien 1995	Julien, P.Y., 1995, *Erosion and sedimentation:* Cambridge University Press.
Konrad et al. 2003	Konrad, C.P.; Drost, B.W.; and Wagner, R.J. 2003, *Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington*. US Geological Survey Water-Resources Investigations Report 03-4244, 137 p.
Lane 1955	Lane, E.W., 1955, "Design of Stable Channels" *Transactions, Am. Soc. Civil Eng.* 120:1234.
McLennan and Mamias 1992	McLennan, D.S., and Mamias, A.M. 1992. *Cottonwoods in British Columbia –Problem analysis.* FRDA Report 195, Canada-British Columbia Partnership Agreement on Forest Resource Development, FRDA II, 50 p.

IN TEXT	FULL CITATION
NMFS 1996	National Marine Fisheries Service, 1996, *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale*, August 1996. "Matrix of Pathways and Indicators"
Portman 2002	Portman, S., 2002, *The Smiling Country – A History of the Methow Valley*. Sun Mountain Resorts, Inc., Winthrop, WA.
PWI 2003	Pacific Watershed Institute, 2003, *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.
Smith et al. 2000	Smith, J. E., Fisher, B., and Farmer, S., 2000, *Lower Chewuch River fisheries habitat survey, final report.* Prepared for CI Johnson and Associates in cooperation with the Methow Basin Planning Unit by the Pacific Watershed Institute, Winthrop, WA. December 2000. 58 p.
USFS 2001	US Forest Service, 2001, *Twisp River stream survey summary:* Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.
USFS 2002	US Forest Service, 2002, *Chewuch River stream survey summary.* Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.

APPENDIX F –
BIOLOGICAL SETTING

This appendix focuses on describing existing biological use within the assessment area to document what habitat features are currently functioning that should be considered for protection and what habitat features are not functioning and in need of restoration.

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LIST OF FIGURES

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1. INTRODUCTION

This appendix focuses on describing existing biological use within the assessment area to document what habitat features are currently functioning that should be considered for protection. Habitat processes that are not functioning adequately are also described to help guide concept development for restoration projects aimed at improving habitat complexity. *Water Resource Inventory Area (WRIA) 48 Limiting Factors Analysis* (Andonaegui, 2000) documents the basic biology and recent management history of the Upper Columbia River spring Chinook salmon, summer steelhead trout, and Columbia River bull trout; this information is not repeated here.[1]

The assessment area provides spawning and rearing areas for listed salmonids and projects will benefit listed species at the site scale, but possibly more important, the assessment area also provides the physical and biological linkages and connections between major and minor tributary streams and populations. As a result, an additional goal is to restore or maintain habitat within the assessment area so that the upstream and downstream linkages and population connectivity is protected — this will ensure that the long-term capability for species recovery in the Methow Subbasin is protected.

Roni et al. (2002) suggests that following watershed assessment, restoration project selection and prioritization should focus first on protection of high-quality habitat and then on reconnection of high quality in-channel and off-channel habitat isolated by culverts or other artificial obstructions. Once habitat has been reconnected, emphasis should be placed on restoring physical processes and riparian function through road management, livestock exclusion, and riparian restoration. In-channel habitat enhancement should be considered after channel restoration and habitat-maintaining processes or where an emergency fix is needed to protect endangered or threatened species. Since 1996, work to restore fish passage at road crossings and irrigation dams has been implemented throughout the Methow Subbasin; most, but not all, main channel fish passage issues have been addressed. Reconnection of off-channel areas blocked by artificial structures has not yet been addressed and is the goal of many of the projects that could result from this assessment. Protection of existing high-quality habitat is being addressed on private land by acquisition by the Washington Department of Fish and Wildlife (WDFW), Methow Salmon Recovery Foundation (MSRF), and by conservation easements through the Methow Conservancy.

1.1 SPATIAL DISTRIBUTION OF ESA FISH

Spring Chinook and steelhead spawning locations that are observed within the assessment reaches are surveyed as part of an annual monitoring program. Surveys are repeated on an annual basis because numbers can vary from year to year

[1] For brevity, these species will be referred to as spring Chinook, steelhead, and bull trout.

depending on short-term factors. These include but are not limited to the number of steelhead removed at Wells Dam on the Columbia River for hatchery broodstocks, out-of-basin effects, and the positive and negative effects of disturbances like floods, wildfire, and drought. Data has been collected by WDFW (and prior to that by the Yakama Nation) to monitor hatchery supplementation programs funded by Douglas County Public Utility District (PUD) to monitor spring Chinook hatchery supplementation effects. Table F–1 shows an overview of fish usage by reach within the assessment area for ESA and other species of interest. Usage is broken out by life stage and is based on a combination of historical spawning data, snorkel data, communication with other biologists working in the area and observation. The following text provides more detailed spawning information relative to spring Chinook, steelhead, and bull trout.

Table F–1. Species and life stage usage for ESA and non-ESA listed fish within the assessment area.

Explanation: **F** = Foraging; **H** = Holding; **M** = Migration; **OW** = Over-wintering; **P** = Present; **R** = Rearing; **S** = Spawning;
Letters in parentheses: **(j)** = juvenile; **(a)** = adult;
Bold letter (**M, S, R)** show types and location of high density or abundant use. Non-bold letters show general use.

Biologic Reach	Spring Chinook	Steelhead	Bull trout	Summer Chinook	Coho	Pacific lamprey	Westslope cutthroat trout	Sockeye	Non-native brook trout
Methow River									
Carlton to Twisp (Twisp River) (RM 27–41)	M (j, a), OW, R	M, OW (j, a), R, S	F, M, OW	M, S	M, S	M, R, S	P	M, S	
Twisp River to Winthrop (Chewuch River) (RM 41–51)	H, M, R, OW, S	M, OW (j, a), R, S	F, M, OW	M, S	S	M, R, S	P		
Winthrop (Chewuch River) to Weeman Bridge (RM 51–61)	H, M, OW, R, **S**	M, OW (j, a), R, **S**	F, M, OW	M, S			P		P
Weeman Bridge to Mazama (RM 61–68)	M, OW, M, **S**	M, R, S	F, M, OW				P		P
Mazama to Lost River (RM 68–75)	M, R, S (when flows allow)	M, R, S	F, M, OW				P		
Chewuch River									
Winthrop to Falls Creek RM 0–14	**M, S, R**	**M, S, R**	F, M, OW			M,R, S	P		P
Twisp River									
Twisp to Buttermilk Creek RM 0–15	**M**, S, R	, S, R	F, M, OW				P		P

M

1.2 SPRING CHINOOK SPAWNING LOCATIONS

Table F–2 shows the preliminary spring Chinook 2006 spawning data from WDFW. The data shows the overall distribution of spring Chinook spawning by major tributary and for the mainstem Methow River. Suspension Creek is a spring-fed side channel about ¼-mile long on the Methow River (about RM 64, just downstream of Little Boulder Creek) that is surveyed because of heavy spawning use. The WDFW Methow State Fish Hatchery (Methow SFH) and FWS Winthrop National Fish Hatchery (Winthrop NFH) just upstream of the Chewuch River confluence on the Methow River are also surveyed.

The 2006 spawning data for spring Chinook show that the Upper Methow and Chewuch watersheds accounted for most spawning in 2006. One of the reasons for the higher redd counts in the Chewuch and the Upper Methow watersheds is that more hatchery juvenile spring Chinook are released in those two watersheds than in the Twisp watershed (Snow 2007). In 2006 the percentage of spawning wild adult spring Chinook to hatchery adults for the Methow Subbasin (including Early Winters Creek., Lost River, Suspension Creek, both hatchery outfalls) was 9.5% wild; the Chewuch watershed was 23.8% wild; and the Twisp watersheds was 31.7% wild (Charles Frady, WDFW, unpublished data).

Table F–2. Preliminary spring Chinook 2006 redd count data (Snow and Frady, 2006).

Tributary	**August**		**September**		**Total**		**Est. sample rate (%)**
	Redds	Carcs	Redds	Carcs	Redds	Carcs	
Chewuch River (RM 0 to 30)	161	24	112	199	273	223	37.1
Methow River (RM 0 to 76)	252	73	143	315	395	388	44.6
Twisp River (RM 0 to 26.1)	45	4	42	37	87	41	21.4
Lost River (RM 0 to 4.1)	25	4	3	2	28	6	9.7
Early Winters Cr (RM 0 to 4.8)	14	0	0	4	14	4	13.0
Suspension Cr	23	0	13	6	36	6	7.6
MSFH Outfall	65	29	10	56	75	85	51.5
WNFH Outfall	12	0	9	8	21	8	17.3
Basin total	**597**	**134**	**332**	**627**	**929**	**761**	**37.2**

Preliminary WDFW spring Chinook redd count data 2006 Methow Subbasin spring Chinook redd and carcass counts by survey week (Snow and Frady, 2006). Sample rates are based on an estimated 2.2 fish per redd expansion rate. Estimated sample rate is redd count x 2.2 fish/redd shown as a percentage of carcasses sampled.

1.3 STEELHEAD SPAWNING LOCATIONS

Spawning data for steelhead shows that steelhead spawn in all reaches of the Methow River, the mainstems of the Chewuch and Twisp Rivers, and in smaller tributary streams. These include Beaver Creek and Gold Creek in the Middle Methow watershed, Little Bridge Creek in the Twisp watershed, and lower Eightmile Creek in the Chewuch watershed. Steelhead spawning can overlap spring Chinook and summer Chinook spawning areas. Steelhead redd counts are useful for learning where steelhead spawn; however, because they spawn in the spring, rising water and increased turbidity from snow melt makes complete spawning counts difficult and makes redd count data less useful for determining total spawning effort.

1.4 BULL TROUT

Reclamation is charged with improving habitat conditions for spring Chinook salmon and steelhead. Most of the opportunities that are identified by this assessment will also benefit ESA-listed Columbia River bull trout and species of concern such as Westslope cutthroat trout, Pacific lamprey, summer Chinook, and Coho salmon. Benefits to bull trout include an improved prey base, improved winter holding and foraging habitat, improved migration corridors, and improved thermal refuge and habitat complexity. Other species of fish that reside in the Methow Subbasin that will benefit from this work include rainbow trout, sockeye salmon, and whitefish, sculpins, dace, and bridgelip suckers.

Introduced brook trout are abundant in many small streams and some off-channel areas in the Methow and Twisp watersheds and are considered undesirable because they hybridize with native bull trout and pose a threat to bull trout recovery, and because they compete with all native species (that is spring Chinook and steelhead, bull trout).

The Twisp watershed presently accounts for most migratory bull trout production in the Methow Subbasin followed by the upper Methow and Chewuch watersheds, including Lake Creek (Table F–3). The contributions of the West Fork Methow River and the Chewuch River (including Lake Creek) may be increasing following the effects of the 2001 and 2003 wildfires. A study on the North Fork John Day River (in Oregon) suggests that fires are an integral part of the natural system and provide more benefits than impacts to the ecosystem (Howell, 2006).

After the 2001 and 2003 fires in the Methow Subbasin, bull trout and some spring Chinook spawning areas in the Upper Methow and Chewuch watersheds experienced massive amount of debris torrent activity; these completely buried spawning and rearing areas (MVRD, 2007). Despite the huge disturbance, local observations by the US Forest Service (USFS) suggest that spawning has been maintained and possibly increased over pre-fire levels and distribution of spawning has increased slightly. Rearing areas and spawning habitat have also appeared to increase (based on observations) due to the creation of wetlands above debris torrent toe slopes and delivery of fresh gravel and logs to river channels creating high levels of complex habitat. Future stream survey efforts will help provide quantitative information to better examine the fisheries response to fires over both short-term and long-term time periods.

Table F–3. Migratory bull trout redd survey, Summary 2006 (USFS, 2006).

Surveyed Area within the Methow Subbasin	Surveyor and number of visits	Miles surveyed	Total redds	Bull Trout 1/	
				Migratory 14"or >	Resident or juvenile <14"
Twisp River	USFS (3)	4.4	76	21	6
North Creek	USFS (3)	0.5	9	2	0
Buttermilk Creek (East and West Forks)	USFS (1)	4.5	4	1	0
West Fork Methow River	USFS (2)	3.3	25	5	0
Early Winters Creek	USFS (2)	4.0	12	5	1
Goat Creek	FWS (3)	2.7	8	2/ 1	21
Chewuch River	USFS (3)	1.3	35	> 30	0
Lake Creek	USFS (2)	2.3	19	2	6
Wolf Creek	FWS (3)	4.0	18	7	several
Crater Creek	WDFW (2)	1.5	3	2	25
Foggy Dew Creek	USGS (1)	2.5	1	0	?
Total Methow Subbasin	**25**	**31.0**	**210**	**76**	**?**

1/ Incidental bull trout counted during the surveys.

2/ A 43 cm bull trout tagged at Wells Dam in 2006 was radio-tracked to the reach, but not visibly observed.

2. TIMING OF FISH USAGE

Table F–4 displays the general timing of different life stages of spring Chinook, steelhead, and bull trout in the Methow Subbasin based on spawning data from the WDFW and stream survey observations by USFS personnel. Rearing occurs throughout the year, but the timing of spawning and migration vary by species.

Table F–4. Timing of steelhead, spring Chinook, and bull trout spawning, rearing, and migration use in the Methow Subbasin.

Species Life stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Steelhead												
Spawning												
Rearing												
Migration												
Spring Chinook												
Spawning												
Rearing												
Migration												
Bull Trout												
Spawning												
Rearing												
Migration												

3. BIOLOGICAL OVERVIEW BY REACH

The following sections summarize habitat components presently in place for the Methow River, Chewuch River, Twisp River, Early Winters Creek, and Lost River. Opportunities to improve habitat closer to natural conditions are listed in terms of restoration objectives. Drainages are subdivided for the discussion based on areas of similar characteristics from a biological perspective.

All of the reaches provide important habitat for a variety of life stages of each of the listed species of fish; all of the reaches are interconnected and provide important physical and biological connectivity to upstream and downstream areas. The need for restoration, protection, or both in any given reach depends several factors. These include the natural resiliency of the reach to human disturbance, potential threats to natural function and processes in the reach, the current level of impairment in a reach, and presence of one or more life stages or species of listed fish. Reaches with multiple species and multiple life functions with a high risk of threat are a high priority for protection (and perhaps restoration) if function is impaired; some examples are the Upper Methow from Wolf Creek to RM 65 (just downstream of Goat Creek), the Twisp River from Little Bridge Creek upstream to RM 27, and the Chewuch River from Boulder Creek to Eightmile Creek. Reaches with multiple species and multiple life functions that have some impairment of function should be a high priority for restoration and protection — examples are the lower Twisp River, the Chewuch River, and the Methow River between Twisp and Winthrop. Reaches with very impaired function should be considered for restoration and protection once more functional areas have been secured.

The general objective for habitat protection and restoration strategies are to increase rearing areas, over-wintering areas, and spawning habitat by allowing the river to access and interact with historic side channels and ensuring that the floodplain is well forested to provide potential large woody debris (LWD) recruitment to the river. LWD recruitment, transport and accumulation are important for bar formation, revegetation of floodplains and for channel migration, which reworks the floodplain and creates complex habitat that consists of deeper pools for over-wintering habitat. This could be accomplished through the following strategies:

- Protect existing riparian cottonwood and coniferous forests to provide shade and large wood debris (LWD) recruitment, bank stability and root mass hiding cover.
- Reforestation of floodplains with riparian vegetation where cleared; areas with the most potential for interaction with the river would be a priority for re-vegetating.

- Levee and dike removal and bridge lengthening to allow river access and reworking of floodplain.
- Reconnect off-channel areas by removing artificial blockages or providing passage around dams, by removing riprap, modifying road embankments, and replacing culverts.
- Increase in-channel LWD levels where in-channel wood removal has occurred and/or where present wood recruitment is not available because of loss of riparian forest.
- Protection and restoration of hyporheic function between river and aquifer
- Beaver reestablishment where feasible with adjacent land use.
- Reduce brook trout populations where posing a threat to native species (eliminate if possible).

3.1 LOWER METHOW –MOUTH TO CARLTON (RM 0–28.1)

This 28-mile segment of the Methow River is outside of the scope of the geomorphic assessment, but because it is important for the species in the assessment area, it is added in the biological assessment for completeness.

The segment has a higher gradient and is generally more confined than the upstream reaches of the Methow River. Every anadromous adult steelhead and salmon, and many migratory bull trout returning to the Methow River rely on this reach for safe passage to upstream spawning reaches, and their offspring rely on safe passage through this reach on their downstream migration to the Pacific Ocean. Deep bedrock-controlled pools and turbulent water provide hiding cover from predators for adult salmon, steelhead, and bull trout, and for juvenile salmon and steelhead. Deep pools also provide resting areas for migrating adults. Steelhead and summer Chinook spawn in some places within this reach where water wells up through the river bed through gravel accumulations to provide suitable habitat. Although this reach is very important for listed fish, it is naturally confined by high glacial terraces with limited human impacts and is, therefore, not presently a priority for restoration or protection. The state highway does generally follow the alignment of the river, and certain sections have been riprapped or contain bridges that affect channel alignment and roughness. Basic habitat assessments have not been conducted on this reach and are a data gap.

Key uses by ESA-listed fish and other species of concern:

- Migration of juveniles and adults.
- Adult holding prior to final spawning migration
- Steelhead over-wintering and spring spawning
- Migratory bull trout foraging and over-wintering
- Summer Chinook and coho salmon spawning

3.2 MIDDLE METHOW – CARLTON TO TWISP (RM 28.1–41)

The Middle Methow contains a wider floodplain relative to the downstream section in the Lower Methow. Many off-channel areas have been cut off by levees, reducing the interaction and reworking of the river with its floodplain, and thereby eliminating the process that produces and maintains rearing habitat for juvenile fish and spawning gravel for steelhead and summer Chinook. Conversion of the riparian cottonwood forests to agricultural crops along the river has reduced the LWD recruitment potential to the river and further reduced habitat complexity, sorting of spawning gravels, and the creation of scour pools and hiding cover. Reduced populations of beaver have also lead to an extensive loss of wetlands adjacent to the river.

The reach has some confined deep water reaches with large boulders which provide good holding cover for adult steelhead and salmon, and holding and foraging habitat for bull trout. The reach is used by steelhead, summer Chinook, and sockeye salmon for spawning. The reach is downstream of all the major spawning areas for spring Chinook salmon and is potentially a very important reach for juvenile rearing and over-wintering. Winter conditions in the Twisp and Chewuch watersheds and Beaver Creek are harsh, and juvenile fish could be migrating downstream to larger and deeper water found in this reach. This reach likely has a substantial hyporheic zone (Stanford and Ward, 1993). This would have important influences on nutrient exchange and water chemistry for stream organisms, including fish. Additional temperature profiling and a FLIR (forward looking infrared flight) would help illuminate where major hyporheic/surface water exchanges are occurring and may be helpful as a project prioritization tool. Human development on the floodplain could have a major ecological influence on the hyporheic zone and surface-water interactions of the river and the organisms that live there (Stanford and Ward, 1993).

Key uses by ESA-listed fish and other species of concern:

- Rearing and over-wintering for juvenile spring Chinook and steelhead
- Migration of juveniles and adults salmon, bull trout and steelhead
- Adult holding prior to final spawning migration
- Steelhead spawning
- Migratory bull trout foraging
- Summer Chinook, steelhead, sockeye and Coho spawning

3.3 MIDDLE METHOW – TWISP TO WINTHROP (RM 41–51)

This reach is used by steelhead, spring Chinook, summer Chinook, coho salmon, and lamprey for adult holding, spawning and juvenile rearing. It is also a migration corridor for all of these species and for bull trout. This reach has been extensively constrained by riprap and levees, and river access to the floodplain and channel migration is impaired. Much of the cottonwood forest on the floodplains has been converted to agricultural lands that have reduced LWD recruitment potential to the river. The combination of impaired channel migration, loss of access to off-channel areas and reduced LWD has eliminated a large amount of juvenile rearing and spawning habitat. Reduced beaver populations have led to loss of wetlands and rearing areas and water, nutrient and sediment storage they provide. This reach is downstream of major spring Chinook and steelhead spawning areas in the Chewuch and Upper Methow watersheds and has the potential to provide winter refugia for juvenile fish. The reach currently supports a small amount of spring Chinook spawning and restoration of the natural channel processes could yield increased spawning habitat.

Konrad and other (2003) identified this reach as transient, meaning that they did not see a consistent trend in gain or loss to the flow in the river during low flow. However, the reach does gain flow in some years, and the section downstream of RM 45 has gained flow during two years that they monitored. Although observations to date are inconsistent, it is possible that this reach has a hyporheic zone that has important influences on nutrient exchange and water chemistry for stream organisms — including fish — as noted by Stanford and Ward (1993). Human development on the floodplain could have a major ecological influence on the hyporheic zone and surface-water interactions of the river and the organisms that live there (Stanford and Ward, 1993).

Key uses by ESA-listed fish and other species of concern:

- Year-round juvenile spring Chinook and steelhead rearing
- Steelhead and a small amount of spring Chinook spawning
- Adult holding prior to final spawning migration
- Migration of juvenile and adult salmon, bull trout and steelhead
- Migratory bull trout foraging
- Summer Chinook, coho salmon and lamprey spawning

3.4 UPPER METHOW –WINTHROP TO WEEMAN BRIDGE (RM 51–61)

Above the Wolf Creek alluvial fan, this reach is relatively unconfined by natural or artificial features and, although it is confined in places by road embankments and culverts, most of this reach is functioning at close to natural potential for aquatic habitat. However, recently constructed houses are potentially at risk from lateral migration of the Methow River, placing the reach at risk of being modified by some form of bank armoring to protect the houses. The embankment for the Weeman Bridge does artificially cut off the floodplain and should be considered for modification to allow connectivity of the floodplain processes upstream and downstream of the bridge. High densities of spring Chinook salmon are currently using the reach for spawning, especially in places where log jams have accumulated and caused smaller channels to form through cottonwood forests. These channels are deep with undercut banks and complex tangles of roots and woody debris providing excellent refugia for juvenile and adult salmon, steelhead and bull trout. Frequent channel reworking and large amounts of sediment in storage in the floodplain result in recruitment of fine-sized gravel that is heavily used by spawning salmon. This reach is also a gaining reach (Konrad et al., 2003) with many springs that moderate stream temperatures in the winter and summer and provide off channel rearing areas. The hyporheic zone in this reach is very broad and is important to nutrient cycling and the food web in the main river. The hyporheic zone in this reach is probably in the highest functional state of all the reaches considered in this assessment. Human development on the floodplain could have a major ecological influence on the hyporheic zone and surface water interactions of the river and the organisms that live there (Stanford and Ward, 1993). Loss or reduction of hyporheic function could result in diminished nutrient supply in surface waters where fish reside. Non-native brook trout are present in large numbers in isolated ponds in the area. Brook trout are a threat to native bull trout (Kanda et al., 2002).

Key uses by ESA-listed fish and other species of concern:

- Spring and summer Chinook spawning, rearing, and migration
- Steelhead spawning, rearing, and migration
- Bull trout rearing, foraging, and migration
- Key winter rearing area

3.5 UPPER METHOW –WEEMAN BRIDGE TO MAZAMA (RM 61– 68)

The Weeman Bridge to Mazama reach is naturally unconfined with a low gradient and broad floodplains. Dikes and levees are present and block access to adult salmon, rearing juvenile salmon, and rearing steelhead. Conversion of cottonwood forests to agricultural fields and residential development is increasing the need for bank protection and reducing off-channel access and LWD recruitment potential to the river. Large spring-fed, off-channel areas are important sources of cool, high-quality water. A major spring at the suspension trail bridge is used by spring Chinook for spawning and rearing (Humling and Snow, 2006). The reach is used by spring Chinook and steelhead for spawning, migration and rearing, and by bull trout and West slope cutthroat trout for foraging, holding and migration. Brook trout are present in some of the off-channel areas.

Goat Creek is a major tributary to this reach and is important for bull trout, steelhead migration to spawning habitat, and for juvenile spring Chinook rearing in the lower mile. The alluvial fan of Goat Creek has been channelized, resulting in its main channel being located at the highest point of the fan and being dewatered in late summer. Konrad et al. (2003) reported for most of this reach, the section downstream of Goat Creek at RM 65.5, groundwater is consistently discharged into the Methow River during low flow conditions. This portion of the reach has a substantial hyporheic zone that has important influences on nutrient exchange and water chemistry for stream organisms including fish (Stanford and Ward, 1993). However, the Methow River in the 2.5-mile-long section of this reach upstream of Goat Creek experiences large losses of flow and is dry eight out of twelve years (Konrad et al., 2003). It is likely that ground water levels in this section are lower than the river surface, so that the aquifer is recharged (Konrad et al., 2003). Human development on the floodplain could have a major ecological influence on the hyporheic zone and surface water interactions of the river and the organisms that live there (Stanford and Ward, 1993).

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook spawning, rearing and migration
- Steelhead spawning, rearing and migration
- Bull trout rearing, foraging and migration
- Key winter rearing area

3.6 UPPER METHOW –MAZAMA TO LOST RIVER (RM 68–75)

This reach often dewaters during base-flow conditions from September into the winter (Konrad et al. 2003). The dewatering is more pervasive above the confluence with Early Winters Creek up to the confluence with the Lost River. The reach includes the confluence with Early Winters Creek. Summer steelhead spawn from late March into May; juveniles emerge in late May through early July when flow is available in the river. Spring Chinook also spawn in the reach and in some years spring Chinook redds can dewater when the river goes dry. Spring Chinook, steelhead, and bull trout depend on the reach to migrate as adults to excellent spawning habitat in the West Fork Methow River and the Lost River, and also for juvenile out migration and rearing.

LWD, boulders, and well-forested floodplains with dense root mats are essential for providing refuge habitat for fish as the river dewaters and will often allow for survival in years when fall rains bring flow back to the river. Increasing residential development on the floodplain is creating a conversion of floodplain forests into lawns or open areas and is also increasing the need for bank protection during flooding. Large wood levels have been increasing but are potentially threatened by the increasing loss of floodplain forest and bank protection. The Methow River upstream of Goat Creek, which includes this reach, experiences large losses of flow and is dry 8 out of 12 years (Konrad et al., 2003). It is likely that ground water levels in this section are lower than the river surface, so that the aquifer is recharged (Konrad et al., 2003). More investigation is needed to determine the effects of natural dewatering on fish populations and the possibility of juvenile survival during dewatering.

Key uses by ESA-listed fish and other species of concern:

- Steelhead spawning, rearing and migration corridor to early Winters, west Fork Methow River and Lost River
- Spring Chinook spawning (when flow allows), rearing and migration corridor to early Winters Creek, West Fork Methow River, and Lost River
- Bull trout rearing, foraging and migration corridor to early Winters Creek, West Fork Methow River, and Lost River

3.7 LOST RIVER (RM 0–7.7)

The lower Lost River from the mouth up to Monument Creek (at RM 7.7) provides fully functional spawning and rearing habitat for spring Chinook, steelhead and large migratory bull trout. To reach this excellent habitat, spring Chinook, steelhead, and bull trout depend on good migration habitat and flow conditions in the mainstem Methow River. The lower one mile of the Lost River has been developed with residences close to or in the flood-prone area of the Lost River (Golder, 2005). The county road bridge over the Lost River (about RM 0.25) constricts the floodplain at flood flows. Upstream of private land, the Lost River is managed by the USFS as Wilderness and is pristine.

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook and steelhead spawning and rearing
- Bull trout spawning, rearing, and foraging

3.8 EARLY WINTERS CREEK (RM 0–8)

Early Winters Creek provides an important flow source to the mainstem Methow River at about RM 70, especially when the mainstem is dry. Flow from Early Winters Creek provides for viable spring Chinook spawning habitat in this reach of the Methow River. Spring Chinook spawn from the mouth of Early Winters Creek to Klipchuck Campground. Steelhead also use Early Winters Creek to spawn and rear, but spawning locations have not been thoroughly investigated. Bull trout also spawn and rear in Early Winters Creek. Early Winters Creek has a very large alluvial fan which has been impacted by confinement with riprap and the undersized Highway 20 Bridge and an adjacent trail bridge. These disruptions in alluvial fan function have decreased the channel length and available spawning and rearing habitat for spring Chinook and steelhead. Because the mainstem Methow River dewaters in the reach that includes Early Winters Creek, additional losses of spring Chinook spawning habitat in Early Winters Creek carry a substantial loss for production in the upper Methow watershed.

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook spawning and rearing
- Bull trout and steelhead spawning, rearing and foraging

3.9 LOWER TWISP RIVER (RM 0–15)

The lower Twisp River extends from the mouth up to Buttermilk Creek around RM 15. Most of the spring Chinook spawning and all of the bull trout spawning in the Twisp River takes place above RM 12 up to RM 27 at Roads End; the reach downstream of this spawning is important for juvenile rearing and out-migration. A recent stream survey found spawning gravel was abundant in most segments of the Twisp River, although bank hardening and channel straightening in some segments of the lower 13.7 miles of the stream may reduce the amount of gravel available for spawning salmonids (PWI, 2003).

The first 12 miles of the lower Twisp River are naturally confined by the narrow lower valley. This natural confinement has been compounded by artificial channel confinement to protect roads and property from the river. This has reduced access to off channel rearing areas, reduced localized spawning areas and reduced floodplain function and LWD recruitment potential to the Twisp River. Large wood levels are low due to natural transport of wood through the reach and because of post flood wood removal and loss of natural wood recruitment because of stream side logging, conversion to agricultural and residential development, and to accommodate roads. Above the confluence with Little Bridge Creek, the channel is less confined and provides spawning habitat for spring Chinook salmon. Quality of spawning habitat and rearing habitat is reduced by low levels of large wood between Little Bridge Creek and the Buttermilk Bridge. Wood levels in this reach are beginning to rebuild naturally, resulting in an increase of spawning habitat around gravel accumulations above large wood pieces. Low flows and high water temperatures in late summer in the lower 4 to 6 miles reduces the available rearing habitat and the quality of migration habitat for fish migrating upstream in late August and September. Introduced brook trout spawn in off-channel areas that have been cutoff from the main channel and are a threat to the native bull trout population, such as the beaver ponds at Elbow Coulee (about RM 7) and the Jennings property on the Twisp River between Little Bridge Creek and Buttermilk Creek confluence (about RM 15).

The glacial history and geomorphology of the Twisp River drainage limit natural fine sediment recruitment, so there is less fine sediment in the spawning gravel of the Twisp River compared to the Chewuch River. Fine sediment in spawning gravels increased in three of four reaches sampled in 2006 relative to 2000–2005 sample levels (MVRD, 2007). The increase in percent of fines in spawning gravels may be due to the higher-than-average peak run-off in 2006, which may have scoured the banks and/or recruited sediment from the floodplain and tributaries. In addition, large amounts of sediment may have been deposited when anchor ice moved downstream during a thaw in February 2005, scouring the banks of the river (MVRD, 2007). Data collection in additional water years is needed to determine the natural variability and sampling error before making any conclusions about trends in fine sediment levels in the Twisp River.

Numbers of spring Chinook spawning in the Twisp River are low compared to the Chewuch and mainstem Methow rivers. This could be due to differences in hatchery supplementation and/or to high late summer temperatures in the lower Twisp River and very low stream flows during the initiation of spawning. In the section adjacent to the Buckley floodplain, low flows form a passage barrier to migrating adults. Twisp River redd counts for bull trout are currently the highest values recorded in the Methow Subbasin.

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook and bull trout migration to upstream spawning areas
- Steelhead spawning, migration and rearing

- Spring Chinook spawning, juvenile downstream migration and rearing
- Foraging and downstream migration for bull trout

3.10 UPPER TWISP RIVER (RM 15–29)

The upper Twisp River is where the bulk of spring Chinook and all bull trout are known to spawn in the watershed. The lower portion of the reach, off the National Forest, is threatened by recent construction of houses in flood-prone areas adjacent to heavily used spring Chinook spawning and rearing areas. Throughout the upper Twisp River, brook trout are found in off-channel areas and are sometimes seen among spawning bull trout during redd counts. On the National Forest, some of the developed campgrounds have localized effects to LWD levels and are adjacent to spring Chinook and bull trout spawning areas — the “Respect the River” program is designed to address recreational effects on riparian and aquatic habitat through manipulation of recreation sites to minimize recreation impacts combined with visitor contact and information sharing. On the National Forest, eight undersized culverts have been replaced with larger metal arches and one bridge with natural stream beds restoring fish passage to many of the tributaries to the Twisp River. The larger metal arches also allow for the downstream transport of large wood and bedload which should help with long-term channel maintenance in the mainstem Twisp River (PWI, 2003).

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook spawning and rearing
- Bull trout rearing, foraging, and migration to and from upstream spawning areas
- Steelhead spawning, migration, and rearing
- Juvenile downstream migration, and rearing

3.11 LOWER CHEWUCH RIVER (RM 0–20)

The Chewuch River produces roughly a third of the spring Chinook production in the Methow Subbasin. The lower Chewuch River includes the mouth up to Twenty-mile Creek at about RM 20. Almost half of the lower Chewuch flows through private land; the upper quarter flows through the National Forest and some WDFW land. Spring Chinook and steelhead spawn from RM 0 up to Chewuch Falls (about RM 35) with the bulk of spawning occurring between RM 2–RM 20. High densities of spring Chinook and steelhead spawning throughout most of the lower Chewuch River creates a demand for quality rearing habitat throughout the reach. Redds downstream of Boulder Creek may be influenced by high number of hatchery fish returning to the area of the WDFW spring Chinook acclimation pond located just downstream of the creek (Snow, 2007).

Some of the most heavily used spring Chinook spawning habitat can be found in the Chewuch River between the confluence of Boulder Creek and Eightmile Creek. This area is upstream of all major irrigation diversions and has the greatest late summer stream flows and the coldest water. This is because of spring-fed water from Eightmile

Creek as can be seen in the FLIR water temperature data collected by Watershed Sciences (on August 10, 2001). The lower Chewuch River is an important migration corridor for large migratory bull trout and for spawning and rearing lamprey. Bull trout also use the reach for foraging, especially in the cold water areas near Eightmile Creek. Lamprey spawn in gravel and the young rear in silts for up to four years making them extremely vulnerable to disturbance.

Major wildfires have burned with varying intensities in 70% of the Chewuch watershed in 2001, 2003, and again in 2006 (MVRD, 2007). In the summer of 2004, major landslides and debris torrents (Andrews Creek and Lake Creek drainages) occurred in the upper watershed and had a dramatic effect on the watershed. There was concern at the time that ESA-listed fish species would be negatively affected by the 2001 and 2003 fire effects. However, bull trout and spring Chinook redd counts show that populations have been maintained at pre-disturbance levels and the distribution of redds has slightly expanded to take advantage of new habitat created by the landslides. This observation is supported by research on post-fire effects on anadromous fish populations in the John Day Subbasin in Oregon where fish populations were maintained or possibly enhanced following wildfire, landslides, and debris torrents (Howell, 2006).

The quality of habitat in the lower Chewuch River has been reduced in places by road embankments, dikes and riprap that block access to potential high quality, off-channel rearing areas, and late summer irrigation withdrawals. Late-summer low-flow issues are being addressed by irrigators in the Chewuch watershed (personal communication with Greg Knott, Reclamation’s Methow Subbasin Liaison). On the National Forest and WDFW lands, if left unmanaged, recreation in riparian areas has the potential to degrade stream banks and reduce LWD recruitment potential to the river. Recreationists often construct “play dams” that can block salmon and bull trout upstream migration during summer low flows. The Respect the River program has been in place since 1994 and has been used to reduce the effect of recreation on riparian and aquatic habitat by physically manipulating recreation sites to limit vehicle access to stream banks and by contacting visitors to share information about fish and riparian areas.

Key uses by ESA-listed fish and other species of concern:

- Spring Chinook spawning, rearing and migration to upstream spawning areas
- Steelhead spawning, rearing to upstream spawning areas
- Bull trout migration to and from upstream spawning areas
- Juvenile downstream migration and rearing

4. DEWATERING REACHES

During drought years, certain reaches of the river within the assessment area naturally go dry from August to October and sometimes freeze from December through February. The reaches that go dry during low-flow years expand in length during extreme drought years. The ability of salmon to survive during dewatering periods is not fully understood. Dewatering would be expected to impede or at a minimum delay salmon migration to upstream spawning grounds in drought years. Juveniles may be able to tolerate the dewatering if LWD is present that creates holding pools that do not dry out. Areas with springs may also be able to sustain enough flow for salmon to survive. Redds may be able to survive if the water table is still high enough to provide oxygen even though the riverbed is not visually flowing. Caldwell and Catterson (2005) noted that Gorman (1899) observed in 1898 in summer and early autumn some reaches of the Methow River disappear, notably just downstream of the Lost River confluence during October. Although irrigation diversions were already in place by this time, this notation suggests dewatering was a natural occurrence in some reaches.

Some studies have indicated that dewatering may be exacerbated by water diversions, thus increasing the amount of time the river goes dry relative to natural conditions. Caldwell and Catterson (1992) note the susceptibility of the Upper Methow to wells:

> "…the upper level of the groundwater aquifer is the same as the surface water level in the Methow River. If the water depth of the Methow River is one foot and the groundwater aquifer drops one foot due to pumping of wells, then the Methow River is dry even though a large quantity of water is flowing downstream through the gravels under the bed of the Methow River."

Caldwell and Catterson also note that Golder (1991) found well levels rose 10 to 25 feet in the Upper Methow in one-to-two-week periods from an increase in river flow indicating high conductivity between groundwater and river. Removal of riparian forests could also exacerbate the extent and length of time that dewatering occurs by accelerating bank erosion and channel widening within the active floodplain which could lead to a loss of pool habitat (Chamberlin et al., 1991). Removal of stream side forests also reduces large wood recruitment and the formation of scour features that provide cover and refuge for aquatic life during low flow periods.

One dewatering area that has been of interest to stakeholders to further understand is in the upper portion of the Methow River assessment area between Lost River (RM 75) and the Weeman Bridge (RM 61). This area was further researched to better understand the natural potential for dewatering based on available literature and anecdotal information. Flow measurements were also done to look at the longitudinal increase in flow downstream of the Weeman Bridge. The documentation suggests this reach does dewater in some (not all) years during low flow periods in late fall through a portion of the winter (unless rains bring flow back up). The longitudinal extent and duration of dewatering varies from year to year depending on flow conditions (wet or dry year). A spring at Suspension Creek at RM 64.5 helps mitigate for the dewatering and can keep pools wetted between the spring and the Weeman Bridge. More detailed documentation on the dewatering is listed below.

A key consideration for restoration or protection within the dewatering reach is to

- Protect the timing of dewatering so that the dewatering window is not extended into the June-July migration for spring Chinook and bull trout and into the juvenile steelhead emergence window. Riparian forests provide the root strength to stabilize banks, maintain a deeper thalweg and reduce channel widening — these forests also provide shade to keep water cooler and wood that helps to define the channel and provide deep scour holes for refuge as the water drops.
- Locate and protect springs and pools in the reach that maintain flow through the dewatering window or that are dewatered for a short period of time — these are important refuge areas. One very important area is the Early Winters alluvial fan — it maintains stream flow and provides for spring Chinook spawning into the mainstem Methow River and within Early Winters Creek.

4.1 AQUIFER EXCHANGE WITH RIVER

Konrad et al. (2003) describes the hydrogeology of unconsolidated sediments that fill the Methow River valley, the quality of groundwater and surface water, and exchanges between groundwater and surface water for the mainstem Methow and the Twisp River (see Appendix M). The assessment notes the following:

- The mainstem Methow River is a losing reach (supplies water to the aquifer at low flows rather than the aquifer providing water to the river) between RM 75 (Lost River) to RM 65.5 (just upstream of Goat Creek).
- At Goat Creek (RM 65.5) the Methow switches to a gaining reach that extends downstream to the confluence with the Chewuch River (RM 51).

This indicates there is a natural tendency for the river to be subject to dewatering during low-flow periods between Lost River and Goat Creek.

4.2 EXTENT AND DURATION OF DEWATERING

Anecdotal information was used to document the actual occurrence of the Methow River dewatering in this area. The reach noted to dewater corresponds to the USGS losing reach between Lost River and Goat Creek, but also extends farther downstream to a maximum location of RM 61 at the Weeman Bridge. However, the extent of the dewatering varies year to year depending on how low the base flow gets.

The timing of dewatering allows for steelhead spawning, incubation and emergence within the dewatered reaches. Timing of dewatering also allows for spring Chinook and bull trout migration into spawning areas in Early Winters Creek, West Fork Methow River, and into very high quality spawning areas in the Lost River. Downstream migration of post-spawning bull trout takes place when fall rains restore surface flow. As the reach dewaters there is a high level of mortality to fish in residual pools that were not able to escape the lowering tide. Major predators are other fish, birds and garter snakes.

There is some anecdotal speculation among local residents that some fish may survive in the intergravel spaces under the bed of the river. This would be an interesting investigation because surface fines are at low levels and there does appear to large interstitial spaces between river cobbles. There are biological benefits the dry river bed. The water that disappears into the river bed at the confluence of the Lost River and West Fork Methow River re-emerges downstream below Mazama as strong springs that are nicely cooled to the earth's temperatures and are possibly recharged with nutrients from the hyporheic chemical and ecological interactions. These springs provide very high quality habitat for fish with moderated temperatures that are beneficial in the summer and the winter.

Anecdotal information was also used to estimate the amount of years the reaches dewater:

- The reach from Lost River (RM 75) to Mazama (RM 64.4) dewaters about 90% of years during low flow periods.
- The reach from Mazama (RM 64.4) to Weeman Bridge (RM 61) dewaters roughly 75% of the years. A natural spring at the Suspension Bridge near RM 64.5 maintains steady flow (amount unknown) and there are often pools that maintain water in the dewatered reach between Mazama to Weeman Bridge even in dry years.
- Usually once the river dewaters it stays dry through the winter until flow values rise. The winter of 2005 to 2006 was an exception and heavy rains brought the river back to the surface in November and it has maintained flow since this time.

Flow measurements were taken in October 2005 and March 2006 to document how much flow the river gains and over what distance downstream of the Weeman Bridge (Figure F– 1). The data indicate the river recovers fairly quickly from the dewatered reach. During one measurement in March the flow in Hancock Springs, located just downstream of Weeman Bridge, was noted to provide 9 of about 60 cfs of total river flow. More measurements are needed to fully understand the dynamics of the trend relative to dry and wet hydrologic regimes.

Additional literature references found on dewatering occurrences are provided below. Caldwell and Catterson (1992) noted reaches of the Upper Methow tend to go dry in the following sequential order:

1. Downstream of Gate Creek (RM 72) for almost 1.5 miles to RM 70.5

2. Mazama gage reach (~RM 67.5); USGS gage records often show no flow during low-flow periods
3. Lost River reach upstream of its confluence with the Methow River at RM 75
4. Reach upstream of Gate Creek (RM 72)

During Yakama Indian Nation spawning surveys in two drought years (1987 and 1988), observations showed 14.4 miles of dry river on the Methow from 2.8 miles downstream of Mazama Bridge (RM 64.4 in present assessment river miles) to 4 miles upstream of Lost River confluence (RM 75) except for pools at Lost River and Early Winters Creek confluence.

During the Reclamation river channel survey (October 2005), it was noted that the riverbed was dry (subsurface) between RM 69.75 (Early Winters confluence) to RM 72.75 (¾-mile upstream of Gate Creek confluence). It was noted by locals that 2005 was a drier than normal year.

Andonaegui (2000) noted that the Goat Creek from Goat Creek Road Bridge to the mouth also commonly experiences dewatering during August and September. Salmon spawning surveys in 1987 for Yakama Indian Nation found additional dry riverbeds. These dry river beds were located at:

- Lost River from RM 7.1 to 11.7 (Monument Creek to Drake Creek)
- Twisp River at Poplar Flats campground (RM 23.4)
- Mouth of Wolf Creek (confluence with Methow at RM 54)

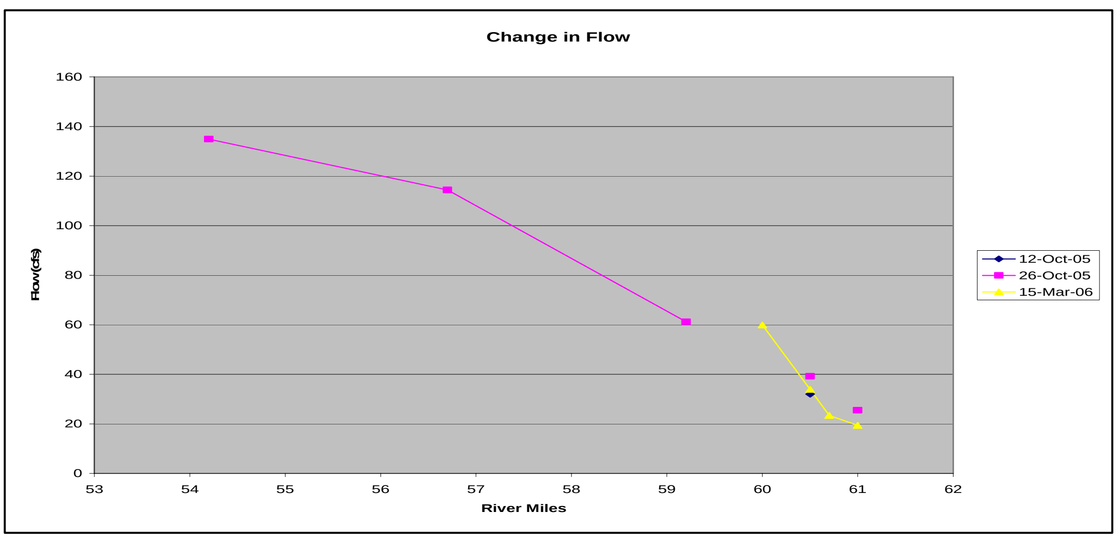

Figure F– 1. Change in flow along Methow River channel downstream of Weeman Bridge during low flow conditions.

5. WATER TEMPERATURE

During low flow periods in late summer and early fall, river water temperatures naturally rise as air temperature increases and river flow reduces. Fires can exacerbate water temperatures within the burn area. The effect on water temperature can sometimes be carried into downstream river sections, particularly in smaller streams and/or during base flow periods. The river bed can also freeze, which can result in flow barriers. One foot of ice was noted for 0.5 mile upstream and downstream of the Mazama gage in certain years, and zero flow also at Gate Creek on Jan 30, 1992, by observation. (Flows with no ice noted at Lost River confluence, Mazama Bridge, and Weeman Bridge on Jan 30, 1992.) Periods of high water temperature are a concern for salmonid survival and are discussed in this section.

5.1 METHOW DATA

A total of 40 temperature monitors were deployed throughout the Methow Subbasin and in major tributaries to the Methow River in the summer of 2005 to determine if there were any temperature influences on habitat during low-flow periods (see Appendix I "Water Temperature Assessment"). Overall, the Methow River has a trend of increasing temperature in the downstream direction (Figure F–2). There is a large range of temperature fluctuation measured between the maximum temperatures recorded during the peak sunlight hours and the minimum temperatures recorded at night. Natural spring locations tended to correlate with a localized decreased temperature in the main channel. Both the Chewuch River and the West Fork Methow River drainages had recent fires and very low-flow conditions during the measurement period. This resulted in higher temperatures that raised the Methow River water temperature near the confluence.

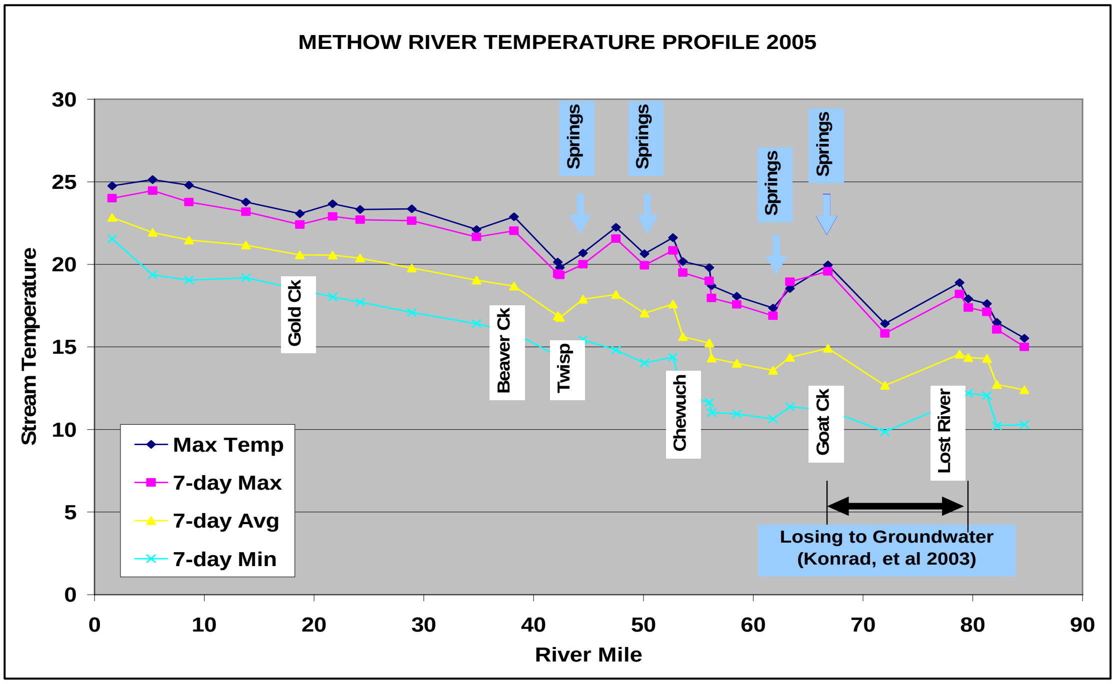

Figure F–2. Methow River – Longitudinal thermal profile showing 7 day maximum temperature, 7-day average maximum, 7-day average, and 7-day average minimum water temperatures for July and August 2005. Losing indicates loss of flow in river to groundwater.

5.2 TWISP AND CHEWUCH DATA

Water temperature data collected by Pacific Watershed Institute (PWI, 2003; Smith et al., 2000) included TIR remote sensing in August 2001 and in-stream temperature monitor data. Both the Twisp and Chewuch showed overall warming trends in the downstream direction (Figure F–3 and Figure F–4). Both rivers had reach-scale variation in this trend. Springs and groundwater seeps not identified on USGS 7.5 minute quads had significant influence on cooling local temperatures. Cold-springs and sub-surface processes appear to play a larger role in defining stream temperature patterns than surface water. The Twisp and Chewuch temperature reports focused on large-scale patterns; more detailed analysis may be needed to assess temperature issues at a particular project site.

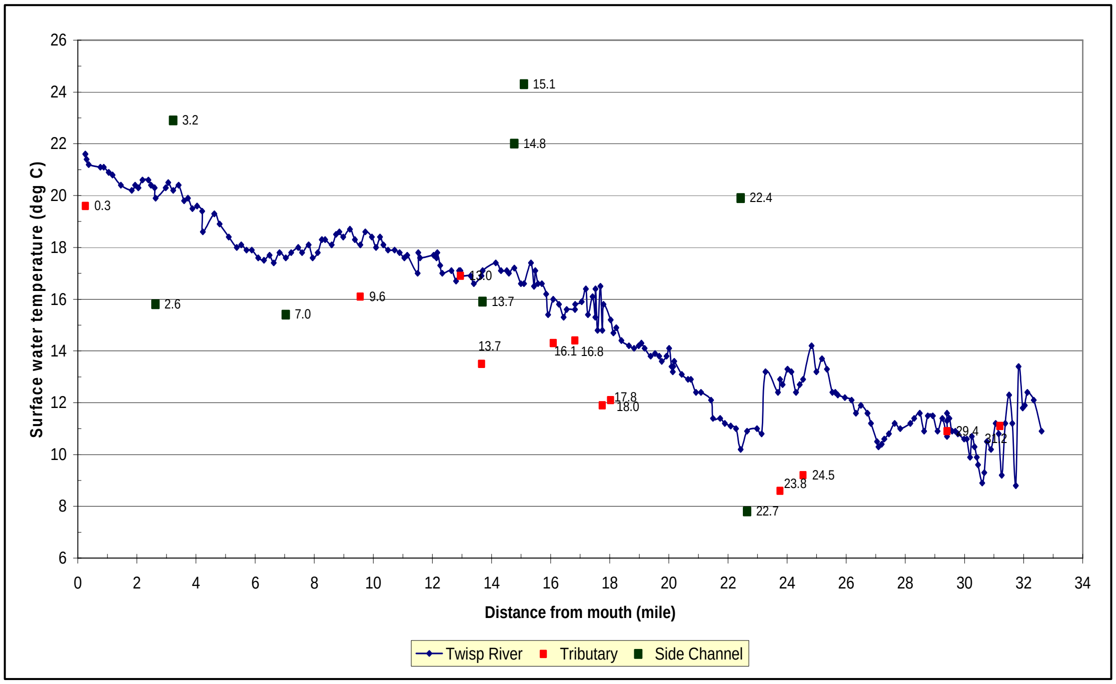

Figure F–3. Twisp River – Longitudinal thermal profile surface-water temperature from mouth to RM 33 (PWI, 2003). Plot also includes median temperature of surface water inflows (tributaries and canals) and off-channel features (side-channels and backwaters).

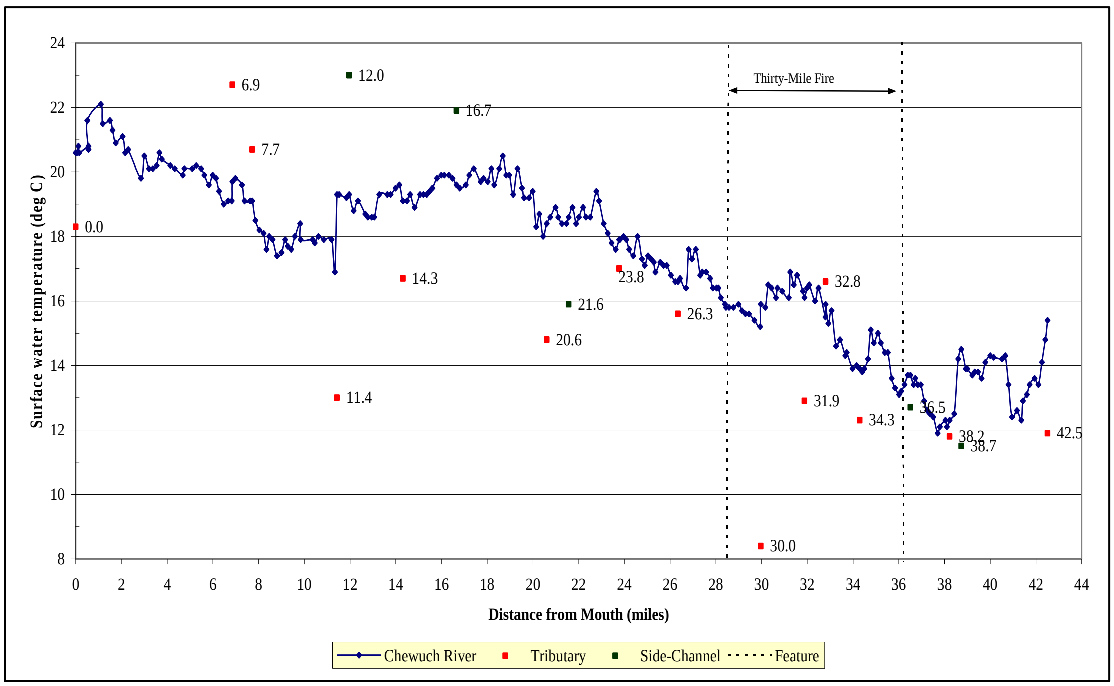

Figure F–4. Chewuch River – Longitudinal thermal profile from mouth to RM 44 (Smith et al., 2000). Plot also includes median temperature of surface water inflows (tributaries and canals) and off-channel features (side-channels and backwaters).

5.3 THERMAL TOLERANCES OF SALMONIDS

The range of water temperatures tolerated by juvenile and resident salmonids is variable but most species are at risk when temperatures exceed 23-25 ºC (J. Molesworth, 2006, personnel communication). The lower lethal range for Chinook is 0.8 ºC and the lower lethal limit for steelhead is 0 ºC; the upper lethal limit for these two species is 26.2 ºC and 23.9 ºC for steelhead and the preferred temperature for these species is 12 to 14 ºC (Bjornn and Reiser, 1991). High water temperatures are easier for fish to tolerate if they are acclimated to them. Temperatures above lethal levels may be tolerated for brief periods, particularly if there is thermal recovery and/or refugia such as cold water sources (Spence et al., 1996). In small streams where temperatures reach lethal levels, salmonids can thrive if the exposure is of short duration, and returns to optimum levels (Bjornn and Reiser, 1991).

The temperature profile for the Methow shows the 7-day maximum temperatures; these occur for short periods of time during the hottest days. The average minimum temperature gives an idea of the temperature recovery at night and diurnal fluctuation of temperature in July and August — the warmest time of the year. The profile also shows that there are significant groundwater sources that have a cooling influence on the river and would provide localized thermal refugia when temperatures rise to over 20 ºC.

5.4 APPLICATION OF DATA TO REGIONAL HABITAT CRITERIA

The Middle Methow, Upper Methow, Twisp, and Chewuch valley segments were broken into biological subreaches based on tributaries and temperature monitor locations. Known steelhead, spring Chinook, and bull trout use (spawning, rearing and, migration) was identified within each subreach. The new Methow data and recently collected data on Chewuch and Twisp (USFS) were compared by USFS biologists for this geomorphic assessment to a temperature indicator rating based on National Marine Fisheries Service (NMFS or NOAA Fisheries) and US Fish and Wildlife Service (FWS); value criteria was made for each type of fish use (spawning, rearing and migration). Most of the habitat area in the three rivers was found to have a “not properly functioning” rating (NMFS) and “functioning at an unacceptable risk” rating (FWS) for stream temperatures. However, stream temperature was only one of many stream attributes used by NMFS and FWS to help determine the conditions of habitat used by ESA-listed fish species. The numeric values of the attributes are not meant as absolutes, but are presented as a diagnostic tool to promote discussions of differences between the data collected and values suggested by NMFS and FWS.

Riparian vegetation, stream morphology, hydrology, including surface and groundwater interactions, climate, geological location such as elevation and aspect all influence stream temperature (WDOE, 2003). Development of individual restoration projects in the Chewuch, Twisp, and mainstem Methow will consider how temperature in the project reach is affected by the different variables, if the observed temperatures are functioning at natural capability and, if appropriate, what types of restoration activities may possibly improve temperature conditions. Areas strongly influenced by groundwater tend to have more favorable temperatures and could provide the core area from which restoration projects proceed in any given reach. Projects that improve groundwater and surface water exchange and stream shade, and access to thermal refuge areas could be extremely beneficial in any of the areas where high temperatures are observed. Projects that provide shade to un-shaded off-channel areas or tributaries could be beneficial to help maintain or improve thermal refuge areas in the Methow River and lower segments of the Twisp and Chewuch rivers.

6. REFERENCES

IN TEXT	FULL CITATION
Andonaegui, 2000	Andonaegui, C. 2000. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48: Final Report.* Washington State Conservation Commission, 232 p.
Bjornn and Reiser 1991	Bjornn, T.C. and Reiser, D.W. 1991. "Habitat Requirements of Salmonids in Streams." *American Fisheries Society Special Publication 19:83-138.* Meehan, W.R., ed.
Caldwell and Catterson 1992	Caldwell, B. and Catterson, D., 1992, *Methow River Basin fish habitat analysis using the instream flow incremental methodology:* Washington Department of Ecology, Olympia, WA. Publication No. 92-82, 196 p.
Chamberlin et al. 1991	Chamberlin, T.W., Harr, R.D., and Everest, F.H. 1991. "Timber harvesting, silviculture, and watershed processes —Influences of forest and rangeland management on salmonid fishes and their habitats" in *American Fisheries Society Special Publication, V-19,* p.181-205.
Golder 2005	Golder Associates, Inc., 2005, *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Gorman 1899	Gorman, M.W. 1899. *The eastern part of the Washington Forest Reserve, Part V*: in *US Geologic Survey, 19th Annual Report of the Survey of Forest Reserves.*
Howell 2006	Howell, Phillip. 2006. "Effects of Wildfire and Subsequent Hydrologic Events on Fish Distribution and Abundance in Tributaries of North Fork John Day River." in *North American Journal of Fisheries Management* 26:983-994.
Humling and Snow 2006	Humling, M. and Snow, C. 2006. *Spring Chinook spawning ground surveys in the Methow River Basin in 2005.* Washington Department of Fish and Wildlife, Olympia, WA. Report prepared for Public Utility District Number 1 of Douglas County.

IN TEXT	FULL CITATION
Kanda et al. 2002	Kanda, N., Leary, R.F., and Allendorf, F.W., 2002, "Evidence of introgressive hybridization between bull trout and brook trout" in *Transactions of the America Fisheries Society*, Vol. 131, no. 4, p. 772-782.
Konrad et al. 2003	Konrad, C.P.; Drost, B.W.; and Wagner, R.J. 2003, *Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington*. US Geological Survey Water-Resources Investigations Report 03-4244, 137 p.
MVRD 2007	Methow Valley Ranger District, revised June 2007, *Sediment Monitoring Report: 2000 to 2006, Chewuch River and Twisp River*. Winthrop, WA.
PWI 2003	Pacific Watershed Institute, 2003, *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.
Roni et al. 2002	Roni, P., Beechi, T.J., Bilby, R.R., Leonetti, F.E., Pollock, M.M., and Pess, G.R. 2002, "A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds." in *North American Journal of Fisheries Management*, Vol. 22. p. 1-20.
Snow 2007	Snow, Charlie. 2007. Personal communication, February 2, 2007. Washington Department of Fish and Wildlife, Fish Program/Science Division/Methow Field Station.
Snow and Frady 2006	Snow, C. and Frady, C. 2006. *September hatchery and natural production report.* Washington Department of Fish and Wildlife, Fish Program Science Division, Methow Field Station, October 6, 2006.
Spence et al. 1996	Spence, B.C.; Lomnicky, G.A.; Hughes, R.M.; and Novitzki, R.P. December 1996. *An Ecosystem Approach to Salmonid Conservation.* TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR. See at http://www.nwr.noaa.gov/Publications/Reference-Documents/ManTech-Report.cfm (as of 11/30/07)

IN TEXT	FULL CITATION
Stanford and Ward 1993	Stanford, J.A., and Ward, J.V., 1993, “An ecosystem perspective of alluvial rivers – Connectivity and the hyporheic corridor” in *Journal of the North American Benthological Society*, v. 12, no. 1, p. 48-60.
WDOE 2003	Washington Department of Ecology. 2003. “Wenatchee National Forest Water Temperature Total Maximum Daily Load, Technical Report.” Publication Number 03-10-063.

APPENDIX G –

GEOMORPHIC MAPPING AND ANALYSIS

Appendix G provides documentation on the methods and findings for geomorphic mapping accomplished in the assessment area. The determination of the low surface is described first, which represents the extent of potential protection and restoration projects. Results from GIS mapping of channel change and bank erosion are presented based on repeat historical aerial photography. Evaluation of impacts from human features on channel and floodplain width is also provided.

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1. LOW SURFACE DEFINITION, DELINEATION, AND BOUNDARY COMPOSITION

1.1 DEFINITION OF LOW SURFACE

The "low surface" includes the main channel and the floodplain area adjacent to it. The low surface includes present secondary channels, overflow channels, and the area between all of these channels. This is the area where flood flows are most likely to occur, although flows may extend beyond the low surface during large floods. The low surface also includes historical main, secondary, and overflow channels. Geomorphic surfaces of several relative heights are present within the low surface, and these probably represent surfaces of several different ages.

Deposits within the low surface are primarily of two types: channel deposits and floodplain (or overbank) deposits. The deposits are composed of sediments from silt to boulder; however, the channel deposits are predominantly sand through cobbles, and the overbank deposits are sand and silt. The unconsolidated character of these deposits makes them highly susceptible to erosion. The sources for the deposits within the low surface are reworked older fluvial deposits, glacial deposits, alluvial-fan deposits, and landslide deposits.

The majority of the low surface is frequently inundated. The maximum height of geomorphic surfaces within the low surface is about 3 m, but most surfaces within the low surface are <1 to 2 m high. The low surface adjacent to the active main channel and some secondary channels are unvegetated. The low surface elsewhere is commonly vegetated with alders and willows, and a few small conifers.

1.2 DELINEATION OF THE LOW SURFACE

The low surface was delineated primarily using the main, secondary, and overflow channels (mapped on aerial photographs taken in 2004; Figure G–1), and natural geomorphic boundaries, such as terrace scarps, that were identified on 1:12,000-scale, stereo aerial photographs taken in 2000 or in the field.

The area delineated as the low surface was checked using the historical aerial photographs to assure that the low surface encompasses historical areas that appear to have had channels and riparian vegetation were included (Figure G–2). The historical channels were mapped on aerial photographs taken in 1945, 1948, 1954, 1964, 1974, and 1994, when available, on historical maps that date from 1893, 1895, 1900, 1905, and 1915, and on topographic maps that date from the middle 1980s.

Some surfaces with channels that are visible on the historical aerial photographs were not included, because these channels are poorly defined and evidence that they were connected to the main channel historically could not be detected. The surfaces with the visible channels are in some place 15 to 20 feet above the present active channel.

These surfaces are interpreted to be post-glacial, and the channels are probably remnants of channels that were active a few thousand to about 10,000 years ago. They do not appear to be related to present or historical channels. Consequently, these areas were not included in the low surface. In places, where more detailed mapping was done, these surfaces are shown as an intermediate surface. Elsewhere, these surfaces are included with the glacial deposits.

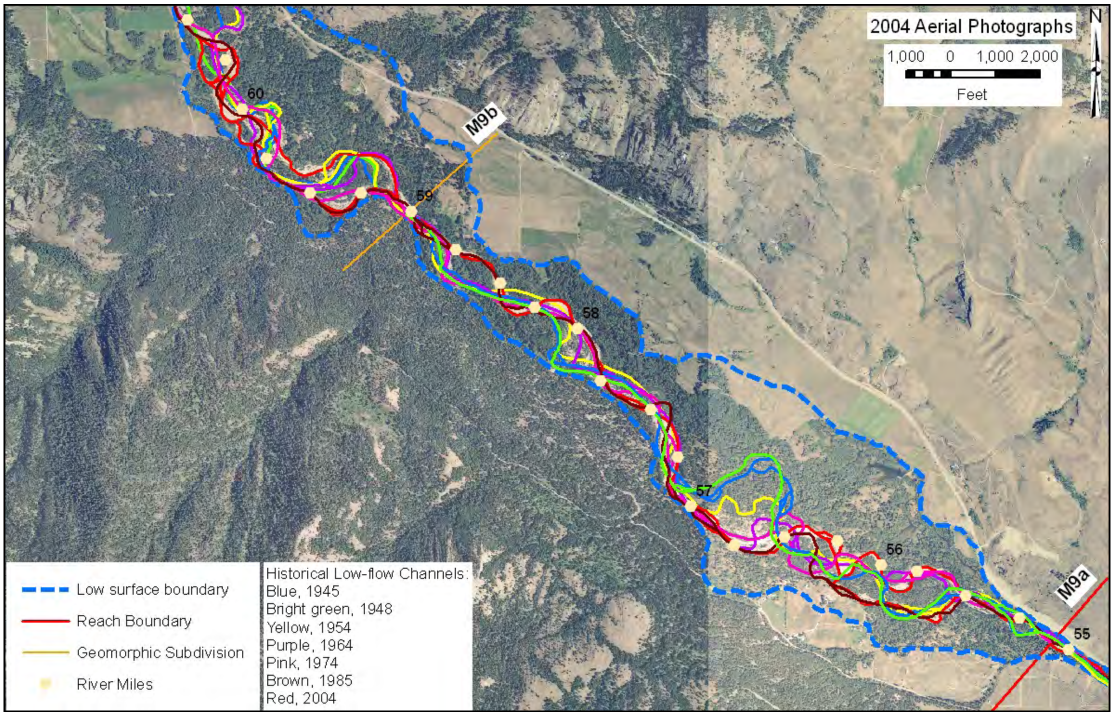

Figure G–1. An example of the low surface relative to present and historical channels for geomorphic subdivision M9a (Methow RM 55–59).

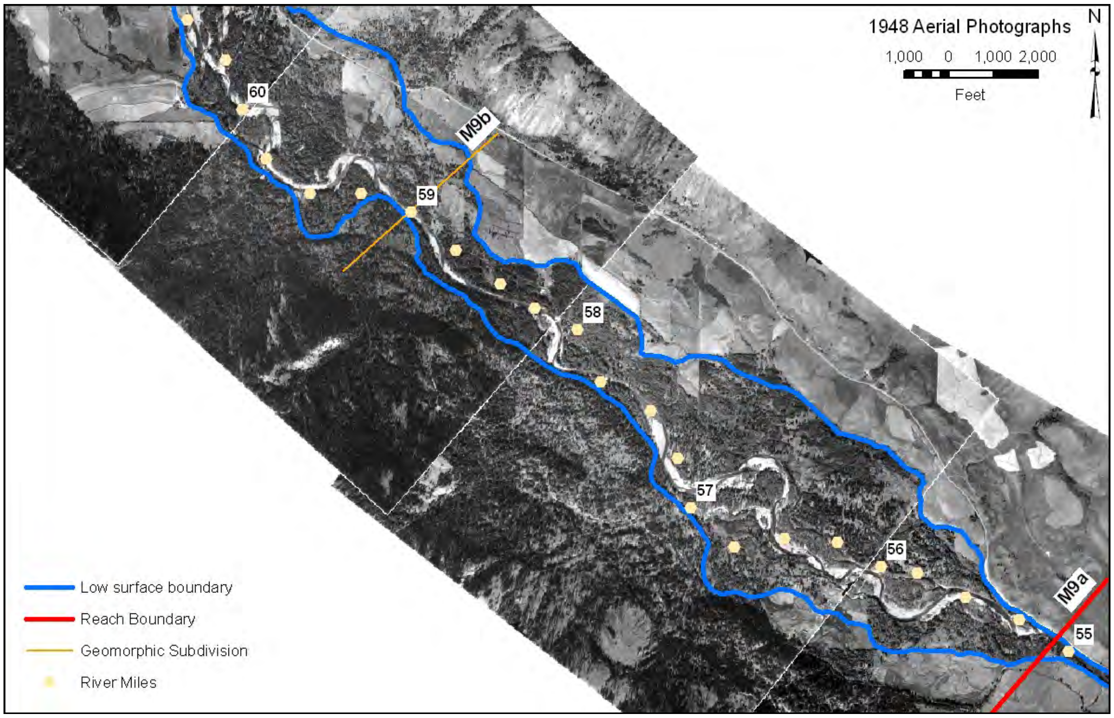

Figure G–2. The 1948 aerial photograph for the geomorphic subdivision M9a (Methow RM 55–59).

Once delineated, the low surface was compared to previously mapped floodplain areas to see if the low surface included these areas or if significant areas had been excluded. Beck and Associates (1973) and Norman Associates (1974) mapped a designated floodway and 100-year floodplain for a portion of the Methow River after the 1972 flood (Figure G–3). Both of these areas are included within the low surface. Golder Associates (2005) defined an avulsion hazard zone (zcAHZ) and an extreme hazard zone (zcEHZ) for the Methow River (Figure G–4). The low surface includes the entire zcAHZ and nearly all of the zcEHZ. The Federal Emergency Management Agency (FEMA) defined 100-year and 500-year floodplains for the Methow, Twisp, and Chewuch rivers (Figure G–5). The low surface includes most of these two areas, although in a few places small areas extend beyond the low surface.

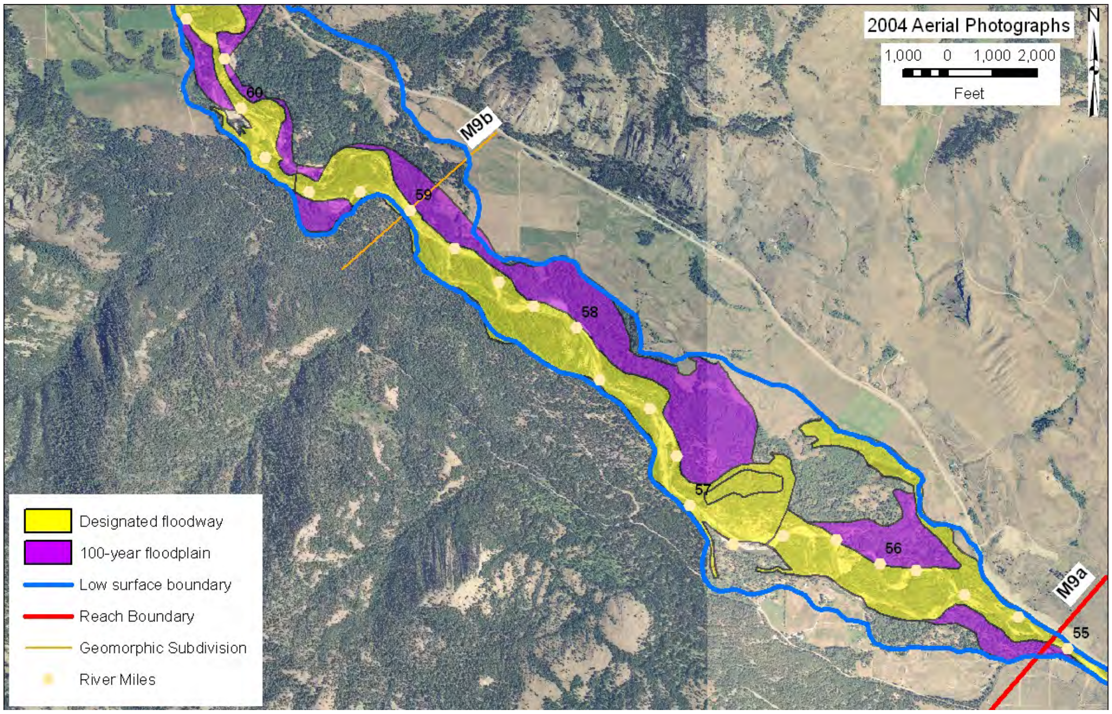

Figure G–3. The designated floodway and 100-year floodplain defined by Beck (1973) and Norman (1974) and the low surface for geomorphic subdivision M9a (Methow RM 55–59).

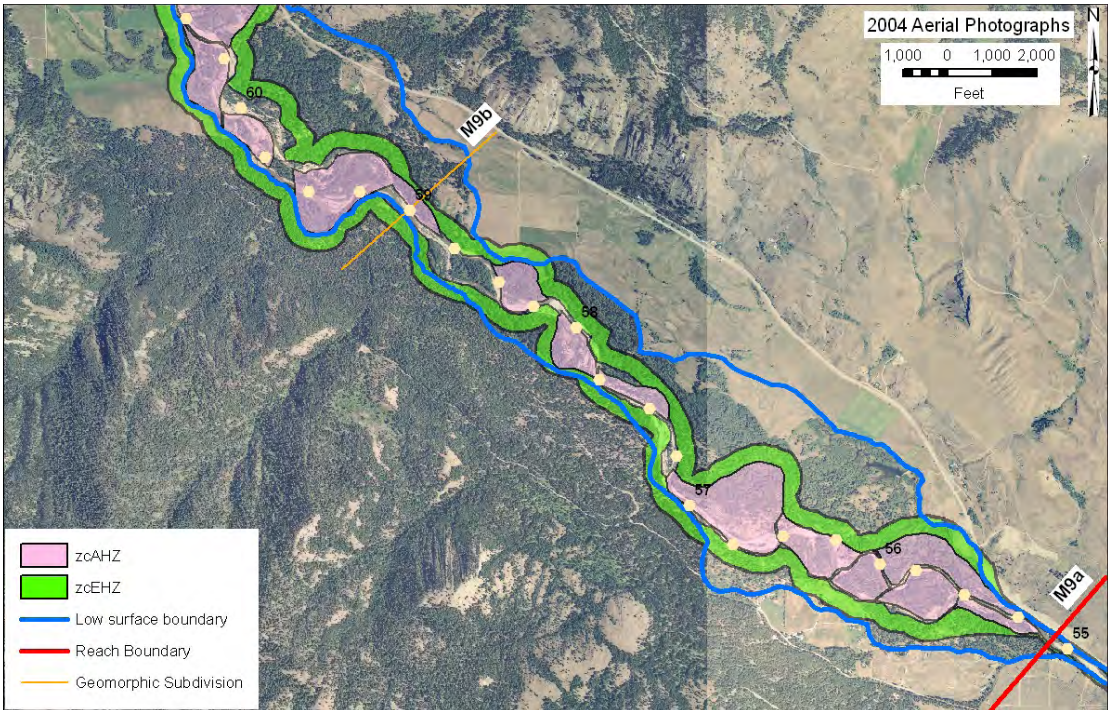

Figure G–4. The avulsion hazard zone (zcAHZ) and the extreme hazard zone (zcEHZ) defined by Golder (2005) compared to the low surface for geomorphic subdivision M9a (Methow RM 55–59).

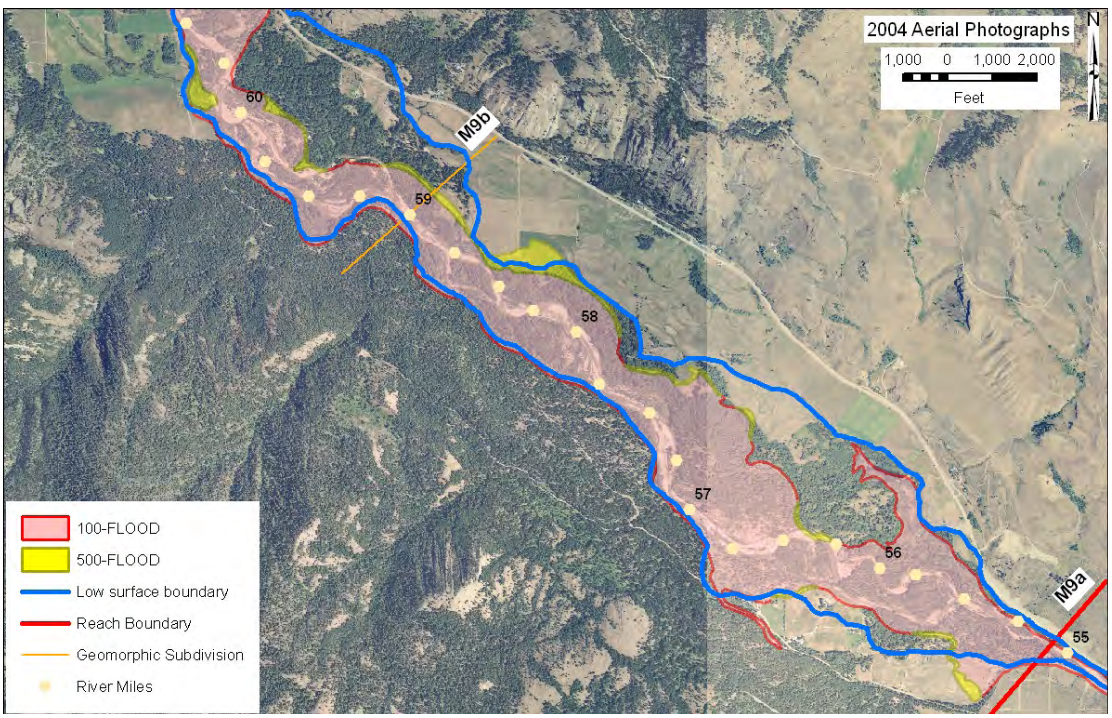

Figure G–5. The 100-year and 500-year floodplains defined by FEMA and the low surface for geomorphic subdivision M9a (Methow RM 55–59).

1.3 NATURAL COMPOSITION OF LOW SURFACE BOUNDARY

1.3.1 METHODS

The geologic units along the boundary of the low surface were determined from the geologic mapping. Four geologic units have been mapped: alluvial-fan deposits, bedrock, glacial deposits, and landslide deposits. The intermediate surface that is shown on the geologic map has been combined with glacial deposits in this analysis, because the intermediate surface was mapped only in selected areas. The boundaries of the left and right (looking downstream) boundaries were mapped for each geomorphic reach in Arc (Figure G–6). The lengths of each unit were calculated in Arc. The lengths were used to calculate the percent of each geologic unit along the low surface boundary in each geomorphic reach.

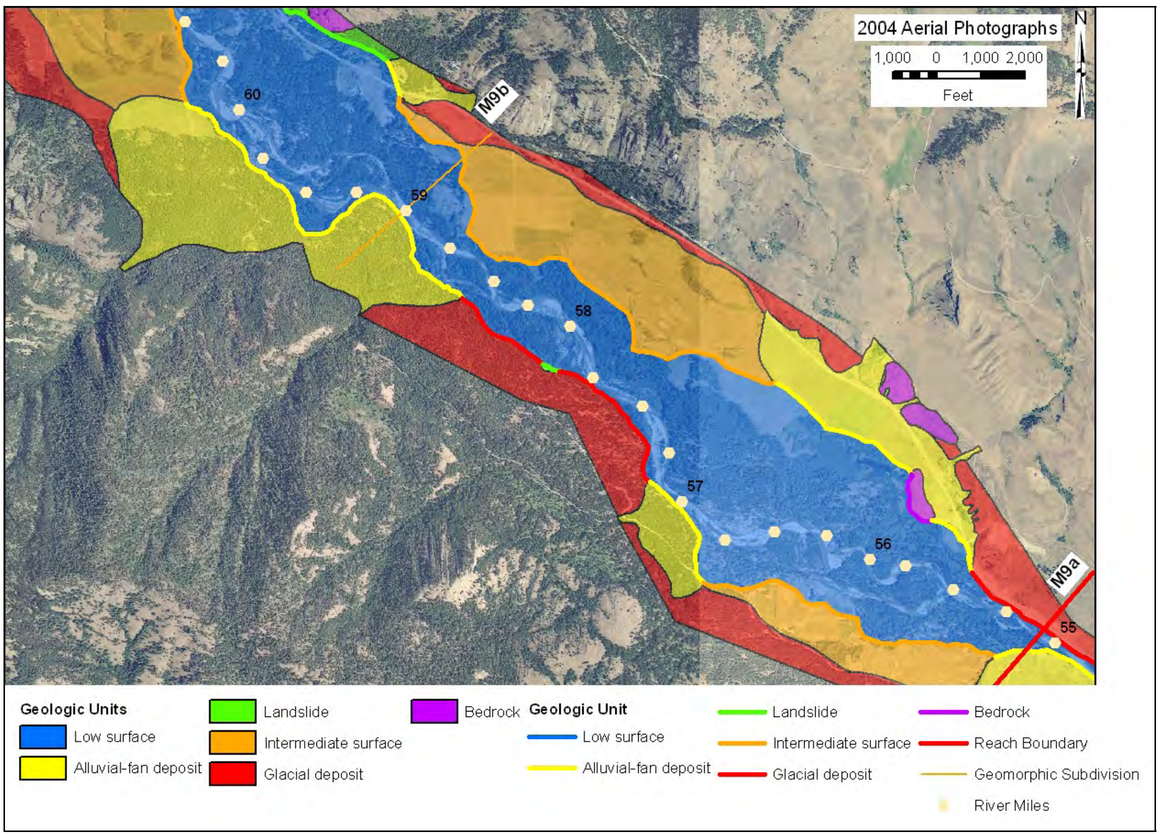

Figure G–6. Geologic units along the low surface boundary for geomorphic subdivision M9a (Methow RM 55–59).

1.3.2 INTERPRETATION

Methow River

For the Methow River, the low surface boundary in geomorphic reaches M1 through M7 is dominated by glacial deposits (75% to 95% of the boundary; Figure G–7; Table G-1). Although glacial deposits still form about a half to two-thirds of the low surface boundary in geomorphic reaches M8 through M11, alluvial-fan deposits compose between 21% and 35% of the boundary in these upstream reaches. Alluvial-fan deposits form a few percent of the low surface boundary in geomorphic reaches M1, M2a, and M2b. Bedrock forms between about 10% and 20% of the low surface boundary in geomorphic reaches M2c (9%), M3 (19%), M4 (10%), M5 (14%), and M11 (17%). It forms a few percent of the low surface boundary in geomorphic reaches M2a (7%), M7 (2%), M9a (4%), and M9b (2%). The areas with bedrock are the only places where the low surface is naturally constrained. Landslide deposits are present along the low surface boundary in only three geomorphic reaches, M1, M9b, and M11, where they compose about 10% of the boundary. The limited areas of landslide deposits suggest that they do not contribute significant sediment overall, but could be important locally.

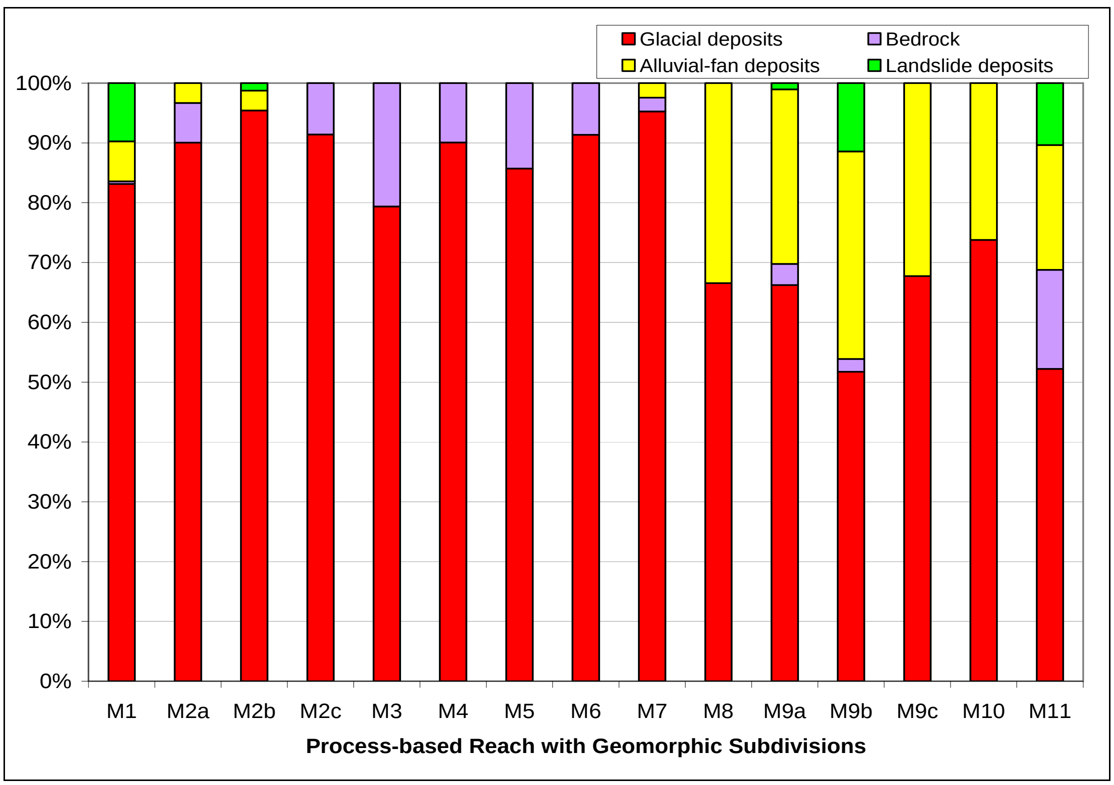

Figure G–7. Methow River – Geologic units along the low surface boundary shown by geomorphic subdivision.

Table G–1. Methow River – percentages of each geologic map unit along the boundary of the low surface by geomorphic subdivision.

Reach	Alluvial-fan deposit	Landslide	Low surface	Glacial deposit	Bedrock
M1	7	10	0	83	0
M2a	3	0	0	90	7
M2b	3	1	0	95	0
M2c	0	0	0	91	9
M3	0	0	6	75	19
M4	0	0	0	90	10
M5	0	0	0	86	14
M6	0	0	0	91	9
M7	2	0	0	95	2
M8	33	0	0	67	0
M9a	29	1	0	66	4
M9b	35	11	0	52	2
M9c	32	0	0	68	0
M10	26	0	0	74	0
M11	21	10	0	52	17

Chewuch River

For the Chewuch River, glacial deposits or bedrock dominate the low surface boundary in all of the geomorphic reaches except C6, where alluvial-fan deposits dominate (76% of the boundary; Figure G– 8; Table G–2). Bedrock forms and constrains the entire boundary in geomorphic reach C4a. Bedrock forms 40% to 50% of the low surface boundary in geomorphic reaches C2b, C4b, and C5a, so that significant portions of the boundary in these reaches are constrained. Glacial deposits dominate the low surface boundary in geomorphic reaches C1 (85%), C2a (97%), C3a (71%), C4c (66%), and C5b (74%). Alluvial-fan deposits compose between 9% and 22% of the low surface boundary in geomorphic reaches C2b, C4c, C5a, and C5b. Landslide deposits are present along the low surface boundary in only one geomorphic reach, C1, where they compose 5% of the boundary.

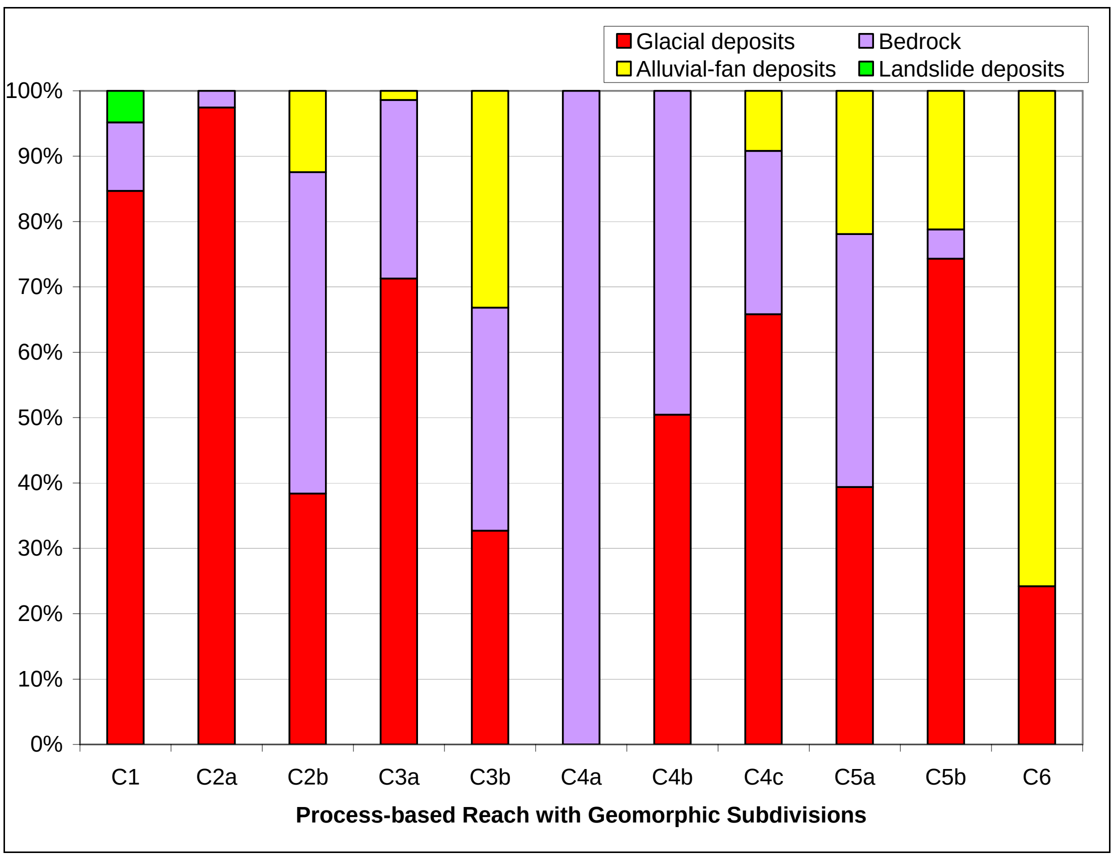

Figure G– 8. Chewuch River – Geologic units along the low surface boundary shown by geomorphic subdivision.

Table G–2. Chewuch River – Percentages of each geologic map unit along the boundary of the low surface by geomorphic subdivision.

Reach	Alluvial-fan deposit	Landslide	Glacial deposit	Bedrock
C1	0	5	85	10
C2a	0	0	97	3
C2b	12	0	38	49
C3a	1	0	71	27
C3b	33	0	33	34
C4a	0	0	0	100
C4b	0	0	50	50
C4c	9	0	66	25
C5a	22	0	39	39
C5b	21	0	74	4
C6	76	0	24	0

Twisp River

For the Twisp River, glacial deposits dominate along the low surface boundary in all of the geomorphic reaches except the two upstream reaches, T6a and T6b, where alluvial-fan deposits dominate (Figure G–9; Table G–3). Glacial deposits form 100% of the low surface boundary in geomorphic reach T1, and form more than 85% of the boundary in geomorphic reaches T2a, T2b, T3b, and T3c. The highest percent of bedrock along the low surface boundary is in geomorphic reach T3a, where it is 31% of the boundary. Bedrock forms up to 10% of the boundary in geomorphic reaches T2b (2%), T3b (3%), T4 (7%), and T5 (10%). Bedrock is not present along the low surface boundary in the other reaches. Other than in geomorphic reaches T6a and T6b, alluvial-fan deposits are present along the low surface in only four other geomorphic reaches: T5 (27%), T3b (13%), T3c (12%), and T2b (4%). Landslide deposits are present along the low-surface boundary in only three geomorphic reaches and compose only a few percent of the boundary in these reaches: T2b (5%), T4 (9%), and T6b (5%).

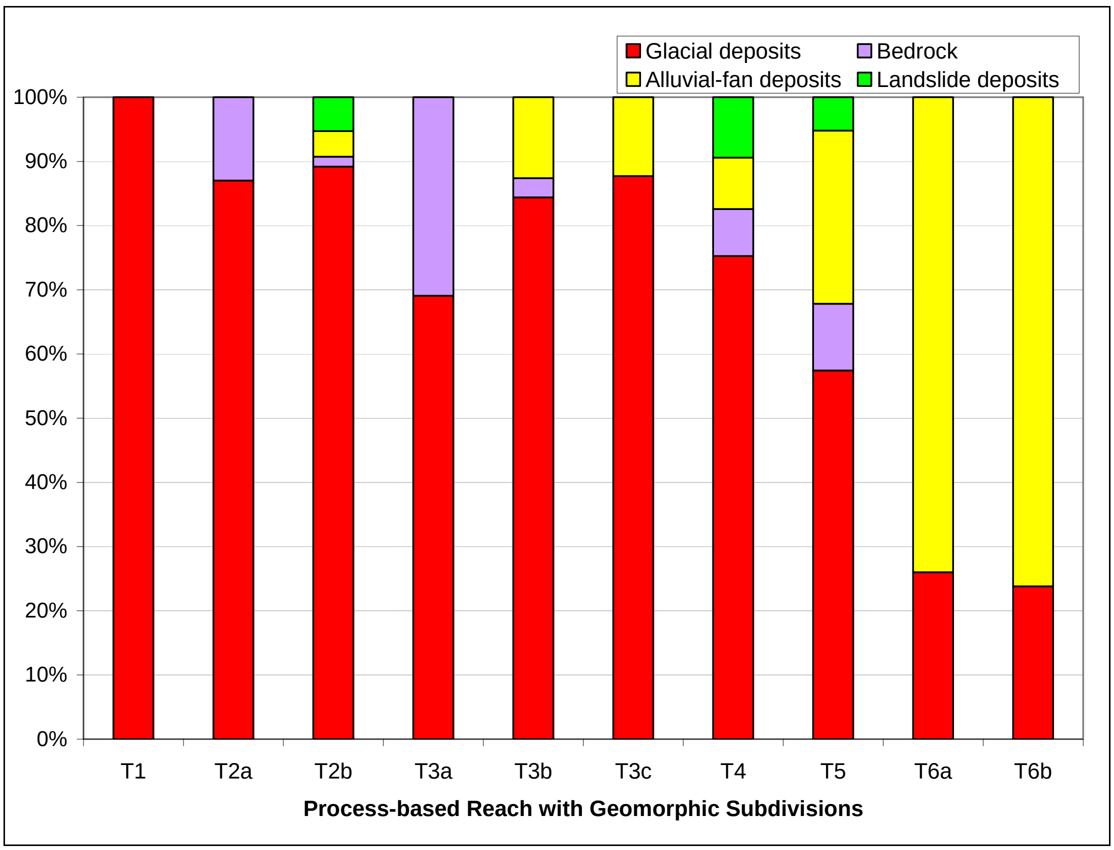

Figure G–9. Twisp River – Geologic units along the low surface boundary shown by geomorphic subdivision.

Table G–3. Twisp River – Percentages of each geologic map unit along the boundary of the low surface by geomorphic subdivision.

Reach	Alluvial-fan deposit	Landslide	Glacial deposit	Bedrock
T1	0	0	100	0
T2a	0	0	87	13
T2b	4	5	89	2
T3a	0	0	69	31
T3b	13	0	84	3
T3c	12	0	88	0
T4	8	9	75	7
T5	27	5	57	10
T6a	74	0	26	0
T6b	76	0	24	0

1.4 HUMAN FEATURES ALONG THE LOW SURFACE BOUNDARY

1.4.1 METHODS

The human features that are present along the low surface boundary were mapped from aerial photographs taken in 2000 and 2004 and from field reconnaissance. All were plotted in Arc by geomorphic reach. Those along the low surface boundary — mostly riprap, levees, and road-bridge embankments —were identified by left or right (looking downstream) boundary. The lengths of the human features along the low surface boundary were calculated in Arc. The lengths were used to calculate the percent of the low surface boundary that is protected by human features in each geomorphic reach.

This analysis is dependent upon the mapping of human features, which are often difficult to see on the aerial photographs because of vegetation cover, primarily, and photograph quality. Consequently, the lengths used here are considered to be minimum values. Additional human features undoubtedly exist along the low surface boundary, but it was beyond the scope of this assessment to do a more detailed assessment of these features.

1.4.2 INTERPRETATION

Methow River

The highest percentage of the low surface boundary that is protected by human features for the Methow River is in geomorphic reach M3, where 57% of the low surface boundary is protected (Figure G–10). Other geomorphic reaches of the Methow River that have relatively high percentages of low surface boundary protected by human features are M8 with 40% human features, M2b with 29% human features, M1 with 27% human features, and M2a with 21% human features (Figure G–10; Table G–4). No human features were mapped in one geomorphic reach: M7.

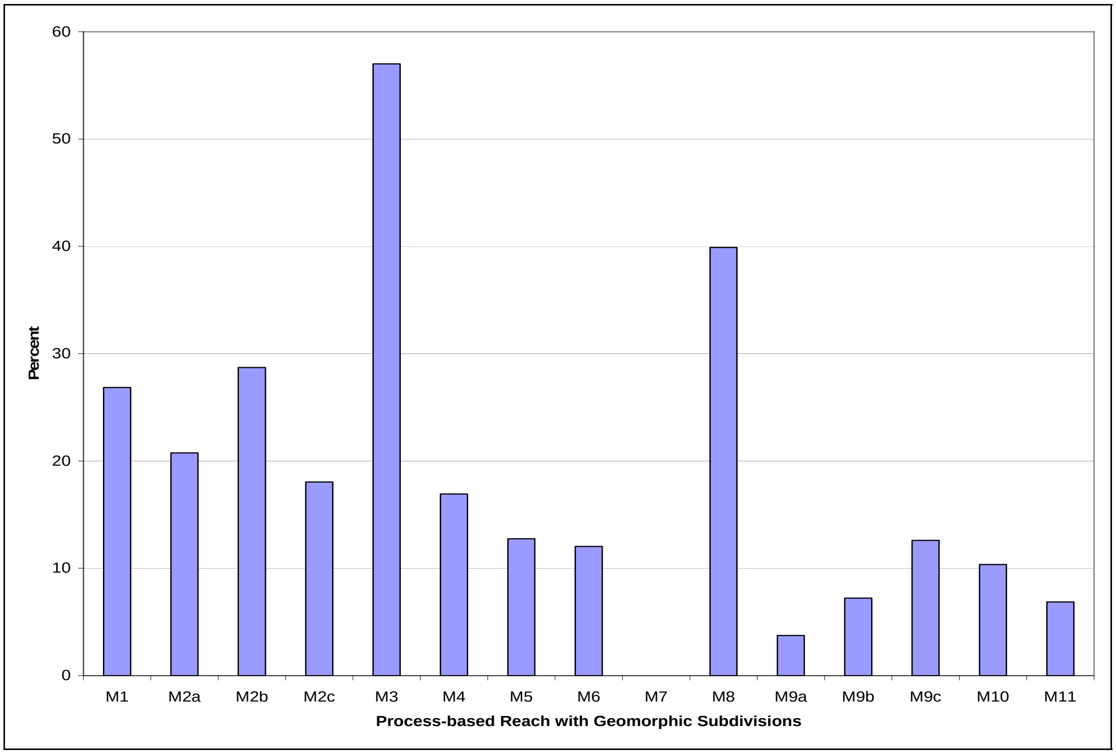

Figure G–10. Methow River – Percent of the low surface boundary (both left and right sides) that is protected by mapped human features by geomorphic subdivision.

Table G–4. Methow River – Percentages of the lengths of the boundary of the low surface that are protected by human features by geomorphic subdivision.

Reach	Percent of the Total Length		
	Left Bank	**Right Bank**	**Both Banks**
M1	22	32	27
M2a	4	41	21
M2b	38	20	29
M2c	8	30	18
M3	69	45	57
M4	22	10	16
M5	3	23	13
M6	24	0	12
M7	0	0	0
M8	44	35	40
M9a	8	0	4
M9b	7	7	7
M9c	22	3	13
M10	3	18	10
M11	14	0	7

The percentages of the low surface boundary that are protected by human features were compared to the percentages of the geologic map units along the boundary for each geomorphic reach. Since bedrock sections are nearly unerodible, the geomorphic reaches with the most bedrock along the low surface boundary might be the ones with the lowest percentages of human protection. However, the correlation is not clear from our mapping.

The geomorphic reach with the greatest percentage of human features, M3, is also the reach with the greatest percentage of bedrock (19%) along the Methow River assessment reach. The low surface boundary in reach M3 is primarily glacial deposits (75%), so most of the boundary is potentially erodible without the protection of human features. Similarly, the geomorphic reach without the protection of human features, M7, is composed mostly of alluvial-fan deposits (95%). The sediment in these deposits may be large enough that they are essentially unerodible by present flows on the Methow River, even if bedrock does not bound the low surface in this reach. Another complication in comparing the lengths of human features along the low surface boundary and the lengths of potentially erodible geologic units is that human features **within** the low surface can limit the present area of the low surface that can be used by the river. Consequently, the river may not be able to access the boundary of the geologic low surface, so that human features are not needed along the boundary to protect against erosion of the boundary.

Twisp River

The highest percentage of the low surface boundary that is protected by human features on the Twisp River is 19%, which occurs in geomorphic reaches T3b and T4 (Figure G–11; Table G–5). Ten percent of the low surface boundary in geomorphic reach T1 is protected by human features. For other geomorphic reaches where human features have been mapped along the low surface boundary, the human features compose only a few percent of the low surface length: 3% for reach T5, 2% for reach T2b, and 1% for reach T3c. No human features were noted along the low surface boundary in the other four geomorphic reaches on the Twisp River.

In the two geomorphic reaches that have the longest lengths of low surface boundary protected by human features, the low surface boundary is primarily glacial deposits (84% and 88%; Figure G–9). Of the four geomorphic reaches for which human features were not mapped along the low surface boundary, two (T3a and T2a) have relatively long sections that are bedrock (31% and 13%, respectively). The other two geomorphic reaches without mapped human features along the low surface boundary (T6a and T6b) have high percentages of alluvial-fan deposits along the boundary (about 75%).

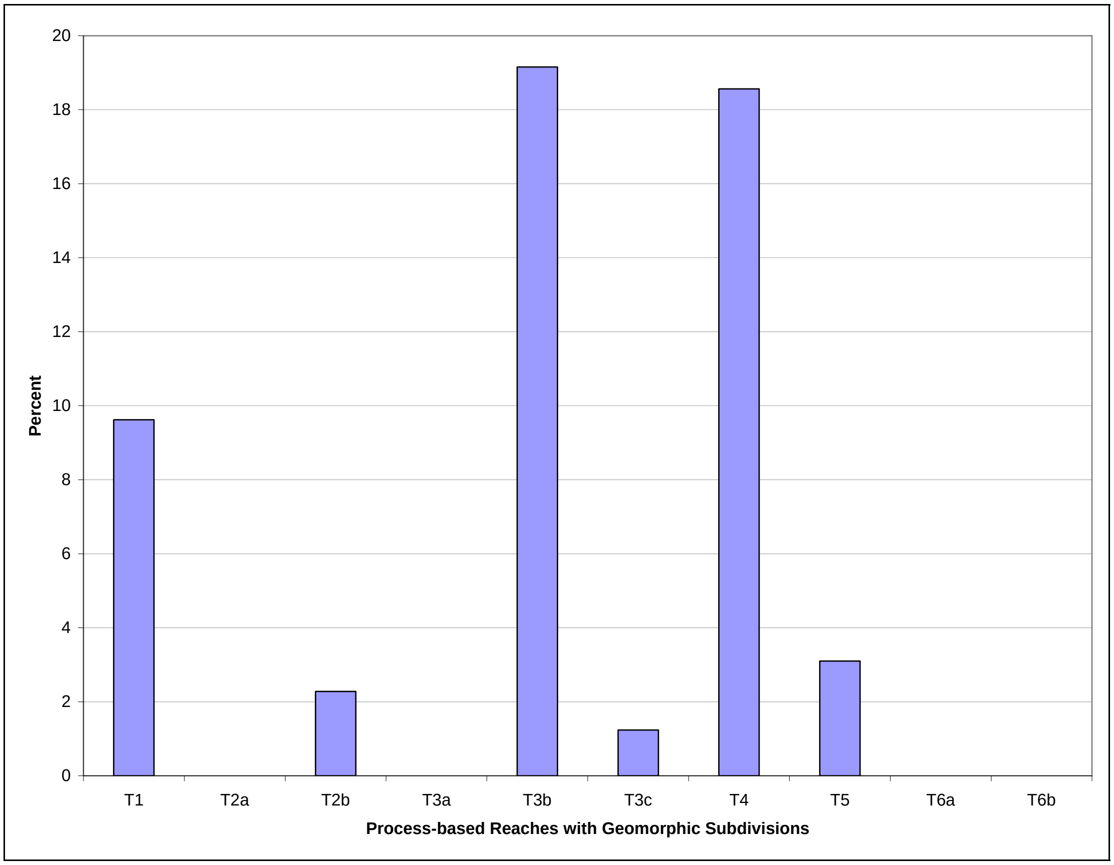

Figure G–11. Twisp River – Percent of the low surface boundary (both right and left sides) protected by mapped human features by geomorphic subdivision.

Table G–5. Twisp River – Percentages of the lengths of the boundary of the low surface that are protected by human features by geomorphic subdivision.

	Percent of the Total Length		
Reach	**Left Bank**	**Right Bank**	**Both Banks**
T1	6	13	10
T2a	0	0	0
T2b	0	5	2
T3a	0	0	0
T3b	39	0	19
T3c	2	0	1
T4	36	1	19
T5	4	2	3
T6a	0	0	0
T6b	0	0	0

Chewuch River

The highest percentage of the low surface boundary that is protected by human features along the Chewuch River is 20% in geomorphic reach C4a (Figure G–12; Table G–6). For the only other geomorphic reaches in which human features have been mapped along the low surface boundary, only a few percent of the length of the boundary is protected by human features: 6% in reach C4c, 2% in reach C2a, and 1% in reach C5b. No human features were noted along the low surface boundary in the other seven geomorphic reaches of the Chewuch River.

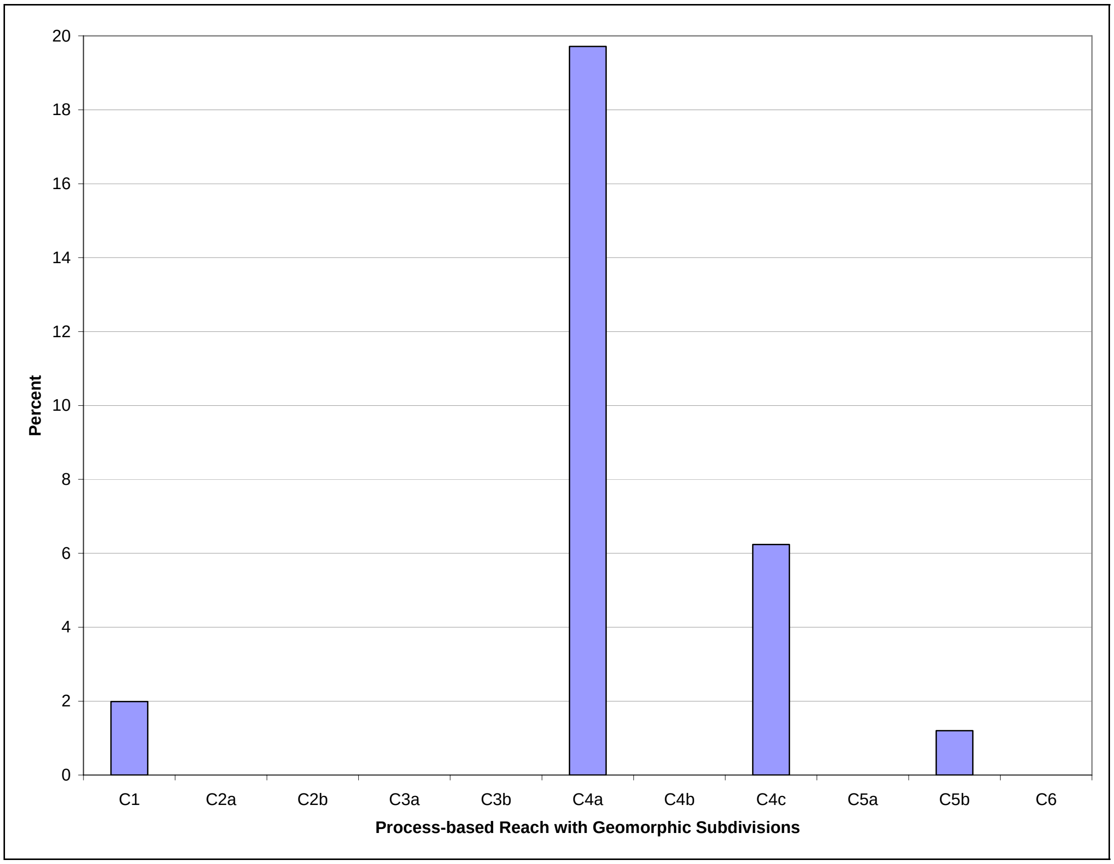

Figure G–12. Chewuch River – Percent of the low surface boundary (both left and right sides) that is protected by mapped human features by geomorphic subdivision.

Table G–6. Chewuch River – Percentages of the lengths of the boundary of the low surface that are protected by human features by geomorphic subdivision.

Reach	Percent of the Total Length		
	Left Bank	Right Bank	Both Banks
C1	4	0	2
C2a	0	0	0
C2b	0	0	0
C3a	0	0	0
C3b	0	0	0
C4a	0	35	20
C4b	0	0	0
C4c	0	14	6
C5a	0	0	0
C5b	2	0	1
C6	0	0	0

Similar to the Methow River, the percent of bedrock along the low surface boundary does not seem to predict the percent of the boundary protected by human features. The boundary in geomorphic reach C4a is entirely composed of bedrock (Figure G– 8), but has the longest length that is protected by human features (Figure G–12; Table G–6). For the entire Chewuch River within the assessment area, the low surface boundary is primarily composed of potentially erodible glacial deposits, but there does not appear to be a correlation between the percentages of the glacial deposits and the percentages of protection from human features.

2. BANK EROSION

Bank erosion along the unvegetated channel was studied (1) to determine where banks have eroded historically, (2) to estimate how much they have eroded, and (3) to infer which deposits have eroded. The goal of this analysis was to estimate how much sediment and what kinds have been contributed to the three drainage systems by bank erosion. Erosion within low surface is discussed in Appendix G.

Erosion along the low surface boundary, which results in expansion of the low surface, has been minimal on all three drainages in the assessment reaches. For the Methow River, about 3% of the measured length of the low surface boundary (14,123 feet eroded out of a total measured length of 485,322 feet) in the entire assessment reach eroded between 1948 and 2004. For the Chewuch River, about 0.5% of the measured length of the low surface boundary (340 feet eroded out of a total length of 68,410 feet) has eroded between 1954 and 2004. For the Twisp River, about 4% of the measured length of the low surface boundary (3,161 feet eroded out of a total length of 86,128 feet) has eroded between 1954 and 2004.

2.1 METHODS

2.1.1 MAPPING AND MEASUREMENTS

The following steps were used to map and evaluate bank erosion along the assessment reaches of the Methow, Chewuch, and Twisp rivers.

The banks of the unvegetated channel were mapped on the rectified 2004 aerial photographs for the Methow, Chewuch, and Twisp rivers in Arc. The banks of the unvegetated channel were mapped at the edges of the area that lacks vegetation. The left and right banks (looking downstream) were delineated, as well as banks around islands (vegetated areas between the left and right banks).

The banks of the historical unvegetated channels were mapped on the oldest available rectified aerial photographs (except for the 1945 set; see Section 2.2) for each drainage: 1948 for the Methow River, and 1954 for the Chewuch and Twisp rivers. This was done to get an idea of areas where long-term bank erosion has occurred, because the large size of the assessment area did not allow for detailed examination of historical bank erosion at shorter time intervals. Because the banks of the historical unvegetated channels are more difficult to delineate than the banks of the 2004 unvegetated channel, the banks of the historical channels were compared to the banks in 2004 and adjusted, if necessary.

The banks of the 2004 unvegetated channel were compared to the banks of the historical unvegetated channels in each drainage to locate areas that have eroded historically.

The geologic mapping was used to determine the geologic unit along the banks in 2004. The geologic mapping, topography, and surface appearance on the aerial photographs were used to infer the geologic unit along the banks historically and the geologic unit that was likely eroded.

The areas of bank erosion by time interval and geomorphic reach were calculated in Arc.

The lengths of eroded areas were measured along the low surface boundary, if this boundary was eroded. The lengths of the eroded area also were measured along the centerline of the 2004 channel to assess all areas of erosion along the unvegetated channel, not just those that occurred along the low surface boundary.

2.1.2 CALCULATIONS

Historical Erosion Along the Boundary of the Low Surface

Percentage of the Boundary of the Low Surface That Has Eroded — Erosion along the boundary of the low surface has occurred when deposits other than those within the low surface (alluvium) have been removed. For each geomorphic reach in the three drainages, the lengths of the boundary of the low surface (both left and right boundary looking downstream) along which erosion has occurred were combined and compared to the entire length of the boundary of the low surface (both left and right) for each reach. Deposits that have been eroded along the boundary are primarily glacial deposits, which include the intermediate surface geologic unit, and alluvial-fan deposits. Because the intermediate surface was not mapped consistently among the geomorphic reaches, it has been combined with the glacial deposits.

Percentage of a Geologic Unit Along the Boundary of the Low Surface That Has Eroded — At each locality where erosion along the boundary of the low surface has occurred historically, the geologic unit that has been eroded was inferred. The lengths of each eroded geologic unit were compared to the total mapped length of that geologic unit along the boundary of the low surface (Section 1.3.). The percentage of the mapped geologic unit that has eroded was calculated for each geomorphic reach for the three drainages.

Historical Progression of Erosion of Geologic Units Along the Boundary of the Low Surface — For sections of the boundary of the low surface that have experienced progressive historical erosion, the areas that have eroded were mapped on each of the available aerial photographs, and the amounts and rates of erosion were calculated for each time interval between the photographs. In addition, the geologic units that were eroded were inferred from the mapped geologic units, topography, and expression of the historical aerial photographs. The time intervals for which amounts and rates of erosion were calculated on the Methow River are 1945 to 1948, 1948 to 1954, 1954 to 1964, 1964 to 1974, and 1974 to 2004. The time intervals for which amounts and rates of erosion were calculated on the Twisp River are 1954 to 1964, 1964 to 1974, and 1974 to 2004.

Two areas along the Methow River, one in geomorphic reach M2b and the other in geomorphic reach M9b, are shown. This analysis was done for each area where progressive historical erosion of the boundary of the low surface has occurred, but not all have been updated for the recent revisions. Because erosion of the boundary of the low surface has been limited, it was not considered important enough to the overall analysis to update these computations.

Historical Erosion Along the Banks of the Unvegetated Channel

Erosion has occurred not only along the boundary of the low surface, but also within the low surface along the banks of the unvegetated channel. The boundary of the low surface is eroded only where the boundary has coincided with the banks of the unvegetated channel. Although erosion within the low surface is reworking recent alluvium, which has a composition similar to that of the channel bed, erosion of the deposits within the low surface adds sediment to the river system. In order to determine the relative amounts of erosion within the low surface and along the boundary of the low surface (expansion of the low surface), the lengths of the eroded sections were mapped relative to the centerline of the 2004 channel. The percentages of each eroded geologic unit were calculated relative to entire length of the channel, in order to compare the different units that have been eroded.

2.2 LIMITATIONS OF THE MAPPING AND ANALYSIS

The use of this analysis requires consideration of certain limitations as described below.

In places it is difficult to determine the location of the banks of the unvegetated channel, partially because of vegetative cover (e.g., trees extend out beyond the bank) and partially because of the quality of some of the historical aerial photographs. It is because of photograph quality that the 1945 aerial photographs were not used in this analysis.

The determination of the geologic units that have been eroded historically depends upon interpretation of units that are now gone.

The bank erosion analysis was done in the early phases of our assessment. Some revision has been done of the banks of the historical unvegetated channel, the geologic mapping, the boundary of the low surface, and the centerline of the 2004 unvegetated channel. (See GIS files.) Some of these changes were made in the bank erosion analysis, but consistent review and revision of the data used in this analysis have not been done. Consequently, the information presented in this analysis may not be consistent with the revised GIS files. In particular, the measured values and calculated percents may not be consistent with those measured and calculated using the GIS files. However, the relative numbers presented in this analysis would probably not be changed markedly by the revisions.

2.3 RESULTS AND INTERPRETATIONS

For all three drainages, deposits within the low surface (unconsolidated gravelly and sandy alluvium) make up most of the historical bank erosion in nearly all of the geomorphic reaches (Figure G–13). In only a few places has the boundary of the low surface been progressively eroded historically. The erosion along the boundary makes up only a few percent of the total erosion along the banks of the unvegetated channel in most reaches.

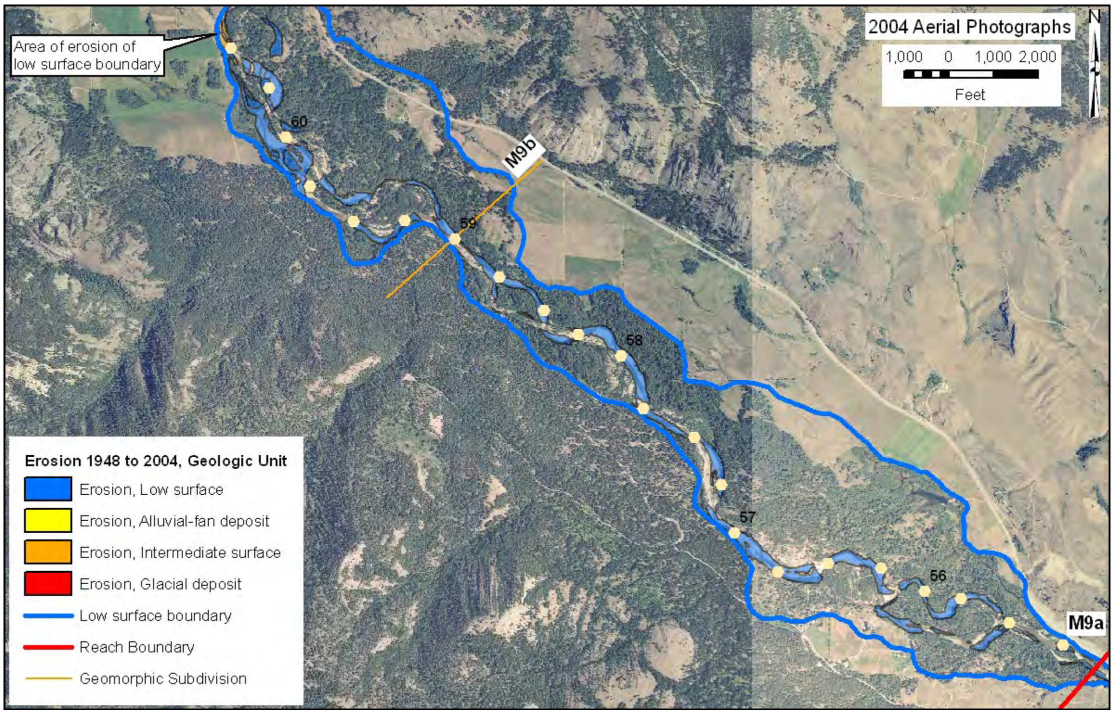

Figure G–13. An example of the relative amounts of erosion of alluvial deposits within the low surface and those along the boundary of the low surface (Methow geomorphic reaches M9a and M9b).

2.3.1 METHOW RIVER

Percentage of the Boundary of the Low Surface That Has Eroded

The geomorphic reach that has experienced the most erosion along the boundary of the low surface for the Methow River between 1948 and 2004 is reach M2b, where about 12% of the boundary has eroded (Figure G–14). Other geomorphic reaches where the boundary of the low surface has eroded historically are M2c where 9% of the boundary has eroded, M9b and M5 where 5% of the boundary has eroded, and M2a where 4% of the boundary has eroded. Erosion of the boundary of the low surface has not occurred in geomorphic reaches M3, M8, M9a, and M11. The length of the section that has eroded between 1948 and 2004 makes up about 3% of the total length of the low surface boundary in the entire assessment reach.

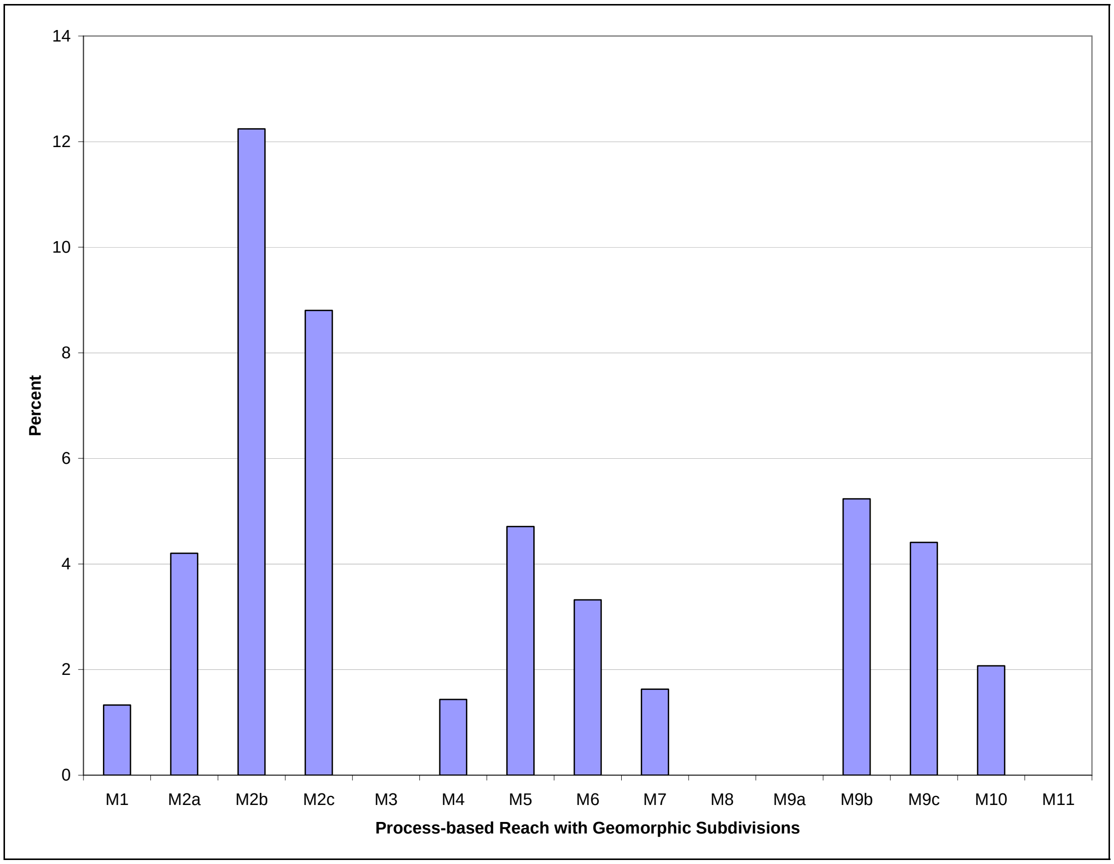

Figure G–14. Methow River – Percentages of the boundary of the low surface that has eroded between 1948 and 2004 by geomorphic subdivision.

Percentage of a Geologic Unit Along the Boundary of the Low Surface That Has Eroded

The highest percentage of a mapped geologic unit to erode between 1948 and 2004 along the boundary of the low surface along the Methow River has occurred in geomorphic reach M2b, where 72% of the length of mapped alluvial-fan deposits had eroded between 1948 and 2004 (Figure G–15). Also in this geomorphic reach, about 26% of the mapped length of glacial deposits along the low surface boundary eroded. The erosion occurred near river mile 35.8 near the mouth of Beaver Creek (Section 2.4.2). For other geomorphic reaches where historical erosion of the low surface has occurred, 15% of the mapped length of glacial deposits has eroded in reach M2c, 12% in M5 and M9b, and 10% in M2a. About 10% of the mapped length of alluvial-fan deposits has been eroded along the boundary of the low surface in geomorphic reach M6.

Of the mapped geologic units along the low surface boundary along the Methow River, 8% of the length of the mapped glacial deposits, which includes 6% of the length of mapped intermediate surface, and about 3% of the length of the mapped alluvial-fan deposits have eroded between 1948 and 2004.

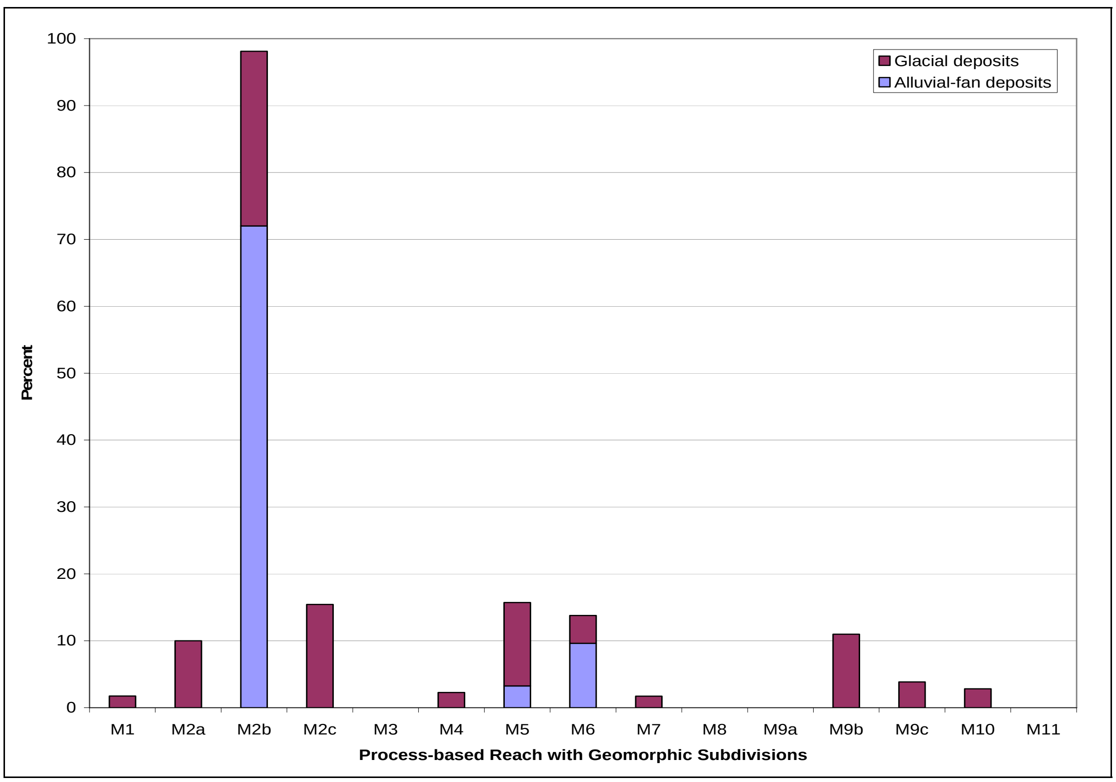

Figure G–15. Methow River – Percentages of the lengths of mapped geologic units that have eroded between 1948 and 2004 along the boundary of the low surface by geomorphic subdivision.

Historical Erosion Along the Banks of the Unvegetated Channel

Most of the erosion along the banks of the unvegetated channel of the Methow River between 1948 and 2004 has been low surface deposits in all of the geomorphic reaches (Figure G–16). Glacial deposits are the next most eroded geologic unit along the banks of the unvegetated channel, which correspond to erosion along the boundary of the low surface. The percentage of erosion of glacial deposits is about 20% of the 2004 channel, which has occurred primarily in geomorphic reaches M2b and M2c. Alluvial-fan deposits have been eroded in only three geomorphic reaches along the Methow River: M2b and M9c, where 5% of the channel length has eroded, and M9b, where 2% of the channel length has eroded.

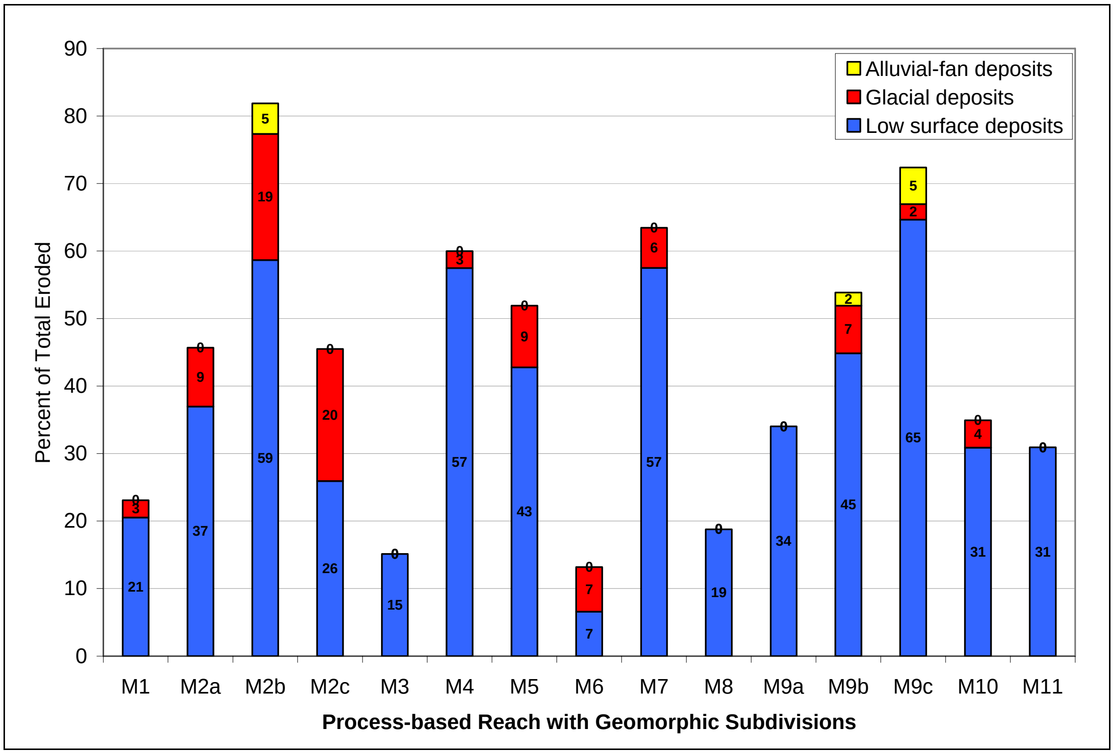

Figure G–16. Methow River – Percentages of the geologic units that have eroded between 1948 and 2004 along the banks of the unvegetated channel by geomorphic subdivision.

2.3.2 TWISP RIVER

Percentage of the Boundary of the Low Surface That Has Eroded

The geomorphic reach that has experienced the most erosion along the boundary of the low surface between 1954 and 2004 for the Twisp River is reach T3a, where about 53% of the boundary has eroded (Figure G–17). Only three other geomorphic reaches have experienced historical erosion of the low surface boundary: T2b, where 11% of the boundary has eroded, and T3b and T3c, where 4% of the boundary in each reach has eroded. The length of the section that has eroded between 1954 and 2004 makes up about 4% of the total length of the low surface boundary in the entire assessment reach.

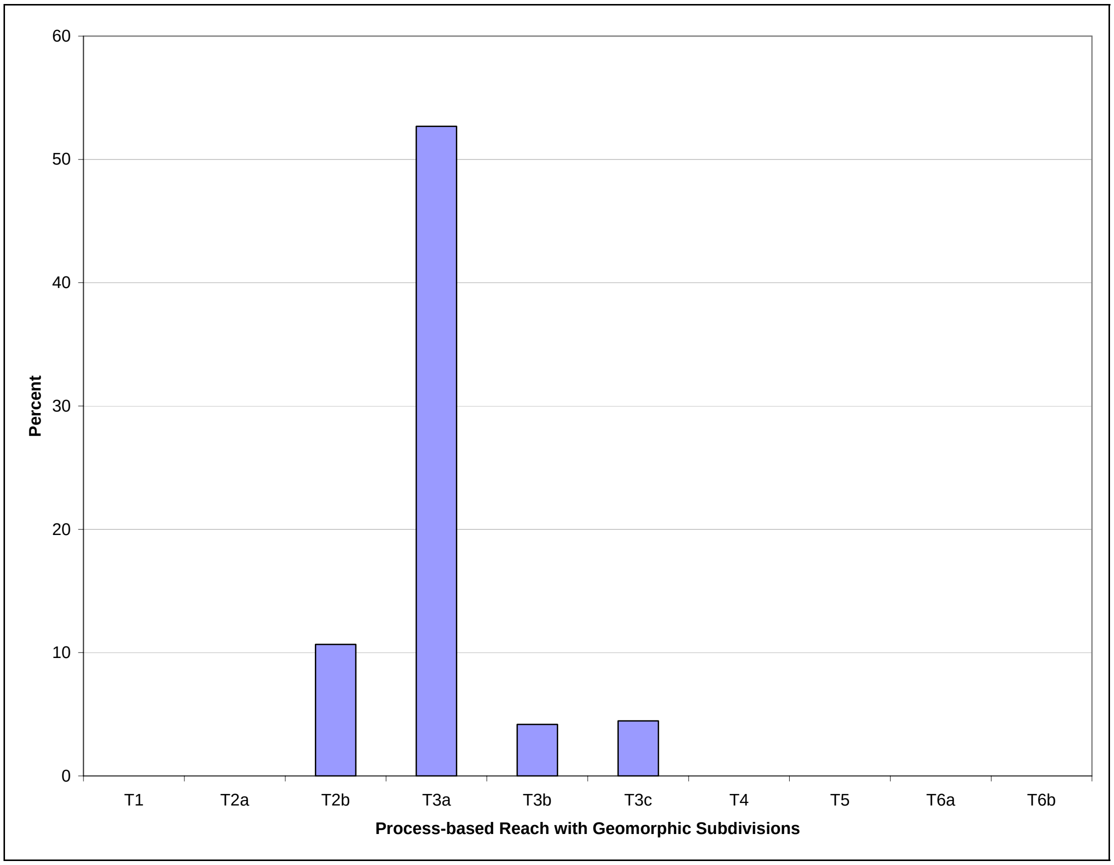

Figure G–17. Twisp River – Percentages of the boundary of the low surface that has eroded historically by geomorphic subdivision.

Percentage of a Geologic Unit Along the Boundary of the Low Surface That Has Eroded

Of the lengths of the geologic units that have been mapped along the boundary of the low surface, about 37% of the length has eroded between 1954 and 2004 in geomorphic reach T3a (Figure G–18). In the other three geomorphic reaches where historical erosion of the boundary of the low surface has occurred, 7% of the length of mapped glacial deposits along the boundary has eroded in reach T2b, and 18% of the length of mapped alluvial-fan deposits has eroded in reach T3c. The erosion of the boundary of the low surface in geomorphic reach T3b has occurred along artificial fill that is not shown on the geologic map and so is not shown on Figure G–18.

Of the mapped geologic units along the low surface boundary along the Twisp River, 3% of the length of the mapped glacial deposits and about 1% of the length of the mapped alluvial-fan deposits have eroded between 1954 and 2004.

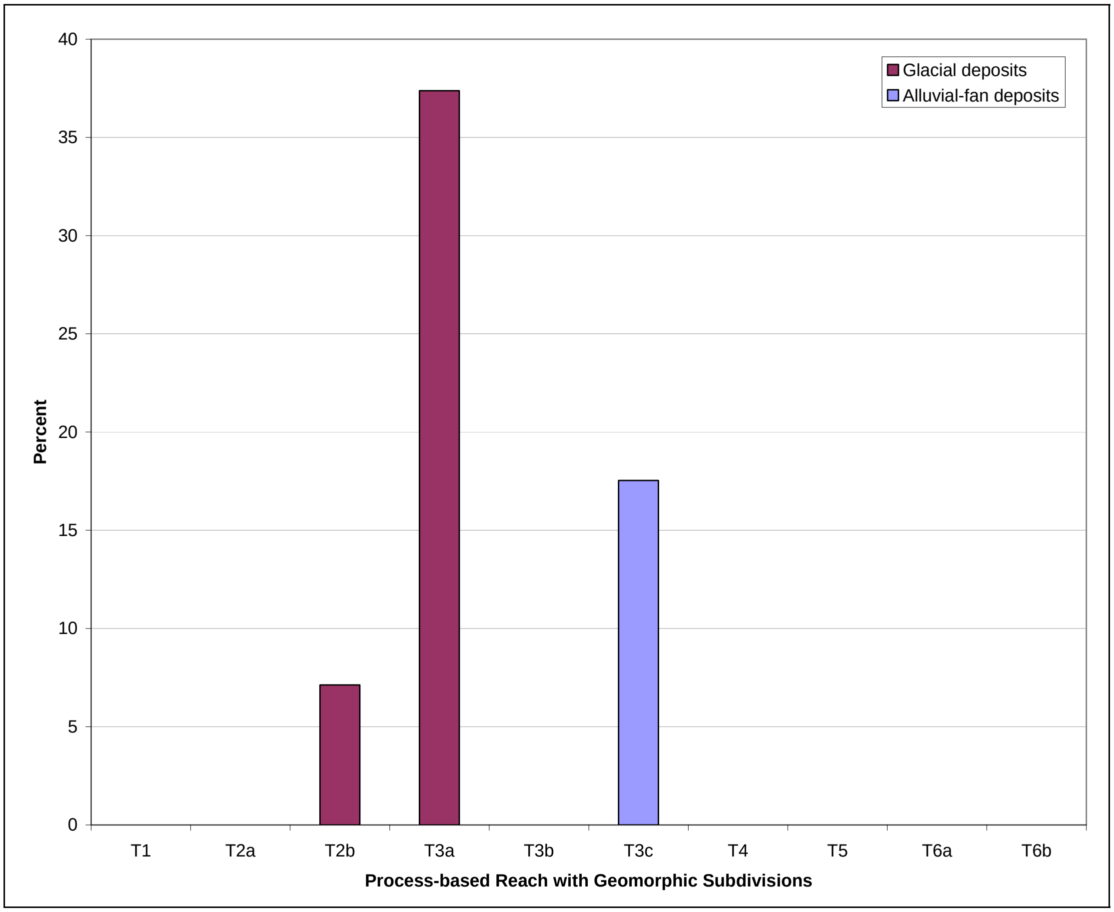

Figure G–18. Twisp River – Percentages of the lengths of the mapped geologic units that have been eroded between 1954 and 2004 along the boundary of the low surface by geomorphic subdivision.

Historical Erosion Along the Banks of the Unvegetated Channel

Nearly all of the erosion along the banks of the unvegetated channel of the Twisp River between 1954 and 2004 has been low surface deposits, except in geomorphic reach T3a, where erosion has been in glacial deposits and along the boundary of the low surface (Figure G–19). In geomorphic reaches T1, T2a, and T3b, all of the historical erosion along the banks of the unvegetated channel has been low surface deposits. In geomorphic reaches T2b and T3c, a small percentage of the erosion has been in either glacial deposits or alluvial-fan deposits along the boundary of the low surface.

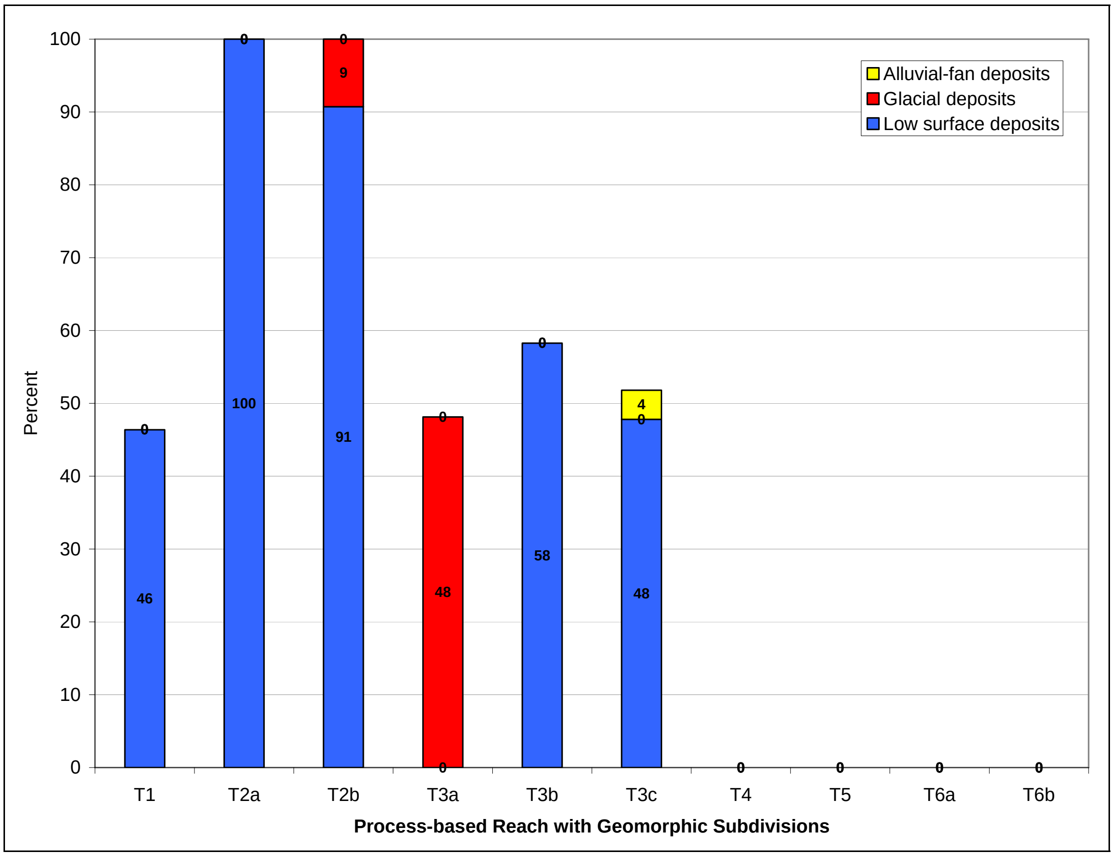

Figure G–19. Twisp River – Percentages of the geologic units that have eroded between 1954 and 2004 along the banks of the unvegetated channel by geomorphic subdivision.

2.3.3 CHEWUCH RIVER

Percentage of the Boundary of the Low Surface That Has Eroded

Erosion along the boundary of the low surface between 1954 and 2004 has been identified along only one geomorphic reach for the Chewuch River (Figure G–20). In geomorphic reach C2a about 2% of the length of the low surface boundary has eroded. The length of the section that has eroded between 1954 and 2004 makes up about 0.5% of the total length of the low surface boundary in the entire assessment reach.

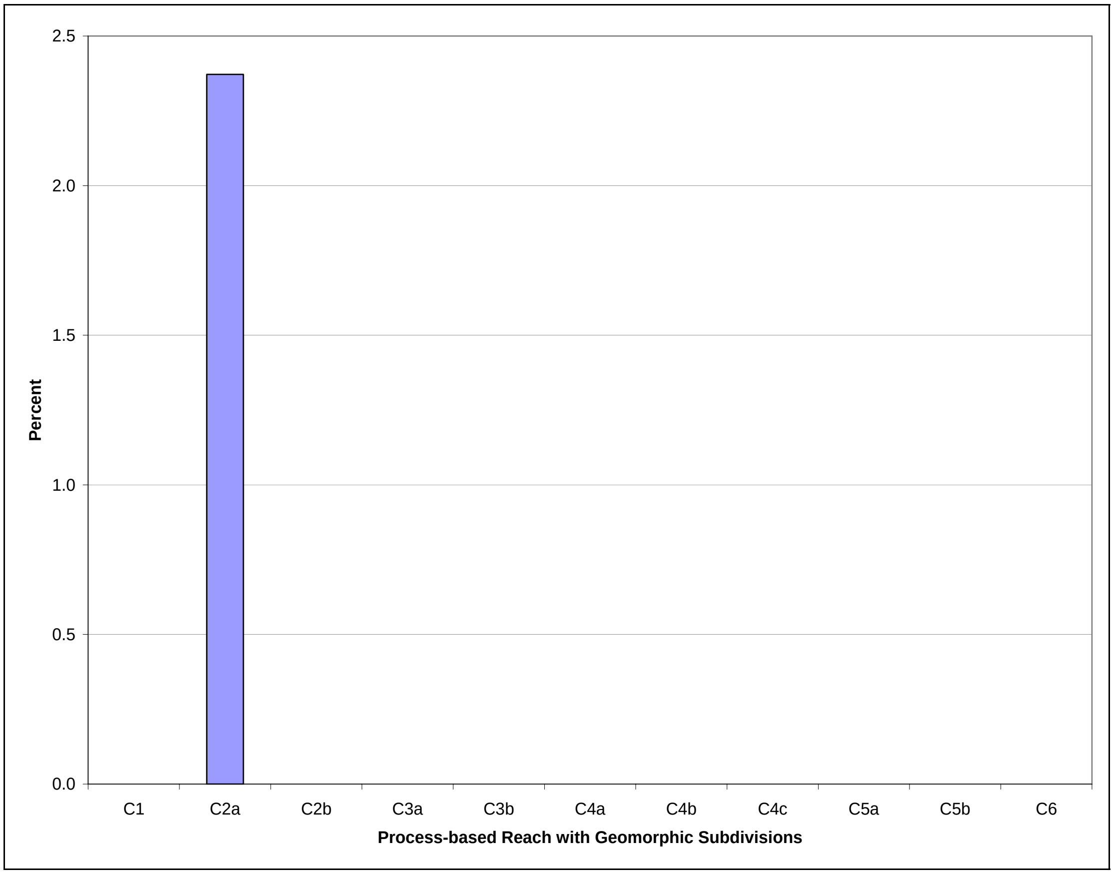

Figure G–20. Chewuch River – Percentages of the boundary of the low surface that has eroded between 1954 and 2004 by geomorphic subdivision.

Percentage of a Geologic Unit Along the Boundary of the Low Surface That Has Eroded

In the one geomorphic reach where erosion of the boundary of the low surface has occurred between 1954 and 2004, C2a, about 50% of the length of mapped glacial deposits in that reach has eroded (Figure G–21).

Of the mapped geologic units along the low surface boundary along the Chewuch River, only glacial deposits have eroded. The length of glacial deposits eroded between 1954 and 2004 makes up about 16% of the total length of the glacial deposits mapped along the low surface boundary.

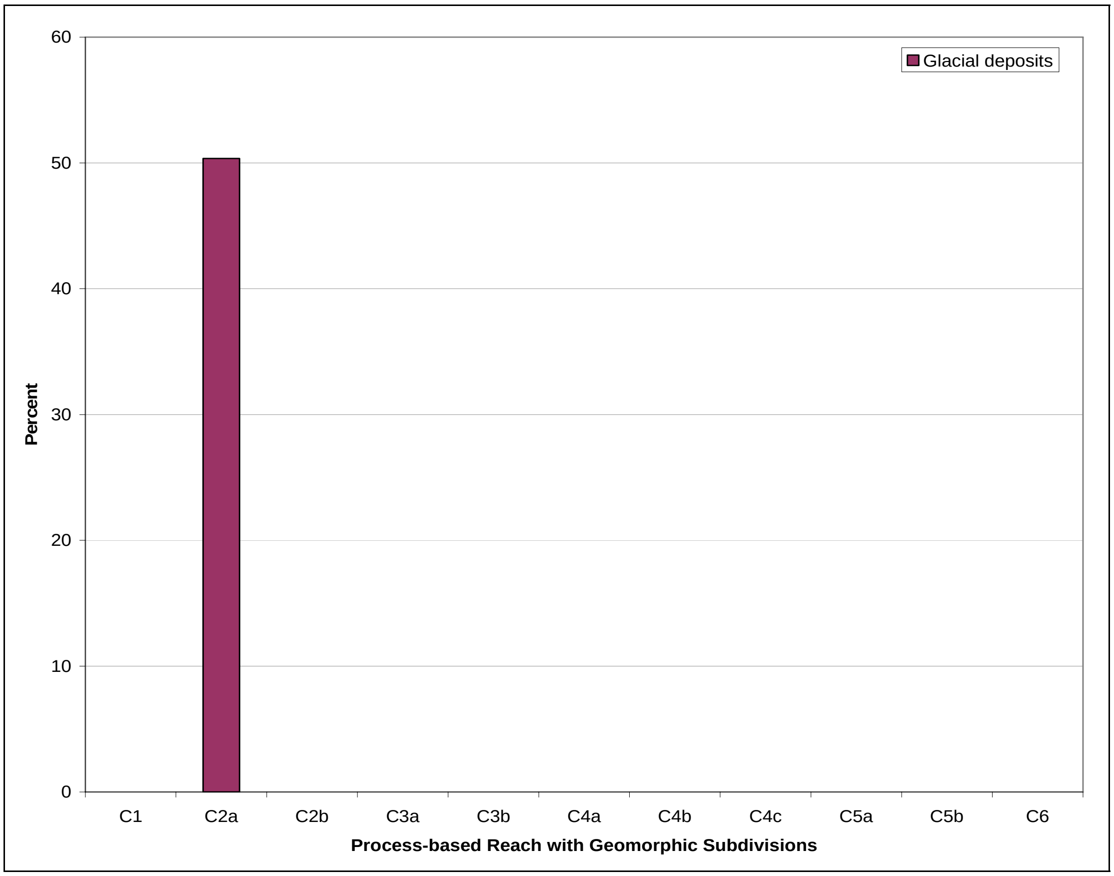

Figure G–21. Chewuch River – Percentages of the lengths of the mapped geologic units that have been eroded between 1954 and 2004 along the boundary of the low surface by geomorphic subdivision.

Historical Erosion Along the Banks of the Unvegetated Channel

Nearly all of the historical erosion along the banks of the unvegetated channel of the Chewuch River between 1954 and 2004 has been low surface deposits (Figure G–22). The greatest length of erosion has occurred in geomorphic reach C2a, where about 86% of the length of the 2004 channel has eroded along low surface deposits. This is also the only reach where erosion of the boundary of the low surface has occurred, but this erosion has been only 2% of the length eroded. Other geomorphic reaches with erosion of low surface deposits along the banks of the unvegetated channel are C4a (32%), C3b (28%), C4b (23%), C2b (21%), and C1 (8%).

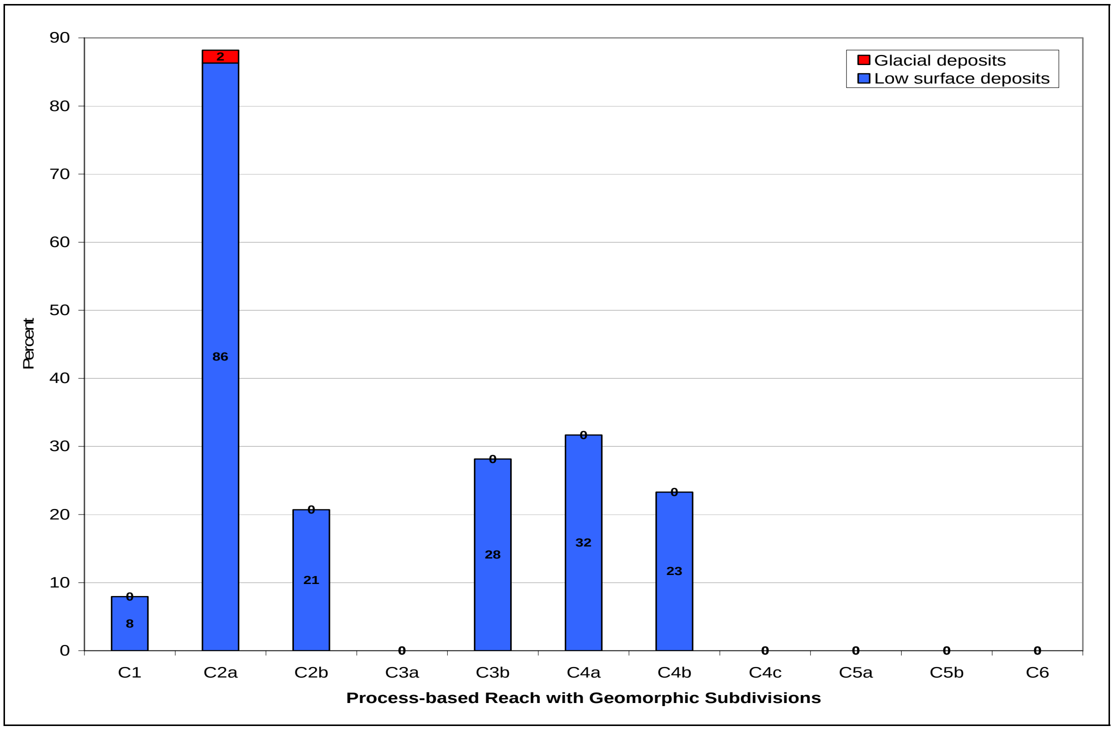

Figure G–22. Chewuch River – Percentages of the geologic units that have eroded 1954 and 2004 along the banks of the unvegetated channel by geomorphic subdivision.

2.4 HISTORICAL PROGRESSION OF EROSION OF GEOLOGIC UNITS ALONG THE BOUNDARY OF THE LOW SURFACE: TWO EXAMPLES FROM THE METHOW RIVER

2.4.1 EROSION ALONG THE BOUNDARY OF THE LOW SURFACE IN GEOMORPHIC SUBDIVISION M9B

Progressive historical erosion has occurred along the Methow River in geomorphic reach M9b near RM 60.5 (Figure G–23). The boundary of the low surface has continued to erode in each time interval for which we have aerial photographs beginning in the interval between 1945 and 1948 and continuing to the interval between 1974 and 2004 (Figure G–24 and Figure G– 25).

A plot of the area eroded during each time interval shows that the largest area was eroded between 1964 and 1974 (about 73,000 ft^2), and the smallest area eroded between 1945 and 1948 (about 22,000 ft^2; Figure G–**26**). However, the length of time represented by the time intervals between aerial photographs markedly varies. Consequently, the rate of erosion (area eroded/number of years) was plotted for each time interval (Figure G–27). The highest rate of erosion occurred between 1948 and 1954 (about 11,000 ft^2/yr); the lowest rate occurred between 1974 and 2004 (about 1,100 ft^2/yr). The average rate for the entire time interval (1945 to 2004) has been about 4,000 ft^2/yr).

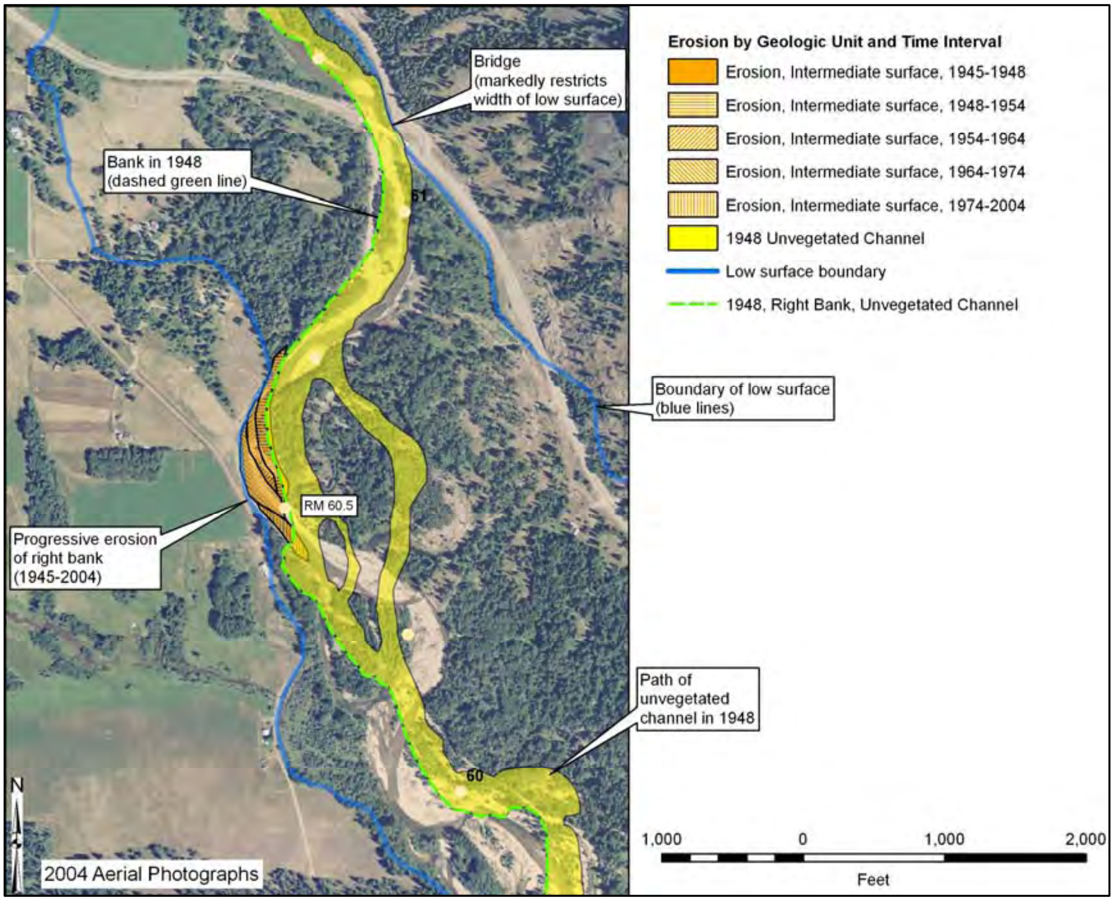

Figure G–23. Methow River – Map of the area of continued erosion of the boundary of the low surface between 1945 and 2004 in geomorphic subdivision M9b near RM 60.5.

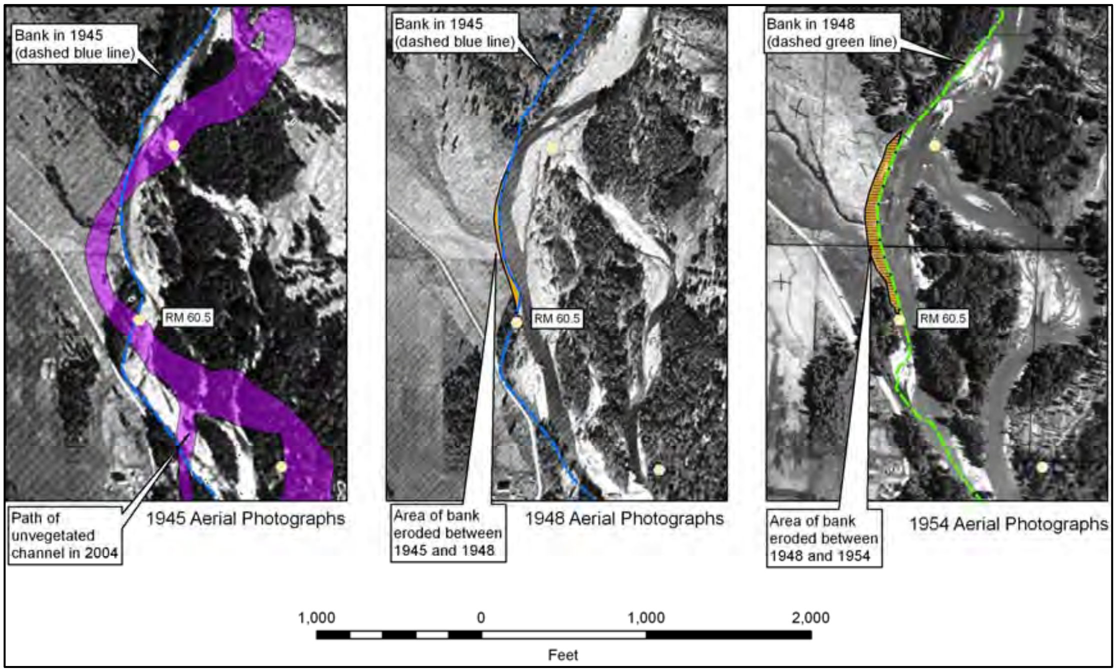

Figure G–24. Methow River – Progression of erosion of the boundary of the low surface between 1945 and 1954 in geomorphic subdivision M9b.

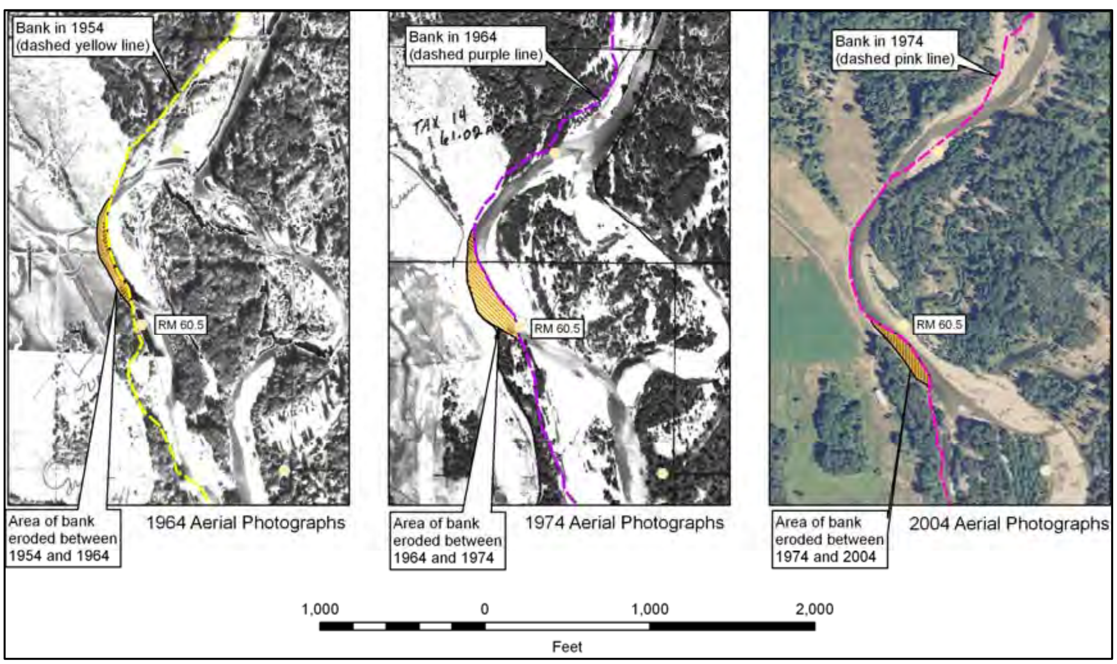

Figure G– 25. Methow River – Progression of erosion of the boundary of the low surface between 1964 and 2004 in geomorphic subdivision M9b.

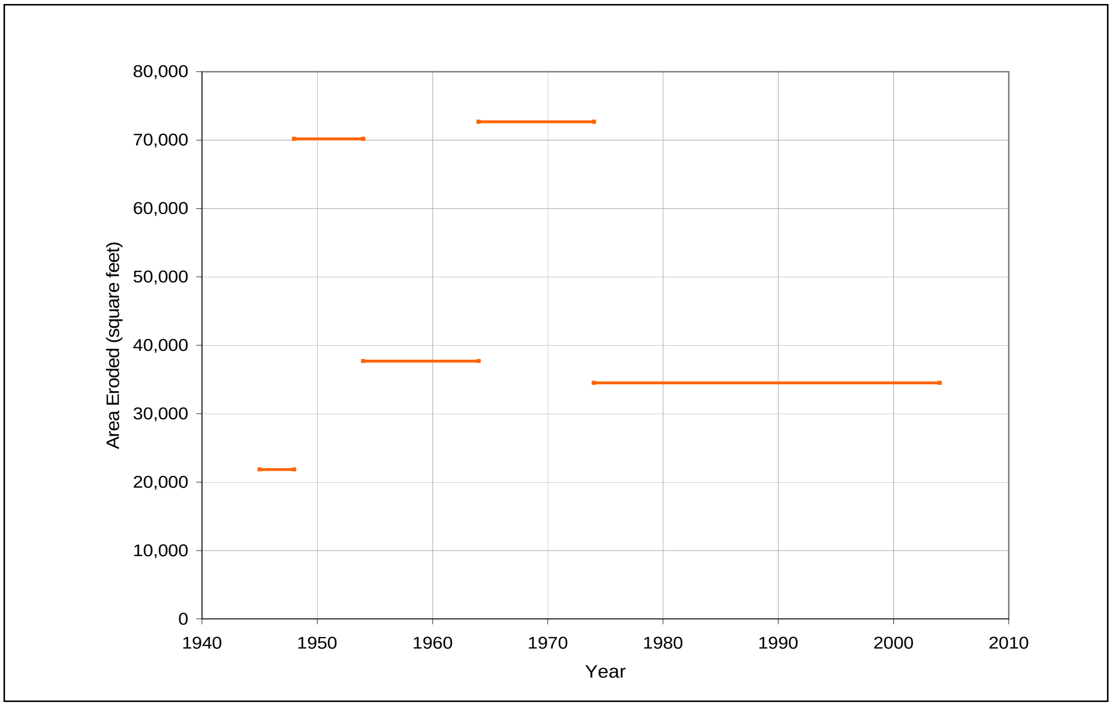

Figure G–26. Methow River – Area of the low surface that has been eroded by time interval in geomorphic subdivision M9b.

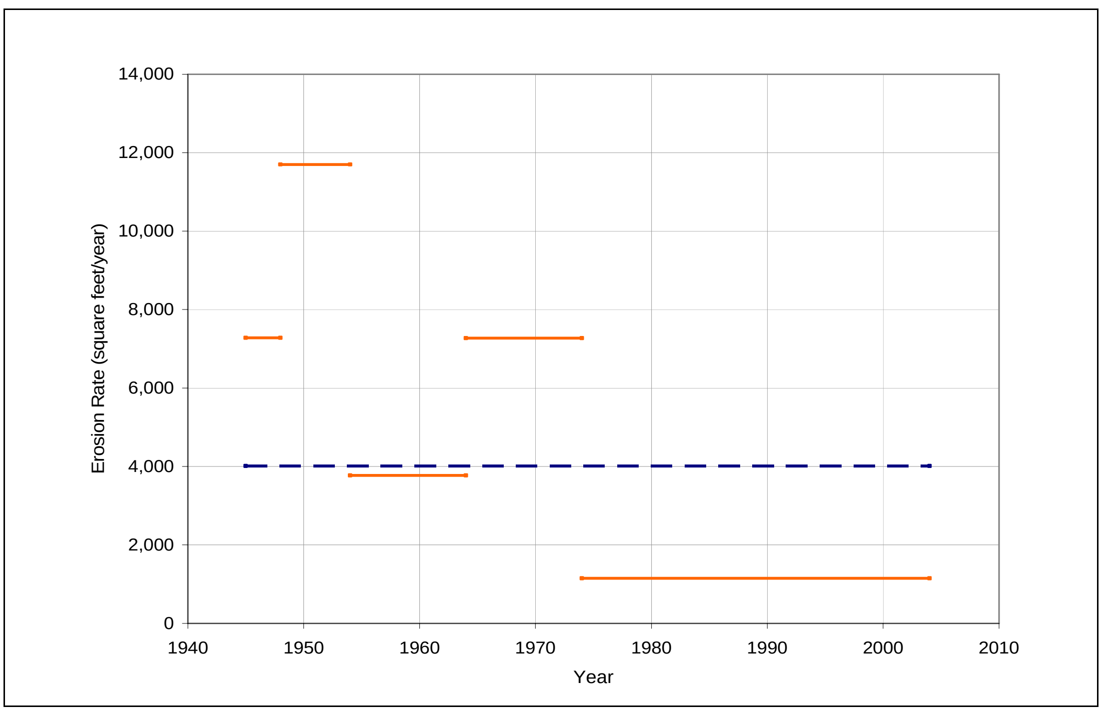

Figure G–27. Methow River – Erosion rates for the low surface by time interval in geomorphic subdivision M9b.

2.4.2 EROSION ALONG THE BOUNDARY OF THE LOW SURFACE IN GEOMORPHIC SUBDIVISION M2B

Progressive historical erosion has occurred along the Methow River in geomorphic reach M2b near RM 36 (Figure G–28). Both alluvial-fan and glacial deposits have been eroded. The boundary of the low surface has continued to erode in each time interval for which we have aerial photographs beginning in the interval between 1945 and 1948 and continuing to the interval between 1974 and 2004 (Figure G–29 and Figure G–30).

A plot of the area eroded during each time interval shows that the largest area was eroded between 1948 and 1954 (nearly 128,000 ft^2), and the smallest was eroded between 1974 and 2004 (about 55,000 ft^2; Figure G–31). However, the length of time represented by the time intervals between aerial photographs markedly varies. Consequently, the rate of erosion (area eroded/number of years) was plotted for each time interval (Figure G–32). The highest rate of erosion occurred between 1945 and 1948 (about 28,000 ft^2/yr); the lowest rate occurred between 1974 and 2004 (about 1,800 ft^2/yr). The average rate for the entire time interval (1945 to 2004) has been about 6,500 ft^2/yr.

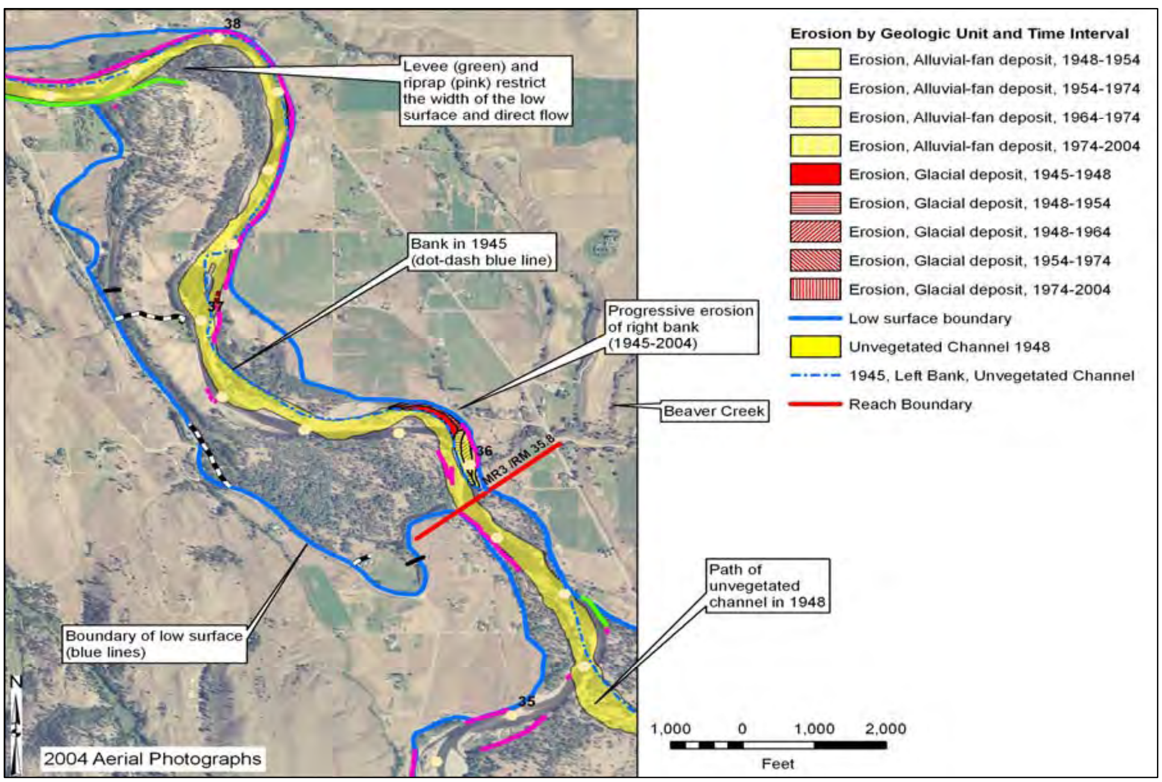

Figure G–28. Methow River – Map of the area of continued erosion of the boundary of the low surface in geomorphic subdivision M2b.

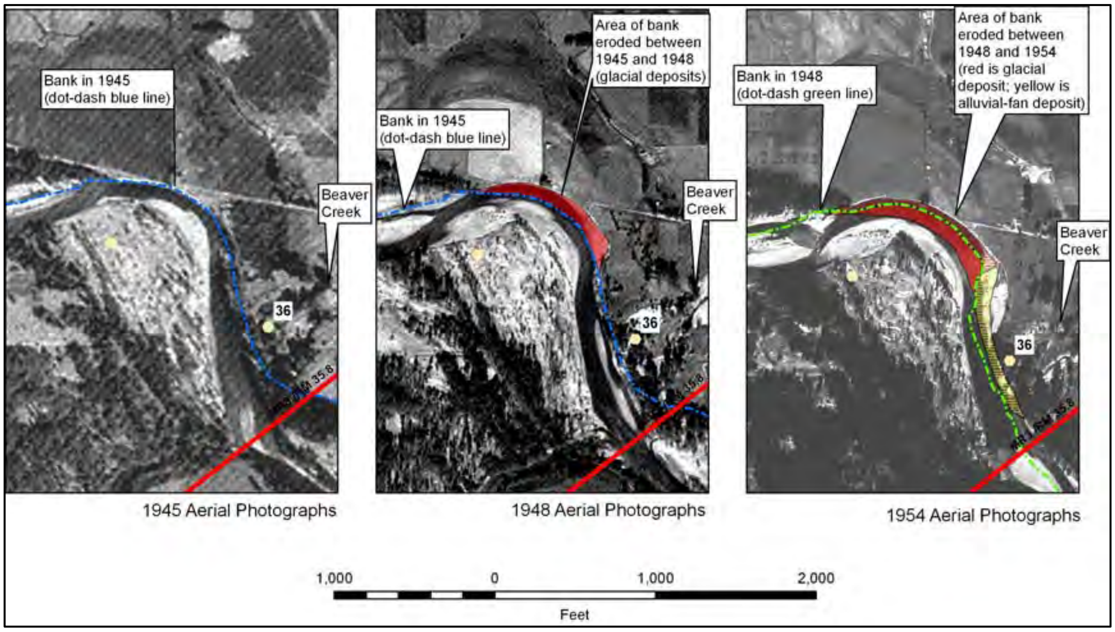

Figure G–29. Methow River – Progression of erosion of the boundary of the low surface between 1945 and 1954 in geomorphic subdivision M2b.

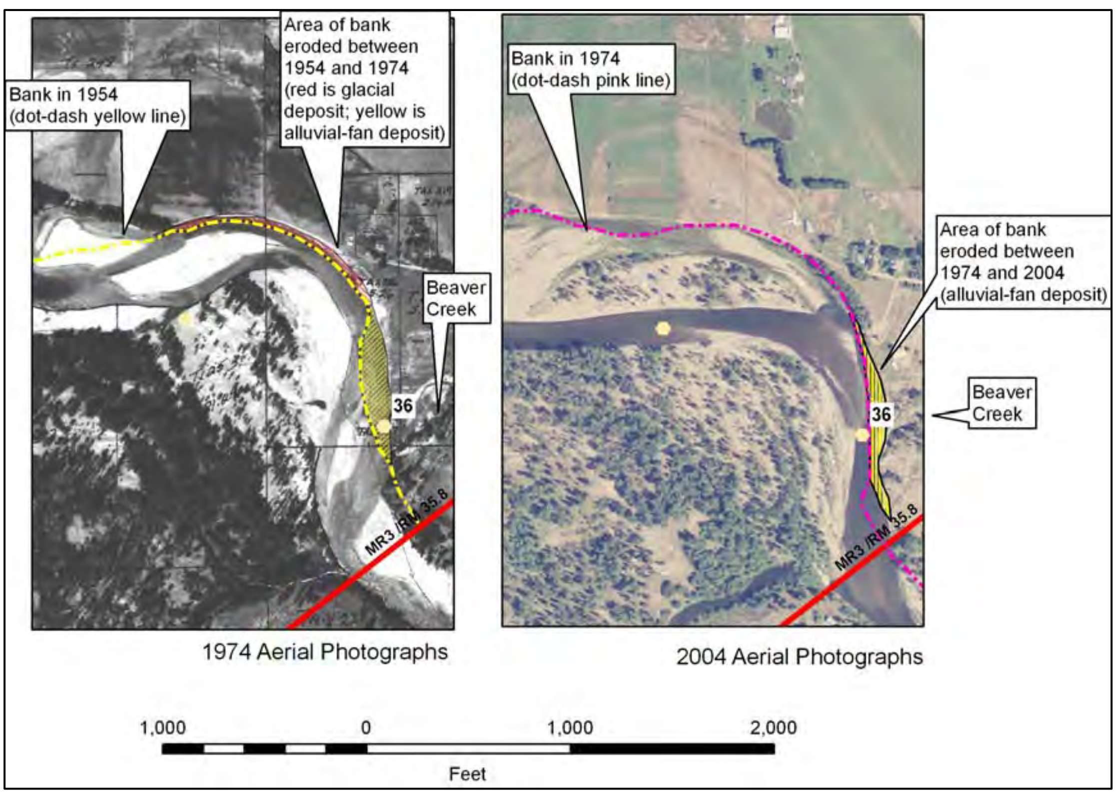

Figure G–30. Methow River – Progression of erosion of the boundary of the low surface between 1974 and 2004 in geomorphic subdivision M2b.

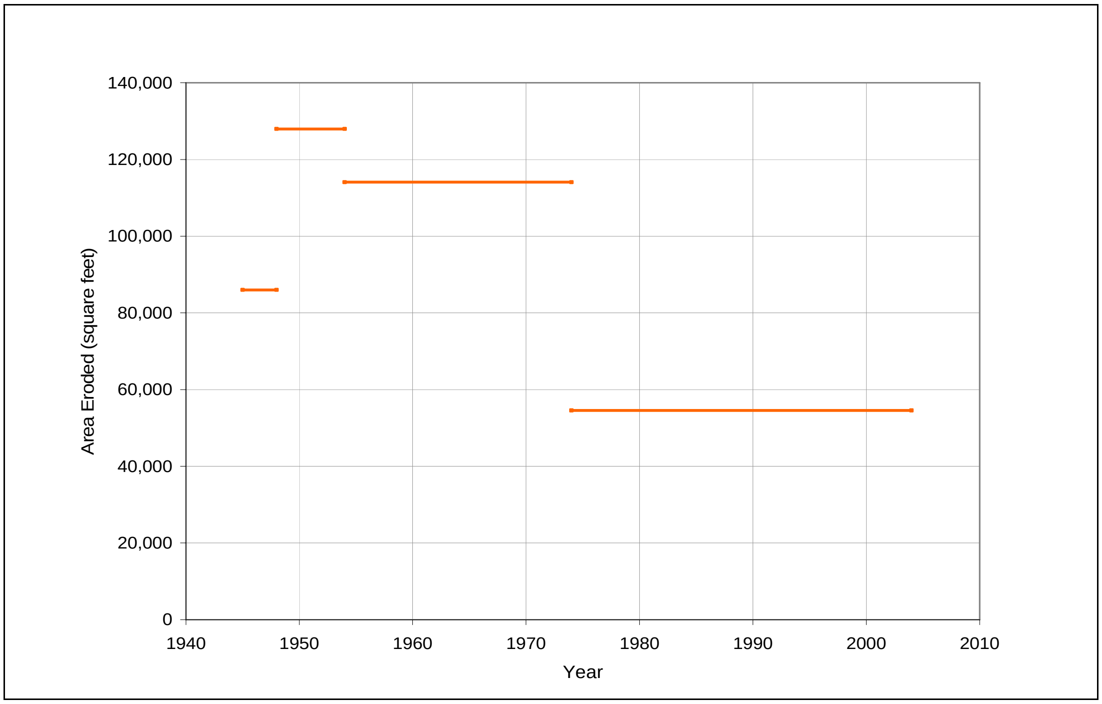

Figure G–31. Methow River – Area of low surface that has been eroded by time interval in geomorphic subdivision M2b.

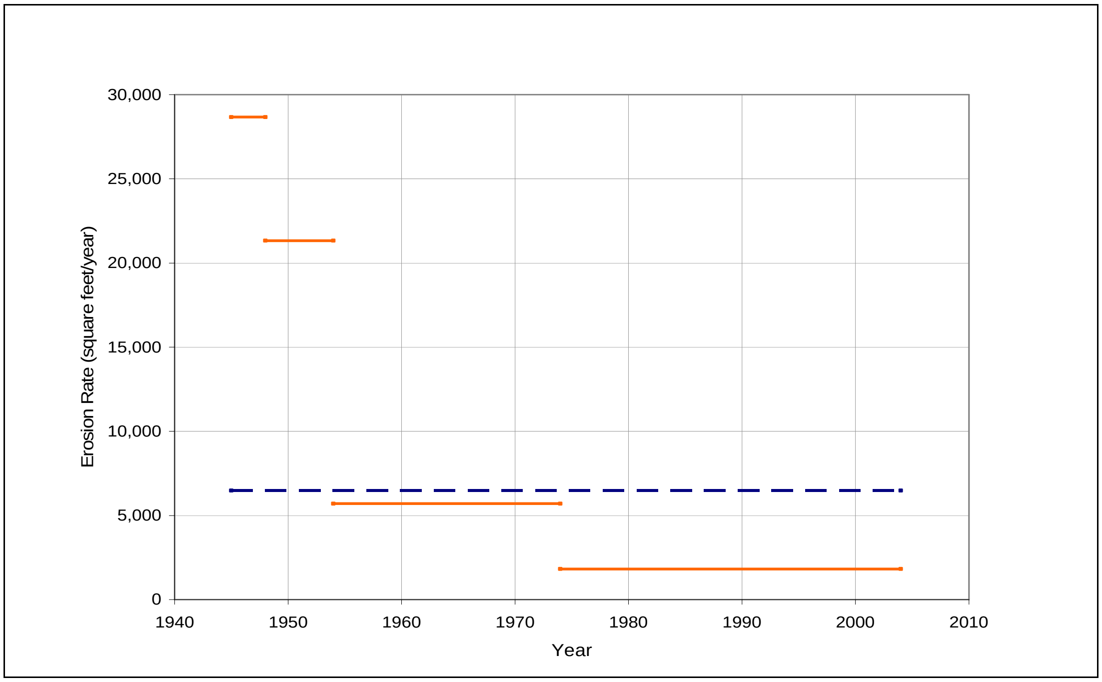

Figure G–32. Methow River – Erosion rates for the low surface by time interval geomorphic subdivision M2b.

3. COMPARISON OF UNVEGETATED CHANNELS OF THE METHOW RIVER

Unvegetated channels were mapped for 1948 and 2004 using rectified aerial photographs from those years (Figure G–33). The entire extent of the 1948 photographs was used, which included the entire assessment area along the Methow River, but did not include the assessment areas along either the Chewuch or Twisp rivers.

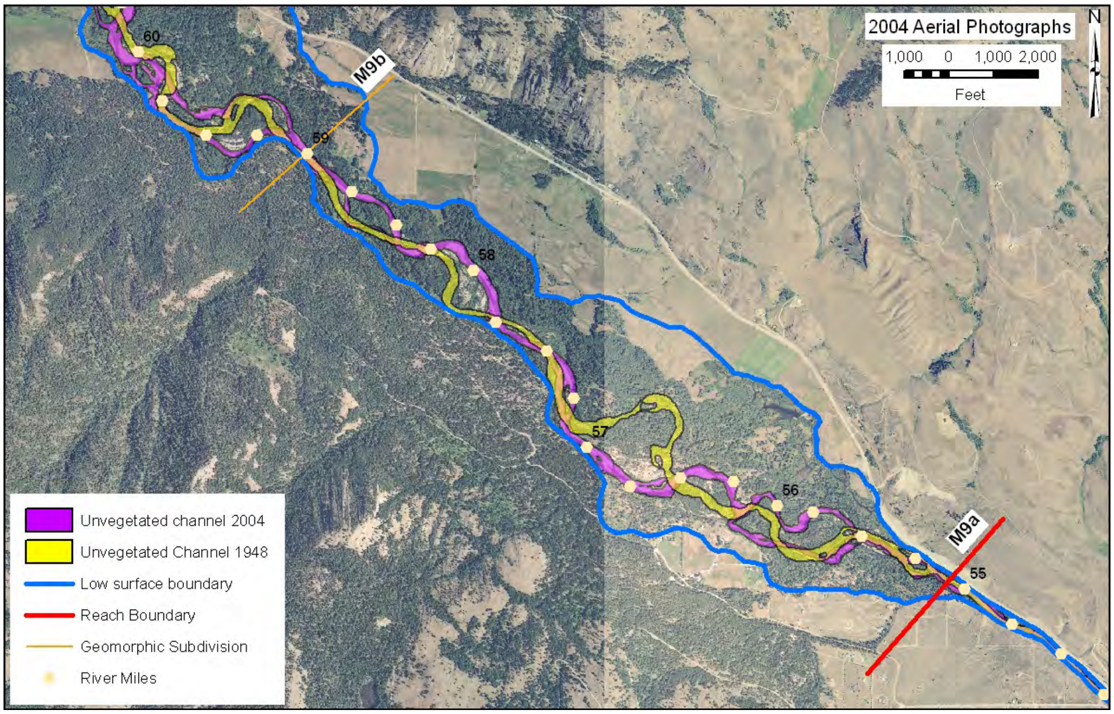

Figure G–33. Methow River – Unvegetated channels in 1948 and 2004 for geomorphic subdivision M9a (RM 55–59).

Using Arc, the areas of the two unvegetated channels were subdivided into three categories by geomorphic reach.

- Areas that were unvegetated channel in both years (Figure G–34).
- Areas that were unvegetated channel in 1948 but were no longer unvegetated channel in 2004 (Figure G–35). These areas had been abandoned by the unvegetated channel by 2004, and were secondary or overflow channels in 2004 or had been revegetated and appear to be no longer active by 2004.
- Areas that were unvegetated channel in 2004 but had not been unvegetated channel in 1948 (Figure G–35). These are areas that were vegetated in 1948, but were unvegetated and part of the channel by 2004.

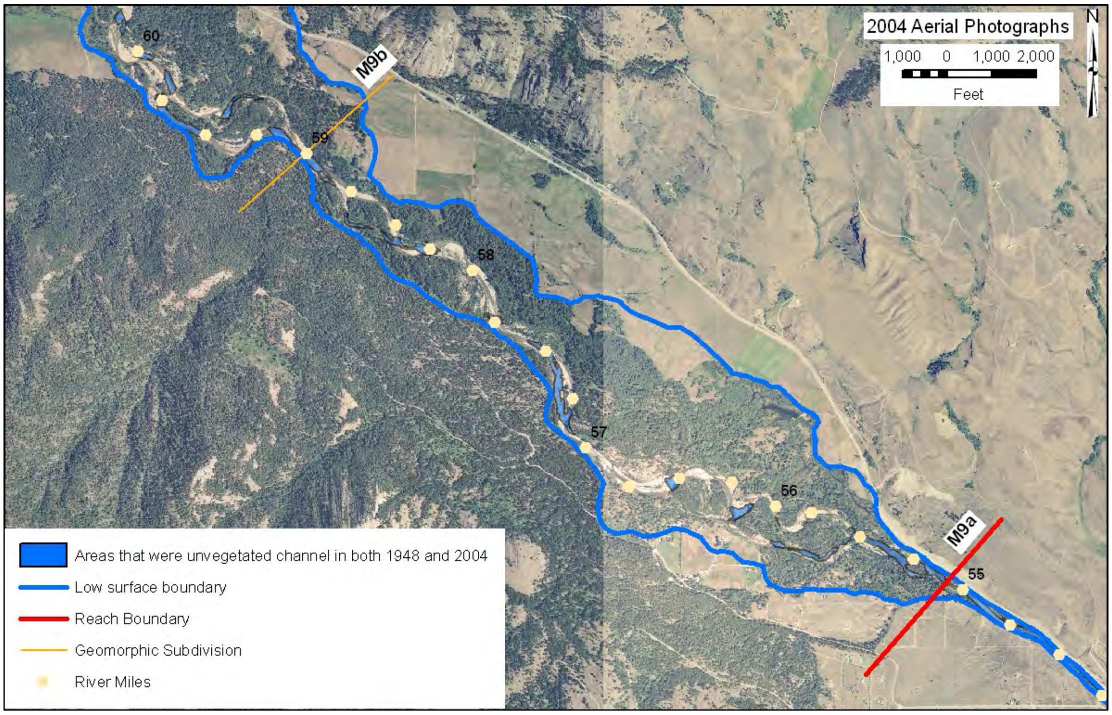

Figure G–34. Methow River – The areas that were unvegetated channel in both 1948 and 2004 for geomorphic subdivision M9a.

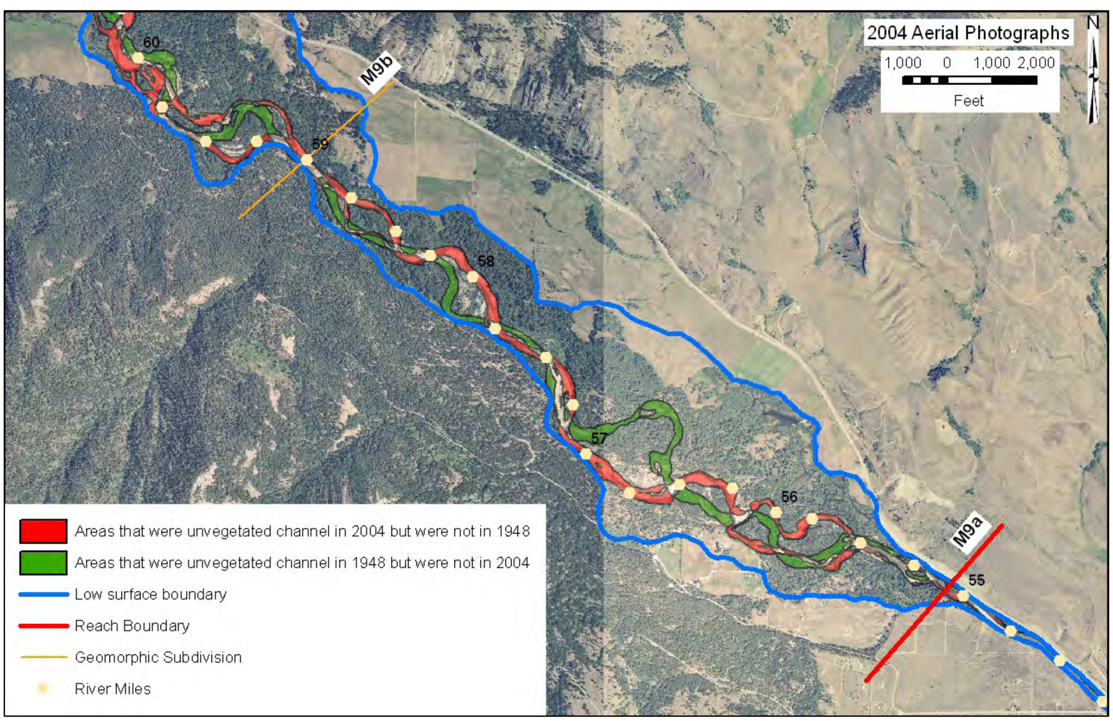

Figure G–35. Methow River – The areas that were unvegetated channel in 2004 but not in 1948 and areas that were unvegetated channel in 1948 but not in 2004 for geomorphic subdivision M9a (RM 55–59).

The areas of three categories described above were plotted by geomorphic reach to determine (1) in which reaches the 1948 and 2004 unvegetated channels were in similar locations and (2) in which reaches the two channels were in markedly different locations. Geomorphic reaches with a high percentage of area that was unvegetated channel in both 1948 and 2004 are inferred to have been the most stable. Geomorphic reaches with a high percentage of areas that were different in the two years are inferred to have been had the most change. However, this analysis uses only two years and additional changes undoubtedly occurred during the 56-year time interval. This analysis provides a broad idea of where the channel may have changed position repeatedly, but additional evaluation using aerial photographs taken in the intervening years is necessary to truly understand changes in channel position over time.

The geomorphic reaches with the least change are M1, M5, M6 (the least), and M8 (Figure G–36). The reaches with the most change are M2a, M7, M9a (the most), M9b, M9c, and M11 (Figure G–37). This is consistent with the reaches that were noted to have the most change in historical channels since the late 1800s. (See Section 4.)

Of the four geomorphic reaches with the least change, half or more of the change in reaches M6 (60%) and M8 (50%) was the result of the 2004 unvegetated channel being in a different location than the 1948 channel (Figure G–37). Of the six geomorphic reaches with the most change, 40% or more of the change was from the 2004 unvegetated channel being in a different location from the 1948 channel for four of the reaches: M2a (46%), M9a (54%), M9b (51%), M9c (41%). The rest of the change in these reaches is the result of the 1948 unvegetated channel being in a location that was abandoned, and in some cases revegetated, by 2004.

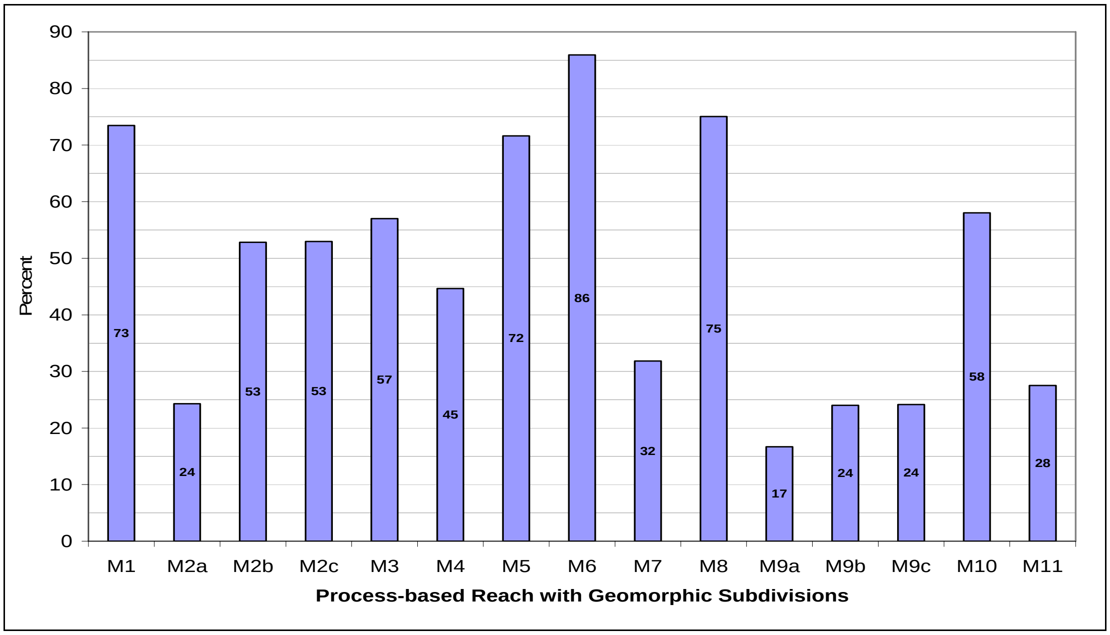

Figure G–36. Methow River – The area that was unvegetated channel in both 1948 and 2004 by geomorphic subdivision.

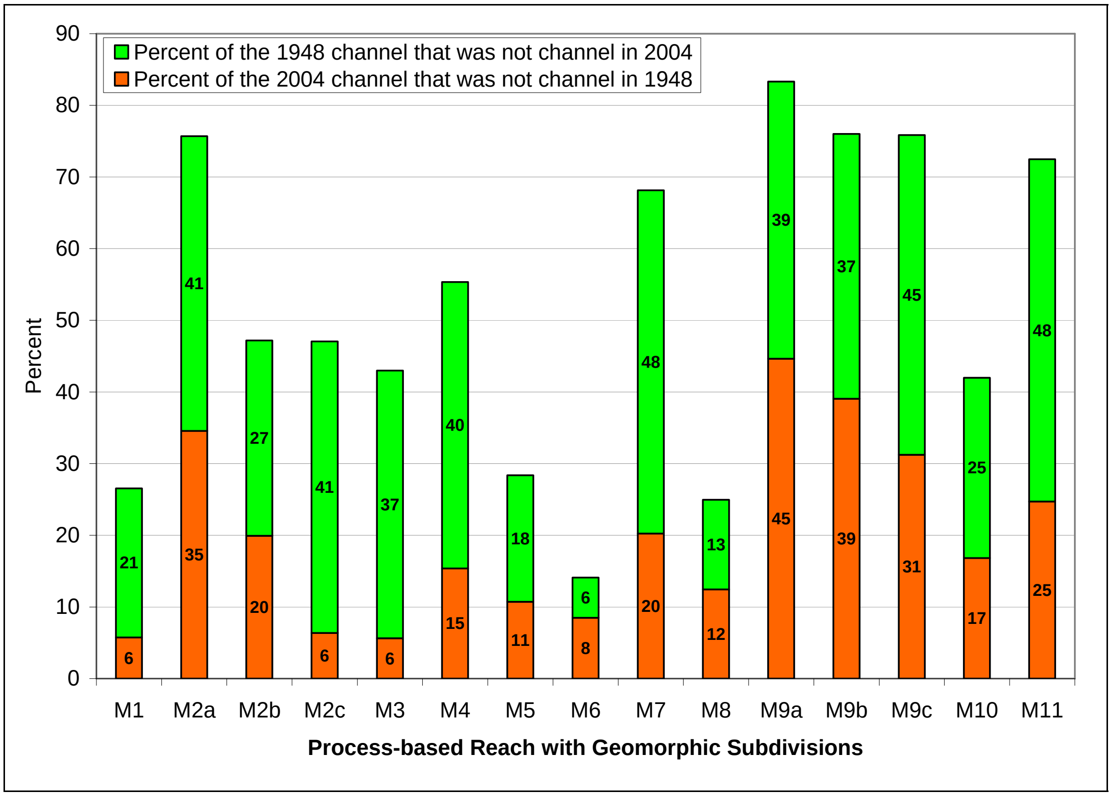

Figure G–37. Methow River – The areas of the 1948 and 2004 unvegetated channels that were active in only one of these years by geomorphic subdivision.

4. HISTORICAL CHANNELS

4.1 METHODS

Channels were mapped in ARC GIS on rectified maps and aerial photographs at about 10-year intervals for the Methow, Chewuch, and Twisp rivers between the late 1800s or early 1900s and 2004. The years that were used depended upon the available rectified maps and photographs (Table G–7). Centerlines for the main channel were mapped on all of the years of available maps and aerial photographs. Centerlines for secondary and overflow channels were mapped on the 2004 photographs, and some of the historical photographs, primarily the 1948 photographs for the Methow River and the 1954 photographs for the Twisp River. Some secondary and overflow channels were mapped on other historical aerial photographs, but because of time constraints not all of these channels were mapped.

Table G–7. Historical maps and aerial photographs used in historical channel mapping.

Year	Methow River		Twisp River		Chewuch River	
	RM	Reaches	RM	Reaches	RM	Reaches
*1893					0-8.8	C1-C3; d/send C4
*1894	34.25-43.75	M2-M3; d/s half of M4	0-1.6	T1-T2	0-8.7	C1-C3; d/s third of C4
	46.2-56.5	M4-M8; d/s half of M9	—	—	—	—
*1897	26-34.25	M1; d/s part of M2	—	—	—	—
*1900	56.5-64.25	M9	—	—	—	—
*1907	64.25-67	u/s part of M9; d/s third M10	—	—	—	—
1915					0-8.2	C1-C2; d/s two-thirds of C3
1945	28-75	All	0-1.6	T1-T2	0-3.5	C1; downstream third C2
1948	28-75	All	0-1.2	T1; d/s half T2	0-1.6	d/s ¾ of C1
1954	35.75-69.6	u/s part of M2 through M11	0-8	T1-T4; d/s part T5	0-4.6	C1; d/s ¾ C2
1964	0-66.25	M1-M10; d/s third of M11	0-8.4	T1-T4; d/s end of T5	0-9.1	C1-C2; d/s part of C3
1974	#28-73.3	#MR1-M10; d/s ¾ of M11	0-7.8	T1-T4	0-10.2	C1-C3; d/s half of C4
1985	28-75	All	0-18	All	0-14.5	All
1994					0- u/s of 18	All
2004	28-75	All	0- u/s of 18	All	0- u/s of 14.5	All

* These are the Government Land Office (GLO) maps, and the channels mapped from them are plotted together and listed as 1893-1907.
# Gaps in coverage are between RM 50.75 and RM 52.25 (part of reaches M6 and M7, near Chewuch River confluence) and between RM 43.5 and 45.25 (part of reach M4, just upstream of Twisp).

4.2 HISTORICAL CHANNEL CHANGES

Changes in low-flow channel location and planform were noted after the mapping on the historical maps and aerial photographs was complete. The changes are summarized below. Areas where changes have not been noted either (1) have not experienced changes, or (2) have experienced changes that cannot be tracked on the available maps and aerial photographs. Additional maps and photographs are needed to track changes at time intervals shorter than about 10 years. However, our analysis tracks long-term changes and identifies areas of repeated changes since the late 1800s. Some geomorphic reaches are narrowly incised into bedrock, alluvial-fan deposits, and (or) glacial deposits, and are unlikely to have experienced channel changes. Section 6 provides a list of definitions related to channels.

4.2.1 METHOW RIVER

The most changes in the low-flow channel location and planform have occurred in the upstream geomorphic reaches, M9 through M11. In these reaches, changes have occurred in all of the years, often in the same locations (Table G–8 and *Methow Atlas*). Some changes have occurred in the downstream reaches, but M4 is the only other reach that has had significant historical change. This has occurred primarily at one locality between RM 41.25 and RM 42.75, where the channel had a split path in 1893, and a single path in 1945 and later. The abandoned 1893 path remains an overflow path afterwards.

Table G–8. Methow River – Primary changes in historical channels by geomorphic reach.

Reach	Change in Historical Channels	Year or Time Interval	Location (river miles)	Observation or Change
M1	Very little			
M2a	Yes	1948 to 1964	34.25 to 35.25	Change in channel path
		1948 to 1964	35.5 to 36	Minor changes in channel path
M2b	Minor			
M2c	Very little			
M3	Very little			
M4	Yes	1893 to 1945	41.25 to 42.75	Channel has a split flow path in 1893, and a single path to the east in 1945
		1945 to 2004	41.25 to 42.75	Meander moves downstream
		1954	44 to 45.75	Channel has a split flow path in 1954; a single flow path before and after this year
M5	Minor		48.5 to 49	Flow path changes slightly historically
M6	Very little			
M7	Minor		51.5 to 52	Flow path changes slightly historically
M8	Very little			
M9a	Yes	1893	57 to 58	Channel has a straighter path than in later years

Reach	Change in Historical Channels	Year or Time Interval	Location (river miles)	Observation or Change
		1945	56.5 to 57	Channel path is meandering; meander is cut off in later years
		1945 to 1954	56.5 to 57	Meander shrinks in size
		1954 to 1964	56.5 to 57	Meander changes position
			55.5 to 56	Meander is cut off
		1964 to 1974	56.5 to 57	Meander changes position
		1974 to 1985	56.5 to 57	Meander changes position and moves downstream
		1985 to 2004	56.5 to 57	Meander changes position and moves downstream
			55.5 to 56	Channel has split flow in two paths
M9b	Yes	1900	For reach	Channel has a straighter path than in later years
		1900 to 1945	59.5 and 59.75 to 60	Channel has sharp meanders
		1945 to 1954	For reach	Meanders change
			60.5	New meander
		1954 to 1964	For reach	Meanders change
			59.75 to 60	Channel path is straighter
		1964 to 1974	For reach	Meanders change
			59.75 to 60	Channel path meandering again
			59.5 to 60.5	Channel path is straighter
		1974 to 1985	For reach	Meanders change slightly
		1985 to 2004	For reach	Meanders change
			59 to 60	Channel path is split at meanders
			60.25	Channel path is split at meanders
M9c	Yes	1900	For reach	Channel is slightly straighter than it is in 2004
		1900 to 1945	For reach	Channel path meandering
			62.5 to 64	Meander has formed
			62.5 to 62.75	Meander has formed
			63 to 63.25	Meander has formed; meander directed up-valley
			65	Meander has formed
		1945 to 1954	For reach	Meanders change slightly
			63 to 63.25	Meander broader and not directed up-valley so much
			63.75 to 64.25	Meanders slightly more
		1954 to 1964	For reach	Meanders similar to those in 1954
			65	Meander has moved upstream; more flow directed up-valley
		1964 to 1974	62.5 to 62.75	Meander has cut off
			63.75 to 64.25	Meander has cut off
		1974 to 1985	For reach	Meanders similar to those in 1974
			63 to 63.25	Meander is sharper

Reach	Change in Historical Channels	Year or Time Interval	Location (river miles)	Observation or Change
		1985 to 2004	62.75 to 63	Meander smaller
			63 to 64.25	Channel path straighter
M10	Very little upstream of RM 66.75			
	Yes downstream of RM 66.75	1945 to 1948	66.25 to 66.75	Channel path on west side
		1948 to 1954	66.25 to 66.75	Channel has split flow path
		1954 to 1974	66.25 to 66.75	Channel path on west side again; east channel path is an overflow path
		1974 to 1985	66.25 to 66.75	Channel remains in west path; east channel path is still an overflow path
		1985 to 2004	66.25 to 66.75	Channel remains in west path; east channel path is still an overflow path
		1945 to 1985	65.75 to 66.25	Channel path changes slightly
M11	Yes	1945	For reach	Channel is meandering
		1945 to 1948	For reach	Meanders move downstream or outward
		1948 to 1974	For reach	Meanders move downstream or outward
			72.75	Meander broader
		1974 to 1985	For reach	Meanders move slightly
			70.5 to 71.25	New flow path on east side
			73.75	Channel path has split flow
		1985 to 2004	For reach	Meanders move slightly
			70.5 to 71.25	Channel remains in path on east side
			73.75	Meanders change

4.2.2 TWISP RIVER

Low-flow channel changes have occurred historically along the Twisp River primarily in geomorphic reaches T2, T3b, T3c, T6a, and T6b (Table G–9). In Reach T2, a meander cut off between RM 0.8 and RM 1.6. In reaches T3b and T3c, changes have involved split flow paths between RM 5.5 and RM 5.6, and between RM 7.3 and RM 8. In reach T5, a meander has cut off and reformed between RM 11.2 and RM 11.7. In reach T6a, a meander has cut off between RM 13.8 and RM 14, and changes in split flow paths and meanders have changed between RM 15.2 and RM 15.7. In reach T6b, flow paths have change between RM 17.4 and 18.

Table G–9. Twisp River – Primary changes in historical channels by geomorphic reach.

Reach	Change in Historical Channels	Year or Time Interval	Location (river miles)	Observation or Change
T1	Very little			
T2	Yes	1945 to 2004	For reach	Channel is straighter in 2004 than it was in 1945
		1945 to 1954	0.9 to 1	Meander has cut off
			1.1 to 1.6	Channel has split flow path
		1954 to 1964	For reach	Channel is similar to that in 1954
		1964 to 1974	For reach	Channel changes
			0.8 to 0.9	Channel is more meandering
			1.1 to 1.6	Channel in north path only
T2b	Minor	1994	2.3 to 2.5	Meander is present that is not present in 1954, 1964, 1974, or 2004
T3a	Very little			
T3b	Yes	1954	5.5 to 5.6	Meandering
			6.5 to 6.6	Channel has split flow path
		1954 to 1964	5.5 to 5.6	Meander has moved upstream
			6.5 to 6.6	Channel is south flow path only
		1964 to 1974	5.5 to 5.6	Meander has cut off
		1974 to 1985	5.5 to 5.6	Meander has formed again
		1985 to 1994	5.5 to 5.6	Meander has cut off
		1994 to 2004	5.5 to 5.6	No change; meander the same path as it was in 1994
T3c	Yes	1954	For reach	Channel is slightly meandering
			7.3 to 7.6	Channel has split flow path
		1954 to 1964	7.6 to 8	Channel has split flow path
		1964 to 1974	7.3 to 7.6	Changes in the channel paths
		1974 to 2004	7.3 to 7.6	Changes in the channel paths
T4	Very little			

Reach	Change in Historical Channels	Year or Time Interval	Location (river miles)	Observation or Change
T5	Very little, except at one locality	1964	11.2 to 11.7	Channel has two meanders
		1964 to 1985	11.2 to 11.7	Meanders have cut off
		1985 to 1994	11.2 to 11.7	Meanders have formed again in slightly different positions
		1994 to 2004	11.2 to 11.7	Upstream meander has cut off
T6a	Yes	1964	Downstream of 14.4	Channel has very tight meanders; extent of photo coverage
		1985	14.5 to 15.1	Channel has broad meanders
			Upstream of 15.1	Channel has tight, sinuous meanders
		1964 to 1985	Downstream of 14.4	Channel has very tight meanders
			13.8 to 13.9	Meander has cut off
		1985 to 1994	13.8 to 14	Meanders tighter than in 1985
			14.3 to 14.8	Meanders higher than in 1985; change in pattern
			14.8 to 15.2	Channel has split flow path
			Upstream of 15.2	Change in meanders; paths in opposite positions to those in 1985
		1994 to 2004	For reach	Meanders different from those in 1994
			13.8 to 14	Change in meanders; path in opposite position to that in 1994
			15.2 to 15.7	Change in meanders; path in opposite position to that in 1994
T6b	Minor, except at one locality	1985	17.4 to 18	Channel is in northeast path
		1985 to 1994	16.6 to 16.8	Meander has moved downstream
			17.4 to 18	Channel is in a straighter path to the southwest; overflow paths are present in the area of the 1985 main channel path

4.2.3 CHEWUCH RIVER

The low-flow channels along the Chewuch River have not changed much historically (Table G–10). The most dramatic changes have been meander cut offs, which have occurred in geomorphic reach C2a between RM 4.5 and RM 5.6, in reach C2b between RM 6.1 and RM 7.1, in reach C5a between RM 12.2 and RM 12.3, and in reach C5b between RM 13.6 and RM 13.8.

Table G–10. Chewuch River – Primary changes in historical channels by geomorphic reach.

Reach	Change in Historical Channels	Year or Time Interval	Location (river miles)	Observation or Change
C1	Very little			
C2a	Minor		2.7 to 2.9	Some changes historically
			3.5 to 4.2	Some changes historically
		1893/1915 to 1964	4.5 to 5.6	Meander that was present in 1893 and 1915 is cut off by 1964
C2b	Yes	1893/1915 to 1964	6.1 to 6.3	Meander that was present in 1893 and 1915 is cut off by 1964
			6.5 to 7.1	Meander that was present in 1893 and 1915 is cut off by 1964
C3a	Very little			
C3b	Very little			
C4a	Very little			
C4b	Very little			
C4c	Very little			
C5a	Very little, except at one location	1985 to 2004	12.2 to 12.3	Meander that was present in 1915 and 1985 is cut off; meander is an overflow channel by 2004
C5b	Very little			
C6	Very little			

5. HUMAN FEATURES AND CHANGES IN LOW-SURFACE WIDTH

5.1 HUMAN FEATURES WITHIN THE LOW SURFACE

The human features along the Methow, Twisp, and Chewuch rivers were mapped in order to identify human features within the low surface and along its boundary using aerial photographs primarily, some additional field observations, and previous compilations of human features. This compilation also assesses the impact of each human feature on the geologic low surface, such as limiting channel migration or low surface area.

In many places, the human features influence the width of the low surface. As shown by an example from geomorphic reach M5 on the Methow River, in some places the human features appear to have been in place by 1945, the earliest year of aerial photographs that we had available for mapping (Figure G–38 and Figure G–39). In contrast, other sections, as shown for geomorphic reach M9c, the channel does not appear to have been constrained by human features in 1948, although the present width of the low surface is less than it would be without any human features (Figure G–40 and Figure G–41).

Human features are noted by reach in Appendix P.

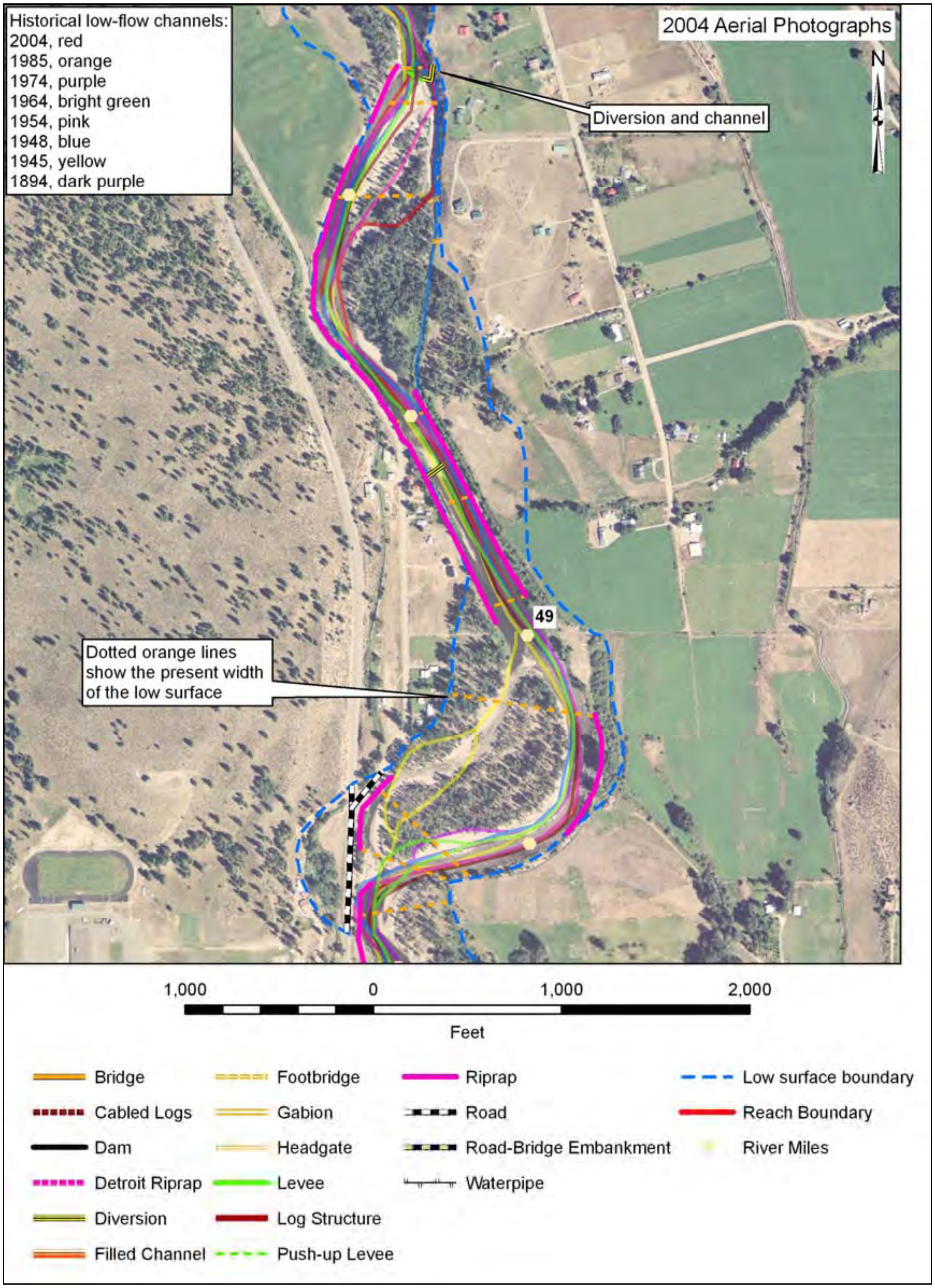

Figure G–38. Methow River – Human features, historical low-flow channels, and present widths of the low surface for a section of geomorphic reach M5.

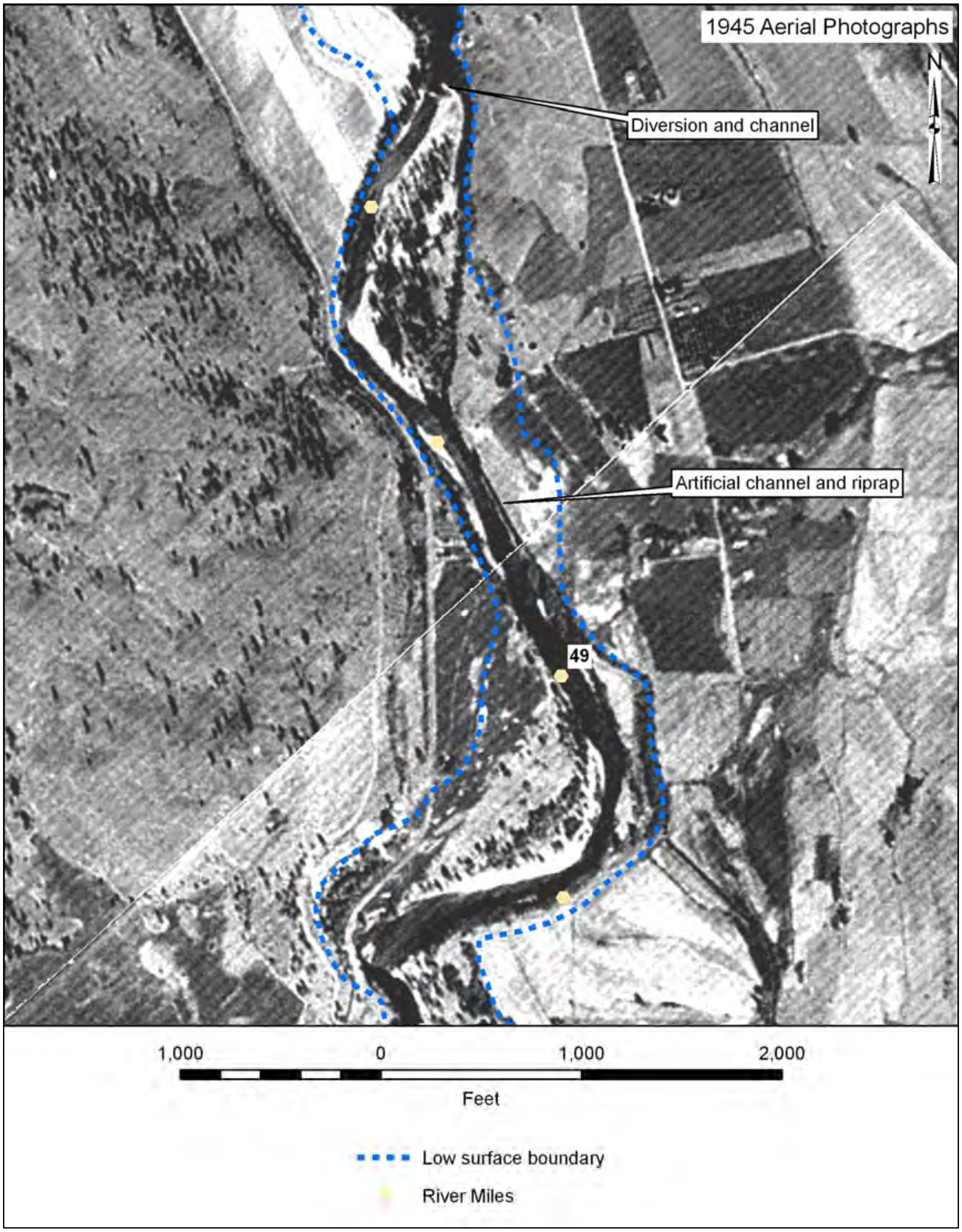

Figure G–39. Methow River – The section of geomorphic reach M5 shown in Figure G–38 as it was in 1945.

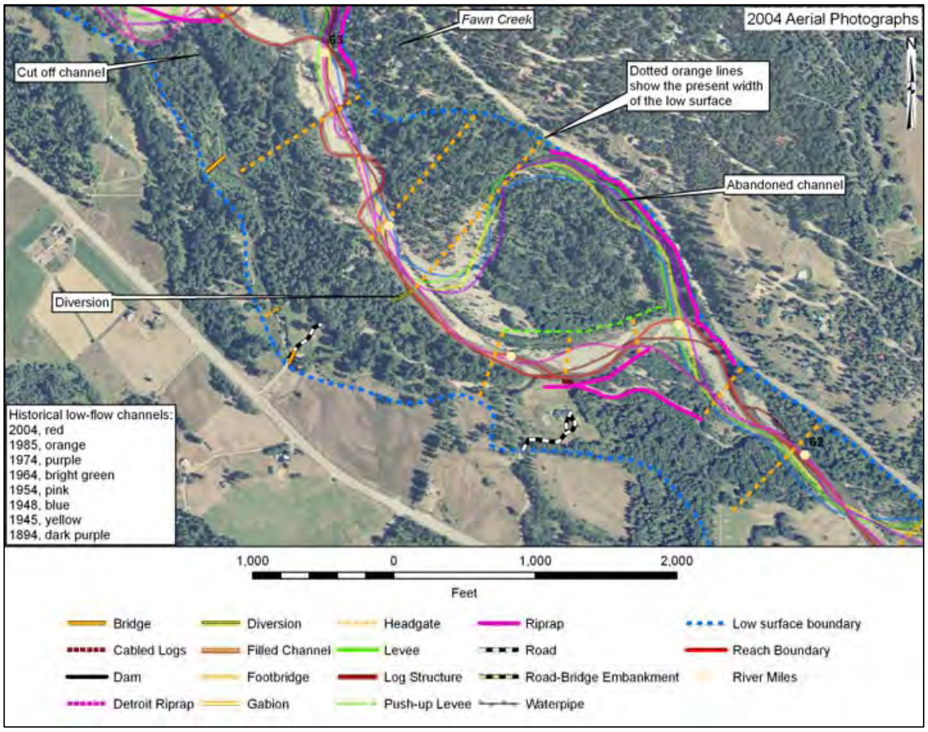

Figure G–40. Methow River – Human features, historical low-flow channels, and present widths of the low surface for a section of geomorphic subdivision M9c.

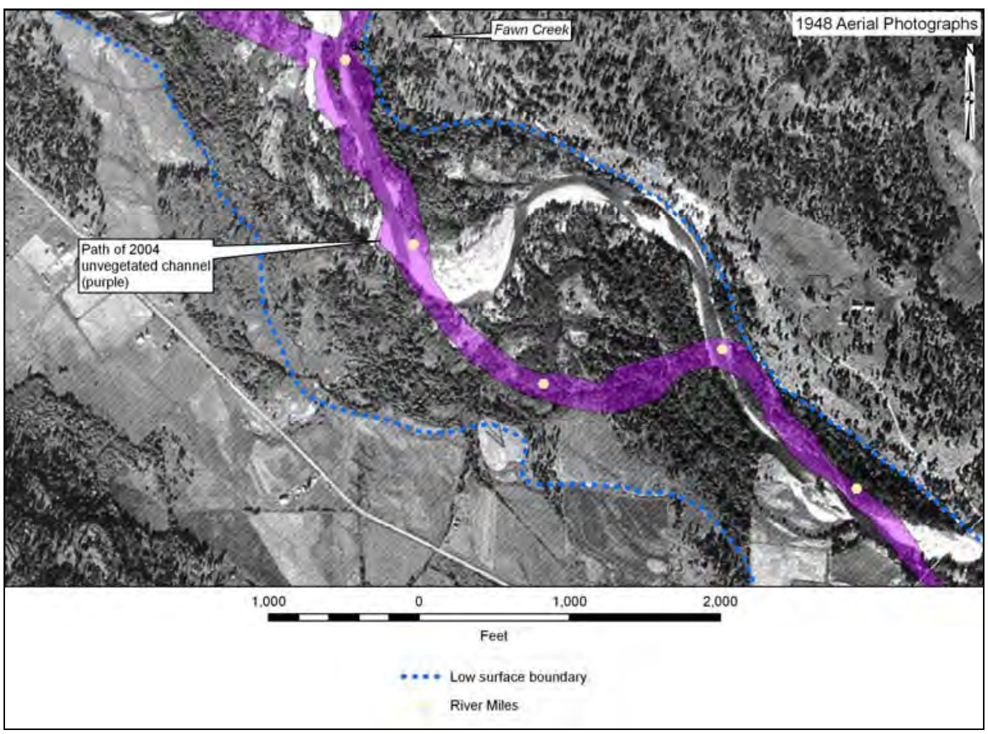

Figure G–41. Methow River – The section of geomorphic subdivision M9c that is shown in Figure G–40 as it was in 1948.

5.2 IMPACTS OF HUMAN FEATURES ON THE WIDTHS OF THE LOW SURFACE

The maximum, minimum, and mean geologic and present widths of the low surface were calculated for each geomorphic reach in the assessment sections of the Methow, Chewuch, and Twisp rivers, using widths measured about every 0.1 mile in Arc. (See Arc files.) The geologic and present widths of the low surface were compared for each geomorphic reach to see which values (maximum, minimum, or mean) and which reaches have been most affected by human features. The percent change was calculated for the maximum, minimum, and mean widths for each reach in order to compare the amount of change among the reaches. This was done because the absolute amount of change may be small, but the percent of change, especially for a reach where the geologic width of the low surface in narrow, may be large.

5.2.1 MAXIMUM WIDTHS OF THE LOW SURFACE

For all three rivers, Methow, Chewuch, and Twisp, human features do not markedly impact the maximum geologic widths of the low surface.

For the Methow River, human features do not decrease the maximum width of the low surface noticeably, except in three geomorphic reaches: M4, M9c, and M10 (Figure G–42; Table G–11). Of these three reaches, the greatest percent change is in reach M4 (27% change) (Figure G–42; Table G–12).

For the Twisp River, human features decrease the width of the low surface at least slightly for all but the two upstream geomorphic reaches: T6a and T6b (Figure G–43; Table G–13). The greatest percent change in the maximum width is in Reach T1, which has experienced a 58% change (Table G–14). This percent change in maximum width is the highest for the three drainages. Of other geomorphic reaches for the Twisp River that have experienced a change in the maximum width of the low surface, reach T3a has the next highest percent change (34%), reach T2a has the next highest percent change (29%), and reach T5 has the next highest percent change (16%). Four other geomorphic reaches exhibit changes in the maximum width (T2b, T3b, T3c, and T4), but all of the changes in these reaches are 3 to 5% (Figure G–43).

For the Chewuch River, human features decrease the maximum width of the low surface in only three geomorphic reaches: C1, C3b, and C4c (Figure G–44; Table G–15). Of these three reaches, the greatest percent change is in reach C1 (25% change; Table G–16). The percent changes in reaches C3b and C4c are only 4% (Figure G–44).

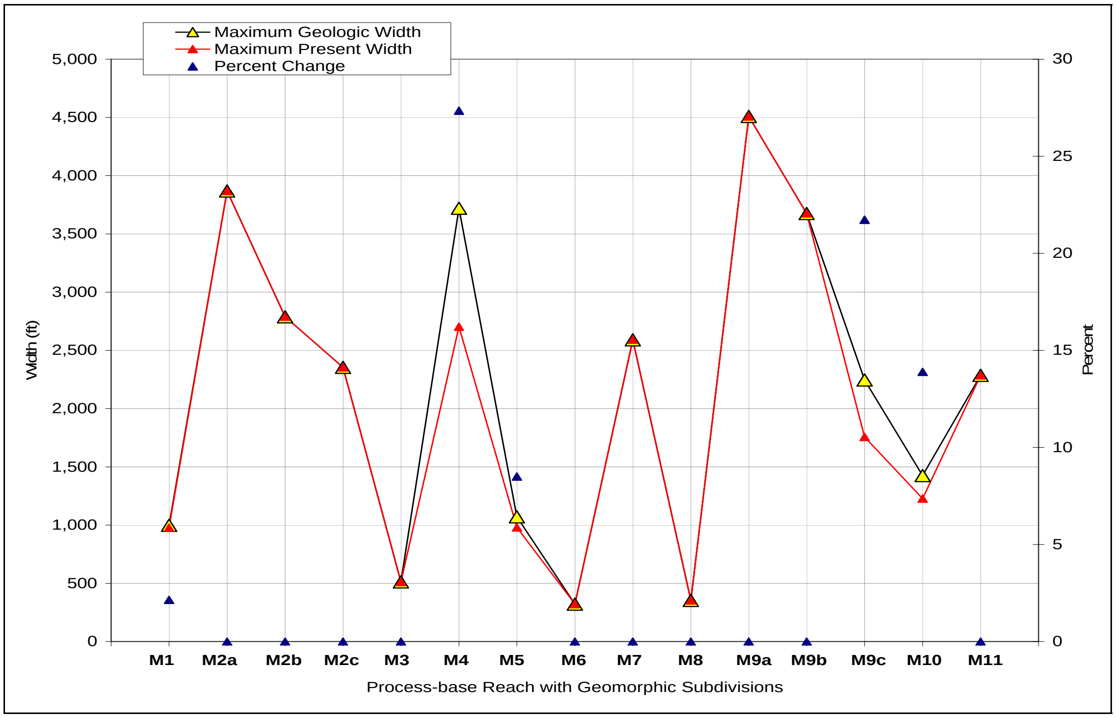

Figure G–42. Methow River – Comparison of the maximum geologic and present widths of the low surface by geomorphic subdivision.

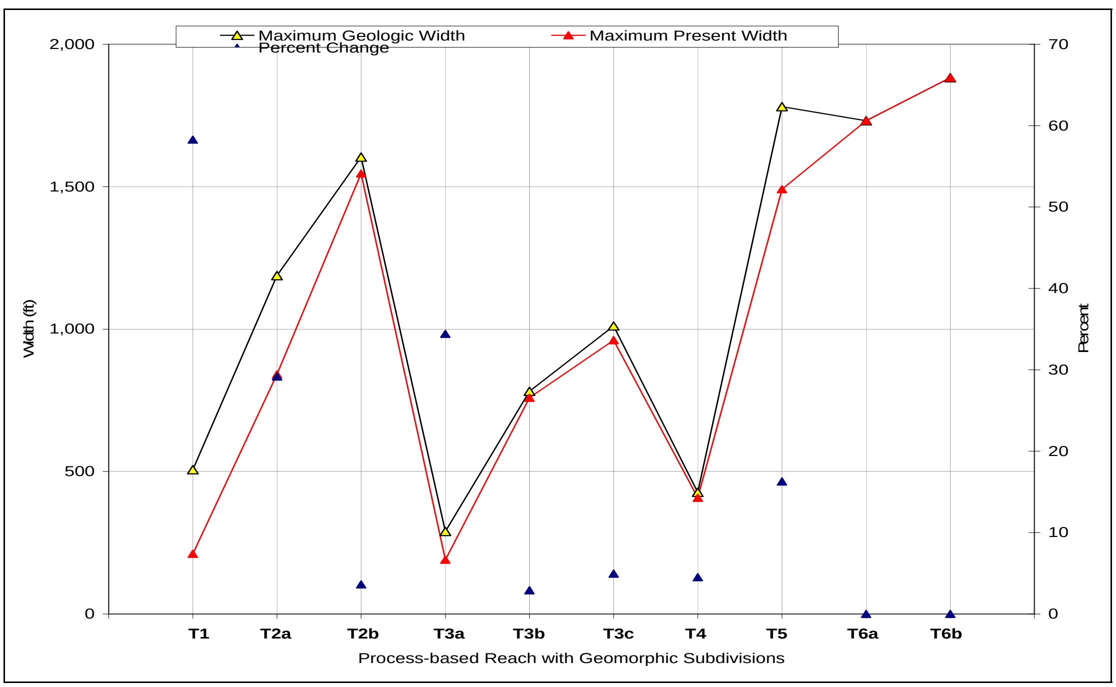

Figure G–43. Twisp River – Comparison of the maximum geologic and present widths of the low surface by geomorphic subdivision.

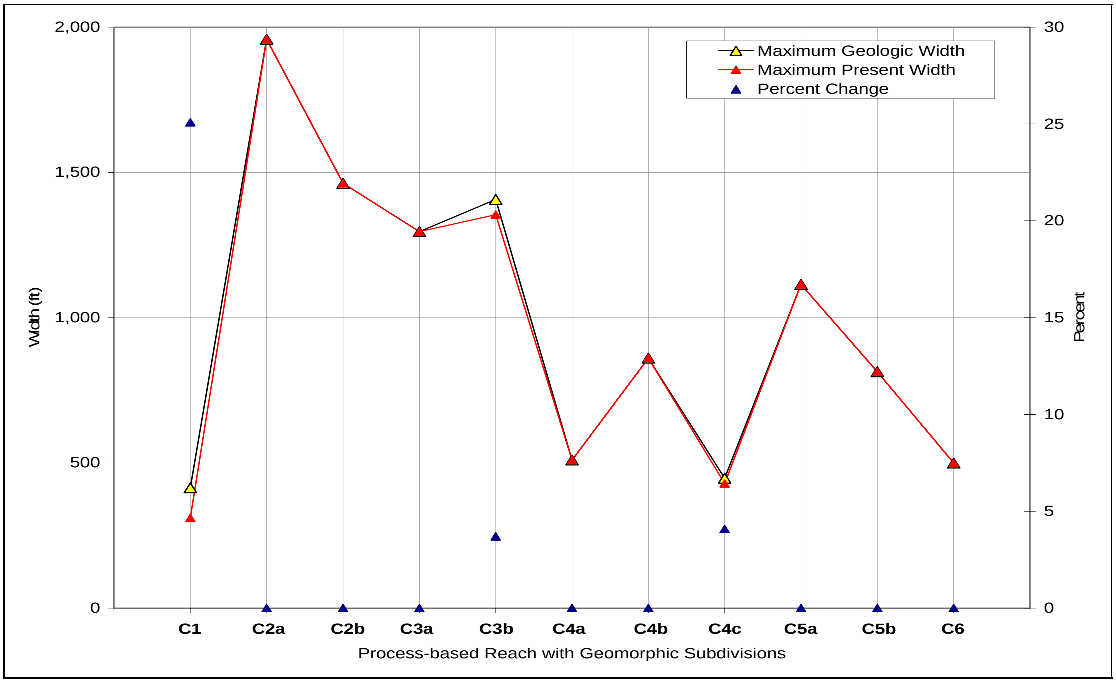

Figure G–44. Chewuch River – Comparison of the maximum geologic and present widths of the low surface by geomorphic subdivision.

5.2.2 MINIMUM WIDTHS OF THE LOW SURFACE

For all three drainages, the minimum widths of the low surface are the most affected by human features. This is particularly important because the minimum width may be the most important for maintaining high flows within the low surface.

For the Methow River, the minimum widths are decreased by human features in all but four geomorphic reaches: M2c, M6, M8, and M9a (Figure G–45; Table G–11). The minimum widths are markedly affected in four reaches: M4, M7, M9b, and M9c (Figure G–45). The highest percent change is in reach M9b (94% change). The other three of these reaches have changes of 79% for reach M9c, 77% for reach M4, and 72% for reach M7 (Figure G–45; Table G–12). Two other reaches have greater than 50% change in minimum width: M11 (53% change) and M1 (52% change).

For the Twisp River, the minimum widths are decreased by human features in all of the geomorphic reaches. The decrease is especially marked in reaches T2b, T3b, T5, and T6b (Figure G–46; Table G–13). The greatest percent changes are in reaches T3b (85% change) and T5 (84%). Reach T2b has had 79% changes, whereas reach T6b has had a 56% change in minimum width. Other reaches that do not appear to have had such a large absolute change in minimum width have had greater percent changes in width than has reach T6b. These reaches are T1 (65% change), T3c (69%), T4 (63%), T6a (60%), and T2a (58%) (Figure G–46; Table G–14).

For the Chewuch River, the minimum widths are markedly decreased by human features in all but three geomorphic reaches: C1, C4a, and C6, where the minimum geologic and present widths are about the same (Figure G–47; Table G–15). The greatest percent change in the minimum width is in reach C5b (80% change). Other reaches with greater than 50% change in minimum width are C3a (76% change), C2b (75%), C2a (66%), and C4b (50%) (Figure G–47; Table G–16).

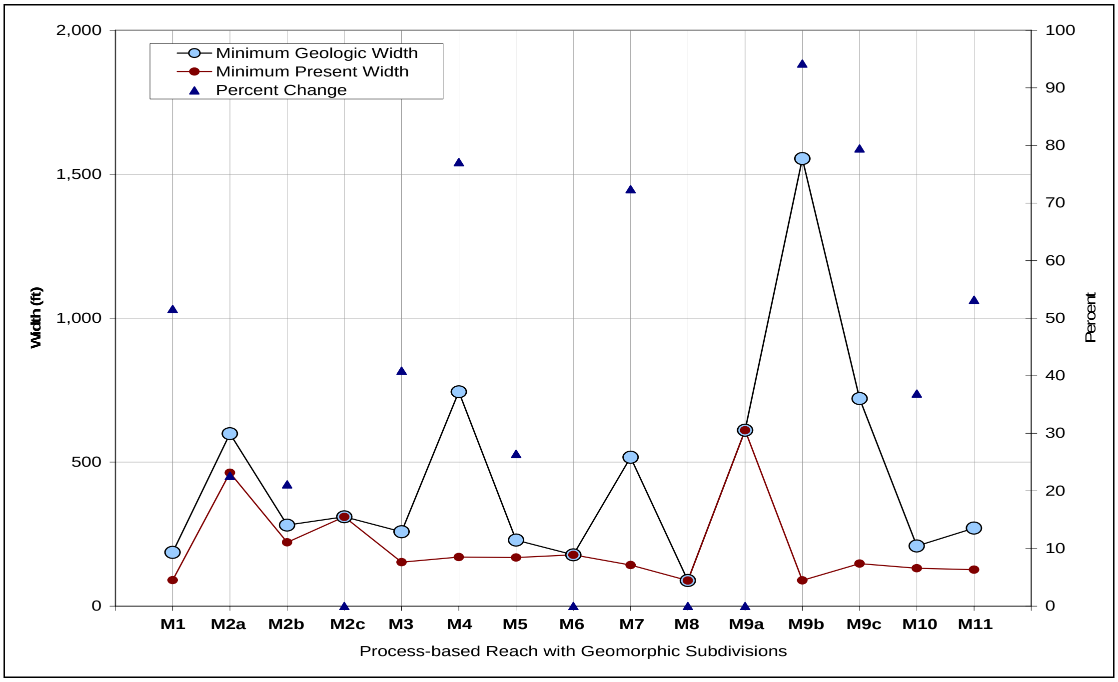

Figure G–45. Methow River – Comparison of the minimum geologic and present widths of the low surface by geomorphic subdivision.

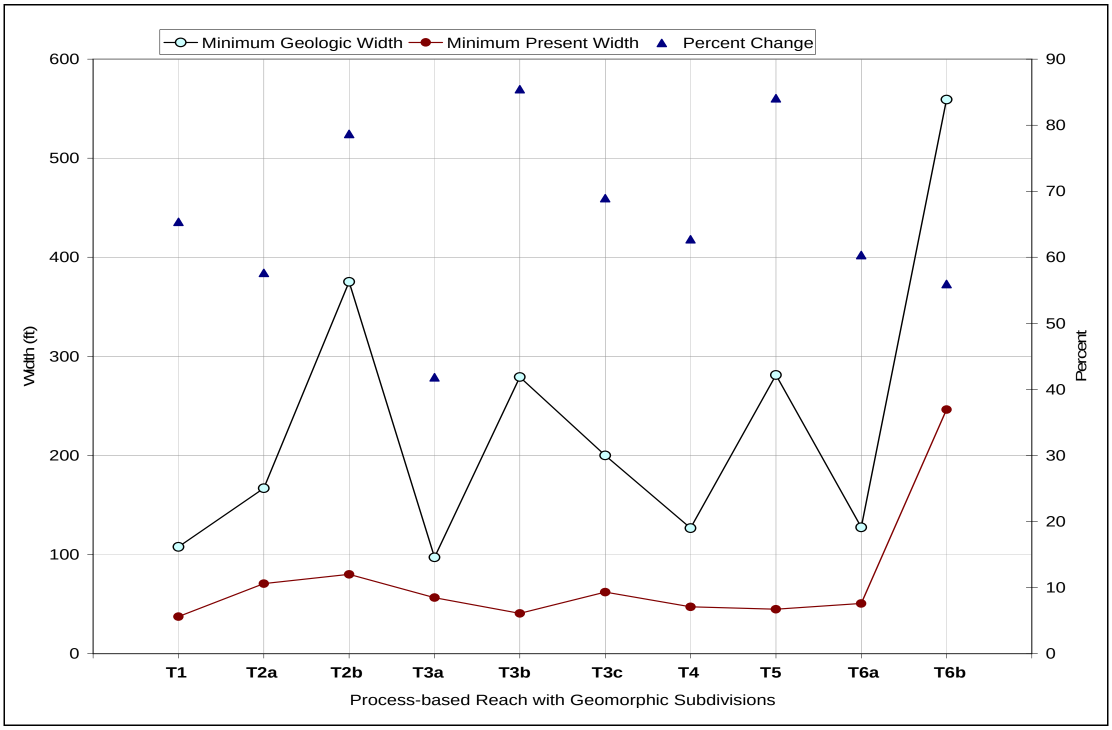

Figure G–46. Twisp River – Comparison of the minimum geologic and present widths of the low surface by geomorphic subdivision.

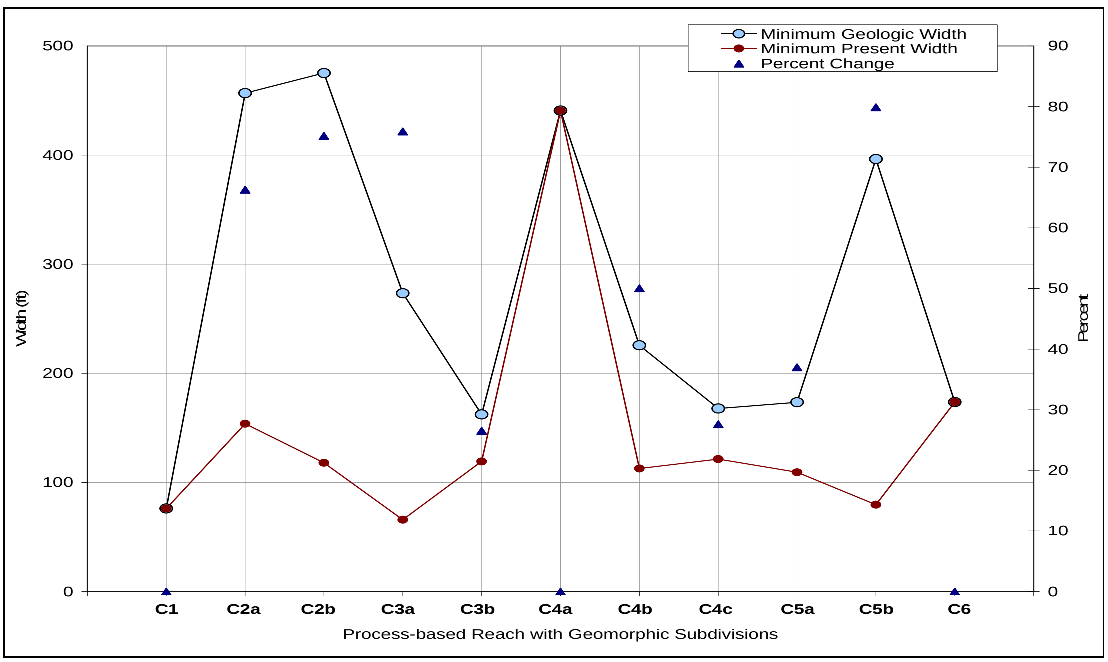

Figure G–47. Chewuch River – Comparison of the minimum geologic and present widths of the low surface by geomorphic subdivision.

5.2.3 MEAN WIDTHS OF THE LOW SURFACE

For all three drainages, the mean width of the geologic low surface is generally decreased by human features.

For the Methow River, the present mean width is less than the geologic mean width for all of the geomorphic reaches (Figure G–48; Table G–11). However, the mean present widths are only slightly less than the mean geologic widths for five reaches: M1, M3, M6, M8, and M10 (Figure G–48). The greatest percent change in mean low surface width is in reach M7 (60% change). The reaches with the next highest percent change are M9b (38% change), M9c (29%), M4 (29%), M2b (25%), M2a (21%), and M11 (20%) (Figure G–48; Table G–12).

For the Twisp River, the mean present widths of the low surface are less than the mean geologic widths for all of the geomorphic reaches (Figure G–49; Table G–13). The greatest change in mean widths is in four reaches: T2b, T3c, T5, and T6a (Figure G–49). However, reach T1 has the greatest percent change in mean width (54% change), although it is seventh in the amount of absolute change in mean width. Of the four reaches with the most absolute change in mean width, reach T5 has the highest percent change (46%). Reach T5 has 46% change, reach T2b has 38% change; reach T3c has 36% change, and reach T6a has only 24% change (Figure G–49; Table G–14).

For the Chewuch River, the mean present widths of the low surface are less than the mean geologic widths for all but two geomorphic reaches: C4a and C6 (Table G–15). The greatest percent change in the mean width is in reach C4b (35% change). The reaches with the next highest percent change are C3a (29%), C2b (23%), C3b (19%), C1 (17%), and C4c (26%) (Figure G–50; Table G–16).

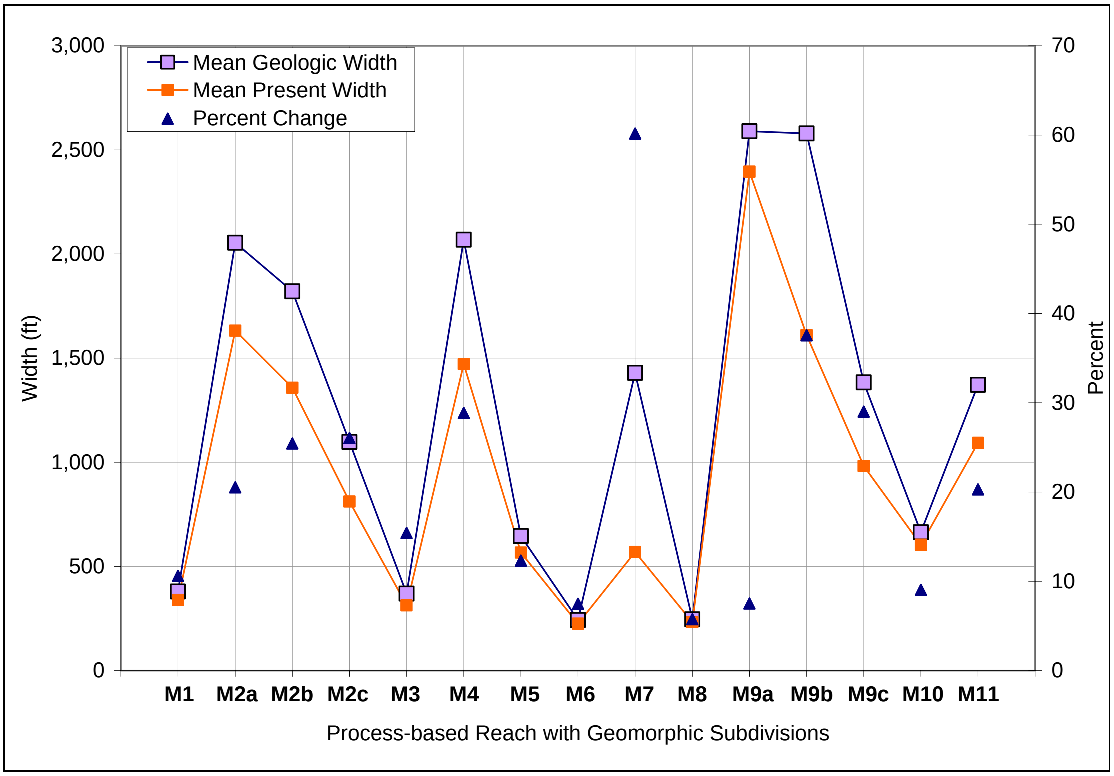

Figure G–48. Methow River – Comparison of the mean geologic and present widths of the low surface by geomorphic subdivision.

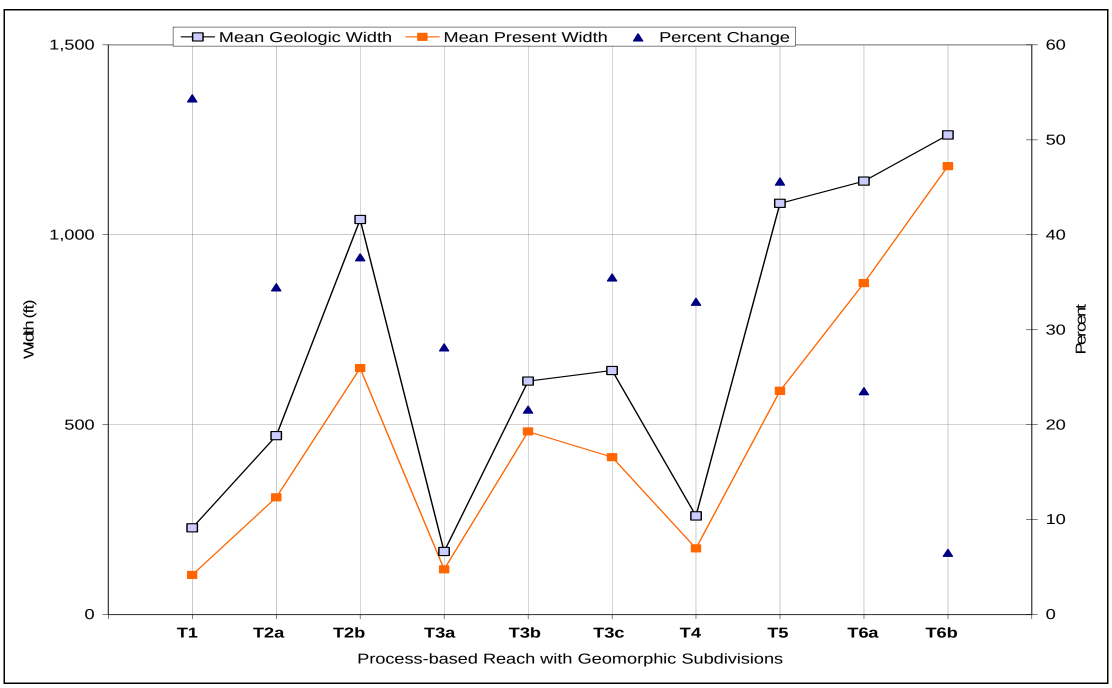

Figure G–49. Twisp River – Comparison of the mean geologic and present widths of the low surface by geomorphic subdivision.

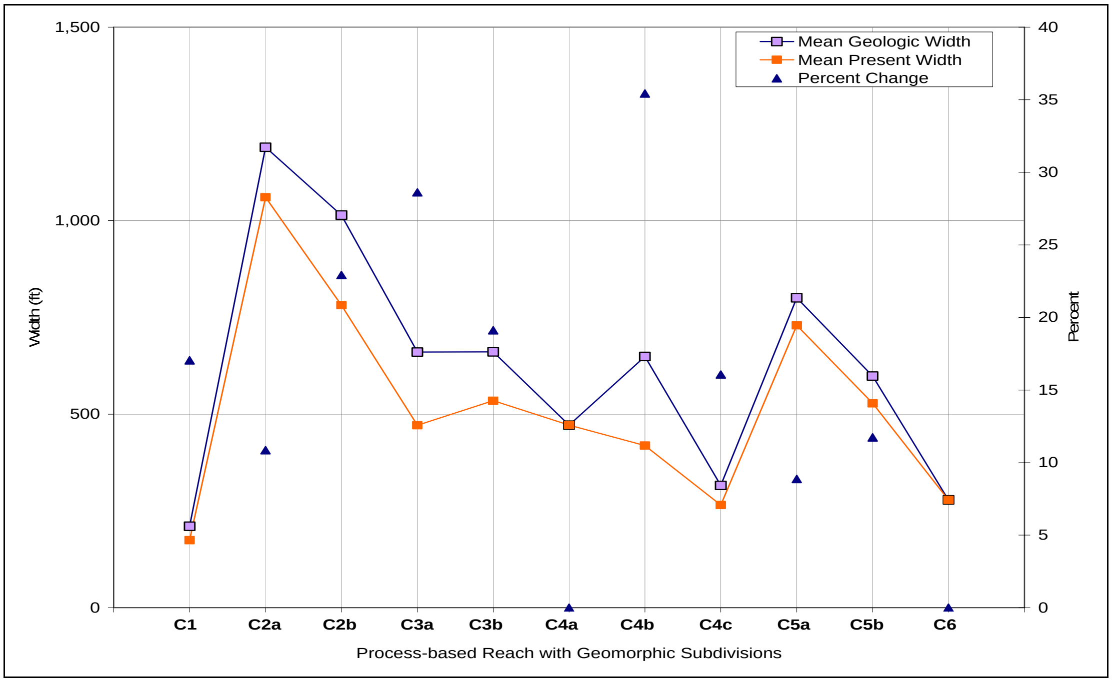

Figure G–50. Chewuch River – Comparison of the mean geologic and present widths of the low surface by geomorphic subdivision.

Table G–11. Methow River – Maximum, minimum, and mean geologic and present widths of the low surface by geomorphic subdivision.

Reach	Maximum Geologic Width (ft)	Minimum Geologic Width (ft)	Mean Geologic Width (ft)	Maximum Present Width (ft)	Minimum Present Width (ft)	Mean Present Width (ft)
M1	999	187	380	977	90	339
M2a	3,868	599	2,054	3,868	463	1,632
M2b	2,789	281	1,821	2,789	222	1,358
M2c	2,354	310	1,098	2,354	310	812
M3	512	258	370	512	153	313
M4	3,720	744	2,069	2,703	170	1,472
M5	1,071	229	646	980	169	566
M6	321	178	243	321	178	225
M7	2,591	517	1,429	2,591	143	569
M8	354	89	246	354	89	232
M9a	4,508	611	2,590	4,508	611	2,395
M9b	3,676	1,554	2,579	3,676	90	1,610
M9c	2,246	721	1,383	1,758	148	982
M10	1,426	209	664	1,228	132	604
M11	2,286	271	1,371	2,286	127	1,093

Table G–12. Methow River – Percent change in the maximum, minimum, and mean geologic and present widths of the low surface geomorphic subdivision.

Reach	Change in Maximum Width (ft)	Change in Minimum Width (ft)	Change in Mean Width (ft)	Percent Change in Maximum Width	Percent Change in Minimum Width	Percent Change in Mean Width
M1	21	96	40	2	52	11
M2a	0	136	422	0	23	21
M2b	0	59	463	0	21	25
M2c	0	0	286	0	0	26
M3	0	106	57	0	41	15
M4	1,017	574	597	27	77	29
M5	91	61	79	9	26	12
M6	0	0	18	0	0	7
M7	0	374	860	0	72	60
M8	0	0	14	0	0	6
M9a	0	0	195	0	0	8
M9b	0	1,465	968	0	94	38
M9c	488	573	401	22	79	29
M10	198	77	60	14	37	9
M11	0	144	278	0	53	20

Table G–13. Twisp River – Maximum, minimum, and mean geologic and present widths of the low surface by geomorphic subdivision.

Reach	Maximum Geologic Width (ft)	Minimum Geologic Width (ft)	Mean Geologic Width (ft)	Maximum Present Width (ft)	Minimum Present Width (ft)	Mean Present Width (ft)
T1	506	108	228	211	37	104
T2a	1,188	167	471	841	71	309
T2b	1,604	375	1,040	1,546	80	649
T3a	290	97	166	190	57	119
T3b	782	279	615	759	41	482
T3c	1,011	200	643	961	62	414
T4	427	127	260	408	47	174
T5	1,781	281	1,083	1,491	45	589
T6a	1,732	127	1,141	1,732	51	873
T6b	1,883	559	1,263	1,883	246	1,181

Table G–14. Twisp River – Percent change in the maximum, minimum, and mean geologic and present widths of the low surface by geomorphic subdivision.

Reach	Change in Maximum Width (ft)	Change in Minimum Width (ft)	Change in Mean Width (ft)	Percent Change in Maximum Width	Percent Change in Minimum Width	Percent Change in Mean Width
T1	295	70	124	58	65	54
T2a	347	96	162	29	58	34
T2b	58	295	391	4	79	38
T3a	100	41	47	34	42	28
T3b	23	239	133	3	85	22
T3c	50	138	228	5	69	36
T4	19	79	86	5	63	33
T5	290	236	494	16	84	46
T6a	0	77	268	0	60	24
T6b	0	313	82	0	56	6

Table G–15. Chewuch River – Maximum, minimum, and mean geologic and present widths of the low surface by geomorphic subdivision.

Reach	Maximum Geologic Width (ft)	Minimum Geologic Width (ft)	Mean Geologic Width (ft)	Maximum Present Width (ft)	Minimum Present Width (ft)	Mean Present Width (ft)
C1	414	76	211	310	76	175
C2a	1,959	457	1,190	1,959	154	1,061
C2b	1,462	475	1,014	1,462	118	782
C3a	1,296	273	661	1,296	66	472
C3b	1,407	162	661	1,355	119	535
C4a	510	441	472	510	441	472
C4b	861	226	649	861	113	419
C4c	447	168	316	429	121	265
C5a	1,114	174	801	1,114	109	730
C5b	814	396	598	814	80	528
C6	499	174	279	499	174	279

Table G–16. Chewuch River – Percent change in the maximum, minimum, and mean geologic and present widths of the low surface by geomorphic subdivision.

Reach	Change in Maximum Width (ft)	Change in Minimum Width (ft)	Change in Mean Width (ft)	Percent Change in Maximum Width	Percent Change in Minimum Width	Percent Change in Mean Width
C1	104	0	36	25	0	17
C2a	0	303	129	0	66	11
C2b	0	357	233	0	75	23
C3a	0	208	189	0	76	29
C3b	52	43	126	4	27	19
C4a	0	0	0	0	0	0
C4b	0	113	230	0	50	35
C4c	18	46	51	4	28	16
C5a	0	64	71	0	37	9
C5b	0	317	70	0	80	12
C6	0	0	0	0	0	0

6. DEFINITIONS

The following channel definitions were used:

TERM	DEFINITION
Low-flow channel	A channel that carries flow even during low-flow conditions.
Secondary channel	A channel that is not part of the main channel, but appears to have water during low-flow conditions and has evidence for recent higher flow (e.g., may include unvegetated areas (bars) adjacent to the channel). At least the upstream end of the channel connects to, or nearly connects to, the main channel. The downstream end of the secondary channel may connect to the main channel or to an overflow channel.
Possible secondary channel	Same as a secondary channel, except that the presence of water is questionable (especially on the older historical aerial photographs, where photograph quality is poorer than on the more-recent photographs). The channel may not have a clear connection to the main channel.
Overflow channel	A channel that is expressed by no or little vegetation through a vegetated area. There is no evidence for water at low-flow conditions. The channel appears to have carried water recently during a high-flow event. The upstream and (or) downstream ends of the overflow channel usually connect to the main channel.
Possible overflow channel	Same as an overflow channel, except that evidence for recent flow is not as obvious. The channel may be expressed only as a sinuous break in vegetation. The channel may lack direct evidence (e.g., unvegetated areas) for recent flow.
Overflow channel, modified	Overflow channel that appears to have been modified by human structure or activity.
Overflow channel, cutoff	Overflow channel that has been cutoff by a human structure or activity.
Overflow/Tributary channel	A channel that appears to act as a path for an overflow channel of the main drainage and an unvegetated channel for a tributary. These channels occur where a tributary flows along the valley

	floor before joining the main drainage.
Old channel	A channel that appears to be entirely cut off from the main channel, but still has unmistakable channel form. The channels may contain obvious water (indicated as wet), but they usually are partially or entirely vegetated. The source of the water may be a surface connection to the river or ground water.
Channel remnant (wet)	Same as an Old channel (wet) for channels on the U.S. Geological Survey topographic maps from the middle 1980s. Mapped as a channel remnant (wet), because this is how they appear on the topographic maps.
Slough	Same as an Old channel for channels digitized on the Government Land Office (GLO) maps. Mapped as sloughs, because this is how they are labeled on the GLO maps.
Tributary	An unvegetated channel of a tributary to the main drainage.
Tributary/Possible secondary channel	A tributary channel that may also be a secondary channel to the main drainage. These channels occur where a tributary flows along the valley floor before joining the main drainage.

7. REFERENCES

IN TEXT	**FULL CITATION**
Beck 1973	R R.W. Beck and Associates, 1973, *Flood plain information, Methow River, Twisp to Mazama, Okanogan County, Washington:* R.W. Beck and Associates, Analytical and Consulting Engineers, Seattle, WA. Report prepared for Washington Department of Ecology, Olympia, WA. 13 p., 20 figures.
Golder 2005	Golder Associates, Inc., 2005, *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Norman 1974	Norman Associates, 1974, *Flood plain information, Methow River, Twisp to Carlton, Okanogan County, Washington.* Report prepared for County of Okanogan Office of Planning and Development, Okanogan, WA, by Norman Associates Consulting Engineers, Bellevue, WA, 12 p., 10 figures.

APPENDIX H – VEGETATION

Appendix H contains two reports on vegetation conditions.

The first report, Appendix H-1, "Vegetation Assessment on Methow and Chewuch River," was prepared by Heieke Baesecke of Geosis Consulting (of ***Twisp, WA) under contract with the Bureau of Reclamation and completed November 2005.*** *It provides classification of riparian vegetation along the Methow and Chewuch assessment areas based on aerial photography and local knowledge of the subbasin vegetation conditions. This data was placed in a GIS database by Reclamation (Technical Appendix Q). This report also provides a literature review of previous vegetation work performed on the Twisp River.*

The second report, Appendix H-2, "Biological Evaluation of Condition of Black Cottonwood," was prepared by forest pathologist James S. Hadfield of the Okanogan/Wenatchee National Forest. It is intended to field-validate hypotheses generated in the vegetation assessment report. It documents the condition of black cottonwood and other relevant riparian vegetation features based on a field assessments at four potential restoration areas along the Twisp and Methow Rivers, Okanogan County, Washington.

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1. VEGETATION ASSESSMENT ON METHOW AND CHEWUCH RIVERS

1.1 METHOW RIVER

1.1.1 GENERAL FINDINGS

The Methow River shows the largest extensions of riparian vegetation with high species' diversity of trees and shrubs in the upper reaches of the study area (Lost River confluence to just upstream of Wolf Creek confluence). The mid and lower sections of the study area (Wolf Creek to Twisp and Twisp to Carlton) have increasingly less riparian extension and diversity with some exceptions. In particular, the stretches upstream of Carlton are defined by only a narrow line of single trees or no trees at all with a significant amount of non-native trees, shrubs and forbs.

Premature coloring and shedding of leaves among the Black Cottonwood trees in the riparian area of the Upper Methow River reaches was noticed. During the time of observation (8/22/05 and 8/23/05), the same tree species were still bearing green leaves in other sections of the Methow River and also in the Chewuch and Twisp River drainages. However, the trees in the Upper Methow were showing fall conditions that are generally expected in mid October, two months later. Although the Upper Methow reaches generally show good riparian vegetation condition, this could be a sign of disease and/or drought.

The regeneration of Black Cottonwood throughout the riparian area is compromised and often non-existent, or is restricted to areas that receive periodic inundation (instream bars, active side channels, low banks). Trees do not appear to reach maturity in many places and die back during middle age (50-60 years) instead of old age.

True riparian vegetation species are being replaced by tree species commonly associated with upland forest such as Douglas-fir and ponderosa pine throughout the system, suggesting an overall drying trend in the riparian area. Possible reasons are climate change (drought), water diversion, channel incision.

Few areas that show Black cottonwood regeneration are heavily targeted by wildlife (white tail and mule deer) and animals browse the plants down or destroy them entirely.

1.1.2 FINDINGS BY GEOMORPHIC REACH LEVEL

[Note: Revised geomorphic reach designations and river miles are shown in italics in brackets.]

Reach MR1 *[M1; RM 28.1–33.4]*: Agricultural lands and settlements along the river and an incised channel bed and high cut banks support little riparian vegetation in this reach. Often the riparian is merely a line of trees along the river; sometimes those trees are Ponderosa pine, which is not a riparian species, or other species that are often non-native. A few instream bars support mostly shrubs and non-native forbs. A few dying, individual black cottonwood trees are found along the sides of the river bank.

Reach MR2 *[portion of M2; RM 33.4–35.7]:* The lower section of Reach 2 shows a similar situation to Reach 1 with only sporadic remnants of riparian vegetation. The mid and upper sections of the reach in the vicinity and upstream from Leecher Canyon (Silver site) have some areas with good riparian vegetation establishment of either deciduous shrub associations (river right) or bar vegetation. There is good potential for possible riparian restoration on the river left, now a stand dominated by Ponderosa pine with few remnants of the past riparian stand of Black cottonwood. The remainder of the reach shows the same picture, with Ponderosa pine stands along the river where cottonwood stood in the past, and bar vegetation of non-native plants with mixed regenerating cottonwood.

Reach MR3 *[portion of M2; RM 35.7–38.75]*: A large area on river right just above the reach break (2/3) should be further surveyed because of the potential of future cottonwood recruitment. At this time the area supports some mature cottonwoods but the conditions are unknown. Further upstream, the shrub zones along an old side channel and present beaver ponds are cut off from the river by agricultural fields. Yet further upstream, just below the reach break (3/4) on river right, old remnant but extensive stands of cottonwood trees are situated. The condition of those trees is unknown and should be further investigated. The entire reach supports bar vegetation with some cottonwood recruitment.

Reach MR4 *[portion of M2 and M3; RM 38.75–41.2]:* Throughout the reach there are only few places with remnant riparian vegetation, mostly old and dying cottonwood stands and individual trees lining the lower parts of the river bank.

Reach MR5 *[M4; RM 41.2–47.9]:* The area just upstream from the reach break (4/5) on river left shows some healthy galleries of regenerating cottonwood and riparian shrubs that have established here over the last 10-15 years in response to river flood events. Although this area is small it should be protected from livestock grazing and wildlife. A number of other regions with either old cottonwood trees or mixed cottonwood/Ponderosa pine within the reach are located within cattle grazing areas and agricultural fields and it appears as though the cottonwoods are dying and not regenerating. Further investigation is needed in this reach, in particular on the river right just below the Intercity airport and downstream from there on the river left.

Reach MR6 *[M5 and M6; RM 47.9–51.45]:* The reach below Winthrop just shows remnants of old cottonwood stands that have been altered and removed by agricultural activities, settlement and river channel incision. Most of the stands are now dominated by Ponderosa pine and cattle has removed the understory. Non-native forbs have migrated into those areas and reduced the possibility of native plant establishment.

Reach MR7 *[M7 and portion of M8; RM 51.45–54]:* As in Reach 6, this reach has only remnants of riparian vegetation which is often disconnected from the present river channel and is being replaced with upland species. The upstream portions of the reach only show individual trees or single lines of trees and sometimes no riparian indicators at all where agricultural lands extend onto the river bank.

Reach MR8 *[portion of M8; RM 54–55.06]:* The narrowest section of the Methow River which is lined by roads on each side has very little riparian vegetation. There are some remnants of black cottonwood stands along the river; however, they are diseased and dying.

Reach MR9 *[portion of M9; RM 55.06–61.1]:* This reach supports some of the largest extension of riparian associations and also some of the apparently healthiest stands. A number of side channels, wetlands and seeps in the region of the Big Valley Ranch show larger areas of riparian shrub and tree associations, including cottonwood stands that are regenerating. This area should be further surveyed to investigate the river dynamics and their effects on the vegetation as well as the conditions of the vegetation. Many bars show regenerating cottonwoods and riparian shrubs all the way up to Weeman Bridge. Shrub and tree galleries can be seen from the aerial photos that have established over a number of years during flood events. The river is very dynamic and has changed its bed many times throughout this reach which has had a positive effect on the riparian vegetation. Trembling aspen mix with black cottonwood trees in the upper parts of the reach and form very valuable deciduous riparian forests which are reoccurring in several sections along the Methow River from this reach on upstream.

Reach MR10 *[portion of M9; RM 61.1–63.5]:* Reach 10 has a number of mixed riparian shrub associations, wetlands and some remnant cottonwood stands that are being encroached by conifers (Ponderosa pine and Douglas-fir). Increasing settlement along the river banks is present in this reach and partially responsible for degradation of the still comparatively extensive riparian areas. As in the previous reach, there are a number of instream bars in a dynamic river bed that support regeneration of cottonwood and riparian shrub species.

Reach MR11 *[portion of M9 and M10; RM 63.5–67.18]:* Several wetlands and seepage areas in the lower and mid section of the reach support large riparian shrub associations, and bars show regeneration of cottonwood trees. Other past cottonwood dominated stands are now only visible as remnants and are being encroached by Ponderosa pine and Douglas-fir. Some of these areas should be further investigated to find out what conditions the recruitment and remnant stands are in. The upper part of the reach is more incised and less dynamic with again only remnants of cottonwood and quaking aspen stands that are now dominated by non-riparian conifers.

Reach MR12 *[portion of M10; RM 67.18–68.3]:* This short reach shows remnants of cottonwoods stands, being replaced by coniferous vegetation and increased settlement on the river banks, including some clearing of the riparian vegetation. Where high banks line the river, upland forest has replaced riparian vegetation.

Reach MR13 *[portion of M10; RM 68.3–70.13]:* The vegetation of Reach 13 is similar to Reach 12 with mixed stands of old cottonwoods and younger conifers. The reach has a few more instream bars with mostly shrub and forb vegetation.

Reach MR14 *[portion of M11; RM 70.13–72.7]:* The river is restricted by Goat Wall on its left side in this reach and has established several channels to the other side, which are changing often and inundate the surrounding areas. Those dynamics support a variety of riparian stands in the narrow floodplain. Riparian shrub associations, black cottonwood stands and mixed riparian deciduous/coniferous forests with Western red cedar can be found throughout this stretch of the river. Galleries of riparian shrubs and cottonwood trees have established on bars and along the river banks in some areas. Large deposits of LWD retain moisture in the form of pools and provide landing areas for removed and uprooted cottonwood trees and shrubs that will re-sprout in those regions. This reach should be further investigated for its high potential of riparian vegetation recruitment. On the higher banks, upland vegetation has replaced historical riparian stands.

Reach MR15 *[portion of M11; RM 72.7–73.5]:* This reach has high banks on its river right side and supports only rudimentary riparian vegetation. On the river left, a stark increase in settlement and land clearing has removed several areas of its riparian stands over the last 10 years. This process is continuing and targets a lot of the old cottonwood trees that are diseased and dying because they are seen as a hazard to people moving into the riparian. The remaining stands are mixed coniferous upland and riparian species (some red cedar) and deciduous tees (aspen and cottonwood), and some riparian shrubs.

Reach MR16 *[portion of M11; RM 73.5–75.3]:* Although the river is dynamic here as in Reach 14, a similar settlement development as in Reach 15 is taking place in this reach as well, especially in its upper portion. The reach supports some of the richest mixed coniferous/deciduous riparian stands and galleries of regenerating cottonwood and riparian shrub vegetation. The settlement is occurring only on the river left where large areas of riparian vegetation have been cleared. The vegetation on the river right appears dense and healthy from the aerial photo but a further investigation into the conditions of red cedar and cottonwood are suggested.

1.2 CHEWUCH RIVER

1.2.1 GENERAL FINDINGS

The largest extensions of riparian vegetation along the Chewuch River within the assessment area (from mouth to the Forest Service boundary) are located from approximately RM 2.6 upstream to approximately RM 7. At the time of study, Reclamation had not yet designated reach breaks on the Chewuch River, therefore RM will be used to refer to certain locations.

As along the Methow River, the regeneration of Black Cottonwood is also compromised along the Chewuch River. Few areas exist that are supportive of the Cottonwood's natural regeneration cycles and the reproduction of the species occurs only where water is available on a regular basis (instream bars, active side channels, low banks).

The areas that show Black Cottonwood regeneration are also heavily targeted along the Chewuch River by wildlife (white tail and mule deer), as well as cattle, and the animals browse the plants down or destroy them.

The riparian area is increasingly restricted by settlement, roads and agricultural use in many places.

Riparian vegetation species are being replaced by tree species commonly associated with upland forest such as Douglas-fir and Ponderosa pine where the river channel has become incised and the banks are high.

Several regions with ground moisture or backwaters support mixed riparian shrub stands, but don't appear to allow the regeneration of Cottonwoods. The reasons are unknown and it a ground survey would be helpful to gain more information.

1.2.2 FINDINGS BY RIVER MILES

RM 0 to RM 2.6: Settlement and channel bed incision in this section of the Chewuch River has reduced the riparian areas to merely single lines of trees, often those are non-riparian species. Some regions have remnants of Black Cottonwood stands with single, mature individuals. The trees are however dying and no regeneration is occurring. Mixed deciduous riparian vegetation and riparian shrubs in the lower and upper portion of this river section form a little wider riparian corridor in few places.

RM 2.6 to RM 4.9: Less settlement along the river and a more dynamic floodplain in this section of the Chewuch River allow for a better development of the riparian vegetation on the river left and in some stretches on the river right throughout this region. A number of wetlands and possibly seepages and old meanders support riparian shrubs, Quaking Aspen stands and residual Black Cottonwood stands. The Cottonwoods are old and not regenerating, although there may be potential for reproduction. Further investigation is needed. Agricultural use on the river left and a golf course on the river right in the mid and upper sections of this stretch have replaced riparian vegetation and its extension is limited on the right side of the river due to the adjacent West Chewuch Road. In the very northern portion of this stretch and ongoing into the next section of the river, some apparently healthier Cottonwood stands occur on both sides of the stream. This area should also be included in a ground survey.

RM 4.9 to RM 6.1: The left side of the Chewuch River is experiencing further development and settlement in the riparian area throughout this stretch with few regions that support a riparian corridor. Remnants of previously existing Black Cottonwood stands can still be seen in from of old individual and dying trees. The river right side on the other hand has a well-developed riparian buffer between the river and the East Chewuch Road. Mixed riparian shrub and Quaking Aspen stands are growing in this region, with upland forest adjoining them on the upper terraces. Leftovers of the past Cottonwood stands can be seen here as well with mature trees in the overstory and a regeneration of riparian shrubs in the understory. The reasons for the lacking Cottonwood reproduction are not visible from the aerial photos and ground surveys are needed.

RM 6.1 to USFS Boundary: In the downstream part of this riparian area, river left is naturally confined by a high bank which supports upland forest and then by agricultural use. Several stands of old and dying Cottonwood trees in the mid and upper sections of the stretch still exist but are not regenerating and are being utilized as cattle range. The river right has a comparably extensive riparian area with mixed riparian shrub species and old Cottonwood overstory in the lower reach of this section. In the mid and upper parts the riparian is very confined between the river and the West Chewuch Road or non-existent. Residuals of the historic extension of the riparian can still be found in the very northern part of this river section, just below the bridge on the river right, where a small old Cottonwood stand persists.

1.2.3 TWISP RIVER

The *Twisp River Assessment* (TRA) from the Pacific Watershed Institute (PWI, 2003) provides detailed information about the riparian vegetation and its conditions along the Twisp River. The conditions have not changed significantly within the last two years; it is thus recommended to review the TRA chapters that talk about the riparian vegetation. Part 2.1 of the TRA “Reach Level Summary of Mainstem Twisp River” includes riparian vegetation. Part 5.2 “Riparian Plant Associations” provides detailed descriptions of the surveyed associations. Part 5.3 “Successional Trends and Health Conditions of The Riparian Vegetation” and Part 7 “Current Land Use and Management Trends and Impacts” give localized information about the conditions, health and extensions of the riparian area.

1.3 VEGETATION CODES – AERIAL PHOTO DELINEATION

The following codes were used to delineate the vegetation types along the Methow and Chewuch Rivers from aerial photo interpretation. The vegetation was not ground surveyed and it is therefore possible that certain areas or vegetation types appear different on the aerial photos than what they are in reality. In order to be sure about the actual riparian vegetation and its health, it is necessary to conduct ground surveys.

The vegetation codes/numbers generally follow the same codes and numbers that were used during the Twisp River Assessment (PWI, 2003). Along the Twisp River it was necessary to use a wider range of vegetation codes, which explains the skipped code numbers. However, the assigned numbers and colors from the Methow and Chewuch River delineation work are changeable and it is up to the GIS personnel what codes will be used.

Some areas received a double code, meaning that two different vegetation types are existent in a given area. This is most likely the case in situations where Black Cottonwoods used to dominate the stand but are now being replaced with a different type of vegetation. The overstory may still consist of Cottonwoods, but the understory is now made up of riparian shrubs.

Table H–1. Vegetation Types – Numerical and Color Codes.

Code Number/Color	Vegetation Type
Riparian Forest Vegetation Types	
1 green	POTR1 – Quaking Aspen
2 green	POTR2 – Black Cottonwood
9 green	Mixed Coniferous/Deciduous
Riparian Shrub and Mixed Riparian Forest/Shrub Vegetation Types	
5 orange	Bars with Deciduous Shrubs
6 orange	Bars with Forbs or no Vegetation
7 purple	Mixed Deciduous Shrubs (not on bars)
Upland Vegetation Types	
7a purple	Shrub Steppe
8a brown	Upland Forest
Other	
4 blue	Wetlands, Water other than River
10 yellow	Agricultural Areas (Current and Fallow)
11 red	Residential Areas
12 black	Other use areas (runway, golf course, etc.)

In addition to the vegetation type codes, vitality codes were used for Black Cottonwood stands, where the conditions are known. In those areas, where the vegetation only received a code number, the health conditions are unknown. The vitality codes follow these stand conditions.

Table H–2. Stand Vitality Codes.

Code	Meaning
++	Very healthy stand – all ages well represented; regeneration is present; some disease but little mortality (only in old trees).
+	Healthy stand – fewer age classes; regeneration is present; disease and mortality in all age classes but the youngest.
–	Unhealthy stand – no regeneration; only 1 or 2 age classes; mortality in all ages.

Table H–3. Additional Codes Added During Digitizing.

Code	Meaning
1a	POTR1 – Quaking Aspen with deciduous shrub
2a	POTR2 – Black Cottonwood with mixed coniferous/deciduous
2b	POTR2 – Black Cottonwood with mixed deciduous shrubs
13	Cut Bank
14	ROAD
15	RIVER CHANNEL

1.4 DOCUMENTATION OF AVAILABLE REPORTS

The data includes information about riparian vegetation along the Methow, Chewuch and Twisp Rivers.

1.4.1 METHOW RIVER

The following reports and data containing information on riparian vegetation along the Methow River are available at the listed *Locations*. The *Content Overview* lists the parts in the documents that refer to riparian vegetation and only those; it does not provide a content overview of the entire document.

Middle Methow Watershed Analysis, Okanogan National Forest, Methow Valley Ranger District, March 1997.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862 (Fisheries Department).

Content Overview*:* The Okanogan National Forest MVRD compiled a watershed analysis of the middle Methow to fulfill the requirements of the Northwest Forest Plan prior to any management activities and provide information to meet the aquatic conservation strategy objectives. In the analysis it is stated that the identification and management of riparian reserves are the foundation of the aquatic conservation strategy, and the resource information in the document will be used to determine the width and treatment of the reserves. The document also follows PACFISH recommended guidelines to meet the goals of the PACFISH environmental assessment. The document:

- Sets general goals and management objectives for riparian areas.
- Sets similar guidelines for a variety of timber stands such as Ponderosa pine, Douglas-fir, Lodgepole pine etc, pertaining to stocking levels, fire hazard reduction, disease control and restoration of stand canopy structure.
- Maps and individual vegetation series descriptions for the timber stands and other vegetation units in the middle Methow watershed are provided, without detail to riparian vegetation.
- The same descriptions and maps for the biophysical environment classes are provided, without detail to riparian vegetation.
- Aquatic habitat and large woody debris situations in the sub-watersheds are reported on.
- A small general part on riparian reserves can be found in the end of the document, discussing mostly anticipated widths of riparian buffers.

Upper Methow River Stream Survey Report, Okanogan National Forest, Methow Valley Ranger District, September 1997.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862 (Fisheries Department).

Content Overview: The MVRD crews performed a Hankin & Reeves stream survey along the Methow River form 7/7/1994 to 8/7/1994. The start of the survey is described as T 36N, R 20E, Section 32, the end as T 37N, R 17E, Section 9. The objective of the survey is to monitor and manage the Upper Methow River.

- The document contains information about LWD in the surveyed river sections in a general part and then again by reach survey (data summaries and data collection sheets).
- The necessity of establishing a riparian vegetation buffer and additional LWD is acknowledged in land management plan standards and guidelines.
- Some info on sensitive plants in the surveyed parts of the river and a list of species is included.
- Riparian habitat is described in brief in a general part, outlining the overall conditions and dominant tree and shrub species, and then again by reach level survey, listing the successional class codes for riparian vegetation along the river bank, following the guidelines of the "Stream Inventory Handbook Level I & II", USFS, Region 6, Version 7.5. The reach level survey information also contains a brief characterization of the riparian vegetation and photos of each reach include some riparian cover.

A Baseline Monitoring Report for Conservation Easements: Boesel Property, prepared for the Methow Conservancy by the Pacific Watershed Institute, August 1998.

Location: Methow Conservancy, Winthrop, WA 98862.

Content Overview: PWI performed a riparian survey and established baseline monitoring locations along the Methow River corridor on the Boesel property as part of a conservation easement for the Methow Conservancy.

- The report provides information about the site environment and natural resources on the property.
- The proposed riparian zones and management guidelines are listed.

Methow and Chewuch River Watershed Riparian Habitat Restoration and Revegetation Monitoring Report, CCS-95-06-08-07-011, 1999-2003 Final Project Report, prepared for the Okanogan National Forest, Methow Ranger District by the Pacific Watershed Institute, April 2003.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862 (Botany Department).

Content Overview: Report on the Pacific Watershed Institute's riparian restoration and monitoring efforts and accomplishments along the Methow and Chewuch Rivers from 1999 to 2003.

- List of PWI's riparian revegetation and restoration sites along the two rivers, including revegetation methods, plant species and -amounts.

- Outcomes of four years of monitoring efforts in the revegetation sites, including assessment of methods, non-native plant distribution, and total plant cover in restoration sites.
- Analysis of restoration and monitoring activities and recommendations for riparian revegetation implementations.

Assessment of The Riparian Area on the Campion Property, prepared for the landowner (Campion) by Geosis Consulting, December 2004, unpublished report.

Location: Geosis Consulting/Heike Baesecke, P.O. Box 242, Winthrop, WA 98862.

Content Overview: Riparian area assessment of a property along the south side of the Upper Methow River.

- Property is broken up into riparian zones, depending on floodplain and vegetation criteria.
- Document includes detailed descriptions of the riparian plant associations on the property, including plants species, ages of trees, health and regeneration conditions.
- Non-native riparian plant species and disturbances of the riparian area are listed.
- Management recommendations for the different riparian zones are provided.

1.4.2 CHEWUCH RIVER

The following reports and data containing information on riparian vegetation along the Chewuch River are available at the listed *Locations*. The *Content Overview* lists the parts in the documents that refer to riparian vegetation and only those; it does not provide a content overview of the entire document.

Chewuch River Stream Survey Report 1993, Okanogan National Forest, Winthrop Ranger District, September 1993.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview: The WRD crews performed a Hankin & Reeves stream survey along the Methow River from 9/7/1993 to 10/7/1993. The survey starts at the National Forest boundary and ends at the confluence of Remmel and Cathedral Lakes in the Pasayten Wilderness. The objectives of the study are to characterize the current fish habitat conditions in the Chewuch River that will help with management decisions.

- The document contains information about LWD in the surveyed river sections in a general part and then again by reach survey (data summaries and data collection sheets), and describes the problematic situation of future LWD recruitment in the Chewuch River.

- The report has three general pages of riparian habitat descriptions, outlining the overall conditions and dominant tree and shrub species along the surveyed parts of the river. Canopy cover, riverbanks conditions and occurrences of wetlands and lakes are also addressed in this part.
- Riparian successional class codes are listed by reach level survey, following the guidelines of the "Stream Inventory Handbook Level I & II", USFS, Region 6, Version 7.5. The reach level survey information also contains a brief characterization of the riparian vegetation and photos of each reach include some riparian cover.
- Two riparian vegetation summary sheets (zone 1 and zone 2) are included in the data summary forms

Chewuch Watershed Analysis, Winthrop Ranger District, Okanogan National Forest, 1994.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview: The WRD compiled a "pilot" watershed analysis of the Chewuch River Watershed to provide a general overview of the watershed and help shape future projects and management decisions. The analysis was initiated through the Forest Ecosystem Management Team's (FEMAT) identification of the Chewuch Watershed as a key watershed. For this document, only existing data were used. The analysis followed the directions given in the *Record of Decisions for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl* (1994) and in *Standards and Guidelines for Management of Habitat for Late-Successional and Old Growth Forest Related Species within the Range of the Northern Spotted Owl* (1994).

- Most of the vegetation-related information is on a watershed-wide scale, focused on dominant tree species and diameter size, obtained from spectral scanning of 1998 LANDSAT imagery.
- Riparian vegetation is not discussed in particular. The LWD situation, bank erosion and fish habitat conditions, including some mention of vegetation cover along the river, are described in the aquatic habitat section of the document in Chapter 2.
- Non-native plants and species of concern receive attention and each non-native species is described in detail and by distribution and location in Chapter 2.
- The riparian reserves are mentioned in Chapter 3, where a definition and initial identification guidelines are given.

Pre-Restoration Chewuch River Survey by Rolf Aalto, December 1996.

Location: as of October 2005: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview*:* The survey documents the pre-restoration survey of four proposed restoration sites and two reference sites on the Chewuch River.

- The survey includes documentation of the cross- section surveys and a summary of survey errors.
- Data analysis, transect locations, aerial photos, cross-section diagrams and maps of the sites are provided.

Lower Chewuch River Fisheries Habitat Survey, Final Report, prepared for CI Johnson and Associates in cooperation with the Methow Basin Planning Unit by the Pacific Watershed Institute, December 2000.

Location: CI Johnson and Associates, P.O. Box 1608, Okanogan, WA, 98840.

Content Overview*:* PWI completed a Hankin & Reeves Level II fisheries habitat survey on the lower 8.8 miles of the Chewuch River mainstem. The objectives of the survey were to characterize fish habitat conditions, identify concerns, management issues and restoration and protection opportunities and provide results that are compatible and comparable to previous habitat surveys completed by the Methow Valley Ranger District of the Okanogan National Forest for the upper Chewuch River mainstem and tributaries.

- The document reports on the outcomes of the survey, which was conducted in the same manner of the USFS fish habitat surveys, using the Stream Inventory Handbook guidelines.
- Riparian vegetation information is limited to a general characterization part, talking about dominant vegetation, canopy cover and bank erosion in the surveyed portion of the river.
- The riparian vegetation is characterized by reach level as in USFS studies.

Lower Chewuch River Snorkel Survey Report, prepared for the Okanogan County Department of Water Resources and the Methow Basin Planning Unit, Pacific Watershed Institute, December 2000.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview*:* PWI crew performed a snorkel survey of the lower Chewuch River in the summer of 2000 to establish fish species distribution in selected sites. The snorkel survey has very limited information about riparian vegetation.

- The info that is listed pertains to shade conditions, i.e. unidentified species providing certain amounts of shade and cover to the river.
- Photos of snorkel sites include some of the riparian vegetation along the banks.

Chewuch River & Early Winters Creek Restoration Program, 1998-2000 Final Project Report, prepared for the Jobs for the Environment Program by the Pacific Watershed Institute, Grant # JFE9807, June 2000.

Location: US Fish and Wildlife Service, Western Washington Office, 510 Desmond Drive SE, Suite 102, Lacey, WA 98503.

Content Overview: Report about the PWI's Chewuch River (Early Winters and Cub Creeks) riparian restoration and monitoring efforts.

- Document reports about the accomplishments (plantings into riparian sites, weed control, site maintenance, revegetation monitoring) in a given format.
- Includes site descriptions, monitoring results, list of site disturbances, photos, channel transect data and figures.

Chewuch River Stream Survey Report 2002, Okanogan-Wenatchee National Forest, Methow Valley Ranger District, 2002.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview: The MVRD crews performed a Hankin & Reeves Level II stream survey along the Chewuch River in the summer of 2002. The survey starts at the confluence with Boulder Creek (RM 9.5) and ends at Chewuch Falls (RM 36.4). The objectives of this survey are to characterize the fish habitat conditions in the Chewuch River, compare the results to the stream survey of 1993, make better management recommendations and identify locations for restoration opportunities.

- The document contains information about LWD in the surveyed river sections in a general part and then again by reach survey (data summaries and data collection sheets), and once again describes the problematic situation of future LWD recruitment in the Chewuch River, while acknowledging the amount of LWD recruited through restoration work.
- The report discusses the management implications and enhancement opportunities for LWD and the negative results of LWD removal on the stream system.
- A small section in the report briefly talks about riparian reserves.
- Individual reach characterizations contain limited information about riparian vegetation along the river banks and photos of the reaches show some of the riparian covers.

Methow and Chewuch River Watershed Riparian Habitat Restoration and Revegetation Monitoring Report, CCS-95-06-08-07-011, 1999-2003 Final Project Report, prepared for the USDA Forest Service, Methow Ranger District by the Pacific Watershed Institute, April 2003.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862 (Botany Department).

Content Overview*:* Report on the Pacific Watershed Institute's riparian restoration and monitoring efforts and accomplishments along the Methow and Chewuch Rivers from 1999 to 2003.

- List of PWI's riparian revegetation and restoration sites along the two rivers, including revegetation methods, plant species and -amounts.
- Outcomes of four years of monitoring efforts in the revegetation sites, including assessment of methods, non-native plant distribution, and total plant cover in restoration sites.
- Analysis of restoration and monitoring activities and recommendations for riparian revegetation implementations.

Jobs In The Woods (MM1 &MM2) 2000-2003 Final Report, prepared for the US Department of Fish and Wildlife by the Pacific Watershed Institute, April 2003.

Location: US Fish and Wildlife Service, Western Washington Office, 510 Desmond Drive SE, Suite 102, Lacey, WA 98503.

Content Overview*:* Report on the Pacific Watershed Institute's riparian restoration accomplishments and revegetation monitoring efforts along the Methow River sites from 2000 to 2003.

- Report includes a description of sites, restoration accomplishments, results of revegetation monitoring, figures and data for vegetation ground cover in the sites and non-native plant species, and a discussion of the revegetation methods.
- Photos of restoration sites, maps and site sketches and data tables are included in the report.

Chewuch Watershed Biological Assessment for New and Ongoing Projects, Methow Valley Ranger District, August 2000, updated in March 2003, updated in October 2005.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862 (Fisheries Department).

Content Overview*:* This assessment was originally completed in the summer of 2000. An update of this document was completed in March 2003 with new survey data and assessed the impacts of forest management activities and natural disturbance that occurred between 1999 and 2002. The newest edition of the Chewuch Watershed BA (October 2005) includes new survey information and updates the baseline to address effects of the Farewell Fire and completed projects. The documents have limited information about riparian vegetation. The need for additional surveys of riparian vegetation was first stated in the 1994 Chewuch watershed analysis. The documents:

- List the past and current projects in the Chewuch watershed, mostly pertaining to instream fish habitat and flow conditions.

- Provide information about grazing allotments and wetlands in the allotments.
- Include new information on the effects of burned and felled trees in the Thirtymile and Farewell fires vicinity on river shade conditions and calculated temperature increase.
- Give general information on livestock impacts on riparian vegetation.
- Provide LWD and bank erosion statistics in the watershed.
- Include a part about riparian habitat conservation areas, stating that they are functioning appropriately in the upper half of the watershed, with some areas functioning at risk in the lower half.

1.4.3 TWISP RIVER

The following reports and data containing information on riparian vegetation along the Twisp River are available at the listed *Locations*. The *Content Overview* lists the parts in the documents that refer to riparian vegetation and only those; it does not provide a content overview of the entire document.

Twisp River Stream Survey Report 1990, Okanogan National Forest, Twisp Ranger District, unpublished report.

Location: Location unknown, the Twisp Ranger District was combined with the Winthrop Ranger District and the report was not found.

Content Overview: no information.

Twisp River Stream Survey Report 1993, Okanogan National Forest, Twisp Ranger District, March 1994.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview: The TRD crews performed a Hankin & Reeves stream survey along the Twisp River from 8/9/1993 to 9/3/1993. The objectives of the study are to characterize the current fish habitat conditions in the Twisp River in order to help with management decisions.

- The document contains information about LWD in the surveyed river sections in a general part and then again by reach survey (data summaries and data collection sheets).
- The necessity of establishing a riparian vegetation buffer and additional LWD is acknowledged in land management plan standards and guidelines.
- Some info on sensitive plants in the surveyed parts of the river and a list of species is included.
- Riparian habitat is described in brief in a general part, outlining the overall conditions and dominant tree and shrub species, and then again by reach level survey, listing the successional class codes for riparian vegetation along the river bank, following the guidelines of the “Stream Inventory Handbook Level I & II”, USFS, Region 6, Version 7.5. The reach level survey information also contains a brief characterization of the riparian vegetation and photos of each reach include some riparian cover.

- A vegetation summary lists the collected data on riparian vegetation.

Twisp River Tributaries Stream Survey Report, Okanogan National Forest, Methow Valley Ranger District, April 1995.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview*:* MVRD did a stream survey of the following tributaries to the Twisp River in the summer of 1994: Eagle, War, Reynolds, South and North Creeks. A general part of the document lists the issues, concerns and opportunities, the existing conditions, land use and management implications in the tributaries. It then summarizes the survey findings of each tributary. The riparian habitat information included in the document entails

- a brief description of the riparian vegetation and stream canopy cover,
- stream temperature measurements,
- presence/absence of beaver activity,
- presence/absence of wetlands or lakes.
- Data for dominant vegetation types and some photos are included.

Twisp Watershed Analysis, Okanogan National Forest, Methow Valley Ranger District, June 1995.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview*:* MVRD compiled a watershed analysis for the Twisp River in the same fashion and with the same goals as the Chewuch River analysis from 1994. The Twisp River analysis focuses on the part of the river that is within USFS management. Similar vegetation classifications into timber stands are provided, not specifically targeting riparian areas. The riparian vegetation information in this document is very limited and mostly pertaining to:

- general information on large woody debris in the river,
- land use and management along the river and the existence of non-native plant species,
- stating the necessity for existence of riparian and wetland habitat.

Twisp River Stream Survey Report 2001, Okanogan-Wenatchee National Forest, Methow Valley Ranger District, 2001.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview: MVRD crews performed a Hankin & Reeves stream survey along the Twisp River during the summer of 2001. The survey stats at RM 5.4 and ends at RM 30.4. The objectives of the study are to characterize the current fish habitat conditions in the Twisp River, compare the findings to the Twisp River survey of 1993, improve management recommendations with the obtained information and identify locations for restoration opportunities.

- The document contains information about LWD in the surveyed river sections in a general part and then again by reach survey (data summaries and data collection sheets).
- A small section in the report briefly talks about riparian reserves and individual reach characterizations contain limited information about riparian vegetation along the river banks, mostly pertaining to shade conditions.
- One riparian vegetation summary sheets is included in the data summary forms.

Twisp River Assessment, Vegetation and Soils Part, prepared for the Salmon Recovery Funding Board by the Pacific Watershed Institute, 2000.

Location: Methow Valley Ranger District Work Center, 24 West Chewuch Road, Winthrop, WA, 98862, (Fisheries Department).

Content Overview: The Pacific Watershed Institute performed an assessment of the Twisp River, including a Riparian Vegetation and Soils part, which covers the entire length of the Twisp River riparian area and several of its tributaries. The document

- Determines and lists all existing plant associations along the river corridor.
- Analyses the successional trends and health conditions in the riparian area, with particular attention to deciduous tree species, wetlands, and riparian buffers.
- Identifies possible areas for riparian vegetation improvement to benefit the anadromous fish population.
- Determines the most necessary watershed-wide riparian restoration activities.
- Provides data tables and photos for all survey plots and each riparian plant association.
- Includes maps on riparian buffers, riparian vegetation cover, wetland distribution, agricultural lands, POTR2 vitality in relation to channel change, -hydro-modifications, -river temperature, -stream gradient, -and stream confinement.

Vegetation Monitoring Report for the Lower Twisp River Project, prepared for the Methow Salmon Recovery Fund by Geosis Consulting/Heike Baesecke, 2004.

Location: Methow Salmon Recovery Fund, P.O. Box 1608, Okanogan, WA, 98840.

Content Overview: Document reports about the Pacific Watershed Institute's riparian revegetation efforts and the monitoring of those sites along the Lower Twisp River between 2002 and 2003.

- Document includes brief outline of the restoration activities and the results of the vegetation monitoring efforts.
- Revegetation and maintenance plans for the sites are included in the report.

2. BIOLOGICAL EVALUATION OF CONDITION OF BLACK COTTONWOOD

2.1 INTRODUCTION

The Bureau of Reclamation asked for assistance with assessment of the health of black cottonwoods in five potential vegetation restoration floodplain areas along the Twisp and Methow Rivers in Okanogan County.

The Twisp and Methow Rivers are important salmon and steelhead trout producers. There are indications that habitat conditions favorable for good production and maintenance of salmon and steelhead fisheries have deteriorated over the course of many years from a variety of factors. Reclamation has been charged with developing and implementing plans to improve quality of habitat for salmon and steelhead production in the rivers. One basic key to improving salmon and steelhead production is to have healthy vegetation, especially trees, along the banks of the rivers to provide shade and large woody debris.

Black cottonwoods potentially could provide shade, large woody debris, river bank stabilization, nutrients from foliage, and insects. Healthy cottonwoods have the potential to contribute significantly to improving salmon and steelhead habitat along the rivers.

2.2 BLACK COTTONWOOD CHARACTERISTICS

Some characteristics of black cottonwoods and the species growth requirements are described because they bear directly on potential actions that might be used to maintain and/or improve cottonwoods along the rivers. DeBell (1990) provides a good description of black cottonwood.

Black cottonwood, *Populus trichocarpa*, is the largest hardwood tree species growing in the Pacific Northwest. It is the fastest growing hardwood species in this region. Individual black cottonwood stems can be 200 feet tall and have diameters (DBH) of 6 feet. It is common for the stems in northcentral Washington to be 60 feet to 120 feet tall and 2 feet to 4 feet in diameter. Large diameter branches develop in the upper crowns. The tall stems have excellent potential to provide ample shade over rivers because of their large crowns. Cottonwoods can produce large amounts of large woody debris as they die and break apart.

Black cottonwoods require moist soils. In north central Washington cottonwood is “limited to protected valleys and canyon bottoms, along stream banks and edges of ponds and meadows, to moist toe slopes” (DeBell 1990). “Cottonwood tolerates rooting zone flooding and soil waterlogging during the dormant season, but prolonged flooding in the rooting zone during the growing period reduces productivity." (McLennan and Mamias, 1992). Black cottonwood is poorly adapted to soil drought.

Black cottonwoods reproduce by seeds and sprouting from stumps and roots. Large quantities of seeds are produced. Seeds are light and buoyant and can be transported relatively long distances by wind and flowing water. Seed viability is initially high but declines relatively quickly to low germination percentages within 2 weeks to a month. "Moist seedbeds are essential for high germination, and seedling survival depends on continuously favorable conditions for the first month." Bare soil is required for seed germination. Gravel bars created or exposed by recent flooding can provide good seed beds and typically become well-stocked with black cottonwood seedlings. Seedling failures are the rule, not the exception, because conditions for germination and survival are seldom present long enough for the seedlings to become established.

Cottonwoods reproduce vegetatively by sprouting from stumps. They can produce sprouts from roots, but not as dependably or as abundantly as aspen. Cottonwoods can also produce sprouts from partially buried branch fragments. Cottonwood "has the unusual ability to abscise small shoots complete with green leaves. These shoots drop to the ground and may root where they fall or may be dispersed by water transport" (DeBell 1990).

"Black cottonwood is classed as very intolerant of shade. It grows best in full sunlight. On moist lowland sites, it makes rapid initial growth and thereby survives competition from slower growing associated species" (DeBell 1990). It "rapidly expires at all ages if shaded" (McLennan and Mamias 1992).

Black cottonwood is a relatively short-lived tree species. In some locations, such as the Willamette Valley, it may reach maturity in 60 years. Typically, most cottonwood stems reach maturity around 70 to 90 years and then begin to decline and display progressively greater amount of crown dieback with time. Some black cottonwoods in British Columbia reportedly have grown well for up to 200 years, but that appears to an exception to their relatively short life span in most portions of its range.

Black cottonwoods are infected, infested, and attacked by a lengthy list of pathogens and insects. However, somewhat surprisingly, very few pathogens and insects kill black cottonwoods. Foliage diseases, especially cottonwood rust, can affect a great many cottonwood stems in a very short span of time and alter the appearance of the trees creating the impression they may be dying. However, foliage diseases seldom kill cottonwoods and typically subside into barely noticeable infections in the next growing season. Several species of wood decay fungi have been found to decay stems of living cottonwoods, but only two, *Spongipellis delectans* and *Pholiota populnea* (*destruens*), account for almost all the decay losses. Volume of stemwood affected by wood decay fungi increases with age of the stems. Wood decay of cottonwood can be beneficial along streams because it contributes to large woody debris as the affected trees break apart.

Most lethal damage to larger stems of black cottonwoods results from abiotic factors. Cottonwoods are readily killed by fires. Drought and/or receding water tables kill large numbers of cottonwoods. Cottonwood roots need to be in moist soil and they die if water is not available. Cottonwoods in sites that are being “dewatered” by increasingly greater numbers of competing conifers experience dieback and death. The species experiences considerable wounding and breakage from wind, snow, and ice. Prolonged flooding, especially during the active growing season, can damage and kill trees. Trees may die as a result of streambank erosion.

Deer and cattle may browse cottonwood sprouts and seedlings. Repeated browsing can kill the small stems. Light browsing can lead to stem deformities, however, some stems can recover.

Black cottonwoods can be successfully planted to start new stands or expand existing stands. Rooted and unrooted cuttings from stems and branches collected in the dormant season are inserted 12 inches to 16 inches into moist soil in the spring. Rooted cuttings are produced by planting cottonwood cuttings in nursery beds and allowing them to develop roots by keeping them well-watered. Planting sites must have moist soils and must be exposed to full sunlight for cottonwood cutting plantings to succeed.

2.3 ASPEN CHARACTERISTICS

A few comments concerning characteristics and growing requirements of aspen, especially in comparison to black cottonwood, are in order. Aspen is considerably more abundant than black cottonwood in the five potential vegetation management areas. Aspen could provide many of the same benefits as cottonwoods for enhancing salmon and steelhead habitat along the Twisp and Methow Rivers.

Aspen stems can reach heights of 85 feet, but typically are in the range of 50 to 75 feet. Aspen does not get as tall or big in diameter as cottonwoods. Individual aspen stems typically would produce less large woody debris than cottonwood because of the smaller stem and branch size. However, because aspen stems are much more abundant than cottonwood stems the larger numbers of aspen stems could generate rather large amounts of large woody debris. Aspen trees can provide substantial amounts of shade, but not as much as cottonwood stems. Aspen grows best in moist, well-drained, but not wet soils. It will not grow well if the water table is within 2 feet of the soil surface. Aspen typically does not grow immediately adjacent to perennially flowing or standing water, unlike cottonwood. Aspen will not grow in droughty soils, but it will grow in drier soils than cottonwood. Aspen is a short-lived tree species, with a pathological rotation around 100, somewhat longer than cottonwood. Like cottonwood, aspen is very intolerant of shade and needs full sunlight to grow and survive. Aspen regenerates most commonly by sprouting from the roots following major disturbances to the above ground portions of the stands. Regeneration from seeds is uncommon. Aspen is seldom planted, except for ornamental and residential settings.

Reclamation provided detailed maps of the five potential floodplain restoration areas. Elbow Coulee and Jennings are on the Twisp River. Big Valley East, Big Valley West, and Lehman floodplain areas are on the Methow River. The maps were excellent evaluation tools in that they showed detailed vegetation cover classifications developed by the Pacific Watershed Institute and road systems where they exist. I walked through almost all portions of the Elbow Coulee and Jennings floodplain areas and noted the amount and condition of the black cottonwoods. East and West Big Valley floodplain areas are well-roaded, so I was able to drive through them observing the condition of the cottonwoods. I walked and drove through most of the Lehman floodplain area. I looked at the crowns and foliage of cottonwoods to assess their vigor and especially to see if crown dieback was occurring. The areas were examined for cottonwood regeneration. Cottonwood seedlings and saplings, where present, were examined for damage, especially browsing by ungulates. The abundance of cottonwood stems was noted. The presence of tree species that could be significant competitors of cottonwoods for growing space and sunlight was also recorded. Although the focus of the evaluation was on assessing the condition of black cottonwoods, I quickly realized aspen was more abundant than cottonwoods at each of the five potential floodplain areas, so I made observations on the health of aspens at all five areas.

2.4 OBSERVATIONS OF POTENTIAL FLOODPLAIN AREAS

Present vegetation conditions at five potential floodplain restoration areas were observed through field investigations, two on the Twisp River (Elbow Coulee at RM 6.5 and Jennings at RM 11.5) and three on the Methow River (Big Valley East at RM 56.5, Big Valley West at RM 58.6, and Lehman at RM 44.4).

2.4.1 ELBOW COULEE, TWISP RM 6.5

Black cottonwoods are basically restricted to the perpetually moist to wet areas in this potential floodplain restoration area (

Figure H–1). Cottonwoods along the southernmost part of the floodplain area by the sharp bend in the Twisp River are relatively vigorous because the site is quite moist. Cottonwoods by the berm and yellow coded side channel shown on the project map (conceptual draft of Elbow Coulee Side Channel Proposed Project Features) have top dieback resulting from the dry site conditions. Cottonwoods growing along the perimeter of the beaver ponds and wet areas by the Twisp River road are in good condition. There is active feeding on cottonwoods by beavers on the edge of the beaver pond.

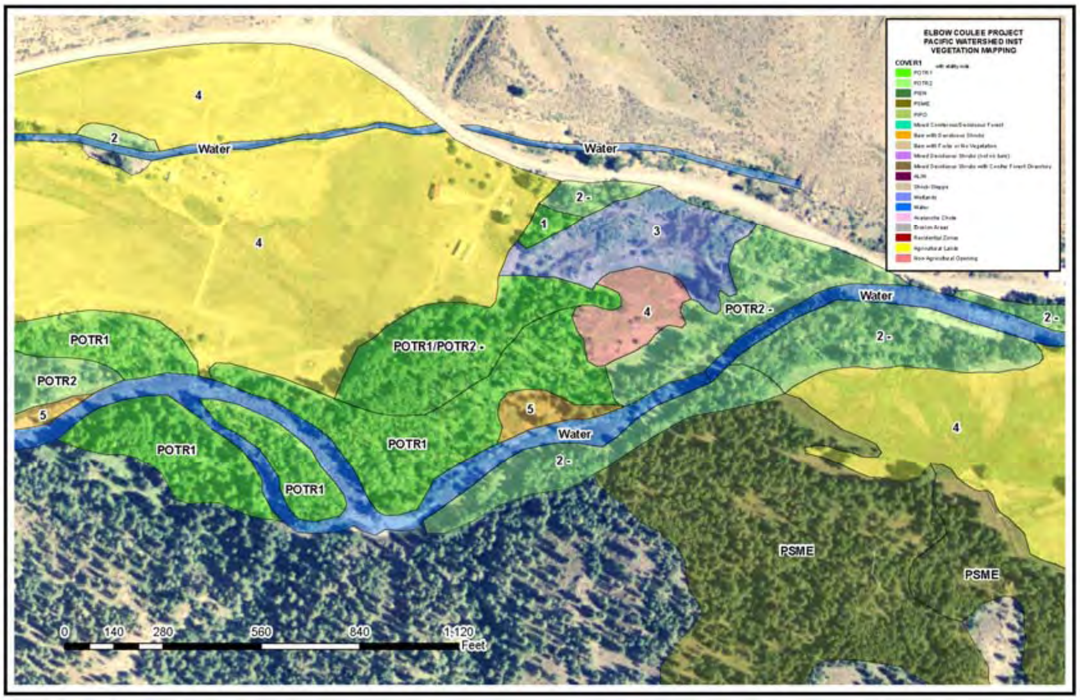

Figure H–1. Vegetation map used for field investigation at Elbow Coulee project area (at Twisp RM 6.5).

Cottonwood stems that are pole size (DBH 5.0" to 9.9") and mature size (DBH 10.0" and larger) predominate; there are few to no cottonwood seedlings and saplings. I did not determine the ages of any cottonwoods, but it appears it has been at least several decades since any significant cottonwood regeneration has successfully occurred at the Elbow Coulee site.

Aspen is more abundant than cottonwood in the Elbow Coulee area and is in good condition. There are some conifers, Douglas-firs and ponderosa pines that could over time replace many of the aspen stems.

The "revegetation area" shown in cross-hatched green on the project map is dry. Douglas-fir seedlings in the "revegetation" opening are displaying drought symptoms. Ponderosa pine seedlings and saplings in the revegetation area are in relatively good condition. The revegetation area is currently too dry to support growth of cottonwood. Aspens along the southern perimeter of the revegetation area and along the Twisp River immediately to the south are in relatively good condition.

Cottonwoods at the Elbow Coulee site are affected by foliage diseases. Cottonwood rust caused by *Melampsora occidentalis* is present on most of the trees. This disease has very little potential to adversely affect the growth and longevity of cottonwoods. Infection of cottonwood leaves by the fungus causes yellow-orange discoloration with distinctive orange fungal growths on the underside of infected leaves. Severe infection, which I did not observe, can cause premature defoliation. Cottonwoods are almost never killed by cottonwood rust. Douglas-fir is an alternate host for the fungus and it can experience some defoliation and foliage discoloration. Septoria leaf blight caused by *Septoria populicola* was seen on some trees. Affected foliage has brown-black splotches of killed tissues. Septoria leaf blight almost never kills cottonwoods.

It does not appear that the Twisp River has changed its channel by the project area for many years.

No cattle grazing evidence was observed in the project area.

Most of the Elbow Coulee project area is presently too dry to support natural establishment and vigorous growth of black cottonwoods. There is too much cover and shade from other tree species over most of the project area for cottonwood regeneration to occur. Cottonwoods could be planted along the edges of the beaver pond, the pink-coded "Wetland access channel", and immediately adjacent to the Twisp River. If side channels are opened or reopened and the soils on the edges are perpetually moist then cottonwoods could be successfully planted. Any over-topping trees over planted cottonwoods would have to be removed or killed for the planted cottonwoods to grow and thrive. Cottonwoods should only be planted in sites that have moist soils all year long. Ponderosa pine should be planted in the revegetation area. If the "revegetation area" could be well-watered by opening the wetland, primary side, and secondary side channels it could be possible to get cottonwoods established by planting rooted cuttings.

Aspen is a major tree species in the Elbow Coulee project area. Aspen stands are in relatively good condition, but conifers in the understory could over many decades replace many of the aspen stems. This could be slowed or prevented by removing conifers, especially Douglas-firs that could overtop aspen stems.

If no management actions are undertaken at the Elbow Coulee project area the numbers of living, vigorous cottonwood stems will decline. Most of the project area has too much shade and is too dry to support cottonwoods. The area will be increasingly dominated by Douglas-firs and ponderosa pine. Aspen stems will be present longer than cottonwoods but eventually they will be largely replaced by conifers.

2.4.2 JENNINGS, TWISP RM 11.5

Note: Observations were made inside the yellow line area shown in

***Figure* H–2.**

Black cottonwoods are found primarily in and adjacent to sites that are perpetually moist. Cottonwoods are common along the Twisp River on the southern edge of the project area (

Figure H–2*)*. There is a small amount of cottonwood crown dieback in the drier portions many yards (meters) away from the river. Ponderosa pines are becoming established among the cottonwoods in the drier areas several yards away from the river because the river apparently has not flooded out of its banks for many years and the soils are sandy, gravelly, and rather dry. There are cottonwoods along the edges of the beaver ponds and standing water in the center of the project area. Cottonwoods in these wet areas appear to be in good condition. Small clusters of large cottonwoods were seen along the old drainage ditch on the northwest edge of the project area. Very little cottonwood regeneration (seedlings and saplings) was observed. Apparently several years have passed since the last significant amount of natural regeneration of black cottonwoods has occurred in the project area. There has been some browsing by deer. There was no evidence of cattle grazing and browsing.

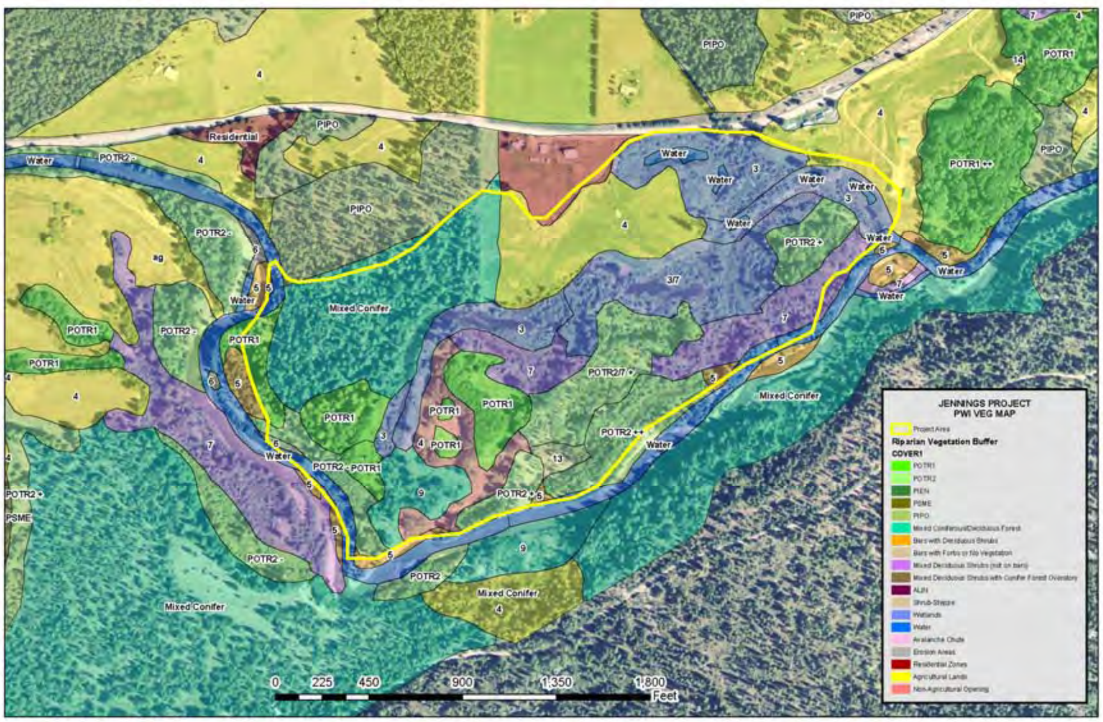

Figure H–2. Vegetation map used for field investigations at Jennings project area (at Twisp RM 11.5).

Aspen is the predominant tree species in the Jennings project area, especially in the western half. Most of the aspen stands appear to be in good condition, however, conifers, particularly Douglas-firs, are present as an understory species in many aspen areas. Ponderosa pines are also present in some of the aspen stands. A ponderosa pine stand with scattered aspen stems on the northwest edge of the project area was prescribed burned and the aspen sprouting response was excellent. The longevity of the aspen stands could be extended by removing some of the understory conifers, especially the Douglas-fir.

The areas described as mixed deciduous and wetlands are dominated by deciduous shrubs, particularly willows and alder. The shrubs appear relatively healthy.

Cottonwoods in the potential project area have been infected by cottonwood rust, but the impact of the disease appears to be insignificant.

There may be some opportunities to increase the amount of cottonwoods in the project area. Cottonwood cuttings could be planted along the edges of the perpetually moist areas, especially the beaver ponds and areas of standing water in the center. Overtopping vegetation would have to be removed for the cottonwood plantings to become established and to grow well. Cottonwoods could probably be planted along the old ditch if water could be allowed to flow through it, even periodically. It is doubtful that cottonwoods will successfully regenerate naturally in the project area because there is an abundance of overtopping vegetation, especially shrubs and trees. There is little evidence of recent flooding that could create bare soil seed beds.

If no vegetation management actions are undertaken at the Jennings project area the cottonwood presence will decline. There is too much shade over most of the area for cottonwoods to regenerate naturally and there is very little exposure of bare soils. Aspens are quite abundant and will persist much longer, but eventually the stands will be fragmented and diminished by competing conifers.

2.4.3 BIG VALLEY EAST, METHOW RM 56.5

Much of the Big Valley East project area is well-roaded, enabling observation of most of the potential project area (Figure H–4). Big Valley East has extensive areas described as mixed deciduous shrubs and mixed conifer/deciduous. Mixed deciduous shrubs, including alders, willows, cherry, and aspen are especially common around the areas of standing and moving water. There are manmade impoundments of water, especially on the east end of the project area. The condition of the deciduous shrubs appears to be quite good. The mixed deciduous shrubs are typically short stature plants. There are very few black cottonwoods in the Big Valley East deciduous shrub areas. The mixed conifer/deciduous areas are drier than mixed deciduous shrub areas and cottonwoods are scarce. Ponderosa pine is common and is becoming more abundant as it is regenerating in the drier sites. Douglas-fir is also relatively common. Aspen is present in the moist, but not wet areas. In general, the aspen stems appear to be in good condition; however, conifers are encroaching in the aspen stands and could eventually replace aspen.

There are old agricultural clearings in Big Valley East; they do not appear to be actively used for agricultural endeavors. Ponderosa pines are invading the old agricultural openings, which tend to be dry.

Black cottonwoods occur along the banks of the active Methow River. However, cottonwood abundance declines quickly as distance from the active river banks increases. There is almost no cottonwood regeneration. There is some deer browsing of cottonwood and aspen. Cattle browsing seems to be quite minor based on the very few cow pies seen. Most of the cottonwoods have some cottonwood rust on the leaves but the effects are insignificant.

Dalmatian toadflax was seen in a few spots in the Big Valley East area. This noxious weed is widespread in the Methow valley. It could be spread and population increased by construction activities.

There may be some opportunity to increase the amount of black cottonwood in Big Valley East by planting rooted cuttings adjacent to the areas of standing and flowing water. In many cases overtopping shrubs would have to be removed to encourage establishment of cottonwoods. It is unlikely cottonwoods could become established in the old agricultural openings because the soils are too dry.

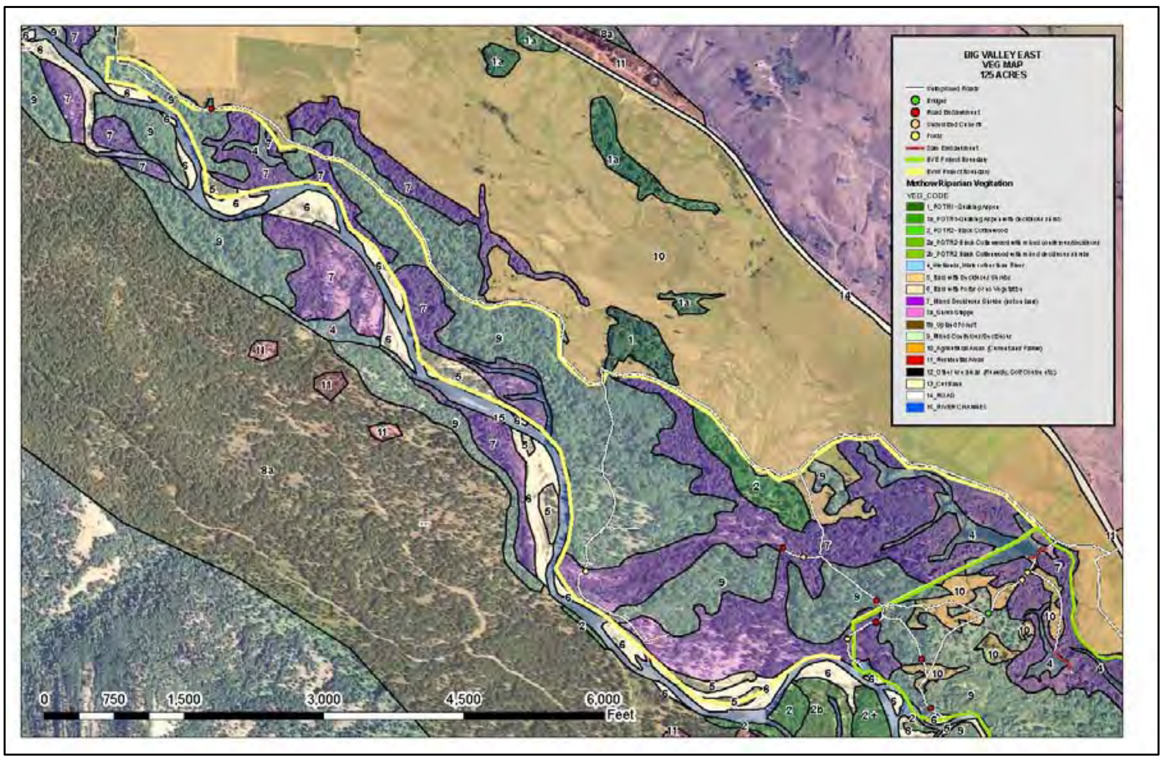

Figure H– 3. Vegetation map used for field investigations, Big Valley East (at Methow RM 56.5)

2.4.4 BIG VALLEY WEST, METHOW RM 58.6

This area is also well-roaded, allowing easy observation of most of the project area. Big Valley West is almost totally forested with few openings and agricultural clearings.

Black cottonwood is more abundant in Big Valley West than in Big Valley East. It is seldom the most abundant tree species in any stand. Practically all the cottonwood stems are relatively large. There is very little cottonwood regeneration because there are almost no large openings in the forest canopy and few potential seed beds of exposed moist soils. Deer have browsed both cottonwoods and aspens but browsing appears relatively light.

Aspen is the most abundant hardwood tree species and in general appears to be in good condition. Most of the aspen stands do have Douglas-firs and ponderosa pines which over a long time could eventually replace the aspen. There are several stands of pole and mature size aspen stems.

It is doubtful that the abundance of cottonwoods can be increased in the Big Valley West project area in its present condition. Most of the area has too much forest cover for cottonwoods to become established. Cottonwood needs full sunlight to survive and grow. Openings would have to be created in the forest to get cottonwoods to regenerate and thrive. If openings were created and then planted with cottonwood cuttings they would probably have to be protected from browsing by deer for up to five years.

2.4.5 LEHMAN, METHOW RM 44.4

The Lehman floodplain area has been altered more by humans than the other potential project areas (see Figure H–4). Most of the Lehman project area is occupied by agricultural clearings. The clearings are quite dry. There has been little tree invasion of the clearings due to the dry conditions. There are a few ponderosa pine seedlings and saplings in the agricultural openings. Most irrigation ditches that cross the site appear to be inactive in that there is no flowing water in them, but the soils around them are moist because there appears to be some subterranean connection to the Methow River. Aspen and deciduous shrubs occupy the old ditches and their banks. The aspen and shrubs appear to be in good condition. There are a few active irrigation ditches and they have abundant deciduous shrubs along them.

Cottonwoods are largely confined to the banks of the Methow River and a small area of standing water on the southern portion of the potential project area. Cottonwood regeneration close to the river banks has been severely browsed by deer. Cottonwood stems many yards away from the river banks are experiencing top dieback as a result of dry soils. Ponderosa pine seedlings and saplings are becoming established in these relatively dry areas along the river.

There are several dead cottonwoods along the banks of the Methow River in the northern portion of the potential project area. The site now appears to be too dry for cottonwoods, but at one time conditions were appropriate for good growth. Ponderosa pines now dominate the dry sites along the Methow River in the northern portion of the project area.

It should be possible to increase the amount of cottonwood in the Lehman area by planting rooted cuttings along the edges of the irrigation ditches. If the amount of water that periodically flows through the ditches could be increased the success of cottonwood planting would be increased. Competing deciduous shrubs might have to be removed to enhance success of cottonwood plantings. Rooted cuttings would probably have to be protected from severe browsing by temporarily fencing them for up to five years after planting.

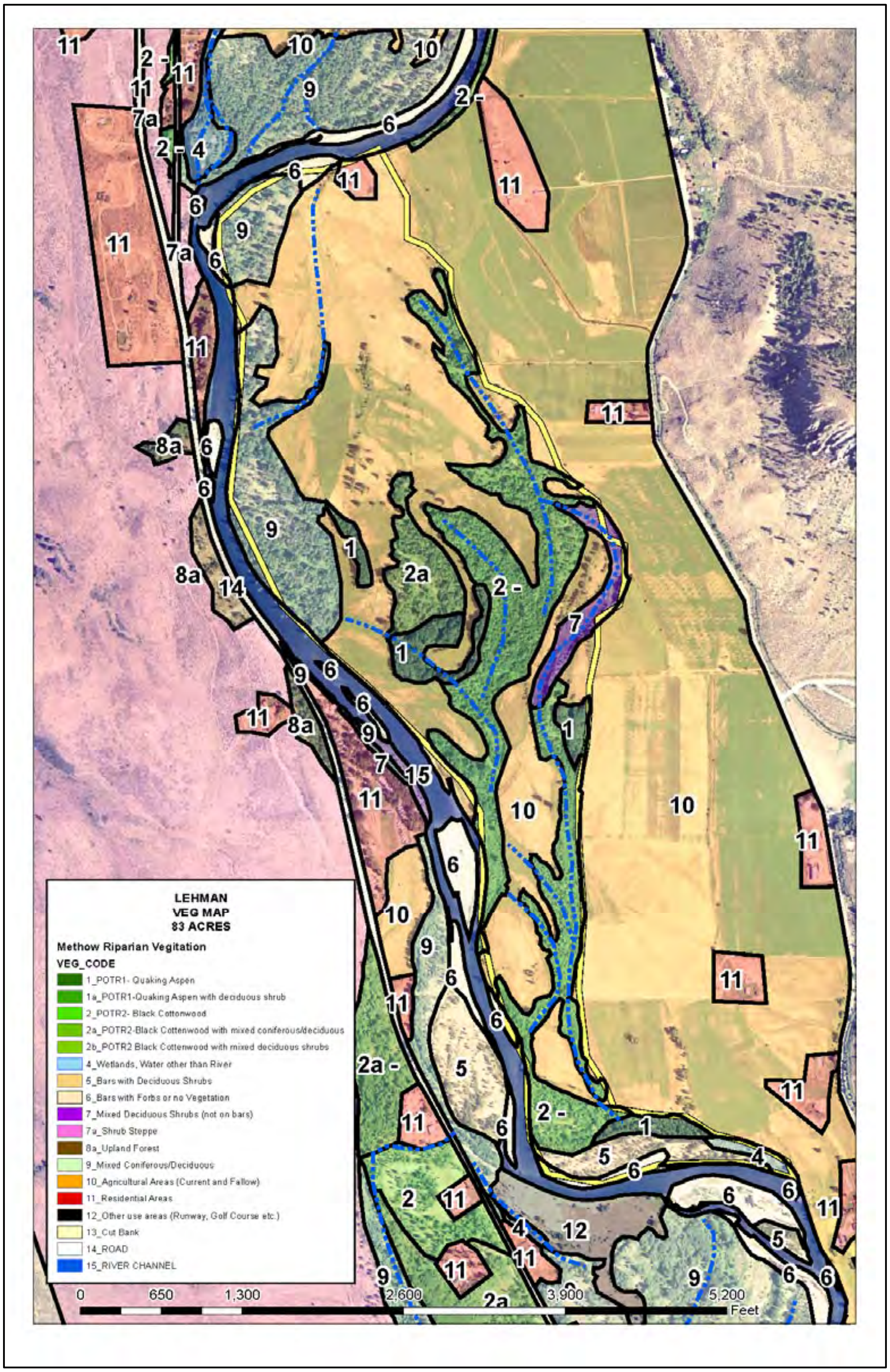

Figure H–4. Vegetation map used for field investigations at Lehman Area (at Methow RM 44.4).

3. REFERENCES

IN TEXT	FULL CITATION
DeBell 1990	DeBell, D.S. 1990. "*Populus trichocarpa*" p. 570–576, in *Silvics of North America, Volume 2, Hardwoods*: USDA Forest Service, Agriculture Handbook 654.
McLennan and Mamias 1992	McLennan, D.S., and Mamias, A.M. 1992. *Cottonwoods in British Columbia –Problem analysis.* FRDA Report 195, Canada-British Columbia Partnership Agreement on Forest Resource Development, FRDA II, 50 p.
PWI 2003	Pacific Watershed Institute, 2003, *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.

APPENDIX I –

METHOW RIVER WATER TEMPERATURE MEASUREMENTS

This appendix provides results for water temperature data collected on the mainstem Methow River in 2005 and to assess which stream reaches in the Methow Subbasin meet National Marine Fisheries Service (NMFS or NOAA Fisheries) and US Fish and Wildlife Service (FWS) stream temperature guidelines for "properly functioning habitat" for ESA-listed fish species — spring Chinook salmon, summer steelhead, and bull trout.

. The purpose of this information was to evaluate water temperatures in terms of habitat quality, and look for cold water influences on river temperatures that may locally improve habitat conditions. A complete set of summer temperature data at any of the monitor sites discussed in this appendix can be obtained upon request by contacting the author, Dave Hopkins, at dhopkins@fs.fed.us or 509-996-4037.

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1. RESULTS OF 2005 WATER TEMPERATURE ANALYSIS

An analysis was conducted in 2005 to help determine influences on water temperature in the Methow River. This appendix presents results and data from that analysis.

In the summer of 2005, 40 temperature monitors were deployed throughout the Methow River and its major tributaries. The monitors were deployed during the last week in June and retrieved at the beginning of October. The monitors were tested and calibrated before deployment. They were set to record the water temperature every hour. The monitors were placed in deep riffles and checked in mid summer to ensure that they were still under water.

For this analysis, temperature data on the Methow River has been broken into three sections: Area 1, Needle Creek, from the headwaters (RM 84.7) to Weeman Bridge (RM 63.4); Area 2, from Weeman Bridge to Beaver Creek (RM 37); and Area 3, from Beaver Creek to the mouth (RM 0). The findings are discussed by area.

1.1 AREA 1. NEEDLE CREEK TO WEEMAN BRIDGE (RM 84.7–63.4)

1.1.1 1A: NEEDLE CREEK TO LOST RIVER (RM 84.7–77.7)

Lost River: The Lost River enters the left bank of the Methow River at about RM 77.7 (river mileage in ARCMAP, version 8.0). The average mean flow of the Lost River is approximately the same as the Methow River at the confluence (Mullan et al., 1992). The Methow River often flows subsurface or at very low flow in mid to late summer from just upstream of the Weeman Bridge (RM 63.4) to about 1 mile above the confluence with Lost River. Flow from Lost River quickly disappears in the Methow River channel not far below the confluence (low flow in Lost River is estimated at 40 to 50 cfs).

Water temperature in Lost River is colder than water temperature in the Methow River above the confluence due largely to the effects of the Needle Creek fire, which burned much of the upper Methow River Subbasin in late summer, 2003. Table I-1 shows the effect of the fire on water temperatures in the upper Methow River.

Table I-1. Upper Methow River and Lost River. Maximum Water Temperature Recorded by Site (2003 to 2005).

Year	Elevation (in feet)					
	Upper Methow River monitor site					Lost River
	3500	3120	2760	2500	2400	2400
2005	15.52 ºC	16.49 ºC	17.62 ºC	17.91 ºC	18.89 ºC	14.77 ºC
2004	15.51 ºC	16.33 ºC	—	18.24 ºC	18.68 ºC	—
2003 (pre-burn)	13.01 ºC	13.79 ºC	14.61 ºC	15.87 ºC	17.30◦ C	14.59 ºC

Temperatures in the Methow warm significantly below Robinson Creek (elevation 2500 feet) due largely to the wide and shallow channel of the Methow in this area. Robinson Creek contributes very cool water to the Methow River (max temperature of 10 ºC at the confluence in 2003).

1.1.2 AREA 1B: LOST RIVER TO EARLY WINTERS CREEK (RM 77.7 TO 71.9)

Early Winters Creek: Early Winters Creek enters the right bank of the Methow River at RM 71.9. Early Winters Creek is the fourth largest tributary to the Methow River, and the second largest tributary to the Methow River above the confluence with the Chewuch River (average mean flow is about 30% lower than Lost River (Mullan et al. 1992). The maximum water temperature at the mouth of Early Winters Creek was 16.82 ºC in 2005. The maximum water temperature in the Methow River about 300 feet above Early Winters Creek was 16.41 ºC in 2005. Water temperature in the Methow River at this site was probably influenced by underground and backwater flow from Early Winters Creek (the Methow River flows subsurface not far above the confluence with Early Winters Creek). Nearly the entire length of the Methow River flows subsurface between Lost River and Early Winters Creek.

1.1.3 AREA 1C: EARLY WINTERS CREEK TO WEEMAN BRIDGE (RM 71.9 TO 63.4)

Much of the Methow River in this area often flows subsurface or nearly subsurface in mid to late summer. The water temperature was significantly warmer in the Methow River at RM 66.8 than in areas of the river directly upstream and downstream of this analysis area (maximum temperature was 19.96 ºC in 2005 at RM 66.8). The warm temperature was likely due to the lack of stream flow at the site.

Goat Creek: Goat Creek is a medium size tributary (about the size of Wolf Creek) that enters the right bank of the Methow River at about RM 67.4. The maximum water temperature near the mouth of Goat Creek was 20.24 ºC in 2005. The warm water temperature is likely due to the low stream flow in Goat Creek in mid to late summer.

“Suspension” Creek: Suspension Creek is a large, cold spring that enters the right bank of the Methow River at about RM 66.8. The spring contributes very cold water to the Methow River even at low flow. The maximum temperature in Suspension Creek was 10.06 ºC in 2005.

1.2 AREA 2. WEEMAN BRIDGE TO BEAVER CREEK (RM 63.4–73)

1.2.1 AREA 2A: WEEMAN BRIDGE TO WOLF CREEK (RM 63.4–56.0)

Flows increase significantly and incrementally going downstream in the Methow River in this 7-mile stream segment. Stream temperatures cool slightly between the Weeman Bridge and the top of the Big Valley Ranch (below Hancock Springs). Stream temperatures warm only slightly in the 5 mile segment between the top of Big Valley Ranch and Wolf Creek. Wolf Creek appears to be warming stream temperatures in the Methow River.

Hancock Springs: Hancock Springs enters the right bank of the Methow River about 1¼ miles below the Weeman Bridge. Beaver dams have created a wetland complex at the confluence of Hancock Springs and the Methow River. The springs are cooling water temperatures in the Methow River. The maximum water temperature recorded in 2005 in Hancock Springs at the road crossing was 16.08 ºC. The maximum water temperature recorded in the Methow River at Weeman Bridge (RM 63.4) was 1.22 ºC warmer than in the Methow River below Hancock Springs (RM 61.8). (The maximum temperature recorded at Weeman Bridge was 18.54 ºC compared with a maximum temperature of 17.36 ºC below Hancock Springs.)

Wolf Creek: Wolf Creek enters the right bank of the Methow River at about RM 56.1. Average mean flow in Wolf Creek is about 40 cfs (Mullan et al., 1992). Wolf Creek appears to be warming water temperatures in the Methow River. The maximum water temperature recorded in Wolf Creek in 2005 was 20.49 ºC at the monitor site about 500’ above the mouth. The maximum water temperature recorded in the Methow River about 500 feet above the confluence was 18.71 ºC; the maximum water temperature recorded in the Methow River about 500’ below the confluence was 19.80 ºC. The flow of the two streams probably was not completely mixed at the site below the confluence, possibly exaggerating the difference in water temperature between the two sites. Factors contributing to the relatively warm water in Wolf Creek include low flow in late summer in its alluvial fan (RM 0 to 1.5) and the Hubbard Burn near the headwaters.

1.2.2 AREA 2B: WOLF CREEK TO MVID DIVERSION (RM 56.0–47.5)

The Chewuch River enters the left bank of the Methow River at about RM 53, and it is the primary temperature influence on the Methow River in this analysis area.

Chewuch River: The Chewuch River is the largest tributary of the Methow River, with an average mean flow of about 374 cfs (Mullan et al., 1992). The Chewuch River contributes almost as much flow as the Methow River at its confluence (USGS gage data). The Chewuch River is warming the Methow River by close to 1 ºC; the maximum temperature at the monitor site (which is about a half-mile above the confluence with the Chewuch) was 20.17 ºC in 2005 compared with a maximum temperature of 21.62 ºC about a half mile below the confluence. The maximum water temperature at the mouth of the Chewuch River was 22.15 ºC in 2005. The Thirtymile Fire (2001) and Farewell Fire (2003) burned large segments of the Chewuch watershed and two of its largest tributaries (Lake Creek and Andrews Creek), probably causing warmer stream temperatures in the Chewuch (especially evident after the Farewell Creek Fire). The maximum water temperature recorded at the mouth of the Chewuch River in six different years is shown in the table below:

Table I-2. Chewuch River – Maximum Temperature Recorded at the Mouth (1999–2005).

Year	1999	2000	2001	2002	2003	2005
Max. Temp.	18.31 ºC	21.14 ºC	22.23 ºC	20.56 ºC	22.38 ºC	22.15 ºC

The water temperature in the Methow River was cooler about 3 miles below the Chewuch River; the reasons for this are unknown and merit further investigation. A cold spring (Gilbertson Springs) enters the left bank of the Methow River at RM 50. Flow in the spring does not fluctuate much throughout the summer (estimated at 2 to 4 cfs). The maximum temperature recorded at the mouth of the spring was 12.28 ºC during the summer of 2005.

1.2.3 AREA 3B: MVID DIVERSION TO BEAVER CREEK (RM 47.5–37.0)

Water temperatures cool significantly between the MVID diversion (RM 47.5) and the Twisp River (RM 42.3). The maximum water temperature at the monitor site above the MVID diversion was 22.24 ºC in 2005. In the same year, the maximum water temperature at the monitor site at RM 44.5 was 20.68 ºC and at RM 42.4 was 19.80 ºC. The cooler water temperatures are likely caused by springs and wetlands that enter the right bank of the Methow River below the MVID diversion.

Twisp River: The Twisp River is the second largest tributary to the Methow River, entering the right bank of the Methow at RM 42.2 (mean average flow of 226 cfs; Mullan et al., 1992). Water temperatures in lower Twisp River are relatively warm and are slightly increasing the water temperature in the Methow River. The highest recorded water temperature at the monitor site in lower Twisp River (at RM 2) was 23.12 ºC in 2005. The highest recorded water temperatures at the monitor sites about 0.1 miles above and below the Twisp River were 19.80 ºC and 20.14 ºC, respectively, in 2005.

Beaver Creek: Beaver Creek enters the left bank of the Methow River at about RM 37.0 (average mean flow in Beaver Creek is 58 cfs (Mullan et al. 1992). [Author's comment: this seems high based on personal observation.] Water temperatures at the mouth of Beaver Creek are relatively warm, probably due to high irrigation withdrawal in the lower 2 miles. The maximum water temperature recorded at the RM 0.3 in Beaver Creek was 24.21 ºC in 2005. Despite warm temperatures in Beaver Creek, the water temperature in the Methow River was cooler two miles below Beaver Creek than one mile above. The reason for cooling temperatures in the Methow River in this 3 mile stream segment warrants further investigation.

1.3 AREA 3. BEAVER CREEK TO MOUTH (RM 37–0)

1.3.1 AREA 3A: BEAVER CREEK TO LIBBY CREEK (RM 37–27)

In 2005, the maximum water temperature in the Methow River increased by 1.25 ºC between RM 34.8 (two miles below Beaver Creek) and RM 28.9 (two miles above Libby Creek).

Libby Creek: Libby Creek enters the right bank of the Methow River at about RM 27 (mean average flow in Libby Creek is 15 cfs; Mullan et al., 1992). Libby Creek is a source of colder water to the Methow River. The maximum water temperature recorded at RM 0.2 in Libby Creek was 17.80 ºC in 2005. The maximum recorded water temperature in the Methow River was about the same at the monitor sites above Libby Creek (RM 28.9) and above Gold Creek (RM 24.2), 23.36 ºC and 23.32 ºC, respectively.

1.3.2 AREA 3B: LIBBY CREEK TO GOLD CREEK (RM 27–22)

Gold Creek: Gold Creek enters the right bank of the Methow River at about RM 22.5. The water temperature in the Methow River did not increase significantly between the monitor sites above and below Gold Creek in 2005 (23.32 ºC maximum temperature at RM 24.2 and 23.67 ºC maximum temperature at RM 21.7). WDFW will provide temperature data for 2005 in Gold Creek.

1.3.3 AREA 3C: GOLD CREEK TO MOUTH (RM 22–0)

There are possibly no significant changes in stream flow occurring in the lower 22 miles of the Methow River. Three very small tributaries (McFarland, Squaw, and Black Canyon Creeks) enter the right bank of the lower Methow River.

Water temperatures cool slightly between in the 3-mile segment RM 21.7–18.7 for reasons unknown. Water temperatures warm progressively downstream between RM 18.7 and RM 5.3. The water temperature in the Methow River at the town of Pateros (mouth) was slightly cooler than at RM 5.3. The Methow River is likely influenced by the Columbia River and its dams in the lower two miles (the monitor was dewatered for about a week in early July, possibly from increased flow through Wells Dam).

Table I-3 (on several pages following) provides substantial data by sites. These include maximum temperatures, maximum seven-day maximum temperatures, maximum seven-day averages, and the related dates of occurrence.

Table I-3. Methow River Temperatures in 2005.

Site	RM[1/]	Max. Temp.		Max. 7-day Max		Max. 7-day Avg		Notes
		ºC	date	ºC	date	ºC	date	
Above Mouth	1.6	24.76	08-07	24.00	08-06	22.84	08-06	Possible influence from Columbia River. No data after 8-22
Below Black Canyon	5.3	25.13	08-08	24.46	08-05	21.93	08-06	No major tributaries between this site and Columbia River.
Below Squaw Creek	8.6	24.41	08-08	23.77	08-06	21.47	08-06	Known steelhead spawning site.
Above town of Methow	13.8	23.77	08-08	23.18	08-05	21.17	08-06	French Creek flows subsurface on left bank below this site.
Below McFarland Cr	18.7	23.07	08-08	22.41	08-05	20.57	08-06	No major tributaries between this site and town of Methow
Below Gold Creek	21.7	23.67	08-08	22.90	08-05	20.56	08-06	Site is 0.7 miles below Gold Creek.
Above Gold Creek	24.2	23.32	08-08	22.70	08-05	20.38	08-05	Site is 1.5 miles above Gold Creek. WDFW will send Gold Creek temperature data (avg. mean flow in Gold Creek is about 33 cfs (Mullan et al. 1992).
---Libby Creek RM 0.2	*27.0*	*17.8*	*08-08*	*17.22*	*08-06*	*15.34*	*08-07*	Mean average discharge *about 15 cfs (Mullan et al., 1992).*
Above Libby Creek	28.9	23.36	08-08	22.64	08-05	19.77	08-05	Texas Creek flows subsurface into Methow above this site.
Below Beaver Creek	34.8	22.11	08-08	21.66	08-05	19.04	08-05	Benson Creek flows subsurface into river above this site.
-Beaver Creek RM 0.3	*37.0*	*24.21*	*08-07*	*22.25*	*08-03*	*18.95*	*08-05*	Mean average discharge is about 58 cfs (Mullan et al. 1992).
Above Beaver Creek	38.2	22.88	08.08	22.03	08-05	18.68	08-05	About 1.5 miles above Beaver Creek – land owned by DOT
Below Twisp River	42.2	20.14	08-07	19.44	08-03	16.88	08-05	Site is 500 feet below Twisp River on right side of Methow.
--Twisp River RM 2--	*42.3*	*23.12*	*08-08*	*22.74*	*08-05*	*18.22*	*08-05*	Mean average discharge is about 226 cfs (Mullan et al., 1992).
Above Twisp River	42.4	19.80	08-07	19.35	08-05	16.78	08-05	Site is 500 feet above Twisp River on right side of Methow.
Above River Bend CG	44.5	20.68	08.08	20.00	08-05	17.89	08-05	Springs on right side of floodplain below the MVID diversion are cooling the Methow River to Twisp River.
Above MVID diversion	47.5	22.24	08-08	21.55	08-04	18.17	08-05	River is wide with little shading above MVID diversion.
--Gilbertson Springs--	*50.0*	*12.28*	*09-01*	*12.28*	*09-01*	*12.10*	*09-11*	Estimated at 2 to 4 cfs. Enters left bank of Methow River.
Above Gilbertson Spr.	50.1	20.64	08-08	19.94	08-04	17.04	08-05	Bear Creek flows into irrigation ditch above springs.
Below Chewuch River	52.7	21.62	08-08	20.84	08-05	17.60	08-05	Just below Winthrop bridge on left side of river.
--Chewuch Mouth---	*53.1*	*22.15*	*08-08*	*21.29*	*08-05*	*18.56*	*08-05*	Mean average discharge is about 374 cfs (Mullan et al., 1992).
Above Chewuch R.	53.6	20.17	08-08	19.50	08-05	15.62	08-05	About ¼ mile above Chewuch. Chewuch warms Methow.
Below Wolf Creek	56.0	19.80	08-07	19.00	08.04	15.24	08-05	About 500' below Wolf Creek.
--Wolf Creek RM 0.1--	*56.1*	*20.49*	*08-08*	*19.94*	*08-05*	*16.76*	*08-06*	Mean average discharge is about 40 cfs (Mullan et al., 1992).
Above Wolf Creek	56.2	18.71	08-08	17.96	08-04	14.32	08-05	Wolf Creek appears to be warming the Methow River.

Site	RM[1/]	Max. Temp.		Max. 7-day Max		Max. 7-day Avg		Notes
		ºC	date	ºC	date	ºC	date	
Lower Big Valley	58.5	18.07	07-28	17.58	07-25	14.01	07-25	Below confluence of 2 major channels of Methow River. The Methow River gains flow between RM 63 and RM 53.
Below Hancock Sprg.	61.8	17.36	07-28	16.88	07-25	13.58	07-25	In right channel of Methow River (almost 50-50 split flow).
--Hancock Springs--	*62.2*	*16.08*	*08-06*	*15.65*	*08-03*	*10.62*	*08-03*	Spring, beaver ponds on right side of Methow River.
At Weeman Bridge	63.4	18.54	08-08	17.95	08-05	14.36	08-05	Methow flows mainly subsurface above Weeman Bridge to just below confluence with Robinson Creek (RM 79).
Below Goat Creek	66.8	19.96	07-28	19.57	07-25	14.92	07-25	Across the channel from Suspension Creek. Most of the channel at this location flows subsurface. Temperature monitor was in pocket pool on left side of channel.
--Suspension Creek---	*66.8*	*10.06*	*08-08*	*9.97*	*08-23*	*9.24*	*08-23*	"Suspension Creek" is a major spring on the right side of Methow River channel.
--Goat Creek RM 0.6-	*67.4*	*20.24*	*08-08*	*19.39*	*08-05*	*16.35*	*08-06*	Left bank tributary similar in size to Wolf Creek.
--Early Winters Creek	*71.9*	*16.82*	*08-08*	*16.30*	*08-05*	*13.86*	*08-06*	Methow River flows subsurface above Early Winters Cr in mid to late summer. "Avg" mean flow about 119 cfs. (Mullan et al. 1992).
Above Early Winters	72.0	16.41	07-18	15.82	07-24	12.57	07-25	River flows subsurface above. This site is about 300' above Early Winters Creek, probably influenced by creek.
--Lost River RM 0.5--	*77.7*	*14.77*	*08-08*	*14.39*	*08-04*	*11.25*	*08-05*	Mean average discharge is about 164 cfs (Mullan et al. 1992). Lost River contributes about 50% of flow to Methow River at mean flow. The Methow River usually flows subsurface at the confluence with Lost River in mid to late summer.
Above Lost River	78.8	18.89	08-08	18.20	08-04	14.56	08-06	Site is about ½ mile below Robinson Creek.
Above Robinson Cr	79.6	17.91	08-08	17.39	08-04	14.35	08-05	Robinson Creek contributes about 10% of flow, and has much lower water temperatures (max temperature at the mouth of Robinson Creek was 10 ºC in 2003).
Above Rattlesnake Cr	81.3	17.62	08-08	17.12	08-04	14.30	08-05	Rattlesnake Creek contributes less than 5% of flow.
Above Trout Creek	82.2	16.49	08-08	16.06	08-04	12.72	08-05	Trout Creek contributes about 10% to 15% of flow.
Above Needle Creek	84.7	15.52	08-08	15.00	08-05	12.40	08-06	Several small tributaries between Trout Cr. and Needle Cr.

1/ River mileage in ARCMAP Version 8.0.

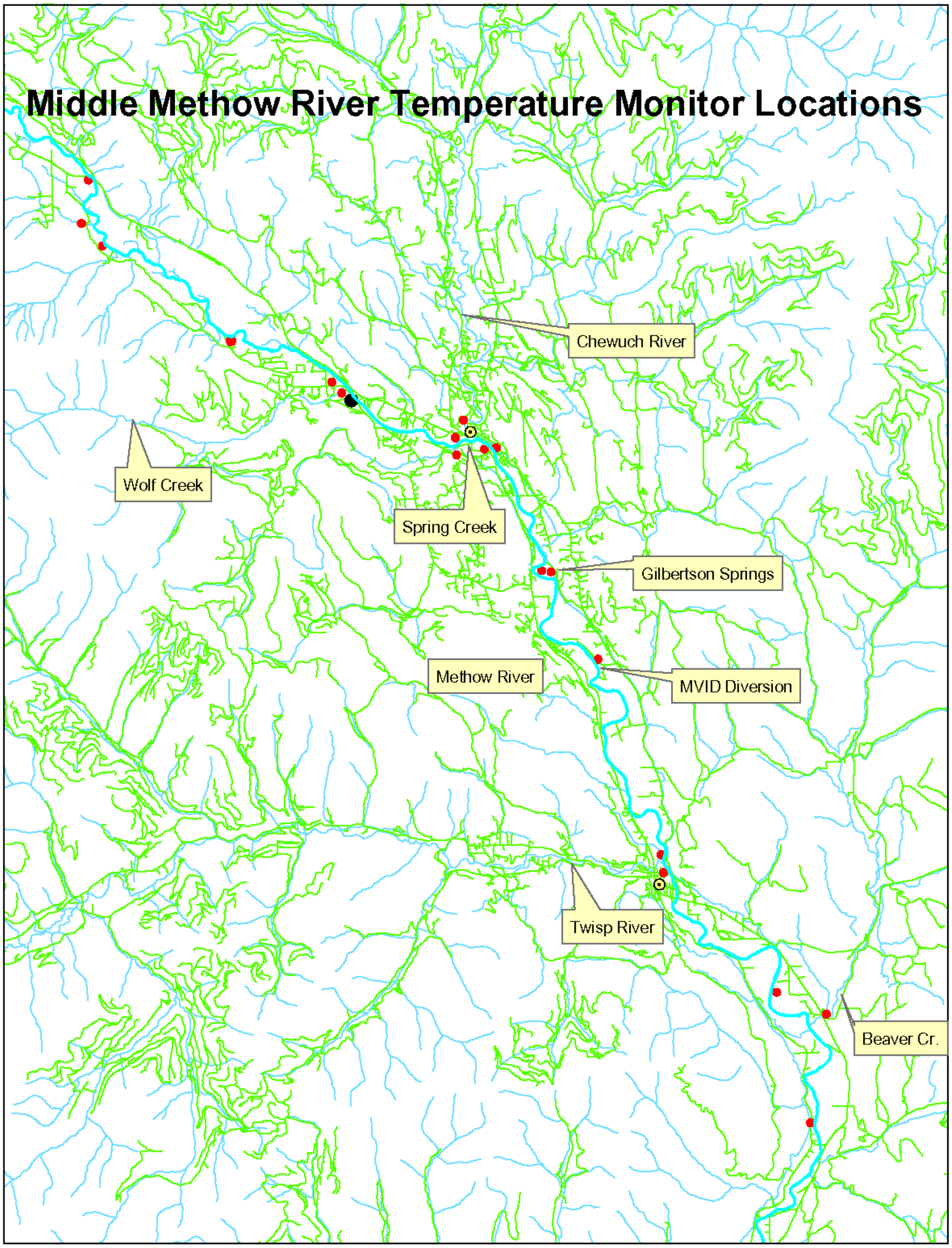


Figure I-1. Middle Methow River temperature monitor locations.

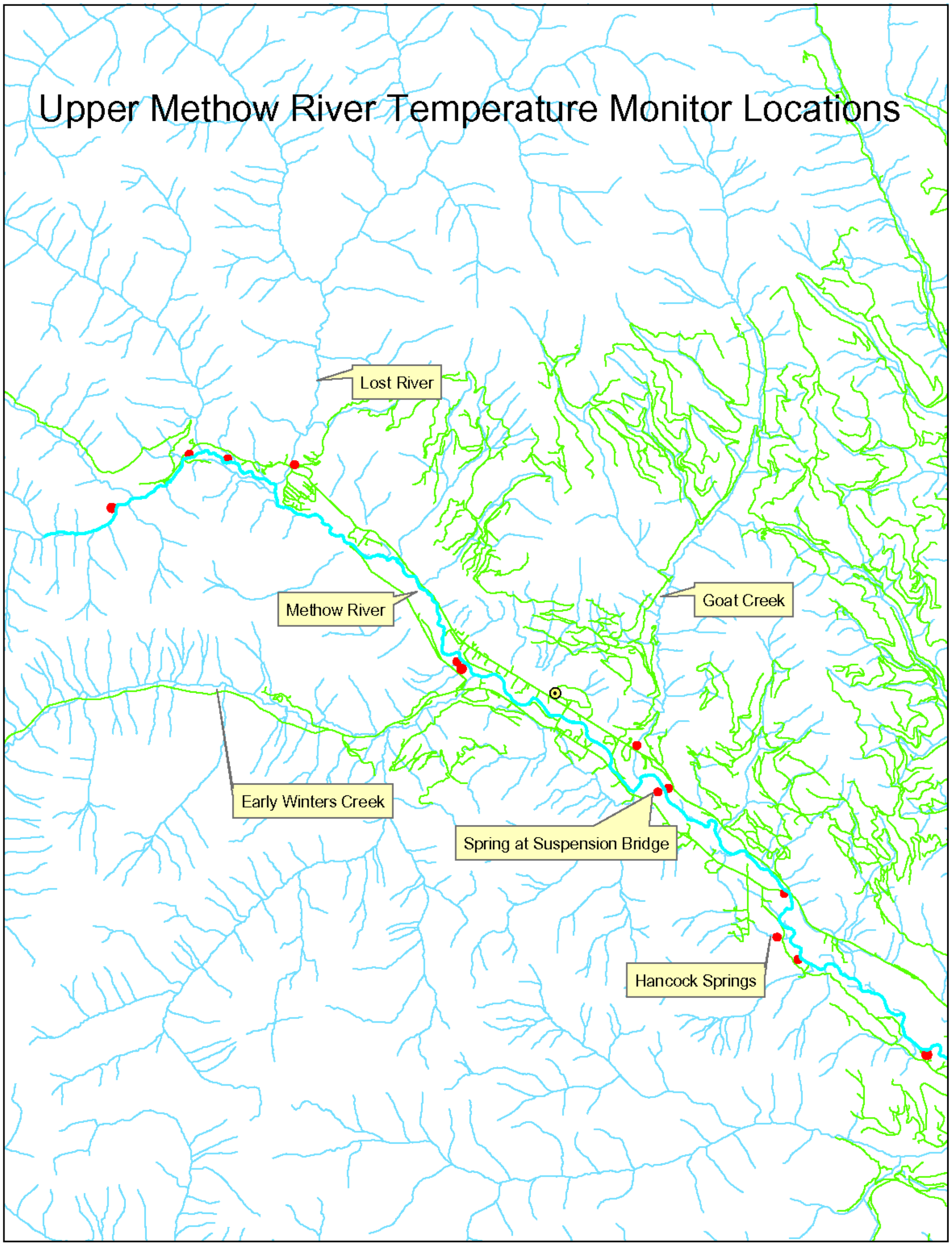


Figure I-2. Upper Methow River temperature monitor locations.

2. STREAM TEMPERATURE RISK ASSESSMENT OF ESA-LISTED FISH

2.1 INTRODUCTION

The purpose of this section is to help determine which stream reaches in the Methow Subbasin meet National Marine Fisheries Service (NMFS or NOAA Fisheries) and US Fish and Wildlife Service (FWS) stream temperature guidelines for properly functioning habitat for ESA-listed fish species — spring Chinook salmon, summer steelhead, and bull trout. The various reaches are in the Methow, Chewuch, and Twisp Rivers.

The temperature guidelines promulgated by NMFS (for all ESA-listed salmonids) and by FWS (for bull trout) were developed to assist in establishing an environmental baseline and to assist in making effects determinations on listed fish. The NMFS guidelines are found in *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale* (NMFS, 1996). The FWS guidelines are in *A Framework to Assist in Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Bull Trout Subpopulation Watershed Scale* (FWS, 1998a). Table I-4 summarizes stream temperature guidelines established by the two agencies:

Table I-4. Temperature Indicators for ESA Listed Salmonids.

Effects determination	**NMFS guidelines** [1/] (for all salmonids)	**FWS guidelines** (for bull trout)
"Properly functioning fish habitat " (NMFS) "Functioning appropriately" (FWS)	50-57 ºF [1/] (10-13.9 ºC)	7-day average maximum temperature in a reach during the following life history stages: Incubation = 2-5 ºC Rearing = 4-12 ºC Spawning = 4-9 ºC Also, temperatures do not exceed 15 ºC in areas used by adults during migration (no thermal barriers)
"At Risk "(NMFS) "Functioning at risk " (FWS)	Spawning 57-60 ºC, (13.9-15.5 ºC) Rearing and Migration 57-64 ºC, (15.5-17.8 ºC)	Incubation = <2 ºC or 6 ºC Rearing = <4 ºC or 13-15 ºC Spawning = <4 ºC or 10 ºC Also, sometimes in areas used by adults during migration temperatures exceed 15 ºC.
"Not Functioning Properly Functioning "(NMFS) "Functioning at unacceptable risk" (FWS)	Spawning > 60 ºC (>15.5 ºC) Rearing and Migration > 64 ºC (17.8 ºC)	Incubation = <1 ºC or >6 ºC Rearing = >15 ºC Spawning = >4 ºC or >10 ºC Also, temperatures in areas used by adults during migration regularly exceed 15 ºC (thermal barriers present).
1/ Bjornn and Reiser, 1991		

The NMFS guideline for properly functioning fish habitat is based on the results of water-temperature preference values for salmonids in laboratory conditions. In the study, fish mortality occurred at sustained temperatures above 57 ºC. Salmonids survived for short times at lethal temperatures as long as these temperatures were not sustained.

2.2 METHODOLOGY

Reclamation has identified stream restoration projects in the Methow River (from Benson Creek to Lost River), in the Chewuch River (from the mouth to Falls Creek) and in the Twisp River (from the mouth to War Creek). These streams segments were broken into reaches based on tributaries and temperature-monitor locations rather than landform features. Known spring Chinook, steelhead, and bull trout use (spawning, rearing and migration) was identified within each reach.

The temperature-monitor location within each stream reach, the year the temperature monitor was deployed, the data source (agency), and two stream-temperature attributes ("maximum 7-day average maximum temperature" and "highest 7-day average temperature") are displayed by stream in Table I-5, Table I-6, Table I-7, and Table I-8. A temperature indicator rating based on NMFS and FWS value criteria was made for each type of fish use (spawning, rearing, and migration). The indicator rating is based on a more complete temperature analysis than shown in the two temperature attributes in the table. Most of the habitat area in the three rivers was found to have a "not properly functioning" rating (NMFS) and "functioning at an unacceptable risk" rating (FWS) for stream temperatures. Stream temperature was only one of many stream attributes used by NMFS and FWS to help determine the conditions of habitat used by ESA listed fish species. The numeric values of the attributes are not meant as absolutes, but presented as a diagnostic tool to promote discussions of differences between the data collected and values suggested by NMFS and FWS.

Notes to be read in conjunction with the four tables following:

- River mileage in the attached tables is taken from maps generated by Reclamation (October 2005).
- Fish spawning data in the attached tables was taken from spawning survey reports provided by the Washington Department of Fish and Wildlife.
- The indictor ratings for stream temperatures were analyzed in three life stages for each species: spawning, rearing and migration. The (normal) timing of each life stage for each species is show in the table below.

Table I-5. Species and life stage use on a monthly cycle within Methow Subbasin.

[More detailed species and life stage use is presented in Appendix F, "Biological Setting."]

Species ▪ **life stage**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Steelhead												
Spawning			●	●	●							
Rearing	●	●	●	●	●	●	●	●	●	●	●	●
Migration	●	●	●	●	●				●	●	●	●
Spring Chinook												
Spawning								●	●			
Rearing	●	●	●	●	●	●	●	●	●	●	●	●
Migration					●	●	●	●				
Bull Trout												
Spawning									●	●		
Rearing	●	●	●	●	●	●	●	●	●	●	●	●
Migration					●	●	●					

Table I-6. Methow River: Benson Creek to Lost River.

[More detailed species and life stage use is presented in Appendix F, "Biological Setting']

Reach	Known Fish Use:			Summer Temperature Data				Temperature Indicator Rating		
	Steelhead	Spring Chinook	Bull Trout	Monitor Location	Data Source	Max 7-day Avg. Max	Highest 7-day Average	Steelhead (NMFS)	Chinook Salmon (NMFS)	Bull Trout (FWS)
Benson Cr (RM 33.2)– Beaver Cr.	S, R, M	M	M	RM 34.0	USFS 2005	21.66 ºC	19.04 ºC	Spawning: 1: Rearing: 3 Migration: 1	Migration: 1-3	Migration: 1 to 3
Beaver Cr (RM 36) to Twisp River	S, R, M	M	M	RM 37.5 RM 40.9	USFS 2005 USFS 2005	22.03 ºC 19.44 ºC	18.68 ºC 16.88 ºC	Spawning: 1 Rearing: 3 Migration: 1	Migration: 1-3	Migration: 1 to 3
Twisp River (RM 41) to Diversion	S, R, M	S, R, M	M	RM 41.1 RM 43.5	USFS 2005 USFS 2005	19.35 ºC 20.00 ºC	16.78 ºC 17.89 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration: 1- 3	Migration: 1 to 3
Diversion (RM 46) to Chewuch River	S, R, M	S, R, M	M	RM 46.1 RM 48.5 RM 51.1	USFS 2005 USFS 2005 USFS 2005	21.55 ºC 19.94 ºC 20.84 ºC	18.17 ºC 17.04 ºC 17.60 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration: 1- 3	Migration: 1 to 3
Chewuch River (51.5) to Wolf Cr.	S, R, M	S, R, M	M	RM 51.7 RM 52.1	USFS 2005 USFS 2005	19.50 ºC 19.00 ºC	15.62 ºC 15.24 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration: 1- 3	Migration: 1 to 3
Wolf Cr (RM 54.2) to Hancock Sp	S, R, M	S, R, M	M	RM 52.3 RM 55.3 RM 58.4	USFS 2005 USFS 2005 USFS 2005	17.96 ºC 17.58 ºC 16.88 ºC	14.32 ºC 14.01 ºC 13.58 ºC	Spawning: 1 Rearing: 2 Migration: 1	Spawning: 2 Rearing: 2 Migration: 1, 2	Migration: 1 to 3
Hancock Sp (RM 59) to Weeman Br	S, R, M	S, R, M	M	RM 61	USFS 2005	17.95 ºC	14.36 ºC	Spawning: 1 Rearing: 2 Migration: 1	Spawning: 2 Rearing: 2 Migration: 1, 2	Migration: 1 to 3
Weeman Br (RM 61) to Early Winters	S, R, M	S, R, M	M	RM 64.3	USFS 2005	19.57 ºC	14.92 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration: 1, 2	Migration: 1 to 3
Early Winters (RM 69.1) to Lost River	S, R, M	S, R, M	M	RM 69.2	USFS 2005	15.82 ºC	12.57 ºC	Spawning: 1 Rearing: 2 Migration: 1	Spawning: 2 Rearing: 2 Migration: 1, 2	Rearing: 2 Migration: 1, 2

Table I-7. Twisp River: Mouth to War Creek.

Reach	Known Fish Use:			Summer Temperature Data				Temperature Indicator Rating		
	steel-head	spring Chinook	bull trout	Monitor Location	Data Source	Max 7-day Avg. Max	Highest 7-day Average	steelhead (NMFS)	Chinook salmon (NMFS)	bull trout (FWS)
Mouth to USGS gage (RM 2.0)	S, R, M	S, R, M	M	RM 2.0	USFS 2005 USFS 2001	22.74 ºC 21.81 ºC	18.22 ºC 17.77 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration: 1–3	Migration: -3
USGS gage to Poorman Cr Bridge (RM 5.0)	S, R, M	S, R, M	M	RM 5.0	USFS 2001	19.37 ºC	16.61 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration: 1–3	Migration: -3
Poorman Cr. bridge to Newby Cr (RM 7.8)	S, R, M	S, R, M	M	RM 5.3	USFS 2001 USFS 2000	19.32 ºC 18.59 ºC	16.55 ºC 15.54 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration: 1-3	Migration: 1-3
Newby Cr to Little Bridge Cr. (RM 9.8)	S, R, M	S, R, M	M	No data	No data					
Little Br. Cr to Butter- milk Creek (RM 13.7)	S, R, M	S, R, M	M	RM 13.5	USFS 2000	16.82 ºC	13.42 ºC	Spawning: 1 Rearing: 2 Migration: 1	Spawning: 2 Rearing: 2 Migration: 1,2	Migration: 1, 2
Buttermilk Cr. to War Cr. (RM 17.6)	S, R, M	S, R, M	R, M	RM 17.6	USFS 2001	16.12 ºC	12.55 ºC	Spawning: 1 Rearing: 2 Migration: 1	Spawning: 2 Rearing: 2 Migration: 1, 2	Rearing: 2 Migration: 1, 2

Table I-8. Chewuch River: Mouth to Falls Creek .

"Known fish use": **S** = spawning; **R** = rearing; **M** = migration

NMFS "temperature indicator rating": **1** = properly functioning; **2** = functioning at risk; **3** = not properly functioning

FWS "temperature indicator rating": **1**= functioning appropriately; **2** = functioning at risk; **3** = functioning at an unacceptable risk

	Known Fish Use:			Summer Temperature Data				Temperature Indicator Rating		
Reach	steel-head	spring Chinook	bull trout	Monitor Location	Data Source	Max 7-day Avg. Max	Highest 7-day Average	steelhead (NMFS)	Chinook salmon (NMFS)	bull trout (FWS)
Mouth to RM 2 (end of bedrock)	R, M	R, M	M	Mouth	USFS 2005 USFS 2003 USFS 2002	21.29 ºC 21.91 ºC 19.84 ºC	18.56 ºC 18.85 ºC 17.23 ºC	Rearing: 3 Migration: 1	Rearing: 3 Migration:1-3	Migration: 1-3
RM 2 to 3.5 (Pete Creek)	S, R, M	S, R, M	M	RM 3.5	USFS 2002 USFS 2001	19.23 ºC 21.08 ºC	16.51 ºC 17.61 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration:1-3	Migration: 1-3
RM 3.5 to 6.9 (Cub Creek)	S, R, M	S, R, M	M	RM 5.4	USFS 2004 USFS 2003 USFS 2002	19.77 ºC 20.59 ºC 18.83 ºC	17.34 ºC 17.08 ºC 17.25 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration:1-3	Migration: 1-3
RM 6.6 to 9.4 (Boulder Creek)	S, R, M	S, R, M	M	RM 8.4	USFS 2002 USFS 2001	18.04 ºC 21.17 ºC	15.61 ºC 17.31 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration:1-3	Migration: 1-3
RM 9.4 to 11.6 (Eightmile Creek)	S, R, M	S, R, M	M	RM 9.9	USFS 2002 USFS 2001	17.98 ºC 19.19 ºC	15.26 ºC 15.91 ºC	Spawning: 1 Rearing: 2 Migration: 1	Spawning: 2 Rearing: 2 Migration:1-2	Migration: 1-3
RM 11.2 to 14.2 (Falls Creek)	S, R, M	S, R, M	M	RM 12.2	USFS 2002	19.78 ºC	16.54 ºC	Spawning: 1 Rearing: 3 Migration: 1	Spawning: 3 Rearing: 3 Migration:1-3	Migration: 1-3

3. REFERENCES

IN TEXT	FULL CITATION
Bjornn and Reiser 1991	Bjornn, T.C. and Reiser, D.W. 1991. "Habitat Requirements of Salmonids in Streams." *American Fisheries Society Special Publication 19:83-138.* Meehan, W.R., ed.
FWS 1998a	US Fish and Wildlife Service. 1998a. *A Framework to Assist in Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Bull Trout Subpopulation Watershed Scale*, February 1998.
Mullan et al. 1992	Mullan, J.W.; Williams, K.R.; Rhodus, G.; Hillman, T.W.; and McIntrye, J.D. 1992. *Production and Habitat of Salmonids in Mid-Columbia River Tributary Streams,* US Fish and Wildlife Service, Monograph 1. Leavenworth, WA.
NMFS 1996	National Marine Fisheries Service. 1996. *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale*, August 1996. Includes the "Matrix of Pathways and Indicators" (MPI).

APPENDIX J –

HYDROLOGY ANALYSIS AND GIS DATA

This appendix documents hydrology data and a GIS database developed for utilization in hydraulic and sediment computations presented in Appendix K.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This appendix documents hydrology data and a GIS database developed for the *Methow Subbasin Geomorphic Assessment* being accomplished by Reclamation's Technical Service Center for the Pacific Northwest Region. The report contains the following information:

- Subbasin characteristics.
- Historical flood accounts.
- Flood frequency computations for peak flows at USGS gage station locations.
- Flood frequency computations with GIS integration for ungaged locations based on two methods.
- Maximum, average, and minimum daily flow values at gaging stations for the period of record.
- Flow duration curves for mean daily flows for USGS gage station locations.
- Summary of the effects of PDO on Pacific Northwest salmon production.

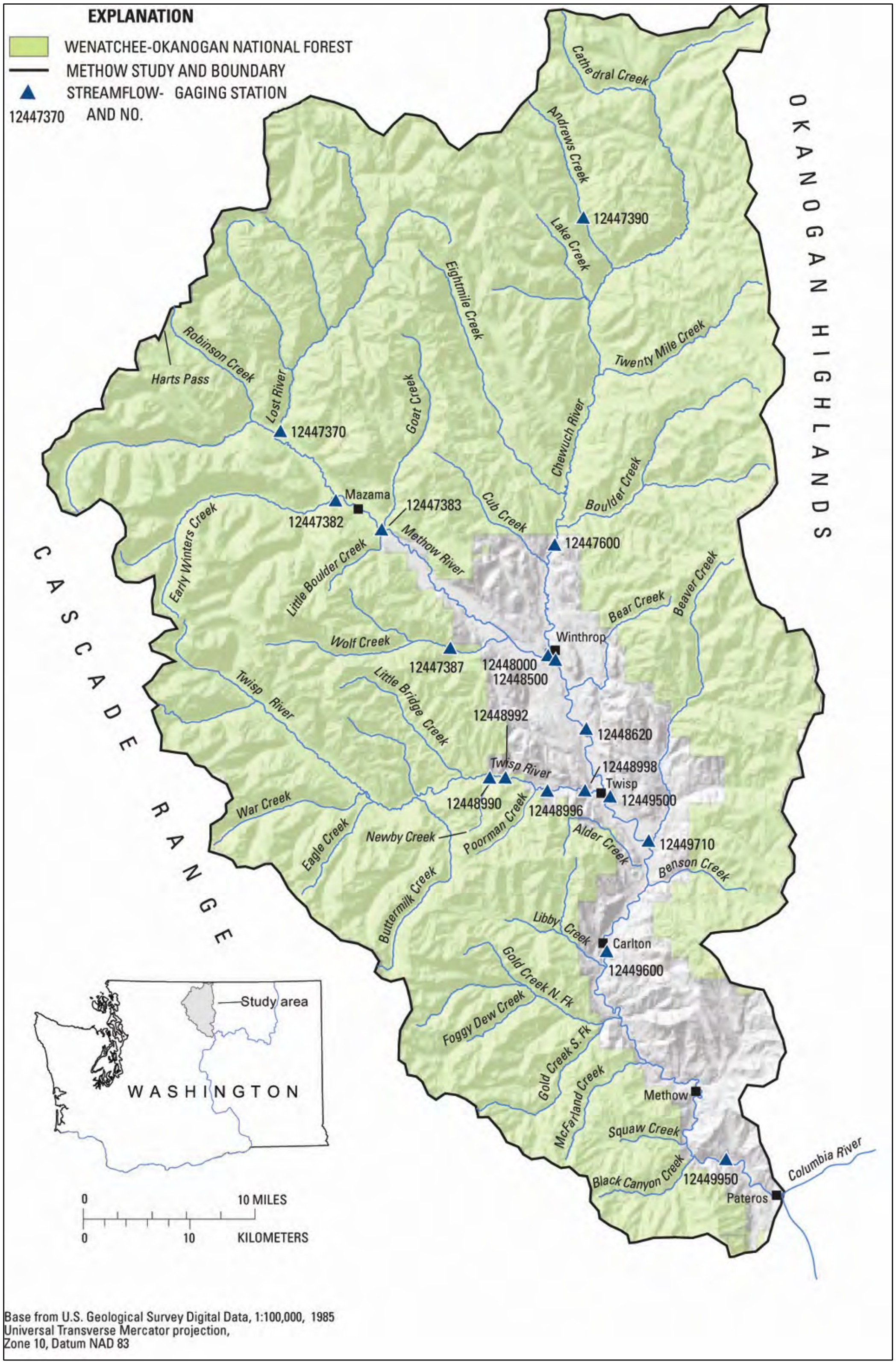


Figure J–1. Methow Subbasin drainage vicinity map.

2. METHOW SUBBASIN CHARACTERISTICS

The Methow Subbasin is located in western Okanogan County, Washington. The drainage basin above the mouth of the Methow River is 1,814 mi^2 which accounts for 35% of the total area of Okanogan County. Within the Methow Subbasin, there are two major sub-drainages that contribute runoff to the Methow River. These are the Twisp River watershed (245 mi^2) and the Chewuch River watershed 525 mi^2). All runoff generated from the Methow Subbasin empties into the Columbia River near Pateros, Washington (at RM 524).

The topography of the Methow Subbasin varies significantly. The elevation of the mouth of the Methow River is approximately 780 feet above sea level. The highest point, at elevation 8500 feet, is located just above the headwaters of the Lost River.

The USGS maintains stream gage stations throughout the Methow Subbasin which provide mean daily flow data and instantaneous annual peak flow data (see Figure J–1). Of the nineteen gages, eight have greater than ten years of record (Table J–1).

Table J–1. Methow Subbasin – USGS stream gage information for the eight gages with more than 10 years of record.

USGS Gage No.	Description	Date of peak discharge	Years of record	Drainage area (mi^{2})
12449950	Methow River near Pateros, WA	5/29/1948	47	1,772
12449600	Beaver Creek below South Fork near Twisp, WA	5/29/1972	20	62
12449500	Methow River at Twisp, WA	5/29/1948	52	1,301
12448998	Twisp River near Twisp, WA	5/29/1948	19	245
12448500	Methow River at Winthrop, WA	5/31/1972	16	1,007
12448000	Chewuch River at Winthrop, WA	6/16/1999	13	525
12447390	Andrews Creek near Mazama, WA	6/10/1972	36	22
12447383	Methow River above Goat Creek near Mazama, WA	6/17/1999	14	373

3. HISTORICAL FLOOD ACCOUNTS:

Based on the annual trends for each gage, the Methow Subbasin is subject to large late-spring and early-summer floods. Major floods have occurred in the valley in 1894, 1948, and 1972 (Beck, 1973). The Flood of 1894 occurred prior to the establishment of stream flow records, but high water marks were used to estimate a peak discharge of 50,000 cubic feet per second (cfs or ft^3/s) (Beck, 1973). The dollar value of the damage caused by the 1894 flood was not great in comparison with subsequent floods because of the minimal development in the river valley at that time. The largest flood of record occurred on May 29, 1948 at the Pateros, WA gage (12449950). The magnitude of this flow was 46,700 cfs.

Figure J–2 and Figure J–3 display the annual peak flow data available at the two USGS stream gages in the Methow Subbasin with the longest period of record.

Beck (1973) notes the following regarding the 1948 Flood:

> "…occurred in 1948 at a time when severe flooding occurred throughout Columbia River basin. The snowpack accumulated during the winter was 19 percent above normal on the first of April and was augmented by unusually heavy precipitation and cool temperatures until mid-May when the temperatures rose to unseasonably high readings. Above average rainfall began in mid-May which accelerated the rate of snowmelt resulting in a rapid rise in the river discharge…. This flood destroyed roads and bridges, caused severe erosion of agricultural lands and inundated homes and thousands of acres of land. The estimated damage caused by this flood was $2,250,000 based on 1948 prices."

The peak discharge of 46,700 ft^3/s was recorded at the Pateros gage near the mouth of the Methow River on May 29, 1948.

Regarding the 1972 flood, Beck (1973) notes the following:

> "The flood was initiated from a snow accumulation averaging approximately 175 percent of normal from an unusually cool, long, and stormy winter. Near the end of May the weather cleared bringing two periods of high temperatures which caused rapid snowmelt and rapid rise of the discharge of the river….A short period of cool temperatures caused the river crest to recede, however, a subsequent period of high temperatures resulted in second river crest approximately two weeks later….Widespread erosional damage and large inundated areas resulted from this flood…Damages resulting from this flood had an estimated magnitude of $420,000 consisting mostly of bank erosion and crop loss due to inundation of farm lands."

The peak discharge of 28,800 ft^3/s was recorded at the Pateros gage near the mouth of the Methow River on May 31, 1972.

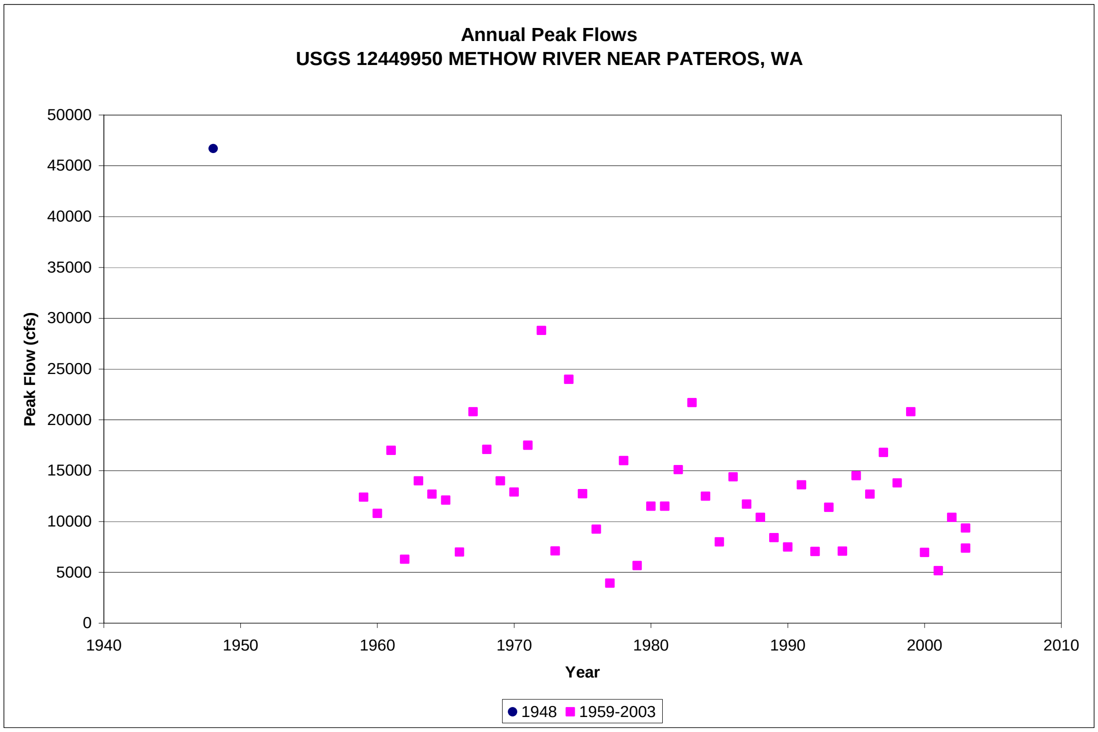


Figure J–2. Annual peak flow data for the Methow River at Twisp, WA.

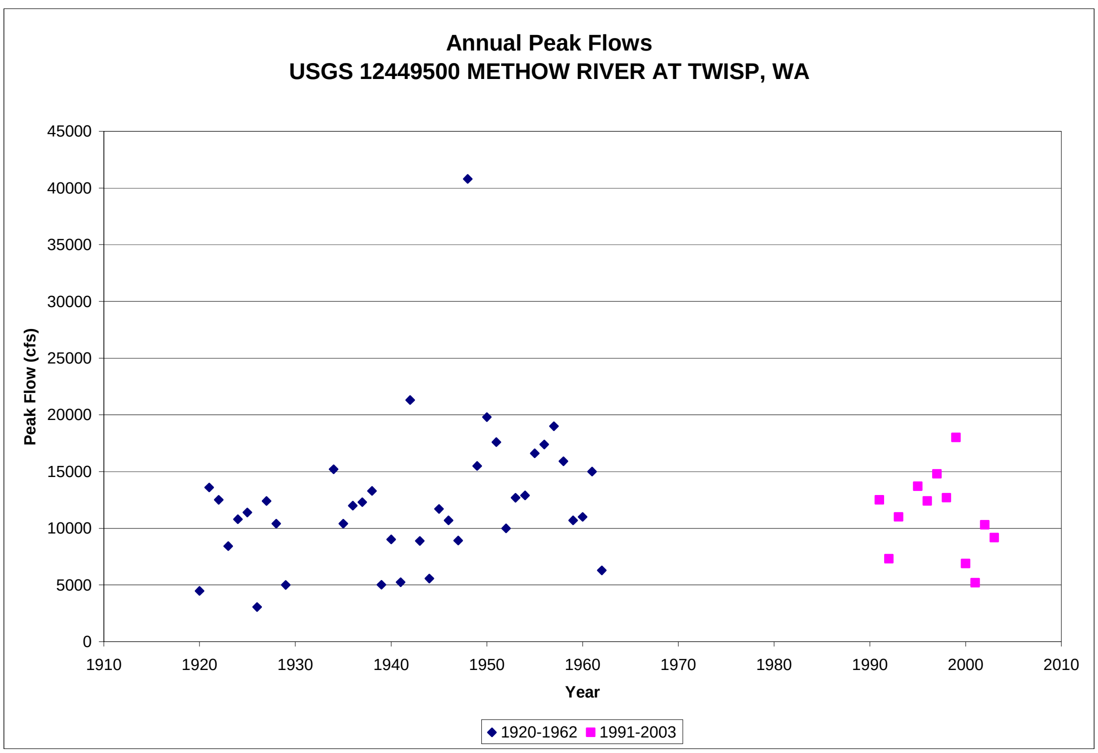


Figure J–3. Annual peak flow data for the Methow River at Pateros, WA.

4. PEAK FLOW CALCULATIONS AT GAGED LOCATIONS

The annual flow data for the eight selected USGS stream gages were sought from its National Water Information System (NWIS) web site. [1/] A Log-Pearson III distribution was fit to the gaged record of peak flows using the method of moments to develop the flood frequency values for 2-, 5-, 10-, 25-, 50-, and 100-year periods. This process is consistent with the procedure described in *Guidelines for Determining Flood Flow Frequency*, *Bulletin 17B* (WRC, 1981). A Regional skew value was not included in the calculations because it was determined to be approximately equal to zero. Table J–2and Figure J–4 provide the results of the statistical analysis for each gage.

Table J–2. Methow Subbasin – Peak flow data computed for USGS stream gages.

USGS Gage No.	Description	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
12449950	Methow River near Pateros, WA	11,500	17,200	21,400	27,200	31,900	36,800
12449600	Beaver Creek below South Fork near Twisp, WA	136	267	367	506	615	727
12449500	Methow River at Twisp, WA	11,100	16,000	19,200	23,000	25,700	28,300
12448998	Twisp River near Twisp, WA	2,120	3,160	3,890	4,860	5,610	6,390
12448500	Methow River at Winthrop, WA	9,020	13,300	16,600	21,400	25,400	29,700
12448000	Chewuch River at Winthrop, WA	3,240	4,980	6,100	7,470	8,450	9,390
12447390	Andrews Creek near Mazama, WA	362	508	619	778	911	1,060
12447383	Methow River above Goat Creek near Mazama, WA	5,250	6,900	7,890	9,040	9,840	10,600

1/ http://waterdata.usgs.gov/nwis

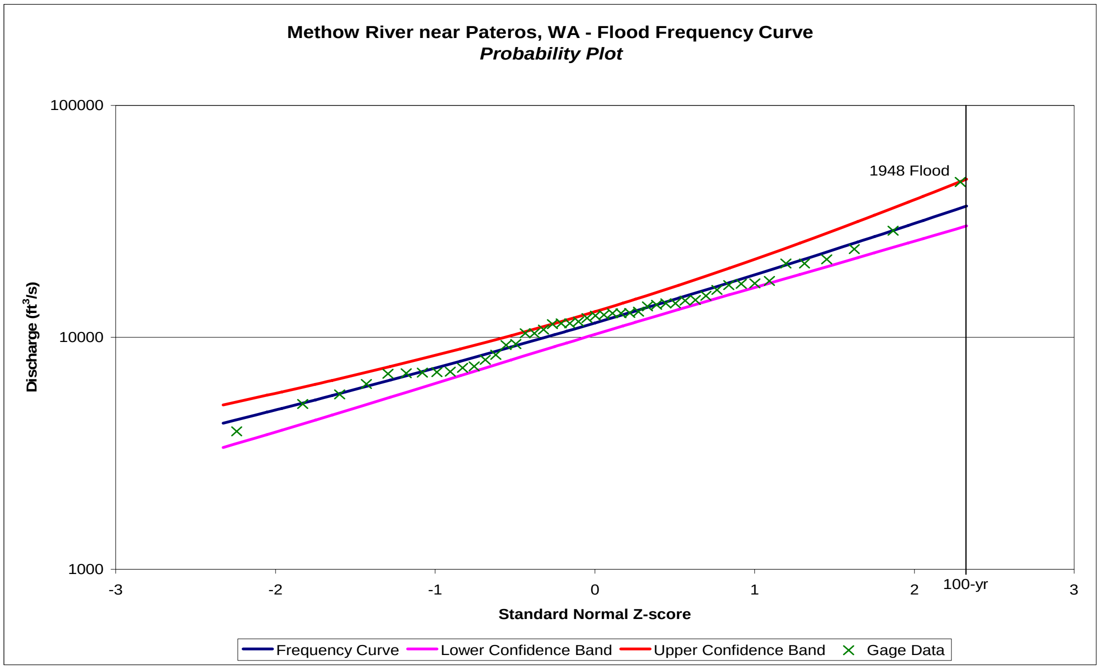


Figure J–4. Methow River Flood Frequency Curve – Probability Plot (to AEP 0.01).

5. PEAK FLOW CALCULATIONS AT UNGAGED SITES WITH GIS INTEGRATION

Because a stream channel restoration project site could potentially be located along any reach within the Methow Subbasin, peak flow calculations were also computed over the entire drainage basin and incorporated into a geographic information system. The user of the Methow GIS database can easily acquire the desired peak flow information by simply clicking on a potential project site within the Methow Subbasin. This system was created using the watershed processing tools in ESRI's ArcHydro and the USGS publication: *Methods for Estimating Flood Magnitude and Frequency in Washington, 2001* (USGS, 2001). Two independent methods were used for computing peak flow computations at ungaged locations which will be described in further detail below. The results from each computation method can vary at individual sites and should be considered tools to represent a range of possible flood frequency values.

A GIS was created in order to quickly access specific peak flow information associated with potential project sites. This system incorporates "digital elevation models" (DEM) of the topography, aerial photography, precipitation isohyetal maps, existing stream networks, existing project locations, and a graphical database that contains the peak flow information for the Methow Subbasin's individual watersheds, drainage basins, or subbasins. Once the DEM of the basin is imported into the GIS, ArcHydro delineated all of the subbasins. For this system, a minimum subbasin size of 3.5 mi^2 was selected because most stream channel restoration projects have watersheds greater than this size. After the watershed processing was complete, ArcHydro had created 519 subbasins within the entire Methow basin. For each of these subbasins peak flows for recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100-years were calculated based on a local gage data analysis and a regional gage data analysis.

5.1 PEAK FLOWS AT UNGAGED LOCATIONS BASED ON LOCAL GAGE DATA ANALYSIS

Using the guidelines specified (USGS, 2001), the peak flows at the USGS gages were used to compute the flows for the appropriate subbasins. The guidelines state that the ungaged location must be on the same stream as the gaged location and the ungaged watershed area must not exceed ±50 percent of the gaged watershed area. The following expression (Equation J–1) was used to estimate the ungaged peak flows at the ungaged subbasin outlets.

Equation J-1

$$Q_u = Q_g \left(\frac{A_u}{A_g} \right)^{0.97}$$

Where

- $\mathbf{Q_u}$ is the peak discharge, in cfs, at the ungaged site for a specific recurrence interval,
- $\mathbf{Q_g}$ is the peak discharge, in cfs, at the gaged site for a specific recurrence interval,
- $\mathbf{A_u}$ is the contributing drainage area, in mi^2, at the ungaged site,
- $\mathbf{A_g}$ is the contributing drainage area, in mi^2, at the gaged site, and,
- **0.97** is the regional exponent for Okanogan County, Washington.

Of the 519 subbasins, peak flows in 81 basin were computed using this method. If a subbasin happens to fall in range of two gages, then the closest gage is used to compute the peak flows. For this method, only the gages listed in Table 1 were used to estimate peak flows. Figure J–5 highlights the subbasins with peak flows computed using local gage data.

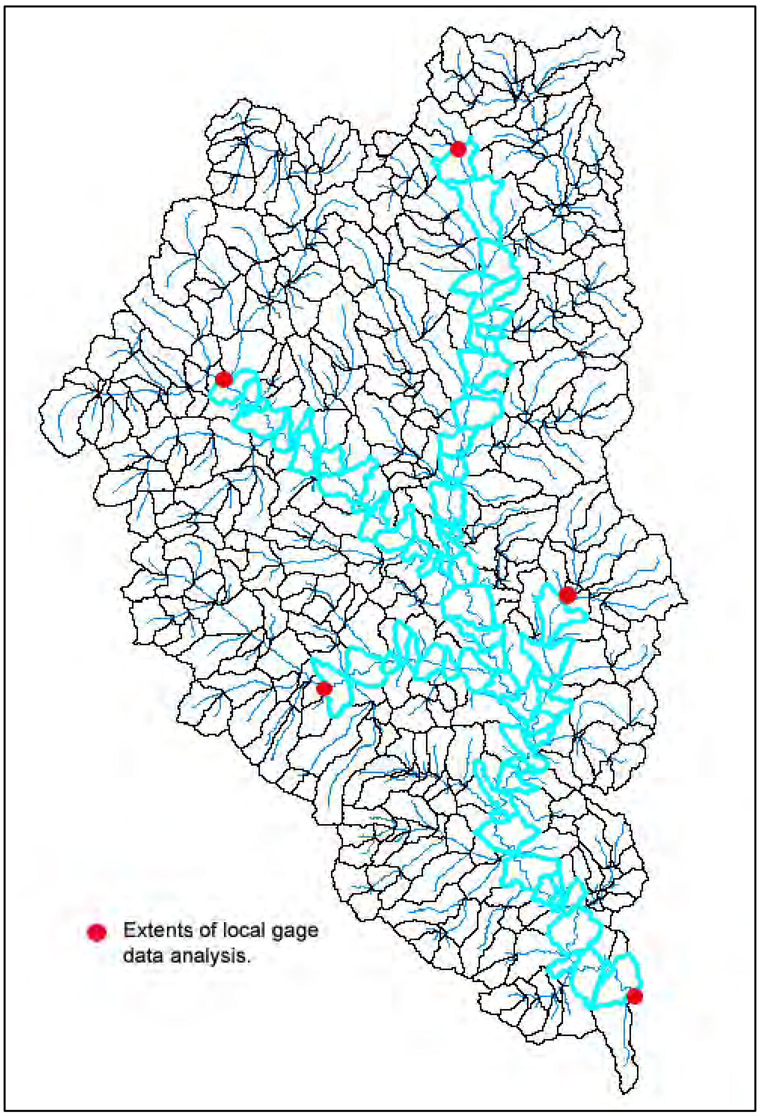


Figure J–5. Methow Subbasin – Highlighted subbasins with peak flows computed using local gage data.

5.2 PEAK FLOWS AT UNGAGED LOCATIONS BASED REGIONAL GAGE DATA ANALYSIS

Because only 81 of the 519 subbasins met the criteria above, a regional gage data analysis was implemented to fill the gaps. Using annual peak flow data from the eight USGS gage stations within the Methow Subbasin, regional parameters for the log skewness and log variance were computed. Then a linear trendline was added to the regional log mean flow versus log area data. This yielded Equation J–2 which had a correlation coefficient of 0.8532.

Equation J–2

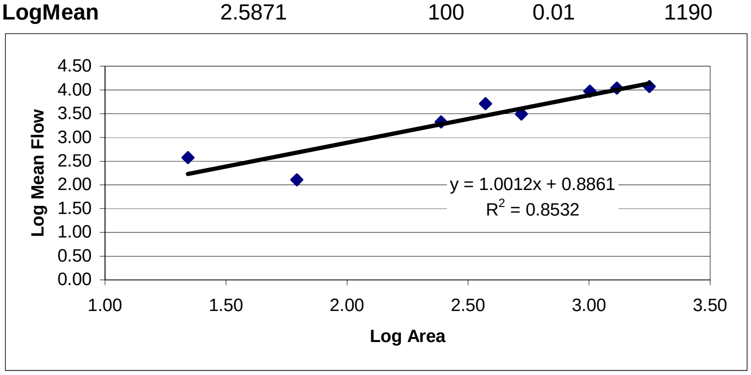
$$\text{log mean flow} = 1.0012*(\text{log area}) + 0.8861$$

The log mean flows for the remaining subbasins were computed using the above equation, and finally a Log Pearson III analysis was performed to compute the peak flows for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. Table J–3 is an example of this process.

Table J–3. Example of Regional Gage Data Analysis for a 50 mi^2 subbasin.

Site ID	Area (mi^2)	LogArea	LogMean	N	LogSkew	N*LogSkew	LogVar	n*LogVar
12447383	373.0	2.57	3.71	14	-0.28	-3.974	0.148	2.065
12447390	22.0	1.34	2.57	36	0.57	20.549	0.165	5.922
12448000	525.0	2.72	3.50	13	-0.41	-5.269	0.236	3.065
12448500	1007.0	3.00	3.97	16	0.43	6.824	0.191	3.063
12448998	245.0	2.39	3.33	19	0.02	0.329	0.205	3.889
12449500	1301.0	3.11	4.04	52	-0.32	-16.635	0.200	10.380
12449600	62.0	1.79	2.11	20	-0.39	-7.799	0.369	7.375
12449950	1772.0	3.25	4.07	47	0.20	9.409	0.204	9.580
					Sum	**3.435**		**45.339**

		Regional Analysis		
LogSkew	0.0158			
LogVar	0.2089			
		Return Period	**Probability**	**Peak Flow**
Slope	1.001	2	0.5	386
Intercept	0.886	5	0.2	579
Effective N	27	10	0.1	716
Sub-basin Area	50	25	0.04	900
LogArea	1.6990	50	0.02	1042
LogMean	2.5871	100	0.01	1190



5.3 USING THE GIS DATABASE

Once the computations for all of the subbasins were completed, they were integrated in the GIS. Figure J–6 is an example of the output from the GIS for a specific subbasin. It contains the information listed in Table J–4. Note that if the "Ref_Gage" field is 0, then the regional gage data analysis was used to calculate the peak flows for the selected subbasin.

Table J–4. GIS output description.

Field	Description
Area_mi^2	Subbasin area in square miles
Q2_cfs	2-year peak flow in cubic feet per second
Q5_cfs	5-year peak flow in cubic feet per second
Q10_cfs	10-year peak flow in cubic feet per second
Q25_cfs	25 year peak flow in cubic feet per second
Q50_cfs	50-year peak flow in cubic feet per second
Q100_cfs	100-year peak flow in cubic feet per second
Ref_gage	Gage used to estimate peak flows (used for local analysis only)

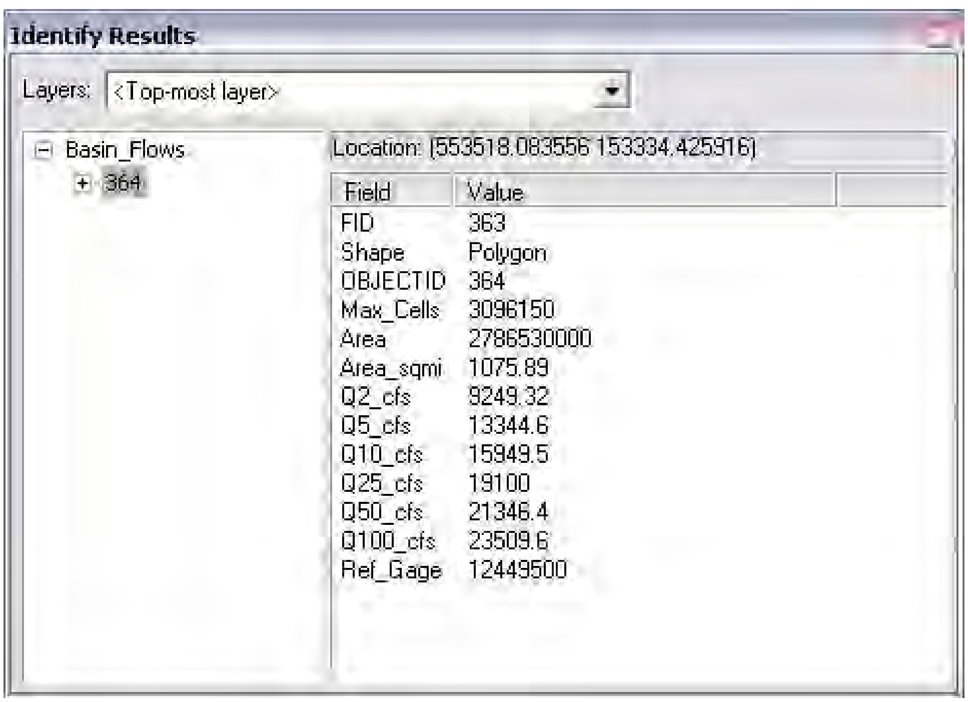


Figure J–6. Output summary example for an ungaged subbasin.

6. SUMMARY OF DISCHARGES

The final GIS layer entitled "Basin_Flows.shp" contains the 2-, 5-, 10-, 25-, 50-, and 100-year flood frequency values for 519 subbasins within the Methow Subbasin. Table J–5 is a summary of the computed peak discharges compared to those calculated in *Okanogan County Flood Insurance Study* (FIS) (FEMA, 2003).

Table J–5. Summary of Discharges.

Flooding Source and Location	Drainage area (mi^2)	Peak Discharge (ft^3/s)					
		10-year		50-year		100-year	
		GIS	FIS	GIS	FIS	GIS	FIS
Early Winters Creek at confluence with Methow River	79.2	**1,150**	2,760	**1,670**	4,290	**1,910**	5,090
Twisp River at confluence with Methow River	250	**3,900**	5,500	**5,540**	7,600	**6,400**	8,470
Chewuch River at confluence with Methow River	530	**6,100**	6,200	**8,500**	9,400	**9,400**	11,000
Methow River at confluence with Chewuch River	1,039	**15,400**	18,000	**20,600**	25,000	**22,700**	29,000
Methow River at Confluence with Twisp River	1,325	**16,140**	21,500	**24,000**	25,500	**27,800**	35,000

All of the peak discharges computed for the flood insurance study have larger magnitudes than those contained in the new GIS layer created for this assessment. The sources and methods used in this assessment vary significantly. For the Methow and Twisp Rivers, flood frequency estimates were based on the results from the 1975 FIS for the town of Twisp (FIA, 1975). For the Chewuch River, flood frequency estimates were taken from *Flood Hazard Analyses Chewuch River* (SCS, 1975) which utilized the hydrologic simulation model TR-20.

In order to graphically represent the discharge results from the analysis, a color coded grid file of the 100-year peak discharges for the Methow River subbasins was created. Figure J–7 contains nine zones of 100-year peak discharges; each is represented by a unique color.

It is recommended that the flood frequency discharges for the Methow River GIS be updated, at a minimum, every five years. This should include updating the gage data to include new annual peak discharges and updating the flood frequency calculations to include the new data.

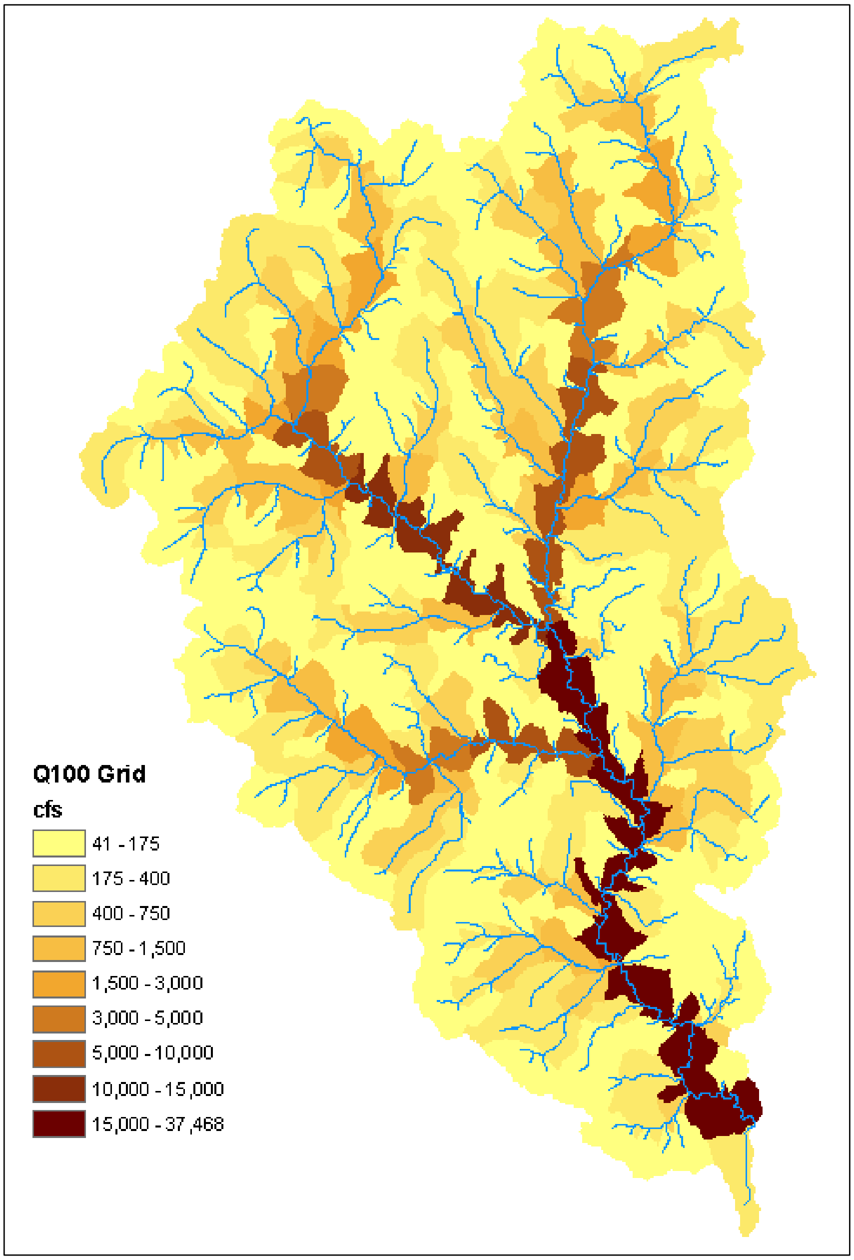


Figure J–7. Spatial distribution of 100-year peak discharges in the Methow Subbasin.

6.1 MAXIMUM, AVERAGE, AND MINIMUM DAILY FLOWS

Figures Figure J–8 thru Figure J–12 represent a summary hydrograph analysis of the mean daily flows for five major USGS gages in the Methow Subbasin. Maximum, mean, median, minimum and the upper and lower quartiles of daily flow values are presented for each day. A simple routine was developed in Microsoft Excel's Visual Basic editor to compute the above statistics for each calendar day of a gage's period of record and output them in a graphical format.

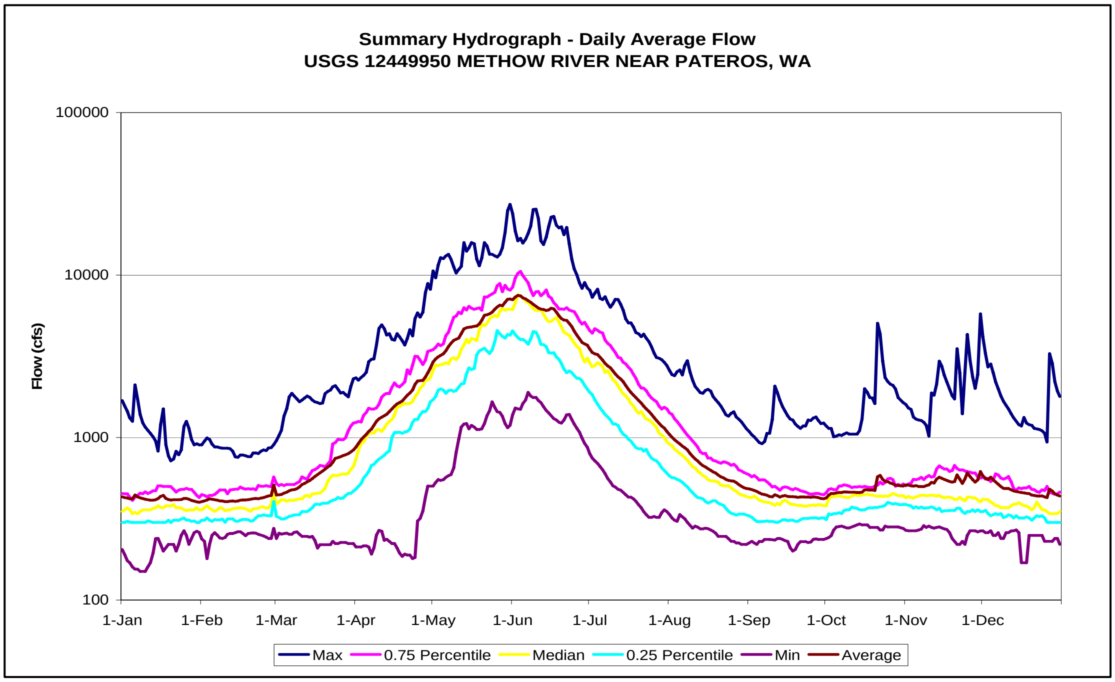


Figure J–8. Mean daily flow statistics for Methow River near Pateros, WA.

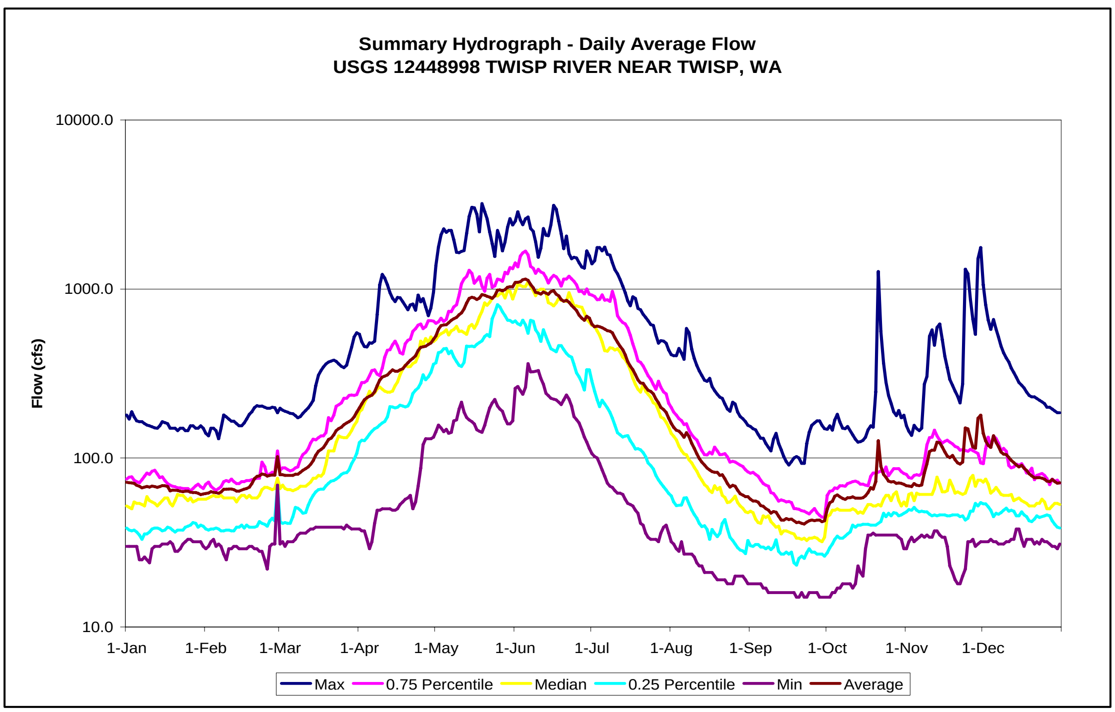


Figure J–9. Mean daily flow statistics for Methow River at Twisp, WA.

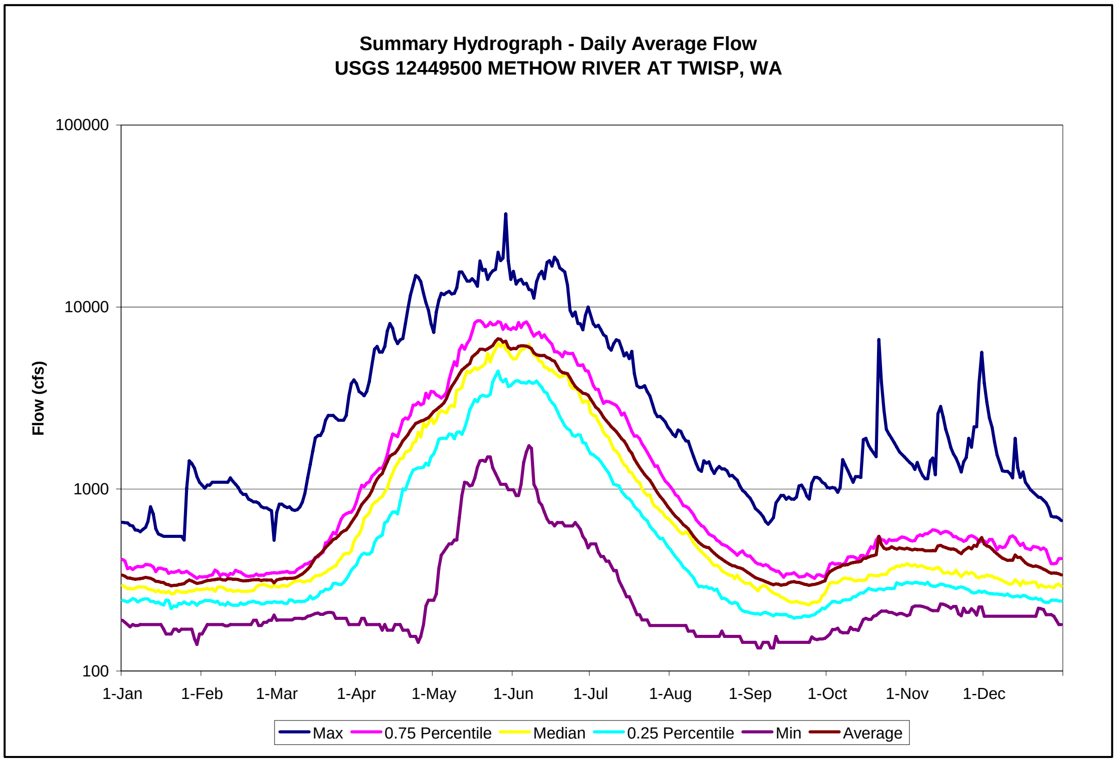


Figure J–10. Mean daily flow statistics for Twisp River near Twisp, WA.

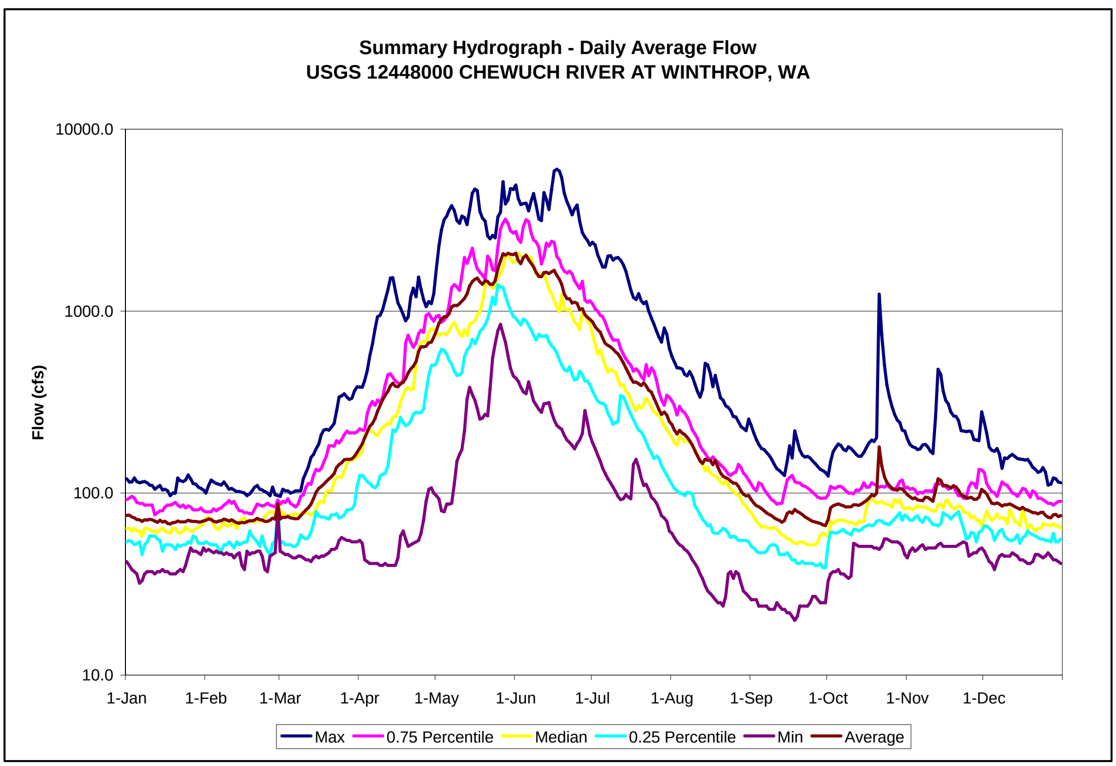


Figure J–11. Mean daily flow statistics for Chewuch River at Winthrop, WA.

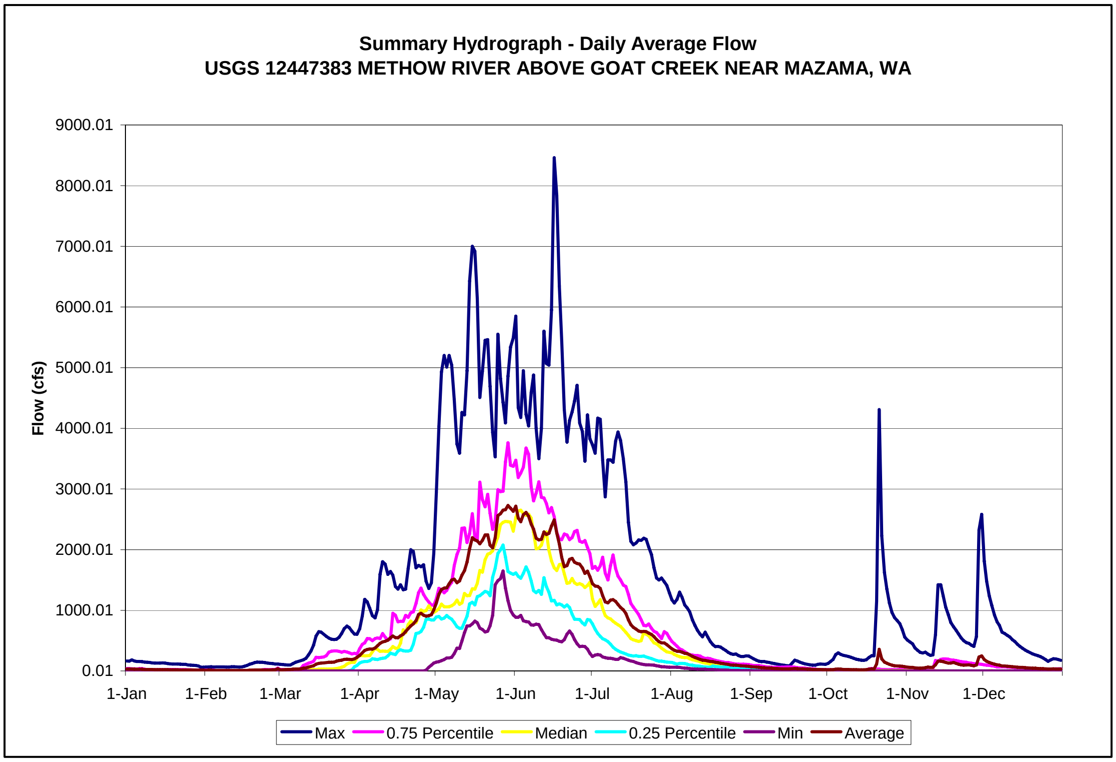


Figure J–12. Mean daily flow statistics for Methow River above Goat Creek near Mazama, WA.

6.2 FLOW-DURATION CURVES

Analysis of the mean daily flow data was performed to produce standard flow duration curves that depict the fraction of time that the river flows are below a specific flow. In addition to the curve, "bins" have been created that represent estimates of the volume of water for a specific discharge and duration. This volume is then used to estimate sediment loads at the selected discharge. The height of the bin is the discharge (ft^3/s) and the width of the bin is the duration displayed as a fraction of a year (365.25 days). The gage records were used to estimate the duration for each desired discharge. For each of the five gages analyzed, the 1-, 2-, 5-, and 10-year discharges have bins. There are also bins representing recurrence intervals between 1 and 2 years. Figure J–13 thru Figure J–17 display these curves.

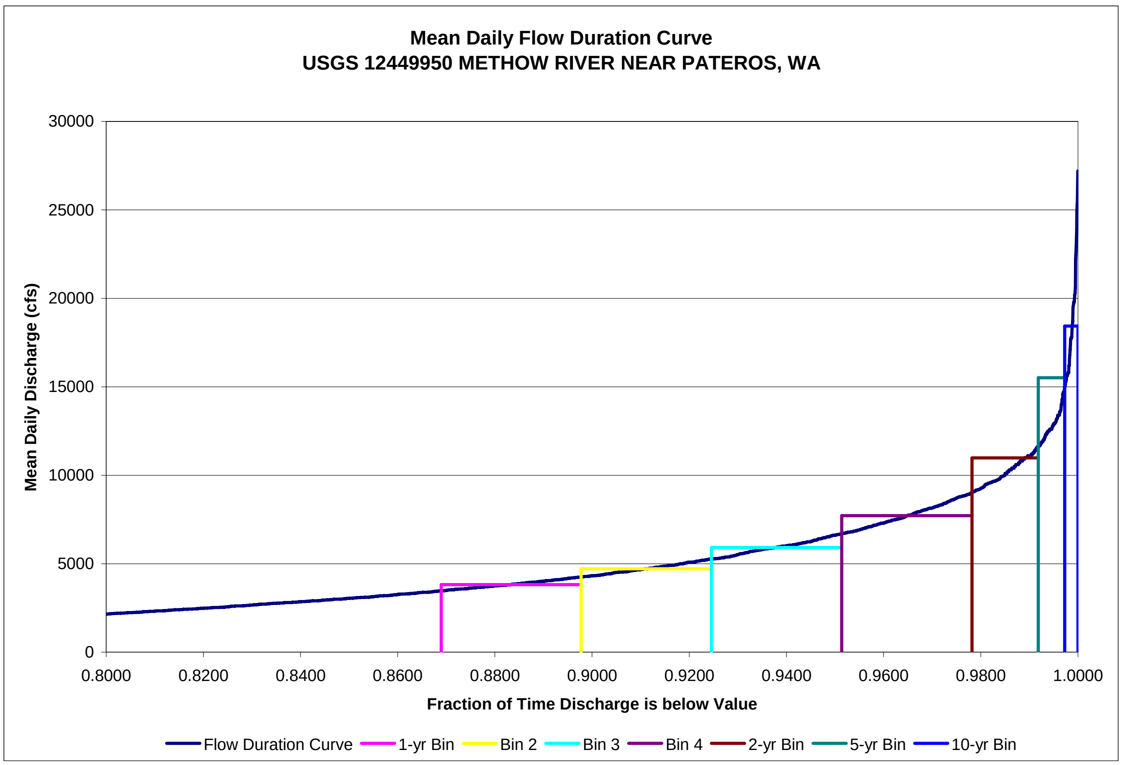


Figure J–13. Mean daily flow duration curve for Methow River near Pateros, WA.

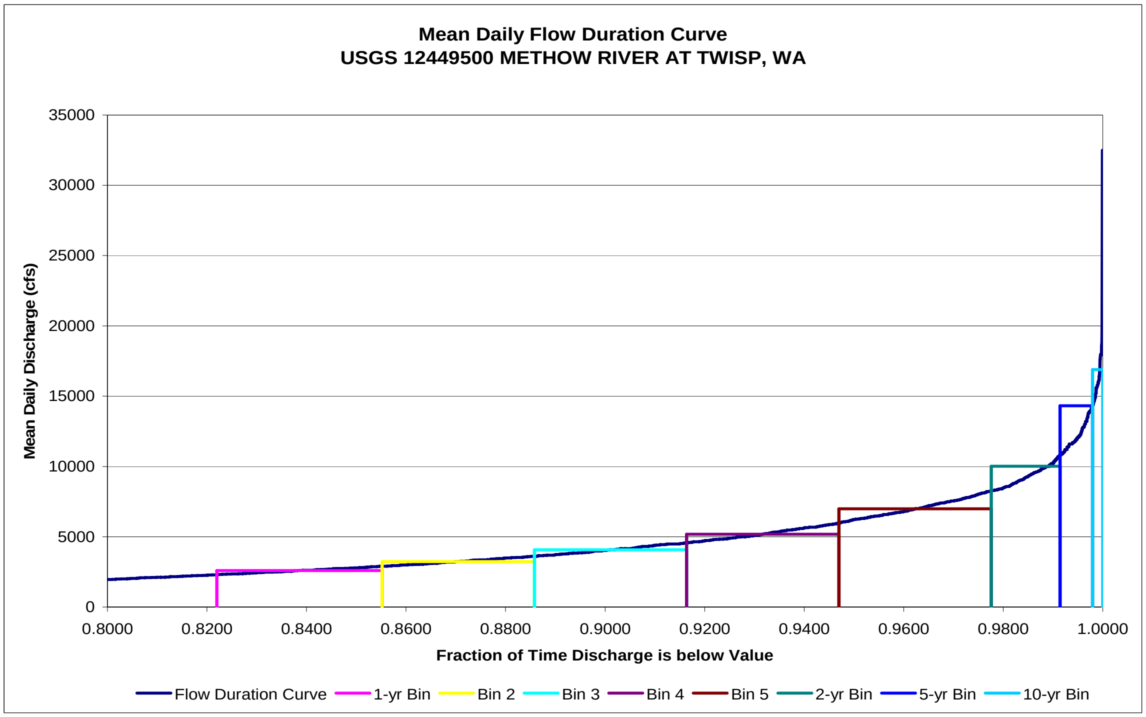


Figure J–14. Mean daily flow duration curve for Methow River at Twisp, WA.

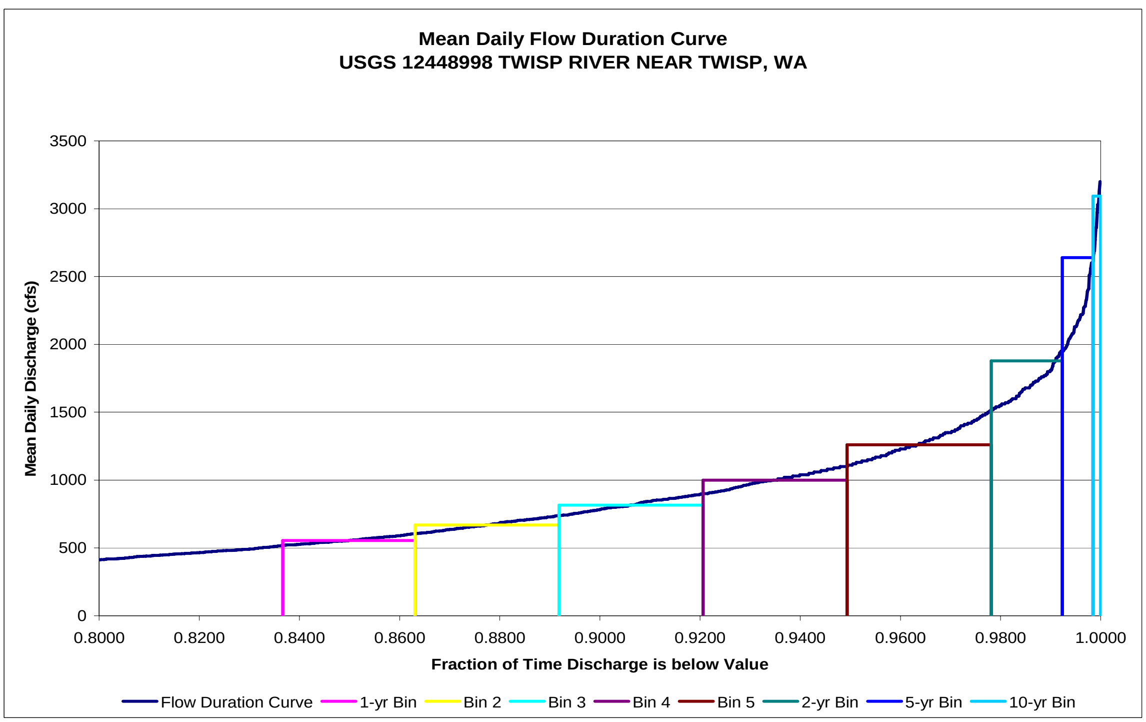


Figure J–15. Mean daily flow duration curve for Twisp River near Twisp, WA.

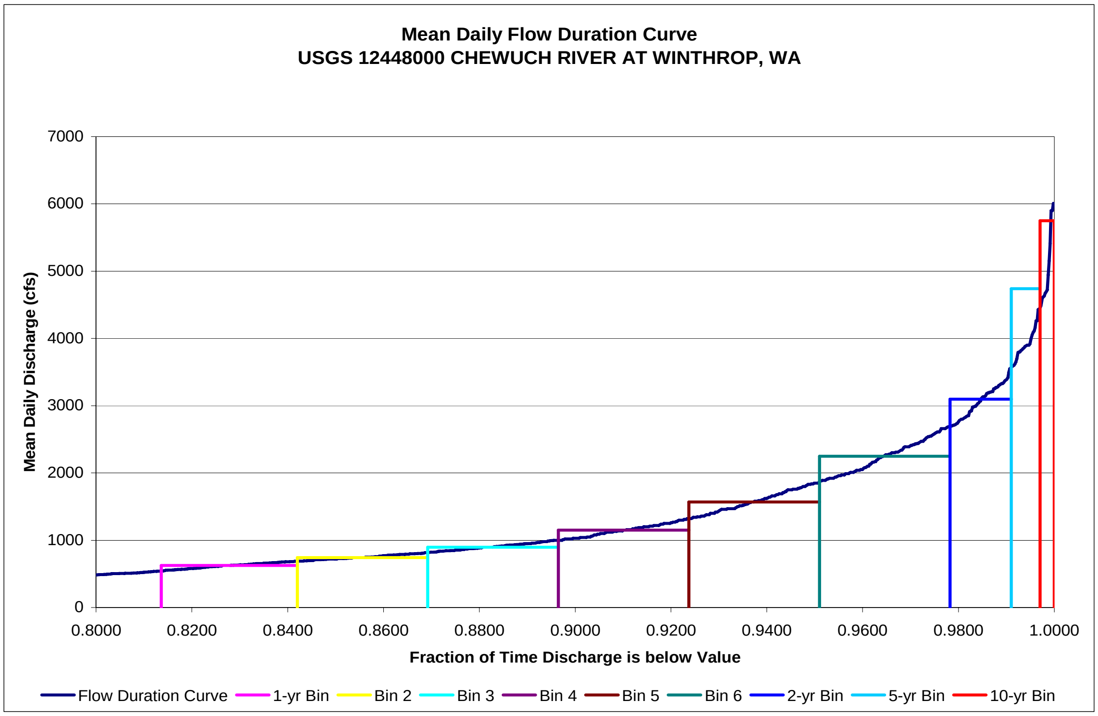


Figure J–16. Mean daily flow duration curve for Chewuch River at Winthrop, WA.

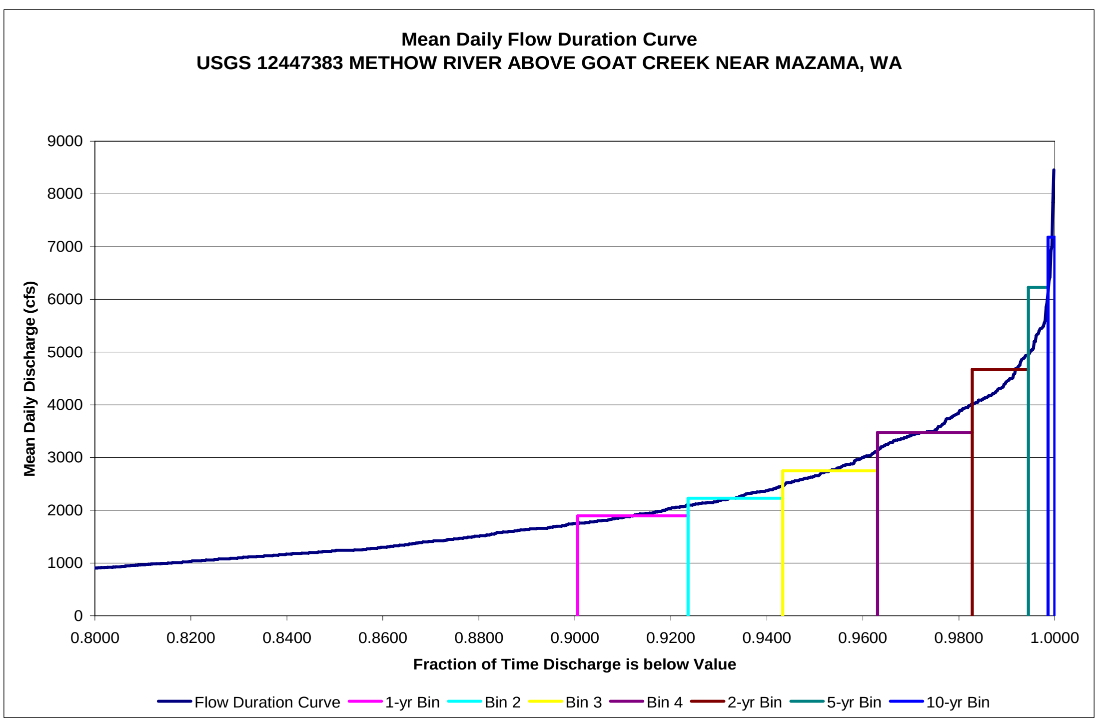


Figure J–17. Mean daily flow duration curve for Methow River above Goat Creek near Mazama, WA.

6.3 THE EFFECTS OF PDO ON PACIFIC NORTHWEST SALMON PRODUCTION:

"Pacific Decadal Oscillation" (PDO) is a term that has been created to describe the climate variability in the North Pacific and North American sector. During the 20th century, PDO events persisted for 20 to 30 years. A specific PDO event is assigned a "polarity." In the last century, the North Pacific PDO was predominantly positive between 1925 and 1946, negative between 1947 and 1976, and positive since 1977. Table J–6 summarizes the climate anomalies associated with positive and negative PDO phases (Mantua, 1999).

Table J–6. Summary of Pacific and North American climate anomalies associated with extreme phases of PDO (Mantua, 1999).

Climate Anomalies	**Positive** PDO (warm phase)	**Negative** PDO (cool phase)
Ocean surface temperatures in northeastern and tropical Pacific	Above average	Below average
October-March northwestern North American air temperatures	Above average	Below average
October-March southeastern US air temperatures	Below average	Above average
October-March southern US/ northern Mexico precipitation	Above average	Below average
October-March northwestern North American and Great lakes precipitation	Below average	Above average
Northwestern North American springtime snow pack and water year (October-September) stream flow	Below average	Above average
Winter and springtime flood risk in the Pacific Northwest	Below average	Above average

During negative or cool phases of PDO, climate conditions are the most favorable for salmon production in the Pacific Northwest. Relatively cool winter air temperatures and high precipitation yield increased snowpack. As a result, the annual water year discharge in the Skeena, Fraser, and Columbia Rivers is on average 8%, 8%, and 14% higher, respectively. For Pacific Northwest salmon, the typical negative PDO year brings enhanced streamflows and nearshore ocean mixed-layer conditions favorable to high biological productivity (Mantua et al. 1997).

7. REFERENCES

IN TEXT	FULL CITATION
Beck 1973	R.W. Beck and Associates. 1973. *Flood plain information, Methow River, Twisp to Mazama, Okanogan County, Washington:* R.W. Beck and Associates, Analytical and Consulting Engineers, Seattle, WA. Report prepared for Washington Department of Ecology, Olympia, WA. 13 p., 20 figures.
FEMA 2003	Federal Emergency Management Agency, 2003, *Flood insurance study: Okanogan County, Washington, unincorporated areas.* January 2003 revision.
FIA 1975	Federal Insurance Administration, *Flood Insurance Study, City of Twisp, Okanogan County, Washington*, December 1975. US Department of Housing and Urban Development.
Mantua 1999	Mantua, N., 1999, *The Pacific Decadal Oscillation.* University of Washington Joint Institute for the Study of the Atmosphere and Oceans, Seattle, WA.
Mantua et al. 1997	Mantua, N.J.; Hare, S.R.; Zhang, Y.; Wallace, J.M.; and Francis, R.C. 1997: "A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production." *Bulletin of the American Meteorological Society*, Vol. 78, pp 1069-1079.
SCS 1975	Soil Conservation Service, *Flood Hazard Analyses, Chewuch River*, July 1975. US Department of Agriculture, Portland, OR.
USGS 2001	US Geological Survey, 2001. *Methods for Estimating Flood Magnitude and Frequency in Washington, 2001*, US Geological Survey Fact Sheet 016-01.
WRC 1981	US Water Resources Council. 1981. *Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Committee,* US Department of the Interior.

APPENDIX K –

HYDRAULICS AND SEDIMENT ANALYSIS

The interaction between the river hydraulics and bed-material were evaluated to look for indicators of historical, present, and potential future channel bed elevation changes within the assessment area; the results are provided in this Appendix K.. Combined with geomorphic assessments (Appendix G), the results from this analysis provide baseline, reach-averaged information (Appendix E). This information can be used to develop restoration projects with an increased knowledge of sediment processes, potential changes to channel form following construction, and the likelihood of project sustainability (Appendix A). The analysis does not quantify the amount of material moving through the system or predict the geomorphic impacts associated with altering transport characteristics once floodplain areas are re-opened through removal of flood protection features.

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1. INTRODUCTION

The ability of a channel to access and rework its active floodplain has an impact on both the health of riparian vegetation and the quality and quantity of main channel and off-channel habitat.

Many local stakeholders hypothesized that channel incision and subsequent increased sediment transport capacity occurred in portions of the assessment area as a result of flood protection structures that have cut off the natural floodplain. It was hypothesized that channel incision reduced the frequency of active floodplain inundation resulting in a decline in the regeneration of riparian vegetation, particularly cottonwood galleries. Local stakeholders also hypothesized that increased sediment transport capacity had reduced the abundance of spawning sized sediments in the channel.

However, no prior studies quantified the locations and amounts of vertical channel change since the late 1800s (natural setting). The present sediment transport capacity and potential future changes to the channel bed elevation were unknown. Resource managers were interested in filling these data gaps to better understand natural or human induced processes that could have an impact on the immediate success and long-term sustainability of proposed habitat projects aimed at restoring floodplain access and complexity.

The interaction between the river hydraulics and bed-material were evaluated to look for indicators of historical, present, and potential future channel bed elevation changes within the study area. Combined with geomorphic assessments (Appendix G), the results from this analysis provide baseline, reach-averaged information. This information can be used to develop restoration projects with an increased knowledge of sediment processes, potential changes to channel form following construction, and the likelihood of project sustainability. This analysis also provides a baseline to evaluate local sediment processes at individual project sites including the following items:

- Channel and bar sediment sizes along the surface
- Representative channel geometry in each geomorphic reach including cross-section and slope
- Ability of the present river to mobilize the channel and sediment bars at high flows

More detailed data and analysis may be needed at a project level to address localized hydraulic and sediment processes, and provide more predictive and quantitative information. Questions at a project scale that may be of interest to address project benefit, sustainability, and risk may include:

- What are the resulting changes in bed material as a result of project construction (e.g. coarsening or fining of channel and bar material)?
- How will the availability of spawning sized sediment be altered as a result of project construction?
- Will the interaction between basin scale processes, individual projects, and cumulative impacts from multiple projects have an impact on sediment availability?

2. STUDY METHODS

A river channel is dynamic and has natural fluctuations in channel position, bed elevation and geometry that is dependent on the balance between flow, sediment supply and sediment transport capacity. These fluctuations can result in localized changes in channel bed elevations or positions, such as when a channel avulses to a new location during a flood. However, if no observable trend over a decadal period is present regarding the amount of sediment in storage and/or average bed elevations, a given reach would be considered in equilibrium. When the sediment supply and transport is not in equilibrium, the channel can respond by changing laterally (widening or narrowing) or vertically (aggrading or incising). These changes can be temporary or can occur over a series of several floods and years timeframe. Natural geologic controls, both lateral and vertical, can limit the amount of channel change that can occur.

In the original scope of work a modeling tool, SIAM (Sediment Impact Analysis Methods) was planned to compare reach-averaged sediment transport capacity for present conditions and for proposed conditions that may impact sediment supply and transport capacity. However, historical channel mapping indicated there have not been any changes in channel form over the last century that could be attributed to a change in coarse sediment supply. Localized changes were observed in a few locations, but they were not thought to propagate very far upstream or downstream. Changes in fine sediment supply as a result of fires in the Chewuch watershed have been documented, but these processes appear to have a larger impact on altering the composition of spawning gravels rather than altering channel form (e.g. braided or straight to meandering or vice versa).

As part of the geologic mapping, minimal field evidence for reach scale channel aggradation or incision was found. With this new information, the current sediment analysis was focused on evaluating the amount of past channel incision, the likelihood of additional future channel incision, the ability of the river to presently rework the channel bed, and the ability of the river to reconnect with side channels if flood protection features are removed. If a SIAM model is applied in the future, additional sediment data will need to be collected to document sizes of bed-material being supplied to the study reach.

River miles noted in this study were generated from delineating river distance along the active, unvegetated channel in a GIS system on 2004 aerial photographs (and 1998 where 2004 photos were not available) for the Chewuch and Twisp Rivers. For the mainstem Methow River, river miles were based on a previous study by Golder (2005) to allow consistency between information. The longitudinal profile plots have a slightly different river mile designation because they are based on river distance along the low flow channel as surveyed, which is slightly longer in length than the active channel in some reaches.

2.1 HYDROLOGY

Hydraulic computations were based on discharges from Sutley (2006) who evaluated historical discharge data from USGS gages to develop flood frequency relationships for the 2-, 5-, 10-, 25-, 50-, and 100-year floods. At other non-gaged locations, flood frequency estimates were developed based on drainage area using a regional equation adjusted for local conditions. Hydraulics and sediment analysis was performed by varying the discharge based on significant changes in drainage area identified by Sutley (2006). Gains and losses due to ground water interactions were not accounted for because they are assumed to be insignificant to the magnitude of surface flow during floods, the focus of this study. Sutley (2006) is included as Appendix J "Hydrology."

2.2 GEOMETRY AND HYDRAULICS METHODS

Hydraulic calculations used the normal depth equation based on the 2005 measured slope of the river and cross-section geometry as described below.

2.2.1 SURVEY DATA

All survey data was collected in Washington State Plane North, NAD 1983, NAVD 1988 feet based on a control network established by Reclamation with global positioning system (GPS) equipment. Survey data was collected by both Reclamation survey crews from Ephrata, Washington and from a private contractor. Data was collected between June and November of 2005 and is available in ASCII format or in a GIS format with metadata from the Reclamation Pacific Northwest Regional Office. Data was generally collected during low-flow conditions.

Longitudinal profiles of the river bed and water surface were surveyed by boat using a RTK GPS system and a depth sounder for the following reaches:

- Methow River, RM 21 (confluence with Gold Creek) to 68 (near Mazama) on June 15 and 16, 2005
- Chewuch River, RM 2 to 8 in August 2005

Elevations collected by boat were generally recorded every 50 to 100 feet and do not capture all hydraulic controls present in the bed (riffles and rapids). Data had to be post-processed for these reaches to compute the channel bed elevations by subtracting recorded depths from measured water surface elevations. Profiles for the remaining study reaches were surveyed by wading along the river thalweg using either GPS or total station equipment:

- Methow River, RM 68 (near Mazama) to 76 (confluence with Lost River) on August 23 to September 16, 2005
- Chewuch River, RM 0 to 2 and 8 to 14 during August and September of 2005

- Twisp River, RM 0 to 17 during September and November of 2005

Cross-sections were also surveyed approximately every ½-mile from September thru November of 2005. Cross-section locations were chosen in GIS using aerial photographs over a range of hydraulics (riffles, pools, etc) with the intent to provide average geometric conditions along each geomorphic assessment reach. For cross-sections including sediment bars, the section was generally located in the middle of the sediment bar. Localized geometric conditions were generally not chosen for cross-section locations, such as at a bridge location. In some areas, more detailed surveys were also available from concurrent project work by Reclamation. Cross-sections were generally surveyed from top of bank to top of bank perpendicular to the flow. In some cases the top of bank was not surveyed due to restricted land access. Densely vegetated areas were generally not surveyed due to budget constraints. However, the data collected was deemed appropriate for the high-flow analysis in this assessment. The cross-section data was generally not detailed enough to allow comparison of side channel and main channel elevations, which are often used to look for signs of channel aggradation (perched main channel) or channel incision (flow does not access side channels at frequent floods). LiDAR data from 2006 is now available that will allow more detailed cross-sections or topographic surfaces to be generated for future analysis.

2.2.2 SLOPE COMPUTATIONS

Longitudinal profiles of the measured channel bottom and water surface elevation were processed in a spreadsheet. Two methods were utilized to compute reach-based average slopes of the river. In the first method, slopes were computed based on geomorphic reach boundaries as identified in Appendix C, "Geomorphic Reaches." In the second method, slopes were computed based on visually identifying significant changes in grade along the computed profile. A significant change in grade was defined as a shift in a line connecting the top of hydraulic controls along the channel. Computing slopes based on geomorphic reach boundaries subsumed some large changes in grade, even though from a lateral perspective the floodplains had similar geomorphic characteristics. This may be partially due to the fact that geomorphic reaches often include "transition areas" between confined reach boundaries and wider floodplains in the middle of the reaches. Therefore, normal depth computations were based on the localized slopes (identified visually) rather than reach averages that could result in over or under-estimating water surface elevations.

2.2.3 CROSS-SECTION PROCESSING

The cross-section survey consisted of points capturing significant topographic features (

Figure K–1). The measured cross-section survey data approximated but did not form a straight line. River cross-section data were projected onto a best-fit straight line to estimate a more representative stationing and reduce bias in the hydraulic calculations due to zigzagging. This prevents over-estimating the wetted perimeter of the section.

Points marking the left and right extents of the active channel were estimated based on the unvegetated area from aerial photography and lateral breaks in grade. The cross-section survey did not always encompass the entire width inundated during floods. An attempt was made to fill in missing data using USGS 10-m NED data, but the discrepancy between data sets in overlapping areas spanned several meters in an unpredictable pattern and could not be done. Therefore, in some cases the channel widths are narrower than actual conditions. This creates an artificial "wall" at the edge of the cross-section, particularly for higher flows. For reach-based computations, this should not have a large effect on results. However, individual sections should be used with caution for more detailed, localized analyses that may be done in the future. Processed stationing and elevation data for each cross-section are available in spreadsheet format and the original survey data used and locations of cross-sections are available in GIS shape files.

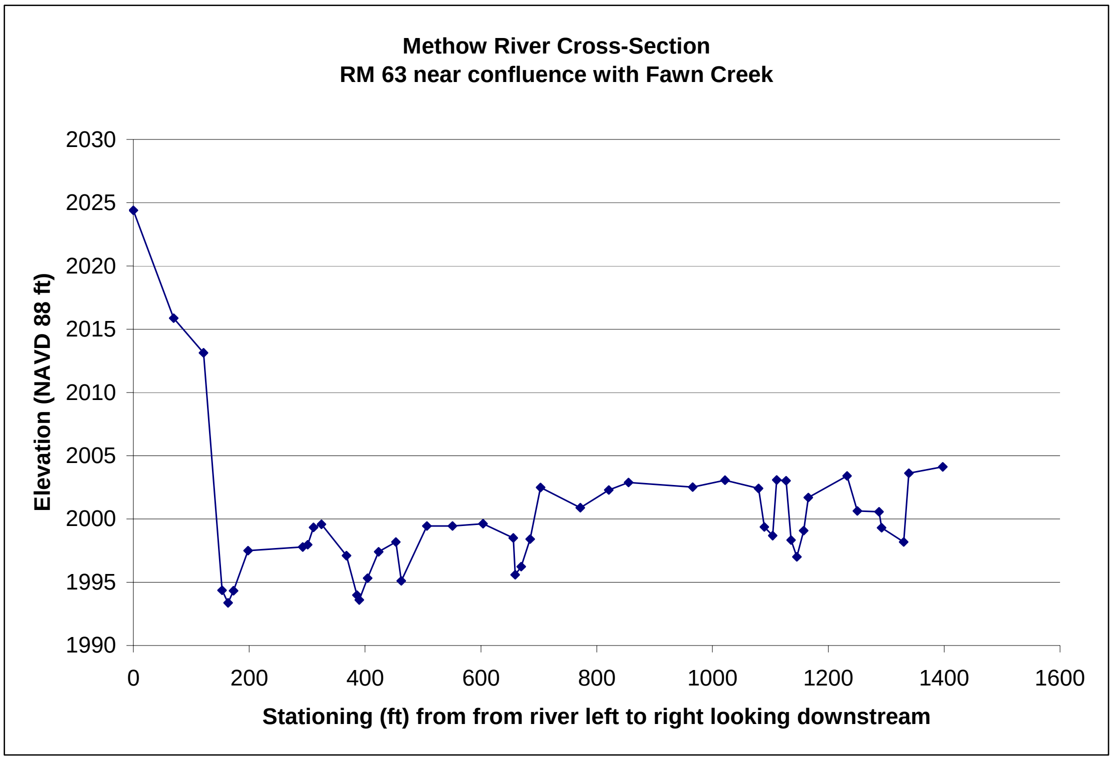


Figure K–1. Example of cross-section on Methow River (at RM 63 near Fawn Creek).

2.2.4 NORMAL DEPTH HYDRAULIC ESTIMATES

Under conditions where the slope and roughness of a channel dominate over the influence of downstream-measured cross-sections, normal depth provides a good approximation of the hydraulic conditions. The surveyed cross-sections are spaced at a large-enough distance and on a steep-enough slope that the hydraulics at one cross-section are unlikely to be influenced by the next downstream measured section. Using a backwater model on widely spaced cross-sections can result in misrepresentative profiles and incorrect estimates of energy losses due to assumed interactions in the model that are not present in the field. Results from a backwater model become sensitive to the selection of cross-section locations and less representative of the reach. The intent of the sediment study is to represent average conditions along each geomorphic reach for relative comparison to other geomorphic reaches from a limited number of cross-sections. A backwater influence cannot be justified from the available data, therefore, hydraulic evaluation of the cross-sections assumed normal depth conditions. A uniform roughness value of 0.045 was used for all channel and overbank sections. A Federal Emergency Management Agency study (FEMA, 2003) used channel-roughness values of 0.032 to 0.045 and floodplain values of 0.040 to 0.160 in the assessment area. Because the Reclamation geomorphic analysis was most interested in relative comparisons between reaches at flood flows, roughness was not varied. Calibration of roughness values should be performed at a more detailed level for any project level analysis in the future.

In general, the surveyed portion of the cross-section contained flows up to the 10-year discharge. When water surface elevations exceeded the top elevation surveyed, the normal depth calculations assumed a vertical wall and "stacked" the water. Where this occurred the result is artificial confinement of the flow at large floods. Therefore, this cross-section data is most appropriate for looking at reworking of the bed rather than prediction of flood inundation areas at less frequent, large flood events.

Floods including the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence periods were evaluated. Results are from the 2- and 100-year floods bracket the range of flows where the majority of channel reworking is occurring on a decadal scale. The 1949 flood of record exceeds the 100-year flood value but was not modeled for this analysis.

2.2.5 HISTORICAL SURVEY DATA

To look at channel bed elevations over time, historical survey data for the Methow and Chewuch Rivers were compared to 2005 data as described below.

A hydraulic model was done on the mainstem Methow River for Okanogan County following the 1972 flood to assess flood inundation (Norman, 1974; Beck, 1973). As part of this study, 184 cross-sections were collected along the Methow River between RM 28 to 69. This data provides an indication of the river bed elevations approximately three decades prior to the present setting. Many human features had already been constructed to cut off floodplain by the 1970s, so this data can be used to indicate whether the river bed has been stable following the impact of human features over a decadal timescale (rather than providing an estimate of the natural, pre-disturbed river bed elevations). The cross-section data is available in hard copy sheets as entered into a HEC-2 hydraulic model for the most recent FEMA study

(FEMA, 2003). There were no coordinates (northing and easting) available for the data, although planview locations of the cross-sections are provided on aerial photography in the FEMA and 1970s flood study reports. The 1970s cross-section data was utilized at RM 46 (MVID East) on the Methow River for a project level assessment. This was done by estimating coordinates in GIS and hand typing in the elevation data. However, typing in the cross-section data for the remainder of the Methow assessment reach was beyond the scope of this reach level analysis.

Longitudinal profiles of the thalweg of each cross-section, along with modeled water surface elevations and high water marks were available in the back of the flood study reports. The cross-section locations were approximated by Reclamation on an aerial photograph in GIS, and river miles were correlated to enable matching up the new thalweg profile surveyed in 2005. Therefore, there is some uncertainty in the location of the thalweg elevations. Periodic checks were done of the adjusted 1970s cross-section river stationing using landmarks and unique river features to ensure any errors were not extrapolated upstream or downstream. Elevations from the 1970s survey were collected in NGVD 1929 feet, and were, therefore, adjusted to match the NAVD 1988 datum of the 2004 data (average adjustment for length of assessment reach from 1929 to 1988 of +4.1 feet based on Corpscon software). The thalweg elevations pulled off the profiles in the flood reports were then plotted and compared to the 2004 thalweg data. Because the elevations had to be pulled off a hard copy report with 1-foot gridlines, they were rounded to the nearest 0.5 foot. The uncertainty in the 1970s cross-sections is mostly due to the possible error in location of the cross-sections. The uncertainty in the 2005 data resulting from the GPS and depth sounding equipment survey method is about ±0.5 foot. The 2005 data was collected by boat and, therefore, does not always represent the thalweg of the bed, whereas the 1970s cross-section data should provide thalweg elevations for each cross-section taken based on a few sample cross-sections in the back of the flood study report that show a fair amount of detail across the sections.

A USGS map for the Chewuch River provides historical survey data from 1912 of the water surface elevation in 5-ft contour intervals (Marshall, 1915). The survey was done by USGS to evaluate the elevation drop along the river for the purpose of evaluating the potential for hydropower. This data can be used to provide an estimate of the pre-disturbed channel bed, or natural setting. Although many settlers had already homesteaded in the Methow Subbasin by 1912, major human features within the active river channel were not believed to be constructed until a later time period. The map was rectified in ArcMap to allow it to be overlaid on the 2004 aerial photograph. Locations of the 46 contour lines were identified in GIS using the rectified map, and stationing created to allow comparison to the 2005 profile data. The vertical datum of historic surveys prior to use of the 1929 NGVD is often difficult to adjust to a more modern datum. Fortunately, the USGS map notes the benchmark name (1765 T, PID TQ0047, Winthrop) and the stamped elevation (1765 feet) that the survey was tied to. This benchmark still exists today, and has been resurveyed by National Geodetic Survey (NGS). The NGS datasheet states the NAVD 88 elevation as 1764.51 feet, suggesting a minus-0.5-foot conversion from the 1912 map contours to match the 2005 Reclamation survey.

No other river bed survey data was found that had been collected along the assessment area in a known datum with the exception of a few localized project areas. The USGS digital elevation map (DEM) 10-meter data was not utilized because large discrepancies were found when compared to new survey data collected with GPS equipment in 2005 in a known datum. Cross-sections on the Chewuch River from an IFIM study (Caldwell and Atterson, 1992; RM 1.3) and (Golder Associates, 2002; mouth to RM 9.0) were investigated but both were in a local datum. Golder Associates did attempt to locate some of the IFIM cross-section benchmarks for comparison to new data collected, but they could not be found in the field. Cross-sections from an IFIM study (Caldwell and Atterson, 1992) on the Methow River (32 sections at RM 31.5, 49, 59, and 66.5), Twisp River (RM 1.8), and Early Winters Creek (RM 1.0) were also investigated, but this data was also in a local datum. The Pacific Watershed Institute did collect survey data on the Chewuch River at RM 12.9 to 13.5 in a known horizontal datum, but the data was not tied to a known vertical datum (PWI, 2004b). As part of a monitoring project, survey data had been collected at RM 21.5 to 26.2 (PWI, 2004a) but this was beyond the assessment reach evaluated by Reclamation.

2.3 SEDIMENT ANALYSIS METHODS

Sediment characteristics and the likelihood of future incision were addressed through an analysis of surrogate sediment transport parameters (stream power) and by comparing measured sediment sizes in the channel bed with incipient motion computations. Comparison with incipient motion indicates the ability of the river to mobilize the present channel bed. The locations and general characteristics of sediment sources to the assessment reach were identified as part of the geologic investigation, but were not quantified or measured. Sensitivity of the channel bed to a change in sediment supply and/or sediment transport capacity as a result of construction of individual or multiple projects could be considered for future analysis if required. Geologic field observations suggested only minor channel incision had occurred since the late 1800s. To validate observations of vertical channel stability, comparison between the present channel profile and historical surveys on the Methow River (1970s) and Chewuch River (1912) were done (discussed in Section 2.2.5). The limitations of not using a predictive, quantitative sediment transport model in this assessment include losses in analysis resolution such as magnitude of incision or deposition of sediment, changes in bar and channel sediment storage as a result of proposed project construction, interactions of sediment supply and storage between proposed projects in close proximity, and changes in bed character.

2.3.1 TOTAL STREAM POWER

Generally, discharge tends to increase in the downstream direction in river basins as additional tributaries and runoff provides more flow. Increasing discharge provides more potential energy to transport sediment and large woody debris if hydraulic conditions are otherwise comparable. Increasing the slope can also increase the river's ability to transport sediment and large woody debris while decreasing the slope can reduce the transport capacity.

The total stream power computation shows how the combination of discharge and slope vary along the river from a reach-based perspective. The total stream power is computed by multiplying the product of discharge, slope and the specific weight of water for a given reach length (γQSX with units of power) (Bagnold, 1966). Stream power is typically computed per unit length, $X = 1$. In this report total stream power is simply computed as discharge multiplied by slope without the constant of specific weight of water or reach length.

Total stream power is often used to indicate and compare the relative magnitude of sediment loads a stream is capable of transporting between reaches. It does not provide quantitative information as to the actual quantities or sizes transported. If the total stream power increases or decreases in a downstream direction, the sediment transport potential of the stream would also be expected to increase or decrease, respectively. Increases or decreases in sediment transport potential can indicate the likelihood of a reach to trend towards deposition or incision. If changes in slope and discharge are balanced out by the river, total stream power will remain relatively constant along the river's length and the reach would be expected to be in dynamic equilibrium. Computations utilized the 2- to 100-year discharge combined with bankfull slopes and did not differentiate between in-channel and floodplain flows.

2.3.2 UNIT STREAM POWER

The "unit stream power" is defined as the rate of potential energy expenditure per unit weight of water (Yang, 1996). It is often used as an indicator of the relative energy required to transport a given sediment load among various cross-sections.

The unit stream power is computed by multiplying the bankfull slope and velocity (typically depth-averaged) for a given cross-section (VS with units of ft/s). Velocity incorporates the impact of channel geometry on sediment transport. Unit stream power provides a way to compare the relative ability of the stream to transport sediment at various cross-sections. By using a series of cross-sections to represent a range of hydraulic conditions within each geomorphic reach, unit stream power can be used to look at relative comparisons of sediment transport capacity between reaches. It does not provide quantitative information as to the actual quantities or sizes transported. The depth-averaged velocity was computed using the normal depth assumption and did not differentiate between floodplain areas and the active channel.

2.3.3 MEASUREMENT OF BAR AND CHANNEL SEDIMENT

Pebble counts were performed by USFS staff at approximately the location of each cross-section surveyed for the geomorphic assessment (about 2 per mile) during low flow in fall of 2005. A pebble count on the surface of a sediment bar indicates the sizes of material in storage that must be mobilized before channel reworking processes are initiated. A pebble count in the wetted channel provides information that can be used to assess whether the present channel is being reworked and at what flows. Table K–1 provides definitions of sediment size categories used in this report.

Table K–1. Sediment size class and particle diameter range.

Sediment Size Class	Particle Diameter Range (mm)
Clay	< .004
Silt	.004 to .062
Sand	.062 to 2
Gravel	2 to 64
Cobble	64 to 256
Boulder	256 to 4096
Sediment size classes are from Julien (1995).	

At each sample site, a total of 100 sediment particles were measured and ground photographs were used to document site conditions. Where the channel was confined and the low flow wetted channel extended across the entire active channel, one sample was done along the bed of the main channel. At cross-sections where sediment bars were exposed, one sample was done in the wetted channel and one on the sediment bar. Sediment in the channel banks were not included because the majority of sediment load in this system (on a reach scale) originates from upstream supply or reworking of the channel bed. Sediment in the channel banks is often much different than sizes present in the channel bed and active floodplain and would not be appropriate for analysis of when the channel bed becomes mobilized.

In the wetted channel, 100 particles were counted in a straight line from wetted edge to wetted edge. Spacing between particles measured along the line varied depending on the width of the channel, but were generally uniformly spaced across the section. Any sediment particles that were embedded in other material along the measurement line (could not be picked up) were noted along with any presence of exposed bedrock. All cross-sections where pebble counts were done included a measurement in the channel section unless the channel was too deep and swift to safely wade. In these cases, visual estimates of the range and average sizes of sediment were documented by the measurement crews.

Along cross-sections including sediment bars, a grid was made extending from the water edge away from the river. The location of the sediment grid was generally placed in the middle of the bar feature with the intention of capturing the limiting (largest) sizes of sediment that must be mobilized to initiate reworking of the bar. Areas with local deposition or scour conditions due to human features or logs were avoided. Areas at the upstream, downstream, or along channel banks were generally avoided due to localized hydraulics that often cause finer sediment to deposit during the recession of floods. Typically the grid was extended away from the river 25 feet and four lines perpendicular to the river (25 feet each) were used to count 100 particles at 1-foot intervals. The spacing between the four lines varied, but was generally about 10 to 20 feet. The largest size of sediment present on the surface of the bar was noted along with the presence of any large woody debris. Human features at the cross-section location were also noted by the USFS staff to assist with field verification of the geomorphic mapping.

2.3.4 INCIPIENT MOTION

"Incipient motion" identifies the largest particle diameter the stream is likely to move at a given flow rate. Comparing incipient motion to the size of material present in the channel identifies ranges of flood frequencies at which the channel is likely to mobilize the channel bed and sediment bars and result in reworking of the active floodplain. Incipient motion computations were based on Yang's criteria shown in Equation K1 for Reynolds numbers greater than 70, and applies to all streams in the Methow Subbasin.

$$\frac{v_{cr}}{\omega} = 2.05$$

Equation K–1.

Where,

v_{cr} = critical velocity to cause motion; and

ω = fall velocity of a particle.

The equivalent spherical diameter, movable by the flow, is estimated from the fall velocity. Yang's criterion does not consider the bed-material size gradation.

3. METHOW RIVER – HYDROLOGY, HYDRAULICS, AND SEDIMENT RESULTS

The Methow River analysis included 92 cross-sections on about 50 miles of river from the confluence with Libby Creek (RM 26.5) to the confluence with the Lost River (RM 76). The cross-sections generated included two project sites that provided more closely spaced cross-section data than the typical 2 per mile: MVID East (RM 46.0) collected in 2002 and 2003, Barclay diversion (RM 49.5) collected in 2001, and Rockview collected in 2005. Although these survey data were collected at an earlier date than the other data collected in 2005 for this assessment, the river channel is not believed to have significantly changed and was considered appropriate to use for this analysis. Surface layer pebble counts were done at 52 cross-sections that included 34 channel samples and 39 bar samples. Results of the hydrology, hydraulic, and sediment analysis are described below.

3.1 DISCHARGE

Figure K–2 shows the variation in discharge over the assessment reach for the Methow River according to the flood frequency data based on USGS gage records (Sutley, 2006). Tributaries account for significant changes in flow as reflected in the flood frequency computations. Table K–2 shows the river miles of tributaries within the assessment reach that contribute noticeable flow volumes during floods. The Chewuch drainage area is nearly one-third (29%) of the total Methow drainage area and the Twisp drainage area is the next largest comprising 14%. The small reduction in flow for the 2- and 5-year floods at RM 42 indicates a shift to a different reference gage for flood frequency computations. Because each gage has a different number of annual peak flood data available, the computed flood frequencies can be different in overlapping sections even when the drainage areas are increasing. The reduction is small enough that it is not anticipated to affect reach-based results.

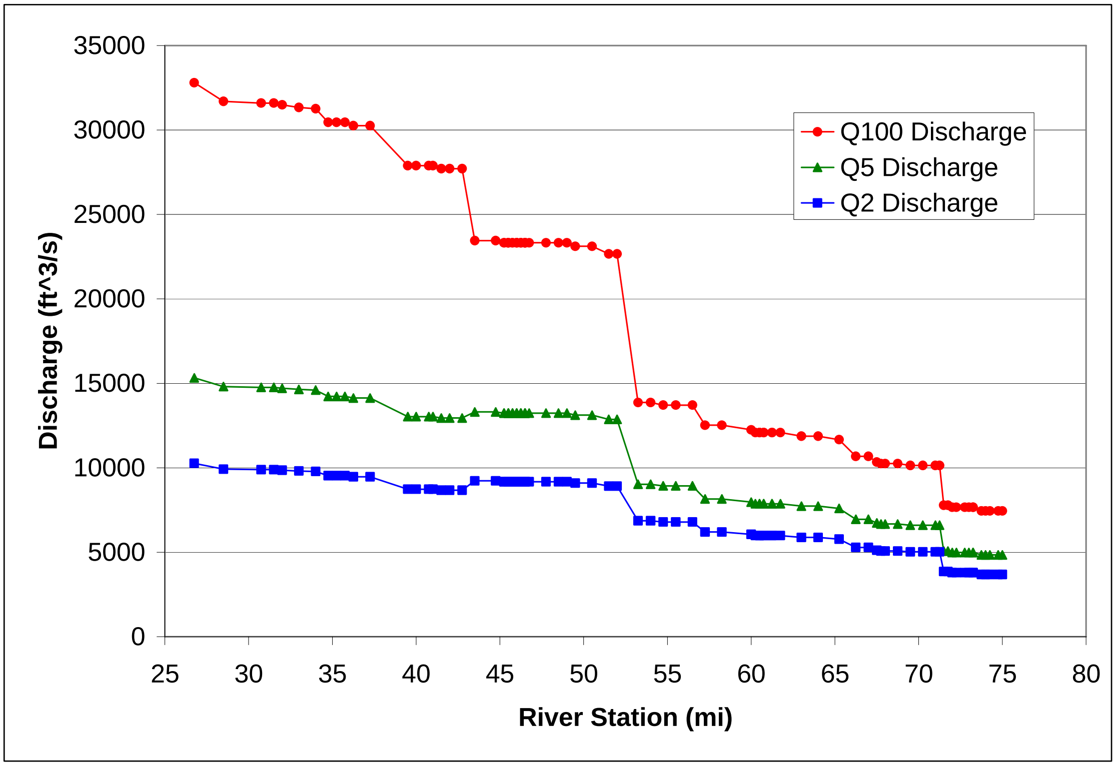


Figure K–2. Methow River – Discharge by river mile.

Table K–2. Methow River – Tributary locations along the assessment reach.

Tributary	RM
Libby Cr.	26.4
Beaver Cr.	36.0
Twisp	41.3
Chewuch	51.5
Wolf Cr.	54.2
Goat Cr.	64.9
Early Winters Cr.	69.1

3.2 SLOPE

Figure K–3 shows the overall elevation breaks of the Methow River from the Lost River confluence downstream to the mouth at the confluence with the Columbia River based on 2005 measured data and USGS 40-ft contours downstream of Gold Creek. Figure K–4 shows average slopes along the Methow River within the assessment reach divided according to local breaks in the gradient (independent of geological features). Figure K–5 shows the elevation drop per mile based on the 2005 measured water surface elevations. The slope has a decreasing trend from Lost River to Chewuch River, remains relatively constant from Chewuch River to Gold Creek, and then steepens in the downstream direction until the backwater from the Columbia River. The backwater from the Columbia River is controlled by Wells Dam, located about 9 miles downstream of the confluence with the Methow River. Localized steeper slopes relative to upstream and downstream reaches occur at the confluence with the three largest pre-historic alluvial fans, Early Winters Creek (RM 70), Chewuch River (RM 52), and the Twisp River (RM 42).

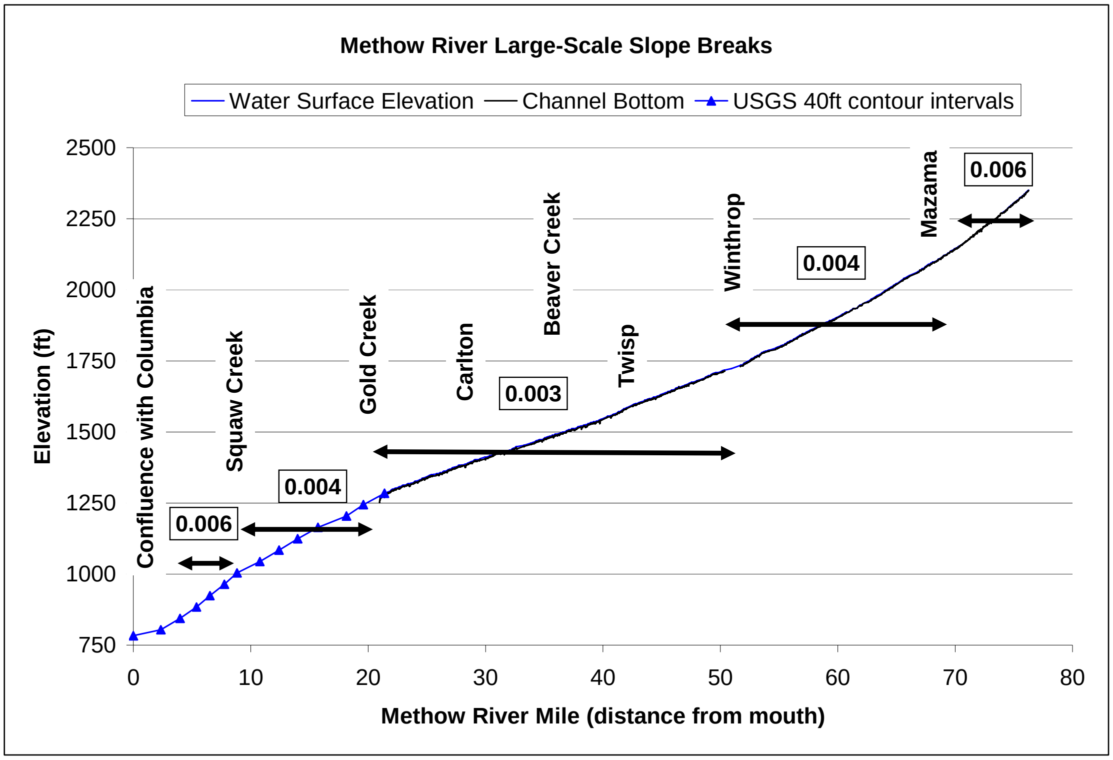


Figure K–3. Methow River – Large-scale slope breaks.

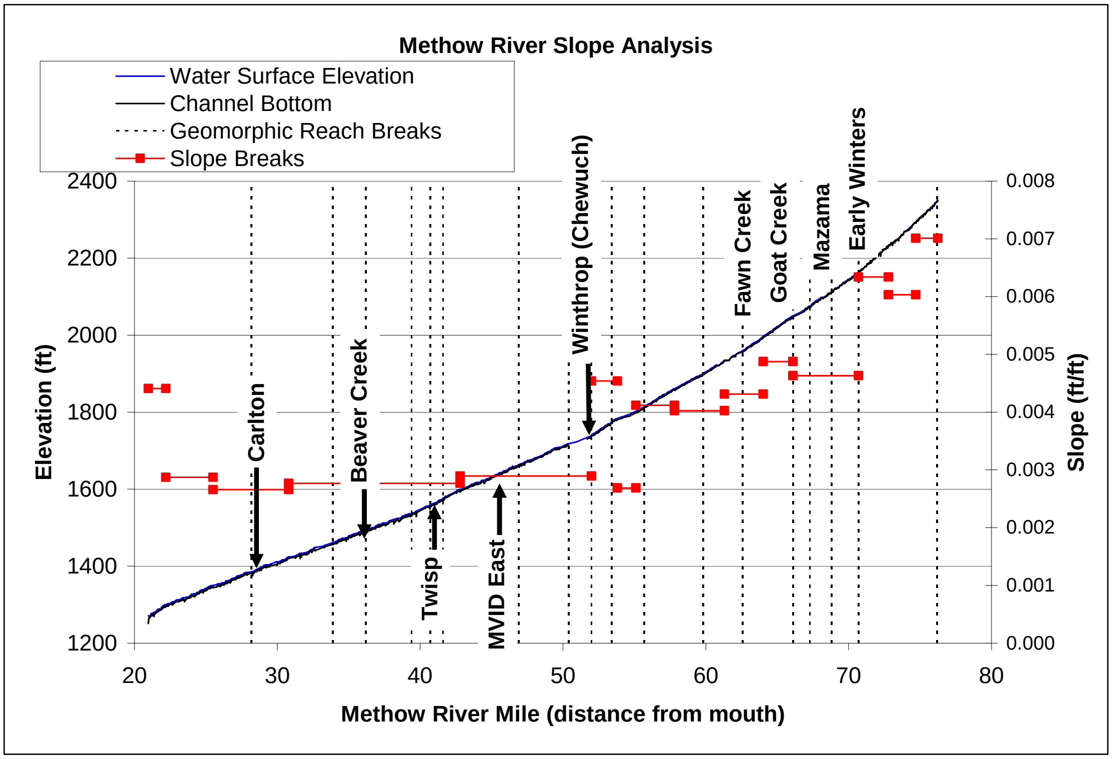


Figure K–4. Methow River – Slope by river mile

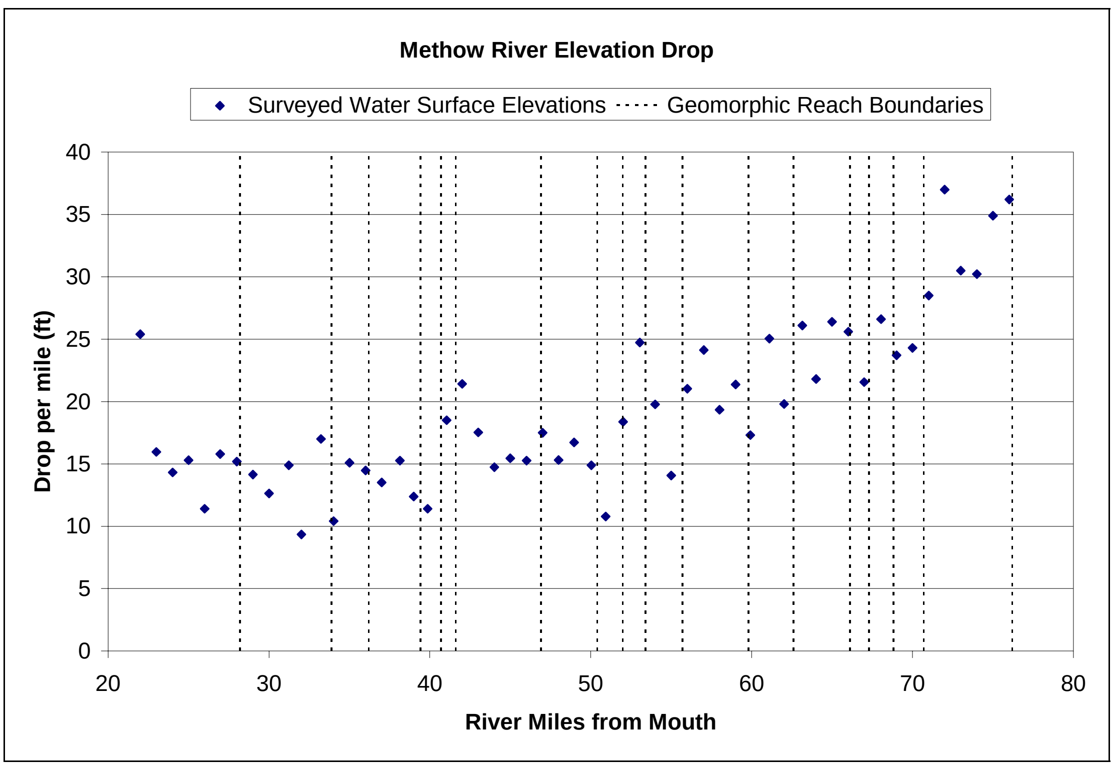


Figure K–5. Methow River – Elevation drop by river mile.

3.3 TOTAL STREAM POWER

Figure K–6 shows the total stream power along the Methow River. From previously discussed Figure K–2, the discharge is known to increase in the downstream direction with a large increase at the Chewuch River confluence (RM 52). From Figure K–3, the slope is known to gradually decrease in the downstream direction to the Chewuch River confluence, and then remain fairly constant to the downstream end of the assessment reach.

The total stream power shows a relative balance between the increasing discharge and decreasing slope for the 2- and 5-year floods, with spikes at the confluences of Early Winters Creek, Chewuch River, and Twisp River. The 2- and 5-year floods are mostly contained within the active floodplain without spilling off onto relatively higher elevation, less frequently inundated surfaces. At the 100-year flood, the increase in discharge at the Chewuch River confluence overwhelms the decrease in slope and total stream power increases in the downstream direction.

Total stream power results would suggest that the Methow River does not have an increased sediment transport capacity in the downstream direction at more commonly occurring floods, except for a small shift due to the contribution of flow from the Chewuch River. However, at more extreme floods an increase does occur between RM 52 downstream to RM 28. In reality, historic flood documentation indicates that a portion of the 100-year flood likely spills off onto terraces out of the active floodplain, thus reducing the amount of flow available to transport sediment. In other words, once flow spills out of the active floodplain the wetted width increases faster than water depth with increasing discharge and limits transport potential. The influence on sediment transport capacity can be further evaluated with unit stream power computations, discussed in Section 3.5.

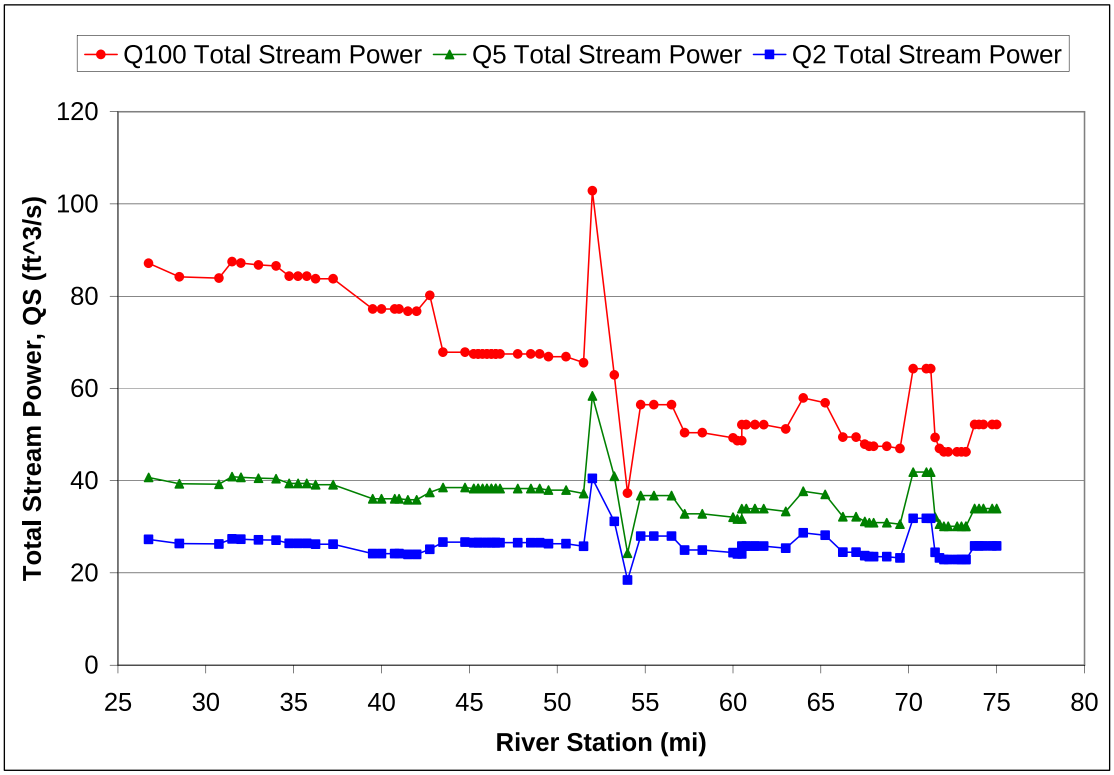


Figure K–6. Methow River – Total stream power by river mile.

3.4 VELOCITY

Depth-averaged velocity is largely dependent on discharge, cross-section geometry and the slope of the riverbed. Figure K–7 shows the velocity profile along the Methow River for the 2- and 100-year floods. Many local variations in velocity occur due to the range of hydraulic conditions represented (for example, pools compared to riffles; geologically confined compared to including a vegetated floodplain with overflow channels). The overall depth-averaged velocities generally range between 3 to 8 ft/s for the 2-year flood, and between 4 to 11 ft/s for the 100-year flood.

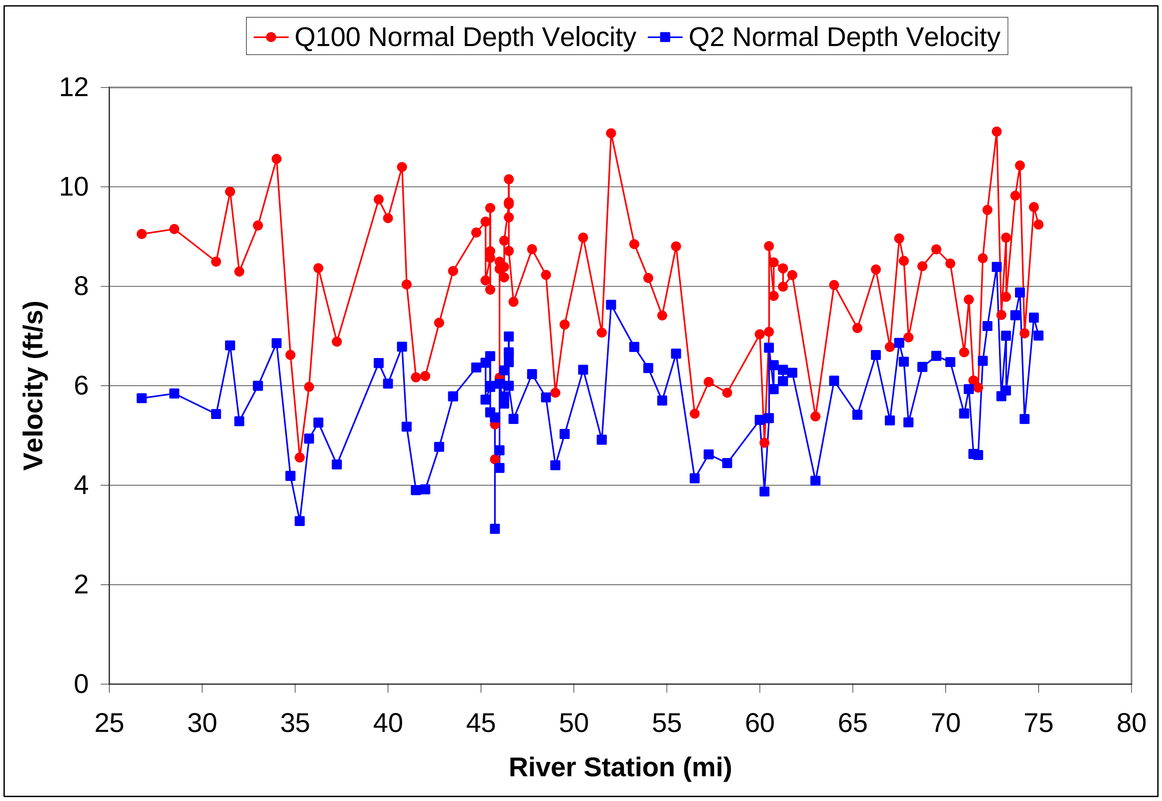


Figure K–7. Methow River – Velocity by river mile.

3.5 UNIT STREAM POWER

Figure K–8 shows the unit stream power along the Methow River. Local variability in unit stream power represents the difference between surveying pool, riffle, and glide cross-sections. The unit stream power suggests that the ability to transport sediment decreases in the downstream direction between Early Winters Creek to the Chewuch River, and then stabilizes between the Chewuch River to the downstream end of the assessment reach at Carlton. Between the Lost River (RM 76) and the Chewuch River confluence (RM 52) the unit stream power decreases in a downstream direction as a result of decreasing velocities and slope. This contradicts the total stream power which is relatively consistent in this reach. The unit stream power indicates that there is not enough increase in discharge in this reach to overcome decreasing slopes in the river. The decreasing sediment transport capacity trend on the Methow River upstream of the Chewuch River correlates with the geomorphic observations of more frequent sediment bars, large woody debris, and channel complexity. The consistent unit stream power downstream of the Chewuch River confluence compared to the trend of increasing total stream power at the 100-year flood suggests that this large flood flow expands onto overbank areas and does not contribute to increased transport capacity.

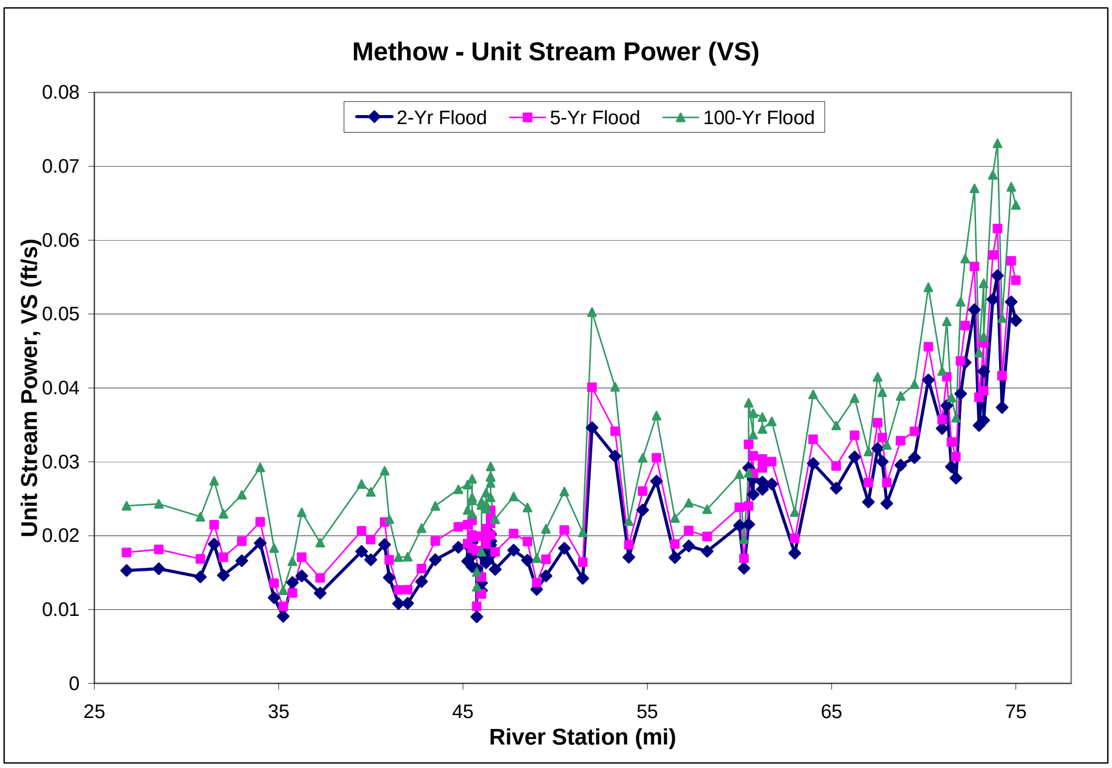


Figure K–8. Methow River – Unit stream power by river mile.

3.6 WETTED WIDTH TO DEPTH RATIO

The active channel wetted width to depth ratio was computed for the 2-year flood (

Figure K–9). In general, wetted widths are an order of magnitude larger than wetted depths at the 2-year flood. This means the width to depth ratio is mostly dependent on fluctuation in active channel width. For the Methow River, the width to depth ratios range from 10 to 150. Computed wetted active channel widths (not plotted) range from 80 feet to 880 feet, with one exception of 1,400 feet at RM 35. Widths of the entire active floodplain (low surface) measured from aerial photography range from 90 to 4,510 feet. The width of the entire active floodplain is often larger because it includes additional wetland and overflow channels and surfaces.

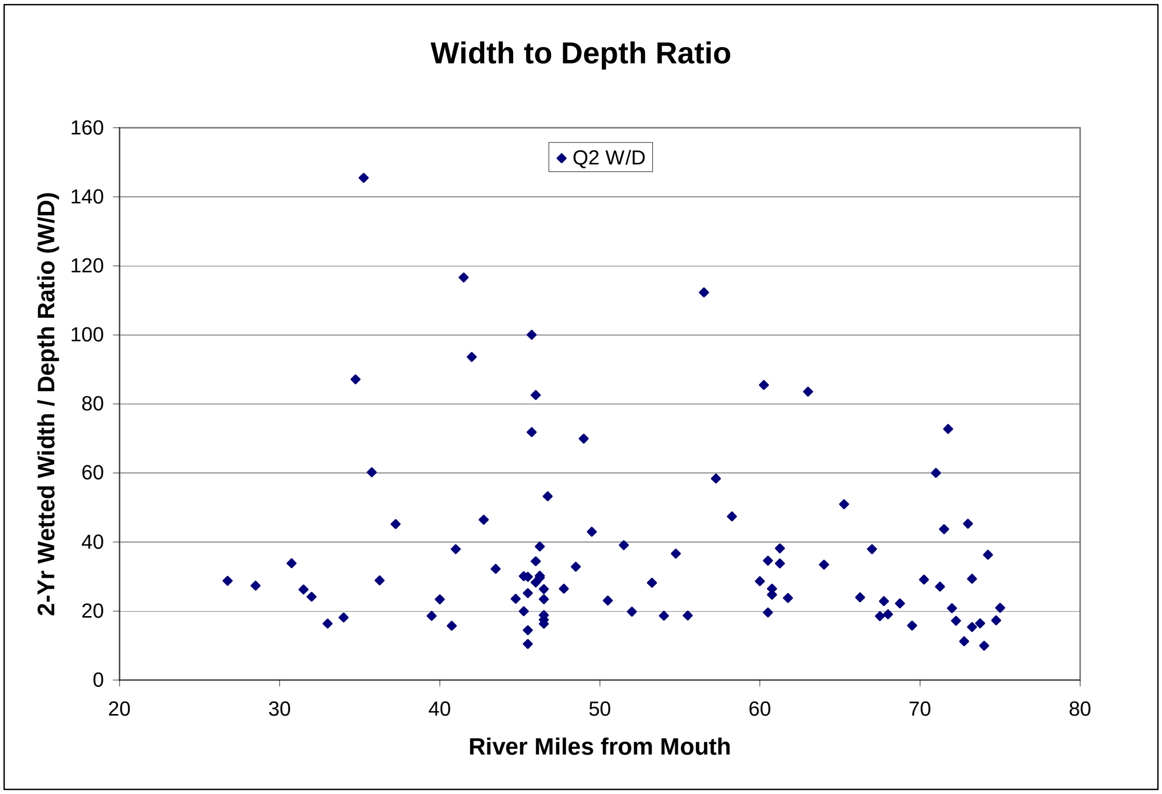


Figure K–9. Methow River – Active channel wetted width to depth ratio.

3.7 SURFACE GRADATION

Figure K–10 shows the gradation of the surface layer from pebble counts taken on bars and in the channel. The points indicate the median diameter, D_{50}, while the whiskers show the particle diameter at which 35% and 84% of the material are smaller, referred to as the D_{35} and the D_{84}. The whiskers show the range of material present in the armor layer. The D_{50} indicates the typical size of material the river must transport to access underlying bar or channel material. The D_{50} bar material ranged from coarse gravel to large cobble sized sediment. In many locations the channel bed-material was coarser in size than the surface layer of the bar material. The maximum sizes found on bars that were measured ranged from small cobbles to boulders.

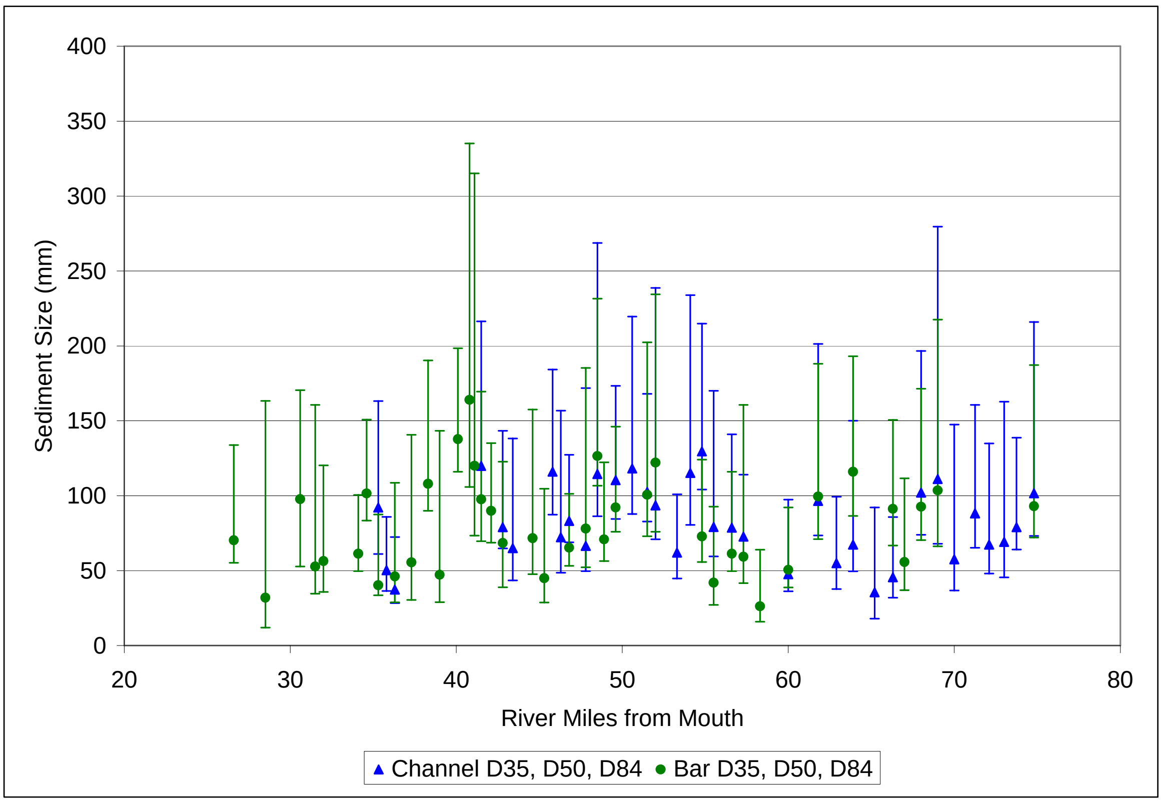


Figure K–10. Methow River – Surface gradation by river mile.

3.8 INCIPIENT MOTION

Figure K–11 shows the incipient motion, channel material median diameter, and bar material median diameter along the Methow River for the 2-, 5-, and 100-year floods. This provides a bracket on the range of flows that can be expected to accomplish the majority of channel reworking and coarse sediment mobilization over decadal periods of time. For the Methow River, the 2-year flood mobilizes both channel and bar material in many locations. The 5-year flood mobilizes channel and bar material at almost all locations. At a few locations, a flow between the 5- and the 100-year flood is required to mobilize material. On a reach perspective, the data suggests it is more typical to require a larger than 2-year flood to rework the channel and sediment bars in reaches downstream of the Chewuch River confluence than in upstream reaches.

From the confluence with Lost River (RM 76) downstream to Early Winters Creek (RM 70), the incipient motion computations suggest a larger sediment size is mobilized during floods relative to downstream reaches. From Early Winters Creek downstream to RM 55 the river is generally capable of reworking the channel and bars at a flow equal to or less than the 2-year flood, suggesting frequent reworking of the active floodplain.

Between RM 55 and the Chewuch River confluence at RM 52 the river is geologically confined and the bed sizes increase and require a larger flow to be mobilized. Downstream of the Chewuch River confluence to RM 34, the measured channel and bar sediment and computed sizes of sediment that can be mobilized fluctuate largely. When cross-sections were compared to geomorphic mapping of the low surface on aerial photography, reaches with side and overflow channels generally could be mobilized at the 2-year flood. However, confined reaches had larger measured sediment sizes and required a larger than 2-year flood to mobilize the bed relative to the wider reaches with side and overflow channels. From RM 28 to 34 the floodplain width is geologically confined but has frequent reworking of bar sediments.

The data suggest that incipient motion criteria are largely dependent on whether the floodplain is geologically confined or not. To test this correlation, a dimensionless analysis was done by plotting the 2-year flood wetted width to depth ratio against the $D_{critical}$ to the D_{50} ratio at each cross-section (Figure K–12). Depths are very small relative to wetted widths, so the width to depth ratio is largely dependent on fluctuating widths. To make the $D_{critical}$ dimensionless, each value was divided by 80 mm, the average of the D_{50} bar and channel measurements. The analysis suggest the more confined the floodplain, the larger the $D_{critical}$ in the channel bed, and thus the greater the channel armoring. Comparisons were also made between $D_{critical}$ and both flow and channel slope but there was no significant correlation.

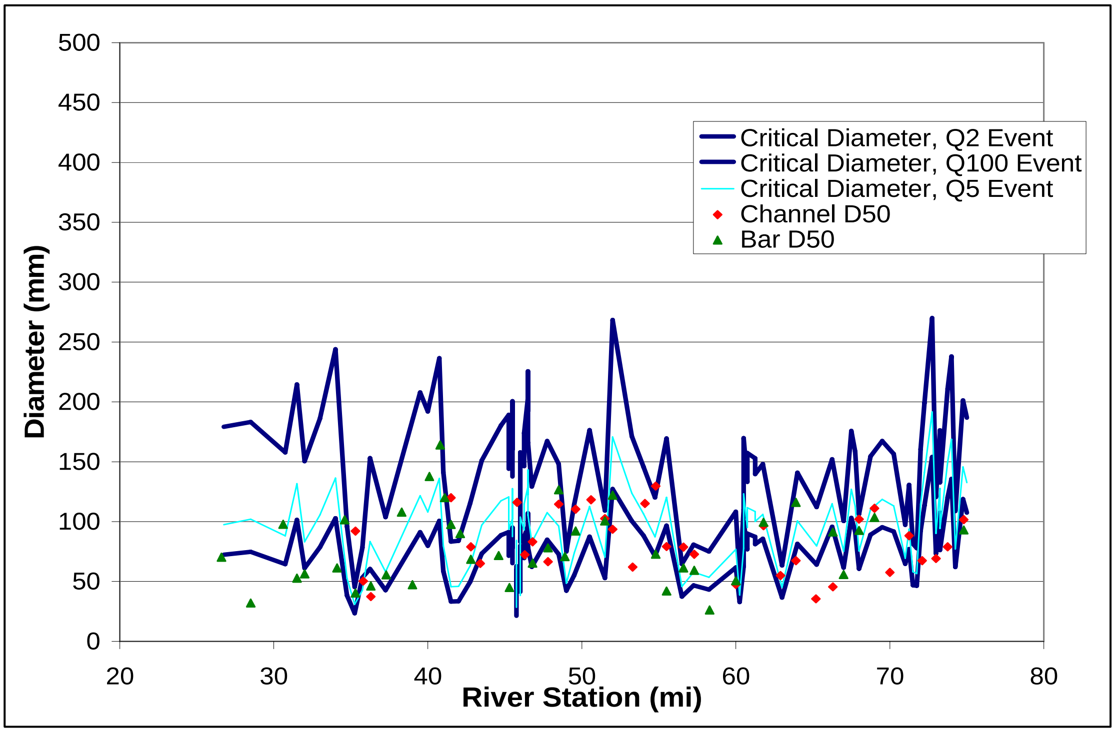


Figure K–11. Methow River – Incipient motion, channel, and bar D_{50} by river mile.

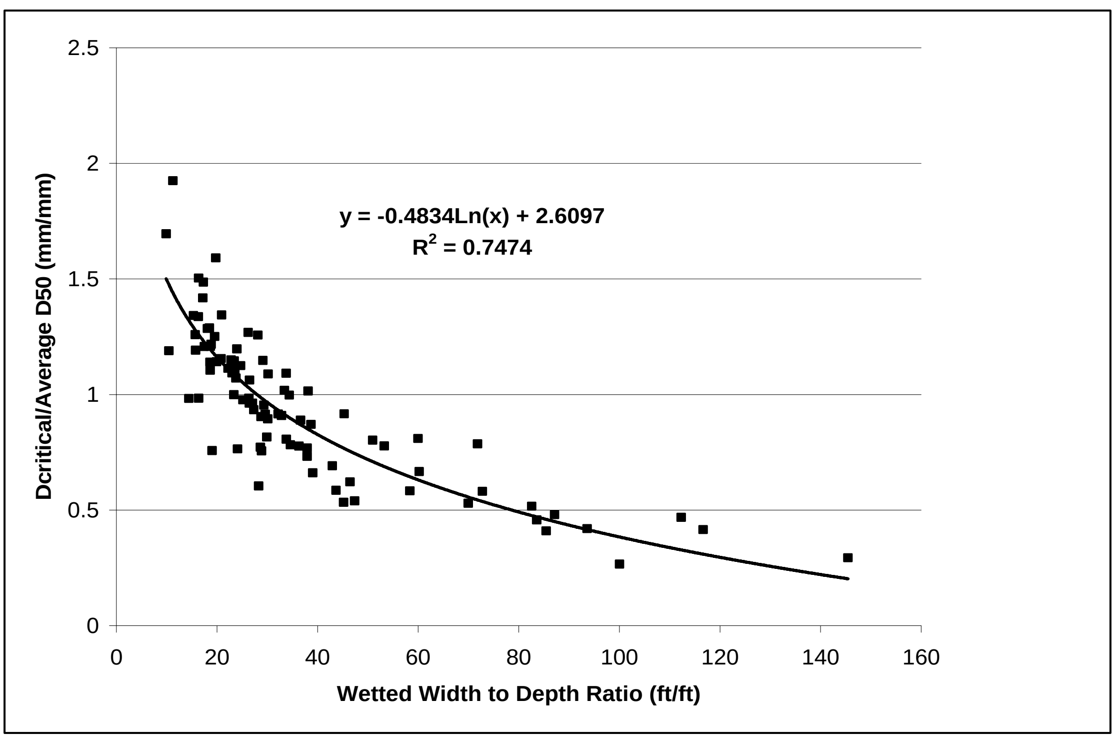


Figure K–12. Dimensionless correlation analysis between wetted width and $D_{critical}$ at 2-year flood.

3.9 HISTORICAL METHOW RIVER SURVEY DATA COMPARISON

The 2005 measured channel bottom was compared to 184 surveyed channel thalweg points that were collected following the 1972 flood (see attachment A for comparison plots). If the 2005 data was consistently lower in elevation it would be evidence of incision since the 1970s. If the 2005 data was consistently higher in elevation since the 1970s it would be evidence of aggradation. There was no observable reach scale trend of incision or aggradation between the 1970s and 2005 data. Nearly all the points (93%) had less than 2 feet of elevation difference between the 1970s and the 2005 data. In most cases where differences were measured the 2005 data were slightly higher in elevation. This is likely due to the fact that the 2005 data was collected in one longitudinal profile by boat and did not always capture the thalweg of the channel, where as the 1970s data would have captured the thalweg where the cross-section was located.

Localized elevation changes greater than 5 feet occurred at 7% (13) of the 184 cross-sections compared. Eight of the 184 cross-sections had a 2005 channel bottom that was 3 to 5 feet higher than the 1970s thalweg data, one was 8.5 feet higher, and four had a 2005 channel bottom elevation that was 2 to 5 feet lower than the 1970s data (see table A-1 in attachment A). Each of these locations was evaluated on aerial photographs from 1945, 1948, 1964, 1974, and 2004 to look for explanations of the channel changes that are documented in Table A-1 in attachment A. All of the sections except one showed dynamic split flow channels, lateral channel migration, and/or depositional bars that are plausible explanations of the elevation changes between the 1970s and 2005. At RM 49.56 the aerial photographs do not show any obvious reasons why the 8.5-foot change occurred, and this section is likely an outlier possibly due to survey error.

3.10 CONCLUSIONS

The slope of the Methow River ranges from 0.003 to 0.007 and generally decreases in a downstream direction within the assessment reach. The dominant size of bar and channel surface sediment within the active channel ranges from coarse gravel to small cobble. The ability of the river to rework this sediment is largely tied to floodplain width, which fluctuates throughout the assessment area. In areas where the floodplain widens to contain side and overflow channels, the 2-year flood generally mobilizes both bar and channel sediment suggesting frequent reworking. Geologically confined channel reaches (little or no floodplain) appear to be fairly armored with relatively larger sized sediment that requires the 5-year or greater flood to rework the channel and bars where present.

A comparison to historical survey data from the 1970s suggests there has been no reach-scale aggradation or incision within the Methow assessment reaches in the last three decades. Further channel bed incision is not anticipated in any of the assessment reaches on the Methow River because of bed armoring and/or geologic controls in the channel bed. Localized changes in channel bed elevation do occur during high flows as the river changes position and builds and erodes channels and bars within the active floodplain (low surface).

Section RM 25–38 and section 55–72 are sections that can be reworked at lower frequency floods relative to other assessment areas on the Methow River. These reaches may require additional analysis to ensure sediment processes do not prevent projects from meeting their intended objectives. Smaller material with more frequent reworking is more sensitive to hydraulic changes caused by modification to the channel geometry. Reductions in transport capacity may cause deposition or constrictions may more easily initiate incision.

4. TWISP RIVER – HYDROLOGY, HYDRAULICS, AND SEDIMENT RESULTS

The Twisp River analysis included 87 cross-sections on 17 miles of river ranging from the mouth of the Twisp River to the confluence with Eagle Creek (RM 17). The survey data included more closely spaced cross-sections from 4 project sites: Jennings (RM 12; collected in 2005), State Fish Hatchery (RM 7.5; collected in 2001), Chain of Lakes (RM 4; collected in 2005), and Elbow Coulee (RM 6.5; collected in 2005). Surface layer pebble counts were done at 40 of the surveyed cross-sections and included 19 channel samples and 25 bar samples.

4.1 DISCHARGE

Figure K–13 shows the flood discharges along the Twisp River for the 2-, 5-, and 100-year recurrence intervals. The upstream end of the assessment reach contains significant flow changes at Eagle and War Creek (RM 17.1 to 17.4) and also at Buttermilk and Canyon Creek confluences (RM 13.6 to 13.9). Downstream, the flow has a more gradual increase in magnitude as additional tributaries and drainage areas are incorporated.

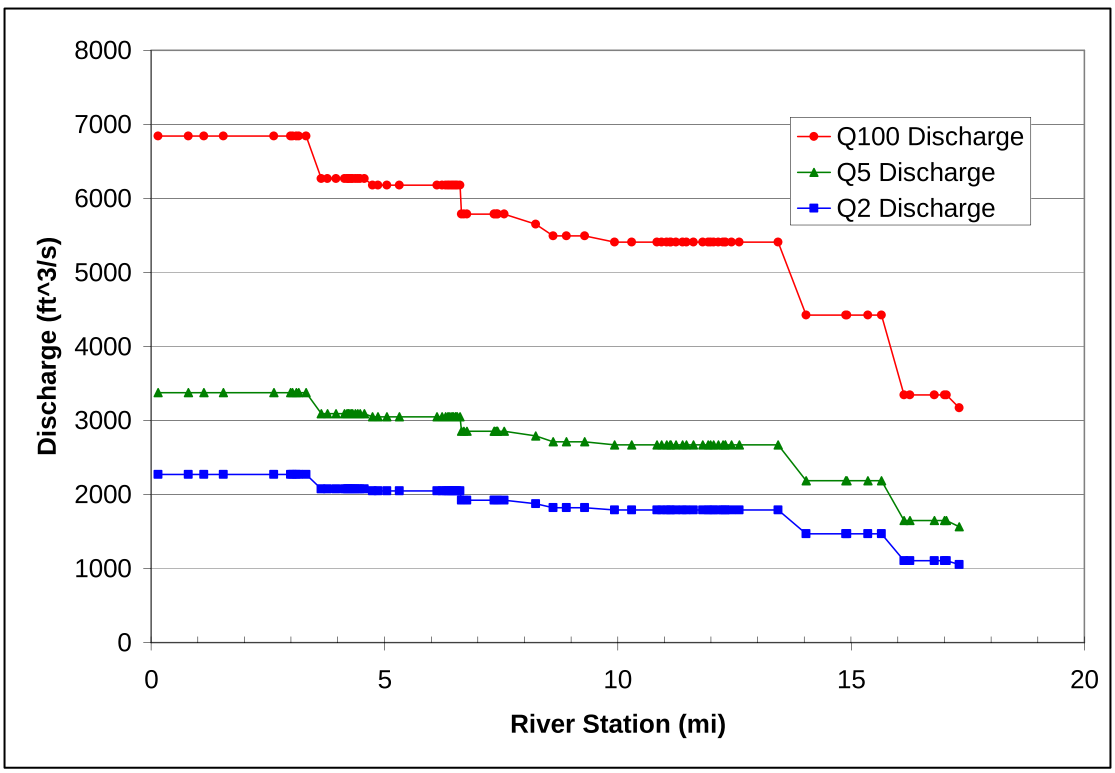


Figure K–13. Twisp River – Discharge by river mile.

4.2 SLOPE

Figure K–14 shows the slope breaks along the Twisp River based on the 2005 surveyed profile. By looking at the elevation drop per mile (Figure K–15), the data suggest a relatively constant slope upstream of Little Bridge Creek, where as the slope has an increasing trend between Little Bridge downstream to around Elbow Coulee, and then a decreasing trend downstream to the mouth. On this larger scale, the Twisp River slope upstream of the confluence of Little Bridge Creek is an average of 0.006 (between RM 10.3 to 18.2). The channel slope averages 0.012 from Little Bridge Creek downstream to RM 2.9, and 0.008 from RM 2.9 downstream to the mouth. The large break in slope around RM 10 occurs because this point coincides with the maximum extent of the alpine (valley) glacier that came down the Twisp River valley. Glacial erosion and deposition occurred upstream of this point, and has resulted in a flatter slope. Fluvial erosion, which during times of glacier melting was much greater than present, occurred downstream of the ice, and has resulted in a steeper slope.

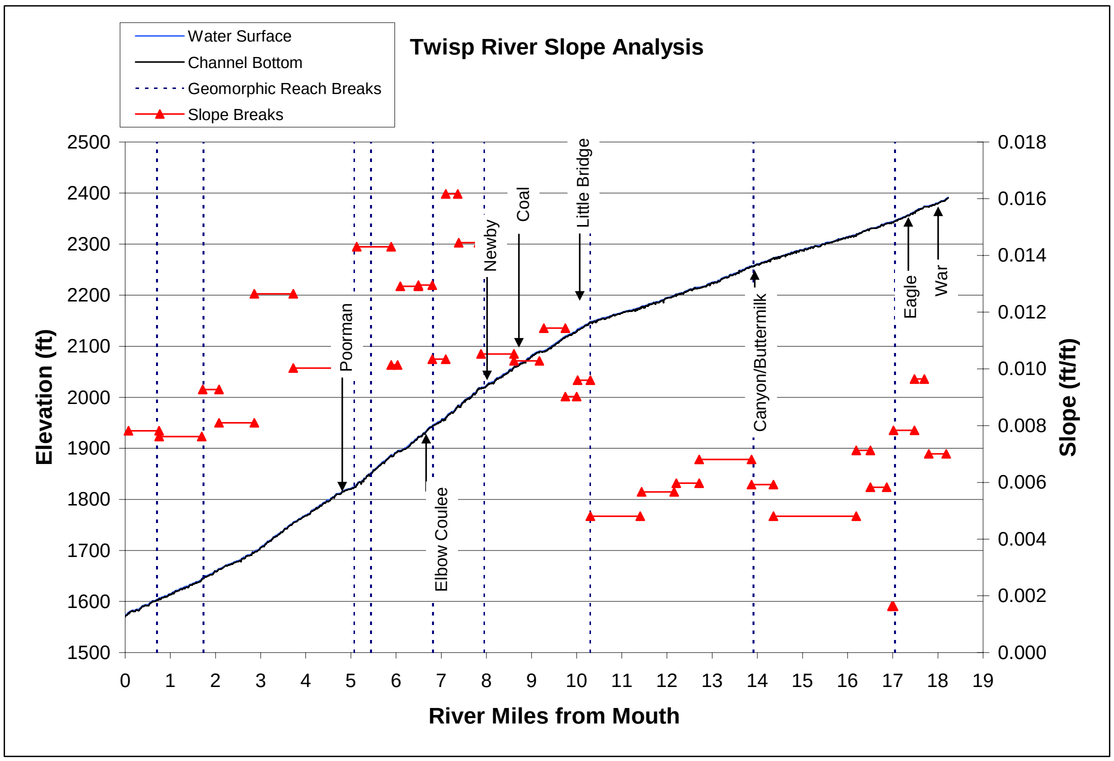


Figure K–14. Twisp River – Slope by river mile.

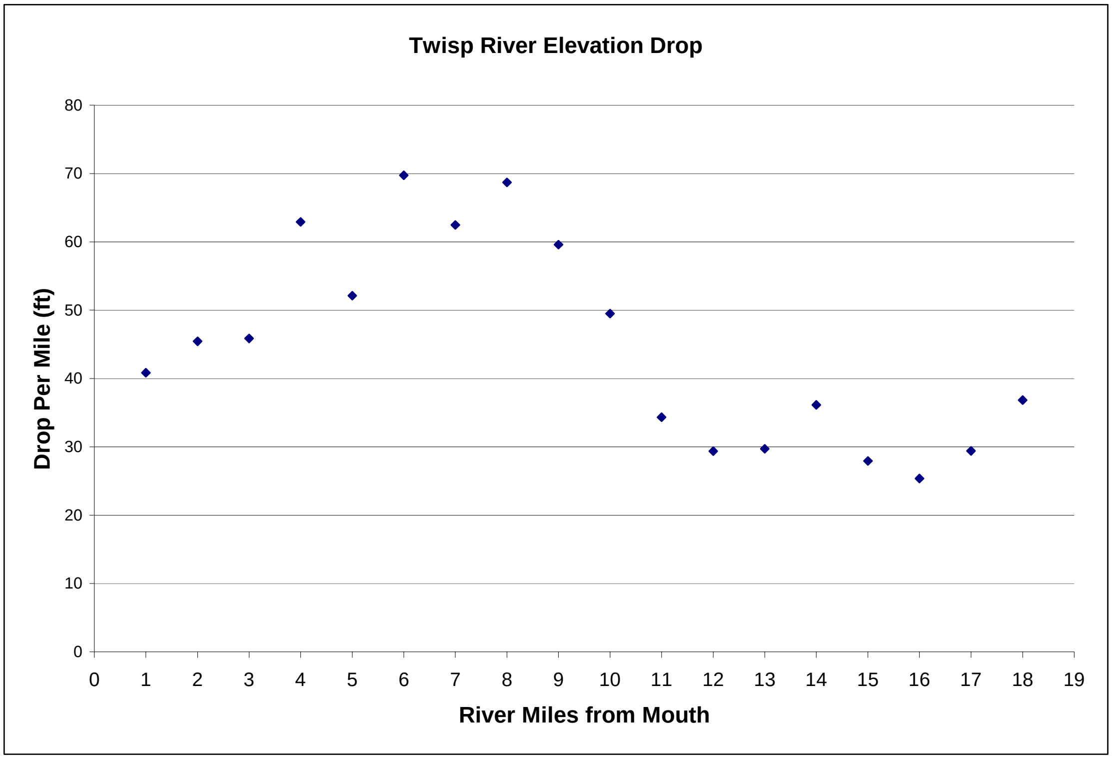


Figure K–15. Twisp River – Elevation drop per river mile.

4.3 TOTAL STREAM POWER

Figure K–16 shows a plot of the total stream power for the Twisp River. Total stream power has a strong correlation with changes in channel slope, where as changes in discharge have a relatively smaller impact.

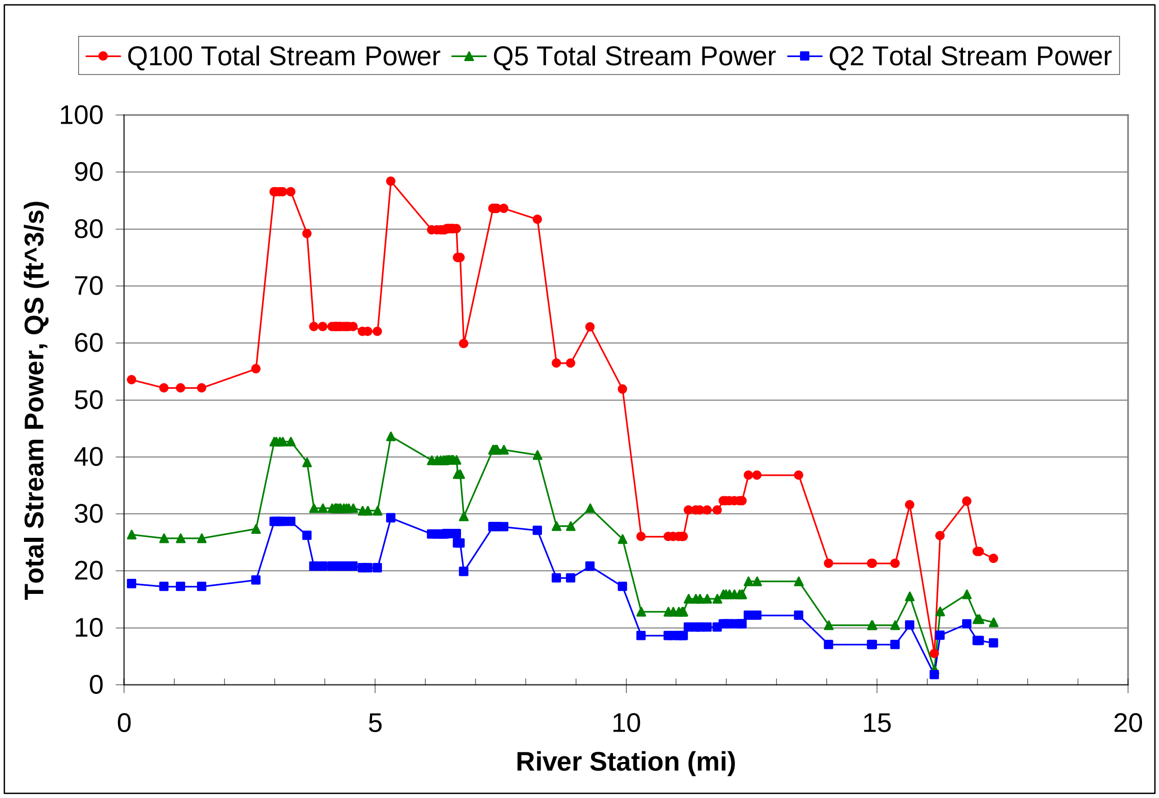


Figure K–16. Twisp River – Total stream power by river mile.

4.4 VELOCITY

Figure K–17 shows a velocity profile of the Twisp River for the 2- and 100-year floods. Trends in the velocity profile match changes in slope. The range of variability in the velocity magnitude is small reflecting partial compensation by the channel geometry.

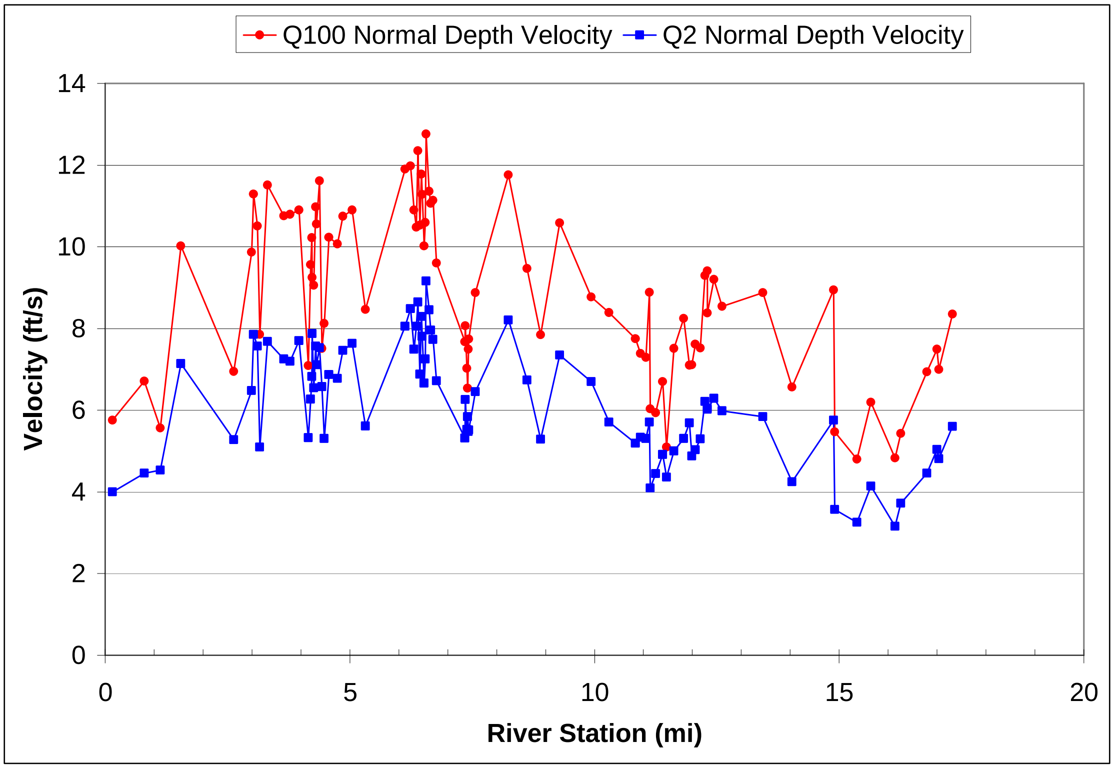


Figure K–17. Twisp River – Velocity by river mile.

4.5 UNIT STREAM POWER

Figure K–18 shows the unit stream power for the 2-, 5-, and 100-year floods along the Twisp River. The unit stream power remains consistent with the trends for total stream power, both having strong correlations with changes in channel slope. The total and unit stream power results suggest that sediment transport capacity is relatively constant upstream of Little Bridge Creek. The sediment transport capacity downstream of Little Bridge Creek has an increasing trend between RM 10 downstream to RM 8, stays high between RM 8 to 6, and then begins to have a decreasing trend downstream to the mouth.

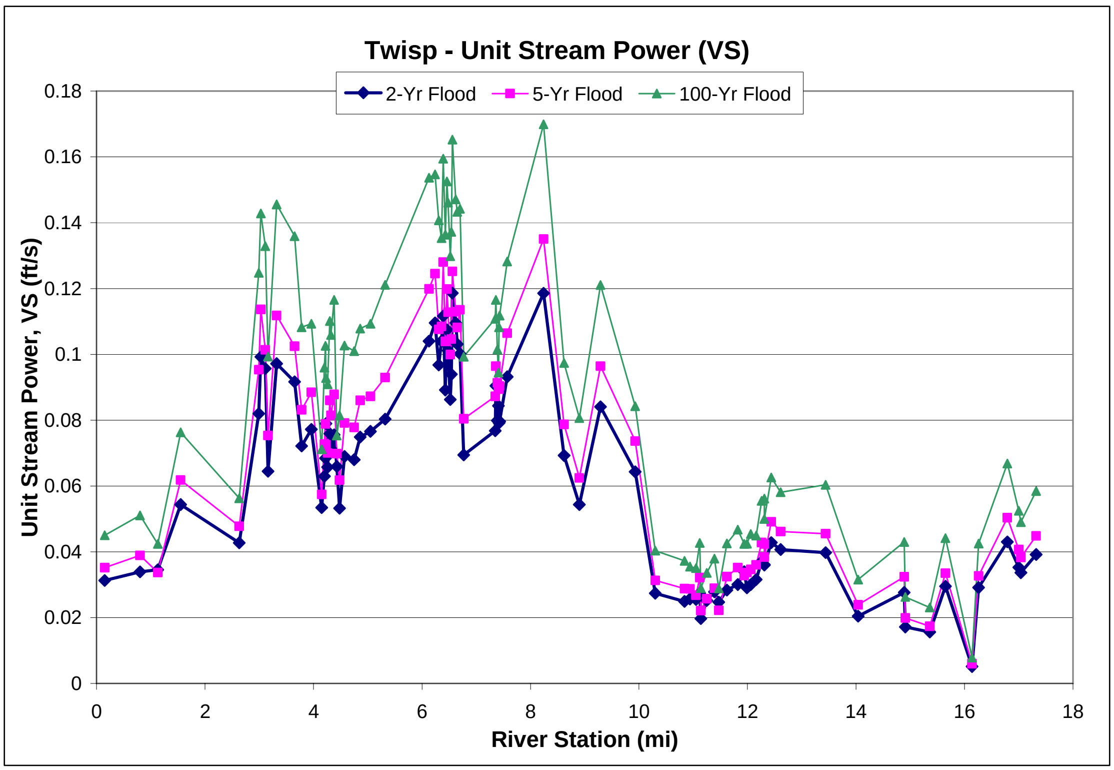


Figure K–18. Twisp River – Unit stream power by river mile.

4.6 WETTED WIDTH TO DEPTH RATIO

The active channel wetted width to depth ratio was computed for the 2-year flood (Figure K–19). In general, wetted widths are an order of magnitude larger than wetted depths at the 2-year flood. This means the width to depth ratio is mostly dependent on fluctuation in active channel width. For the Twisp River, the majority of channel areas have a width to depth ratio range from 10 to 60. There are a few exceptions along the assessment reach and at the mouth where the width to depth ratio increases above 60. Four of these cross-sections near RM 7 originated from a project level survey at the Twisp Fish Hatchery. Computed wetted active channel widths (not plotted) range from 50 to 480 feet, where as widths of the entire active floodplain (low surface) measured from aerial photography range from 100 to 1,880 feet. The width of the entire active floodplain is often larger because it includes additional wetland and overflow channels and surfaces.

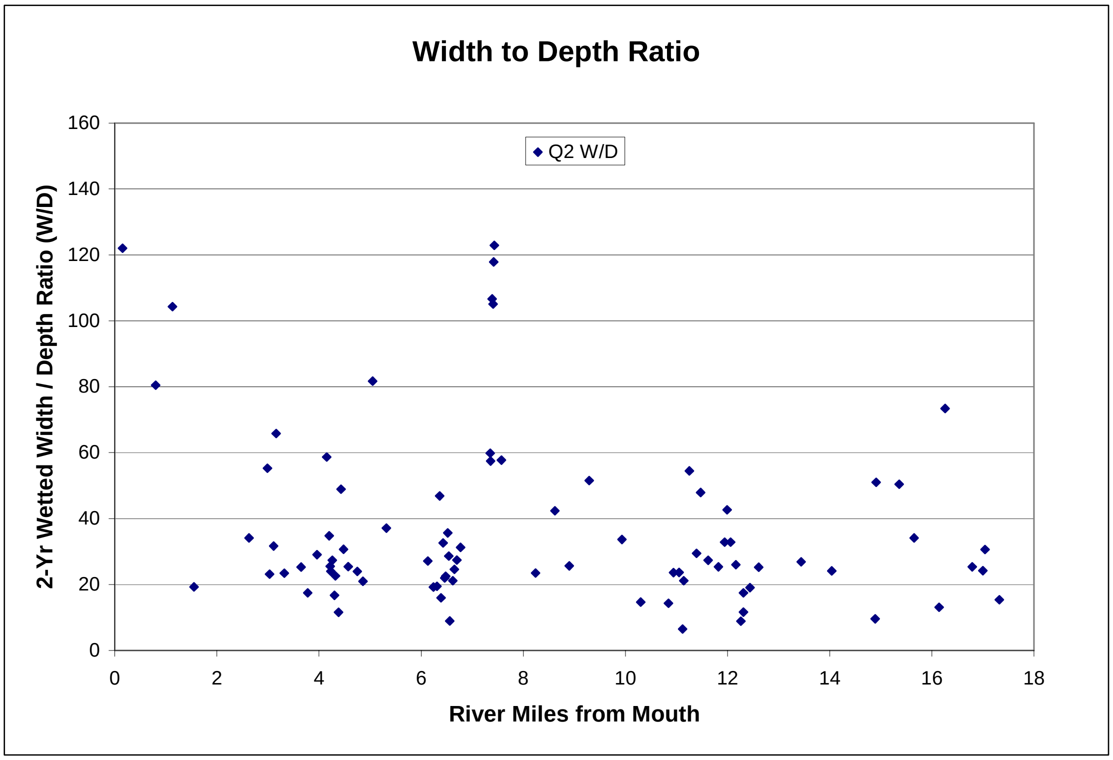


Figure K–19. Twisp River – Active channel wetted width to depth ratio.

4.7 SURFACE GRADATION

Figure K–20 shows the pebble count results for the Twisp River with the median diameter, D_{50} indicated by the points and the D_{35} and D_{84} shown as minimum and maximum bars. The reach upstream of Little Bridge Creek (RM 10) shows smaller gradations in the channel bed and bars than the downstream section of the assessment reach. There is also a greater range in sediment sizes between the D_{35} and D_{84} in the reach downstream of Little Bridge Creek.

As part of a stream survey monitoring effort, the USFS and Pacific Watershed Institute (PWI) measured 16 pebble counts in the reach from RM 0 to 30 (USFS, 2002; PWI, 2003). Pebble counts were done on riffles and include bank materials (bankfull to bankfull). Pebble count data from USFS and PWI are compared to the new Reclamation data collected in 2005 which was only done in the wetted channel (no banks) and over a range of hydraulic geometries (Figure K–21). Note that the RM locations of pebble count locations between RM 0 to 5 were estimated based on local USFS knowledge of the sites. The data generally falls within the same trends as the Reclamation data, and appears to be closer to the channel measurements as opposed to the bar samples.

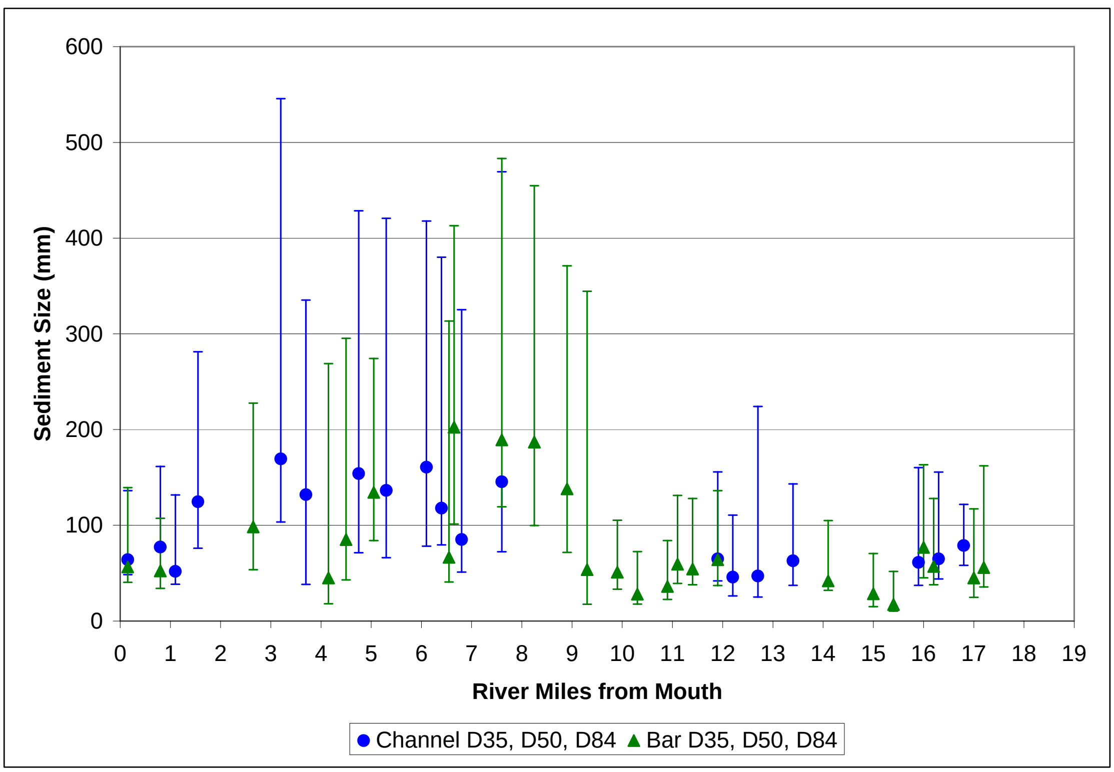


Figure K–20. Twisp River – Surface gradation by river mile.

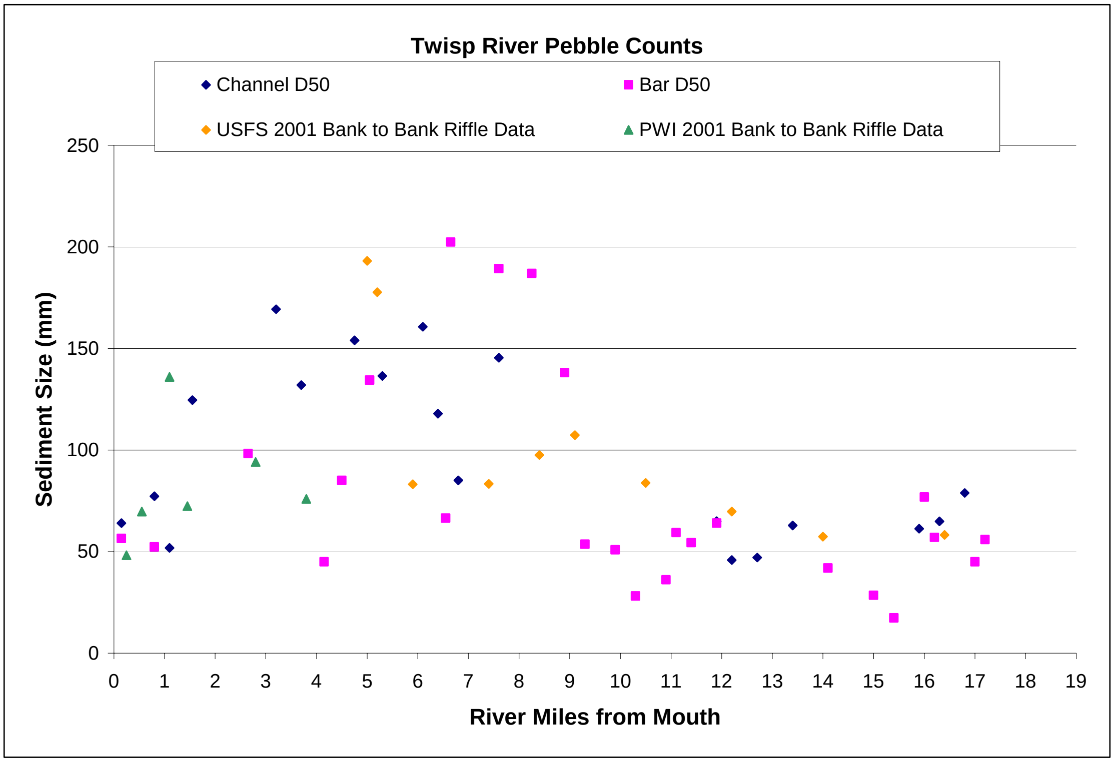


Figure K–21. Twisp River – Comparison of Reclamation D_{50} pebble count data with data collected by USFS and Pacific Watershed Institute.

4.8 INCIPIENT MOTION

The incipient motion computations were used to compare how a given discharge and cross-section geometry can mobilize sediment versus sizes of channel bed and bar material measured.

Figure K–22 shows the incipient diameter (maximum particle size that can be mobilized for a given flow) along with the measured channel and bar sediment. The results indicate the 2-year flood can generally result in channel and sediment bar reworking upstream of RM 10, with a few exceptions where the channel is locally confined by geologic surfaces (little or no vegetated floodplain). Downstream of RM 10, higher recurrence intervals are required to exceed incipient motion criteria suggesting the channel and sediment bars are not reworked as often as reaches upstream of RM 10.

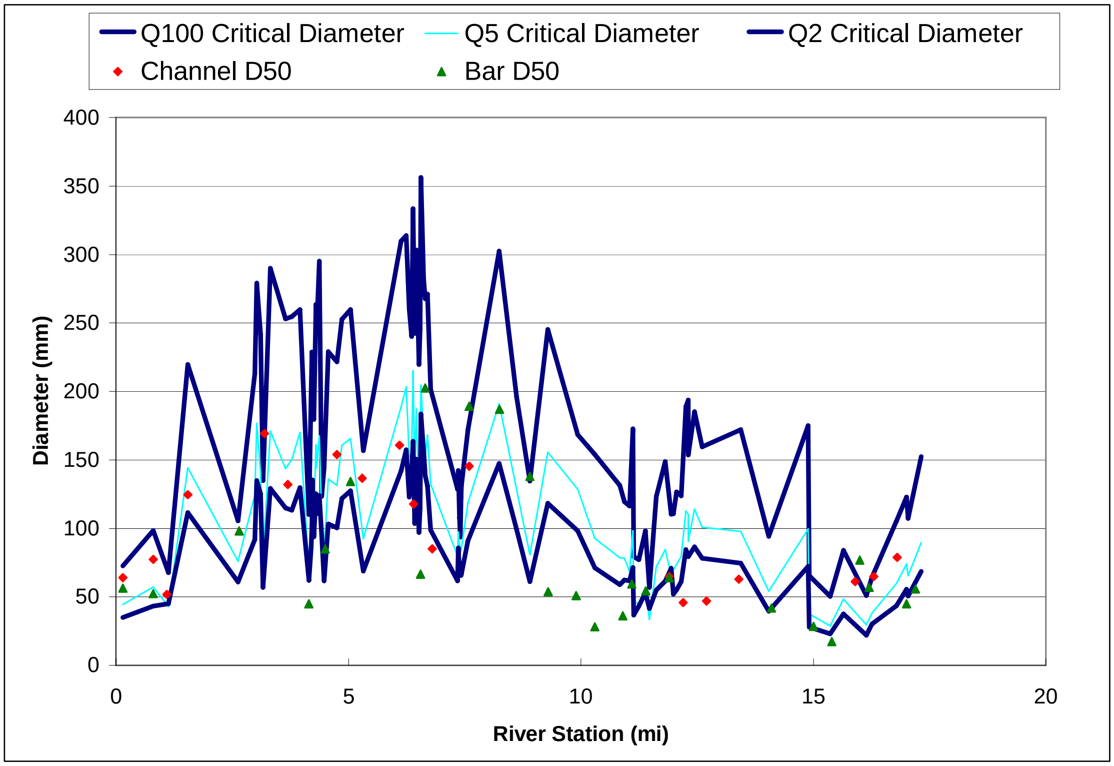


Figure K–22. Twisp River – Incipient motion, channel, and bar D_{50} by river mile.

4.9 FINE SEDIMENT ANALYSIS

Excessive amounts of fine sediment in spawning gravels can cause problems to fish redds and fry survival because the sediment depletes the oxygen supply. Analysis of fine sediment levels was beyond the Reclamation scope of work, but key findings from work accomplished by available literature is documented below.

The Twisp River does not naturally produce high volumes of fine sediment supply relative to the Chewuch River, which has several sources within the upper basin. However, fires have not occurred for many years on the Twisp River and if one were to occur fine sediment levels would likely increase temporarily. The USFS has conducted McNeil core samples in spawning riffles along four reaches of the Twisp River since 2001.

In 2006, the percent fines in spawning gravel increased substantially from survey years 2001 to 2004 in three of the four reaches sampled on the Twisp River (no sediment sampling was done in 2005 in Twisp River due to funding restraints) (MVRD, 2007). The USFS hypothesizes that the increase is largely due to increases in spring run-off (MVRD, 2007). The 2006 peak spring run-off was almost 80% higher than the average peak spring run-off between 2001 and 2004. In addition, large amounts of sediment may have been deposited when anchor ice moved downstream during a thaw in February 2005, scouring the banks of the river (MVRD, 2007). The mean % fines < 0.85 mm for the four sample reaches were 11.6% from survey years 2001 to 2004 (before the ice flows in February 2005 and high 2006 run-off) and 18.0% in 2006 (after these events). The increase in fine sediments in spawning gravel in the Twisp River may have changed the USFWS functional rating from functioning appropriately to functioning at risk.

The USFS (2001) notes that the highest levels of surface fines measured were in the lowest 5 miles of the Twisp River, with about 15% of the substrate consisting of fine sediments less than 6 millimeters in size (USFS, 2001). USFS (2001) also references observations collected by PWI in 2001 that notes substrate embeddedness may also be a problem in the lower 5 miles. The 2006 McNeil core sample at RM 0.2 was 25% fines less than 0.85 mm. This location is in a depositional zone near the confluence with the Methow River and would be expected to have higher levels of fine sediment compared to upstream reaches with steeper slopes. The amount of surface fines less than 6 mm in size was about 12% in the low gradient stream segment of the river between river mile 5 and 26 (ranging from 7% to 14% per reach) (USFS, 2001).

The USFS found that spawning-sized sediment (gravel) was abundant in most segments of the Twisp River. The report notes that the natural potential of spawning gravel deposition in the lower 13.7 miles may have be reduced due to bank and flood protection features confining the river and increasing sediment transport capacity. However, reach scale geologic mapping by Reclamation indicates this area has a naturally low potential for deposition of spawning size sediment.

4.10 CONCLUSIONS

A combination of channel slope and floodplain width play a large role in relative sediment transport capacity among reaches in the assessment area. The Twisp River can be grouped into three reaches for purposes of sediment and hydraulic conclusions. The upper reach from RM 10 to RM 17 has slopes ranging from 0.0016 to 0.0096 with typical bar and channel material in the very coarse gravel classes that is generally mobilized at the 2-year flood. An exception occurs around RM 16 where the river is fairly confined. The range of surface sediment present in the bed is small relative to downstream reaches and the majority of sediment in storage can be mobilized.

The middle reach from approximately RM 2 to 10 contains slopes ranging 0.0076 to 0.014 with typical bar material consisting of small cobble while the channel material consists of large cobble. Sediment computations show high variability from RM 2 to 10, but mobility of the channel and bars generally requires flows larger than the 5-year flood. From RM 2 to 10 the sediment bars are mobilized more easily than the channel material. Many areas within this reach contain large boulders or bedrock that armor the channel bed and limit additional incision. No historical survey data was available to verify the amount of historical incision, but field evidence of surface heights relative to the present bed suggest it is generally not more than 5 feet.

The most downstream reach from the mouth to RM 2 maintains a relatively uniform bed slope of 0.008 with typical bar and channel material measured as very coarse gravel. The mouth of the Twisp River is a depositional area as it receives backwater influences from the Methow River, but still requires flows greater than the 5-year flood to mobilize the bed and bar material.

The reach from RM 9 to 17 can be reworked at lower frequency floods relative to the downstream section on the Twisp River. These reaches may require additional analysis to ensure sediment processes do not prevent projects from meeting their intended objectives. Smaller material with more frequent reworking is more sensitive to hydraulic changes caused by modification to the channel geometry. Reductions in transport capacity may cause deposition or constrictions may more easily initiate incision.

5. CHEWUCH RIVER – HYDROLOGY, HYDRAULICS, AND SEDIMENT RESULTS

The Chewuch River hydraulics and sediment analysis was based on 30 cross-sections surveyed along 14 miles of river between the mouth and Falls Creek (RM 14). The survey data included more closely spaced cross-sections at 2 project sites: the Fulton Dam (RM 1) and the Chewuch Dam (RM 9). Surface layer pebble counts were done at 25 cross-sections and included 24 channel samples and 12 bar samples.

5.1 DISCHARGE

Figure K–23 shows the change in discharge along the Chewuch River for the 2-, 5-, and 100- yr floods. Overall the discharge shows a gradual increase in the downstream direction from the addition of tributaries and additional runoff area. The largest discharge increase occurs at the confluence with Eight-mile Creek at RM 11.6. There are five ditches diverting water within the subwatershed; three from the Chewuch River and two from Eightmile Creek (Andonaegui, 2000).

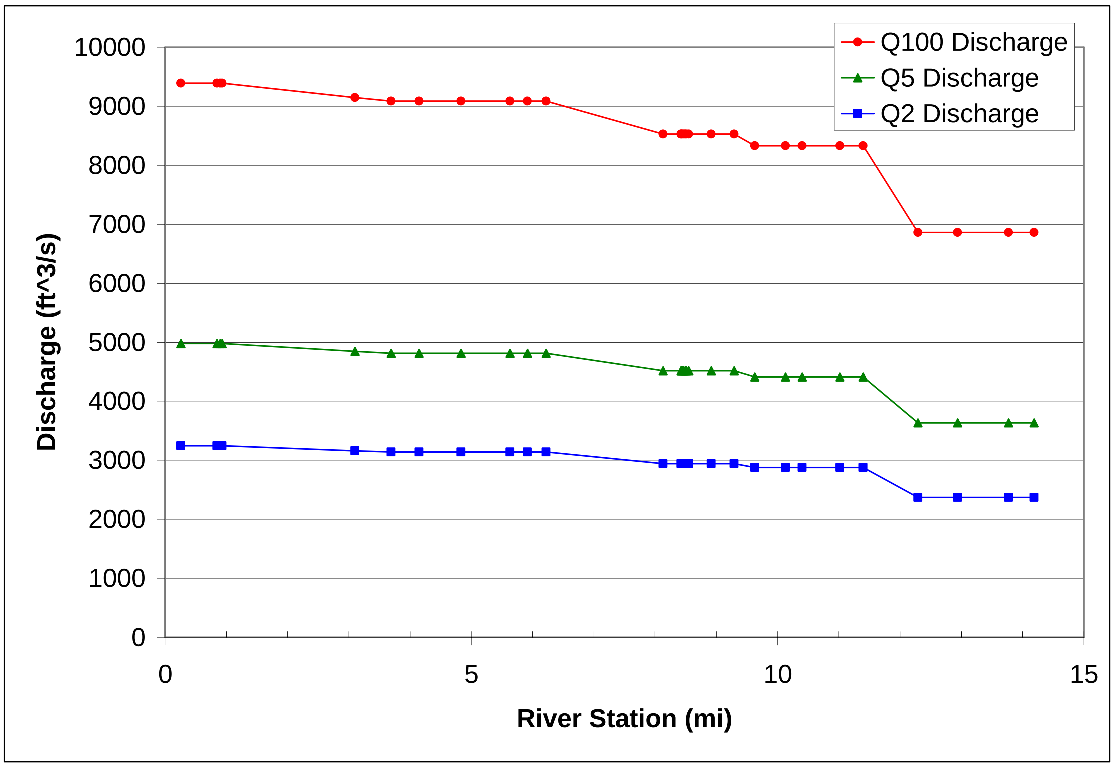


Figure K–23. Chewuch River – Discharge by river mile.

5.2 SLOPE

Figure K–24 shows the measured slope breaks along the Chewuch River assessment reach from RM 0 to 14. A major slope break occurs over the Boulder Creek alluvial fan as a result of a graben-bounding fault that crosses the valley at an oblique angle near RM 9 and is relatively easy for the river to erode. Upstream of RM 9 the bedrock is crystalline and is relatively resistant to erosion. Downstream of RM 9 the bedrock is sedimentary and volcanic rocks which are generally less resistant to erosion. The differences in rock types create a resistant “step” in the longitudinal profile of the Chewuch River. Very large boulders that have been deposited by glacial or debris-flow processes at the mouth of Boulder Creek enhance the resistant character of the near-surface crystalline rocks.

Surveyed slopes show a high degree of local fluctuation, and can be further assessed by looking at the elevation drop per river mile (Figure K–25). Upstream of Falls Creek the river alternates between steep and flat reaches (USFS, 2002). The channel has an average slope of 0.003 between RM 9.8 and 14.4 with a large increase in slope at RM 10. There is a decreasing trend in slope between RM 10 and 6 (range of 0.006 to 0.018), and then an average slope of 0.004 between RM 6 and 1.8, with a slightly steeper section in the last 1.5 miles of river where the river is naturally confined by bedrock. Localized, short steep sections of river slope were also measured within the assessment area that generally represents hydraulic drops (rapids).

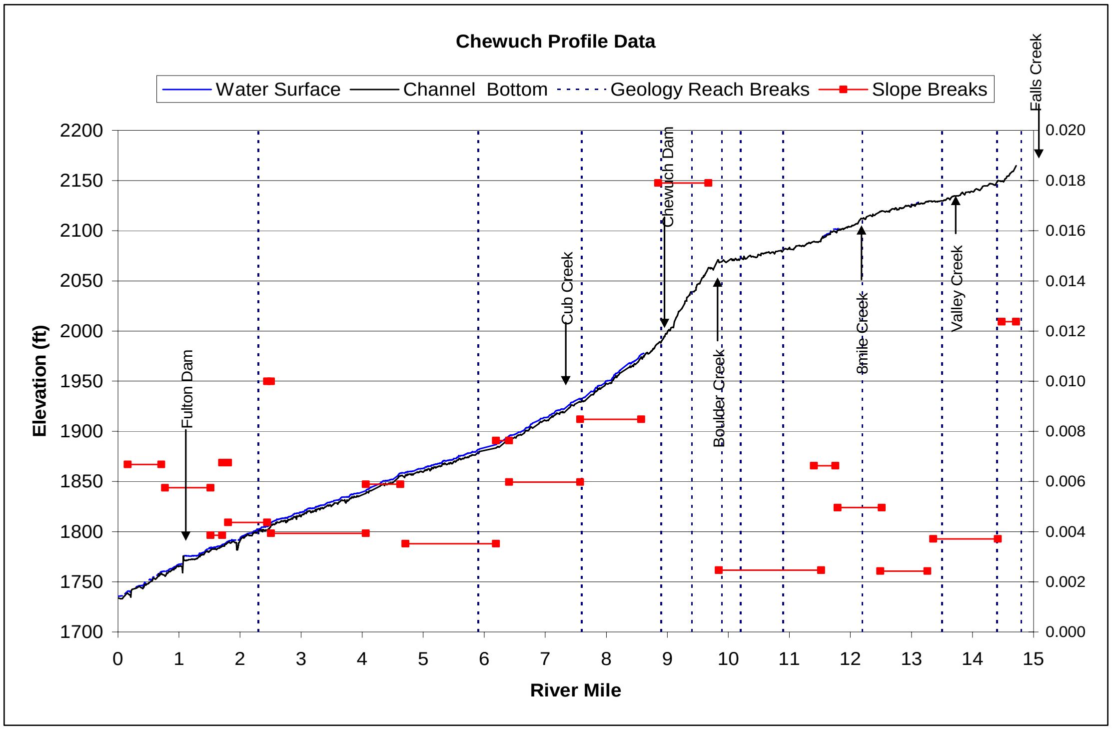


Figure K–24. Chewuch River – Slope breaks by river mile.

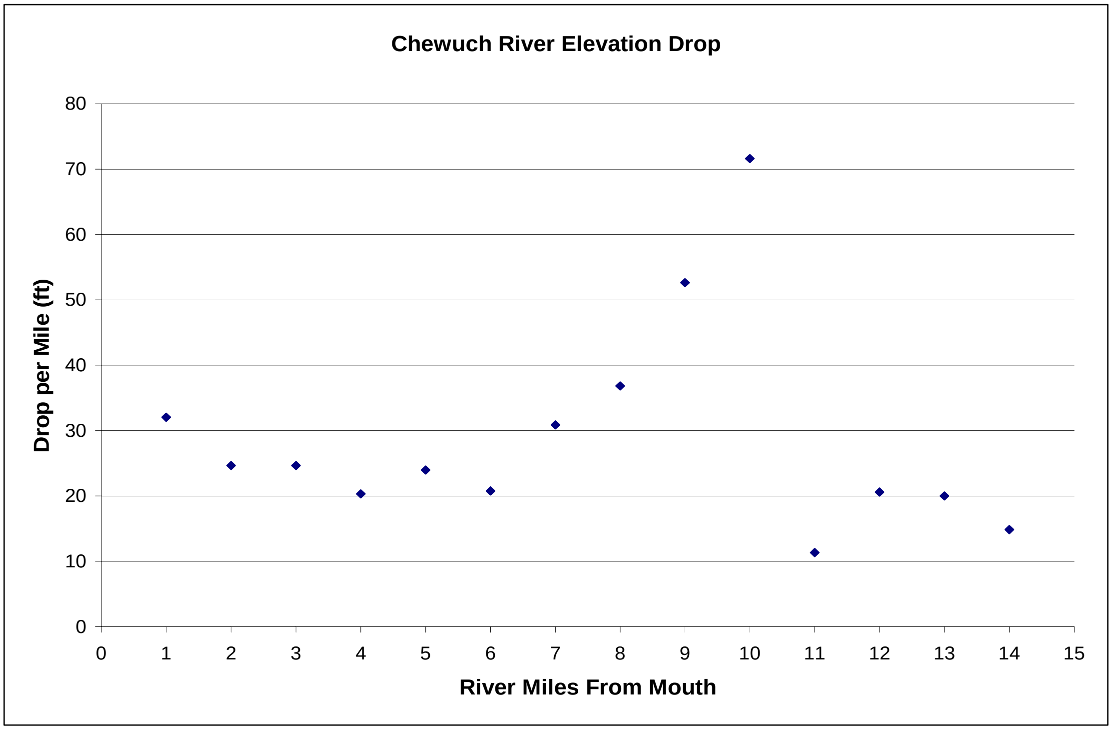


Figure K–25. Chewuch River – Elevation drop per river mile.

5.3 TOTAL STREAM POWER

Figure K–26 shows the total stream power for the Chewuch River. Total stream power has a close tie to channel slope with little influence from changes in discharge along the assessment area. The steep slopes downstream of the Boulder Creek confluence at RM 10 result in a spike in total stream power values. Total stream power results suggest that in locations where the slope increases, the sediment transport capacity also increases.

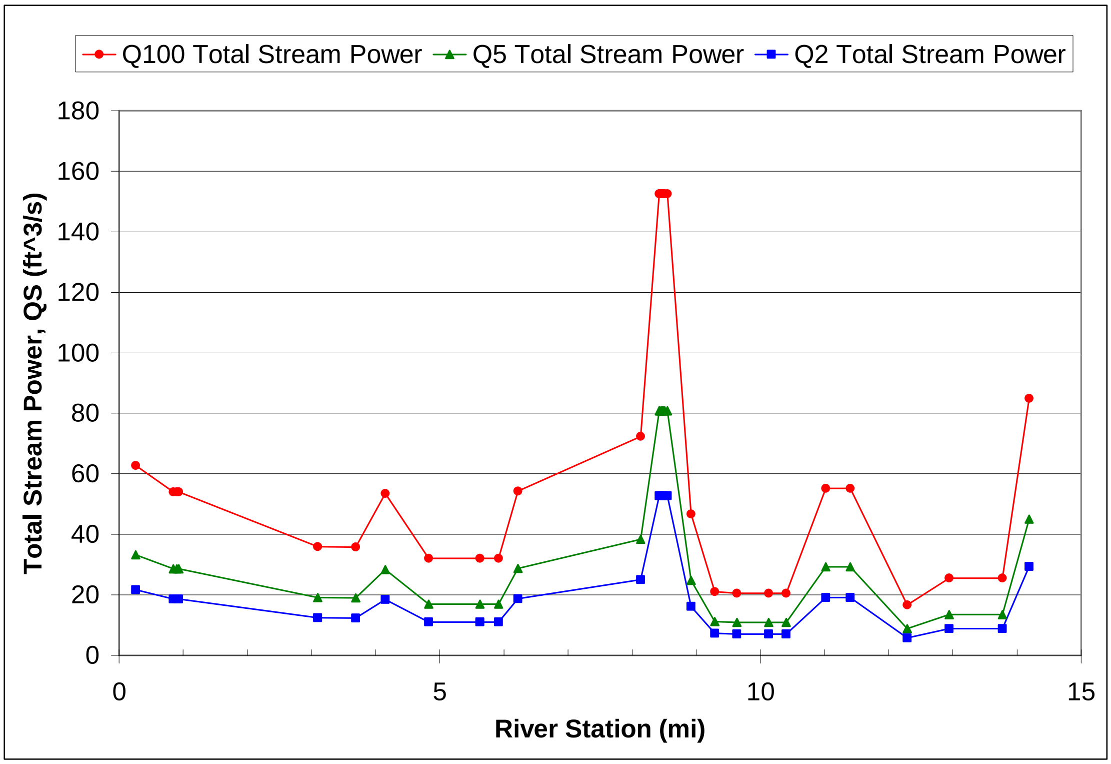


Figure K–26. Chewuch River – Total stream power by river mile.

5.4 VELOCITY

Figure K–27 shows the velocity profile along the Chewuch River. The velocity profile shows a strong correlation with slopes in that higher velocities are computed in sections of steeper slope. The largest velocities occur in the steepest slope reach just downstream of Boulder Creek.

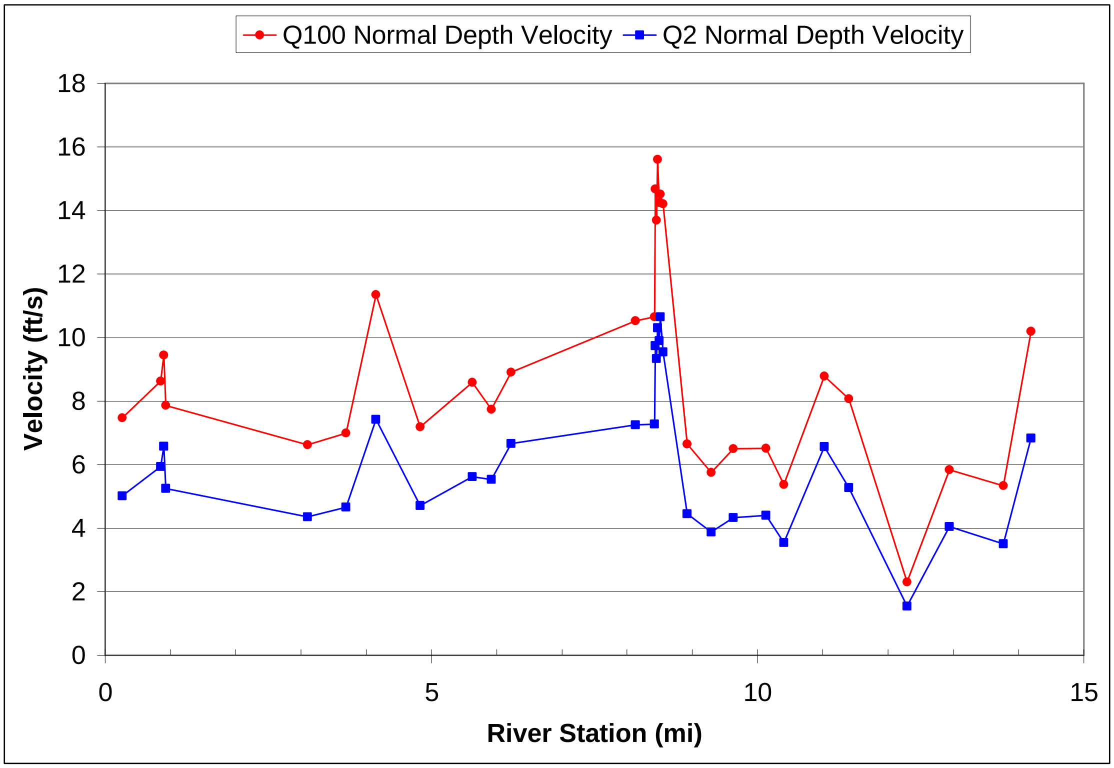


Figure K–27. Chewuch River – Depth-averaged velocity by river mile.

5.5 UNIT STREAM POWER

Figure K–28 shows the unit stream power for the Chewuch River for the 2-, 5-, and 100-year flood. The trends in unit stream power are closely correlated with trends in channel slope.

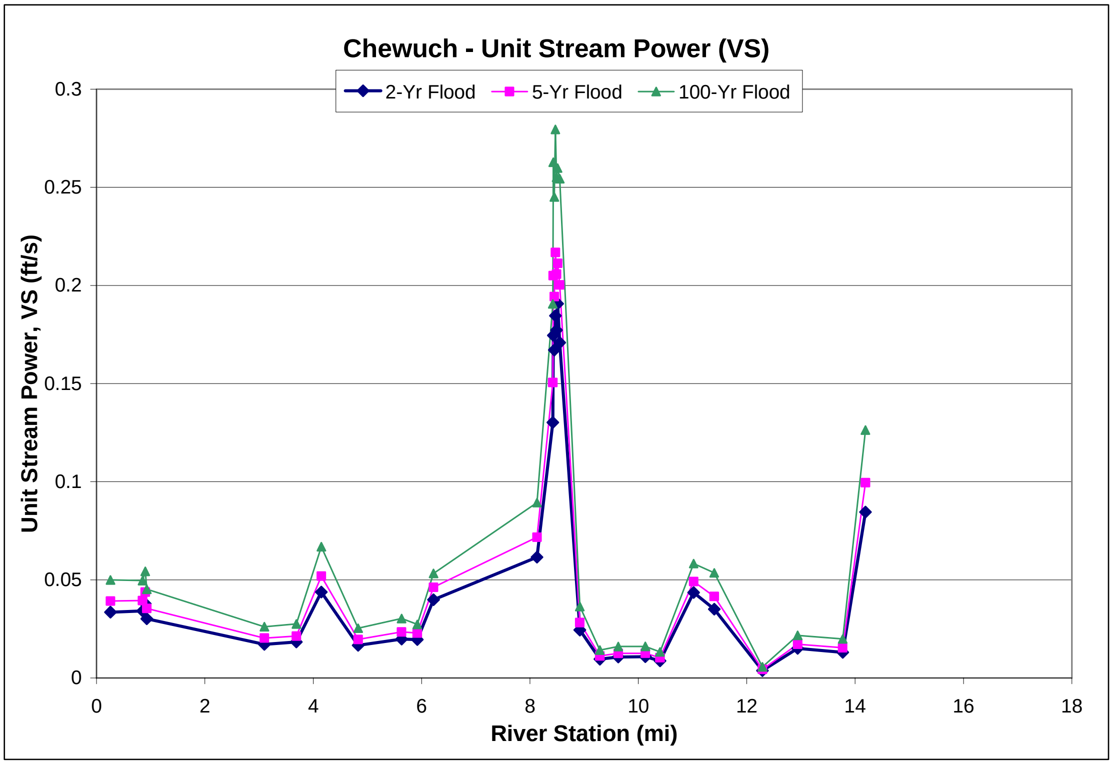


Figure K–28. Chewuch River – Unit stream power by river mile.

5.6 SURFACE GRADATION

Figure K–29 shows pebble count results for the Chewuch River assessment reach including the D_{35}, D_{50}, and D_{84} diameters. The very high D_{84} bars near RM 1 and 2 indicate bedrock. The upper portion of the watershed contains finer grain classes than the lower portion. Areas of high velocity and slope have a correlating coarser surface gradation than areas with lower velocity and flatter slopes. The reach downstream of RM 9 has less sediment bars present in the active channel than upstream of RM 9.

As part of a stream survey monitoring effort, the USFS and Pacific Watershed Institute measured pebble counts within the Reclamation assessment reach (USFS, 2002). Both pebble counts were done on riffles and include bank material (bankfull to bankfull sample). This is slightly different than the method used by Reclamation, which only included the active channel or adjacent gravel bar. Pebble count data from this report and the USFS effort are compared to the new Reclamation data collected in 2005 (Figure K–30). The PWI data sets are well within expected variation, showing similar longitudinal trends on a reach level. One exception is at RM 12, where the Reclamation data was collected in a localized split flow, backwater reach that would be expected to have finer sediment sizes in the channel.

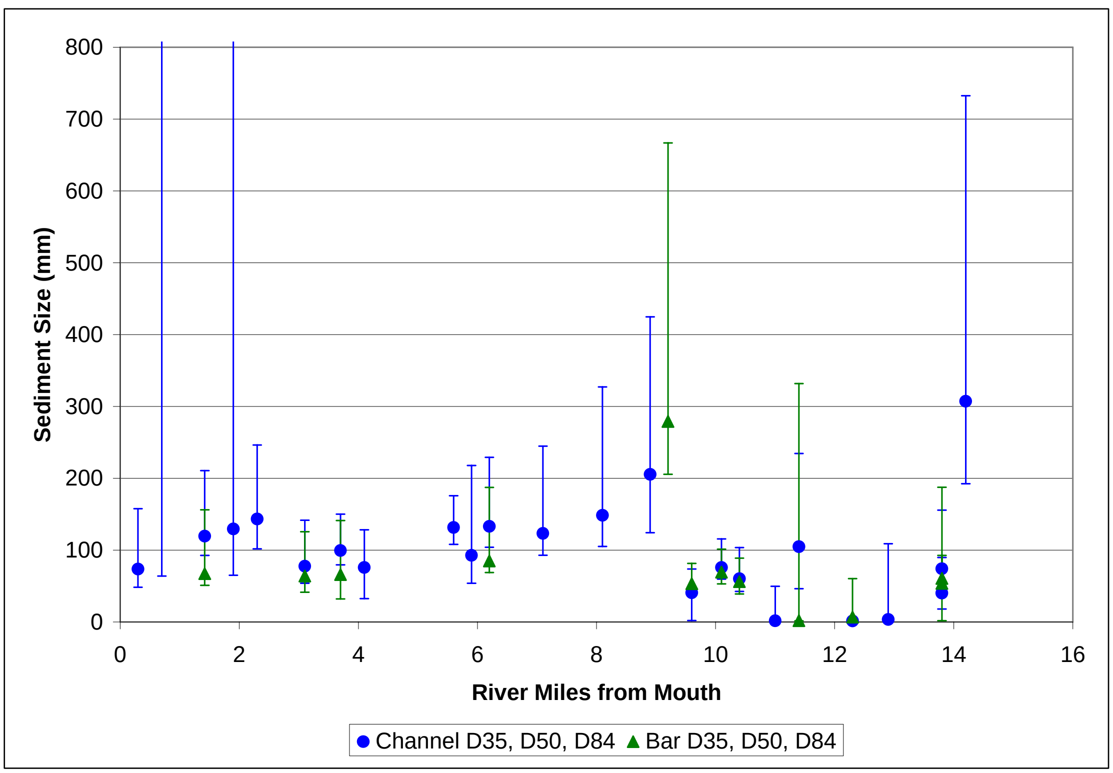


Figure K–29. Chewuch River – Surface gradation by river mile.

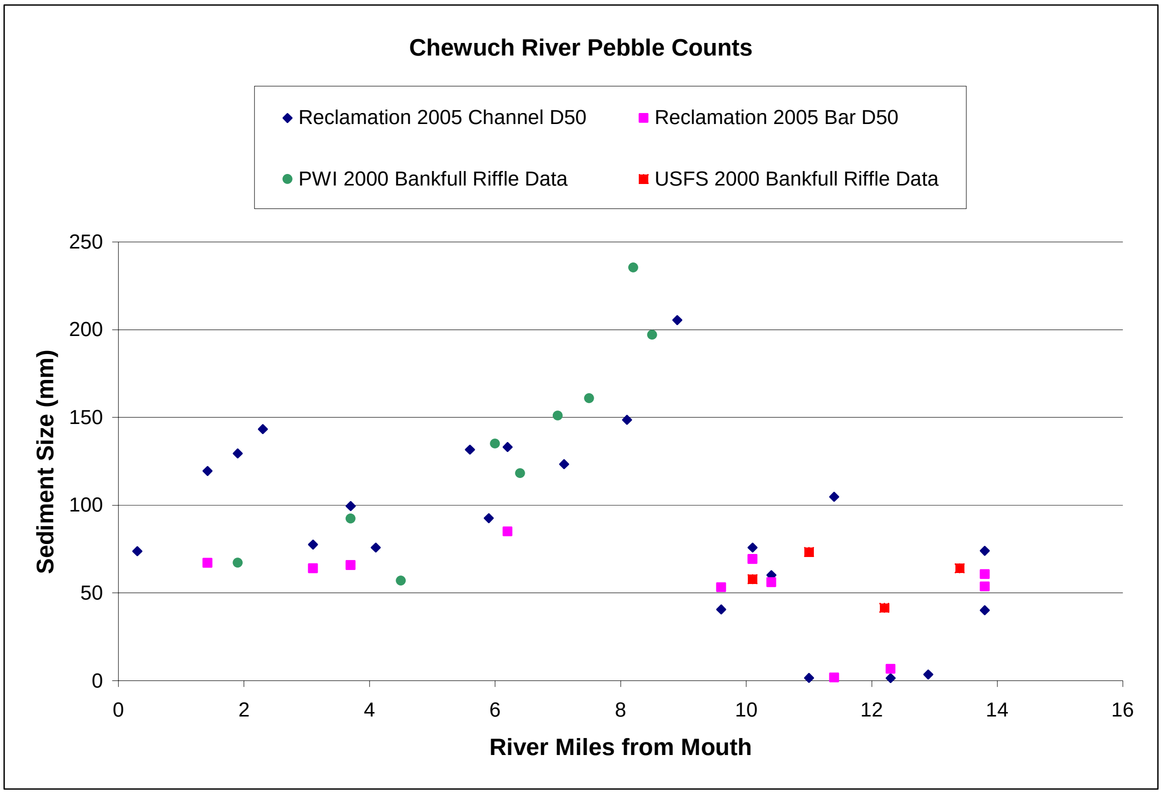


Figure K–30. Chewuch River – Comparison of new 2005 pebble count D_{50} data with data collected by recent studies.

5.7 INCIPIENT MOTION

Figure K–31 shows the incipient motion calculations for the Chewuch River assessment reach. The incipient motion analysis shows a less frequent ability to mobilize bed material downstream of RM 6. The channel is capable of moving larger sized sediment downstream of RM 9 relative to the upstream reach RM 9–14.

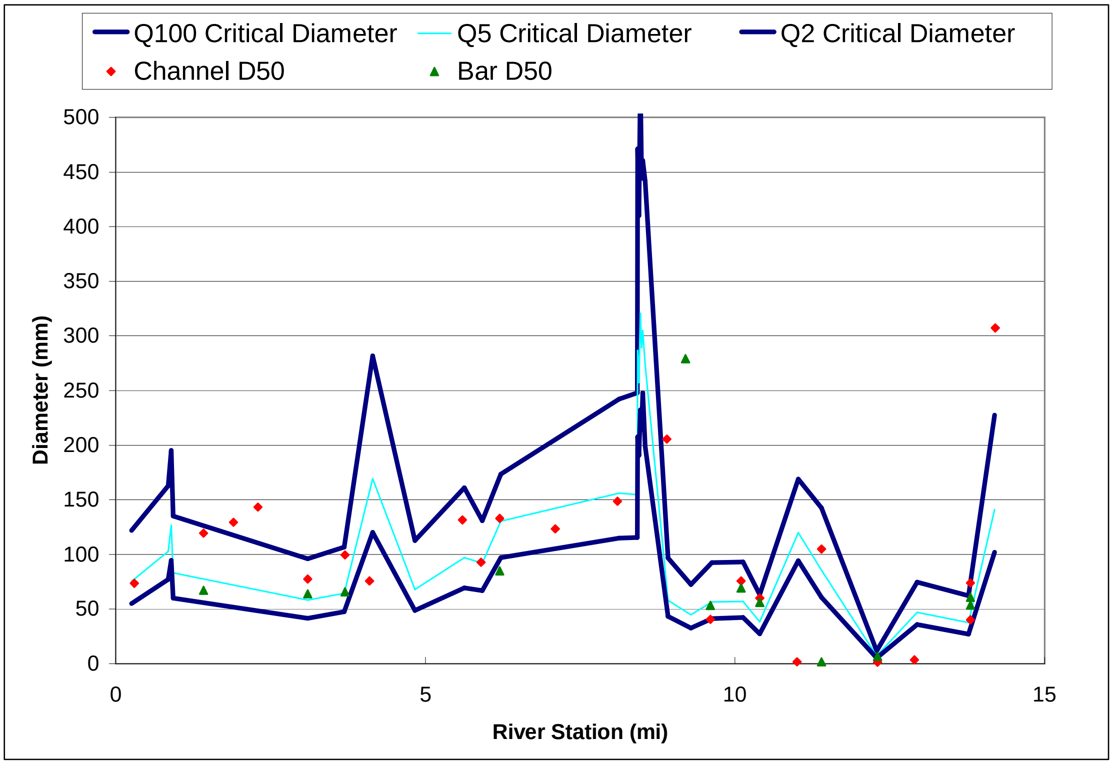


Figure K–31. Chewuch River – Incipient motion, channel, and bar D_{50} by river mile.

5.8 WIDTH TO DEPTH RATIO

The active channel wetted width to depth ratio was computed for the 2-year flood (

Figure K–32). In general, wetted widths are an order of magnitude larger than wetted depths at the 2-year flood. This means the width to depth ratio is mostly dependent on fluctuation in active channel width. The width of the entire active floodplain is presented separately in the main report, and is often larger because it includes all wetland and overflow channels. For the Chewuch River, the channel generally has a width to depth ratio from 10 to 40. At RM 12.3 the width to depth ratio is much larger where the cross-section captures a large split flow not typical of the assessment reach as a whole. Computed wetted widths (not plotted) range from 70 to 250 feet, with the exception of RM 12.3 with a wetted width of 670 feet. Widths of the entire active floodplain measured from aerial photography range from 80 to 1960 feet.

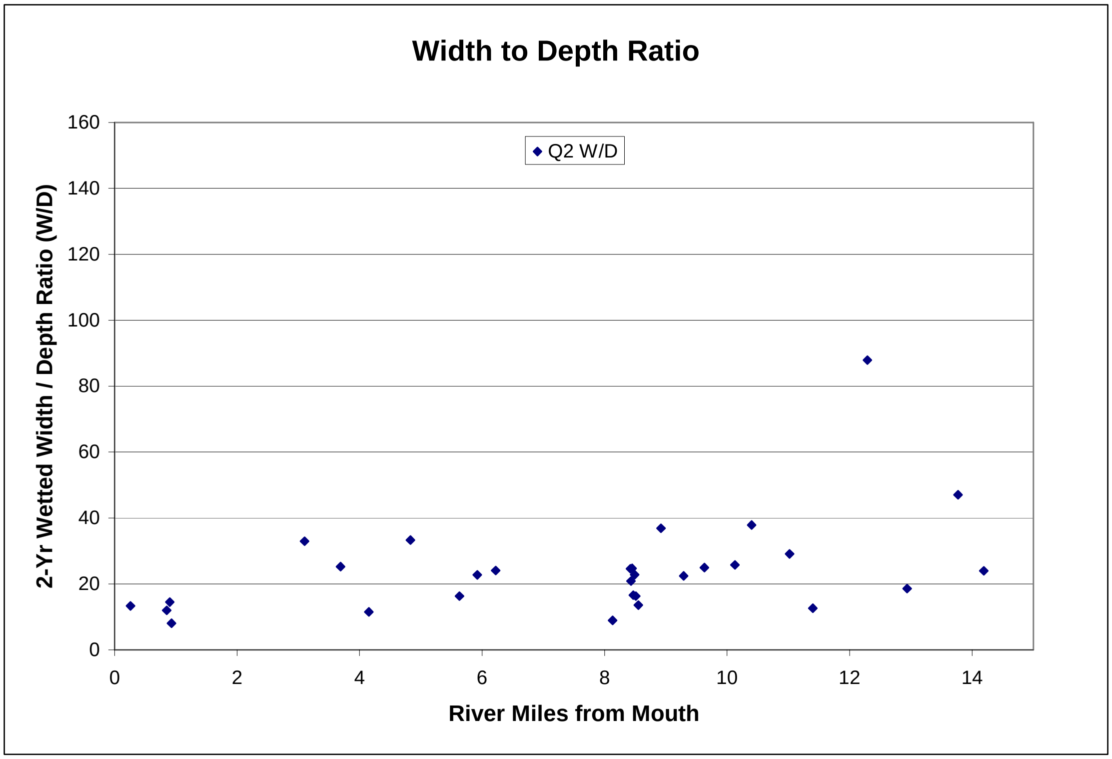


Figure K–32. Chewuch River – Active channel wetted width to depth ratio.

5.9 HISTORICAL CHEWUCH RIVER SURVEY DATA COMPARISON

The 2005 measured water surface elevation data was compared to 46 water surface elevation contours from a 1912 USGS survey map to evaluate potential channel elevation changes over nearly a century time period (see Attachment B for profile comparison plots). Overall the 1912 contour elevations matched fairly closely with the 2005 data. Of the 46 contour locations between RM 0.5 to 8.5, there were 4 locations where no data was collected in 2005. Three of the contour locations are affected by the Fulton Dam crest and backwater, although a dam was shown at this same location in 1912 at a crest height 3 feet lower than the present dam. Of the remaining 39 contour locations, 31 had changes in water surface elevation less than 1.5 feet, and 8 had changes from 2.0 to 3.5 feet. No reach-based trend in aggradation or incision was observed from this elevation comparison. Channel position on the 1912 USGS map and subsequent aerial photographs between 1954 and 2004 were used to determine the amount of change in channel planform at the contour locations. All but one of the 8 sections with change greater than 2 feet did have at least a small amount of channel position change. It is difficult to positively correlate the channel change with planform change from just a historical map that does not show the details of depositional features or split flow characteristics.

5.10 FINE SEDIMENT ANALYSIS

Excessive amounts of fine sediment in spawning gravels can cause problems to fish redds and fry survival because the sediment prevents flowing water to supply oxygen. Analysis of fine sediment levels was beyond the Reclamation scope of work, but key findings from work accomplished by the other studies is documented below. Monitoring of fines on the Chewuch River is of particular interest for habitat because of recent fires that have occurred in the upper basin.

The Methow Valley Ranger District monitors the percentage of surface fine sediment in the Chewuch River between RM 9.5 to 36.4 to evaluate possible impacts to habitat management parameters. Sediment surveys are done by conducting pebble counts in spawning riffles (two counts in each of 13 reaches identified) to evaluate the percentage of fines less than 6 mm in the surface material. The USFS stream survey study found that surface fine sediments are at or exceed the referenced guideline from RM 9.5–18, RM 29.3–33.7, and in RM 34.6–36.2 (USFS, 2002). These reaches are the low gradient (<1%) segments of the river. Surface fine sediments were far less abundant in the stream segments with a gradient greater than 1% (Cross, 2005).

Other monitoring of fine sediment levels are done using “embeddedness” surveys in pools. Embeddedness is defined by the USFS as surface small cobble and coarse gravel substrate that is > 35% buried in sediment. Within RM 9.5–14 (upstream portion of Reclamation assessment reach), the USFS noted that a mile-long segment below the confluence with Eightmile Creek showed signs of embeddedness (USFS, 2002). It was believed this was caused by a local sediment source supplied from Eightmile Creek.

The Thirtymile Fire (2001) burned approximately 9,324 acres and the Farewell Fire (2003) perimeter included approximately 79,000 acres of the upper Chewuch watershed. A series of cloud bursts in the summer of 2004 in the two fire areas triggered landslides that muddied the water for weeks and covered substrate with a layer of sand (Cross, 2005). Two sediment pulses were subsequently observed by USFS biologists in the Chewuch watershed at the Thirtymile Memorial (near RM 30) and Andrews Creek (confluence near RM 26). Multiple slides were noted on Lake Creek (confluence near RM 23) that are expected to reach downstream areas of the Chewuch watershed in the next 10 years (Cross, 2005). McNeil core sediment sampling by USFS in 2004 did not show any effect on levels of fine sediment in spawning gravels in the Chewuch River that might be expected from the fires, but the 2005 samples appeared to have slightly elevated levels that may be a signature of the fires (Cross, 2005). Much of the east side of the Chewuch watershed (about 175,000 acres) was included within the perimeter of the Tripod fire of 2006.

The USFS has annually monitored salmonid spawning gravel composition in the Chewuch River using McNeil core samples since 2000 (MVRD, 2007). Four sites are sampled on the Chewuch River, with only Site 1 (RM 9.3) within the Reclamation assessment reach. In each reach, samples are done at 3 riffles known to be used for spawning. Overall, the Chewuch River is considered functioning at risk for fine sediment in spawning gravel. Although reaches 1 and 4 are above the 20% criteria established by the FWS, the functional rating is not "functioning at an unacceptable risk" since the high amount of sediment is from natural causes (fire and landslides). The data collected in 2006 shows the mean percent fine sediment <0.85mm to be greater than 12% and less than 28% for all reaches. For the RM 9.3 site, quantity of fines less than 0.85 mm has averaged to be 15.0% between 2000 and 2004 and to be 20.7% from 2005 and 2006 samples, a 38% increase from the previous four years (MVRD, 2007). The upstream three samples sites also showed a positive increase in fines from the two time periods.

5.11 CONCLUSIONS

Overall the Chewuch River has much larger variations in slope than width and discharge within the assessment reach. These variations in slope are the biggest factor in fluctuations in sediment transport capacity. Historical survey data for RM 0 to 8.5 suggest less than 1.5 feet of vertical channel change in most locations since the early 1900s. A few locations did have up to 3.5 feet of change, which is likely due to changes in channel position or inaccuracies in adjusting the 1912 data positions to match 2005 locations. This suggests reach-scale incision has not occurred from RM 0 to 8.5 despite the steep slopes and human features that have altered the floodplain connectivity. Additional incision is not anticipated due to armoring of the channel bed and geologic controls (bedrock).

The Chewuch River reach from RM 10 to 14 contains slopes ranging from 0.002 to 0.007 with average bar and channel sediment sizes of very coarse gravel. The 2-year flood generally is capable of mobilizing the channel and bar surface sediment, but some locations show variations with much finer or coarser material. This indicates that in this reach the majority of active channel and bar sediment is available to be mobilized and transported downstream on a frequent basis.

The Chewuch River reach from RM 6 to 10 contains slopes from 0.006 to 0.018 with average bar and channel sediment sizes of small cobble. Minimal sediment bars in this reach indicates there is little sediment in storage that can be accessed by the river during floods. Mobilization of the channel bed requires flows greater than the 5-year flood. This implies this reach presently has sediment transport capacity in excess of the sediment supply from upstream. In other words, the finer-sized sediment transported into this reach from the upstream RM 10 to 14 is transported through to the next downstream reach and does not reside in the channel for any significant length of time.

The slopes in the lower reach from the mouth to RM 6 range from 0.004 to 0.007. Bar material consists of very coarse gravel, and channel material of small cobble. Bars generally can be mobilized at the 2-year flood, while mobilization of the channel bed requires flows greater than the 5-year flood.

6. SUMMARY

Table K–3 shows the range of discharges and measured slopes for the three basins. The Twisp and Chewuch Rivers have a much wider range of slopes than the Methow River within the assessment area.

Table K–3. Range of Discharges and Slopes.

River	2-Year flood peak (ft^3/s)	100-Year Flood Peak (ft^3/s)	Slope (ft/ft)
Methow (RM 28.1–76)	3,700-10,300	7,400-32,800	0.003-0.007
Chewuch (RM 0–14)	2,400-3,200	6,900-9,400	0.002-0.018
Twisp (RM 0–17)	1,100-2,300	3,200-6,800	0.0016-0.014

The Methow River has a gradually decreasing slope within the assessment area that balances out increasing discharge in the downstream direction. The largest discharge change on the Methow River is at the confluence of the Chewuch River. This increase in discharge is compensated for by a decreasing slope such that sediment transport capacity remains relatively constant even with the large increase in flow. Sediment sizes present in the Methow River channel bed and bars are more sensitive to fluctuations in wetted width than to slope changes.

The Twisp and Chewuch Rivers each have a unique geologic feature that causes a significant slope change within the assessment areas at about RM 9 to 10. The result is flatter sloped reaches upstream of the slope break and steeper sloped reaches downstream. Consequently, the sediment sizes in the channel bed and bars on the Twisp and Chewuch Rivers are largely influenced by slope, with only minimal influence from changing discharge. The Twisp River has a wider range of wetted width values than the Chewuch River, which is naturally more confined throughout the assessment reach. This range in wetted widths also influences the size of sediment present in the channel bed and bars.

Mobilization of sediment is related to processes of channel reworking, floodplain interaction, and bar formation. Table K–4 and Table K–5 provide a summary of average measured bar and channel sediment sizes and the flood frequency required to move these particles. Results are provided based on major breaks in relative sediment transport capacity along each basin assessment area. Each reach has local variations within these averages. Three sections appear to be the most frequently reworked — Twisp RM 9–17, Methow RM 25–38, and Methow RM 55–72. These reaches may require additional analysis to ensure sediment processes do not prevent projects from meeting their intended objectives. Smaller material with more frequent reworking is more sensitive to hydraulic changes caused by modification to the channel geometry. Reductions in transport capacity may cause deposition or constrictions may more easily initiate incision. Hydraulics and sediment properties in other reaches are likely to have smaller sensitivity to removal of human features or structures.

In general, the Chewuch and Twisp Rivers upstream of the large slope breaks at RM 9–10 within the assessment area provide more opportunity for sediment storage and frequent channel reworking (2-year flood) that allows this sediment to be supplied to downstream reaches. On the Chewuch and Twisp Rivers, the middle reaches shown in Table K–4 are steeper than upstream reaches. Sediment sizes present in the channel and bed in the middle reaches are 2 to 3 times larger than the upstream storage sections. This indicates the majority of smaller-sized sediment supplied to these reaches from the upstream storage area is being transported through the reach. The downstream-most reach of the Chewuch River has a fairly armored channel that is reworked less frequently than bars (where present). The mouth of the Twisp River is depositional but requires a 10-year or greater flood to rework the channel and bars.

Upstream of the confluence with the Chewuch River, the Methow River is on average reworked at a 2-year flood, but downstream it takes a 5-year flood or greater on average to rework the bed and bars. The average sediment sizes in the bar and channel is fairly consistent throughout the Methow assessment area, but many local variations occur when looking at the data at a finer scale. These local variations appear to be correlated with changes in floodplain width.

Table K–4. Incipient Motion Summary.

River	Reach	Bar D_{50}	Chan. D_{50}	Q_2 $D_{critical}$	Q_5 $D_{critical}$.	Q_{100} $D_{critical}$
Chewuch	RM 0–5.5	66	106	68	94	150
	RM 5.5–9.5	182	141	180	241	380
	RM 9.5–14	43	45	41	55	88
Twisp	RM 0–1.5	54	64	41	48	80
	RM 1.5–9.8	127	136	109	136	220
	RM 9.8–17	48	61	57	73	122
Methow	RM 28–50	80	85	70	93	152
	RM 50–70	78	79	75	93	128
	RM 70–76	93	83	92	114	160

Table K–5. Minimum flood frequency at which typical bar and channel sediment sizes are mobilized.

River	Reach	Bar D_{50}	Chan. D_{50}
Chewuch	RM 0–5.5	2-yr	10-yr
	RM 5.5–9.5	2-yr	2-yr
	RM 9.5–14	2-yr	2-yr
Twisp	RM 0–1.5	10-yr	25-yr
	RM 1.5–9.8	5-yr	5-yr
	RM 9.8–17	2-yr	2-yr
Methow	RM 28–50	5-yr	5-yr
	RM 50–70	2-yr	2-yr
	RM 70–76	2-yr	2-yr

7. CONCLUSIONS

The hydraulics and sediment evaluation used a combination of measured data, field observations, and surrogate parameters to evaluate the present ability of the river to rework the channel and adjacent sediment bars. Historical survey data was also utilized in some reaches to compare changes in channel bed elevations over time. This data was able to provide answers to many of the geomorphic questions for selecting project sites.

Removal of human features can achieve restoration of floodplain access and complexity that is now absent in many locations without risking impacting the baseline morphology of the channel. The river hydraulics and sediment sizes present along the channel bed within the assessment area are most notably dominated by geologic controls that control the river bed slope and the lateral extent of the active channel and floodplain (width). There appears to be adequate sediment available to the system from tributaries and from sediment in storage (bars and floodplain) in a range of sizes from sand to cobble. Supply of finer-sized spawning sediment is often episodic following fires, ice jams, or high spring runoff events that induce landslides, debris flows, and mobilize sediment in bars and banks. The ability of the river to rework the channel and bar sediment and access the floodplain is closely tied to geologic influences.

Human features and historical human activities that have disrupted floodplain connectivity and altered the riparian zone do not appear to have altered channel slopes and bed sediment characteristics on a reach scale. Even though human impacts can not be detected on reach-based hydraulics and sediment characteristics, they have impacted localized hydraulics, complexity within the floodplain, and spawning-sized sediment availability that are critical to habitat quantity and quality. Hydraulic conditions have been most impacted by reducing flow access to off-channel areas at the entrance to side channels, and to some degree altering access to overbank flooding. In-channel or bankline features may be added to create local pockets of backwater and deposition of spawning size sediments. These features may be successful in improving habitat conditions, but will not alter channel slope and sediment transport along a given reach.

Historical survey data and geomorphic observations and mapping were used to evaluate the potential changes in the channel bed elevation over a decadal time period. The channel bed elevations appear stable in most locations with minimal or no detectable channel bed incision or aggradation on a decadal scale. In many locations cobble-sized bed material that takes large flows to mobilize limits the potential for incision. Bedrock is also exposed in some locations which also limits the potential for incision. Localized changes do occur in areas where the channel changes course and sediment is eroded and deposited across the floodplain.

The presence of sediment bars in areas where the floodplain is not confined suggests sediment has historically been adequately supplied from upstream reaches. In most locations the bars and channels are being reworked at the 2- to 5-year flood which indicates there is a good potential to jump start lateral reworking of the floodplain once human features are removed to allow access.

The present sediment analysis provides information on vertical channel stability, flows required to mobilize channel and bar sediment, and relative transport capacity among assessment reaches. The analysis does not quantify the amount of material moving through the system or predict the geomorphic impacts associated with altering transport characteristics once floodplain areas are re-opened through removal of flood protection features. Quantitative sediment budget and modeling tools are available that could be applied to address these questions at a localized project area and to address the interaction of sediment among adjacent project areas if needed.

8. REFERENCES

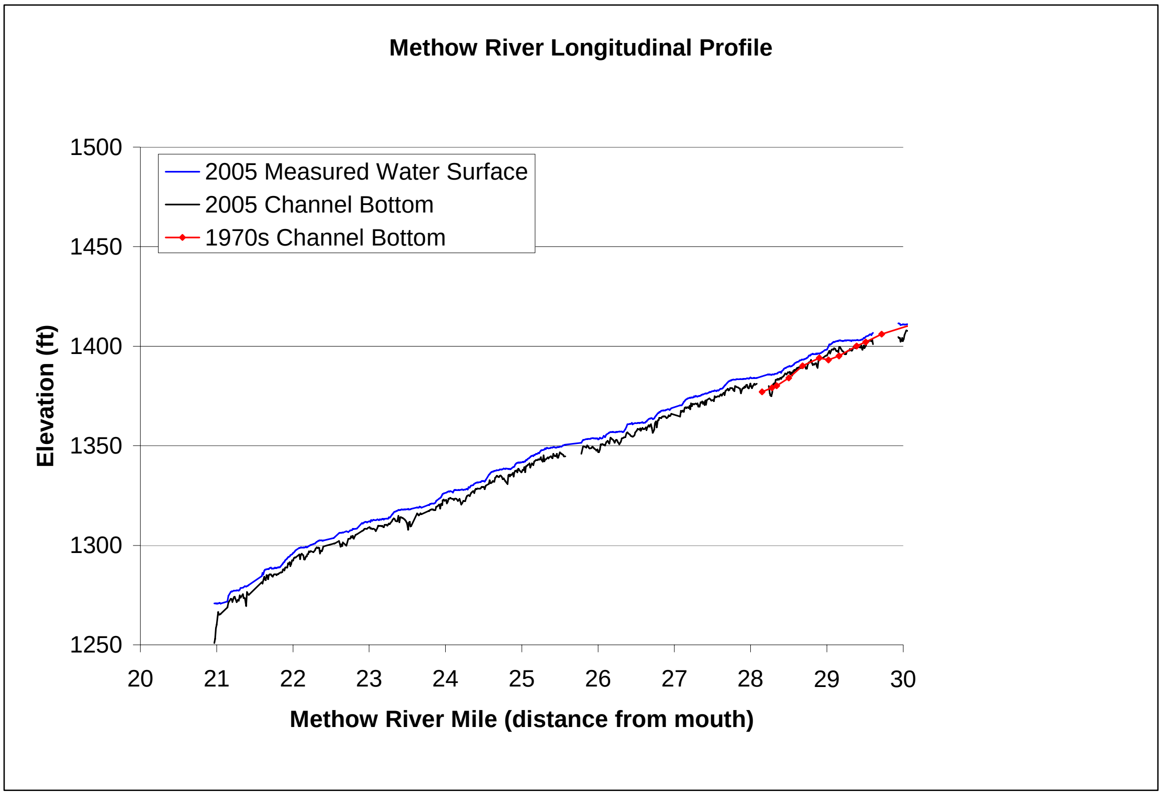
IN TEXT	FULL CITATION
Bagnold 1966	Bagnold, R.A. 1966. *An Approach to the Sediment Transport Problem from General Physics*: US Geological Survey Professional Paper 422-1, Washington.
Beck 1973	R.W. Beck and Associates. 1973. *Flood plain information, Methow River, Twisp to Mazama, Okanogan County, Washington:* R.W. Beck and Associates, Analytical and Consulting Engineers, Seattle, WA. Report prepared for Washington Department of Ecology, Olympia, WA. 13 p., 20 figures.
Caldwell and Catterson 1992	Caldwell, B. and Catterson, D., 1992, *Methow River Basin fish habitat analysis using the instream flow incremental methodology:* Washington Department of Ecology, Olympia, WA. Publication No. 92-82, 196 p.
Cross 2005	Cross, D.M. 2005. *Sediment monitoring report, 2000-2005, Chewuch River and Twisp River.* US Forest Service, Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA, 29 p.
FEMA 2003	Federal Emergency Management Agency. 2003. *Flood insurance study: Okanogan County, Washington, unincorporated areas.* January 2003 revision.
Golder 2002	Golder Associates, Inc. October 31, 2002. *Draft report on streamflow and channel analysis Chewuch River*, submitted to Chewuch Basin Council, Winthrop, WA.
Golder 2005	Golder Associates, Inc. 2005. *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Julien 1995	Julien, P.Y. 1995. *Erosion and sedimentation:* Cambridge University Press.

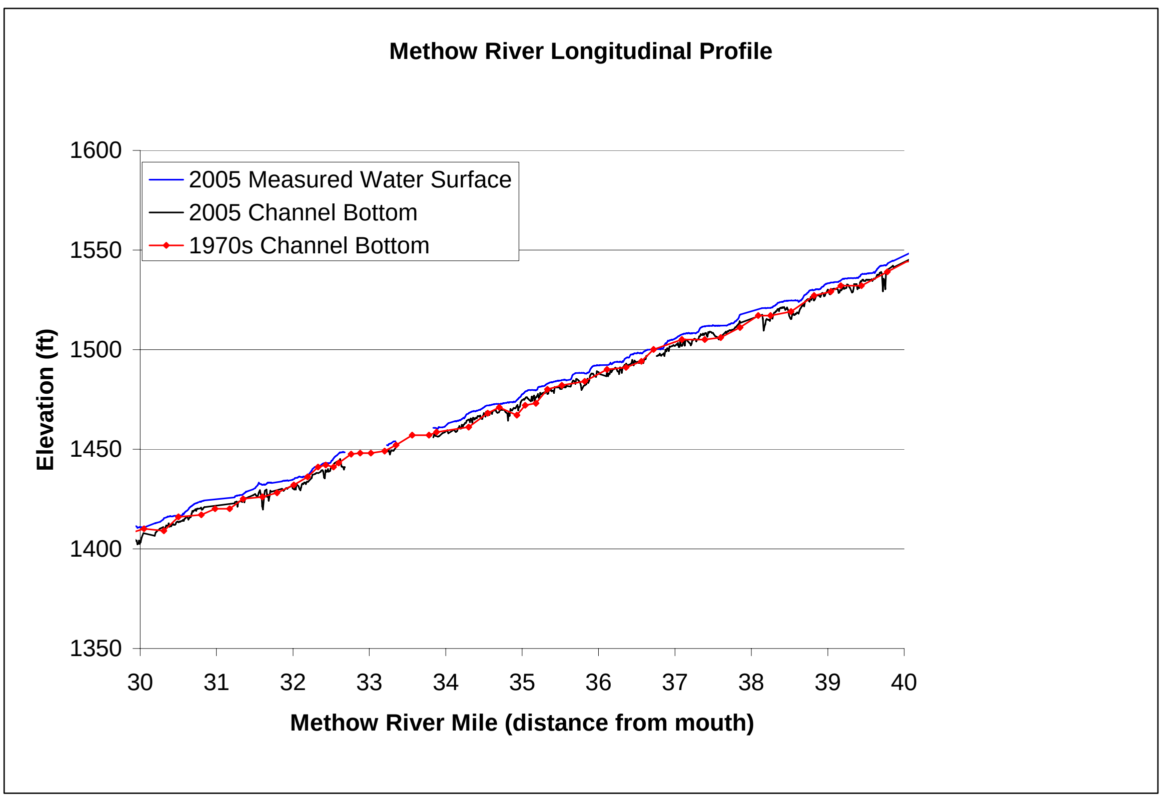
IN TEXT	FULL CITATION
Marshall 1915	Marshall, R. 1915. *Profile surveys in Chelan and Methow River Basins, Washington*: US Geological Survey Water-Supply Paper 376.
MVRD 2007	Methow Valley Ranger District. Revised June 2007. *Sediment Monitoring Report: 2000 to 2006, Chewuch River and Twisp River.* Winthrop, WA.
Norman 1974	Norman Associates. 1974. *Flood plain information, Methow River, Twisp to Carlton, Okanogan County, Washington.* Report prepared for County of Okanogan Office of Planning and Development, Okanogan, WA, by Norman Associates Consulting Engineers, Bellevue, WA, 12 p., 10 figures.
PWI 2003	Pacific Watershed Institute. 2003. *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.
PWI 2004a	Pacific Watershed Institute. March 28, 2004. *Chewuch River: Restoration Monitoring Project 2000-2003 Final Report,* Prepared for US Fish and Wildlife Service, Western Regional Office.
PWI 2004b	Pacific Watershed Institute. October 28, 2004. *Chewuch River: Channel Baseline Monitoring Report.* Prepared for Methow Valley Ranger District, USFS Cooperative Agreement #134100J008.
Sutley 2006	Sutley, D.E. 2006. *Methow River Drainage Basin: Hydrology Data and GIS.* Bureau of Reclamation Technical Service Center, Denver, CO. [Included as Technical Appendix J]
USFS 2002	US Forest Service. 2002. *Chewuch River stream survey summary.* Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.
Yang 1996	Yang, C.T. 1996. *Sediment Transport Theory and Practice*: McGraw-Hill Companies, Inc.

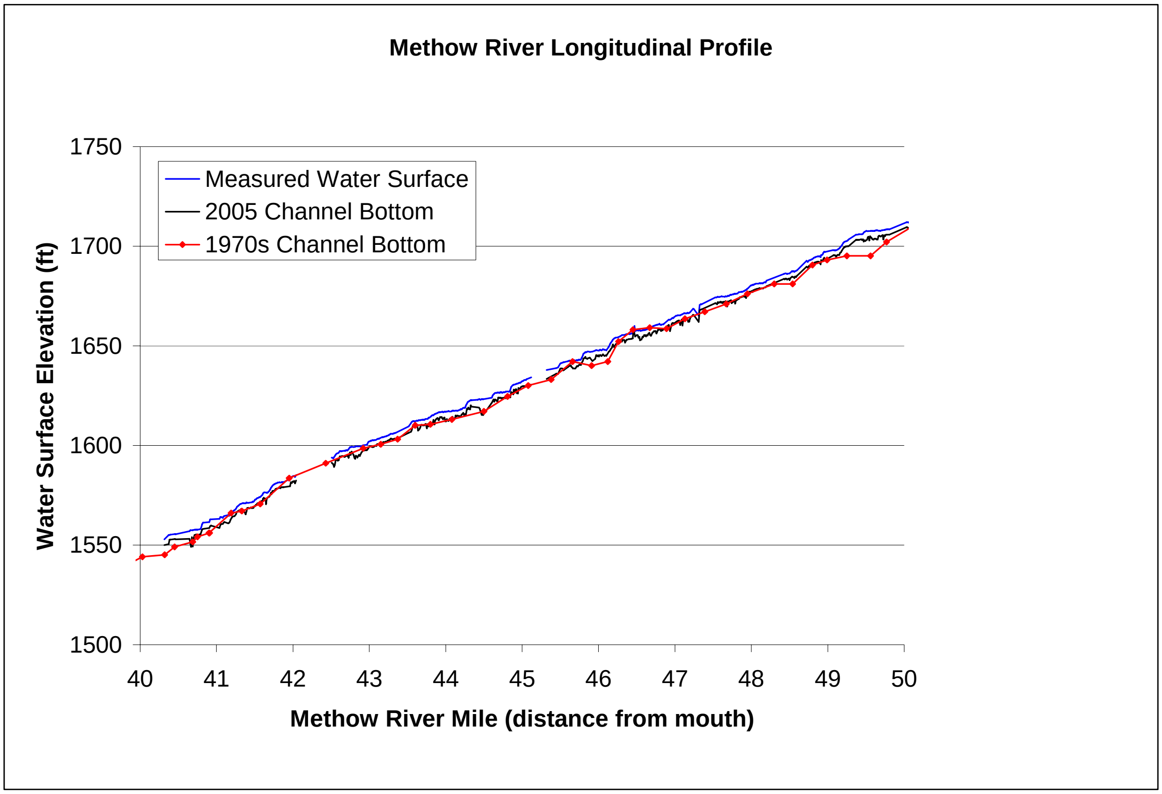
9. ATTACHMENT A – HISTORICAL COMPARISON OF METHOW RIVER LONGITUDINAL PROFILE

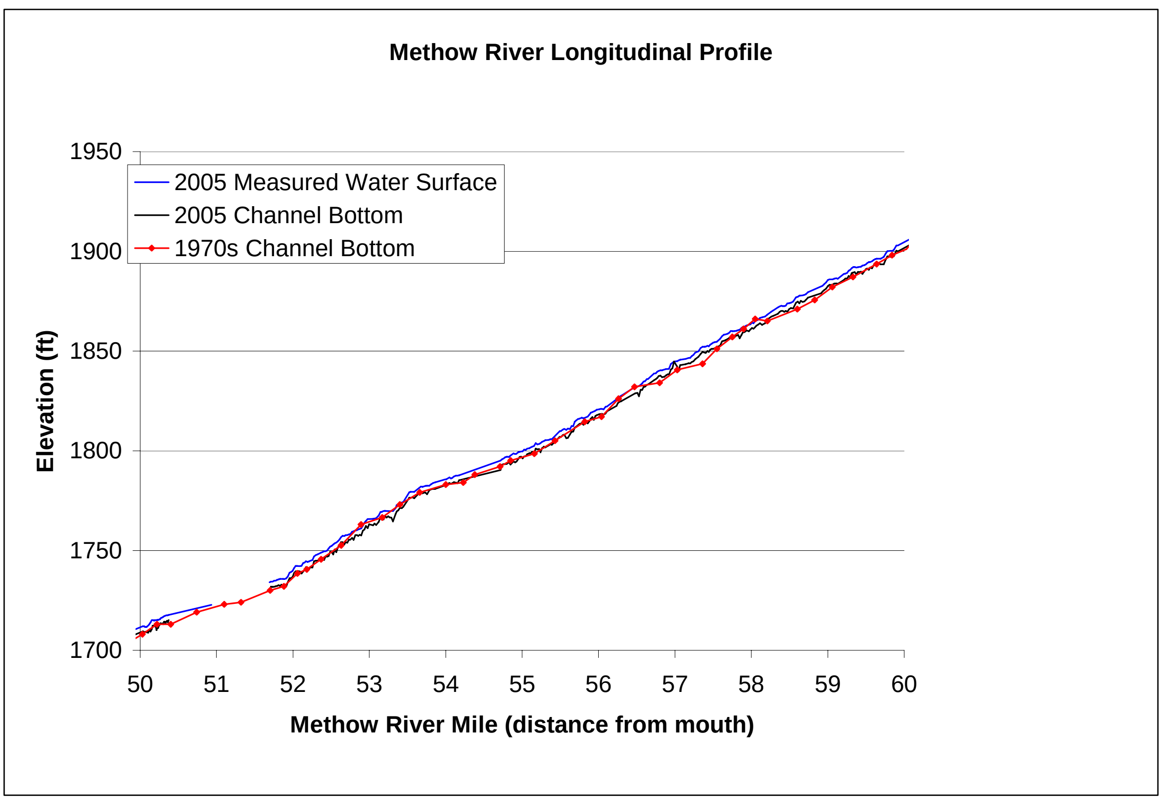
The following table and figures show documentation of Methow channel bed changes greater than 2 feet based on 1970s and 2005 data comparison. Positive change represents a higher elevation in 2005; negative change represents a lower elevation in 2005.

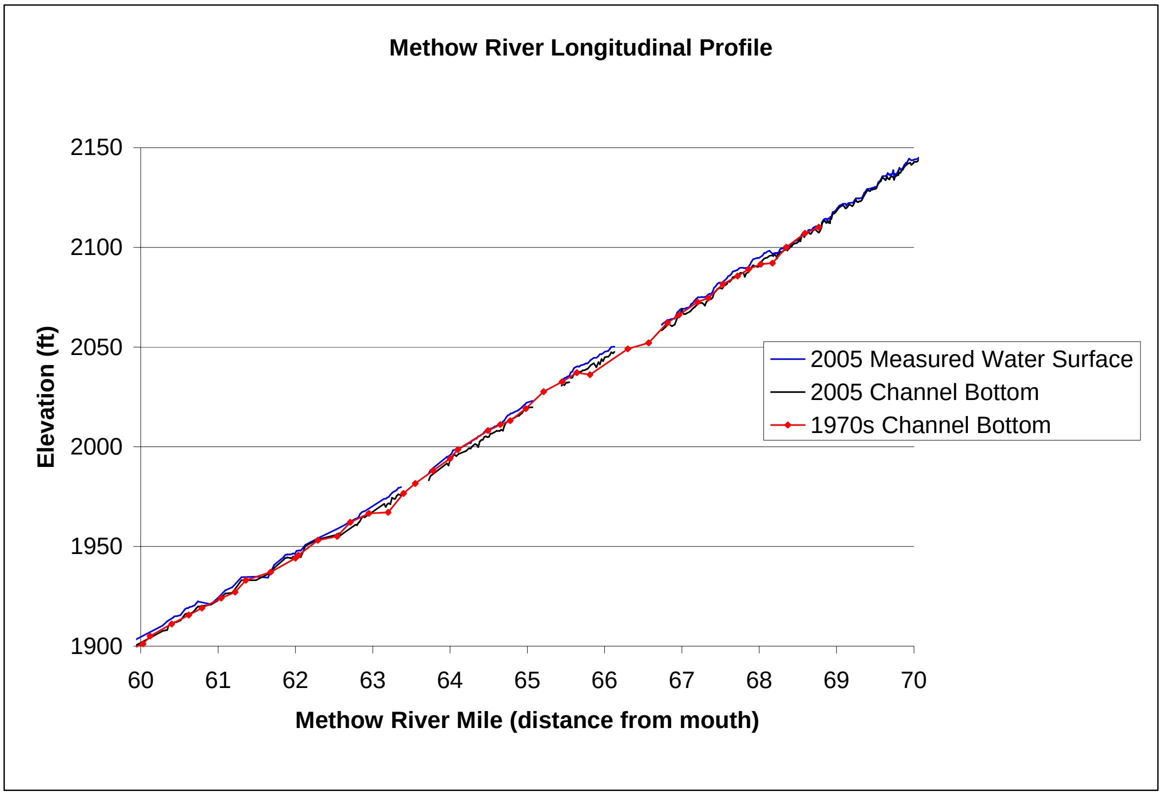
Profile River Mile	1970s thalweg elevation (feet)	2005 channel bottom elevation (feet)	Elevation Change (feet)	Aerial Photograph Comparison
45.9	1640.1	1643.4	3.3	Just below confluence of side and main channel below MVID East dam; side channel has enlarged since 1974 and more bar deposition observed in 2005 than 1974 just below where 2 channels come together; new survey data in 2006 indicates the 2005 profile data may be erroneous in this location
46.1	1642.1	1645.0	2.9	In main channel just upstream of confluence described in 45.91
46.7	1659.1	1657.0	-2.1	About 1000 feet us of MVID East Dam
49.3	1695.1	1700.0	4.9	In main channel near center of split flow (side channel on river right); side channel existed in 1974, but small prior to 1948 flood
49.6	1695.0	1703.5	8.5	No obvious reason for difference; survey error?
49.8	1702.1	1705.0	2.9	Dynamic mid-channel longitudinal bar that is variable in presence between 1945 and 2004; not present in 1974, present in 2004
52.9	1763.1	1760.0	-3.1	Almost 1 mile us of Chewuch confluence adjacent to Winthrop hatchery; split flow that has been dynamic between 1945 and 2004; river eroded left bank between 1945 and 1974 but has been stable since 1974 to 2004 (riprapped)
56.5	1832.1	1828.9	-3.2	Large split flow; channel has shifted from majority of flow down left channel in 1974 to right in 2004
57.4	1843.6	1848.6	5.0	New channel formed since 1974 (area of channel migration)
58.1	1866.1	1862.0	-4.1	Split flow in 1974 but now majority of flow in one channel
63.2	1967.1	1971.1	4.0	Downstream end of confluence of side and main channel; side channel appeared more recently active in 1974 (possibly due to 1972 flood)
65.8	2036.1	2040.8	4.7	Located on outside of channel meander bend that has been migrating to the left
68.2	2092.1	2095.3	3.2	Just us of bridge at Mazama; bridge present back to 1945 but appeared to be improved (wider deck) between 1974 and 2004


Methow River Longitudinal Profile
2005 Measured Water Surface
2005 Channel Bottom
1970s Channel Bottom
Elevation (ft)
1250
1300
1350
1400
1450
1500
20 21 22 23 24 25 26 27 28 29 30
Methow River Mile (distance from mouth)


Methow River Longitudinal Profile
2005 Measured Water Surface
2005 Channel Bottom
1970s Channel Bottom
Elevation (ft)
1350
1400
1450
1500
1550
1600
30 31 32 33 34 35 36 37 38 39 40
Methow River Mile (distance from mouth)


Methow River Longitudinal Profile
Measured Water Surface
2005 Channel Bottom
1970s Channel Bottom
Water Surface Elevation (ft)
1750
1700
1650
1600
1550
1500
40
41
42
43
44
45
46
47
48
49
50
Methow River Mile (distance from mouth)


Methow River Longitudinal Profile
2005 Measured Water Surface
2005 Channel Bottom
1970s Channel Bottom
Elevation (ft)
1950
1900
1850
1800
1750
1700
50
51
52
53
54
55
56
57
58
59
60
Methow River Mile (distance from mouth)

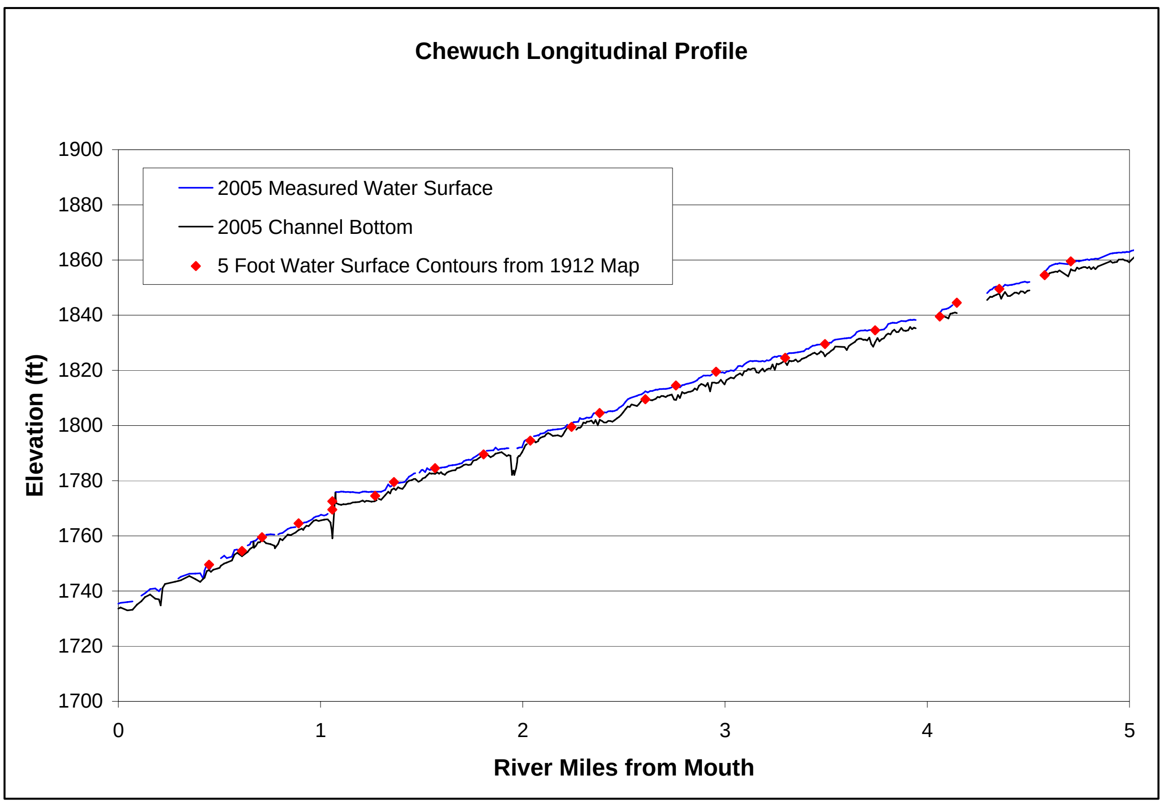

Methow River Longitudinal Profile
2150
2100
2050
2000
1950
1900
Elevation (ft)
60
61
62
63
64
65
66
67
68
69
70
Methow River Mile (distance from mouth)
2005 Measured Water Surface
2005 Channel Bottom
1970s Channel Bottom

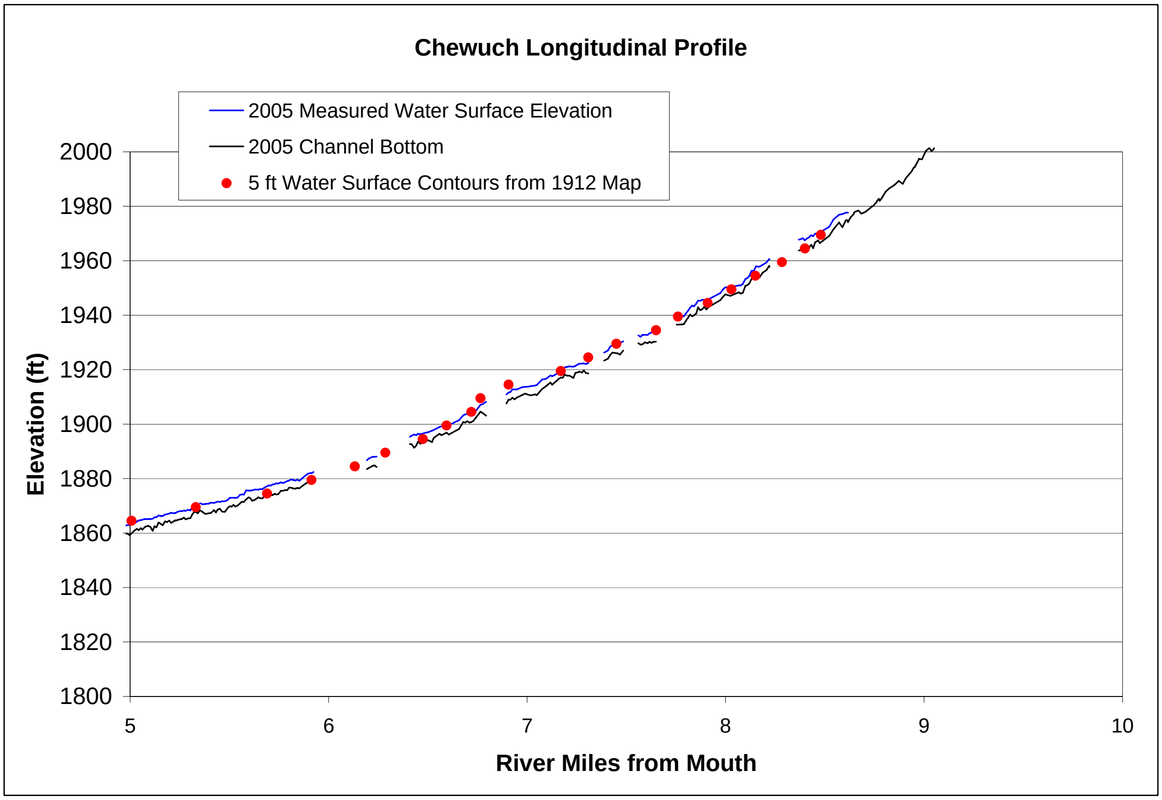
10. ATTACHMENT B – HISTORICAL COMPARISON OF CHEWUCH LONGITUDINAL PROFILE

Appendix K's Attachment Table B-1 (below) is a comparison of 1912 and 2005 water surface elevation data on Chewuch River from RM 0 to 8.5. Cells in yellow denote locations with greater than 2 feet of elevation change. Positive change represents a higher elevation in 2005; negative change represents a lower elevation in 2005.

Profile River Mile	**Elevation Change** (feet)	**Comparison of lateral channel change between 1912 map and 2004 aerial photograph**
0.4489	-0.1	Geologically confined; no change in position
0.6116	-0.5	Geologically confined; no change in position
0.7105	0.7	Geologically confined; no change in position
0.8909	-1.0	Geologically confined; no change in position
1.0580	No 2005 data	Dam noted on map; crest 3 feet lower in elevation than present 2005 dam crest
1.2700	1.5	Affected by backwater of Fulton Dam
1.3630	-0.6	Geologically confined; no change in position
1.5660	-0.2	Geologically confined; no change in position
1.8060	1.0	Geologically confined; no change in position
2.0370	1.0	Geologically confined; no change in position
2.2410	1.3	No change in position
2.3800	0.2	No change in position
2.6060	2.9	No change in position
2.7570	-0.7	No change in position
2.9560	-1.2	Small changes in position
3.2970	1.4	Small changes in position
3.4940	0.2	Small changes in position
3.7420	0.0	Small changes in position
4.0620	1.4	Small changes in position
4.1460	-0.3	Small changes in position
4.3560	1.2	Small changes in position
4.5800	1.3	Small changes in position
4.7100	-0.4	Small changes in position
5.0073	-1.2	Different flow path
5.3310	1.1	Different flow path
5.6900	3.0	Different flow path
5.9140	2.5	Different flow path
6.1324	No 2005 data	No change in position
6.2855	No 2005 data	No change in position
6.4750	No 2005 data	No change in position
6.5940	-0.3	Longer meander in 1912; straight path in 2005
6.7190	-0.5	Longer meander in 1912; straight path in 2005
6.7650	-2.4	Small changes in position
6.9070	-2.9	Small changes in position

Profile River Mile	Elevation Change (feet)	Comparison of lateral channel change between 1912 map and 2004 aerial photograph
7.1700	0.7	Different flow path
7.3080	-2.1	Different flow path
7.4500	-0.5	Different flow path
7.6500	-0.5	Small changes in position
7.7600	0.5	Small changes in position
7.9100	1.3	Small changes in position
8.0300	0.9	Small changes in position
8.1500	3.4	Small changes in position
8.2844	No 2005 data	Small changes in position
8.4000	3.0	Small changes in position
8.4800	0.8	Small changes in position




Chewuch Longitudinal Profile
2005 Measured Water Surface Elevation
2005 Channel Bottom
5 ft Water Surface Contours from 1912 Map
Elevation (ft)
2000
1980
1960
1940
1920
1900
1880
1860
1840
1820
1800
5
6
7
8
9
10
River Miles from Mouth

APPENDIX L –
FIRE HISTORY

This appendix provides background information that describes the history of fire occurrence in the Methow Subbasin from the 1700s to present. The majority of information presented in this section has been provided by the USFS.

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LIST OF FIGURES

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There are no tables in this Appendix L.

1. FIRE HISTORY

Fires occur annually in the Methow Subbasin, and major fires spanning large areas are frequent. The areas that have burned have been documented since the 1700s (Figure L– 1 thru Figure L– 6). Some fires extended outside of the Methow Subbasin, but only the portion within the subbasin are shown. The low surface boundary shows the extent of the nearly 80-mile assessment area discussed in this technical report.

Based on data compiled by Okanogan County, nearly 40% of the Chewuch watershed burned in the 1700s and 1800s, but only about 10% each of the Twisp watershed and the Methow watershed burned during this time period (Figure L– 1). Between 1890 and 1910, about 3% of the Chewuch watershed burned and about 1% of the Methow watershed burned (

Figure L– 2). Fires during this time period were concentrated in the upstream portions of the watersheds.

The next year in which fire information is available from Okanogan County is 2001 (

Figure L– 3). The Thirtymile Fire burned about 3% of the Chewuch watershed, about 9,324 acres. The Libby South Fire, which was smaller, burned about 1% of the Methow watershed that year.

In 2002, the only fire noted in the Methow Subbasin was the Middle Quartz Mountain Fire, which burned about 1% of the Methow watershed (Figure L– 4).

In 2003, two large fires and several smaller ones burned about 24% of the Chewuch watershed (mostly the Farewell Fire) and about 3% of the Methow watershed (mostly the Needles Fire) (Figure L– 5). The Farewell Fire perimeter included approximately 79,000 acres of the upper Chewuch watershed.

Major wildfires have burned (with varying intensities) in 70% of the Chewuch subwatershed in 2001, 2003 and again in 2006 (MVRD, 2007). Both the 2001 Thirtymile Fire and the 2003 Farewell Fire resulted in a major alteration of the upper Chewuch subwatershed. The 2006 Tripod Complex Fire burned about 175,000 acres along the divide between the Chewuch or Methow Rivers and the Okanogan Subbasin to the east (USFS, 2006; Figure L– 6). Subwatersheds affected are Boulder, Twentymile, and Windy Creeks (in the Chewuch subwatershed) and Beaver Creek (a tributary to the Methow River). The fires provided additional sediment and LWD (large woody debris) to the river system, and fresh and bare soil for germination of riparian vegetation.

A series of cloud bursts in the summer of 2004 in the areas of the Thirtymile Fire and Farewell Fire triggered landslides that muddied the water for weeks and covered substrate with a layer of sand (Cross, 2005). Two sediment pulses were subsequently observed by USFS biologists in the Chewuch watershed at the Thirtymile Fire Memorial (near RM 30) and Andrews Creek (at confluence near Chewuch RM 26). Multiple slides were noted on Lake Creek (confluence near Chewuch RM 23) that are expected to reach downstream areas of the Chewuch watershed in the next 10 years (Cross, 2005). Large amounts of sediment and organic debris help to capture fine sediment on adjacent floodplains, thereby removing it from active channels. The fires resulted in both fine sediment and also debris flows that range in size from silt to boulders to be deposited into the river.

In addition, the fires decimated vegetation and allowed the river to rework surfaces, particularly in reaches with limited water available for channel and floodplain reworking.

Fires can remove the forest canopy over streams resulting in increased solar exposure and increased stream temperatures. In very cold stream reaches, this can be beneficial to fish, but it may be detrimental to fish in stream reaches that have adversely high temperatures prior to the fire. The reduction in forest canopy reduces evapo-transpiration and reduces snow and rain interception, which can increase base-flow conditions until vegetation re-grows to the point that it can take up available soil moisture. The exact effects depend upon the severity of the fire and the plant associations that are present. High-intensity, short-duration rain storms on slopes where fires have left exposed soil can initiate sheet wash and rill erosion, which in turn can lead to mass wasting and debris torrents. These events can rebuild habitat in intact and functioning watersheds with fish populations that are connected to populations in neighboring watersheds (Bisson et al., 2003).

USFS biologists believe fish populations in the Methow Subbasin have evolved with fire and appear to be well-adapted to it (Appendix F “Biological Setting”). They likely are dependent upon fire and subsequent landscape responses. Fires in unmanaged landscapes are thought by local biologists to be a natural part of replenishing organic debris, spawning substrates, and habitat complexity in affected streams with only short-term impacts on habitat. In the natural setting, fires would occur at different places within the watershed at different times. If one drainage was impacted and temporarily depleted of habitat or if fish populations were locally extirpated, then the fish from neighboring watersheds could strengthen or re-establish fish populations in the impacted areas, provided that there was physical passage available to the affected area and that the populations are robust enough to provide individuals to the affected habitat. The general effects of fires on fish populations are discussed in detail in Appendix F, along with the specific effects that were observed after the Farewell fire.

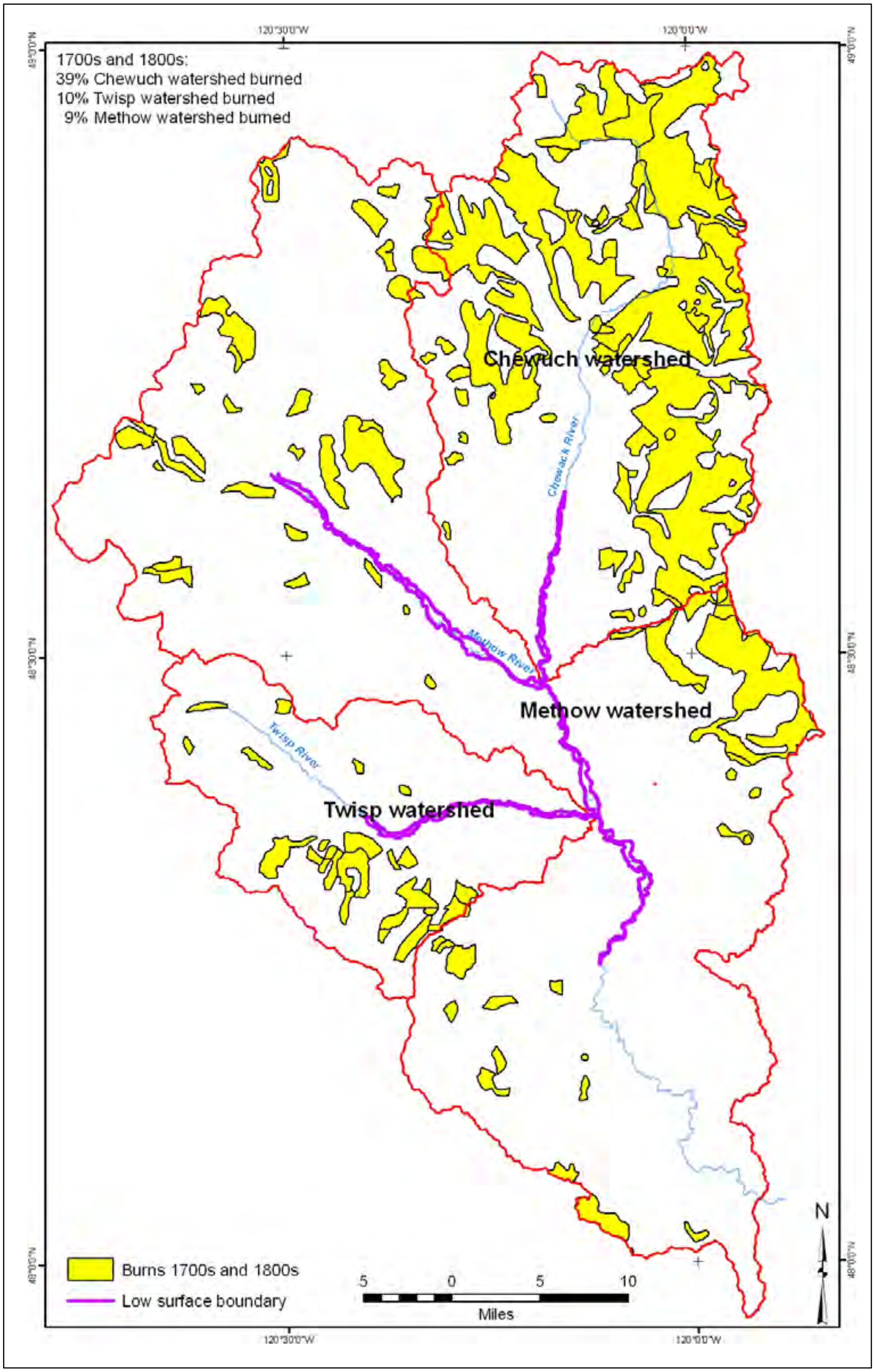

Figure L– 1. Map of Methow Subbasin showing the distribution of fires that occurred in the 1700s and 1800s.

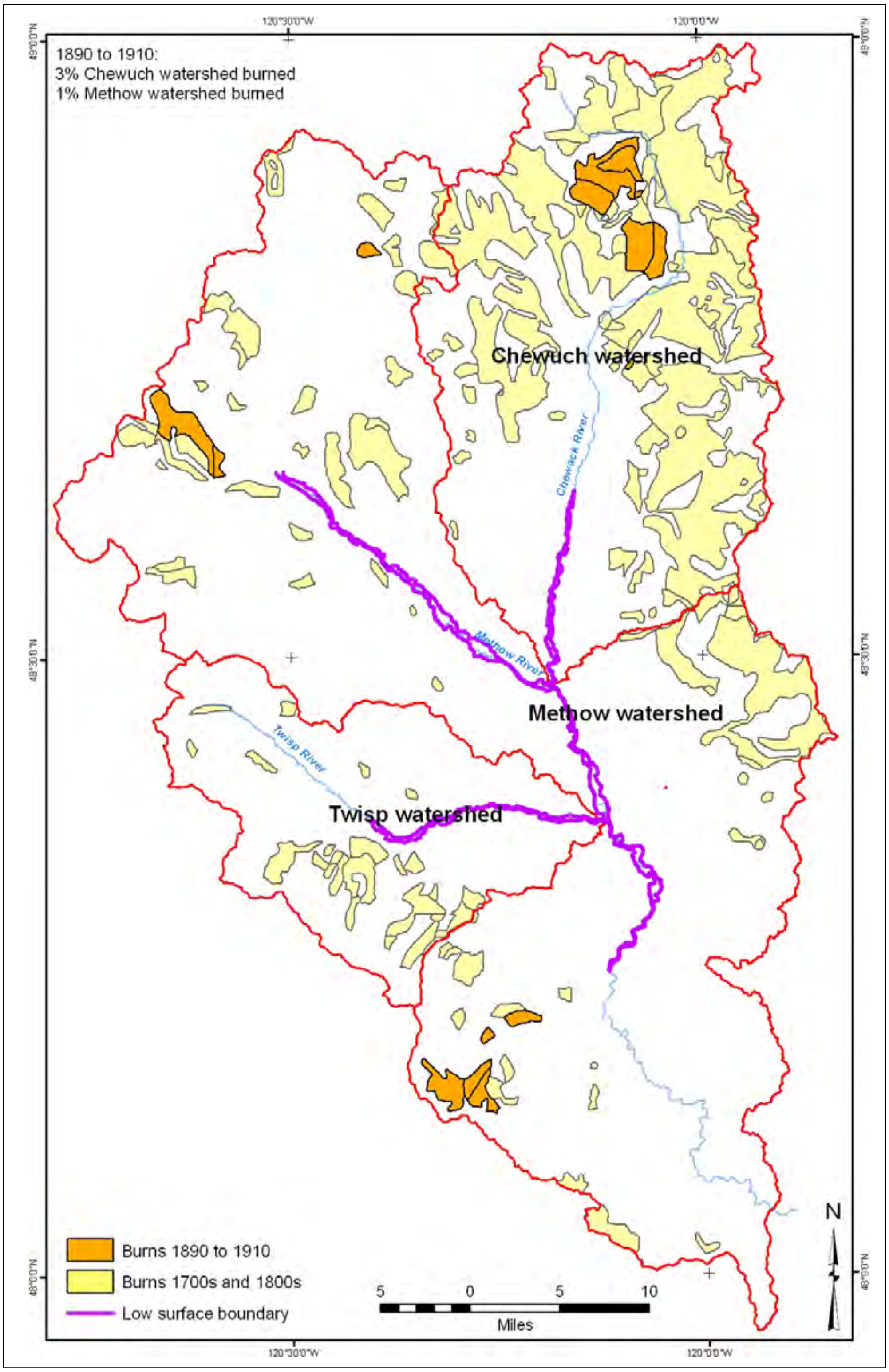

Figure L– 2. Map of Methow Subbasin showing the distribution of fires that occurred between 1890 and 1910.

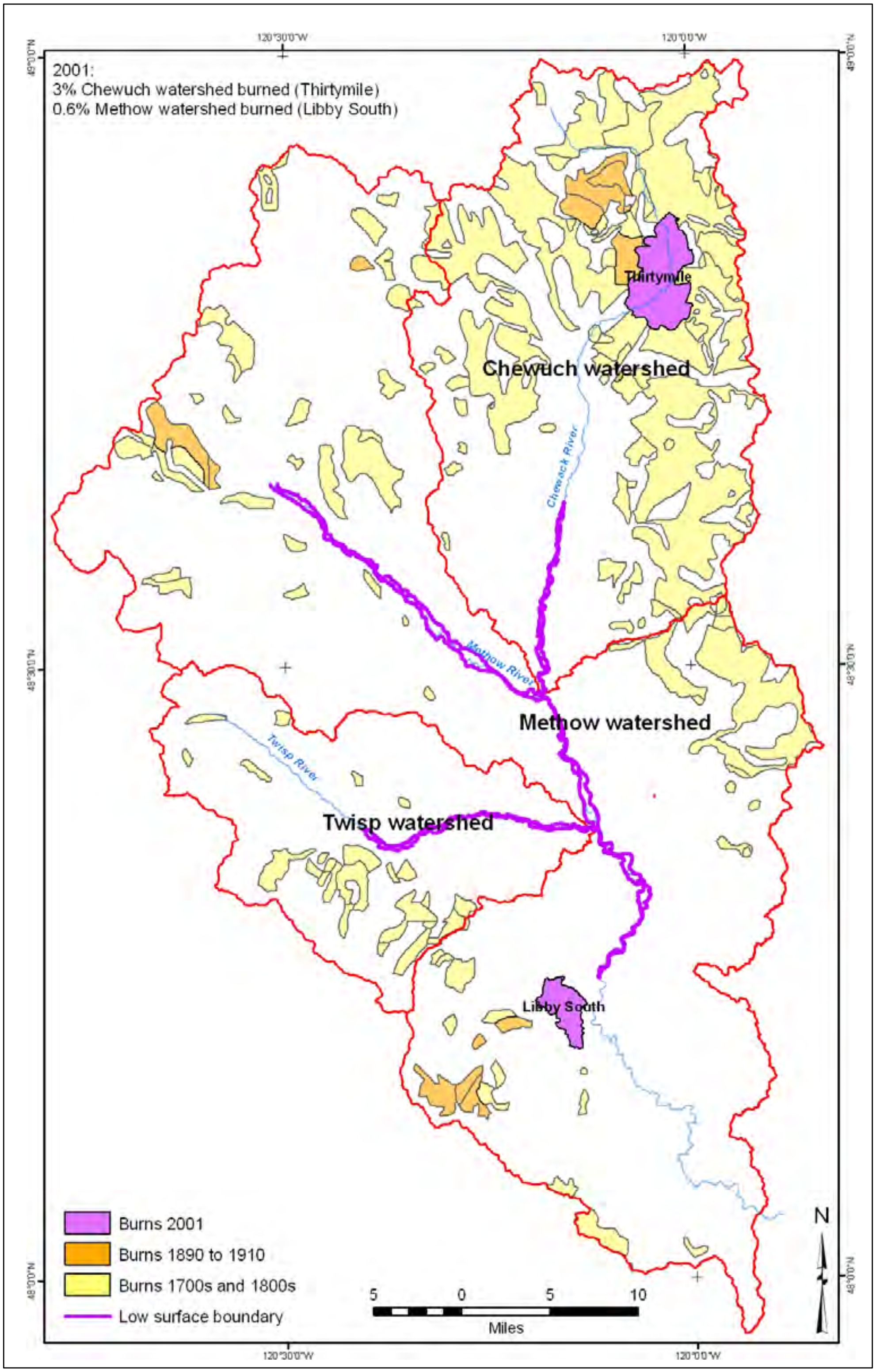

Figure L– 3. Map of Methow Subbasin showing the distribution of fires that occurred in 2001.

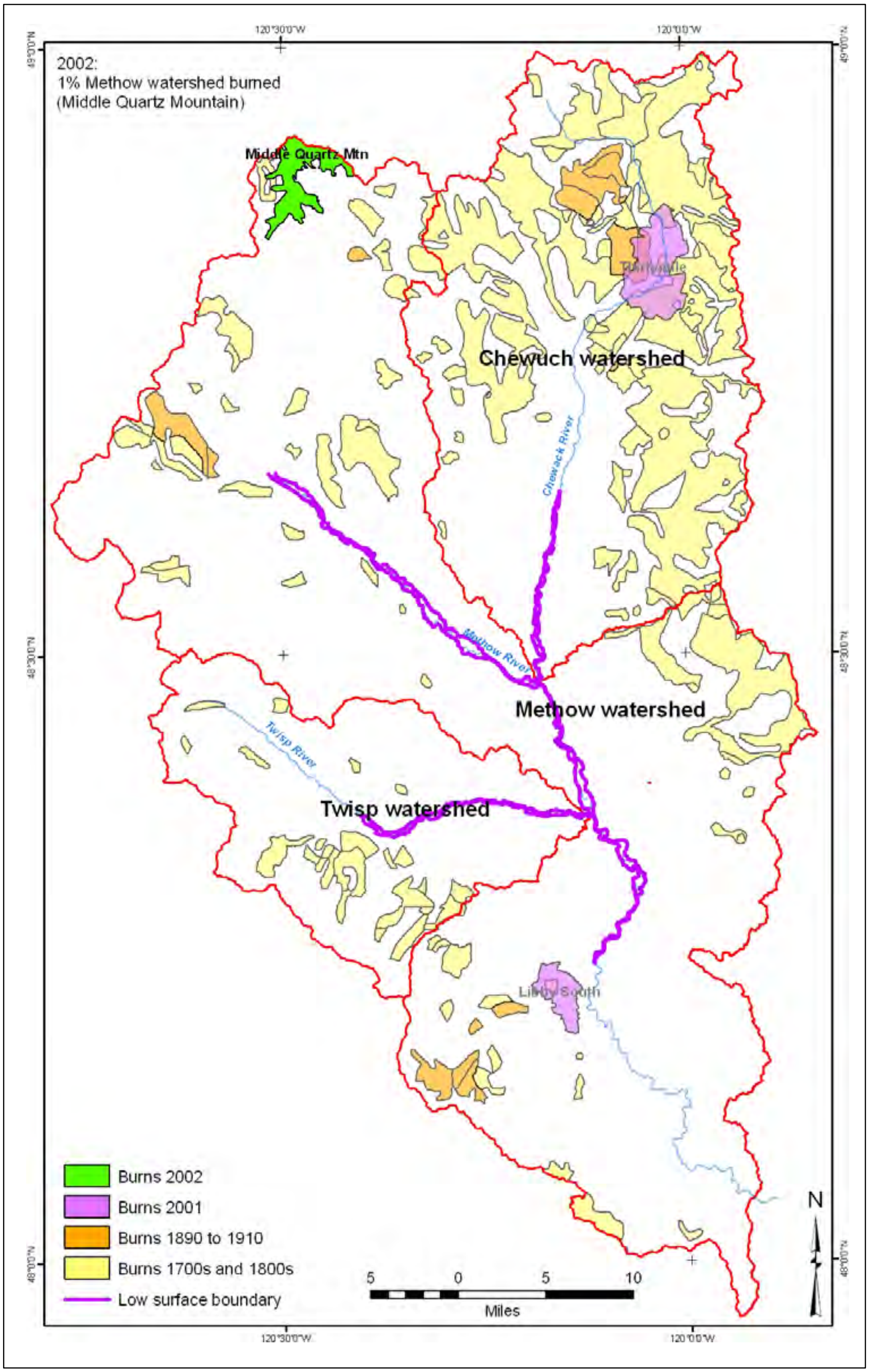

Figure L– 4. Map of Methow Subbasin showing the distribution of fires that occurred in 2002.

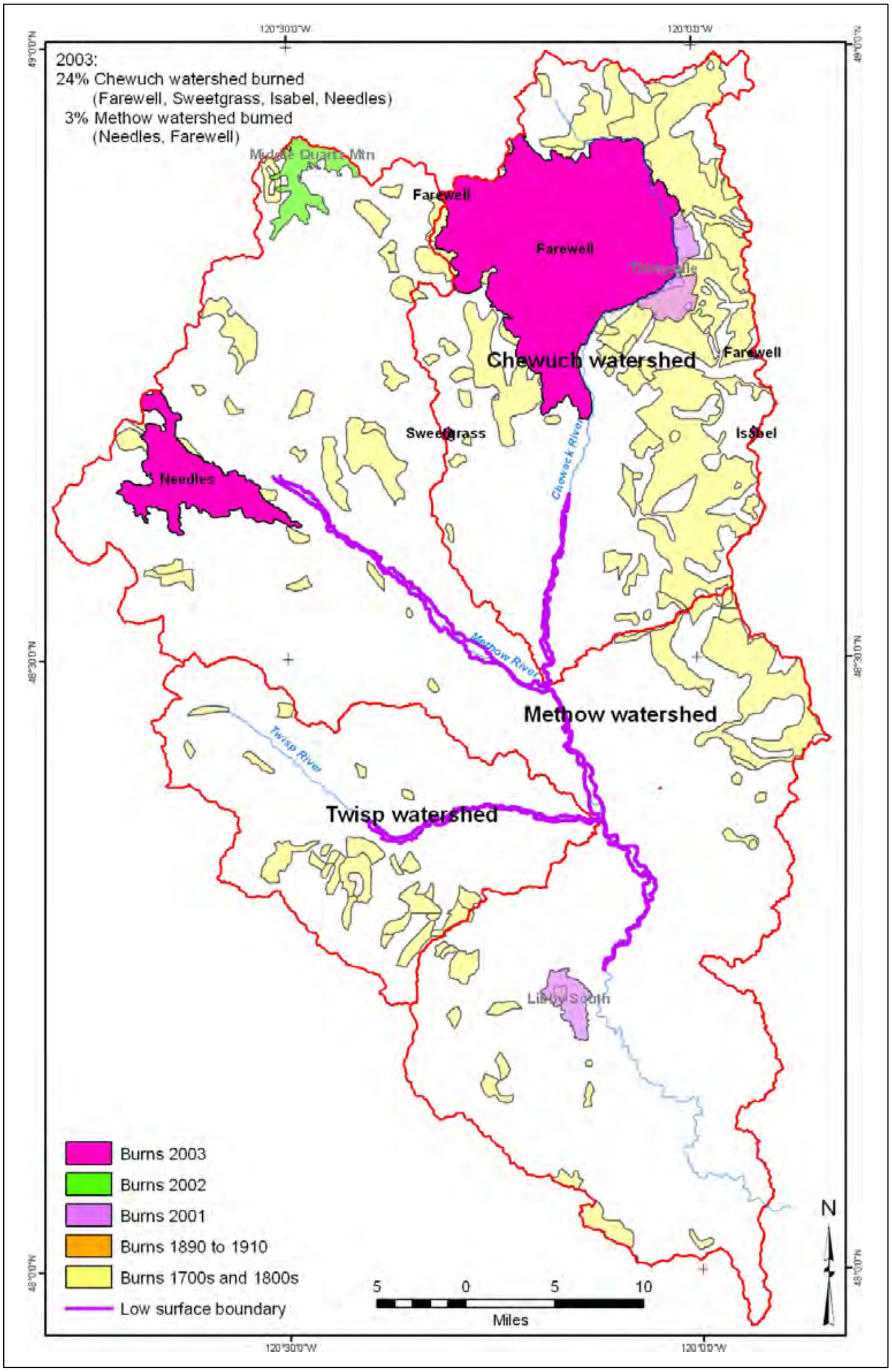

Figure L– 5. Map of Methow Subbasin showing the distribution of fires that occurred in 2003.

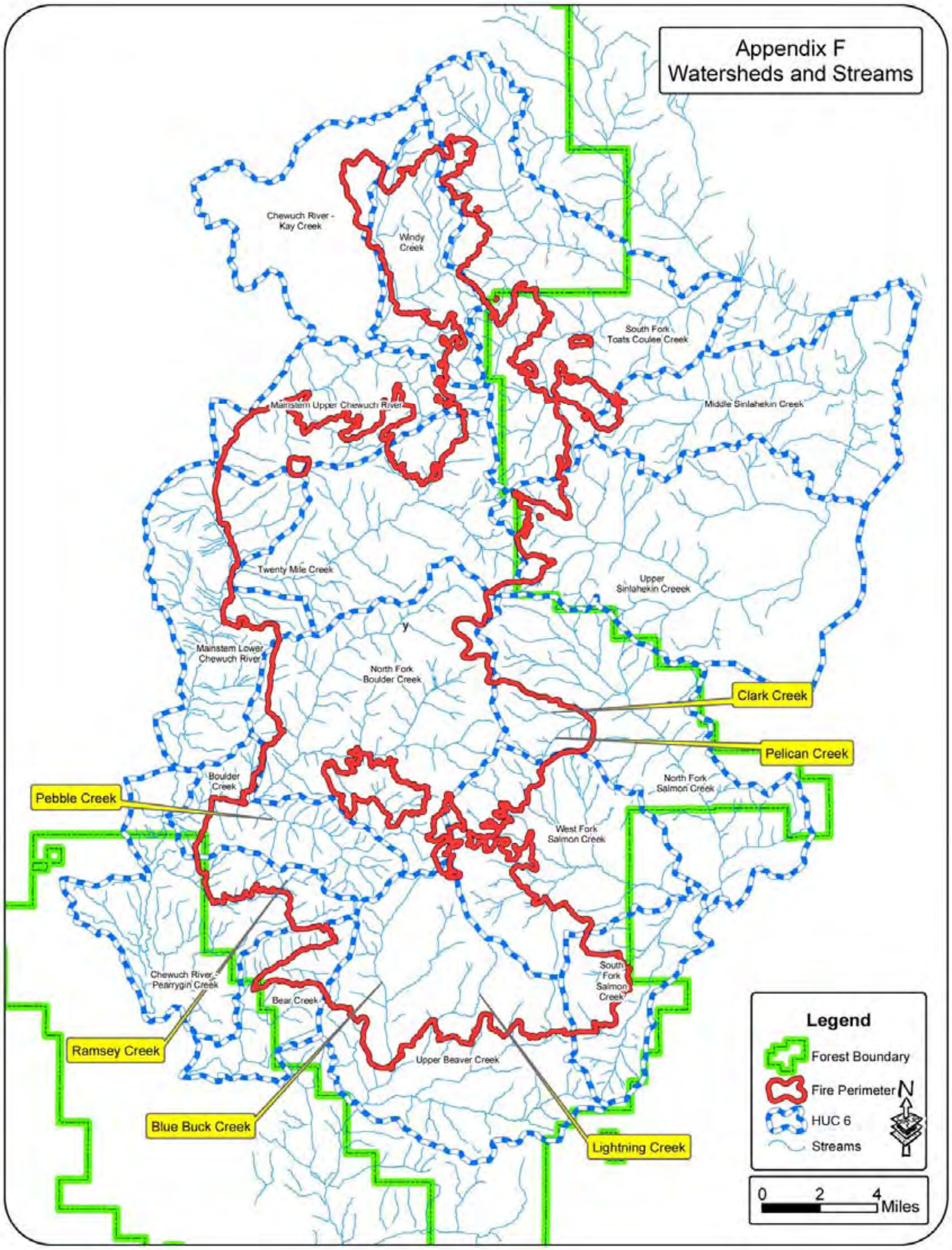

Figure L– 6. Map showing the distribution the 2006 Tripod complex fires within the Methow Subbasin and the adjacent Okanogan drainage basin. (Figure is from USFS, 2006).

2. REFERENCES

IN TEXT	FULL CITATION
Bisson et al., 2003	Bisson, P.A.; Rieman, B.E.; Luce, C.; Hessburge, P.F.; Lee, D.C.; Kershner, J.L.; Reeves, G.H.; and Gresswell, R.E. 2003. "Fire and aquatic ecosystems of the western USA – Current knowledge and key questions" in *Forest Ecology and Management*, v. 178, p. 213-229.
Cross 2005	Cross, D.M. 2005. *Sediment monitoring report, 2000-2005, Chewuch River and Twisp River.* US Forest Service, Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA, 29 p.
MVRD 2007	Methow Valley Ranger District. Revised June 2007. *Sediment Monitoring Report: 2000 to 2006, Chewuch River and Twisp River.* Winthrop, WA.
USFS 2006	US Forest Service. 2006. *Tripod Complex fires, Okanogan-Wenatchee National Forest – Burned-area report*: US Forest Service Report FS-2500-8, June 2006, 26 p.

APPENDIX M –

GEOLOGIC HISTORY AND MAPPING

This appendix provides a discussion of the geologic setting of the Methow Subbasin. The focus is how these processes have influenced the present river position and morphology, and provided constraints to vertical and lateral adjustments resulting from either natural or human induced influences on the physical river processes.

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There are no tables in this Appendix M.

1. PHYSIOGRAPHIC SETTING

The Methow Subbasin is located along the east-aspect of the Cascade Range (the Cascades) in north-central Washington (Figure M–1). The watershed drains about 1,890 square miles with the Methow River being the principle hydrologic feature. Major tributaries to the Methow River include Lost River, Early Winters Creek, Wolf Creek, Chewuch River, Twisp River, and Beaver Creek. From its confluence with the Columbia River at river mile (RM) 524, near Pateros, the Methow River extends approximately 86 river miles northwest to the crest of the Cascades (Andonaegui, 2000).

The terrane in the watershed is steep and mountainous along the Cascades' crest, but transitions downslope to a relatively broad alluvial valley bounded by hills and glacial terraces. The elevation ranges from about 775 feet at the confluence with the Columbia River to over 8,950 feet at the crest of the Cascades with a total relief of about 8,200 feet (Konrad et al., 2003).

Annual precipitation exceeds 80-inches along the crest of the Cascades and decreases downslope to about 10 inches near Pateros, Washington (Richardson, 1976). Most precipitation (about 66 percent) in the watershed is delivered as rain and snow between late fall and early spring, and thunderstorms deliver precipitation during the hot, dry summer months (Andonaegui, 2000). Most of the annual spring runoff flows (about 60 percent) occurs in the months of May and June (Milhous et al., 1976).

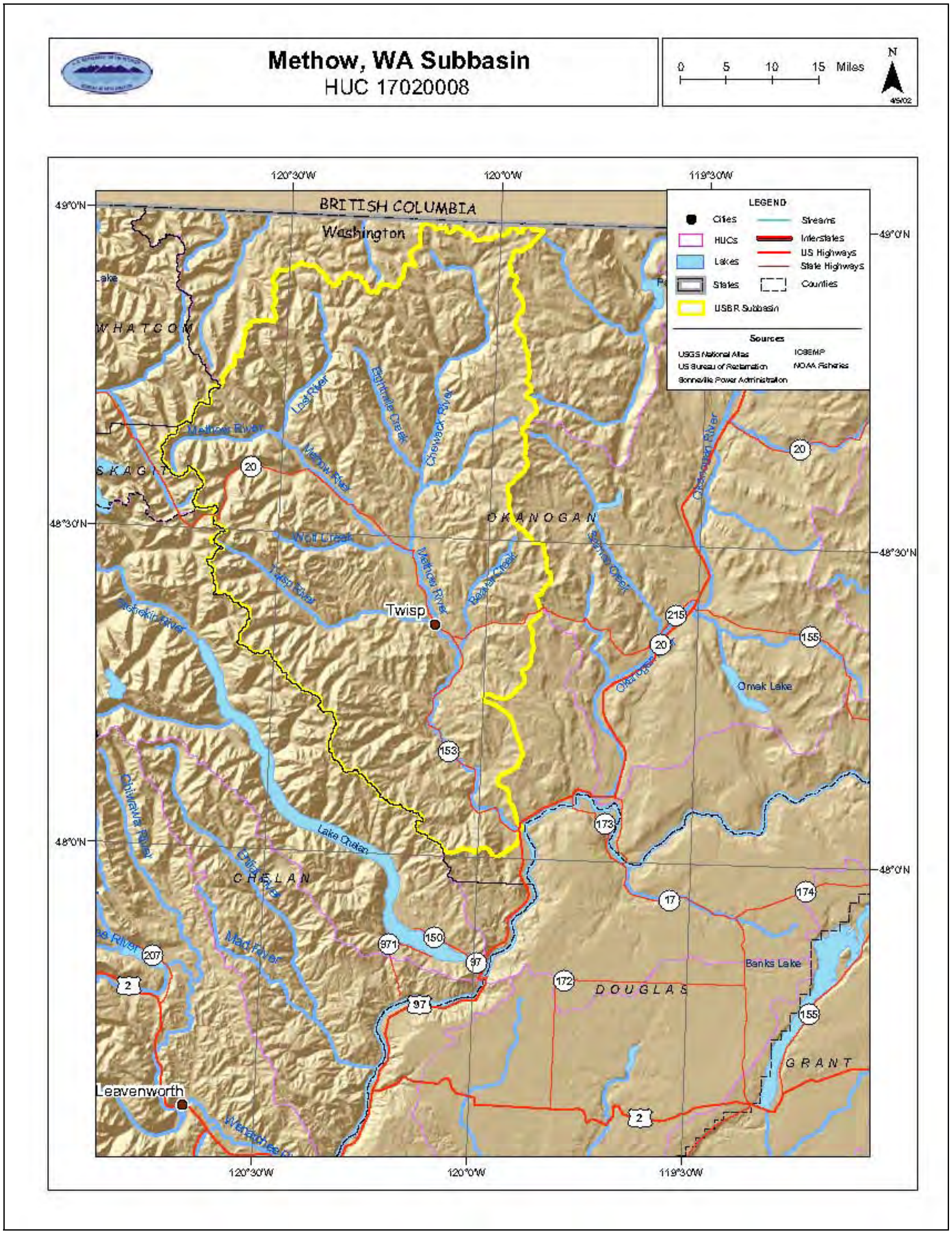

Figure M–1. Location map of the Methow Subbasin in northcentral Washington

2. REGIONAL GEOLOGY

According to Tennyson and Cole (1987), there are three prominent geologic terranes within the Methow Subbasin (Figure M–2); these are:

- the North Cascades crystalline core
- the Methow terrane
- the Okanogan-Shuswap terrane.

The Methow terrane is a structural basin (Barksdale, 1948) bounded by the Fraser-Yalokum fault system (Tennyson and Cole, 1987). The Fraser-Yalokum fault system juxtaposes the Methow terrane against the Okanogan-Shuswap terrane to the east and the North Cascades crystalline core to the west (Tennyson and Cole, 1987). The Methow terrane is about 170 miles long and about 50 miles wide in state of Washington, and extends an additional 120 miles into British Columbia, Canada (Barksdale, 1975), comprising the Methow and Tyaughton basins (DeGraaff-Surpless et al., 2003).

The Methow structural basin was an active sedimentary trap prior to and during the Cretaceous. Crustal deformation of the basin began during the Cretaceous through the early Late Cretaceous due to movement along the east-vergent Chuwanten thrust fault that underlies the basin. Subsequently, the basin was deformed into a southeast-plunging synclinorium during and after the final stages of basin filling (McGroder and Miller, 1989). The Methow basin ceased to be a sedimentary trap by the Late Cretaceous due to infilling by orogenic clastics, internal deformation and regional uplift (McGroder, 1988).

The Methow basin is predominantly Mesozoic in age and comprised of low-grade metamorphic rocks of marine and nonmarine origin (Miller et al., 1994). The Methow terrane consists of Jurassic and Cretaceous marine and volcanic rocks that overlie allochthonous Triassic mid-oceanic ridge basalt (Ray, 1986; DeGraaff-Surpless et al., 2003). These strata are subsequently overlain by the Upper Cretaceous Pasayten Group (Miller et al., 1994).

The Cretaceous strata overlying the Methow terrane is exposed along an elongate structural block (Methow basin) bound on the east by the Chewack-Pasayten fault zone and on the west by the Hozameen-North Creek fault zone that are elements of the Fraser-Yalokum fault system (Tennyson and Cole, 1987; DeGraaff-Surpless et al., 2003; Miller and Bowring, 1990). Seismic reflection data conducted across the Chewack-Pasayten fault zone suggest the fault zone dips eastward juxtaposing Cretaceous volcanic rocks over sedimentary successions (Varsek et al., 1993). Hurlow (1993) believes the fault zone has experienced multiple deformational processes including Late Cretaceous sinistral displacement, Late Cretaceous to Tertiary west-vergent contractional motion and Tertiary extension.

Quaternary strata in the Methow Subbasin consist predominantly of glacial and alluvial valley fill deposits of boulders, cobbles, gravel, sand and silt. Alpine glaciers have eroded the valley walls and floors followed by the less erosive continental glaciation. The glacial history of the valley strongly affects the groundwater aquifer and the baseflow of the river systems in the subbasin. Because of its importance to understanding the hydrology of the basin, the glacial history is further discussed in this appendix in Section 3 "Glacial Geology" and Section 4 "Hydrogeology."

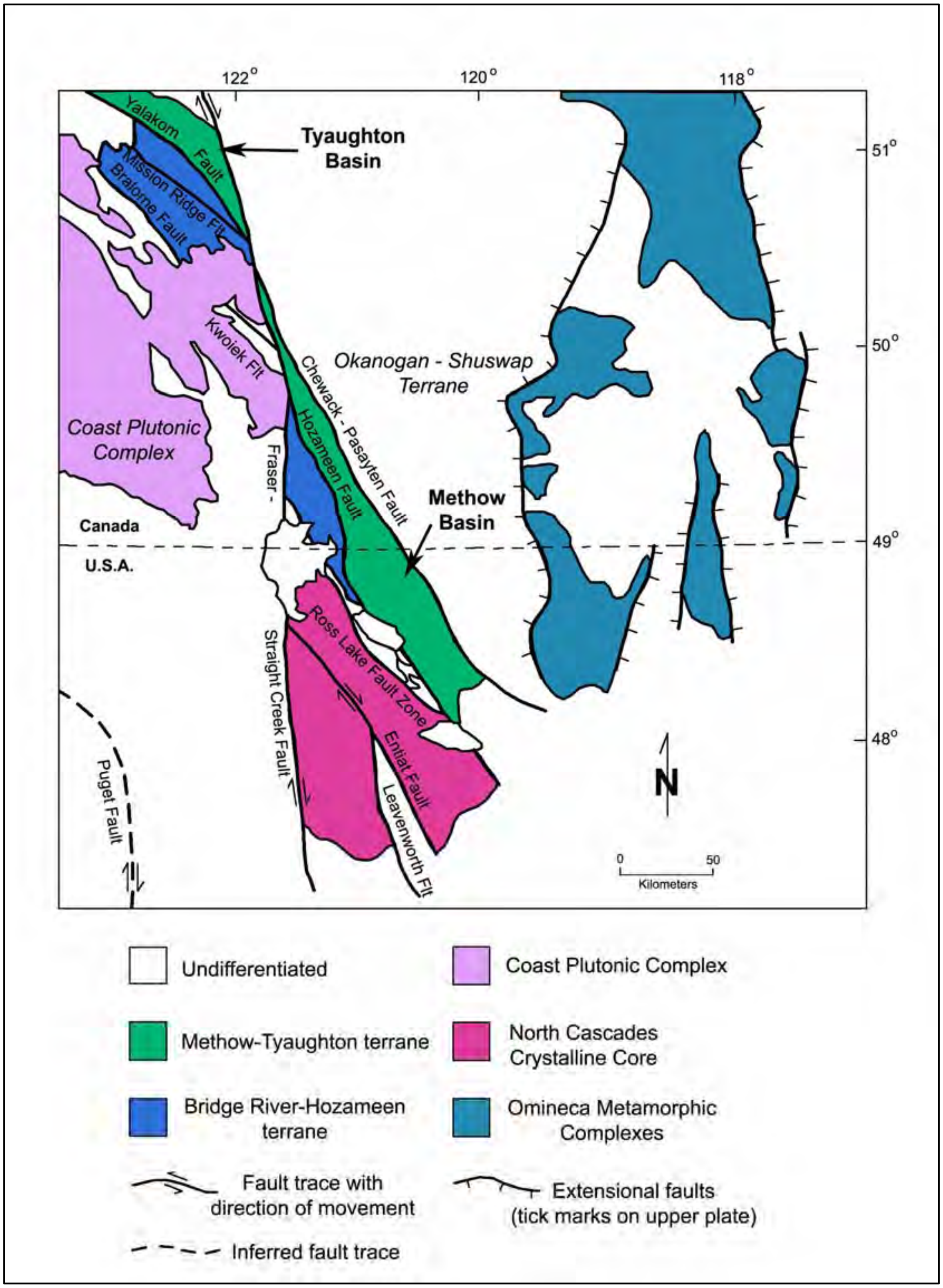

Figure M–2. Generalized tectonic sketch map showing the major fault systems and geologic terranes in northern Washington and British Columbia, Canada.

This figure is modified from Miller and Bowring (1990), Johnson (1985); Parrish, Carr, and Parkinson (1988); Potter (1986); Price, Monger and Roddick (1985): and Roddick, Muller and Okulitch (1979).

3. GLACIAL GEOLOGY

3.1 PREVIOUS WORK

The last glacial cycle affecting the Methow Subbasin is correlative to the Fraser Glaciation about 30,000 and 9,500 years B.P. (before present). The Fraser Glaciation is comprised of at least one alpine phase and a continental phase in the North Cascades (Waitt, 1972). Waitt and Thorson (1983) believe that the expansion of the glacial lobes from the continental ice sheet did not fluctuate in phase or with the advance of the alpine glaciers.

Alpine glaciers advanced in the Methow Subbasin (Figure M–3) about 22,000 to 18,000 years B.P. during the Evans Creek stade prior to the arrival of the continental ice sheet (Cordilleran Ice Sheet). These alpine glacial advances are responsible for the U-shaped cross valley profiles in the Methow Valley. Waitt (1972) analyzed several cross valley profiles and showed that the Methow Valley is U-shaped above the town of Carlton (RM 28) and V-shaped below Carlton, suggesting the Pleistocene alpine glaciers flowed down the Methow Valley at least to Carlton. Additionally, alpine glaciers flowed down the Chewuch River valley to the confluence with the Methow River; and in the Twisp River valley the alpine glaciers flowed to about RM 9.3, just downstream of Little Bridge Creek.

The Cordilleran Ice Sheet expanded southward from the Canadian border about 17,000 to 13,500 years B.P. during the Vashon stade (Burtchard, 1998). During its maximum stand the ice sheet buried much of the northeastern North Cascade Range (Barksdale, 1941; Waitt, 1972). The Okanogan Lobe of the ice sheet flowed south from Canada overriding prominent mountain ranges and converged into ice streams down the Skagit, Chelan, Methow, Okanogan, and Columbia valleys (Barksdale, 1941; Waitt and Thorson, 1983). The Okanogan Lobe covered most of the Methow Subbasin and was broken up by only a few scattered peaks (nunataks) rising above the ice (Barksdale, 1975).

Waitt (1972) and Barksdale (1975) believed that the advancing Okanogan Lobe post-dated the most recent alpine glaciation. Their interpretation is based on the lack of constructional landforms associated with alpine glaciers in the Methow Valley. Waters (1933) recognized that the Okanogan Lobe did not significantly erode the valleys in the Methow Subbasin but smoothed-out topographic irregularities. Constructional landforms from the Okanogan Lobe interpreted by Barksdale (1941) to be moraines were re-interpreted by Waitt (1972) as kame-kettle complexes constructed by the downwasting of the lobe during the very late stages of deglaciation.

During the retreat of the Cordilleran Ice Sheet, the Okanogan Lobe impounded glacial Lake Columbia east of the Grand Coulee in Washington (Bretz, 1923 and 1932; Flint, 1935 and 1936; Flint and Irwin, 1939). This ice dam failed at least once releasing a catastrophic glacial outburst flood as deep as 215 meters that flowed down the Methow-Chelan segment of the Columbia River Valley (Waitt, 1972, 1980, and 1982).

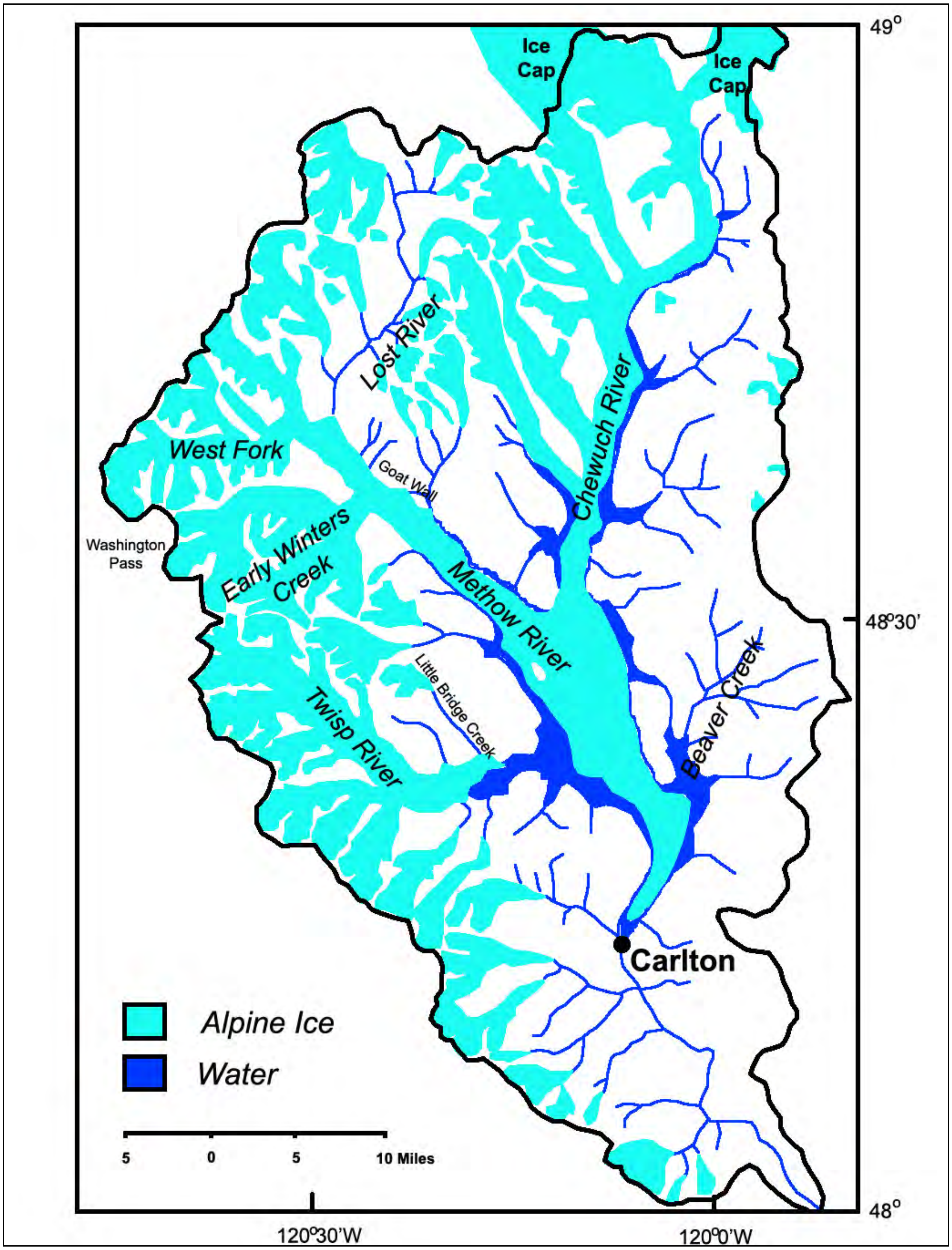

Figure M–3. Map showing the maximum extent of alpine glaciers in the Methow Subbasin (modified from Waitt, 1972.)

3.2 DISCUSSION

In the Early Winters Creek drainage, the alpine glaciers were apparently very erosive (see Figure M–3 for location). The Early Winters Creek trunk glacier eroded headward up the drainage leading to the capture of another alpine glacier flowing westward at Washington Pass (Waitt, 1972 and 1975). The significance of the Early Winters Creek alpine glacier is that it cut a glacial trough that extended into the Methow Valley, eroding Goat Wall as it flowed across the valley and then the valley floor as it flowed downslope.

The lateral erosion of Goat Wall by the Early Winters Creek alpine glacier also suggests that the Early Winters Creek alpine glaciers reached the Methow Valley prior to the West Fork alpine glacier. However, it is most likely that the two ice streams coalesced into one glacier soon after the arrival of the Early Winters Creek glacier in the Methow Valley.

The glacial trough eroded by the Early Winters Creek and West Fork alpine glaciers was filled-in by glaciofluvial sediments during the retreat of the alpine glaciers and by the subsequent retreat/downwasting of the Okanogan Lobe of the Cordilleran Ice Sheet. These glaciofluvial sediments are believed to be more than 1,000 feet thick along the mainstem Methow River from Weeman Bridge (RM 61; about 10 miles upstream of the Chewuch River confluence) to above Early Winters Creek (Waitt, 1972; EMCON *in* Andonaegui, 2000). Presently, these unconsolidated glacial sediments along the trough are very significant in that they form an unconfined aquifer that maintains baseflow in the upper Methow River (Konrad et al., 2003).

The glacial geochronology of the alpine and continental phases in the Methow Subbasin is fairly well understood with the exception of a possible late alpine phase that may have been contemporaneous with the retreat/downwasting of the continental ice sheet (Figure M–4). Waitt (1972) and Barkdale (1975) suggest there were no alpine glacial advances following the retreat/downwasting of the continental ice sheet in the Methow Valley. An alternative interpretation is that about 11,000 to 9,500 years B.P. during the Sumas stade (Burtchard, 1998) an alpine glacial advance occurred in the North Cascades including the Methow Subbasin. The alpine phase would have been confined to the upper valleys as the Okanogan Lobe remnants stagnated in these upper valleys and melted away in the lower valleys. This interpretation is based on the Late Pleistocene to Holocene climatic sequence (Figure M–4) and stratigraphic relationships of the large alluvial fans (i.e. Early Winters and Wolf Creek alluvial fans) observed on the valley floors in the Methow Subbasin. The Okanogan Lobe advancement down the Methow Valley would have obliterated (or at least significantly modified) the alluvial fan deposits if they pre-dated the arrival of the continental ice.

Therefore, the construction of these alluvial fans is believed to post-date the melting of the continental ice in the lower valleys. And there must have been a re-advancement of the alpine glaciers during the Sumas stade that significantly thickened the stagnated continental ice remnants remaining in the upper valleys after the continental ice melted in the lower valleys. These ice remnants remaining in the upper valleys were essential to provide the necessary streamflows and sediment supplies to construct the large alluvial fans. Further support for this interpretation of alpine glacial resurgence in the Methow Subbasin is provided by an alpine glacial resurgence (Rat Creek advance) in the Wenatchee Subbasin that occurred between 13,000 and 7,000 years B.P. (Waitt et al., 1982); the McNeely advance about 11,000 to 9,500 years B.P. during the Sumas stade on Mount Rainier (Burtchard, 1998); and terminal moraines found in five valleys across (west to east) the North Cascades that are 14,000 to 10,000 years B.P. (Riedel et al., 2003).

Additionally, Waitt and Thorson (1983) acknowledge that the continental ice lobes both east and west of the Cascades were not in-phase and generally retreated from their maximum positions to the international boundary about 14,000 to 11,000 years B.P. The chronological overlap provided by the relative ages (13,000 to 11,000 years B.P.) and the acknowledgement that the continental ice sheet retreat was not in-phase, but varied from west to east (and most likely south to north) suggest the alpine glaciers in the Methow Subbasin could have had a resurgence during the Sumas stade.

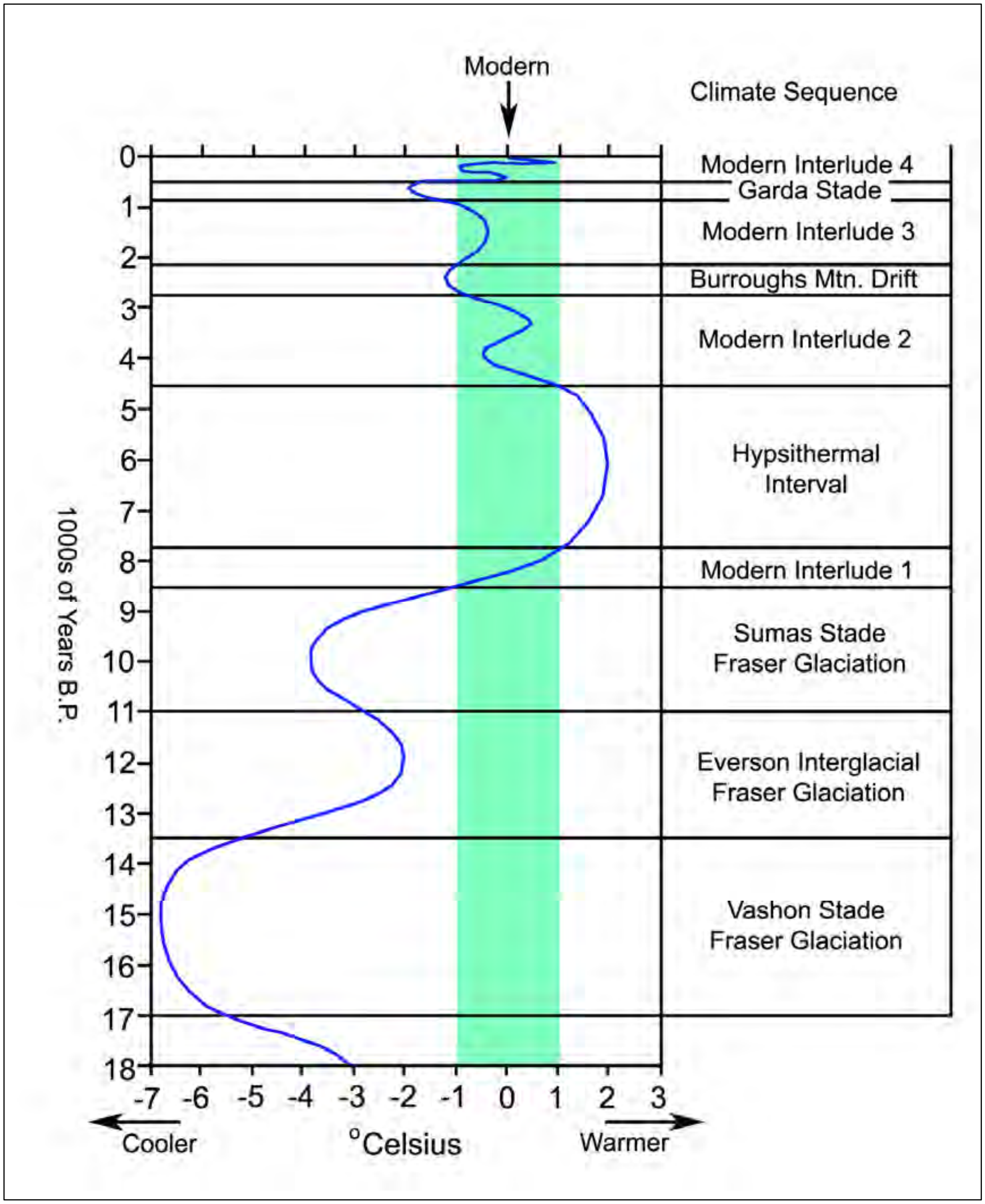

Figure M–4. Late Pleistocene to Holocene climatic sequence.

This figure was modified from Heusser (1977) and Burtchard (1998).

4. HYDROGEOLOGY

The unconsolidated alluvial and glaciofluvial deposits form the primary groundwater aquifers in the Methow Subbasin (Figure M–5). These unconfined aquifers have discharge/recharge relationships with the streams in the subbasin that vary seasonally with valley position (Konrad et al., 2003).

The unconsolidated alluvial and glaciofluvial deposits extend continuously along the Methow River from Lost River downstream to about Black Canyon Creek. Similar deposits that are contiguous with those of the Methow River occur along the Lost, Chewuch, and Twisp Rivers, and Beaver, Benson, and Libby Creeks. Additional unconsolidated deposits can also be found along valley walls, in tributary valleys, and in some upland areas (Konrad et al., 2003).

The unconfined aquifers are primarily recharged by snowmelt and rainfall infiltration, groundwater flow from adjacent aquifers and seepage from rivers and irrigation ditches (Konrad et al., 2003). Topsoil in the subbasin is generally sandy loams that have permeabilities from 2.0 to 6.0 inches per hour; underlying the topsoil are unconsolidated alluvium and glaciofluvial deposits that have permeabilities greater than 6.0 inches per hour (Andonaegui, 2000). Major sources of aquifer recharge, especially during high-flow periods, are the Methow and Twisp Rivers. During low-flow periods, groundwater discharges from the unconfined aquifers are the primary sources for maintaining the baseflow in the Methow River. Understanding these high-flow/low-flow relationships between the unconfined aquifers and rivers are essential to determine the availability of water for use both in-stream and out-of-stream (Konrad et al., 2003).

The largest rises in groundwater levels are in the upper Methow Valley (above Weeman Bridge) that occurs during the spring to summer months; other areas with large rises in groundwater levels include Bear Creek (Figure M–6), the high glacial terrace north of the Twisp River, and the northeast side of the Methow River from the town of Twisp to the confluence with Beaver Creek (Konrad et al., 2003).

There are two gaining reaches along the Methow River from Goat Creek to the town of Winthrop and from Twisp River to Beaver Creek where the river consistently gains flows from the unconfined aquifer (Figure M–6); there is one loosing reach along the Methow River from Lost River to Goat Creek where the river consistently loses flow to the unconfined aquifer (Konrad et al., 2003).

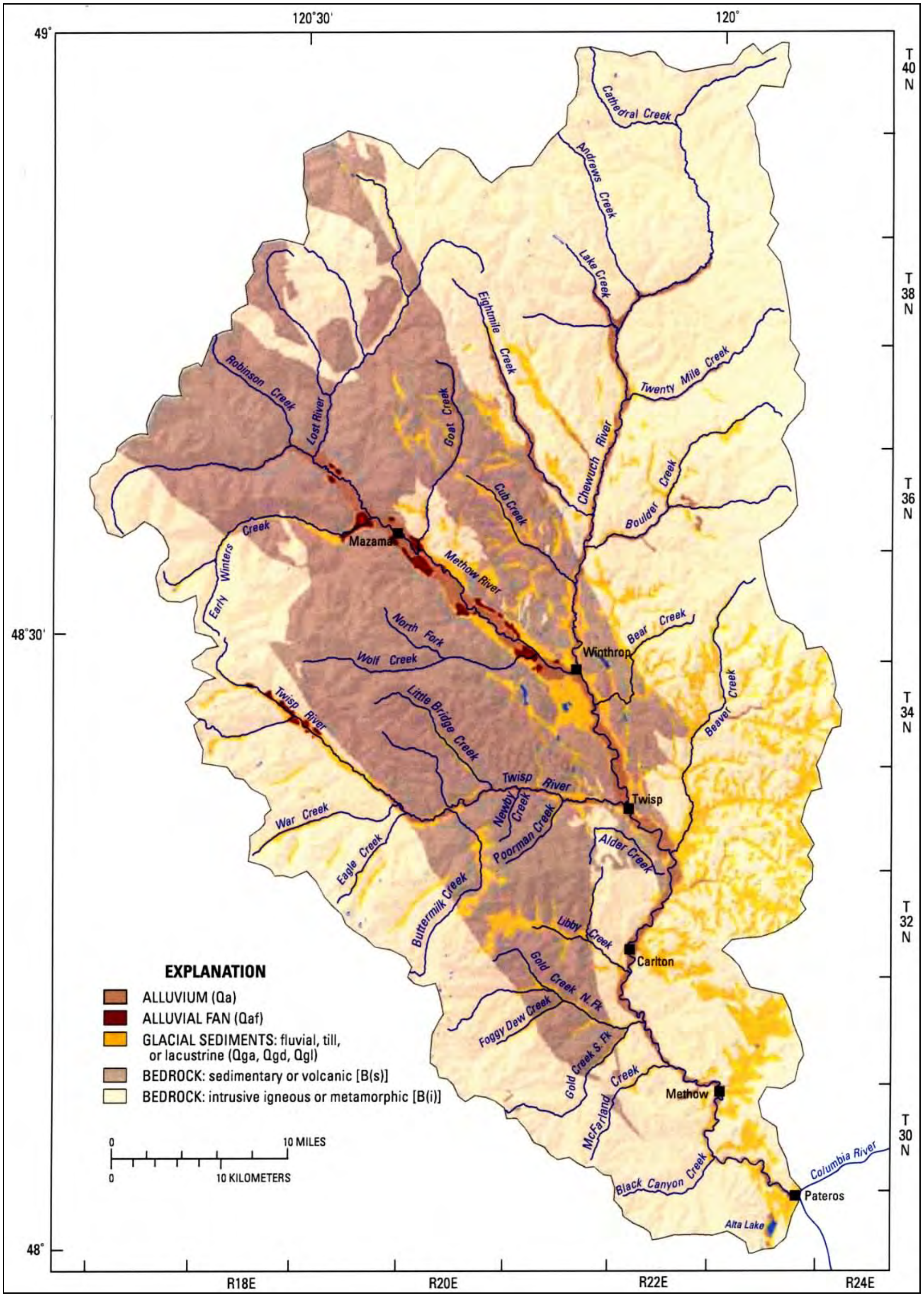

Figure M–5. Geologic map of the Methow Subbasin (figure from Konrad et al., 2003).

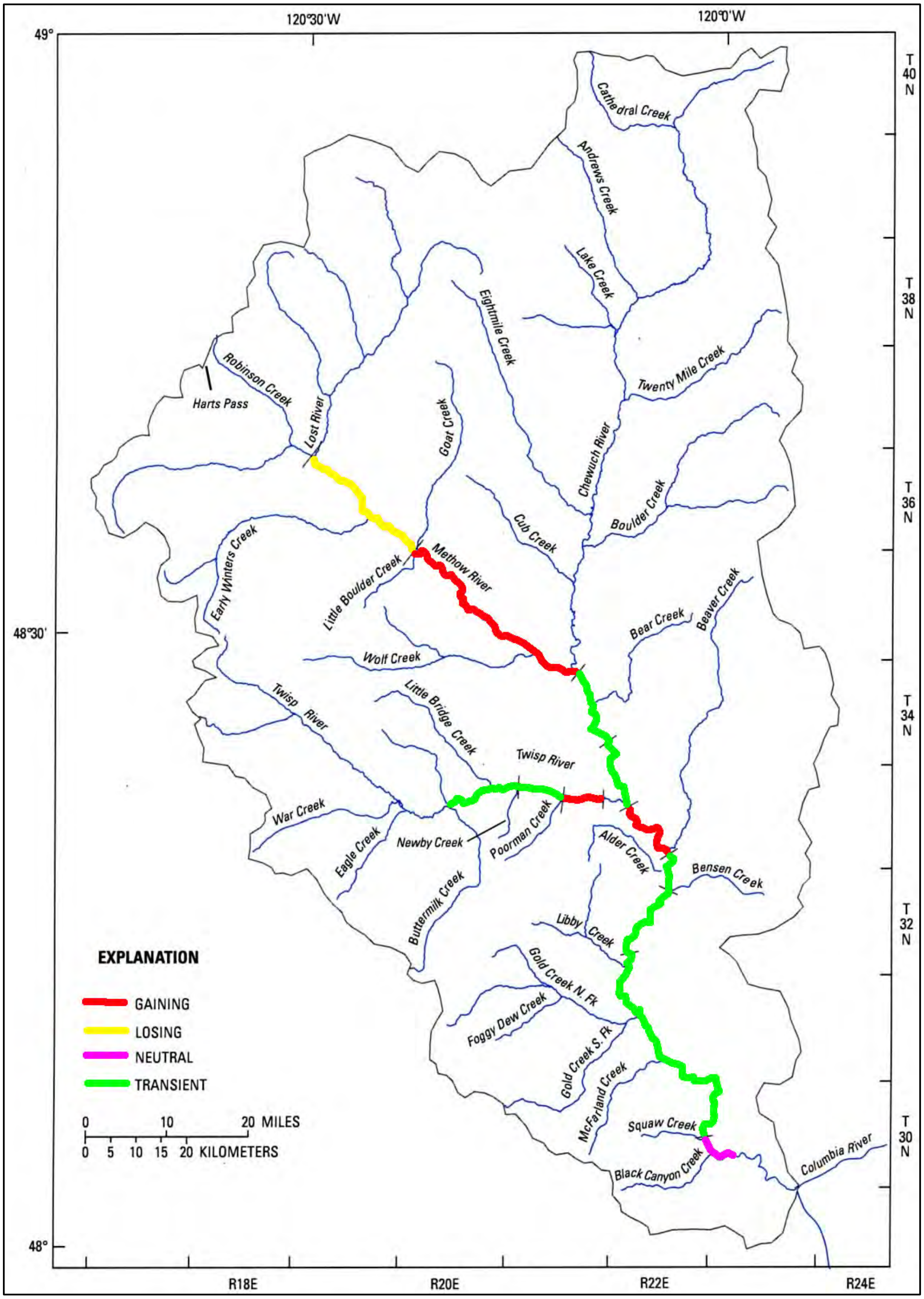

Figure M–6. Map showing the locations of gaining, losing, neutral, and transient reaches along the Methow and Twisp rivers (modified from Konrad et al., 2003).

A recent study identified three distinct annual seasonal patterns that occur along the Methow River and Twisp River with respect to the aquifer-river exchanges at the reach scale (Konrad et al., 2003).

On the Methow River the seasonal patterns are:

- consistent losses from Lost River to Goat Creek
- consistent gains from Goat Creek to the town of Winthrop
- seasonally dependent gains and losses from the towns of Winthrop to Twisp and from Twisp to Pateros.

On the Twisp River seasonal patterns include

- groundwater discharge to the river decreasing from late summer to early spring
- fluctuating groundwater discharge and recharge as the river rose during the late spring
- groundwater recharge in early summer.

The thickest unconsolidated sediments forming the unconfined aquifer are found along the Methow Valley downstream of Lost River to the town of Winthrop. The alluvial and glaciofluvial sediments in this valley reach ranges from at least 500 feet to more than 1,000 feet. Downstream of Lost River the unconsolidated sediments increases to as much as 1,000 feet and the valley width increases from less than 1,000 feet to as much as 1.2 miles. Downstream of Winthrop the sediments are generally less than 200 feet thick, with some exceptions like the reach from the town of Twisp to Benson Creek (Konrad et al., 2003).

5. SITE GEOLOGY

The Methow River Subbasin is underlain by bedrock that is mantled with a relatively thin veneer of Holocene to Pleistocene alluvial and glaciofluvial sediments. Conversely, along the valley floors these alluvial and glaciofluvial sediments are quite thick and can be in excess of 1,000 feet thick (Konrad et al., 2003; Waitt, 1972).

Beginning south of the town of Twisp and extending up the Methow River (Figure M–7), the bedrock consists of sedimentary and volcanic rocks that have been folded and downfaulted between blocks of igneous and metamorphic rocks that trend northwest and southeast (Walters and Nassar, 1974; Konrad et al., 2003; Stoffel et al., 1991). Further downstream of the town of Twisp the bedrock is comprised of igneous and metamorphic rocks (Stoffel et al., 1991).

The sedimentary and volcanic rocks are comprised of shales, siltstones, sandstones, conglomerates, breccias and tuffs (Konrad et al., 2003). Their ages range from the Cretaceous (or possibly Jurassic) to the Tertiary (Barksdale, 1975). The igneous and metamorphic rocks are comprised of granite, gneiss, marble and schist. The igneous rock ages range from the Cretaceous to the Oligocene and the metamorphic rock ages are poorly known (Barksdale, 1975).

The Methow basin is bounded by the Chewack-Pasayten fault zone to the east and the Hozameen-North Creek fault zone to the west. These local faults are elements of the Fraser-Yalokom fault system and juxtapose the sedimentary and volcanic rocks against the intrusive igneous and metamorphic rocks of the Okanogan complex (element of the Okanogan-Shuswap terrane) and the North Cascades crystalline core (Barksdale, 1975; Tennyson and Cole, 1987; Miller and Bowring, 1990).

The graben-bounding faults as well as smaller faults result in rocks that are pervasively fractured and weakened. These zones provide linear areas of less competent rock along which the rivers can more easily erode, for example the Twisp River upstream of Scaffold Creek, or where less competent rocks juxtapose more competent rocks, for example the Chewuch River (Stoffel et al., 1991).

Periodic advances and retreats by alpine and continental glaciers have sculpted the drainages in the Methow Subbasin and the thick glaciofluvial deposits left by the glaciers have created irregularities along the valley profiles. As a result, bedrock is very shallow in some locations in the valleys, and thick sequences of unconsolidated deposits are preserved in other places. Variations of unconsolidated deposits occur both longitudinally along the valleys and across the valleys.

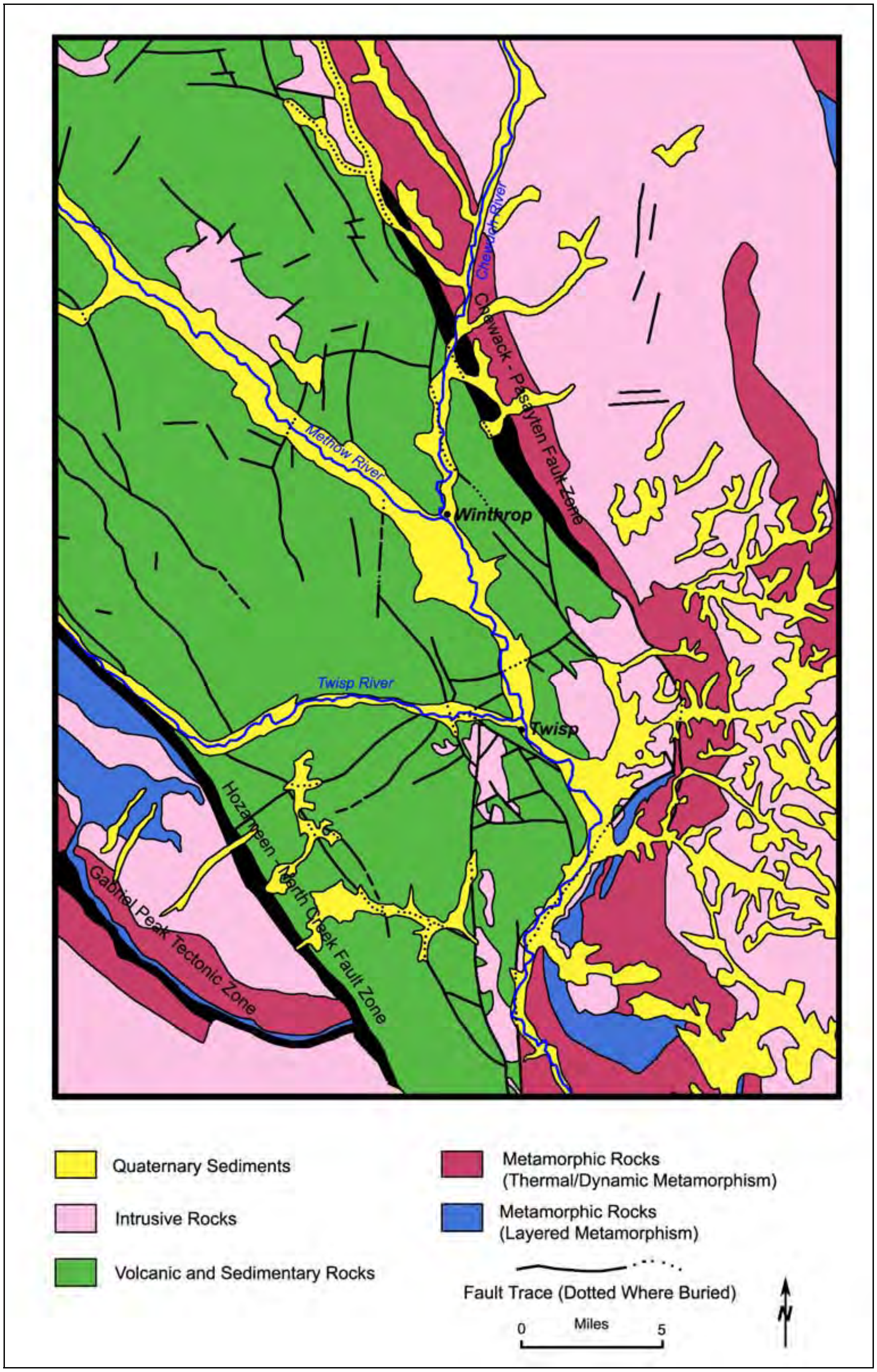

Figure M–7. Generalized geologic map of the Methow Subbasin showing primary rock types, geologic structures, and Quaternary sediments (modified from Stoffel et al., 1991).

5.1 METHOW RIVER CHANNEL PROFILE

Along the Methow River the slope gradually decreases in the downstream direction within the study area (Figure M–8). Major slope changes, such as those on the Chewuch and Twisp Rivers, are not present. The primary geologic controls along the Methow River are bedrock, glaciofluvial deposits and alluvial fans.

From Lost River to Weeman Bridge coalescing alpine glaciers from Early Winters Creek and the West Fork are believed to have carved a glacial trough. The trough was subsequently filled-in with glaciofluvial deposits during the retreat of the alpine glaciers followed by the advance and downwasting of the continental glacier. In areas, the thickness of the unconsolidated sediments along the trough is greater than 1,000 feet (Waitt, 1972).

From Weeman Bridge downstream to Carlton, the thickness of unconsolidated sediments overlying bedrock varies considerably. In some areas, the thickness of the unconsolidated sediments are believed to be over 200 feet. However, there were several areas where bedrock was exposed along the riverbank and in the river channel.

5.2 TWISP RIVER CHANNEL PROFILE

There is a major slope change along the Twisp River that occurs near RM 10 (Figure M–9). Upstream of this point the slope is relatively flatter than the steeper downstream reach. The maximum extent of the alpine glaciers that came down the Twisp River valley was about RM 9.3 (Waitt, 1972) and generally coincides with the slope change at RM 10. Glacial erosion and deposition occurred upstream of this point and may have contributed to the flatter slope. Fluvial erosion occurred downstream of the ice and has resulted in a steeper slope. Although minor variations in bedrock are present, the rock types are primarily the same across the slope change. The Hozameen-North Creek fault zone does not appear to have affected the slope upstream of Scaffold Creek (located about RM 15.5).

5.3 CHEWUCH RIVER CHANNEL PROFILE

There is a major slope change along the Chewuch River between RM 9 and RM 10 (Figure M–10). In this area the slope is very steep and upstream of RM 10, it becomes much flatter. The Pasayten fault crosses the valley at an oblique angle near RM 9. The fault juxtaposes the sedimentary and volcanic rocks of the Methow terrane against the igneous (crystalline) rocks of the Okanogan-Shuswap terrane. The differences in rock types may have formed a resistant “step” in the longitudinal profile. In addition, very large boulders from glacial outburst floods in the Boulder Creek drainage were deposited in the same area enhancing the resistant character of the near-surface crystalline rocks.

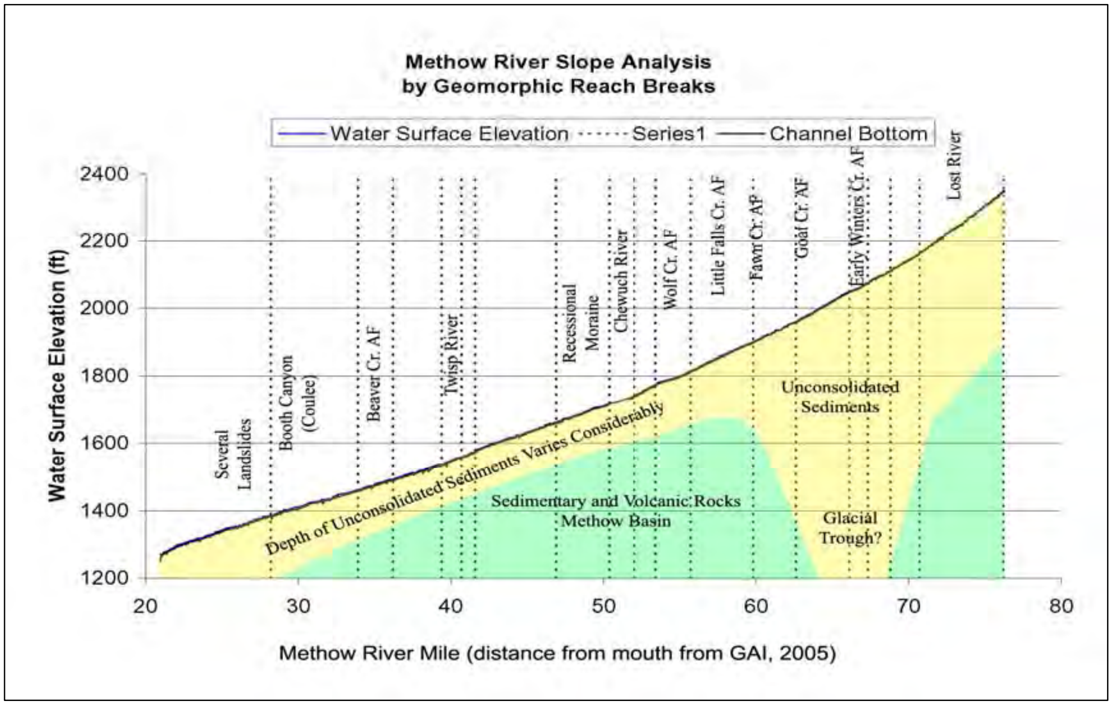

Figure M–8. Longitudinal profile of the Methow River channel showing relative depth of Quaternary sediments and geomorphic reaches in the study area.

Profile data was surveyed in 2005 using total station and GPS equipment (see Appendix K).

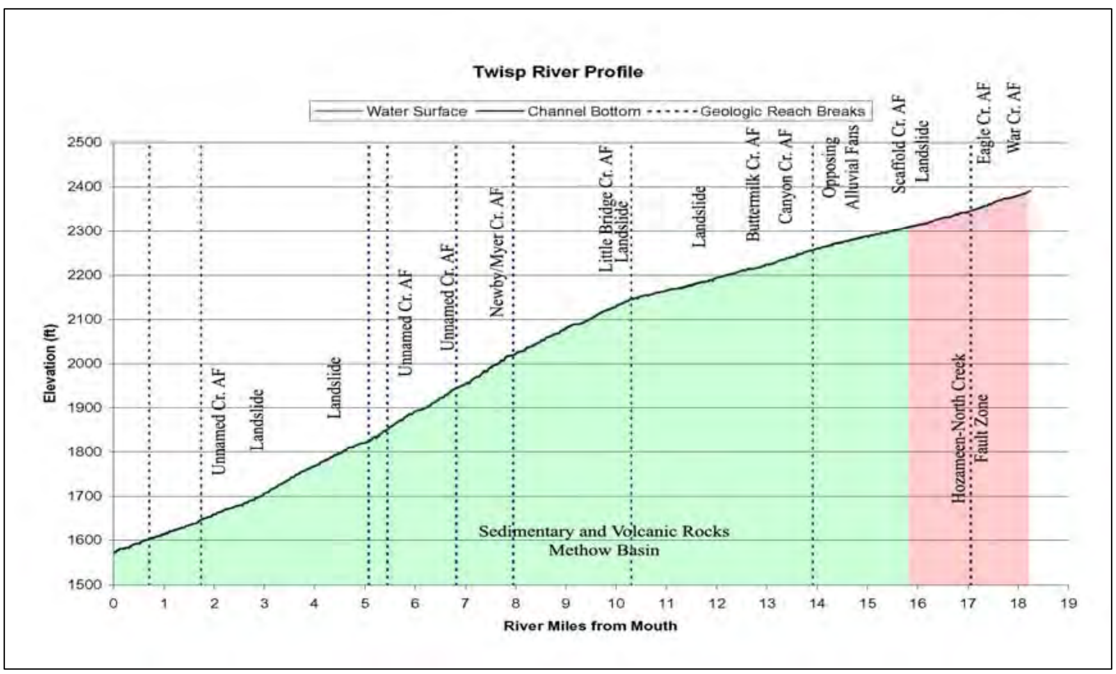

Figure M–9. Longitudinal profile of the Twisp River channel showing geologic and geomorphic reaches in the study area.

Profile data was surveyed in 2005 using total station and GPS equipment (see Appendix K).

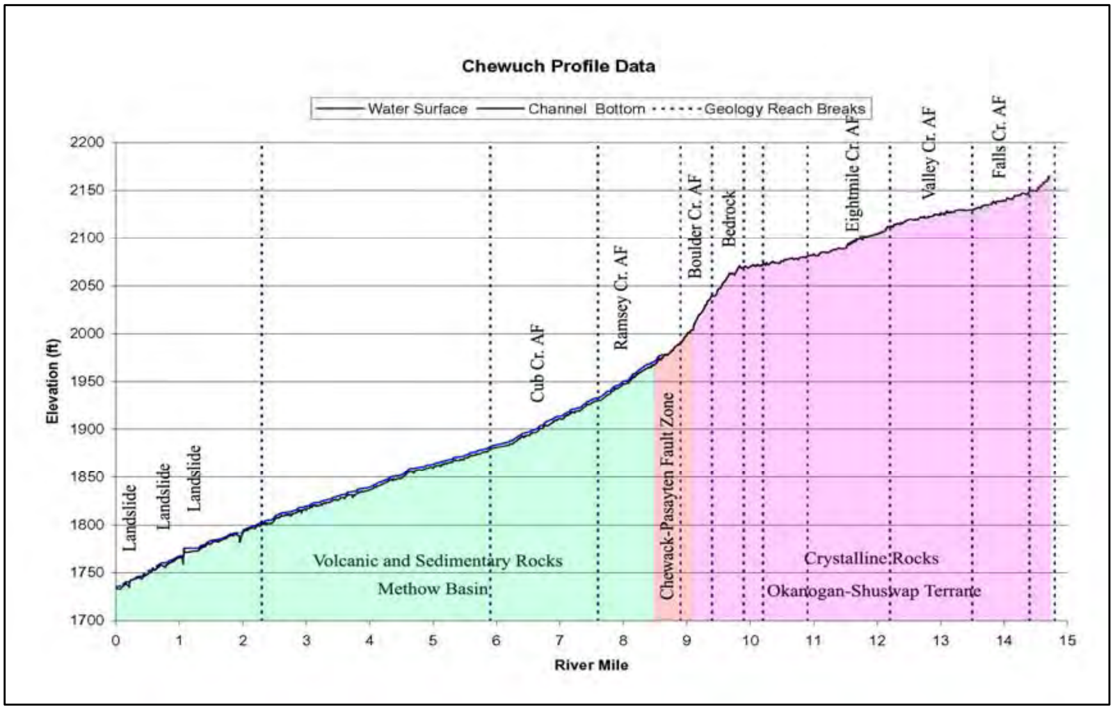

Figure M–10. Longitudinal profile of the Chewuch River channel showing geologic and geomorphic reaches in the study area.

Profile data was surveyed in 2005 using total station and GPS equipment (see Appendix K).

5.4 GEOLOGIC UNIT DESCRIPTIONS

Within the 80-mile study area, geologic mapping was done to distinguish various surfaces along the river corridor. Mapping was accomplished using stereo-pair aerial photographs from 2000 and 2001, and then rectifying the mapping into ARC GIS on 2004 color aerial photographs. Historical aerial photography from 1948, 1954, 1964, 1974, and 1994 was also used to validate and refine mapping boundaries. Field checking was done by walking or boating along the course of the river within the study reach, but not all surfaces were visible from the river. This section describes the geologic units that were mapped. Units are broken out by the geologic time period during which they were formed.

5.4.1 QUATERNARY DEPOSITS

Holocene Nonglacial Deposits

Low Surface (Floodplain) – Consists of a mixture of reworked glacial deposits and fluviolacustrine deposits comprised of silt- to boulder-size material, but is predominantly sand, gravel, and cobbles. These deposits occur along stream channels and their active floodplains. These materials are unconsolidated and highly susceptible to fluvial erosion.

The low surface is frequently reworked and inundated by floods. The lower surface generally includes areas with an elevation of less than 3 meters above the normal water surface in the active channel. This low surface is coincident with the active floodplain and is commonly vegetated with alders, willows and small conifers.

Holocene to Pleistocene Deposits

Landslides – Consists of a heterogeneous mixture of silt, sand, gravel, cobbles and boulders. Occur predominantly along glacial terrace deposits and valley walls. Mass wasting along the active river channels typically result in a “self-armoring” bank in that the finer materials are transported by the fluvial system and the larger materials are retained along the toe of the slope protecting the slope except during flood events.

Alluvial Fan – Comprised of Pleistocene glaciofluvial and Holocene fluvial deposits that form fans on the valley floors. Excessively large fans are interpreted to be glacially generated in that they most likely formed less than 10,000 years B.P. after the retreat/downwasting of the Okanogan Lobe of the Cordilleran Ice Sheet in the lower valleys. In the upper valleys remnants of the Okanogan Lobe most likely stagnated and the ice thickened during an alpine glacial advance (Sumas stade of the Fraser Glaciation). Smaller fans, typically inset within the much larger fans, are generated by fluvial processes related to ephemeral and perennial streams under the current climatic regime. These materials are unconsolidated and susceptible to fluvial erosion.

Intermediate Surface – Comprised of glaciofluvial deposits that form a series of terrace risers and terrace treads that are elevated between 3 to10 meters above normal water surface in the active channel. These surfaces are intermittent throughout the major drainages, but were only locally mapped where they have an influence on the morphology of the rivers. This surface is rarely flooded by the river during the current climatic regime. The intermediate surface is considered stable on a decadal time scale. These materials are unconsolidated and susceptible to fluvial erosion.

Glacial Deposits (Undifferentiated) – Consists primarily of glaciofluvial deposits of sand, gravel, cobbles and boulders deposited by retreat/downwasting of the Okanogan Lobe of the Cordilleran Ice Sheet and most likely glacial deposits from alpine glacial advances post-dating and/or contemporaneous with the retreat of the Okanogan Ice Sheet. Unit also includes glacial outburst flood, lacustrine, delta, till and moraine deposits. The materials are generally unconsolidated and susceptible to fluvial erosion.

5.4.2 PRE-JURASSIC TO TERTIARY DEPOSITS

Bedrock – Comprised of pre-Jurassic to Tertiary sedimentary, volcanic, metamorphic and igneous rocks, undifferentiated. The bedrock is generally hard and considered resistant to fluvial erosion.

5.5 REACH-BASED DESCRIPTION OF BEDROCK AND GEOLOGIC STRUCTURES

This section summarizes, by river reach, the bedrock and geologic structures within the 80-mile study area.

5.5.1 METHOW RIVER – CARLTON TO LOST RIVER (RM 27.5-73.0)

Carlton to Alder Creek (RM 27.5-33.5)

Bedrock along river right is predominantly Cretaceous and Jurassic volcanic and sedimentary rocks comprised of conglomerate, sandstone, siltstone and shale: part of the Buck Mountain Formation and Newby Group, Undifferentiated (Barksdale, 1975; Stoffell et al., 1991).

Bedrock along river left is predominantly pre-Jurassic metamorphic rocks comprised predominantly of intercalated gneiss, schist, quartzite, and amphibolite: Leecher Metamorphics (Barksdale, 1948; Stoffel et al., 1991).

The Methow River follows a buried thrust fault trending north-northeast that links a splay of the Smith Canyon fault to the Pasayten fault (Stoffell et al., 1991).

Alder Creek to Peters Puddles (RM 33.5-42.5)

Bedrock along both sides of the river is predominantly Cretaceous and Jurassic volcanic and sedimentary rocks comprised of conglomerate, sandstone, siltstone and shale: part of the Buck Mountain Formation and Newby Group, Undifferentiated (Barksdale, 1948 and 1975; Stoffell et al., 1991).

A normal fault trending northeast and displaced to the southeast transects the valley near Bonner Lake (Stoffell et al., 1991).

Peters Puddles to Patterson Creek (RM 42.5-52.5)

Bedrock along river right is predominantly Jurassic marine sedimentary rocks comprised of shale interbedded with sandstone, siltstone and some conglomerate: Twisp River Formation (Barksdale, 1975; Stoffell et al., 1991).

Bedrock along river left is predominantly Cretaceous and Jurassic sedimentary rocks comprised of conglomerate, sandstone, siltstone, and shale: part of the Twisp Formation, Buck Mountain Formation and Newby Group, Undifferentiated (Barksdale, 1948 and 1975; Stoffell et al., 1991).

Buried fault near Patterson Lake outlet trending north, displacement unknown (Stoffell et al., 1991).

Patterson Creek to Lewis Butte (RM 52.5-54.5)

Bedrock along river right is predominantly lower Cretaceous sedimentary and volcanic rocks comprised of conglomerate, sandstone and mudstone: Patterson Lake conglomerate (Maurer, 1958; Stoffell et al., 1991).

Bedrock along river left is predominantly Jurassic marine sedimentary rocks comprised of shale interbedded with sandstone, siltstone and some conglomerate: Twisp Formation (Barksdale, 1975; Stoffell et al., 1991).

Lewis Butte to Boesel Canyon (RM 54.5-58.0)

Bedrock along both sides of the river is predominantly upper Cretaceous continental sedimentary rocks comprised of massive sandstone with interbeds of siltstone, mudstone and shale: part of the Midnight Peak Formation (Barksdale, 1948), Virginian Ridge Formation (Barksdale, 1948) and the Winthrop Sandstone (Russell, 1900; Stoffell et al., 1991).

A fault trending north-northeast and down to the west-northwest transects the valley near Grizzly Mountain (Stoffell et al., 1991).

Boesel Canyon to Mazama (RM 58.0-65.5)

Bedrock along the right side of the river is predominantly upper Cretaceous continental sedimentary rocks comprised of massive sandstone with interbeds of conglomerate, siltstone and shale: part of the Midnight Peak Formation (Barksdale, 1948) and Winthrop Sandstone (Russell, 1900; Stoffell et al., 1991).

Bedrock along the left side of the river is predominantly Cretaceous plutonic rocks comprised of diorite: part of the Fawn Peak stock (Barksdale, 1975), McFarland Creek stock (Hopkins, 1987), Texas Creek stock (Barksdale, 1975), and Aeneas Creek pluton (Rinehart and Fox, 1976; Stoffell et al., 1991).

Mazama to Lost River (RM 65.5-73.0)

Bedrock along the right side of the river is predominantly upper Cretaceous continental sedimentary rocks comprised of massive sandstone with interbeds of conglomerate, siltstone and shale: part of the Midnight Peak Formation (Barksdale, 1948) and Winthrop Sandstone (Russell, 1900; Stoffell et al., 1991).

Bedrock along the left side of the river is predominantly upper Cretaceous sedimentary rocks comprised of massive sandstone with interbeds of conglomerate, siltstone and shale, and volcanic rocks comprised of flows, breccia and tuff: part of the Midnight Peak Formation (Barksdale, 1948) and Winthrop Sandstone (Russell, 1900; Stoffell et al., 1991).

There is a normal fault along the left side of the Lost River that trends north-northeast and is down to the west-northwest (Stoffell et al., 1991).

5.5.2 CHEWUCH RIVER – WINTHROP TO FALLS CREEK (RM 0.0-14.3)

Winthrop to Lake Creek (RM 0.0-2.8)

Bedrock along both sides of the river is predominantly Jurassic marine sedimentary rocks comprised of shale interbedded with sandstone, siltstone and some conglomerate: Twisp River Formation (Barksdale, 1975; Stoffell et al., 1991).

Lake Creek to Cub Creek (RM 2.8-7.2)

Bedrock along the right side of the river is predominantly Jurassic marine sedimentary rocks comprised of shale interbedded with sandstone, siltstone and some conglomerate: Twisp River Formation (Barksdale, 1975; Stoffell et al., 1991).

Bedrock along the left side of the river is predominantly Cretaceous and Jurassic volcanic and sedimentary rocks comprised of conglomerate, sandstone, siltstone and shale, and tuff and flows: part of the Buck Mountain Formation and Newby Group, Undifferentiated (Barksdale, 1975; Stoffell et al., 1991).

There is a buried fault following the valley floor trending north, displacement is unknown (Stoffell et al., 1991).

Cub Creek to Boulder Creek (RM 7.2-9.6)

Bedrock along both sides of the river is predominantly Cretaceous and Jurassic volcanic and sedimentary rocks comprised of conglomerate, sandstone, siltstone and shale, and tuff and flows: part of the Buck Mountain Formation and Newby Group, Undifferentiated (Barksdale, 1975; Stoffell et al., 1991).

The Chewack-Pasayten fault zone trending north-northwest transects the valley floor (Stoffell et al., 1991).

Boulder Creek to Falls Creek (RM 9.6-14.3)

Bedrock along both sides of the river is predominantly Cretaceous and Jurassic tonalitic and granodioritic orthogneiss: part of the Okanogan-Shuswap terrane (Barksdale, 1975; Stoffell et al., 1991; Miller and Bowring, 1990).

5.5.3 TWISP RIVER – TWISP TO WAR CREEK (RM 0.0-17.9)

Twisp to Elbow Canyon (RM 0.0-3.5)

Bedrock along both sides of the river is predominantly Cretaceous and Jurassic volcanic and sedimentary rocks comprised of conglomerate, sandstone, siltstone and shale, and tuff and flows: part of the Buck Mountain Formation and Newby Group, Undifferentiated (Barksdale, 1975; Stoffell et al., 1991).

Fracture zone containing three faults trending north-northwest, northeast, and southeast (Stoffell et al., 1991).

Elbow Canyon to Poorman Creek (RM 3.5-4.9)

Bedrock along the right side of the river is predominantly Cretaceous and Jurassic volcanic and sedimentary rocks comprised of conglomerate, sandstone, siltstone and shale, and tuff and flows: part of the Buck Mountain Formation and Newby Group, Undifferentiated (Barksdale, 1975; Stoffell et al, 1991).

Bedrock along the left side of the river is predominantly Jurassic marine sedimentary rocks comprised of shale interbedded with sandstone, siltstone and some conglomerate: Twisp River Formation (Barksdale, 1975; Stoffell et al., 1991).

Poorman Creek to Lime Creek (RM 4.9-15.3)

Bedrock along both sides of the river is predominantly upper Cretaceous sedimentary and volcanic rocks comprised of sandstone, siltstone, mudstone, shale, flows, breccia and tuff: part of the Midnight Peak Formation (Barksdale, 1948), Virginian Ridge Formation (Barksdale, 1948) and Winthrop Sandstone (Russell, 1900; Stoffell et al., 1991).

There is a fault trending north-northwest and is down to the east-northeast at Canyon Creek Ridge, but does not appear to transect the valley (Stoffell et al., 1991).

Lime Creek to War Creek (RM 15.3-17.9)

Bedrock along the right side of the river is predominantly Triassic and Permian metasedimentary rocks comprised of amphibolite, quartzite, schist and marble: includes the Twisp Valley schist (Adams, 1961; Miller, 1987; Stoffell et al., 1991).

Bedrock along the left side of the river is predominantly upper Cretaceous sedimentary and volcanic rocks comprised of massive sandstone interbedded with siltstone, shale, flows, breccia and tuff: part of the Midnight Peak Formation (Barksdale, 1948) and Winthrop Sandstone (Russell, 1900; Stoffell et al., 1991).

Twisp River flows along the Hozameen-North Creek fault zone above War Creek (Stoffell et al., 1991; Miller and Bowring, 1990).

6. REFERENCES

IN TEXT	FULL CITATION
Adams 1961	Adams, J. B. 1961. *Petrology and structure of the Stehekin-Twisp Pass area, northern Cascades, Washington.* University of Washington, Seattle, WA. Doctor of Philosophy thesis, 172 p.
Andonaegui 2000	Andonaegui, C. 2000. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48: Final Report.* Washington State Conservation Commission, 232 p.
Barksdale 1941	Barksdale, J.D. 1941. "Glaciation of the Methow Valley, Washington" in *Journal of Geology*, v. 49, no. 7, p. 721-737.
Barksdale 1948	Barksdale, J.D. 1948. "Stratigraphy in the Methow quadrangle, Washington," in *Northwest Science*, v. 22, no. 4, p. 164-176.
Barksdale 1975	Barksdale, J.D. 1975. *Geology of the Methow Valley, Okanogan County, Washington*, Washington Division of Geology and Earth Resources Bulletin 68, 72 p., 1 plate.
Bretz 1923	Bretz, J. 1923. "Glacial drainage on the Columbia Plateau" in *Geological Society of America Bulletin*, v. 34, p. 573-608.
Bretz 1932	Bretz, J. 1932. "The Grand Coulee" in *American Geographical Society Special Publication* No. 15, 89 p.
Burtchard 1998	Burtchard, G. 1998. *Technical Report, Environment, Prehistory & Archaeology of Mount Rainier National Park, Washington.* Prepared for National Park Service, Seattle, WA by International Archaeological Research Institute, Inc., G.C. Burtchard with contributions by S.C. Hamilton and R.H. McClure, Jr. Originally published February 1998; Reprinted February 2003. Accessed at http://www.nps.gov/archive/mora/ncrd/archaeology/index.htm (October 10, 2007).
DeGraaff-Surpless et al., 2003	DeGraaff-Surpless, K.; Mahoney, J.; Wooden, J.; and McWilliams, M. 2003. "Lithofacies control in detrital zircon provenance studies –Insights from the Cretaceous Methow basin, southern Canadian Cordillera" in *Geological Society of America Bulletin*, v. 115, no. 8, p. 899-915.

IN TEXT	FULL CITATION
Flint 1935	Flint, R. 1935. "Glacial features of the southern Okanogan region" in *Geological Society of America Bulletin*, v. 46, p. 169-194.
Flint 1936	Flint, R. 1936. "Stratified drift and deglaciation in eastern Washington" in *Geological Society of America Bulletin*, v. 47, p. 1849-1884.
Flint and Irwin 1939	Flint, R. and Irwin, W. 1939. "Glacial geology of Grand Coulee Dam, Washington" in *Geological Society of America Bulletin*, v. 50, p. 661-680.
Golder 2005	Golder Associates, Inc. 2005. *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Hopkins 1987	Hopkins, W. 1987. *Geology of the Newby Group and adjacent units in the southern Methow trough, northeast Cascades, Washington:* San Jose State University, San Jose, CA. Master of Science Thesis, 95 p.
Huesser 1977	Huesser, C. 1977. "Quaternary Palynology of the Pacific Slope of Washington" in *Quaternary Research*, v. 8, p. 282-306.
Hurlow 1993	Hurlow, H. 1993. "Mid-Cretaceous strike-slip and contractional fault zones in the western intermontane terrane, Washington, and their relation to the North Cascades-southeastern Coast Belt orogen" in *Tectonics*, v. 12, p. 1240-1257.
Johnson 1985	Johnson, S. 1985. "Eocene strike-slip faulting and nonmarine basin formation in Washington" in Biddle, K. T., and Christie-Blick, N., eds., "Strike-slip deformation, basin formation, and sedimentation" in *Society of Economic Paleontologists and Mineralogists Special Publication* 37, p. 283-302.
Konrad et al. 2003	Konrad, C.P.; Drost, B.W.; and Wagner, R.J. 2003. *Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington*. US Geological Survey Water-Resources Investigations Report 03-4244, 137 p.

IN TEXT	FULL CITATION
Maurer 1958	Maurer, D.L. 1958. *Biostratigraphy of the Buck Mountain member and adjacent units in the Winthrop area, Washington:* University of Washington Master of Science thesis, 111 p.
McGroder 1988	McGroder, M. 1988. *Structural evolution of the eastern Cascades fold belt – Implications for late Mesozoic accretionary tectonics in the Pacific Northwest*. University of Washington, Seattle, WA. Doctor of Philosophy thesis, 140 p.
McGroder and Miller 1989	McGroder, M. and Miller, R. 1989. “Geology of the eastern North Cascades” in Joseph, N. and other editors, *Geologic Guidebook for Washington and Adjacent Areas.* Washington Division of Geology and Earth Resources Information Circular 86, p. 97-118.
Milhous et al., 1976	Milhous, R., Sorlie, G., and Richardson, D. 1976. *Water Resources of the Methow Basin*. Washington Department of Ecology, Olympia, WA. Water Resources Analysis and Information Section, *Office Report* No. 56, 57 p.
Miller 1987	Miller, R.B. 1987. *Geology of the Twisp River-Chelan Divide region, North Cascades, Washington.* Washington Division of Geology and Earth Resources Open File Report 87-17, 12 p., 12 plates.
Miller and Bowring 1990	Miller, R. and Bowring, S. 1990. “Structure and chronology of the Oval Peak batholith and adjacent rocks –Implications for the Ross Lake fault zone, North Cascades, Washington” in *Geological Society of America Bulletin*, v. 102, p. 1361-1377.
Miller et al., 1994	Miller, R., Haugerud, R., Murphy, F., and Nicholson, L. 1994. “Tectonostratigraphic framework of the Northeastern Cascades” in *Washington Division of Geology and Earth Resources Bulletin* 80, p. 73-92.
Parrish et al., 1988	Parrish, R., Carr, S., and Parkinson, D. 1988. “Eocene extensional tectonics and geochronology of the southern Omineca belt, British Columbia and Washington” in *Tectonics*, v. 7, p. 181-212.
Potter 1986	Potter, C. 1986. “Origin, accretion, and post accretionary evolution of the Bridge River terrane, southwest British Columbia” in *Tectonics*, v. 5, p. 1027-1041.

IN TEXT	FULL CITATION
Price et al. 1985	Price, R., Monger, J., and Roddick, J. 1985. "Cordilleran cross-section; Calgary to Vancouver" in Templeman-Kluit, D., ed., *Field guides to geology and mineral deposits in the southern Canadian Cordillera:* Geological Society of America, Cordilleran Section Meeting, Vancouver, p. 3-1 thru 3-85.
Ray 1986	Ray, G. 1986. "The Hozameen fault system and related Coquihalla serpentine belt of southwestern British Columbia" in *Canadian Journal of Earth Sciences*, v. 23, no. 7, p. 1022-1041.
Richardson 1976	Richardson, D. 1976. *Natural monthly streamflow in the Methow Basin*. Washington Department of Ecology, Olympia, WA. Water Resources Analysis and Information Section, Office Report No. 46, 7 p.
Riedel et al., 2003	Riedel, J., Clague, J., Scott, K., and Swanson, T. 2003. "Late Fraser alpine glacier activity in the North Cascades, Washington" [abstract] in *Geological Society of America Abstract with Programs*, v. 35, no. 6, p. 216.
Rinehart and Fox 1972	Rinehart, C.D., and Fox, K.F., Jr. 1972. *Geology and mineral deposits of the Loomis quadrangle, Okanogan County, Washington*: Washington Division of Geology and Earth Resources Bulletin 64, 124 p., 3 plates.
Roddick and Okulitch 1979	Roddick, J.; Muller, J.; and Okulitch, A. 1979. *Fraser River, British Columbia-Washington.* Geological Survey of Canada Map 1386a, scale 1:1,000,000.
Russell 1990	Russell, I. 1900. "A preliminary paper on the geology of the Cascade mountains in northern Washington" in US Geological Survey *20th Annual Report, Part 2*, p. 83-210.
Stoffel et al., 1991	Stoffel, K.L., Joseph, N.L., Waggoner, S.Z., Gulick, C.W., Korosec, M.A., and Bunning, B.B. 1991. *Geologic Map of Washington – Northeast Quadrant*. Washington Division of Geology and Earth Resources, Geologic Map GM-39.
Tennyson and Cole 1987	Tennyson, M.E. and Cole, M.R. 1987. "Upper Mesozoic Methow-Pasayten sequence, Northeastern Cascade Range, Washington and British Columbia" in Schuster, J. E. ed., 1987, *Selected Papers on the Geology of Washington.* Washington Division of Geology and Earth Resources Bulletin 77, p. 73-84.

IN TEXT	FULL CITATION
Varsek et al., 1993	Varsek, J., Cook, F., Clowes, R., Journeay, J., Monger, J., Parrish, R., Kanasewich, E., and Spencer, C., 1993, "Lithoprobe crustal reflection structure of the southern Canadian Cordillera 2: Coast Mountains transect" in *Tectonics*, v. 12, p. 334-360.
Waitt 1972	Waitt Jr., R.B. 1972. *Geomorphology and glacial geology of the Methow drainage basin, eastern North Cascade Range, Washington.* University of Washington, Seattle, WA. Doctor of Philosophy thesis, 154 p.
Waitt 1975	Waitt, R.B., Jr. 1975. "Late Pleistocene alpine glaciers and the Cordilleran ice sheet at Washington Pass, North Cascade Range, Washington" in *Arctic and Alpine Research*, v. 7, no. 1, p. 25-32.
Waitt 1980	Waitt, R.B., Jr. 1980. *Cordilleran Icesheet and Lake Missoula catastrophic floods, Columbia River Valley, Chelan to Walla Walla:* Guidebook for West Coast Friends of the Pleistocene Field Conference.
Waitt 1982	Waitt, R.B., Jr. 1982. "Surficial geology" in *Geologic Map of the Wenatchee 1:100,000 quadrangle, Washington* (R.W. Tabor et al.). USGS Miscellaneous Investigations Map MI-1311.
Waitt and Thorson 1983	Waitt, R. and Thorson, R. 1983. "The Cordilleran Ice Sheet *in* Washington, Idaho, and Montana" in Wright, Jr., H., and Porter, S., editors, *Late-Quaternary environments of the United States, Volume 1, The Late Pleistocene,* University of Minnesota Press, Minneapolis, MN, p. 53-70.
Waitt et al., 1982	Waitt, R., Yount, J., and Davis, P. 1982. "Regional significance of and early Holocene moraine in Enchantment Lakes Basin, North Cascade Range, Washington" in *Quaternary Research*, v. 17, p. 191-210.
Walters and Nassar 1974	Walters, K. and Nassar, E. 1974. *Water in the Methow River Basin, Washington.* Washington Department of Ecology, Water-Supply Bulletin 38, 73 p.
Waters 1933	Waters, A. 1933. "Terraces and coulees along the Columbia River near Lake Chelan, Washington" in *Geological Society of America Bulletin*, v. 44, p. 783-820.

APPENDIX N –

SEDIMENT SOURCES AND HUMAN FEATURES FOR SUBWATERSHEDS WITHIN THE ASSESSMENT AREA

This appendix provides a qualitative assessment of sediment sources and human features that affect sediment recruitment to qualitatively assess if the timing and volume of sediment delivered to the channel have been altered within the last 50 years. Additional work may be needed in areas where projects are implemented if sediment recruitment is an important factor. More detailed analysis may assist with determining project design, predicting future channel processes, or identifying habitat concerns or benefits. Examples are recruitment of spawning gravels or plugging of redds with fine sediment. Locations of observed bank erosion, landslides and debris flows are noted for each subwatershed, along with a list of irrigation diversions in section 2. General characteristics of each subwatershed are also provided.

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1. OVERVIEW

Changes in channel morphology can result from a natural or human induced change to the upstream water and sediment supply over decadal time scales. For example, a large, sustained increase in sediment could cause a meandering reach to become straighter if the change in the balance overwhelms the ability of the river to transport the sediment through a given reach.

Within the assessment area historical aerial photograph analysis indicates there is no large-scale change in channel morphology since 1948 (the first available aerial photograph). Additionally, bank erosion that resulted in measurable expansion of the boundary of the low-surface between 1945 and 2004 was limited to only a few places. This occurs partly because the low-surface boundary naturally has a low erosion potential in many areas (bedrock, glacial surfaces with cobbles, alluvial fans), and because the areas that are prone to erosion have been largely armored with riprap. This would indicate any changes to the balance between water and sediment supply have not been significant enough to impact channel form on a decadal reach scale (localized, short-term impacts are more prevalent). To provide a check on these findings, a qualitative assessment was done of sediment sources and human features that affect sediment recruitment to assess if the timing and volume of sediment delivered to the channel have been altered within the last 50 years. Where there have been alterations the impacts were evaluated to determine if they validate historical aerial photograph analysis or whether they are significant enough to impact reach-based morphology.

The locations of sediment sources and human features affecting sediment recruitment were qualitatively evaluated based on available literature, historical aerial photographs, and field observations. Delivery rates were classified in general terms of either continual delivery as a function of stream flow and runoff, or episodic such as from landslides, bank erosion, or debris flows. The focus of the assessment was mainly on coarse sediment sources that are most closely linked to channel form within the assessment area. More detailed discussions on the historical aerial photography assessment and human feature mapping can be found in Appendix G (“Geomorphology”) and Appendix P (“Human Features”). Fine-sized sediment impacts to spawning gravel quality within the Chewuch and Twisp are discussed in Appendix K (“Hydraulics and Sediment Analysis”); these are based on McNeil core sampling by the USFS since 2000 (no data currently available in Methow River).

Field observations validate that the impacts to sediment recruitment are difficult to detect in terms of reach level channel morphology. The impacted sediment sources from human features are generally small relative to the total sediment supply and recruitment process on the Methow, Twisp, and Chewuch assessment areas. Therefore, these impacts can only be observed in a localized vicinity of the sediment source itself. For example, bank erosion and landslides were documented in several locations along the assessment area. However, the volume and timing of sediment contributed from an eroding bank is dependent on the height of the bank, the size of sediment in the bank, and the lateral extent of erosion. Many banks that are documented as eroding in available literature are along the active channel within the low surface (floodplain). Many of these areas are considered part of the natural migration process and thus part of the natural sediment recruitment. In a few areas, the bank erosion rate may be exasperated by human features, but more closely spaced measurements in time at a more detailed scale would be needed to further evaluate these areas.

Based on historical photograph analysis, other banks along the boundary of the low surface, debris flows, and landslides appear to be eroding but likely only provide limited, episodic pulses of sediment over decades of time. Many of these sources contain large cobble-size sediment that fall to the toe of the bank and provide natural armoring. These sediment sources may cause a temporary sediment bar to form until a large-enough flow occurs to mobilize and transport the sediment downstream. Lower elevation banks that would have more potential to erode have largely been armored with riprap and thus do not tend to provide much sediment if properly designed. In a few cases, banks that are poorly engineered do fail and provide bank sediment and angular riprap to the river.

A quantitative sediment budget and sediment load measurements were beyond the available resources for this assessment, but could be done in future studies to confirm this qualitative assessment. A sediment budget would require sampling of bedload and suspended load at key locations along the river at a range of low-to-high flows to develop a sediment-rating curve. It would also require bulk sampling of sediment contributed from landslides, bank erosion, and floodplain and riverbed sediment to develop a particle size distribution for each source area. The rate of delivery (frequency) and volume of sediment from each of these sources would then need to be estimated. This information could be coupled with a sediment transport or budget model that would route the sediment along the assessment area and adjust the sediment in storage in the channel bed and floodplain based on an input hydrograph.

The following text provides a summary of significant subwatersheds present within the assessment area and the general sources that have been observed in the field to provide sediment to the river. In each subwatershed, human features that have the potential to alter the recruitment and delivery of sediment to the river have been noted, such as bank armoring and channel confinement features.

2. WATER SUPPLY AND IRRIGATION DIVERSIONS

During floods, there are limited human impacts to the upstream water supply in the Methow Subbasin that would impact the peak or timing of flows to the 80-mile assessment area; that is, there are no upstream flood control reservoirs or significant diversions relative to flood peaks. A few exceptions exist where significant logging have occurred which have the potential to alter flood peaks. The most notable example is in Beaver Creek, which enters the Methow River at RM 35.2. Fires have also occurred in many of the subwatersheds and are expected to continue to occur throughout the assessment area in the future. A quantitative evaluation of to what degree fires, timber harvests, and roads have impacted flood peaks was not included in the scope of this assessment because the impacts are limited relative to the total flow available to the assessment area.

Diversions have more potential to impact habitat conditions at low flows during the irrigation season, but this does not tend to impact channel morphology. Water storage during spring runoff floods has been impacted along the assessment area where the floodplain has been constricted and cleared of vegetation, thus increasing the rate that water travels through a given reach. This is not detectable in the channel morphology, but can impact low-flow habitat conditions. Winter floods can be fairly flashy and short in duration, and thus the impact on storage would be expected to be less than during spring runoff which is of a longer duration. A quantitative analysis of whether impacts to flood storage are of a detectable level that would impact recharge or habitat function was beyond the scope of this assessment.

An inventory of Methow Subbasin irrigation diversions was provided in Andonaegui (2000). Several of these diversions have been abandoned or converted to wells since that report was published. The list has been updated and provided below for each subwatershed based on local knowledge by Reclamation’s Methow Field Station (Knott, 2007).

Methow River:
- Foghorn Ditch (Fish Hatchery) Diversion, RM 52.95
- MVID East, RM 46

Chewuch
- Fulton Diversion, RM 0.9
- Chewuch Diversion, RM 8.1
- Skyline ditch, RM 9.0
- Lucille Mason ditch

Twisp River
- Risley (Airey) Ditch, RM 0.7, converted to well

- Northside/Doran, unknown RM, abandoned
- MVID West, RM 3.9,
- Brown/Gillihan Ditch, RM 4.6, active but converted to MSRF habitat restoration project (non-consumptive use)
- Hottell Diversion, RM 6.0,
- Twisp River Power and Irrigation Ditch, RM 6.9,
- Elmer Johnson/Libby/Culbertson Ditch, RM 11.1, converted to wells

Buttermilk Creek

- RM 1.8

Little Bridge Creek

- Aspen Meadows Maintenance Corporation diversion

Eightmile Creek

- the Eightmile Ranch ditch, RM 0.25, converted to well

Early Winters

- irrigation ditch, RM 0.6
- Willis ditch RM 1.4, abandoned

Goat Creek

- Foster Diversion, RM 1.2, diverting 4.5 cfs

Wolf Creek

- Haub Brothers Enterprises Trust (HBET) and Bud Hover, RM 0.25 to 0.5, inactive
- Perrow Ditch at RM 0.5,
- Wolf Creek Reclamation District (WCRD) at RM 4.0.

Beaver Creek

- Fort-Thurlow Diversion
- Tice Ranch Diversion
- Lower Stokes Diversion (Miller Ditch)
- Thurlow Transfer Ditch
- Upper Stokes Diversion
- Red Shirt Diversion
- Batie Diversion
- Marracci Diversion

Black Canyon Creek – One diversion

Libby Creek

- Larson Libby Creek Diversion
- Larson Chicamun Creek Diversion

Scaffold Creek – One diversion

3. UPPER METHOW RIVER SUBWATERSHED

The Upper Methow subwatershed contains about 322,385 acres from its confluence with the Chewuch River (RM 50.1) to the Cascade crest (RM 86.8). The river section is approximately 36 miles long and has fourteen tributaries — Bush Creek, Trout Creek, Rattlesnake Creek, Robinson Creek, Lost River, Early Winters Creek, Gate Creek, Goat Creek, Little Boulder Creek, Fawn Creek, Hancock Creek, Little Falls Creek, Wolf Creek, and the Chewuch River (Andonaegui, 2000). The Goat Creek subdrainage, Lost River subwatershed, Early Winters Creek subwatershed, and Chewuch River subwatershed are discussed in their own sections in this appendix.

Precipitation in the Upper Methow subwatershed is about 80 inches at the Cascade crest and about 20 inches in the town of Mazama (Andonaegui, 2000). About 85% of the subwatershed is under federal ownership (KWA, 2004). Occasionally, portions of the reach dewater between Robinson Creek (RM 74.0) and Weeman Bridge (RM 59.7) (Andonaegui, 2000). From 1987 to 1999, approximately 40% of spring Chinook salmon spawning occurred in the Upper Methow subwatershed between the Lost River confluence (RM 73.0) and the Winthrop Bridge (RM 49.8) (USFS, 1998a).

3.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

Portions of the upper Methow River have been constricted by bank protection (riprap), flood protection (levees), and bridges.

Between RM 49.75–51.25, the river is tightly confined by high terraces (approximately 40 feet above the river) with a bedrock exposure between RM 51–51.5. At the Winthrop Bridge, the right bridge support at RM 51.15 appears to be impeding flow and developing a gravel bar (Golder, 2005).

Between RM 51.25–53.0, the banks are composed of alluvium and many of them are being actively eroded. This reach is extensively riprapped. The 1948 Flood inundated the River Run Resort located in this reach. At the confluence of the Chewuch and Methow Rivers (Methow RM 51.5), the left bank is generally armored with riprap and underlain by bedrock. The Fish Hatchery dike at RM 51.75 on river right is about 6 to 7 feet above the floodplain and 15 to18 feet above the active channel. Upstream of the dike, the right bank is armored with riprap. Between RM 52.25–52.5, the floodplain is broad with old channels present on the opposite side of Highway 20. The right bank in this section is armored with riprap. At RM 52.3, the river is actively eroding an island and a 3-meter-high terrace along river right. Along river left the bank is extensively riprapped. The Foghorn Ditch (Fish Hatchery) diversion is located at RM 52.95 with riprap on both upstream and downstream banks (Golder, 2005).

Between RM 53.0 –55.5, the river is tightly confined by Wolf Creek alluvial fan and glacial deposits. The alluvial fan appears to be very active. Currently the toe of the alluvial fan is being eroded by the river. Along river left (RM 54.5), there is a kame terrace about 10-30 meters high (Golder, 2005). Wolf Creek enters the Methow River at RM 54.5.

The reach from RM 55.5–60.75 has multiple active and abandoned channels. Large woody debris (LWD) in the channel and floodplain is abundant in this reach. The riverbanks are being actively eroded within the floodplain as part of the natural lateral reworking and migration of the channel. This reach is generally not confined by bedrock, glacial terraces, or alluvial fans. The right riverbank is actively eroding at the Wolf Creek Lodge near RM 56.0 and the property at RM 56.3. A cable tram is located at RM 56.8 that constricts the river between riprap along river right to protect the right abutment and the left tower abutment with exposed concrete. Active erosion is also occurring along river right at RM 57.5 and river left at RM 59.1. The floodplain and historic channels are bisected by Highway 20 at RM 59.5. At RM 60.25, the river is actively eroding both banks along the outside of meander bends (Golder, 2005).

Between RM 60.75–65.5, the river is less dynamic and there is less LWD. The river is deflected and actively eroding three alluvial fans — Fawn Creek fan (RM 63), Goat Creek fan (RM 65), and Boulder Creek fan (RM 65) (Golder, 2005). The largest sediment sizes are found at the alluvial fans. LWD is abundant in this reach. Channels on the left floodplain were dug by the Army Corp of Engineers in the 1940s and 1950s, and the local public utility department (PUD) packed trees into the channels after clearing trees along the powerline right-of-way.

The Weeman Bridge is located at RM 61.1 and constricts the river. There is riprap placed along the base of Goat Creek Road (RM 62.4) above an old channel along river left. Along river right (RM 62.5), there is a small placement of riprap and downstream of the riprap the river is actively eroding. A house washed into the river at RM 63.0 along river left and the lower riverbank is now heavily protected with riprap. There has been riprap placed along river left about RM 63.25, below the Goat Creek Road. The McKinney Mountain Dike was built in 1975 by the Army Corps of Engineers (ACOE) on private lands at about RM 63.75. The dike was "washed-out" during a historical flood and then reconstructed in 1997 and 1999 by ACOE (Andonaegui, 2000). The dike is adjacent to a community trail that cuts off a historic channel. The dike is about 2 meters above the abandoned channel and about 3 meters above the present active channel. There is active erosion along river right (RM 64.3), no erosion along river left where the soil is more cohesive. Little Boulder Creek enters the Methow River at RM 65.25; downstream of a culvert on the creek, there appears to be channel incision. Goat Creek enters the Methow River at RM 65.0; the channel has been artificially straightened, and the stream appears to have considerable transport capacity (Golder, 2005).

From RM 65.5–70.5, the river is generally a meandering channel. There is active riverbank erosion and the river appears to be eroding the toe of the Early Winters Creek alluvial fan. There is riprap along river right at RM 65.75 and a sugar dike along river right between RM 65.3–65.8. The right riverbank is actively eroding at RM 66.25 and along the outside of meander bends at RM 67.3. There is active erosion along the left riverbank at RM 68.5 where the river runs against a 3-meter-high terrace that appears to be self-armoring. Downstream of RM 69.5, there is erosion along both riverbanks (Golder, 2005).

From RM 70.5–75.0, the river is deflected by the McGee Creek alluvial fan. The confluence of the Lost and Methow Rivers is located at RM 75. There is an abundance of large woody debris in this reach. At RM 70.5, both riverbanks are actively eroding. Large boulders (greater than 2 meters in diameter) dislodged from the valley walls rolled into the river at RM 71.0. There is a channel spanning logjam and right bank along the outside of a meander bend is actively eroding at RM 71.5. There is a small dike along the property at RM 72.5. A house was reportedly built on an old channel that was filled in along the left bank at RM 72.95. Houses were built on floodplain near RM 73.1. Cedarosa Way and River Lane appear to follow a historic river channel. There is a small dike at RM 73.45 that cuts off several old channels. The left riverbank at RM 73.85 has eroded back about 150 feet since the 1980s, and timber and stone revetments have been placed to protect a house. Houses have been built on the floodplain at RM 74.2 and river left is actively eroding along a terrace 10 to 30 meters high. There is a poorly maintained levee built in 1983 along river left from RM 74.6–75.0. At RM 74.9, there is a historic channel along river left. At RM 75.0, both riverbanks are eroding along a talus slope underlain by bedrock and a push-up levee located downstream on river left (Golder, 2005).

3.2 SEDIMENT SOURCES

Fine sediment sources include sheet and rill erosion from subwatersheds and subdrainages from natural processes, or where the landscape has been disturbed by timber harvest, road construction, and forest fires.

Coarse sediments supplied to the Upper Methow subwatershed are primarily from the river's reworking of the floodplain and from sediment supplied from four subwatersheds — Robinson Creek, Goat Creek, Lost River, Early Winters, and the Chewuch River. Coarse sediment sources also include mass wasting and bank erosion along the mainstem and tributary channels. There are also several areas where the river is eroding high glacial banks that can provide fine and coarse sediment to the system during high water events. The lateral extent of this terrace erosion is limited which tends to reduce the volume supplied. There is chronic erosion of colluvium along the valley walls, and debris avalanches in the Lost River subwatershed and Robinson Creek subdrainage. There is also chronic erosion along the banks of lower Early Winters Creek and Goat Creek where the creeks have been channelized.

Other coarse sediment sources include episodic debris flows and landslides entering the Methow River. The following drainages have the potential to provide debris flows to the Methow River based on field observations and previous literature, or where observed on historical aerial photographs following the 1948 Flood, the 1972 Flood, or both (noted after drainage name if documented):

- Wolf Creek (RM 54.2) in 1948 and 1974
- Cassal Creek (RM 61.72) in 1974
- Un-named #31 (RM 61.8) in 1974
- Little Boulder Creek in 1948 and 1974
- Goat Creek (RM 64) in 1945, 1948, 1974, and 1998
- Un-named #7 (RM 70.8)
- Goat Wall Creek (RM 71.3)
- McGee Creek (RM 73.0)
- Un-named #2 (RM 74.25).

Landslides along the Methow River were observed during 2005 field investigations at the following locations:

- RM 72.45-72.8 (right bank)
- RM 74.01-74.1 (right bank)
- RM 74.2-74.25 (right bank)
- RM 74.29-74.35 (right bank)
- RM 74.5-74.7 (right bank).

4. LOST RIVER SUBWATERSHED

The Lost River subwatershed is generally a north-to-south drainage containing about 107,400 acres. The elevations range from about 6900 feet in the headwaters to 2600 feet at the confluence with the Methow River (RM 70.0). The river is about 22.5 miles long and includes as tributaries Eureka, Monument, and Drake Creeks. Several of the tributaries head in glacial cirques. Numerous debris avalanches and debris flow tracks as observed on the 2004 aerial photographs enter the river and its tributaries. The subwatershed has remained virtually unchanged with the exceptions of fire suppression, isolated livestock use, recreational riparian use, and residential development at the confluence. During late summer, the river flows subsurface between Drake Creek (RM 11.7) and Monument Creek (RM 7.1). Spring Chinook salmon utilize Lost River for spawning to about Eureka Creek (RM 4.0). Steelhead and bull trout utilize the river for both spawning and rearing and several of its tributaries (Andonaegui, 2000).

4.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

The Lost River subwatershed from Lost River Bridge at RM 1.0 to the headwaters is in near-pristine condition. Floodplain and LWD in the river system are functioning properly and temporarily storing much of the sediment as it moves through the system (Andonaegui, 2000). The lower mile of the river is constricted due to channelization of the lower 0.6 miles, Lost River Bridge, and the Lost River Dike. The Lost River Dike was built on private and USFS land at the confluence with the Methow River (Andonaegui, 2000). Between the confluence and RM 1.0, the Lost River is interpreted to be a transport reach with limited sediment storage and recruitment due to the artificial confinement.

4.2 SEDIMENT SOURCES

Sediment loads entering the Lost River system are primarily from erosion of the colluvium adjacent to the river and debris avalanches. These are chronic sources of sediment being supplied to the system. The 1998 aerial photographs show a fresh debris avalanche that has entered the river above Eureka Creek. Fine sediment sources include sheet and rill erosion at background levels as the watershed remains in a relatively pristine condition. Coarse sediment sources include mobilization of riverbed and floodplain sediment, mass wasting and bank erosion along the mainstem and tributary channels.

5. EARLY WINTERS CREEK SUBWATERSHED

Early Winters Creek is generally a south-to-north drainage containing about 51,900 acres. Elevations in the drainage range from about 8440 feet down to 2140 feet at the confluence with the Methow River at RM 67.3. Maximum annual precipitation ranges from 80 inches in the upper watershed to a low of 20 inches at Mazama (Andonaegui, 2000). The creek is about 15.7 miles long with two major tributaries, Cedar Creek and Varden Creek. Early Winters Creek heads in glacial cirques and since the Pleistocene has constructed a broad alluvial fan where it enters the Methow Valley floor. Debris avalanches along the over-steepened valley walls are common. Spring Chinook salmon spawning and year-round rearing occur in the downstream-most four river miles. At RM 8.0, a 6-meter-high natural falls forms a barrier to upstream migration (Andonaegui, 2000).

5.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

Sediment processes in the subwatershed upstream of RM 2 are affected by some degree from historical fire suppression and more notably from the construction of State Highway 20. There are significant impacts in the lower two miles due to recreational use, irrigation withdrawals, dike construction, and residential development (Andonaegui, 2000).

State Highway 20 traverses across the Early Winters alluvial fan and then follows the creek upstream to Washington Pass. The highway crosses the creek in three locations and its location precludes natural floodplain function. There are two designated USFS campgrounds located in the riparian area along the creek at Early Winters Creek (RM 0.3–0.7) and Lone Fir (RM 9.5). Early Winters Creek campground has experienced about 100 meters of bank erosion along the north side (J. Molesworth, verbal communication). At RM 0.0–1.9, the channel was noted by the USFS to be incised as a result of riprap and dikes, leading to increased stream gradient, increased stream velocities and loss of gravel (USFS, 1998b). The lower 0.5 mile has riprap and dikes to keep the channel in a stable location. LWD has been removed from the channel in the vicinity of Early Winters Creek Campground for flood control measures, and the removal of hazardous trees along the riparian zone has negatively affected LWD recruitment potential. These actions have likely resulted in higher velocities and shear stresses on the bank during high flows (Andonaegui, 2000).

5.2 SEDIMENT SOURCES

Sediment sources in the subdrainage are primarily debris flows entering the stream during spring runoff and summer thunderstorms.

6. GOAT CREEK SUBDRAINAGE

Goat Creek is generally a north-to-south drainage containing about 22,200 acres. Elevations in the drainage range from about 8000 feet to 2100 feet at the confluence with the Methow River (at RM 64). Maximum annual precipitation ranges from 35 to 40 inches in the upper watershed to a low of 15 to 20 inches at the mouth (Andonaegui, 2000). The creek is about 12.5 miles long with nine tributaries, including Montana, Whiteface, Long, Short, Round, and Cougar Creeks.

Goat Creek heads in what topographically appears to be a glacial cirque and since the Pleistocene has constructed a broad alluvial fan where it enters the Methow Valley floor. The 1998 aerial photographs show numerous debris avalanches and debris-flow tracks entering Goat Creek in the upper reaches. In late summer and fall the creek typically flows subsurface through the lower section of the alluvial fan (Andonaegui, 2000). Spring Chinook salmon spawn in the Methow River above and below the confluence and probably near the creek's mouth. At RM 12.0, a natural falls forms a barrier to upstream fish passage (Andonaegui, 2000).

6.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

In the 1930s, Crown Point Mine Road was constructed across Goat Creek and changed the stream's course. The constriction resulted in the stream depositing large amounts of sediment and widening its channel downstream (Andonaegui, 2000).

There has been extensive timber harvest with associated road construction in the Whiteface Creek, Roundup Creek, Long Creek, and Short Creek subdrainages. In addition, the lower ten miles of the Goat Creek drainage has been logged extensively, including the riparian zone. Timber harvests in the riparian zone have reduced LWD recruitment and reduced beaver activity in the lower section of Goat Creek (Andonaegui, 2000).

Other notable watershed impacts include channelization of the lower 1.5 miles of the creek in 1970's (to maintain the creek on the apex of the alluvial fan) and the 1994 Whiteface Fire that burned 3,672 acres in the drainage (Andonaegui, 2000).

6.2 SEDIMENT SOURCES

Fine sediment sources include chronic sheet and rill erosion exacerbated by high road densities, cattle grazing in the headwaters, timber harvests, and wildfires in the subdrainages.

Coarse sediment sources include sediment in storage in the riverbed and floodplain, mass wasting, road failures, and bank erosion along the tributary channels.

Review of historical aerial photographs (1945, 1948, 1974, and 1998) show evidence of debris flow tracks entering the Methow River via Goat Creek. The channel confinement of the lower 1.5 miles of Goat Creek in the 1970's has likely increased the sediment transport capacity, but may also have limited the sediment supply. In the 1974 aerial photograph, a sediment slug had begun entering the Methow River shortly after re-alignment of the lower Goat Creek channel. A rough volume estimate was determined using the 1948 and 1998 aerial photographs in GIS to approximate the area of fan progradation at the mouth. The sediment slug appears to cover roughly 6,700 square yards; assuming its depth is about 1 yard, the total volume of sediment is approximately 6,700 cubic yards. The Methow River appears to be slowly eroding the sediment slug in the 1998 and 2004 aerial photographs.

7. WOLF CREEK SUBWATERSHED

Wolf Creek is generally a west-to-east drainage containing about 25,800 acres. Elevations in the drainage range from about 8900 feet to 2000 feet at the confluence with the Methow River (at RM 52.8). The creek is about 14 miles long with four named tributaries that include Little Wolf Creek, North Fork Wolf Creek, South Fork Wolf Creek, and Hubbard Creek. Wolf Creek heads in a glacial cirque and, since the Pleistocene, it has constructed a broad alluvial fan where it enters the Methow Valley floor. In late summer and fall, the creek typically flows subsurface through the lower section of the alluvial fan from RM 0.0–0.5 (Andonaegui, 2000). Wolf Creek is a spawning and rearing stream for bull trout, steelhead, and spring Chinook salmon. A 12-foot-high waterfall at RM 10.6 is a barrier to upstream fish passage (Andonaegui, 2000).

7.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

Most of the upper drainage is located in the wilderness with the exception of USFS land and privately owned land below RM 4.6. Impacts related to timber harvests and roads are mainly located within the Little Wolf Creek drainage. Impacts from cattle grazing have occurred in the Wolf Creek headwaters and the confluence of Wolf Creek and the North Fork. Conversion of land to agriculture and residential use below RM 4.6 has contributed to a loss of riparian habitat (Andonaegui, 2000).

A dike was constructed within the upper 1,000 feet of the Wolf Creek alluvial fan; the lower 1.5 miles of the creek are also channelized. Further channel confinement on the alluvial fan is the result of residential development, County Road #1145, and Wolf Creek Road (Andonaegui, 2000).

7.2 SEDIMENT SOURCES

Fine sediment sources include chronic sheet and rill erosion exacerbated by roads, cattle grazing in the headwaters, and timber harvests in the subdrainages. The fine sediments are being transported through the stream system to the Methow River by high-gradient channels in the upper drainages to the confined channel crossing the alluvial fan.

Coarse sediment sources include mass wasting, gully erosion, and bank erosion.

Reviews of the 1948 and 1974 historical aerial photographs show evidence of debris-flow tracks crossing the Wolf Creek alluvial fan and probably entering the Methow River during the 1948 Flood and 1972 Flood. However, there are no debris-flow tracks on the 1998 and 2004 photographs, but significant manipulation to the channel and alluvial fan has occurred due to development since 1948. Based on this interpretation, coarse sediment volumes reaching the Methow River have not significantly increased since 1974. A cursory review of the 1998 photograph in the upper drainage suggest that the system is stable with a riparian corridor and is, most likely, providing a minimal amount of coarse sediment to the Methow River. This interpretation is also supported by the presence of a lateral bar on river right directly downstream of the mouth that appears to have been stable for the last 30 years.

8. CHEWUCH RIVER SUBWATERSHED

The Chewuch River is generally a north-to-south drainage containing about 340,000 acres. Elevations range from about 8700 feet to 1700 feet at the confluence with the Methow River at RM 44.8 (Andonaegui, 2000). Annual precipitation is approximately 35 inches in the upper subwatershed to about 15 inches at the mouth (Richardson, 1976 as referenced in Andonaegui, 2000). The river is about 44.8 miles long with nine major tributaries — Cub, Boulder, Eightmile, Falls, Lake, Andrews, Twentymile, Thirtymile, and Dog Creeks. Several of the tributaries head in small glacial cirques, and there are numerous debris avalanches, debris-flow tracks, and landslides entering the drainage. Much of the subwatershed upstream of RM 8.1 is in the granitic Okanogan Range Batholith. Weathering of the batholith has created a veneer of highly erosive soils. Spring Chinook salmon spawn in the mainstem Chewuch; steelhead rear in the mainstem and spawn in tributaries. About 26% of spring Chinook salmon spawning in the Methow River watershed occurs in the Chewuch River (Andonaegui, 2000). The USFS manages about 95% of the drainage (above RM 7) of which the upper portion is located in the Pasayten Wilderness. There is a mix of private and federal lands between RM 7–8. Downstream of RM 7, the drainage is predominantly under private ownership.

8.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

Above RM 25, the subwatershed is believed to be functioning properly with most of the human impacts along the mainstem and tributaries occurring downstream of RM 25 (Andonaegui, 2000).

From the mouth to about RM 2, the Chewuch River flows through a bedrock confined valley with minimal floodplain. Most of the pools in this reach are created by bedrock controls (Smith et al., 2000).

Between RM 2–5.2, there is chronic bank erosion and about 19% of both river banks are actively eroding due to lateral migration and re-working of depositional features (Smith et al., 2000).

Predominantly natural processes are causing bank erosion from RM 5.2–6.5; about 10% of both banks are actively eroding, and there is a mass wasted bank about 12 meters wide and 15 meters high at RM 6.5 (Smith et al., 2000). There is a bedrock constriction at RM 6.3.

About 4% of both banks are actively eroding by natural forces and with some contributions due to streamside grazing from RM 6.5–7.8 (Smith et al., 2000). There is riprap to protect houses at RM 6.7 and RM 7.6, and also along the road adjacent to river. Riparian grazing is believed to be causing erosion from RM 7.1–7.3. There is a bedrock “nickpoint” at RM 7.0 and a dike at RM 7.6. The Chewuch Bridge (at RM 7.8) and associated bank protection are constricting the channel and limiting floodplain access. There are several houses on the floodplain that are protected by a push-up levee (situated below the bridge) that constricts the channel and floodplain. The predominant substrate size in this reach is cobbles (Smith et al., 2000).

Between RM 7.8 –8.8, about 7% of both banks are actively eroding (Smith et al., 2000).

A total of 16,600 feet of bank erosion was seen by USFS surveyors during a 2002 survey of the Chewuch River between RM 9.5–36.4 (6% of the banks were eroding, total of both banks) (USFS, 2002). Within RM 9.5–14 of the Reclamation assessment reach, 500 feet of bank erosion was noted by the USFS report. This is from RM 11.4–11.6, along USFS Eightmile Ranch. and the East Chewuch Road downstream of Eightmile Creek confluence.

There are chronic sediment impacts to streams related to timber harvests and roads in the Boulder Creek, Eightmile Creek, Falls Creek and Doe Creek subdrainages (USFS, 2000). Impacts from cattle grazing have occurred in Thirtymile Creek and Dog Creek subdrainages.

Fires have impacted the Boulder Creek subdrainage (South Fork Fire, 1970’s) and the upper Chewuch River subwatershed from about Andrews Creek upstream (Thirtymile Fire, 2001). Following the Thirtymile Fire, heavy rains mobilized debris flows in the upper watershed that delivered sediment to the valley floor and lesser amounts to the Chewuch River. The Tripod Fire (in 2006) burned extensively in the eastern subdrainages and will most likely impact the amount of sediment supplied to the Chewuch River.

Channelization across the alluvial fans of Farewell Creek, Lake Creek, Twentymile Creek, and Boulder Creek has exacerbated the sediment input reaching the Chewuch River. Further road construction across the Brevicomis Creek and Twentymile Creek alluvial fans has affected flood channel formation, run-off patterns, and sediment transport to the Chewuch River (Andonaegui, 2000).

There was large-scale channel clearing and debris removal following the 1948 Flood and the 1972 Flood. The Army Corps of Engineers and the National Guard assisted with channel clearing and levy construction following the 1972 Flood (Andonaegui, 2000; Smith et al., 2000).

8.2 SEDIMENT SOURCES

Fine sediment sources include chronic sheet and rill erosion exacerbated by timber harvests, roads, cattle grazing and forest fires. The fine sediments are being transported through the stream system to the Chewuch River by high gradient tributary channels in the upper drainages to the confined channel crossings on the alluvial fans.

Coarse sediment sources include mass wasting, gully erosion, and bank erosion. Chronic bank erosion is occurring from the mouth to RM 20 (Andonaegui, 2000). About 10% of both streambanks along the lower 8.8 miles of the Chewuch River are actively eroding (Smith et al., 2000). Recreational use impacts the riparian corridor along the river and tributaries by soil compaction, increasing bank erosion, and reducing large woody debris recruitment (Andonaegui, 2000).

Episodic events such as forest fires followed by rapid snowmelt or severe thunderstorms result in floods that trigger mobilization of the stored sediments on the hillslopes. In the upper watershed that was burned during the Thirtymile Fire, heavy rains mobilized the sediment stored in the colluvial hollows as debris flows. Many of these debris flows made it to the Chewuch River, but most of their coarse sediment was deposited on the valley floor prior to intercepting the river. Andrews Creek was observed in the field to have significant coarse sediment delivered to the Chewuch River, but the river flow is likely too small at this location to mobilize the majority of coarse sediment deposited.

Boulder Creek is the largest tributary system and contributes about 10% of summer low flow to the Chewuch River (Smith et al., 2000). The confluence of Boulder Creek and the Chewuch River is near RM 8.8, and there is a natural series of bedrock shoots that are fish passage barriers during some flows at about RM 1 (Smith et al., 2000). The lower reach of Boulder Creek has been channelized across its alluvial fan; this has increased the stream's transport capacity and has accelerated bank erosion (Andonaegui, 2000). Extensive timber harvest and poor road placement in the drainage has resulted in frequent mass wasting delivering coarse sediment directly into stream channels (Andonaegui, 2000; Smith et al., 2000).

Cub Creek contributes less than 5% of summer low flow to the Chewuch River. About RM 1.5, there is a natural falls that is a fish passage barrier (Smith et al., 2000). Residential development on the Cub Creek alluvial fan has confined the stream channel to one location. This has increased the streams transport capacity resulting in increased bank erosion and sediment delivery to the Chewuch River (Andonaegui, 2000). Disturbances in the Cub Creek drainage have the potential to provide predominantly fine sediment (silt and sand) to the Chewuch River (Smith et al., 2000).

Other notable sediment sources include Falls Creek and Doe Creek where poor road placement in the highly erodible soils have lead to large-scale mass wasting directly into streams (Andonaegui, 2000).

Other coarse sediment sources include episodic debris flows entering the Chewuch River. The following drainages have the potential to provide debris flows to the Chewuch River based on field observations and previous literature, or where observed on historical aerial photographs (noted after drainage name if documented):

- Cub Creek (RM 6.9) in 1974, 1998, and 2004

- Ramsey Creek (RM 7.1)
- Boulder Creek (RM 9.4), 1998, and 2004
- Un-named #65 (RM 9.5)
- Eightmile Creek (RM 11.67)
- Butte Creek (RM 14.15), 1998 and 2004
- Falls Creek (RM 14.2), 1998 and 2004
- Spring Creek (RM?), 1998 and 2004.

9. MIDDLE METHOW RIVER SUBWATERSHED

The Middle Methow River subwatershed is designated as that portion of the drainage from Winthrop (RM 50.1) to Carlton (RM 26.8), covering about 15,600 acres. The river has six major tributaries — Chewuch River, Twisp River, Alder Creek, Bear Creek, Beaver Creek, and Benson Creek. The Chewuch River, Twisp River, and Beaver Creek subwatersheds are discussed in their own sections. Spring Chinook salmon use the Middle Methow River reach for spawning, rearing and migration (Andonaegui, 2000).

9.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

Sediment recruitment and transport is influenced by anthropogenic impacts that include roads paralleling the river, levees disconnecting the floodplain, bank protection, diversion dams and bridges. Levees have disconnected the floodplain from the river in several locations. Opposite of Smokejumpers’ Base, a levee cuts off about one mile of side-channel habitat. The Vandermyers Dike has partially disconnected about 0.5 mile of side channel. The Twisp Army Corps Dike, constructed in 1972 along the right bank about one mile north of Twisp, is approximately 1,600 feet long and disconnects the floodplain. The Alder Creek Side Channel Dike, constructed at the confluence in 1972, disconnects about one mile of side channel habitat. The West County Road Side Channel is no longer connected to main channel.

RM 26.8–33.75 is tightly constricted by bedrock, glacial terraces, and several alluvial fans. The floodplain is narrow, and the river is confined to a single channel. Terraces and fans consist of sand, gravel, and cobbles. Lateral migration is minimal and limited to small areas along the river not bounded by bedrock or high terraces (Golder, 2005).

At RM 30.75, there is riprap along the left bank at the base of the highway. A landslide on the terrace above the left bank was caused by a road washout during a historical flood of unknown date. The river bank on river right is a terrace about 30 to 60 meters high that has signs of erosion.

RM 33.75–38.50 is characterized by a relatively broad floodplain and the presence of several secondary and abandoned channels. The outside of meander bends are generally bounded by bedrock or high terraces, and point bars are on broad low floodplains. River right is generally bordered by bedrock and river left by lower elevation terraces. River left is actively eroding between RM 34-34.5 along the outside of the meander bends. At RM 34.6, there is a secondary channel that is essentially a slough. At RM 34.75, the right bank is underlain by bedrock. The historic town of Silver was located at about RM 35. Following the 1972 Flood, the Silver side channel was disconnected from the mainstem by a dike. A pond occupies a former channel below the Twisp-Carlton Road at RM 37. At RM 37.5, the river is actively eroding a fluvial terrace along river left that is partially protected by riprap. The river has changed channel location between 1998 and 2004. There is a dike from RM 38–38.5 on river right. The dike is about 4 meters above active channel and there is riprap on river left constricting the channel (Golder, 2005).

RM 38.50–41.50 is generally confined to a narrow floodplain by low fluvial terraces. Riprap has been placed along the left bank at RM 38.75. There is a historic channel below a terrace on river left at RM 39 and the right bank of the river is underlain by bedrock. At RM 39.2, the right bank has been protected with riprap below Twisp-Carlton Road deflecting the river almost 90 degrees. There is a pond located along river right at RM 39.3. The Twisp-Carlton Road was washed-out by the 1948 Flood at RM 39.5, and the new road is densely armored with riprap. Riprap has also been placed along river right from RM 39.8–39.95. At RM 40.0, there is a cutbank that has riprap below some houses and the houses may have been built on fill. Bedrock is exposed on river right at RM 40.25. The Twisp Bridge is located at RM 40.5; it was overtopped during the 1948 Flood and rebuilt; the abutments and riprap now constrict the river. A water pipe crosses the river at RM 40.6; the pipe is supported by concrete pillars that are protected by riprap on both sides. A pedestrian bridge once crossed the river at RM 40.85. The Twisp-Winthrop Eastside Road at RM 40.85 is underlain by bedrock and protected along the toe by riprap.

Between RM 41.50–49.75, the river is composed of a broad floodplain with several inactive channels and historical channels located along the edge of the floodplain. River left is controlled by bedrock at RM 41.2, and river right is eroding along the outside of the meander bend. From RM 41.35–41.6, the right riverbank is also eroding along outside meander bend. There is a dike from RM 42.3–42.35 with a road over the top that runs along river; the top of the dike is about 4 meters above the active channel and 1.5 meters above the floodplain. From RM 42.3–42.35, there is a push-up levee. At RM 43.8, the river is eroding into the floodplain. Side channels along river left have standing water at about RM 44.25. The old highway is in the floodplain at RM 45.5, and there is an oxbow lake located on the other side of highway at RM 45.75. Other oxbow lakes are located downstream at RM 44.25. The Methow Valley Irrigation District (MVID) East Diversion Dam spans the river at RM 46.0. There is riprap along river right from RM 46.0–46.4. Downstream of the diversion a small push-up dike blocks a secondary channel along river right at RM 46.45. Bedrock is exposed above the Old Twisp Highway at RM 47.0 and river right is protected with riprap on the outside meander bend. There is bedrock along river right at RM 47.05, and the left riverbank is actively eroding. There is also bedrock along river left at RM 48.1 and possible bedrock along outside meander bend. The Witte Road at RM 48.75 was washed out in the1948 Flood. The river is constricted by bedrock and Witte Road at RM 49.2. Both riverbanks have been protected by riprap at about RM 49.5 (Golder, 2005).

The reach RM 49.75–51.25 is constricted by high terraces with bedrock exposed at RM 51–RM 51.5. There is a high terrace (about 10 meters above the riverbed) along the right bank where the Winthrop Water Treatment Plant is located (RM 50.7), and along the left bank is a terrace 2.5 meters high. Near Winthrop Bridge (at RM 51.15), the left bank had been protected with riprap and is underlain by bedrock. The right bridge support appears to be constricting the flow and forming gravel bar downstream (Golder, 2005).

9.2 SEDIMENT SOURCES

Fine sediment sources include chronic sheet and rill erosion exacerbated by timber harvests, roads, and cattle grazing. The fine sediments are being transported through the stream system to the Methow River.

Coarse sediments supplied to the Middle Methow River subwatershed are primarily from the river's re-working of the floodplain and the subwatersheds (Chewuch River, Twisp River, and Beaver Creek). Other tributaries that show evidence of coarse sediment contributions based on aerial photograph interpretations are Un-named #55 (RM 42.8), Un-named #56 (RM 42.5), Benson Creek (RM 33.2), and Canyon Creek (RM 32.9).

Other coarse sediment sources include episodic debris flows and landslides entering the Methow River. Debris flows have the potential to enter the Middle Methow River from the following drainages based on field observations, previous literature, or historical aerial photography (year observed noted where applicable):

- Canyon Creek (RM 32.9) has actively eroding banks probably contributing sand-sized sediment,
- Benson Creek (RM 33.2) active debris flow tracks and probably provides sand-sized sediment,
- Alder Creek (RM 34.25),
- Un-named #56 (RM 42.5), active debris flows in 1948 and 1974,
- Un-named #55 (RM 42.8).

Landslides along the Methow River were observed during 2005 field work to occur at the following locations:

- RM 28.51-28.76 (right bank),
- RM 29.7-29.9 (right bank), upstream section is protected with riprap,
- RM 30.1-30.35 (right bank), downstream section is protected with riprap,
- RM 30.6-30.8 (left bank), downstream section is protected with riprap,
- RM 31.45-31.55 (right bank), toe is protected with riprap.

10. BEAVER CREEK SUBDRAINAGE

Beaver Creek subdrainage is generally a northeast-to-southwest drainage and contains about 71,400 acres. The stream is about 22.3 miles long and enters the Methow River at RM 35.2. There are five major tributaries — Frazer Creek, South Fork Beaver Creek, Middle Fork Beaver Creek, Lightning Creek, and Blue Buck Creek.

Water rights in the Beaver Creek drainage have been adjudicated and in most years during late irrigation season water use exceeds water availability (USFS, 1997). Toward the end of the irrigation season during low-water years, the creek flows subsurface to about RM 0.5 (Andonaegui, 2000). Juvenile spring Chinook salmon utilize the confluence area of Beaver Creek during rearing, and steelhead use the stream for spawning and rearing (Andonaegui, 2000).

10.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

The USFS (2004) found that amounts of sediment in spawning gravels in Beaver Creek were considered very high. The stream survey noted that past management activities — particularly timber harvest and cattle grazing — have likely exacerbated already naturally high levels (USFS, 2004). Surface fine sediments are at or exceed the guideline of 20% in almost every reach of all four streams surveyed by USFS. The highest amount of surface fines were found in the low-gradient, upper three miles of the South Fork Beaver Creek (RM 2.9–6.1), where surface fines exceeded 30% (USFS, 2004). Surface fine sediments exceeded 25% in the two lower reaches of Beaver Creek (RM 9.4–11.1) (USFS, 2004). The lowest amount of surface fine sediments were found in Reach 2 of Lightning Creek (RM 2.3–2.7) and in Reach 2 of Blue Buck Creek (RM 0.8–2.2), with 12% and 17% surface fines, respectively (USFS, 2004).

Intensive timber harvests and roads have impacted sediment loads and reduced large woody debris recruitment (USFS, 2004). The amount of newly created openings in the watershed and high road densities have the potential to impact the timing and duration of flood peaks. The left bank from RM 0.2–1.8 has had significant logging in the riparian area with the bank nearly cleared of timber for more than 0.75 miles (USFS, 2004).

Beaver Creek Road runs parallel to the creek confining the floodplain in some reaches. One location where this has been identified is a reach of upper Beaver Creek (in Section 35 T34N R22E) where the stream has been channelized and lined with riprap for a one-mile stretch (Andonaegui, 2000).

10.2 SEDIMENT SOURCES

Fine sediment sources include chronic sheet and rill erosion. Coarse sediment sources include mass wasting, gully erosion, and bank erosion. Less than 2% of the total banks in the 15.5 miles of stream surveyed by USFS were found to be actively eroding (USFS, 2004).

11. TWISP RIVER SUBWATERSHED

The Twisp River subwatershed is generally a west-to-east drainage containing about 157,000 acres. The stream is about 30 miles long and enters the Methow River at RM 40.2. Elevations range from 8500 feet to 1600 feet at the confluence. Annual precipitation ranges from 90 inches along the Cascade crest to 20 inches in Twisp (Andonaegui, 2000). There are nine major tributaries — Poorman, Newby, Little Bridge, Canyon, Buttermilk, Eagle, War, Reynolds, South, and North Creeks. About 95% of the subwatershed is under federal ownership, and about 50% of that land is located in the Lake Chelan-Sawtooth Wilderness Area. The remaining 5% of the subwatershed is in private ownership. In the vicinity of Poplar Flats Campground, the Twisp River naturally goes dry almost every year. There is a natural falls fish passage barrier at RM 29.4. Spring Chinook salmon and summer steelhead spawn and rear in the Twisp River for nearly its entire length. About 25% of spring Chinook salmon spawning in the Methow watershed occurred in the Twisp River (Andonaegui, 2000).

11.1 IMPACTS AFFECTING SEDIMENT SUPPLY AND TRANSPORT

Between the mouth and RM 5.4, the Twisp River is confined by the Highway 20 Bridge, periodic levees, and bank armoring. Levees are located at RM 1.8 and RM 4.2–4.3. The floodplain has been filled in at RM 0.8–1.0 and a side channel has been filled in disconnecting it from the river at RM 2.9 (PWI, 2003). At RM 1.0, about ½-mile of side channel has been converted to ponds with a flow control structure. At the confluence of Poorman Creek (RM 3.0), about ½-mile of side channel habitat has been converted to ponds with flow control structure (Andonaegui, 2000).

Between RM 5.4–RM 17.6, the road embankment is protected with riprap along river right and there has been road fill and terrace erosion observed. At Elbow Coulee (RM 5.7), a side channel entrance has been cut off by a push-up levee, and ponds have been created in what is believed to be historic river channel paths. A levee disconnects the river from its floodplain from RM 10.7–11.3. A levee protects the Twispavia Residential Development at RM 13.5 along the left bank and disconnects the floodplain.

Between RM 20.4–22.7, there has been some bank hardening and riprap has been placed along road embankments on river left. Road fill and terrace erosion have been observed in this reach (PWI, 2003).

Between RM 22.7–27.3, a debris flow intercepted the Twisp River from the Reynolds Burn. This reach is generally unconfined and is believed to be aggraded with chronic failures along terrace margins (PWI, 2003). During the 1960’s and 1970’s, an undocumented volume of large woody debris was removed from the channel from the mouth to the end of the Twisp River Road (RM 27.0) (Andonaegui, 2000).

In the reach RM 27.3–30.4, the bedrock and boulders form channel "nickpoints." The riverbanks are generally protected by mature riparian vegetation although there has been some erosion of the alluvial banks and the glaciofluvial deposits (PWI, 2003).

11.2 SEDIMENT SOURCES

Fine sediment sources include chronic sheet and rill erosion exacerbated by timber harvests, roads, cattle grazing, and recreation. Coarse sediment sources include mass wasting, gully erosion and bank erosion.

The Twisp River subwatershed is generally sediment rich. Sediments are supplied through episodic inputs (debris torrents, terrace-toe failures and deep-seated landslides) and chronic inputs (surface gravel, soil creep, remobilization of stored sediments in fans and floodplains). Primary sources of spawning gravel are glaciofluvial deposits, conglomerates, breccias and weathered granite. Subwatershed-wide, annual erosion rates per acre of road prism are estimated to have varied from as low as 9.0 tons/acre to a high of 34.0 tons/acre (USFS, 1998b).

Two stream segments noted to have bank erosion by USFS were a 2-mile segment between Newby Creek and Little Bridge Creek (RM 8–10) and a 2¼-mile segment between Cook Creek and Reynolds Creek (RM 20.4–22.6). There are two large mass-wasted banks below Reynolds Creek confluence (RM 20.9) and in the vicinity of the Mystery Campground (RM 20.5) (USFS, 2001).

Based on limited review of 1974, 1998 and 2004 aerial photographs, there were no debris flow tracks entering the Twisp River from tributaries. However, from the literature review War Creek is noted to have periodic avalanche/debris flows down the drainage that have reached the Twisp River (PWI, 2003). War Creek is constricted by a road/levee across its alluvial fan causing incision by concentrating flood flows.

Following the 1972 Flood, Little Bridge Creek was channelized below the Twisp River Road Bridge by the ACOE (Andonaegui, 2000). Little Bridge Creek has two major bank erosion sites, one located about ½ mile downstream from the crossing of (Forest Service) FS Road 030, the other between the crossing of FS Road 100 and the confluence of Sheep Creek (USFS, 2001). FS Road 4415 is delivering sediment to the creek, with large areas of erosion along the road cut.

After the 1972 Flood, large woody debris was removed from Buttermilk Creek; the creek was re-channeled below Twisp River Road Bridge by the ACOE (Andonaegui, 2000). Large bank failures are present in the mainstem Buttermilk Creek and in the first 2.5 miles of West Fork Buttermilk Creek (USFS, 2001). In 1995, a beaver dam blew out in this drainage, putting a pulse of sediment into the creek. On the West Fork Buttermilk Creek, there have been multiple landslides noted in areas of timber harvests and road cuts that are contributing sediment.

Landslides along the Twisp River were observed during 2005 field work at the following locations:

- RM 2.95-3.8 (left bank),
- RM 4.53-4.64 (right bank),
- RM 9.55-9.76 (right bank),
- RM 11.84-11.96 (right bank),
- RM 16.5-16.59 (left bank).

12. REFERENCES

IN TEXT	FULL CITATION
Andonaegui 2000	Andonaegui, C. 2000. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48: Final Report.* Washington State Conservation Commission, 232 p.
Golder 2005	Golder Associates, Inc. 2005. *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Knott 2007	Knott, G. 2007. Personal communication. US Bureau of Reclamation Methow Field Station, Winthrop, WA.
KWA 2004	KWA Ecological Sciences Ltd. 2004. *Methow Subbasin Plan.* Prepared under contract for Washington Department of Fish and Wildlife and funded by the Northwest Power and Conservation Council. April 23, 2004; 463 p.
PWI 2003	Pacific Watershed Institute. 2003. *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.
Richardson 1976	Richardson, D. 1976. *Natural monthly streamflow in the Methow Basin*. Washington Department of Ecology, Olympia, WA. Water Resources Analysis and Information Section, Office Report No. 46, 7 p.
Smith et al. 2000	Smith, J. E., Fisher, B., and Farmer, S. 2000. *Lower Chewuch River fisheries habitat survey, final report.* Prepared for CI Johnson and Associates in cooperation with the Methow Basin Planning Unit by the Pacific Watershed Institute, Winthrop, WA. December 2000. 58 p.

IN TEXT	FULL CITATION
USFS 1997	US Forest Service. 1997. *Middle Methow Watershed Analysis*. Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA.
USFS 1998a	US Forest Service. 1998a. *Upper Methow watershed analysis*: Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA.
USFS 1998b	US Forest Service. 1998b. *Biological Assessment for authorization for water conveyance by the Wolf Creek Reclamation District Irrigation Ditch.* Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA. March 25, 1998.
USFS 2000	US Forest Service. 2000. *Goat Creek stream survey summary, 08-92 to 09-92:* Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA.
USFS 2001	US Forest Service. 2001. *Twisp River stream survey summary:* Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.
USFS 2002	US Forest Service. 2002. *Chewuch River stream survey summary.* Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.

APPENDIX O –

HISTORICAL HUMAN ACTIVITIES AND FLOOD MANAGEMENT

This appendix provides documentation on the historical settlement and management of river flooding within the Methow Subbasin based on local accounts, historical records, books, and available literature. Many photographs documented in this appendix were graciously provided by the Shafer Museum Collection, Winthrop, Washington, for use in this assessment.

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1. OVERVIEW

The purpose of this appendix is to document human activities within the Methow Subbasin, so that their impact to river processes can be addressed in Appendix E (“Conceptual Model of Physical Processes Important to Salmonid Habitat Formation”), based on the timing, duration, and extent of the human activities. A wealth of historical information on the Methow Subbasin has been documented in expedition journals, local museums, books, and reports that provided the information for this appendix.

2. EARLY ACCOUNTS OF BASIN AND HUMAN SETTLEMENT

“Methow” is the Anglo-European version of the Native American name for the valley, which was “Smeethhowe” (Portman, 2002). The first inhabitants of the Methow valley are thought to have arrived 8,000 to 10,000 years B.P. (before present) and may have been permanent (year-round) residents (Portman, 2002). Native Americans were noted to have used the land along the Methow River for many years, as evidenced by old paintings, pit houses, and artifacts found along the river (Devin, 1997). More recent Methow Native Americans are noted to have been seasonal inhabitants, leaving the Methow River area during the cold winter months. It is noted that large, 500-year-old cedar stumps were found in the Lost River area. The large cedars were used by Native Americans to make canoes. This size of tree stump is noted to not have been documented in other downstream areas. The Native Americans generally left only minor traces of their activity in the riverine areas. Anecdotal accounts suggest the valley floor was occasionally burned by Native Americans, which would have altered the native vegetation.

The first known occurrence of Anglo-Europeans visiting the basin was fur trappers in 1811. These trappers were noted to mainly hunt beavers to sell pelts. The first journal account of Europeans in the Methow valley was by Alexander Ross (*The Fur Traders of the Far West*, 1855; Portman, 2002). Ross traveled from the mouth of the Methow River upstream to north of Alta Lake and, because the banks of the Methow River were too steep to traverse, went northwesterly, parallel to the Chelan divide. Ross passed Hoodoo Peak and went to West Fork Buttermilk Creek and noted the land as “…country gloomy, forest almost impervious with fallen as well as standing timber. A more difficult route to travel never fell to a man’s lots.” Visits by Anglo-Europeans continued until 1848 when the Methow Subbasin became a U.S. territory.

First Lieutenant George Benjamin Backus led a six-man party in 1883 for the federal government to map a pass through the North Cascades for the purpose of facilitating settlement and economic growth and to protect the northern frontier. Backus had previously been on the Pierce Expedition in 1882. The Methow valley was designated as "Indian Land" under Executive Orders in 1878 and 1880, but then was opened to Anglo-European settlement and mining claims under orders issued by the federal government in 1883 and 1886. The earliest accounts of white men in the valley were from the Pierce Expeditions (1882) and Miller party (1880) who encountered one or two miners. The Backus expedition generally followed Indian trails along the river, but occasionally followed higher ground. The expedition mainly explored the Twisp River. From the confluence of the Twisp River, "…we followed the Methow on the right (southwest) bank in a general northwest direction for two days making in all 20 miles. An Indian whom we met near the end of our first day's journey warned us against proceeding too far on the trail, as marshes would be found (about 3 miles beyond the mouth of Wolf Creek) to stop our progress and return would be necessary… ." The Robinson diary claims that only nine men lived in the Methow valley in 1886-87.

Homesteading within the Methow valley by Anglo-Europeans began occurring in the late 1800s. Most of the land in the Methow valley was settled by using the United States Congress Homestead Act of 1862 and the Homestead Entry Survey (HES) Act of 1906 (Devin, 1997). The 1906 HES Act was initiated to identify lands suitable for agriculture purposes, but most of the land in the Upper Methow was noted as unsurveyed. Property boundaries were vague until the government surveyed the valley in the late 1890s (Figure O–1). The surveyors divided the Methow valley into townships, ranges, and sections that today still define all parcels in the valley. The first homestead was noted in 1888 (Devin, 1997). By 1891, a few more homesteads had been established near the present location of Winthrop (RM 52 on Methow River), upstream about seven miles at Rockview (log mill), and downstream at Sullivan's Flat (Devin, 1997).

The first town in the Methow valley was the mining community of Silver, located on the Methow River between the present towns of Twisp and Carlton (Schmidt, 1964). Its post office was founded in the town store in 1890, but settlers had been at the site since the winter of 1886–87. The town was located about five miles southeast of the present-day Twisp in NW/SW, section 35, T33N, R22E (part of property shown as owned by Chickamon [Chickamin] on Figure O–3). At one time Silver included a trading post/store, hotel, saloon, blacksmith shop, and three houses. The original site of Silver, on a low surface that was at one time part of the riverbed, was destroyed by the river in the Flood of 1894 (see Section 6.1). Soon afterwards, a new townsite was established on the bench above the original site. But Twisp and Carlton were growing rapidly at this time, and the store that had been built at the new Silver townsite was abandoned in 1904, and was torn down and moved to Carlton in 1907.

By 1910, the towns of Winthrop and Twisp (RM 42), and the communities of Robinson, Lost River, and Mazama (RM 68) were well-established along the Methow River (Devin, 1997). Homestead plots were continuously located along the river between Winthrop to Lost River, and Devin (1997) provides many accounts regarding the ownership and land use on each homestead.

- Small cabins were typical, and many cabins, barns, and mills burned down and had to be rebuilt.
- Land was usually cleared of trees and used for farming or grazing.
- Log mills were common and trees were often harvested on the homestead itself.
- Water from either the Methow River or from its tributaries was used for irrigation ditches and mills. In 1909 the Early Winters ditch was built to convey water down valley for irrigation on fields that were being logged and converted to crops.
- Many homestead areas along the alluvial fans and near Mazama had large amounts of stone that had to be cleared. The stones were often used to build rock walls along the property, and these can still be observed today.

Figure O–1. Photograph from 1903 survey party on the Methow River near present-day Winthrop, Washington.

Photograph copy courtesy of the Shafer Museum Collection, Winthrop, Washington.

3. LAND USE

Farming, grazing, and diversions represent typical land use within the Methow Subbasin in the early settlement times. Sheep grazing was common in the 1920s and 1930s. The sheep were grazed from the Columbia River north to the Canadian border along mountain ridges on both sides of the valley (Devin, 1997). Recreational skiing started in the 1930s (Devin, 1997). In the 1940s and 1950s roads were improved and tourism became popular for hunting, fishing, and skiing. In recent decades, many homesteads have been converted from single family dwellings to subdivision lots, particularly upstream of Winthrop on the mainstem Methow River.

Mining was historically very active, but there are no longer any active mines in the valley. In 1860, Chinese placer miners diverted water into the China Ditch, which ran from about 3 miles upstream of the confluence with the Columbia River downstream to Pateros. The ditch was abandoned in 1903, and settlers began using the ditch to irrigate apple orchards until the 1948 Flood. The rush for gold mines by Anglo-Europeans may have started in 1886, when a gold ledge was discovered on War Creek on the Twisp River (www.ghosttownsusa.com). In the early 1900s, miners were along Goat Creek (Montana Mine), lower Methow River (Flag Mine; location unknown), at Mazama (Danlee Mine; opened in 1931), Goat Wall Creek (Mazama Queen Mine and mill), Mill Creek (Azurite Mine, in full swing in 1930s), Slate Creek Mines (started in 1895), Squaw Creek (started in 1895 and located near present town of Methow), between Benson Creek and Beaver Creek (1890s, known as Red Shirt Mine), Gold Hill, and Flagg (Devin, 1997). By the late 1890s to early 1900s, mining in the Methow valley had slowed, but some mining continued for another about 50 years (Devin, 1997). Elevated contaminant levels were noted in Alder Creek (Andonaegui, 2000) from historic mining activity, but generally have not been documented as a major concern for any other drainage.

4. LAND MANAGEMENT

Over 80% of all of the lands in the Methow Subbasin are owned by the federal government and managed by the USFS (Methow Valley Water Pilot Planning Project Planning Committee, as cited in KWA, 2004). Most of the land along the mainstem Methow River downstream of the Lost River confluence is privately owned with some Washington Department of Fish and Wildlife (WDFW) and USFS holdings. Most of the land above the valley floor and in the tributaries is managed by the WDFW or the USFS.

About 90% of the land (about 145,000 acres) in the Twisp River watershed is managed by the USFS, including nearly all of the land above the valley floor upstream of the confluence with Little Bridge Creek (RM 10) (USFS, 2001). About half of the USFS land (about 72,000 acres) lies within the Chelan-Sawtooth Wilderness and is administratively withdrawn from most management activities, including timber harvest and road construction. Most of the Twisp River valley bottom from the mouth to the confluence with Eagle Creek (at about RM 17) is privately owned. The USFS manages several small segments of land along the river or in the floodplain in the lower 17 miles of the river; these include parcels at Elbow Coulee (RM 6), Little Bridge Creek (RM 10), at the Gary Brown irrigation diversion (RM 12), and above the south shore in the Scaffold Creek area (RM 16) (USFS, 2001). All of the land along the river bottom upstream of the confluence with Eagle Creek is managed by the USFS. The State of Washington owns land near Elbow Coulee and near the Twisp Power and Light irrigation diversion at RM 7.5.

Today, the US Forest Service (USFS) manages about 95% (320,000 acres) of the Chewuch River watershed, 34% (108,000 acres) of which are in the Paysayten Wilderness bordering Canada (Andonaegui, 2000). Along the Chewuch River, the USFS boundary begins at RM 7.0 and includes a mixture of private and federal lands between RM 7.0–8.0. Lands downstream of RM 7.0 along the Chewuch River are all privately owned (Andonaegui, 2000). The majority of human-related impacts have occurred outside of the wilderness area and along the mainstem Chewuch River and its tributaries downstream of RM 25.0 (Andonaegui, 2000).

5. DAMS, BRIDGES, AND ROADS

The Methow River Dam was constructed about 3 miles upstream of the city of Pateros (near the mouth) (Figure O–2). Construction was started in 1913 and completed in 1914 (Mansfield and Cain, March 2001). The dam, thought to have been in place until 1929, is noted in some documents to have blocked fish passage. However, based on photographs of the site it appears some fish, particularly spring and early summer migrating fish, may have likely been able to pass the dam, but additional historical information on the dam would be needed to validate this. The dam was used to divert water into the China Ditch for irrigation; the ditch was originally constructed by Chinese placer miners around 1860; it trapped modest amounts of Methow valley gold and was abandoned in 1903. Relatively small, privately operated diversion dams continue to be utilized throughout the basin. Although small, any of the dams that are believed to impede fish passage have already been either replaced or are in the process of being replaced to eliminate any passage barriers.

Figure O–2. Photograph looking upstream at Methow River Dam (irrigation dam) completed in 1914 and located about 3 miles upstream from the mouth.

Photograph courtesy of Shafer Museum Collection, Winthrop, Washington.

Before any bridges were built, the river was crossed by early settlers at low-water fords and with cableways. During and immediately after floods when bridges went out, cable cars were also used as a temporary way to cross the river. School children used to cross the Methow River at "Black Bear Ford" near Goat Wall Creek (RM 71.25) by walking across a "big old fallen cottonwood tree" (1920s and/or 1930s) (Devin, 1997). The first documented bridge to be built over the Methow River was in 1894, but the bridge was soon washed out during the Flood of 1894 (Devin, 1997). The old road used to cross the Methow River just downstream of Fender Mill at a low-water road crossing (Perrine Ford) that was located just upstream of the Hancock Creek confluence. The first bridge at this location was built in 1911 or 1912 and was washed out in a large flow in 1932. The Three Mile Bridge, located just upstream of the confluence with Wolf Creek near RM 54, was the major crossing point of the Methow River for many years (Devin, 1997).

The North Cascades Highway was completed in 1972. It allowed access into the Methow valley, however, it is still closed about one-third of the year during winter months. State Highway 153 currently crosses the Methow River seven times between Carlton (RM 28) and Pateros at the mouth. This section of the river is naturally constricted, but bank protection and embankments associated with the bridges do have an impact on bank roughness and river alignment. The degree of impact is likely localized but has not been addressed by this assessment because this section is downstream of the assessment area.

Two main roads parallel the Chewuch River from the mouth upstream to about RM 32 on the west side and to about RM 20 on the east side. Many tributaries in the lower two-thirds of the watershed have roads paralleling the river (Andonaegui, 2000). There are an estimated 1,000 stream crossings in the Chewuch watershed (USFS, 2002).

Roads parallel the Twisp River along the valley bottom to about RM 18, and in some segments of the river roads continue upstream from there (USFS, 2001). There are numerous roads and high road density in the watershed below RM 13.7.

6. FLOOD MANAGEMENT

The three largest known floods in roughly the last century were in 1894, 1948, and 1972. Based on historical accounts and aerial photography, the majority of flood protection structures are believed to have been built after the 1948 and 1972 floods. Bank protection in the form of rock riprap, woody debris, and even cars can be found throughout the Methow Subbasin on both low banks within the floodplain and on higher glacial terraces that are along the boundary (outside edge) of the floodplain. Levees have also been placed within the floodplain, often to reduce or to prevent flow from entering side and overflow channels during high flows. Levees range from large structures with rock protection to smaller, partially breached structures that are likely no longer maintained. The locations of flood protection structures are documented in the *Methow Atlas* (Reclamation, 2008c) and in Appendix P, "Human Features."

6.1 FLOOD OF 1894

The Flood of 1894 occurred prior to the establishment of stream-flow records but high-water marks were used to estimate a peak discharge at or just below the 1948 flood of record (Beck, 1973). The 1894 Flood washed out the mining community of Silver, located on the Methow River just downstream of the confluence with Beaver Creek.

The damage caused by the 1894 Flood was not as great as it was in subsequent smaller floods because development in the Methow valley at that time was minimal (ACOE, 1952; Beck, 1973). One local account of the 1894 Flood said, "…wild flood waters changed the course of the Methow River which has flowed in a different channel ever since" (Portman, 2002).

A fairly detailed account of the flood at the town of Silver, which was destroyed in the flood, was written in 1894. Buildings for the town had been constructed in the floodplain and on a large, level surface that "showed signs of having been at one time a part of the riverbed." (U.E. Fries, 1894, *in* Schmidt, 1964). Before 1894, the river apparently "… had changed course and flowed west of the townsite, leaving its old bed, a narrow channel east of the post office, and cutting between it [post office] and the main road." (U.E. Fries, 1894, *in* Schmidt, 1964) (Figure O–3).

Fries's account continues, in part.

> "As the June flood began to rise, the increased volume of water caused the river to change direction, the water flowing into the old river course after eating away the riverbank. But nature had been kind and had filled the old channel with quaking aspens dense enough to prevent a swift current. The land south of the post office was flooded.... I noticed that the bank above the post office was caving in.
>
> "The road going north to Winthrop had washed away, and again I had to cross the narrow channel between the post office and the main road. The water reached the horse's stomach. The next day, on my way back, I found the water swimming deep when I crossed….. The foundation of the hotel was washed away on the West Side and the gable end protruded about three feet over the water. People were leaving their homes because the river, large as it was, was rising fast. Nothing could be done to save the buildings."

Surveying for the Government Land Office map for T33N, R22E, where Silver was located, was done in late June and July 1894, shortly after the early June flood (Figure O–3). Fries's description suggests that the main channel before the flood was to the west, possible in a channel that was reoccupied by the main channel by the middle 1980s (Figure O–3 and Figure O–4). The 1894 map shows the main channel to the east in a channel that was active in the middle and late 1940s, although the position appears to have changed slightly since 1894, probably from bank erosion to the east (Figure O–3 and Figure O–4). Fries's description suggests that the 1894 Flood at this location resulted in a shift of the location of the main channel into a channel that had been abandoned by the river before the flood.

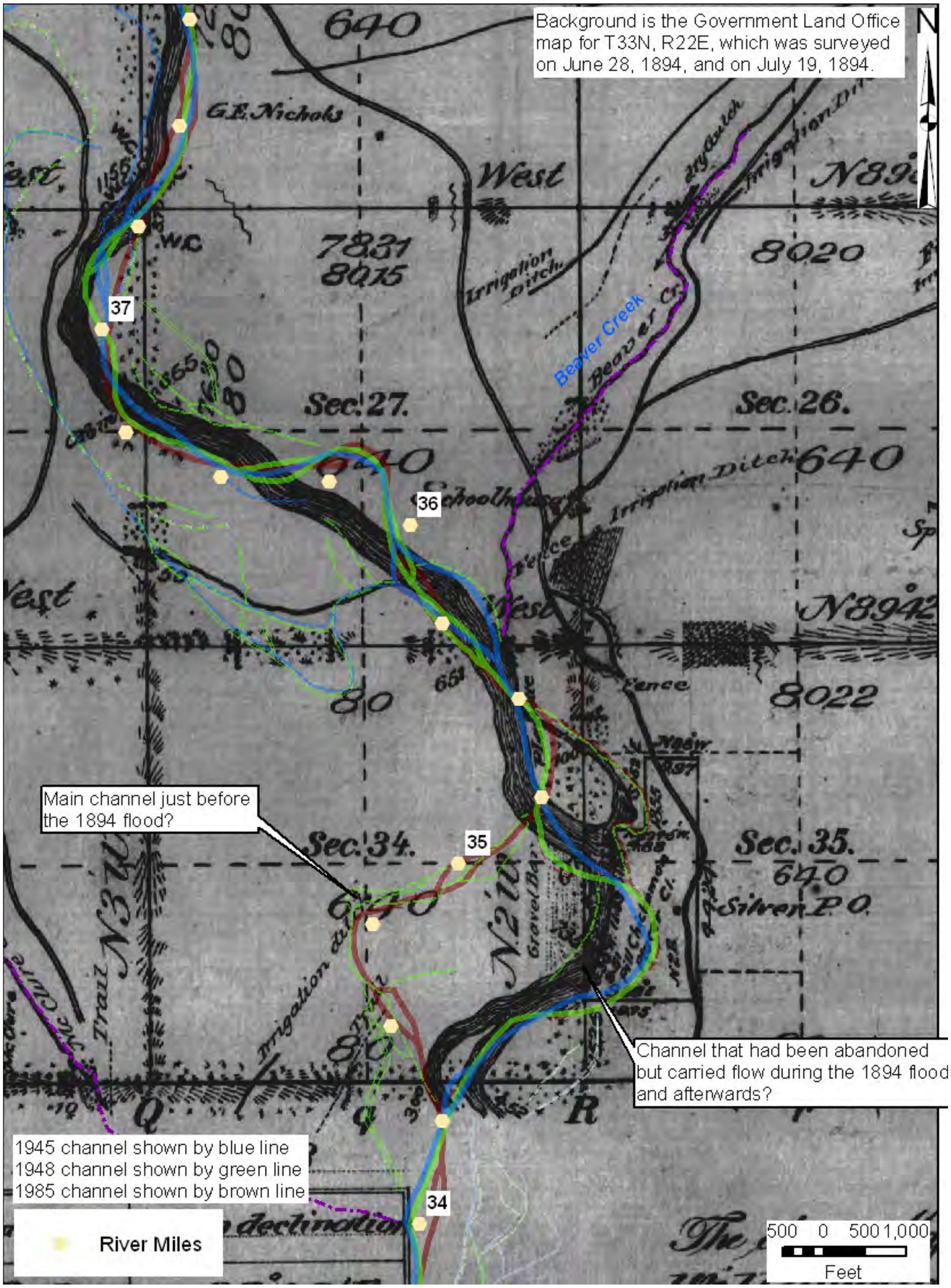

Figure O–3. A portion of the Government Land Office map for the area near the town of Silver. The survey was made shortly after the 1894 Flood, which destroyed the town.

Possible interpretations of channel change accounts are shown along with a centerline of the main river channel from 1945, 1948 and 1985 aerial photographs.

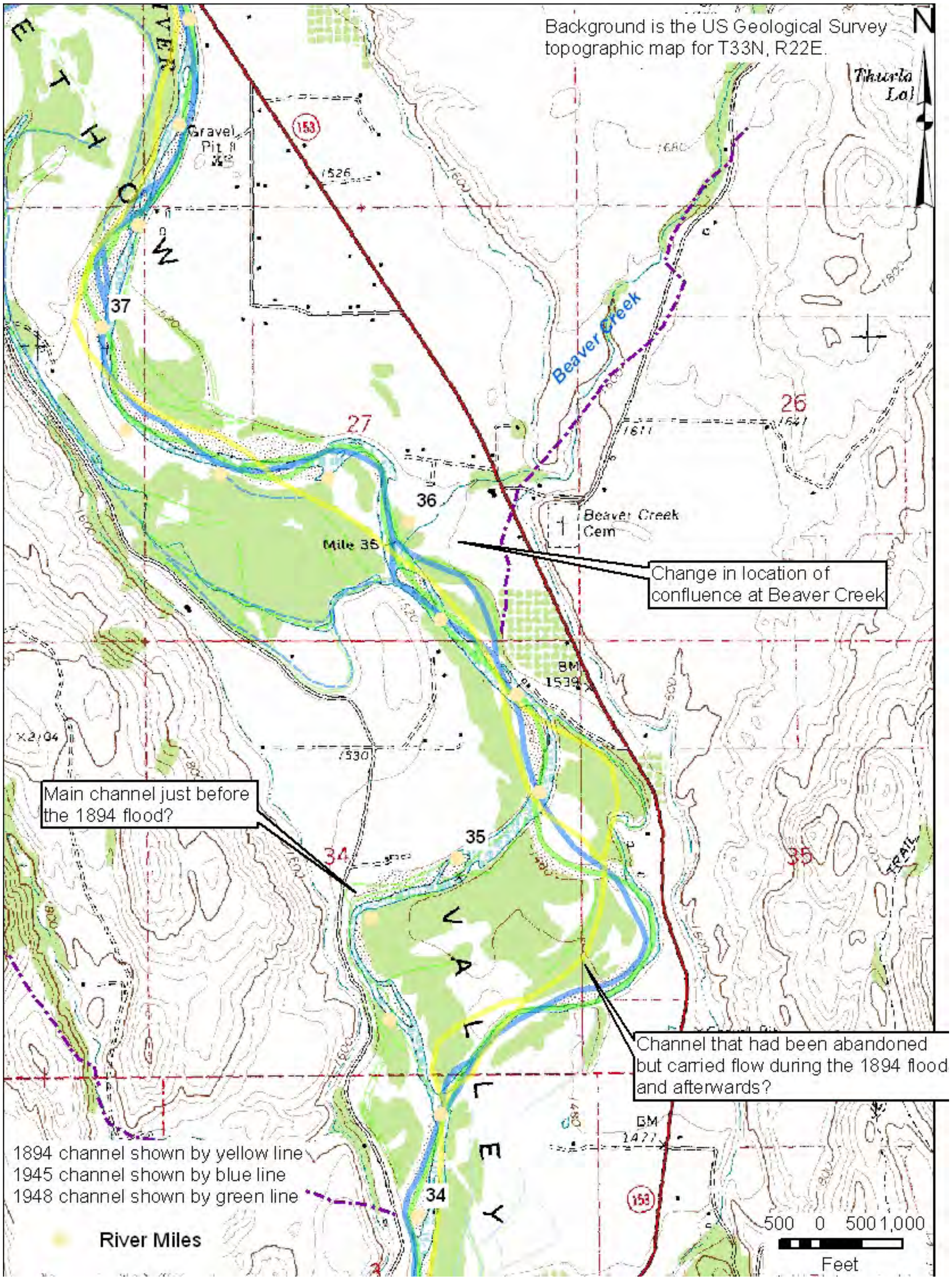

Figure O–4. The area near the town of Silver as it is portrayed on the US Geological Survey map from the mid 1980s.

This is the same area that is shown in Figure O–3.

6.2 FLOOD OF 1948

The 1948 Flood coincided with severe flooding throughout the Columbia Basin. The snowpack that accumulated during the winter was 19 percent above normal on the first of April. The snowpack was augmented by unusually heavy precipitation and cool temperatures until mid-May, when the temperatures rose to unseasonably high readings (Beck, 1973). A rain-on-snow event occurred when above average rainfall began in mid-May, which accelerated the rate of snowmelt resulting in a rapid rise in the river discharge. Near the mouth of Beaver Creek, the 1948 Flood left a high-water mark 4 feet above that of the 1894 Flood; 200-year-old trees that grew along the Methow River before the 1948 Flood were uprooted and washed away (Portman, 2002). Bank erosion occurred during the flood of both low river banks and higher banks (Portman, 2002). A local observer described the flood" "Big trees, debris and parts of buildings rode swiftly down the river" (Portman, 2002) (Figure O–5).

Figure O–5. Photograph of river taken during the 1948 Flood.

Courtesy of the Shafer Museum, Winthrop, Washington.

Ground photographs and aerial photographs taken before, during, and after the 1948 Flood are available to document the extent of flooding. The 1948 Food destroyed roads and bridges, caused severe erosion of agricultural lands, and inundated homes and thousands of acres of land. The 1948 Flood was noted in one homesteader's journal to have washed out six bridges on Methow River and many houses at Twisp (Devin, 1997). The estimated flood damage was $2,250,000 based on 1948 prices (Beck, 1973). Several log jams were likely destroyed after the flood, particularly in areas where bridges and roads were washed out (Figure O–6). Following the 1948 Flood, the US Army Corps of Engineers (ACOE) recommended that only minimal protection works be funded near municipalities because it would be too costly to implement protection everywhere along the river on private property where there was damage (ACOE, 1952).

Figure O–6. Photograph of "large woody debris" pile on the north side of the bridge across the Twisp River following the 1948 Flood. The bridge is thought to have been located just upstream from the highway bridge.

Photograph copy courtesy of the Shafer Museum Collection, Winthrop, Washington.

6.3 FLOOD OF 1972

The 1972 Flood was initiated from a snowpack that accumulated averaging approximately 175 percent of normal that resulted from an unusually cool, long, and stormy winter (Beck, 1973). Near the end of May, the weather cleared bringing two periods of high temperatures, which caused rapid snowmelt and rapid rise of the discharge of the river. A short period of cool temperatures caused the river crest to recede; however, a subsequent period of high temperatures resulted in a second river crest approximately two weeks later. Widespread erosion damage and large inundated areas resulted from this flood (Beck, 1973). Flood damages had an estimated magnitude of $420,000 and consisted mostly of bank erosion and crop loss due to inundation of farm lands (Beck, 1973). It was noted that Goat Creek, which had flowed in a channel on the edge of the alluvial fan at the mouth of the creek, moved to its present location and channelized on the highest portion of the alluvial fan after the Flood of 1972.

There was minimal flood protection noted on the Methow River at the time of the post-1972 Flood report by Beck (1973).

- One rock and gravel fill dike approximately ¼-mile long located 2 miles above Twisp which directs river into its current channel
- One dike approximately 0.4 miles long located 2 miles below Twisp on right bank
- Spur dike on left bank approximately 250 feet long and 4.6 miles downstream from Twisp which directs flow into present (1970s) channel
- Channelization in the alluvial fans of Farewell, Lake Creek, Twentymile, and Boulder Creek has occurred.

7. CLEARING OF RIPARIAN VEGETATION AND LARGE WOODY DEBRIS

Anecdotal accounts suggest that in early times, prior to Anglo-Euro settlement, times, the Native Americans burned portions of the floodplain and valley to maintain pasture lands for horses. Logging was actively done by Anglo-European settlers from the late 1800s through the 1980s in the middle and lower parts of the basin. Logging still persists today, but not to the same degree. There are high road densities from past logging activities in Buttermilk Creek and Little Bridge Creek (in the Twisp watershed); in Cub Creek, Eightmile Creek, Falls Creek, Does Creek, Boulder Creek, and Ramsey Creek (in the Chewuch watershed); and in Beaver Creek (a tributary to the Methow River).

The total number and locations of riparian vegetation clearing within the river floodplain are not known, but several accounts have documented that clearing was extensive in certain parts of the basin. In 1892, a local named McKinney noted his planned homestead claim (RM 61 on river right near Hancock Springs) contained level land, ponds, beaver dams, and lots of timber. His diary noted, “Cleaned out the spring and fixed it up with stone, then cut brush at head of pond.” Devin (1997) documents historic log mill locations along the mainstem Methow River at the following locations:

- RM 56 (left side, built in 1940s near pond/slew),
- RM 58 (left side, known as Rockview Mill, operated in early 1900s),
- RM 61 (left side, known as Fender Mill, operated into 1930s),
- RM 66 (right side),
- RM 73 (left side, known as Green Mill),
- RM 71.5 (Goat Wall Creek, known as Goat Wall Mill),

- RM 72 (Gate Creek),
- RM 63 (right side),
- Gambel Mill (location unknown),
- near Boesel Creek,
- at Lost River,
- in Mazama (Peters Mill),
- in Twisp (Fender Box Mill),
- North Fork of Slate Creek (Eureka Mill)

At about RM 64, it was noted that large fir trees were logged on the south side of the road, processed at Fender Mill, and used for the Chelan Falls power house (Devin, 1997). One instance of a log chute in Boesel Creek has been noted. The chute was a trench dug into the ground. If the ditch crossed rock or ravines it was built from logs. The chute was iced with water at the end of the day. Logs up to sixteen feet in length were skidded to the top of the chute with teams, fed in by men with peaveys, and slid to the bottom.

Anecdotal accounts describe historical clearing of large woody debris (LWD) from the Methow River, but only limited documentation of actual locations, frequency, or volumes is available (Andonaegui, 2000). On the Methow River, log drives transported cut timber downriver to log mills (Figure O–7 and Figure O–8), which required log jams to be cleared. In 1913, there was a log drive when the river was up from spring melt, but the river water fell again and dynamite was used to break up the large log jam that occurred (Devin, 1997). The mill is thought to have lost “2000 feet of logs” from the blast, but this was small relative to the total volume being pushed down the river. “A million feet of logs were moving toward the mill [Fender Mill] where booms are ready to divert them into the mill pond. The drive lasts for days …” (Devin, 1997). Accounts noted that people would come to see the log drive between Weeman Bridge (RM 61) and Mazama (RM 68) (Devin, 1997). Local rafting guides have noted that in recent years log jams have been removed on the mainstem Methow River when they have posed a danger to recreation or fisherman.

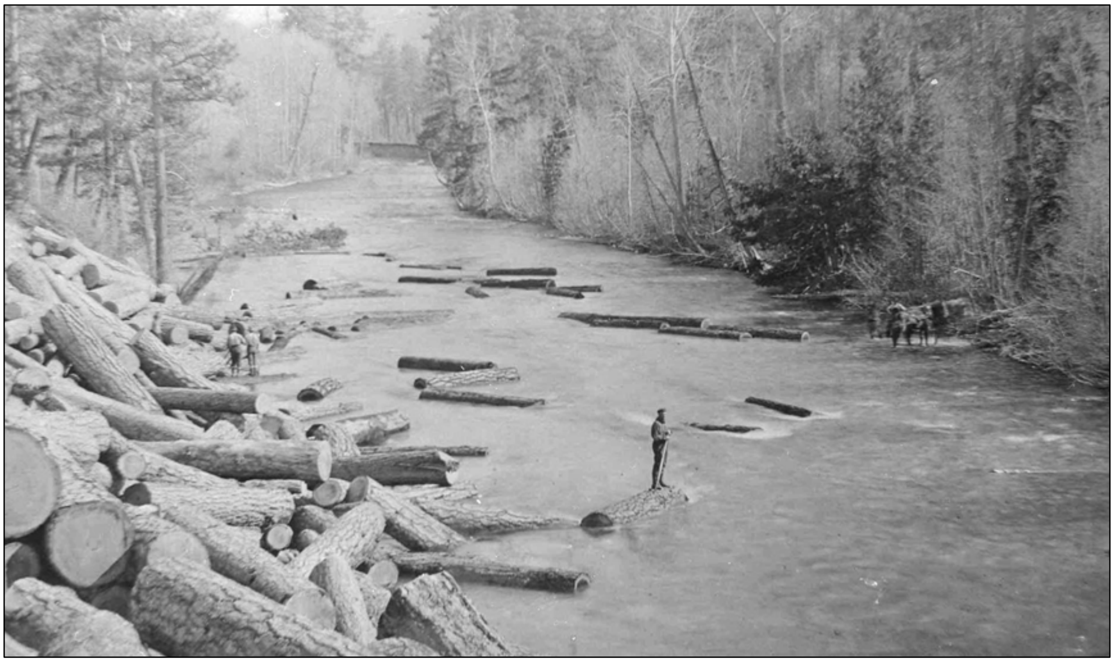

Figure O–7. Ground photograph of log drive likely in the 1920s or 1930s on upper Methow River.

Location is believed to be above Winthrop (RM 55) because the most commonly referenced log mills during this period were between 4 to 6 miles upstream of Winthrop

Photograph copy courtesy of the Shafer Museum Collection, Winthrop, Washington.

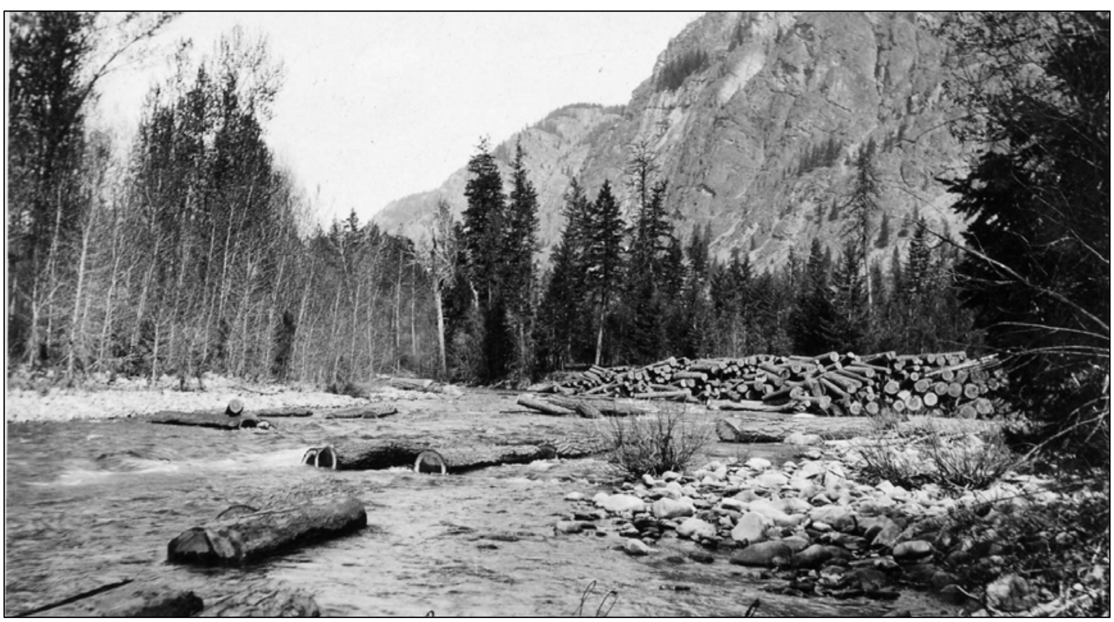

Figure O–8. Another logging scene in the Upper Methow believed to be looking at Goat Wall near Mazama.

Photograph copy courtesy of the Shafer Museum Collection, Winthrop, Washington.

In 1961, the USFS funded the removal of debris and logjams in portions of both the Chewuch River and Boulder Creek (Andonaegui, 2000). The Chewuch Watershed Analysis reports that large-scale, channel-clean-out efforts removed LWD and logjams following the 1948 and 1972 floods (Smith et al, 2000). In 1962, log jams in the Sheep Creek and Thirtymile Creek area were removed (Figure O–9 and Figure O–10). Surveyors collecting data for a recent stream survey on the Chewuch River saw evidence of ongoing wood removal near the Boulder Creek Campground, where wood was cut up for firewood (Smith et al., 2000). After the 1972 Flood, the ACOE and the National Guard assisted with channel clearing and levee building (Andonaegui, 2000). Ongoing restoration efforts have occurred in some areas of the Chewuch watershed to restore LWD (Andonaegui, 2000; PWI, 2004b). During the 1960s and the 1970s, LWD was removed from the channel of the Twisp River from the mouth to the end of the Twisp River Road (RM 27.0) (Andonaegui, 2000).

Figure O–9. Log jam in the Sheep Creek/Thirtymile Creek area in the upper Chewuch drainage basin in 1962.

Photograph courtesy US Forest Service.

Figure O–10. The same area as shown in Figure O-9 after the log jam in the Sheep Creek/Thirtymile Creek area has been cleared in 1962.

Photograph courtesy US Forest Service.

8. BEAVER

Beaver ponds and wetlands are important for this discussion because they create fish habitat, store sediment, provide nutrients, reduce stream velocities, and store water. Beaver trapping was one of the first documented activities by Anglo-Europeans in the Methow Subbasin. Fort Okanogan was established in 1811 at the mouth of the nearby Okanogan River and became a base for trading goods for beaver pelts collected from the north by Native Americans. Fort Okanogan was taken over by the Northwest Co. in 1814, which sold it to the Hudson's Bay Company in 1821. By 1887 the beaver business was noted as unproductive at Beaver Creek and other areas on the Methow River because most of the beavers had been trapped out by the Hudson’s Bay Company years before (Portman, 2002). The largest historical beaver trapping areas documented were at Thirty Mile (located in upper Chewuch watershed), Hidden Lakes, and in the headwaters of the Methow River (Portman, 2002).

Although beaver can still be found within the Chewuch watershed, historical records indicate a much higher level of use in the past (F.G. Bryant and Z.E. Parkhurst (1950) *as noted in* Andonaegui, 2000). Historically, more beaver were found than at present in the off-channel areas along the mainstem Chewuch River. The extent to which loss of beaver activity in off-channel areas along the mainstem has affected salmon productivity is unknown.

Historical beaver activity resulted in creation of most of the wetland ponds along the Twisp River (USFS, 2001). Although beaver have been very active in the Twisp River in the past, little current beaver activity was seen during a recent USFS survey. The reasons for the decline include the loss of habitat, food sources, and trapping (Andonaegui, 2000). Much of the wetland and side channel habitat in the lower Twisp River (below RM 5) has been disconnected from the main channel by man-made dikes and by roads. Several side channels connect large wetlands created by beaver to the main channel between RM 6.2–7.5.

9. IRRIGATION DIVERSIONS

Ten of the largest irrigation diversions were built between 1898 and 1914 and pre-date any aerial photography or flow measurements (Caldwell and Catterson, 1992). There are presently more than 30 diversions in the Methow Subbasin, both public and private, of which nine divert flow greater than 10 cfs (see Appendix N, Section 2 for a complete list). Several studies have been done in recent decades to evaluate the impact of diversion flows on base flows in the river. For this reason and because the scope of this assessment was focused on physical processes impacted by floods, this topic is not addressed in detail in this report.

10. REFERENCES

IN TEXT	FULL CITATION
ACOE 1952	US Army Corps of Engineers. 1952, *Columbia River and Tributaries Northwestern United States, Letter from the Secretary of the Army,* United States Government Printing Office.
Andonaegui 2000	Andonaegui, C. 2000. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48: Final Report.* Washington State Conservation Commission, 232 p.
Beck 1973	R.W. Beck and Associates. 1973. *Flood plain information, Methow River, Twisp to Mazama, Okanogan County, Washington:* R.W. Beck and Associates, Analytical and Consulting Engineers, Seattle, WA. Report prepared for Washington Department of Ecology, Olympia, WA. 13 p., 20 figures.
Devin 1997	Devin, D. 1997. *Mazama, The Past 100 Years – Life and Events in the Upper Methow Valley & Early Winters,* Peanut Butter Publishing, Seattle, WA.
KWA 2004	KWA Ecological Sciences Ltd. 2004. *Methow Subbasin Plan.* Prepared under contract for Washington Department of Fish and Wildlife and funded by the Northwest Power and Conservation Council. April 23, 2004; 463 p.
Portman 2002	Portman, S., 2002, *The Smiling Country – A History of the Methow Valley.* Sun Mountain Resorts, Inc., Winthrop, WA.
PWI 2004b	Pacific Watershed Institute. October 28, 2004. *Chewuch River: Channel Baseline Monitoring Report.* Prepared for Methow Valley Ranger District, USFS Cooperative Agreement #134100J008.
Schmidt 1964	Schmidt, Jessie, 1964, "Silver First Town in the Methow Valley" from website http://www.ghosttownsusa.com/silver.htm (as of 12/03/07).

IN TEXT	FULL CITATION
Smith et al. 2000	Smith, J. E., Fisher, B., and Farmer, S. 2000. *Lower Chewuch River fisheries habitat survey, final report.* Prepared for CI Johnson and Associates in cooperation with the Methow Basin Planning Unit by the Pacific Watershed Institute, Winthrop, WA. December 2000. 58 p.
USFS 2001	US Forest Service. 2001. *Twisp River stream survey summary:* Okanogan/ Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.

APPENDIX P –

DOCUMENTATION OF HUMAN FEATURES IN PRESENT RIVER SETTING

This appendix provides documentation on the types, locations, and length of human features that are present in the channel and floodplain areas. Human features are presented by river mile, by reach, and by tributary valley segment to allow comparison at a variety of spatial scales. The impact of these features on channel and floodplain connectivity is further discussed in Appendix E and G. Historical human activities that have occurred are documented in Appendix O (that is, removal of large woody debris, logging, and development).

CONTENTS

LIST OF FIGURES

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1. INTRODUCTION

Restoration efforts need to consider areas that are both functioning properly and areas that have been disturbed by human activities or features. This appendix focuses on documentation of human features present in the active channel and floodplain assessment area. Documentation of human features provides a starting point for understanding the type, extent, and locality of features; this documentation can be utilized to assess how these features have impacted channel and floodplain function (see Appendix E "Conceptual Model of Physical Processes Important to Salmonid Habitat Formation" and Appendix G "Geomorphic Mapping and Analysis").

Human features were mapped on 2004 aerial photographs and validated in the field where possible. Most of the present active channel areas were field-validated, but many of the extensive vegetated floodplain areas could not be validated due to land access, time constraints, and budget limitations. Additional field verification and mapping during future, more-detailed assessments could reveal additional features or provide updating and refinement to features documented in this assessment. LiDAR was collected in 2006 that will provide another tool to identify human features in future assessments.

Features were subdivided as to those that are located within the floodplain ("low surface") and limit connectivity of river processes, and those that are on the boundary of the floodplain and can limit expansion (erosion). Features can be located at a unique location, such as a bridge, or along a longer distance within the floodplain, such as bank protection, a levee or a road embankment.

In general, the human features that have the largest impact on disrupting channel and floodplain connectivity and lateral reworking processes are levees, push-up dikes, bridges, and roads. Features such as riprap and road embankments along the boundary of the low surface have not altered floodplain connectivity, but have altered complexity along the boundary, particularly where the river flows against the boundary. Where vegetation has been cleared, rates of bank erosion may have been altered.

2. HUMAN FEATURES COMPARED BY RIVER MILE

This section documents which types of human features are most common along each valley segment (that is, the Methow, Twisp, and Chewuch), and where the features are located relative to river miles. Human feature types included are:

- Bridges (vehicle)
- Footbridges (pedestrian)
- Levees (fill is generally stable and resistant to erosion)
- Push-up levees (often formed using floodplain sediment and can be easily eroded by the river during high flows)
- Roads
- Riprap
- Detroit riprap (old vehicles placed on bank)
- Cabled logs (several logs placed along bank for protection against erosion)
- Log structure (log jam type structure)
- Dam
- Diversion location
- Headgate present
- Water pipe

2.1 METHOW RIVER

Less than 30% of the boundary of the low surface has human features along it. The greatest length of human features occurs between RM 34–46, and the shortest length occurs between RM 70–75. The largest component along the low surface boundary is riprap that has been placed for bank protection (Figure P–1). Five bridges are also present. Along the boundary of the low surface, there is more bank protection in the downstream half of the Methow River assessment area.

Within the low surface, there are a range of human features present (Figure P–2). Some of these features restrict access to the floodplain, while others have been placed to protect surfaces within the low surface from erosion. Many of the features restrict only access to the upstream entrance of a side channel, or only a portion of the floodplain. In many cases the downstream entrance to a side channel is still accessible, and portions of the floodplain are still active due to lateral overtopping of flow from the river downstream of a human feature. Therefore, to develop an indicator of the degree of impact from human features in the floodplain, the length of human features present were compared relative to the total reach length.

There is a greater length of human features within the low surface (red bars) than along the boundary of the low surface (blue bars) in reaches M2, M4, M5, M7, M9, and M11 (Figure P–3). There is a shorter length of human features within the low surface than along the boundary of the low surface in reaches M1, M3, M6, M8, and M10. Reach MP has the longest length of human features within the low surface, with nearly 6 miles of cumulative length. Reaches M4 and M2 also have long lengths of human features within the low surface with between about 4 and 4.5 miles of cumulative length. The longest lengths of human features along the low surface boundary, about 3 miles each, are in Reach M2 and Reach M1.

Based on a ratio of the cumulative length of the human features to the length of the reach or the low surface boundary, Reach M7 has the highest ratio for human features within the low surface (1.9) (Figure P–4). This ratio is greater than twice the next highest value (0.8), which is in Reach M4. Reach M9, which has the longest length of human features within the low surface (Figure P–3), has only the fifth largest ratio when the length is compared to the total reach length (Figure P–4). The highest ratios for human features along the low surface boundary are in Reach M3 (~0.6) and M8 (~0.4). The ratios for human features along the low surface boundary are greater than those for human features within the low surface for reaches M1, M3, M6, M8, and M10.

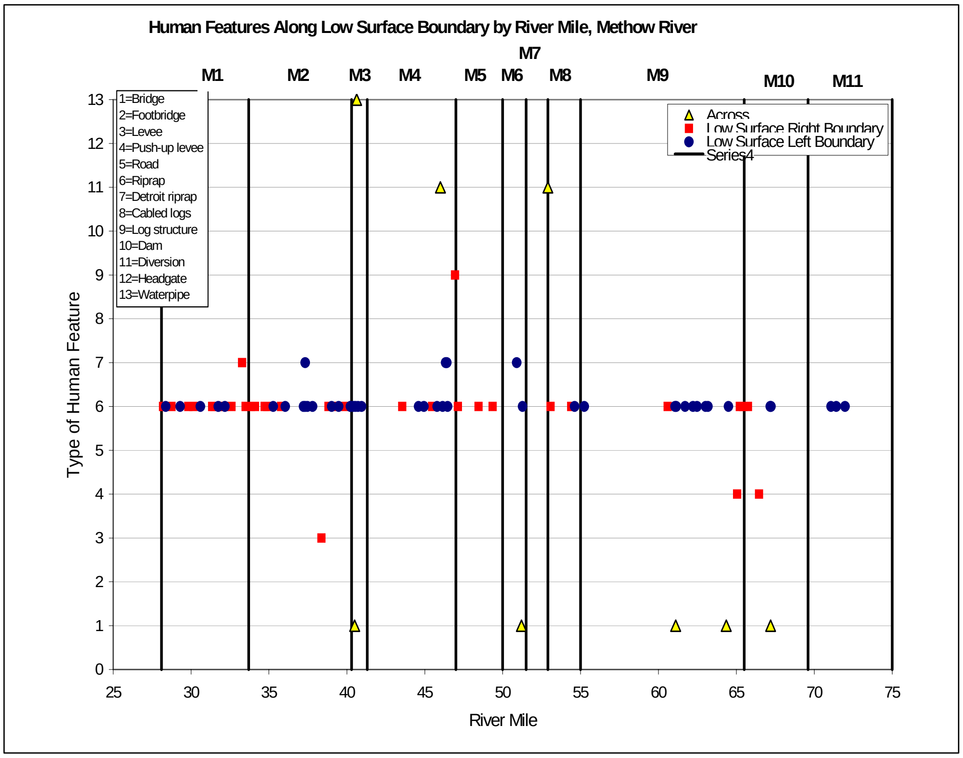

Figure P–1. Human features along the low surface boundary by river mile in Methow River assessment area. "Detroit" riprap is vehicles that are put along a bank to protect it from erosion.

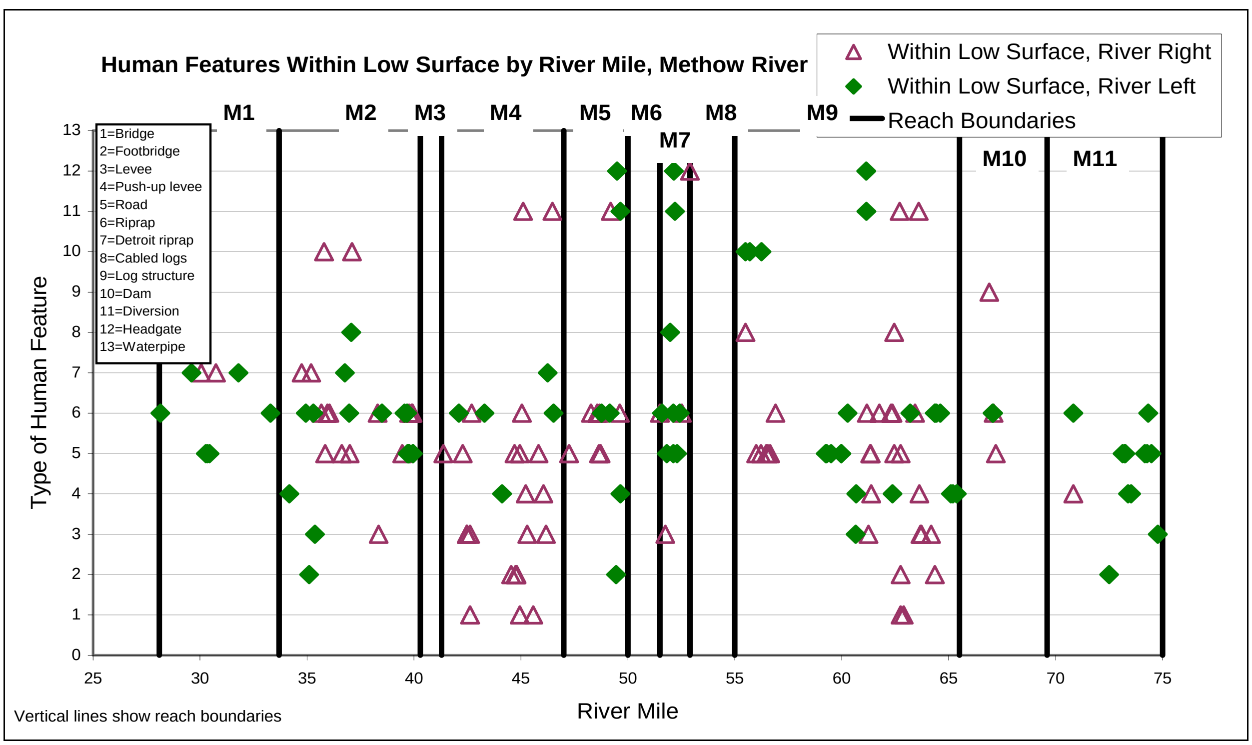

Figure P–2. Human features within low surface boundary by river mile in Methow River assessment area.

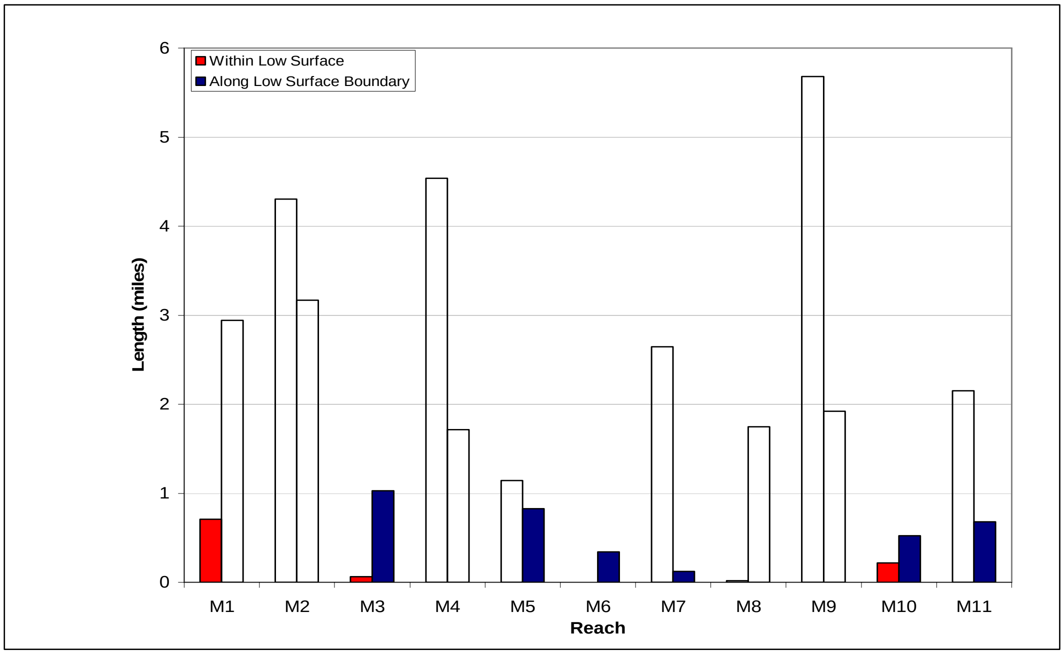

Figure P–3. Methow River – Total length of human features within low surface and along low surface boundary by geomorphic reach.

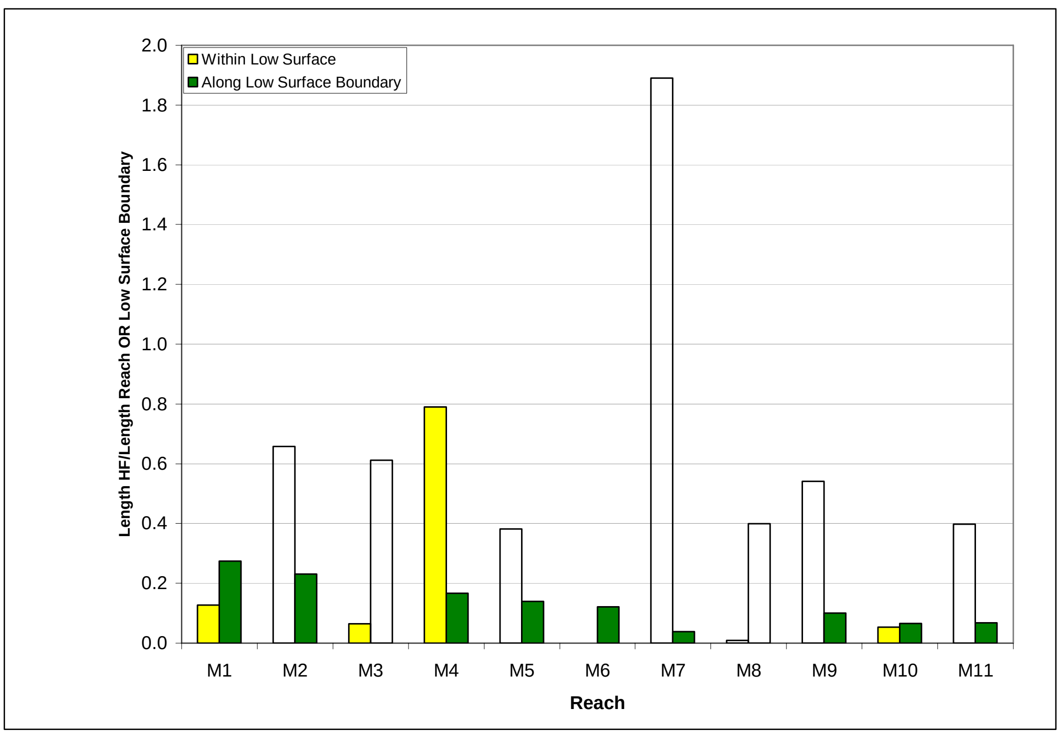

Figure P–4. Methow River – Ratio of length of human features to length of the reach or the low surface boundary by geomorphic reach. Features within the low surface are compared to the reach length. Features along the low surface boundary are compared to the low surface boundary.

2.2 TWISP RIVER

Less than 20% of the boundary of the low surface has human features along it. The largest components along the low surface boundary are road embankment and riprap that has been placed for bank protection (Figure P–5). Eight bridges are also present. Along the boundary of the low surface, the highest number of riprap and roads occur between RM 6–10.

Within the low surface, there are a range of human features present (Figure P–6). Some of these features restrict access to the floodplain, while others have been placed to protect surfaces within the low surface from erosion.

The length is greater for human features within the low surface than for those along the low surface boundary in reaches T2, T3, T5, and T6 (Figure P–7). The values are nearly equal for the two categories in reaches T1 and T4. The longest length of human features within the low surface is in Reach T2 (nearly 4.5 miles). The next longest length for human features within the low surface is in Reach T5, which has a length of just over 1.5 miles. For human features along the low surface boundary, reaches T3, T4, and T5 have similar values near 0.5 mile.

Based on a ratio of the cumulative length of the human features to the length of the reach or the low surface boundary, the highest values for human features within the low surface is in Reach T2 (nearly 1.0) (Figure P–8). Reach T1 also has a high value, slightly greater than 0.6. For human features along the low surface boundary, Reach T1 has the highest value (about 0.3), although the total length of human features along the low surface boundary for Reach T1 is next to last when compared to the values for the other reaches (Figure P–7). Based on length, most of the human features along the Twisp River are within the low surface.

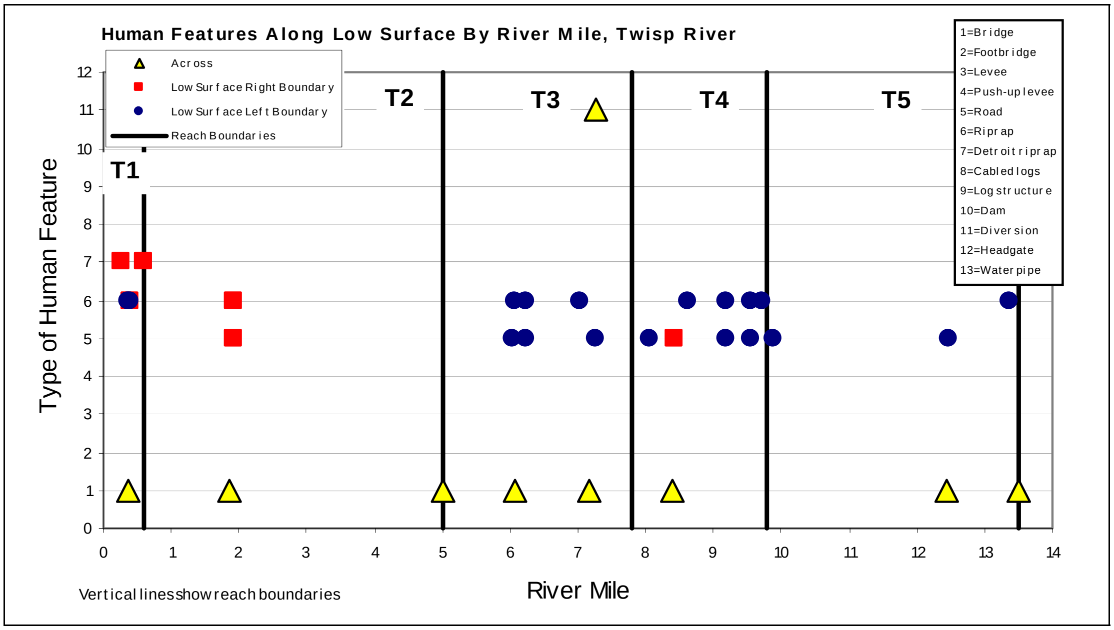

Figure P–5. Twisp River – Human features along low surface boundary by river mile.

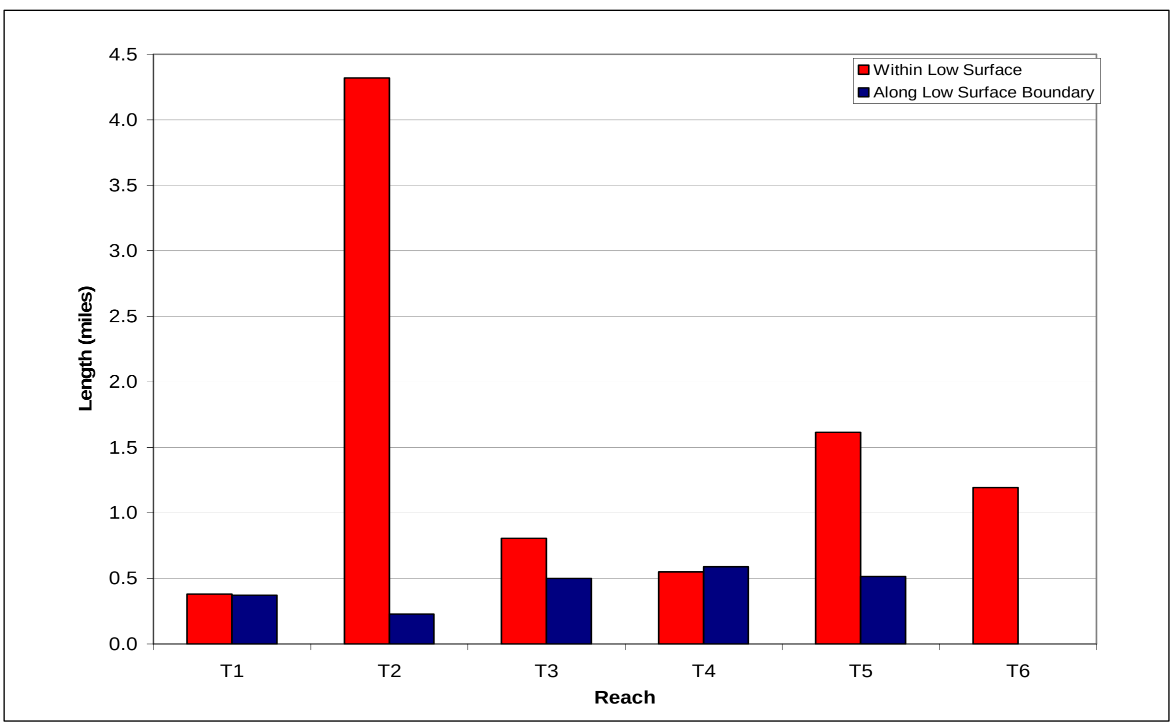

Figure P–6. Twisp River – Human features within low surface. "Detroit riprap" is vehicles that are put along a bank to protect it from erosion.

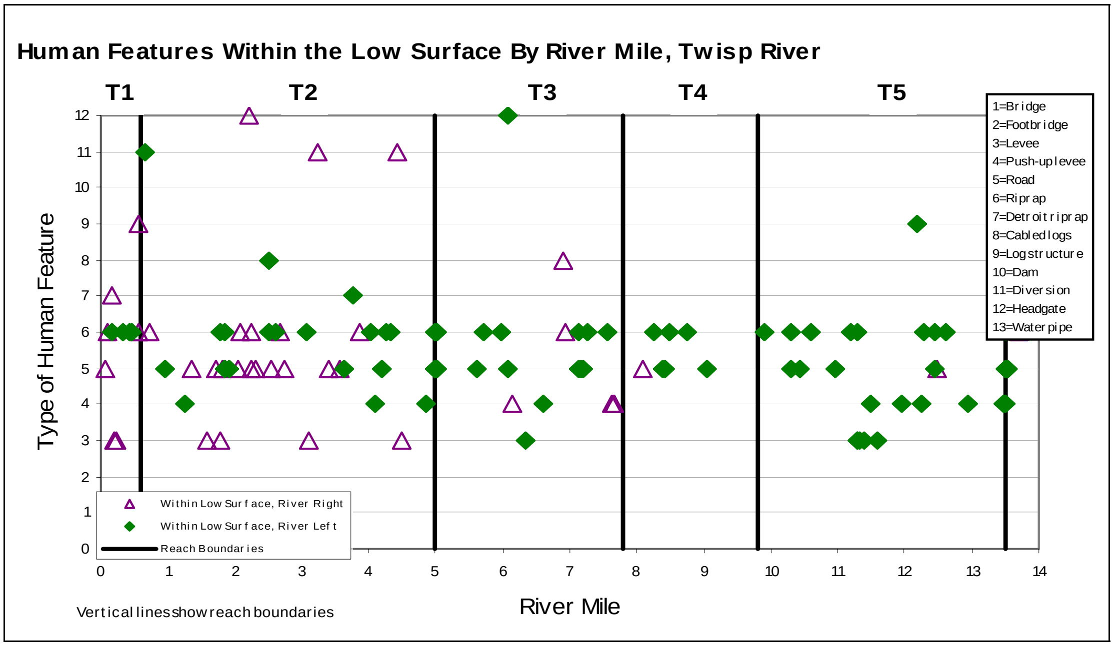

Figure P–7. Twisp River – Total length of human features along low surface boundary and within low surface by geomorphic reach.

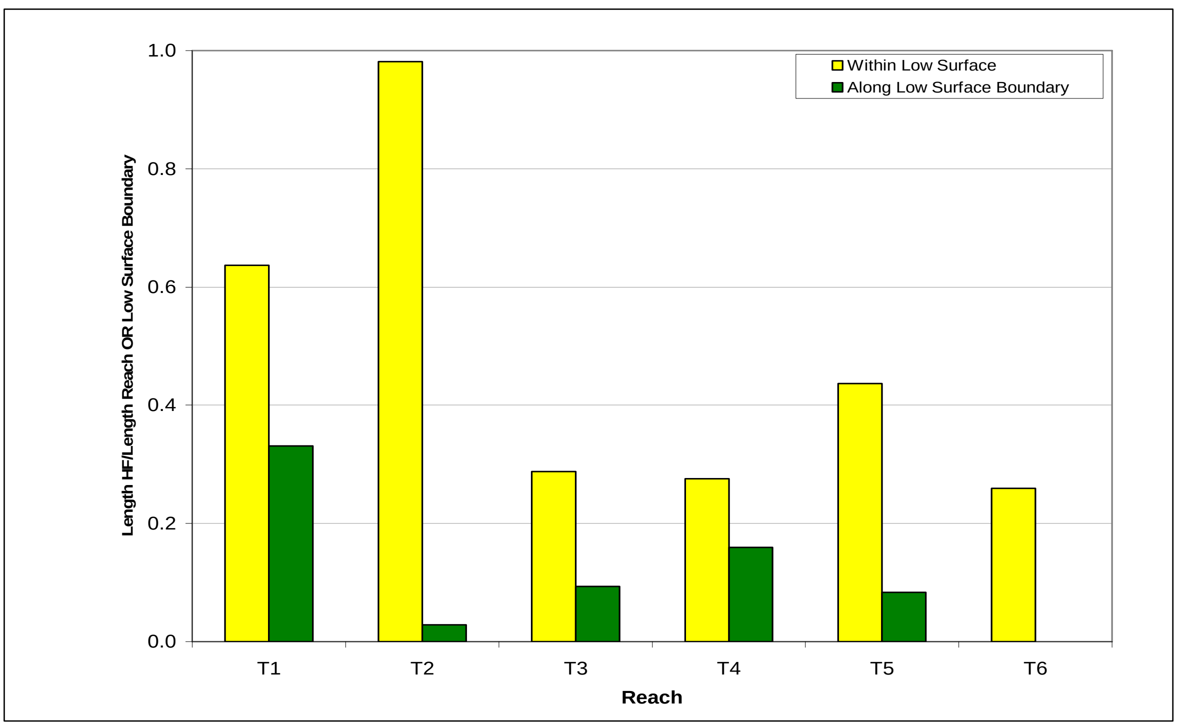

Figure P–8. Twisp River – Ratio of length of human features to length of the reach or the low surface boundary by geomorphic reach. Features within the low surface are compared to the reach length. Features along the low surface boundary are compared to the low surface boundary.

2.3 CHEWUCH RIVER

Less than 5% of the boundary of the low surface has human features along it (Figure P–9). Within the low surface, the largest component of human features is road embankment and riprap (Figure P–10). The largest component along the low surface boundary is riprap that has been placed for bank protection. Two bridges are also present.

The total length of human features within the low surface is greater than the total length of human features along the boundary of the low surface in reaches C2, C3, and C5, but the values for both of these lengths are nearly the same in reaches C1 and C4 (Figure P–11). In the reaches C2 and C3, all of the human features are within the low surface. The reach with the longest length of human features within the low surface is Reach C3 (nearly 1 mile). The reach with the longest length of human features along the low surface boundary is Reach C4 (about 0.3 mile).

Based on a ratio of the cumulative length of the human features to the length of the reach or the low surface boundary, the lengths of the human features within the low surface are greater than the lengths of human features along the low surface boundary in all of the reaches (Figure P–12). The highest value for human features within the low surface is in Reach C3 (~0.45). The highest value for human features along the low surface boundary is in Reach C4 (~0.06).

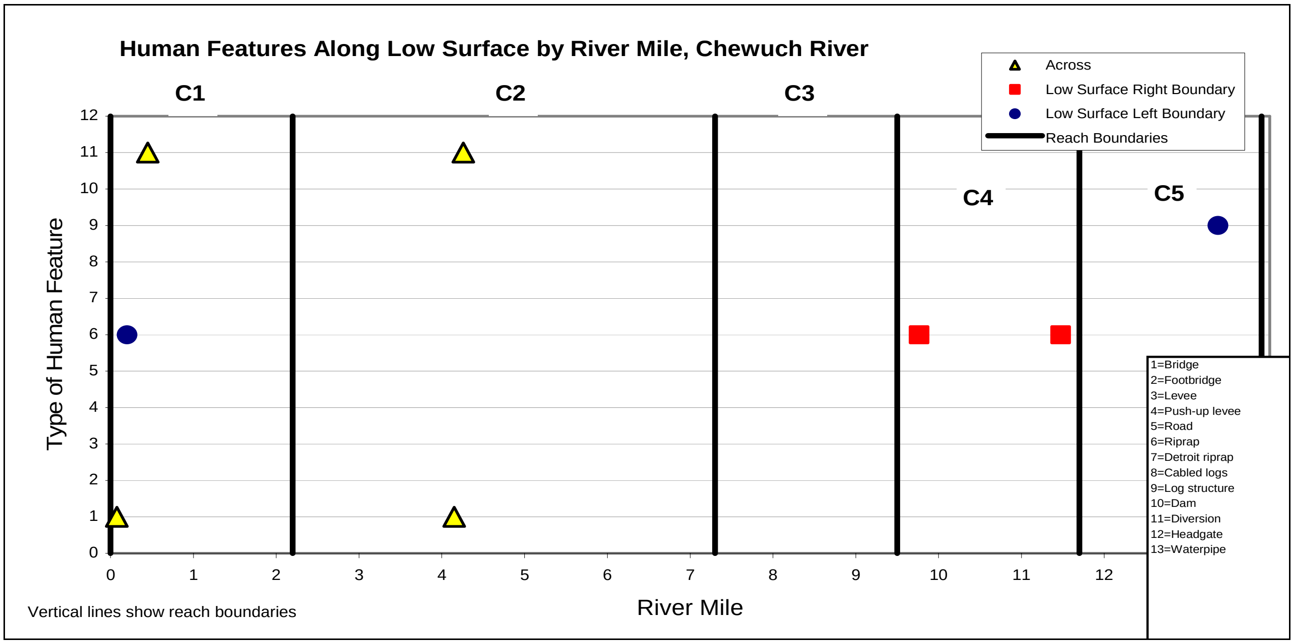

Figure P–9. Chewuch River – Human features along low surface boundary by river mile. "Detroit" riprap is riprap that is composed of vehicles that are put along a bank to protect it from erosion.

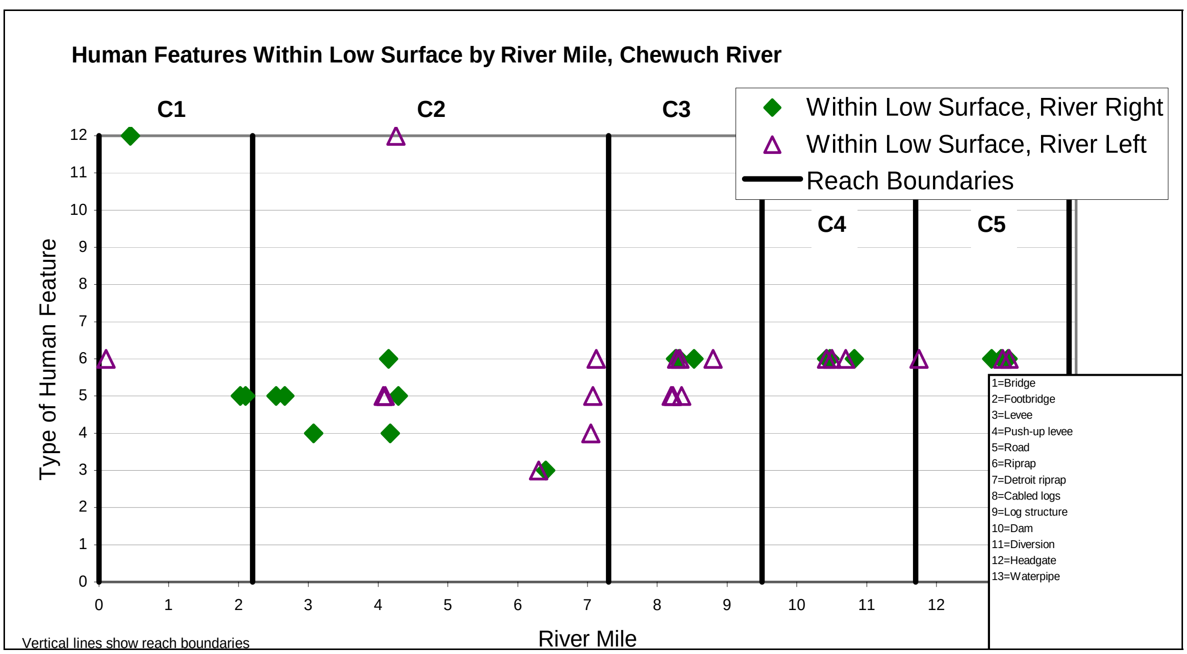

Figure P–10. Chewuch River – Human features within low surface by river mile. Detroit riprap is riprap that is composed of vehicles that are put along a bank to protect it from erosion.

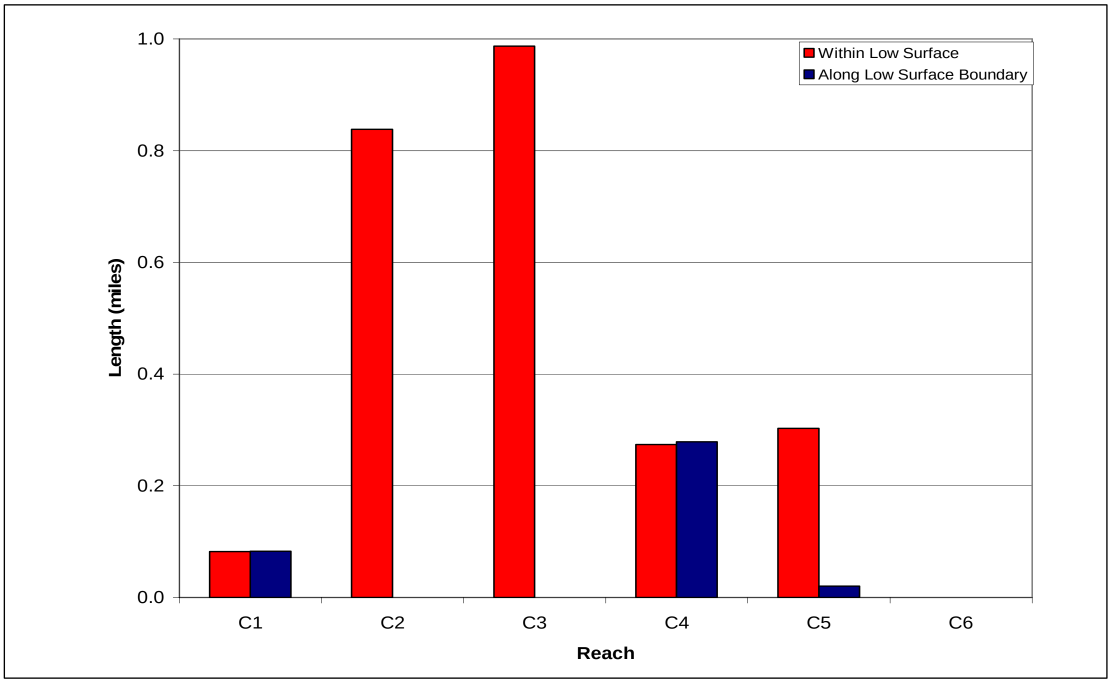

Figure P–11. Chewuch River – Total length of human features along low surface boundary and within low surface by geomorphic reach.

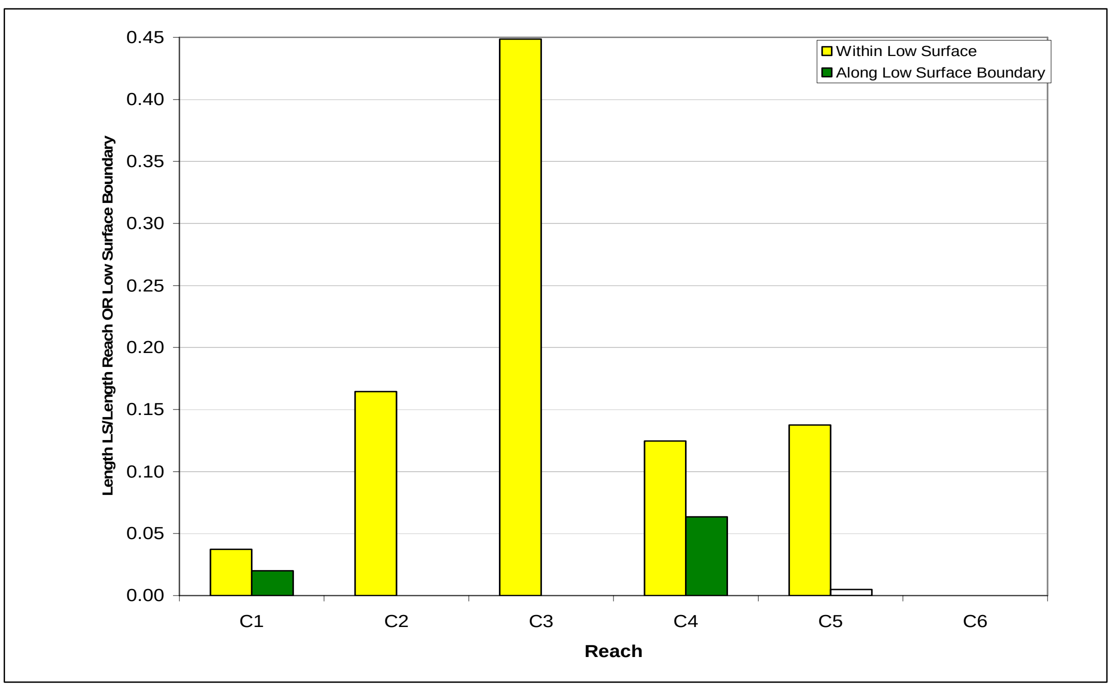

Figure P–12. Chewuch River – Ratio of length of human features to length of the reach or the low surface boundary by geomorphic reach. Features within the low surface are compared to the reach length. Features along the low surface boundary are compared to the low surface boundary.

3. HUMAN FEATURES COMPARED BY DRAINAGE

3.1 NUMBER OF HUMAN FEATURES PER MILE

In order to compare the impact of human features among the three drainages, the number of human features was calculated per mile. Within the low surface in the assessment reaches, the Twisp River has many more human features per mile (7.8) than the Methow River (3.6) (Figure P–13). The Chewuch River has slightly fewer human features per mile (2.8) than the Methow River. For human features along the low surface boundary within the assessment reaches, the Methow River and Twisp River have about the same number of human features per mile (about 1). The Chewuch River has markedly fewer human features per mile along the low surface boundary (0.16).

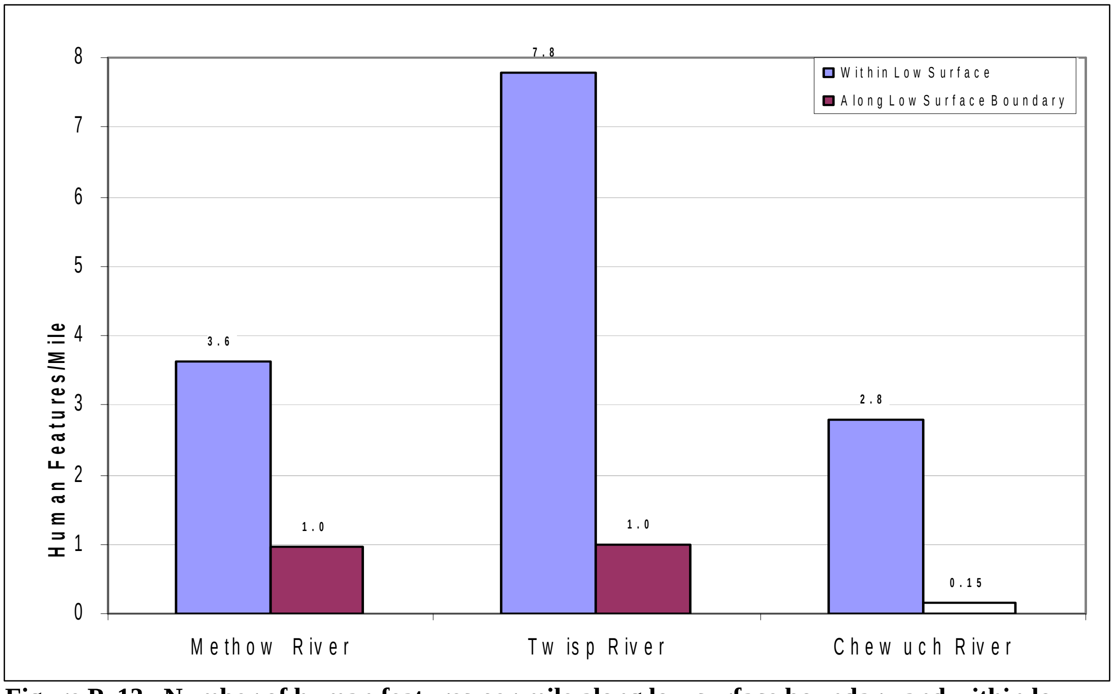

Figure P–13. Number of human features per mile along low surface boundary and within low surface by drainage.

3.2 RATIO OF LENGTH OF HUMAN FEATURES TO LENGTH OF THE ASSESSMENT REACH OR LOW SURFACE BOUNDARY

Another method used to compare the impact of human features between the three drainages was a ratio of the cumulative length of the human features to the length of the assessment reach or low surface boundary. Within the low surface in the assessment reaches (Figure P–14), the Twisp River has a slightly longer length ratio (0.49) than the Methow River (0.48); however, the number of human features per mile within the low surface is much greater for the Twisp River (7.8) than it is for the Methow River (3.6). The Chewuch River has a much lower length ratio (0.17) than either the Twisp or Methow rivers.

For human features along the low surface boundary within the assessment reaches (Figure P–14), the length ratio for the Methow River (0.17) is much greater than the length ratio for the Twisp River (0.07), although the number of human features per mile is nearly the same for the two drainages (1.0). The Chewuch River has a much lower length ratio (0.01).

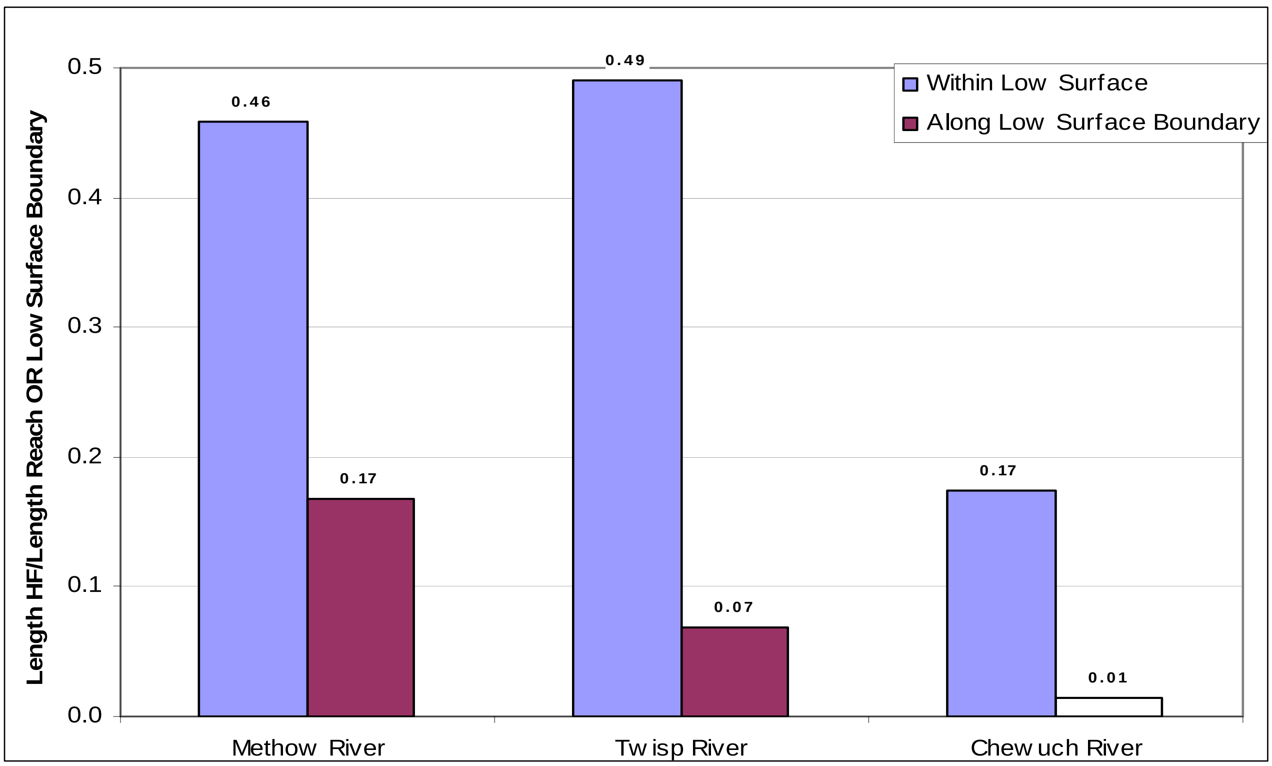

Figure P–14. Ratio of cumulative lengths of human features along low surface boundary and within low surface to the lengths of the assessment reach by drainage.

4. HUMAN FEATURES COMPARED BY REACH

The following discussion summarizes the number and extent of human features in the Methow, Twisp, and Chewuch assessment areas in the context of whether the reach is "unconfined", "moderately confined", or "confined" (three floodplain types described in Appendix B). The number, lengths, and percentages of the human features within the low surface and along the low surface boundary are summarized below for the Methow, Twisp, and Chewuch assessment areas.

4.1 METHOW RIVER

The Methow River assessment area is approximately 47 river miles in length. There are 178 human features within the low surface, and 86 human features along the low surface boundary (Table P–1). The majority of human features within the low surface are in three of the unconfined reaches (M2, M4, and M9) (Figure P–15).

The number of human features along the low surface boundary is high in three (M2, M4, and M9) of the four unconfined reaches, but also in two of the confined reaches (M1 and M3).

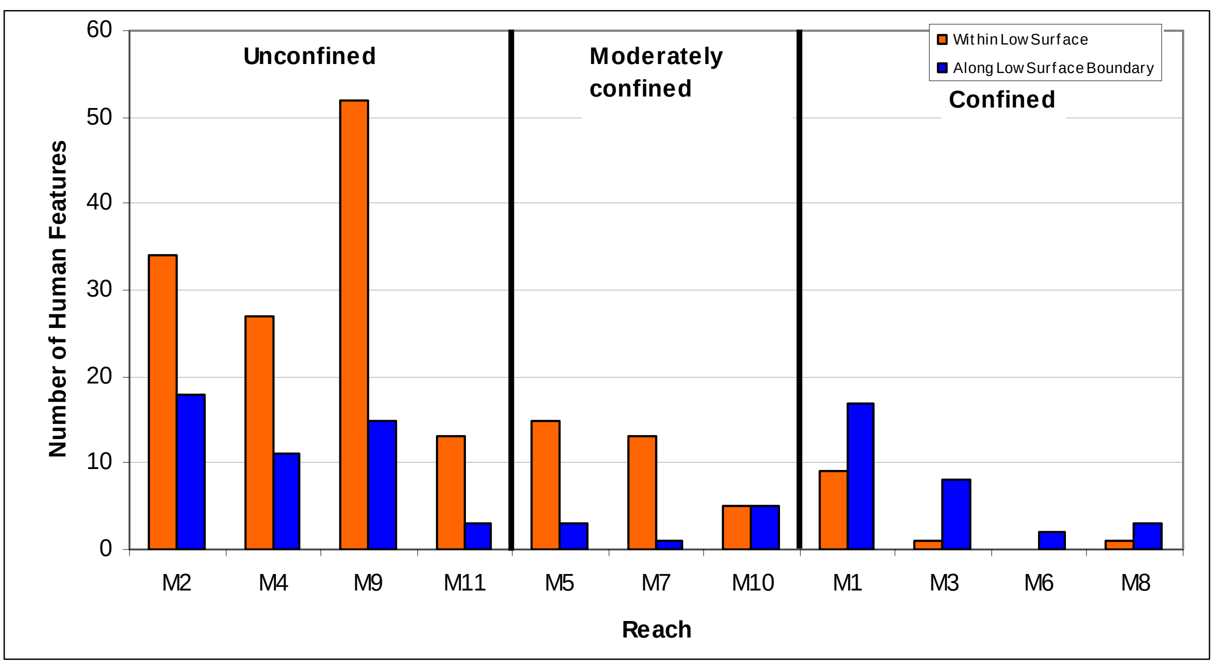

Figure P–15. Methow River – Number of human features mapped within the low surface (orange bars) and along the low surface boundary (blue bars) between RM 28–75.

Of the human features that affect the river over a distance, the total length of human features within the low surface is about 20.5 miles. This is about 44% of the 47-mile-long assessment section. The longest cumulative lengths and percentages of total length of human features within the low surface are in three of the unconfined reaches (M2, M4, M9) and in one of the moderately confined reaches (M7) (Figure P–16).

The total length of human features along the low surface boundary is about 79,000 feet (about 15 miles). This is about 17% of the total length of the low surface boundary (about 474,000 feet). The longest cumulative lengths and percentages of total length are in three of the unconfined reaches (M2, M4, and M9; Figure P–16) and in two of the confined reaches (M1 and M8; Figure P–16). The two highest values for total length of human features along the low surface boundary are in the two downstream reaches of the assessment area, reaches M1 and M2. Reach M1 is confined and Reach M2 is unconfined.

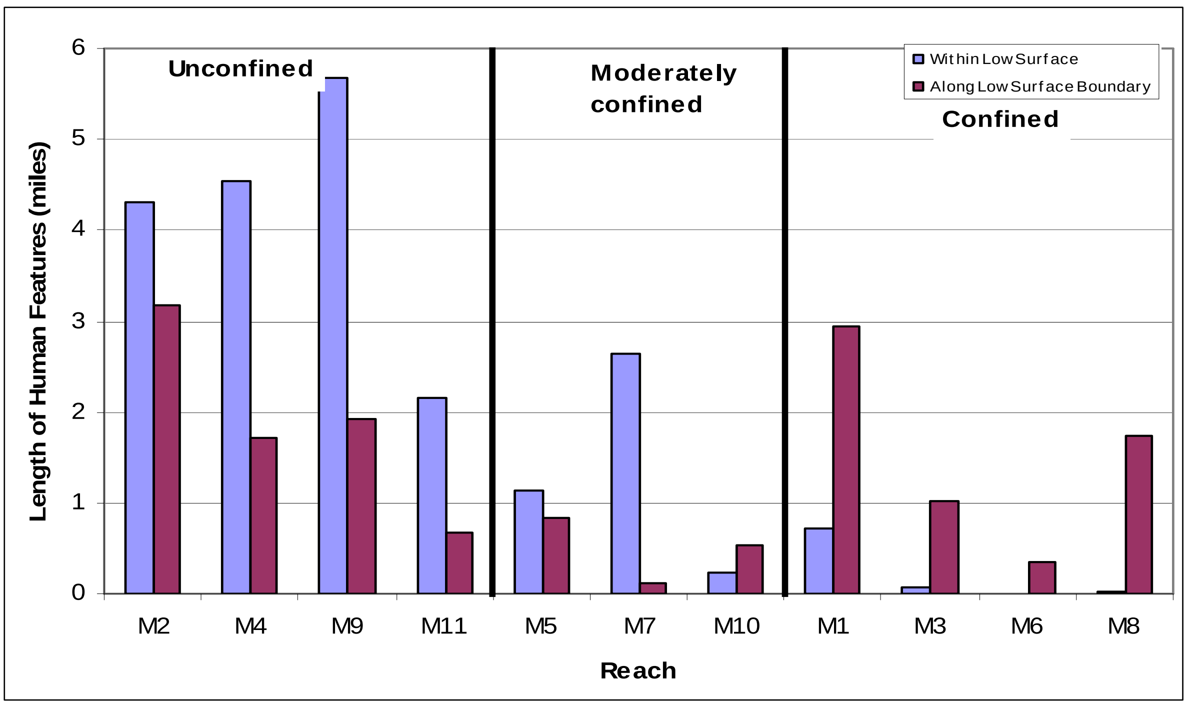

Figure P–16. Methow River – Cumulative lengths of human features mapped within the low surface (blue bars) and along the low surface boundary (maroon bars) between RM 28–75.

As a percentage of the reach length, moderately confined Reach M7 has the highest value (~1.9). Three of the unconfined reaches (M2, M4, and M9) have the next highest values for human features within the low surface (0.55 to 0.8; Figure P–17). As a percentage of the length of the low surface boundary, three of the confined reaches (M1, M3, and M8) have the highest percentage of human features along the low surface boundary. Because the unconfined reaches are wider, more human features are within the low surface than along the boundary. Conversely, the confined reaches, which are relatively narrow, have higher percentages of human features along the low surface boundary than within the low surface.

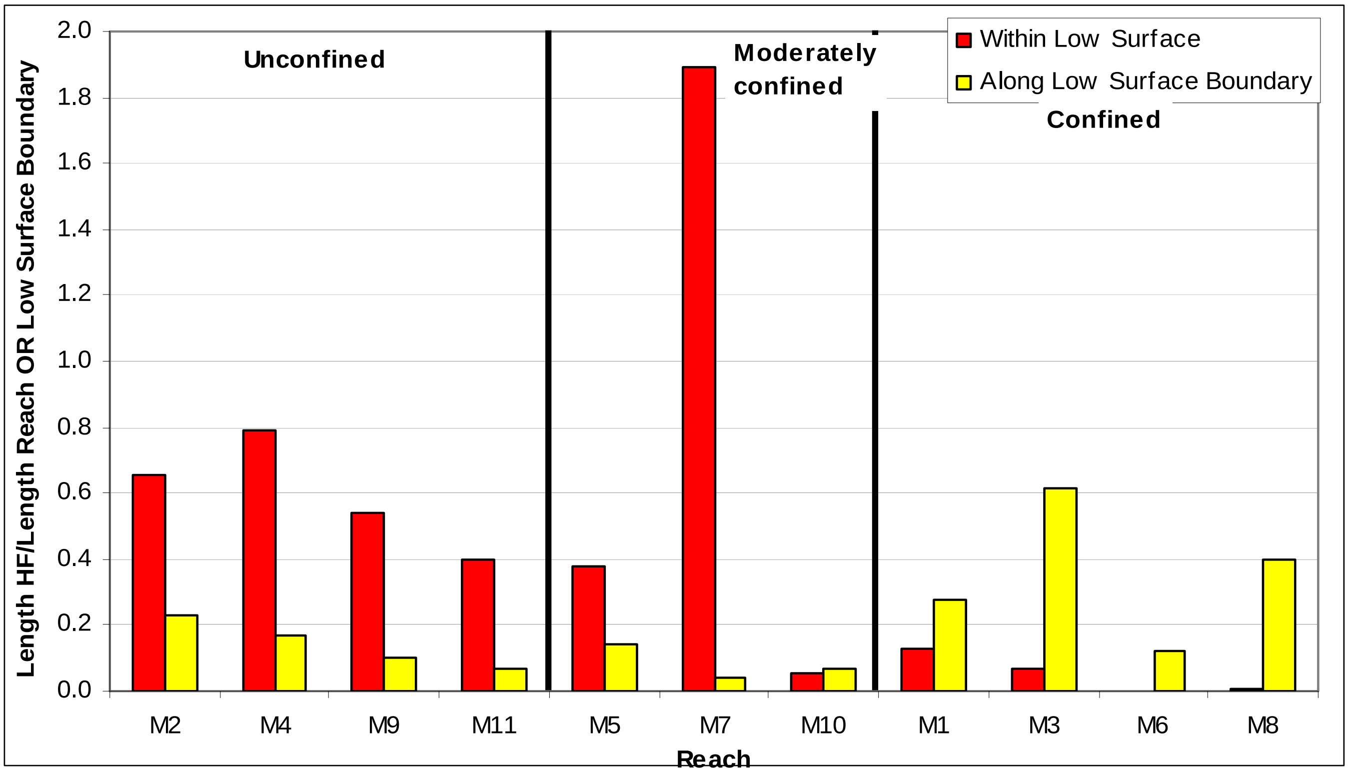

Figure P–17. Methow River – Cumulative lengths of human features as a percentage of the total reach length for features within the low surface (red bars) and total length of the low surface boundary for features along the low surface boundary (yellow bars) between RM 28–75.

4.2 TWISP RIVER

The Twisp River assessment section is approximately 18 river miles in length. There are 151 human features within the low surface and 32 human features along the low surface boundary (Table P–2). The greatest number of human features within the low surface is in two of the unconfined reaches (T2 and T5) and in the moderately confined reach (T3) (Figure P–18). The number of human features along the low surface boundary is relatively high in one of the confined reaches (T4) and in one of the unconfined reaches (T5).

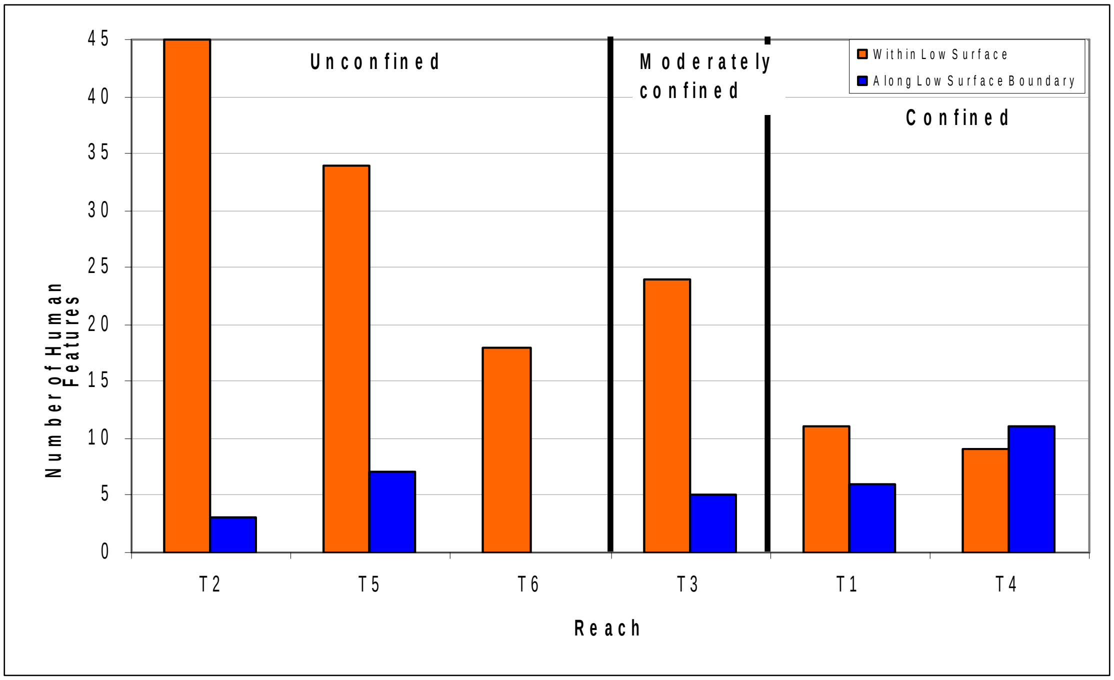

Figure P–18. Twisp River – Number of human features mapped within the low surface (orange bars) and along the low surface boundary (blue bars) between RM 0–18.

Of the human features that affect the river over a distance, the total length of human features within the low surface is about 8.8 miles. This is 48% of the 18-mile assessment section. The longest cumulative length of human features within the low surface is in unconfined Reach T2, with nearly 4.5 miles (Figure P–19). The next two longest lengths also are unconfined reaches, T5 with slightly a cumulative length of just over 1.5 miles and T6 with a length of about 1.25 miles.

The total length of human features along the low surface boundary is about 11,600 feet (2.2 miles). This is about 7% of the total length of the low surface boundary (about 171,000 feet). The longest cumulative lengths and highest percentages of total length are in one of the confined reaches (T4), one of the unconfined reaches (T5), and in the moderately confined Reach T3. These three reaches each have a cumulative length of about 0.5 miles of human features along the low surface boundary.

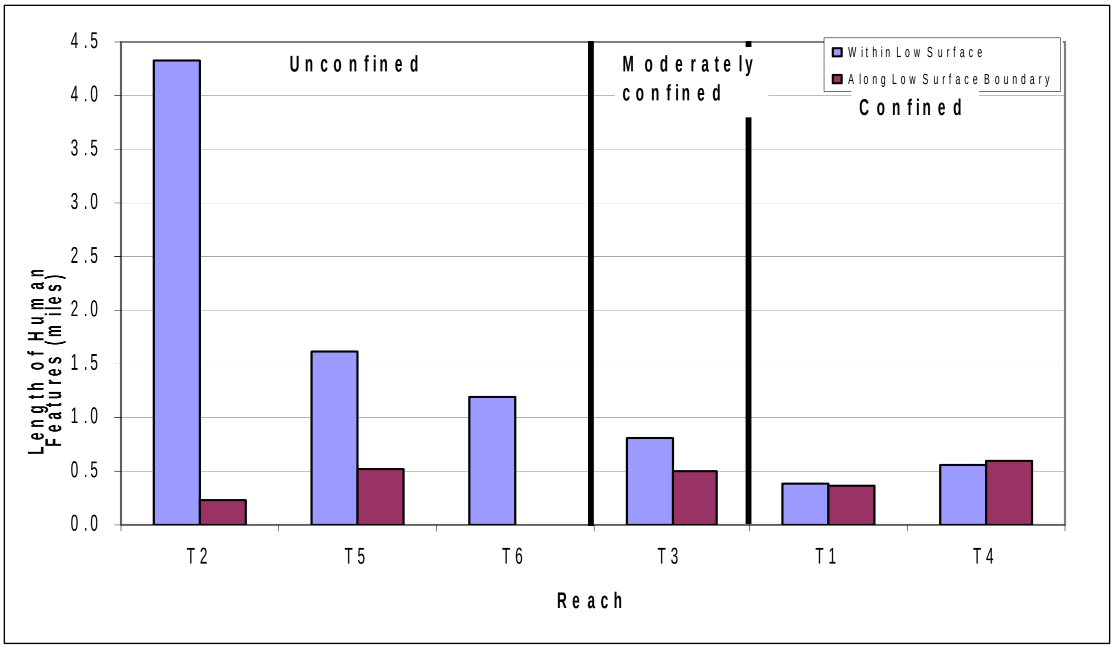

Figure P–19. Twisp River – Cumulative lengths of human features mapped within the low surface (blue bars) and along the low surface boundary (maroon bars) between RM 28–75.

As a percentage of the reach length, one of the unconfined reaches (T2) and one of the confined reaches (T1) have the highest percentages of human features within the low surface (Figure P–20). The value of nearly 1.0 for Reach T2 is higher than the value of nearly 0.65 for Reach T1. As a percentage of the length of the low surface boundary, two of the confined reaches (T1 and T4) have the highest percentage of human features along the low surface boundary.

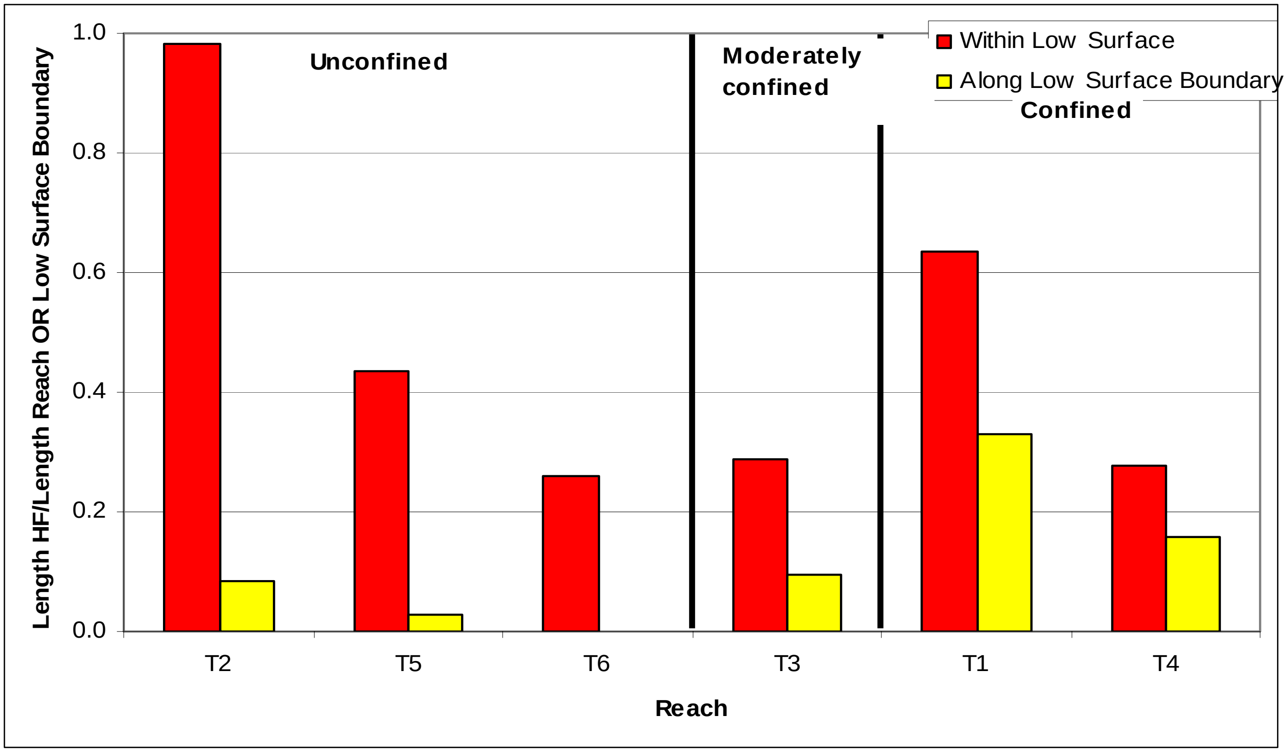

Figure P–20. Twisp River – Cumulative lengths of human features as a percentage of the total length of the reach for features within the low surface (red bars) and total length of the low surface boundary for features along the low surface boundary (yellow bars) between RM 0–18.

4.3 CHEWUCH RIVER

The Chewuch River assessment section is approximately 14.3 river miles long. There are 40 human features within the low surface and four human features along the low surface boundary (Table P–3). The highest number of human features within the low surface is in the moderately confined Reach C3 and in one of the unconfined reaches (C2) (Figure P–21). The number of human features along the low surface boundary is highest in one of the confined reaches (C4).

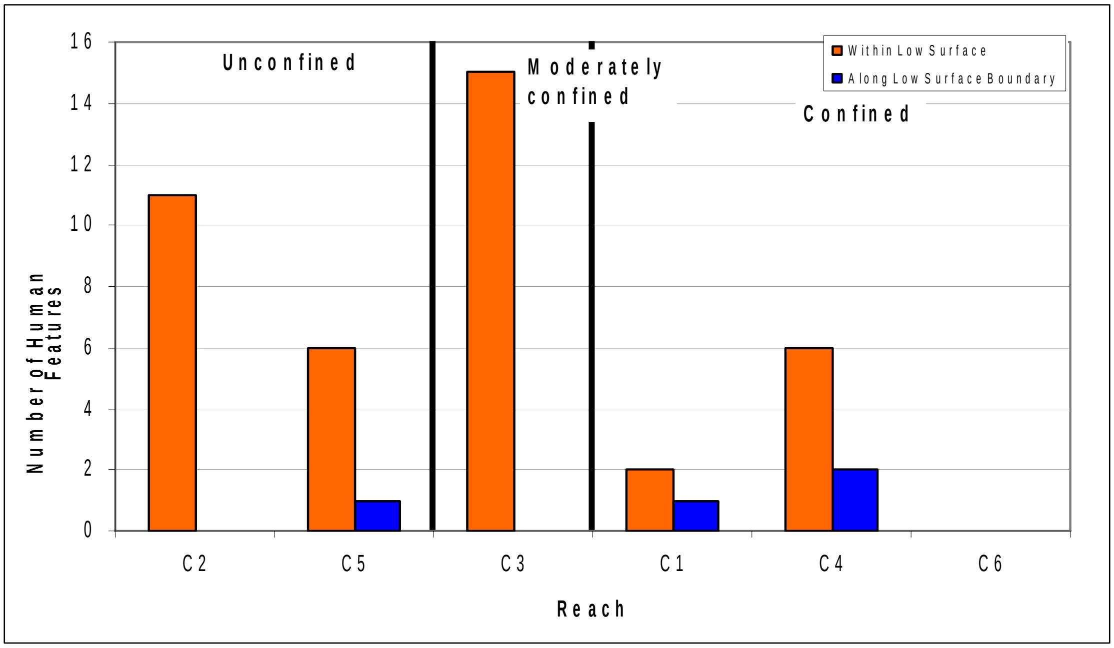

Figure P–21. Chewuch River – Number of human features mapped within the low surface (orange bars) and along the low surface boundary (blue bars) between RM–14.3.

Of the human features that affect the river over a distance, the total length of human features within the low surface is about 2.5 miles. This is about 17% of the 14.3 mile assessment section. The longest cumulative lengths of human features within the low surface are in the moderately confined Reach C3 and in one of the unconfined reaches (C2) (Figure P–22).

The total length of human features along the low surface boundary is about 2,000 feet (about 0.4 mile). This is about 1.5% of the total length of the low surface boundary (about 141,000 feet). The longest cumulative lengths of human features along the low surface boundary are in two of the confined reaches (C1 and C4) (Figure P–22).

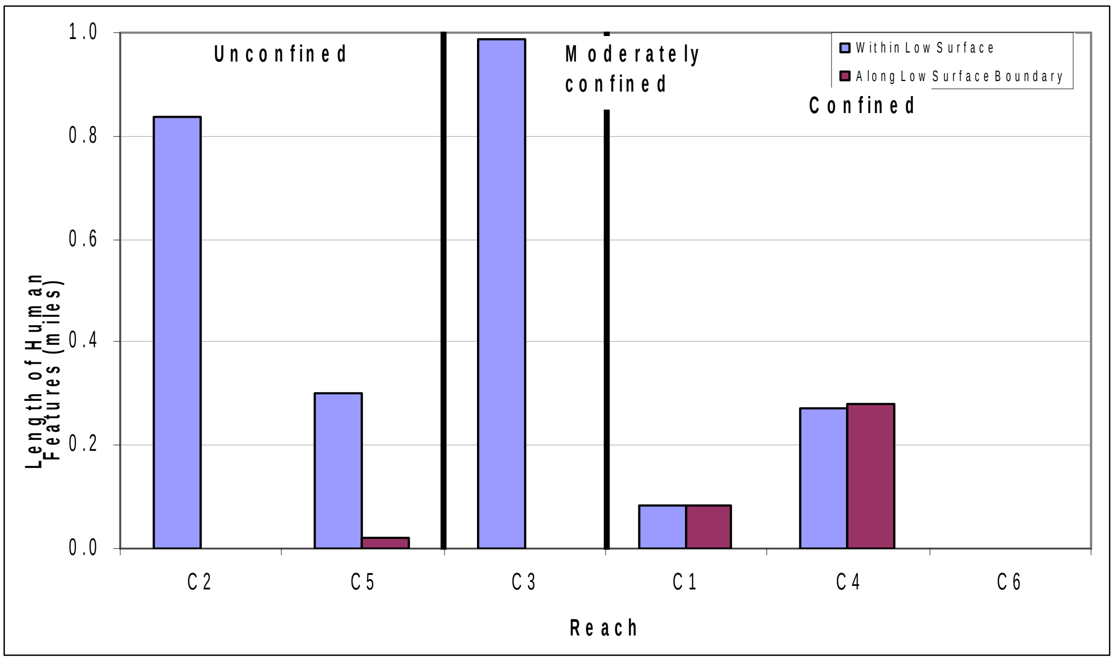

Figure P–22. Chewuch River – Cumulative lengths of human features mapped within the low surface (blue bars) and along the low surface boundary (maroon bars) between RM 0–14.3.

As a percentage of the reach length, the moderately confined Reach C3 has the highest value (~0.45) for human features within the low surface (Figure P–23). As a percentage of the length of the low surface boundary, one of the confined reaches (C4) has the highest value (~0.13) for human features along the low surface boundary.

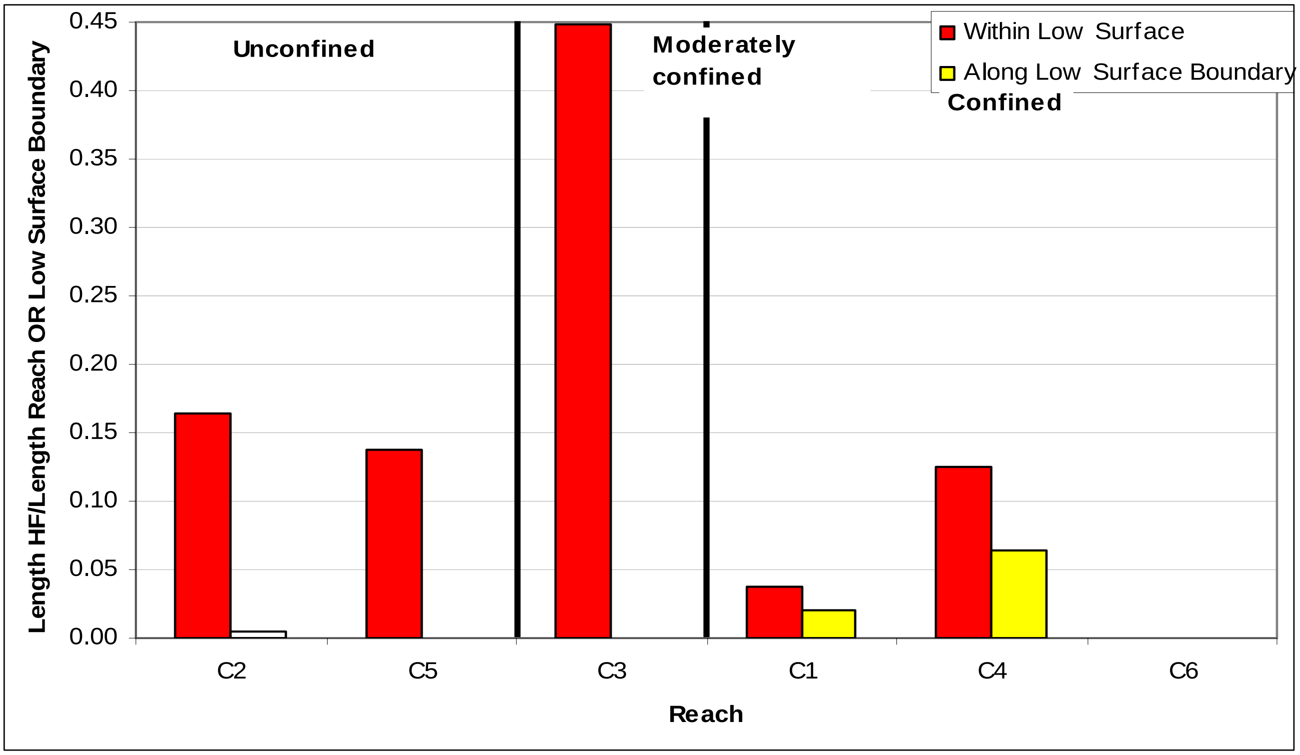

Figure P–23. Chewuch River – Cumulative lengths of human features as a percentage of the total length of the reach for features within the low surface (red bars) and total length of the low surface boundary for features along the low surface boundary (yellow bars) between RM 0–14.

Table P–1. Methow River – Number, lengths, and percentages of human features mapped within the low surface and along the low surface boundary between RM 28–75.

Type	Reach	D/S RM	U/S RM	Total Number of Human Features		Total Length of Human Features (ft)		Percent of Cumulative Human Feature Length for all Methow Reaches		Length of Human Features as Percent of Total Reach or Low Surface Boundary Length[1]	
				Within Low Surface	Along Low Surface Boundary	Within Low Surface	Along Low Surface Boundary	Within Low Surface	Along Low Surface Boundary	Within Low Surface	Features Along Boundary
Unconfined	M2	33.7	40.3	34	18	22,732	16,723	20.0	21.1	0.66	0.23
Unconfined	M4	41.3	47	27	11	23,969	9,049	21.1	11.4	0.79	0.17
Unconfined	M9	55	65.5	52	15	30,004	10,147	26.5	12.8	0.54	0.10
Unconfined	M11	69.6	75	13	3	11,356	3,578	10.0	4.5	0.40	0.07
Moderately confined	M5	47	50	15	3	6,041	4,377	5.3	5.5	0.38	0.14
Moderately confined	M7	51.5	52.9	13	1	13,968	655	12.3	0.8	1.89	0.04
Moderately confined	M10	65.5	69.6	5	5	1,162	2,762	1.0	3.5	0.05	0.07
Confined	M1	28.1	33.7	9	17	3,752	15,538	3.3	19.6	0.13	0.27
Confined	M3	40.3	41.3	1	8	342	5,418	0.3	6.8	0.06	0.61
Confined	M6	50	51.5	0	2	0	1,795	0.0	2.3	0.00	0.12
Confined	M8	52.9	55	1	3	97	9,221	0.1	11.6	0.01	0.40
TOTALS				**178**	**86**	**108,008**	**79,263**			**0.46**	**0.17**

D/S=Downstream; U/S=Upstream

1/ For features within the low surface, the length of the 2004 channel between the reach boundaries was used for the reach length. For features along the low surface boundary, the length of the actual boundary was used for the reach length.

For an explanation of reach type, see Appendix C.

Table P–2. Twisp River – Number, lengths, and percentages of human features mapped within the low surface and along the low surface boundary between RM 0–18.

Type	Reach	D/S RM	U/S RM	Total Number of Human Features		Total Length of Human Features (ft)		Percent of Cumulative Human Feature Length		Length of Human Features as Percent of Total Reach or Low Surface Boundary Length[1]	
				Within Low Surface	Along Low Surface Boundary	Within Low Surface	Along Low Surface Boundary	Within Low Surface	Along Low Surface Boundary	Reach Length for Features Within Low Surface	Low Surface Boundary Length for Features Along Boundary
Unconfined	T2	0.6	5	45	3	22,798	1,204	48.7	10.3	0.98	0.03
Unconfined	T5	9.8	13.5	34	7	8,526	2,721	18.2	23.4	0.44	0.08
Unconfined	T6	13.5	18.1	18	0	6,301	0	13.5	0.0	0.26	0.00
Moderately confined	T3	5	7.8	24	5	4,254	2,643	9.1	22.7	0.29	0.09
Confined	T1	0	0.6	11	6	2,016	1,969	4.3	16.9	0.64	0.33
Confined	T4	7.8	9.8	9	11	2,910	3,115	6.2	26.7	0.28	0.16
TOTALS				**141**	**32**	**46,806**	**11,652**			**0.49**	**0.07**

D/S=Downstream; U/S=Upstream

1/ For features within the low surface, the length of the 2004 channel between the reach boundaries was used for the reach length. For features along the low surface boundary, the length of the actual boundary was used for the reach length.

For an explanation of reach type, see Appendix C.

Table P–3. Chewuch River – Number, lengths, and percentages of human features mapped within the low surface and along the low surface boundary between RM 0–14.3.

Type	Reach	D/S RM	U/S RM	Total Number of Human Features		Total Length of Human Features (ft)		Percent of Cumulative Human Feature Length		Length of Human Features as Percent of Total Reach or Low Surface Boundary Length[1]	
				Within Low Surface	Along Low Surface Boundary	Within Low Surface	Along Low Surface Boundary	Within Low Surface	Along Low Surface Boundary	Reach Length for Features Within Low Surface	Low Surface Boundary Length for Features Along Boundary
Unconfined	C2	2.2	7.3	11	0	4,426	0	33.7	0.0	0.16	0.0
Unconfined	C5	11.7	13.9	6	1	1,598	106	12.2	5.3	0.14	0.0
Moderately confined	C3	7.3	9.5	15	0	5,212	0	39.7	0.0	0.45	0.0
Confined	C1	0.0	2.2	2	1	408	439	3.3	21.8	0.04	0.02
Confined	C4	9.5	11.7	6	2	1,447	1,471	11.0	73.0	0.12	0.06
Confined	C6	13.9	14.3	0	0	0	0	0	0.0	0.0	0.0
TOTALS					**4**	**13,116**	**2,016**			**0.17**	**0.01**

D/S=Downstream; U/S=Upstream

1/ For features within the low surface, the length of the 2004 channel between the reach boundaries was used for the reach length. For features along the low surface boundary, the length of the actual boundary was used for the reach length.

For an explanation of reach type, see Appendix C.

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5. HUMAN FEATURES COMPARED BY REACH TYPE

5.1 HUMAN FEATURES WITHIN THE LOW SURFACE

The highest number of human features per mile within the low surface in all of the drainages is in the confined Reach T1 (>18), but the rest of the reaches have less than about 10 human features per mile (Figure P–24).

Reach T1 is in the town of Twisp and has eight areas with riprap, which range in length from about 3 feet to 500 feet, two levees, and one area with Detroit riprap. The short length of the reach, only 0.6 miles, results in a high value for the number of human features per mile. The next highest numbers of human features within the low surface are in the unconfined reaches: T2 (~10) and T5 (~9). Moderately confined Reach M7 has about the same number of human feature per mile (~9). The next highest value is in moderately confined Reach T3 (~8.5).

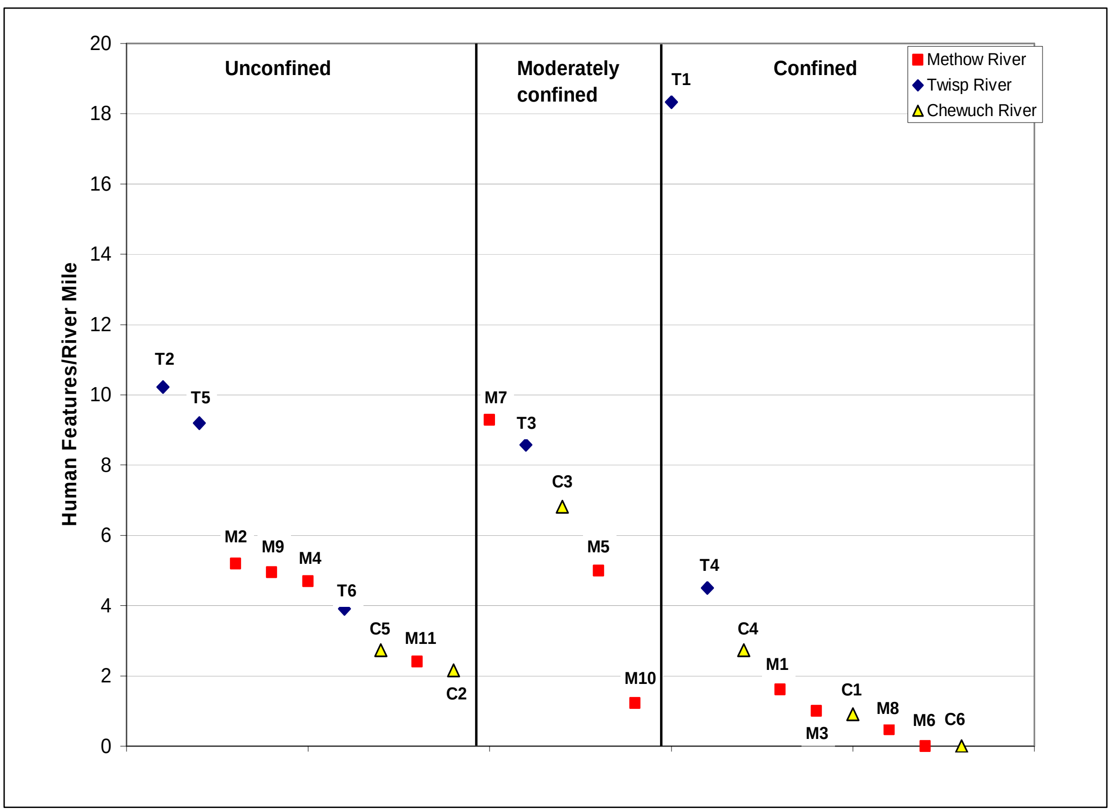

Figure P–24. Number of human features per mile within the low surface for all three drainages by reach type.

The ratios of the cumulative length of the human features to the length of the reach for human features within the low surface show a different pattern (Figure P–25). The highest ratio is in moderately confined Reach M7 (1.9). The next highest values are in unconfined reaches, but all have values of less than 1.0.

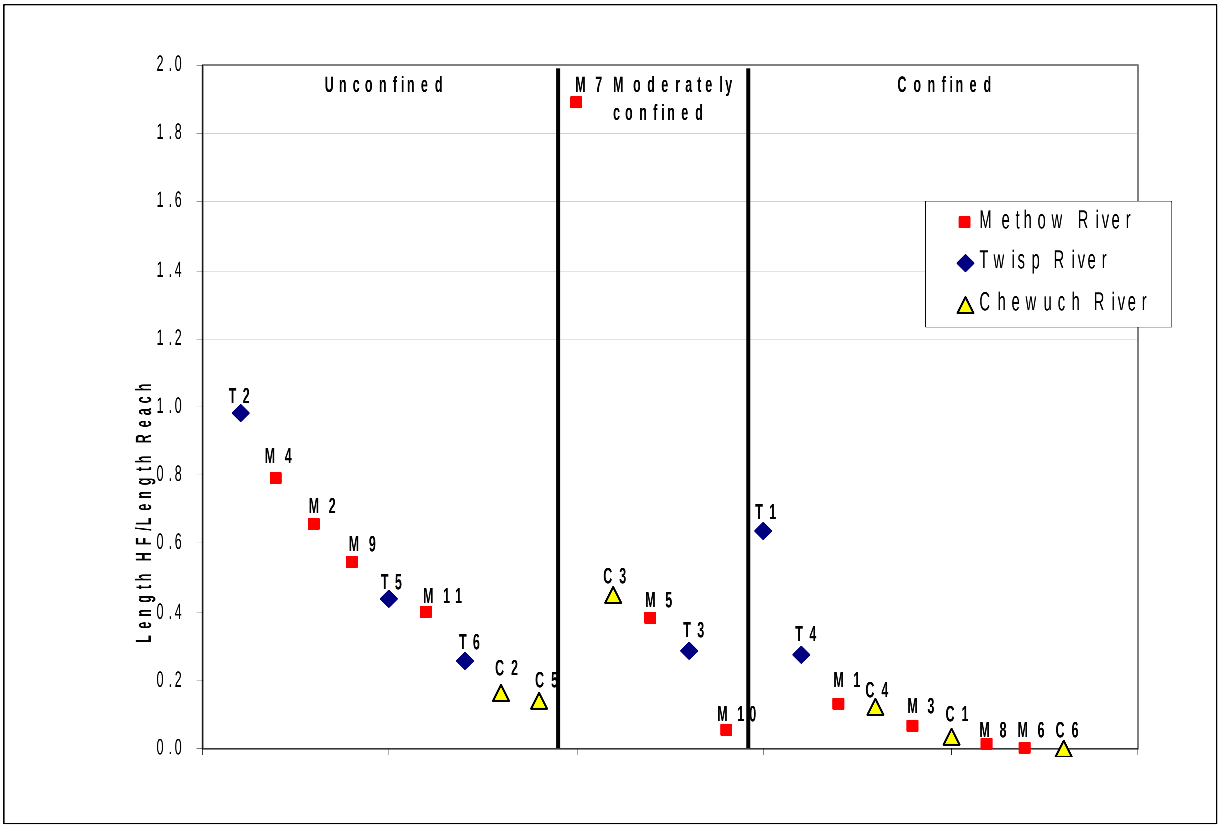

Figure P–25. Ratio of the cumulative length of human features to the length of the reach for human features *within the low surface* for all three drainages by reach type.

5.2 HUMAN FEATURES ALONG THE LOW SURFACE BOUNDARY

The highest numbers of human features per mile along the low surface boundary in all of the drainages are in confined ReacheT1 (5.3) and confined Reach M3 (4.8) (Figure P–26). The number of human features per mile are all ≤1.4 for the unconfined reaches and <1.0 for the moderately confined reaches.

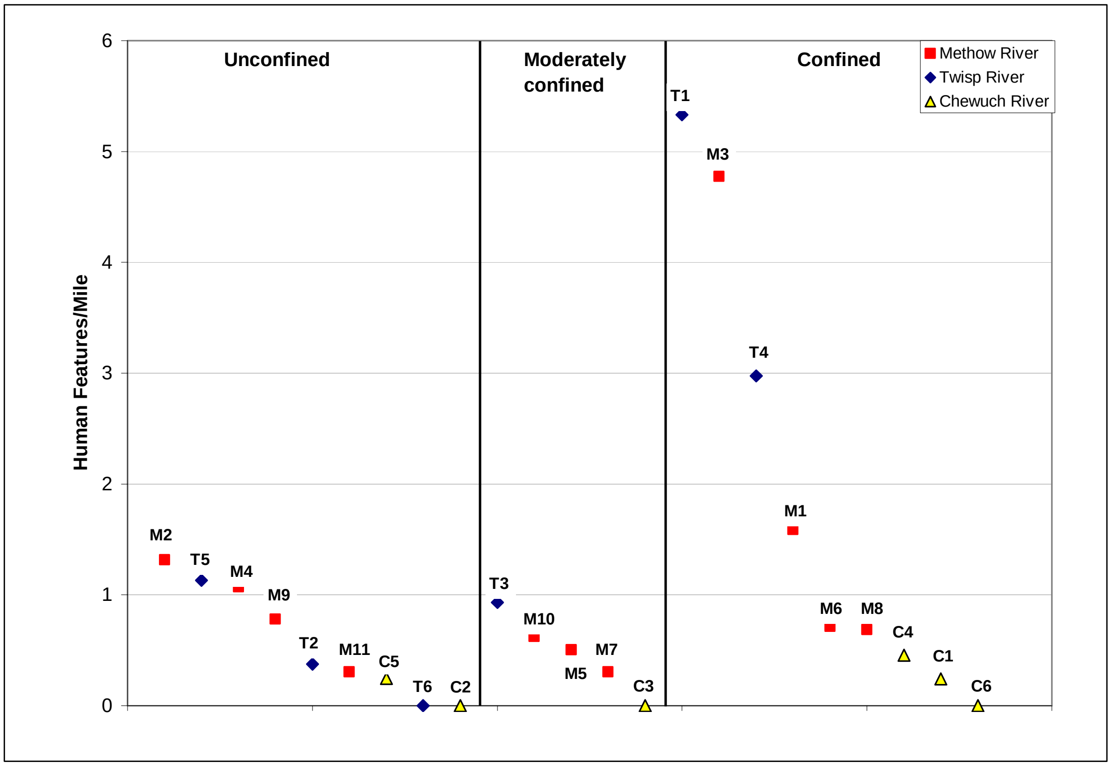

Figure P–26. Number of human features per mile along the low surface boundary for all three drainages by reach type.

The ratios of the cumulative length of the human features to the length of the reach for human features along the low surface boundary show a slightly different pattern (Figure P–27). The highest ratio is in the confined Reach M3 (0.61). The next highest values are in confined Reach M8 (0.4) and confined Reach T1 (0.33). The ratios for the unconfined reaches are all less than 0.25. The ratios for the moderately confined reaches are all less than 0.15.

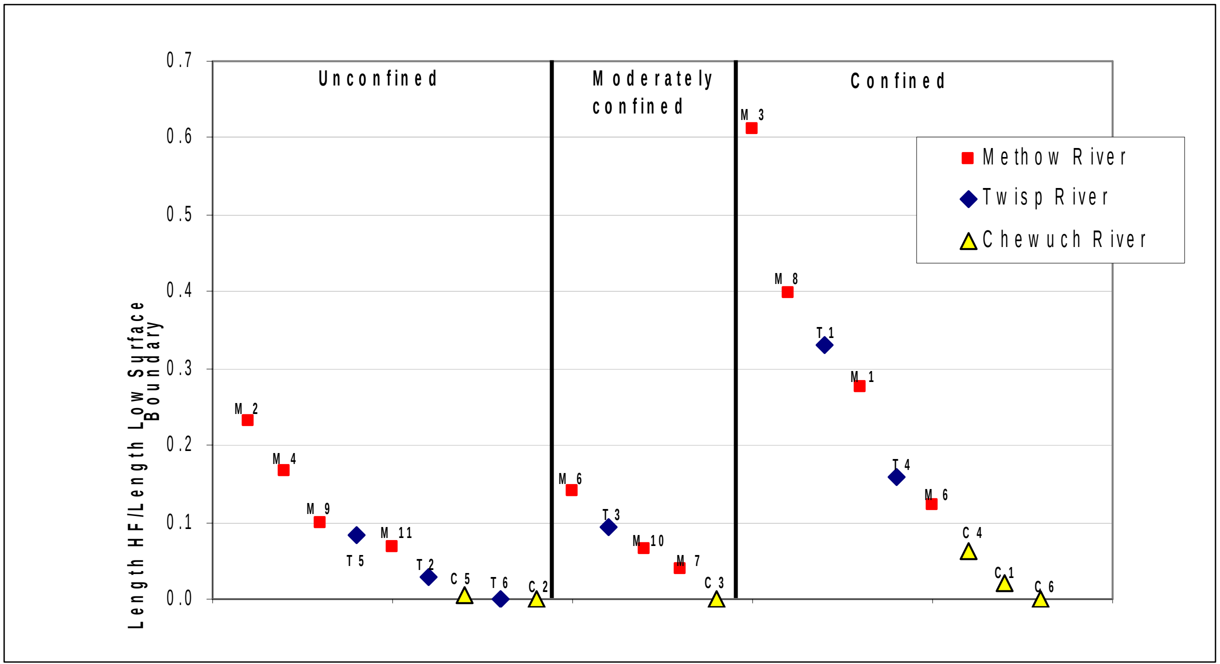

Figure P–27. Ratio of the cumulative length of human features to the length of the reach for human features along the low surface boundary for all three drainages by reach type.

APPENDIX Q –

GIS DATABASES

The GIS (Geographic Information System) data base was produced in support of the document, Methow Subbasin Geomorphic Assessment (Reclamation, 2008a), *or the "Geomorphic Assessment."*

The **MethowBOR2** *database includes three feature data sets: Geomorphology, Hydraulics, and Projects. Feature classes are listed below with a brief description of each. Geomorphology has 22 feature classes; Hydraulics has six feature classes; and Projects has four feature classes.*

The **MethowBOR_SurveyData** *database includes three feature data sets: Chewuch, Methow, and Twisp. The Chewuch data set includes five feature classes. The Methow data set includes five feature classes. The Twisp data set includes four feature classes.*

For more information or to request a copy of the GIS database (on DVD), contact Kristin Swoboda at the Reclamation's Pacific Northwest Regional Office, kswoboda@pn.usbr.gov.

CONTENTS

LIST OF FIGURES – There are no figures in this Appendix Q.

LIST OF TABLES – There are no tables in this Appendix Q.

1. METHOWBOR2 DATABASE

1.1 GEOMORPHOLOGY FEATURE DATA SET

1.1.1 Feature Class – BankLines

Title

Historical banks of unvegetated channels: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Historical unvegetated channels

Abstract

The lines show the locations of the banks of historical unvegetated channel for sections of the Methow River (RM 28–75), Twisp River (RM 0–18), and Chewuch River (RM 0–14.5). The banks represent the edges of the unvegetated channel as digitized by Lucy Piety (Reclamation, 2007a) using rectified historical aerial photographs (1945, 1948, 1954, 1964, 1974, 1994, and 2004 available for parts of the study area). The boundaries of islands within the active channel were also mapped and labeled as “island.” The banks are characterized by geomorphic reach, bank (left, right, or island), and year.

The purpose of mapping the banks of the historical unvegetated channels was to determine if the banks have changed position over time. The banks were used to identify areas of erosion along the edges of the unvegetated channels.

1.1.2 Feature Class – ChannelAreas

Title

Historical unvegetated channel areas: A polygon data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Historical unvegetated channels

Abstract

The polygons define the unvegetated channels in 1948 and 2004 for a section of the Methow River between RM 28–75. Channels were interpreted and digitized in ArcGIS™ (Reclamation 2007a) using rectified aerial photographs taken in 1948 and 2004. The channels are organized by geomorphic reach. The areas of each channel were calculated in ArcGIS™ for comparison.

The purpose of creating the polygons was to identify areas where the path of the unvegetated channel has changed between 1948 and 2004. The polygons were used to identify areas that were part of the channel in both years, areas where the unvegetated channel had expanded into vegetated areas (erosion), and areas that were abandoned by the unvegetated channel and, usually, revegetated. This analysis only shows long-term changes. Changes over shorter time intervals have occurred, but would require additional photographs to evaluate.

1.1.3 Feature Class – ChannelChangesGeology

Title

Historical channel changes and geology: A polygon data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Historical bank erosion, historical erosion of low surface, channel changes

Abstract

The polygons show the areas affected by historical changes in the location of the unvegetated channels for sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. The BankLines and ChannelChanges GIS files were used to develop these data. Additionally, the type of geologic unit was identified for areas of change from the GeologicUnits or an interpretation from historical aerial photographs. The change represents a comparison between two aerial photographs, but does not account for changes at intermediate time scales. Areas of the mapped polygons were calculated in ArcGIS™; the mapping was done by Reclamation (2007a).

The purpose was to identify areas that have had channel change and areas that have remained relatively stable. Additionally, for areas that have had change, the geologic unit was identified to determine if the change resulted in reworking of the active floodplain or erosion of the low surface boundary.

1.1.4 Feature Class – ChannelHistorical

Title

Historical channels: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Historical channels, low-flow channel, overflow channel, secondary channel, old channel, abandoned channel, slough, cutoff channel.

Abstract

The lines delineate the historical channels for sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. The centerline for each channel was mapped in ArcGIS™ using rectified historical aerial photographs and maps (Reclamation, 2007a). Maps date from 1893, 1897, 1900, 1907, and 1915. Historical aerial photographs date from 1945, 1948, 1954, 1964, 1974, 1994, and 2004. USGS topographic maps from the middle 1980s also were used. Coverage varies depending on the extent and availability of rectified maps and photographs. The low-flow channels were mapped on each historical photograph and map that was available. In addition, some secondary, overflow, and old (abandoned) channels were mapped, although this mapping is not complete for every year and geomorphic reach. The channels are characterized by type, year, and geomorphic reach.

The purpose of this mapping was to track historical changes in the location and planform of the low-flow channel, in particular, and in channel type (such as an active channel path that becomes an abandoned path in a later year). In addition, the locations of the channels were used to help define the extent of the low surface, which is the zone of channel migration and flooding during historical times.

1.1.5 Feature Class – ErodedLengths

Title

Lengths of Eroded Sections: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Unvegetated channel, historical changes, lengths of channel

Abstract

The lines show the sections affected by historical changes in the location of the unvegetated channels for sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. The BankLines, ChannelChanges, and ChannelAreas GIS files were used to develop these data. Additionally, the geologic unit was identified for sections where changes have occurred from the GeologicUnits or an interpretation from historical aerial photographs. The changes represent a comparison between two aerial photographs but do not account for changes at intermediate time scales. Lengths of the mapped lines were calculated in ArcGIS™, and the mapping was done by Reclamation (2007a). The mapped lengths are subdivided by geomorphic reach, time interval between the aerial photographs used, and bank (left or right looking downstream, island (bounding an island), or channel (eroded by an avulsion into a previously vegetated area).

The purpose was to estimate the lengths of the 2004 channel that have changed historically, and to compare these lengths among the geomorphic reaches.

This file was generated early in the study and was not revised for changes in the BankLines, ChannelChanges, or ChannelAreas files.

1.1.6 Feature Class – FloodArea

Title

Floodplain areas: A polygon data file digitized for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Floodplain, designated floodway, 100-year floodplain

Abstract

The polygons show the designated floodway and 100-year floodplain defined for a section of the Methow River between RM 28 (Carlton) and RM 68 (Mazama). The areas were digitized by Reclamation (2007a) from published reports (Beck, 1973; Norman, 1974). The units were digitized in ArcGIS™ using rectified aerial photographs taken in 1974, which are similar to the 1973 aerial photographs used in the publications. The designated floodway and 100-year floodplain were digitized by visually estimating the locations of the boundaries from paper copies of the original reports.

The purpose of digitizing the designated floodway and 100-year floodplain was to compare and contrast these boundaries with those of the low surface that is defined by Reclamation on the basis of geologic mapping, topography, and the locations of historical channels.

1.1.7 Feature Class – GeologicObservations

Title

Geologic observation points: A data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Geology, surface heights, channel constrictions, human features

Abstract

The points show geologic observations made along portions of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. Data are from two sources. One source is the geologic observations and estimates of surface heights above adjacent floodplain or channel that are reported in Golder (2005, Appendix C-2) and summarized by Ed Lyon (Pacific Northwest Regional Office, Boise, ID). These observations were digitized by Reclamation (2007a) using rectified color aerial photographs taken in 2004, and maps or descriptions in Golder (2005). Observations include channel constrictions (bedrock), human features (riprap, dike, and old bridge), and bank erosion. In some cases, the observations are for areas that are visible from the point, but are not actually at the point. The locations of these observations were adjusted, if the actual location could be estimated from statements in the report, topography, etc. Other observations also may be for areas near, but not at, the data point. Reported terrace heights were converted to feet.

The other source of data points and geologic observations is survey data collected by Reclamation (Ephrata Field Office, WA) in 2005. The survey points were collected with GPS and total station in a known datum, and observations that were recorded in survey notes. These observations include edge of terrace, terrace surface, and top of bar, etc. Surface heights were computed by Lucy Piety by subtracting the nearest measured thalweg elevation from the measured surface elevation. The heights are to the nearest foot.

Data points are listed by source, observation, surface height, and river mile.

The purpose of plotting these observations was to identify areas where the active channel or floodplain may be constrained by geology, and to note the surface heights, where information is available. The observations were used to refine and validate the locations of geomorphic reach boundaries. The surface heights were used to refine and validate the geologic map units.

1.1.8 Feature Class – GeologicUnits

Title

Geologic units: A polygon data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Geology, alluvial-fan deposits, bedrock, glacial deposits, intermediate surface, landslide, low surface

Abstract

The polygons show the geologic units along and adjacent to the channels along sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. The geologic map units include alluvial-fan deposits, bedrock, glacial deposits, intermediate surface (shown only in a few areas), landslides (includes all types of mass-movement deposits), and low surface. The geology units were mapped using paper copies of 1:12,000-scale, color aerial photographs taken in 2000. The mapping was done by Ed Lyon and Rob McAffee (Reclamation, 2007c) using stereo pairs. Some areas were checked in the field. The mapped units were digitized by hand using rectified color aerial photographs taken in 2004 and displayed in ArcGIS™ (Reclamation, 2007c). Some areas near potential project sites were mapped in more detail, and include an intermediate surface. Some geologic units, especially the low surface, were revised using historical aerial photographs and maps by Reclamation (2007a) (See <u>ChannelsHistorical</u>). The drainage and geomorphic reach are noted for the geologic units.

The purpose of the geologic mapping was to define the types of geologic deposits that are present along the river corridors, and to determine their extent. The most consideration was given to the delineation of the low surface, which includes present and historical main channels, side channels, and overflow channels.

1.1.9 Feature Class – GeologyLengths

Title

Geologic units along the low surface boundary: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Geology, low surface

Abstract

The lines show the geologic units that bound the geologic low surface for portions of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. (See Geologic Units.) Characteristics include the bank (left or right looking downstream), the geomorphic reach, and the approximate upstream and downstream river miles of each unit.

The purpose of subdividing the low surface boundary on the basis of geology was to determine the geologic units that bound the low surface, and the location and extent of each unit, in order to identify sections of the low surface boundary that may be constrained by geology, or that may be easily eroded.

1.1.10 Feature Class – GeologyPts

Title

Geology points: A data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Geology, bedrock, fault

Abstract

The points show the locations of observed exposed bedrock and faults along the channels and floodplains along portions of the Methow (RM 28–75), Twisp (RM 0.–18), and Chewuch (RM 0–14.5) rivers. Bedrock locations are from field observations by Reclamation (2007c) and by U.S. Forest Service personnel during pebble-count surveys. Fault locations are from published geologic maps (Dragovich et al.; 1995; Gulick and Korosec, 1990; McGroder et al.; 1990; Stoffel, 1990; and Stoffel et al., 1991). Data points were noted and mapped on 1:12,000-scale, color paper copies of aerial photographs taken in 2000 and examined in stereo and (or) from field observations. The points were digitized in ArcGIS™ using rectified color aerial photographs (not in stereo) taken in 2004 (Reclamation, 2007d). The channel bank (left or right looking downstream), the channel locations (channel), and the observation (bedrock or fault) are identified for each data point.

The purpose of compiling these observations was to identify areas where the location of the active channel and floodplain may be constrained or markedly influenced by geology.

1.1.11 Feature Class – HisHumanLines

Title

Historical human features: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Historical human features, road, ditch, wagon road, bridge, mill race, 1893, 1897, 1900, 1907

Abstract

The lines show historical human features around 1900. The linear features were digitized by Reclamation (2007a) from rectified Government Land Office (GLO) maps that were surveyed and published in 1893, 1897, 1900, and 1907. Scanned (electronic) versions of the GLO maps were obtained from the Bureau of Land Management (BLM, 2007). The electronic copies were geo-referenced to the USGS topographic maps in ArcGIS™ by Reclamation (2007a).

The area covered by the GLO maps is the Methow River between RM 28 and RM 67, the Twisp River between RM 0 and RM 1, and the Chewuch River between RM 0 and RM 8. The digitized features that are shown on the GLO maps are roads, ditches, bridges, wagon roads, and mill races.

The purpose of digitizing the linear human features on the GLO maps was to be able to compare and contrast human uses and disturbances over time by overlaying the features on later historical aerial photographs and maps. Present human features and historical channel positions were compared to the human features that are shown on the GLO maps.

1.1.12 Feature Class – HisHumanPts

Title

Historical human features: A point data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Historical human features, house, spring, post office, school, 1893, 1897, 1900, 1907

Abstract

The points show historical human features around 1900. Points were digitized by Reclamation (2007a) from rectified Government Land Office (GLO) maps that were surveyed and published in 1893, 1897, 1900, or 1907. Scanned (electronic) versions of the GLO maps were obtained from BLM (2006). The electronic copies were georeferenced to the USGS topographic maps in ArcGIS™ by Reclamation (2007a).

The area covered by the GLO maps is the Methow River between RM 34 and RM 66, the Twisp River between RM 0 and RM 1, and the Chewuch River between RM 0 the RM 8. The digitized features that are shown on the GLO maps are houses, springs, post offices, schoolhouses, and sawmills.

The purpose of digitizing the points was to compare the locations of historical human disturbances with other historical aerial photographs and maps, later human features, and historical channel positions.

1.1.13 Feature Class – Human_Development

Title

Human disturbance within low surface: A polygon data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Human disturbance, buildings, clearing, low surface

Abstract

The polygons delineate areas within the low surface that have significant human disturbance for sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. Areas that have buildings or that have been cleared of natural vegetation were mapped by Reclamation (2007a) on rectified color aerial photographs taken in 2004. The mapped areas were limited to the extent of the geologic low surface.

The purpose of mapping these areas was to identify areas of the low surface that have been significantly impacted by human activities, either construction or clearing.

1.1.14 Feature Class – HumanFeatures

Title

Human features: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Human features, levee, riprap, bridge, push-up levee, Detroit riprap, cabled logs, dam, diversion, headgate, log structure, filled channel, gabion, footbridge, road, embankment, low surface

Abstract

The lines show the location and type of linear human features within and adjacent to the geologic low surface along section of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. The human features were compiled from Golder (2005) and Okanogan County (1996) by MacAfee (Reclamation, 2007d) and these sources are cited. Human features without a cited source were identified on aerial photographs (stereo paper copies of 1:12,000-scale, color photographs taken in 2000) or in the field and plotted on the aerial photographs. Most of this mapping was done by Lyon and MacAfee (Reclamation 2007c). The human features were then digitized in ArcGIS™ (Reclamation, 2007d) from the paper maps using rectified aerial photographs taken in 2004, primarily, and some historical aerial photographs. Additional human features were mapped by Reclamation (2007a) using the rectified aerial photographs.

Human features are characterized by type (such as riprap, levee, and bridge), by geomorphic reach, by upstream and downstream river mile, by location relative to the geologic low surface (along its edge, within, or across (a bridge), by bank (left or right looking downstream) if the human feature is along the edge of or within the low surface (bank relative to the 2004 active channel), and whether the feature limits the width of the geologic low surface (Reclamation, 2007a).

The purpose of this mapping was to identify as many of the human features within and adjacent to the low surface as possible using aerial photographs primarily and some additional field observations. This compilation also assesses the impact of each human feature on the geologic low surface, such as limiting channel migration or floodplain area.

References

Golder, 2005; Okanogan County, 1996; Reclamation 2007a, 2007b, 2007c, and 2007d.

1.1.15 Feature Class – LowSurfaceBoundary

Title

Low surface boundary and geology: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Low surface, erosion, geology

Abstract

The lines show the extent of the low surface for sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. The low surface includes present and historical main channels, side channels, and overflow channels. The boundaries are organized by geomorphic reach.

1.1.16 Feature Class – LowSurfaceWidths

Title

Low surface widths: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Low surface, pre-development width, present width

Abstract

The lines show the widths of the geologic low surface for sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. Lines were drawn across the low surface about every tenth of a mile (Reclamation, 2007a). The lines were oriented as much as possible perpendicular to the centerline of the low surface. Lines that represent the present widths as confined by human features were also drawn. The lengths of the mapped lines were calculated in ArcGIS™.

The purpose of measuring these widths was to compare and contrast the geologic and present widths of the low surface in order to determine which sections of the geomorphic reaches have been most impacted by human features.

1.1.17 Feature Class – MethowTempMonitoring_Loc

Title

MethowTempMonitoring_Loc

Keywords

Abstract

This file represents the locations of 28 temperature monitors placed along the mainstem Methow River (RM 0–75) by the USFS. A total of 40 temperature monitors were deployed throughout the Methow River and in major tributaries to the Methow River in the summer of 2005. The monitors were deployed during the last week in June and retrieved at the beginning of October. The monitors were tested and calibrated before deployment. The monitors were set to record the water temperature every hour. The monitors were placed in deep riffles, and checked in mid summer to ensure that they were still under water.

1.1.18 Feature Class – MethowUSGSquadcontours

Title

MethowUSGSquadcontours

Keywords

Abstract

This file was created to compute centerline distances between USGS Quad contour lines that crossed the mainstem Methow River between RM 0–28. The purpose of this data was to extend a longitudinal profile plot of channel elevation to compute the average slope between RM 0–28. Channel survey data was collected by GPS for RM 28–76, and so the USGS Quad contours were only used for the lower portion of the Methow River where ground survey data was not available. The U.S. contour field documents the contour crossing at the upstream end of each line segment in NGVD 1929 feet datum. The second elevation column documents the same contour elevation converted to NAVD 1988 feet datum.

1.1.19 Feature Class – Reach Boundaries

Title

Geomorphic reach boundaries: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Geomorphic reach boundary, subreach boundary, reach, river mile

Abstract

The lines show the boundaries of the geomorphic reaches identified along sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. The boundaries were drawn to designate a change in reach-level geomorphic characteristics of the river. The geomorphic characteristics that define each boundary are noted. Two types of boundaries are mapped. One is reach boundaries, which are defined by a geomorphic change. Most of the boundaries are reach boundaries. The other is a few subreach boundaries, which are defined by local geologic features that influence river characteristics and geomorphology. The geomorphic reach designation and river mile are shown for each reach and subreach boundary.

1.1.20 Feature Class – RechargeAreas

Title

Recharge areas: A point data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Springs, Gilbertson Springs, Hancock Springs, Suspension Creek, Eagle Creek, Wolf Creek, Eightmile Creek, Falls Creek, beaver ponds

Abstract

The points show the locations of springs and recharge areas for sections of the Methow (RM 28–75), Twisp (RM 0 to upstream of RM 18), and Chewuch (RM 0–14.5) rivers. The points on the Methow River are from observations by Dave

Hopkins (U.S. Forest Service, Winthrop, WA) during stream temperature monitoring. The points were digitized in ArcGIS™ (Reclamation, 2007d). The points on the Twisp River are from a GIS file provided by Pacific Watershed Institute (PWI, 2003) that was based on field observations and FLIR data. The points on the Chewuch River are from a water temperature analysis by Pacific Watershed Institute that included field observations and FLIR data. The points were generated in ArcGIS™ (Reclamation, 2006a).

The purpose of creating this point file was to document areas where groundwater is being added to the river system. Once in ArcGIS™ the locations can be used with other GIS data.

Reference

PWI, 2003.

1.1.21 Feature Class – RiverMiles

Title

River miles: A point data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

River miles

Abstract

The points show river miles for the active channel along sections of the Methow (RM 28–75), Twisp (RM 0–18), and Chewuch (RM 0–14.5) rivers. River miles for the Methow River are based on the 1998 channel as provided by Golder (2005). The river miles for the Twisp and Chewuch Rivers are based on the 1998 and 2004 channels as digitized by using rectified aerial photographs taken in those years (Reclamation, 2006a). Both the 1998 and 2004 channels were used because the 2004 photographs were not obtained for the entire study area during the initial phase of the study.

Reference

Golder, 2005.

1.1.22 Feature Class – TribChannels

Title

Historical tributary channels: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Historical tributary channels, Beaver Creek, Benson Creek, Boulder Creek, Cook Canyon Creek, Fawn Creek, Goat Creek, Lake Creek, McClure Creek, Pete Creek, Puckett Creek, Texas Creek, Wolf Creek, 1893, 1897, 1900, 1907

Abstract

The lines show the location of the downstream sections of tributary channels about 1900. The channels were digitized by Lucy Piety (Reclamation, 2007a) from rectified Government Land Office (GLO) maps that were surveyed and published in 1893, 1897, 1900, and 1907. Scanned (electronic) versions of the GLO maps were provided by BLM (2006). The electronic copies were rectified to the USGS topographic maps (Reclamation, 2007a).

Tributaries are shown on the maps for the Methow River between RM 28 and RM 67 and for the Chewuch River between RM 0 and RM 5.5.

The purpose of digitizing the tributaries was to determine if any significant changes in the locations of these channels had occurred between about 1900 and 1948 to 2004, the time interval covered by the historical aerial photographs. Changes in the tributaries might influence or show changes on the mainstems of the study rivers, because some tributaries share channel pathways with the mainstem channels.

1.1.23 Feature Class – Vegetation

Title

Vegetation: A polygon data file created by a contractor for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Vegetation, black cottonwood, deciduous shrubs, quaking aspen, mixed coniferous/deciduous, shrub steppe, upland forest, agricultural areas, residential areas, cut bank, road, channel

Abstract

The polygons show the distribution of vegetation types along and adjacent to the river corridor for sections of the Methow (RM 28–75) and Chewuch (RM 0–10.5) rivers. The vegetation units were mapped by Heike (2005) under a contract for Reclamation. Vegetation map units are shown by a designation code. The area of each polygonal unit was calculated by Arc.

The purpose in mapping the vegetation was to determine the distribution of different vegetation types along the river corridor.

Reference

Baesecke, 2005a.

1.2 HYDRAULICS FEATURE DATA SET

1.2.1 Feature Class – ChewuchXSCutline_FINAL

Abstract

This file represents the alignments of cross-sections along the Chewuch River (RM 0–14) that were generated for the purpose of making hydraulic and sediment computations for the Geomorphic Assessment (Reclamation, 2008a). Resulting station-elevation data along the cross-section alignments are documented in Excel™ files. The survey data (collected in 2006) used to develop the station-elevation data are documented in separate GIS files.

1.2.2 Feature Class – Chewuch_XS_PebbleCtSites_RM0to14

Abstract

Survey request for locations of cross-section lines that were surveyed in fall 2005 along the Chewuch River between RM 0–14. The naming convention of the cross-section also correlates to pebble count data collected at or near the cross-section lines in fall of 2005.

1.2.3 Feature Class – ChewuchXSPointsXYZ_FINAL

Abstract

This file represents points used to generate station-elevation data along the alignments of cross-sections on the Chewuch River (RM 0–14) that were generated for the purpose of making hydraulic and sediment computations for the Geomorphic Assessment (Reclamation, 2008a). Resulting station-elevation data along the cross-section alignments are documented in Excel™ files. The survey data presented in this file was snapped to the cross-section lines within a given tolerance. The original survey data (mostly collected in 2006) used to develop the station-elevation data are documented in separate GIS files.

1.2.4 Feature Class – MethowXSCutline_FINAL

Abstract

This file represents the alignments of cross-sections on the Methow River (RM 26–75) that were generated for the purpose of making hydraulic and sediment computations for the Geomorphic Assessment (Reclamation, 2008a). Resulting station-elevation data along the cross-section alignments are documented in Excel™ files. The survey data (collected in 2006) used to develop the station-elevation data are documented in separate GIS files.

1.2.5 Feature Class – Methow_XS_PebbleCtSites_RM27to67

Abstract

Approximate locations of cross-section lines that were surveyed in fall 2005 along the Methow River between RM 26–67. The naming convention of the cross-section also correlates to pebble count data collected at or near the cross-section lines in fall of 2005.

1.2.6 Feature Class – Methow_XS_PebbleCtSites_RM67to75

Abstract

Approximate locations of original request for cross-section lines that were to be surveyed in fall 2005 along the Methow River between RM 67–75. Note that GPS did not work in this section of the Methow River, and actual survey data locations of cross-sections were changed in the field to accommodate use of total station equipment and land permission constraints (see survey data GIS file). The original naming convention of the cross-section request also correlates to pebble count data collected at or near the cross-section lines in fall of 2005.

1.2.7 Feature Class – MethowXSPointsXYZ_FINAL

Abstract

This file represents points used to generate station-elevation data along the alignments of cross-sections on the Methow River (RM 26–75) that were generated for the purpose of making hydraulic and sediment computations for the Geomorphic Assessment (Reclamation, 2008a). Resulting station-elevation data along the cross-section alignments are documented in Excel™ files. The survey data presented in this file was snapped to the cross-section lines within a given tolerance. The original survey data (mostly collected in 2006) used to develop the station-elevation data are documented in separate GIS files.

1.2.8 Feature Class – TwispXSCutline_FINAL

Abstract

This file represents the alignments of cross-sections along the Twisp River (RM 0–17) that were generated for the purpose of making hydraulic and sediment computations for the Geomorphic Assessment (Reclamation, 2008a). Resulting station-elevation data along the cross-section alignments are documented in Excel™ files. The survey data (collected in 2006) used to develop the station-elevation data are documented in separate GIS files.

1.2.9 Feature Class – Twisp_XS_PebbleCtSites_RM0to17

Abstract

Approximate locations of cross-section lines that were surveyed in fall 2005 along the Twisp River between RM 0–17. The naming convention of the cross-section also correlates to pebble count data collected at or near the cross-section lines in fall of 2005.

1.2.10 Feature Class – TwispXSPointsXYZ_FINAL

Abstract

This file represents points used to generate station-elevation data along the alignments of cross-sections on the Twisp River (RM 0–17) that were generated for the purpose of making hydraulic and sediment computations for the Geomorphic Assessment (Reclamation, 2008a). Resulting station-elevation data along the cross-section alignments are documented in Excel™ files. The survey data presented in this file was snapped to the cross-section lines within a given tolerance. The original survey data (collected in 2006) used to develop the station-elevation data are documented in separate GIS files.

1.2.11 Feature Class – Twisp_XS_PebbleCtSites_RM0to17

Abstract

Approximate locations of cross-section lines that were surveyed in fall 2005 along the Twisp River between RM–17. The naming convention of the cross-section also correlates to pebble count data collected at or near the cross-section lines in fall of 2005.

1.3 PROJECTS FEATURE DATA SET

1.3.1 Feature Class – Project_Areas

Title

Potential project areas: A polygon data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Preservation, project, project area, restoration

Abstract

The polygons define project areas delineated for the Methow River study area, including the Methow River between RM 27–75, the Twisp River between RM 0–18, and the Chewuch River between RM 0–14.5. Areas were interpreted by Piety and Bountry (Reclamation, 2006b) and were digitized in ArcGIS™ using rectified aerial photographs taken in 2004 (Reclamation, 2007a). The purpose of creating the polygons was to identify reaches where preservation or restoration projects may be present. One or more projects may be present within each area shown by the polygons.

1.3.2 Feature Class – Project_Channels

Title

Potential project channels: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Channels, projects, channel history, channel definition

Abstract

The lines define potential project channels, ones that could be reconnected as part of restoration projects on the Methow River between RM 28–75, on the Twisp River between RM 0–18, and on the Chewuch River between RM 0–14.5. The majority of channels were interpreted and digitized in ArcGIS™ (Reclamation, 2007a) using rectified aerial photographs taken in 2004. Additional channels were interpolated using 2006 LiDAR where channels could not be detected from aerial photography in densely vegetated areas. The purpose of creating the lines was to identify channels that no longer appear to be active because of human features or activities, but could be reconnected to the main channel as potential projects.

The history of the channels as interpreted from historical aerial photographs is listed with the following abbreviations: **AB**, abandoned; **OF**, overflow channel; **POF**, possible overflow channel; **PSC,** possible side channel; **SC,** side channel, and **UV**, unvegetated or active channel. Definition refers to how well the channel is defined as interpreted from its expression on the aerial photographs. Definition is listed as a number between 1 and 4, with 1 being the poorest defined and 4 being the best defined.

1.3.3 Feature Class – Project_Points

Title

Points Indicating the Upstream Ends of Potential Project Areas: A point data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Potential project areas, project type, river-mile extent

Abstract

The points indicate the upstream ends of potential project areas, and show the upstream and downstream river miles of the project area, the type of project(s) that might be included in the area, the process-based reach, and the number of potential channel projects included. The points were digitized at the upstream end of each project reach in ArcGIS™ using the delineated potential project areas (Reclamation, 2007a).

The types of projects are the main type for the project area and are 1) preservation and monitoring, 2) restoration, 3) restoration but largely developed with human features, and 4) existing projects (shown by name). The priority column shows a number designation for each of these types, so that the information could be plotted.

1.3.4 Feature Class – Project_Points_Channels

Title

Points Indicating the Upstream Ends of Potential Project Channels: A line data file created for the Geomorphic Assessment (Reclamation, 2008a).

Keywords

Potential project channels, project type, river-mile extent

Abstract

The points indicate the upstream ends of potential project channels, and show the approximate upstream and downstream river miles of the project channel, the type of project(s) that might be included, the process-based reach, and the number of potential channels included. The points were digitized at the upstream end of each potential project channel in ArcGIS™ by using the delineated channels (Reclamation, 2007a).

The types of projects are the main type for the channel and are 1) channel preservation and monitoring, 2) channel reconnection, and 3) channel reconnection but largely developed with human features. The priority column shows a number designation for each of these types, so that the information could be plotted.

2. METHOWBOR_SURVEYDATA DATABASE

2.1 CHEWUCH DATA SET

2.1.1 Feature Class – Chewuch_Profile_RM8to14

Abstract

Chewuch River survey of channel bottom and water surface data collected in August 2005. Data contains longitudinal profile data from RM 8–14.

2.1.2 Feature Class – Chewuch_RM0to14_XS_Prof_Original

Abstract

Chewuch River survey of channel bottom and water surface data collected in November 2005. Data contains longitudinal profile data from RM 0–2 (November 11) and cross-section data between river miles 0–14 (November 9, and 16-18).

2.1.3 Feature Class – Chewuch_RM2to8_Profile_Original

Abstract

Chewuch River survey of water surface data collected in August 2005 by boat and GPS survey equipment. Data contains longitudinal profile data from RM 2–8.

2.1.4 Feature Class – Chewuch_WS_CBProf_2to8_Centerline

Abstract

Processed GIS Data. Longitudinal profile points along 10-foot spacings created by TSC GIS group along centerline of Chewuch River using survey of water surface data collected in August 2005 by BOR. Data contains longitudinal profile data from RM 2–8.

2.1.5 Feature Class – Chewuch_WS_CBProf_RM0to14_Final

Abstract

Generated longitudinal profile of Chewuch River channel bottom and water surface elevation from RM 0–14. Surveyed data points were selected by hand picking data points in GIS to be used in profile, and then computing a distance between points in Excel™. Survey points were collected in August and October of 2005.

2.2 METHOW DATA SET

2.2.1 Feature Class – Methow_June2005_WSProfile_RM21to68

Abstract

Methow River survey of water surface profile collected on June 15 and 16 2005 from RM 21 (Carlton) to RM 67 (Mazama). Survey method was GPS on boat.

Depth soundings were collected separately with Innergraph depth sounder, and added to water surface data using a GIS routine.

2.2.2 Feature Class – Methow_WS_CBProf_Centerline_RM21to68

Abstract

Processed GIS Data. Longitudinal profile points of water surface and channel bottom along 10foot spacings created by TSC GIS group along centerline of Methow River using survey of water surface data collected in June 2005 by Reclamation. Data contains longitudinal profile data from RM 21–67.

2.2.3 Feature Class – Methow_WS_CBProf_RM21to76_Centerline

Abstract

Longitudinal profile of Methow River channel bottom and water surface elevation from RM 21–76. Surveyed data points were selected by hand picking data points in GIS to be used in profile for RM 67–76, and using a GIS program to select points along centerline from RM 21–67, and then computing a distance between points in Excel™. Survey points were collected in June 15 and 16 of 2005 for RM 21–67, and from Aug 23 to Sept 16 of 2005 for RM 67–76. River miles are based on longitudinal spacing between profile points, and are different (longer) than river miles from 1998 or 2004 aerial photography centerline distance.

2.2.4 Feature Class – Methow_XS_OctNov2005_RM26to67

Abstract

Methow River Cross-Section Survey from Carlton to Mazama, or 2004 RM 26–67. Data collected in October and November and 2005 by private contractor with GPS and total station survey equipment. Includes underwater data in river channel done by wading.

2.2.5 Feature Class – Methow_XS_Profile_RM67to73

Abstract

Methow River survey of channel bottom and water surface profile and cross-section data collected in August and September 2005 from RM 67 (Mazama) to 73 (Lost River). Survey method was GPS and total station, river sections were waded.

2.3 TWISP DATA SET

2.3.1 Feature Class – Twisp_Profile_Points_RM0to17

Abstract

Generated longitudinal profile of Twisp River channel bottom and water surface elevation from RM 0–17. Surveyed data points were selected by hand picking data points in GIS to be used in profile, and then computing a distance between points in Excel™. Survey points were collected in September and November of 2005.

2.3.2 Feature Class – Twisp_Profile_RM0to6

Abstract

Twisp River longitudinal profile survey of channel bottom and water surface data collected in November 16, 2005.

2.3.3 Feature Class – Twisp_XS_Profile_RM6to17

Abstract

Twisp River survey of channel bottom and water surface data collected in September 9 to 27, 2005 and November 3 to 11, 2005. Data contains cross section and longitudinal profile data from RM 6–17.

2.3.4 Feature Class – Twisp_XSData_RM0to6

Abstract

Twisp River cross section survey data collected in October 27 to 29, 2005.

3. REFERENCES

IN TEXT	FULL CITATION
Baesecke 2005a	Baesecke, H. 2005a. GIS mapping and report on documentation of findings from aerial photo delineations. Prepared for Bureau of Reclamation by Geosis Consulting. Unpublished report.
Beck 1973	R.W. Beck and Associates. 1973. *Flood plain information, Methow River, Twisp to Mazama, Okanogan County, Washington:* R.W. Beck and Associates, Analytical and Consulting Engineers, Seattle, WA. Report prepared for Washington Department of Ecology, Olympia, WA. 13 p., 20 figures.
BLM 2006	Bureau of Land Management. 2006. Oregon/Washington State Office; Division of Resource Planning, Use and Protection; Lands, Realty and Minerals Group. Telephone 503-808-6008. http://www.blm.gov/or/contacts_list.php (as of 10/16/07).
Dragovich et al. 1995	Dragovich, J., Norman, D., and McClelland, W. 1995. *Geologic map of the west half of the Twisp* 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 95-3, 1 plate, 63 p.
Golder 2005	Golder Associates, Inc. 2005. *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.
Gulick and Korsec 1990	Gulick, C., and Korosec, M. 1990. *Geologic map of the Omak* 1:100,000 quadrangle, Washington Division of Geology and Earth Resources Open File Report 90-12, 1 plate, 52 p.
McGroder et al. 1990	McGroder, M. 1988. *Structural evolution of the eastern Cascades fold belt – Implications for late Mesozoic accretionary tectonics in the Pacific Northwest*. University of Washington, Seattle, WA. Doctor of Philosophy thesis, 140 p.

IN TEXT	FULL CITATION
Norman 1974	Norman Associates. 1974. *Flood plain information, Methow River, Twisp to Carlton, Okanogan County, Washington.* Report prepared for County of Okanogan Office of Planning and Development, Okanogan, WA, by Norman Associates Consulting Engineers, Bellevue, WA, 12 p., 10 figures.
Okanogan County 1996	County of Okanogan Office of Planning and Development, Okanogan County. 1996. *Draft multi-objective river corridor plan for the Methow Basin*. Okanogan, WA.
PWI 2003	Pacific Watershed Institute. 2003. *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.
Reclamation 2006a	Bureau of Reclamation. 2006a. Work performed by Jennifer Bountry, Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, CO.
Reclamation 2006b	Bureau of Reclamation. 2006b. Work performed by Lucy Piety, Technical Service Center, Seismotechtonics and Geophysics Group (M/S 86-68330) and Jennifer Bountry, Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68540) , Denver, CO.
Reclamation 2007a	Bureau of Reclamation. 2007a. Lucy Piety, Technical Service Center Seismotechtonics and Geophysics Group (M/S 86-68330), Denver, CO.
Reclamation 2007b	Bureau of Reclamation. 2007b. Ed Lyon, Pacific Northwest Regional Office Geology, Exploration, and Instrumentation Group (M/S PN-3600), Boise, ID.
Reclamation 2007c	Bureau of Reclamation. 2007c. Ed Lyon and Rob McAffee, Pacific Northwest Regional Office Geology, Exploration and Instrumentation Group (M/S PN-3600), Boise, ID.

IN TEXT	FULL CITATION
Reclamation 2007d	Bureau of Reclamation. 2007c. Work performed by Rob McAffee, Pacific Northwest Regional Office, Geology, Exploration and Instrumentation Group (M/S PN-3600), Boise, ID.
Reclamation 2008a	Bureau of Reclamation. 2008a. *Methow Subbasin Geomorphic Assessment*. February 2008. Prepared by Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, CO in cooperation with Pacific Northwest Regional Office, Boise, ID and Methow Field Station, Winthrop, WA.
Stoffel 1990	Stoffel, K. 1990. *Geologic map of the Oroville* 1:100,000 quadrangle. Washington Division of Geology and Earth Resources Open File Report 90-11, 1 plate, 58 p.
Stoffel et al. 1991	Stoffel, K.L., Joseph, N.L., Waggoner, S.Z., Gulick, C.W., Korosec, M.A., and Bunning, B.B. 1991. *Geologic Map of Washington – Northeast Quadrant*. Washington Division of Geology and Earth Resources, Geologic Map GM-39.

APPENDIX R –

TECHNICAL RANKING OF RESTORATION SITES BASED ON DEGREE OF DEPARTURE FROM NATURAL CONDITIONS

This appendix provides a technical ranking of the types and extent of disturbance to channel and floodplain processes in each of the restoration areas. The intent of this information is to provide an initial perspective on the level of effort (feasibility) needed to implement restoration concepts. This information may be useful in developing future scopes of work and in planning efforts.

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LIST OF FIGURES

There are no figures in this Appendix R.

LIST OF TABLES

1. INTRODUCTION

Following the completion of this 80-mile assessment, smaller reaches of river will be selected to focus in and develop an implementation strategy for restoration. Although each reach has similar geomorphic processes in place, the degree of departure from the natural setting varies throughout the reach. The variance depends on the extent and type of human features presently in place, and past human activities such as channel filling and clearing of LWD. The information in this appendix was developed to help subsequent assessment teams understand the degree of departure for each potential project area. Although the information will need to be field-checked and refined, this appendix is meant to provide an initial perspective on the level of effort (feasibility) needed to implement restoration concepts.

The ranking was based on a combination of quantitative mapping and professional judgment of the assessment team following completion of the geomorphic analysis presented in other sections of this report. Seven categories were used. Five categories incorporate the geomorphic potential and effort it would take to restore processes. The remaining two categories incorporate the floodplain and channel length of the project areas.

For each of the seven categories, the projects were given a number of **5** (the highest or best ranking) to **1** (the lowest or worst ranking). Averaging of the ranking values was computed for each project area in several ways:

1) averaging all seven categories (A to G);
2) averaging all categories except floodplain area and channel length (A, D, E, F, and G);
3) Average of Channel Definition and Human Features (“Effort”);
4) Average of Floodplain Area and Channel Length (“Project Size”).

The size of the project could be an important analysis factor, but the separate computations allow a comparison based only on geomorphic criteria if desired. The criteria used to evaluate the projects in each category are shown in Table R–1, followed by a detailed methodology for each of the seven categories. The results of the ranking are provided in Table R–2.

Table R–1. Criteria used to rank potential restoration project areas.

(**5** = highest or best**; 1 =** lowest or worst**)**

Rank	**A. Geomorphic Potential**	**B. Flood-plain area** (acres)	**C. Channel length** (miles)	**D. Channel and floodplain definition** (degree of disturbance, except clearing)	**E. Degree of incision** (relative to re-watering of floodplain)	**F. Vege-tation** (percent cleared)	**G. Feasibility of addressing human features and land use to restore processes** (includes the number, type, location, and significance of features**)**
5	Full restoration of wetland or network area	>200	> 2	Most of channel length or wetland area appears to be intact, except for upstream **OR** downstream connections	Low to none (undetectable)	<10	Channel not blocked or only partially blocked by an older, non-designed structure; no houses/buildings; site may include some riprap, but no major human feature; site has one or two features
4	Partial restoration of wetland or network area	100–200	1 to 2	Most of channel length or wetland area appears to be intact, except for upstream **AND** downstream connections for a channel and <25% of an area	Slight to moderate (1 to 2 D_{50} particle diameters)	11-25	Levee or fill at upstream **OR** downstream end of a channel, but no houses/buildings; site may have levees or riprap at one to three
3	Primary side or secondary side channel with floodplain reconnection	50–100	0.5 to 1	Less than half of channel length (25 to 50%) appears to have been filled and would need to be re-excavated, or 25 to 50% of an area has been disturbed	Moderate (2 to 3 D_{50} particle diameters)	26-50	Levee or fill at upstream **AND** downstream end of a channel; only one or two houses/buildings, and these are not in locations that are critical to project completion; site may have levee or riprap at several locations
2	Primary side or secondary side channel with partial or little floodplain reconnection	25–50	0.25 to 0.5	More than half of channel length (50 to 75 %) appears to have been filled and would need to be re-excavated, 50 to 75% of an area has been disturbed	Moderate to severe (3 to 5 D_{50} particle diameters)	51-75	Levee or fill at upstream **AND** downstream end of a channel; site includes houses/buildings/minor roads in several locations
1	Overflow channel or low surface (floodplain)	0–25	0 to 0.25	Most of channel length (>75 %) appears to have been filled and would need to be re-excavated, area has no visible/mapped channel, or >75% of an area has been disturbed	Severe (Greater than 5 D_{50} particle diameters)	>75	Numerous human features of any type; features are usually in scattered locations throughout the area; sites may include human features that are significant (e.g., a highway)

Table R–2. Ratings for the seven ranking categories and four summaries of ranking alternatives.

Potential restoration projects are listed in groupings with similar restoration potential.

Project Designation	Rank by							Average of			
	Restoration Potential	Floodplain Area	Channel Length	Channel Definition	Degree of Incision	Cleared Area	Human Features	All 7 Categories (of "Rank)	Five Categories (no area or channel length)	Channel Definition and Human Features ("Effort")	Floodplain Area and Channel Length ("Metric")
CR_Prj-10.1	5	1	1	5	4	4	4	3.4	4.4	4.5	1.0
CR_Prj-10.2	5	1	1	5	4	5	4	3.6	4.6	4.5	1.0
MR_Prj-56.5	5	4	5	4	5	4	5	4.6	4.6	4.5	4.5
MR_Prj-62.9	5	3	4	5	4	5	5	4.4	4.8	5.0	3.5
TR_Prj-12.6	5	1	1	4	5	3	5	3.4	4.4	4.5	1.0
TR_Prj-13.5	5	1	1	5	5	5	5	3.9	5.0	5.0	1.0
TR_Prj-15.2	5	1	1	5	5	5	5	3.9	5.0	5.0	1.0
TR_Prj-15.9	5	2	2	4	5	4	4	3.7	4.4	4.0	2.0
TR_Prj-17.1	5	2	1	5	5	5	5	4.0	5.0	5.0	1.5
TR_Prj-4.95	5	1	1	2	4	1	5	2.7	3.4	3.5	1.0
CR_Prj-10.4L	4	1	1	3	4	1	2	2.3	2.8	2.5	1.0
CR_Prj-10.4R	4	1	1	5	4	3	3	3.0	3.8	4.0	1.0
MR_Prj-39.9	4	2	3	4	3	2	3	3.0	3.2	3.5	2.5
MR_Prj-44.4	4	5	5	3	3	2	4	3.7	3.2	3.5	5.0
MR_Prj-60.25	4	4	1	4	5	5	2	3.6	4.0	3.0	2.5
MR_Prj-63.7	4	3	4	4	4	5	2	3.7	3.8	3.0	3.5
MR_Prj-64.4	4	3	4	4	4	5	4	4.0	4.2	4.0	3.5
MR_Prj-65.2	4	3	4	4	4	5	4	4.0	4.2	4.0	3.5
MR_Prj-74.15	4	5	3	3	5	4	1	3.6	3.4	2.0	4.0
TR_Prj-10.63	4	1	1	4	5	3	2	2.9	3.6	3.0	1.0
TR_Prj-11.25	4	2	1	3	5	3	2	2.9	3.4	2.5	1.5

Project Designation	Rank by							Average of			
	Restoration Potential	Floodplain Area	Channel Length	Channel Definition	Degree of Incision	Cleared Area	Human Features	All 7 Categories (of "Rank")	Five Categories (no area or channel length)	Channel Definition and Human Features ("Effort")	Floodplain Area and Channel Length ("Metric")
TR_Prj-16.1	4	2	1	4	5	4	1	3.0	3.6	2.5	1.5
TR_Prj-3.3	4	4	5	3	4	2	2	3.4	3.0	2.5	4.5
TR_Prj-4.9	4	2	4	3	4	3	3	3.3	3.4	3.0	3.0
CR_Prj-12.15	3	1	1	5	4	4	5	3.3	4.2	5.0	1.0
CR_Prj-12.8	3	2	3	4	4	5	5	3.7	4.2	4.5	2.5
CR_Prj-13.3	3	1	1	1	4	5	5	2.9	3.6	3.0	1.0
CR_Prj-6.45	3	4	4	5	4	5	4	4.1	4.2	4.5	4.0
CR_Prj-7.2	3	2	2	5	4	5	4	3.6	4.2	4.5	2.0
CR_Prj-7.3	3	1	2	4	4	5	2	3.0	3.6	3.0	1.5
MR_Prj-35.5	3	4	4	4	3	5	3	3.7	3.6	3.5	4.0
MR_Prj-37.1	3	2	4	5	3	3	4	3.4	3.6	4.5	3.0
MR_Prj-49.1	3	1	2	4	3	5	4	3.1	3.8	4.0	1.5
MR_Prj-49.2	3	1	2	4	3	2	4	2.7	3.2	4.0	1.5
MR_Prj-49.65	3	1	2	4	3	4	3	2.9	3.4	3.5	1.5
MR_Prj-66.75	3	3	4	2	4	3	2	3.0	2.8	2.0	3.5
TR_Prj-13.85	3	1	1	3	5	4	2	2.7	3.4	2.5	1.0
TR_Prj-18.2	3	1	1	4	5	5	1	2.9	3.6	2.5	1.0
TR_Prj-18.35	3	1	1	4	5	5	1	2.9	3.6	2.5	1.0
TR_Prj-2.95	3	1	1	2	4	2	4	2.4	3.0	3.0	1.0
TR_Prj-3.15	3	1	1	5	4	5	5	3.4	4.4	5.0	1.0
TR_Prj-4.55	3	1	2	3	4	4	2	2.7	3.2	2.5	1.5
TR_Prj-5.95	3	1	1	5	4	4	5	3.3	4.2	5.0	1.0
TR_Prj-7.64	3	1	1	4	4	5	5	3.3	4.2	4.5	1.0

Project Designation	Rank by							Average of			
	Restoration Potential	Floodplain Area	Channel Length	Channel Definition	Degree of Incision	Cleared Area	Human Features	All 7 Categories (of "Rank)	Five Categories (no area or channel length)	Channel Definition and Human Features ("Effort")	Floodplain Area and Channel Length ("Metric")
CR_Prj-4.9	2	3	3	4	4	2	3	3.0	3.0	3.5	3.0
CR_Prj-8.55	2	1	1	4	4	3	1	2.3	2.8	2.5	1.0
MR_Prj-38.4	2	5	5	3	3	4	2	3.4	2.8	2.5	5.0
MR_Prj-42.6	2	3	2	2	3	2	2	2.3	2.2	2.0	2.5
MR_Prj-45.4	2	4	4	4	3	3	1	3.0	2.6	2.5	4.0
MR_Prj-46.75	2	3	1	2	3	3	3	2.4	2.6	2.5	2.0
MR_Prj-56.8	2	2	1	2	5	4	1	2.4	2.8	1.5	1.5
MR_Prj-62.4	2	4	4	3	4	4	1	3.1	2.8	2.0	4.0
TR_Prj-1.3	2	1	1	2	4	2	2	2.0	2.4	2.0	1.0
TR_Prj-1.9	2	1	1	2	4	5	1	2.3	2.8	1.5	1.0
TR_Prj-10.28	2	1	1	4	5	3	5	3.0	3.8	4.5	1.0
TR_Prj-7.25	2	1	1	4	4	3	1	2.3	2.8	2.5	1.0
TR_Prj-8.43	2	1	1	4	5	5	2	2.9	3.6	3.0	1.0
TR_Prj-8.6	2	1	1	4	5	3	2	2.6	3.2	3.0	1.0
CR_Prj-10.6	1	1	1	5	4	5	5	3.1	4.0	5.0	1.0
CR_Prj-11.0	1	1	1	1	4	3	1	1.7	2.0	1.0	1.0
CR_Prj-8.5	1	1	1	2	4	3	1	1.9	2.2	1.5	1.0
MR_Prj-35.8	1	1	1	1	3	5	5	2.4	3.0	3.0	1.0
MR_Prj-38.9	1	2	4	3	3	1	2	2.3	2.0	2.5	3.0
MR_Prj-42.25	1	2	1	1	3	2	4	2.0	2.2	2.5	1.5
MR_Prj-43.4	1	1	1	1	3	2	1	1.4	1.6	1.0	1.0
MR_Prj-47.3	1	1	1	1	3	5	1	1.9	2.2	1.0	1.0
MR_Prj-65.8	1	1	1	1	4	3	5	2.3	2.8	3.0	1.0

Project Designation	Rank by							Average of			
	Restoration Potential	Floodplain Area	Channel Length	Channel Definition	Degree of Incision	Cleared Area	Human Features	All 7 Categories (of "Rank)	Five Categories (no area or channel length)	Channel Definition and Human Features ("Effort")	Floodplain Area and Channel Length ("Metric")
MR_Prj-75.0R	1	2	1	1	4	4	1	2.0	2.2	1.0	1.5
TR_Prj-13.1	1	1	1	4	5	1	4	2.4	3.0	4.0	1.0
TR_Prj-16.35	1	2	2	3	5	3	4	2.9	3.2	3.5	2.0
TR_Prj-6.4	1	2	1	4	4	1	3	2.3	2.6	3.5	1.5
TR_Prj-7.0	1	1	1	1	4	4	4	2.3	2.8	2.5	1.0
TR_Prj-9.05	1	1	1	1	5	3	4	2.3	2.8	2.5	1.0

2. CATEGORY A – RESTORATION POTENTIAL

The restoration potential ranking is based on the amount of floodplain complexity that naturally existed at each site, and whether this reference floodplain setting can be fully restored. It is an estimate of what the final floodplain connectivity results of a project might be, based on assumptions about whether human features can be only partially or fully addressed. The natural conditions at each site are different, so that total floodplain connectivity, while desirable, is different depending on the setting of the site.

Naturally, the most complex, interconnected floodplain areas consisted of reaches where the floodplain is relatively wide, channel slopes are mild, and numerous side channels, and/or wetland areas persist. In these areas, the main channel frequently accessed and reworked the floodplain, which resulted in a network of diverse, interconnected channels. The groundwater was often near the ground surface, so that side channels contain water and provide habitat most of the year. The channels were dynamic, and channel shifting was largely driven by sediment and LWD transport and deposition. Sediment and woody debris could originate from upstream river reaches, reworking within the active floodplain, and also from adjacent tributaries and unstable hillslopes. These areas are in the upstream sections of the assessment reaches on the three rivers, and are given the highest rankings (**5** and **4**) depending upon the possibility of reconnecting all of the floodplain (**5**) or part of it (**4**). The determination of whether a project area could be fully or only partially restored was made based on the types and locations of human features within a project area. Partial restoration means only a portion of the floodplain area out of the total project site would be restored, but within that smaller area there would be full floodplain reconnection.

In sections further downstream in the assessment reaches, the active floodplain is naturally relatively narrow, and the channel migrated less frequently than the upstream, more complex floodplain areas. In the reference setting, side and secondary channels did persist, but were often separated by higher surfaces that only got reworked during large, less frequent floods. Side channels that did exist were often locations of past main channels. Presently, many of these side channels and higher floodplain surfaces have been cut off limiting connectivity and access. Secondary channels are rare, and those that are present are relatively stable. Because there is less complexity in these areas relative to upstream complex network and wetland areas, these reaches are given a lower ranking of **3** or **2**. In these areas, projects that consist of restoring flow to an abandoned or cut off channel path with restoration of the adjacent floodplain and its processes are considered full restoration and given a ranking of **3**. Partial restoration in these projects can be connecting a defined channel alone without including the entire floodplain, or it can mean connecting only a portion of the total project floodplain area.

Throughout the assessment reach, another category of floodplain reconnection was defined that would reconnect a higher surface that had either no channels or only overflow channels in the natural setting. For these project areas, restoration would result in an increase in floodplain area but would be limited to affecting processes mostly during high flows. These projects would provide some reduction of floodwater in the main channel and possibly increase the amount and longevity of water storage in the floodplain following high flows. However, because these projects offer less complexity and lower year-round habitat value relative to other sites, these projects are rated the lowest from a restoration of floodplain complexity perspective (**1**).

3. CATEGORY B – FLOODPLAIN AREA

This is a measure of the area in which floodplain processes might be restored. Because of the size of the assessment reaches, the boundaries of the projects are approximate, and will be refined during future phases of assessment. The next phase will be reach assessments, in which sections of the river with similar characteristics will be assessed in more detail than allowed by the present assessment. Each reach that is assessed will contain several project areas, and the benefits and concerns of each potential project will be considered in the larger framework of these reaches. In addition, project areas could be subdivided into several smaller projects that could be completed individually or as a group. The range in projects areas mapped was subdivided into five ratings, from the largest (**5**) at greater than 200 acres to the smallest (**1**) at less than 25 acres, based on a rough estimate of frequency distribution.

4. CATEGORY C – CHANNEL LENGTH

This is an approximation of the length of channel that might be reconnected to the main channel and to floodplain processes. This may be the length of a single channel, or the combined length of two or more channels in a project area. Because of the size of the assessment reaches, only the most defined channels were mapped. In areas where a network of channels is present, particularly if there was a lot of dense vegetation, channels were not mapped and this rating is not as useful. Floodplain area is used as an indicator of the number and total length of channels that may be present. Consequently, for some projects, the rankings are based on the actual measured lengths of channels; for other projects, the rankings are based on an approximation of the channel length that might be present. Channel length rankings range between greater than 2 miles for the longest (**5**) to less than 0.25 mile for the shortest (**1**).

5. CATEGORY D – CHANNEL AND FLOODPLAIN DEFINITION

This is an estimate of the degree of disturbance to a channel or floodplain area. Channels or floodplain areas that appear to be mostly intact or the least disturbed relative to a reference condition are given the highest rating (**5**). Channels that have been filled or altered over >75% of their length or area and would need extensive excavation or redesign are given the lowest rating (**1**).

6. CATEGORY E – DEGREE OF INCISION RELATIVE TO REWATERING OF THE FLOODPLAIN

As discussed for the Restoration Potential category, incision is variable among the assessment reaches. In general, the upstream sections are not incised; whereas the downstream sections are slightly incised on the order of one to a few feet. This category is a measure of the relative differences in incision within the assessment reaches. The ratings were estimated for sections of the assessment reaches, and projects within that section are given the same rating. Projects in sections with little or no incision are given the highest rating (**5**), because they could most easily be nudged back to a reference condition from a processes perspective. These are generally in the upstream sections. Projects where there has been more incision are given lower ratings, because restoration of floodplain processes and connectivity would be more difficult. Although five rating values are shown in Table R–1, only the ratings **5, 4,** and **3** were used, because incision is thought to only be minor even in the reaches that are different from the reference setting.

7. CATEGORY F – VEGETATION (PERCENT CLEARED)

In order to restore floodplain processes, some projects may require replanting of riparian vegetation to provide cover for habitat and future LWD recruitment to maintain floodplain complexity and channel processes. This ranking is a measure of the amount of a project area that has been mostly cleared of natural vegetation based on interpretation from 2004 aerial photographs. It generally does not include areas where vegetation has been thinned but still persists. The historical year in which the area was cleared was not specified, but could be added to the ranking criteria in future reach assessments. Future reach assessments may also want to consider areas that are currently vegetated, but have departed from the natural setting because of non-native species or a change in species and age class diversity. Projects where vegetation is primarily intact are given the highest rating (**5**). Projects where vegetation has been cleared from more than 75% of the project area are given the lowest rating (**1**). This ranking does not distinguish between vegetation along a channel versus the entire floodplain surface. For partial side channel reconnection projects, a channel may be restored but some of the floodplain would be left in its current condition. For these areas, this ranking value is a conservative estimate of what it would take to restore riparian processes because some of the cleared areas may not need to be addressed to accomplish the project.

8. CATEGORY G – FEASIBILITY OF ADDRESSING HUMAN FEATURES AND LAND USE TO RESTORE PROCESSES

This is an estimate of the number, type, location, and significance of human features for each project area that would need to be addressed to fully restore processes. Projects with fewer and smaller features (such as riprap or one push-up levee) can probably be done with less effort and so are given the highest rating (**5**). Projects with numerous and more extensive human features, especially houses or buildings that would be difficult to move or redesign, or with a significant infrastructure feature (such as a major road or highway) are given the lowest rating (**1**).

APPENDIX S – ALL REFERENCES

This appendix includes all of the references cited in the *Methow Subbasin Geomorphic Assessment* (Reclamation 2008a) and the *Geomorphic Assessment Technical Appendices* (Reclamation 2008b).

IN TEXT	FULL CITATION	APPX.
ACOE 1952	US Army Corps of Engineers. 1952. *Columbia River and Tributaries Northwestern United States, Letter from the Secretary of the Army*, United States Government Printing Office.	O
Adams 1961	Adams, J. B. 1961. *Petrology and structure of the Stehekin-Twisp Pass area, northern Cascades, Washington.* University of Washington, Seattle, WA. Doctor of Philosophy thesis, 172 p.	M
Andonaegui 2000	Andonaegui, C. 2000. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors, Water Resource Inventory Area 48: Final Report.* Washington State Conservation Commission, 232 p.	C, D, F, M, N, O
Baesecke 2005a	Baesecke, H. 2005a. GIS mapping and report on documentation of findings from aerial photo delineations. Prepared for Bureau of Reclamation by Geosis Consulting. Unpublished report.	Q
Baesecke 2005b	Baesecke, H. November 2005. "Vegetation in Methow Subbasin" in *Geomorphic Assessment Technical Appendices* as Appendix H, Section 1 (Reclamation 2007f).	E, H
Bagnold 1966	Bagnold, R.A. 1966. *An Approach to the Sediment Transport Problem from General Physics*: US Geological Survey Professional Paper 422-1, Washington.	K
Barksdale 1941	Barksdale, J.D. 1941. "Glaciation of the Methow Valley, Washington" in *Journal of Geology*, v. 49, no. 7, p. 721-737.	M
Barksdale 1948	Barksdale, J.D. 1948. "Stratigraphy in the Methow quadrangle, Washington," in *Northwest Science*, v. 22, no. 4, p. 164-176.	M
Barksdale 1975	Barksdale, J.D. 1975. *Geology of the Methow Valley, Okanogan County, Washington*, Washington Division of Geology and Earth Resources Bulletin 68, 72 p., 1 plate.	M

IN TEXT	FULL CITATION	APPX.
Beck 1973	R.W. Beck and Associates. 1973. *Flood plain information, Methow River, Twisp to Mazama, Okanogan County, Washington:* R.W. Beck and Associates, Analytical and Consulting Engineers, Seattle, WA. Report prepared for Washington Department of Ecology, Olympia, WA. 13 p., 20 figures.	G, J, K, O, Q
Benda et al. 1998	Benda, L.E.; Miller, D.J.; Dunne, T.; Reeves, G.H.; and Agee, J.K. 1998. "Dynamic Landscape Systems" in Naiman, R.J.; and Bilby, R.E. (editors). *River Ecology and Management: Lessons from the Pacific Coastal Ecoregion.* Springer, Verlag Publishing.	
Bisson et al. 2003	Bisson, P.A.; Rieman, B.E.; Luce, C.; Hessburge, P.F.; Lee, D.C.; Kershner, J.L.; Reeves, G.H.; and Gresswell, R.E. 2003. "Fire and aquatic ecosystems of the western USA – Current knowledge and key questions" in *Forest Ecology and Management*, v. 178, p. 213-229.	L
Bjornn and Reiser 1991	Bjornn, T.C. and Reiser, D.W. 1991. "Habitat Requirements of Salmonids in Streams." *American Fisheries Society Special Publication 19:83-138.* Meehan, W.R., ed.	F, I
BLM 2006	Bureau of Land Management. 2006. Oregon/Washington State Office; Division of Resource Planning, Use and Protection; Lands, Realty and Minerals Group. Telephone 503-808-6008. http://www.blm.gov/or/contacts_list.php (as of 10/16/07).	Q
Bretz 1923	Bretz, J. 1923. "Glacial drainage on the Columbia Plateau" in *Geological Society of America Bulletin*, v. 34, p. 573-608.	M
Bretz 1932	Bretz, J. 1932. "The Grand Coulee" in *American Geographical Society Special Publication* No. 15, 89 p.	M
Brookes et al. 1996	Brookes, A.; Knight, S.; and Shields, F.D., Jr. 1996. *River Channel Restoration, Guiding Principles for Sustainable Projects*. Wiley and Sons, p.103.	

IN TEXT	FULL CITATION	APPX.
Burtchard 1998	Burtchard, G. 1998. *Technical Report, Environment, Prehistory & Archaeology of Mount Rainier National Park, Washington.* Prepared for National Park Service, Seattle, WA by International Archaeological Research Institute, Inc., G.C. Burtchard with contributions by S.C. Hamilton and R.H. McClure, Jr. Originally published February 1998; Reprinted February 2003. Accessed at http://www.nps.gov/archive/mora/ncrd/archaeology/index.htm (October 10, 2007).	M
Caldwell and Catterson 1992	Caldwell, B. and Catterson, D., 1992, *Methow River Basin fish habitat analysis using the instream flow incremental methodology:* Washington Department of Ecology, Olympia, WA. Publication No. 92-82, 196 p.	F, K
Chamberlin et al. 1991	Chamberlin, T.W., Harr, R.D., and Everest, F.H. 1991. "Timber harvesting, silviculture, and watershed processes —Influences of forest and rangeland management on salmonid fishes and their habitats" in *American Fisheries Society Special Publication, V-19,* p.181-205.	F
Cross 2005	Cross, D.M. 2005. *Sediment monitoring report, 2000-2005, Chewuch River and Twisp River.* US Forest Service, Okanogan-Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA, 29 p.	K, L
DeBell 1990	DeBell, D.S. 1990. "*Populus trichocarpa*" p. 570–576, in *Silvics of North America, Volume 2, Hardwoods*: USDA Forest Service, Agriculture Handbook 654.	E, H
DeGraaff-Surpless et al. 2003	DeGraaff-Surpless, K.; Mahoney, J.; Wooden, J.; and McWilliams, M. 2003. "Lithofacies control in detrital zircon provenance studies –Insights from the Cretaceous Methow basin, southern Canadian Cordillera" in *Geological Society of America Bulletin*, v. 115, no. 8, p. 899-915.	M
Devin 1997	Devin, D. 1997. *Mazama, The Past 100 Years – Life and Events in the Upper Methow Valley & Early Winters,* Peanut Butter Publishing, Seattle, WA.	O
Dollar et al. 2006	Dollar, E.S.J.; James, C.S.; Rogers, K.H.; and M.C. Thoms. 2006. "A framework for interdisciplinary understanding of rivers as ecosystems" in *Geomorphology* v. 89, p. 147-162.	

IN TEXT	FULL CITATION	APPX.
Dragovich et al. 1995	Dragovich, J., Norman, D., and McClelland, W. 1995. *Geologic map of the west half of the Twisp* 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 95-3, 1 plate, 63 p.	Q
Fausch et al. 2002	Fausch, K.D.; Torgersen, C.E.; Baxter, C.V.; and Li, H. W. 2002. "Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes," *BioScience,* 52: 1 – 16.	
FEMA 2003	Federal Emergency Management Agency. 2003. *Flood insurance study: Okanogan County, Washington, unincorporated areas.* January 2003 revision.	J, K
FIA 1975	Federal Insurance Administration, *Flood Insurance Study, City of Twisp, Okanogan County, Washington*, December 1975. US Department of Housing and Urban Development.	J
Flint 1935	Flint, R. 1935. "Glacial features of the southern Okanogan region" in *Geological Society of America Bulletin*, v. 46, p. 169-194.	M
Flint 1936	Flint, R. 1936. "Stratified drift and deglaciation in eastern Washington" in *Geological Society of America Bulletin*, v. 47, p. 1849-1884.	M
Flint and Irwin 1939	Flint, R. and Irwin, W. 1939. "Glacial geology of Grand Coulee Dam, Washington" in *Geological Society of America Bulletin*, v. 50, p. 661-680.	M
Frissell et al. 1986	Frissell, C.A.; Liss, W.J.; Warren, C.E.; and Hurley, M.D. 1986. "A hierarchical framework for stream habitat classification: viewing stream in a watershed context" in *Environmental Management,* 10: 199 – 214.	
FWS 1998a	US Fish and Wildlife Service. 1998a. *A Framework to Assist in Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Bull Trout Subpopulation Watershed Scale*, February 1998.	I

IN TEXT	FULL CITATION	APPX.
FWS 1998b	US Fish and Wildlife Service. 1998b. *Endangered and Threatened Wildlife species, Determination of Threatened Status for the Klamath River and Columbia River Delisting of several Evolutionarily Significant Units (ESUs) of West Coast steelhead. Final rule.* Federal Register, Vol. 63, No. 111, Wednesday, June 10, 1998. pp. 31647-31674.	
FWS 2005	Fish and Wildlife Service. 2005. *Endangered and Threatened Wildlife Plants; Designation of Critical Habitat for the Bull Trout; Final Rule.* Federal Register, Vol. 70, No. 85, Monday, September 26, 2005. Pages 56212–56311. See at http://www.fws.gov/pacific/bulltrout/ then link to "Final Rule" (as of 12/14/07).	
Golder 1993	Golder Associates, Inc., 1993, *Report to Economic and Engineering Services, Inc. on water budget for the Methow Basin,* 28 p.	
Golder 2002	Golder Associates, Inc. October 31, 2002. *Draft report on streamflow and channel analysis Chewuch River,* submitted to Chewuch Basin Council, Winthrop, WA.	K
Golder 2005	Golder Associates, Inc. 2005. *Methow River channel migration assessment – Channel migration zone components and channel migration hazard zones:* Prepared for Okanogan County Department of Planning and Development, Okanogan, WA by Golder Associates, Inc., Redmond, WA. Project Number 043-1193.35, 29 p. plus appendices; 35 figures.	C, E, F, G, K, M, N, Q
Gorman 1899	Gorman, M.W. 1899. *The eastern part of the Washington Forest Reserve, Part V*: in *US Geologic Survey, 19th Annual Report of the Survey of Forest Reserves.*	F
Gulick and Korsec 1990	Gulick, C., and Korosec, M. 1990. *Geologic map of the Omak* 1:100,000 quadrangle, Washington Division of Geology and Earth Resources Open File Report 90-12, 1 plate, 52 p.	Q

IN TEXT	FULL CITATION	APPX.
Hadfield 2007	Hadfield, J.S., 2007, "Biological Evaluation of Condition of Black Cottonwood in Bureau of Reclamation Potential Vegetation restoration project areas along the Twisp and Methow rivers, Okanogan County, Washington" in *Geomorphic Assessment Technical Appendices* as Appendix H, Section 2 (Reclamation 2007f).	E
Hillman 2006	Hillman, T.W. 2006. *Monitoring Strategy for the Upper Columbia Basin, Second Draft Report*, prepared by BioAnalysts, Inc., Boise, ID for Upper Columbia Salmon Recovery Board, Bonneville Power Administration, and National Marine Fisheries Service.	A
Hopkins 1987	Hopkins, W. 1987. *Geology of the Newby Group and adjacent units in the southern Methow trough, northeast Cascades, Washington:* San Jose State University, San Jose, CA. Master of Science Thesis, 95 p.	M
Howell 2006	Howell, Phillip. 2006. "Effects of Wildfire and Subsequent Hydrologic Events on Fish Distribution and Abundance in Tributaries of North Fork John Day River." in *North American Journal of Fisheries Management* 26:983-994.	F
Huesser 1977	Huesser, C. 1977. "Quaternary Palynology of the Pacific Slope of Washington" in *Quaternary Research*, v. 8, p. 282-306.	M
Humling and Snow 2006	Humling, M. and Snow, C. 2006. *Spring Chinook spawning ground surveys in the Methow River Basin in 2005.* Washington Department of Fish and Wildlife, Olympia, WA. Report prepared for Public Utility District Number 1 of Douglas County.	F
Hurlow 1993	Hurlow, H. 1993. "Mid-Cretaceous strike-slip and contractional fault zones in the western intermontane terrane, Washington, and their relation to the North Cascades-southeastern Coast Belt orogen" in *Tectonics*, v. 12, p. 1240-1257.	M
ICBTRT 2007	Interior Columbia Basin Technical Recovery Team, July 2007, *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* ["current draft"], 49 pp. See at http://www.nwfsc.noaa.gov/trt/col_docs/viabilityupdatememo.pdf (as of 12/04/07).	D

IN TEXT	FULL CITATION	APPX.
Johnson 1985	Johnson, S. 1985. "Eocene strike-slip faulting and nonmarine basin formation in Washington" in Biddle, K. T., and Christie-Blick, N., eds., "Strike-slip deformation, basin formation, and sedimentation" in *Society of Economic Paleontologists and Mineralogists Special Publication* 37, p. 283-302.	M
Julien 1995	Julien, P.Y. 1995. *Erosion and sedimentation:* Cambridge University Press.	E, K
Kanda et al. 2002	Kanda, N., Leary, R.F., and Allendorf, F.W., 2002, "Evidence of introgressive hybridization between bull trout and brook trout" in *Transactions of the America Fisheries Society*, Vol. 131, no. 4, p. 772-782.	F
Knott 2007	Knott, G. 2007. Personal communication. US Bureau of Reclamation Methow Field Station, Winthrop, WA.	N
Konrad et al. 2003	Konrad, C.P.; Drost, B.W.; and Wagner, R.J. 2003. *Hydrogeology of the unconsolidated sediments, water quality, and ground-water/surface-water exchanges in the Methow River Basin, Okanogan County, Washington*. US Geological Survey Water-Resources Investigations Report 03-4244, 137 p.	C, E, F, M
KWA 2004	KWA Ecological Sciences Ltd. 2004. *Methow Subbasin Plan.* Prepared under contract for Washington Department of Fish and Wildlife and funded by the Northwest Power and Conservation Council. April 23, 2004; 463 p.	D, N. O
Lane 1955	Lane, E.W., 1955, "Design of Stable Channels" *Transactions, Am. Soc. Civil Eng.* 120:1234.	E
Mansfield and Cain 2001	Mansfield, R., and Cain, N. March 2001. "The Methow River Dam, An Interview with Harold Otto", *Okanogan County Heritage*.	
Mantua 1999	Mantua, N., 1999, *The Pacific Decadal Oscillation.* University of Washington Joint Institute for the Study of the Atmosphere and Oceans, Seattle, WA.	J

IN TEXT	FULL CITATION	APPX.
Mantua et al. 1997	Mantua, N.J.; Hare, S.R.; Zhang, Y.; Wallace, J.M.; and Francis, R.C. 1997: "A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production." *Bulletin of the American Meteorological Society*, Vol. 78, pp 1069-1079.	J
Marshall 1915	Marshall, R. 1915. *Profile surveys in Chelan and Methow River Basins, Washington*: US Geological Survey Water-Supply Paper 376.	K
Maurer 1958	Maurer, D.L. 1958. *Biostratigraphy of the Buck Mountain member and adjacent units in the Winthrop area, Washington:* University of Washington Master of Science thesis, 111 p.	M
McElhary et al. 2000	McElhany, P., Ruckelshaus, M.H., Ford, M.J., Wainwright, T.C., and Bjorkstedt, E.P. 2000. *Viable salmonid populations and recovery of evolutionary significant units, Technical Memorandum NMFS-NWFSC-42:* National Marine Fisheries Service, Seattle, WA.	A
McGroder 1988	McGroder, M. 1988. *Structural evolution of the eastern Cascades fold belt – Implications for late Mesozoic accretionary tectonics in the Pacific Northwest*. University of Washington, Seattle, WA. Doctor of Philosophy thesis, 140 p.	M
McGroder and Miller 1989	McGroder, M. and Miller, R. 1989. "Geology of the eastern North Cascades" in Joseph, N. and other editors, *Geologic Guidebook for Washington and Adjacent Areas.* Washington Division of Geology and Earth Resources Information Circular 86, p. 97-118.	M
McGroder et al. 1990	McGroder, M., Garver, J., and Mallory, V. 1990. *Bedrock geologic map, biostratigraphy, and structure sections of the Methow Basin, Washington and British Columbia*, Washington Division of Geology and Earth Resources Open File Report 90-19, 3 plates, 32 p.	Q
McLennan and Mamias 1992	McLennan, D.S., and Mamias, A.M. 1992. *Cottonwoods in British Columbia –Problem analysis.* FRDA Report 195, Canada-British Columbia Partnership Agreement on Forest Resource Development, FRDA II, 50 p.	E, H

IN TEXT	FULL CITATION	APPX.
Methow Atlas 2008	Bureau of Reclamation. February 2008. *Map Atlas for 80-Mile Study Area Reach, Geomorphic Assessment for Methow In-Channel Habitat Rehabilitation Plan, Methow River Subbasin, Okanogan County, Washington*, Technical Service Center, Remote Sensing and Geographic Information Group (M/S 86-68260), Denver, CO. Also cited as "Reclamation, 2008c"	C
Milhous et al. 1976	Milhous, R., Sorlie, G., and Richardson, D. 1976. *Water Resources of the Methow Basin*. Washington Department of Ecology, Olympia, WA. Water Resources Analysis and Information Section, *Office Report* No. 56, 57 p.	M
Miller 1987	Miller, R.B. 1987. *Geology of the Twisp River-Chelan Divide region, North Cascades, Washington.* Washington Division of Geology and Earth Resources Open File Report 87-17, 12 p., 12 plates.	M
Miller and Bowring 1990	Miller, R. and Bowring, S. 1990. "Structure and chronology of the Oval Peak batholith and adjacent rocks –Implications for the Ross Lake fault zone, North Cascades, Washington" in *Geological Society of America Bulletin*, v. 102, p. 1361-1377.	M
Miller et al. 1994	Miller, R., Haugerud, R., Murphy, F., and Nicholson, L. 1994. "Tectonostratigraphic framework of the Northeastern Cascades" in *Washington Division of Geology and Earth Resources Bulletin* 80, p. 73-92.	M
Montgomery and Bolton 2003	Montgomery, D.R. and Bolton, S. M. 2003. "Hydrogeomorphic variability and river restoration," in Wissmar , R.C. and Bisson, P.A. [editors], *Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems,* American Fisheries Society, Bethesda, MD. pp. 39-76.	
Mullan et al. 1992	Mullan, J.W.; Williams, K.R.; Rhodus, G.; Hillman, T.W.; and McIntrye, J.D. 1992. *Production and Habitat of Salmonids in Mid-Columbia River Tributary Streams,* US Fish and Wildlife Service, Monograph 1. Leavenworth, WA.	I

IN TEXT	FULL CITATION	APPX.
MVRD 2007	Methow Valley Ranger District. Revised June 2007. *Sediment Monitoring Report: 2000 to 2006, Chewuch River and Twisp River.* Winthrop, WA.	F, K, L
NMFS 1996	National Marine Fisheries Service. 1996. *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale,* August 1996. Includes "Matrix of Pathways and Indicators" (MPI).	I
NMFS 1997	National Marine Fisheries Service. 1997. *Endangered and Threatened species; listing of several Evolutionarily Significant Units (ESUs) of West Coast steelhead. Final Rule.* Federal Register Vol. 62, August 18, 1997; pp. 43937-43954.	
NMFS 1999	National Marine Fisheries Service. 1997. *Endangered and threatened species, listing of several Evolutionarily Significant Units (ESUs) of West Coast steelhead. Final rule.* Federal Register, Vol. 63, No. 111, Wednesday, June 19, 1998.	
NMFS 2000	National Marine Fisheries Service. 2000. *Biological Opinion, Reinitiation of Consultation on Operation of the Federal Columbia River Power System, Including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin.* Northwest Region, Seattle. WA, December 21, 2000.	
NMFS 2004	National Marine Fisheries Service, 2004, *Endangered Species Act – Section 7 Consultation Biological Opinion: Consultation on Remand for Operation of the Columbia River Power System and 19 Bureau of Reclamation Projects in the Columbia Basin. (*Revised and reissued pursuant to court order, NWF v. NMFS Civ. No. CV 01-640-RE (D. Oregon)). Portland, OR, November 30, 2004.	
NMFS 2007a	National Marine Fisheries Service. 2007a. *Adaptive Management for ESA-Listed Salmon and Steelhead Recovery: Decision Framework and Monitoring Guidance*: 56 pp. NMFS Northwest Region and Northwest Fisheries Science Center. See http://www.nwr.noaa.gov/Salmon-Recovery-Planning/ESA-Recovery-Plans/upload/Adaptive_Mngmnt.pdf (as of 12/17/07).	A

IN TEXT	FULL CITATION	APPX.
NMFS 2007b	National Marine Fisheries Service. 2007b. *Notice of Adoption of … the Upper Columbia River Spring Chinook Salmon and Steelhead Recover Plan.* Federal Register Vol. 72, No. 194, October 9, 2007. Pages 57303-57307. This adopts UCSRB 2007 as the Federal recovery plan. See at http://www.nwr.noaa.gov/Publications/FR-Notices/2007/upload/72FR57303.pdf (as of 12/06/07). Linked at http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/Upper-Col-Plan.cfm (as of 12/06/07)	
Norman 1974	Norman Associates. 1974. *Flood plain information, Methow River, Twisp to Carlton, Okanogan County, Washington.* Report prepared for County of Okanogan Office of Planning and Development, Okanogan, WA, by Norman Associates Consulting Engineers, Bellevue, WA, 12 p., 10 figures.	G, K, Q
Northwest Forest Plan 1994	US Forest Service and US Bureau of Land Management, April 1994 (since amended) • *Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl* • *Standards and Guidelines for Management of Habitat for Late-Succession and Old-Growth Forest Related Species with the Range of the Northern Spotted Owl* See at http://www.fs.fed.us/r6/nwfp.htm (as 12/04/07)	A
Okanogan County1996	County of Okanogan Office of Planning and Development, Okanogan County. 1996. *Draft multi-objective river corridor plan for the Methow Basin*. Okanogan, WA.	Q
Parrish et al. 1988	Parrish, R., Carr, S., and Parkinson, D. 1988. “Eocene extensional tectonics and geochronology of the southern Omineca belt, British Columbia and Washington” in *Tectonics*, v. 7, p. 181-212.	M
Portman 2002	Portman, S., 2002, *The Smiling Country – A History of the Methow Valley*. Sun Mountain Resorts, Inc., Winthrop, WA.	E, O

IN TEXT	FULL CITATION	APPX.
Potter 1986	Potter, C. 1986. "Origin, accretion, and post accretionary evolution of the Bridge River terrane, southwest British Columbia" in *Tectonics*, v. 5, p. 1027-1041.	M
Price et al. 1985	Price, R., Monger, J., and Roddick, J. 1985. "Cordilleran cross-section; Calgary to Vancouver" in Templeman-Kluit, D., ed., *Field guides to geology and mineral deposits in the southern Canadian Cordillera:* Geological Society of America, Cordilleran Section Meeting, Vancouver, p. 3-1 thru 3-85.	M
PWI 2003	Pacific Watershed Institute. 2003. *Twisp Watershed Assessment: Restoration Strategies and Action Plan.* Funded by the Salmon Recovery Funding Board, US Forest Service, US Fish and Wildlife Service, and the Pacific Watershed Institute. Prepared by Pacific Watershed Institute, Winthrop, WA. 169 p.	D, E, F, H, K, N, Q
PWI 2004a	Pacific Watershed Institute. March 28, 2004. *Chewuch River: Restoration Monitoring Project 2000-2003 Final Report*, Prepared for US Fish and Wildlife Service, Western Regional Office.	K
PWI 2004b	Pacific Watershed Institute. October 28, 2004. *Chewuch River: Channel Baseline Monitoring Report.* Prepared for Methow Valley Ranger District, USFS Cooperative Agreement #134100J008.	K, O
Randle et al. 2006	Randle, T.J.; Bountry, J.A.; Makar, P.W.; Fotherby, L.M.; Bauer, T.R.; and Murphy, P.J. 2006. "River Processes and Restoration," pages 7-1 – 7-64, in *Erosion and Sedimentation Manual*, Bureau of Reclamation.	
Ray 1986	Ray, G. 1986. "The Hozameen fault system and related Coquihalla serpentine belt of southwestern British Columbia" in *Canadian Journal of Earth Sciences*, v. 23, no. 7, p. 1022-1041.	M
Reclamation 2005	*Decision Document Concerning the Final Updated Proposed Action and NOAA Fisheries' November 30, 2004, Biological Opinion Consultation on Remand for Operation of the FCRPS including 19 Bureau of Reclamation Projects in the Columbia Basin*, 12 January 2005, PN Region	

IN TEXT	FULL CITATION	APPX.
Reclamation 2006a	Bureau of Reclamation. 2006a. Work performed by Jennifer Bountry, Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, CO.	Q
Reclamation 2006b	Bureau of Reclamation. 2006b. Work performed by Lucy Piety, Technical Service Center, Seismotechtonics and Geophysics Group (M/S 86-68330) and Jennifer Bountry, Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68540) , Denver, CO.	Q
Reclamation 2007a	Bureau of Reclamation. 2007a. Lucy Piety, Technical Service Center Seismotechtonics and Geophysics Group (M/S 86-68330), Denver, CO.	Q
Reclamation 2007b	Bureau of Reclamation. 2007b. Ed Lyon, Pacific Northwest Regional Office Geology, Exploration, and Instrumentation Group (M/S PN-3600), Boise, ID.	Q
Reclamation 2007c	Bureau of Reclamation. 2007c. Ed Lyon and Rob McAffee, Pacific Northwest Regional Office Geology, Exploration and Instrumentation Group (M/S PN-3600), Boise, ID.	Q
Reclamation 2007d	Bureau of Reclamation. 2007c. Work performed by Rob McAffee, Pacific Northwest Regional Office, Geology, Exploration and Instrumentation Group (M/S PN-3600), Boise, ID.	Q
Reclamation 2008a	Bureau of Reclamation. 2008a. *Methow Subbasin Geomorphic Assessment*. February 2008. Prepared by Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, CO in cooperation with Pacific Northwest Regional Office, Boise, ID and Methow Field Station, Winthrop, WA.	Q
Reclamation 2008b	Bureau of Reclamation. 2008b. *Methow Subbasin Geomorphic Assessment, Technical Appendices.* February 2008. Prepared by Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, CO in cooperation with Pacific Northwest Regional Office, Boise, ID and Methow Field Station, Winthrop, WA.	

IN TEXT	FULL CITATION	APPX.
Reclamation 2008c	Bureau of Reclamation. 2007c. *Methow Subbasin Geomorphic Assessment, Map Atlas.* February 2008. Prepared by Technical Service Center, Sedimentation and River Hydraulics Group (M/S 86-68240), Denver, CO.	
Richardson 1976	Richardson, D. 1976. *Natural monthly streamflow in the Methow Basin*. Washington Department of Ecology, Olympia, WA. Water Resources Analysis and Information Section, Office Report No. 46, 7 p.	M, N
Riedel et al. 2003	Riedel, J., Clague, J., Scott, K., and Swanson, T. 2003. "Late Fraser alpine glacier activity in the North Cascades, Washington" [abstract] in *Geological Society of America Abstract with Programs,* v. 35, no. 6, p. 216.	M
Rinehart and Fox 1972	Rinehart, C.D., and Fox, K.F., Jr. 1972. *Geology and mineral deposits of the Loomis quadrangle, Okanogan County, Washington*: Washington Division of Geology and Earth Resources Bulletin 64, 124 p., 3 plates.	M
Roddick and Okulitch 1979	Roddick, J.; Muller, J.; and Okulitch, A. 1979. *Fraser River, British Columbia-Washington.* Geological Survey of Canada Map 1386a, scale 1:1,000,000.	M
Roni 2005	Roni, P., editor, 2005, Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, MD.	
Roni et al. 2002	Roni, P., Beechi, T.J., Bilby, R.R., Leonetti, F.E., Pollock, M.M., and Pess, G.R. 2002, "A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds." in *North American Journal of Fisheries Management*, Vol. 22. p. 1-20.	F
Russel 1990	Russell, I. 1900. "A preliminary paper on the geology of the Cascade mountains in northern Washington" in US Geological Survey *20th Annual Report, Part 2*, p. 83-210.	M
Schellhaus et al. 2001	Schellhaus, R.; Spurbeck, D.; and Ohlson, P. 2001. *Fire disturbance effects in subalpine forests of North Central Washington.* 30 p. Unpublished document. On file with USFS Methow Valley Ranger District, Winthrop, WA.	

IN TEXT	FULL CITATION	APPX.
Schmidt 1964	Schmidt, Jessie, 1964, "Silver First Town in the Methow Valley" from website http://www.ghosttownsusa.com/silver.htm (as of 12/03/07).	O
SCS 1975	Soil Conservation Service, *Flood Hazard Analyses, Chewuch River*, July 1975. US Department of Agriculture, Portland, OR.	J
Smith et al. 2000	Smith, J. E., Fisher, B., and Farmer, S. 2000. *Lower Chewuch River fisheries habitat survey, final report.* Prepared for CI Johnson and Associates in cooperation with the Methow Basin Planning Unit by the Pacific Watershed Institute, Winthrop, WA. December 2000. 58 p.	E, N, O
Snow 2007	Snow, Charlie. 2007. Personal communication, February 2, 2007. Washington Department of Fish and Wildlife, Fish Program/Science Division/Methow Field Station.	F
Snow and Frady 2006	Snow, C. and Frady, C. 2006. *September hatchery and natural production report.* Washington Department of Fish and Wildlife, Fish Program Science Division, Methow Field Station, October 6, 2006.	F
Spence et al. 1996	Spence, B.C.; Lomnicky, G.A.; Hughes, R.M.; and Novitzki, R.P. December 1996. *An Ecosystem Approach to Salmonid Conservation.* TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR. See at http://www.nwr.noaa.gov/Publications/Reference-Documents/ManTech-Report.cfm (as of 11/30/07)	F
Stanford and Ward 1993	Stanford, J.A., and Ward, J.V., 1993, "An ecosystem perspective of alluvial rivers – Connectivity and the hyporheic corridor" in *Journal of the North American Benthological Society*, v. 12, no. 1, p. 48-60.	F
Stoffel 1990	Stoffel, K. 1990. *Geologic map of the Oroville* 1:100,000 quadrangle. Washington Division of Geology and Earth Resources Open File Report 90-11, 1 plate, 58 p.	Q
Stoffel et al. 1991	Stoffel, K.L., Joseph, N.L., Waggoner, S.Z., Gulick, C.W., Korosec, M.A., and Bunning, B.B. 1991. *Geologic Map of Washington – Northeast Quadrant*. Washington Division of Geology and Earth Resources, Geologic Map GM-39.	M, Q

IN TEXT	FULL CITATION	APPX.
Sutley 2006	Sutley, D.E. 2006. *Methow River Drainage Basin: Hydrology Data and GIS.* Bureau of Reclamation Technical Service Center, Denver, CO. [Included as Technical Appendix J]	K
Tennyson and Cole 1987	Tennyson, M.E. and Cole, M.R. 1987. "Upper Mesozoic Methow-Pasayten sequence, Northeastern Cascade Range, Washington and British Columbia" in Schuster, J. E. ed., 1987, *Selected Papers on the Geology of Washington.* Washington Division of Geology and Earth Resources Bulletin 77, p. 73-84.	M
UCRTT 2007	Upper Columbia Regional Technical Team, 2007, *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region, A report to the Upper Columbia Salmon Recovery Board.* August 2007. Wenatchee, WA. Appendix H of UCSRB 2007. See at http://www.ucsrb.com/plan.asp (as of 12/14/07).	B, C, D
UCSRB 2006	Upper Columbia Salmon Recovery Board. June 2006. *Proposed Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan*. Wenatchee, WA. Superseded by UCSRB 2007.	
UCSRB 2007	Upper Columbia Salmon Recovery Board, 2007, *Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan.* Wenatchee, WA. 300 pp. See at http://www.ucsrb.com/plan.asp (as of 12/03/07). Federally adopted by NMFS 2007b.	B, C, D
USFS 1997	US Forest Service. 1997. *Middle Methow Watershed Analysis*. Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA.	N
USFS 1998a	US Forest Service. 1998a. *Upper Methow watershed analysis*: Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA.	N
USFS 1998b	US Forest Service. 1998b. *Biological Assessment for authorization for water conveyance by the Wolf Creek Reclamation District Irrigation Ditch.* Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA. March 25, 1998.	N

IN TEXT	FULL CITATION	APPX.
USFS 2000	US Forest Service. 2000. *Goat Creek stream survey summary, 08-92 to 09-92:* Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA.	N
USFS 2001	US Forest Service. 2001. *Twisp River stream survey summary:* Okanogan/ Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.	E, N, O
USFS 2002	US Forest Service. 2002. *Chewuch River stream survey summary*. Okanogan/ Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.	E, K, N
USFS 2004	US Forest Service. 2004. *Beaver Creek Stream Survey Summary, 08-92 to 09-92:* Okanogan/ Wenatchee National Forest, Methow Valley Ranger District, Winthrop, WA.	N
USFS 2006	US Forest Service. 2006. *Tripod Complex fires, Okanogan/ Wenatchee National Forest – Burned-area report*: US Forest Service Report FS-2500-8, June 2006, 26 p.	L
USFS 2007	US Forest Service. March 2007. *Sediment Monitoring Report, 2000-2006, Chewuch River and Twisp River*. Okanogan National Forest, Methow Valley Ranger District, Winthrop, WA.	
USGS 2001	US Geological Survey, 2001. *Methods for Estimating Flood Magnitude and Frequency in Washington, 2001*, US Geological Survey Fact Sheet 016-01.	J
Varsek et al. 1993	Varsek, J., Cook, F., Clowes, R., Journeay, J., Monger, J., Parrish, R., Kanasewich, E., and Spencer, C. 1993. “Lithoprobe crustal reflection structure of the southern Canadian Cordillera 2: Coast Mountains transect” in *Tectonics*, v. 12, p. 334-360.	M
Waitt 1972	Waitt Jr., R.B. 1972. *Geomorphology and glacial geology of the Methow drainage basin, eastern North Cascade Range, Washington.* University of Washington, Seattle, WA. Doctor of Philosophy thesis, 154 p.	M
Waitt 1975	Waitt, R.B., Jr. 1975. “Late Pleistocene alpine glaciers and the Cordilleran ice sheet at Washington Pass, North Cascade Range, Washington” in *Arctic and Alpine Research*, v. 7, no. 1, p. 25-32.	M

IN TEXT	FULL CITATION	APPX.
Waitt 1980	Waitt, R.B., Jr. 1980. *Cordilleran Icesheet and Lake Missoula catastrophic floods, Columbia River Valley, Chelan to Walla Walla:* Guidebook for West Coast Friends of the Pleistocene Field Conference.	M
Waitt 1982	Waitt, R.B., Jr. 1982. "Surficial geology" in *Geologic Map of the Wenatchee 1:100,000 quadrangle, Washington* (R.W. Tabor et al.). USGS Miscellaneous Investigations Map MI-1311.	M
Waitt and Thorson 1983	Waitt, R. and Thorson, R. 1983. "The Cordilleran Ice Sheet *in* Washington, Idaho, and Montana" in Wright, Jr., H., and Porter, S., editors, *Late-Quaternary environments of the United States, Volume 1, The Late Pleistocene*, University of Minnesota Press, Minneapolis, MN, p. 53-70.	M
Waitt et al. 1982	Waitt, R., Yount, J., and Davis, P. 1982. "Regional significance of and early Holocene moraine in Enchantment Lakes Basin, North Cascade Range, Washington" in *Quaternary Research*, v. 17, p. 191-210.	M
Walters and Holling 1990	Walters, C.J. and Holling, C.S. 1990,. "Large-scale management experiments in learning by doing" in *Ecology*, 71: 2060 – 2068.	
Walters and Nassar 1974	Walters, K. and Nassar, E. 1974. *Water in the Methow River Basin, Washington.* Washington Department of Ecology, Water-Supply Bulletin 38, 73 p.	M
Waters 1933	Waters, A. 1933. "Terraces and coulees along the Columbia River near Lake Chelan, Washington" in *Geological Society of America Bulletin*, v. 44, p. 783-820.	M
WDOE 2003	Washington Department of Ecology. 2003. "Wenatchee National Forest Water Temperature Total Maximum Daily Load, Technical Report." Publication Number 03-10-063.	G
Whitlock et al. 2003	Whitlock, C.; Shafer, S.L.; and Marlon, J. 2003. "The role of climate and vegetation change in shaping past and future fire regimes in the northwest US and the implications for ecosystem management" in *Forest ecology and management* 178 (2003) 5 – 2.	

IN TEXT	FULL CITATION	APPX.
WRC 1981	US Water Resources Council. 1981. *Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Committee*, US Department of the Interior.	J
Yang 1996	Yang, C.T. 1996. *Sediment Transport Theory and Practice*: McGraw-Hill Companies, Inc.	K