Abstract: While extensive literature exists on the cause and effect of changes in channel form, documentation on side channel formation, features particularly important as off-channel habitat, is limited. The findings of this paper describe the geomorphic and hydraulic characteristics of side channels along the Middle Methow (M2) reach of the Methow River between Twisp and Winthrop in central 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 was used to identify river areas that have the most potential for side channel development and hydraulic connectivity with the main channel. The information was developed by the Bureau of Reclamation to provide a technical resource for discussions by design engineers, stakeholders, and project sponsors regarding potential rehabilitation opportunities and possible risks, benefits, and/or general constraints on specific projects or treatments (Reclamation, 2008).

INTRODUCTION

Side channels are an important component of salmonid habitat in river systems in the Pacific Northwest. Side channels are dynamic and physical features within river systems and are transient over both space and time. Understanding why side channels exist and how they may change, along with understanding where future side channels are likely to form, is critical for the development of strategies to preserve and increase sustainable side channel salmonid habitat. Human activities can alter the main channel and floodplain geometry, hydrology, and sediment load, which in turn can result in modifications to side channels including the frequency and extent of inundation. Recognition of these changes is needed to identify areas where channel and floodplain processes are impaired, but may be amenable to rehabilitation opportunities.

The Methow River is located on the east side of the Cascade Range in north-central Washington (Figure 1). The Methow River flows about 86 river miles (RM) from the crest of the Cascade Range (elevation 8,950 feet) to its confluence with the Columbia River at RM 524 (elevation 775 feet) and drains about 1,814 square miles. The present study focused on the Methow River between two major tributaries: the Chewuch River (RM 50) and the Twisp River (RM 40). This section is referred to as the Middle Methow (M2) reach. The Methow River is subject to flooding when rain storms occur during late spring-early summer snow melt. The largest documented floods occurred in 1894 and on May 29, 1948. The 1948 flood had a discharge of 31,360 ft³/sec (cfs) at Winthrop (at the Chewuch River confluence). Additional large floods occurred in 1972 (about 25,000 cfs at Winthrop) and in 2006 and 2008 (both about 11,000 cfs). These floods contrast to low-flow conditions of 300 to 400 cfs, which occur from early September through March in most years.
METHODS

To provide a better understanding of side channel development, surficial geology was mapped for the M2 reach. As part of this mapping, side channel characteristics and processes were evaluated by noting changes in the position or planform of the main channel and changes in the existence, position, path, length, or expression of side channels. The side channels and three geomorphic units with which they are associated were delineated using 2004 stereo aerial photographs, elevations and a hillshade created from light distance and ranging (LiDAR) data collected in 2006, field reconnaissance, and inundation depths from two-dimensional (2D) hydraulic modeling (Piety et al, 2010). Age ranges for the geomorphic units were estimated based on historical data, radiocarbon analysis 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. Formation of and changes in side channels
over time were evaluated using historical maps and aerial photographs (1894 or 1900, 1945, 1948, 1954, 1964, 1974, 2004, and 2006), along with historical accounts and ground photographs. The 2D hydraulic model was used to help understand flow patterns that occur in association with the active channel and floodplain and to make predictions for the extent and depth of inundation of side channels and intervening floodplain. Steady state flows (single discharges as opposed to a variable flood hydrograph) were numerically modeled for higher flows. Low-flow modeling was limited to a single flow of 285 cfs for which measured channel survey data were available.

SIDE CHANNEL TYPES, LOCATION, AND HYDRAULIC CONNECTIVITY

Channel types described in this paper are referred to as the main, side, and overflow channels. The active main channel includes the main channel, any split flow paths, and unvegetated or sparsely vegetated bars associated with it. It is the area that carries the vast majority of the sediment load and flow, and it is modified on an annual basis during the highest seasonal flows. Side channels are the smaller channels located adjacent to the main channel or in the active floodplain 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). The active floodplain is a compound unit including surfaces and deposits a few hundred to about a thousand years old (Table 1). The term overflow channels is used to distinguish secondary channels that are present on higher elevation portions of the floodplain, which includes deposits and surfaces a few thousand years old. 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 except during large floods.

Table 1. Types of side channels identified in the M2 reach

<table>
<thead>
<tr>
<th>Side channel type</th>
<th>Geomorphic unit</th>
<th>Estimated age range of surfaces and deposits</th>
<th>Numeric ages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side channels</td>
<td>Active main channel and floodplain (unvegetated)</td>
<td>Historic (a few years to a few hundred years)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Active floodplain (vegetated)</td>
<td>Latest Holocene 300 to 1,000 years (a few hundred years to a thousand years)</td>
<td>≤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</td>
</tr>
<tr>
<td>Overflow channels</td>
<td>Higher floodplain</td>
<td>Late Holocene 1,000 to 2,000 years (a few thousand years)</td>
<td>1,270 to 1,080 cal yr BP; 1,170 to 980 cal yr BP</td>
</tr>
</tbody>
</table>

1See Piety et al (2010) for detailed unit descriptions, surficial map, and explanation of numeric ages.

2Ages shown are for the surfaces on which the side channels are superimposed, not the channels themselves. All geomorphic units include deposits and surfaces with a range of ages. The age range in years indicates the range inferred for most of the unit; the age range in parentheses shows the entire range inferred for the unit.
Along the M2 reach, side channels are present at different positions on the landscape, and, as a result, differ in the way they are formed, how they can be modified over time, their persistence on the landscape, their ability to convey sediment and flow, and the frequency and magnitude of their surface connection with the main channel. As shown on Figure 2, the characteristics of the side and overflow channels differ by the spatial location of the channel relative to the main channel and floodplain, but the characteristics of any single channel also may shift among categories over time as the channels are modified. For purposes of identifying potential habitat, side channels are distinguished primarily by their hydraulic connectivity and, thus, by their capability for transporting flow and sediment (Figure 2). The discharge needed to inundate a side channel is primarily dependent on the location of the side channel relative to the main channel, the elevation of the side channel entrance and exit relative to the surface water elevation in the main channel, and the geometry of the side channel entrance, primarily the angle of departure from the main channel.

![Channel characteristics](image)

Figure 2. Conceptual illustration of characteristics of the main, side, and overflow channels in the M2 reach. The most frequent values are shown by the darker lines; the total range in values is shown by the lighter lines.

Side channels within the active main channel are found at flow splits around islands or mid-channel bars, and along bars located adjacent to the margins of the main channel (Figure 3).
They 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. Consequently, these side channels have the most potential to be inundated during the low-flow periods that occur from late summer through the winter. However, in the M2 reach, many side channels along the main channel do not contain water at low flow (300 to 400 cfs) unless they are inundated by groundwater. Therefore, low-flow habitat is currently limited to the main channel with a few exceptions. At about 11,000 cfs (roughly equivalent to the 2-year flood), all of these side channels are inundated because of their proximity and relative elevation to the main channel. Because of the fairly open upstream and downstream ends that are well connected to the main channel, inundation of these side channels often occurs at both ends of the channel. These channels can transport gravel and wood on an annual basis. Modeling was not performed to determine at what point between 300 and 11,000 cfs inundation occurs and may be beneficial in the future.

The active floodplain has side channels that range from prominent, well-defined side channels to smaller, variably defined overflow channels. The side channels may be connected to the main channel at either their upstream end, downstream end, or both during certain flows. These channels can be large enough to have unvegetated bars associated with them. Wood is often present near upstream entrances and within these channels. The elevations of these channels may be similar to those of side channels along the main channel. Even the most prominent side channels within the active floodplain are not inundated by surface flow during low-flow periods, but some can be inundated at a discharge of about 11,000 cfs, although the floodplain surface is generally not inundated (Figure 4). If the entrance elevation is low relative to the main channel and the depth of inundation is great enough, these side channels convey gravel and wood similar to the side channels along the main channel. If a flow connection with the main channel is sustained, erosion within floodplain side channels may enhance their hydraulic connectivity until they have characteristics similar to those of side channels along the main channel (see Figure 2). Some of the side channels within the active floodplain were observed to have groundwater connections, particularly within their downstream-most sections. One channel also exhibited evidence of a beaver dam.

Figure 3. Examples of side channel along the main channel near RM 47 (left) and near RM 42 (right).
Overflow channels within the active and higher floodplain are only inundated by larger floods (greater than 5-to-10-year floods), and typically convey flood flows only when overtopping and inundation of the floodplain occurs (Figure 4). The form of the overflow channels may be quite variable from shallow channels that convey essentially sheet flow at their upstream ends to well-defined, deeper channels that convey flow that has coalesced at their downstream ends. Because overflow channels are inundated primarily by overbank flow, suspended sediment (fine sand, silt and clay) is transported and deposited in these channels. Gravel in these channels is usually found in their downstream portions and appears to be a lag deposit derived from older underlying deposits that have been exposed by erosion. As the overflow channels deepen at their downstream ends, they may become inundated by backwater flow from the main channel before they develop an upstream surface water connection. 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 lifespans of the salmonid species that might utilize them.

Overflow channels are also present on the higher floodplain. These channels have low relief and can be poorly defined, especially at their upstream ends. They may be only sparsely vegetated, which appears to be the result of artificial clearing, rather than recent channel flow. Wood is rarely present in these channels. The elevations of these channels are usually well above the elevation of the main channel, so that they are activated only during the largest floods (25-year floods or larger), and have little potential of salmonid habitat except as off-channel refuge during these large flood events.

Figure 4. Examples of inundation of channels within the active floodplain. The large side channel shown on the left is inundated by flow up to 5 feet deep at a discharge of about 11,000 cfs. The smaller overflow channels, which require overbank flow for inundation, are shown on the right. A discharge of about 16,600 cfs (about a 10-year flood) is needed to inundate these channels by flows deeper than a foot.
HISTORICAL SIDE CHANNEL FORMATION

In the M2 reach, the formation of side channels is dependent on primarily two processes: main channel migration, including channel avulsion, and floodplain inundation and subsequent erosion (Figure 5). These two processes dominate in different sections of the M2 reach, at different flows, and during different time periods in the historical record.

Figure 5. Example of side channel formation along the study reach illustrated on a 2008 oblique aerial photograph taken during the waning stage of a large flood.

Formation of side channels adjacent to the main channel is directly linked to main channel processes. These channels form in response to annual floods, the movement of sediment, the presence of large wood transported by the river and other physical characteristics of the channel at specific locations that affect flow. Side channels along the main channel form as the main channel switches its dominant path, usually around a bar or vegetated island, or as the main channel erodes into the adjacent floodplain abandoning its original channel path (Figure 6). This can result from localized sediment deposition and erosion or from the growth and removal of vegetation on bars. Formation and erosion of side channels along the main channel are present in each time interval examined.
Figure 6. Formation of a side channel along the main channel near RM 43.75. Only a main channel existed in 1964 (left), but by 2006 the main channel had eroded through the floodplain and an unvegetated bar had formed leaving a side channel where the main channel had been in 1964 (right).

Large side channels within the active floodplain have formed and been eroded primarily through channel migration and avulsion. Because large flows are needed for the substantial bank erosion that accompanies large-scale channel migration and avulsion, these side channels are formed infrequently during the largest floods. In the M2 reach, nearly all of the large floodplain side channels that have formed since 1945 formed as the result of the 1948 flood. Large floodplain side channels were eroded during this flood near RM 42, where avulsion of the main channel left the initial main channel path as a large side channel, and near RM 45, where two new side channels were eroded through active and higher floodplain along the inside of a large meander (Figure 7). In both cases the floodplain surfaces were sparsely vegetated.

Figure 7. Example of formation of large side channels within the floodplain during the 1948 flood. Side channels were not present in 1945 (left), formed during the 1948 flood (center), and were still present in 1954 (right).
Formation of overflow channels is more difficult to assess on the historical aerial photographs, because of the small size of the channels and the sometimes thick riparian vegetation on the active floodplain. On the basis of field observations, overflow channels appear to have formed through overbank flow and headward erosion (Figure 2). Once a small channel forms, it can provide a channel path where subsequent overbank flows are concentrated, so that the channel may widen, deepen, and (or) lengthen in subsequent overbank flows. In order for overflow channels to form, discharges that are large enough to inundate the active floodplain are needed. This occurs during a 2-year flood (about 11,000 cfs), and so these channels can form more frequently than the large side channels on the active floodplain.

**HISTORICAL SIDE CHANNEL EVOLUTION**

Side channel evolution, or modification of a side channel over time, is dependent upon processes that occur both within the main channel as the result of annual flooding and on the floodplain in response to larger infrequent flooding. Modification of side channels includes any detectable change in the topography including geometry, channel alignment, elevation, width, length, or planform. Most side channel modifications occur during floods as a result of erosion and deposition of sediment and wood either in the main channel or in the side channels themselves. When side channels or overflow channels are infrequently inundated, other processes (slope retreat, mass wasting, eolian, biological) may control channel evolution.

Side channels along the main channel and the large side channels within the active floodplain tend to be modified by flood flows, either annually as is the case for the side channel along the main channel, or by larger floods as is the case for the large floodplain side channels. Every time the main channel and floodplain are reworked by the river, mostly during high flows, the discharge needed to inundate a side channel may be modified. Erosion or deposition of sediment and wood near a side channel entrance can either increase or decrease the amount of flow directed into the side channel (Figure 8). If significantly more flow is directed into the side channel, incision of the channel bottom or erosion of the channel banks can result, and the side channel may enlarge. Migration of the main channel away from the side channel entrance may increase the discharge needed to inundate the side channel. If significantly less flow is directed into the side channel, the sediment transport capacity will decrease resulting in deposition of sediment and wood in the side channel (Figure 8). Over time, particularly if the time period between inundation lengthens, vegetation may encroach into a side channel further reducing the capacity of the channel.

Deposition of wood and sediment near the exit of a side channel can cause modification to a side channel by creating backwater or ponding at its downstream end. Ponding may increase the stage in the side channel for a given discharge if the upstream connection to the main channel is maintained. The backwater or ponding may also enhance sediment deposition at the downstream end of the side channel. 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. Backwater at the downstream end of a side channel can also occur due to the presence of beaver dams or human features, such as levees or roads.
Figure 8. Examples of side channels modified by sediment deposition (left) or wood deposition (right). In the example on the left, the side channel was formed when a section of main channel was abandoned due to an avulsion during the 1948 flood. By 1954, a sediment bar formed on the inside of a meander limited the flow directed into the side channel. In later years, this side channel filled with sediment and vegetation, and by 2006 required a 10-year flood for inundation. In the example on the right, wood at the head of a large floodplain side channel can be seen during the May 2008 flood.

The most frequent modifications to side channels have occurred as a result of channel migration at the downstream end of the M2 reach, between about RM 43 and RM 41, where floodplain characteristics create ideal conditions for recurrent, large-magnitude changes in the location and planform of the main channel. In this section, the floodplain is wide and is constrained at its downstream end by bedrock on the left and the sediment and flow that enter from the Twisp River on the right. Modifications in this section of the river have occurred during each historical time interval that was examined. Historical modifications to side channels have occurred elsewhere in the study reach as both a result of natural changes and human activities.

SIDE CHANNEL PERSISTENCE

Although historical side channel modifications have been documented in the M2 reach, many of the large side channels, either along the main channel or within the active floodplain, have remained on the landscape since their formation. The persistence of any particular side channel on the landscape is dependent upon time, the types of processes that contribute to its modification, and the rates at which these processes operate. As long as a side channel is being influenced by the main channel, which occurs primarily during floods, the side channel will persist because it is modified at regular intervals. Once a side channel is no longer being
impacted by main channel processes, the side channel will begin to stabilize and infill. Five large side channels in the M2 reach, those at RM 49.6, at RM 48, near RM 47, near RM 46, and at RM 44.75, have been present since at least 1945, or a minimum of about 60 years. Two of these side channels have remained relatively unchanged over this time interval. Of the large side channels that formed during the 1948 flood, all still persist as side channels except for a short section of a side channel that was destroyed when the main channel migrated into it near the confluence of the Twisp River. Other side channels that have formed more recently also are still present, although for shorter time intervals. However, some side channels, especially those along the main channel and those in the section between RM 43 and RM 41, were present only for one or two of the time intervals examined.

IMPACTS ON SIDE CHANNEL FORMATION AND EVOLUTION

Side channel formation and evolution have been impacted by human intervention in several sections of the M2 reach. At the turn of the century, much of the floodplain appears to have been cleared for agriculture, homesteads, or grazing. To make the active floodplain suitable for these activities, dredging and filling of side channels likely occurred in several locations. Although evidence of these activities can still be seen only in a few locations in the field, human modification of side channels is suspected for other areas. Construction of diversion dams and other irrigation infrastructure, dredging, clearing, and filling in the main channel, along with construction of dikes, levees, and homes in the floodplain, have impacted side channels. These activities alter the amount of flow and sediment in the main channel or in side channels, which in turn alter the topography and hydraulics of these channels. Anecdotal accounts suggest that large wood has been removed repeatedly from the main channel in the M2 reach. Wood and sediment are frequently dredged from a side channel near RM 49.5, an activity that has been done since at least 1945, to maintain surface water diversion capabilities. Many main channel banks have been riprapped, which reduces the quantity of large wood sources within the M2 reach. It is not known if wood has been removed historically from the main or side channels elsewhere. However, logging, log drives in the river, and timber mills were prevalent along many portions of the Methow River historically (Reclamation, 2008). Although wood has been observed on islands and bars in the main channel and in many of the large side channels within the floodplain, the amount of large wood has likely been artificially limited because the floodplain was historically cleared of vegetation.

CONCLUSIONS

Side channels, as defined in this study, are the smaller channels located adjacent to the main channel or in the active floodplain 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 the M2 reach may flow through the active floodplain or along the main channel. In either location, side channels tend to be shallower and narrower than the main channel, and as a result they convey less flow. Side channels that have a well defined entrance and exit with the main channel have the most opportunity to be inundated by surface flow. However, in the M2 reach, side channels that can provide low-flow habitat for salmonids during late summer and winter base flows are currently
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 (Piety et al, 2010; Reclamation, 2008; USFS, 2009, P. Connolly, U.S. Geological Survey, verbal communication, 2009). Observations throughout the M2 reach, as well as along other rivers, suggest that the formation, development, and persistence of side channels is greatly influenced by the frequency and magnitude of inundation (flooding), and the deposition of large wood and sediment. There have been no major changes to the incoming flow and sediment during high flows in the M2 reach, but several small surface water diversions do modify low flows. Analysis of historical aerial photographs indicates that the larger, less frequent discharges are generally responsible for the major changes in the channel geometry for the majority of the reach (i.e., channel migration, avulsion, development of side channels, bar formation, deposition of large wood complexes). The exceptions are the side channels along the main channel and the side channels in RM 41 to 43, where channel migration occurs on a more frequent basis and during smaller floods. Historically, the most significant impacts to side channel development and modification have been dredging activities and small dams constructed in the main channel. These structures increase side channel conveyance. In contrast, roads and levees limit main channel migration or side channel inundation, and hence modify side channel development and evolution. Additionally, clearing of vegetation from channel banks and removal of large wood from the main channel and side channels have altered the hydraulics and connectivity of side channels.

A multi-year biological monitoring effort is being undertaken to improve understanding of existing fish habitat usage, fish migration patterns, and predator and food components. Future modeling efforts could be expanded to include the smaller, more frequent discharges to 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. Repeat survey of side channel topography would also improve understanding of the magnitude and frequency of side channel changes related to the occurrence of floods and human activities in the reach.

REFERENCES

U.S. Forest Service (USFS). (2009). “Middle Methow River Habitat Assessment, River Mile 40.3 to 52.4 (From 0.9 miles below the confluence with Twisp River to the confluence with Wolf Creek)”, U.S. Forest Service, Winthrop, WA.