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Geomorphology and Hydraulic Modeling for the Middle Methow River from Winthrop to Twisp

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Cover Figure: Photograph of confluence between Methow and Twisp Rivers taken by Dave Walsh, Pacific Northwest Regional Office, Bureau of Reclamation, May 21, 2008.

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Executive Summary

The Bureau of Reclamation (Reclamation), U.S. Army Corps of Engineers, and Bonneville Power Administration contribute to the implementation of salmonid habitat improvement projects in Columbia River Basin tributaries to help meet commitments contained in the 2008 Federal Columbia River Power System Biological Opinion (BiOp, NOAA 2008). This BiOp includes a Reasonable and Prudent Alternative (RPA), or a suite of actions, to protect listed salmon and steelhead across their life cycle. Habitat improvement projects in various Columbia River tributaries are one aspect of this RPA. Reclamation provides technical assistance to States, Tribes, Federal agencies, and other local partners for identification, design, and construction of stream habitat improvement projects that primarily address stream flow, access, entrainment, and channel complexity limiting factors. This report provides scientific information on geomorphology and hydraulic modeling that can be used to help identify, prioritize, and implement sustainable fish habitat improvement projects and to help focus those projects on addressing key limiting factors to protect and improve survival of salmon and steelhead listed under the Endangered Species Act (ESA).

Specifically, this report describes the geomorphic and hydraulic characteristics of the Middle Methow (M2) reach of the Methow River between Twisp and Winthrop, Washington. An integrated application of surficial mapping and geochronology in combination with numerical hydraulic modeling was undertaken to better understand the geomorphic processes responsible for the evolution of the river and for the formation and development of salmonid habitat features in the M2 reach. The information contained in this report is intended to be utilized as a technical resource for discussions regarding potential rehabilitation opportunities and in determining possible risks, benefits, and/or general constraints on specific projects or treatments.

A surficial map that was compiled for this report refines the reconnaissance-level map prepared for a prior regional study (Reclamation, 2008). The new map benefited from the availability of 2006 LiDAR data and more extensive field investigations. The emphasis of the mapping focused on deposits associated with the active channel and floodplain because these areas provide the most opportunity for improving salmonid habitat over both the short (a few years) and longer (decades) time scales. A two-dimensional hydraulic model was also developed and used to make predictions for the extent and depth of inundation of these geomorphic features. Steady state flows (single discharges as opposed to a variable flood hydrograph) were modeled. Age ranges for the map units were established based on historical data, radiocarbon analyses of detrital charcoal, and the geochemical analysis of a volcanic ash. The ages provide a chronological perspective on the geomorphic processes affecting channel change, including channel migration, incision, bar deposition, and the formation and development of side channels and large woody debris complexes.

The geomorphic relationships identified from the surficial mapping and the hydraulic modeling results were analyzed for specific sites that had been recognized by the Methow

Restoration Council (a local stakeholder group) as potential opportunities for habitat rehabilitation efforts (Figure 1 and Appendix G of this report). Although the total area of the active floodplain is nearly the same in 2006 as it was in 1945, it is important to recognize that the river system had already been highly modified by that time. Historical photographs and maps suggest that much of the floodplain had been cleared of vegetation and in some locations modified, probably by the turn of the century (circa 1900), as the result of logging and agricultural activities. There are also anecdotal accounts of removal of large wood and localized manipulation in the channel for surface water diversions. Many of the sites addressed specifically in this report continue to be impacted by constructed features (levees, dikes, riprap, and channel manipulation associated with diversions) that limit floodplain connectivity and side channel development.

The areas where these impacts are most pronounced are in the Barclay-Bear Creek, Methow Valley Irrigation District (MVID) East, and the sugar dike-Twisp river areas. Barclay-Bear Creek and MVID East have historically had the most frequent in-channel disturbance from dredging and construction of push-up levees and dams. The sugar dike-Twisp area has the largest area of impacted floodplain, which is cut off by the highway and levee construction. Habermehl and Lehman areas also are impacted by constructed features, but the impact is limited to blocking of single side channel in each area.

Side channels, as defined for this study, are the smaller channels located adjacent to the main channel that generally have a well defined flow path for their entire length and have a frequent surface water connection with the main channel at one or both ends (upstream and downstream). Side channels identified in this study may be either part of the active floodplain (Qa3) or associated with gravel bars (Qa4) in the main channel. In either location, side channels tend to be shallower than the main channel, and as a result they convey lesser volumes of flow and/or sediment. Observations throughout the M2 reach, as well as along other rivers, suggest that the formation, development, and persistence of side channels are greatly influenced by deposition of large wood and sediment. Hydraulic modeling results in combination with historical aerial photography indicate that larger, less frequent discharges are primarily responsible for the major changes in channel geometry (i.e., channel migration, avulsion, development of secondary channels, bar formation, deposition of large wood complexes). Conclusions from this and previous studies suggest that in the M2 reach side channels that can provide low-flow habitat for salmonids are limited to only a few areas that are either manually dredged on a frequent basis (thus lowering the channel bed elevation) or have a groundwater source (Reclamation, 2008; USFS, 2009, P. Connolly, verbal communication, 2009). Additional modeling of the smaller more frequent discharges would provide important information on flows required to inundate and maintain surface water connections in side channels and with other habitat elements currently found in the reach.

Bedrock is present at numerous locations in the valley, along the main channel, and in the channel bed. Bedrock was observed to constrict the channel of the Methow River at two locations: upstream of the Barclay-Bear Creek area and at the downstream end of the sugar dike-Twisp area. Bedrock may limit the lateral channel migration at each of these sites, but the bedrock also controls the gradient of the Methow River. In the sugar dike-Twisp area, river mile (RM) 43 to 41, this control combined with a wide floodplain and the influx of sediment from the Twisp River has resulted in widespread lateral channel migration as the river adjusts its course. Although the highway and levee limit channel migration in the sugar dike-Twisp area, about 60 percent of all floodplain erosion from channel migration that occurred in the M2 reach between 1945 and 2006 occurred in this 2-mile section. While the occurrence of bedrock in the channel may limit reach-scale incision, it may also promote local scour in areas (e.g., the Lehman area). Channel survey data indicate that bedrock is commonly associated with deepest pools (6 to 18 ft) in the active channel. Main channel pool habitat in this reach is expected to exist over long periods of time exclusive of any major channel avulsions, which would result in the formation of new pools varying in size and location.

Given objectives to improve opportunities for main channel migration, floodplain access, and side channel habitat for salmonids, from a geomorphic and hydraulics perspective, the following actions are recommended:

- Consider actions that will increase complexity (diverse channel geometry) and wetted area during low-flow periods in;
    - side channels (split flow areas) present within the unvegetated, active channel area (Qa4) that provide potential to increase wetted area and complexity due to their close proximity and hydraulic connectivity with the main channel;
    - a few well-developed side channels present within the active floodplain (Qa3) that provide opportunities for increasing low-flow habitat;
    - scour pools where local increases in water depth could be accomplished by the addition of large wood features along channel margins as the main channel is generally devoid of large wood except at the heads of vegetated islands.
- Actions should avoid construction of in-stream features in locations that would “lock the channel in place”, thus preventing or limiting channel migration.
- Allow the river to access its floodplain to improve connectivity by removing or setting back (move away from the active channel) man-made features that prevent channel migration and side channel development.
- Avoid establishing a connection between the main channel and channels on the floodplain (Qa3 or Qa2) that would increase flooding and erosion hazards for developed areas. Channel avulsion risk is highest where the main channel is or has the potential to cutoff a meander bend.
- Encourage river use practices that limit or avoid dredging and removal of large wood from the main channel and prominent side channels that could otherwise provide viable salmonid habitat features.

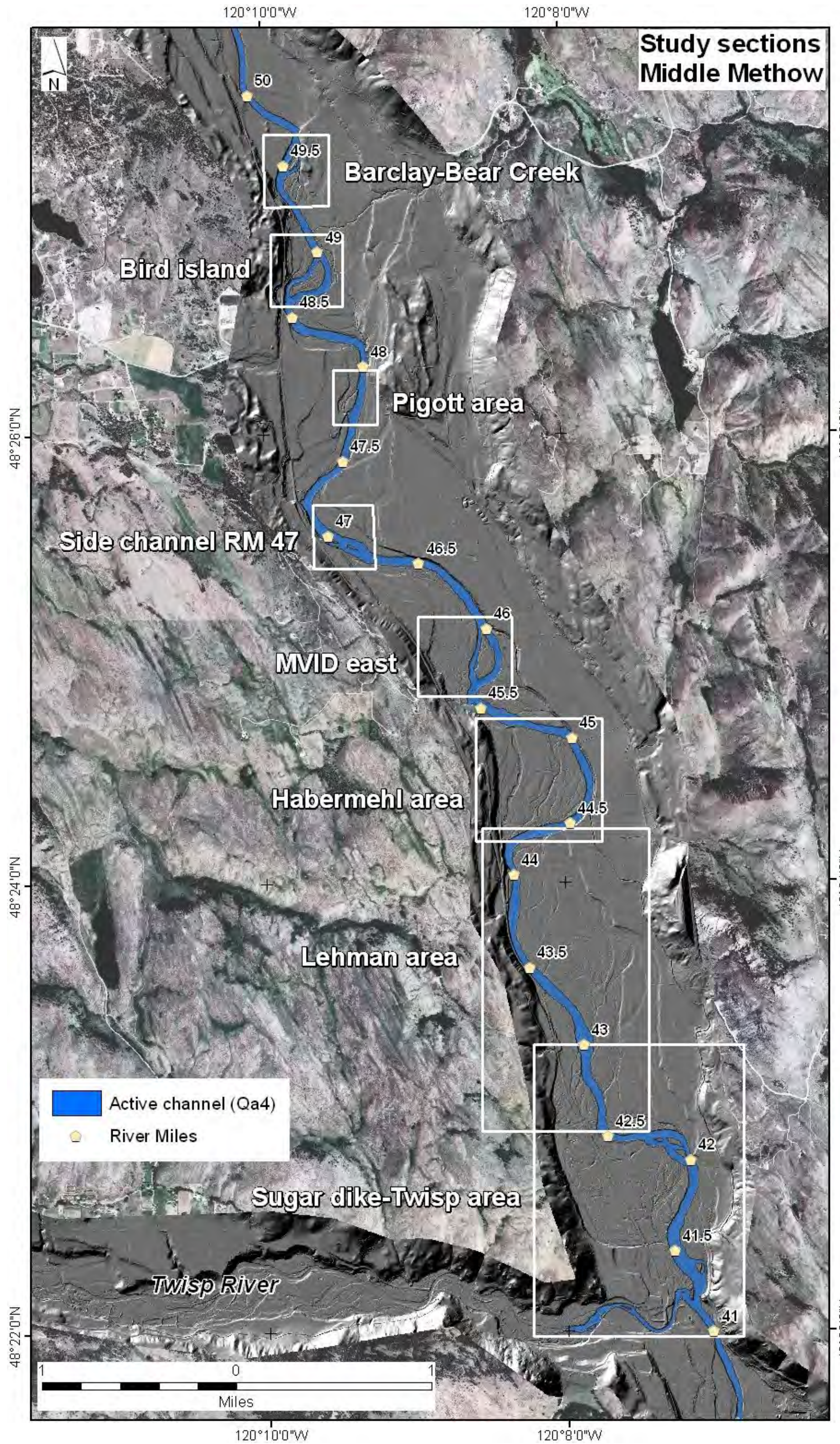

Figure 1. Location map of specific sites addressed in this report.

Acknowledgements

This report would not have been possible without the assistance of local landowners and staff from the Reclamation and U.S. Forest Service offices in Twisp and Winthrop. We would like to thank all of the landowners who allowed us access to the river and their property for channel survey and geomorphic field work, provided anecdotal accounts of particular issues and river history, and helped dig test pits. We would like to thank Ron Gross and Brandon Sheely for assistance with river survey work, and Mike Notaro, who arranged property access. We would also like to thank members and guests at the Methow Restoration Council (MRC) meeting and float trip in July 2009 for providing information and comments on our study findings. Many of their ideas have been incorporated into this report or noted as potential needs for future study that will expand on this effort. Funding for this assessment was provided to the Technical Service Center by the Columbia Snake-Salmon Recovery Office in the Pacific Northwest Region of Reclamation in Boise, Idaho.

1.0 Introduction

The findings of this report focus on the geomorphic and hydraulic properties of the Middle Methow reach (M2) of the Methow River between Twisp and Winthrop, Washington (Figure 2). An integrated application of surficial mapping and geochronology in combination with numerical hydraulic modeling was undertaken to better understand the physical processes responsible for the evolution of the river and for the formation and development of salmonid habitat in this reach. The technical methodologies utilized in developing and interpreting the data presented in this report are outlined in Section 2. Additional detail on methodology and supporting data are included in six appendices (Appendices A through F). Section 3 describes the surficial geology and the physical characteristics that help differentiate the active channel and floodplain from older alluvial deposits in the reach. In Section 4, a discussion of channel migration, incision, and side channel development based on an interpretation of the results is provided. Section 5 presents overall conclusions on the condition of the channel and floodplain along with recommendations and data needs that may be useful for future planning of rehabilitation efforts. In Appendix G, an analysis of the geomorphic relationships and numerical hydraulic modeling results is presented for specific sites that have been identified as having rehabilitation possibilities (see Figure 1 in executive summary for locations).

1.1 Background

The Bureau of Reclamation (Reclamation), U.S. Army Corps of Engineers, and Bonneville Power Administration contribute to the implementation of salmonid habitat improvement projects in Columbia River Basin tributaries to help meet commitments contained in the 2008 Federal Columbia River Power System Biological Opinion (BiOp, NOAA 2008). This BiOp includes a Reasonable and Prudent Alternative (RPA), or a suite of actions, to protect listed salmon and steelhead across their life cycle. Habitat improvement projects in various Columbia River tributaries are one aspect of this RPA. Reclamation provides technical assistance to States, Tribes, Federal agencies, and other local partners for identification, design, and construction of stream habitat improvement projects that primarily address stream flow, access, entrainment, and channel complexity limiting factors. This report provides scientific information on geomorphology and hydraulic modeling for the M2 reach that can be used to help identify, prioritize, and implement sustainable fish habitat improvement projects and to help focus those projects on addressing key limiting factors to protect and improve survival of salmon and steelhead listed under the Endangered Species Act (ESA).

The Methow Subbasin of the Upper Columbia River is located on the east side of the Cascade Range in north-central Washington (Figure 2). The Methow River flows about 86 river miles from the crest of the Cascades (elevation 8,950 feet) to its confluence with the Columbia River at river mile (RM) 524 (elevation 775 feet) and drains about 1,814 square miles. The Methow Restoration Council (MRC) and other funding entities are interested in understanding the physical processes that are responsible for the development and evolution of particular channel and floodplain features that are important as salmonid habitat in the Methow Subbasin. Ten miles of the mainstem Methow River (from RM 40 to 50) between the confluence with the Chewuch and Twisp Rivers were evaluated in this study to provide a better understanding of the geomorphic processes that are responsible for the formation of these habitat elements. The results of this study could be used in combination with fisheries and vegetation data to identify opportunities to protect or improve salmonid habitat.

For the 10-mile-long M2 reach, this study refines information provided in a report that examined the geomorphology and hydraulics for 80 miles of the subbasin, including sections along the Methow, Chewuch, and Twisp Rivers (Reclamation, 2008; referred to by Reclamation as a tributary assessment). Additional studies are being completed concurrently in support of habitat rehabilitation efforts in the Methow Subbasin. A spring Chinook and steelhead habitat assessment was completed earlier this year (USFS, 2009). This assessment identified the location and characteristics of specific physical habitat elements along M2. A vegetation survey that outlines the current state of vegetation found through the riparian corridor within the reach is currently being finalized (Prichard, written communication, December 7, 2009). An assessment of potential rehabilitation options is also being compiled (Lyon, written communication, November 17, 2009) and will be used in conjunction with all of the above studies to allow resource managers to better determine which areas in the reach present the best opportunities to improve salmonid habitat and the type of projects that might have the greatest potential for success.

1.2 Objectives

The primary purpose of the geomorphic and hydraulic modeling studies presented in this report is to better understand the physical processes responsible for the formation and development of specific salmonid habitat elements. The information in this report is intended to be utilized by design engineers, interdisciplinary teams (IDTs), basin stakeholders, and project sponsors as the technical basis for discussions regarding potential rehabilitation opportunities and possible risks, benefits, and/or constraints on specific projects or treatments. Specifically, this report addresses the following objectives:

- Describe the channel and floodplain processes that are responsible for the development of side channels;
- Evaluate the potential for erosion of older, higher elevation terrace and floodplain surfaces along the margins of the main channel;
- Evaluate historical main channel migration and avulsions and the potential for channel changes in the future;
- Evaluate historical channel change in regards to bed elevation (incision) and channel width (bank erosion);
- Describe the impacts of constructed features (levees, bridges, riprap, etc.) and historical human activities (e.g., vegetation and wood clearing, excavation and/or

fill done in channel and floodplain, etc.) on channel migration and floodplain inundation;

- Model the extent and depths of inundation over the various terraces and floodplain surfaces for a range of discharges;
- Provide an understanding of channel processes that can be used by Reclamation staff and the Methow Resource Council in identifying and planning potential rehabilitation strategies in the M2 reach.

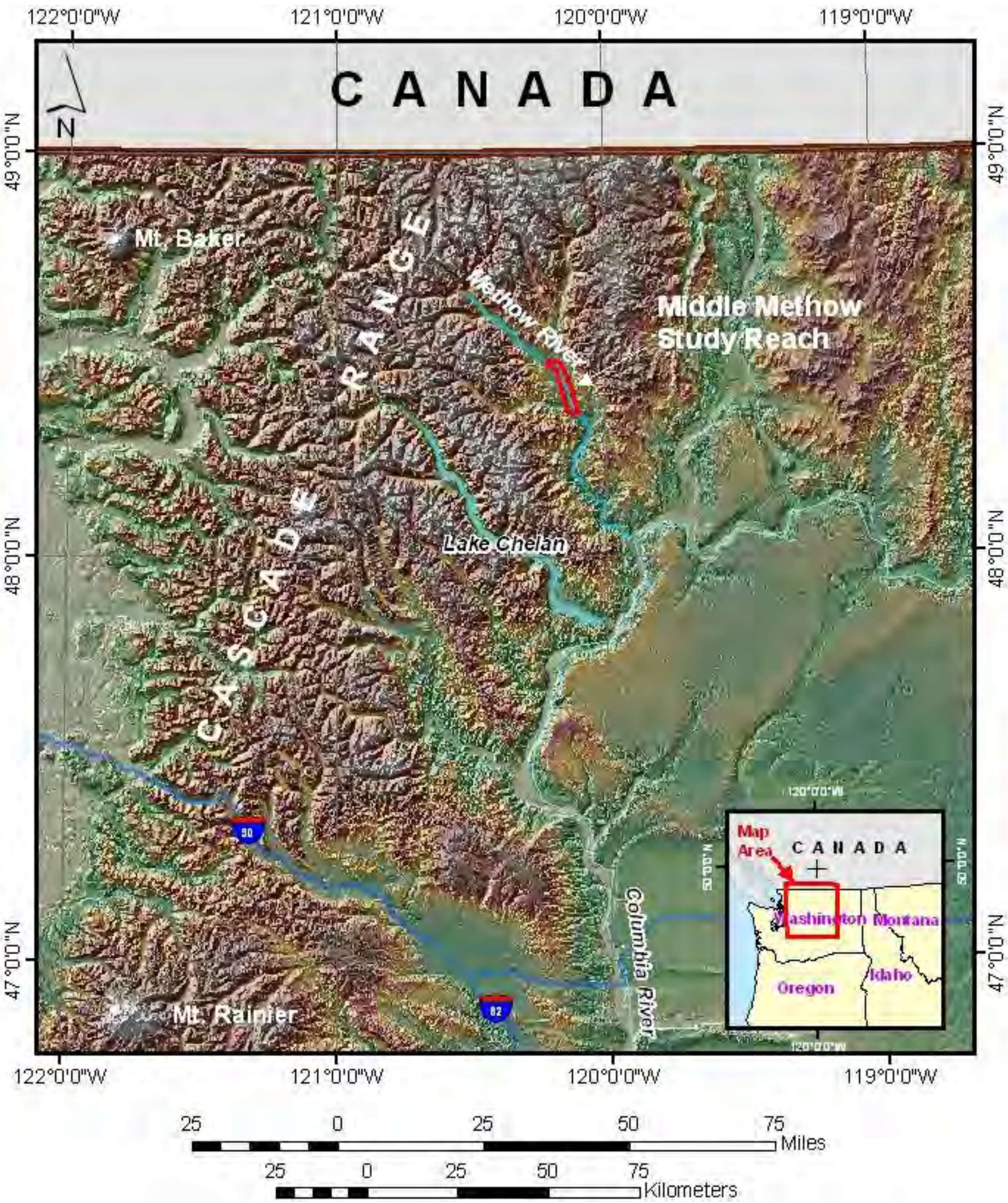

Figure 2. Map showing the location of the Middle Methow (M2) reach within the Methow Subbasin of the Upper Columbia River and surrounding area.

2.0 Methods

The technical methodologies utilized in developing and interpreting the geomorphic and hydrologic data and modeling components of this study are outlined in the following sections.

2.1 Geomorphology

Reconnaissance-level mapping of the surficial geology was completed for 80 miles of the Methow Subbasin, including sections along the Methow, Chewuch, and Twisp Rivers as part of a tributary assessment (Reclamation, 2008). For this study, the surficial mapping was refined by focusing on the active channel and floodplain (the low surface of the tributary assessment; Reclamation, 2008). More detailed data were collected in these areas, because they were viewed as having the most opportunities for improving salmonid habitat. The refined surficial map (Appendix A) benefited from the availability of 2006 light distance and ranging (LiDAR) data. Historical aerial photographs and maps ranging from 1894 to 2006 also were used. The initial mapping was revised and refined with the aid of 1) cross sections generated from a combination of the 2006 LiDAR data and the 2008 channel survey, 2) field observations made during 2008 and 2009, and 3) two-dimensional (2D) hydraulic model results for the M2 reach (described in section 2.2 and Appendix B). In addition, areas of bedrock that were mapped for the tributary assessment were verified and delineated in greater detail because of the important role the bedrock plays in forming scour pools in the main channel. Alluvial deposits outside of the floodplain were mapped in less detail.

Side channel evolution, channel migration, and incision were evaluated using historical accounts, aerial and ground photography, Government Land Office (GLO) and geologic maps, and existing ground and channel surveys. Changes in the existence, position, path, length, or expression of the side channels were also noted on the historical aerial photographs and their formation and development were tentatively correlated to specific floods. Channel types described in this report are referred to as main, side, and overflow channels. The main channel includes the primary channel of the Methow River, including unvegetated bars, and its flow path for a given point in time. It carries the vast majority of the sediment load and flow. Side channels are generally located adjacent to or along the main channel, generally have a well defined flow path for their entire length, and have a frequent surface water connection with the main channel at either or both their upstream and downstream ends. Side channels may be associated directly with the main channel where they may represent the smaller of two or more channels (a split in the main channel) and convey lesser volumes of flow and/or sediment or they may be part of the floodplain. Overflow channels are channels formed within the floodplain and convey flood flows. An important distinction between side channels and overflow channels as defined here is that overflow channels generally do not have a surface connection with the main channel at lower discharges and are only inundated by larger floods (greater than 5-10 year floods). Overflow channels may not represent reliable habitat as they are only connected to the main channel by surface flow on time frames greater than the lifespan of the salmonid species that might utilize them. Locations of the most prominent side channels, their physical form, the types and sizes of sediment transported through them, the surficial deposits adjacent to them, and large wood and sediment deposits in them were noted in the field. Smaller side channels can be observed on aerial photography and in the LiDAR data.

To provide a better understanding of the geomorphic processes affecting channel migration, incision, and side channels, age ranges for the surficial map units were estimated on the basis of historical data, radiocarbon analyses of detrital charcoal, geochemical analysis of volcanic ash, and descriptions of the physical characteristics of the sediment comprising the floodplain deposits and the soils developed on them. Thirty charcoal samples and a single volcanic ash were collected from eight sites along exposed banks or in pits excavated on the different map units. The charcoal samples were submitted to Paleo Research in Golden, Colorado, where they were cleaned and identified (see Appendix D). Six charcoal samples were prepared and submitted for radiocarbon analyses (see Appendix D). The volcanic ash was submitted to the Microbeam Laboratory at Washington State University in Pullman, Washington, for analysis (see Appendix E).

Ten soil profiles were described on the different surficial map units. Particular soil properties on alluvial deposits have been shown to increase in development and become more pronounced with age (Birkeland, 1999). Changes in these properties among alluvial units of different ages can be used to correlate deposits across the map area and to deposits of known age. Soil properties on the floodplain and terrace deposits along the M2 reach were described primarily to delineate the physical characteristics of the various map units and to facilitate correlation of the map units in the study reach. Detrital charcoal recovered from the soil test pits was utilized in radiocarbon analyses to establish the chronology for the deposition of the various units and to document the history of channel migration and incision. Five soil profiles were described on the Qa3 map unit; three profiles were described on the Qa2 map unit; and one soil profile was described on each of the map units Qa1 and Qgo3. Five of the profiles were described in hand-dug pits; three of the profiles were described in natural bank exposures. One soil profile was described in a shallow trench (about 2 meters deep) that had been excavated for a water line associated with new house construction, and one pit was excavated by the landowner with a backhoe. Field properties for all of the soil profiles were described following methodologies outlined in Birkeland (1999) (see Appendix C).

2.2 Hydrology

The Methow River at Twisp (USGS gage no. 12449500, about RM 50) has a drainage basin area of about 1,301 square miles (Table 1). The Twisp River, which enters the Methow River just upstream from this gage, contributes about 245 square miles to the drainage area of the Methow River basin. Given the objectives of this study (see section 1.2) discharges equivalent to the 2-year flood and greater were modeled to assess changes in floodplain inundation over a range of discharges. Discharges utilized in this study were derived from a flood frequency analysis of annual peak discharge (Reclamation, 2008) for gages in the M2 reach (Table 2).

Table 1. USGS stream gages with more than 10 years record in the M2 reach.[1]

USGS Gage No.	Gage Location	Peak of record (date)	Years of record	Drainage area (mi^2)
12449500	Methow River at Twisp, WA	40,800 cfs 5/29/1948	52	1,301
12448998	Twisp River near Twisp, WA	9,440 cfs 5/29/1948	19	245
12448500	Methow River at Winthrop, WA	24,400 cfs 5/31/1972	16	1,007

[1)] Table modified from Table J-1, Appendix J of Reclamation (2008).

Table 2. Annual Peak Discharge Frequency data computed for USGS stream gages.[1]

Gage Location	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	1948 Flood
Methow River at Twisp	11,100	16,000	19,200	23,000	25,700	28,300	40,800
Twisp River near Twisp	2,120	3,160	3,890	4,860	5,610	6,390	9,440
Methow River at Winthrop	9,020	13,300	16,600	21,400	25,400	29,700	N/A

[1)] Table modified from Table J-2, Appendix J of Reclamation (2008). Unit cfs is cubic feet per second. Note that these flood frequency values do not include data from 2005-2009.

Large floods occur in the Methow Subbasin in late-spring and early-summer from snowmelt with occasional rainstorms throughout the winter. Snowmelt floods last several weeks, where as the rainstorm generated floods are fairly flashy, occurring over a matter of days. In a prior report, analysis of the mean daily flow data at the Methow River USGS gage below Winthrop was performed to produce standard flow duration curves that depict the fraction of time that the river flows are below a specific flow (Appendix J of Reclamation, 2008) (Figure 3).

Of particular interest in terms of channel evolution were the two largest documented floods of 1894 and 1948 (both are considered to have peak discharges greater than a 100-year flood), the flood of 1972 (the peak discharge is about equal to the 25-year flood), and the floods of 2006 and 2008 (peak discharges for both range from about the 10- to 25-year floods). A comparison of the available annual flood peaks relative to flood frequency values developed in Reclamation (2008) at the USGS gages is provided in

Figure 4 and Figure 5. Note that the flood frequency values do not include data from 2005 through 2009 and could be updated in future studies if necessary.

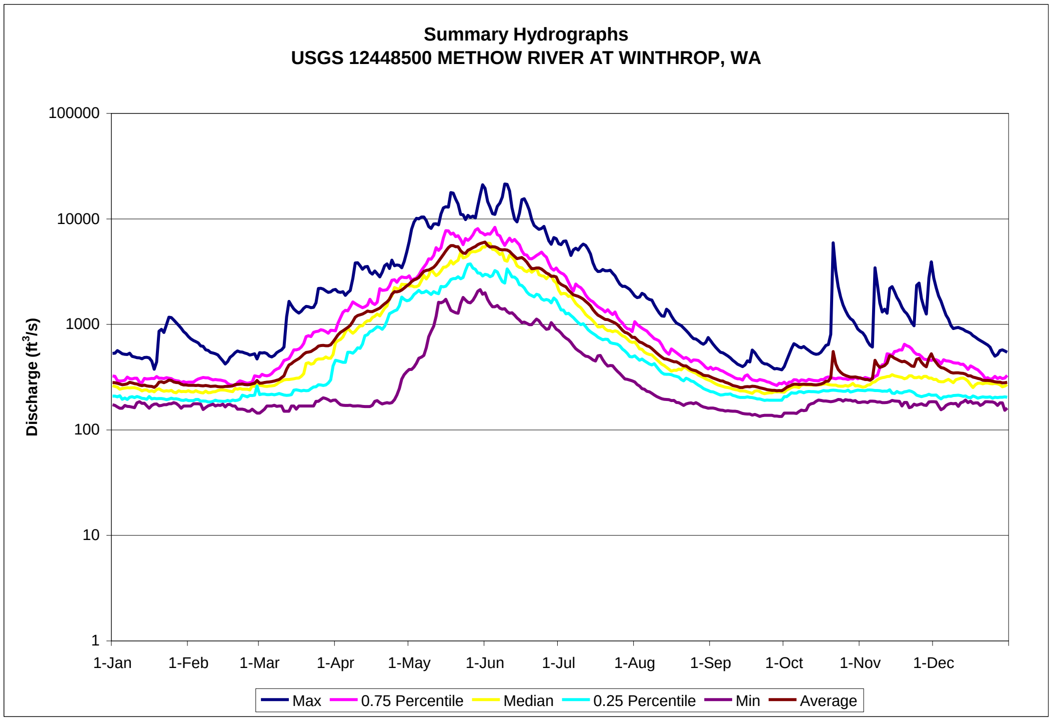

Figure 3. Mean daily flow statistics for the Methow River at Winthrop, WA.

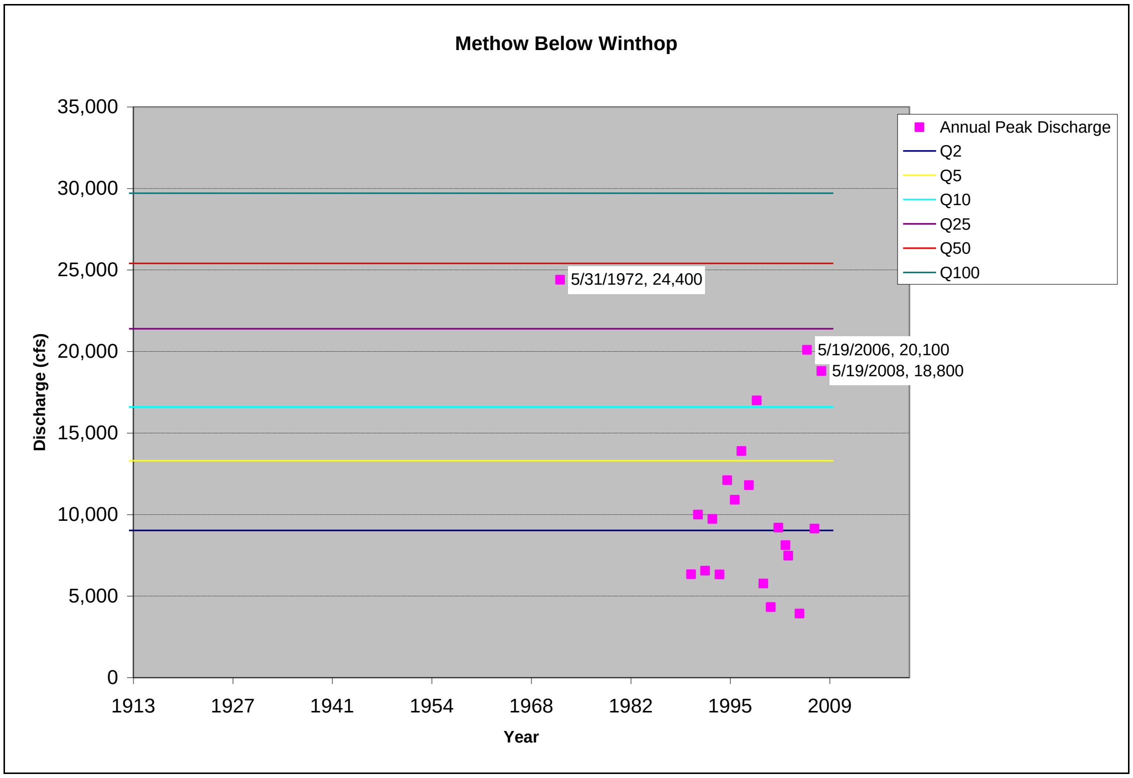

Figure 4. Flood frequency values plotted against annual peak discharges for the USGS gage below Winthrop.

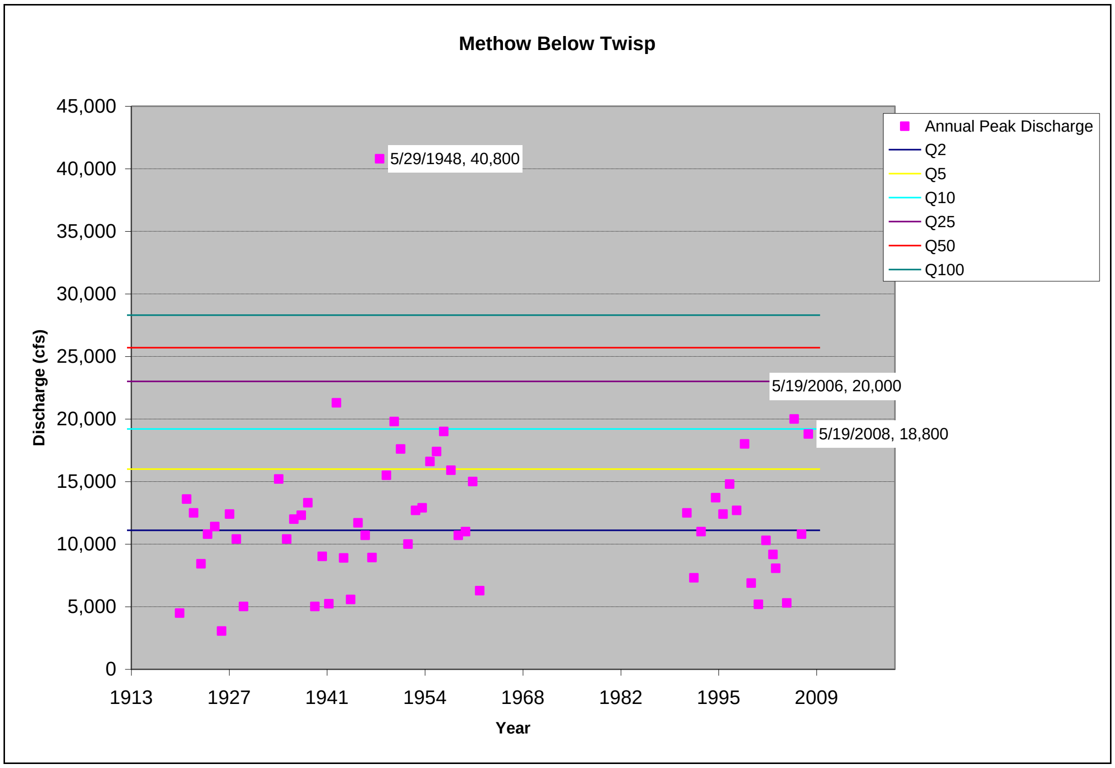

Figure 5. Flood frequency values plotted against annual peak discharges for the USGS gage below Twisp.

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 cfs (Beck, 1973). The location of the estimate was not described in the 1973 report, but may likely have been at the mouth near the gage at Pateros. 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.

Beck (1973) notes the 1948 Flood occurred 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.

Beck (1973) notes the 1972 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 a rapid rise in discharge. 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. The flood caused widespread damage from erosion and large amounts of inundation.

A published report on the local weather was not found for the 2006 or 2008 floods. As an example of the flood duration, a hydrograph of 2008 mean daily flows from the USGS gage below Winthrop is shown in Figure 6.

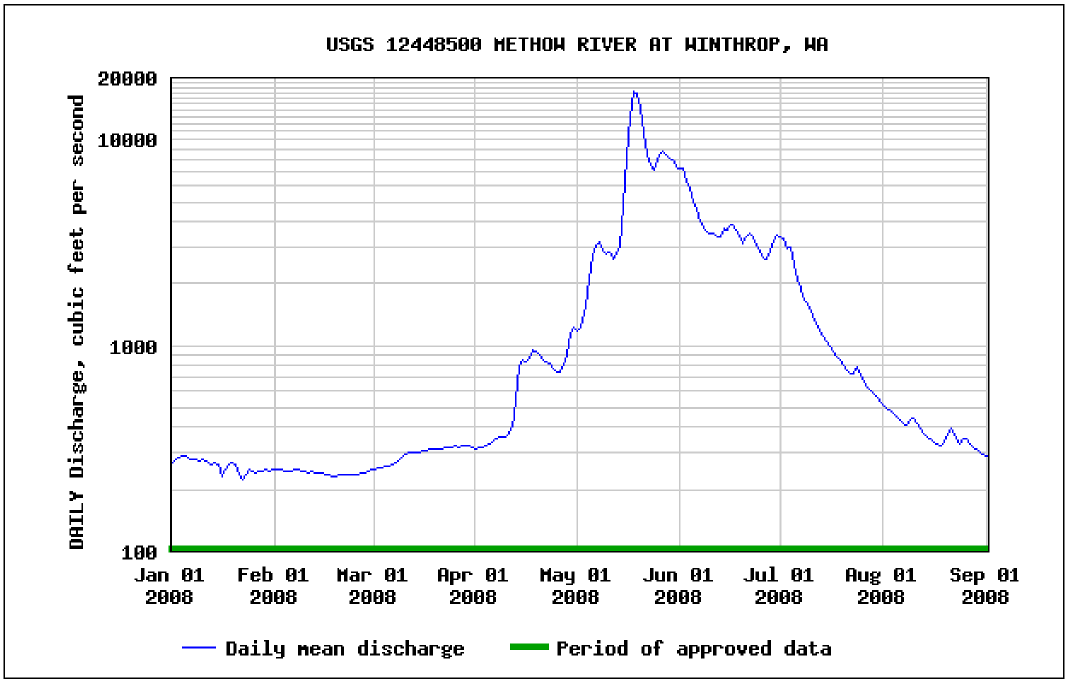

Figure 6. Example hydrograph of mean daily flows from USGS web site for the Methow gage below Winthrop (USGS gage 12448500). The peak discharge of 18,800 cfs occurred on May 19, 2008.

2.3 Modeling

The two dimensional (2D) numerical model, SRH-2D v3.0, was used for analysis of river hydraulics in the M2 reach. A 2D model was utilized to accurately represent complex flow patterns. To facilitate the modeling effort, the 10-mile reach was subdivided into two shorter reaches:

- Area #1: RM 40.9 (USGS gage below Twisp confluence; Methow River at Twisp) to 45.5 (downstream end of MVID East)
- Area #2: RM 45.5 to 50.8 (USGS gage downstream of Chewuch River confluence; Methow River at Winthrop)

A range of discharges was modeled as steady flows (single discharge for each model run) based on recorded flow values at the USGS Methow River gage below Winthrop (Table 3). The flow contribution from the Twisp River was incorporated by coarsely modeling the downstream-most 1 mile of the Twisp River based on either flow values at the

Methow River below Twisp (minus the value at Winthrop) or values derived from the Twisp River gage as described below (Table 3).

Discharge data was not available at all 3 gages in the study reach for the modeled floods. Additionally, the recorded gage value at the gage below Twisp does not typically equal the value at the gage below Winthrop plus the value recorded on the Twisp River near the mouth. At low flows the reason for the discrepancy may be due to a combination of factors, including measurement errors, two surface water diversions near RM 49 and 46, and numerous undocumented groundwater sources. At high flows, flood attenuation and measurement errors are the most likely contributors to this discrepancy. Availability of data and judgment was used to determine values for modeling that would most closely meet study objectives.

The Methow River value of 285 cfs was determined by taking the average mean daily flow value for the survey period, October 6 to 10, 2008, from the Methow gage below Winthrop. At the Methow gage below Winthrop the mean daily flow values ranged from 274 to 297 cfs. For the Twisp River, the 70 cfs value was determined by averaging the five days of mean daily values at the Methow River below Twisp gage (355 cfs) and subtracting the 285 cfs Methow River at Winthrop gage. Actual Twisp River flow values near the mouth ranged from 44 to 55 cfs during the survey, which is about 20 cfs lower than the modeled 70 cfs. There are also two diversions and numerous groundwater contributions to the M2 reach at low flows. It was beyond the scope of this study to incorporate these contributions for the low-flow model. Hydraulic model results for the low-flow model are approximate given the uncertainty in flow estimates.

The 2006 flood value on the Methow was determined by taking the mean daily flow on May 23, 2006 at the gage below Winthrop. The 2006 value for Twisp was taken from the Twisp River gage on May 23, 2006. It should be noted that the total of these two flows is 12,920 cfs but the flow value at Methow below Twisp was recorded on May 23, 2006 as 11,600 cfs.

Values for the 10-year flood were taken from a prior flood frequency study (Reclamation, 2008) at the Methow River at Winthrop gage and at the Twisp River gage.

The 1972 flood peak for the Methow River was the recorded value on May 31 for the Methow River below Winthrop. The 1972 flood peak for the Twisp River was determined by subtracting the Methow River below Winthrop (24,100 cfs) from an estimate of the peak for the Methow River below Twisp (26,120 cfs) reported in Beck (1973). No 1972 flood value was available from USGS gage data for the Twisp or the Methow below Twisp.

The 1948 flood peak for the Methow River (31,360 cfs) was determined by subtracting the Twisp River gage value (9,440 cfs) from annual peak recorded on the same day (May 29) for the Methow River below Twisp (40,800 cfs). The 1948 flood value for the Twisp River was based on the Twisp River gage value (9,440 cfs).

Table 3. Discharges used in the numerical two-dimensional hydraulic model.

Methow River (cfs)	Twisp River (cfs)	Notes
285	70	Low flow discharge; mean daily flows during channel survey in October 2008
10,900	2,020	Equivalent to about 2-yr flood; falling limb of May 23, 2006, flood
16,600	3,890	10-yr flood
24,400	1,720	1972 peak; equivalent to about the 25-yr flood
31,360	9,440	1948 peak; larger than the 100-yr flood

Model runs only evaluated existing topography. Existing topography was not modified to show the effect of removing constructed features (e.g., dikes, levees, and riprap), addition of large wood, construction of channels, or other potential restoration concepts. Model mesh elevations were developed from the LiDAR data collected in 2006 and the main channel survey collected from October 2008. The low-flow model run was validated with water surface elevations (WSE) collected during the October 2008 survey. In addition, model output was compared to aerial photography taken during the falling limb of the 2006 and 2008 floods at known discharges, and to a limited number of historical high water marks for the 1972 and 1948 floods reported in Beck (1973).

The model results are applicable for understanding main channel flow characteristics and side channel and floodplain connectivity at the discharges modeled. Water surface elevations predicted by the model are estimated to be within 0.5 ft, but the error may be larger in areas where LiDAR data did not accurately represent ground elevations due to dense tree cover or because the area was inundated at the time of the survey. A summary of the modeling results for specific sites is in Appendix G; detailed discussion of the numerical model is in Appendix B.

3.0 Surficial Geology

Surficial geologic units were delineated within the M2 reach. These units include alluvium along the present river corridor, bedrock and colluvium, alluvial-fan deposits, and glacial outwash terraces. Delineation and description of these units help in the understanding of the formation and evolution of the channel and floodplain. The surficial geologic units were delineated on the basis of their surficial expression, the character of the associated deposits and the soils developed in them, and their heights above and relationship to the present channel and other surficial geologic units. In places, material for absolute dating was collected and submitted for analysis. Surficial geologic maps and a table of the characteristics of the units are in Appendix A. Individual map units are described in the following sections. Channel, floodplain, and terrace units and the youngest (lowest) glacial outwash are the most important units defined in the reach assessment and are the ones that were examined in the most detail. These units are unconsolidated deposits that are commonly related to the main channel and floodplain. Older glacial outwash units, alluvial-fan deposits, and colluvium were mapped primarily from their surficial expression, their height above the channel, and brief field observations (e.g., exposures in road cuts). These units are described only briefly in the final sections.

3.1 Geomorphic Map Units

Characteristics of the individual map units are shown in Table 4 and Appendix A. All of the fluvial map units (e.g., Qa1, Qa2, Qa3, Qa4) and glacial map units (Qgo1, Qgo2, Qgo3) are composite units and include surfaces with variable surficial expression, heights above the main channel, and, presumably, variable ages. In order to keep the map units as simple as possible and to complete mapping of the entire reach within the time and budget allowed by this reach assessment, the four units were delineated on the basis of major differences in their physical characteristics. More detailed mapping could refine the present map units.

Elevation above the main channel was one characteristic that was used to define the four fluvial map units. These elevations vary longitudinally along the river corridor between sections of the reach that are narrower and sections that are wider. In general, the units are higher above the main channel and the differences in the heights among the map units are greater in the narrower sections than in the wider sections. Longitudinal correlations of surfaces among discontinuous remnants are based primarily on surface expression and deposit characteristics. Limited absolute dates confirmed these correlations where possible (Table 4).

Table 4. Numeric and estimated ages for geomorphic units.

Unit	Unit designation	Estimated age range of surfaces and deposits	Numeric ages[1]
Qa4	Active channel (unvegetated)	Historic (a few years to a few hundred years)	None
Qa3	Active floodplain (vegetated)	Latest Holocene 300 to 1,000 years (a few hundred years to a thousand years)	≤270 cal yr BP
			≤310 cal yr BP
			480 to 310 cal yr BP
			1480 A.D. (Mount St. Helens ash)
			640 to 510 cal yr BP
Qa2	Higher floodplain	Late Holocene 1,000 to 2,000 years (a few thousand years)	1,270 to 1,080 cal yr BP
			1,170 to 980 cal yr BP
Qa1	Terrace	Middle Holocene (age unknown but older than Qa2 and younger than Qgo3)	No datable material recovered
Qgo3	Glacial terrace (younger)	Latest Pleistocene 10,000 to 12,000 years (end of last major regional glaciation)	None
Qgo2	Glacial terrace (intermediate)	Pleistocene	None
Qgo1	Glacial terrace (older)	Pleistocene	None

[1]Radiocarbon analyses are in Appendix D. Ash identification is in Appendix E.

3.2 Qa4: Active Channel

The active channel (Qa4) includes the main channel, split flow paths, and unvegetated or sparsely vegetated bars associated with the main channel (Figure 7). It is the area that has flow and is modified on an annual or semi-annual basis during the highest seasonal flows. At low flows of 300 to 400 cfs, many side channels within Qa4 do not contain water except for areas with groundwater contributions. The 2-year flood inundates all channels and bars within Qa4. The unvegetated bars are positioned as point bars on the inside of meander bends, lateral bars along straight sections, and as mid-channel bars between split flow paths in the main channel. The bars are commonly 4 to 8 feet above the main channel, but can be as high as about 10 feet. Deposits associated with the Qa4 map unit are composed of gravelly sand or sand and lack soil development.

Side channels are present along the edges of the main channel, and are usually separated from the main channel by an unvegetated bar or vegetated island. Unit Qa4 is often bounded by the next oldest fluvial unit, Qa3, but can also be bound by any of the older units listed in Table 4. On the basis of mapping from historical aerial photographs and the estimated age of the next oldest map unit (Qa3), unit Qa4 are estimated to be a few years (where a new avulsion has occurred) to a few hundred years in age. It should be noted that although the Qa4 channel remains in the same lateral position in some locations, reworking of sediment along the channel bed is still occurring from year to year.

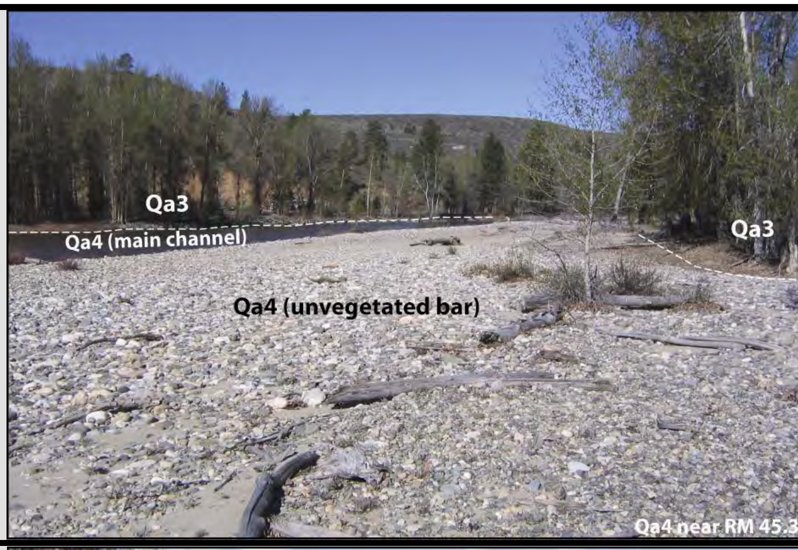

Figure 7. Main channel and unvegetated bars that compose map unit Qa4.
Upper photograph was taken near RM 45.3 looking upstream and shows the difference between the unvegetated bars of Qa4 and the vegetated surfaces of Qa3. Lower photograph was taken near RM 43 looking downstream and shows the main channel and unvegetated bar of Qa4 and the vegetated active floodplain (Qa3).

3.3 Qa3: Active Floodplain

Unit Qa3 includes the active floodplain. The Qa3 surfaces are highly irregular and include prominent side and overflow channels of various sizes and morphology (Figure 8). The most prominent side channels in Qa3 can have a surface water connection with the main channel at the 2-year flood. At the 10-year flood, the majority of the Qa3 surface is overtopped. The 1948 flood is generally contained within unit Qa3.

The Qa3 surfaces are present continuously along one or both sides of the main channel, Qa4. The Qa3 map unit includes vegetated islands that are surrounded by split flow paths within the active channel (Qa4).

Most of the side channels within Qa3 are distinct and well defined. They may be connected to the main channel at either their upstream end, downstream end, or both during certain flows. These channels may be unvegetated or vegetated, and can be large enough to have unvegetated bars associated with them. Wood is often present within these channels, especially at or near their upstream ends. The elevations of these channels may be similar to that of the main channel. Overflow channels are common within Qa3, and are often small and of limited extent. Overbank flow must occur for these channels to be inundated. Characteristics of the side and overflow channels are discussed in Section 4.3. Some areas mapped as Qa3 have nearly smooth surfaces and channels are not readily visible. These areas have been substantially modified by human activity, and surface morphology is not representative (e.g., much of the Qa3 surface on river right downstream of the sugar dike near RM 42.5). These areas are included in the Qa3 map unit on the basis of their elevation and their relationship to adjacent undisturbed surfaces.

Deposits associated with the Qa3 map unit include sandy alluvium (overbank deposits) of variable thickness often over gravelly alluvium (channel deposits). In places, gravelly alluvium is present to the ground surface. The Qa3 surfaces are often vegetated with riparian species, but may be unvegetated in recently active channels or in areas of human use.

Four soil profiles were described on Qa3 surfaces: M2-4 near RM 44.5, M2-6 near RM 41.7, M2-7 near RM 42.25, and M2-9 near RM 43 (Appendix C). Soils on the Qa3 surfaces consist of a sequence of sandy overbank deposits with no or minimal soil development. Profile M2-4 and probably M2-6 (Figure 9) include buried A horizons that indicate a brief period of stability between flood events that deposited sand at these sites. These sites record evidence for recurrent overtopping by flood flows at intervals short enough to limit soil development. The youngest deposits at these sites may have been left by the 1948 flood. Gravelly channel deposits are present at depths of >0.5 meter at two sites. At M2-7, the gravelly channel deposits are overlain by silty and clayey sediment that was deposited in a backwater area (e.g., a cutoff oxbow).

Figure 8. Examples of the morphology, vegetation, and wood on map unit Qa3.

Upper left photograph shows subtle channels with recently deposited sand and wood through cottonwood trees (R.E. Klinger photograph #7081). Upper right photograph shows recently deposited wood in foreground and conifers on a slightly higher surface within Qa3 in background. Lower left photograph shows wood that has been deposited during a recent flood that overtopped the Qa3 surface just upstream of the sugar dike (R.E. Klinger photograph #7668). Lower right photograph shows the open tree cover on Qa3 surface in background and the extent of sand and wood indicating recent flow in foreground.

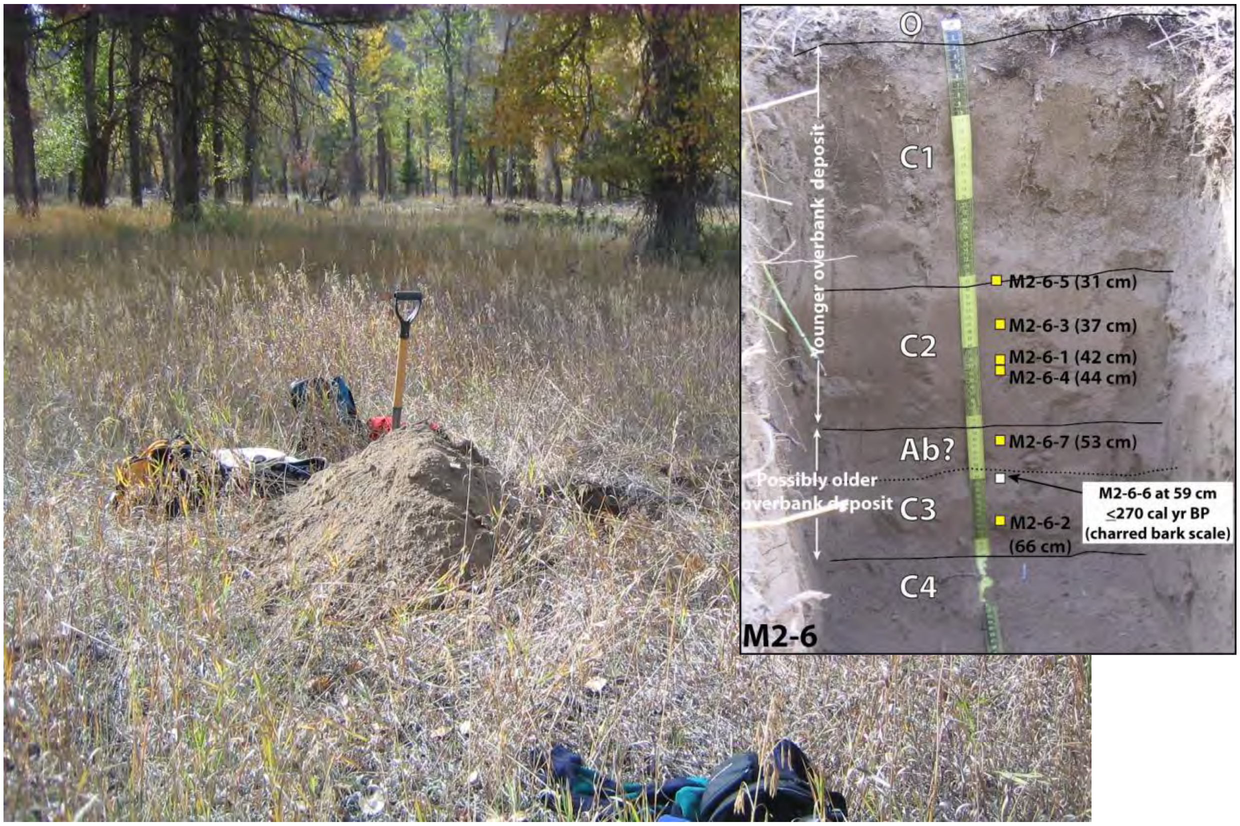

Figure 9. Soil profile M2-6 on Qa3 surface on river right near RM 41.7.
The surface is between overflow channels that carried flow during the 1948 flood. Soil profile (inset photograph) includes a possible buried A horizon at a depth of 52 cm and indicates a brief period of stability and no deposition between floods that overtopped the surface at this locality. A radiocarbon date on charcoal from the deposit beneath this buried surfaces yielded an age of ≤270 cal years BP (Appendix D).

Charcoal collected from three of the soil profiles yielded radiocarbon dates of several hundred years or less (Table 4; Appendix D). The volcanic ash present in backwater deposits at M2-7 was erupted from Mount St. Helens about 1480 A.D. (Appendix E). These dates suggest that the Qa3 deposits range between a few hundred, to perhaps a thousand, years old to the present.

Qa3 surfaces vary in height above the main channel longitudinally along the river, depending upon the width of the floodplain. In narrower sections of the study reach (upstream of RM 46.75 and downstream of RM 41.25), Qa3 surfaces are commonly 10 to 17 feet above the present main channel. In wider sections (RM 41.25 to RM 46.75), Qa3 surfaces are commonly 2 to 12 feet above the present main channel, but can be up to about 15 feet above. Similarly, the height differences between the Qa3 and Qa4 surfaces vary longitudinally. In the narrower sections, Qa3 surfaces are commonly 4 to 6 feet above adjacent unvegetated bars in unit Qa4, but range between 2 and 8 feet above the bars. In the wider sections, Qa3 surfaces are commonly 2 to 4 feet above adjacent unvegetated bars, but range between about 0.5 and 7 feet above the unvegetated bars.

Model results show that some channels within Qa3 are inundated at a discharge of about 11,000 cfs (a 2-year flood) (Figure 10). At a discharge of 16,600 cfs (a 10-year flood), the majority of the Qa3 surface becomes inundated by at least shallow flow except in the widest areas of Qa3 or where human features or fill has been placed and block or limit access by the river. A discharge of 31,360 cfs (1948 flood peak) is contained within Qa3, which is nearly entirely inundated by water deeper than about 2 ft. Most of the Qa3 surfaces were inundated during the 1948 flood. Some areas that were not inundated or only minimally inundated during the 1948 flood were included in the Qa3 map unit on the basis of their height above the present channel and their surface morphology. An example is the Lehman area, on river left between RM 42.75 and RM 44.25. Most of this area is the same elevation as areas inundated during the 1948 flood, but flooding of the entire Qa3 area is difficult to determine on the 1948 aerial photographs. Because of the elevation of this area, it is included in the Qa3 map unit, although major inundation during the 1948 flood likely occurred only in the section within about 1,500 feet of the present main channel.

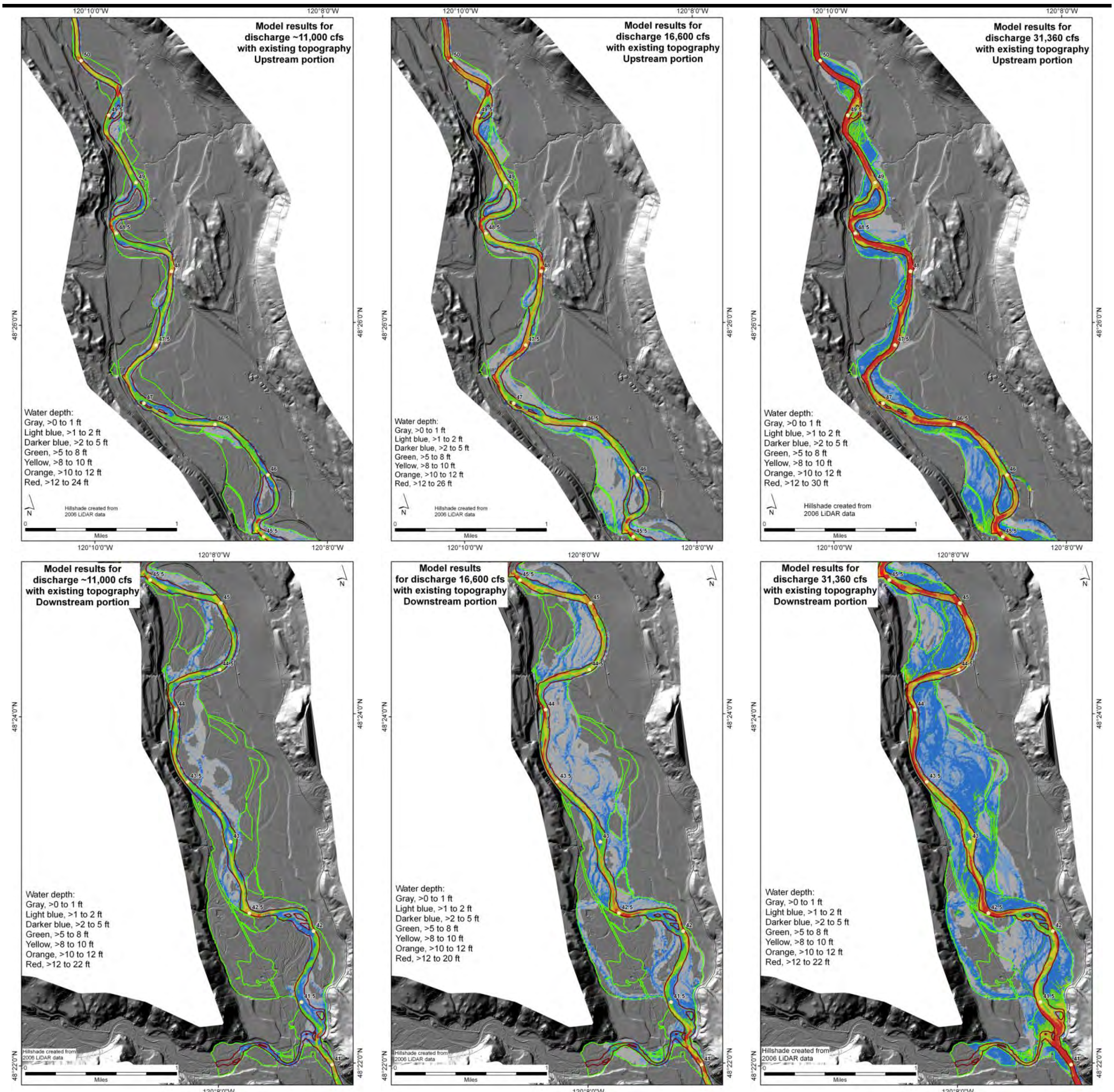

Figure 10. Hydraulic modeling results showing inundation of Qa4 and Qa3 surfaces at discharges of, from left to right, (1) about 11,000 cfs (about a 2-yr flood), (2) 16,600 cfs (a 10-year flood), and (3) 31,360 cfs (the 1948 flood peak).
Colors indicate potential water depths as shown on the maps. Channel area within the brown outline is Qa4. Areas outlined in green are Qa3. Areas outside the green outline are other map units older than the Qa3 and Qa4. Upper figures are for the upstream section of the M2 reach. Lower figures are for the downstream section.
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3.4 Qa2: Higher Floodplain

The higher floodplain includes areas that are inundated only during very large floods or areas that are at the same elevation as these rarely inundated areas but have received little, if any, flood flow historically. The Qa2 surfaces are present as discontinuous remnants along both sides of the valley. Most of the Qa2 remnants are separated from the main channel (Qa4) by active floodplain (Qa3).

The Qa2 surfaces are slightly irregular and include some low-relief overflow channels (Figure 11). Most channels are readily visible on LiDAR hillshade or on the ground, but are not as well-defined as channels on the Qa3 surfaces. The channels on the Qa2 surfaces may not extend across the entire surface. They are often better defined at their downstream ends and become poorly defined upstream as they are likely formed by headward erosion from the edge of the Qa2 surface. These channels may be only sparsely vegetated, which appears to be the result of artificial clearing, rather than recent channel flow. Wood is rarely present within these channels. The elevations of the channels are usually well above the elevation of the main channel, so that they are activated only during the largest floods. During the 1948 flood, one channel (in the Habermehl area near RM 45) was eroded through a Qa2 surface to an elevation low enough to be mapped as Qa3. After the channel was eroded by this large flood, it could be inundated during floods with smaller discharges.

The deposits associated with the Qa2 map unit include sandy alluvium (overbank deposits) of variable thickness over gravelly alluvium (channel deposits) (Figure 12). The Qa2 surfaces are often cleared of natural vegetation and have been used for pasture, crops, and building sites (Figure 11).

Four soil profiles were described on Qa2 surfaces: M2-2 near RM 40.75, M2-3 near RM 41.75, M2-5 near RM 44.75, and M2-10 near RM 45.25 (Appendix C). The soils are developed in sandy overbank deposits and (or) in gravelly channel deposits. The soils either show moderate development in areas that have been stable for about 1,000 years or more or they show minimal development in areas that have been overtopped one or more times during about the last 1,000 years.

Qa2 surfaces vary in height above the main channel longitudinally along the river, depending upon the width of the floodplain. In narrower sections of the study reach (upstream of RM 46.75 and downstream of RM 41.25), Qa2 surfaces are commonly 10 to 18 feet above the main channel. In wider sections (RM 41.25 to RM 46.75), Qa2 surfaces are commonly 5 to 10 feet above the main channel, but range between about 8 feet and 20 feet above the channel. Similarly, the height differences between the Qa2 and Qa3 surfaces vary longitudinally. In the narrower sections, Qa2 surfaces are commonly 5 to 10 feet above adjacent Qa3 surfaces, but can also be only about 2 feet above them. In the wider sections, Qa2 surfaces are commonly 1 to 2 feet above adjacent Qa3 surfaces.

Qa2 surfaces are generally not inundated by 2- to 10-year floods (~11,000 cfs and 16,600 cfs, respectively). Qa2 surfaces in wider sections are inundated by at least shallow (>0 to <1 ft) during a 25-year flood (24,400 cfs), but Qa2 surfaces in narrower sections are not (Figure 13). At a discharge of 31,360 cfs (1948 flood peak flow), most Qa2 surfaces are inundated by flow between 0 and 2 feet deep. The edges of the Qa2 surfaces or channels across them were inundated during the 1948 flood.

Figure 11. Morphology and vegetation on Qa2 surfaces.
Note the subdued form of overflow channels on these surfaces (indicated by arrows).

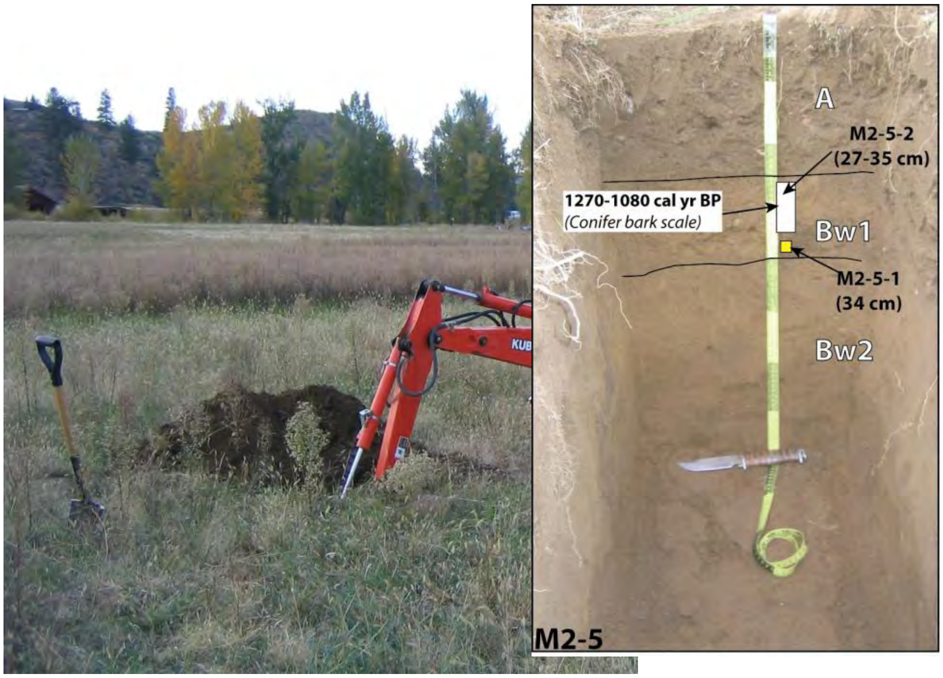

Figure 12. Soil profile M2-5 on Qa2 surface, river right near RM 44.75.
Soil is developed in sandy overbank deposits and has a color B horizon (inset photograph). Radiocarbon date on charcoal from depths between 27 and 35 cm indicates that the Qa2 soil is between 1,000 and 2,000 years old (Appendix D) and has received little deposition since that time.

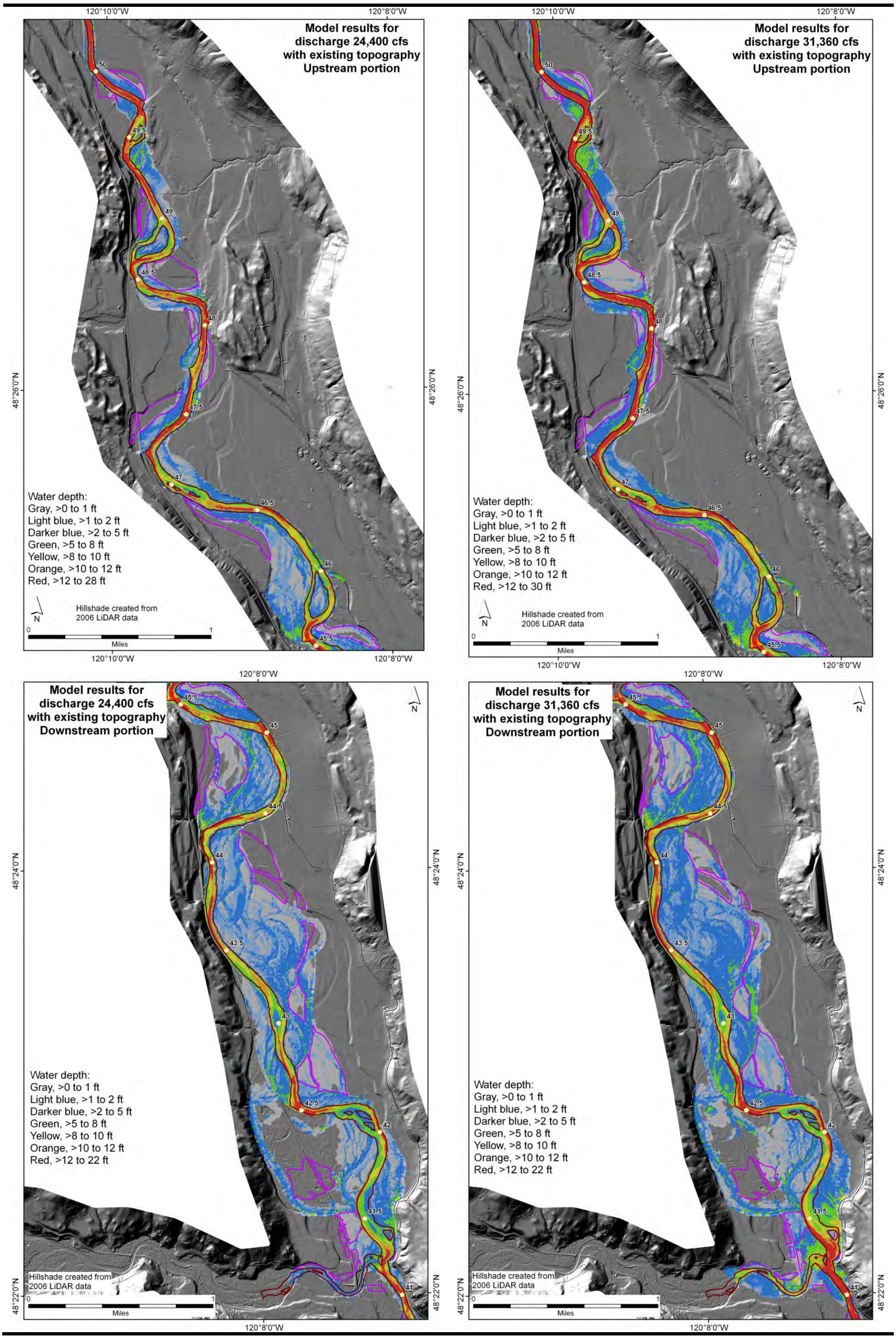

Figure 13. Hydraulic modeling results and inundation of Qa2 surfaces at discharges of, from left to right, (1) 24,400 cfs (a modeled 25-year flood), and (2) 31,360 cfs (a modeled 1948 flood).

Qa2 surfaces are outlined in purple. Colors indicate potential water depths as shown on the maps. Area within brown outline is Qa4. Areas not outlined are other map units. Upper figures are for the upstream section of the M2 reach. Lower figures are for the downstream section.

3.5 Qa1: Terrace

Terrace Qa1 includes those areas that did not receive flow during the 1948 flood (31,360 cfs) and are in a position that they have received little, if any, flood flow historically. The Qa1 surfaces are present as discontinuous remnants along both sides of the valley Most of the Qa1 surface remnants are along the higher floodplain (Qa2) or active floodplain (Qa3) and are found rarely along the main channel (Qa4).

The Qa1 surfaces are slightly irregular and include some broad, low-relief channels. Most of the channels are readily visible on the LiDAR hillshade or on the ground. They have various orientations relative to the main channel, which suggests that the main channel was in a different location when some of these channels were formed and active. These channels are well above the elevation of the main channel, so that they are not activated even during the largest floods.

The deposits associated with the Qa1 map unit include sandy alluvium (overbank deposits) of variable thickness over gravelly alluvium (channel deposits). The Qa1 surfaces are often cleared of natural vegetation and have been used for pasture, crops, and building sites. One soil profile was described on a Qa1 surface (Figure 14; Appendix C). The soil has a color B horizon developed in sandy overbank sediments and gravelly channel deposits. Patchy silica (SiO_2) coatings also are present on the bottoms of the gravel.

Qa1 surfaces vary in height above the main channel longitudinally along the river, depending upon the width of the floodplain. In narrower sections of the study reach (upstream of RM 46.75 and downstream of RM 41.25), Qa1 surfaces are commonly 17 to 25 feet above the main channel, but can be up to 40 feet above the channel. In wider sections (RM 41.25 to RM 46.75), Qa1 surfaces are commonly 17 to 25 feet above the present main channel. Similarly, the height differences between the Qa1 and Qa2 surfaces vary longitudinally. In the narrower sections, Qa1 surfaces are commonly 2 to 12 feet above adjacent Qa2 surfaces. In the wider sections, Qa1 surfaces are commonly 2 to 5 feet but can be up to 12 feet above adjacent Qa2 surfaces. Qa1 surfaces are not inundated by any of the modeled flows, even 31, 360 cfs (the discharge of the 1948 flood; Figure 15).

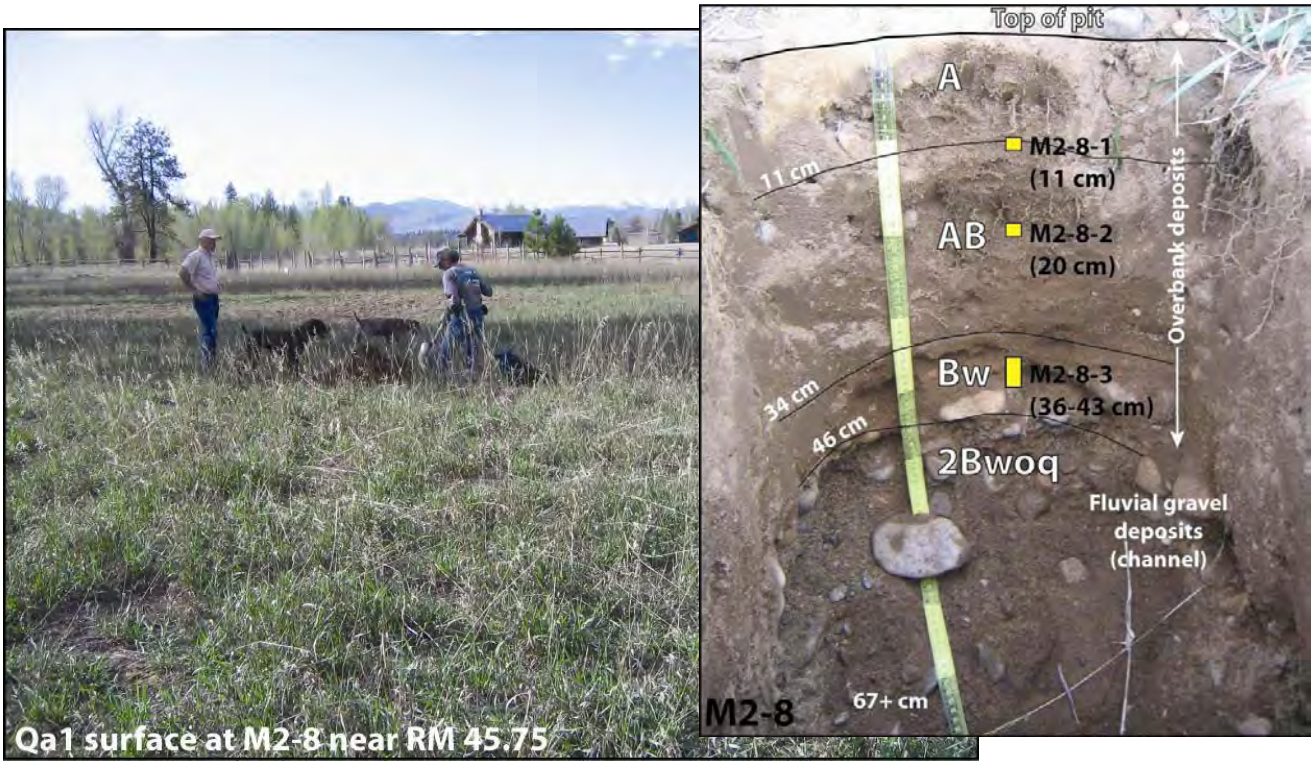

Figure 14. Morphology of Qa1 surface at soil description site M2-8 near RM 45.75.
Left: Photograph from the ground looking northwest at soil profile description site M2-8. Right: M2-8 soil profile.

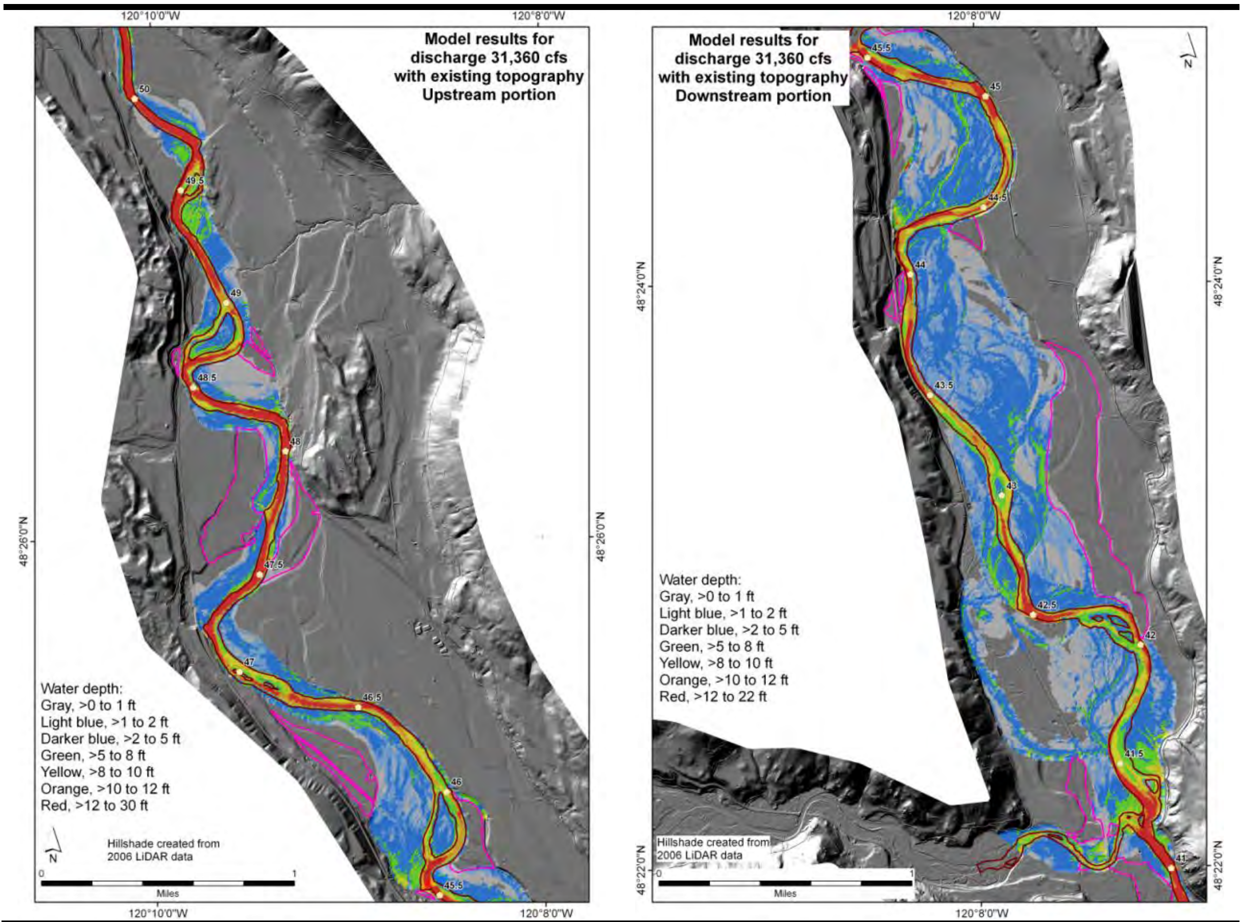

Figure 15. Qa1 surfaces are not inundated by a discharge of 31,360 cfs (the modeled 1948 flood) as shown for the upstream section (left) and the downstream section (right) of the M2 reach.
Colors indicate potential water depths as shown on the maps. Area within brown outline is Qa4. Areas outlined in pink are Qa1. Areas not outlined are other map units.

3.6 Qgo3, Qgo2, and Qgo1: Glacial Deposits

Several surfaces higher than the Qa1 surfaces are present throughout the study reach. These higher surfaces are underlain by outwash deposits related to regional glaciations (Waitt, 1972). The surfaces were subdivided into three broad map units (Qgo3, Qgo2, and Qgo1) on the basis of their surficial expression and heights above the present channel. These surfaces are high terraces at least 15 feet above the main channel and are no longer inundated by even the largest floods. These surfaces have probably not been active in the recent geologic past (≤10ka). All of these terraces are at least partially covered by alluvial-fan deposits and (or) colluvium from tributaries or adjacent higher slopes.

Only the youngest glacial outwash terrace, Qgo3, was examined in any detail. It is the main high terrace in the valley, especially on river left. Qgo3 surfaces are nearly continuous on river left between about RM 40.5 (Twisp area) to RM 47.75. The surfaces are present on both sides of the valley upstream of RM 49.5. The Qgo3 surfaces are nearly smooth but include very broad channels that are visible on the LiDAR hillshade and on the ground (Figure 16). These channels have various orientations and some are truncated by younger channels either on the Qgo3 surfaces or on younger surfaces. These channels are well above the elevation of the main channel, so they are not activated even during the largest floods.

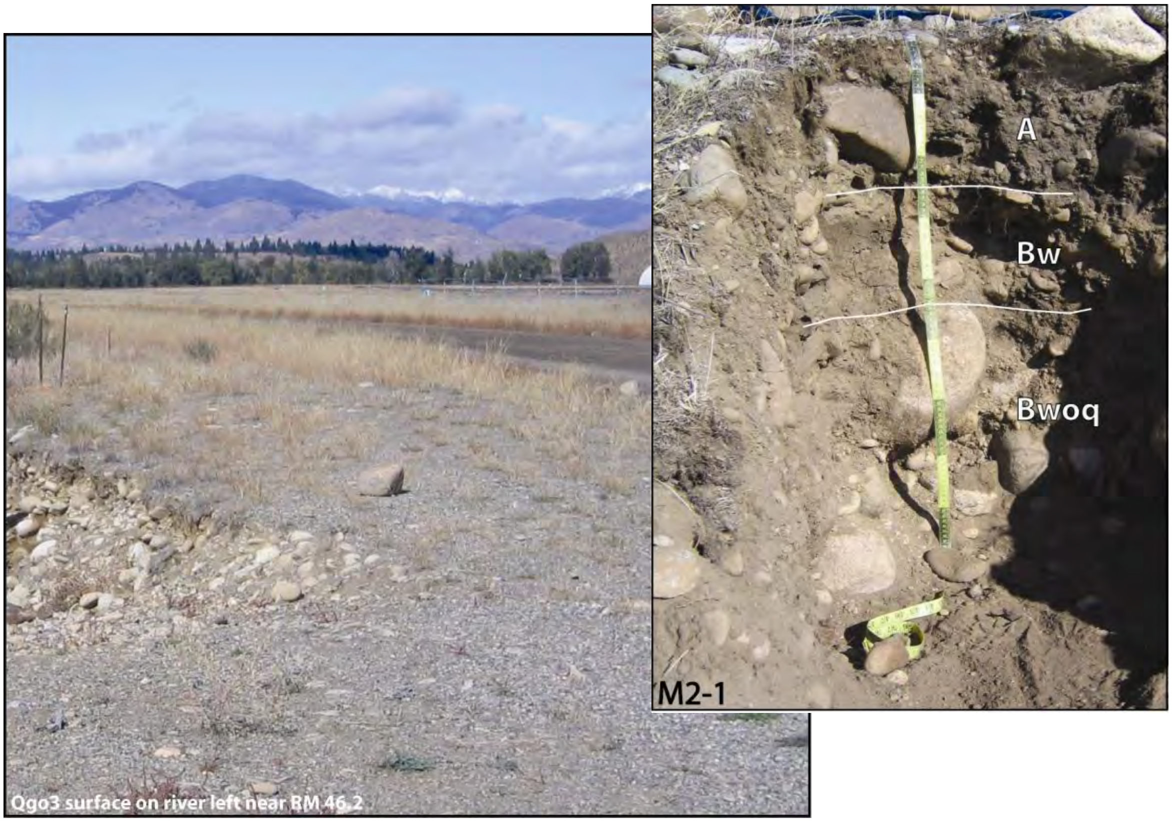

Figure 16. Qgo3 surface and soil profile M2-1 between RM 45.75 and 46.25.

The deposits associated with the Qgo3 surfaces are primarily sandy gravel that is finer in the upper 20 to 30 cm from addition of eolian deposits of silt and fine sand. The Qgo3 surfaces are generally free of trees, which is probably partly the result of clearing for use as pastures, for crops, or for building sites. Bedrock is often visible in terrace risers and road exposures beneath the gravelly outwash deposits. Bedrock also protrudes above the surfaces in several places. This suggests that the thickness of the glacial outwash is highly variable, and the surface of the bedrock is very irregular.

One soil profile was described on a Qgo3 surface (Figure 16; Appendix C). The soil has a color B or weak textural B horizon and patchy silica coatings on the bottoms of gravel. These characteristics indicate stability. Datable material was not recovered from the Qgo3 deposits. Outwash is likely from the last regional glaciation during the late Pleistocene, 10,000 to 12,000 years ago (Waitt, 1972).

Qgo3 surfaces vary in height above the main channel longitudinally along the river, depending upon the width of the valley. In narrower sections of the study reach (upstream of RM 46.75 and downstream of RM 41.25), Qgo3 surfaces are commonly 20 to 25 feet above the main channel. In wider sections (RM 41.25 to RM 46.75), Qgo3 surfaces are commonly 15 to 20 feet above the main channel. Similarly, the height differences between the Qgo3 and Qa1 surfaces vary longitudinally. In the narrower sections, Qgo3 surfaces are commonly 10 to 15 feet above adjacent Qa1 surfaces. In the wider sections, Qgo3 surfaces are commonly 10 to 15 feet above adjacent Qa1 surfaces. Qgo3 surfaces are not inundated by any of the modeled flows, including the 1948 flood.

Older glacial map units, Qgo2 and Qgo1, were mapped on the basis of their heights above the main channel and surficial expression. Brief observations were made during field reconnaissance in terrace risers and road exposures, but detailed descriptions were not done. Deposits associated with these surfaces are similar to those described under the Qgo3 surfaces. The Qgo2 surfaces are approximately 30 to 35 feet above the present channel, and about 10 to 20 feet above the Qgo3 surfaces. The Qgo1 surfaces are even higher, but were outside of the contours generated from the LiDAR data. The Qgo2 and Qgo1 surfaces are smooth and channels on them are not readily visible. These surfaces are commonly preserved near the edges of the valley and usually have alluvial-fan deposits over the outwash deposits. The Qgo2 and Qgo1 surfaces are present on river right between RM 40 to RM 41 (Twisp area). The Qgo2 surfaces are present also on river right upstream of about RM 49.5. The Qgo1 surfaces also are present on river left between RM 46.75 and RM 49.25 and on river right upstream of about RM 50. Bedrock is exposed beneath these surfaces in places.

3.7 Qaf: Alluvial-fan Deposits and Qc: Colluvium

Only well-expressed or prominent alluvial fans have been mapped. These include the alluvial fan from Bear Creek on river left near RM 49 and 49.75, and a few small alluvial fans elsewhere in the M2 reach (Figure 17). The deposits associated with the alluvial fans were not examined, but are presumed to be poorly sorted gravel and sand. Some of the alluvial-fan deposits are on higher terraces and do not deliver sediment directly to the present channel of the Methow River.

Colluvium is mapped only in areas where slopes are present adjacent to bedrock but do not appear to be bare rock (Figure 18). The colluvium is associated with and adjacent to areas of bedrock. Colluvium was not examined during the field reconnaissance.

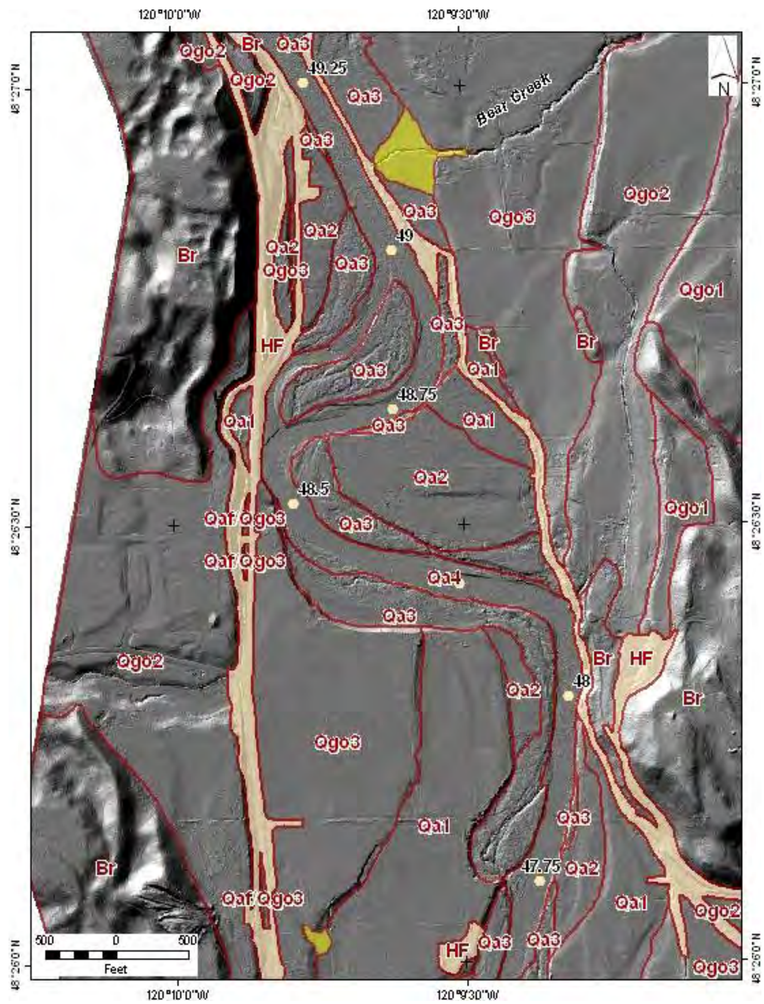

Figure 17. Alluvial fans (in yellow) at the mouth of Bear Creek on river left near RM 49 and another smaller drainage downstream.

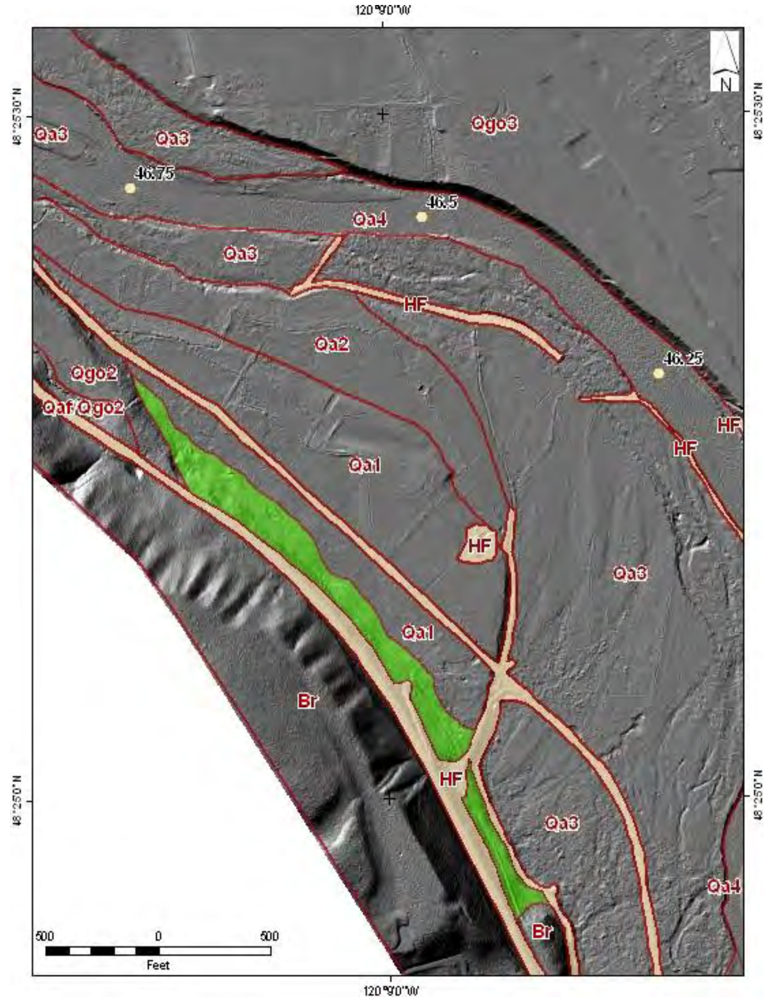

Figure 18. Example of colluvium (in green) along bedrock on river right near RM 46.5.

3.8 Br: Bedrock

The Middle Methow reach lies within a graben (elongate structural basin) that has been present since at least the Cretaceous (~138 to 66 million years ago) or Jurassic (up to about 200 million years ago) (Appendix M, Reclamation, 2008). The structural/topographic low has filled with sedimentary and volcanic deposits. Rocks underneath and adjacent to the valley in the M2 reach are comprised of shale, siltstone, sandstone, conglomerate, breccia, and tuff (Konrad and others, 2003; Appendix M, Reclamation, 2008). During the Cretaceous and Tertiary (66 to 1.6 million years ago), granitic and dioritic rocks intruded the sedimentary/volcanic rocks. Granitic/dioritic intrusions are present on both sides of the Methow River valley at Twisp (Barksdale, 1975). In the M2 reach, bedrock is present beneath the valley at generally shallow depths, although the bedrock surface is highly irregular and in places is quite deeply buried.

4.0 Discussion and Results

This section discusses channel migration, incision, and side channel development in the M2 study reach and summarizes findings from the individual study area presented in Appendix G.

4.1 Main Channel Migration

Historical channel change analyses from 1945 to 2006 identify where channel migration or avulsions have occurred and the relative extent of erosion or deposition. Surficial units that are eroded during channel migration are also noted to determine if the eroded area was existing floodplain (Qa3) or an older surface (Qa2 or older). Channel migration data are provided for reference in Appendix F and summarized below.

The frequency and magnitude of channel migration have been greatest in the downstream end of the M2 reach from just upstream of the sugar dike to the confluence with the Twisp River (Figure 19). Frequent, and often dramatic, channel changes have occurred within the wide floodplain located upstream of a constriction formed by bedrock on river left and sediment from the Twisp River on river right. One major avulsion of the main channel occurred between RM 42 and RM 41 (upstream of Twisp) during the 1948 flood. The area with the next largest amount of change in the M2 reach is the Habermehl area between RM 45.5 and RM 44.2. While some main channel migration has occurred in this area, the creation of new side channels during the 1948 flood has been the most prominent channel change in this area. Upstream of the Habermehl area, channel migration has been limited to less than one channel width. The most significant observed change was the growth of the Bird Island side channel. This channel was initially eroded in the 1948 flood and has experienced alignment and width changes since that time.

Channel changes can occur by erosion and deposition within the active channel (Qa4), between existing channels and bars, or within the active floodplain. An example of channel change within Qa4 is when the dominant flow path in a split flow channel pattern switches to a secondary channel. This can result from localized sediment deposition and erosion or from the growth and erosion of vegetation on Qa4 bars.

There are several areas in the M2 reach where channel migration has led to reworking of the floodplain (outside of Qa4). Floodplain reworking includes both erosion and formation of the floodplain (Qa3) as the channel moves to a new location. Channel migration, and, therefore, floodplain reworking, has been most active between RM 41 and 43, (Figure 20 and Figure 21). About 60 percent of all of the eroded floodplain area in the M2 reach has occurred in the section between RM 41 and RM 43. Of this eroded area, about 25 percent occurred between 1945 and 1948. About 80 percent of all of the newly formed floodplain area in the M2 reach occurred in this section (Figure 20 and Figure 22). Of this area, about half formed between 1974 and 2004. For the section between RM 41 and RM 43, about 15 acres more floodplain was formed than was eroded between 1945 and 2006. The erosion occurred in all time intervals. Formation of Qa3 mostly occurred between 1974 and 2004, although significant areas of Qa3 also formed in the intervals between 1948 and 1974.

Upstream of RM 43, erosion and reworking has been mostly in the Habermehl area (about 25 percent of the total area eroded and about 5 percent of the total area formed). About 85 percent of the erosion occurred between 1945 and 1948; the formation occurred between 1974 and 2004. Erosion occurred in all areas except in the Pigott area. In the area just downstream of the Barclay-Bear Creek area, about 11 acres were eroded between 1945 and 1948, with no measureable erosion occurred after that time. In the Lehman area, about 3.5 acres eroded between 1964 and 2004. In the Bird Island area, the side channel eroded through the floodplain during the 1948 flood. Just downstream of the Barclay-Bear Creek area about 8 acres of floodplain formed between 1948 and 2004. Approximately 2.5 acres of floodplain formed between 1948 and 1964 in this section.

Between 1945 and 1948 floodplain processes in the M2 reach were dominated by erosion of Qa3. The time intervals between 1974 and 2004 and between 1954 and 1964 were dominated by formation of Qa3. The time interval between 1964 and 1974 had about equal amounts of erosion and formation of Qa3.

Channel migration has resulted in bank erosion in older units along the edge of the active channel (Qa4) at only three sites within the M2 reach between 1945 and 2006 (Figure 23). These older units are at least a thousand to a few tens of thousands of years old. The bank erosion at these sites occurred between aerial photograph intervals that covered the 1948 and 1972 floods.

Although the reach between RM 41 and 43 has the most channel migration since 1945, this area has been impacted by man-made features more than any other area in the M2. Lateral channel migration is limited by the highway, which was constructed between 1894 and 1945, and the sugar dike, which was constructed some time after the 1972 flood. If additional flow and sediment are allowed into the 1894 channel path and floodplain area to the west of the highway, it is likely that the channel would actively migrate and rework this floodplain area. If the sugar dike were removed, channel migration could extend toward the highway and rework the area that is currently behind the sugar dike. Even if the sugar dike is not set back, there is potential for the river to continue migrating downstream and erode toward river right into the floodplain downstream from the dike.

Channel migration has also been limited by constructed features where levees and riprap have been built at the entrances to prominent side channels and along the bank of Qa3 floodplain. This occurs at RM 45.3 (Habermehl area) and RM 44.3 (Lehman area). If the levee were removed at the head of the side channel in the Habermehl area, the side channel could be reactivated. Because it is a well developed side channel, it is expected that a significant amount of flow and sediment would be transported through the channel. Because the Qa2 bounding the channel is composed of easily erodible sediment, there is potential for the side channel to widen, particularly if the amount of flow passing down the channel increases. Channel widening was observed between 1948, when the channel was formed, and the 1954 photograph before the levee was constructed (by 1964 photograph). If the levee at the upstream end of the Lehman area were removed or eroded by the river, it would open up the floodplain and increase flow through the Qa3.

At MVID East near RM 46, a levee and riprap on river right along the Qa3 surface limits erosion and the potential for channel migration toward river right. Removal of these features would increase the potential for the river to migrate into this area. This would also increase the risk that the main channel would avulse away from the MVID East surface diversion intake and into the side channel. At RM 49.6 (Barclay area), annual manipulation of the river to maintain flow into a diversion ditch affects the natural rate of channel migration.

Other impacts to channel change within Qa4 also occur as a result of annual dredging and building of push-up levees for diversion purposes, mainly at RM 49.6 (Barclay area) and 46 (MVID East). Impacts to channel change may also occur as a result of historical removal of large wood and vegetation, but these impacts are inferred to be more important in terms of local characteristics and hydraulics rather than impeding channel migration.

There are several road embankments and areas with bank protection along older surfaces that bound the Qa3 and Qa4. The impact of the armored banks to channel migration is perceived as small, because the majority of channel change and migration occurs within the Qa4 and Qa3. Lateral erosion of these older surfaces would be expected to be minimal (less than a channel width) over decadal time periods.

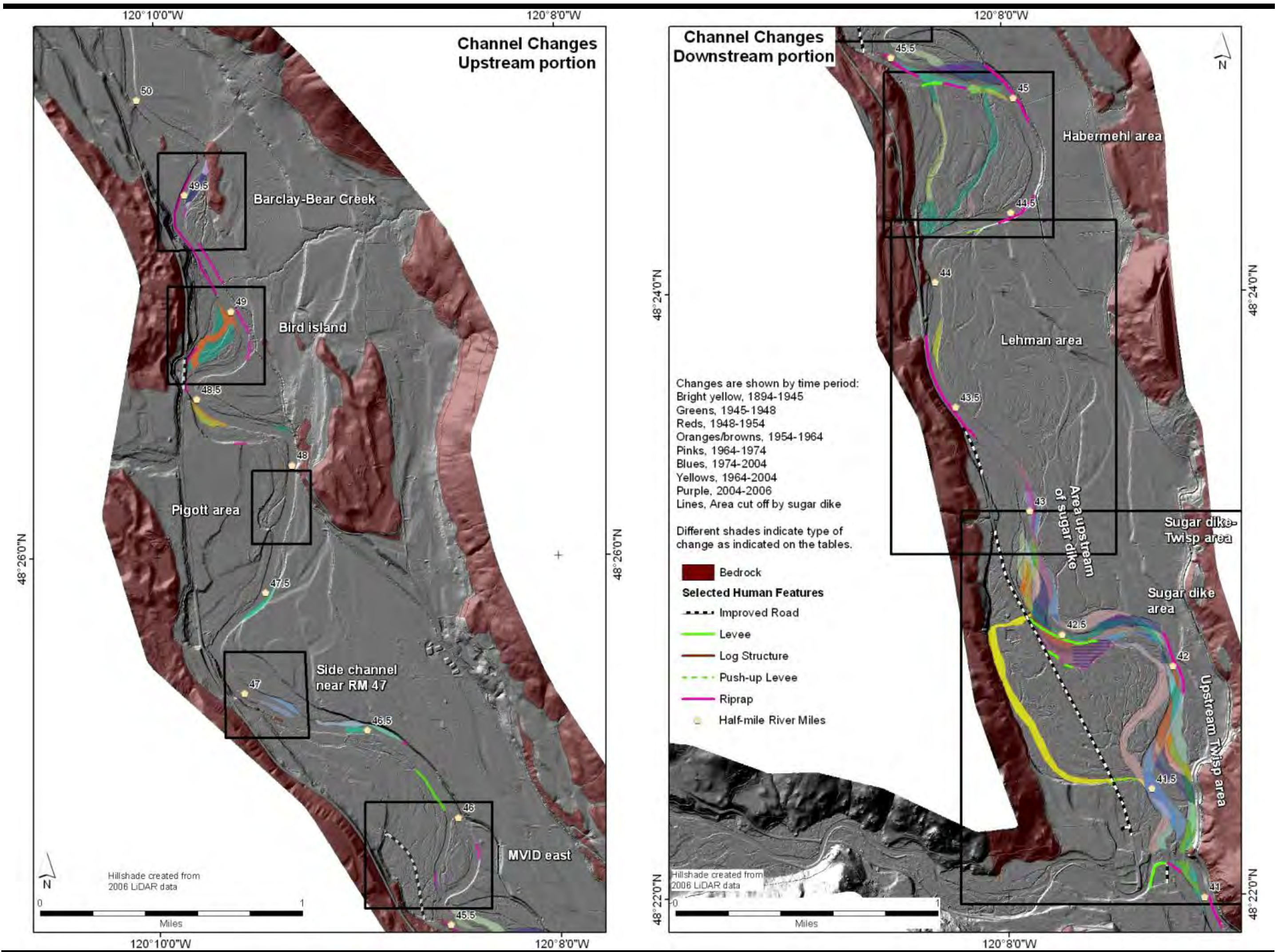

Figure 19. Changes in main and side channels between 1894 and 2006 for the M2 reach.

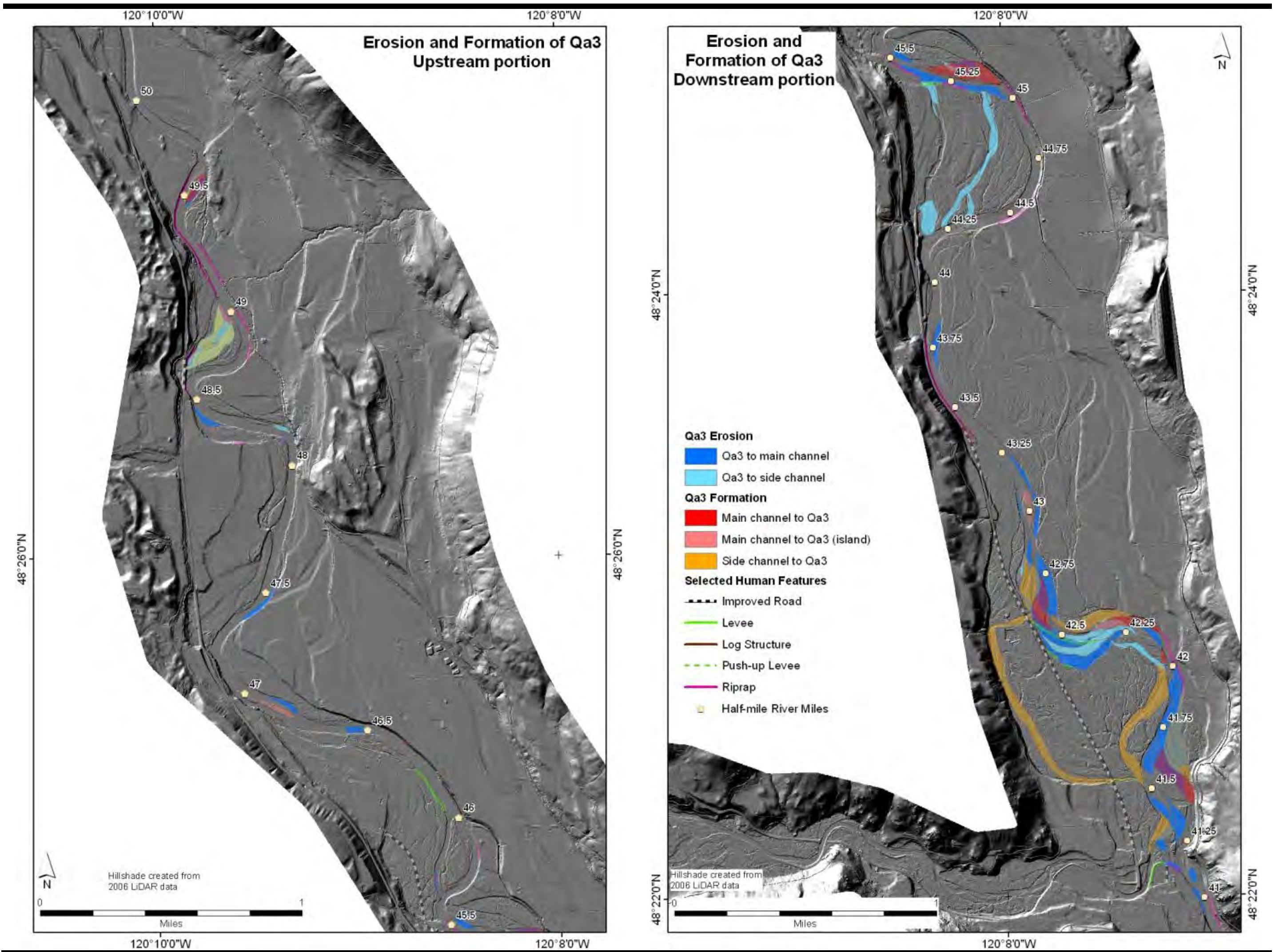

Figure 20. Erosion and formation of Qa3 between 1945 and 2006 for the M2 reach.

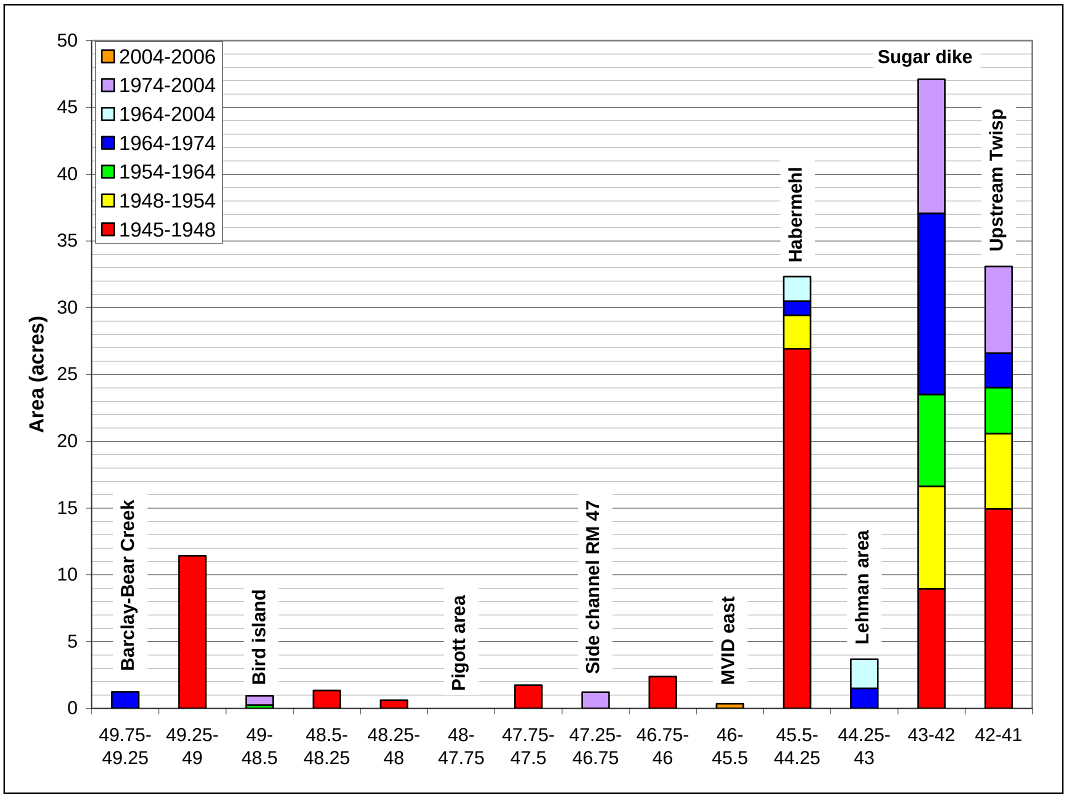

Figure 21. Amount of floodplain erosion based on aerial photographs taken between 1945 and 2006 at time intervals shown in the legend.

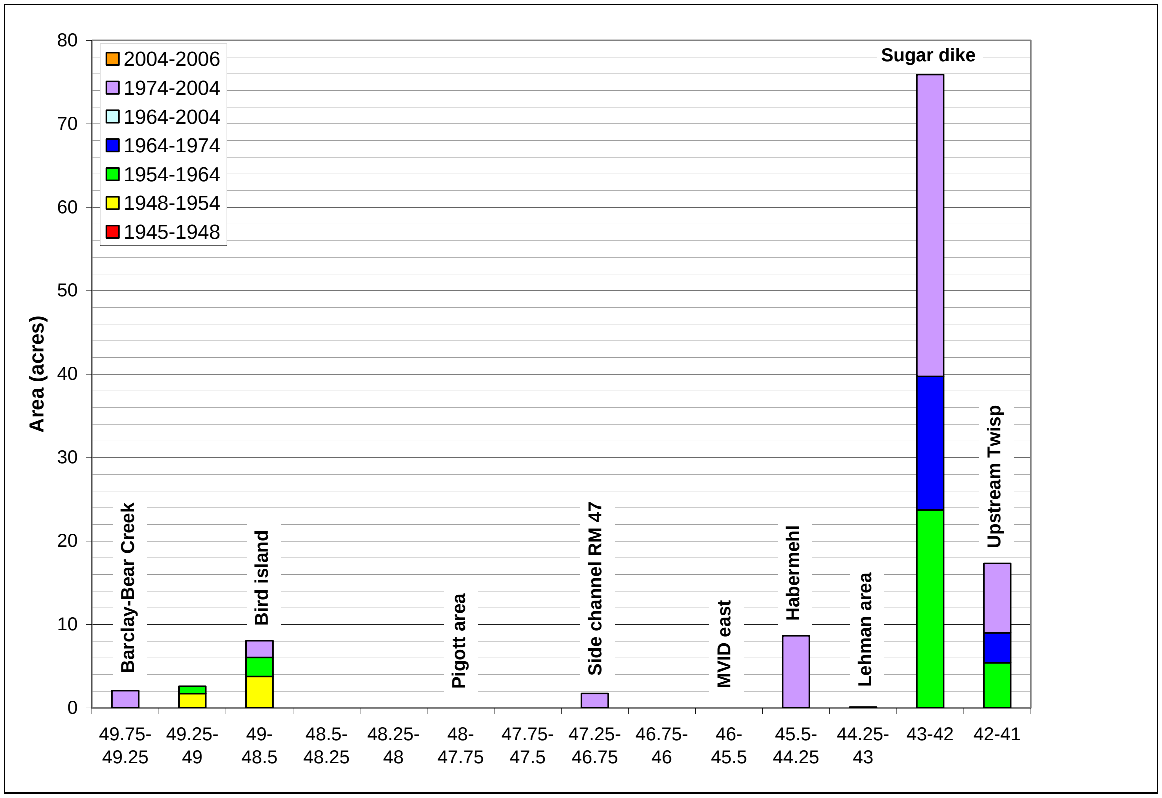

Figure 22. Amount of floodplain formation based on aerial photographs taken between 1945 and 2006 at time intervals shown in the legend.

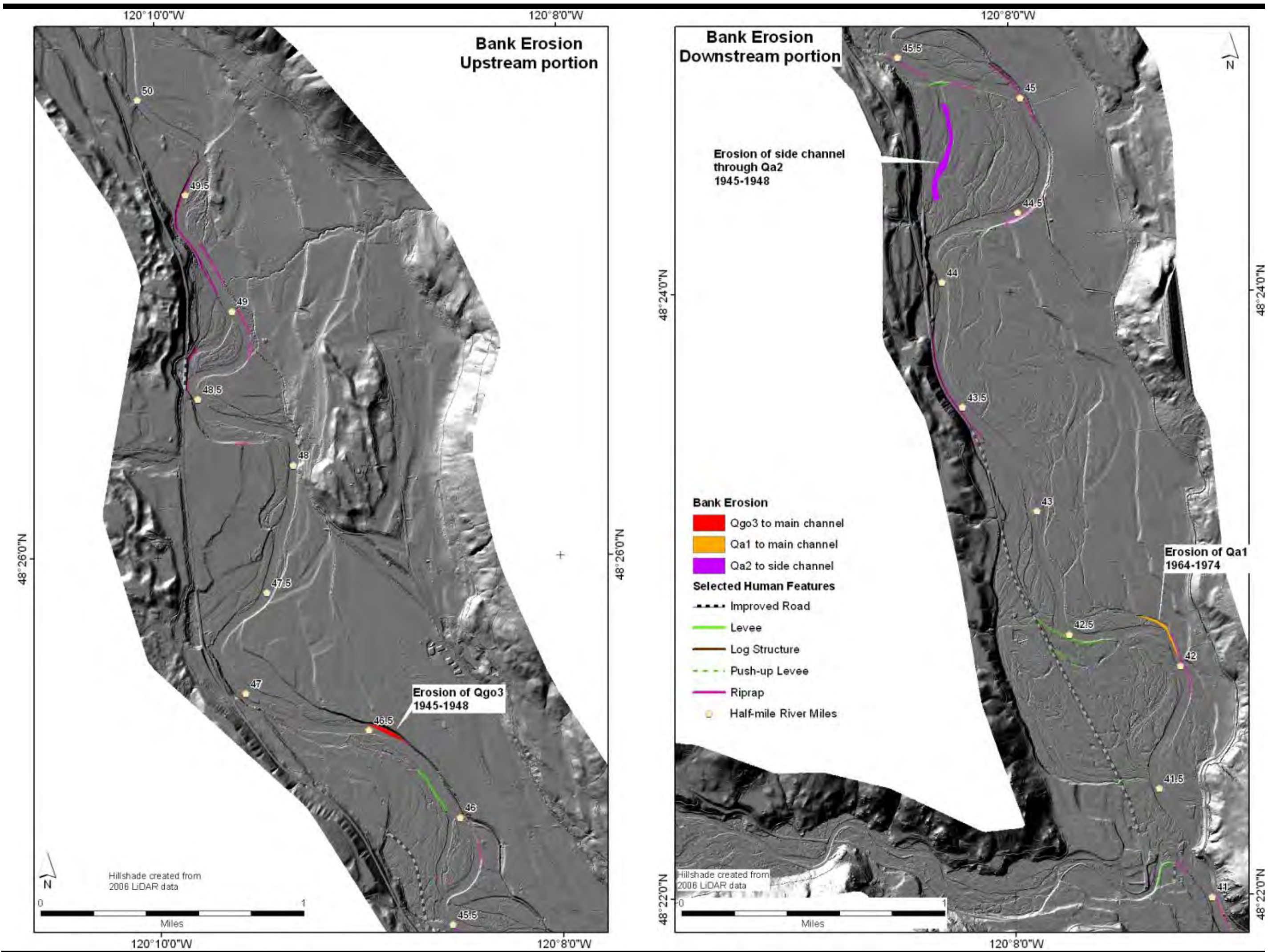

Figure 23. Erosion of units older than Qa3 between 1945 and 2006 for the M2 reach

4.2 Main Channel Incision and Vertical Stability

Neither the geology nor historical use of the Methow Subbasin or the M2 reach suggests that reach-scale incision would be expected. The term incision as used in this report is reserved for reach-scale lowering of the channel bed. However, because local concern was expressed about the potential for incision along the main channel and the impact incision might have on floodplain and side channel reconnection projects, several types of evidence were examined to assess the likelihood that reach-scale incision has occurred during the last 60 years in the M2 reach or might occur in the future. This section summarizes the results of this assessment. First, the geology and historical use of the subbasin and reach are presented. Then, evidence that was examined specifically for this study is summarized. Finally, observations that have been cited as indicating incision in the M2 reach are addressed.

The geology of the M2 reach and historical activities within the reach and upstream in the Methow Subbasin suggest that reach-scale incision would be unlikely to occur in the M2 reach on a scale of tens of years to about a hundred years. First, bedrock is present in the main channel at several locations in the M2 reach and provides grade control that would significantly limit any channel incision that might occur if flow was to increase relative to sediment supply. In particular for the M2 reach, incision is limited by bedrock at the downstream end of the reach near RM 41 (Figure 24 and Figure 25). At this locality, bedrock is present on river left and sediment influx from the Twisp River that enters on river right constrict the channel laterally and provide vertical base level control for the reach. Bedrock exposed at other localities suggests that the elevation of the channel is controlled by bedrock at other places within the M2 reach.

Second, in order for reach-scale incision to occur, an increase in sediment transport capacity is needed. This occurs when sediment supply decreases or flow increases. However, in the Methow Subbasin overall and in the M2 reach specially, there is no apparent change in the systematic gaging record and there are no significant dams, storage impoundment, or interbasin diversions that might alter the natural flow and sediment regime during floods when the potential for incision is greatest. Furthermore, there are no documented changes to the supply of coarse sediment (sand, gravel, and cobble) to the M2 reach, such as would be caused by historical in-channel mining or trapping of sediment behind dams or landslides. Given no disruption to either the flow regime or to the sediment supply, there is no obvious mechanism that would lead to or cause reach-scale incision. If large sections of the Methow River had been channelized, then sediment transport might have increased as the constricted uniform width would result in higher stage and velocities. In the M2 reach, small levees have been constructed. These levees limit channel migration and access to side channels, but they do not constrict the channel to a uniform narrow width by significantly eliminating lateral overtopping of the floodplain. For this reason, the short levees in the M2 reach have not caused channel incision, but rather have limited side channel evolution as will be discussed in the next report section (Section 4.3). Even the highway between about RM

43 and 41, which disconnects the largest area of floodplain from the active channel in the M2 reach, still allows accessibility to large areas of floodplain on river left.

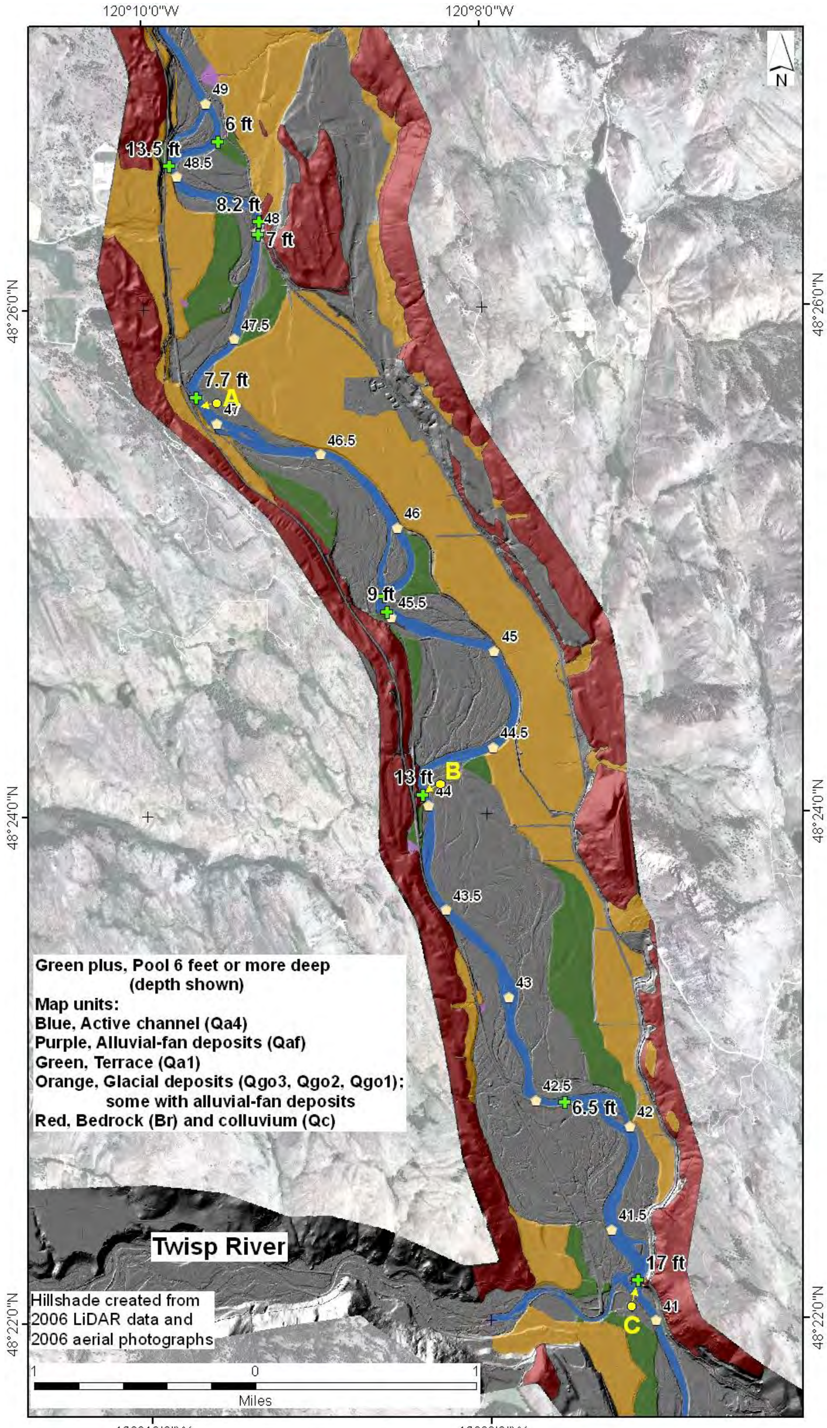

Figure 24. Bedrock (red) and glacial deposits (orange) provide lateral control on the main channel and floodplain. Pools about 6 feet or deeper (green pluses) are present in areas where bedrock is along the main channel. Yellow dots indicate the locations of ground photographs (Figure 25). Yellow arrows show direction of the view in the photographs.

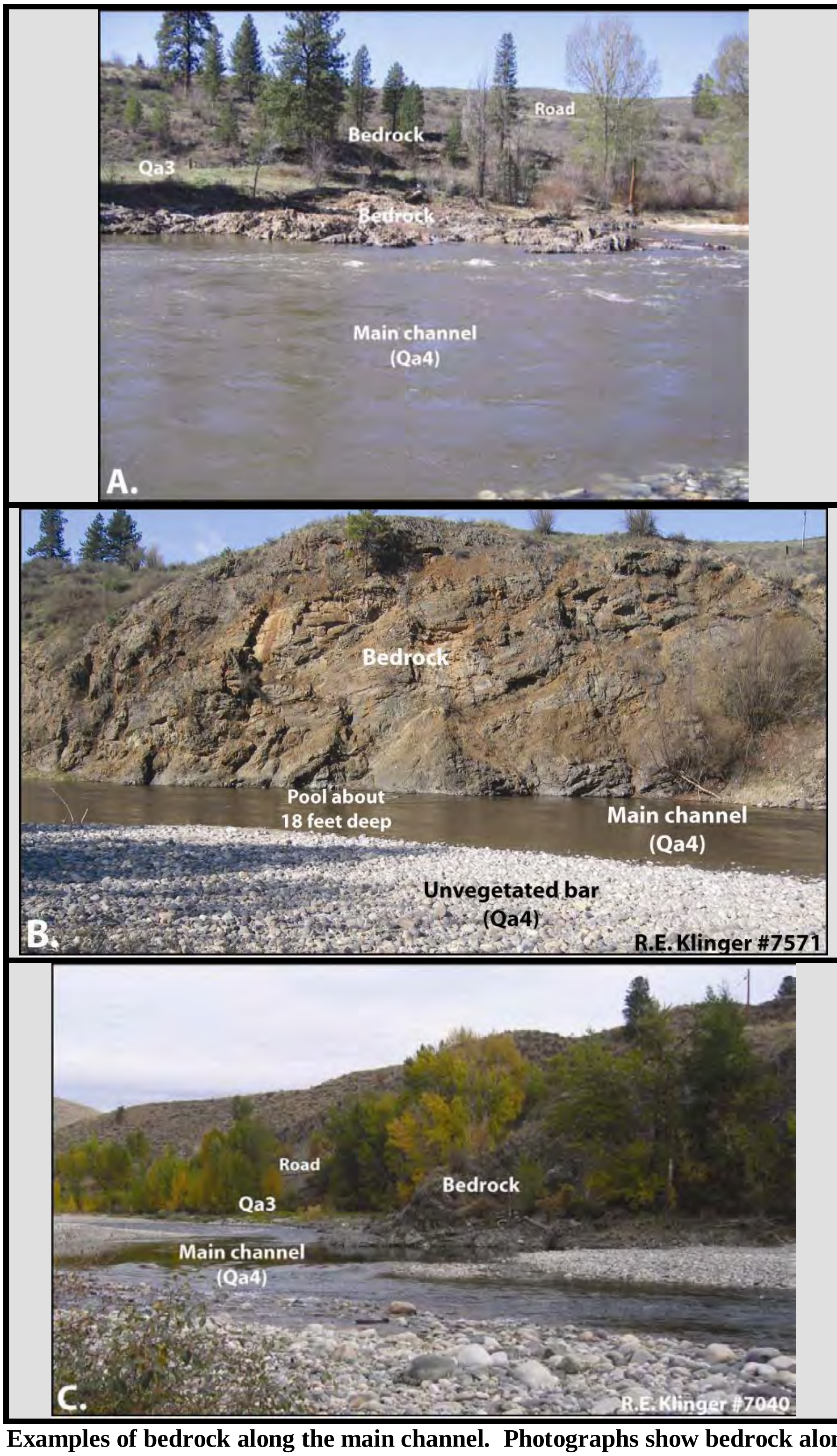

Figure 25. Examples of bedrock along the main channel. Photographs show bedrock along the main channel near RM 45.4 (upper photograph), near RM 44 (middle photograph), and near RM 41.2 (lower photograph).

In order to directly assess whether incision in the M2 reach has occurred during the available historical record (since 1945), several types of evidence were examined. These are high-water marks from the 1948 and 1972 floods, elevations at stream gages, channel survey elevations, and the geomorphic character of the reach. First, flood stages estimated from high-water marks from the 1948 and 1972 floods (Beck, 1973) are similar to those computed from the model results for flood flows of the same size and using present topography. If incision had occurred since 1948, then the flood stages computed using present topography should be noticeably lower for a significant portion of the M2 reach than those estimated from the actual high-water marks located just after the floods. Second, the elevations of stream gaging stations on the Methow River in the M2 reach do not show any evidence of main channel incision over a time periods of several decades. Third, comparison of data from the 2005 channel survey to data from a 1970s survey shows no significant lowering of the main channel bed (Figure 26). The data do show that the channel bed has lowered or aggraded by a few feet in some locations. This occurs in areas where channel migration or split flow is present. To evaluate changes from the 2006 and 2008 floods (10- to 25-year frequency), the 2005 channel bottom data was also compared to 2008 channel bottom data and no reach-wide channel lowering was found. Fourth, the geomorphic character of the channel in portions of the M2 reach suggests that reach-scale incision is not occurring. The nearly continuous point bars and development of a meandering channel (thalweg) within the active channel (Qa4) along M2 indicate that the channel has been moving laterally rather than downward through incision into the floodplain, and continues to transport sediment downstream. Even during the 2-year observation period of this study, growth of bars both laterally and vertically has been observed in several areas of the M2 reach, likely in response to the 2006 and 2008 floods (10 to 25-year magnitude). Additional geomorphic evidence for a lack of incision is the similarity in the heights of some unvegetated bars and vegetated floodplain adjacent to them. Furthermore, in a few areas, gravel has been recently deposited along the edges of the vegetated floodplain indicating that flows large enough to transport gravel are inundating areas that have historically been dominated by overbank flow. All of the above geomorphic observations indicate that the M2 reach has been dominated by lateral channel changes, not by reach-scale incision.

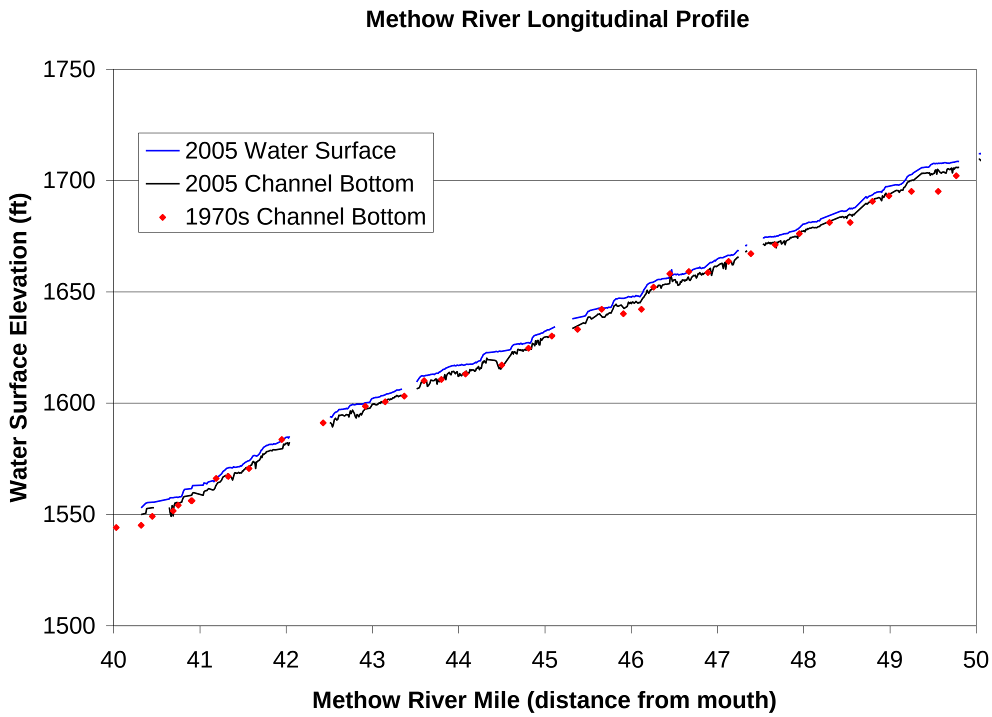

Figure 26. Comparison of 1972 (post 1972 flood) channel bottom with data from 2005 along the 10-mile study reach. Note that MVID East is visible in the data at RM 46.6, but was removed in December 2008.

Several observations within the M2 reach have been attributed to incision. Deeper sections along the channel bed, a lack of consistent inundation of the floodplain, inundation of the floodplain only during 10-year floods and larger, and bank heights have all been cited as evidence for channel incision in the M2 reach. Each of these was considered, but as will be discussed below do not indicate reach-scale incision.

First, deeper areas or pools deeper than about 6 ft, in the channel bed have been cited incorrectly as evidence of incision. Because these pools are limited to a few tens of feet in lateral extent, they do not signal reach-scale lowering, but only a local deepening of the channel bed. While shallow bedrock in the channel limits reach-scale incision, bedrock exposed in some localities along the channel may cause high shear stresses that result in local scour that results deep pools. High shear stresses and local scour may also be found along man-made features (e.g., dikes and levees), but these man-made features are also of limited lateral extent. Channel survey data indicate that the deepest pools (6 to 18 ft) in the active channel are commonly associated with bedrock.

Second, other pools that are less than 6 ft deep (at a flow of 285 cfs) have also been cited as evidence for channel incision. Although these pools are longer in lateral extent than the deep pools, the shallower pool sections alternate with riffle sections along the channel bed and are components of a natural pool-riffle system. The overall elevation of the channel bed has not been lowered (Figure 27). These pools do not indicate reach-scale incision. However, shallower pools are common in areas where riprap has been placed along a bank, and so their presence can be the result of human activities.

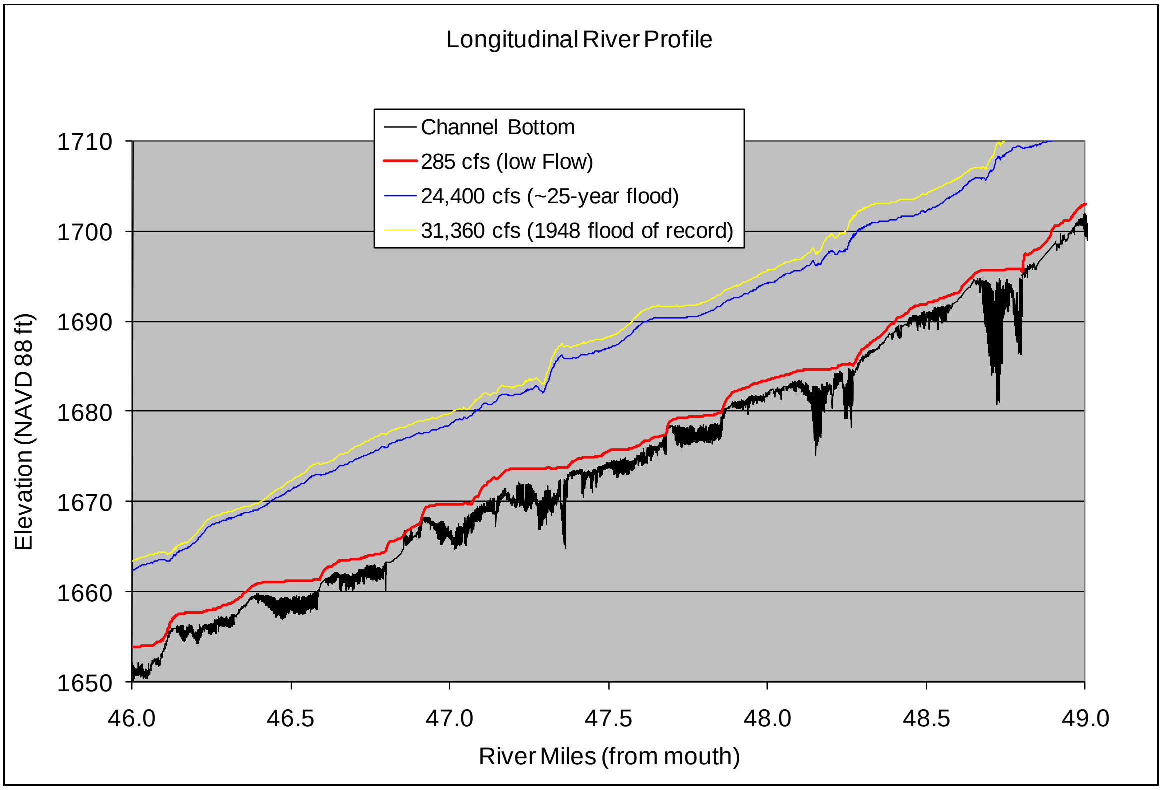

Figure 27. Longitudinal profile and computed water surface profiles of the M2 reach from river mile 46 to 49. Note the pool-riffle water surface slope profile in the low flow that gets largely drowned out at high flows.

Third, the heights of banks and surfaces within the floodplain relative to the channel, inconsistent floodplain inundation, and total inundation of the floodplain only during a 10-year flood and larger have been cited as evidence of reach-scale channel incision. The heights of the banks and elevation of the floodplain are directly related to the channel/valley geometry and are not necessarily the result of reach-scale channel bed incision. The relationship between water depth and channel bed geometry for a given discharge is well illustrated in the longitudinal profile (Figure 27). During a low-flow discharge (red line), the height of the water surface above the channel bed (black line) can be seen to vary with the characteristics of the channel bed. In addition, the area of inundation is directly related to the width of the active channel and floodplain. In wider parts of the reach, floodplain surfaces tend to be lower than they are in narrower sections. For a given discharge, shallow flow is distributed across a broader area in the wider section of floodplain, whereas flow is deeper but more limited in lateral extent in narrower sections, where the same flow is forced through a narrower channel cross-section. Thus, because heights of banks and differences in floodplain inundation in the M2 reach vary with channel properties and floodplain widths, they do not signal reach-scale incision.

An important distinction must be made as to the magnitude and frequency of floods that are expected to inundate parts of the floodplain. The active floodplain (Qa3) as defined in this study is the area that was inundated during the 1948 flood, or is at a similar elevation and has similar characteristics to areas that were inundated during that flood. It is the area that has been historically part of the floodplain. The area that is inundated annually or semi-annually is the active channel (Qa4). Thus, the entire floodplain would not be expected to be inundated at smaller discharges. As described above, the floodplain is composed of surfaces of several heights and is very irregular. It includes side and overflow channels. On the basis of the model results, the active channel and well-developed, lower elevation side channels within the floodplain are inundated during a 2-year flood (about 11,000 cfs). These side channels have an upstream connection to the main channel. These results agree with areas that are visibly inundated during the waning stages of the 2006 and 2008 as captured by photographs taken from a helicopter (see the photograph on the front cover). The discharge at the time of the photographs is about 11,000 cfs. In addition, high water marks provided by floated debris (flotsam), erosion, and fine-grained sediment deposition were commonly observed on the floodplain and in side channels during 2008 and 2009 field reconnaissance. These observations indicate that these areas were recently inundated. Most of the Qa3 surface is overtopped at a discharge of about 16,600 cfs (about a 10-year flood). The variability in the inundation of Qa3 reflects the compound nature of the unit that results in a very irregular surface topography. It does not indicate reach-scale incision along the main channel.

4.3 Side Channels

Channel types described in this report include the main, side, and overflow channels. Side channels are the secondary channels associated with the main channel and convey lesser volumes of flow and/or sediment. They may be part of the floodplain, but they should not be confused with overflow channels that primarily convey flood flows. An important distinction between side channels and overflow channels as defined for this report is that overflow channels generally do not have a surface connection with the main channel and are only inundated by larger floods (greater than 5-10 year floods). Side channels become inundated frequently and maintain a direct surface connection for extended periods of the year.

The location and physical characteristics of side channels observed in the M2 reach are shown in Figure 28. In general, the side channels are differentiated by the way they form, how they can be modified over time, their persistence on the landscape, sediment characteristics, and the frequency and magnitude of their surface connection with the main channel. For each characteristic, the most frequently observed value is shown with the dark gray shading, while the light grey shaded areas represent the total range of values observed. The figure is intended to represent a fluid process by which channels in the M2 reach may shift across categories over time as they are modified by the river. Different types of side and overflow channels exist together along the river and create the variety that is needed for a properly functioning river system (Figure 29).

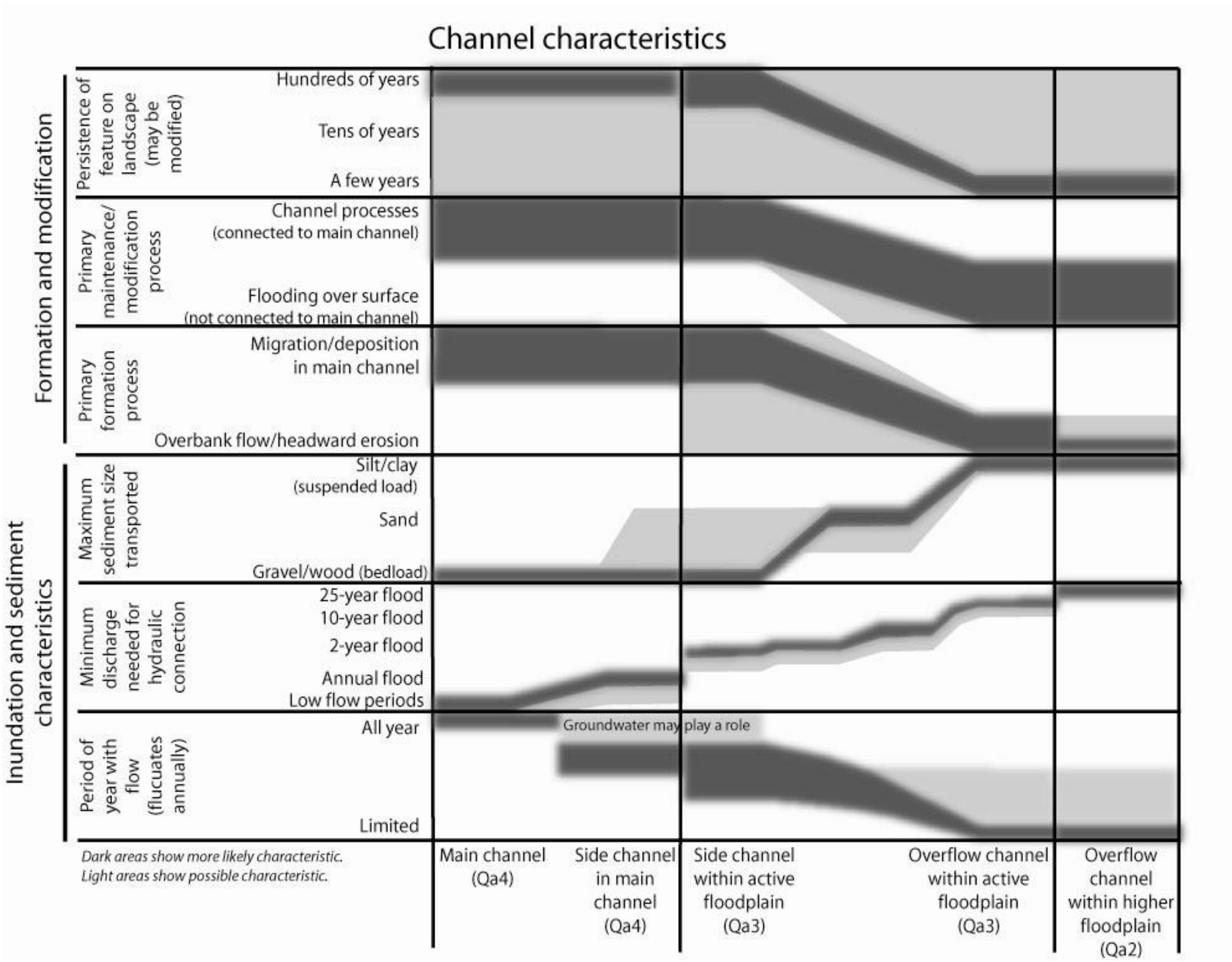

Figure 28. Conceptual illustration of characteristics of side channels in the M2 reach.

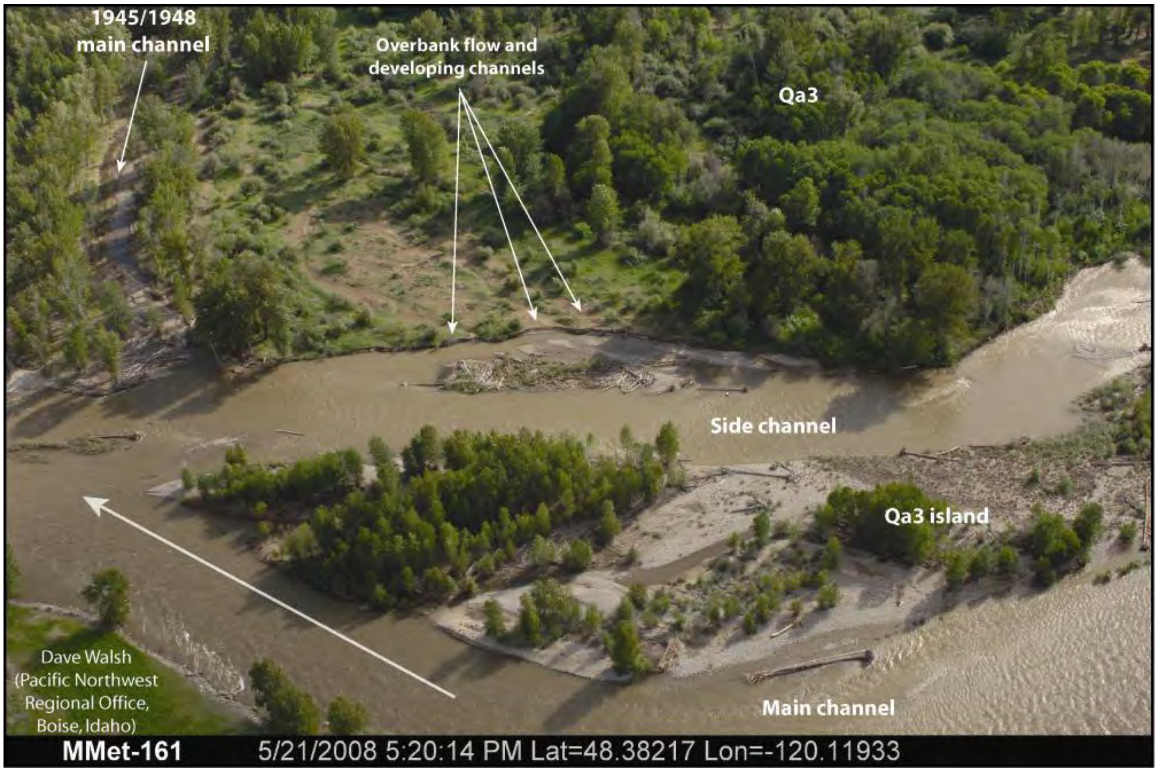

Figure 29. Different types of side channels in the area just downstream of sugar dike two days after the peak of the May 2008 flood.

The wetted side channel is within Qa4 and separated from the main channel by an island of Qa3 (vegetated). The 1945/1948 main channel became a side channel through Qa3 when an avulsion of the main channel during the 1948 flood created a new main channel path. The side channel has progressively filled with sediment and vegetation. Unvegetated sand visible at its upstream end indicates that some flow entered this side channel during the 2008 flood. The small side channels on the unvegetated Qa3 surface in the middle of the photograph are overflow channels that appear to have been activated during this flood.

4.3.1 Inundation and Sediment Characteristics

The discharge needed to inundate a side channel is primarily dependent upon the location of the channel relative to the main channel, the elevation of the side channel entrance and exit relative to the water surface elevation in the main channel, and on the geometry of the side channel entrance, primarily the angle of departure from the main channel. Every time the main channel and floodplain are reworked by the river, mostly during high flows, the flow magnitude needed to inundate a side channel may change. For example, as a side channel fills with sediment due to reduced velocities or is further eroded due to increased velocities during larger magnitude floods, the discharge needed to inundate the channel will either increase or decrease, respectively. Similarly, the volume of flow and sediment that is transported into side channels can also be reduced by the deposition of sediment and wood at the entrance to a side channel. Additionally, deposition of sediment and large wood in the main channel can increase roughness (resistance) and result in increased water surface elevations at the entrance or exit of a side channel. This increase in stage is generally localized and would have the most impact on side channel inundation at smaller discharges. For large floods (e.g., a 10-year flood and greater) that inundate more of the floodplain, roughness changes would have to be fairly continuous along the main channel in order to significantly affect the flood stage.

Presently in the M2 reach, large woody debris is found mainly at the upstream ends of islands, scattered across bars, or at the entrances to side channels. There is virtually no large wood along the majority of banks of the main channel where it would provide localized influences on river hydraulics. During the spring of 2008, a large tree that had fallen into the river near RM 43.5 was reportedly cut and removed. While the cumulative effect and quantity of wood removal from the channel is not known, it is recognized that large wood is presently absent from much of the main channel.

Qa4 side channels have the most potential to be inundated during low-flow periods that occur from late summer through the winter. At about 11,000 cfs (about equivalent to the 2-yr flood), all of the Qa4 side channels are inundated because they are the closest in proximity and relative elevation to the main channel. Qa4 side channels are found at flow splits around islands or mid-channel bars, and along bars located adjacent to the margins of the main channel (Figure 30). Because of the fairly open and well connected upstream and downstream ends with the main channel, inundation of these side channels often occurs from both the upstream and downstream ends of the channels.

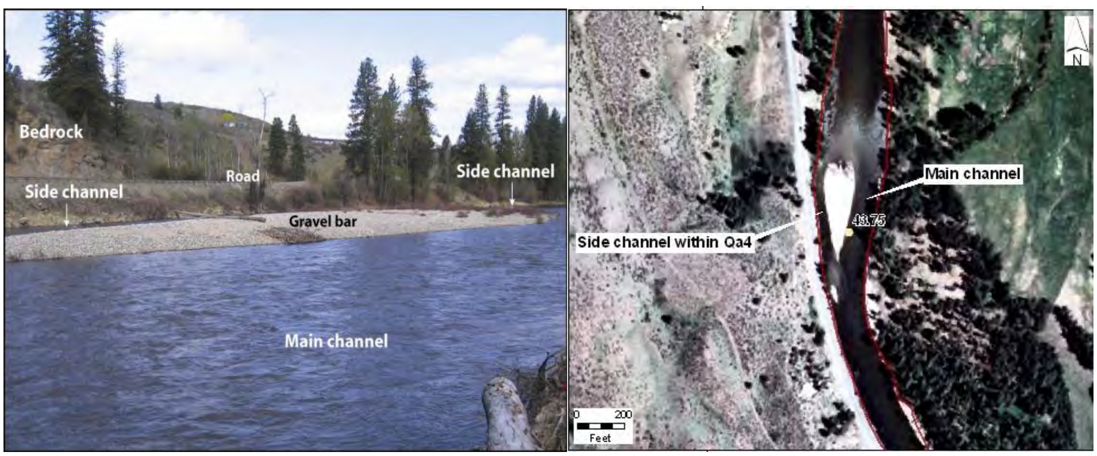

Figure 30. Example of a side channel within Qa4 near RM 43.75.

Although the surface of the Qa3 floodplain is not generally inundated by the 2-year flood, prominent side channels within Qa3 can be inundated (Figure 31). If the depth of inundation is great enough, these Qa3 side channels convey gravel and woody debris similar to the side channels within Qa4. If a flow connection with the main channel is maintained so that the side channel is inundated at 2-year floods or even more frequently, these channels may eventually transition to Qa4 channel as illustrated in Figure 28.

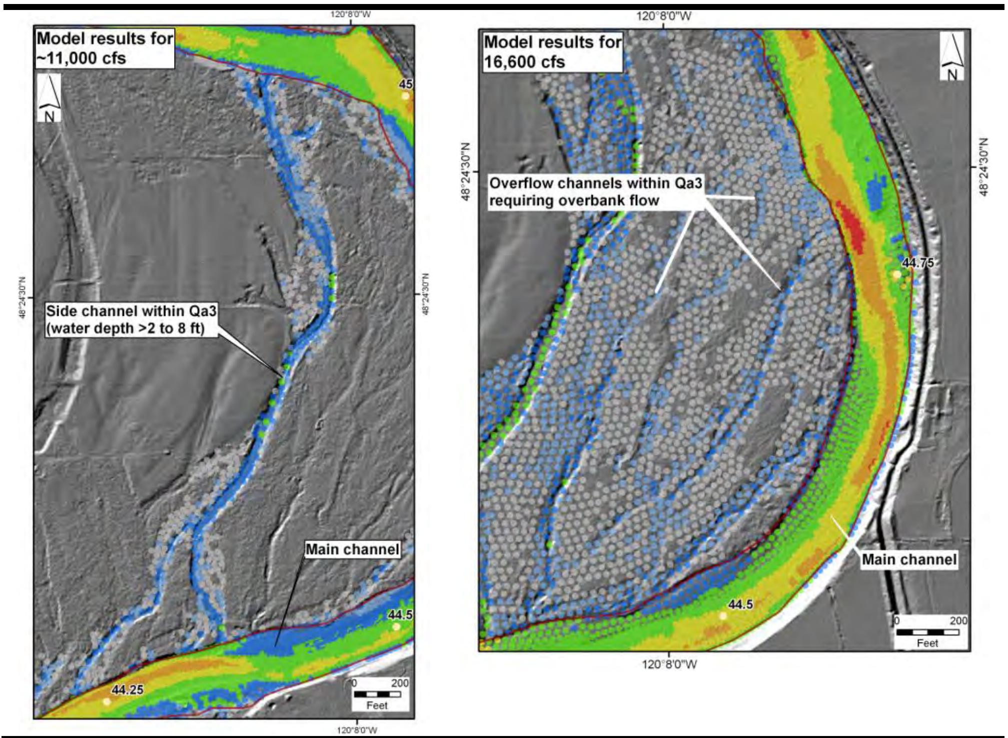

Figure 31. Examples of side channels within Qa3 showing the discharges needed for inundation based on flows used in the 2D model

The side channel shown on the left is the east channel in the Habermehl area. This side channel can be connected to the main channel and inundated at a discharge of about 11,000 cfs by water up to 5 feet deep (shown by dark blue areas). The overflow channels shown on the right are ones within Qa3 that need overbank flow for inundation. In order for inundation to occur flow must first overtop the Qa3 surface so these channels are dry at 11,000 cfs but become inundated at a discharge of 16,600 cfs.

As described above, overflow channels formed within the floodplain are only inundated by larger floods (greater than 5-to-10-year floods). Because of this characteristic, these channels may not represent reliable habitat as they are only directly connected to the main channel by surface flow on time frames greater than the lifespan of the salmonid species that might utilize them. Overflow channels within Qa3 and Qa2 typically convey flood flows when overtopping and inundation of the floodplain occurs (Figure 31). The form of these overflow channels may be quite variable (Figure 32) from shallow channels that may convey essentially sheet flow at their upstream ends (Figure 33) to well-defined, deeper channels that convey flow that has coalesced at their downstream ends (Figure 34). Because the overflow channels are inundated primarily by overbank flow, suspended sediment (fine sand, silt and clay) is transported and deposited in these channels. Gravel that is visible in the bed of these channels is usually found in the downstream portions of the channels and appears to be a lag deposit derived from older underlying deposits that have been exhumed through surface erosion. As these channels deepen at the downstream end, they may become inundated by backwater flow from the main channel before they develop an upstream surface water connection.

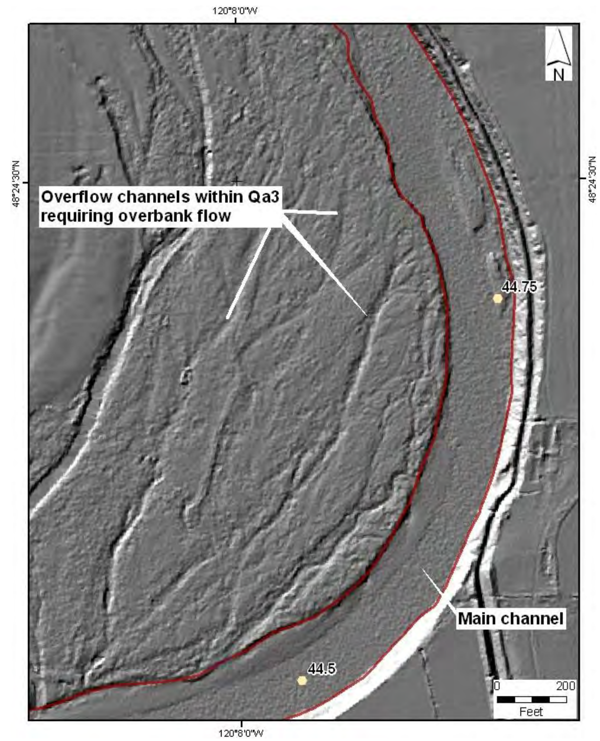

Figure 32. Examples of the surficial expression of overflow channels on the Qa3 surface near RM 44.75 in the Habermehl area

Note that the overflow channels are barely visible at their upstream ends, but become more pronounced in a downstream direction.

Figure 33. Examples of areas of overbank flow at the heads of overflow channels within Qa3. *Note that channel form is poor, but evidence for sheet flow is present. This evidence includes fresh sand (upper photograph) and wood (lower photograph).*

Figure 34. Side channels within Qa3 that require overbank flow for inundation can have well-defined channel form at their downstream ends.

Based on the channel and floodplain conditions visible on the 2006 aerial photographs, about 21,000 feet, or nearly 4 miles, of side channels are present within Qa4 and about 17,000 feet, or about 3.4 miles, of side channels are present within Qa3. The spacing of side channels is nearly continuous throughout the M2 reach from RM 49.75 to 41, except at RM 48.25 to 47.25. In this section, the channel and floodplain are confined by bedrock and older alluvial deposits, so it appears that there has been little opportunity for side channels to develop. Of the more than 7 miles of side channels in the M2 reach, only two channels having a length of about 3,200 feet (0.6 miles) are inundated at a discharge of 285 cfs (Figure 35). One of these side channels is in the Barclay-Bear Creek area near RM 49.6; the other is a split flow in the main channel near RM 47 (Figure 30 and Figure 36). The 1400-ft long side channel in the Barclay-Bear Creek area is likely inundated at low flows due to the repeated dredging that has been undertaken to maintain surface water diversion capabilities. The side channel at RM 47 was observed during the October 2008 channel survey with only shallow flow (channel could be easily waded) and very little variation in depth. At a discharge of about 11,000 cfs, 6 miles of side channels become inundated, an order of magnitude more than are inundated at the low flow of 285 cfs. The additional side channels that are inundated are spaced fairly continuously throughout the M2 reach with the exception of areas blocked by levees and/or fill.

Although there is limited surface water connection with side channels at 285 cfs, some locations were observed to pond water or have a groundwater connection during the October 2008 field work and during a habitat survey by USFS conducted in September 2008 (USFS 2009). For example, at Bird Island a few scour pools around root wads were noted to have ponded water. The influx of groundwater to side channels at the MVID East and Habermehl areas created a surface flow. There may be many more locations where groundwater is surfacing in side channels within the M2 reach during low flow periods. It would be important to document these locations and ensure that these side channels are protected and enhanced if the conditions are warranted. A thorough investigation of groundwater levels would help to refine the length of channel influenced by groundwater. Mean daily discharge plots suggest that low-flow discharge typically varies between 300 and 400 cfs (Reclamation 2008). Modeling of flows between 285 cfs and 11,000 cfs would help to refine the length of channel influenced by groundwater, determine seasonal fluctuations and duration of surface connections, and establish specific discharges at which surface water connections are maintained.

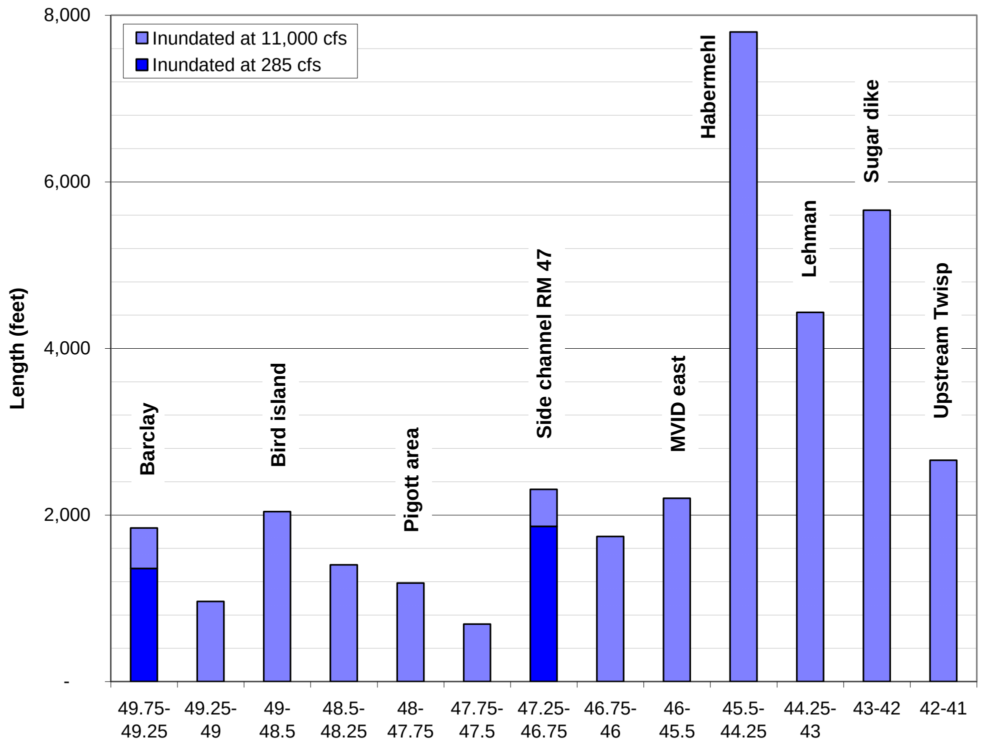

Figure 35. Cumulative length of side channels inundated for 285 cfs vs. 11,000 cfs for river segments along M2.

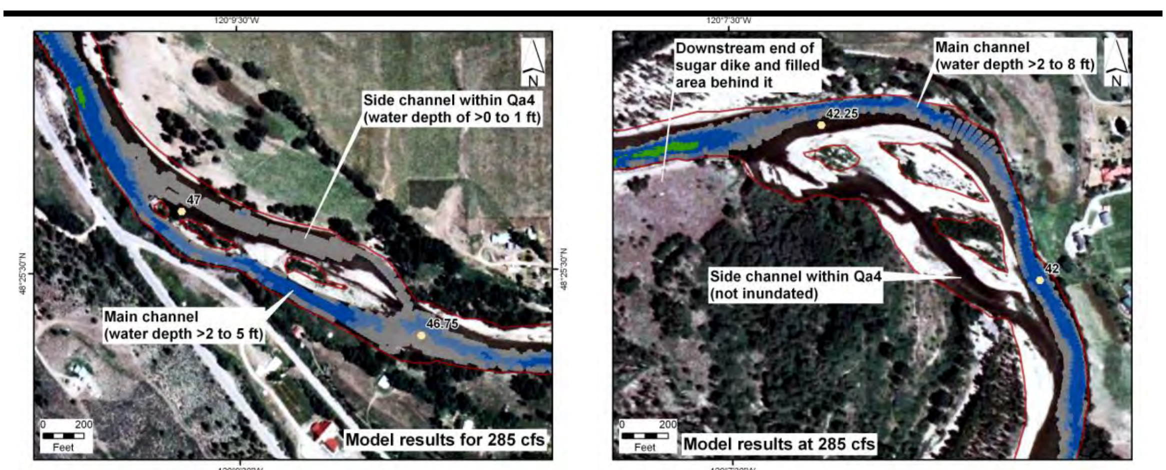

Figure 36. Examples of two side channels within Qa4 showing their inundation during low-flow conditions (285 cfs) relative to the 2006 NAIP aerial photograph presumably taken at a higher discharge.

The side channel shown on the left, near RM 47, is inundated by up to 1 foot of water at low flow, whereas the side channel shown on the right, near RM 42, is not inundated at this discharge. Note that differences in the morphology of the two side channels reflect the difference in inundation. However, the side channel at RM 42 does show inundation at the time the 2006 aerial photographs were taken.

4.3.2 Formation

In the M2 reach, the formation of side channels is dependent on primarily two processes. Side channels formed within the Qa4 are more directly linked to main channel processes and form in response to annual floods, the movement of sediment, the presence of large woody debris transported by the river, and other physical characteristics of the channel at specific locations that affect flow. Side channels formed within the Qa3 are formed in response to processes affecting the floodplain. Generally floodplain side channels are formed as a result of large more infrequent flooding, and channel migration or avulsion. Based on historical information, the majority of new side channel formation is due to these processes and the majority of the floodplain channels were formed as the result of the 1948 flood. Because substantial bank erosion is more likely during larger floods, formation of side channels on the floodplain as a result of main channel avulsion tends to occur rather infrequently. Overbank flow and headward erosion within side channels formed on the floodplain are inferred to be the processes by which smaller overflow channels within Qa3 are formed based on observations in the field (Figure 28). Once a small channel forms, it can provide a channel path for concentration of subsequent overbank flows, so that the channel may be widened, deepened, and (or) lengthened.

In the Habermehl area near RM 45.1 (Figure 31) and near Twisp (RM 41.5 to 42.5), side channels on the floodplain are believed to have formed during the 1948 flood as the result of channel avulsion through the floodplain rather than lateral channel migration. At these two locations, the upstream entrances of new channel paths were eroded on the inside of a meander bend and in both cases the floodplain surfaces were sparsely vegetated. This process can be observed at the upstream end of the Lehman property, where as a result of flooding in 2006 and 2008 flow is beginning to flank a small dike that is blocking an existing side channel.

4.3.3 Modification

Side channel modification is dependent on processes that occur within the main channel as the result of annual flooding and those on the floodplain in response to larger less frequent flooding. Modification of side channels may include any detectable change in the topography including geometry, channel alignment, elevation, width, length, or planform. The majority of side channel modifications occur as a result of erosion and deposition of sediment and woody debris by the river during floods. When side channels or overflow channels are infrequently inundated, other processes (hillslope, mass wasting, biological) may control channel modification.

Side channels and overflow channels within Qa4 and Qa3 tend to be modified by flood flows, annually in the case of the Qa4 side channels, and by larger floods in the case of the Qa3 floodplain channels. When the main channel migrates farther away from or avulses to a different location, other processes tend to dominate the modification or evolution of the side channels. Erosion or deposition of sediment and wood near the side channel entrance can either increase or decrease the amount of flow directed into the side channel (Figure 37). If significantly more flow is directed into the side channel, incision of the channel bottom or erosion of the channel banks can result. If significantly less flow is directed into the side channel, the sediment transport capacity will decrease resulting in the deposition of sediment and wood. Vegetation may also encroach into the channel reducing the capacity of the channel.

An example of this progressive modification can be seen in a side channel near RM 41.75 (Figure 38). In 1945, this side channel was the main channel, so it was initially large and well defined. When the river abandoned this channel, the upstream entrance to the channel became filled with sediment as can be observed in the 1954 aerial photography. Once flow into the channel was reduced, fine sediment carried into the channel by low velocity overbank flow began filling the channel while vegetation encroached from both banks. This same process is currently taking place at the Doran side channel that heads near RM 42.6. GLO maps indicate that this channel was one of two main channel paths in 1894. The overall width and depth of this channel is being reduced by the encroachment of vegetation and more infrequent inundation by flooding. At the present time, the upstream entrance to the channel is almost completely blocked by sediment. A large gravel bar has formed just upstream of the entrance and is building downstream and into the channel.

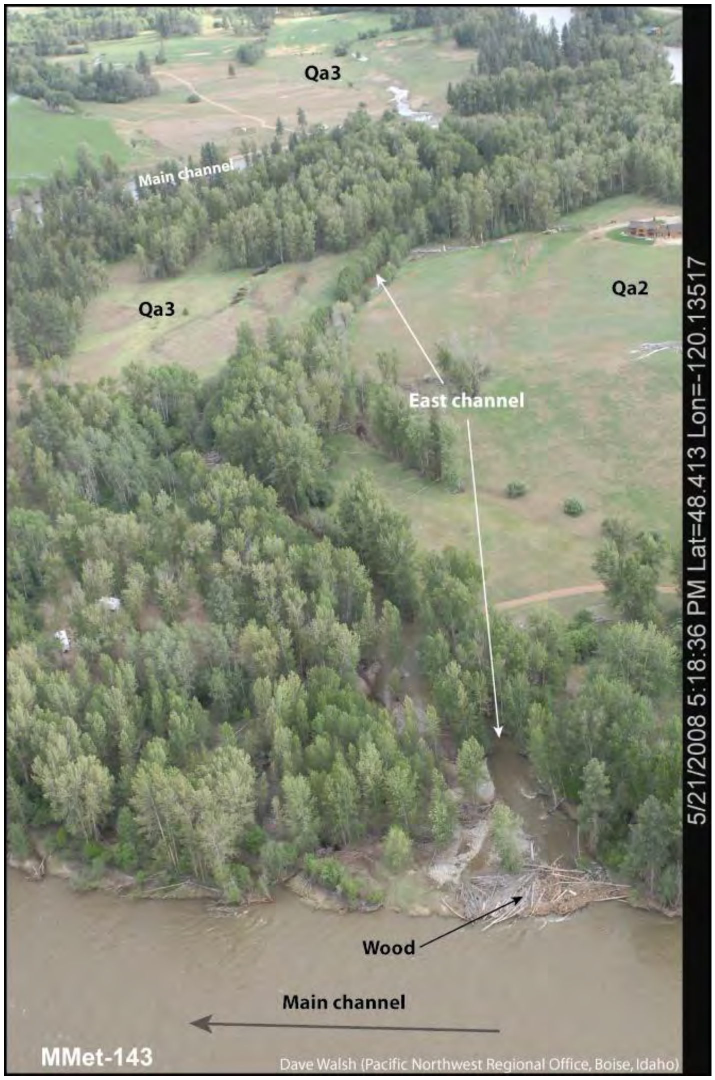

Figure 37. Head of east channel at Habermehl near RM 45.1 with wood and sediment 2 days after the peak of the May 2008 flood.

Figure 38. Example of how the discharge needed to inundate side channels can change over time
The side channel was formed when the main channel avulsed to river left (looking downstream) near RM 42 during the 1948 flood. Following the avulsion, a sediment bar formed on the inside of the meander bend limiting the flow directed into the side channel. As a result, the side channel was observed on subsequent aerial photography to be filling with sediment and vegetation. In 2006, the deposition of sediment had resulted in raising the elevation of the side channel to the point that large floods are needed for inundation of the side channel.

Wood and sediment deposition near the downstream end of a side channel or across the mouth of a side channel can cause backwater or ponding in the side channel. This may increase stage in the side channel if the side channel maintains a strong connection to the main channel at its upstream end, but generally sediment deposition increases at the downstream end. The upstream extent of backwater is dependent on the slope of the side channel relative to the increase in water stage created by the backwater. Within the M2 reach, backwater along the entire length of a side channel was not observed. Backwater at the downstream end of a side channel can also occur due to the presence of beaver dams. An example of this is at the downstream end of the west side channel in the Habermehl area.

Modifications to side channels in the M2 reach have also been related to historical human interventions. At the turn of the century, much of the floodplain in the M2 reach appears to have been cleared of vegetation and modified for agriculture. Also, the construction of diversion dams and other irrigation infrastructure, dikes and levees, dredging activities, and most recently home development have impacted side channels both directly and indirectly. These activities alter the amount of flow and sediment, which in turn alter the topography and hydraulics of the side channel. Dredging and construction of push-up dams is prevalent in the Barclay-Bear Creek and MVID East areas. A side channel in the Barclay-Bear Creek area has been enlarged since 1945 due to dredging that has increased the amount of flow into the side channel. The side channel at MVID East has also increased in size over time as flow has been historically directed into the side channel by a 3-ft high dam on the main channel. Concurrently, a push-up levee was constructed annually out of sediment from the channel bed across the entrance of the side channel at MVID East. The main channel dam was removed in 2008, and the push-up levee has not been rebuilt since that time.

Undocumented dredging and filling of side channels have likely occurred in other locations where land was modified to prevent flooding or to make the land more suitable for farming and grazing. For example, after the sugar dike was constructed near RM 42.5, leftover wood shavings from a timber mill operating near Twisp were reportedly used to fill the old river channel. There are several other examples throughout the M2 reach where modifications to topography indicate some amount of historical filling or dredging of channels.

Accounts that large wood was removed from the main channel are largely anecdotal. In general, it is not known if wood was specifically removed from side channels. While no detailed mapping has been completed, wood has been observed in many of the Qa3 side channels and particularly at the Qa4 side channel in the Barclay-Bear Creek area, where wood has been removed annually from the channel and placed in piles along the channel margins. Wood can also be observed on islands and bars located throughout the M2 reach. However, because the floodplain has been cleared of vegetation in the past, the volume of large wood appears to be artificially limited.

4.3.4 Persistence

The persistence of any particular side channel on the landscape is dependent on time and those processes that contribute to its modification. As long as a side channel is being fluvially modified, primarily by flooding, the side channel will persist. Once a side channel is no longer being impacted by main channel processes, the side channel will begin to stabilize and fill with sediment and vegetation. Five large side channels in the M2 reach have been present since at least 1945, or a minimum of about 60 years. These side channels are in the Barclay-Bear Creek area (RM 49.6), the Pigott area (RM 48), near RM 47, in the MVID East area (RM 46), and in the Habermehl area (RM 44.75). The small side channels in the Pigott and Habermehl areas have remained relatively unchanged over this time (no major modifications). Other large side channels formed between 1945 and 2006, and all still persist as side channels except near the confluence of the Twisp River with the Methow River, where a short section of side channel was destroyed when the main channel migrated into a side channel. Other side channels, which have formed more recently, have only been present for a few years. Given the persistence of other side channels on the landscape, it is likely that these newly formed channels will be present for tens of years depending upon their location relative to the main channel.

5.0 Conclusions

The main channel (referred to as Qa4) and the active floodplain (referred to as Qa3) were mapped to identify areas that offer the most opportunity to maintain and enhance salmonid habitat. Historical changes in the location and form of the main channel (Qa4) and active floodplain (Qa3) were documented using historical aerial photography, LiDAR data, field observations, and channel surveys. The surface of the Qa3 floodplain was found to be irregular with variations in elevation and topography that have been persistent in places for hundreds of years. As a result, the discharges required to inundate and significantly modify or erode the main channel, side channels, and the floodplain are also variable.

Side channels occur within Qa4 along the main channel and within Qa3 on the active floodplain. Formation of the Qa4 side channels occurs through the interaction of annual flood flows with peak discharges up to about 11,000 cfs and the deposition of sediment and wood on bars. This environment is extremely dynamic and erosion and deposition causes frequent shifting of channels. The growth of vegetation on the bars, on islands, and along the margins of the active channel catches wood and helps stabilize and enhance aspects of salmonid habitat in these side channels. This type of change is extremely important to the formation and development of side channel habitat and should be enhanced wherever possible.

The Qa4 side channels, because of their proximity to the main channel, have the most potential for maintaining a surface flow connection during low-flow periods. In the M2 reach, about 21,000 feet (about 4 miles) of Qa4 side channels were present in 2006. However, only two Qa4 side channels with a total length of about 3,200 feet (about 0.6 mile) maintained a surface flow connection at low flows (285 cfs). At a discharge of about 11,000 cfs, an additional 35,000 feet (about 6.5 miles) of side channels have a surface flow connection with about half of these channels being within the Qa3 floodplain. To protect and enhance Qa4 side channels, river practices could be encouraged that limit dredging and removal of large wood. The existing Qa4 side channels generally lack roughness components. Addition of large wood, rocks, or other features could be implemented to increase hydraulic complexity and the presence of localized scour pools to increase the duration of inundation, particularly during low-flow periods.

The formation of Qa3 side channels and overflow channels requires erosion or inundation of the floodplain and as a result they tend to form during larger floods. Because of this tendency for new Qa3 side channels to form during larger floods, these side channels are less dynamic and more stable than those within Qa4. Some of the side channels and overflow channels within the Qa3 in the M2 reach formed as the result of the 1948 flood and have persisted on the landscape for the last 60 years. These channels are present in two areas of the M2 reach: near Twisp and in the Habermehl area. The construction of levees and dikes in other areas of the reach following the floods of 1948 and 1972 has isolated large areas of floodplain (Qa3) from the main channel thereby restricting the formation of this type of habitat. To promote additional side channel formation, these dikes and levees could be relocated (set back) to where they continue to protect infrastructure but improve active channel-floodplain connections. Where possible, dikes and levees could be removed entirely. To protect and enhance existing side channels within the Qa3, river practices that avoid dredging or removal of large wood could be encouraged.

Channel migration and floodplain erosion are processes that are critical to side channel formation and have been most prevalent in the M2 reach just upstream of Twisp. In this area, the floodplain is wide, but becomes constricted at its downstream end. The highway and the sugar dike constructed in the early 1970s cut off portions of the floodplain and limit channel migration. Even so, about 60 percent of all floodplain erosion from channel migration and avulsion that occurred in the M2 reach between 1945 and 2006 occurred in this area. The second largest area of floodplain erosion and side channel formation has been in the Habermehl area. Like the floodplain in the Twisp area, much of this area was inundated by the 1948 flood and some of the best floodplain side channels are in this area. One of the larger tracts of floodplain inundated by the 1948 flood is located in the Lehman area. Modeling results suggest that parts of the floodplain in this area are shallowly inundated by discharges of about 11,000 cfs. Several channels formed on the floodplain in this area appear to be connected hydraulically to the main channel at their downstream ends, but the upstream connections are not established. At low flows, water in the downstream portions of these channels appears to be from irrigation returns. Constructed blockages (e.g., road crossings, culverts) in these channels could be removed and connectivity with the main channel at lower discharges enhanced where possible to increase opportunities to develop viable habitat.

The greatest opportunity for channel migration within the Qa4 main channel that would promote side channel development is from RM 45 downstream to RM 41 (the Twisp area). It is also expected that more channel migration and side channel development within the Qa3 floodplain would occur between RM 45 and 41 in the future if levees, riprap, or other features were either set back or removed. In the present river setting, the greatest opportunity for side channel development is where accessible Qa3 floodplain is currently cut off, such as near MVID East, along the Lehman area, and along the sugar dike in the upstream part of the Twisp area. Although no side channels are present, the meander at RM 42.5 (at the sugar dike) presents an opportunity for side channel development within Qa4. However, these types of projects need to be approached with caution in areas with homes or other critical infrastructure. Areas within the Qa4 main channel and Qa3 floodplain are prone to inundation and have been affected by historical floods. While it may be desirable and appear to be a great opportunity to develop critical habitat, allowing increased flow into these side channels may actually increase the risk of channel avulsion and flooding above that of natural conditions. Given the frequency of inundation and very short duration of surface connection to the main channel on an annual basis, development of side channel habitat in any Qa3 area is suggested as a secondary priority. Exceptions to this recommendation may exist where well developed channels within Qa3 are present. The role of groundwater in all of the side channels is largely unknown and needs to be better understood. Side channels with groundwater connections may also provide good opportunities to sustain critically important low-flow habitat, even when a surface water connection is not present. In the interest of maintaining the ability of the channel to migrate across its floodplain from a geomorphic perspective, future efforts could also incorporate limiting human activities (primarily home development and agriculture) within Qa3 areas.

The greatest opportunities for side channel development and protection are within Qa4, indicating these areas should be considered as the first priority for protection and enhancement for the most immediate benefit. These areas offer the greatest opportunity due to their proximity to the main channel, their dynamic character, and the probably that they will be inundated and maintain a hydraulic connection for longer periods and at important times of the year (Figure 39). It is recommended that the length of side channels that maintain this connection during low-flow periods, generally late summer through winter, should be enhanced or developed wherever possible. Many of these side channels currently contain only shallow flow during low flow periods, or are completely dewatered. In order to increase the length of side channels that are inundated at lower flows and thus the amount of potential salmonid habitat in the reach, large wood and rock could be placed along the margins of the main channel in specific areas (i.e., upstream ends of side channels) in order to raise water surface elevations locally. This action should also help create small pools, reduce velocities, increase channel complexity.

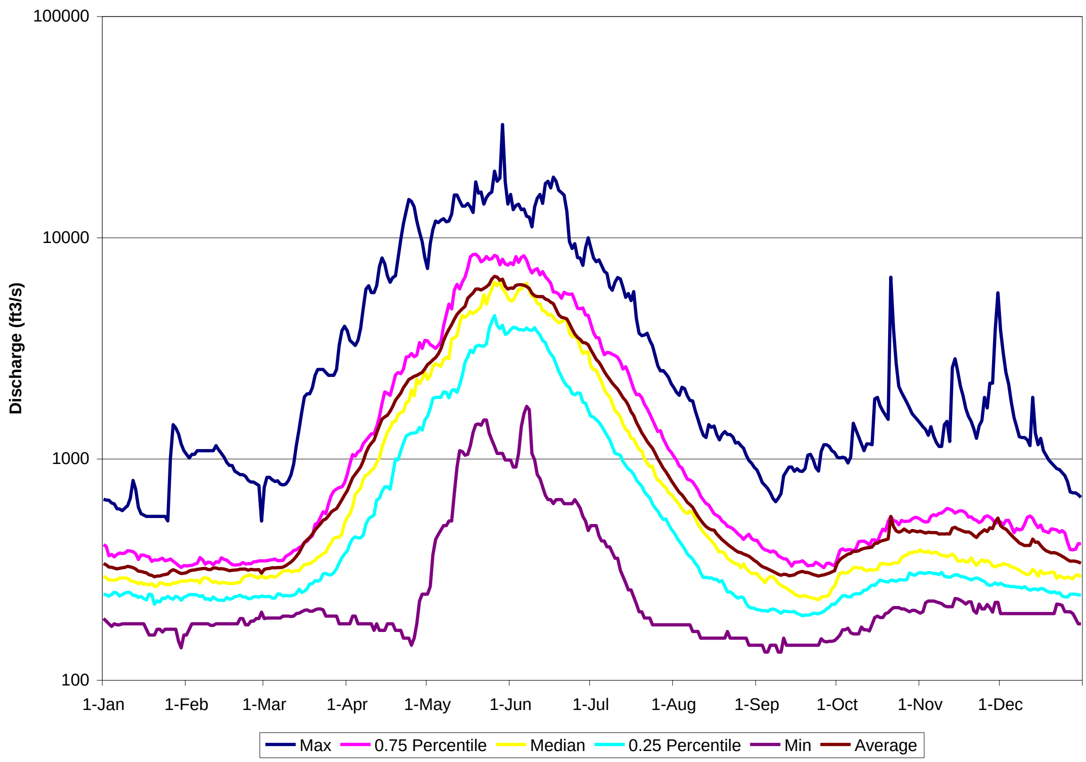

Figure 39. Summary hydrograph showing probability distribution of mean daily discharge based on 56 years of record at the gaging station on the Methow River at Twisp (USGS station #13449500).

Bedrock along the main channel and in the channel bed was observed to constrict the channel of the Methow River at two locations; upstream of the Barclay-Bear Creek area and at the downstream end of the reach near Twisp. Bedrock may limit the lateral channel migration at each of these sites, but in each of these areas the bedrock also controls the gradient of the Methow River. No evidence of sustained main channel incision over a multiple decade period was observed, primarily due the bedrock in the channel that provides base level control. In the Twisp area, bedrock control combined with the influx of sediment from the Twisp River has resulted in widespread lateral channel migration as the river constantly adjusts its course. Bedrock was identified to be the most common cause of the formation of deep pools (6 to 18 ft) in the active channel. These pools are expected to remain over long periods of time barring any large channel avulsions that would move the main channel away from these areas.

While the occurrence of bedrock in the channel may limit reach-scale incision, it also may promote local scour. It should be recognized that in any given area localized scour or an increase in bar or floodplain elevation as a result of deposition can give the appearance of incision due to a change in the relative height between the main channel and these features. Protected banks do have the potential to locally change the channel geometry, and depending on the alignment and slope of the river may produce local scour. However, change in the channel bed elevation and of the hydraulic controls in the river bed (particularly riffle crests) has not been documented, thus lower flood stages that would result from reach-wide incision has not occurred. Riprap on alluvial banks limits the growth and recruitment of riparian vegetation, which can also locally reduce the potential for vegetation to influence changes in channel geometry. Riprap placed along higher surfaces and older alluvial deposits has minimal impact on limiting channel migration because rates in these areas are naturally very low without the bank protection and might actually enhance localized scour. Widespread channel migration or erosion of these deposits is generally associated with other alterations or controls to the channel nearby. This is important to consider in making changes to the channel to enhance habitat and how these projects may negatively impact adjacent areas.

Given objectives to improve opportunities for main channel migration, floodplain access, and side channel habitat for salmonids, from a geomorphic and hydraulics perspective, the following actions are recommended:

- Consider actions that will increase complexity (diverse channel geometry) and wetted area during low-flow periods in;
    - side channels (split flow areas) present within the unvegetated, active channel area (Qa4) that provide potential to increase wetted area and complexity due to their close proximity and hydraulic connectivity with the main channel;
    - a few well-developed side channels present within the active floodplain (Qa3) that provide opportunities for increasing low-flow habitat;
    - scour pools where local increases in water depth could be accomplished by the addition of large wood features along channel

margins as the main channel is generally devoid of large wood except at the heads of vegetated islands.

- Actions should avoid construction of in-stream features in locations that would “lock the channel in place”, thus preventing or limiting channel migration.
- Allow the river to access its floodplain to improve connectivity by removing or setting back (move away from the active channel) man-made features that prevent channel migration and side channel development.
- Avoid establishing a connection between the main channel and channels on the floodplain (Qa3 or Qa2) that would increase flooding and erosion hazards for developed areas. Channel avulsion risk is highest where the main channel is or has the potential to cutoff a meander bend.
- Encourage river use practices that limit or avoid dredging and removal of large wood from the main channel and prominent side channels that could otherwise provide viable salmonid habitat features.

6.0 References

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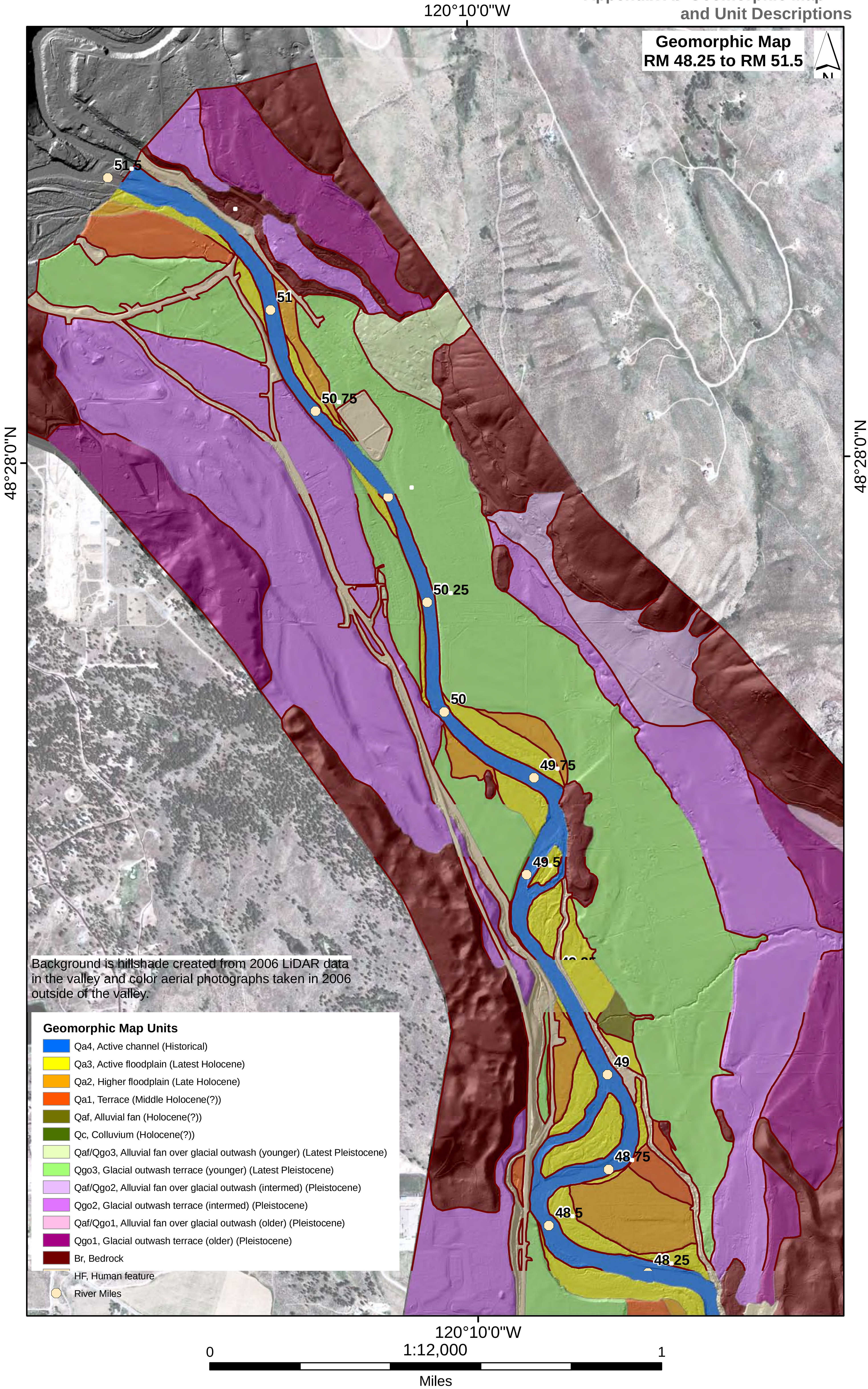
APPENDIX A
GEOMORPHIC MAP AND UNIT DESCRIPTIONS

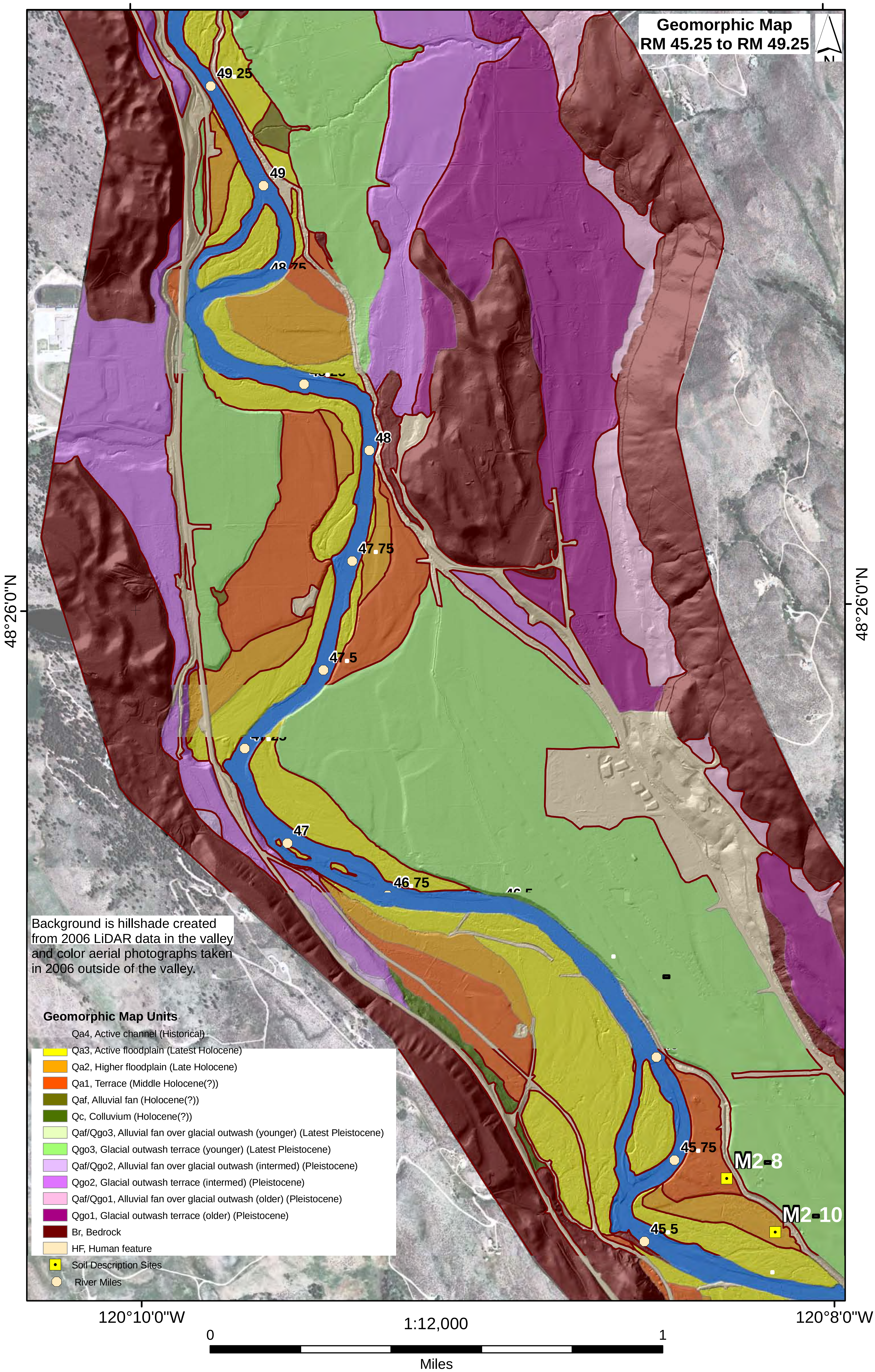
MIDDLE METHOW REACH ASSESSMENT
METHOW RIVER
OKANOGAN COUNTY, WA

U.S. BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER
DENVER, CO

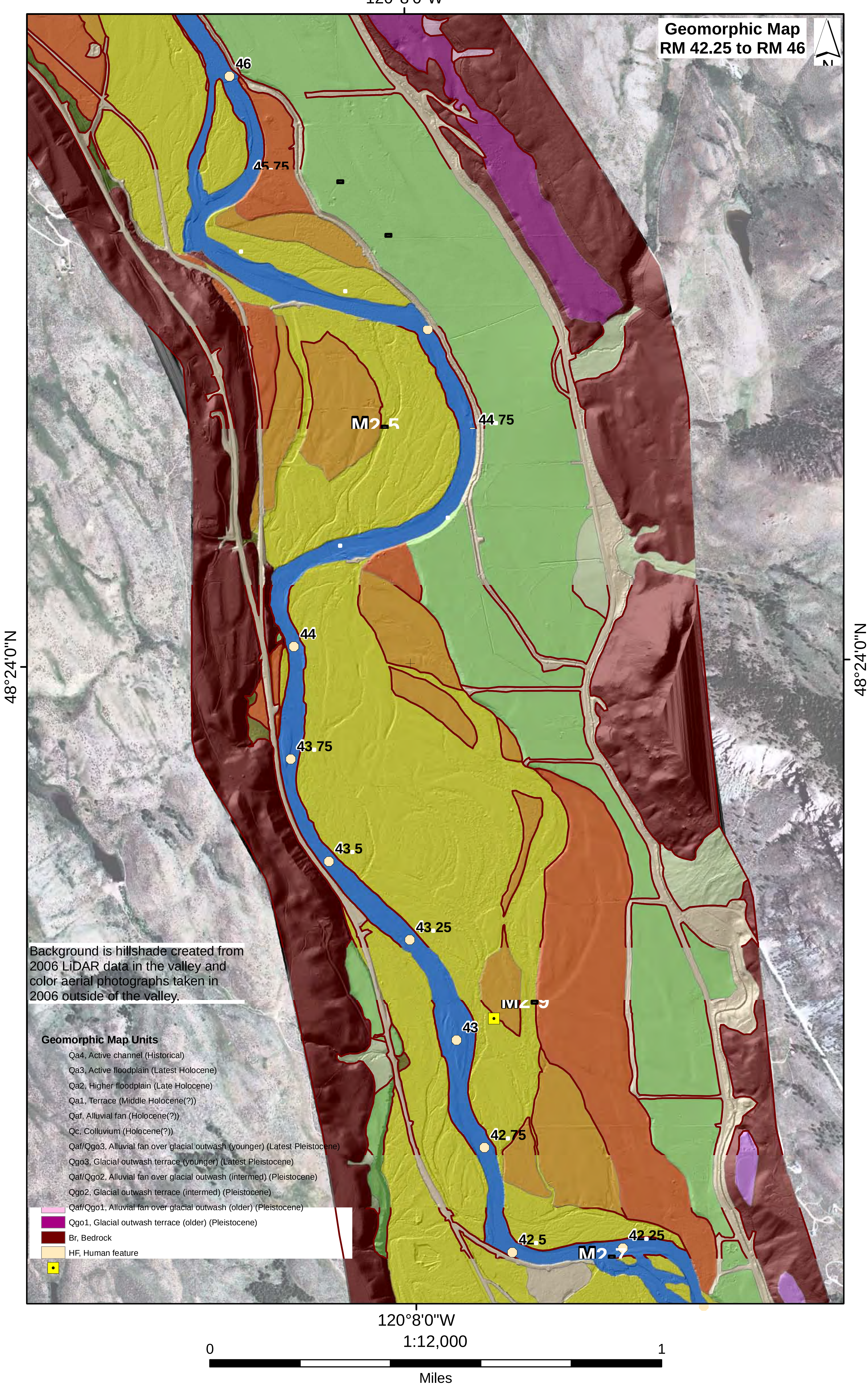
Lucille A. Piety
Seismotectonics and Geophysics Group (86-68330)
and
Ralph E. Klinger
Sedimentation and River Hydraulics Group (86-68240)

January 2010


Geomorphic Map
RM 48.25 to RM 51.5
N
120°10'0"W
48°28'0"N
51.5
51
50.75
50.25
50
49.75
49.5
49
48.75
48.5
48.25
Background is hillshade created from 2006 LiDAR data in the valley and color aerial photographs taken in 2006 outside of the valley.
Geomorphic Map Units
Qa4, Active channel (Historical)
Qa3, Active floodplain (Latest Holocene)
Qa2, Higher floodplain (Late Holocene)
Qa1, Terrace (Middle Holocene(?))
Qaf, Alluvial fan (Holocene(?))
Qc, Colluvium (Holocene(?))
Qaf/Qgo3, Alluvial fan over glacial outwash (younger) (Latest Pleistocene)
Qgo3, Glacial outwash terrace (younger) (Latest Pleistocene)
Qaf/Qgo2, Alluvial fan over glacial outwash (intermed) (Pleistocene)
Qgo2, Glacial outwash terrace (intermed) (Pleistocene)
Qaf/Qgo1, Alluvial fan over glacial outwash (older) (Pleistocene)
Qgo1, Glacial outwash terrace (older) (Pleistocene)
Br, Bedrock
HF, Human feature
River Miles
1:12,000
0
1
Miles



Geomorphic Map
RM 45.25 to RM 49.25
N
120°10'0"W
120°8'0"W
48°26'0"N
49.25
49
48.75
48
47.75
47.5
47
46.75
45.75
45.5
M2-8
M2-10
Background is hillshade created from 2006 LiDAR data in the valley and color aerial photographs taken in 2006 outside of the valley.
Geomorphic Map Units
Qa4, Active channel (Historical)
Qa3, Active floodplain (Latest Holocene)
Qa2, Higher floodplain (Late Holocene)
Qa1, Terrace (Middle Holocene(?))
Qaf, Alluvial fan (Holocene(?))
Qc, Colluvium (Holocene(?))
Qaf/Qgo3, Alluvial fan over glacial outwash (younger) (Latest Pleistocene)
Qgo3, Glacial outwash terrace (younger) (Latest Pleistocene)
Qaf/Qgo2, Alluvial fan over glacial outwash (intermed) (Pleistocene)
Qgo2, Glacial outwash terrace (intermed) (Pleistocene)
Qaf/Qgo1, Alluvial fan over glacial outwash (older) (Pleistocene)
Qgo1, Glacial outwash terrace (older) (Pleistocene)
Br, Bedrock
HF, Human feature
Soil Description Sites
River Miles
1:12,000
0
1
Miles



Geomorphic Map
RM 42.25 to RM 46
N
120°8'0"W
48°24'0"N
48°24'0"N
46
45.75
44.75
44
43.75
43.5
43.25
43
42.75
42.5
42.25
Background is hillshade created from 2006 LiDAR data in the valley and color aerial photographs taken in 2006 outside of the valley.
Geomorphic Map Units
Qa4, Active channel (Historical)
Qa3, Active floodplain (Latest Holocene)
Qa2, Higher floodplain (Late Holocene)
Qa1, Terrace (Middle Holocene(?))
Qaf, Alluvial fan (Holocene(?))
Qc, Colluvium (Holocene(?))
Qaf/Qgo3, Alluvial fan over glacial outwash (younger) (Latest Pleistocene)
Qgo3, Glacial outwash terrace (younger) (Latest Pleistocene)
Qaf/Qgo2, Alluvial fan over glacial outwash (intermed) (Pleistocene)
Qgo2, Glacial outwash terrace (intermed) (Pleistocene)
Qaf/Qgo1, Alluvial fan over glacial outwash (older) (Pleistocene)
Qgo1, Glacial outwash terrace (older) (Pleistocene)
Br, Bedrock
HF, Human feature
120°8'0"W
1:12,000
0
1
Miles

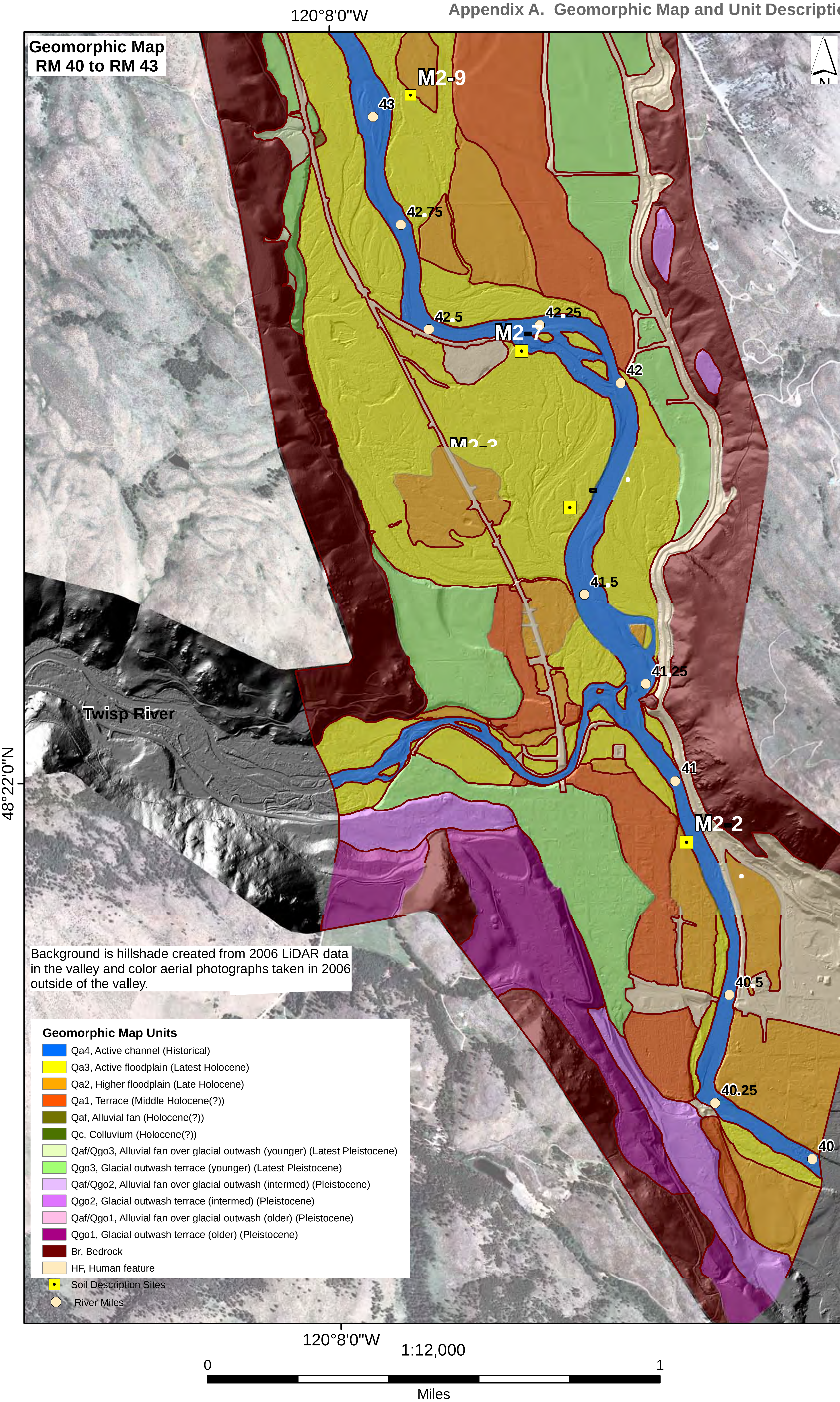

Geomorphic Map
RM 40 to RM 43
120°8'0"W
48°22'0"N
M2-9
M2-7
M2-3
M2-2
43
42.75
42.5
42.25
42
41.5
41.25
41
40.5
40.25
40
Twisp River
Background is hillshade created from 2006 LiDAR data in the valley and color aerial photographs taken in 2006 outside of the valley.
Geomorphic Map Units
Qa4, Active channel (Historical)
Qa3, Active floodplain (Latest Holocene)
Qa2, Higher floodplain (Late Holocene)
Qa1, Terrace (Middle Holocene(?))
Qaf, Alluvial fan (Holocene(?))
Qc, Colluvium (Holocene(?))
Qaf/Qgo3, Alluvial fan over glacial outwash (younger) (Latest Pleistocene)
Qgo3, Glacial outwash terrace (younger) (Latest Pleistocene)
Qaf/Qgo2, Alluvial fan over glacial outwash (intermed) (Pleistocene)
Qgo2, Glacial outwash terrace (intermed) (Pleistocene)
Qaf/Qgo1, Alluvial fan over glacial outwash (older) (Pleistocene)
Qgo1, Glacial outwash terrace (older) (Pleistocene)
Br, Bedrock
HF, Human feature
Soil Description Sites
River Miles
1:12,000
0
1
Miles

Table 1. Descriptions of geomorphic map units

Description	Map unit[1]	Unit designation	Estimated age[2]	Surface morphology	Parent material	Surface height above channel	Surface height above next youngest surface	Occurrence	Soil Characteristics[3]	Inundation[4]	Other characteristics
Fluvial deposits	Qa4	Active channel	Historical (a few years to about 100 years)	Irregular, includes numerous channels and unvegetated bars	Primarily gravelly and sandy alluvium	0 for the channel; commonly 4 to 8 ft and up to 10 ft for unvegetated bars	Not applicable	Continuous	None	Annually	Includes side channels along edges of main channel.
	Qa3	Active floodplain	Latest Holocene (a few hundred years to about a thousand years)	Irregular, includes prominent, numerous, mostly well-defined channels	Primarily sandy alluvium (overbank) over gravelly alluvium (channel) or only gravelly alluvium; thicknesses variable	10 to 17 ft in narrower sections; commonly 2 to 12 ft and up to 15 ft in wider sections	Commonly 4 to 6 ft with a range of 2 to 8 ft above unvegetated bars in narrower sections; commonly 2 to 4 ft and up to 7 ft above unvegetated bars in wider sections	Continuous along main channel (Qa4)	A/C and may include buried soils (in areas of recurrent deposition) or A/Bw(?)/C (on stable surfaces)	Based on model results, better defined side and overflow channels near the main channel may be activated at discharge of ~11,000 cfs; most surfaces inundated by shallow (<1 ft) water at 16,600 cfs ;most surfaces inundated by water with depths of >5 ft at 24,400 cfs	Qa3 surfaces were primarily inundated by 1948 flood; areas marginally or not flooded included if surface elevations are similar to those in areas that were inundated in the 1948 flood Surfaces may or may not have riparian vegetation; can be cleared of vegetation by channel processes or human activities Includes historical main, side, and overflow channels
	Qa2	Higher floodplain	Late Holocene (a few thousand years)	Slightly irregular, includes low-relief channels	Primarily sandy alluvium (overbank) over gravelly alluvium (channel); thicknesses variable	10 to 18 ft in narrower sections; commonly 5 to 10 ft in wider sections	Commonly 5 to 10 ft but can be 2 ft above Qa3 surfaces in narrower sections; 1 to 2 ft above Qa3 surfaces in wider sections	Disconnected remnants usually along active floodplain (Qa3) or locally along main channel (Qa4)	A/Bw or Boq/C (If in gravelly parent material, stones have stage I to I- SiO_3/Mn coats; matrix is gray)	Based on model results, surfaces only partially inundated by shallow (<2 ft) water at discharge of 24,400 cfs, primarily in channels; surfaces inundated or surface edges inundated by shallow (<2 ft) water and channels have water up to 4 ft deep at 31,360 cfs	Surfaces appear to have been either shallowly inundated by the 1948 or inundated just along their edges near the main channel, especially where surfaces have greater heights above the channel (e.g., in narrower sections) Includes historical overflow channels
	Qa1	Terrace	Middle Holocene (about 5,000 years)	Slightly irregular, includes broad, low-relief channels that are variably oriented relative to the present main channel	Primarily sandy alluvium (overbank) over gravelly alluvium (channel); thicknesses variable	Commonly 17 to 25 ft and up to 40 ft in narrower sections; 17 to 25 ft in wider sections	2 to 12 ft above Qa2 surfaces in narrower sections; commonly 2 to 5 ft and up to 12 ft above Qa2 surfaces in wider sections	Disconnected remnants usually along higher floodplain (Qa2), active floodplain (Qa3), or rarely along main channel (Qa4)	A/Bw or Bwoq/C (If in gravelly parent material, matrix in brown and stones have stage I- SiO_3/Mn coats)	Surfaces are too high to be inundated at discharge of 31,360 cfs (model results)	No evidence observed for inundation by 1948 flood
Glacial outwash	Qgo3	Glacial outwash (younger)	Latest Pleistocene (a few tens of thousands of years)	Smooth to slightly irregular, includes prominent, large, very broad, low-relief channels that are variably oriented relative to the present main channel	Primarily gravelly and sandy glacial outwash; finer grained in upper part from addition of eolian sediment	Commonly 20 to 25 ft in narrower sections; commonly 15 to 20 ft in wider sections	10 to 20 ft above Qa1 surfaces in narrower sections; 10 to 15 ft above Qa1 surfaces in wider sections	Nearly continuous on river left for nearly the entire reach (RM 41.5 to RM 51); on river right between RM 40.5 and RM 41.5, RM 41.5 and RM 43.25, and nearly continuous between RM 47.5 and RM 51.5	A/Bt(?) or Bwoq/C (If in gravelly parent material, matrix is brown and stones have stage I SiO_3/Mn coats; coats noticeably thicker and more continuous than those in Qa1 soil)	Surfaces are much too high to be inundated at discharge of 31,360 cfs (model results)	Bedrock underlies gravelly outwash deposits; gravel of variable thickness; near valley edges, outwash surface can be covered with alluvial-fan and colluvial deposits (not mapped), especially toward the edges of the valley

Description	Map unit[1]	Unit designation	Estimated age[2]	Surface morphology	Parent material	Surface height above channel	Surface height above next youngest surface	Occurrence	Soil Characteristics[3]	Inundation[4]	Other characteristics
	Qgo2	Glacial outwash (intermediate)	Pleistocene	Smooth	Primarily gravelly and sandy glacial outwash; finer grained in upper part from addition of eolian sediment	About 30 to 35 ft	10 to 20 ft above Qgo3 surfaces	Present on river right between MR 40 and RM 41, and between RM 46.5 and RM 51.5; present on left between RM 47 and RM 50.25, RM 51 and RM 51.5, and in two small areas between R M 42 and RM 42.5	Not described	Surfaces are much too high to be inundated at discharge of 31,360 cfs (model results)	Bedrock underlies gravelly outwash deposits; often preserved at valley edges and covered with alluvial-fan and colluvial deposits (most not mapped)
	Qgo1	Glacial outwash (older)	Pleistocene	Smooth	Primarily gravelly and sandy glacial outwash; finer grained in upper part from addition of eolian sediment	Unknown (beyond extent of contours)	Unknown (beyond extent of contours)	Present on river right RM 40 to RM 41 (Twisp area), on river left between RM 45 and RM 49.5, and on both sides upstream of RM 50	Not described	Surfaces are much too high to be inundated at discharge of 31,360 cfs (model results)	Bedrock underlies gravelly outwash deposits; often preserved at valley edges and covered with alluvial-fan and colluvial deposits (most not mapped)
Alluvial-fan deposits	Qaf	Alluvial fan	Holocene(?)	Smooth	Not described	Variable	Not applicable	Small deposits graded to floodplain deposits at various localities in the reach	Not described	Not applicable	Mapped alluvial fans are graded to floodplain deposits, primarily to unit Qa3
	Qaf/Qgo3	Alluvial fan over glacial outwash (younger)	Pleistocene to Holocene(?)	Smooth	Not described	Unknown (beyond extent of contours)	Unknown (beyond extent of contours)	Present where larger tributaries enter valley; on river left near RM 50.75, and between RM 43 and RM 45; on river right near RM 43	Not described	Surfaces are much too high to be inundated at discharge of 31,360 cfs (model results)	Includes alluvial fans from tributaries where the alluvial fan can be distinguished from underlying Qgo3 deposits on the basis of surface morphology; contacts with Qgo3 are gradational and approximately located; can include colluvial deposits, especially along valley edges
	Qaf/Qgo2	Alluvial fan over glacial outwash (intermediate)	Pleistocene to Holocene(?)	Smooth	Not described	Unknown (beyond extent of contours)	Unknown (beyond extent of contours)	Present primarily on river left between RM 49.75 and RM 50.5; in small areas on river right between RM 46.5 and RM 47.25	Not described	Surfaces are much too high to be inundated at discharge of 31,360 cfs (model results)	Includes alluvial fans from tributaries where the alluvial fan can be distinguished from underlying Qgo2 deposits on the basis of surface morphology; contacts with Qgo3 are gradational and approximately located; can include colluvial deposits, especially along valley edges
	Qaf/Qgo1	Alluvial fan over glacial outwash (older)	Pleistocene to Holocene(?)	Smooth	Not described	Unknown (beyond extent of contours)	Unknown (beyond extent of contours)	Present on river left between RM 46 and RM 49.5	Not described	Surfaces are much too high to be inundated at discharge of 31,360 cfs (model results)	Includes alluvial fans from tributaries where the alluvial fan can be distinguished from underlying Qgo1 deposits on the basis of surface morphology; contacts with Qgo3 are gradational and approximately located; can include colluvial deposits, especially along valley edges
Colluvium	Qc	Colluvium	Holocene(?)	Irregular	Not described	Variable	Not applicable	Mapped only in limited areas along bedrock; on river right between RM 45.75 and RM 46.75	Not described	Not applicable	None

Description	Map unit[1]	Unit designation	Estimated age[2]	Surface morphology	Parent material	Surface height above channel	Surface height above next youngest surface	Occurrence	Soil Characteristics[3]	Inundation[4]	Other characteristics
Bedrock	Br	Bedrock	Cretaceous through Tertiary (~138 million years to 1.6 million years)	Irregular	Sandstone, siltstone, shale, conglomerate, breccia, tuff, granitic and dioritic intrusive rocks	Variable	Not applicable	Along both sides of entire reach; exposed in places within the valley upstream of about RM 48	Not applicable	Not applicable	Bedrock surfaces commonly carved into channel/ridge topography (glacial erosion); includes colluvium (not mapped), especially at valley edges
Human feature[5]	HF	Human feature	Historical (a few years to about 100 years)	Linear or irregular	For constructed features, mostly unconsolidated gravel and sand	Variable	Not applicable	Along entire reach (e.g., highway) or scattered throughout reach (e.g., levees)	Not applicable	Variable	None

[1]Progressively higher numbers indicate relatively younger units.
[2]Radiocarbon analyses are in Appendix D, and identification of ash sample are in Appendix E.
[3]Field descriptions of soil profiles are in Appendix C.
[4]Area of inundation is dependent upon the width of the floodplain and the location of the surface relative to the main channel. Detailed description of inundation is in Appendix B.
[5]Human features shown on the maps are mostly those that influence the channel and floodplain by their height and (or) extent; all human features have been mapped in detail by E. Lyon (Pacific Northwest Regional Office).

APPENDIX B.

HYDRAULIC MODEL DOCUMENTATION

MIDDLE METHOW REACH ASSESSMENT
METHOW RIVER
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January 2010

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1.0 Introduction

This appendix documents methodology used to generate the two dimensional (2D) numerical model, SRH-2D v2.2, used for analysis of hydraulics in the 10-mile M2 reach (Lai, 2006; http://www.usbr.gov/pmts/sediment/model/srh2d/index.html). Solved variables at each grid node include water surface elevation, water depth, depth-averaged velocity, Froude number, and bed shear stress. Model output can also be generated to provide flow inundation area and velocity vectors.

The following sections describe the topographic data collection and processing for model development, the model boundaries (domain), mesh generation, model setup, and model validation. The model was generated to evaluate floodplain inundation and the flows at which prominent side channels become active from a surface flow connection with the main channel. Modeling was generally focused on flood flows, with the exception of one low flow done to calibrate to the survey data. The model results are applicable for the mainstem Methow River between Winthrop and Twisp. If localized hydraulic results are needed at a given river segment, particularly for low-flow analysis, additional survey data and model grid development may be needed to increase the detail in these areas.

2.0 Model Input Data

This section describes discharge and topographic input data for the model.

2.1 Discharge

A range of discharges was modeled as steady flows (single discharge for each model run) (Table 1). Discharge values were based on recorded values at USGS gaging stations on the Methow River below Winthrop and below Twisp, and on the Twisp River near Twisp as described in the main report Section 2.3.

Only surface flow contributed from the Methow and Twisp Rivers were included. Groundwater and surface water diversions were not addressed in this modeling effort.

Table 1. Discharges used in the numerical two-dimensional hydraulic model.

Methow River (cfs)	Twisp River (cfs)	Notes
285	70	Low flow discharge; mean daily flows during channel survey in October 2008
10,900	2,020	Equivalent to about 2-yr flood; falling limb of May 23, 2006, flood
16,600	3,890	10-yr flood
24,400	1,720	1972 peak; equivalent to about the 25-yr flood
31,360	9,440	1948 peak; larger than the 100-yr flood

2.2 Topographic Data Collection

For the M2 study reach, topographic data in the low-flow wetted channel were collected during October 6 to 10, 2008 at an average flow of 285 cfs (USGS 12448500 METHOW RIVER AT WINTHROP, WA). In non-wetted areas LiDAR data collected November 9, 2006 at a mean daily river flow of 1,590 cfs was utilized (USGS 12448500). The LiDAR data are documented to meet mapping standards for the 1 m grid provided (Watershed Sciences, 2007). All data are provided in Washington State Plane North, NAD 1983 and NAVD 1988 feet. The survey was tied to control points established by the National Geodetic Survey and post processed to improve the vertical accuracy using the OPUS network.

For the channel areas, data were collected by the Sedimentation and River Hydraulics Group of the Technical Service Center (Denver, Colorado) with global positioning system (GPS) and by Ron Gross of the Twisp, Washington Reclamation office with total station equipment. Due to time and budget constraints, only the largest side channels could be surveyed and LiDAR was used for the more numerous, smaller side channels present in the floodplain.

In wetted areas that could not be waded, data were collected by rafts equipped with GPS that recorded the water surface, and depth sounders that collected water depth. On one boat, an acoustic Doppler current profiler (ADCP) was utilized that also collected velocity data. Water surface elevation data were collected with Trimble 4700 or 5800 equipment in an RTK mode. The density of data varied depending on the ability to navigate the boat across the channel (e.g. riffles vs. pools), topographic variation of the channel that needed to be captured, and obstructions to satellite coverage. Generally, two boats floated down the channel collecting a longitudinal profile of data approximately one-third and two-thirds across the wetted width. In pool areas with slower water, "Z" patterns were rowed to increase data collection coverage. Points along the edge of water could generally not be collected due to overhanging vegetation and high banks that blocked satellite views. In faster riffle sections that had shallow depths, the two boats often converged to nearly the same path. If the water depth was less than 1.5 ft the depth was visually estimated and recorded in a field book. The ADCP data was post-processed using WinRiver software (www.rdinstruments.com) and the single beam data was post-processed using Hypac software. The GPS RTK data was used to generate a water surface tin in GIS. Water depths were subtracted in GIS from the water surface tin to get channel bottom elevations. The maximum depth recorded during the survey was 18.5 ft.

A total of 5718 GPS points were collected. For GPS points collected on land in "topo" mode, the accuracy is dependent on the satellite configuration and solution error. The accuracy of the GPS points collected by boat additionally depend on how turbulence on the water surface was affecting the boat position and error associated with the depth sounder reading. The GPS points collected on land (topo points) were not allowed to have a maximum horizontal error greater than 0.07 ft and a maximum vertical error of 0.07 ft. When the GPS points were collected on the boat using the "rapid" mode, the controller was set to only store points if the horizontal precision was less than 0.6 ft and the vertical precision was less than 0.8 ft. The boat points have a greater tolerance for error because each point value is based on only 1 observation. The topo point solution is determined by averaging multiple observations.

The 5718 points were analyzed in the GPS processing software TGO (Trimble Geomatics Office) to determine the actual precision values. The average horizontal precision was 0.06 ft and the average vertical precision was 0.09 ft. The maximum horizontal error was 0.5 ft and the maximum vertical error was 0.7 ft, but this magnitude of error was uncommon. Because of additional error associated with water turbulence, it is estimated that GPS points collected by boat have a total vertical and horizontal error within a range of 0.5 ft.

2.3 Topographic Surface for Model Grid

A TIN was generated in a geographical information system (GIS) to represent existing topographic conditions that were used to determine ground elevations for each node of the 2D model mesh. The TIN was generated from a combination of the October 2008 survey data for the channel areas and 2006 LiDAR data for floodplain areas. Because the

LiDAR was collected at a flow of 1,600 cfs and the channel survey data was collected at 285 cfs, there was a gap in bed elevation data along the margins of the active channel. Ground elevations were estimated along the edge of water during the October 2008 survey using the nearest recorded water surface elevation. Ground elevation between the 2008 edge of water and the start of the LiDAR data (edge of water at 1,600 cfs) was linearly interpolated from the two data sets.

At a few locations, additional survey points were utilized to validate and refine 2006 LiDAR data. At the Barclay diversion near RM 49.6, the October 2008 survey included the push-up dam that was in place at the head of the flow split. At MVID East near RM 46, survey data was utilized for the right side channel that was collected in October 2006. At MVID East in the main channel, a 1-ft high log crib dam was removed shortly after the 2008 survey. Riverbed elevations were adjusted to represent the site with the dam gone. A few ponded areas at the downstream end of side channels near RM 44 were also surveyed.

The channel bottom of the Twisp River was based on a limited amount of data collected in 2005; no new data were collected on the Twisp River for this study because the focus of the modeling was on the mainstem Methow River.

3.0 Mesh Generation

This section describes the boundaries of the model and the generation of the model mesh.

3.1 Model Boundaries

The numerical model extended from just downstream of the Chewuch River confluence (RM 50.8) downstream to the USGS gage below the Twisp River confluence at about RM 40.3 (Figure 1). Two model domains were established that include RM 40.3 to 45.5 (between MVID East and Habermehl) and RM 45.5 to 50.8. The downstream model domain included about 1 mile on the downstream-most Twisp River to account for the flow contribution from the Twisp River. The upstream and downstream boundaries (RM 40.3 and 50.8) were established where there is a single thread channel with limited to no floodplain. The boundary at RM 45.5 was located approximately half way through the study reach in an area with a relatively narrow floodplain.

The model domain was extended laterally a few hundred feet beyond the estimated maximum extent of flooding, including areas inundated from large events such as the 1948 flood of record (9,400 cfs on Twisp River and 40,800 cfs on Methow below Twisp). In areas with little or no floodplain the mesh boundary extended just beyond the active channel along terraces, bedrock, or glacial outwash. In areas with large amounts of floodplain the mesh boundary extended over 1 mile across the floodplain. The surficial geologic units map, the FEMA floodplain boundary, and aerial photographs of the 1948 flood of record were used as a guide for the lateral boundary extents. Man-made features in the river or floodplain such as roads, levees, or bridges were not used as boundaries.

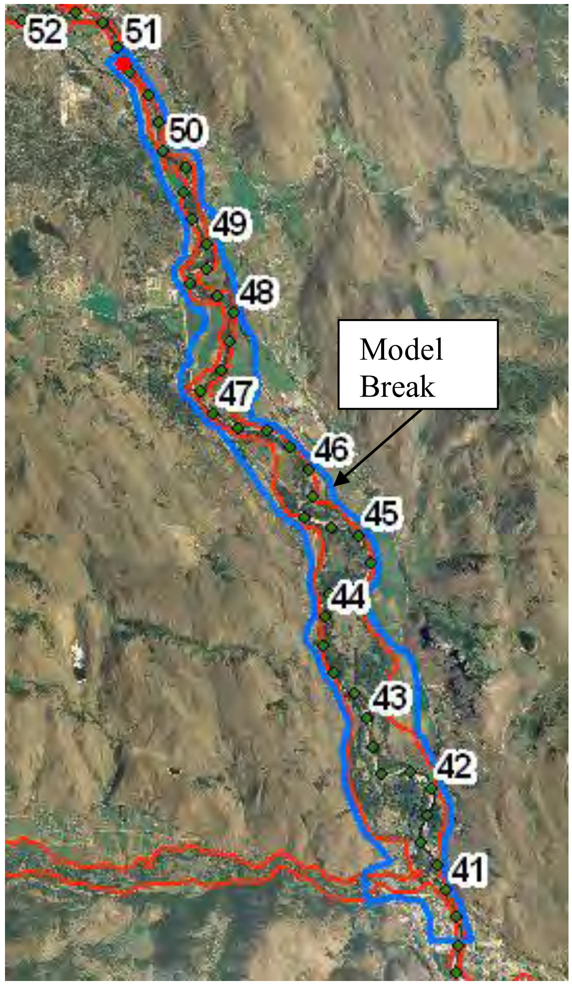


Figure 1. Numerical model boundaries on mainstem Methow River are shown in blue outline and active floodplain (Qa3 as described in main report Section 3) shown in red line.

3.2 Mesh Development

For the M2 models, the mesh was developed using a combination of quadrilateral and triangular elements in the SMS software (version 10) (Figure 2). The mesh was generated by first breaking the study reaches into unique polygons based on roughness variations (e.g. main channel, vegetated floodplain, and unvegetated floodplain). Channel polygons were further sub-divided to orient cells parallel to the direction of flow and perpendicular to banks. Polygons in areas of interest such as along levees, dams, and bridges, were further sub-divided to assess flow connectivity within the channel and floodplain.

The mesh has the following features:

- Unstructured mesh with quadrilateral and triangular element configurations
  - 186,766 elements (mesh cells) for upstream model and 199,240 for downstream model
  - 106,918 nodes for upstream model and 124,622 for downstream model

  - typical cell size of 15 to 30 ft by 15 to 30 ft
  - typical element area of 150 to 300 ft^2
- 15 quadrilateral cells generally used across active, unvegetated channel (perpendicular to flow)
- Tightest density of cells used in channel areas and where rapid changes in elevation occur that may influence floodplain inundation
- Lesser density of cells was used in floodplain areas where there is less elevation change (topographic relief)

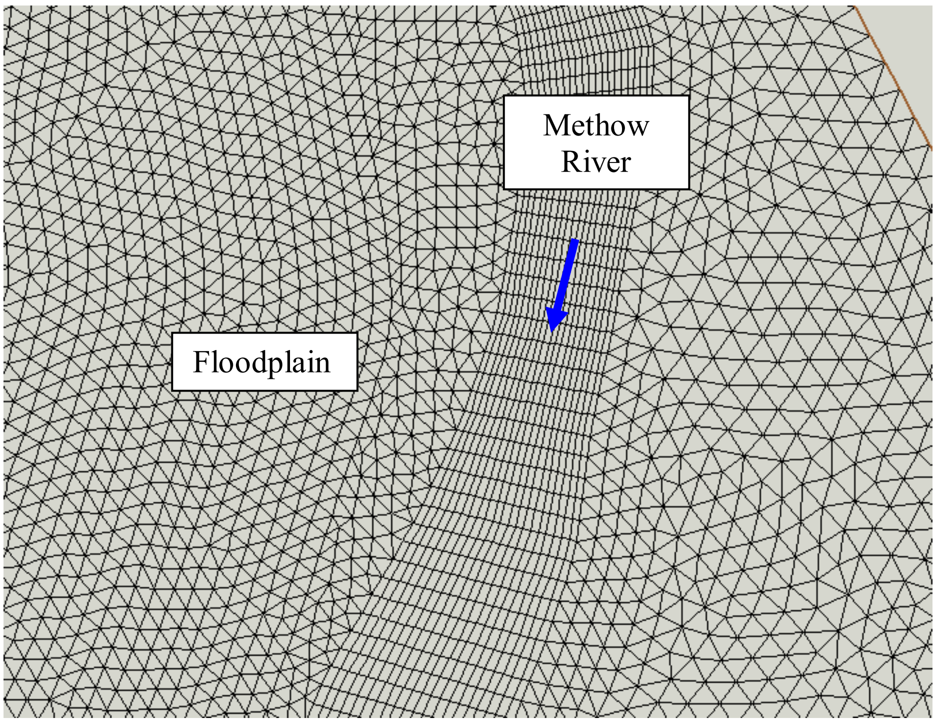


Figure 2. Sample mesh near RM 42.

4.0 Model Setup

SRH-2D solves the 2D depth-averaged form of the dynamic wave equations. The dynamic wave equations are the standard St. Venant depth-averaged shallow water equations. The model utilizes an implicit scheme to achieve solution robustness and efficiency. Steady flow was utilized for the M2 model described in this report. All flow regimes, i.e., subcritical, transcritical, and supercritical flows, were simulated simultaneously. This section documents the boundary conditions and roughness parameters utilized in the model.

4.1 Boundary Conditions

Boundary conditions for this model consist of an incoming flow for the Methow and Twisp Rivers (inlet boundary), and a water surface elevation at the downstream end of the model (exit boundary). For each model run, one flow value was needed for the upstream model that represents the incoming flow of the Methow River. Two input flow locations were needed for the downstream model that represents the incoming flows of the Twisp River and Methow River. The flow values were based on flood frequency values (Reclamation, 2008) or recorded mean daily flow at USGS gage sites (see Section 2 in main report for more information). The only notable tributary in this reach, Bear Creek, has the majority of its water diverted out of the creek upstream of the confluence with the Methow River and was not included in the model. During the irrigation season (spring to fall), water is diverted out of the river at the Barclay (RM 49.6) and MVID East (RM 46) diversion structures. These withdrawals were not included in this modeling effort.

For the upstream model, the water surface elevation values for the exit boundary at RM 45.5 were based on measured survey data for 285 cfs. For all other flows the boundary condition was based on 2D model results at RM 45.5 from the downstream 2D model.

The water surface elevation value for the downstream model exit boundary at RM 40.3 was based on measured survey data for 285 cfs, and a 1D HEC RAS model for all other flows (XS 1341 in Figure 3). The HEC RAS model was generated in GIS using GEORAS from about RM 40.1 to 41 (2008 survey data extended to RM 39.4). Typically, a downstream boundary for the 2D model is chosen at a location where the channel geometry is relatively uniform and there is a confined floodplain. In this case, the confined floodplain section occurs at the location of an adverse water surface slope around station 1000 in Figure 3. It is presumed the adverse water surface occurs due to a natural bedrock constriction in the floodplain at this location. Therefore, the downstream boundary for the 2D model was moved upstream where the floodplain is slightly wider, but the water surface slope has a more consistent slope. A discharge-stage rating curve was available for the USGS gage downstream of Twisp, but was not used because it has only been established for flows up to 21,700 cfs.

The model boundaries were delineated along the edge of the floodplain defined by the surficial geologic map (see Appendix A). The boundary was checked to ensure it included the extent of the 1948 flood of record (R.W. Beck and Associates, 1973). Generally these boundaries are along a topographic break in elevation formed by a glacial deposit, bedrock, or other feature.

Table 2. List of model inlet (flow discharge) and exit (water surface elevation) boundaries for upstream and downstream models.

Flow below Winthrop (cfs)	Flow from Twisp (cfs)	Total flow (cfs)	Water surface elevation at RM 40.3 for downstream model (ft)	Water surface elevation at RM 45.5 for upstream model (ft)	Description
285	70	355	1569.9	1645.7	October 2008 Survey Flow
10,900	2,020	12,920	1566.1	1654.4	Tail end of May 23, 2006 (about a 2-yr flood)
16,600	3,890	20,490	1568.7	1656.4	10-year flood
24,400	1,720	26,120	1570.4	1658.5	1972 flood (about a 25-yr flood)
31,360	9,440	40,800	1574.5	1659.8	1948 flood (> 100-yr flood)

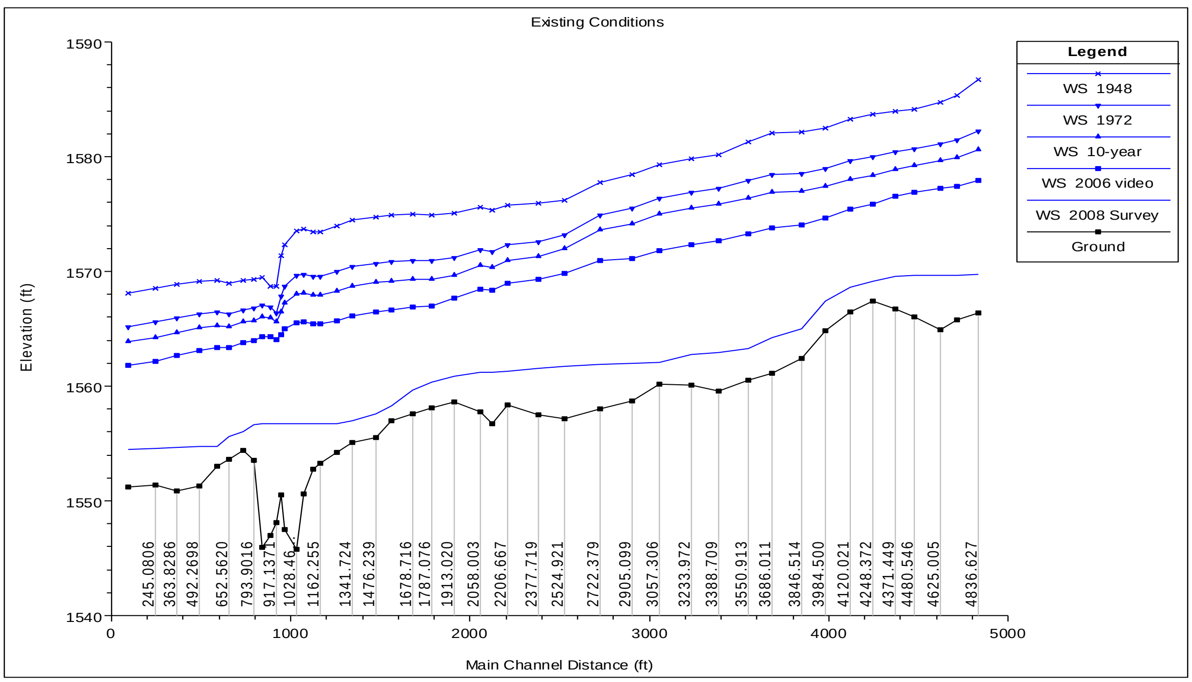


Figure 3. HEC RAS water surface profiles used for 2d model downstream boundary at RM 40.3.

4.2 Roughness Delineation

Delineation of unique roughness areas (polygons) was done using 2006 aerial photography and vegetation mapping based on 2004 conditions (Baesecke, 2005. Roughness values for the main channel and agricultural or pasture type areas were based on calibrated values from a previous study at the MVID East project at RM 46 (Bountry, 2007). In the MVID East project, the remaining floodplain area was mapped as vegetated and assigned a single roughness value. For the M2 model, vegetation mapping based on 2004 conditions (Baesecke, 2005) was available to delineate the vegetated floodplain into more refined categories. Roughness values for these new categories were based on Table 5.6 in Chow 1959. An updated vegetation map based on 2008 conditions is being completed and could be used in future modeling efforts to refine roughness delineation and values (personal communication, Susan Prichard, 2009). Roughness delineations for the M2 model are shown in Figure 4 and the values used are listed as follows:

- Material #1: Main channel (0.035)
- Material #2: Unvegetated bars (0.035)
- Material #3: Trees (0.1)
- Material #4: Shrub-type vegetation (0.06)
- Material #5: Agricultural or pasture areas assuming no crops (0.03)
- Material #6: Residential (0.1)
- Material #7: Major roads, levees, etc (0.02)
- Material #8: Ponded areas (0.04)

4.3 Model Parameters

Model runs utilized a time step between 0.25 and 1 second based on what time step was required to stabilize the computed flow at monitoring lines. Computations were continued until model results for discharge at monitoring lines and water surface elevations at monitoring points stabilized and differences in results between time steps were negligible. Model runs were usually started in the dry, except for a few cases where refinements were made and a previous model solution was available as a starting condition.

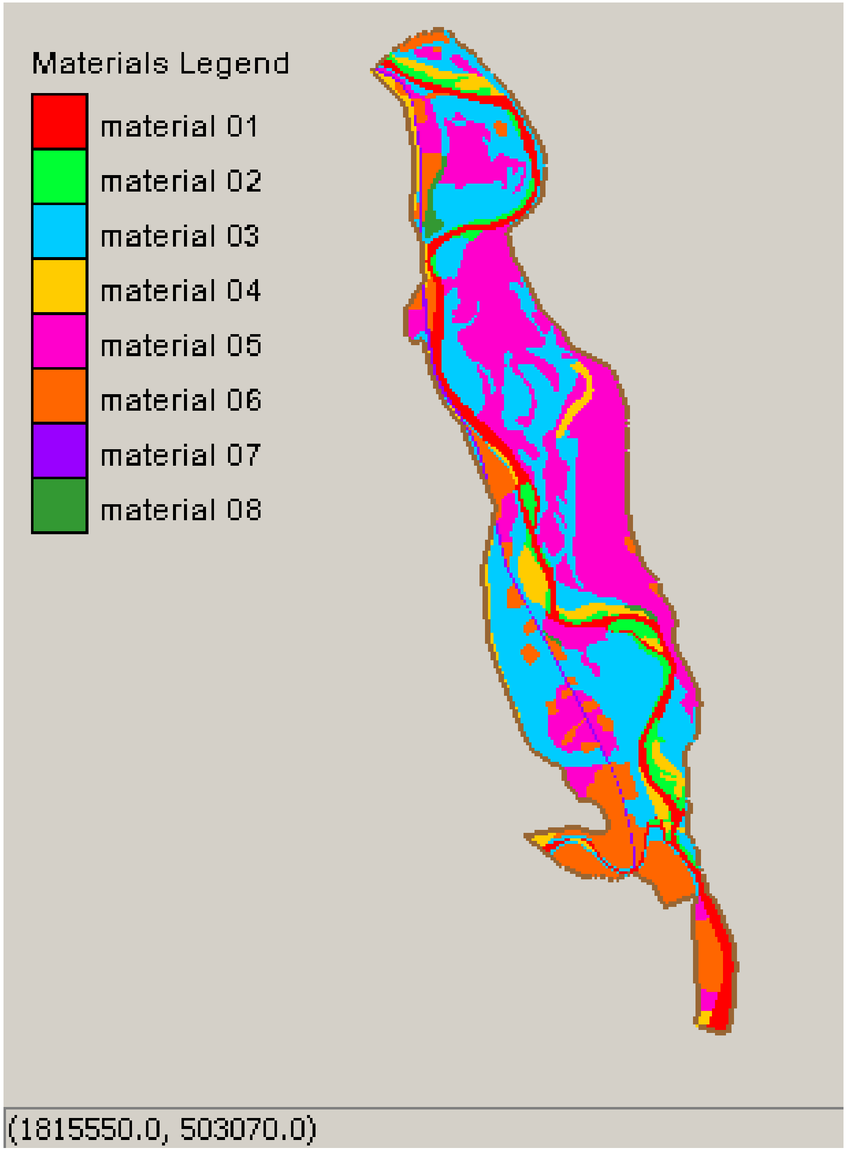


Figure 4. Roughness delineation.

5.0 Comparison to Measured Data

The data available for comparison include measured water surface elevation data from the October 2008 survey (low flow), 1972 and 1948 high water marks including elevation and approximate locations (R.W. Beck and Associates, 1973), 1948 aerial photography during the flood, and aerial video of the 2006 and 2008 snowmelt during spring runoff (photographs during falling limb of floods, not the peak). Validation efforts were limited to the mainstem Methow River and did not include the Twisp River.

5.1 2008 Survey Data

Model results and measured data collected at 285 cfs (labeled as RTK WS) are plotted in Figure 5, Figure 6, and Figure 7. These data were collected at a low flow and are only applicable to the main channel. Initially, a main channel roughness of 0.055 was used based on the MVID East model study (Bountry, 2007). This resulted in higher than measured water surface elevations for the majority of the model reach. The higher roughness utilized in MVID East low flow modeling may have been in part due to losses over a small dam that was included in the model topography. Main channel roughness was reduced to 0.035 as this was the roughness value used for high flows in the 2007 study. A longitudinal profile comparison indicated a value of 0.035 provided a reasonable match to measured water surface elevations for the 285 cfs data collected in October 2008. A statistical comparison of measured RTK water surface elevation values to model results for RM 40 to 50 (boundary areas excluded) showed a range of - 1 to +2 ft and a mean of 0.1 ft (Figure 8). The differences are not distributed evenly, but rather concentrated in certain areas, particularly in the shallow riffles where the depths had to be estimated where data was collected by depth soundings on a boat. Future efforts may consider refining the topography and delineation of roughness, or accounting for groundwater gains and losses in areas where the differences were greatest. There was not adequate scope or data available for this study to allow any further refinements.

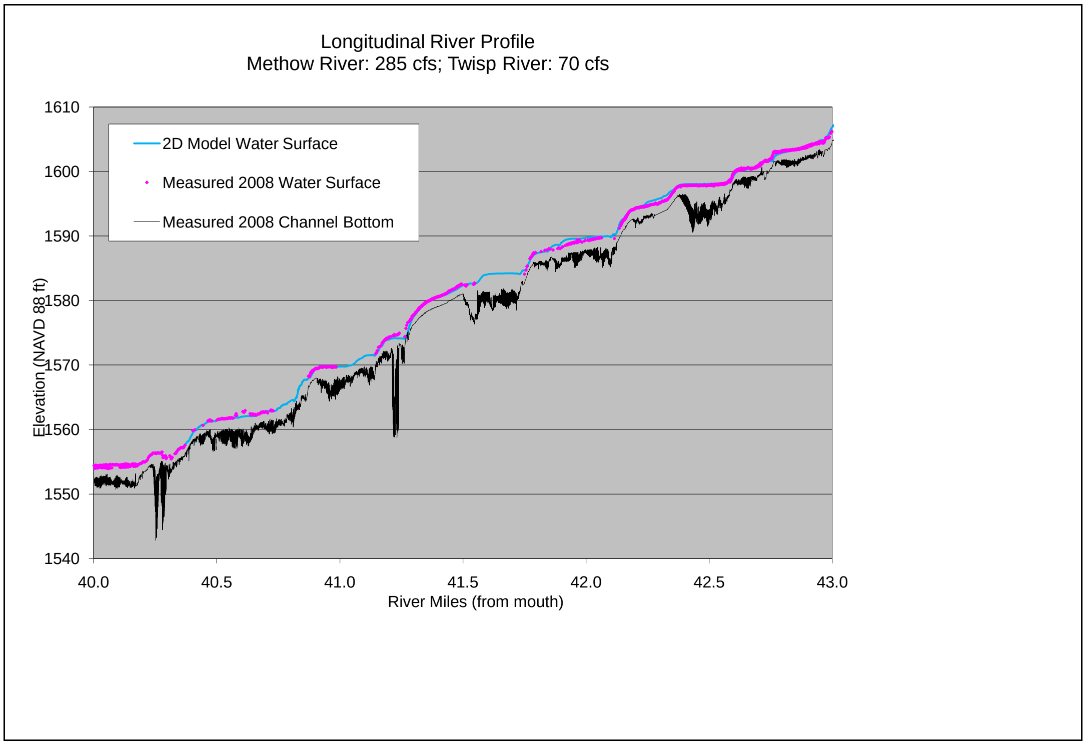


Figure 5. Measured water surface elevation from October 2008 and model results for a discharge of 285 cfs for Methow River and 70 cfs for Twisp River from RM 40 to 43.

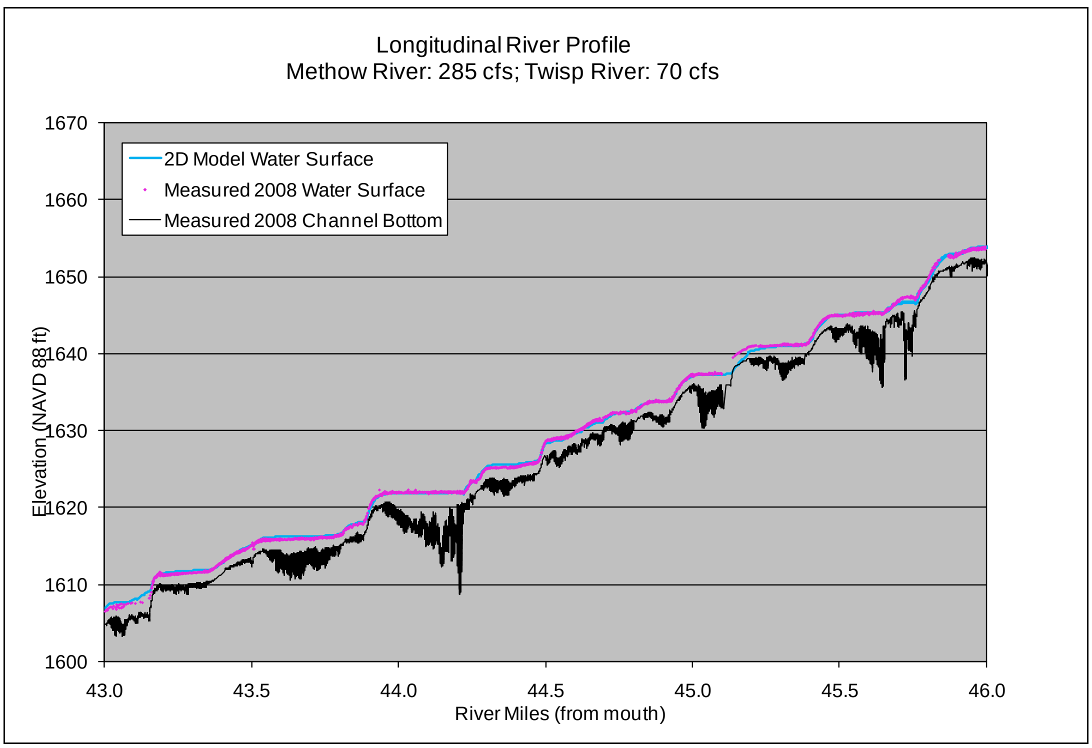


Figure 6. Measured water surface elevation from October 2008 and model results for a discharge of 285 cfs from RM 43 to 46.

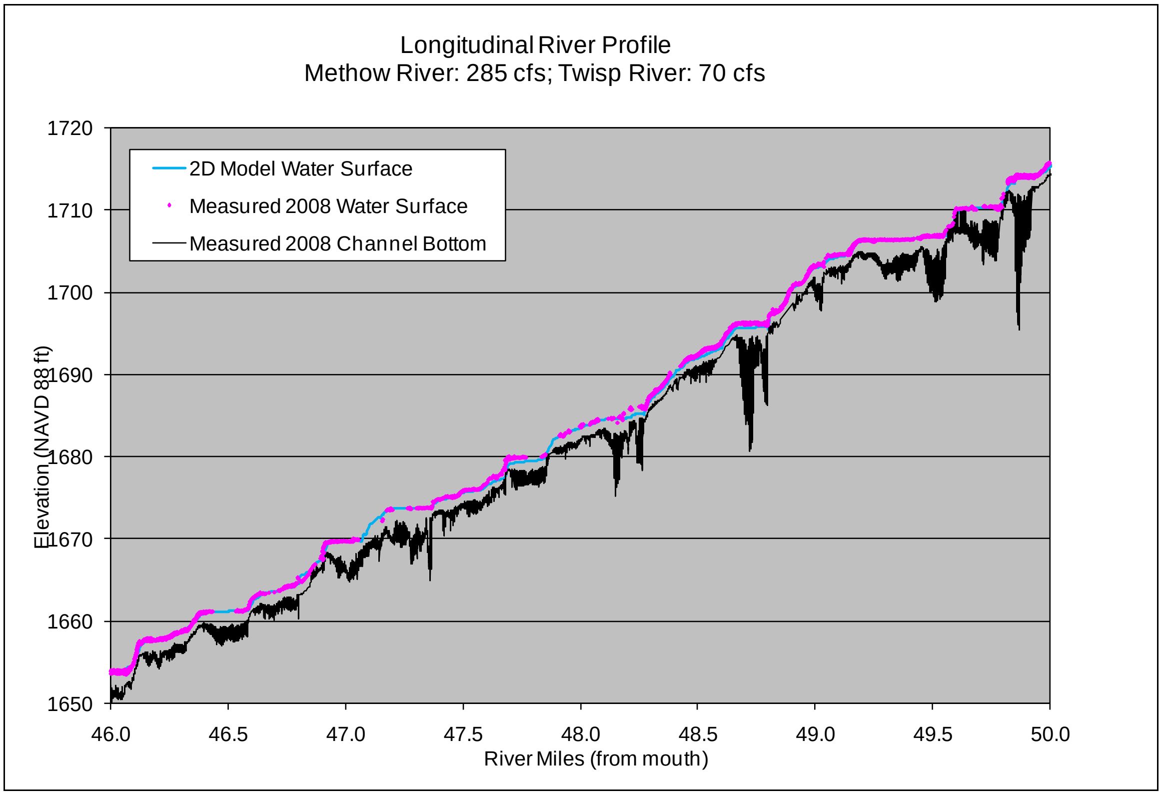


Figure 7. Measured water surface elevation from October 2008 and model results for a discharge of 285 cfs from RM 46 to 50.

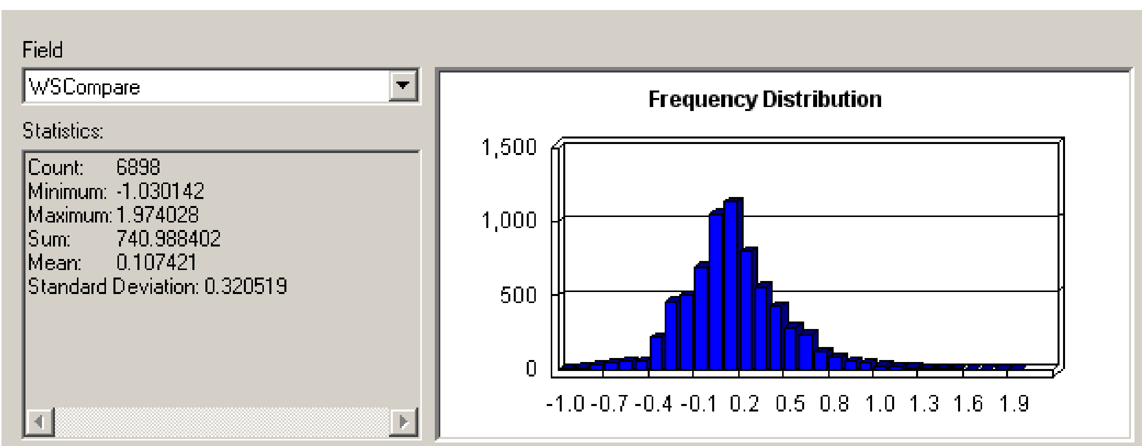


Figure 8. Results of statistical comparison of computed versus measured water surface elevation results at 285 cfs for RM 40 to 50.

5.2 1972 and 1948 floods

The model was run for the peak of the 1972 and 1948 floods, which approximate a 25-year flood and a flood greater than the 100-year flood peak, respectively. The 1972 peak discharge value used was 26,120 cfs: 24,400 cfs for the mainstem Methow River and 1,720 cfs for the Twisp River. The 1948 peak discharge value used was 40,800 cfs: 31,360 cfs for the mainstem Methow River and 9,440 cfs for the Twisp River. Model results were compared to 16 high water marks from the 1972 flood located throughout the model reach, and 4 high water marks from the 1948 flood in the downstream-most 2 miles of the model reach (R.W. Beck and Associates, 1973). High water marks are observed in the field, usually from debris and evidence of inundation after the flood recedes.

The channel and floodplain topography has likely changed since the 1972 and 1948 floods. Based on the geomorphic analysis presented in the main report, the channel changes are mostly due to channel migration rather than reach-scale degradation or aggradation. Where channel migration has occurred, a spatial location from 1972 may be associated with a different river feature than exists today (e.g. riffle changes to pool, channel changes to gravel bar or floodplain, etc.). However, due to the large size of the 1972 and 1948 floods, it would be expected that high water mark elevations along the main channel should be within a reasonable proximity and elevations would be comparable to present day conditions.

During floods, bridges can become obstructed with debris and result in backwater conditions upstream that would locally increase a recorded high water mark. A bridge was present in 1948 near RM 40.7 that washed out in the 1948 flood and was not rebuilt. Another bridge deck near RM 40.3 has been present since at least 1945. Neither bridge deck was accounted for in the 2d model. An example profile from the 1973 study is provided for the reach downstream of the Twisp River. In the profile, observed high water marks indicate local backwater conditions from the bridge at RM 40.3 during the 1948 flood, but not during the smaller magnitude 1972 flood (Figure 9).

In order to utilize the 1972 and 1948 high water marks, the elevations were converted from a 1929 vertical datum to a 1988 vertical datum in a prior study (Reclamation, 2008). In the prior study, it was determined that the conversion ranged from 4.04 at RM 29 and 4.17 ft at RM 75 based on the Corpscon6 program (www.tec.army.mil); an average conversion value of 4.1 ft was utilized for the M2 reach located between RM 40 and 50 (Reclamation 2008). The high water mark locations were estimated in GIS using the 1973 river mile location on a longitudinal profile from the study report (Figure 10). Because the river length has changed since 1973, the river miles do not match current river miles and were approximated using landmarks and historical aerial photography.

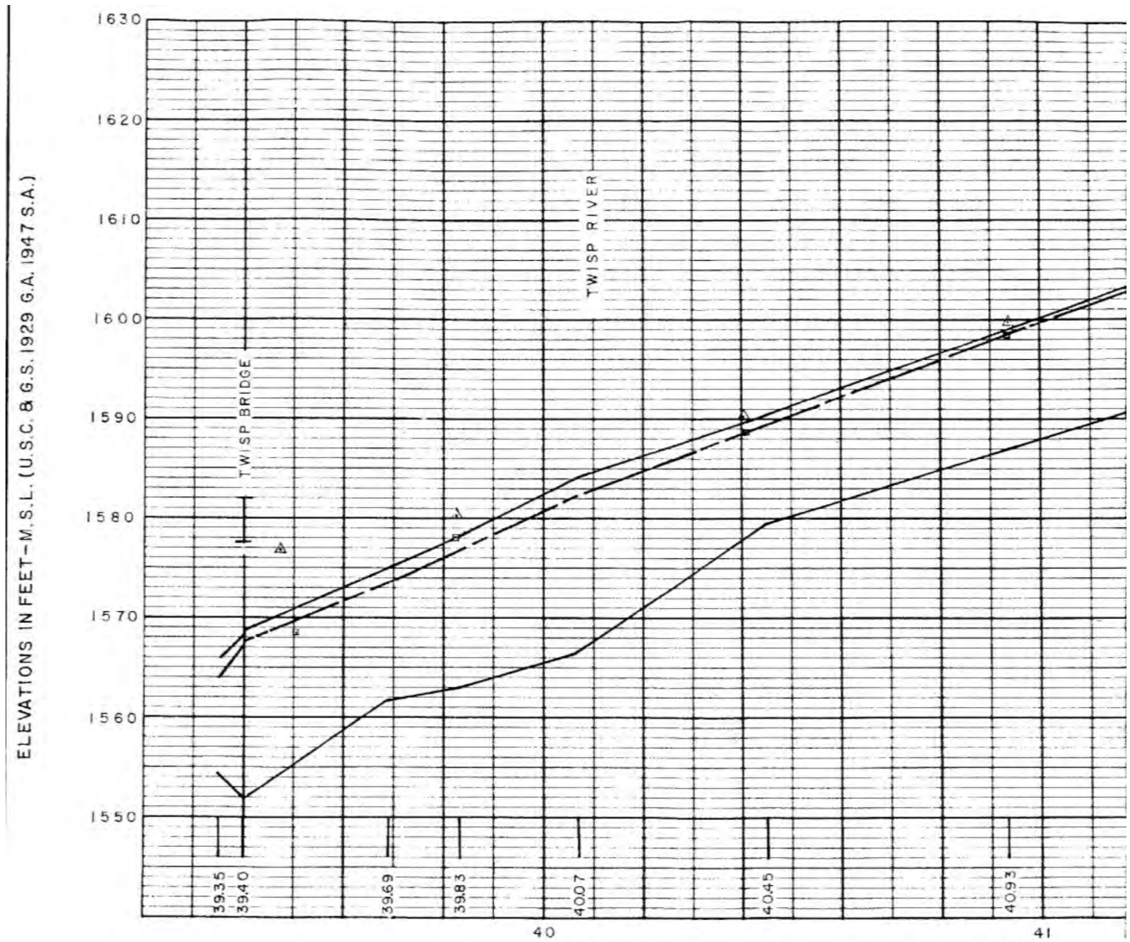


Figure 9. Example longitudinal profile of model results and observed high water marks from 1973 flood study (R.W. Beck and Associates, 1973).

Triangles represent 1948 high water marks and rectangles represent 1972 high water marks. The lowest line represent the channel bottom used in the 1973 study; the next two lines represent model results of the 1972 flood and 100-year flood from the 1973 study. Data is in river miles used in 1973 study and elevations are in a NGVD 1929 datum, about 4.1 ft lower than the NAVD 1988 datum used in the new 2d model study.

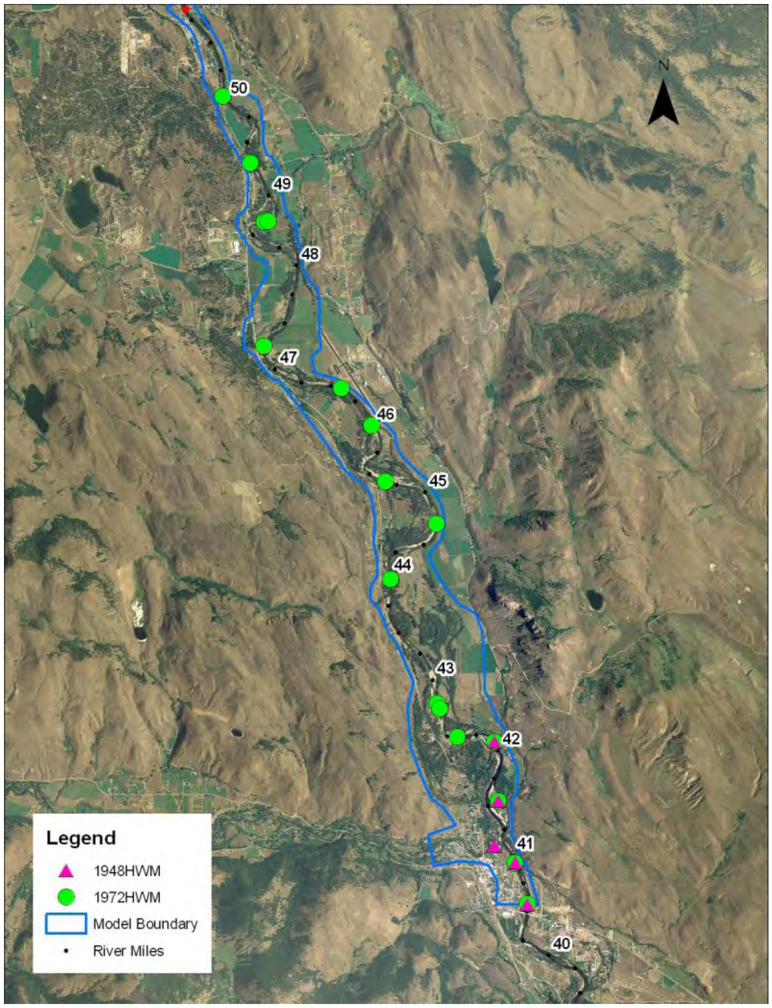


Figure 10. Approximate locations of 1948 and 1972 high water marks utilized for model comparison (R.W. Beck and Associates, 1973).

Computed water surface elevations and observed high water mark elevations are shown in Table 3 for the 1948 flood and Table 4 for the 1972 flood. It is not known which side of the river the high water marks were recorded or how close they were to the main channel. To account for this uncertainty, a minimum and maximum water surface elevation was provided because the water surface elevation in a 2D model is not level across the river at a given location. Upstream of RM 41, the model results compare within 1 to 2 feet and there is no obvious trend of lower or higher model results relative to the 1948 and 1972 high water marks. Downstream of RM 41, the 2D model results are lower than observed values for the 1948 flood. This discrepancy is due in part to the fact that a bridge at RM 40.3 caused a backwater condition during the 1948 flood (see Figure 9). The 1972 model results downstream of RM 41 are inconsistent: one location is higher and one is lower than observed values.

Table 3. List of 1948 high water mark elevations and modeled water surface elevations.

RM	1948 HWM (NAVD 88 ft)	2008 Model Result (minimum) (ft)	2008 Model Result (maximum) (ft)	Notes
40.37	1581	1575.4	1575.9	Bridge built about 500 ft downstream of HWM that was not modeled in 2D model
40.72	1584.2	1582.2	1582.7	Bridge was present in 1945 at this HWM location; bridge washed out in 1948 flood and was not rebuilt
	1591.6	1590.8		high water at Twisp Park
41.29	1594.1	1593.6	1594.0	Channel has migrated
41.82	1604.0	1603.5	1603.9	Channel has migrated

Table 4. List of 1972 high water mark elevations and modeled water surface elevations.

RM	1972 HWM (NAVD 88 ft)	2008 Model Result (minimum) (ft)	2008 Model Result (maximum) (ft)	Notes
40.39	1572.6	1573.2	1573.3	Bridge built about 500 ft downstream of HWM that was not modeled in 2D model
40.72	1582.1	1579.7	1580	
41.29	1592.8	1591.4	1591.9	Channel has migrated
41.82	1602.3	1602.3	1602.8	Channel has migrated
42.17	1608.1	1608	1608.8	
42.54	1613.1	1613.3	1614.9	
42.59	1614.6	1614	1615.3	
43.71	1630.3	1631.6	1632	
44.44	1642.1	1641.3	1643.1	
45.05	1653.3	1653.2	1653.8	
45.69	1665.6	1663.6		3-ft high dam removed in 2008-2009 that explains lower modeled water surface result
46.11	1670.6	1671.7	1672.2	
46.91	1684.6	1684.6	1686	
48.37	1710.3	1710.0	1710.1	
48.4	1711.6	1710.5	1711.6	
48.9	1718.9	1720.2	1720.3	
49.58	1728.9	1729.6	1730.4	

A few ground photographs of the 1972 and 1948 floods were also available (Figure 11, Figure 12, and Figure 13). Due to the limited amount of 1948 high water marks, aerial photography taken during the 1948 flood and flood maps from the 1973 study were also used to visually compare 2D model results. An example is provided in Figure 14.

Figure 11. View looking upstream four and one-half miles north of Twisp during May 1972 flood (R.W. Beck and Associates, 1973). Report notes that photograph is courtesy of Soil Conservation Service, Okanogan, Washington - Mr. A. E. Blomdahl.

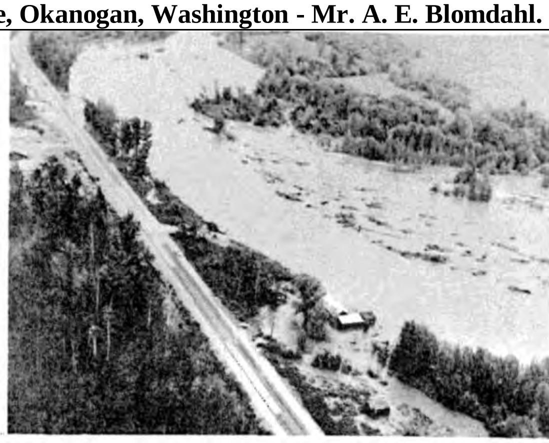
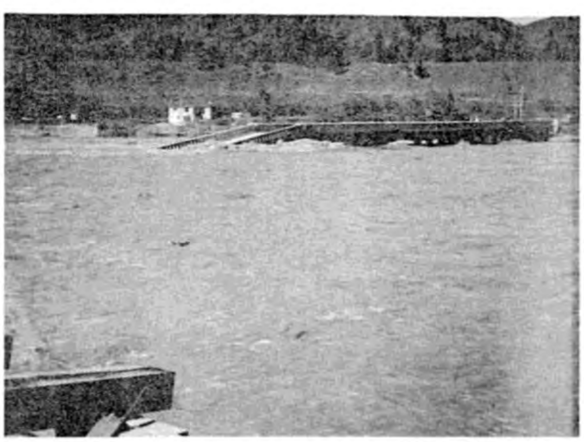


Figure 12. View looking upstream two miles north of Twisp during May 1972 flood (R.W. Beck and Associates, 1973). Report notes that photograph is courtesy of Soil Conservation Service, Okanogan, Washington - Mr. A. E. Blomdahl.



HOTO NUMBER 1 - May, 1948 flood. View shows bridge at sout
d of Twisp. (Photograph courtesy of Mrs. MacFarlane)

Figure 13. View looking at bridge on south end of Twisp River during May 1948 flood (R.W. Beck and Associates, 1973). Report notes that photograph is courtesy of Mrs. MacFarlane.

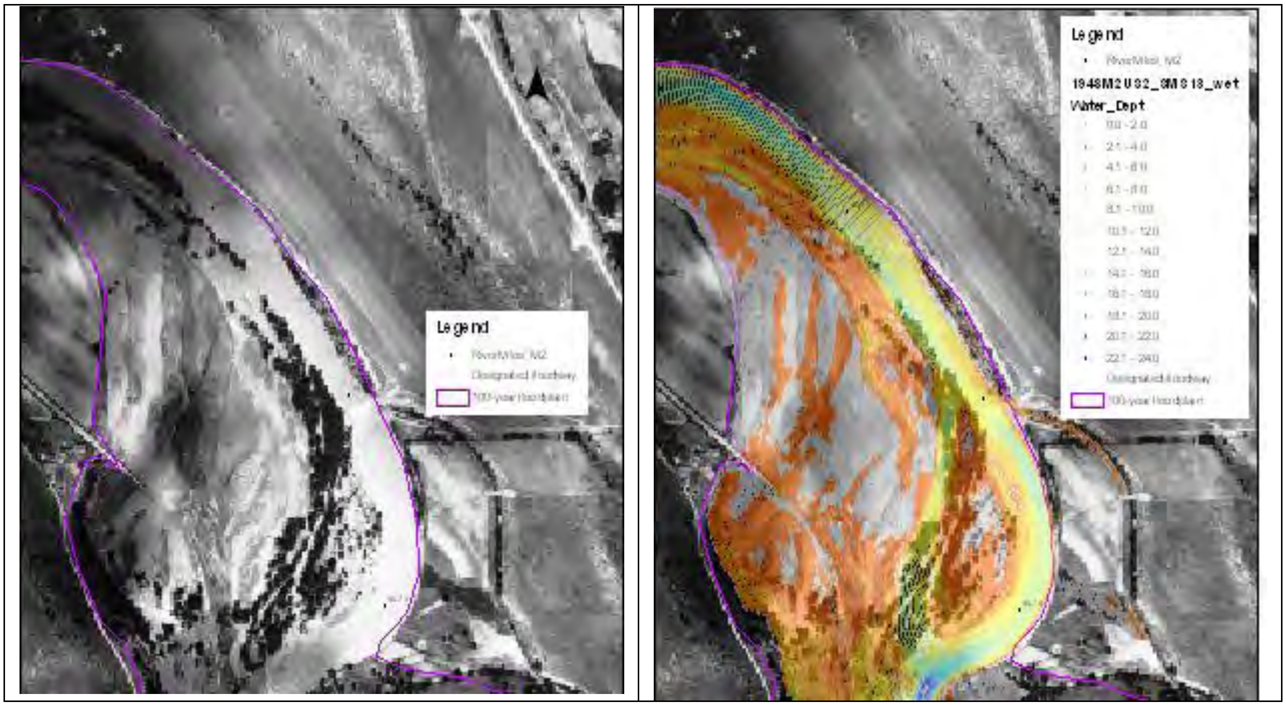


Figure 14. Comparison of aerial photograph taken shortly after the peak of the 1948 flood (shown on left) with model results for 1948 flood peak (shown on right).
The photographs show with a purple line the interpretation of the extent of 1948 flooding, based on a flood study by R.W. Beck (1973). This also correlates with the geomorphic mapping of Qa3 described in the main report Section 3. The model results indicate predicted water depth, grey being the shallowest and colors being 2 ft or greater.

5.3 2006 Spring Snowmelt Floods

No survey data were collected during the 2006 snowmelt flood, but oblique helicopter video and still images are available and were utilized to qualitatively check the extent of model inundation. Several of these photographs are documented in the main report (see Table of Contents of main report for locations). The video and images were collected near the end of the flood on May 23, 2006. The mean daily discharge on the mainstem Methow was approximately 10,900 cfs and 2,020 cfs on the Twisp River based on USGS gage data. These discharges represent slightly greater than the 2-year flood peak on the mainstem Methow which is 9,020 cfs and slightly greater than the 2-year flood peak on the Twisp River which is 2,120 cfs. The model was run at the 10,900 and 2,020 cfs mean daily flows recorded on the day of the video to compare to the extent of inundation. These flows were particularly interesting because they represent flows when many side channels begin to have a surface water connection with the main channel. Model results compared reasonably well with the video and images.

5.4 Downstream Boundary Condition Sensitivity

To test the sensitivity of the downstream 2D model boundary at RM 40.3, the estimated water surface elevation from the 1D model was raised 1 ft relative to the value in Table 2 for the 40,800 cfs model run. With a 1 ft increase in the boundary condition at RM 40.3, the computed water surface elevations had at least a 0.1 ft difference from the original solution from RM 40.3 to 40.7.

6.0 Model Limitations

Mesh elevations, especially in the floodplain and side channels, were largely derived from the 2006 LiDAR. The density of topographic data collected to supplement the LIDAR is considered appropriate for a reach scale floodplain analysis. Additional topographic data may be needed to address localized hydraulic issues, particularly at lower discharges. The mesh elements were sized with the objective of modeling large floods such that only large variations in topography were focused on. If the model is utilized to evaluate low flows or localized removal or setback of manmade features such as levees, rock, or large wood features, additional survey data and mesh refinement should be considered.

Modeling was focused on the mainstem Methow River between Winthrop and Twisp. If model results are needed for the Twisp River or in areas beyond this domain, additional data collection and model development will be needed.

Because this study focused on mostly flood flows, velocity data from the October 2008 survey at a low flow of 285 cfs were not included in the evaluation. This could be done in subsequent studies to further verify and potentially refine model parameters for low-flow conditions. Additional water surface elevation data (high water marks) collected during or immediately after floods and during low flows on channel segments of interest (including side channels) would be valuable for model calibration or validation in future efforts. This could be accomplished using stage recorders in several locations throughout the reach. Only surface flow from the Methow and Twisp Rivers were modeled. Diversion of surface flow at irrigation structures, or addition of flow from groundwater was not included. Surface water diversions at lower discharges comprise a large percentage of the total discharge and may need to be modeled to accurately quantify hydraulic conditions.

7.0 References

Baesecke, H., 2005, GIS mapping and report on documentation of findings from aerial photo delineations, prepared for Bureau of Reclamation by Geosis Consulting, unpublished report.

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Bureau of Reclamation, February 2008, Methow Subbasin Geomorphic Assessment, Okanogan County, Washington.

Chow, V.T., 1959, Open-Channel Hydraulics, McGraw-Hill, Inc.

R.W. Beck and Associates, 1973, Floodplain 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.

Watershed Sciences, January 31, 2007, LiDAR Remote Sensing Data Collection: Upper & Lower Okanogan River, Methow River, Lake Roosevelt, Wenatchee River and John Day River Study Areas.

APPENDIX C
FIELD DESCRIPTIONS OF SOIL PROFILES

MIDDLE METHOW REACH ASSESSMENT
METHOW RIVER
OKANOGAN COUNTY, WA

U.S. BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER
DENVER, CO

Lucille A. Piety
Seismotectonics and Geophysics Group (86-68330)
and
Ralph E. Klinger
Sedimentation and River Hydraulics Group (86-68240)

January 2010

(Locations of the soil description sites are on the maps in Appendix A.)

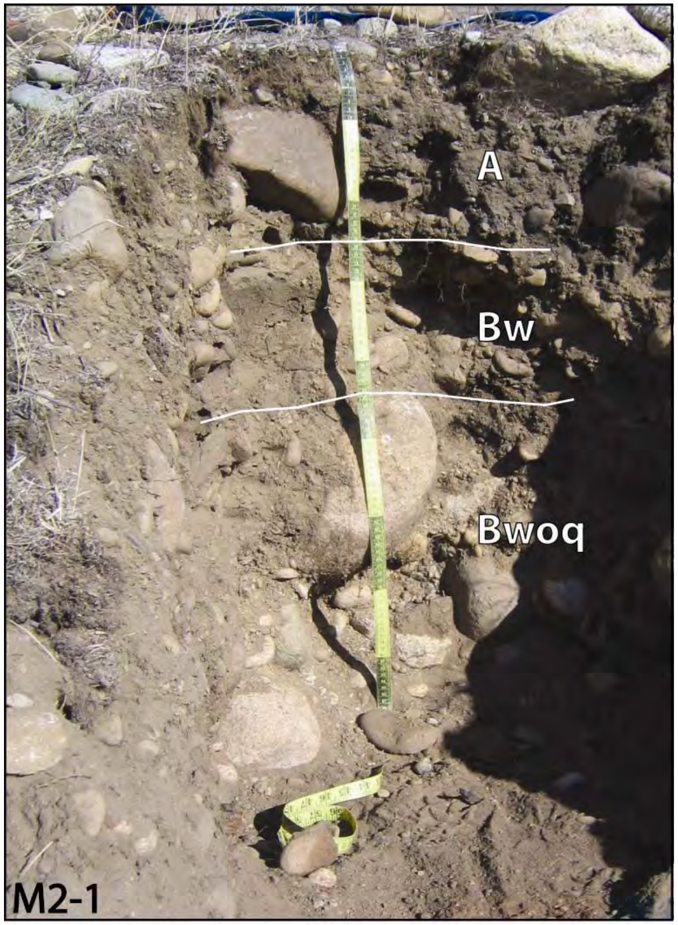
FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-1 **Described by:** Ralph Klinger and Lucy Piety **Date:** 10/7/2008
Map Unit: Qgo3 **Aspect:** SW **Parent Material:** poorly-sorted bouldery alluvium with loess in upper part
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.321/-120.143 (GPS; WGS84) **Elevation:** 1690 ft
Location: Edge of an extensive terrace along the left bank of Methow River near RM 46.25 along airport runway; GPS waypoint # 764.

Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
A	0-25	aw	1cgr	none	-	-	so	cSL	25-50	n/a	10YR2/2
Bw	25-46	cw	1cgr-1msbk	2dco	-	-	so	cSL	50-75	n/a	10YR3/3
Bwoq	46-100+	-	sg	none	-	-	lo	vcS	50-75	I	10YR3/4

Radiocarbon Samples:
None

Miscellaneous Notes:
Gravel is subrounded and rounded pebbles (up to 3 to 5 cm intermediate diameters) with occasional larger stones (up to boulders). Gravel mostly fine-grained volcanic rocks and coarse-grained granitic rocks. Bw horizon has clay films on stones. Bwoq horizon has patchy silica coats (white but do not react with HCl) on the bottoms of stones (stage I) and continuous dark (manganese/iron?) coats on the bottoms of stones (photograph below). On the sides of some stones, silica coats are outside of the manganese coats. Sandy matrix is oxidized in the Bwoq horizon.



FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-2 **Described by:** Ralph Klinger and Lucy Piety **Date:** 10/7/2008
Map Unit: Qa2 **Aspect:** NE **Parent Material:** well-sorted, fine-grained fluvial sand and gravelly colluvium
Quadrangle: Twisp East, Wash (USGS 7.5') **Lat/Long coordinates:** 48.365/-120.117 (GPS; WGS84) **Elevation:** 1577 ft
Location: Margin of a low terrace adjacent to the right bank of Methow River near RM 40.75 downstream of the confluence of Twisp River; GPS waypoint # 765.

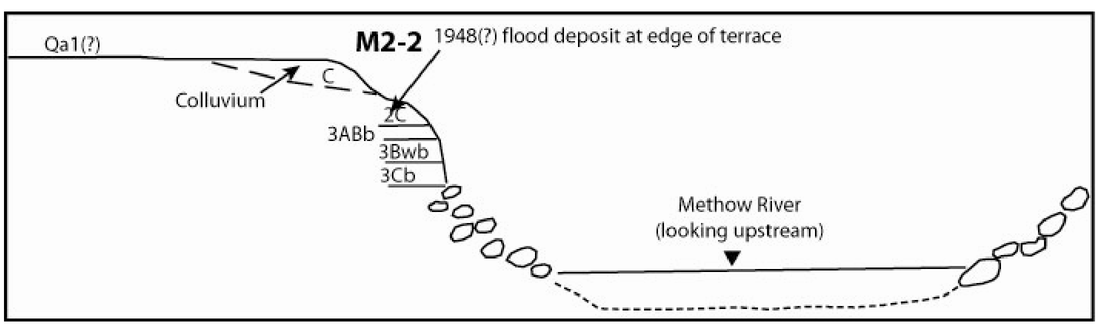
Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
O	5-0	aw	n/a	none	n/a	n/a	n/a	n/a	0	n/a	n/a
C	0-42	aw	2mgr	none	-	-	-	-	50	n/a	-
2C	42-64	aw	sg-m	none	-	-	lo-so	fLS	0	n/a	2.5Y3/2
3ABb	64-85	as	m-1csbk	none	-	-	so	fL	0	n/a	10YR2/2
3Bwb	85-120	as	m-1csbk	none	-	-	so	fSL	0	n/a	2.5Y3/3
3Cb	120-138+	-	sg	none	-	-	lo	f-mS	0	n/a	2.5Y3/2

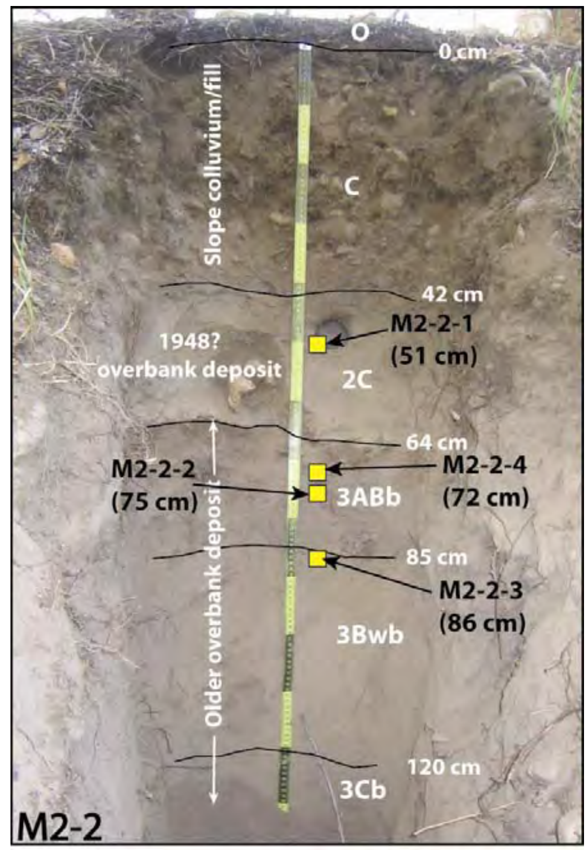
Radiocarbon Samples:

M2-2-1 collected from the upper part of the 2C horizon at 51 cm (Salicaceae 0.0091g single)
M2-2-2 collected from the middle part of the ABb horizon at 75 cm (*Pinus* 0.006 g single)
M2-2-3 collected from the upper part of the Bwb horizon at 86 cm (Root 0.018 g three)
M2-2-4 collected from the upper part of the ABb horizon at 72 cm (Conifer 0.008 g single)

Miscellaneous Notes:

Lower 3 cm of the 2C horizon is finely bedded silty sand. Base of the 2C has been bioturbated and carried downward into the underlying buried soil. Burrows are up to 4 to 5 cm in diameter. A piece of a bone protrudes from the exposure at a depth of 57 cm. Small worm burrows also are present.





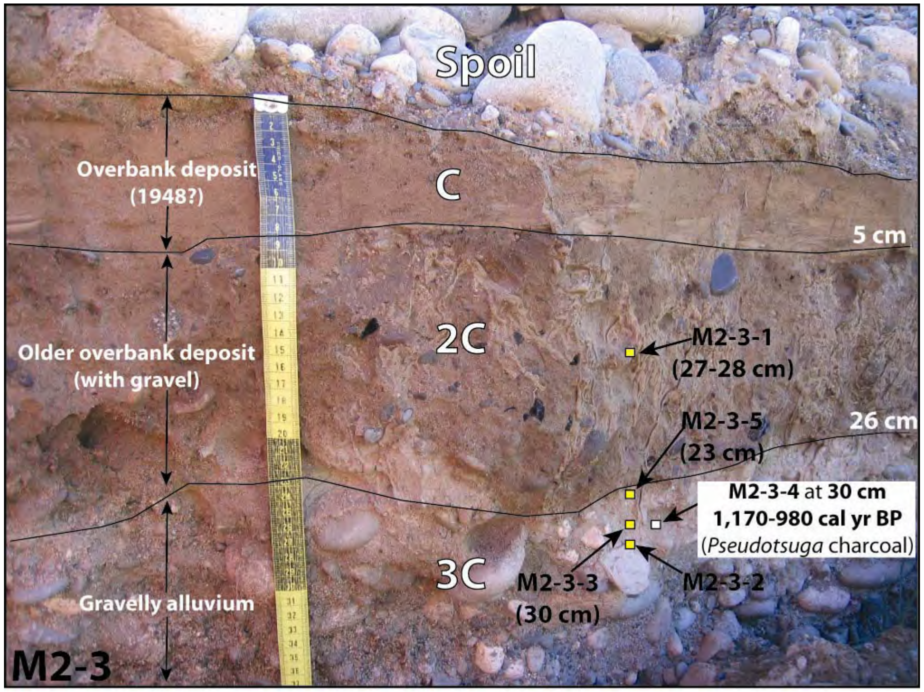
FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-3 **Described by:** Ralph Klinger and Lucy Piety **Date:** 10/8/2008
Map Unit: Qa2 **Aspect:** N **Parent Material:** well-sorted, fine-grained fluvial sand and cobbly and bouldery fluvial gravel
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.377/ -120.128 (GPS; WGS84) **Elevation:** 1581 ft
Location: Trench at house between Highway 20 and cutoff channel along the edge of the valley; near RM 41.75 on the Methow River north of Twisp; GPS waypoint # 768.

Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
C	0-5	aw	m	none	vvss	vvsp	lo-so	fSL	0	n/a	10YR3/3
2C	5-26	cw	1csbk	none	vvss	vvsp	so	fSL	25	n/a	10YR3/3
3C	26-58+	-	sg	none	so	po	lo	vcS	75	n/a	2.5Y6/3

Radiocarbon Samples:

M2-3-1 collected from the 2C horizon at 27-28 cm (Salicaceae 0.079 g single)
M2-3-2 collected from the coarse sand facies of 3C horizon (*Pseudotsuga menziesi*i 0.0183 g single)
M2-3-3 collected from near the top of the 3C horizon at 30 cm (No charcoal)
M2-3-4 collected from near the top of the 3C horizon at 30 cm (*Pseudotsuga menziesi*i 0.127 g single)
M2-3-5 collected from a darker, finer sand facies of the 3C horizon at 23 cm (*Pseudotsuga menziesi*i 0.0062 g five)
(Depths shown above were measured from the ground surface and do not correlate with the description site because of the variability in unit thickness)



Miscellaneous Notes:

C horizon has a trace of well-rounded pebbles. The basal 1 cm of the C horizon has silt/clay beds about 1 mm thick. 2C horizon has well-rounded and subrounded pebbles to small cobbles. Where stones are removed, a cast is left indicating that some clay is present. Where gravel content is less, 2C horizon holds a vertical face. 3C horizon has well-rounded to subangular pebbles through cobbles (mostly) with a few boulders. Gravel content in 3C horizon is variable. In some areas, 3C horizon is primarily sand (sand facies). Thickness of the 3C horizon also varies; maximum thickness is about 75 cm.

FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-4 **Described by:** Ralph Klinger and Lucy Piety **Date:** 10/8/2008
Map Unit: Qa3 **Aspect:** W **Parent Material:** well-sorted fine-grained fluvial sand
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.405/-120.132 (GPS; WGS84) **Elevation:** 1678 ft
Location: Low terrace/flood plain along the right bank of Methow River near RM 44.5; GPS waypoint # 771.

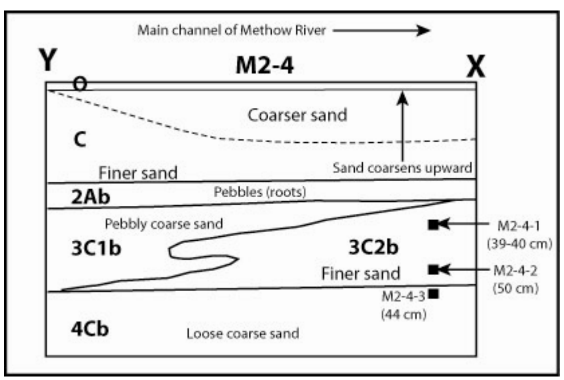
Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
O	2-0	n/a	n/a	none	n/a	n/a	n/a	n/a	0	n/a	2.5Y3/2
C	0-16	aw	m	none	-	-	lo	fS	0	n/a	2.5Y3/2
2Ab	16-24	aw	1fgr	none	so	po	so	mLS	25	vse	2.5Y3/2
3C1b	24-38	gw	m	none	-	-	lo	mS	0	vse	2.5Y3/2
3C2b	38-53	aw	m	none	so	po	so	mLS	0	n/a	10YR3/3
4Cb	53-66+	-	-	none	-	-	lo	c-vcS	0	vse	2.5Y3/2

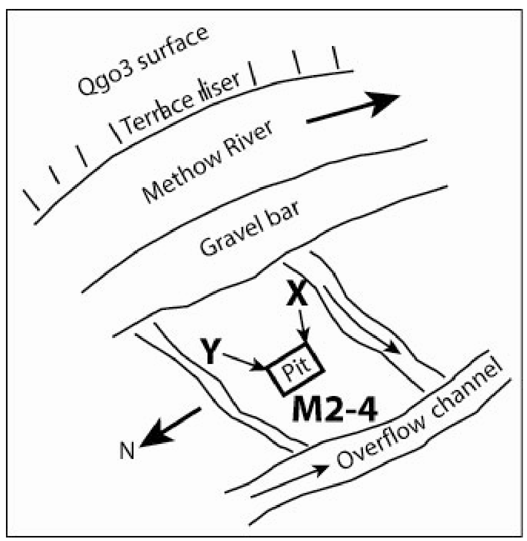
Radiocarbon Samples:

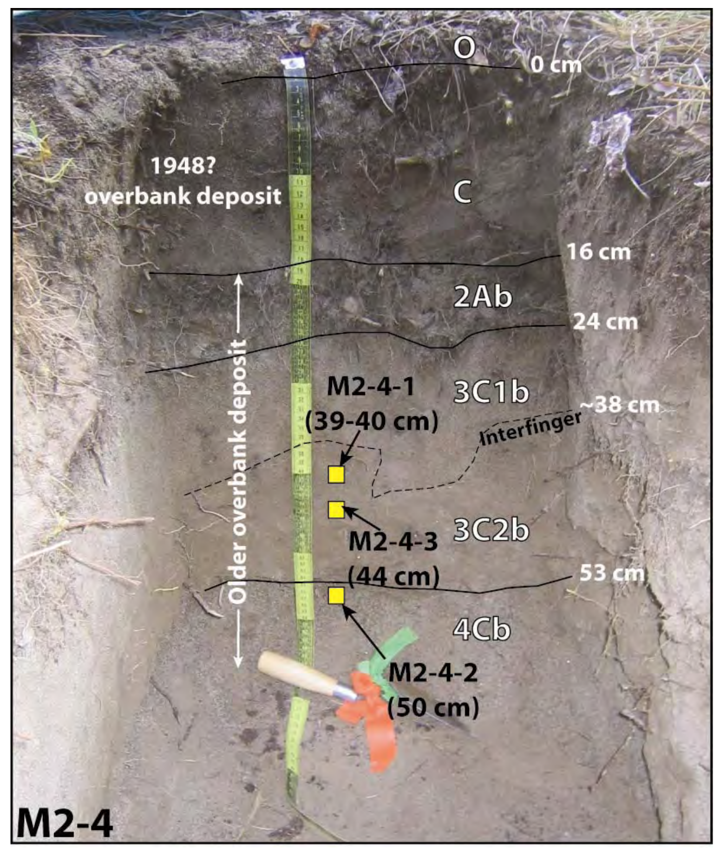
M2-4-1 collected from the 3Cb horizon at 39-40 cm (Conifer <0.001 g)
M2-4-2 collected from the base of the 4Cb horizon at 50 cm (Unidentifiable <0.001 g)
M2-4-3 collected from the 3Cb horizon at 44 cm (*Alnus* 0.006 g four)

Miscellaneous Notes:

Surface where pit was excavated is between the main channel of the Methow River on the east and an overflow channel on the west; and between two small channels that were active during the 1948 flood on the north and south. C horizon coarsens upward with coarse sand in upper 7 cm. 2Ab horizon includes numerous fine roots. 2Ab horizon has a pebbly sand texture; pebbles are rounded and subrounded. 3C1b and 3C2b horizons interfinger in north wall of pit.







FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-5 **Described by:** Ralph Klinger and Lucy Piety **Date:** 10/8/2008
Map Unit: Qa2 **Aspect:** - **Parent Material:** well-sorted fluvial sand
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.407/ -120.136 (GPS; WGS84) **Elevation:** 1666 ft
Location: Higher terrace between two side channels, one that has been cut off from the Methow River by a levee; near RM 44.75 near Habermehl's house; in backhoe pit; GPS waypoint # 775.

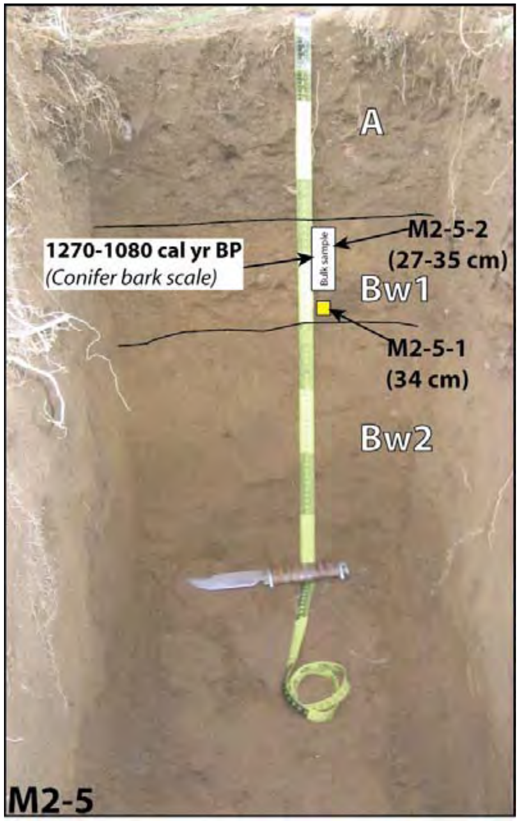
Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
A	0-25	as	2msbk	none	so	po	so	f-mSL	<10	n/a	10YR3/3
Bw1	25-39	cw	m-1m-cgr-sbk	none	so	po	so-lo	mLS	<10	n/a	10YR3/4
Bw2	39-80+	-	m-1csbk	none	so	po	so	mLS	trace	n/a	10YR4/4

Radiocarbon Samples:

M2-5-1 collected from the base of the Bw1 horizon at 34 cm (No charcoal)
M2-5-2 is a bulk sediment sample collected from the Bw1 horizon between 27 and 35 cm (dated)

Miscellaneous Notes:

Gravel is rounded and well-rounded pebbles. Subangular black rocks are common throughout. Small pebbles and granules are about 10% of the gravel. Structure is weaker in the upper 6 to 7 cm of the Bw1 horizon.



FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-6 **Described by:** Ralph Klinger and Lucy Piety **Date:** 10/9/2008
Map Unit: Qa3 **Aspect:** SE **Parent Material:** well-sorted fluvial sand
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.380/ -120.124 (GPS; WGS84) **Elevation:** 1617 ft
Location: Low terrace between channels that were active during the 1948 flood; near RM 41.7 on the Methow River north of Twisp.

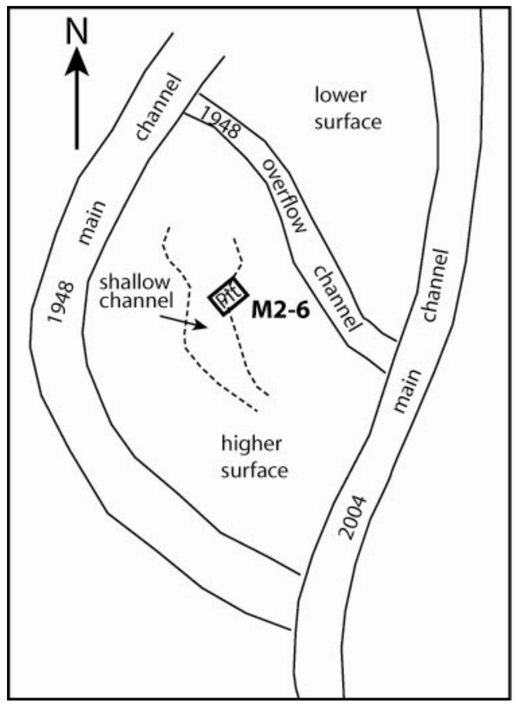
Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
0	5-0	aw	n/a	none	n/a	n/a	n/a	n/a	0	n/a	n/a
C1	0-32	cs	sg	none	so	po	lo	m-cS	0	n/a	2.5Y4/2
C2	32-52	cw	1f-msbk	none	so	po	so	fLS	0	n/a	2.5Y3/3
Ab?	52-56	gw	1m-cgr	none	ss	ps	so	SiL	0	n/a	10YR2/2
C3	56-73	aw	2csbk	none	ss	ps	sh	SiL	0	n/a	2.5Y3/3
C4	73+	-	sg	none	so	po	lo	mS	0	n/a	2.5Y4/2

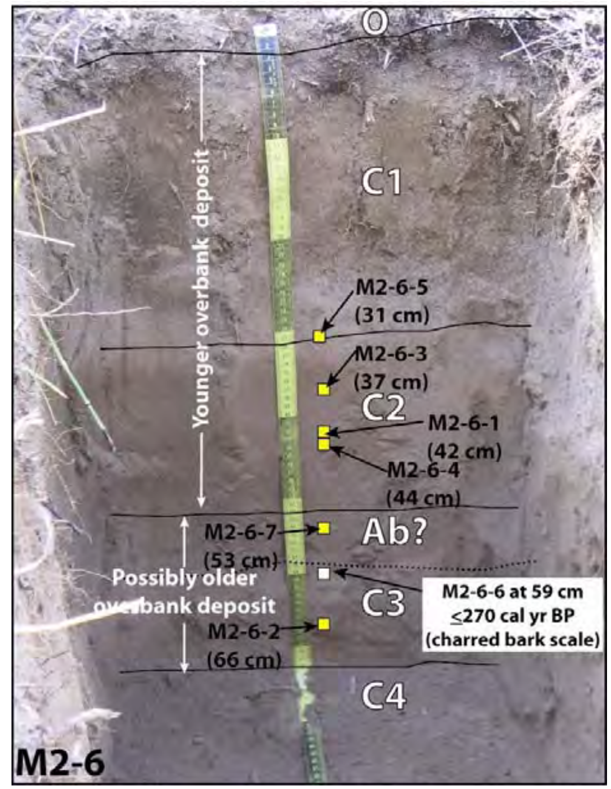
Radiocarbon Samples:

M2-6-1 collected from the C2 horizon at 42 cm (No charcoal)
M2-6-2 collected from the C3 horizon at 66 cm (Unidentifiable <0.001 g)
M2-6-3 collected from the C2 horizon at 37 cm (Conifer 0.004 g single)
M2-6-4 collected from the C2 horizon at 44 cm (Bark 0.004 g five)
M2-6-5 collected from the base of the C1 horizon at 31 cm (Conifer 0.001 g single)
M2-6-6 collected from the upper part of the C3 horizon at 59 cm (Bark scale 0.007 g two)
M2-6-7 collected from the upper part of the Ab? horizon at 53 cm (Conifer <0.001 g single)

Miscellaneous Notes:

The pit was excavated on a surface between the curving 1948 main Methow River channel on the west and south, the 2004 main Methow River channel on the east, and an overflow channel that was active in the 1948 flood on the northeast. Surface not obviously inundated by 1948 flood. Surface slightly irregular with "bar-and-swale" topography. Pit located on a "bar". Shallow inundation and erosion in swales. Boundary of C1 horizon primarily clear and smooth, except where the C1 horizon interfingers with the upper 10 cm of the C2 horizon. C4 horizon is very similar to the C1 horizon, except that it is slightly finer. Ab? horizon is formed between C2 and C3; upper boundary of the Ab? horizon (with C2) is abrupt; lower boundary of the Ab? horizon (with C3) is gradational.





FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-7 **Described by:** Ralph Klinger and Lucy Piety **Date:** 10/9/2008
Map Unit: Qa3 **Aspect:** N **Parent Material:** well-sorted fine-grained fluvial sand, slackwater deposits, channel gravel
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.375/ -120.122 (GPS; WGS84) **Elevation:** 1630 ft
Location: Bank exposure in low terrace/flood plain along the right bank of Methow River near RM 42.25; GPS waypoint # 782.

Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
A	0-29	cw	3m-cgr	none	so	po	sh	fLS	0	n/a	2.5Y3/2
C1	29-51	cw	m-2vcsbk	none	so	po	sh	fSL	0	n/a	2.5Y3/3
C2	51-80	cw	m	none	so	po	so	mLS	0	n/a	2.5Y3/2
2C1	80-90	aw	-	none	-	-	eh	-	0	n/a	10YR4/3*
2C2	90-118	aw	-	none	s	-	sh	SiCL	0	n/a	7.5YR3/3
3C	118+	-	-	none	-	-	lo	c-vcS	>75	n/a	-

*Color is for darker layer in the upper ~2 cm of 2C1 horizon

Radiocarbon and Ash Samples:

M2-7-1A is ash with sediment collected from upper part of 2C2 horizon at 90 cm

M2-7-1B is ash and charcoal collected from upper part of 2C2 horizon at 90 cm (*Pseudotsuga menziesii* 0.0252 g single)

M2-7-1C is ash pieces collected from upper part of 2C2 horizon at 90 cm

M2-7-2 is charcoal collected from 2C2 horizon at ~93 cm (Salicaceae 0.0692 g single)

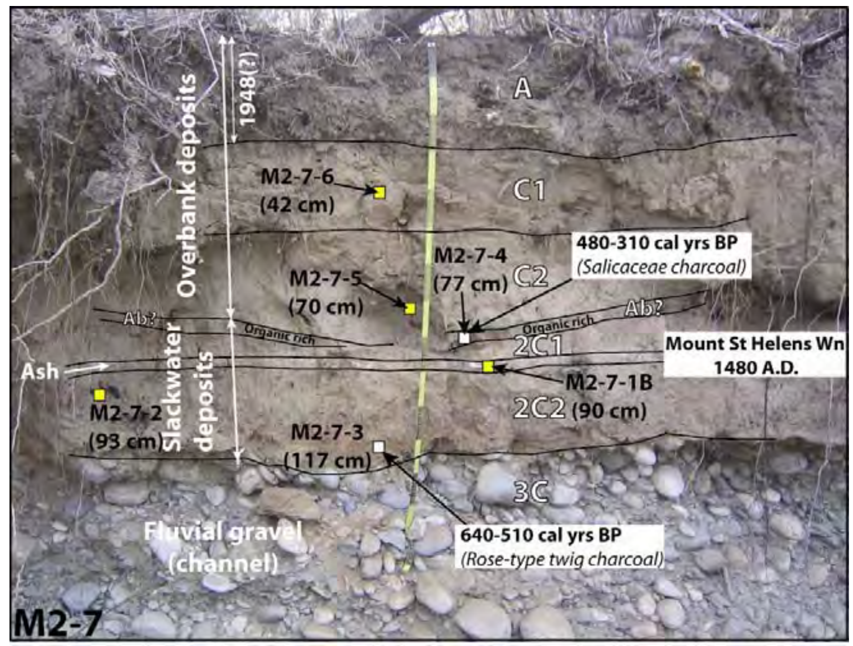
M2-7-3 is charcoal collected from lower part of 2C2 horizon at 117 cm (dated)

M2-7-4 is charcoal from the upper dark layer of 2C1 horizon at 77 cm (dated)

M2-7-5 is charcoal from the C2 horizon at 70 cm (Conifer 0.001 g three)

M2-7-6 is charcoal from the C2 horizon at 42 cm (*Thuja plicata* 0.0174 g single)

(Depths shown above were measured from the ground surface and do not correlate with the description site because of the variability in unit thickness)



Miscellaneous Notes:

Surface with bank exposure is slightly higher, and more stable, than surrounding surfaces. Exposure is along a dry overflow channel. A horizon could have been deposited during the 1948 flood. Ash is between 2C1 and 2C2 horizons. Ash is in rounded patches (infills into burrows or bioturbation of the ash bed?). 2C2 horizon is mottled.

FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-8 **Described by:** Ralph Klinger and Lucy Piety **Date:** 4/21/2009
Map Unit: Qa1 **Aspect:** **Parent Material:** well-sorted fine-grained fluvial sand, channel gravel
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.415/-120.138 (GPS; WGS84) **Elevation:** 1673 ft
Location: Soil pit in terrace on river left of Methow River near RM 45.75; GPS waypoint # 792.

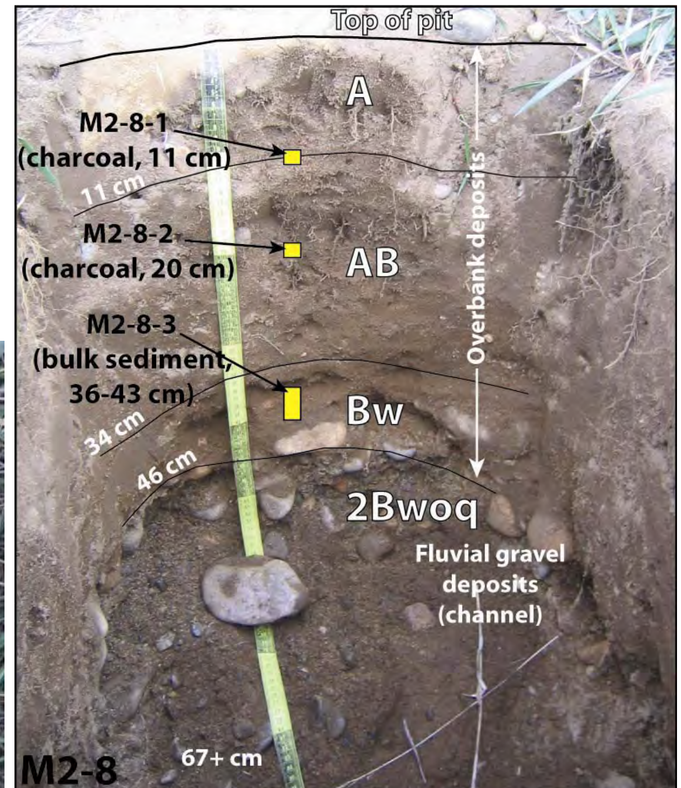
Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
A	0-11	cs	1fsbk	none	so	po	so	mLS	Tr	n/a	10YR3/3
AB	11-34	cs	1msbk	none	so	po	so	mLS	Tr	n/a	10YR3/2.5
Bw	34-46	aw	1msbk	none	so	po	so	cLS	Tr	n/a	10YR4/3
2Bwoq	46-67+	-	sg	none	-	-	lo	vcS	50	I-	10YR4/2

Radiocarbon and Ash Samples:

M2-8-1 is charcoal collected from A/AB horizon boundary at 11 cm
M2-8-2 is charcoal collected from AB horizon at 20 cm
M2-8-3 is bulk sediment sample collected from Bw horizon between 36 and 43 cm

Miscellaneous Notes:

Gravel in A and AB horizons is subrounded to rounded with maximum intermediate diameters of <3 cm. Gravel in Bw horizon is rounded to subrounded. Gravel in 2Bwoq horizon is rounded to subrounded with maximum intermediate diameters of up to 15 cm, but primarily 5 to 10 cm. In the 2Bwoq horizon, iron staining is present on the tops of stones, and patchy silica coats are present on the bottoms of stones (weak stage I-). In the 2Bwoq horizon, coarse sand is very angular.



FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-9 **Described by:** Ralph Klinger and Lucy Piety **Date:** 4/22/2009
Map Unit: Qa3 **Aspect:** N **Parent Material:** fluvial sand, channel gravel
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.389/-120.129 (GPS; WGS84) **Elevation:** 1643 ft
Location: Soil pit in terrace on river left of Methow River near RM 43; GPS waypoint # 811.

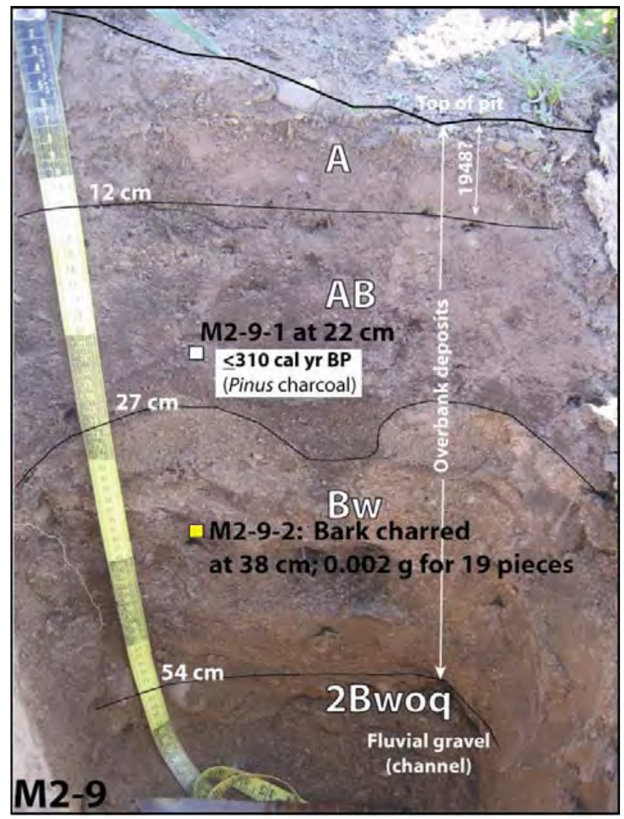
Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO_2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
A	0-12	cw	1fsbk	none	so	po	so	mSL	Tr	n/a	10YR4/2
AB	12-27	ci	1msbk	none	so	po	so	mSL	Tr	n/a	10YR4/2
Bw	27-54	cw	1msbk	none	so	po	so	cSL	Tr	n/a	10YR4/3
2Bwoq	54-63+	-	1fsbk	none	-	-	so	cLS	50	I-	10YR6/4(d)

Radiocarbon and Ash Samples:

M2-9-1 is charcoal collected from AB horizon at 22 cm
M2-9-2 is charcoal collected from Bw horizon at 38 cm

Miscellaneous Notes:

Gravel in A, AB, and Bw horizons fines upward to granules. The A horizon is very gritty. The boundary of the AB horizon is irregular as a result of bioturbation. The Bw horizon contains glass and charcoal fragments. The 2Bwoq horizon has very weak structure and is very soft. The 2Bwoq horizon contain very patchy silica coats on the bottoms and occasional sides of <10% of stones; silica coats are in stringers. The 2Bwoq horizon has thick and readily visible, dark Mn coats on one side of a couple of stones.



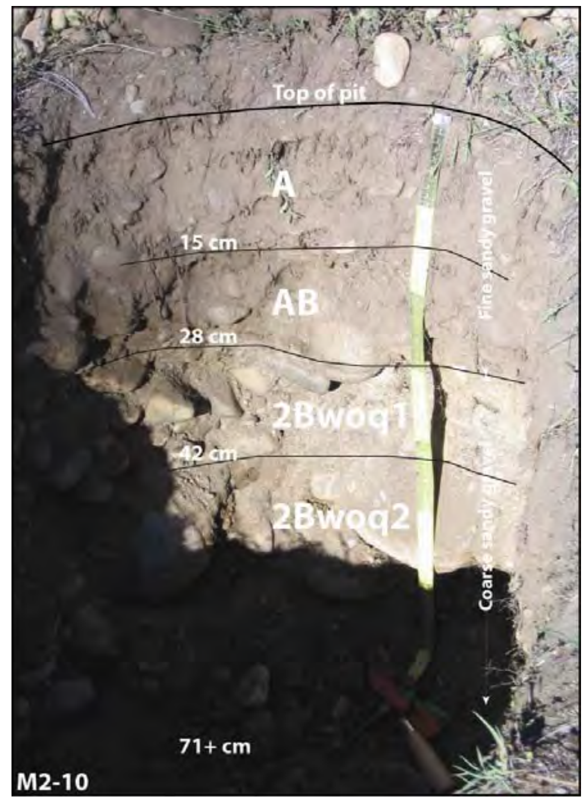
FIELD DESCRIPTION OF SOIL PROPERTIES

Site No.: M2-10 **Described by:** Ralph Klinger and Lucy Piety **Date:** 4/24/2009
Map Unit: Qa2 **Aspect:** N **Parent Material:** fine sandy gravel over coarse sandy gravel
Quadrangle: Winthrop, Wash (USGS 7.5') **Lat/Long coordinates:** 48.413/-120.136 (GPS; WGS84) **Elevation:** 1673 ft
Location: Soil pit in terrace on river left of Methow River near RM 45.25; on old gravel bar; GPS waypoint # 840.

Horizon	Depth (cm)	Boundaries	Structure	Clay Films	Consistence			Texture	Gravel %	SiO2 Morphology	Color (moist)
					Stickiness	Plasticity	Dry				
A	0-15	as	v1fgr	none	so	po	so	fSL	<25	n/a	10YR3/3
AB	15-28	cw	1msbk	none	so	po	so	fSL	>25	n/a	10YR3/3
2Bwoq1	28-42	cw	v1fsbk	none	so	po	lo-so	vcLS	25-50	I-	2.5Y4/3
2Bwoq2	42-71+	-	sg	none	-	-	lo	vcLS	>50	I	2.5Y4/3

Radiocarbon and Ash Samples:
None

Miscellaneous Notes:
Gravel is common on ground surface (embedded). Largest stone removed from pit has an intermediate diameter of 18 cm. Most stones have intermediate diameters of 14 to 16 cm. Change in parent material is interpreted to be coarse sandy gravel that was deposited as a channel/bar, and fines upward due to deposition of sand onto the surface of the bar. The percentage of gravel in the upper parent material is lower than in the underlying parent material 2. A horizon contains common roots. AB horizon has a sandy matrix that holds the form of the stones; it has better structure than the overlying A horizon. 2Bwoq1 horizon has iron/manganese coats on stones, a sandy matrix that holds the form of the stones, and weak structure. 2Bwoq2 horizon has silica coats on bottoms of some stones; the horizon does not have any structure. Manganese/silica coats are much better developed in the lower 2Bwoq2 horizon than in the 2Bwoq1 horizon.



APPENDIX D
MACROBOTANTICAL IDENTIFICATION
AND
RADIOCARBON ANALYSES

MIDDLE METHOW REACH ASSESSMENT
METHOW RIVER
OKANOGAN COUNTY, WA

PALEO RESEARCH INSTITUTE
GOLDEN, CO

Kathy Puseman

September 2009

EXAMINATION OF BULK SOIL/DETRITAL CHARCOAL AND AMS RADIOCARBON ANALYSIS OF MATERIAL FROM THE MIDDLE METHOW RIVER GEOMORPHIC STUDY, WASHINGTON

By

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PaleoResearch Institute
Golden, Colorado

PaleoResearch Institute Technical Report 09-09

Prepared For

Bureau of Reclamation
Reclamation Service Center
Denver, Colorado

September 2009

INTRODUCTION

A total of 30 samples were examined to recover organic fragments suitable for AMS radiocarbon analysis. These samples were recovered from soil profiles adjacent to the Middle Methow River in central Washington, east of the Cascade Range. Botanic components and detrital charcoal were identified, and potentially radiocarbon datable material was separated. Six samples were submitted for AMS radiocarbon dating.

METHODS

Flotation and Identification

A single bulk sample was floated using a modification of the procedures outlined by Matthews (1979). The sample was added to approximately 3 gallons of water. The sample was stirred until a strong vortex formed, which was allowed to slow before pouring the light fraction through a 150 micron mesh sieve. Additional water was added and the process repeated until all visible macrofloral material was removed from the sample (a minimum of five times). The material that remained in the bottom (heavy fraction) was poured through a 0.5-mm mesh screen. The floated portions were allowed to dry.

The light fraction was weighed, then passed through a series of graduated screens (US Standard Sieves with 4-mm, 2-mm, 1-mm, 0.5-mm and 0.25-mm openings to separate charcoal debris and to initially sort the remains. The contents of each screen were then examined. Charcoal fragments were broken to expose a fresh cross section and examined under a binocular microscope at a magnification of 70x. The remaining light fraction in the 4-mm, 2-mm, 1-mm, 0.5-mm, and 0.25-mm sieves was scanned under a binocular stereo microscope at a magnification of 10x, with some identifications requiring magnifications of up to 70x. The material that passed through the 0.25-mm screen was not examined. The coarse or heavy fraction also was examined for the presence of botanic remains.

The remaining samples were water-screened through a 250 micron mesh sieve and allowed to dry. The dried samples were scanned under a binocular stereo microscope at a magnification of 10x. Charcoal fragments were separated and examined under a binocular microscope at a magnification of 70x. Macrofloral remains, including charcoal, were identified using manuals (Core, et al. 1976; Martin and Barkley 1961; Panshin and Zeeuw 1980; Petrides and Petrides 1992) and by comparison with modern and archaeological references. The term "seed" is used to represent seeds, achenes, caryopses, and other disseminules. Because charcoal and possibly other botanic remains were to be sent for radiocarbon analysis, clean laboratory conditions were used during water-screening and identification to avoid contamination. All instruments were washed between samples, and samples were protected from contact with modern charcoal.

AMS Radiocarbon Dating - Charcoal and Wood

Wood and charcoal samples submitted for radiocarbon dating are identified and weighed prior to selecting subsamples for pre-treatment. The remainder of each sample, if there is any, is permanently curated at PaleoResearch. The subsample selected for pre-treatment is first subjected to hot (at least 110 °C), 6N hydrochloric acid (HCl), with rinses to neutral between each HCl treatment, until the supernatant is clear. This removes iron compounds and calcium carbonates that would hamper removal of humate compounds later. Next the samples are subjected to 5% potassium hydroxide (KOH) to remove humates. Once again, the samples are rinsed to neutral and re-acidified with pH 2 HCl between each KOH step. This step is repeated until the supernatant is clear, signaling removal of all humates. After humate removal, each sample is made slightly acidic and left that way for the next step. Charcoal samples (but not wood samples) are subjected to a concentrated, hot nitric acid bath, which removes all modern and recent organics. This treatment is not used on unburned or partially burned wood samples because it oxidizes the submitted sample of unknown age.

Each submitted sample is then freeze-dried using a vacuum system, freezing out all moisture at -98 °C. Each individual sample is combined with cupric oxide (CuO) and elemental silver (Ag^o) in a quartz tube, then flame sealed under vacuum.

Standards and laboratory background samples also are treated in the same manner as the wood and charcoal samples of unknown age. A radiocarbon "dead" EUA wood blank from Alaska that is more than 70,000 years old (currently beyond the detection capabilities of AMS) is treated using the same chemical processing as the samples of unknown age in order to calibrate the laboratory correction factor. Standards of known age, such as Two Creeks wood that dates to 11,400 RCYBP and others from the Third International Radiocarbon Intercomparison (TIRI), are also processed simultaneously to establish the laboratory correction factor. Each wood standard is run in a quantity similar to the submitted samples of unknown age and sealed in a quartz tube after the requisite pre-treatment.

Once all the wood standards, blanks, and submitted samples of unknown age are prepared and sealed in their individual quartz tubes, they are combusted at 820 °C, soaked for an extended period of time at that temperature, and then slowly allowed to cool to enable the chemical reaction that extracts carbon dioxide ($C0_2$) gas.

Following this last step, all samples of unknown age, the wood standards, and the laboratory backgrounds are sent to the Keck Carbon Cycle AMS Facility at the University of California, Irvine, where the $C0_2$ gas is processed into graphite. The graphite in these samples is then placed in the target and run through the accelerator, which produces the numbers that are converted into the radiocarbon date presented in the data section. Dates are presented as conventional radiocarbon ages, as well as calibrated ages using Intcalc04 curves on Oxcal v.3.10.

DISCUSSION

Soil profiles M2-2, M2-3, M2-4, M2-5, M2-6, M2-8, and M2-9 were described in hand-dug or backhoe pits on stream terraces adjacent to the Middle Methow River in central Washington, between river miles 41 and 45. Profile M2-7 was described in a natural exposure in a river bank. The Middle Methow River is noted to be partially restricted by levees. Local vegetation includes cottonwood (*Populus* spp.) and grasses (Poaceae), and some of the terraces have been cleared. A total of 30 samples were collected from these various soil profiles.

Soil Profile M2-2

Soil profile M2-2 is a hand-dug pit located near the edge of a low terrace downstream of the confluence with the Twisp River. Four samples were taken from this profile. Sample M2-2-1 was collected from upper sand at a depth of 51 cm (Table 1). This sample contained two fragments of Salicaceae charcoal weighing 0.018 g (Table 2, Table 3), representing a woody member of the willow family.

Sample M2-2-2 was recovered from the ABb horizon in the lower sand unit at a depth of 75 cm. This sample yielded a piece of probable *Pinus* charcoal weighing 0.006 g.

One charred monocot/herbaceous dicot stem fragment was present in sample M2-2-3 from the Bwb horizon at a depth of 86 cm. Three pieces of unidentified root charcoal weighing 0.018 g also were present.

Sample M2-2-4 was taken from a depth fo 72 cm in the ABb horizon. One fragment of conifer charcoal weighing 0.008 g was present in this sample, as well as two unidentifiable charcoal fragments weighing 0.005 g.

Soil Profile M2-3

Soil profile M2-3 was exposed in a trench for a new house on a very low terrace between a cutoff channel and the highway. Sample M2-3-1 was collected from a depth of 27-28 cm in Unit C2, representing older flood sand. This sample contained three fragments of Salicaceae charcoal weighing 0.079 g. Two fragments of unidentifiable charcoal weighing 0.063 g also were present.

Samples M2-3-2, M2-3-3, M2-3-4, and M2-3-5 were taken from gravelly sand in Unit C3. Sample M2-3-2 consisted of four pieces of *Pseudotsuga menziesii* charcoal weighing 0.034 g, representing Douglas fir wood that burned.

Several fragments of unidentified hardwood wood weighing 0.119 g were present in sample M2-3-3 from a depth of 30 cm. These wood fragments were degraded and old-looking and appear to represent a hardwood with a diffuse porous arrangement of vessels, such as a member of the Salicaceae.

Sample M2-3-4 also was taken from a depth of 30 cm. This sample consisted of a single piece of *Pseudotsuga menziesii* charcoal weighing 0.127 g. This piece of charcoal was submitted for AMS radiocarbon dating and yielded a date of 1150 ± 15 RCYBP (PRI-09-09.2-M2-3-4). The two-sigma calibrated age range for this date is 1170-1160 and 1140-980 CAL yr. BP (Table 4, Figure 1).

Sample M2-3-5 was recovered at a depth of 23 cm. Numerous pieces of *Pseudotsuga menziesii* charcoal weighing 0.049 g were present in this sample, again reflecting Douglas fir wood that burned.

<u>Soil Profile M2-4</u>

Soil Profile M2-4 is a hand-dug pit on the terrace between the main river channel and secondary channels. Three samples were recovered from this pit. Sample M2-4-1 was collected at a depth of 39-40 cm from the finer sand of Unit 4. One piece of conifer charcoal weighing less than 0.001 g and one piece of unidentified hardwood charcoal weighing less than 0.001 g were present in this sample.

Sample M2-4-2 also was taken from the finer sand of Unit 4 at a depth of 50 cm. A single piece of charcoal too small for identification and weighing less than 0.001 g was noted.

Sample M2-4-3 was collected from a depth of 44 cm in Unit 5 (coarse sand). This sample yielded four fragments of *Alnus* charcoal weighing 0.006 g, reflecting alder wood that burned.

<u>Soil Profile M2-5</u>

Soil profile M2-5 is located in a backhoe pit on a terrace between a cutoff channel and active secondary channels. Sample M2-5-1 was taken from the Bw1 horizon at a depth of 34 cm. This sample contained one piece of charred parenchymous tissue weighing 0.001 g. “Parenchyma is the botanical term for relatively undifferentiated tissue, composed of many similar thin-walled cells...which form a ground tissue that surrounds other tissues. Parenchyma occurs in many different plant organs in varying amounts. Large fleshy organs such as ...roots and stems are composed largely of parenchyma. ...The vegetative storage parenchyma in swollen roots and stems stores starch and other carbohydrates and sugars ...” (Hather 2000:1). Recovery of parenchymous tissue most likely reflects burned root or stem tissue.

Sample M2-5-2 consists of bulk sediment from the Bw1 horizon at a depth of 27-35 cm. This sample yielded six pieces of conifer charcoal weighing 0.005 g, one charred fragment of conifer bark weighing 0.003 g, four pieces of charred unidentified bark weighing 0.002 g, and a single fragment of charred PET fruity tissue weighing less than 0.001 g. The term PET (processed edible tissue) was originated by Nancy Stenholm (1993) and refers to softer tissue types, such as starchy parenchymoid or fruity epitheloid tissues. PET fruity tissues resemble sugar-laden fruit or berry tissue without the seeds, as well as tissue from succulent plant parts such as cactus pads. Two uncharred *Chenopodium* seeds and a moderate amount of rootlets represent modern plants at the site. The charred conifer bark fragment was submitted for AMS radiocarbon analysis. This bark fragment yielded a date of 1240 ± 20 RCYBP (PRI-09-09-M2-5-2), with a two-sigma calibrated age range of 1270-1080 CAL yr. BP (Table 4, Figure 2).

Soil Profile M2-6

Soil Profile M2-6 is a hand-dug pit located on a terrace between the present main river channel and main and secondary channels that were active during the 1948 flood. Seven charcoal samples were recovered from this pit. Sample M2-6-1 was collected from Unit C2 at a depth of 42 cm. This sample contained an uncharred plant stem weighing 0.002 g.

Sample M2-6-2 was taken from a depth of 66 cm in Unit C3. Six fragments of charcoal too small for identification and weighing less than 0.001 g were noted in the sample. A few uncharred rootlets from modern plants and a single insect chitin fragment also were present.

Sample M2-6-3 was collected from Unit C2 at a depth of 37 cm. This sample yielded ten pieces of conifer charcoal weighing 0.010 g.

Five fragments of charred bark weighing less than 0.001 g were noted in sample M2-6-4 from Unit C2 at a depth of 44 cm. This sample also yielded a single sclerotia. Sclerotia are commonly called "carbon balls". They are small, black, solid or hollow spheres that can be smooth or lightly sculpted. These forms range from 0.5 to 4 mm in size. Sclerotia are the resting structures of mycorrhizae fungi, such as *Cenococcum graniforme*, that have a mutualistic relationship with tree roots. Many trees are noted to depend heavily on mycorrhizae and may not be successful without them. "The mycelial strands of these fungi grow into the roots and take some of the sugary compounds produced by the tree during photosynthesis. However, mycorrhizal fungi benefit the tree because they take in minerals from the soil, which are then used by the tree" (Kricher and Morrison 1988:285). Sclerotia appear to be ubiquitous and are found with coniferous and deciduous trees including *Abies* (fir), *Juniperus communis* (common juniper), *Larix* (larch), *Picea* (spruce), *Pinus* (pine), *Pseudotsuga* (Douglas fir), *Acer pseudoplatanus* (sycamore maple), *Alnus* (alder), *Betula* (birch), *Carpinus caroliniana* (American hornbeam), *Carya* (hickory), *Castanea dentata* (American chestnut), *Corylus* (hazelnut), *Crataegus monogyna* (hawthorn), *Fagus* (beech), *Populus* (poplar, cottonwood, aspen), *Quercus* (oak), *Rhamnus fragula* (alder bush), *Salix* (willow), *Sorbus* (chokecherry), and *Tilia* (linden). These forms originally were identified by Dr. Kristiina Vogt, Professor of Ecology in the School of Forestry and Environmental Studies at Yale University (McWeeney 1989:229-230; Trappe 1962).

Sample M2-6-5 was taken from a depth of 31 cm in Unit C1. This sample contained a single piece of conifer charcoal weighing 0.001 g.

Sample M2-6-6 was recovered from Unit C3 at a depth of 59 cm. Two charred bark fragments weighing 0.007 g were the only organic remains noted in this sample. These charred bark fragments were submitted for AMS radiocarbon analysis, resulting in a date of 125 ± 20 RCYBP (PRI-09-09.2-M2-6-6). The two-sigma calibrated age range for this date is 270-180 and 150-10 CAL yr. BP (Figure 3).

Eight small, charred bark fragments weighing 0.001 g were present in sample M2-6-7 from Unit C2 at a depth of 53 cm. The sample also yielded a single piece of conifer charcoal weighing less than 0.001 g.

Soil Profile M2-7

Soil profile M2-7 is a natural bank exposure on a terrace along the main river channel near a secondary channel. Six charcoal samples were taken from this exposure. Sample M2-7-1B consists of ash and charcoal at a depth of about 90 cm. This sample contained several fragments of *Pseudotsuga menziesii* charcoal weighing 0.108 g.

Sample M2-7-2 was collected from mottled silica clay in Unit C4 at a depth of about 93 cm. This sample contained several large chunks of Salicaceae charcoal weighing 2.072 g, reflecting a member of the willow family that burned.

Sample M2-7-3 was taken from a depth of 117 cm in the mottled silica clay of Unit C4. Several charred, slightly vitrified *Rosa*-type twig fragments weighing 0.390 g were noted in this sample, suggesting that wild roses might have grown along the river. The largest single piece of charcoal weighing 0.0734 g was submitted for AMS dating, resulting in a date of 550 ± 25 RCYBP (PRI-09-09-M2-7-3). The two-sigma calibrated age range for this date is 640-590 and 570-510 CAL yr. BP (Figure 4).

Six fragments of Salicaceae charcoal were noted in sample M2-7-4 from a depth of 77 cm in the mottled silica clay of Unit C3, reflecting cottonwood or willow that burned. An AMS date was obtained on the largest single piece of charcoal weighing 0.0561 g. This charcoal returned a date of 340 ± 20 RCYBP (PRI-09-09-M2-7-4), with a two-sigma calibrated age range of 480-310 CAL yr. BP (Figure 5).

Several types of charred remains were noted in sample M2-7-5 from Unit C2 at a depth of 70 cm. These included eight bark fragments weighing 0.001 g, three pieces of conifer charcoal weighing 0.001 g, three fragments of unidentified hardwood charcoal weighing less than 0.001 g, and several pieces of charcoal too small for identification weighing 0.001 g. Douglas fir trees are represented by recovery of a charred *Pseudotsuga menziesii* needle fragment weighing less than 0.001 g and four fragments of *Pseudotsuga menziesii* charcoal weighing less than 0.001 g.

Sample M2-7-6 was recovered from Unit C1 at a depth of 42 cm. This sample yielded several fragments of incompletely charred *Thuja plicata* charcoal, representing a western red cedar that burned.

Soil Profile M2-8

Soil profile M2-8 is a hand-dug pit located on a higher floodplain terrace near river mile 43. A single sample was collected from flood sand at a depth of 20 cm. Sample M2-8-2 contained twelve pieces of Asteraceae charcoal weighing 0.004 g, three fragments of unidentified hardwood charcoal with a diffuse porous distribution of vessels weighing 0.001 g, and several fragments of hardwood charcoal too small for identification. A few small rodent fecal pellets were noted, as were a few uncharred rootlets from modern plants.

Soil Profile M2-9

Soil profile M2-9 consists of a hand-dug pit on a higher floodplain terrace near river mile 45.5. Two samples were collected from flood sand in this pit. Sample M2-9-2 from a depth of 38 cm contained several charred bark fragments weighing 0.002 g.

Sample M2-9-1 from a depth of 22 cm yielded six charred *Pinus* charcoal fragments weighing 0.028 g. The largest single fragment of pine charcoal was submitted for AMS radiocarbon dating. This charcoal yielded a date of 210 ± 20 RCYBP (PRI-09-09.2-M2-9-1), with a two-sigma calibrated age range of 310-260, 220-200, 190-140, and 20-(-11) CAL yr. BP (Figure 6).

SUMMARY AND CONCLUSIONS

Examination of samples from soil profiles adjacent to the Middle Methow River in central Washington, east of the Cascade Range, resulted in recovery of charcoal and other charred botanic remains. Charcoal types represent woody vegetation found locally in the area, either along the Middle Methow River or in the broader drainage basin. Six radiocarbon dates were obtained for this project. Douglas fir charcoal in sample M2-3-4 returned a date of 1150 ± 15 BP. Charred conifer bark from sample M2-5-2 yielded a date of 1240 ± 20 BP, while charred bark scale in sample M2-6-6 dated to 125 ± 20 BP. A date of 550 ± 25 BP was returned for a charred, slightly vitrified *Rosa*-type twig in sample M2-7-3, and a piece of Salicaceae charcoal in sample M2-7-4 yielded a date of 340 ± 20 BP. Sample M2-9-1 contained pine charcoal that dated to 210 ± 20 BP.

TABLE 1
PROVENIENCE DATA FOR SAMPLES FROM ALONG THE MIDDLE METHOW RIVER , WASHINGTON

Soil Profile	Sample No.	Depth (cm)	Description	Unit	Analysis
M2-2	M2-2-1	51	Charcoal	Upper sand	Charcoal ID
	M2-2-2	75	Charcoal	Lower sand (ABb horizon)	Charcoal ID
	M2-2-3	86	Charcoal	Lower sand (Bwb horizon)	Charcoal ID
	M2-2-4	72	Charcoal	Lower sand (ABb horizon)	Charcoal ID
M2-3	M2-3-1	27-28	Charcoal	C2; Older Flood Sand	Charcoal ID
	M2-3-2		Charcoal	C3; Gravelly Sand	Charcoal ID
	M2-3-3	30	Charcoal	C3; Gravelly Sand	Charcoal ID
	M2-3-4	30	Charcoal	C3; Gravelly Sand	Charcoal ID AMS ^{14}C Date
	M2-3-5	23	Charcoal	C3; Gravelly Sand	Charcoal ID
M2-4	M2-4-1	39-40	Charcoal	4; Finer sand	Charcoal ID
	M2-4-2	50	Charcoal	4; Finer sand	Charcoal ID
	M2-4-3	44	Charcoal	5 ; Coarse sand	Charcoal ID
M2-5	M2-5-1	34	Charcoal	Bw1 horizon	Charcoal ID
	M2-5-2	27-35	Bulk sediment	Bw1 horizon	Macrofloral AMS ^{14}C Date
M2-6	M2-6-1	42	Charcoal	C2	Charcoal ID
	M2-6-2	66	Charcoal	C3	Charcoal ID
	M2-6-3	37	Charcoal	C2	Charcoal ID
	M2-6-4	44	Charcoal	C2	Charcoal ID
	M2-6-5	31	Charcoal	C1	Charcoal ID
	M2-6-6	59	Charcoal	C3	Charcoal ID AMS ^{14}C Date
	M2-6-7	53	Charcoal	C2	Charcoal ID

TABLE 1 (Continued)

Soil Profile	Sample No.	Depth (cm)	Description	Unit	Analysis
M2-7	M2-7-1B	~90	Ash, Charcoal	Ash	Charcoal ID
	M2-7-2	~93	Charcoal	C4; Molted silica clay	Charcoal ID
	M2-7-3	117	Charcoal	C4; Molted silica clay	Charcoal ID AMS ^{14}C Date
	M2-7-4	77	Charcoal	C3; Molted silica clay	Charcoal ID AMS ^{14}C Date
	M2-7-5	70	Charcoal	C2	Charcoal ID
	M2-7-6	42	Charcoal	C1	Charcoal ID
M2-8	M2-8-2	20	Charcoal	Flood sand	Charcoal ID
M2-9	M2-9-1	22	Charcoal	Flood sand	Charcoal ID
	M2-9-2	38	Charcoal	Flood sand	Charcoal ID AMS ^{14}C Date

TABLE 2
MACROFLORAL REMAINS IN SAMPLES FROM ALONG
THE MIDDLE METHOW RIVER , WASHINGTON

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
M2-2-1	Water-screened Sample Weight						0.020 g
51 cm	CHARCOAL/WOOD:						
	Salicaceae	Charcoal		2			0.018 g
M2-2-2	Water-screened Sample Weight						0.007 g
75 cm	CHARCOAL/WOOD:						
	Conifer, cf. *Pinus*	Charcoal		1			0.006 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-2-3	Water-screened Sample Weight						0.019 g
86 cm	FLORAL REMAINS:						
	Monocot/Herbaceous dicot	Stem		1			<0.001 g
	CHARCOAL/WOOD:						
	Unidentified root	Charcoal		3			0.018 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-2-4	Water-screened Sample Weight						0.015 g
72 cm	CHARCOAL/WOOD:						
	Conifer	Charcoal		1			0.008 g
	Unidentifiable	Charcoal		2			0.005 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-3-1	Water-screened Sample Weight						0.153 g
27-28 cm	CHARCOAL/WOOD:						
	Salicaceae	Charcoal		3			0.079 g
	Unidentifiable	Charcoal		2			0.063 g
M2-3-2	Water-screened Sample Weight						0.039 g
	CHARCOAL/WOOD:						
	Pseudotsuga menziesii (largest single piece = 0.0183 g)	Charcoal		4			0.034 g
	NON-FLORAL REMAINS:						
	Sand					X	

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
M2-3-3	Water-screened Sample Weight						24.624 g
30 cm	CHARCOAL/WOOD:						
	Unidentified hardwood - degraded, old-looking, possibly diffuse-porous	Wood				17	0.119 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	
M2-3-4	Water-screened Sample Weight						0.127 g
30 cm	CHARCOAL/WOOD:						
	*Pseudotsuga menziesii***	Charcoal		1			0.127 g
M2-3-5	Water-screened Sample Weight						1.285 g
23 cm	CHARCOAL/WOOD:						
	Pseudotsuga menziesii	Charcoal		153			0.049 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-4-1	Water-screened Sample Weight						0.204 g
39-40 cm	CHARCOAL/WOOD:						
	Conifer	Charcoal		1			<0.001 g
	Unidentifiable - vitrified	Charcoal		1			<0.001 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-4-2	Water-screened Sample Weight						0.010 g
50 cm	CHARCOAL/WOOD:						
	Unidentifiable - small	Charcoal		1			<0.001 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-4-3	Water-screened Sample Weight						2.981 g
44 cm	CHARCOAL/WOOD:						
	Alnus	Charcoal		4			0.006 g
	NON-FLORAL REMAINS:						
	Sand					X	

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
M2-5-1	Water-screened Sample Weight						1.765 g
34 cm	FLORAL REMAINS:						
	Parenchymous tissue			1			0.001 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-5-2	Liters Floated						0.90 L
27-35 cm	Light Fraction Weight						0.69 g
	FLORAL REMAINS:						
	Conifer**	Bark scale		1			0.003 g
	Unidentified	Bark		4			0.002 g
	PET Fruity	Tissue		1			<0.001 g
	Chenopodium	Seed			2		
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Conifer	Charcoal		6			0.005 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate
M2-6-1	Water-screened Sample Weight						0.027 g
42 cm	FLORAL REMAINS:						
	Unidentified	Stem				1	0.002 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-6-2	Water-screened Sample Weight						0.346 g
66 cm	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Unidentifiable - small	Charcoal		6			<0.001 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				1	
	Sand					X	
M2-6-3	Water-screened Sample Weight						0.014 g
37 cm	CHARCOAL/WOOD:						
	Conifer	Charcoal		10			0.010 g
	NON-FLORAL REMAINS:						
	Sand					X	

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
M2-6-4	Water-screened Sample Weight						0.004 g
44 cm	FLORAL REMAINS:						
	Bark			5			0.004 g
	Sclerotia					1	
	NON-FLORAL REMAINS:						
	Sand					X	
M2-6-5	Water-screened Sample Weight						0.001 g
31 cm	CHARCOAL/WOOD:						
	Conifer	Charcoal		1			0.001 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-6-6	Water-screened Sample Weight						0.008 g
59 cm	FLORAL REMAINS:						
	Bark scale**			2			0.007 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-6-7	Water-screened Sample Weight						0.070 g
53 cm	FLORAL REMAINS:						
	Bark			8			0.001 g
	CHARCOAL/WOOD:						
	Conifer	Charcoal		1			<0.001 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-7-1B	Water-screened Sample Weight						0.110 g
~90 cm	FLORAL REMAINS:						
	Rootlet					1	
	CHARCOAL/WOOD:						
	Pseudotsuga menziesii	Charcoal		21			0.108 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-7-2	Water-screened Sample Weight						2.310 g
~93 cm	CHARCOAL/WOOD:						
	Salicaceae	Charcoal		35			2.072 g
	NON-FLORAL REMAINS:						
	Sand					X	

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
M2-7-3	Water-screened Sample Weight						0.472 g
117 cm	CHARCOAL/WOOD:						
	Rosa-type twig - slightly vitrified**	Charcoal		16			0.390 g
	NON-FLORAL REMAINS:						
	Sand					X	
M2-7-4	Water-screened Sample Weight						0.080 g
77 cm	CHARCOAL/WOOD:						
	Salicaceae**	Charcoal		6			0.072 g
	NON-FLORAL REMAINS:						
	Sediment					X	
M2-7-5	Water-screened Sample Weight						0.777 g
70 cm	FLORAL REMAINS:						
	Bark			8			0.001 g
	Pseudotsuga menziesii	Needle		1			<0.001 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		3			0.001 g
	Pseudotsuga menziesii	Charcoal		4			<0.001 g
	Unidentified hardwood - small	Charcoal		3			<0.001 g
	Unidentifiable - small	Charcoal		12			0.001 g
	NON-FLORAL REMAINS:						
	Muscovite					X	
	Sand					X	
M2-7-6	Water-screened Sample Weight						0.062 g
42 cm	CHARCOAL/WOOD:						
	Thuja plicata	Charcoal		16ic			0.033 g
	NON-FLORAL REMAINS:						
	Sand					X	

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
M2-8-2	Water-screened Sample Weight						25.06 g
20 cm	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Asteraceae	Charcoal		12			0.004 g
	Unidentified hardwood - diffuse porous	Charcoal		3			0.001 g
	Unidentified hardwood - small	Charcoal		14			0.003 g
	NON-FLORAL REMAINS:						
	Muscovite					X	Few
	Rock/Gravel					X	Few
	Rodent fecal pellet - small				X	X	Few
M2-9-1	Water-screened Sample Weight						0.89 g
22 cm	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	*Pinus***	Charcoal		6			0.028 g
	NON-FLORAL REMAINS:						
	Sand					X	Few
M2-9-2	Water-screened Sample Weight						1.24 g
	FLORAL REMAINS:						
	Bark			19			0.002 g
	NON-FLORAL REMAINS:						
	Sand					X	Few

W = Whole
F = Fragment
X = Presence noted in sample
g = grams
ic= Incompletely charred
**= Submitted for AMS ^{14}C Dating

TABLE 3
INDEX OF MACROFLORAL REMAINS RECOVERED IN SAMPLES FROM ALONG THE MIDDLE METHOW RIVER , WASHINGTON

Scientific Name	Common Name
FLORAL REMAINS:	
Chenopodium	Goosefoot, Pigweed
Monocot/Herbaceous dicot	A member of the Monocotyledonae class of Angiosperms, which include grasses, sedges, lilies, and palms/A non-woody member of the Dicotyledonae class of Angiosperms
Parenchymous tissue	Relatively undifferentiated tissue composed of many similar thin-walled cells–occurs in different plant organs in varying amounts, especially large fleshy organs such as roots and stems.
PET fruity tissue	Fruity epitheloid tissues; resemble sugar-laden fruit or berry tissue without the seeds, or succulent plant tissue such as cactus pads
Pseudotsuga menziesii	Douglas fir
Sclerotia	Resting structures of mycorrhizae fungi
CHARCOAL/WOOD:	
Alnus	Alder
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, hemlock, redwood, and cypress
Pinus	Pine
Pseudotsuga menziesii	Douglas-fir
Thuja plicata	Western red cedar
Rosa-type	similar to Wild rose
Salicaceae	Willow family
Unidentified hardwood	Wood from a broad-leaved flowering tree or shrub
Unidentifiable - vitrified	Charcoal exhibiting a shiny, glassy appearance due to fusion by heat

TABLE 4
RADIOCARBON RESULTS FOR SAMPLES FROM ALONG
THE MIDDLE METHOW RIVER , WASHINGTON

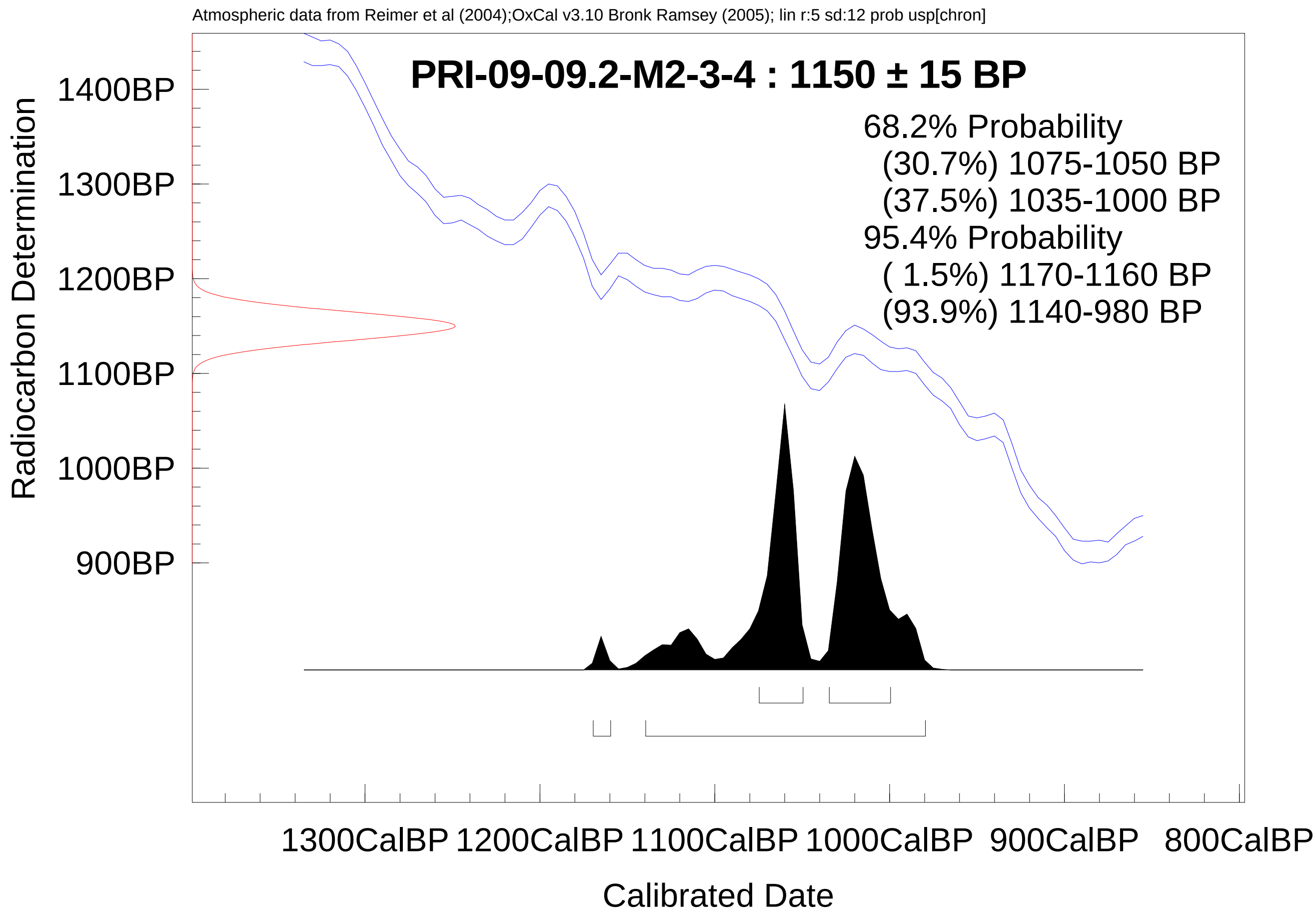
Sample No.	Sample Identification	AMS ^{14}C Date*	1-sigma Calibrated Date (68.2%)	2-sigma Calibrated Date (95.4%)	$\delta^{13}C$** ($^o/_{oo}$)
PRI-09-09.2-M2-3-4	*Pseudotsuga* charcoal	1150 ± 15 RCYBP	1075-1050 1035-1000 CAL yr. BP	1170-1160 1140-980 CAL yr. BP	-18.4
PRI-09-09-M2-5-2	Conifer bark scale	1240 ± 20 RCYBP	1260-1200 1190-1170 1160-1140 CAL yr. BP	1270-1080 CAL yr. BP	-30.3
PRI-09-09.2-M2-6-6	Bark scale-charred	125 ± 20 RCYBP	270-210 150-130 120-70 40-20 CAL yr. BP	270-180 150-10 CAL yr. BP	-21.5
PRI-09-09-M2-7-3	*Rosa*-type twig charcoal	550 ± 25 RCYBP	625-605 560-530 CAL yr. BP	640-590, 570-510 CAL yr. BP	-28.3
PRI-09-09-M2-7-4	Salicaceae charcoal	340 ± 20 RCYBP	460-420 400-310 CAL yr. BP	480-310 CAL yr. BP	-20.8
PRI-09-09.2-M2-9-1	*Pinus* charcoal	210 ± 20 RCYBP	300-280 180-150 10-(-11) CAL yr. BP	310-260 220-200 190-140 20-(-11) CAL yr. BP	-14.8

* Reported in radiocarbon years at 1 standard deviation measurement precision (68.2%), corrected for $\delta^{13}C$

** $\delta^{13}C$ values are measured by AMS during the ^{14}C measurement . The AMS-$\delta^{13}C$ values are used for the ^{14}C calculation and should not be used for dietary or paleoenvironmental interpretations.

FIGURE 1. PRI RADIOCARBON AGE CALIBRATION

Laboratory Number: PRI-09-09.2-M2-3-4
Sample Identification: *Pseudotsuga* charcoal
Conventional AMS ^{14}C Date: 1150 ± 15 RCYBP
1-sigma Calibrated Date (68.2%): 1075-1050; 1035-1000 CAL yr. BP
2-sigma Calibrated Date (95.4%): 1170-1160; 1140-980 CAL yr. BP
$\delta^{13}C$ ($^{o}/_{oo}$): -18.4 (Measured for ^{14}C calculation, not valid for dietary or paleoenvironmental interpretations)



Intercept Statement. PaleoResearch Institute utilizes OxCal3.10 (Bronk Ramsey, 2005) for radiocarbon calibration, which is a probability-based method for determining conventional ages. We prefer this method over the intercept-based alternative because it provides our clients with a calibrated date that reflects the probability of its occurrence within a given distribution (reflected by the amplitude (height) of the curve), as opposed to individual point estimates (Telford 2004). As a result, the probability-based method offers more stability to the calibrated values than those derived from intercept-based methods that are subject to adjustments in the calibration curve (Telford 2004).

References

Telford, R. J., E. Heegaard, and H. J. B. Birks, 2004, *The Holocene* 14(2), pp. 296-298.

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FIGURE 2. PRI RADIOCARBON AGE CALIBRATION

Laboratory Number: PRI-09-09-M2-5-2
Sample Identification: Conifer bark scale - charred
Conventional AMS ^{14}C Date: 1240 ± 20 RCYBP
1-sigma Calibrated Date (68.2%): 1260-1200; 1190-1170; 1160-1140 CAL yr. BP
2-sigma Calibrated Date (95.4%): 1270-1080 CAL yr. BP
$\delta^{13}C$ ($^{o}/_{oo}$): -30.3 (Measured for ^{14}C calculation, not valid for dietary or paleoenvironmental interpretations)

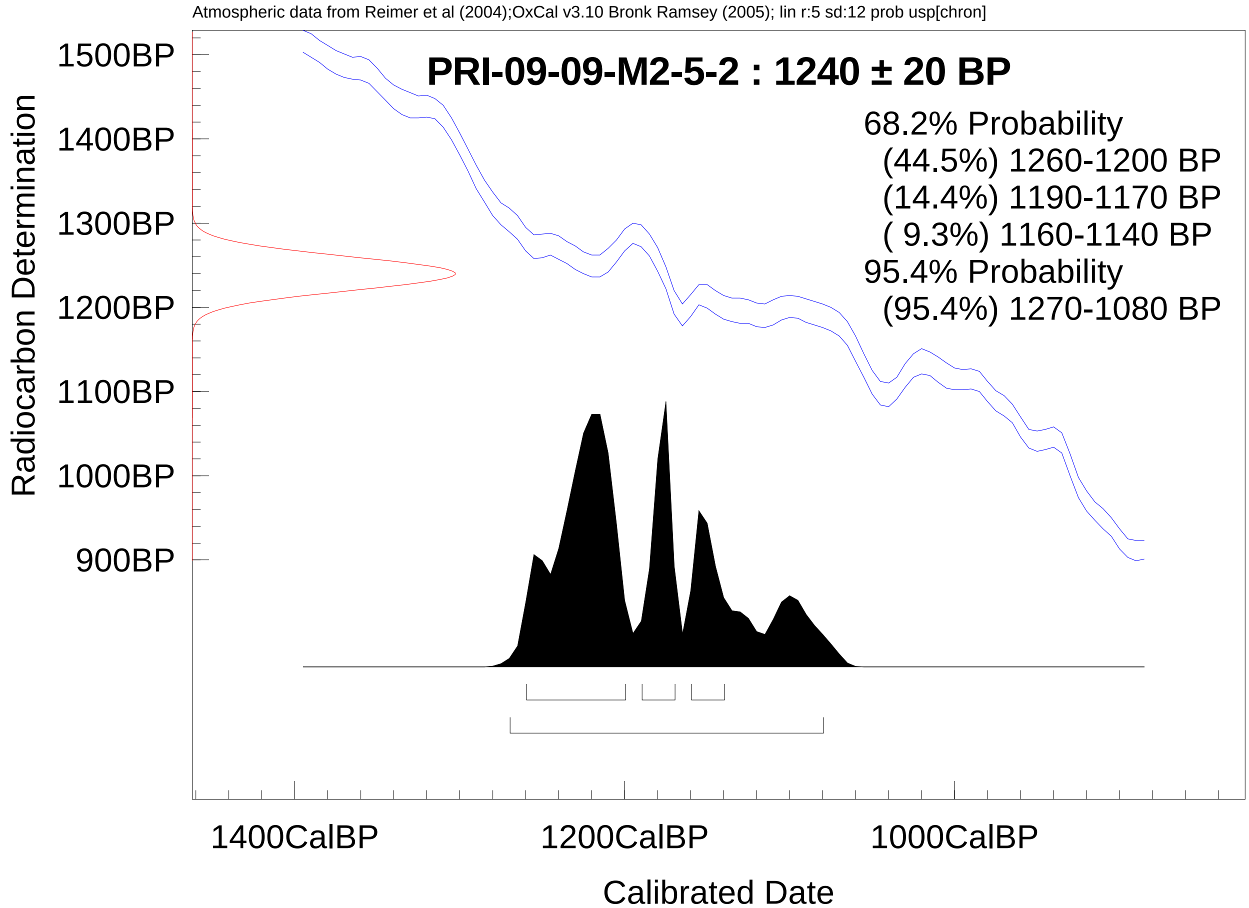

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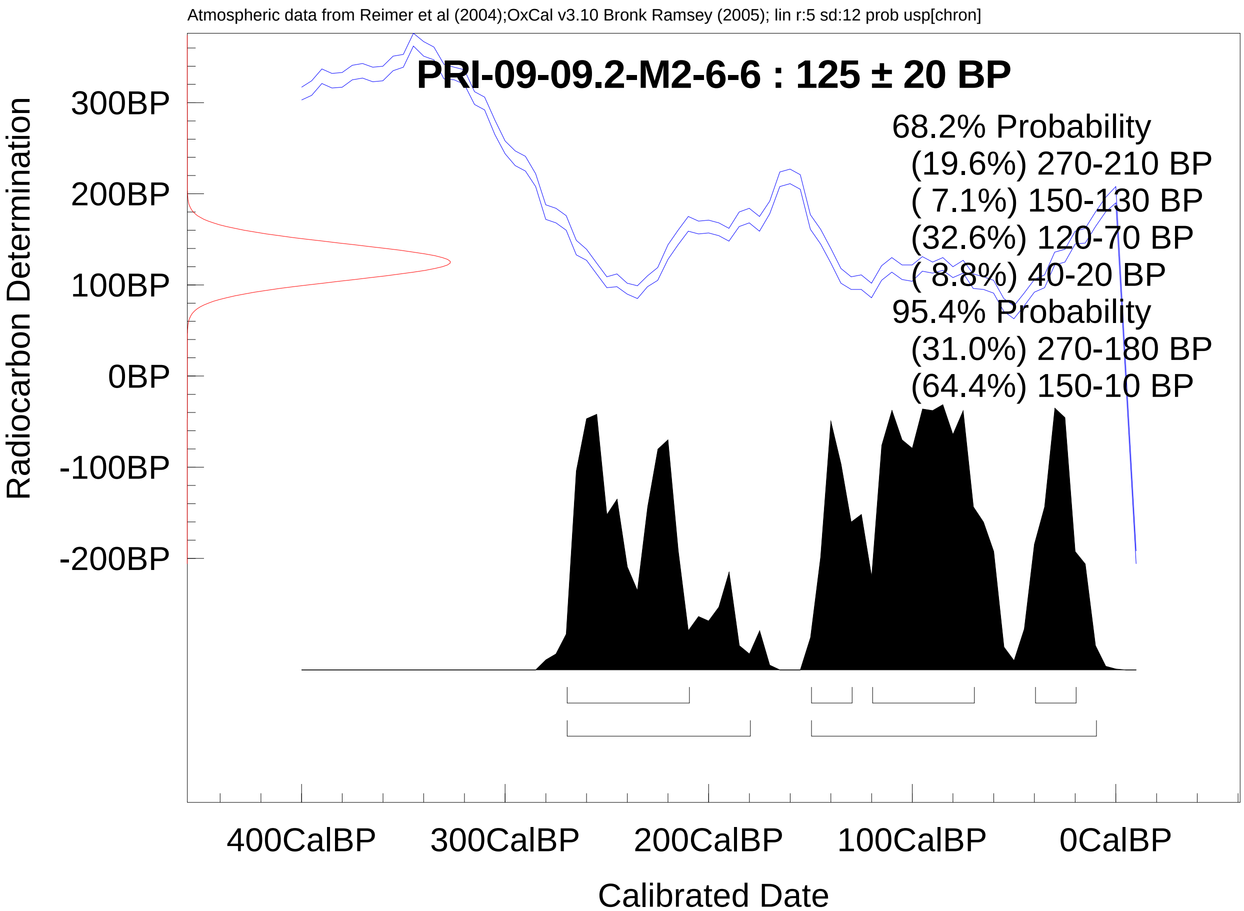
FIGURE 3. PRI RADIOCARBON AGE CALIBRATION

Laboratory Number: PRI-09-09.2-M2-6-6
Sample Identification: Bark scale - charred
Conventional AMS ^{14}C Date: 125 ± 20 RCYBP
1-sigma Calibrated Date (68.2%): 270-210; 150-130; 40-20 CAL yr. BP
2-sigma Calibrated Date (95.4%): 270-180; 150-10 CAL yr. BP
$\delta^{13}C$ ($^{o}/_{oo}$): -21.5 (Measured for ^{14}C calculation, not valid for dietary or paleoenvironmental interpretations)



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References

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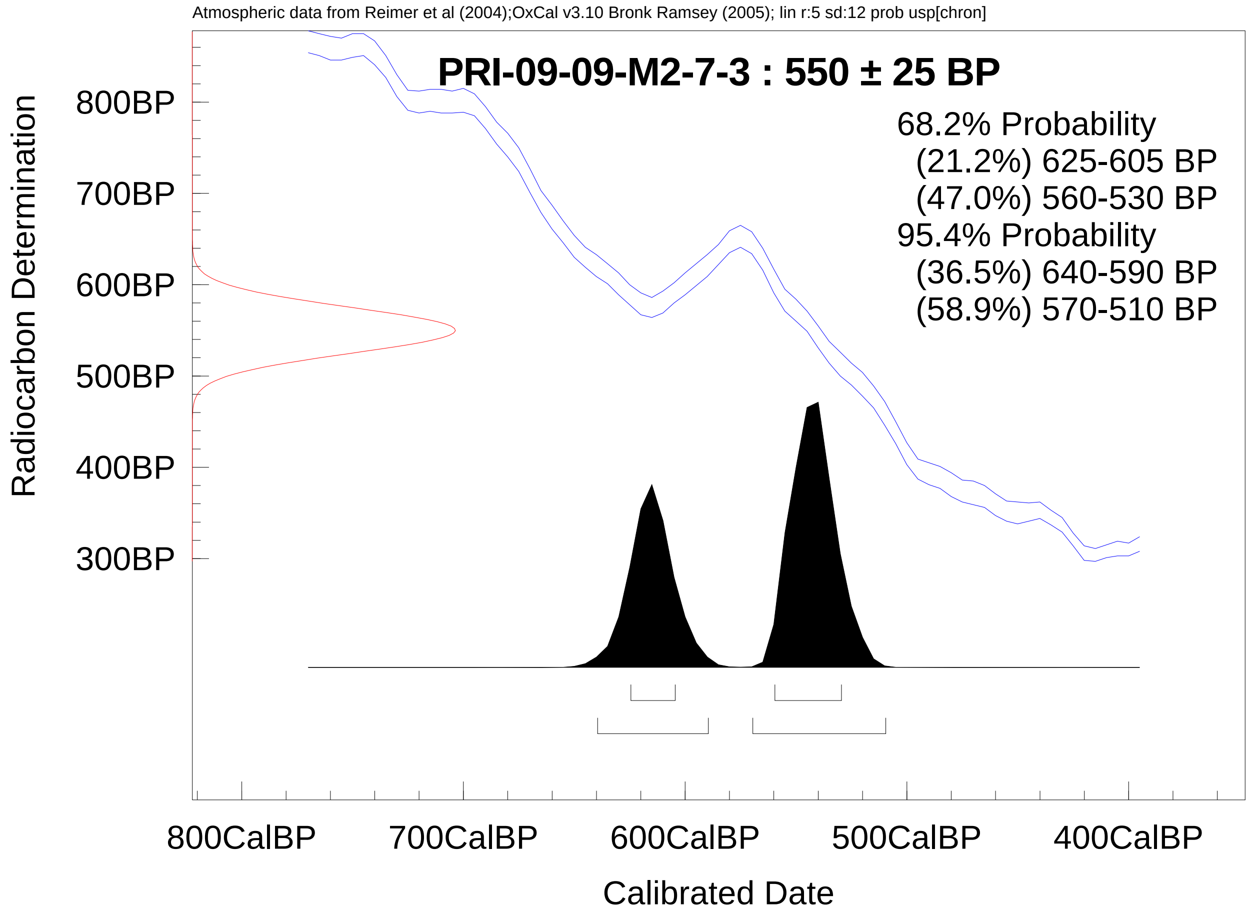
FIGURE 4. PRI RADIOCARBON AGE CALIBRATION

Laboratory Number: PRI-09-09-M2-7-3
Sample Identification: *Rosa*-type twig charcoal
Conventional AMS ^{14}C Date: 550 ± 25 RCYBP
1-sigma Calibrated Date (68.2%): 625-605; 560-530 CAL yr. BP
2-sigma Calibrated Date (95.4%): 640-590; 570-510 CAL yr. BP
$\delta^{13}C$ ($^{o}/_{oo}$): -28.3 (Measured for ^{14}C calculation, not valid for dietary or paleoenvironmental interpretations)



Intercept Statement. Paleoresearch Institute utilizes OxCal3.10 (Bronk Ramsey, 2005) for radiocarbon calibration, which is a probability-based method for determining conventional ages. We prefer this method over the intercept-based alternative because it provides our clients with a calibrated date that reflects the probability of its occurrence within a given distribution (reflected by the amplitude (height) of the curve), as opposed to individual point estimates (Telford *et al* 2004). As a result, the probability-based method offers more stability to the calibrated values than those derived from intercept-based methods that are subject to adjustments in the calibration curve (Telford *et al* 2004).

References

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FIGURE 5. PRI RADIOCARBON AGE CALIBRATION

Laboratory Number: PRI-09-09-M2-7-4
Sample Identification: Salicaceae charcoal
Conventional AMS ^{14}C Date: 340 ± 20 RCYBP
1-sigma Calibrated Date (68.2%): 460-420; 400-310 CAL yr. BP
2-sigma Calibrated Date (95.4%): 480-310 CAL yr. BP
$\delta^{13}C$ ($^{o}/_{oo}$): -20.8 (Measured for ^{14}C calculation, not valid for dietary or paleoenvironmental interpretations)

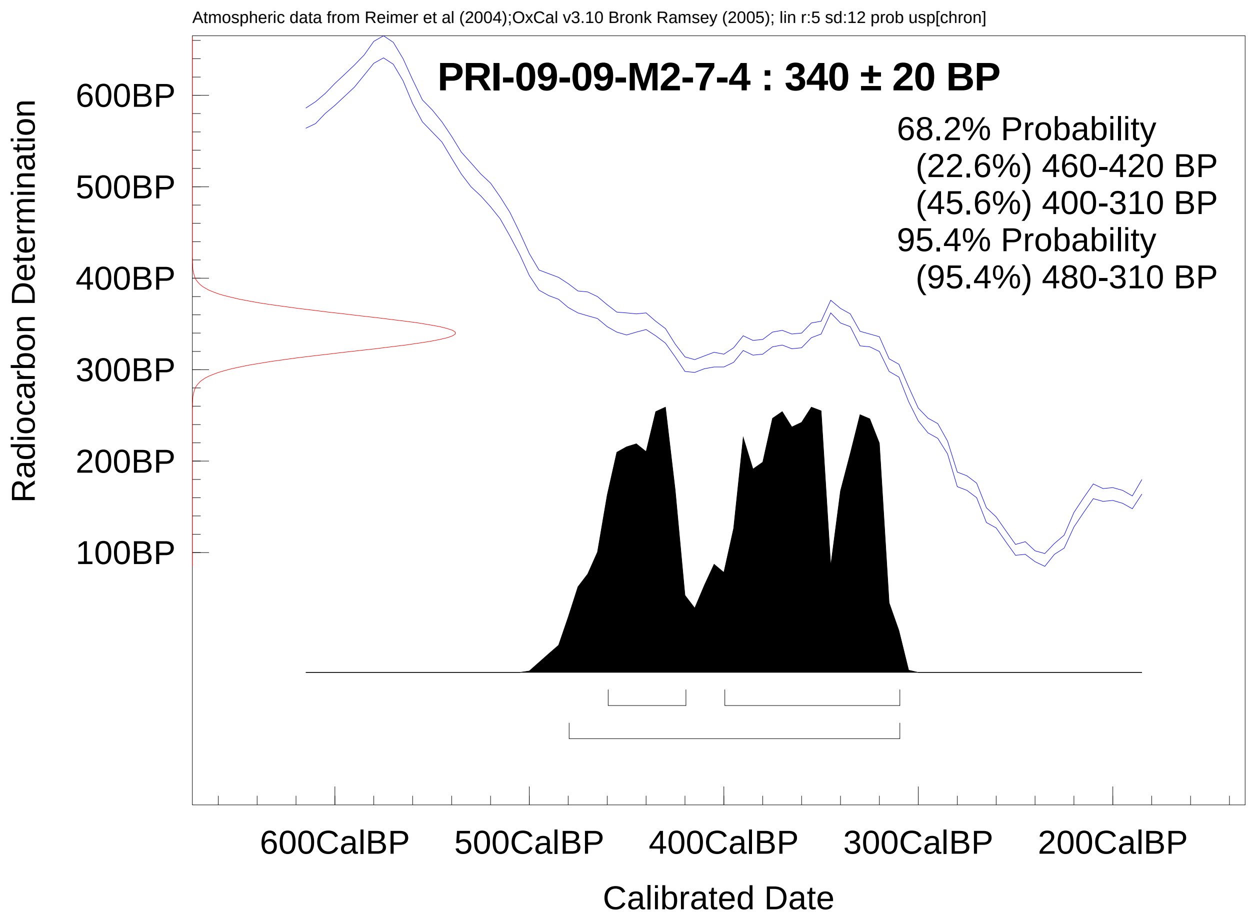

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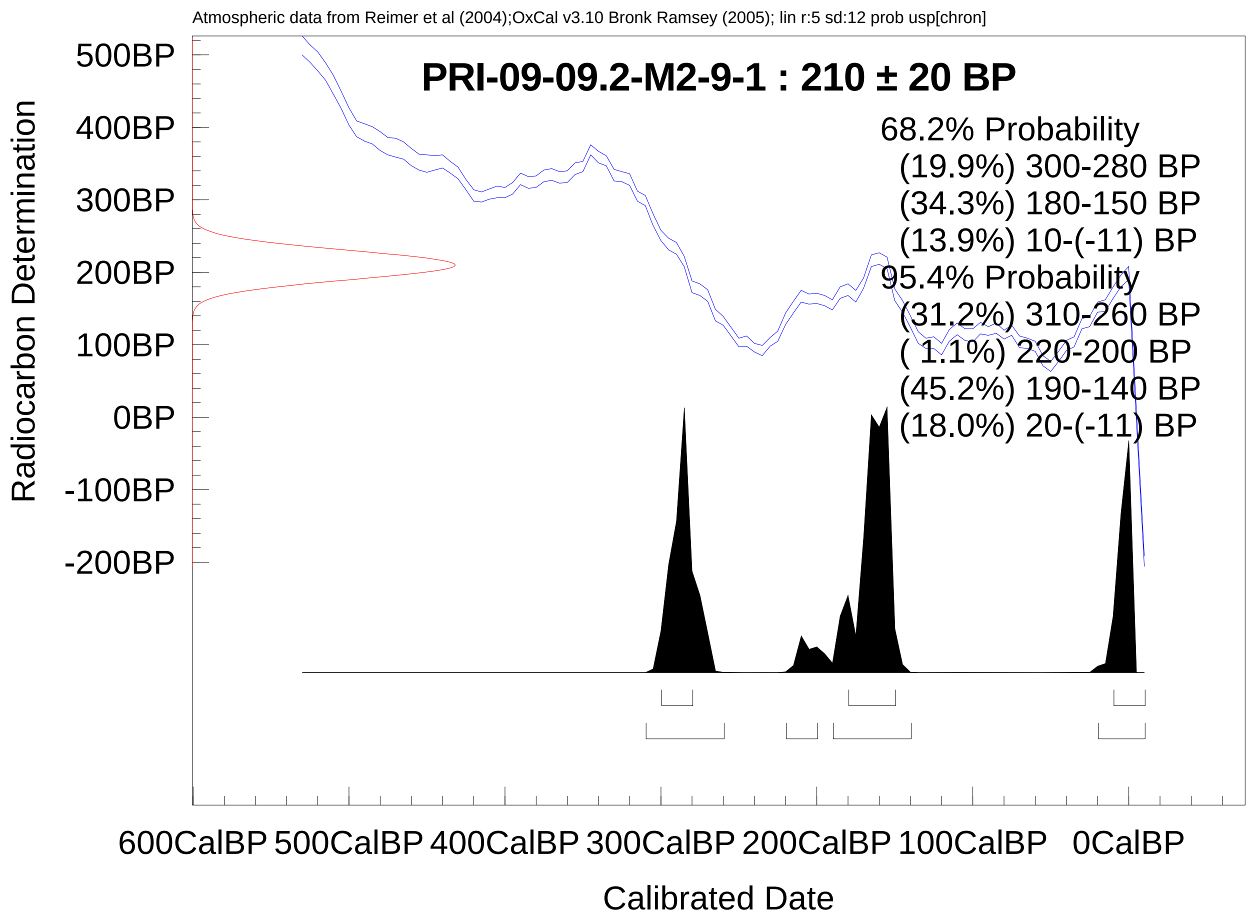
FIGURE 6. PRI RADIOCARBON AGE CALIBRATION

Laboratory Number: PRI-09-09.2-M2-9-1
Sample Identification: *Pinus* charcoal
Conventional AMS ^{14}C Date: 210 ± 20 RCYBP
1-sigma Calibrated Date (68.2%): 300-280; 180-150; 10-(-11) CAL yr. BP
2-sigma Calibrated Date (95.4%): 310-260; 228-200; 190-140; 20-(-11) CAL yr. BP
$\delta^{13}C$ ($^{o}/_{oo}$): -14.8 (Measured for ^{14}C calculation, not valid for dietary or paleoenvironmental interpretations)



Intercept Statement. Paleoresearch Institute utilizes OxCal3.10 (Bronk Ramsey, 2005) for radiocarbon calibration, which is a probability-based method for determining conventional ages. We prefer this method over the intercept-based alternative because it provides our clients with a calibrated date that reflects the probability of its occurrence within a given distribution (reflected by the amplitude (height) of the curve), as opposed to individual point estimates {Telford, 2004 #4527}. As a result, the probability-based method offers more stability to the calibrated values than those derived from intercept-based methods that are subject to adjustments in the calibration curve {Telford, 2004 #4527}.

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APPENDIX E
ASH ANALYSIS AND IDENTIFICATION

MIDDLE METHOW REACH ASSESSMENT
METHOW RIVER
OKANOGAN COUNTY, WA

WASHINGTON STATE UNIVERSITY
PULLMAN, WA

Nick Foit
Director of Microbeam Lab
Professor, School of Earth and Environmental Sciences

April 2009

April 28, 2009

Lucy Piety
Bureau of Reclamation
MC-86-68330
PO Box 25007
Denver Federal Center
Denver, CO 80225-0007

Dear Lucy,

I've completed the analysis of the Middle Methow River tephra samples you provided. The composition of the glass in sample M2-7-1c is an excellent match to that found in Mount St. Helens Wn tephra which is thought to have erupted in 1480 A.D. I prepared both of the samples and analyzed the best one. This is why there is an additional $50 charge for sample preparation.

I trust this data will be useful in your research. Thank you for using our service.

Sincerely,

Franklin F. (Nick) Foit, Jr.
Professor and director of the Microbeam Lab

TABLE 1. GLASS COMPOSITION OF THE MIDDLE METHOW RIVER TEPHRA

Oxide	**Piety**
	Middle Methow River Tephra
	M2-7-1c
SiO_2	75.29(0.38)*
Al_2O_3	13.93(0.29)
Fe_2O_3	1.79(0.07)
TiO_2	0.21(0.03)
Na_2O	4.39(0.16)
K_2O	2.35(0.11)
MgO	0.30(0.04)
CaO	1.66(0.07)
Cl	0.08(0.02)
Total**	100
Number of shards analyzed	20
Probable Source/Age	Mount St Helens Wn
	1480 A.D.
Similarity Coefficient***	0.98+

* Standard deviations of the analyses given in parentheses

** Analyses normalized to 100 weight percent

*** Borchardt et al. (1972) J. Sed. Petrol., 42, 301-306

APPENDIX F.

DOCUMENTATION OF CHANNEL CHANGES

MIDDLE METHOW REACH ASSESSMENT
METHOW RIVER
OKANOGAN COUNTY, WA

BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER
DENVER CO

Lucille A. Piety
Seismotectonics and Geophysics Group

January 2010

Appendix F. Documentation of Channel Changes

This appendix documents the methods used in determining channel changes in the M2 reach and the results of this assessment. The methods are present first. Then the changes are noted in the areas where changes have occurred historically with supporting tables listing the details of the changes.

Methods

Changes in main and side channels and any resulting floodplain expansion and reworking were assessed using the available historical aerial photographs and GLO maps surveyed in 1894 and 1900. Historical aerial photographs were available from 1945, 1948 (taken during the waning stage of the 1948 flood), 1948 (taken some time later), 1954, 1964, 1974, 2004, and 2006. The GLO maps were difficult to georeference and may be somewhat generalized. Only one change, the abandonment of a main channel path near RM 42.6, is interpreted to be significant although the 1894/1900 channels do not align with the 1945 channel in other areas. Channel changes and floodplain erosion were assessed by comparing locations of the unvegetated main channel and large side channels on the year of available aerial photographs. Very small changes were not included as because these changes could be the result of misalignment of the photographs. The 1945 photographs could not be accurately rectified, especially between about RM 43 and RM 44, and so confidence in interpretations for the 1945-1948 time period is less than for the later time periods. Because of the misalignment of the 1945 photographs, channel migration in some areas may have been missed. Areas that are included here as having channel change or floodplain erosion are those where the adjacent banks align suggesting that the rectification is not faulty and where the channel seems to have moved or changed form (e.g., a single channel path has become a split flow path or a new meander is present). Eroded units were inferred from the present units as indicated on the geomorphic map (Appendix A) and the historical aerial photographs. Lateral erosion was measured in the maximum area of erosion using the measurement tool in ArcGIS and should be considered approximate.

For discussion in this appendix, the area between about RM 43 and RM 41, which has been referred to as the sugar dike-Twisp area elsewhere in the report, is subdivided into the area upstream of the sugar dike (RM 43.3 to RM 42.6), the are near the sugar dike (RM 42.6 to RM 42), and the area upstream of Twisp (RM 42 to RM 41.

Channel Changes and Floodplain Erosion

Changes in the main and side channels have been the most common and of the greatest magnitude at the downstream end of the M2 reach, between about RM 43 and RM 41, from just upstream of the sugar dike to the confluence with the Twisp River. These changes include an avulsion of the main channel, erosion of side channels, abandonment of main and side channel paths, reoccupation of main and side channel paths, and migration of main and side channels. The changes have occurred in each time period that was studied between 1894 and 2006. The width of this valley in this section and the constriction created by bedrock and the Twisp River at the downstream end contribute to the frequency and magnitude of channel changes here.

Another area exhibiting channel changes is the Habermehl area between RM 45.5 and RM 44.2. Unlike the area upstream of Twisp, most of the changes in the Habermehl occurred in 1945-1948 time period and can be attributed to the 1948 flood. These changes include erosion of two side channels into Qa3 and Qa2, abandonment of a main channel path, and channel migration. Only minor changes have occurred at the upstream end of the Habermehl area since 1948.

Upstream of the Habermehl area, the changes that have occurred are mostly from the 1945-1948 time period, when the side channel at Bird island was initially eroded and when the main channel between RM 47 and RM 46.5 changed position and migrated outward.

In the following sections, the channel changes along the M2 reach will be discussed briefly, and are listed in the tables that follow. Historical aerial photographs that show these changes are in Section 4.

Upstream section (RM 50 to RM 45.5)

Most of the changes in this section occurred in the 1945-1948 time period and are related to the 1948 flood (Table 1). The main change was erosion of the side channel (SC_49.00_R) in the Bird island area (RM 49.1 to RM 48.6) on river right through an area of Qa3 that had only scattered trees. Once formed this side channel has remained with some changes in the 1948-1954 and 1954-1964 periods. During the 1945-1948 time period, migration of main and side channels resulted in some erosion of Qa3 at the outsides of meanders (RM 48.5-RM 48.35, RM 48.2-RM 48.15, RM 47.6-RM 47.35, and RM 46.55-RM 46.35), but these were all minor changes. Except for changes in the Bird island side channel, between 1948 and 1964 the only change was migration of the main channel to river left between RM 48.5 and RM 48.35 creating a new side channel (SC_48.50_R) and new Qa3. In the 1964-1974 time period, the only change noted was in the Barclay-Bear Creek area (RM 49.6-RM 49.45), where the main channel eroded a path through tree-covered Qa3. In the 1974-2004 time period, the only changes were between RM 46.9 and RM 45.65, where migration of the main channel and a side channel occurred. The only change noted in the 2004-2006 time period was erosion of the right bank of Qa3 at the downstream end of the side channel at MVID east. Riprap has been placed along part of this eroded section.

Habermehl area (RM 45.5 to RM 44.2)

Most of the channel changes observed in the Habermehl area occurred in the 1945-1948 time period during the 1948 flood (Table 2). These changes included erosion of two side channels, one along the west side of the area through Qa3 and Qa2 (SC_45.30_R) and the other further east through Qa3 (SC_45.10_R). Additional changes occurred in this time period between RM 45 and RM 45.5 at the upstream end of the Habermehl area. A split flow path that was present in 1945 between RM 45.5 and RM 45.25 was abandoned and became a side channel by 1948. The remaining right flow path meandered and had split flow around an unvegetated island between RM 45.25 and RM 45. These changes resulted in the erosion of Qa3 lacking trees on river right between RM 45.5 and RM 45, erosion of a tree-covered island between RM 45.5 and RM 45.25, formation of a new side channel on river left between RM 45.25 and RM 45.2, and erosion of Qa3 with sparse trees on river left between RM 45.25 and RM 45.15.

Changes between 1948 and 1954 were limited to widening of the 1948 side channels. These channels had straight paths in 1948, but had more meanders by 1954. Erosion of up to about 50 feet for the west channel and about 65 feet for the east channel occurred on the outsides of meanders. No changes were noted between 1954 and 1964.

Between 1964 and 1974, the main channel developed a split flow path between RM 45.3 and RM 45.05. The new path on river left eroded into a 1964 side channel upstream and tree-covered Qa3 downstream. By 2004, the left channel path had been abandoned and was a side channel or Qa3 with scattered trees. The remaining main channel path had straightened, and tree-covered Qa3 on river right had eroded where the path straightened between RM 45.2 and RM 45. Some of these observations are for the period between 1964 and 2004 because of a gap in coverage for the 1974 aerial photographs.

Between 1974 and 2004, the main channel abandoned a split flow path on river left and straightened, which created a new side channel on river left (SC_45.30_L) and eroded Qa3 on river right.

At some point, riprap was place along river right at the upstream end of the Habermehl area, and a levee was constructed across the west side channel by 1964.

Area upstream of the sugar dike (RM 43 to RM 42.6)

Channel changes in this short section have occurred in each time period examined, except 2004-2006 (Table 3). The changes include shifting of main and side channels and deposition and change in an unvegetated bar. When the bar formed, split flow in the main channel occurred with migration of the main channel paths outward through erosion of Qa3. During two time periods, 1945-1948 and 1974-2004, the main channel in at least part of this area straightened its path. During the other time periods (1948-1954, 1954-1964, and 1964-1974), meanders formed in the main channel path. Some of these changes may be related to the larger changes that occurred in the area of the sugar dike, which is directly downstream. The highway has been along the channel on river right in this area since at least 1945.

Sugar dike area (RM 42.6 to RM 42)

This area has been one of change in each time period examined (Table 4). The major changes are channel migration at the outsides of meander bends. This has occurred on river right between RM 42.6 and RM 42.25 and on river left between RM 42.25 and RM 42. For the meander bend to river right, marked channel migration on the order of 100 to 250 feet of lateral movement occurred until the sugar dike was placed during the 1964-1974 time period. This may have occurred after the 1972 flood as channel migration and lateral Qa3 erosion of nearly 300 feet occurred after 1964 and before the sugar dike was built. Beginning with the 1954-1964 time period and continuing in the 1964-1974 time period, outward movement of the meander to river left occurred between RM 42.25 and RM 42. In the 1974-2004 time period, after the sugar dike was placed, outward movement on river left moved upstream to between RM 42.35 and RM 42.15.

Additional changes in the 1974-2004 time period were erosion on river right between RM 42.35 and RM 42.25, including the downstream end of the sugar dike, and erosion of a side channel (SC_42.30_R) through tree-covered Qa3 between RM 42.3 and RM 42. Before this time period, the channel changes in this area were consistently outward movement of the meanders. The role of the sugar dike in altering the channel changes in this area during the 1974-2004 time period is not clear, but seems to have had some effect.

Area upstream of Twisp (RM 42 to RM 41)

The downstream end of this section is constricted by bedrock on river left. The flow and sediment from the Twisp River on river right tend to direct the Methow River to the left. The marked channel changes in this section, then, do not continue downstream of about RM 41.

Major changes in the channels and floodplain occurred in the 1945-1948 time period, primarily during the 1948 flood (Table 5). The main channel avulsed at a meander bend at RM 42 through the floodplain and into a side channel near RM 41.55, which created a new channel path to river left. In the post-flood 1948 aerial photographs, the flow in the old (right) and new (left) main channel paths appears to be about equal. By 1955, the right channel path had been nearly abandoned by the main channel and was clearly a side channel (SC_42.00_R). Other changes occurred between RM 42.25 and RM 41 with migration of the river right channel path.

In the 1948-1954 time period, in addition to abandonment of the river right channel path, the main channel river (left) path migrated to river right between RM 41.9 and RM 41.55 and eroded through Qa3 with patchy low vegetation (not trees).

Between 1954 and 1974, channel changes were limited to progressively migration of the river left main channel path to river right between RM 41.75 and RM 5.

In the 1974-2004 time period, major changes occurred in the position of the main channel between RM 41.75 and RM 41.25. The river left main channel path migrated far enough to river right that the last area of Qa3 that separated the two channels was eroded. Downstream of RM 41.55, the main channel was once again in the river right channel path, which had been a side channel since at least 1954. Additional areas of Qa3 were eroded between RM 41.5 and RM 41.25, where the main channel changed location to join its old path near RM 41.25.

Except for riprap near RM 42 and at Twisp near RM 41, the area has been relatively free of human features. Bedrock appears to be more important in limiting lateral channel changes.

Floodplain Expansion: Erosion of Units Older Than Qa3

Erosion of banks of older units along the edge of the active floodplain (Qa3) was identified at only three sites within the M2 reach between 1945 and 2006. The eroded units are Qgo3 (younger glacial deposits), Qa1(terrace), and Qa2 (higher floodplain). The largest amount of expansion was where a side channel eroded through Qa2 in the Habermehl area.

At two of the sites, erosion occurred in the 1945-1948 time period, which included the 1948 flood. Bank erosion at the third site (RM 42.25 to RM 42.05) occurred in the 1964-1974 time period, which include the 1972 flood.   Repeated erosion was not noted at any of sites; however the side channel in the Habermehl area was later blocked by a levee at its head.

Floodplain Reworking: Erosion of Qa3

Erosion and reworking ofQa3 has occurred primarily between RM 42 and RM 41 (upstream Twisp). Another area of recurrent erosion of Qa3 is along the sugar dike between RM 42.6 and RM 42.25 on river right. The area upstream of the sugar dike (RM 43.25 to RM 42.6) also has experience repeated reworking of the floodplain, especially during the 1964-1974 and 1974-2004 time intervals. Erosion of Qa3 in the Habermehl area (RM 45.6 to RM 45 2) has been mostly related to the formation of the two large side channels on river right during the 1948 flood. Changes in main and side channels at the upstream end of the Habermehl area account for additional erosion of Qa3.

Upstream of the Habermehl area, erosion of Qa3 has been limited. The main areas are erosion and formation of Bird island (RM 49.1 to RM 48.6) during the 1948 flood, and erosion of a new channel path through wooded Qa3 island during the 1964-1974 time period in the Barclay-Bear Creek area (RM 49.6 to RM 49.4).

Table 1. Channel changes upstream of RM 45.5

Main change	Time period	River miles	Side of river	Study section	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Erosion of side channel	1945-1948	49.1 - 48.6	Right	Bird island	Qa3 (scattered trees) becomes side channel (SC_49.00_R)	Side channel erodes through Qa3	NA	NA	Side channel ~150 ft wide
Migration of main channel	1945-1948	48.5 - 48.35	Right	None	Qa3 (no trees) becomes main channel	Main channel moves to river right	120	Qa3	None
Migration of side channel	1945-1948	48.2 - 48.15	Left	None	Qa3 (scattered trees) becomes side channel	Side channel moves outward to river left	90	Qa3	None
Migration of side channel to river left	1945-1948	47.6 - 47.35	Left	None	Qa3 (scattered trees) become main channel	Main channel moves outward to river left	90	Qa3	None
Migration of main channel	1945-1948	46.55 - 46.35	Left	None	Qgo3 (no trees) becomes main channel	Main channel moves outward to river left	80	Qgo3	Reported change may be due to error in rectifying photos, but other banks in area align; riprap along downstream 80 ft
Migration of main channel	1945-1948	46.55 - 46.5	Right	None	Qa3 (trees) becomes main channel	Main channel moves to river right	135	Qa3	None
Change in side channel	1948-1954	49.1 - 48.6	Right	Bird island	Side channel better defined, has meandering path, and split flow between RM 48.8-48.6	Side channel location and configuration change	NA	NA	Side channel and main channel appear to have approximately equal flow; side channel ~150 ft wide
Change in side channel	1954-1964	49.1 - 48.6	Right	Bird island	Side channel has single path, and very little flow; upstream end narrower; area more vegetated	Side changes configuration changes	NA	NA	Upstream end of side channel narrower with some vegetation; split flow path still present but

Main change	Time period	River miles	Side of river	Study section	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
									poorly defined; side channel ~125 ft wide
Migration of main channel	1954-1964	48.5 - 48.35	Right	None	Main channel path becomes a side channel (SC_48.50_R) and Qa3 (scattered trees)	Main channel moves to river left	NA	NA	Reported change may be due to error in rectifying aerial photos, but changes are present in more than one year and it appears that channel and floodplain change
Erosion of main channel path through island	1964-1974	49.6 - 49.45	Left	Barclay-Bear Creek	Qa3 (island; trees) becomes main channel	Main channel develops new flow path	NA	NA	None
Migration of main channel; bar enlarges	1974-2004	46.9 - 46.75	Left	None	Qa3 (scattered trees) becomes main channel; mid-channel bar enlarges to river left	Left path in main channel moves outward to river left	100	Qa3	None
Migration of main channel	1974-2004	46.75 - 46.5	Right	None	Main channel becomes side channel (SC_46.70_L) on river left as main channel straightens	Main channel moves outward to river right	NA	NA	None
Side channel migration	2004-2006	45.75 - 45.65	Right	MVID east	Qa3 (scattered trees) becomes side channel	Side channel moves outward to river right	40	Qa3	None

Table 2 Channel changes in the Habermehl area (RM 45.5 to RM 44.2)

Main change	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Main channel abandons split flow path	1945-1948	45.55 - 45.25	Left	Main channel river left path (split flow) or large wetted side channel becomes a side channel (dry) (no identifier)	Main channel abandons split flow path on river left	NA	NA	Unvegetated bar at upstream end of river left channel path is visible on 1948 flood photos
Main channel migration	1945-1948	45.5 - 45.05	Right	Qa3 (no or few trees) becomes main channel	Meander in main channel moves outward to river right	115	Qa3	None
	1945-1948	45.52 - 45.45	Center	Qa3 (island with trees) becomes main channel	Main channel 1945 river left path is abandoned; right path meanders to river left	NA	NA	None
Erosion of new side channel	1945-1948	45.3-45.2	Left	Qa3 (scattered trees) becomes side channel	Side channel erodes through Qa3	95	Qa3	None
	1945-1948	45.3 - 44.2	Right	Qa3 (scattered trees) and Qa2 (scattered trees) become side channel (west channel; SC_45.30_R)	Side channel erodes through Qa3 and Qa2	NA	NA	Total length of new side channel is about 3,100 ft; about 1,100 ft eroded through Qa3 at upstream and downstream ends; central about 2,000 ft eroded through Qa2
Migration of main channel to river left	1945-1948	45.25 - 45.15	Left	Qa3 (scattered trees) becomes main channel	Main channel develops split flow path with mid-channel bar	115	Qa3	None
Erosion of new side channel	1945-1948	45.1 - 44.25	Right	Qa3 (scattered trees) becomes side channel (east channel; SC_45.10_R)	Side channel erodes through Qa3			None
Side channel migration	1948-1954	~45.3	Right	Upstream end of west side channel widens into Qa3 (no trees) as meanders develop	Meanders develop in side channel path	50	Qa3	Maximum measurement for erosion in two places

Main change	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Side channel migration	1948-1954	~45.1	Right	Upstream end of east side channel widens into Qa3 (no trees) as meanders and split flow paths develop	Meanders develop in side channel path	65	Qa3	Maximum measurement for erosion in three places
Erosion to form new main channel path	1964-1974	45.35 - 45.2	Left	Side channel and Qa3 (trees) become left path of split main channel or large wetted side channel	Main channel or possibly a large wetted side channel has new split flow path on river left	175	Qa3	None
	1964-1974	42.25 - 45.15+	Left	Qa3 (trees) becomes left main channel path	Main channel or possibly a large wetted side channel has new split flow path on river left	NA	NA	None
Main channel abandons split flow path on river left and straightens	1974-2004	45.35 - 45.15+	Left	Main channel path on river left becomes side channel (SC_45.30_L) and Qa3 (scattered trees)	Main channel abandons path or large side channel on river left	NA	NA	None
	1964-2004	45.15 - 45.05	Left	Continuation of above downstream beyond coverage of 1974 photos	Main channel abandons path or large side channel on river left	NA	NA	None
	1964-2004	45.2 - 45	Right	Qa3 (trees) and side channel become main channel	Main channel abandons path or large side channel on river left	160	Qa3	None

Table 3. Channel changes upstream of the sugar dike (RM 43 to RM 42.6)

Main change in channel	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Main channel straightens through a side channel on river left and tree-covered Qa3 (island)	1945-1948	42.9 - 42.7	Right	Main channel becomes side channel and Qa3 (trees)	Main channel straightens	NA	NA	None
	1945-1948	42.85 - 42.75	Center	Qa3 (island; trees) becomes main channel	Main channel straightens	NA	NA	Eroded Qa3 between main channel and large side channel on river left
	1945-1948	42.9 - 42.7	Left	Large unvegetated side channel becomes main channel	Main channel straightens	NA	NA	None
Main channel moves outward to river right; downstream end of side channel erodes	1948-1954	42.75 - 42.65	Right	Side channel (unvegetated) becomes main channel	Main channel moves outward to river right	NA	NA	Eroded Qa3 between main channel and large unvegetated side channel on river right
Main channel moves to river left; side channel forms on river right; unvegetated bar separates main and side channels	1954-1964	42.85 - 42,65	Right	Main channel becomes side channel and mid-channel bar	Main channel moves outward to river left; mid-channel bar forms	NA	NA	None

Main change in channel	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
	1954-1964	42.8 - 42.75	Right	Qa3 (island; scattered trees) becomes side channel	Main channel moves outward to river left; mid-channel bar forms	NA	NA	Eroded Qa3 between main channel and side channel
	1954-1964	42.85 - 42.65	Left	Qa3 (trees) becomes main channel	Main channel moves outward to river left; mid-channel bar forms	100	Qa3	None
Migration and formation of meanders toward river left in main channel and abandonment of main channel path	1964-1974	43.25 - 43	Left	Qa3 (scattered trees) becomes main channel	Main channel moves outward to river left	90	Qa3	None
	1964-1974	43.1 - 42.8	Left	Side channel (unvegetated) becomes main channel	Main channel moves outward to river left	NA	NA	None
	1964-1974	42.8 - 42.65	Right	Main channel becomes a side channel	Meander forms in main channel toward river left leaving side channel on river right	NA	NA	None
	1964-1974	42.8 - 42.65	Left	Qa3 (trees) becomes main channel	Meander forms in main channel toward river left eroding Qa3	280	Qa3	None
Main channel has split flow paths; mid-channel bar forms near RM 43	1974-2004	43.05 - 42.9	Center	Main channel becomes Qa3 (island; no trees)	Unvegetated bar forms and splits main channel flow	NA	NA	None

Main change in channel	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
	1974-2004	43.05 - 42.95	Right	Qa3 (trees) becomes right main channel path	Right path in main channel moves outward to river right	50	Qa3	None
	1974-2004	43.05 - 42.9	Left	Qa3 (trees) becomes left main channel path (later changes to side channel (SC_43.10_L))	Left path in main channel moves outward to river left	100	Qa3	None
Main channel straightens between RM 42.9 and RM 42.6	1974-2004	42.85 - 42.8	Right	Main channel becomes Qa3 (no trees)	Main channel straightens and moves to river left	NA	NA	None
	1974-2004	42.75 - 42.55	Right	Main channel becomes Qa3 (scattered trees)	Main channel straightens and moves to river left	NA	NA	None
	1974-2004	42.75 - 42.6	Left	Qa3 (trees) becomes main channel	Main channel straightens and moves to river left	250	Qa3	None

Table 4. Channel changes in the sugar dike area (RM 42.6 to RM 42)

Main change	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Main channel abandons split channel path	1894-1945	42.65 - 41.5	Right	Main channel becomes side channel	Main channel abandons west channel path	NA	NA	None
Migration of main channel to river right upstream of RM 42.25 and to river left downstream	1945-1948	42.65 - 42.5	Right	Qa3 (trees or scattered trees) becomes main channel	Meander in main channel moves outward to river right	100	Qa3	None
	1945-1948	42.5 - 42.25	Right	Qa3 (trees or scattered trees) becomes side channel	Side channel forms on river right	200	Qa3	None
	1945-1948	42.25 - 42.1	Left	Qa3 (scattered trees) becomes main channel	Meander in main channel moves outward to river left	130	Qa3	None
Migration of main channel to river right and abandonment of river left path and occupation of side channel	1948-1954	42.6 - 42.35	Right	Qa3 (trees) becomes main channel	Meander in main channel moves outward to river right	200	Qa3	None
	1948-1954	42.35 - 42.25	Right	Qa3 (trees) becomes side channel	Main channel abandons left path of split flow	125	Qa3	None
	1948-1954	42.6 - 42.25	Left	Main channel path becomes side channel (part SC_42.59_L)	Main channel abandons left path of split flow	NA	NA	None

Main change	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Migration of main channel to river right upstream RM 42.25 and to river left downstream	1954-1964	42.55 - 42.3	Right	Qa3 (scattered trees) becomes side channel	Main channel moves outward to river right	230	Qa3	None
	1954-1964	42.3 - 42.25	Right	Qa3 (trees) becomes main channel	Main channel moves outward to river right	95	Qa3	None
	1954-1964	42.25 - 42.15	Left	Side channel becomes main channel	Main channel moves outward to river right	NA	NA	None
Migration of main channel to river right upstream RM 42.35 and to river left downstream	1964-1974	42.55 - 42.25	Right	Qa3 (scattered trees) becomes main channel	Meander in main channel moves outward to river right	290	Qa3	Sugar dike placed after outward movement of main channel; sugar dike cuts off about 590 ft (lateral measurement) of main channel path
	1964-1974	42.35 - 42.25	Left	Side channel becomes main channel	Split flow path in main channel; left path moves outward to river left	NA	NA	None
	1964-1974	42.25 - 42	Left	Qa1 (no trees) becomes main channel	Meander in main channel moves outward to river left	65	Qa1	Riprap along downstream 525 ft

Main change	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Main channel straightens RM 42.5 to RM 42.15; side channel erodes on river right RM 42.3 to RM 42.2	1974-2004	42.55 - 42.5	Left	Side channel (scattered trees) becomes main channel	Main channel straightens and moves to river left	NA	NA	None
	1974-2004	42.5 - 42.3	Right	Old main channel path behind sugar dike is filled	None	NA	NA	None
	1974-2004	42.35 - 42.15	Left	Main channel becomes side channel and Qa3 (scattered trees)	Main channel abandons river left path of split flow	NA	NA	None
	1974-2004	42.35 - 42.25	Right	Cutoff area to main channel	Main channel moves outward to river right	NA	NA	Downstream part of sugar dike is eroded
	1974-2004	42.25 - 42.15	Right	Side channel (unvegetated) becomes main channel	Main channel moves outward to river right	NA	NA	None
	1974-2004	42.3 - 42	Right	Qa3 (trees) becomes side channel (SC_42.30_R)	Side channel erodes from downstream end of sugar dike	NA	NA	None

Table 5. Channel changes upstream of Twisp (RM 42 to RM 41)

Main change in channel	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Avulsion of main channel to river left through Qa3 and side channel	1945-1948	41.85 - 41.55	Right	Qa3 (low vegetation) becomes main channel	Avulsion of main channel across floodplain at outside of meander	NA	NA	None
	1945-1948	41.55 - 41.2	Left	Side channel becomes main channel	Avulsion of main channel across floodplain at outside of meander	NA	NA	None
Migration of main channel to river left	1945-1948	41.4 - 41.2	Left	Qa3 (scattered trees) becomes main channel	Migration of main channel to river left	185	Qa3	None
Straightening of main channel to river right into side channel and Qa3	1945-1948	41.2 - 41.15	Right	Qa3 (trees) and side channel (unvegetated) become main channel	Main channel straightens and moves to river right	240	Qa3	At mouth of Twisp River
	1945-1948	41.2 - 41.05	Right	Side channel becomes main channel	Main channel straightens and moves to river right	NA	NA	None
	1945-1948	41.1 -41.05	Right	Qa3 (trees) becomes main channel	Main channel straightens and moves to river right	NA	NA	None
	1945-1948	41.05 - 40.9	Right	Qa3 (scattered trees) becomes main channel	Main channel straightens and moves to river right	NA	NA	None
Abandonment of river right main channel path; migration of meander in right main channel path to river right	1948-1954	42 - 41.2	Right	Main channel path (1945 and 1948) becomes side channel (SC_42.00_R)	Main channel abandons right path of split flow	NA	NA	None
	1948-1954	42.05 - 41.9	Left	Qa3 (no tress for part; trees for part) to main channel	Straight section of main channel forms meander to river left	100	Qa3	None
	1948-1954	41.9 - 41.55	Left	Main channel path becomes side channel	Straight section of main channel forms meander to river right	NA	NA	None

Main change in channel	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
	1948-1954	41.8 - 41.55	Right	Qa3 (patchy low vegetation) becomes main channel	Straight section of main channel forms meander to river right	320	Qa3	Qa3 is remnant between the two paths in the main channel
Migration of meander in main channel to river right	1954-1964	41.75 - 41.5	Left	Main channel path becomes side channel (part SC_41.70_L)	Meander in main channel moves outward to river right	NA	NA	None
	1954-1964	41.7 - 41.5	Right	Qa3 (trees) becomes main channel	Meander in main channel moves outward to river right	180	Qa3	None
Migration of meander in main channel to river right	1964-1974	41.7 - 41.5	Right	Qa3 (low vegetation) becomes main channel	Meander in main channel moves outward to river right	110	Qa3	None
	1964-1974	41.7 - 41.5	Left	Main channel becomes side channel	Meander in main channel moves outward to river right	NA	NA	None
	1974-2004	42.15 - 41.85	Right	Main channel becomes side channel and Qa3 (trees)	Main channel moves outward to river left	NA	NA	None
	1974-2004	42 - 41.7	Left	Qa3 (no trees upstream RM 41.9; trees downstream) becomes main channel	Main channel moves outward to river left	75	Qa3	None

Main change in channel	Time period	River miles	Side of river	Type of change	Channel movement	Amount of lateral erosion (feet)	Unit eroded	Notes
Migration of main channel to river left upstream RM 41.7; avulsion of main channel across Qa3 and into side channel RM 41.65 to RM 41.25	1974-2004	41.65 - 41.35	Left	Main channel becomes side channels and Qa3 (scattered trees)	Main channel erodes a new channel path to river left	NA	NA	None
	1974-2004	41.35 - 41.25	Left	Main channel becomes side channel (part SC_41.40_L)	Main channel erodes a new channel path to river left	NA	NA	None
	1974-2004	41.65 - 41.55	Right	Qa3 (scattered trees) becomes main channel	Main channel erodes a new channel path to river left	NA	NA	None
	1974-2004	41.55 - 41.25	Right	Side channel becomes main channel	Main channel avulses into side channel	NA	NA	Side channel was right main channel path just after 1948 flood
	1974-2004	41.5 - 41.35	Right	Qa3 (scattered trees) becomes main channel	Main channel erodes a new channel path to river left	NA	NA	None
	1974-2004	41.45 - 41.25	Left	Qa3 (scattered trees) becomes main channel	Main channel erodes a new channel path to river left	NA	NA	Eroded Qa3 between right and left main channel paths

Table 6. Floodplain formation in M2 reach

Time Interval	Downstream River Mile	Upstream River Mile	Type	Area (acres)
1948-1954	48.75	49.10	Side channel to floodplain	1.72
1948-1954	48.60	48.95	Side channel to floodplain	3.13
1948-1954	48.60	48.75	Side channel to floodplain	0.64
1954-1964	49.00	49.10	Main channel to floodplain	0.87
1954-1964	48.65	48.95	Side channel to floodplain	0.54
1954-1964	48.60	48.80	Side channel to floodplain	1.37
1954-1964	48.55	48.60	Side channel to floodplain	0.37
1954-1964	42.25	42.60	Side channel to floodplain	6.46
1954-1964	41.55	41.90	Side channel to floodplain	5.42
1954-1964	41.50	42.65	Side channel to floodplain	17.25
1964-1974	41.50	41.75	Side channel to floodplain	3.59
1974-2004	49.45	49.60	Main channel to floodplain	2.07
1974-2004	48.75	48.95	Side channel to floodplain	0.34
1974-2004	48.65	48.80	Side channel to floodplain	1.13
1974-2004	48.60	48.65	Side channel to floodplain	0.54
1974-2004	46.80	46.90	Main channel to vegetated island	1.73
1974-2004	45.15	45.35	Main channel to floodplain	5.93
1974-2004	45.05	45.15	Main channel to floodplain	2.73
1974-2004	42.90	43.05	Main channel to vegetated island	1.87
1974-2004	42.65	42.85	Side channel to floodplain	4.25
1974-2004	42.65	42.80	Side channel to floodplain	2.33
1974-2004	42.55	42.75	Main channel to floodplain	5.27
1974-2004	42.15	42.35	Main channel to floodplain	5.65
1974-2004	42.00	42.05	Main channel to floodplain	0.48
1974-2004	41.50	41.70	Side channel to floodplain	1.58
1974-2004	41.45	41.65	Main channel to floodplain	6.73
1974-2004	41.20	42.00	Side channel to floodplain	12.86
1974-2004	41.20	42.00	Side channel to floodplain	3.45

APPENDIX G.
SITE DESCRIPTIONS AND ANALYSIS

MIDDLE METHOW REACH ASSESSMENT
METHOW RIVER
OKANOGAN COUNTY, WA

BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER
DENVER, CO

January 2010

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1. Introduction

This appendix describes channel and floodplain features at sites along M2 that have side channels (Figure 1). Historical aerial photographs are used to relate changes in the geomorphic and human features at these sites since 1945, or earlier if GLO maps or ground photographs are available. Time intervals when the larger side channels were eroded and modified are identified. Expected inundation of side channels and floodplain is noted using the results of the 2D modeling. An understanding of the geomorphic and human features present at each site, when they formed and have been modified, and the discharges at which channels and floodplain are inundated at each site is valuable for estimating the potential for salmonid habitat. Types of habitat that are present and may be in the future, inundation magnitude and frequency of habitat and potential habitat areas, and possible alteration of habitat areas by human features are all useful information for proposed preservation and rehabilitation projects. Additional study at a more detailed scale may be needed to adequately assess specific features at any of the sites for the development of specific projects.

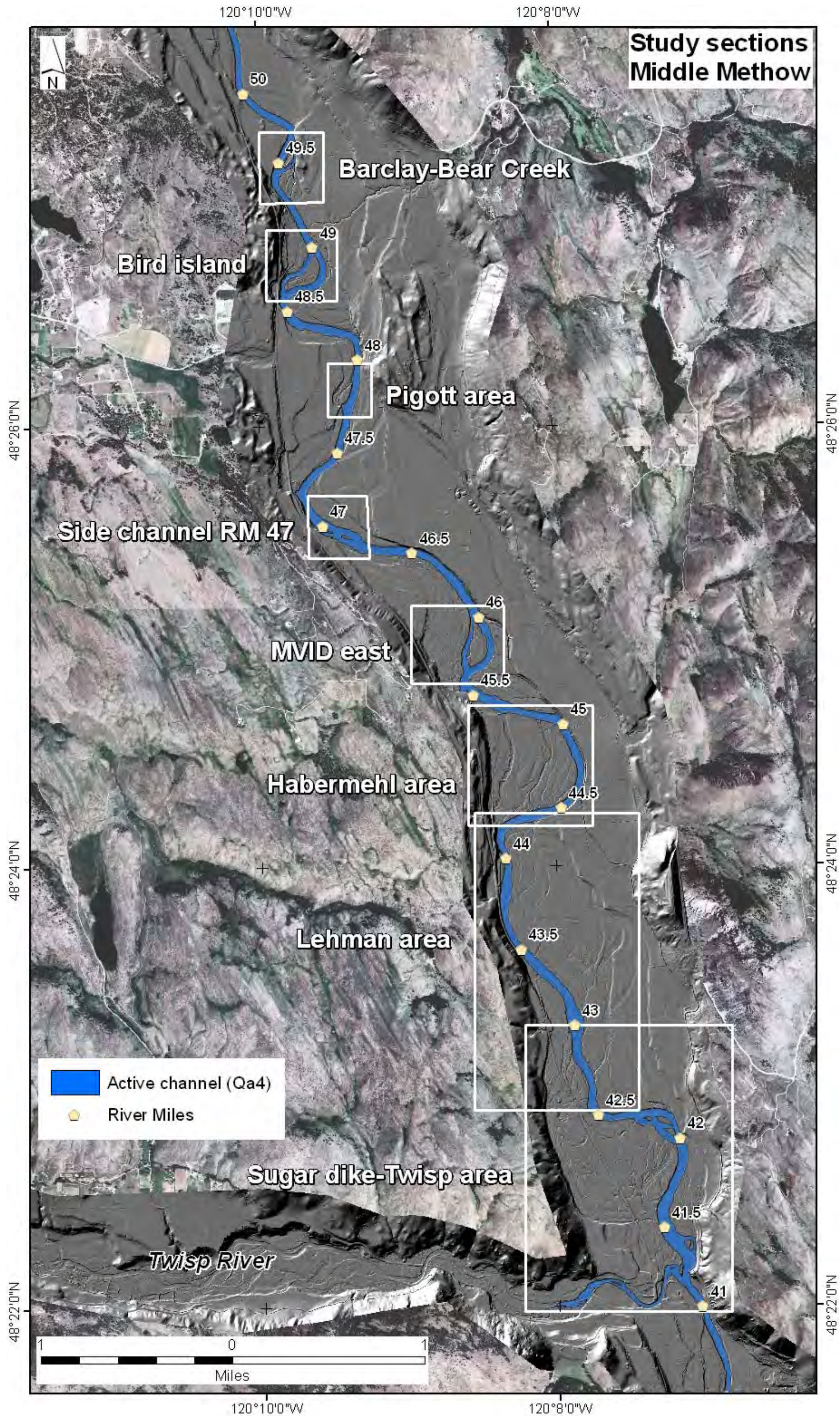


Figure 1. Location map of specific sites within the M2 reach and addressed in this appendix.

2. Barclay and Bear Creek Area (RM 49.75 to RM 49.25)

Between RM 49.75 and 49.25, the main channel of the Methow River meanders to river right (west) and then has a nearly straight path downstream of Bear Creek, which enters the valley from river left near RM 49.1 (Figure 2 and Figure 3). A side channel is present on river left that contains flows at all discharges evaluated in this study. A diversion structure has been built at the point where the side channel bends away from the bedrock, and a canal extends downstream of this diversion along river left. The side channel joins the main channel near RM 49.45. The canal cuts across a large area of active floodplain (Qa3) to about RM 49.25, and then tracks along the main channel (Qa4) downstream of this point. A fish screen is present in the canal downstream of the diversion structure.

Because the head of the side channel is on the outside of the meander in the main channel, the side channel tends to fill with sediment and wood. In order to keep the diversion structure and canal functioning, sediment and wood are periodically removed from the side channel (Figure 3). The sediment and wood are piled along the edges of the side channel and the Qa3 surfaces. This alters the characteristics of the side channel and blocks overflow channels on the Qa3 surfaces on river left and in an island between the main and side channels. The canal captures all of the flow from Bear Creek before it reaches the Methow River near RM 49.1. Lower Bear Creek is used to convey return flow from Barclay and Chewuch ditches back into the Methow River downstream of this area.

Bedrock and a road are present along river right between about RM 49.45 and RM 49.25. Bedrock is present along the side channel on river left between the meander at RM 49.7 and RM 49.45.

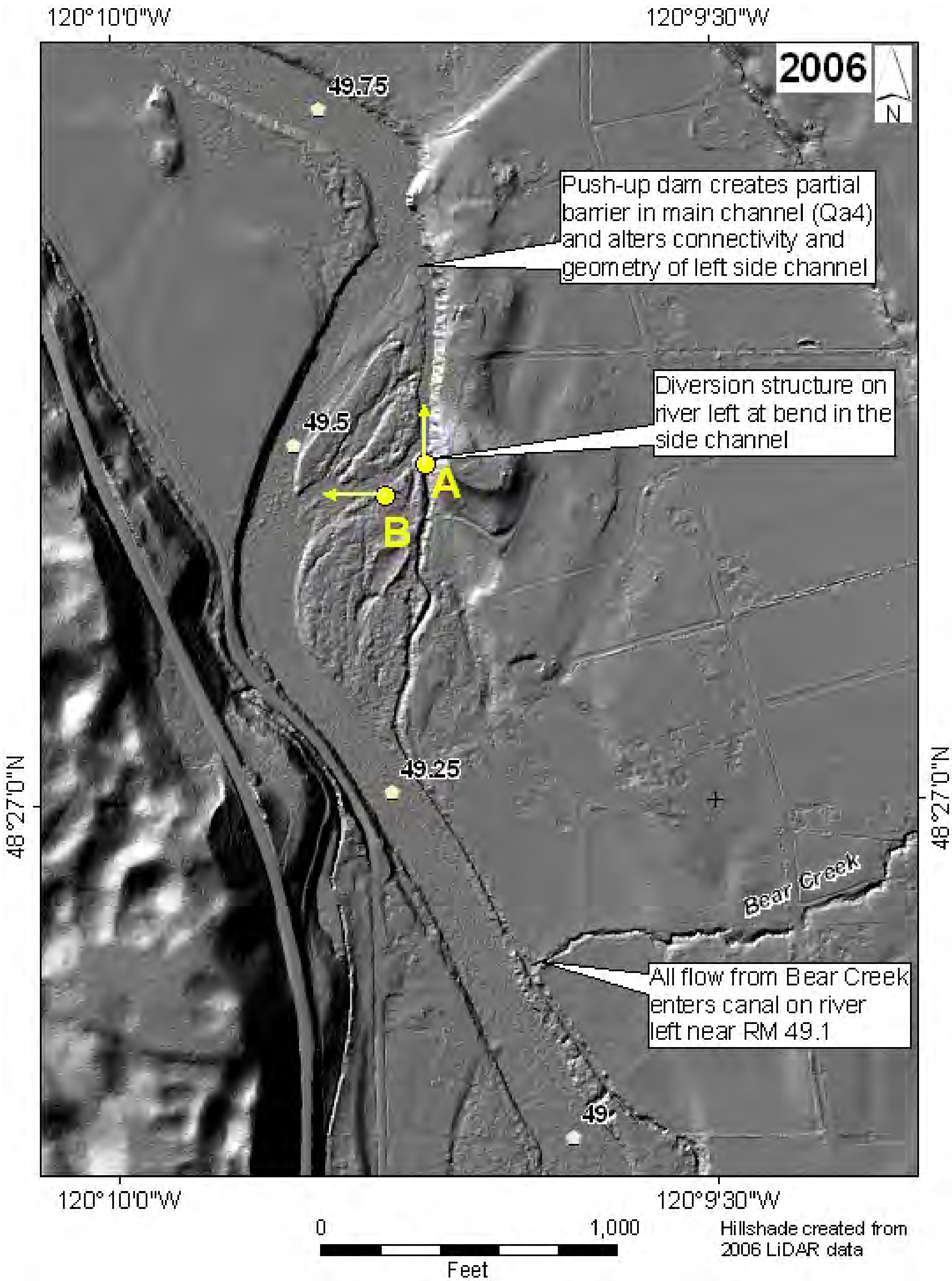


Figure 2. Barclay and Bear Creek area with the main features indicated. Locations at which photographs A and B (Figure 3) were taken are indicated by the yellow dots. Yellow arrows show the direction of view for each photograph.

Figure 3. Ground photographs showing geomorphic and human features in the Barclay-Bear Creek area. Photograph A (left) shows the side channel and bedrock along river left looking upstream from the diversion structure. Photograph B (right) shows the downstream end of side channel and the wood that is removed and piled along the edges of Qa3 surfaces. See Figure 2 for location.

The positions of the main channel on river right and the side channel on river left have had only minor changes since 1945 (Figure 4). The diversion and canal also were present in 1945. The main historical changes occurred during the 1948 flood and between 1964 and 1974. During the 1948 flood, most of the trees were removed from the Qa3 island separating the main and side channels and from the Qa3 surface downstream. The side channel downstream of the diversion became more pronounced. Deposition appears to have occurred at the upstream end of the Qa3 island, and an unvegetated bar nearly blocks the upstream end of the side channel after the 1948 flood (Figure 4).

By 1974, the main channel had created a split flow path by eroding a new path through the Qa3 island that had separated the main and side channels. The side channel on river left is still present. By 2004, the river left main channel flow path has been incorporated into a tree-covered island (Qa3), but is still visible through the island.

The side channel in the Barclay-Bear Creek area sustains a surface water connection during low-flow periods as indicated by model results at a discharge of 285 cfs (Figure 5). This may be because repeated dredging has deepened the side channel. The side channel across the Qa3 island has a surface water connection at a discharge of about 11,000 cfs (Figure 5 and Figure 6). The Qa3 surface downstream begins to be overtopped at this discharge, and is nearly entirely inundated by a discharge of 16,600 cfs.

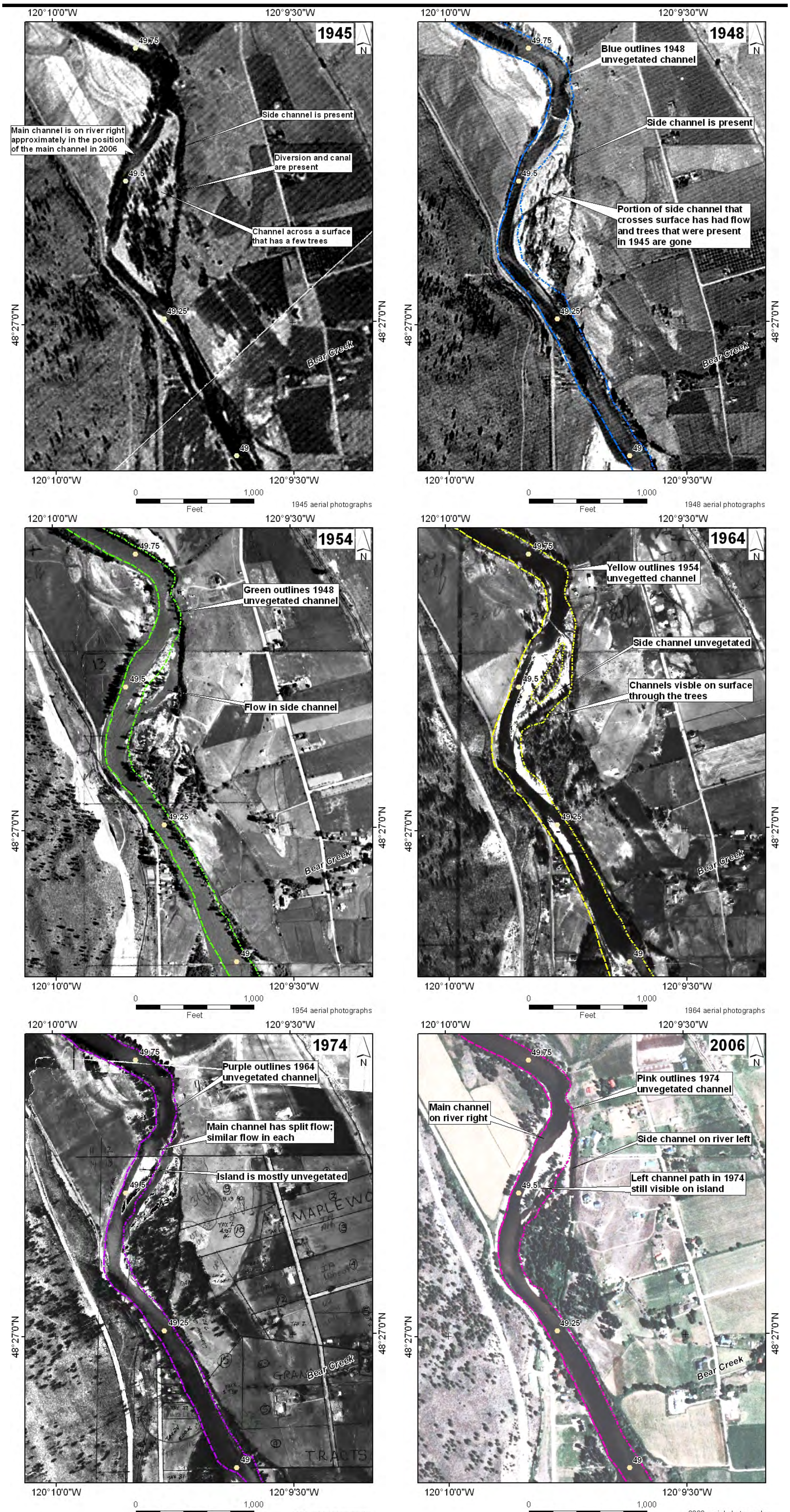


Figure 4. Sequence of historical aerial photographs for the Barclay and Bear Creek areas from 1945 to 2006.

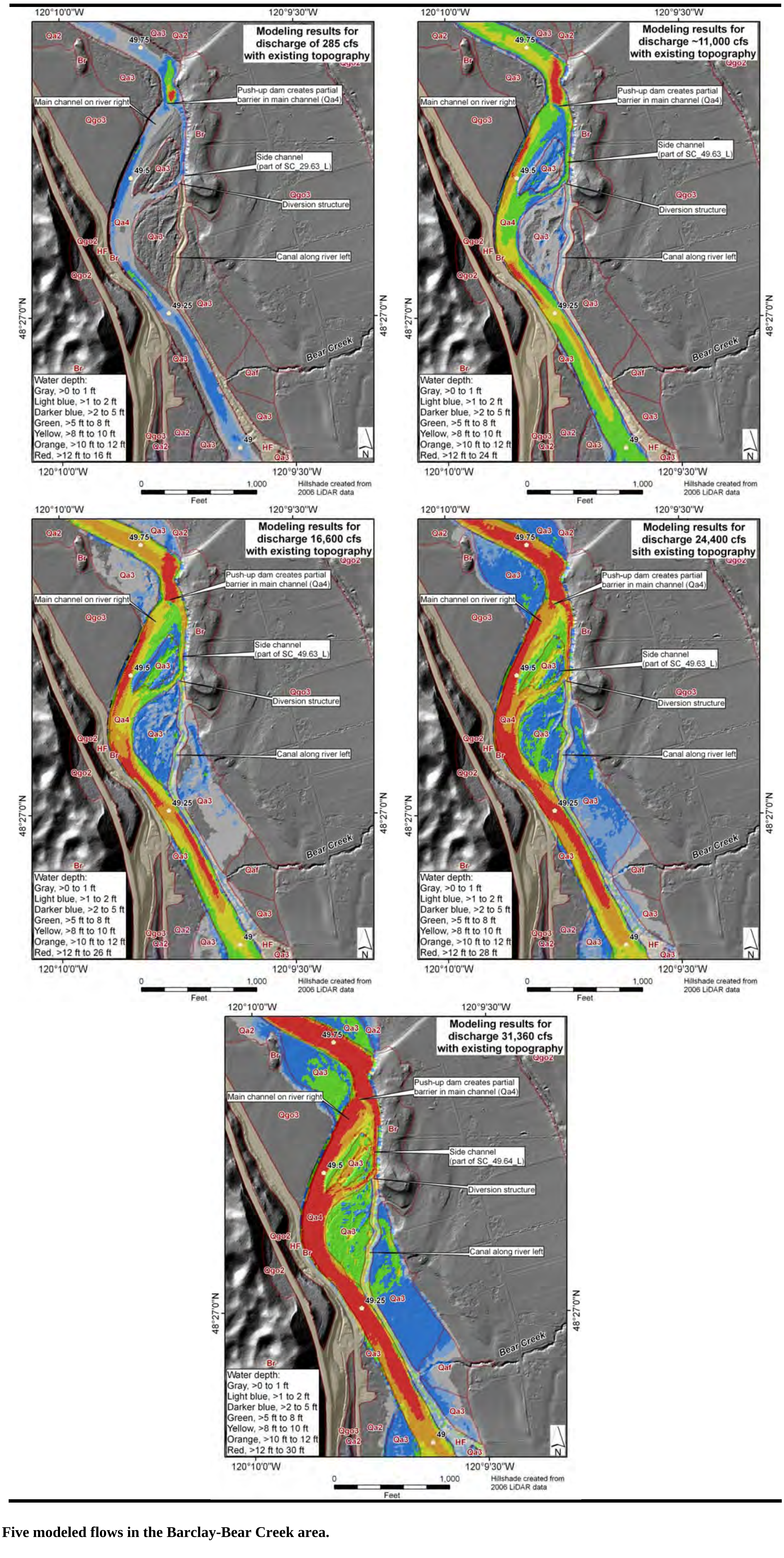


Figure 5. Five modeled flows in the Barclay-Bear Creek area.

Figure 6. Upstream end of the Barclay-Bear Creek area looking downstream 2 days after the peak of the May 2008 flood.
Discharge at the time the photograph was taken was about 11,000 cfs. The photograph shows the activation of the left side channel (at left side of photograph) and the side channel through the Qa3 island (in center of photograph). Main channel is on the right.

3. Bird Island (RM 49.5 to RM 48.5)

Between about RM 49.5 and RM 48.5, the Methow River has a tight meander to river right (west) and then to river left (east) (Figure 7). The main channel is nearly straight upstream and downstream of this meander. Near RM 49.1, the main channel is constricted by alluvial fans from Bear Creek on river left and by higher floodplain (Qa2) on river right. A canal is present along river left downstream to about RM 48.8; roads are present on river right downstream of about RM 48.75. Just downstream of RM 49.1, the floodplain widens, and higher floodplain and terrace are preserved on river left at the left meander. Near RM 49, just downstream from the point where the floodplain widens, a side channel cuts off the right meander in the main channel . The side channel cuts through active floodplain (Qa3) until it reaches the highway, where it bends and joins the main channel near RM 48.6. This side channel was eroded through the Qa3 floodplain during the 1948 flood. It has persisted since that time with some change in position and width in each time interval between historical aerial photographs.

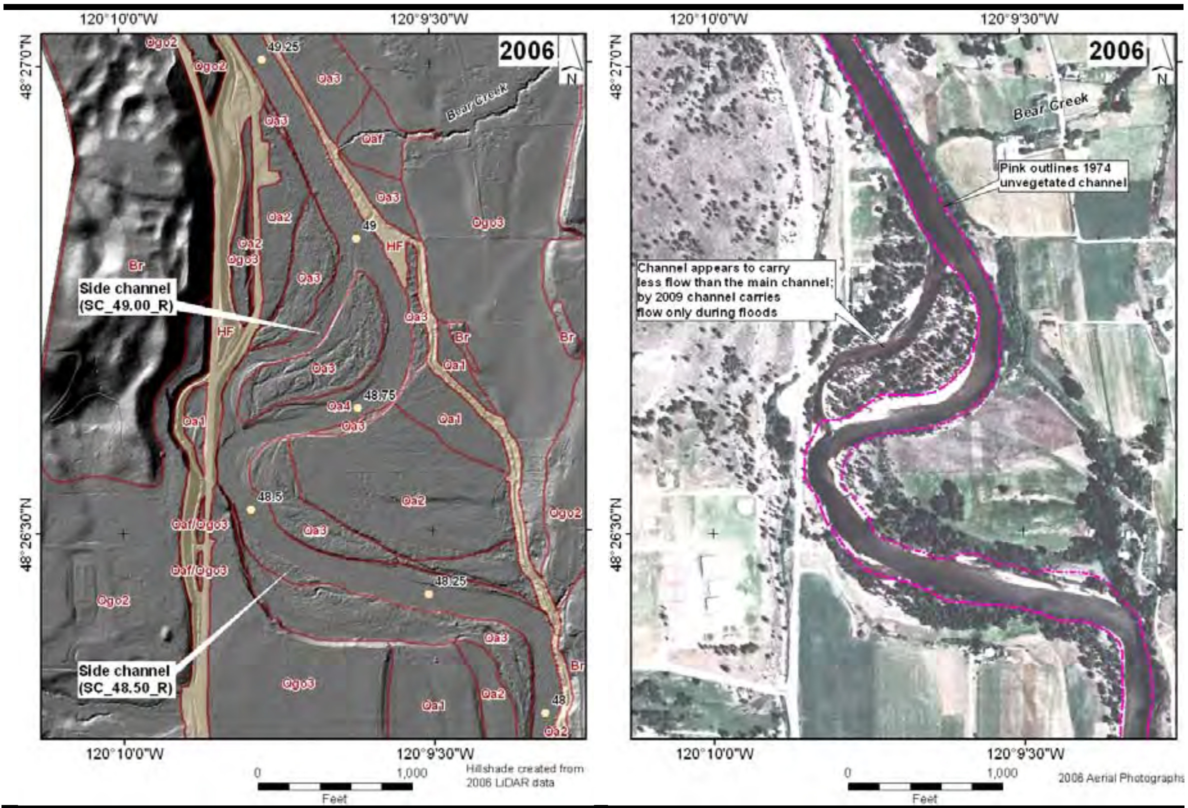


Figure 7. Geomorphic units, human features, and side channel in the Bird island area.
On the left is a hillshade created from 2006 LiDAR data. On the right is an aerial photograph taken in 2006.

In 1945, the main channel was approximately in the same position will be in 2006 (Figure 8). The area of the future side channel on river right was only sparsely vegetated, and the vegetation may have been removed by flow across the floodplain. A small side channel appears to have been present near RM 49.1, upstream of the head of the future side channel. The side channel that was present in 1945 flowed through trees and then along a minor road and entered the main channel near RM 48.6, near the downstream end of the future side channel.

During the 1948 flood, the entire Qa3 surface on river right was covered with flow (Figure 8). Some trees were still present along the outer edge of this surface, but most of the vegetation had been removed. The area affected by the flood flow included the area of the new side channel and the small side channel that was present in 1945. By 1954, the side channel eroded in 1948 had a split path between RM 48.8 and RM 48.6. By 1974, the side channel no longer had this split flow path, which had been incorporated into the floodplain. Between 1964 and 2004, the side channel developed a more meandering path, although the roads on river right limited migration.

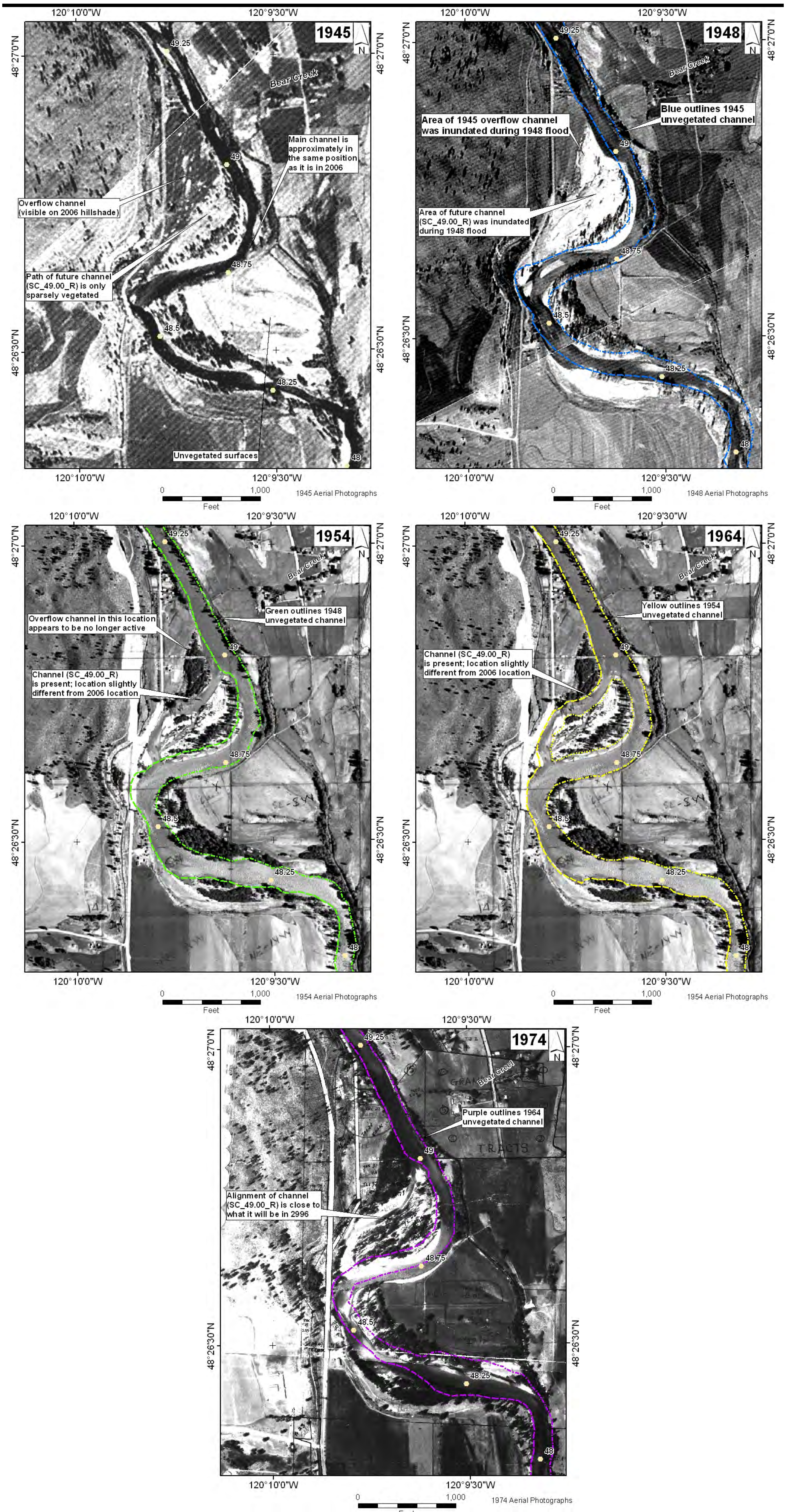


Figure 8. Sequence of historical aerial photographs for the Bird Island area between 1945 and 1974.

The side channel formed in 1948 does not have a surface-water connection at a discharge of 285 cfs (low-low conditions), but does have a surface-flow connection at a discharge of about 11,000 cfs (Figure 9). Small scour holes around root wads were observed to contain ponded water during the October 2008 survey but there is no substantial large wood present in the channel. The channel had a thalweg near the right edge, and gravel was visible throughout the side channel bottom. A large plug of sediment several feet higher than the low-flow main channel water surface was visible at the downstream end. This indicates sediment is transported through this side channel during flows of about 11,000 cfs (2-year flood) and larger. Flow into the side channel is limited by the elevation of the sediment at the side channel entrance (no wood at entrance) (Figure 10). The channels and surfaces of the active floodplain (Qa3) have shallow flow at a discharge of 16,600 cfs. The deep pool at the downstream end of the side channel is readily apparent in all of these flows.

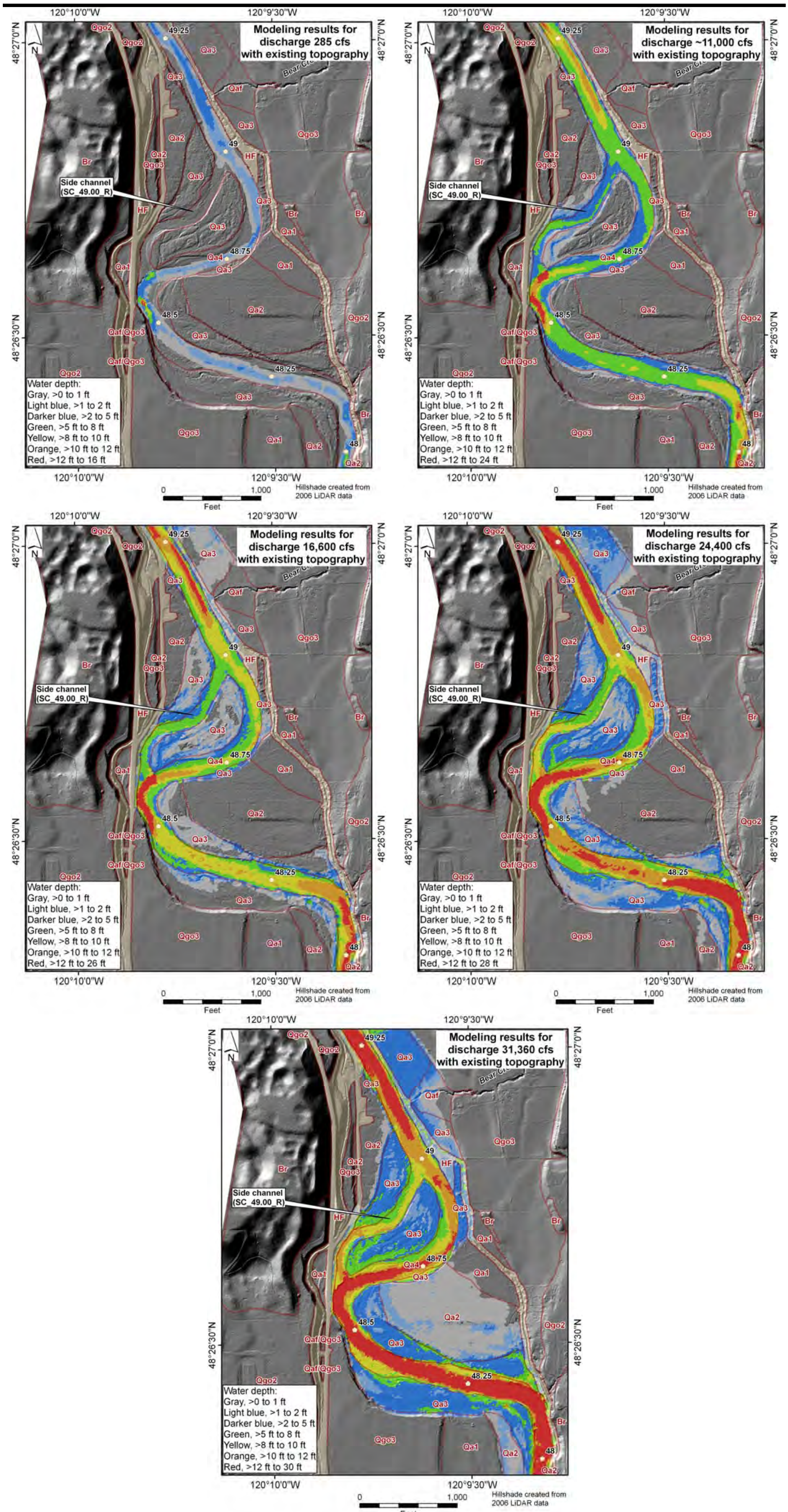


Figure 9. Five modeled flows for the Bird island area

All model runs were done with existing topography. The active floodplain areas (Qa3) have increasingly deeper water, and the higher floodplain (Qa2) has shallow flow in a flood the size of the 1948 flood.

Figure 10. Bird island two days after the peak of the May 2008 flood looking downstream. *Discharge at the time of these photographs was approximately 11,000 cfs.*

4. Pigott Area (RM 48 to RM 47.75)

Between RM 47.8 and RM 47.74, a small side channel is present on river right through a small area of Qa3 (Figure 11). This side channel was visible on the 1945 aerial photographs and has persisted since that time with little visible change in size or location. The Qa3 floodplain is between 8 and 12 ft above the main channel thalweg in this location. The area of Qa3 floodplain surrounding the side channel is bounded by terrace (Qa1). Higher floodplain (Qa2) and terrace (Qa1) are present on river left across from the side channel with only a thin strip of active floodplain (Qa3) along the main channel. This section of the Methow River is relatively narrow between the higher, older surfaces. The area of active floodplain with the side channel may have formed as the Methow River meandered to river right and eroded into the older units. The main channel between about RM 48.5 and RM 48.1 flows across the valley toward river left and bends at RM 48.1, where bedrock is present on river left. The main channel is at present relatively straight between RM 48 to RM 47.5, through the section of the side channel.

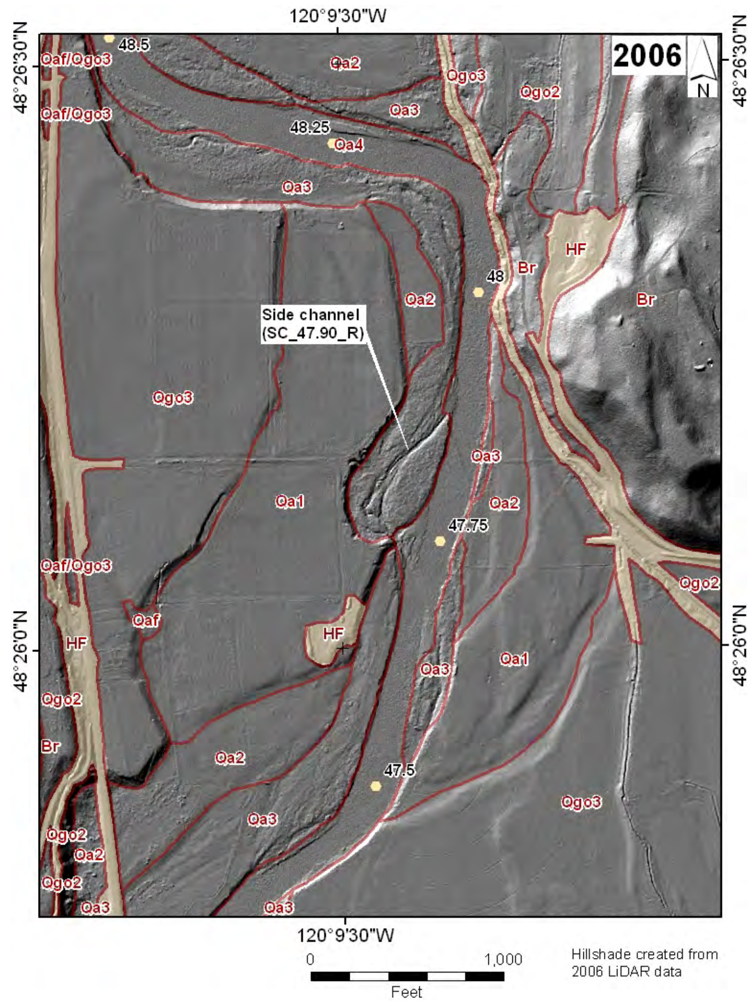


Figure 11. Geomorphic units, human features, and side channel in the Pigott area.
The side channel has been present with little change since at least 1945, or more than 60 years.

The side channel and adjacent Qa3 areas were present in 1945, and have persisted with little change since that time (Figure 12). In addition to the side channel, small overflow channels are and have been present through the trees within Qa3 surfaces adjacent to the side channel. During the 1948 flood, the side channel may have been enlarged slightly. Trees were removed by flows at the downstream end of the Qa3 surface. Areas of Qa3 immediately upstream and downstream of the side channel also were stripped of trees.

The side channel is not inundated at a discharge of 285 cfs (low-flow conditions), but has a surface-flow connection at a discharge of about 11,000 cfs (Figure 13). The Qa3 surfaces adjacent to the side channel begin to be inundated at a discharge of 16,600 cfs.

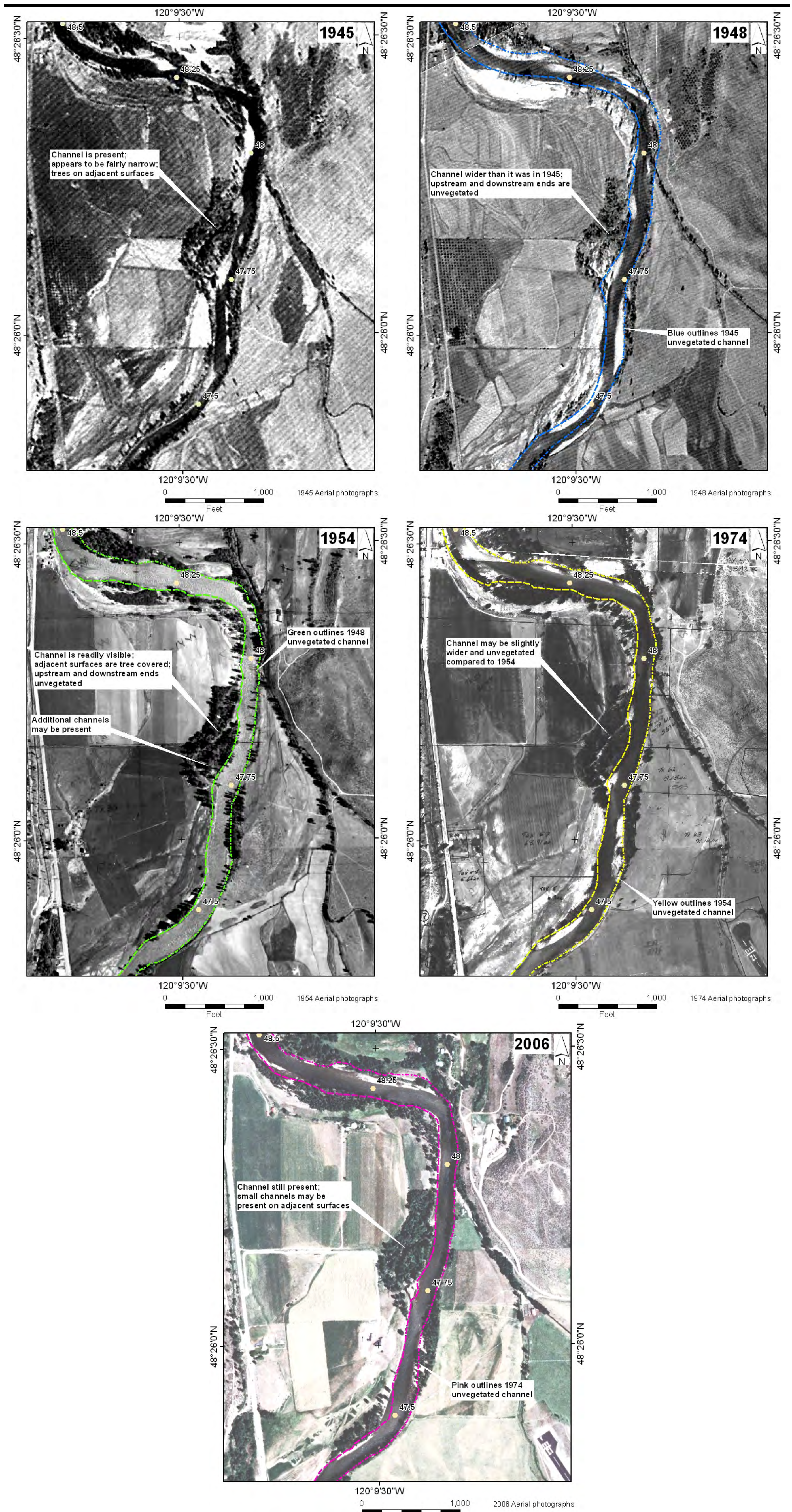


Figure 12. Sequence of historical aerial photographs for the Pigott area between 1945 and 2006.
The channel was present in 1945 and bounded by tree-covered active floodplain surfaces (Qa3)

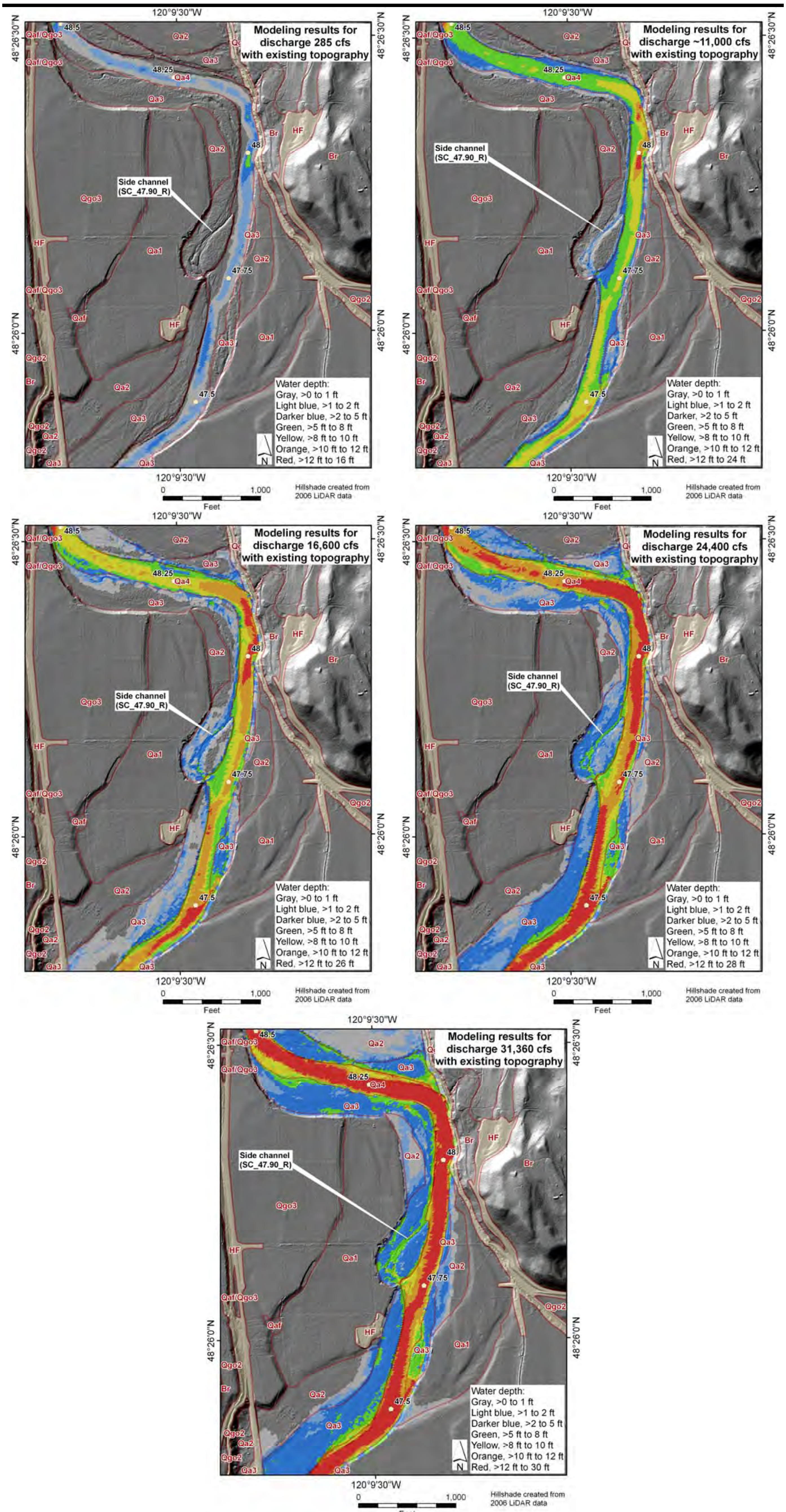


Figure 13. Five modeled flows for the Pigott area.

5. Side Channel near RM 47 (RM 46.75 to RM 47.1)

A side channel about 1,500 feet long is present on river left between RM 46.75 and RM 47.1 (Figure 14). This side channel has been present since at least 1945. It is separated from the main channel by a mid-channel gravel bar, which has also been present since 1945 but is fairly dynamic in terms of extent and location. The side channel was observed to have shallow flow during a low-flow period in October 2008 when the river was at 285 cfs. Bedrock is present on river right along the main channel between RM 47.2 and RM 46.9. A deep pool is present in the main channel near RM 47.2 and between RM 46.9 to RM 46.85, approximately the middle portion of the gravel bar.

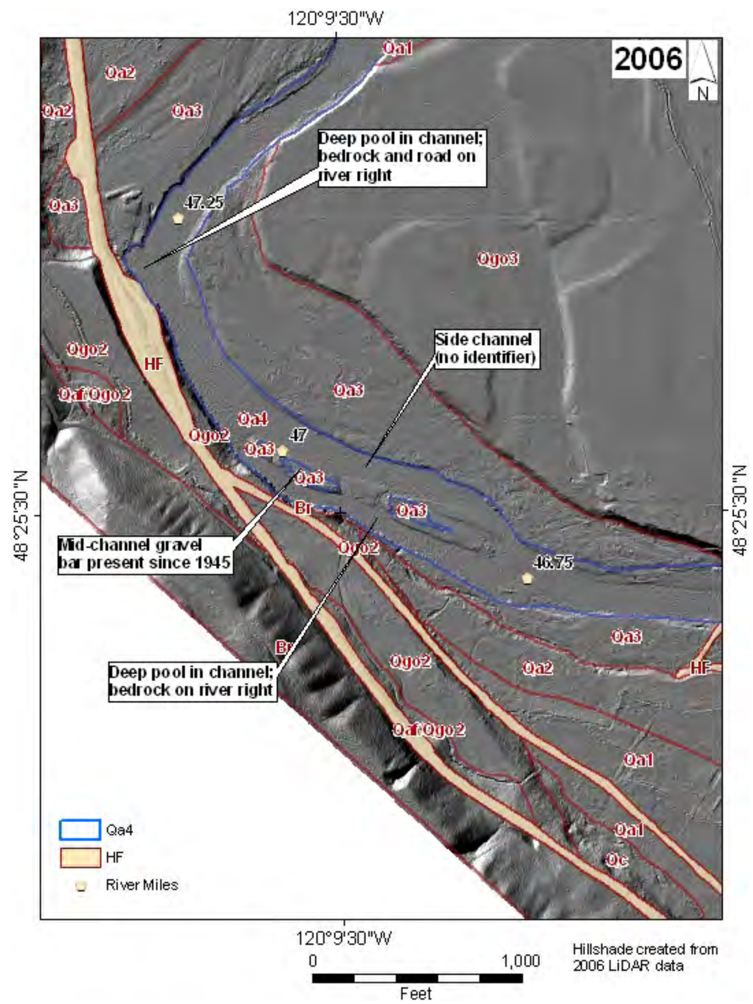


Figure 14. Geomorphic units and human features in the area around an unnamed side channel near RM 47.

In 1945, the side channel and mid-channel bar were present. At this time the bar extends from about RM 47 to RM 46.75 (Figure 15). A small portion of the bar is vegetated. By 1948, the bar and Qa3 surfaces on river left had fewer trees and readily visible multiple channel paths, which suggest that these areas were overtopped during the 1948 flood.

The bar had a slightly different configuration than it did in 1945 and extended between about RM 47 and RM 46.8. Between 1954 and 1974, the mid-channel bar and side channel changed slightly in their location and configuration. By 1974, the side channel between about RM 46.9 and RM 46.8 had straightened and eroded its left bank. By 2006, this same section of the side channel had migrated farther outward to river left, and the island had prograded toward river left as well.

The side channel has a surface-flow connection with shallow (0 to 1 ft) water during low-flow conditions (285 cfs) (Figure 16). This is one of two side channels that have a surface connection at 285 cfs in the M2 reach. The deep pool near RM 47.2 has 5 to 8 ft of water at 285 cfs.

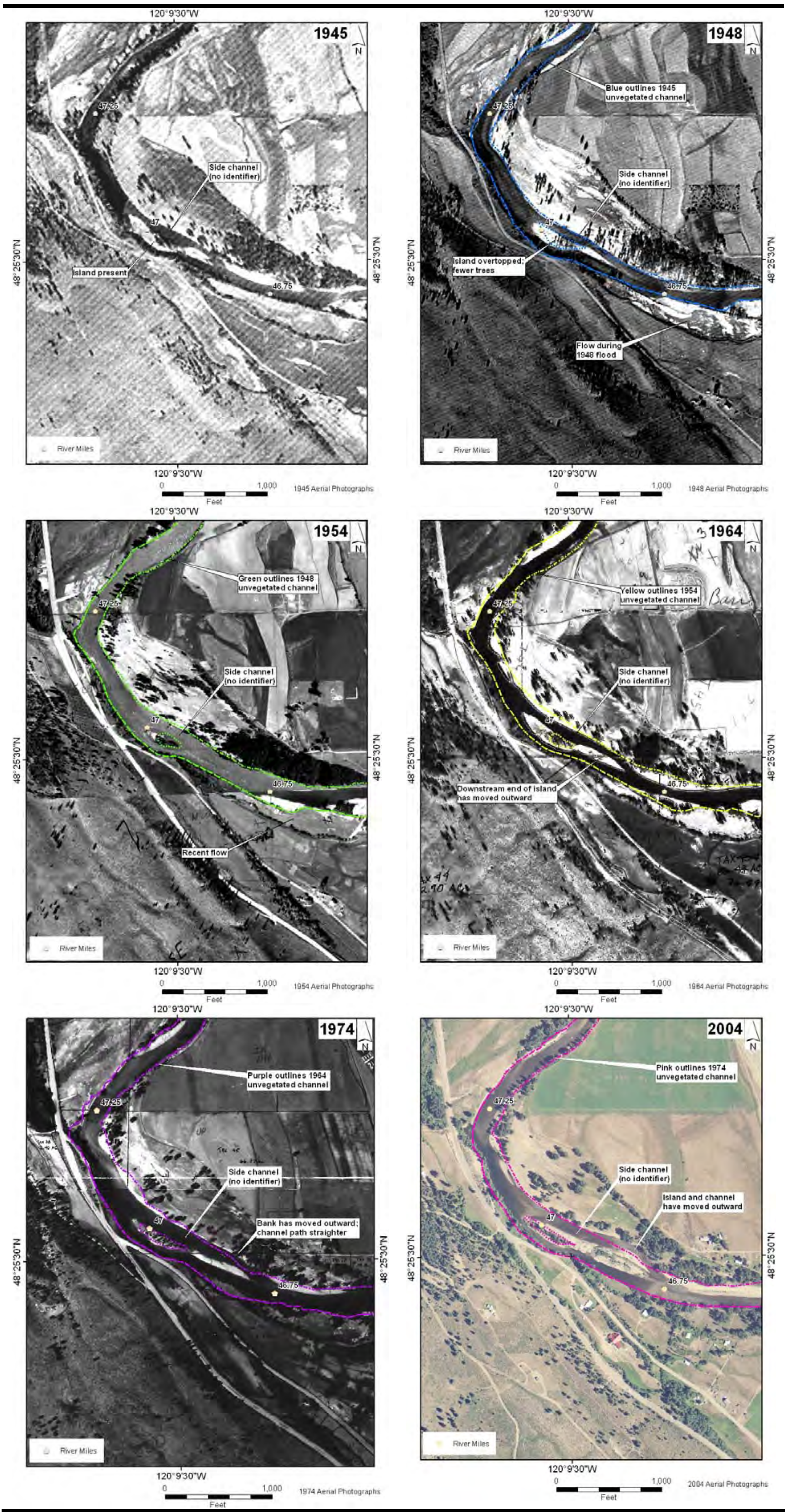


Figure 15. Sequence of historical aerial photographs for the side channel near RM 47

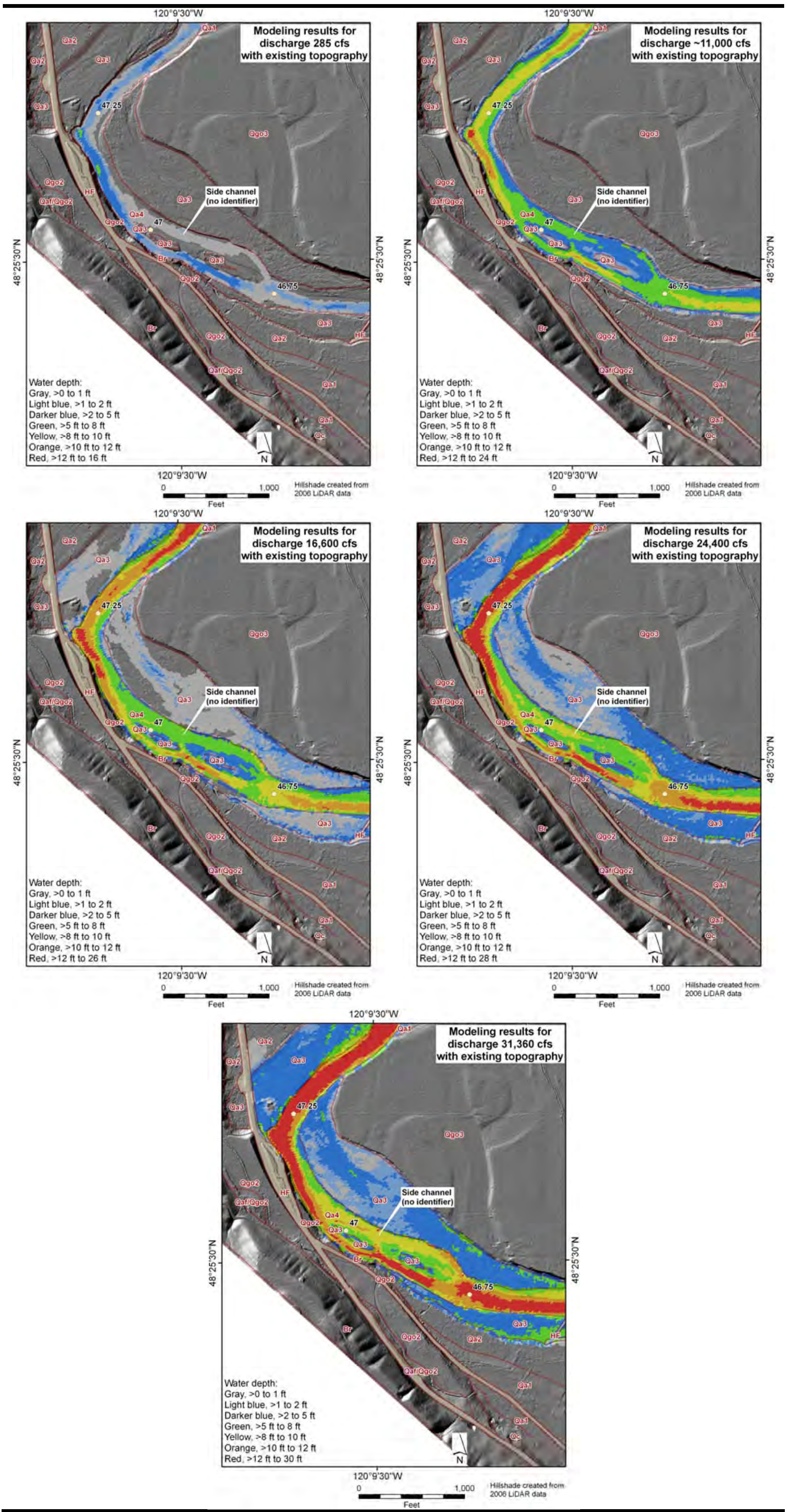


Figure 16. Five modeled flows for the side channel near RM 47.

6. MVID East (RM 46.25 to RM 45.5)

The Methow Valley Irrigation District (MVID) has operated a surface water diversion near RM 46 since the early 1900s. A log crib dam about 3 ft high, locally referred to as the MVID East Diversion Dam, was located on the main channel (river left) to provide enough head to divert water into an irrigation canal. In recent decades, a push-up dam was constructed with river material each spring to limit flow into a right side channel and ensure that the thalweg remained on river left near the intake (Figure 17). In December 2007, the upper 2-feet of the MVID East Diversion Dam were removed. The rest of the dam was removed by December 2008, except for about 40 feet (about a quarter of the entire length) that was left on river right to encourage the thalweg to remain on river left (J. Peterson and J. Molesworth, 2009, written commun.). Surface diversion now occurs several hundred feet upstream of the old dam that was removed.

Channel changes at the MVID East site have been largely governed by the historical dams and channel modifications. The 1894 GLO map indicates that the main channel at MVID East was in the same position as it is today and a sediment bar was present on river right at the downstream end (Figure 18). Historical aerial photography indicates that the position of the main channel has not significantly changed since 1945. Noticeable in 1945, the right side channel appears fairly narrow and vegetated relative to its characteristics in 2008. During the 1948 flood, sheet flow was visible on aerial photography on the Qa3 surface upstream of the dam and along the flow split section; the right side channel did not significantly grow after the 1948 flood. In the 1974 photography, the right side channel appears visibly larger with more flow relative to the 1964 and earlier photography, possibly as a result of the 1972 flood; between 1974 and the present, the right side channel enlarged in size. In 2006, the right side channel was locally documented to carry about half of the river flow at low flows, but at flood flows the main channel still conveyed larger quantities of water. Localized erosion has occurred in the right side channel banks as documented in a cross-section comparison between data collected in 2002 and 2006, particularly in the downstream-most third of the side channel (Bountry, 2007).

Cobbles from the push-up dam still remain and armor the entrance to the right side channel. These cobbles are currently controlling the amount of flow discharged into the right side channel. During an October 2008 field visit at a 285 cfs river flow, the side channel had a shallow surface water connection passing through the remaining cobbles at the entrance. During the survey, about 1 ft of the MVID East Dam was still present on the main (left) channel. For modeling purposes, the dam was completely removed to represent removal of the majority of the dam in December 2008. By 11,000 cfs, there is a prominent surface flow connection that likely is established at a much lower flow magnitude (Figure 19). Model results indicate that the Qa3 at this site is first inundated at a discharge of 16,600 cfs. Presently, a levee and road embankments on the right floodplain upstream of the dam limit, but do not completely cutoff, overbank flooding.

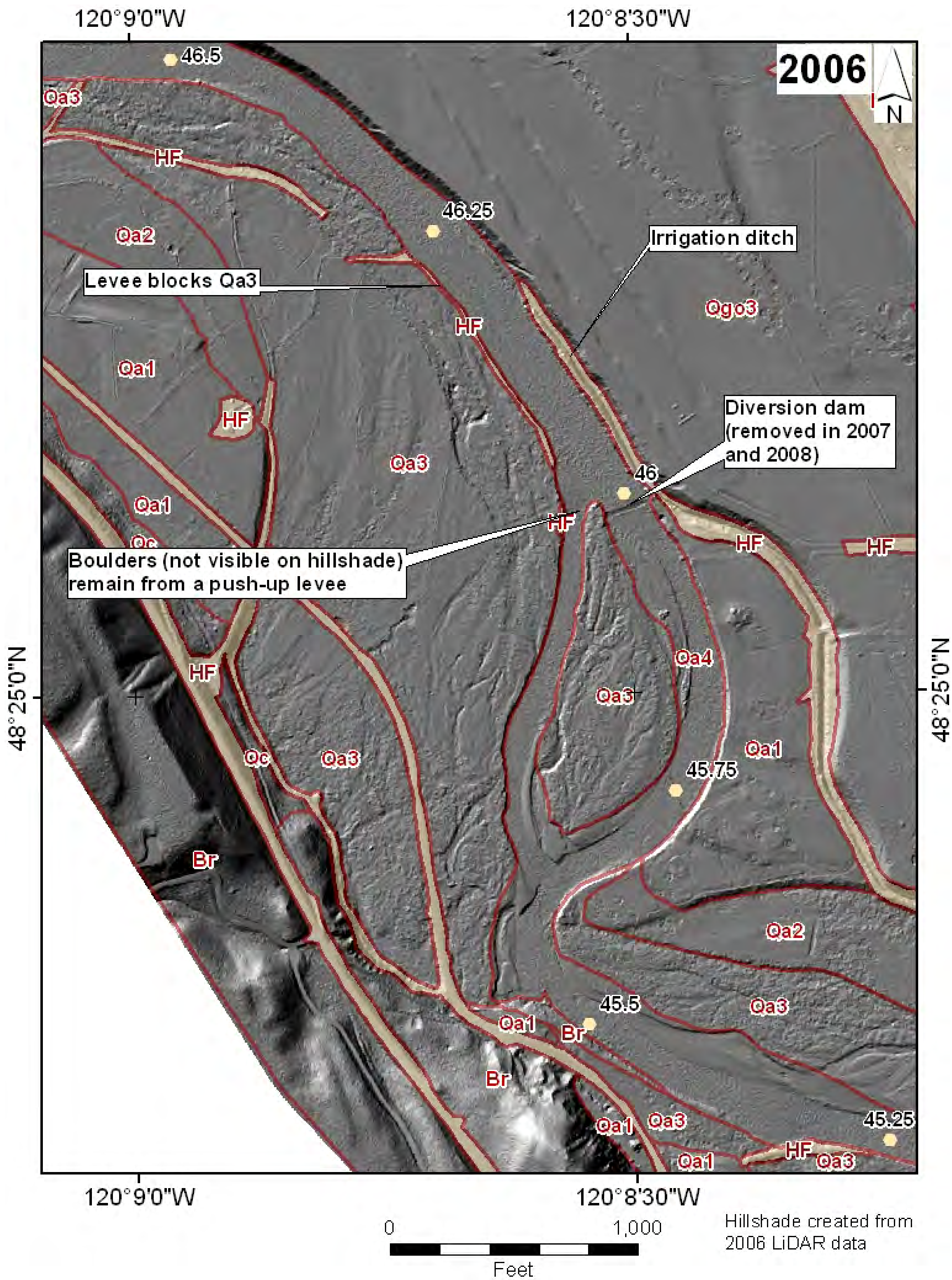
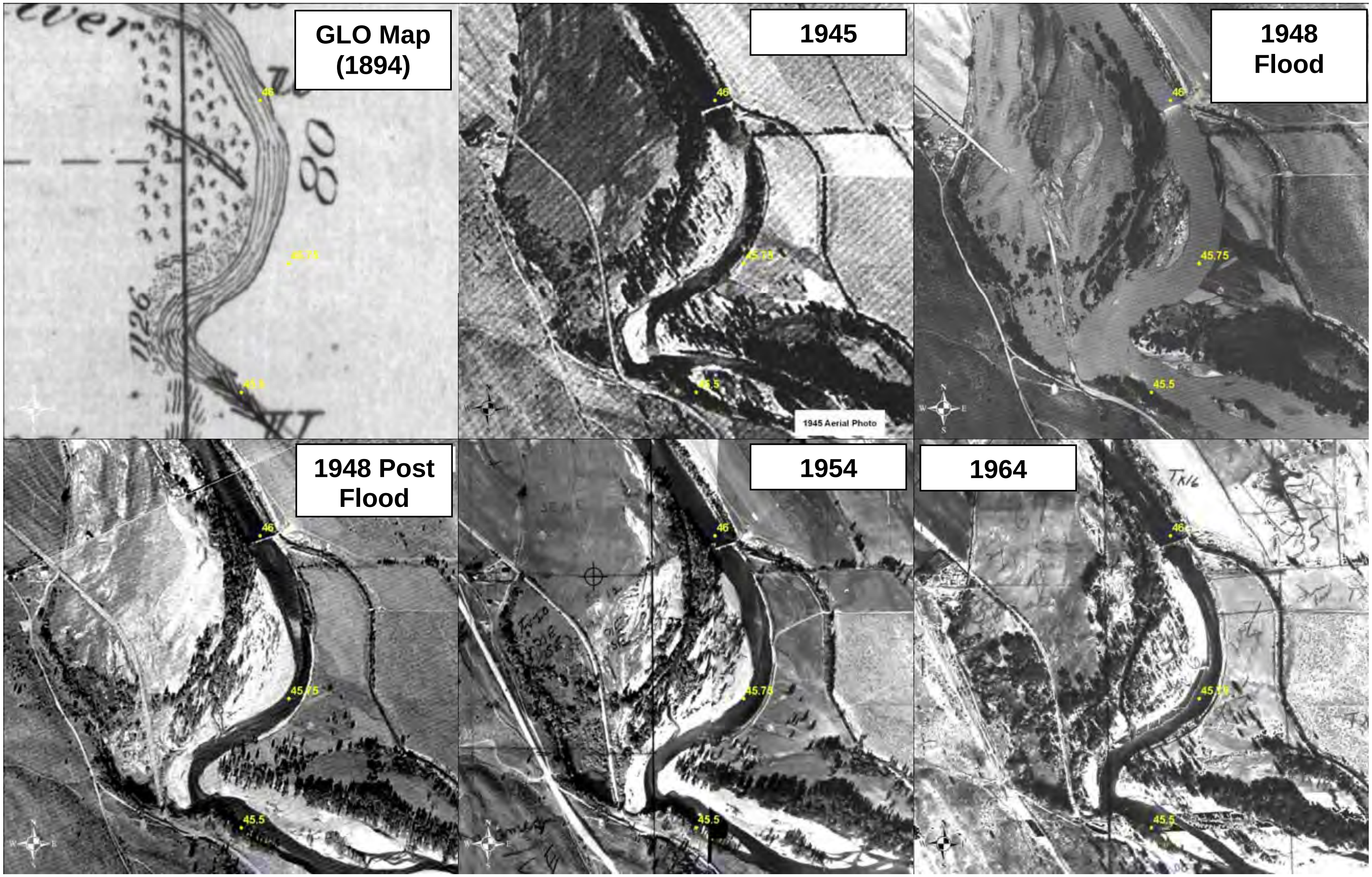


Figure 17. Geomorphic units, human features, and side channel in the MVID East area shown on 2006 LiDAR hillshade.


GLO Map (1894)
1945
1948 Flood
1948 Post Flood
1954
1964
1945 Aerial Photo
46
45.75
45.5

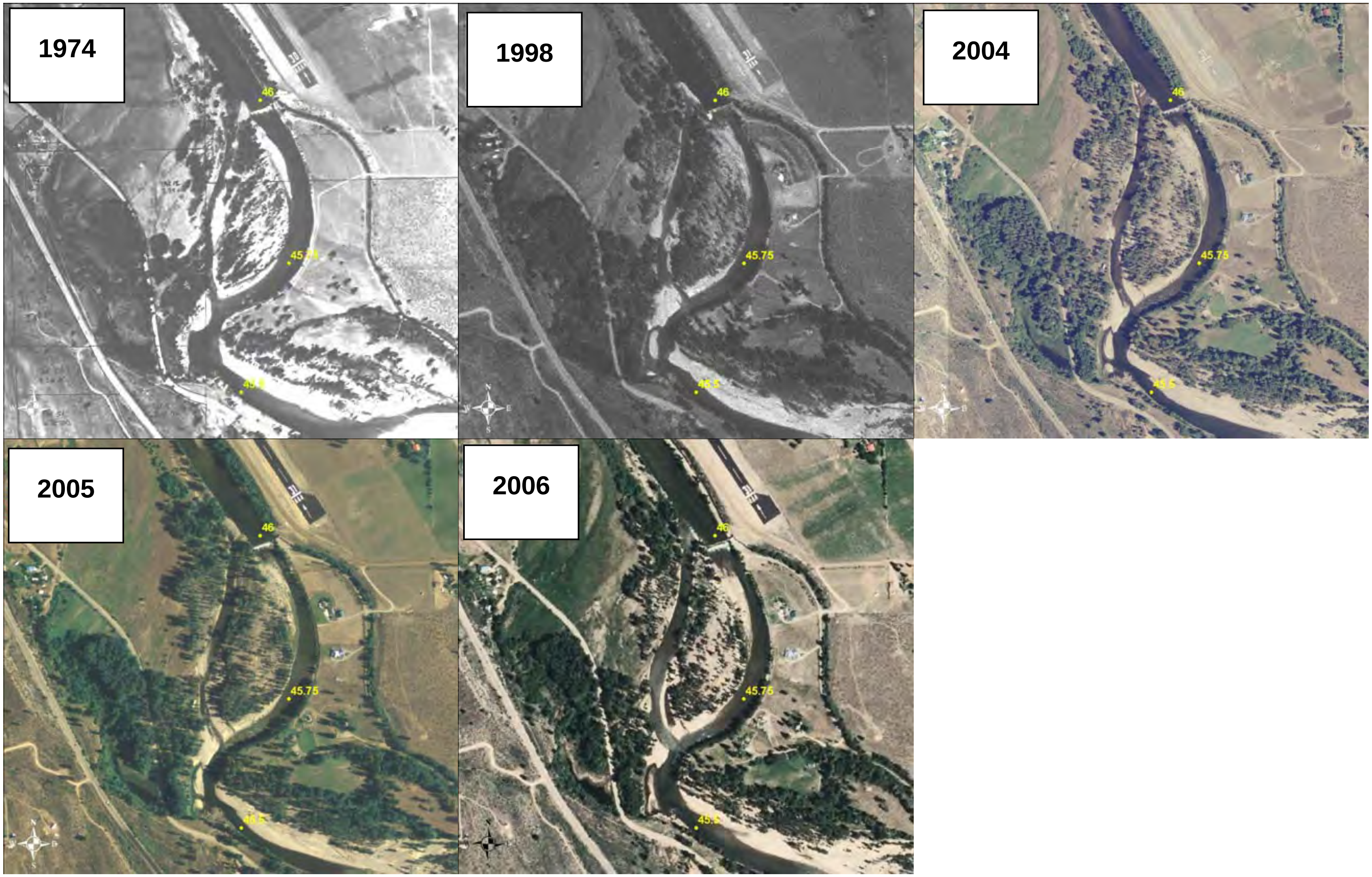


Figure 18. Historical map and aerial photograph comparison for MVID East project site between 1894 and 2006.

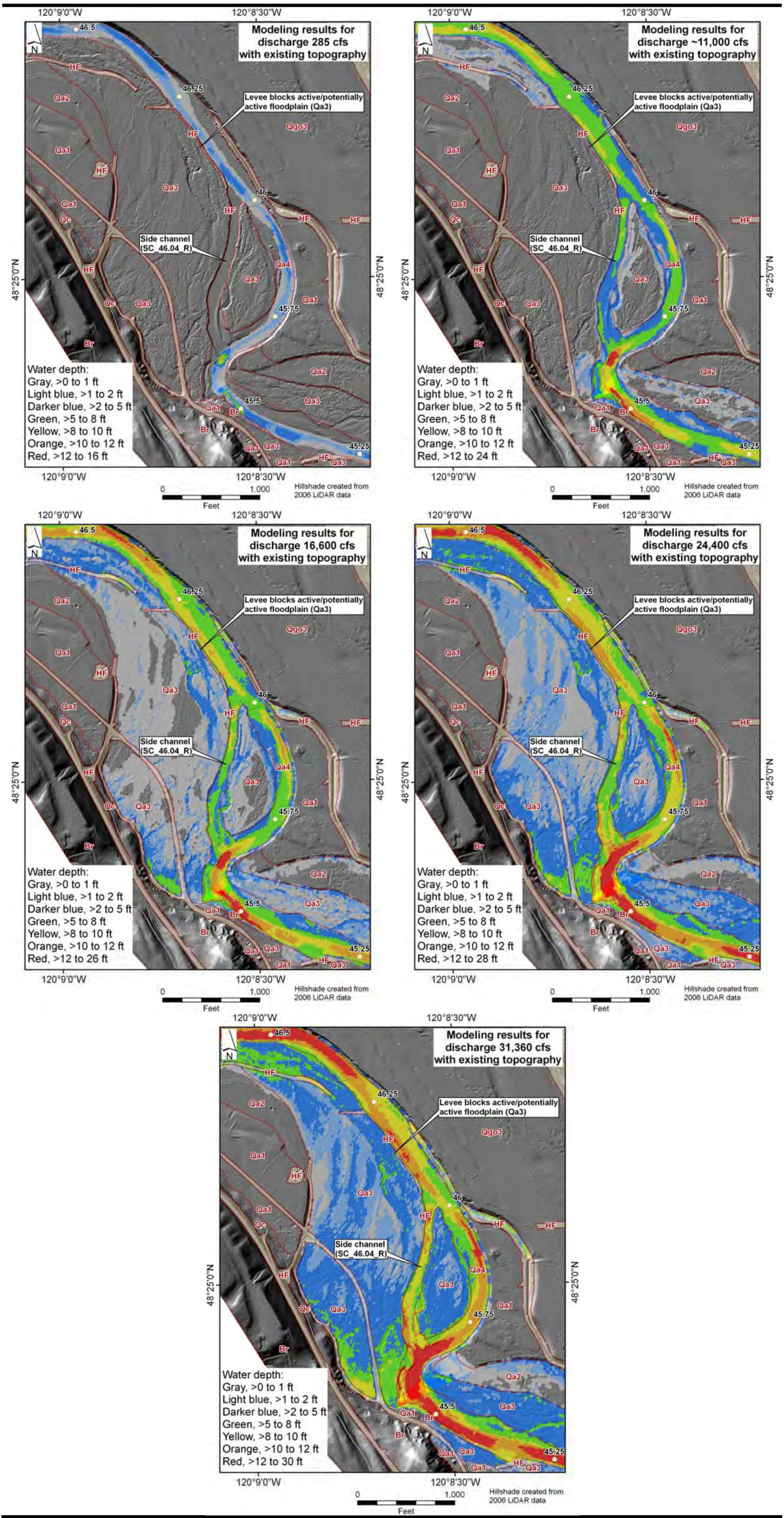


Figure 19. Five modeled flows for MVID east area.

7. Habermehl Area (RM 45.5 to RM 44.25)

The Habermehl river area between RM 45.5 and RM 44.5 contains a complex network of side and overflow channels that function at a variety of river flows (Figure 20). The Methow River has a broad meander toward the left (east) side of the valley through this site. Bedrock is present along the right side of the valley; the meander is bounded on river left by glacial deposits (Qgo3). Because of the broad meander, a large area of floodplain is preserved on river right. Most of this floodplain area is active floodplain (Qa3), but remnants of higher floodplain (Qa2) and terrace (Qa1) are preserved. Side channels and overflow channels of various lengths and forms are present throughout the Qa3 surface and within Qa4. One large side channel through the entire length of the floodplain area is preserved along river right between remnants of higher floodplain (Qa2) in its central part, between Qa3 at its upstream end, and between Qa3 and bedrock at its downstream end. This channel is referred to as the west channel. Another channel through the entire floodplain area is preserved on the Qa3 surface east of the higher floodplain (Qa2) remnant. This channel is referred to as the east channel. Neither of these channels was present prior to the 1948 flood when they formed. A third side channel is present across the southeast edge of the Qa3 area inside the meander. This channel is referred to as the southeast channel. It has been present since at least 1945 with only minor change.

Shorter and smaller side channels are preserved adjacent to the main channel between RM 45 and RM 44.75. A few of these channels are connected to the main channel. For most, overbank flow over the Qa3 surface is needed before they are inundated. Because of their size and the trees on the Qa3 surface, it is difficult to determine when these channels formed.

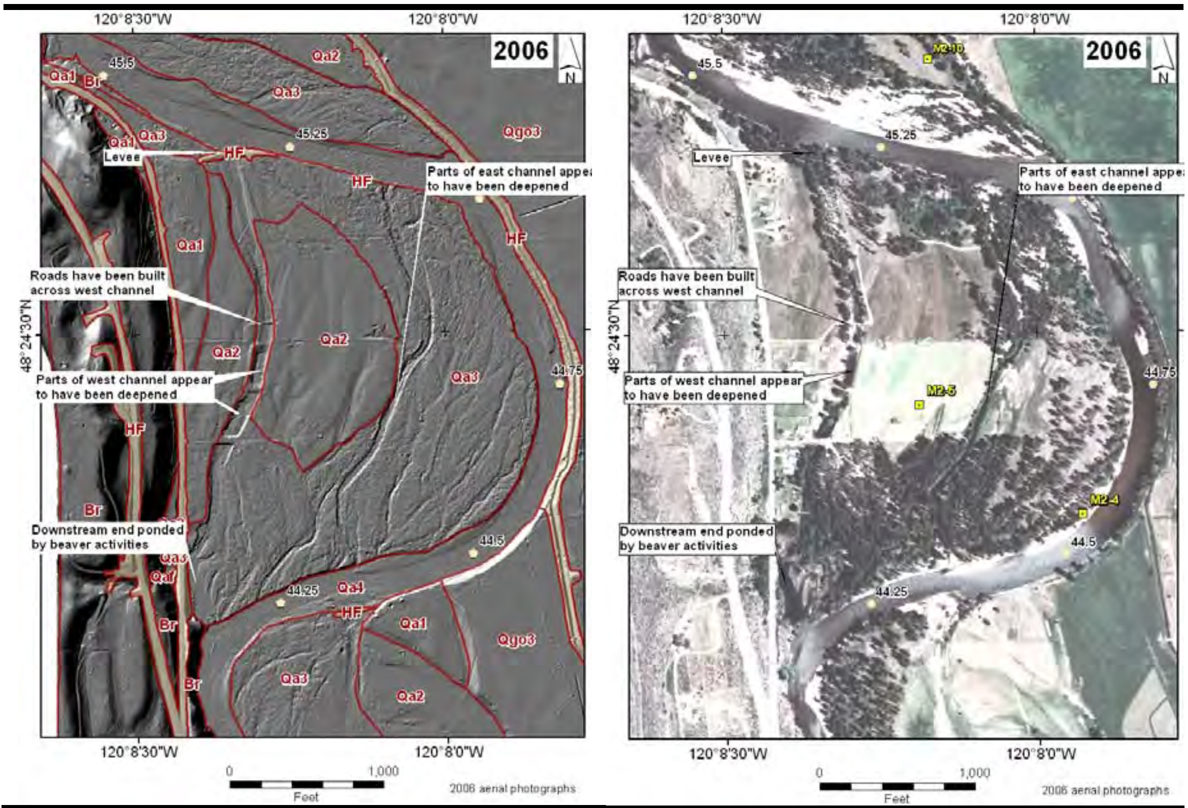


Figure 20. Geomorphic units, human features, and side channels in the Habermehl area shown on 2006 LiDAR data (left) and 2006 aerial photographs (right).

At this time, flow into the west channel is cut off by a levee at the head of the channel. Roads to houses cross the west channel and limit flow. The sections of the channel between the roads appear to have been excavated below their natural depths. Water, possibly groundwater, is present in these sections of the channel, but the roads are barriers to any flow connection. Water is also ponded by a beaver dam at the downstream end of the channel. Juvenile salmonids have been observed in this wetland.

There are no artificial barriers to flow into the east channel, the southeast channel, or other Qa3 channels in this area. Fresh sand deposits and wood at the upstream ends of these channels, especially in the east channel, indicate that these channels periodically contain flow. The central portion of the east channel appears to have been deepened by excavation and has standing water, which may be groundwater.

The main historical change in the Habermehl area is the erosion of two side channels through active and older floodplain during the 1948 flood (Figure 21). On the 1900 GLO map, there are no side channels documented in the Habermehl area. Additionally, in an early 1900s oblique photograph documented in *Bound for the Methow* (McLean and West, 2009), no side channels are visible and the majority of the floodplain has limited riparian vegetation.

In 1945 only a few small overflow channels are visible within the active floodplain near the main channel (Figure 21). Much of the floodplain had been cleared for pasture, crops, or building sites and was sparsely vegetated. An area that will become the upstream end of the west channel appears to have been devoid of vegetation. A 0.2-mile-long channel may have been present in the area of the future east channel. The southeast channel is visible at the southeast edge of the floodplain in an area with some trees. Several other small overflow channels may have been present between RM 44.7 and RM 44.4, although it is difficult to determine given the quality of the 1945 photographs.

On photographs taken during the 1948 flood, both the east and west channels had well-defined single paths at their upstream ends with broad areas of braided flow at their downstream ends. The surfaces adjacent to these two channels also had at least sheet flow during the flood. The locations of these two channels were likely influenced by the sparse vegetation on the floodplain surfaces. The location of the west channel was also likely influenced by bedrock and a slight main channel meander just upstream of RM 45.5. For the east channel, the presence of a channel that is visible in 1945 may have influenced its location. Vegetation that was present in 1945 at the downstream end of the east channel was gone by 1948.

The west channel eroded through a remnant of the higher floodplain (Qa2) that appears to be capped by a thick deposit of overbank sand that was easily eroded. This channel was up to 160 feet wide and included a thalweg and gravel bars. It was nearly the size of the main channel. Because the channel eroded through higher floodplain (Qa2), formation of the side channel created approximately 12 acres of active floodplain (Qa3).

The east channel eroded through active floodplain (Qa3). New active floodplain was not created, but this channel added approximately 8 acres to the total area of large side channels created during the 1948 flood. This channel was smaller than the west channel, perhaps because some flow had been directed into the west channel and (or) because the active floodplain deposits had more gravel, which was more difficult to erode than the sand on the higher floodplain. The east channel was up to 50 feet wide. Part of the flow in the east channel may have gone into the west channel before reentering the Methow River.

During the 1948 flood, the southeast channel and most of the overflow channels were inundated (Figure 21). The Qa3 surface near RM 44.75 appears to have been overtopped and an overflow channel developed downstream.

By 1954, the west and east channels were still visible and remained unvegetated. Both channels had a low-flow channel with water and unvegetated bars along it. Vegetation was returning to the downstream end of the Habermehl area. The upstream portions of both channels were wider than they were in the 1948 post-flood photographs. The downstream section of the east channel, where flow was braided during the 1948 flood, was becoming vegetated between the flow paths. In 1954, the small overflow channels that were formed during 1948 flood were clearly visible as well as the area of overbank flow. The southeast channel was still present and was unvegetated. An additional channel is visible near RM 45. The main channel path was essentially the same as it was in 1948.

By 1964 there was a levee at the head of the west channel and flow into the channel was blocked. Water in the west channel was possibly from groundwater and it appears that the west channel was deepened at its downstream end. The smaller channels that were related to the west channel in the downstream half of the Habermehl area no longer received flow because of the levee at the head of the west channel. The central section of the east channel appears to have been deepened and straightened by excavation between 1964 and 2004.

By 2006, roads had been built across the west channel in three places and a beaver dam was present at the downstream end of the west channel (Figure 20). The downstream half of the Habermehl area was heavily vegetated

The small overflow channels between the east channel and the main channel still appear to have been inundated during the flood in 2006. Some of the 1948 overflow channels in this area are difficult to see, although the southeast channel appears to have been inundated recently. Sand and wood on the active floodplain surfaces and in the heads of side channels observed during the 2008 and 2009 field reconnaissance indicate that overflow channels in this area were still inundated

Although minor compared to the erosion of the east and west side channels, some changes have occurred in the location and configuration of the main channel and a small side channel on river left at the upstream end of the Habermehl area. These changes took place during the 1948 flood, and between 1964 and 2006.

None of the side channels in the Habermehl area are inundated during low-flow conditions (285 cfs; Figure 22). The east and southeast channels have a surface-flow connection at a discharge of about 11,000 cfs. At a discharge of 16,600 cfs, the Qa3 surface and included channels have shallow (>0 to 1 ft) flow, and several channels have water up to 5 feet deep. Surface-water connection in the west channel is blocked by a levee and road that were in place during the model runs. At about 11,000 cfs, the downstream end of the west channel has water as deep as >5 to 8 feet, but the channel does not have a surface-water connection at this discharge. The levee blocking the west channel is nearly overtopped at a discharge of 24,400 cfs.

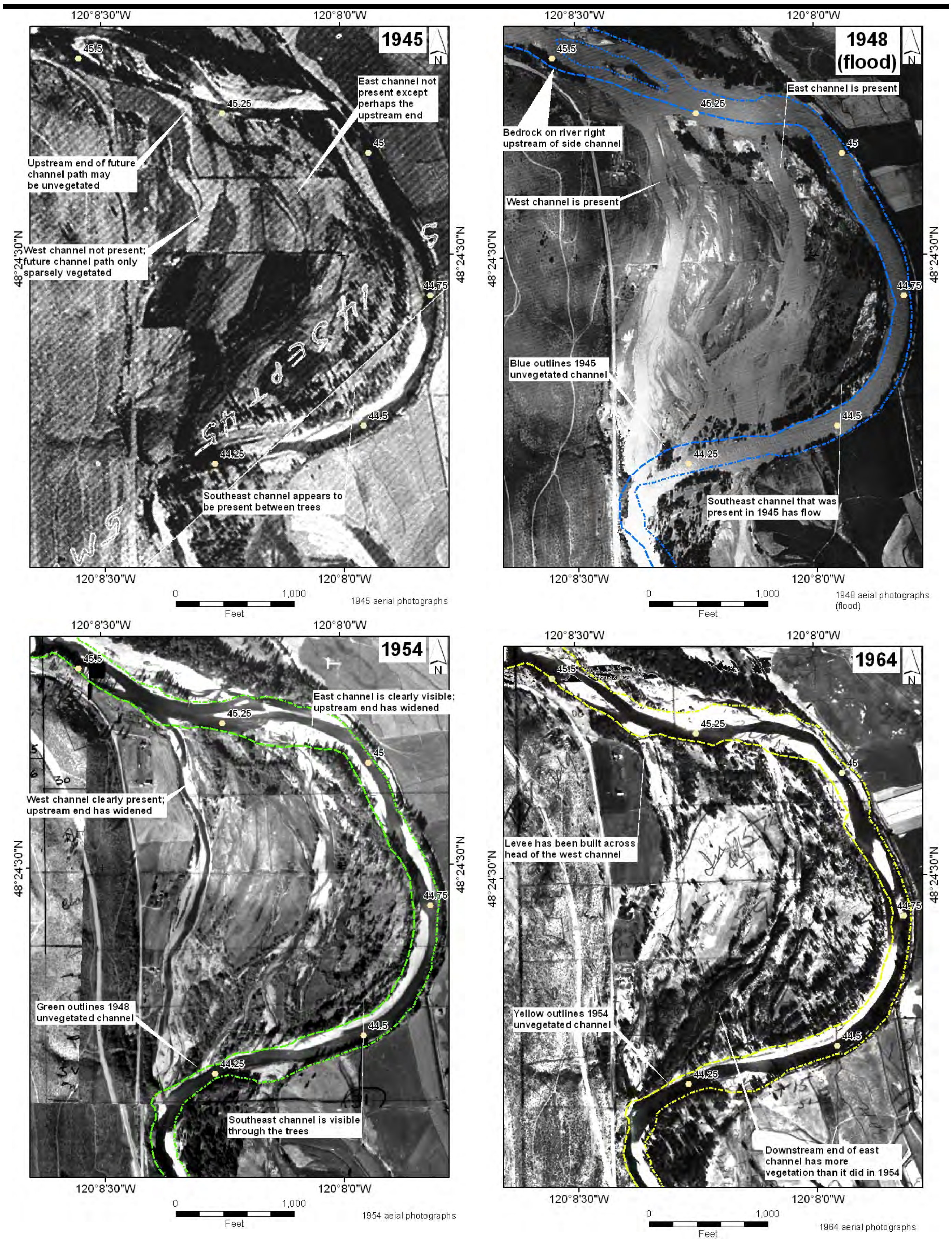


Figure 21. Sequence of historical aerial photographs between 1945 and 1964 for the Habermehl area.

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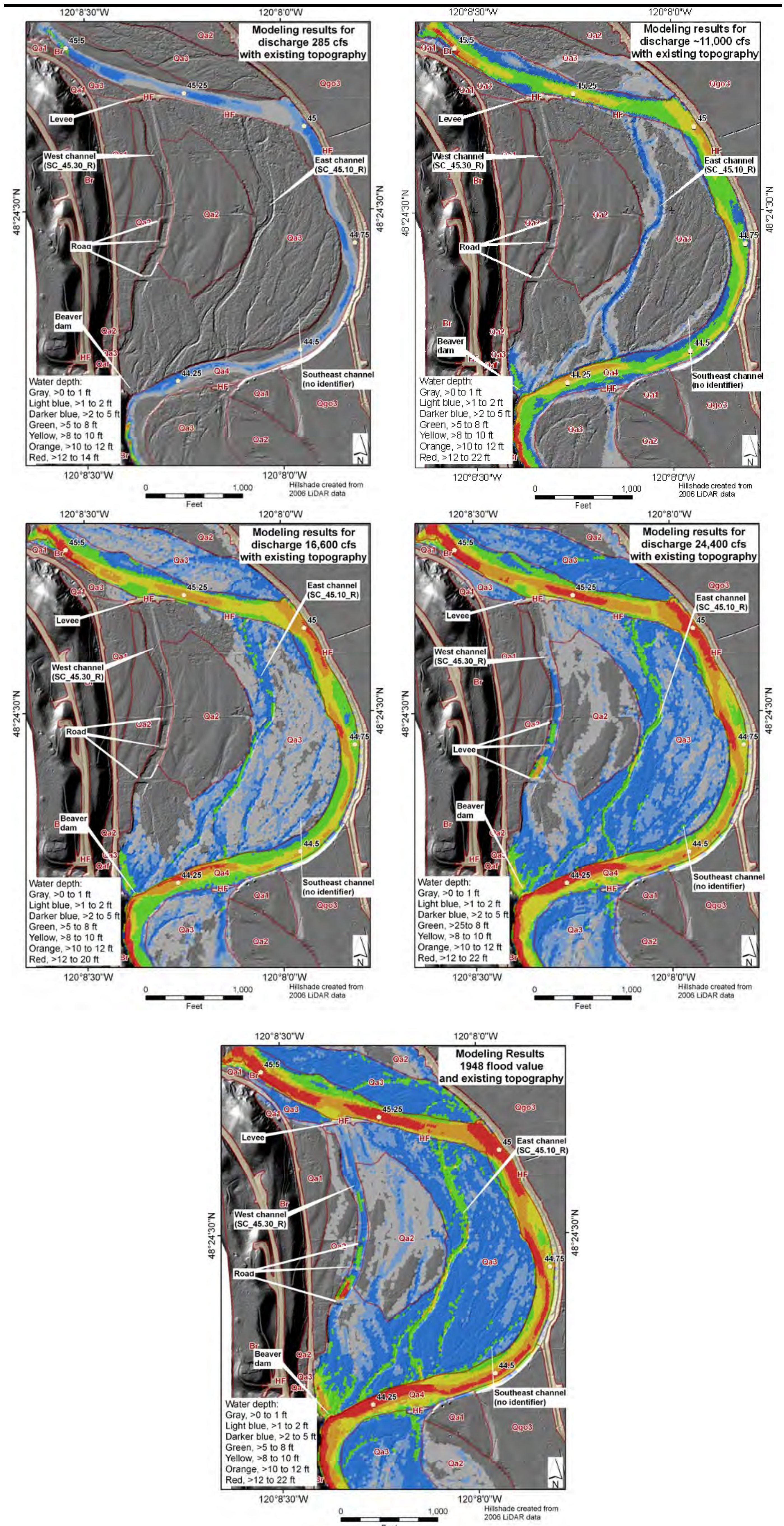

Figure 22. Five modeled flows for the Habermehl area.

8. Lehman Area (RM 44.5 to RM 42.75)

Between RM 44.5 and RM 42.75, the Methow River is a low sinuosity single thread channel along the right edge of the floodplain (Figure 23). Between RM 44.25 and RM 43.5, the river flows along bedrock on river right. The main channel has been in this position with little change since at least 1894/1900 (Figure 25) except for slight changes in meander position. The 10-year floodplain in this area is about 2,000 feet wide on river left and is bounded on the left by glacial outwash (Qgo3). The river has broad meanders to the west at the upstream end of this area and to the east at the downstream end. There is evidence of several old channels on the left floodplain, but presently none of these channels are active until at least a 2-year flood. This results not from incision of the main river channel, but rather from the width of the floodplain, levees, and human modification of the Qa3 surface and channels.

Despite the low elevation of the floodplain on river left, the main channel has migrated little between 1894/1900 and 2008. Although not accurately georeferenced, the GLO maps from 1894/1900 clearly show the main channel along the right side of the valley where it has been since 1945. The main channel in 1894/1900 downstream of RM 43.25 diverges slightly from its later position (Figure 25).

In 1945, side channels on the Qa3 surface appear to have had flow, and the large left channel may have had flow downstream of about RM 43.6. Vegetation had been cleared from part of the Qa3 area, which was only sparsely vegetated.

During the 1948 flood, side channels within about 1,500 feet of the main channel carried flow. Channels that were present in 1945 may have been enlarged during the 1948 flood. The downstream end of the left channel appears to have had flow during the 1948 flood. A channel was cut by headward erosion through a Qa2 surface at the downstream end of the Lehman area.

By 2004, a small levee had been constructed at the upstream end of the Lehman area (Figure 25). The levee blocks side channels that were active during the 1948 flood; one channel extended to near RM 43.5.

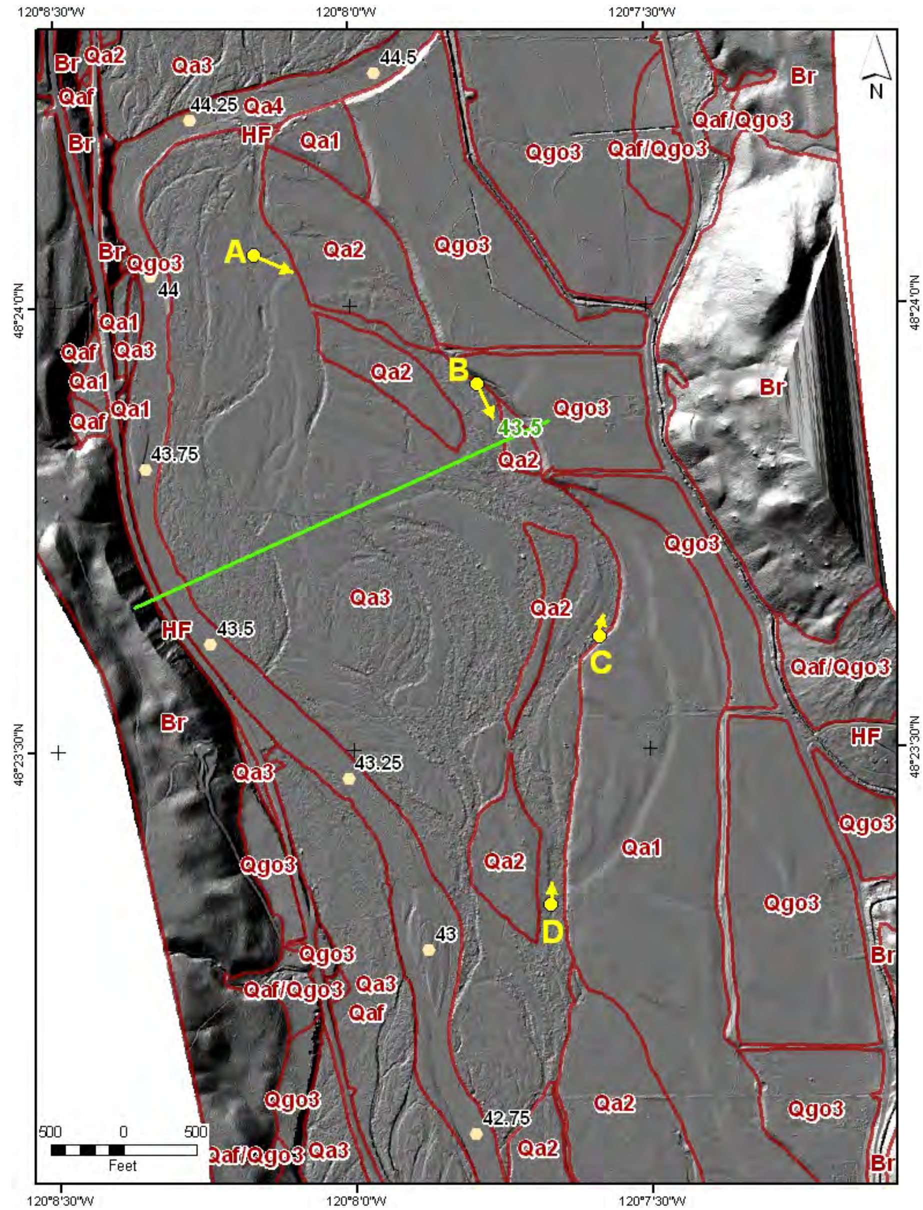

Figure 23 Geomorphic map units, human features, and the location of a cross section in the Lehman area.

Yellow dots and letters show the location of ground photographs (Figure 24). Yellow arrows show the view direction.

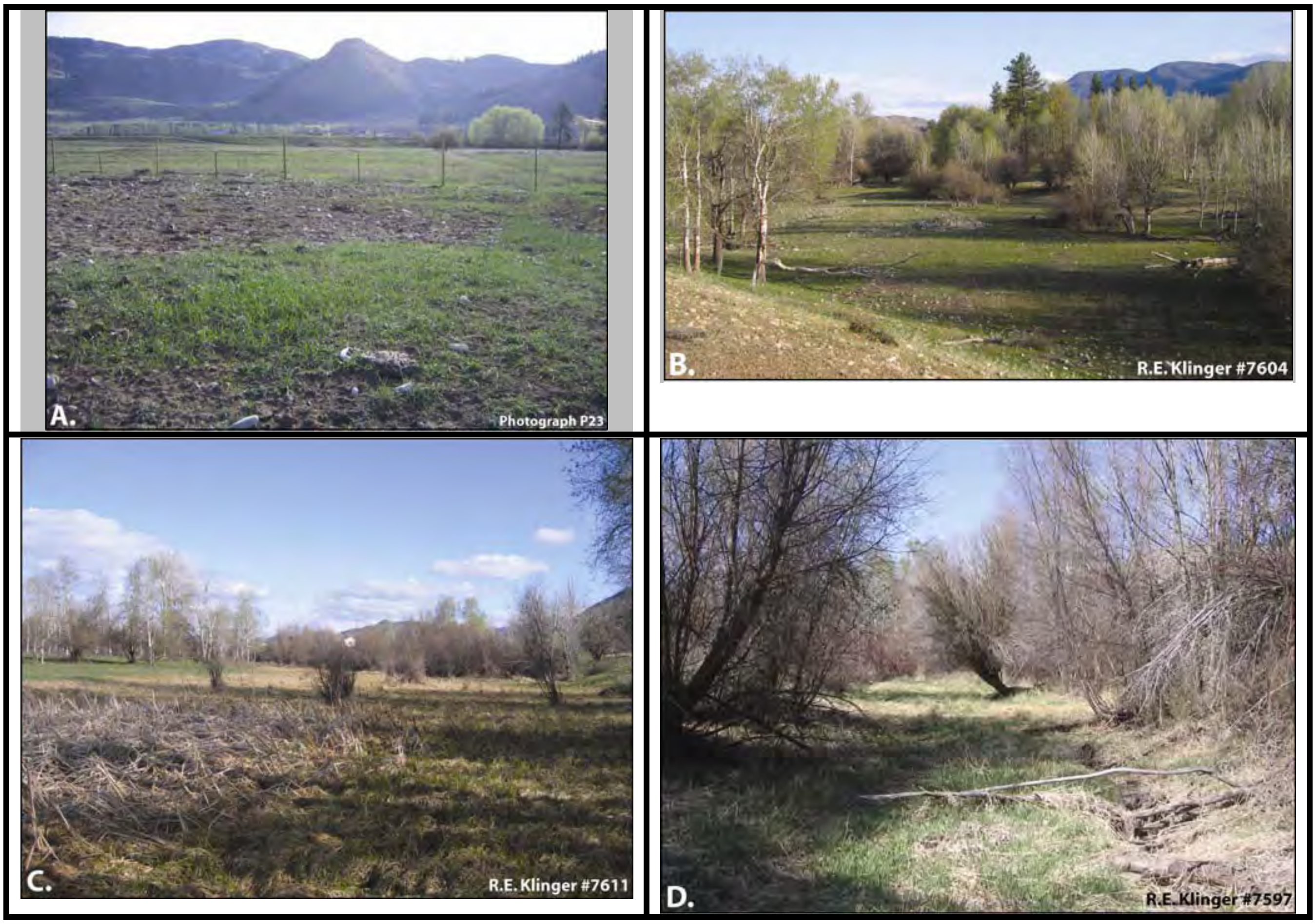

Figure 24. Examples of Qa3 and relict channel in the Lehman area.
Photograph A in upper left is looking southeast across Qa3 and shows the flatness of this surface. The other three photographs show the relict channel along the east side of the Qa3 area from upstream (B, upper right) to central part (C, lower left),, and downstream (D, lower right).

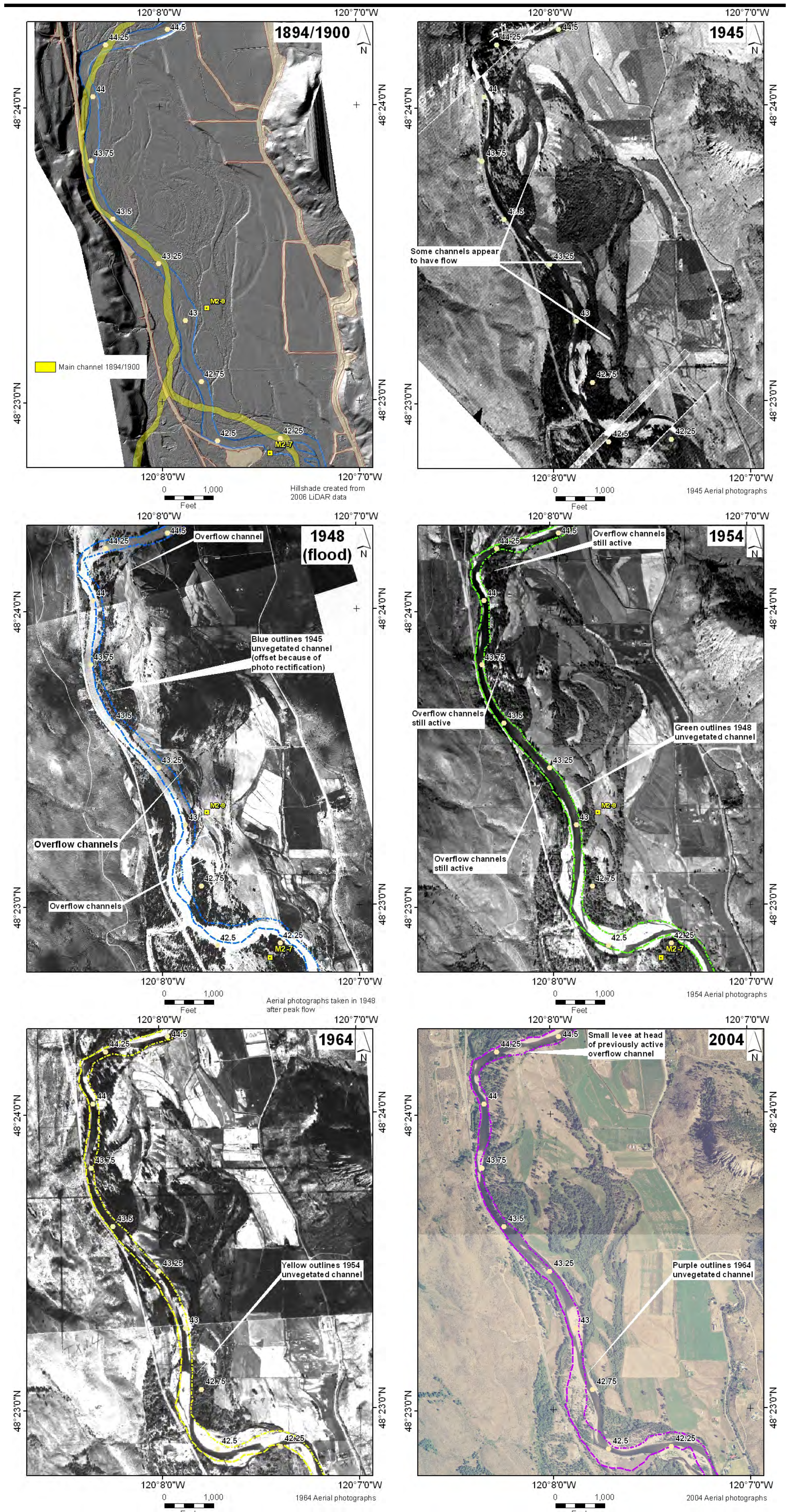

Figure 25. Sequence of historical maps and aerial photographs between 1894/1900 and 2004 for the Lehman area. *Channel in 1984/1900 shown in the upper left was digitized from a Government Land Office (GLO) map. Unvegetated channel in 2006 is shown by blue outline. Human features in 2006 are shown by areas of pale brown shading.*

A fairly large relict channel is present through the Qa3 surface on river left along the edge of the Qgo3 surface (Figure 23). This channel is not noted on the 1894/1900 GLO map, which shows the main channel roughly in its current position along the bedrock on river right indicating that the channel on river left may have been a relict side channel. However, because two paths are shown for the main channel downstream near RM 42.6, it seems likely that, if the channel on river left had been an active main channel path in 1894, it would have been portrayed on the GLO map. Since the left path in the Lehman area is not shown on the GLO map, we infer that the left channel was not active at that time and was already a relict main or side channel path. Based on 1897 notes from the GLO survey, portions of the Qa3 land in this location were documented as fields, implying that the natural vegetation had already been removed. In the 1945 photograph, much of the upstream end of the Lehman area was unvegetated indicating past clearing activity. Additionally, a thalweg and bars are still readily visible in the relict channel. A bank exposure near RM 42.75 has a light-colored bed that may be volcanic ash, and if so, is likely correlative with the one identified downstream that was erupted from Mount St. Helens about 500 years ago. If these assertions are correct, then the relict channel might have been active between about 500 to 100 years ago. It is hypothesized that this channel is now abandoned due natural river migration possibly combined with manipulation at the upstream entrances to channels located in this part of the floodplain.

Based on a cross section generated at RM 43.5 (Figure 26), the relict channel is 8 to 10 ft higher in elevation than the main channel. In addition, model results indicate that the floodplain in this area is overtopped by only shallow water during a 2-year flood (about 11,000 cfs). There have been questions about whether one or both of these observations indicate incision of the present main channel. Incision is not thought to have occurred for the following reasons.

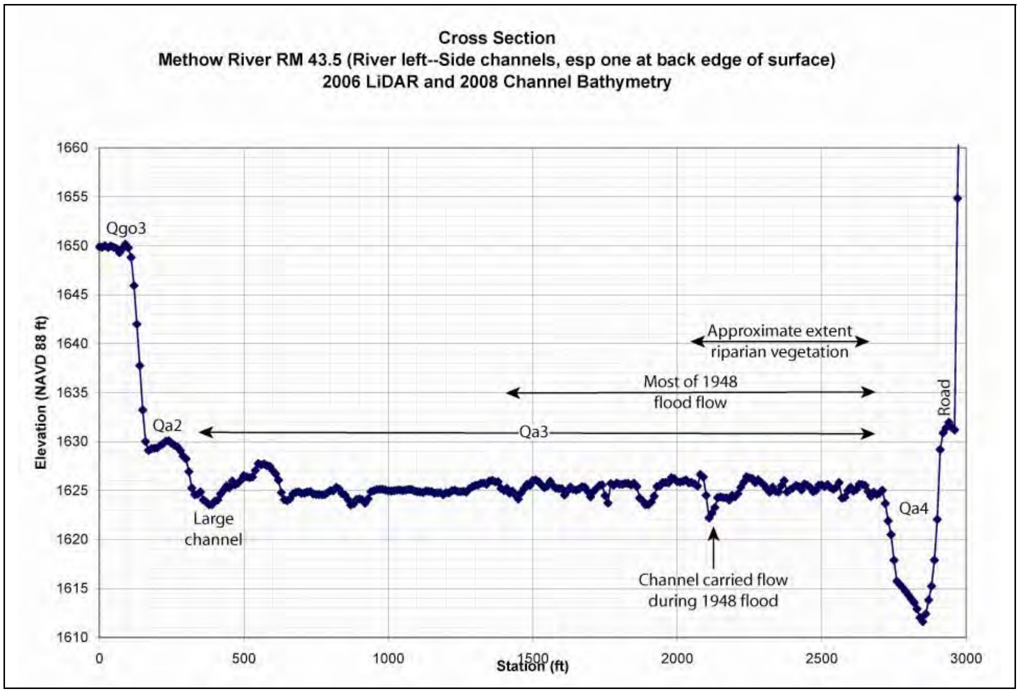

Figure 26. Topographic cross section across the Lehman area near RM 43.5 looking downstream.

First, a comparison of channel bed elevations from the 2008 channel survey and a 1972 survey completed just after the 1972 flood showed no evidence for a change in bed elevation. Furthermore, the 1972 high water elevations were compared to modeled conditions for the same peak. If incision had occurred since 1972, it would be expected that the flood stage would be lower, but it is not.

Second, the 2006 main channel through this section is slightly meandering and has gravel bars. Depositional bars are present just upstream and downstream of the river segment along the highway. The meanders and bars suggest that the channel is moving laterally, and these features would not be present if the channel was incising (cutting downward).

Third, the difference in the elevations of the two channels that can be seen on the cross section does not provide enough evidence to suggest main channel incision do to the following reasons. The main channel is slightly meandering at this location and runs along bedrock and riprap placed along the highway embankment. The bedrock and riprap help form a pool that has a maximum depth of about 6 ft. The relict channel shows evidence of having split flow sections. Based on current channel morphology, this is the configuration often seen in riffles. The difference in depth in a pool versus a riffle can easily be 5 to 10 ft. Further, it is not known if this relict channel was a main channel or simply a higher elevation side channel. These results do not provide enough evidence for main channel incision.

Fourth, the lack of widespread inundation of side channels and the Qa3 surface at a discharge of about 11,000 cfs (2-year flood) does not suggest main channel incision. The Qa3 surface was defined, in part, by the extent of the inundation at a discharge of 31,360 cfs, the peak of the 1948 flood. Qa3 is composed of surfaces and channels of various elevations and location relative to the main channel, and would not be expected to be inundated everywhere by smaller discharges. In the Lehman area, the elevation of the entire area mapped as Qa3 is similar (see Figure 26), indicating that this entire area has equal potential to be inundated once flow overtops the surface. But, because of the width of the Qa3 surface, it is unlikely that all of the surface would be active at one time. This conclusion is supported by the modeling results. The extent of inundation is limited by the volume of the flood and the location of the main channel. Under present conditions with the main channel along the right side of the floodplain, the portion of the Qa3 surface that is within about 1,500 feet of the main channel is the most likely to carry flow of any depth in all but the largest floods. However, should the position of the main channel migrate to the left (e.g., if the levee at the upstream end of the Lehman area is removed), then other portions of the Qa3 surface could be activated because of the low elevation of the entire Qa3 area. In addition, the Qa3 surface in the Lehman area has been cleared of vegetation for pasture, crops, and building sites. Evidence on the surface suggests disturbance from small roads, excavations, filling of old channel paths, and channel diversions (Figure 27), but documenting all of these modifications was beyond the scope of our assessment. These changes to the Qa3 surface likely affect the potential for surface water connection during floods.

Figure 27. Qa3 surface looking downstream from the upstream end of the Lehman area near RM 44.25.

Side channels on Qa3 within about 1,500 feet of the main channel were inundated during the 1948 flood. Model results indicate that a levee now at the upstream end of this area impedes surface-water connection in the side channels and a portion of the Qa3 floodplain up through at least a discharge of 24,400 cfs (Figure 28). Model results show high velocity and shear stress values for flood flows along the downstream end of the levee. Field observations indicate the presence of wood near the downstream end of the levee and several recent localized levee failures where riprap has been placed. These results and observations suggest that there is potential for continued failure of the levee and small amounts of lateral migration of the main channel in this area. The levee was overtopped by the May 2008 flood (Figure 29).

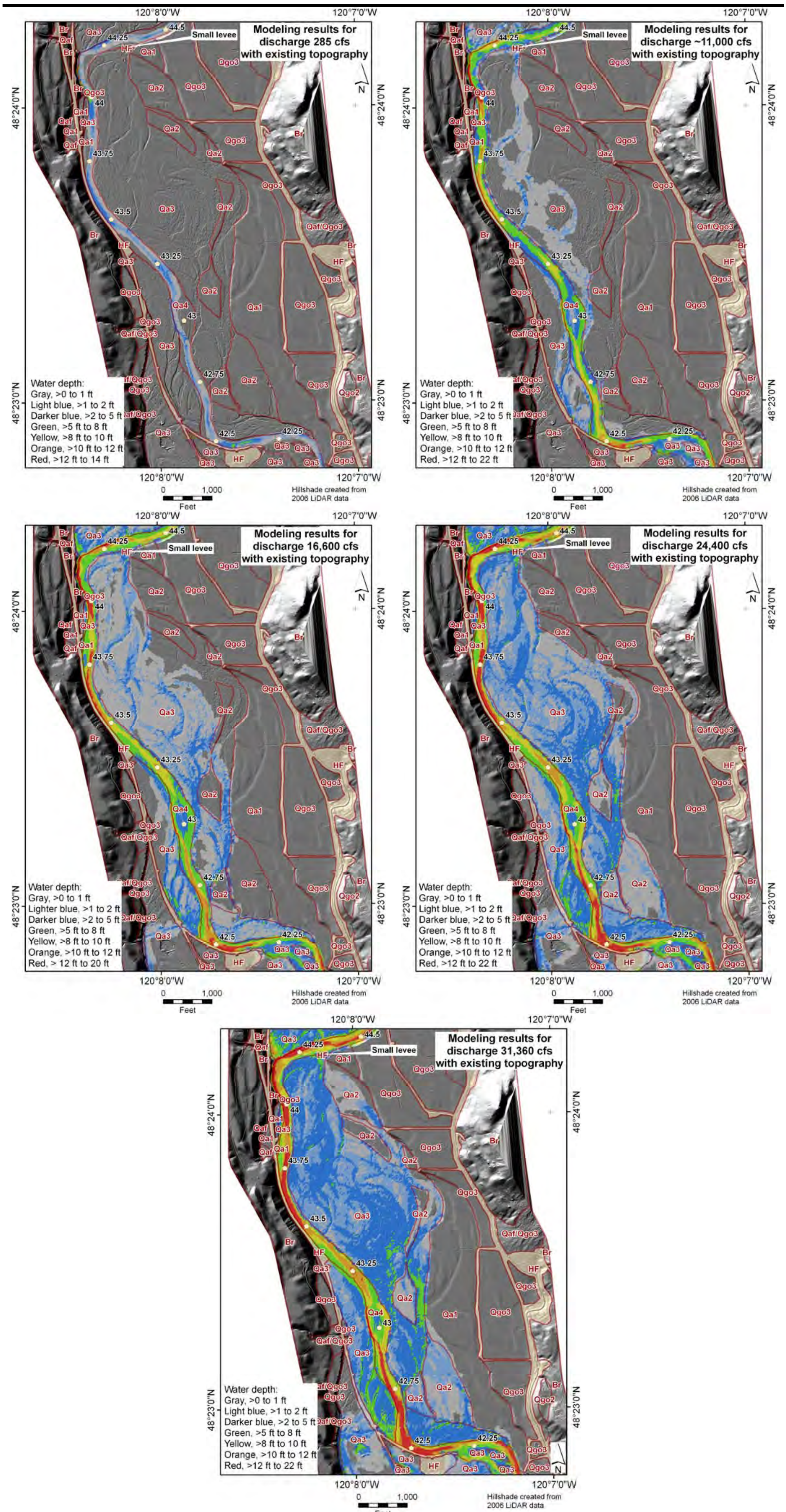

Figure 28. Five modeled flows for the Lehman area.

Figure 29. Upstream end of Lehman area two days after the May 2008 flood. Discharge at the time this photograph was taken is about 11,000 cfs (2-year flood). View is looking downstream. Levee was overtopped in this flood, and flow went into a channel that was active during the 1948 flood.

9. Sugar Dike and Twisp Confluence (RM 43 to RM 41)

The section of the M2 reach between the sugar dike near RM 43 and the confluence with the Twisp River near RM 41 is composed of a wide floodplain, but is confined at its downstream end by bedrock on river left and sediment from the Twisp River on river right (Figure 30). A highway present since at least 1945 and a levee present since 1972 limit the ability of the river to migrate into a large portion of the right floodplain. However, this section of the M2 reach has still experienced the most channel migration and floodplain reworking of any section in the reach (Section 5.1).

At the present time, the Methow River makes a large meander to the east (river left) in this area, leaving a large area of floodplain on river right. Most of this floodplain is active floodplain (Qa3), although a small area of higher floodplain (Qa2) is preserved. The main channel becomes straighter downstream of RM 41.5. Two large overflow channels are present in this section. One large overflow channel along river right between about RM 42.6 and RM 41.5 was the right path of split flow in the 1894 main channel. A second large overflow channel on river right between about RM 42 and RM 41.2 was the main channel path in 1945, 1948 before the flood. This channel is shown as the 1945/1948 channel.

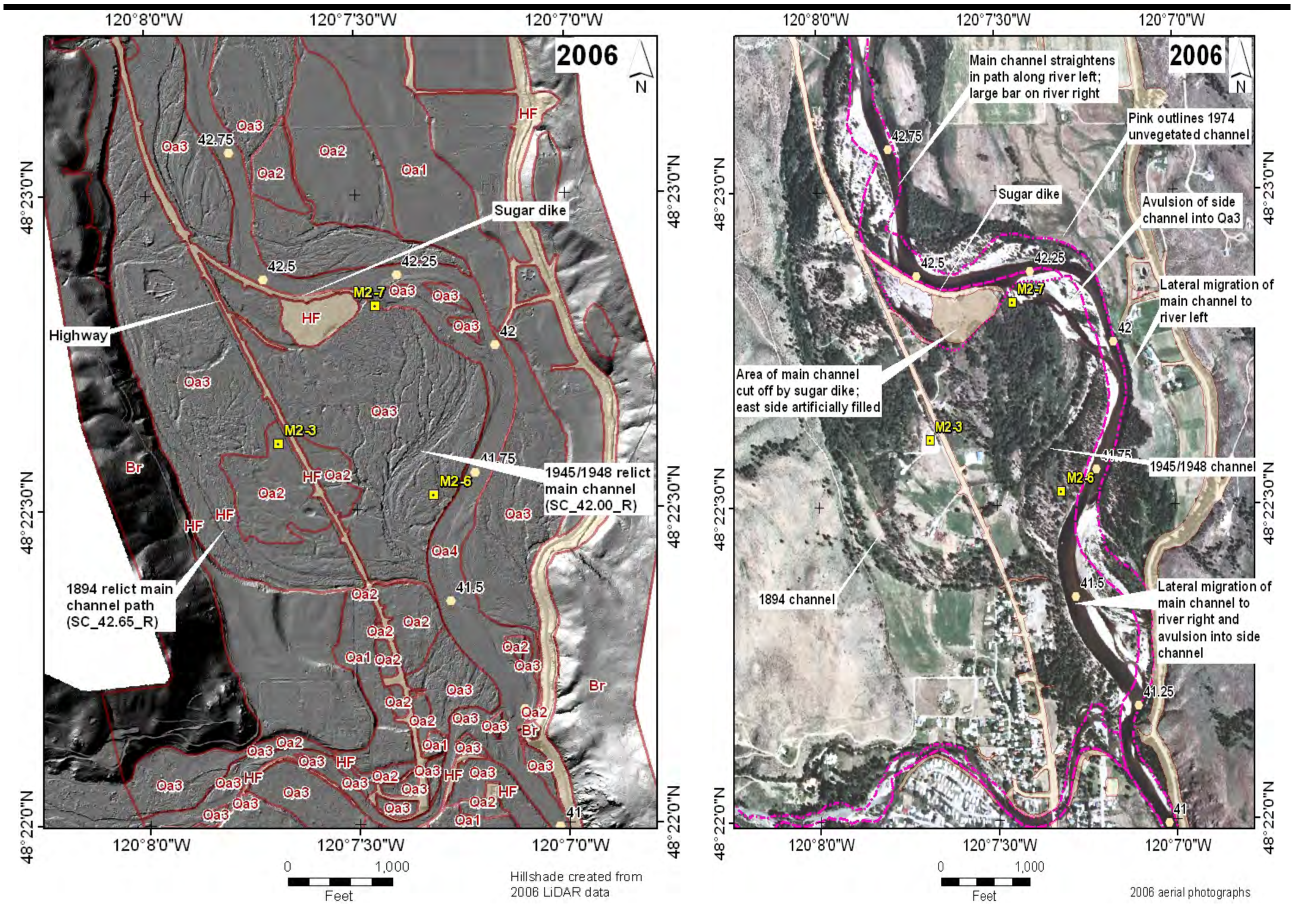

Figure 30. Geomorphic units, human features, and side channels in the sugar dike-Twisp area

The main channel becomes straighter near RM 41.5 and a steep riffle is present based on the 2008 field survey. Bedrock on river left near RM 41 and sediment from the Twisp River on river right provide vertical and lateral control for the Methow River at this point. This constriction limits channel migration and creates a backwater upstream of this point. Modeling results show this short section of on the mainstem Methow River. At low flows there is limited backwater due to the steep riffle. The bedrock outcrop on river left creates a deep scour pool measured to be 16 ft deep during the October 2008 survey (see Appendix B). At the 10-year and larger floods ($\geq$16,000 cfs), the backwater extends upstream to about RM 41.7 where the floodplain begins to expand substantially. The constriction increases the occurrence of channel migration between RM 43 and RM 41, relative channel migration in other sections of the M2 reach (see Section 4.1).

The main historical features in the sugar dike-Twisp section include numerous channel changes and floodplain erosion (Figure 31). In 1894, the main channel had split flow paths. By 1945, the west (river right) path had been abandoned. A change in the location of the main road between 1894, when it was outside of the floodplain, and 1945, when it crossed the floodplain and the head of this channel path, may have contributed to the abandonment of the main channel path. The main channel avulsed through the floodplain on river left near RM 42 during the 1948 flood. After the avulsion, part of the former main channel remained as a side channel but was filled with sediment by 1954. Later, between 1974 and 2004, a section of this side channel (RM 41.6 to RM 41.25) was destroyed when the main channel migrated into it. The channel near the sugar dike (RM 42.6 to RM 42) repeatedly migrated to the outside (river right) of a meander bend until the sugar dike was constructed between 1964 and 1974. Before the sugar dike was constructed, channel migration also occurred on river left just downstream at the next meander. After the sugar dike was in place, the historical patterns of channel migration and channel change altered. Channel migration to river right at the sugar dike ceased. Channel migration to river left just downstream also ceased, as the channel straightened along the sugar dike. A large side channel eroded through Qa3 on river right at the downstream end of the sugar dike.

Small side channels have been present on river right upstream of the sugar dike between RM 43 and RM 42.6. The main chanel has repeatedly migrated through this area until the highway was constructed through the floodplain (between 1894 and 1945) and the sugar dike cut off part of the main channel.

None of the side channels in this section are inundated at a discharge of 285 cfs, or low-flow conditions (Figure 32). By 11,000 cfs, the large side channel at the downstream end of the sugar dike within Qa4 and the side channels within Qa3 just upstream of the sugar dike have a surface-water connection. A few side channels through Qa3 on river left downstream of RM 41.8 also have a surface-water connection at this discharge. Most of the accessible side channels and much of the accessible Qa3 area, including the 1945/1948 channel, are inundated at a discharge of 16,600 cfs.

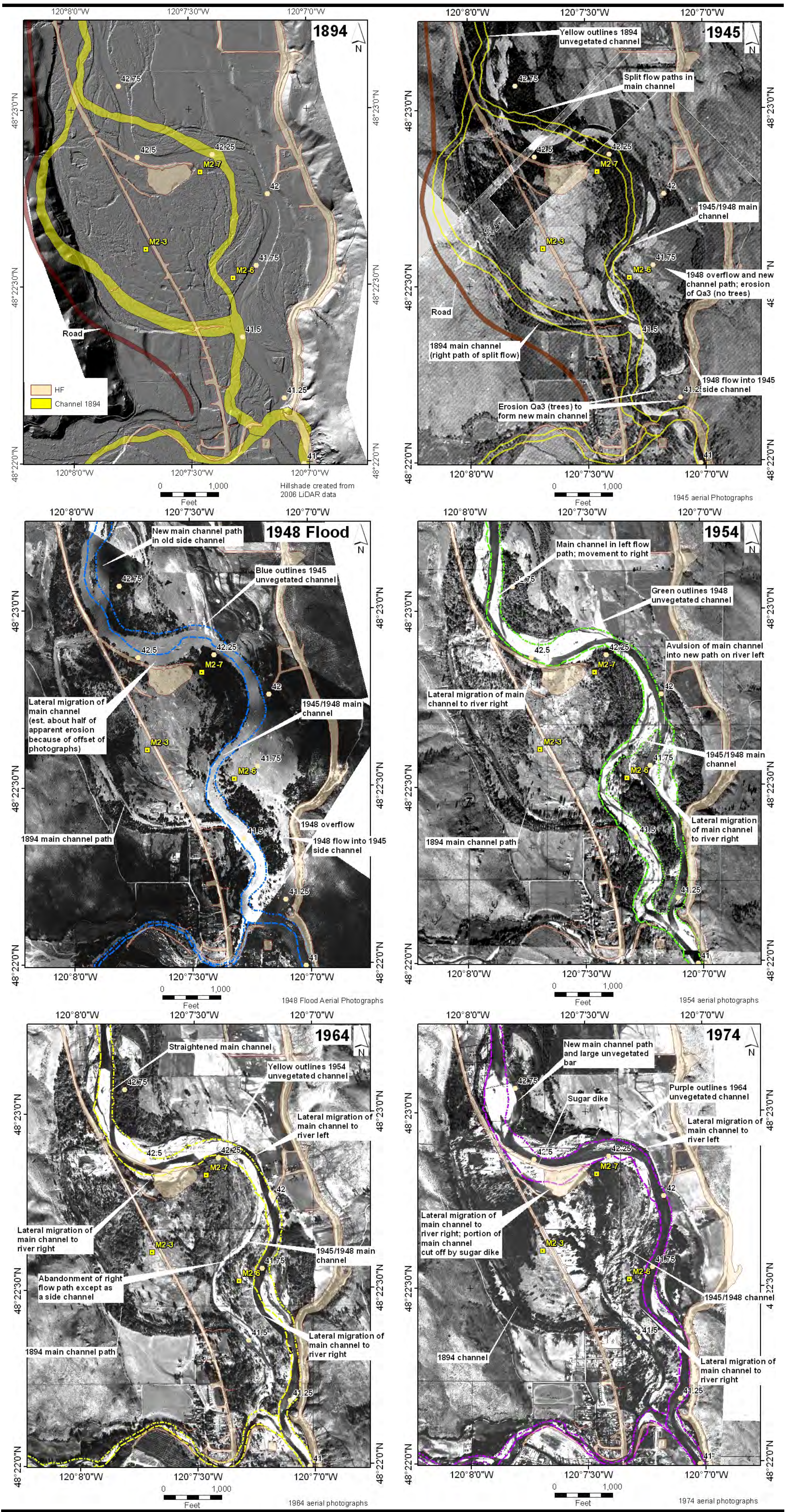

Figure 31. Sequence of historical map and aerial photographs for the sugar dike-Twisp area between 1894 and 2006.

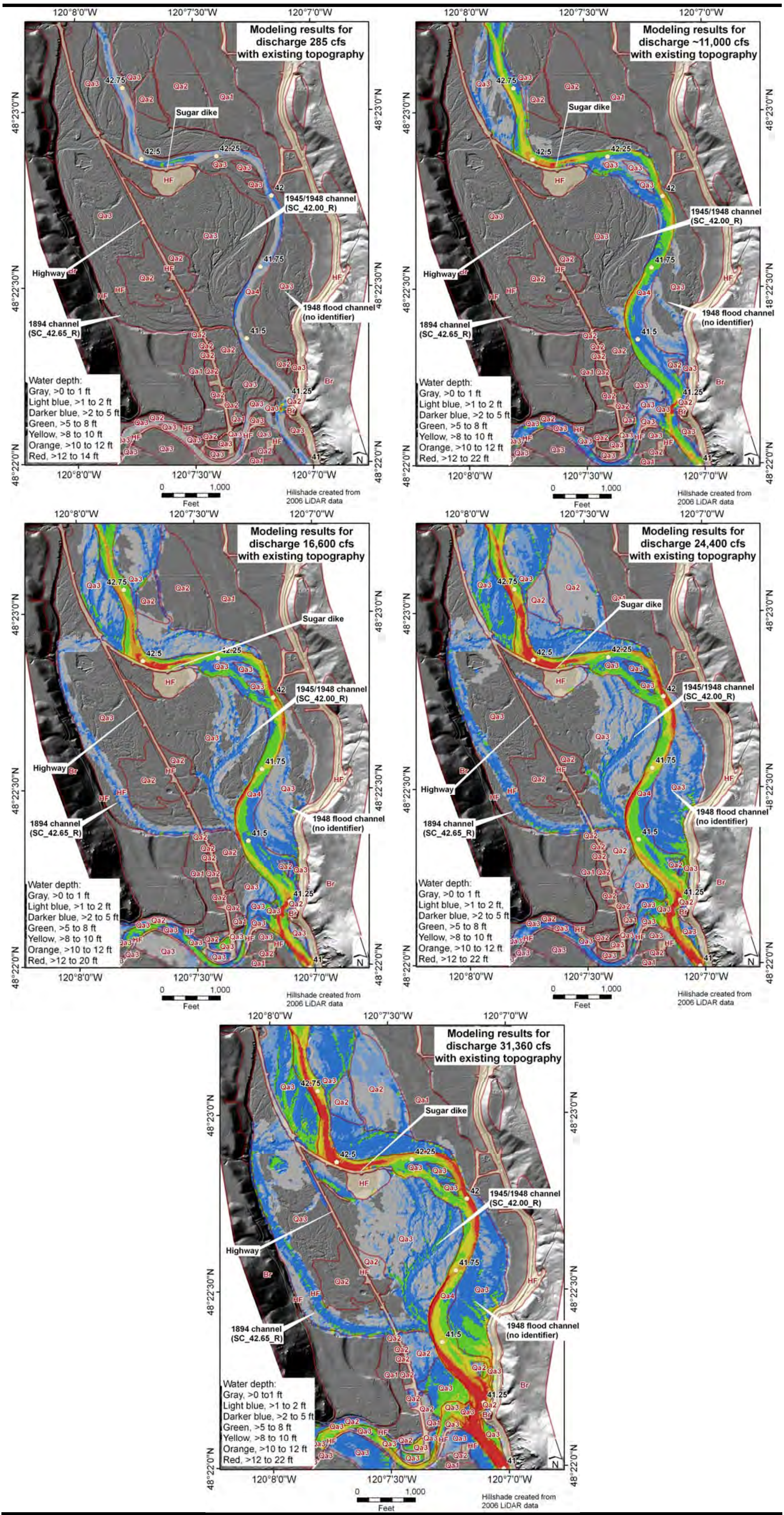

Figure 32. Five model results for the sugar dike-Twisp area.

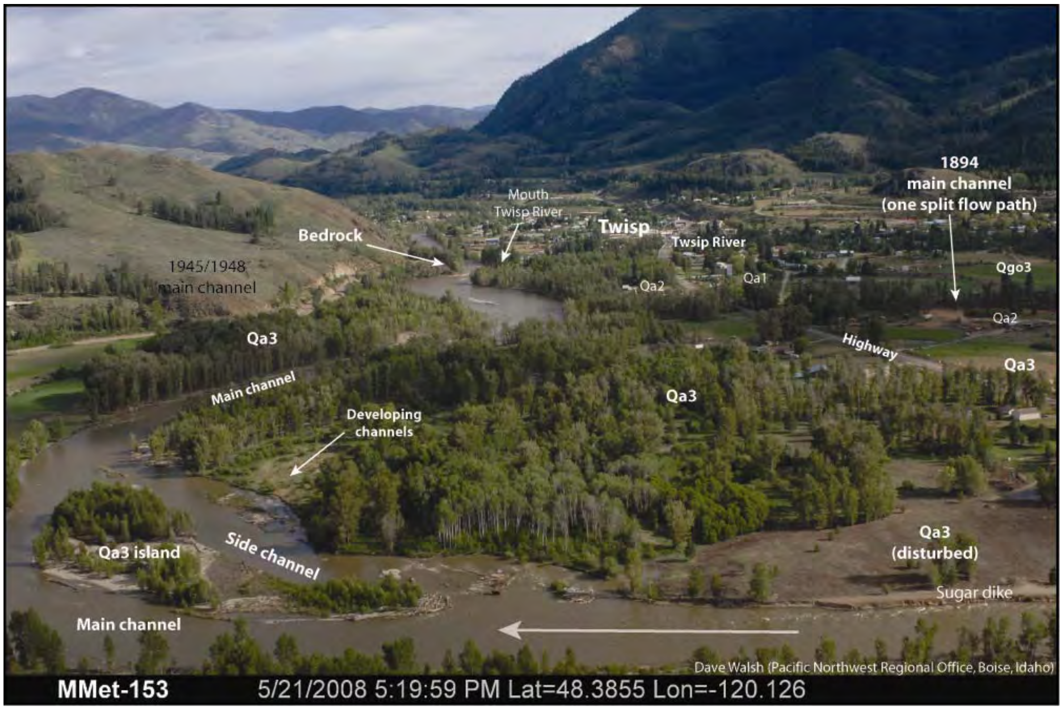

Figure 33. Aerial view looking downstream from near RM 42.25 at the end of the May 2008 flood. *Peak flow was 18,800 cfs on May 19. Photograph was taken on May 21 .*