SEDIMENT AND GEOMORPHIC ASSESSMENT FOR THE POTENTIAL REMOVAL OF CHILOQUIN DAM

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

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Introduction

Chiloquin Dam is located on the Sprague River about 0.9 river miles upstream from the confluence with the Williamson River and is near the town of Chiloquin, Oregon. The confluence with the Williamson River is about 11 miles upstream from Upper Klamath Lake.

Chiloquin Dam was constructed in 1914 to divert water into the Modoc Point Irrigation District Main Canal. The dam has a hydraulic height of 11 feet and forms a permanent reservoir pool that extends about 3,600 feet upstream. The reservoir pool ranges in width from 100 to 250 feet and has an estimated storage capacity of 60 acre-feet.

Fish ladders presently on the dam are damaged and do not function properly. Concerns about fish passage over the dam have prompted the consideration of alternatives that will improve fish passage including replacing, rehabilitating, decommissioning, or constructing new fish ladders on the existing dam. Decommissioning, replacing, or rehabilitating the dam would result in the erosion and downstream transport of sediments (gravel, sand, and silt) presently stored within the reservoir. The Bureau of Reclamation Sedimentation and River Hydraulics Group has been asked to address the sediment and geomorphic related impacts from these alternatives. The volume of sediment deposited within the reservoir and downstream transport of these reservoir sediments is the subject of this report.

Hydrology

The U.S. Geological Survey (USGS) operates a stream gage located on the Sprague River approximately 5.6 river miles upstream of the confluence with the Williamson River (approximately 4.7 river miles upstream of the dam). The USGS also operates a stream gage on the Williamson River approximately 0.8 miles downstream of the confluence with the Sprague River that includes flow from the Sprague River. Figure 1 shows the mean daily discharge for the 2001 water year (October 1, 2000 through September 30, 2001) for the Sprague River and Williamson River, both upstream and downstream of its confluence with the Sprague River. The total drainage area of the flow measured at the Williamson River gage, downstream of the confluence, is approximately 3,000 square miles, which includes the drainage area of the Sprague River basin. The total drainage area of the flow measured at the Sprague River gage is approximately 1,580 square miles. Therefore, the Sprague River represents more than half of the drainage area of the Williamson River where it flows into Upper Klamath Lake.
Mean daily flows begin to rise at the beginning of the water year with the coming of the winter wet season. Since much of the precipitation falls as snow at high elevations, the period of highest mean daily flow occurs during the snowmelt season in the spring. Flow continues to decline throughout the summer reaching a low flow period towards the middle of August into early September. Large floods tend to occur during winter, as shown by the maximum recorded mean daily flows (see figures 2 and 3).

Mean daily flow duration curves were created from available USGS data. Figures 2 and 3 show the maximum and minimum recorded mean daily flows, and the 25, 50, and 75 percent exceedance flows for Sprague and Williamson Rivers, respectively. At the 50 percent exceedance level, flow in the Williamson River ranges from 60% to 30% more than flows in the Sprague River. The same trend holds at the 25 and 75 percent exceedance levels. However, this is not the case for maximum and minimum mean daily flows. Minimum mean daily flows recorded in the Sprague River range from 50 to 280 cfs and minimum mean daily flows in the Williamson River range from 300 to 600 cfs. Maximum recorded flows in the Sprague River are of a similar magnitude to maximum recorded flows for the Williamson River (see figure 4), with flow in the Williamson only 1% greater than flow in the Sprague at times. During low flow, maximum discharge for the Williamson River is as much as 60% greater than flow in the Sprague. Figure 4 shows the annual peak discharge for the two rivers. Figure 5 shows the flow duration
curves for the Sprague and Williamson Rivers, which shows the larger difference in exceedance at low flows with a declining difference in exceedance as flow increases.

Figure 2. Daily flow frequency curve for the Sprague River for the period of record, 1921-2001. Lower line shows the minimum recorded discharge for that date, next line up shows the 75 percent exceedance flow lever (25 percent of all flows recorded on this date are less than this value and 75 percent of flows are greater), red line is the 50 percent exceedance flow level, next line up is the 25 percent exceedance flow level, and the top line in the maximum mean discharge on that date.
Figure 3. Daily flow frequency curve for the Williamson River. Lower line shows the minimum recorded discharge for that date, next line up shows the 75 percent exceedance flow level (25 percent of all flows recorded on this date are less than this value and 75 percent of flows are greater), red line is the 50 percent exceedance flow level, next line up is the 25 percent exceedance flow level, and the top line in the maximum discharge recorded on that date.
Figure 4. Annual flood peaks for the Sprague and Williamson Rivers.

Figure 5. Period of record flow duration curves of mean daily stream flow for the Sprague and Williamson Rivers.
The flow data indicate that the Williamson River is primarily a base flow river. That is, the Williamson River receives most of its water from groundwater sources that tend to be more constant and do not show as much of a response to rainfall events. Groundwater sources will steadily increase during the wet season and decline during the dry season but will not be subject to the extremes of high and low flows as found in surface runoff dominated rivers. The hydrograph (figure 1) of the Williamson River above the confluence with the Sprague shows much less variation in flow and little or no response to rainfall events (no “spikiness”). The Sprague River shows a greater response to surface runoff processes (much “spikiness”) than does the Williamson River, and therefore shows a greater response in the form of higher peak flows and lower flows during the dry season. Overall, baseflow in the Sprague River makes less of a contribution and is much lower than baseflow in the Williamson River.

The bank-full discharge is the discharge at which point the river will begin to overtop its banks and flow onto the floodplain. The 1.5 year flood, which provides an estimate of the bank-full discharge of a river, is 1370 ft$^3$/s for the Sprague River and 2040 ft$^3$/s for the Williamson River below the confluence with the Sprague River.

**Sediment Transport Concepts**

Sediment is the product of weathered rock particles and is transported by wind or water. Sediment particles can be classified by size: including clay, silt, sand, gravel, cobbles, and boulders. The rate at which a river transports sediment is limited either by the supply rate from upstream or by the hydraulic capacity of the river channel. Sediment will aggrade the bed of the river channel if the supply rate is greater than the hydraulic capacity to keep it moving. Sediment can be eroded from the riverbed if the hydraulic capacity exceeds the rate of supply. Downcutting of the river bed can be limited by “armoring” where coarse particles on the bed surface are too large to be mobilized by river flows.

Total stream power is an indicator of a river’s hydraulic capacity to transport sediment. Total stream power ($P$) is computed from the product of river flow ($Q$), longitudinal slope ($S$), and the unit weight of water ($\gamma$), ($P = Q S \gamma$). In general, river slope tends to be steepest in the headwaters and flatten with distance downstream. However, river flow tends to be lowest in the headwaters and increases with distance downstream as more and more tributary streams contribute to the main channel river flow. The unit weight of water can be considered a constant with time and distance. Therefore, total stream power can be computed as a product of discharge and slope ($P = QS$).

The longitudinal profile of the Sprague and Williamson Rivers was computed from the digital elevation model provided by the U.S. Geological Survey and is presented in figure 6. Total stream power for the Sprague and Williamson Rivers was computed for various river reaches using the bank-full discharge for each river and is presented in figure 7. Discharge changes at the confluence, so $Q$ is greater for the Williamson River below the confluence than it is above the confluence and for the Sprague River.
Figure 6. Longitudinal profile of Sprague (red) and Williamson (blue) Rivers.

Figure 7. Stream power for the bank-full discharge of the Williamson (red) and Sprague (black) rivers.
As the Sprague River descends from the mountains, the channel is relatively steep, the bed material is coarse (gravel and cobble sized material), and the sediment transport capacity is moderately high. Therefore, the sand sized sediment supplied from upstream is generally transported through this reach and the coarse channel bed prevents erosion. At about river mile 38.5, the Sprague River enters a meandering reach with a much milder slope and reduced sediment transport capacity. The sediment transport capacity of this reach is likely in balance with the upstream supply rate so that the channel is in dynamic equilibrium. This means that even though the meandering river channel migrates across the river valley, there is no net erosion or deposition over the long term.

At river mile 22.5, the Sprague River enters the bedrock canyon, with Chiloquin Dam located near the exit at river mile 12. The river channel through this bedrock canyon is steep, has a coarse bed of cobbles and boulders, and a relatively high hydraulic capacity to transport sediment. Therefore, sediments are generally transported through this reach without deposition. The reservoir pool behind Chiloquin Dam created a low-velocity environment where sediments deposited until the water depths in the reservoir became shallow enough that river velocities were capable of maintaining sediment transport through the reservoir. The reservoir behind Chiloquin Dam likely filled to its sediment storage capacity after the first few years of operation. Downstream from Chiloquin Dam, the Sprague River maintains a relatively high transport capacity all the way to its confluence with the Williamson River.

Downstream from the confluence with the Sprague River at river mile 11, the Williamson River maintains a relatively high transport capacity to about river mile 9. At this point, there is a significant decrease in the river slope and the transport capacity is relatively low. Sediment deposition is likely to occur in this reach of the lower Williamson River before it enters Upper Klamath Lake.

**Sediment Management Indicators**

The size of the reservoir and the extent of the sediment management problem can be estimated from the following five indicators:

1. The reservoir storage capacity (at the normal pool elevation) relative to the mean-annual volume of river flow.
2. Reservoir width and depth relative to the river width and depth.
3. The purposes for which the dam was constructed and how the reservoir has been operated (e.g., normally full, frequently drawn down, or normally empty).
4. The reservoir sediment volume relative to the mean annual capacity of the river to transport sediment of the same particle sizes within the reservoir.
5. The concentration of contaminants present within the reservoir sediments relative to the background concentrations.

From analyses to date, the approximate reservoir pool volume behind Chiloquin Dam is 60 acre-feet and the average annual river flow is 426,000 acre-feet per year (a mean flow rate of 588 cfs). The ratio of reservoir capacity to mean annual inflow is 0.00014, which corresponds to an expected reservoir sediment trap efficiency of near zero. Trap efficiency is a measure of the amount of sediment that is stored in the reservoir relative to the amount of sediment supplied by the river. A low trap efficiency indicates that very little of the sediment supplied by the river is stored in the reservoir; the majority of sand sized sediment is transported past the dam.

The relative reservoir to river channel width ranges from 1 to 2.5, and the relative reservoir depth ranges from 1.7 to 4.4. These values indicate that the reservoir pool is relatively small. Fine sediments (silt and clay) likely passes through the reservoir, and it is likely that sand-sized sediment passes through the reservoir during high flows. However, gravel and cobble sized sediment would likely continue to deposit in the reservoir.

The dam operations are run-of-the-river meaning that there is no storage of upstream flood flows. The shallow reservoir depth, narrow width, and relatively high reservoir velocity also suggest that most sand sized sediment supplied from upstream is transported through the reservoir to the downstream river channel. Therefore, it is likely that the reservoir sediment storage capacity is full.

Reservoir sediment volume and the transport capacity of the Sprague and Williamson Rivers are analyzed and discussed in the following sections.

Reservoir sediment samples were collected and tested for possible concentrations of contaminants above background levels (see Geologic Design Data Report and Reservoir Sediment Toxicity Assessment). The analysis revealed that contaminants did not exist in concentrations above background levels or detection limits. Therefore, the toxicity of sediments that would be released upon removal of the dam is not considered a problem.

### Sediment Volume Estimate

Two methods were used to estimate the sediment volume behind Chiloquin Dam, a planimetric area method and cross section method, as discussed below.

#### Planimetric Area Method

The planimetric area method was used to approximate the reservoir sediment volume by summing the amount of sediment present in the pre-dam river channel and the amount of sediment present along the margins of the reservoir. The area of the pre-dam main
channel flow through the reservoir was multiplied by the average depth of sediment in the reservoir as obtained from the divers report (Geologic Design Data Report and Reservoir Sediment Toxicity Assessment). Two separate areas were distinguished upstream of the dam in the pre-dam main channel (figure 8). The first area stretched from the dam to 900 ft upstream of the dam. This area was 153,000 square feet and had an average sediment depth of 5 feet. The second area extended from 900 ft to 1600 ft upstream of the dam. This second area was 105,000 square feet and had an average sediment depth of 2 feet. The total volume of sediment estimated from this method is 36,000 cubic yards (49,000 tons, assuming a unit weight for sediment of 100 lbs/ft$^3$). In addition to the sediment within the main channel of the reservoir, there are two areas along the margins that contain a significant amount of sediment (figure 8). These areas are located on the inside of bends in the river, one to the left of the dam (looking downstream) just upstream of the dam, and the other on the right side, approximately 1,000 feet upstream of the dam. The location of these deposits is such that the sediment will likely remain in place during reservoir drawdown and eventually stabilize with vegetative growth. The total estimated sediment volume in these areas is 45,000 cubic yards (61,000 tons). The sediment volume of primary concern is the estimated 36,000 cubic yards (49,000 tons) within the channel area.
Reservoir Sediment Areas

Figure 8. Aerial photograph of the reservoir behind Chiloquin Dam showing the areas distinguished to estimate sediment volume in the reservoir.

Cross Section Method

The cross section method used the existing channel bed slope in the upper reach of the reservoir that does not have any sediment deposition to estimate the pre-dam channel bed slope and elevation for the area currently buried in sediment. A linear regression on the thalweg of cross sections of the river channel above the area of deposition was done to estimate the pre-dam thalweg (see figure 9). The channel cross sections were lowered to the estimated pre-dam elevation and the change in the volume of the channel bed was calculated to determine the volume of sediment deposited behind the dam. Figure 9 shows the current thalweg elevation of the reach behind the dam along with the estimated pre-dam thalweg for areas with sediment deposition. Figures 10 through 12 show cross sections at various locations moving from the dam to approximately 1,500 feet upstream. Sediment deposition extends to approximately 1,700 feet upstream of the dam.
Figure 9. Existing profile of the river channel thalweg of the reservoir (brown), and the estimated pre-dam thalweg (black) for the length of reservoir with sediment deposition.
Figure 10. Current cross section (red) of river channel and estimated pre-dam cross section (black) of river channel. Cross section is located approximately 11 feet upstream of the dam.

Figure 11. Current cross section (red) of river channel and estimated pre-dam cross section (black) of river channel. Cross section is located approximately 885 feet upstream of the dam.
This method tended to include portions of the reservoir margins that were not included in the area method for the main channel sediment deposits. Thus, the cross section method yields a higher sediment volume estimate and is likely an over estimate of the total sediment volume that will be eroded and transported upon removal of the dam. Table 1 shows the current and pre-dam thalweg elevations, change in cross sectional area, and sediment volume in each of the cross sections considered. The sediment volume is calculated as follows.

\[ V_s = (0.5D_d + 0.5D_u)A \]  \hspace{1cm} (1)

Where 
\( D_d \) = distance to the next cross section downstream (ft),
\( D_u \) = distance to the next cross section upstream (ft),
\( A \) = estimated change in area of cross section due to sediment deposition (ft\(^2\)).

This method yields a sediment volume estimate of 45,000 cubic yards (61,000 tons), which is higher than the volume of 36,000 cubic yards (49,000 tons) computed from the planimetric area method. The higher sediment volume of 61,000 tons is used in the sediment transport analysis below since it is a more conservative estimate.
Table 1. Cross sections used to estimate the volume of sediment deposited in the reservoir.

<table>
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<tr>
<th>Distance from Dam (ft)</th>
<th>Current Thalweg Elevation (ft)</th>
<th>Pre-Dam Thalweg Elevation (ft)</th>
<th>Current Hydraulic Depth (ft)</th>
<th>Pre-Dam Hydraulic Depth (ft)</th>
<th>Distance to Downstream Cross Section (ft)</th>
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Total Volume (cubic feet) 1,227,000
Total Volume (cubic yards) 45,000
Total Sediment (tons) 61,000

**Sediment Transport Estimate**

In order to understand and predict the transport of the sediment stored within the reservoir, it is necessary to have a measure of the grain size of the material that will be transported. It is then necessary to estimate the capacity of the river to transport this material from the dam through the Sprague River to the Williamson River and ultimately to Upper Klamath Lake.

**Grain Size Distribution**

Grain size is a significant factor in determining the river’s transport capacity. Larger grain sizes require much greater stream power in order to be moved, while smaller grain sizes are transported more easily through the system. The median grain size, or \(d_{50}\), of the sediment provides a reliable measure of the grain size of the sediment.
Figure 13. Median grain size ($d_{50}$) of sediment from samples taken at 14 location upstream of the dam. See drawing numbers 1898-208-2 and 1898-208-3 for locations of samples.

Sediment samples were taken for toxicity testing that included a grain size analysis. A total of 14 sediment samples were collected primarily from within the reservoir pool from approximately 150 feet upstream from the dam (samples 13 and 14) up to 2,200 feet upstream from the dam (sample 2). Sample 1 was collected approximately 4,000 feet upstream of the dam from the bank of the river before it enters the reservoir. Figure 13 shows the median grain size, $d_{50}$, for each of the samples. Material with a grain size $\leq 0.062$ mm in diameter is fine (silt and clay size) material, and material with a grain size ranging from 0.062 to 2.0 mm is sand size material. The samples were collected on the sides of the pre-dam main channel flow area where more fine material deposits in order to be tested for toxicity. Coarse bed material is not collected for toxicity testing because toxins primarily adsorb to fine grained material. Therefore the grain sizes measured tend to over represent the fine sediment sizes deposited in the reservoir. The fine material will be transported as wash load through the system. Wash load is expected to move through the Sprague and Williamson Rivers to Upper Klamath Lake without significant deposition, but turbidity is expected to increase over a period of days to weeks. Grain size in the main channel of the river where flow is of higher velocity is not as fine as the sediment deposited on the sides of the channel. Sample 2 should be more representative of the average grain size within the channel since it was taken furthest upstream where there is less fine sediment deposition. Additionally, field observations by divers who surveyed the reservoir bottom indicate a median particle size range of 0.2 to 0.4 mm (Mike McCulla, personal communication). This indicates that in the pre-dam channel the $d_{50}$ is within the sand sized range. Therefore, the analysis of sediment transport discussed
below used median particle sizes of 0.25 and 0.5 mm to represent transport of sand sized material.

**Sediment Transport Capacity**

**Sprague River to the Lower Williamson River (River mile 13 to 9.5)**

To assess the potential impact of reservoir sediment released from behind the dam, the estimated reservoir sedimentation volume can be compared to the average annual transport capacity of the river. The average-annual sediment transport capacity was computed using a river hydraulic model, a predictive sediment transport equation, and the long-term flow history of the Sprague River.

Estimated pre-dam river channel cross sections were used for cross sections where sediment deposition had occurred that raised thalweg elevations. These cross sections were used along with existing cross sections in the upper reservoir to obtain estimates of hydraulic parameters needed to compute the sediment transport capacity of the Sprague River if the dam were removed. The US Army Corps of Engineers hydraulic computer model HEC-RAS version 3.0.1 (Brunner, 2001) was used to compute the river profile and hydraulic properties of each cross section. Figure 14 shows the estimated pre-dam thalweg longitudinal profile, the current water surface elevation with the dam, and the water surface calculated using HEC-RAS without the dam at a discharge of 100 cfs. The cross section at 3,600 feet upstream of the dam was used as a representative cross section for all sediment transport capacity calculations. This cross section was chosen because it was in the upstream area of the reservoir not affected by reservoir sedimentation, and the cross section was neither a deep pool nor a riffle. Therefore, it could be used to represent average hydraulic conditions in the pre-dam river channel.
Yang’s (1973) equation for sand was used to estimate sediment transport capacity of the Sprague River. Grain sizes with a $d_{50}$ of 0.5 and 0.25 mm represent medium and fine sand size ranges and were used to represent sand load. Figure 15 shows the resulting sand load rating curves as a function of river discharge (cfs). These sand load rating curves were then applied to all the mean daily flows for the period of record to compute the average annual sand load. The total annual transport capacity for the Sprague River ranges from 206,000 tons for sediment with a $d_{50}$ of 0.5 mm to 315,000 tons for sediment with a $d_{50}$ of 0.25 mm.
The total volume of sediment behind Chiloquin Dam relative to the Sprague River’s capacity to transport sediment over the reach, starting at the head of the reservoir to the confluence with the Williamson, ranges from 20 to 30%. That is, the sediment volume currently behind the dam is only 20 to 30% of the river’s annual transport capacity. The reservoir sediment will readily be transported to the confluence of the Williamson River in a short period of time (weeks to months).

Figure 16 shows the ratio of river transport capacity to the sediment volume behind the dam. For the reach of the Sprague from Chiloquin Dam to the Williamson River (considering the larger sized sediment with a $d_{50}$ of 0.5 mm) the ratio of transport capacity to the sediment volume is approximately 3.3. This indicates that over this reach the river can transport 3.3 times more sediment than the 61,000 tons currently behind the dam. Sand sized sediment will move relatively quickly, over the course of weeks to months, through the lower reach of the Sprague River below the dam to the confluence of the Williamson River. The next reach is the Williamson River from the confluence with the Sprague River downstream to river mile 9.5. The ratio of annual average transport capacity to sediment volume in this reach is approximately 2.3, indicating that the river can transport almost two and one half times the amount of sediment that is behind the dam in an average year. Sand sized sediment would likely be transported through this reach within 6 months of dam removal.
Figure 16. Ratio of annual river transport capacity, by reach, to the total volume of sediment currently stored behind the dam subject to erosion upon removal of the dam for median particle sizes of 0.25 and 0.5 mm.

Lower Williamson River (River mile 9.5 to Upper Klamath Lake)

Sand sized sediment from behind Chiloquin Dam is likely to enter the last 9.5 mile reach within 6 months to a year of dam removal. This last reach of the Williamson River before it reaches Upper Klamath Lake, from river mile 9.5 to the lake, may be divided into 2 reaches—the upper 5 miles extending from river mile 9.5 downstream to near river mile 4.8 (location of the Modoc Point Road Bridge) and a lower reach extending from river mile 4.8 to Upper Klamath Lake. There is not enough detail from the available USGS DEM data to determine the slope of the upper 5 miles. However, it is known that there is a change in slope near the bridge and that the slope of upper 5 miles is steeper than the slope of the lower reach. It is likely that the sediment will move through the upper 5 miles of the lower Williamson River over the course of a few years to a decade depending on the magnitude and frequency of high flows that have a greater capacity to transport sediment.

The majority of reservoir sediment will, over time, likely be deposited in the lower 4.8 mile reach of the Williamson River and not Upper Klamath Lake. The potential impacts of sediment deposition in the lower Williamson River include:
• a rise in water surface elevation increasing the likelihood of flooding, especially for high flow events,
• a reduction in minimum depth of flow that could affect navigation through this reach, and
• a change in substrate and habitat conditions for extant fish species.

The first two potential effects are addressed below.

Graham Matthews & Associates (2002a, 2002b) prepared reports that document changes over time of cross sectional area and substrate in the lower Williamson River for the Nature Conservancy of Oregon. Overall, it was concluded that relatively small geometric changes occurred in cross sections of the lower Williamson River from 1996 to 2001, despite the very large flood event of January 1997. However, there was a net reduction in cross sectional area in this same time period indicating that some deposition is occurring at the some upper cross sections, upstream of river mile 1.95 (see figure 17). The substrate investigation revealed only minor changes in particle size distributions along the reach over the same time period. Figure 18 shows the median particle size at each cross section of the lower Williamson River (substrate data was not presented for cross sections 1.95 and 2.96).

Figure 17. Longitudinal profile of the lower Williamson River from river mile 3.76 to Upper Klamath Lake. Flow is from right to left. Data is from Graham Matthews & Associates (2002a).
The cross section at river mile 2.46 was used as a representative cross section for sediment transport capacity calculations. The sand load rating curves for the lower Williamson River are shown in figure 19. The transport capacity at a median particle size of 0.25 mm is not significantly greater that the transport capacity at a median particle size of 0.5 mm. The average annual sediment transport capacity ranges from 1,200 tons ($d_{50} = 0.5$ mm) to 1,600 tons ($d_{50} = 0.25$ mm). At this rate of sediment transport, the 61,000 tons of sediment from behind Chiloquin Dam would move through the lower reach in 40 to 50 years.

Additionally, the lower reach of the Williamson River was dredged extensively so that it would take 50 to 100 years of natural sediment supply to refill the river bed to pre-dredge conditions (Graham Matthews & Associates, 2002a). Therefore, it is likely that most of the 61,000 tons of sediment released from behind the dam would deposit in the lower reach.
The low average annual transport capacity entails that it will take decades for the sediment deposition on the channel bed to reach dynamic equilibrium. The pattern of deposition (or geometry of the channel bed) was approximated by an analysis of the transport capacity at each cross section and the change of transport capacity that occurs with assumed sediment deposition. The analysis was performed assuming that the total volume of sediment from the dam is present in the lower reach and so that this mass is always conserved. There is a natural tendency for the transport capacity to become uniform over time throughout a given reach and this natural tendency will determine the pattern of deposition. It is not likely that large quantities of sediment will permanently deposit over a very short reach of the lower Williamson River because this will raise bed elevations and increase the transport capacity over the depositional area to such an extent that the sediment will be moved more quickly downstream. The transport capacity would increase significantly and the reservoir sediment would quickly redistribute over a larger area. Therefore, it is expected that over the long term sediment will deposit over a long linear extent in areas of low transport capacity and not cause a significant rise in channel bed elevation or decrease in minimum depth of water.

If the total volume of reservoir sediment were spread out over the entire lower reach of 3.76 miles, the depth of sediment would be approximately 4 inches thick. However, it is much more likely that sediment will move as a wave from the dam to the lower reach of the lower Williamson River, and that there will be intermediate stages of sediment deposition before dynamic equilibrium is reached. If it is assumed that all the sediment is
deposited just below cross section 3.76 extending for 1700 feet (the extent of deposition behind the dam), the depth of sediment would be a maximum of 6 feet. Before sediment could reach this depth, transport capacity would increase greatly and flow would move sediment downstream, especially during high flow periods. Therefore, it is likely that the initial wave of sediment will distribute between the first two cross sections, 3.76 and 3.21, and not exceed 3 feet of deposition.

Figure 20 shows a potential geometry of the longitudinal thalweg profile of the lower Williamson River on the scale of a decade after dam removal. Transport capacities are relatively high between cross sections at river mile 3.76 and 3.21. So it is not likely that more than 3 feet of deposition will occur in this area, and any deposition of sediment from behind the dam will only be temporary in this reach. This is consistent with the measured median particle size at these cross sections since it is coarser than the reservoir sediment (see figure 18). The coarse sand and fine gravel that is currently present will remain between these two cross sections, but not the finer sands that are characteristic of the Chiloquin Dam reservoir sediment. The transport capacity at river mile 2.5 is relatively low, and reservoir sediment will accumulate in this area until the transport capacity is high enough to move sediment to lower cross sections. The higher transport capacity at river mile 3 will transport sediment more readily through this area and cause further deposition at river mile 2.5. Since at the lowest flows the depth of water at cross section 3.76 is the same as the Upper Klamath Lake water surface elevation, the minimum depth of flow does not fall below 7 feet, which will have no impact on navigation.
Figure 20. Longitudinal profile of the lower Williamson River from river mile 3.76 to Upper Klamath Lake. Flow is right to left. Profile shows a likely intermediate geometry of the channel bed a decade after dam removal.

Figure 21 shows the likely geometry of the longitudinal profile of the Williamson River on the scale of decades that probably represents the final depositional pattern of sediment before it reaches Upper Klamath Lake. Deposition will be greater at cross sections with relatively lower transport capacities (cross sections at river mile 1.1 and 2.5) and lesser at cross sections with relatively higher transport capacities.

Figure 22 shows the water surface elevations that result for each estimated channel bed configuration, the original, intermediate, and final (figures 17, 20, and 21, respectively). During high flow, 16,000 cfs, water surface elevation between cross sections 3.76 and 3.21 increases approximately 2 inches as a result of sediment deposition. At flows ranging from 300 to 10,000 cfs, there is no measurable change in water surface elevation as a result of sediment deposition.
Figure 21. Longitudinal profile of the lower Williamson River from river mile 3.76 to Upper Klamath Lake. Flow is right to left. Profile shows a likely final geometry of the channel bed decades after dam removal before sediment is transported into Upper Klamath Lake.
Figure 22. Water surface elevation from Upper Klamath Lake to river mile 3.76 for flows of 3,000, 4,000, 5,000, 10,000, and 16,000 cfs and for varying sediment deposition geometries. Existing WS is for the geometry shown in figure 17, Intermediate WS is for the geometry shown in figure 20, and Final WS is for the geometry shown in figure 21.

Summary and Conclusions

The sediment management indicators for the reservoir sediment are summarized below:

- Relative reservoir size: 0.014 percent
- Relative reservoir width ranges from 1 to 2.5
- Relative reservoir depth ranges from 1.7 to 4.4
- Run of the river operation
- Median reservoir sediment particle size ranges from 0.25 to 0.50 mm (sand)
- Reservoir sediment volume is estimated at 61,000 tons
- Sprague River annual transport capacity is 206,000 to 315,000 tons
- Reservoir sediment volume is 20 to 30 percent of the average annual sand transport capacity
- No contaminants are above background levels

These indicators reveal a minor impact potential if sediment trapped in the reservoir behind Chiloquin dam is released in the river reach between the dam site and Upper Klamath Lake. Reservoir sediment contained in the pre-dam river channel would
completely erode past the dam site by the first winter flood season following dam removal. Silt-sized material would erode rapidly and stay in suspension as wash load until reaching Upper Klamath Lake. This would result in an increase in turbidity for a short period of time, days to weeks, following dam removal. Sand-sized sediment will be transported from the dam downstream to around river mile 9 on the Williamson River relatively quickly, on the order of several months. Sediment will move more slowly from river mile 9 through the next five miles to a point where the slope is further reduced, around Modoc Point Road Bridge. At this point the transport capacity is reduced and reservoir sediment will deposit and likely be permanently stored in the Williamson River, river mile 3.8 to Upper Klamath Lake. Sediment deposition in the lower Williamson River is estimated to have no adverse impact on navigation or flooding risk.

References

