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Sedimen Considerations for Potential Dam Removal Projects

Conducted under Appendix No. 8 to the Agreement between American Institute in Taiwan (AIT) and Taipei Economic and Cultural Representative Office (TECRO) for Technical Assistance and Cooperation for Water Resources

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

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Cover Figure: Looking upstream at Elwha Dam located on the Elwha River in Washington State, USA (photo taken in June, 2009)

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1.0 Introduction

The purpose of this report is to provide planning level guidance to determine the types and level of sediment data collection and analysis needed for potential dam removal projects. This report documents work accomplished in 2009 by Reclamation under the Appendix 8 agreement for Task 5, dam removal consultation. The agreement is part of the technical assistance and cooperation for water resources program between the American Institute in Taiwan (AIT) and the Taipei Economic and Cultural Representative Office (TECRO).

Case studies on sediment analysis are also provided where Reclamation's Sedimentation and River Hydraulics Group at the Technical Service Center was significantly involved in the sediment impact analyses of dam removal. The following case studies are presented:

- Negligible sediment scale
    - Gold Hill Dam, Oregon
- Small sediment scales
    - Chiloquin Dam, Oregon
    - Savage Rapids Dam, Oregon
- Medium to large sediment scales
    - Matilija Dam, California
    - Elwha and Glines Canyon Dams, Washington

In these case studies, the Bureau of Reclamation was not the owner or manager of the dam, but was hired to provide technical assistance because of our extensive experience dealing with reservoir and river sedimentation issues. In the cases discussed in this report, dam removal was selected as the management alternative for river ecological restoration purposes for the following reasons:

- Continued licensing of the dam would require extensive modifications to accommodate fish passage needs that are not economically viable, relative to the benefits of operating the dam;
- The dam no longer provides water supply storage or flood control benefits because the reservoir has filled with sediment; or
- Fish passage and ecological impacts from the dam's presence outweigh the benefits of the dam.

2.0 Deciding on Dam Removal

The total number of dams in the United States is not known. The U.S. National Inventory of Dams has identified slightly more than 80,000 dams that are at least 25 feet (7.6 m) high, store at least 50 acre-feet (64,000 m^3), or are considered a significant hazard if they fail. U.S. National Inventory of Dams website is hosted by U.S. Army Corps of Engineers for 2007 data. Of the dams in the inventory, less than 2 percent are over 100 ft (30 m) high and about half are less than 25 ft (7.6 m). The most common uses of dams and reservoirs are the management of water for industrial and municipal supply, agricultural, flood control, recreation, and power generation purposes. Dams and reservoirs also provide benefits for wildlife and fishery enhancement. In the last 2 to 3 decades, dam decommissioning has become an option for dam owners to consider when the dam no longer meets its original purpose, or the benefits of dam removal outweigh the benefits and costs to maintain the dam's operations. For example, the decision to remove a dam may be focused on eliminating risk associated with the dam's structural integrity, or may be geared toward ecological restoration of river processes and aquatic habitat.

2.1 Available Guidance

The decision to remove a dam is an iterative process that involves establishing and evaluating alternatives in a collaborative framework with several entities. The H. John Heinz III Center for Science, Economics, and the Environment has produced some guidelines to help in the decision making process of whether to remove a dam. This information can be found at www.heinzctr.org. The Aspen Institute has also published a document that provides guidance on dam removal which can be found at http://www.aspeninstitute.org/publications/dam-removal-new-option-new-century-2002. The United States Society of Dams is in the process of developing guidelines to help with determination of construction and engineering considerations for dam removal. The document is expected to be completed in 2010 and more information can be found at http://www.ussdams.org/c_decom.html. Another reference that has been produced is by the American Society of Civil Engineers and can be found at http://cedb.asce.org/cgi/WWWdisplay.cgi?9705367.

In addition, the U.S. Subcommittee on Sedimentation is in the process of developing dam removal sediment analysis guidelines, which are expected to be published in 2010 or 2011.

2.2 Dam Removal Options

When a decision has been made to decommission a dam, structural alternatives range from leaving the dam in place, partial dam removal, complete dam removal, or staged breaching (Morris and Fan, 1997). Partial dam removal could mean leaving a lower portion of the dam in place to retain coarse sediments or leaving portions of the dam near the abutments to retain sediments along the reservoir margins. The selection of which dam removal option is appropriate is usually an iterative process that is not determined until project objectives are defined and alternatives are evaluated, including cost and impacts to people and the environment.

Another important consideration is the timing of dam removal construction that is usually coordinated between sediment management planning and logistical and safety needs associated with construction activities. The rate and magnitude of sediment erosion is closely tied to the rate of reservoir drawdown and the stream discharge available to erode and transport the reservoir sediment. Many dam are removed during low-flow periods, which may have limited erosion immediately following dam removal, but increased sediment erosion and transport during subsequent floods. However, in some cases dam removal is specifically timed to coincide with a high streamflow discharge to maximize the river erosion potential of reservoir sediment and transport the reservoir sediment through the downstream channel over in a shorter timeframe. Downstream impacts may be reduced by removing the dam when there is less risk to water supply and aquatic organisms and their habitat. In systems with multiple reservoirs, it may be possible to coordinate sediment flushing with flow release and sediment sluicing operations of upstream or downstream reservoirs to maximize or limit potential sediment transport and deposition.

The potential for erosion resistant materials within the reservoir should also be considered when selecting a dam removal alternative. Either native or man-made erosion resistant materials could create fish or boat passage problems after dam removal and prevent the erosion of reservoir sediments. For example, investigations may discover that remnants of an older dam or other infrastructure exist in the reservoir impoundment. If field investigations and reconnaissance results indicate a potential for erosion resistant materials, it may be useful to evaluate whether this material is likely to erode through natural river processes. If it is not expected to be eroded, decision makers can consider whether it is desirable to mechanically remove the obstructions as part of the dam removal plan.

3.0 Sediment Management Plan

Management of sediment stored in the reservoir is an inherent component that needs to be considered in any dam removal project. The selection of a sediment management plan is typically determined by weighing the costs with the potential benefits and consequences of allowing reservoir sediment to erode. Sediment management alternatives for dam removal projects can be listed as follows (Reclamation 2006, Morris and Fan 1997):

- River erosion of all or a portion of reservoir sediments
- Bypass river channel around reservoir sediments
- Excavation of sediments
- Hydraulic or mechanical dredging
- Stabilization of sediments (temporary or permanent)
- Staged release of reservoir sediment
- Partial release of reservoir sediment
- Develop a plan that includes capture of released sediment in downstream features such as reservoirs, sediment traps, or other in-stream structures

A sediment management plan can also consist of a combination of these categories. For example, fine sediments could be mechanically removed from the downstream portion of the reservoir to reduce the impacts on water quality. At the same time, the river could be allowed to erode coarse sediments from the reservoir delta to resupply gravel for fish spawning in the downstream river channel. A good reference that provides more information on sediment excavation and dredging methods is Chapter 16 of the Reservoir Sedimentation Handbook (Morris and Fan 1997).

The higher the risk and the more uncertainty associated with sediment impacts, the greater the need for an adaptive management plan that includes monitoring of predicted outcomes. The adaptive management plan should clearly specify initial predictions on sediment processes including rate, duration, and volume of reservoir erosion, sediment transport deposition locations of downstream river changes, and other key areas of concern. Potential monitoring ideas are included in several of the case studies listed at the end of this report.

3.1 Potential Sediment Impacts

The potential impacts from the erosion and subsequent downstream transport and deposition of reservoir sediment should be considered in all dam removal studies. In many cases, there are benefits from the release of reservoir sediment such as the introduction of gravel, woody debris, and nutrients for the restoration of downstream channel morphology (degradation) and aquatic habitats. Alternatively, short-term acute or long-term chronic impacts could result depending on the volume, extent, and particle grain size of reservoir sediment erosion and the duration and timing of the erosion.

The consequence of a dam removal sediment impact could be economic, biological, ecological, or social. Example consequences that could occur are listed below:

1. Partial to no restoration of natural reservoir topography and vegetation
2. Increase in water treatment costs for downstream water users
3. Increased flood stage due to aggradation of the downstream channel
4. Plugging of downstream water intake structures
5. Burial of downstream aquatic habitats
6. Impairment of fish passage or feeding due to increased turbidity
7. Reduction in water table for wells and wetlands in the vicinity of the former reservoir
8. Reduction in the yield of downstream wells to the intrusion of fine reservoir sediments in the upper aquifer.
9. Change in downstream channel migration and bank erosion due to restoration of natural sediment supply or large sediment releases during dam removal
10. Release of contaminants into downstream water supply
11. Downstream reservoir sedimentation

Specifically for river systems with high upstream sediment loads, example consequences of dam removal might include increased sedimentation in downstream reservoir(s) causing a reduction in reservoir life or functionality. In this scenario, it may be desirable to consider reservoir sediment excavation or stabilization prior to dam removal.

3.2 Consideration of Contaminants

In watersheds with industrial histories there is a potential for contaminants to be present in the reservoir sediment that could pose harm if the sediments are released downstream. Impacts from exposure and release of contaminants can affect drinking water, aquatic species in the downstream river, reservoir, or estuary, and potentially terrestrial species. A review of the potential for contaminants in the reservoir sediments should be done in the early phases of dam removal analysis to determine if there is a cause for concern and to help determine what, if any, testing may be needed. The level of the watershed investigation depends on the size of the reservoir and the degree of historical disturbance. Potential questions that can be asked are listed below:

- Were there any historical land use activities (e.g. industrial, urban, and agricultural, etc), in the watershed upstream from the dam, that would have potentially contributed to contaminants within the reservoir?
- What are the most likely contaminants that might be discovered?
- When did reservoir sedimentation occur?
- Have reservoir sediments been periodically flushed from the reservoir?
- Is there a present upstream source of contaminants?
- Is there a substantial (greater than 10%) volume of silt and clay-sized reservoir sediments that would increase the potential for presence of contaminants?

If there is a cause for concern, a sampling plan should be implemented to evaluate reservoir sediment contamination along with upstream and downstream channel sediments to provide present background conditions for comparison. The number of locations of sampling should adequately represent the range of reservoir sediment conditions and take into account any local contamination sources if applicable.
If contaminants are present in the reservoir sediment, it is appropriate to determine what happens to contaminants associated with the fine sediment after dam removal in order to evaluate which sediment management plan is necessary. If the consequences of releasing contaminated sediment to the downstream channel cannot be tolerated, the sediment management plan will need to be focused on stabilizing or excavating the contaminated sediment. Possible contaminant analyses are listed below:

- Predict the concentration and duration of contaminants in the downstream channel and determine whether it will be a acute or chronic source following dam removal
- Compare reservoir sediment contaminant concentrations with background concentrations in the upstream and downstream streambed sediments
- Identify downstream water uses and determine the potential effects of contaminant release water use, aquatic habitat, or other water needs
- Determine the fate and potential consequences of contaminants that are not mobilized following dam removal and remain in the reservoir.

3.3 Scale of the Erodible Reservoir Sediment Volumes

If the reservoir sediment mass that could be eroded following dam removal is large relative to the downstream sediment transport capacity, then alternative dam removal and sediment management strategies should include staged dam removal, partial dam removal, partial sediment stabilization or excavation. Items that may be useful to consider when determining the scale of the reservoir sediment volume include the following concepts (Reclamation, 2008):

- The reservoir sediment trap efficiency, which may be estimated from the original reservoir storage capacity (at the normal pool elevation) relative to the mean annual volume of river flow. The smaller the ratio, the smaller the reservoir sediment trap efficiency and the volume of reservoir sediment.
- The reservoir sediment mass relative to the mean annual sediment transport capacity of the river or the capacity during a flow or flood hydrograph likely to occur during or following dam removal. This can be accomplished for each of the particle size gradations of the reservoir sediment or for the typical reservoir sediment size if the reservoir sediment is fairly uniform.

One potential method for scaling the reservoir sediment is being developed by the U.S. Subcommittee on Sediment, which has been convening workshops of individuals with technical background and experience in sediment processes associated with dam removal in the United States. This information is planned to be published in 2010 in a guidelines to assist with determining the level of sediment data collection and analysis needed based on the scale of the sediment. The Subcommittee on Sedimentation is composed of representatives from U.S. federal agencies, some universities, and other organizations concerned with sediment. The scale of sediment has a separate approach for coarse sediment (sand and larger) and fine sediment (silt and clay) portions of the estimated reservoir volume.

3.3.1 Coarse Sediment

The sediment transport capacity of the downstream channel can be computed for certain discharge frequencies to classify the significance of the coarse reservoir sediment mass:

- Median discharge at time of dam removal (upper limit for negligible mass),
- 2-year flood hydrograph (upper limit for small mass),
- 10-year flood hydrograph (upper limit for medium mass), and
- 50-year flood hydrograph (upper limit for large mass and lower limit for very large mass).

The sediment transport capacity does not have to be computed for all of the above discharge frequencies, only the frequencies that bracket the coarse reservoir sediment mass. The first step is to estimate (using best judgment) the significance of the coarse reservoir sediment mass: Negligible, small, medium, large, or very large.

For coarse sediment (sand and larger), scale the reservoir sediment mass by comparing the reservoir sedimentation mass of sand and gravel to the downstream sediment transport capacity[1]:

- Reservoir sediment mass is less than the transport capacity of the median discharge during the estimated month or season of dam removal **[Negligible coarse sediment mass]**
- Reservoir sediment mass is greater than the transport capacity of the median discharge, during the estimated month or season of dam removal, but less than the sediment transport capacity of the 2-year flood hydrograph **[Small coarse sediment mass];** if no dam removal timing has been determined, consider a range of months in the computation
- Reservoir sediment mass is between the transport capacity of the 2-year and 10-year flood hydrographs **[Medium coarse sediment mass]**
- Reservoir sediment mass is greater than the transport capacity of the 10-year flood hydrograph **[Large coarse sediment mass]**
- Reservoir sediment mass is greater than the transport capacity of the 50-year flood hydrograph **[Very large coarse sediment mass]**

[1] Sediment transport capacity calculated at a downstream river cross section that represents typical capacity to move sediment through the downstream reach.

Analysis Tips:

- If hourly data are available for the 2-, 10-, and 50-year floods, then compute the sediment load for each hour and sum the results to compute the sediment load for the hydrograph.
- If hourly data are not available, then use the mean daily flow for each day of the respective flood hydrograph and sum the results to compute the sediment load for the hydrograph.
- If no discharge data are available for the dam site use regional equations, data from a nearby drainage and scale based on drainage area.

3.3.2 Fine Sediment

For fine (silt and clay) sediment, scale the reservoir sediment using one of two methods, depending on whether suspended sediment data is readily available.

If no suspended sediment load data are available, accomplish the following steps.

- Compute the ratio of the original reservoir storage capacity to the mean annual inflow.
    - Ratio is less than or equal to 0.001 (or 0.1%) and the percent of silt and clay in the total reservoir volume is less than 5 % **[Negligible fine sediment mass]**
- Compute the average annual fine sediment load (see analysis steps below)
    - Average annual fine sediment load less than or equal to 1 year **[Small fine sediment mass]**
    - Average annual fine sediment load between 1 and 5 years **[Medium fine sediment mass]**
    - Average annual fine sediment load greater than 5 years **[Large fine sediment mass]**

Analysis tips:

- Determine the trap efficiency of the reservoir using the Brune trap efficiency curve (see Morris and Fan, 2001)
- Compute the total fine sediment load (Qs) over the period of reservoir sedimentation by dividing the fine reservoir sediment volume(Vfine) by the trap efficiency of the reservoir
- Determine the total years to fill (T) based on the number of years where sediment trapping occurred (e.g. no flushing, excavation, or other removal); include all years regardless of flow magnitude (e.g. dry and wet years);
    - If not sure and the reservoir is still filling with sediment, estimate the total years of sediment as the age of the reservoir
    - If not sure and the reservoir filled long ago, estimate the total years of sediment conservatively as 1 year
- Compute the average annual fine sediment load (Qs avg) by dividing the total sediment load (Qs) by the total years to fill (T)

If fine suspended sediment load data are available, compare the fine reservoir sediment mass of clay and silt to the 2- and 10-year floods.

- Reservoir fine sediment mass is less than the fine sediment load of the median discharge during the estimated month or season of dam removal **[Negligible fine sediment mass]**
- Reservoir sediment mass is greater than the fine sediment load of the median discharge during the estimated month or season of dam removal but less than the sediment load of the 2-year flood hydrograph **[Small fine sediment mass];** if no dam removal timing has been determined, consider a range of months in the computation
- Reservoir sediment mass is greater than the fine sediment load of the 2-year flood hydrograph **[Medium fine sediment mass]**
- Reservoir sediment mass is greater than the fine sediment load of the 10-year flood hydrograph **[Large fine sediment mass]**

3.4 Determining What Portion of Reservoir Sediment is Erodible

Although a large scale of reservoir sediment volume may initially cause concern regarding sediment impacts, the actual volume of reservoir sediment that may erode may be less depending on the reservoir configuration and dam removal option selected. The amount of reservoir sediment that will erode is partially dependent on the inundation area of the reservoir relative to the predicted post-dam removal river channel conditions. In instances where the reservoir width is much wider than the typical river channel width, a significant portion of the reservoir sediment is likely to remain in the reservoir over the long term.

Sediment management plans should also consider the potential for downstream channel degradation to migrate upstream past the dam and reservoir after dam removal, which could alter final reservoir conditions and the amount of sediment introduced to the downstream river system. If there is a moderate to high probability for downstream degradation to progress upstream of the dam and reservoir, then it may be appropriate to consider including some sort of grade control structure in the dam removal and sediment management plan.

4.0 Data Collection and Analysis

This section provides some guidance on questions to ask and considerations for determining what data collection and analysis is needed for sediment assessment associated with dam removal.

4.1 Reconnaissance

The following reconnaissance questions should be answered to help guide the initial data collection for a dam removal study. These questions can be initially answered using relatively low-cost methods including literature review, interviews with dam operators and local residents, field visit and observations, and gathering of easy to obtain data available from public sources.

Dam history and watershed context questions:

- When was the reservoir constructed and by who?
- Who is the present owner of the dam?
- What were the original and present purposes of the dam and reservoir?
- What is the hydraulic height and crest length of the dam?
- Has the dam been raised or lowered?
- Where is reservoir located within the watershed?
- What are the upstream and downstream channel slopes?
- What is the controlling geology at the dam site?
- What is the hydrologic regime, particularly when do floods occur?
- Are there any upstream or downstream storage reservoirs?
- What and where are the major coarse and fine sediment sources and sinks in the watershed where the dam is located? (e.g. tributaries, debris flows, landslides, etc)
- Where are the significant tributaries that affect the downstream reach?
- What is the bed material size of the upstream and downstream channels (e.g., clay, silt, sand, gravel, cobble, D_{50}, D_{90})

Local impact concern questions:

- Why is the dam being considered for removal?
- Who are the local stakeholders?
- What are the key impact concerns?
    - Flooding?
    - Water quality?
    - Infrastructure (e.g. water diversion)?
    - Water supply?
    - Aquatic habitat?
    - Fish passage?
    - Recreation?
    - Cultural resources?
    - Downstream estuary or reservoir sedimentation?

- What is the downstream reach of interest?
- What are the administrative jurisdictions that encompass the reservoir and downstream reach of interest?
- What, if any, endangered species utilize aquatic habitats within the reservoir or downstream channel?
- Where surface water diversions are located downstream of the dam?
- What critical infrastructure is located near the reservoir or downstream channel?

4.2 Reservoir Sediment Characteristics

Determining the reservoir sediment volume, size gradation, and spatial distribution is a critical step in assessing the potential impacts from release of reservoir sediment during dam removal. Errors in these estimates can result in drastic under or over estimations of impacts that can potentially negatively alter dam removal planning and decision making. Answers to the following questions are useful to estimate the reservoir sediment volume. Data collection methods to determine the reservoir sediment volume and mass may include dive inspections, drill holes and sediment cores, estimation of the pre-dam thalweg profile (based on upstream and downstream thalweg profiles), and comparison of bathymetric contour maps of present and pre-dam conditions. The level of investigation should be greater for larger reservoirs than smaller reservoirs. Sediment samples should be taken from representative locations within the reservoir to measure the various types of sediment deposits (tributary deltas, lakebed, and margin deposits).

Reservoir sediment volume questions:

- What is the ratio of the original maximum reservoir depth to maximum natural river pool depth?
- What are the normal operations of the reservoir pool?
  - Run of the river for river diversion or hydropower
  - Moderate to considerable drawdown and refilling for water supply
  - Normally empty for flood control
- Is sediment periodically sluiced from the dam?
- Is there periodic flushing of reservoir sediment due to floods or reservoir drawdown operations?
- What is the ratio of the original reservoir storage volume (at the normal pool elevation) to the mean annual river flow?
- What is the reservoir sediment trap efficiency for fine sediment?
- What was the pre-dam river and floodplain morphology and how would it be expected to influence the magnitude and locations of reservoir sediment deposition? (e.g. is it a riffle-pool morphology, braided, meandering, etc)
- What is the volume of the reservoir sediment?
- What is the ratio of reservoir sediment volume to the original reservoir storage capacity?
- If the reservoir is already filled with sediment, over what period of time did the filling take place?

Reservoir sediment size and spatial distribution questions:

- What is the particle size gradation of reservoir sediment?
  - Delta (typically sand, gravel, and cobble sized-sediment)
  - Lake bed deposit (typically silt and clay sized sediment)
- What is the spatial distribution of reservoir sediment?
  - Is there a distinguishable delta at the upstream end of the reservoir?
  - Has coarse reservoir sediment reached the dam?
- What is the longitudinal profile of the reservoir sediment?
- What is the ratio of the delta length to the original reservoir length?

4.3 Selecting Analysis Techniques

Key questions to be answered are listed below:

- What portion of the reservoir sediment is expected to be eroded past the dam within a few weeks after dam removal, a few months after dam removal, one year after dam removal, and several years to decades after dam removal?
- How quickly will the sediment erode past the dam?
- What will be the fate of the eroded reservoir sediments after they enter the downstream river channel?

The level of analysis completed is dependent on the scale of reservoir sediment volume and the potential consequences associated with release of reservoir sediment. Analysis techniques should at a minimum include a conceptual model of how the reservoir sediment will be eroded. One such conceptual model is available from Doyle et al (2003). Special consideration in the conceptual model is necessary when there is a substantial portion of cohesive sediment or potential for vegetation recruitment in the reservoir that may slow or stop the erosion process following dam removal.

As the scale of the reservoir sediment and potential risk of consequences increases, analysis techniques may be expanded to include analytical tools, physical models, and numerical modeling techniques. Several tools are available and sample techniques are provided in a recently published Erosion and Sedimentation Manual (Reclamation 2006).

5.0 References

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Appendix A: Elwha and Glines Canyon Dams

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Introduction

The U.S. Department of the Interior has purchased, and plans to remove, two large hydroelectric dams on the Elwha River, near Port Angeles, Washington, U.S.A. (Figure 1) to restore the ecosystem and native anadromous fisheries (U.S. Department of the Interior, National Park Service, 1996, 2004, and 2005). Elwha Dam is a 32-m high concrete gravity dam that was constructed 7.9 km upstream from the river mouth in 1913 (U.S. Department of the Interior, National Park Service, 1996). Glines Canyon Dam is a 64-m high concrete arch dam that was constructed 21.7 km upstream from the river mouth in 1927 (Figure 2). Neither dam has provisions for fish passage and there have been significant impacts to native Chinook salmon (spring and summer/fall), steelhead (winter and summer), Coho, chum, pink, and sockeye salmon, coastal cutthroat trout, native char, and forage fish (U.S. Department of the Interior, National Park Service, 1996). After dam removal these fish will have access to more than 100 km of mainstem and tributary-stream habitat.

The headwaters of the Elwha River begin within Olympic National Park and flow northward to the sea in the Strait of Juan de Fuca (Figure 2). The river flows through a series of alluvial valleys and bedrock canyons. Pools, riffles, and rapids are common. Alluvial bars are common upstream from the reservoirs, but the channel bed is characterized by cobbles, boulders, and bed rock in the lower reach that is downstream from the reservoirs. Average river slope in the lower 8 km is 0.4 percent.

Figure 1. The Elwha River is located within the United States of America.

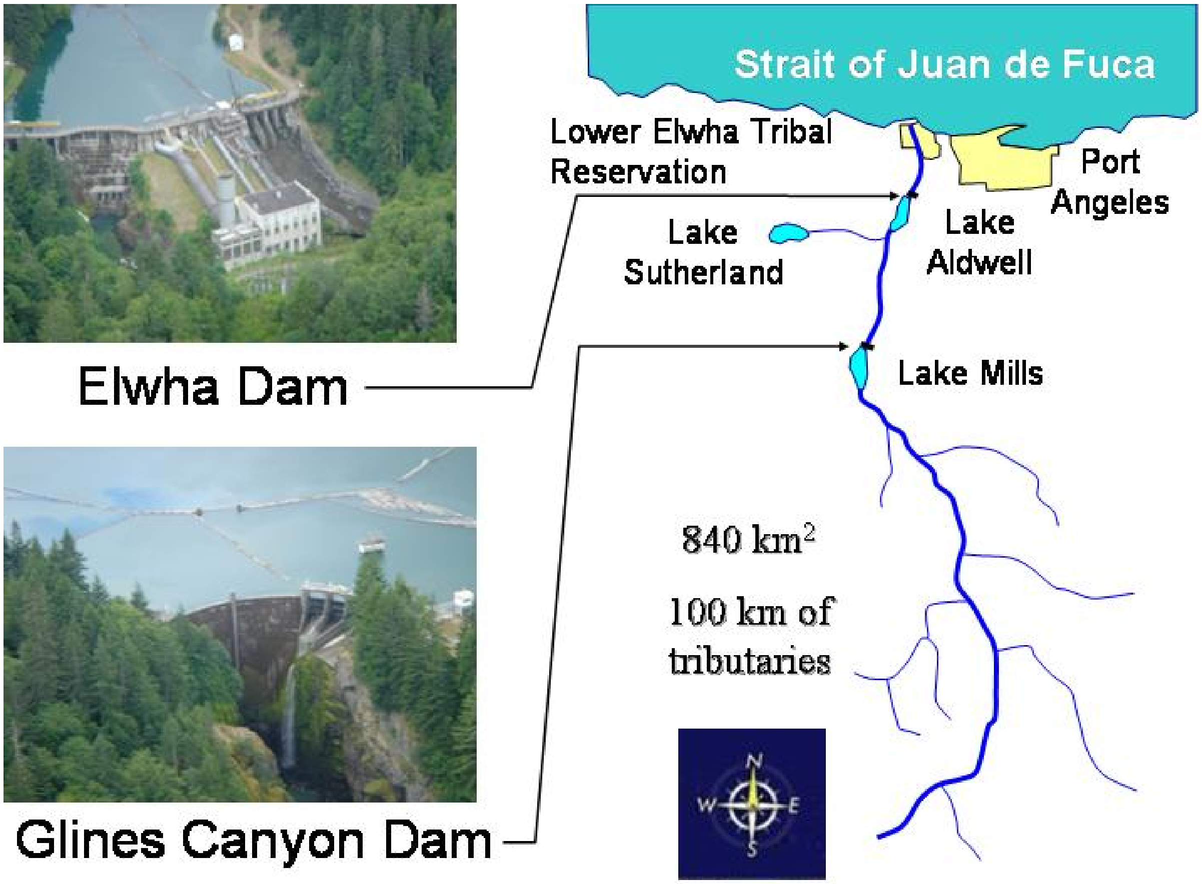


Figure 2. Elwha and Glines Canyon Dams are located on the Elwha River near Port Angeles, Washington, U.S.A..

Lake Aldwell is formed behind Elwha Dam and has a storage capacity of 10 million m^3. Lake Mills is formed behind Glines Canyon Dam and has a storage capacity of 50 million m^3, which is 3.7 percent of the mean annual river flow of 1,300 million m^3/yr (average flow rate of 42 m^3/s). Both dams are operated to keep the reservoir elevations constant (within ± 15 cm) over time, so flood peaks and durations have not been significantly altered.

Reservoir Sedimentation

The reservoirs behind the two dams have trapped the entire upstream load of sand and gravel (67-year average of 82,000 m^3/yr) and are estimated to have trapped 70 percent of the silt and clay load (Randle et al., 1996).

Reservoir sediment volumes were last measured in 1994 (U.S. Department of the Interior, Bureau of Reclamation, 1996a). By 2012, when dam removal may begin, the two reservoirs are predicted to contain 8.4 million m^3 of silt and clay-sized sediments and 8.0

million m^3 of sand and gravel-sized sediments. Sand and gravel-sized sediment have deposited as reservoir deltas while silt and clay-sized sediments have deposited along the lakebeds. The sediment sizes for the two reservoirs are summarized in Table 1.

The total sediment volume of 16 million m^3 for the two reservoirs will be the largest volume of reservoir sediment associated with any prior dam removal and, therefore, offers a unique learning opportunity. Of the original reservoir storage capacity, reservoir sedimentation occupies 27 percent of Lake Mills and 30 percent of Lake Aldwell. The deltas of each reservoir are about 3,000 m upstream from each dam (Figure 3 and Figure 4).

Table 1. Reservoir Sedimentation Volumes and Size Distribution in Lake Mills and Lake Aldwell.

Lake Mills Sedimentation Volumes since 1927		**1994**	**2012**
		Vol (m^3)	Vol (m^3)
Silt and Clay		5,060,000	6,420,000
Sand and Gravel Totals	100%	5,510,000	6,990,000
Lake Aldwell Sedimentation Volumes since 1913		**1994**	**2012**
		Vol (m^3)	Vol (m^3)
Silt and Clay		1,980,000	1,980,000
Sand and Gravel Totals	100%	990,000	990,000
Total Sedimentation within Lake Mills and Lake Aldwell		**1994**	**2012**
		Vol (m^3)	Vol (m^3)
Silt and Clay		7,040,000	8,400,000
Sand and Gravel Totals	100%	6,500,000	7,980,000
Total Reservoir Sedimentation		13,540,000	16,380,000

Figure 3. Photograph looking downstream at Lake Mills, behind Glines Canyon Dam, and the reservoir delta composed of sand, gravel, and large woody debris.

Figure 4. Photograph looking downstream at Lake Aldwell, behind Elwha Dam, and the reservoir delta composed of sand, gravel, and large woody debris.

Elwha River Restoration Plan

The restoration plan is to remove both dams and allow the river to erode a portion of the reservoir sediments for transport to the sea. Downstream water users will be protected by the construction of three new water treatment plants, new wells, and a new water diversion facility with improved fish passage. Downstream landowners will be protected by raising the height of existing levees and the construction of new levees (U.S. Department of the Interior, National Park Service, 2004 and 2005).

The sediment management plan is to concurrently remove both dams in controlled increments over a two to three-year period and allow the Elwha River to erode and redistribute the reservoir sediments. Concurrent removal over a two to three-year period is considered fast enough to limit the sediment impacts to only a few year classes of fish, but slow enough that impacts to downstream water users and landowners can be tolerated (U.S. Department of the Interior, National Park Service, 1996).

Neither dam has a low-level outlet that can drain the reservoir. Each reservoir will be drawn down to the extent possible using the existing spillways and penstocks (U.S. Department of the Interior, Bureau of Reclamation, 1996b). A series of notches will be cut into Glines Canyon Dam to drain the remaining portion of the reservoir. For Elwha Dam, a river diversion channel will be cut below the existing spillway channel to drain about one-half of the reservoir head. A series of notches then will be cut into the remaining portion of Elwha Dam to fully drain the reservoir.

Reservoir Sediment Erosion

Predictions of the sediment impacts associated with dam removal are based on the 1994 drawdown experiment of Lake Mills (Childers et al., 2000), a mass-balance numerical model (Randle et al., 1996), and physical modelling of the reservoir sediment erosion (Bromley et al., 2005).

During dam removal, the reservoir water surface elevation would be held at a constant elevation between drawdown increments of 2 to 3 m to induce lateral erosion of the reservoir sediments (Figure 5). The optimum increment of reservoir drawdown would cause just enough delta erosion to re-deposit a new delta completely across the width of the receded reservoir. The reservoir drawdown increments are expected to create a series of sediment terraces along the reservoir margins until the eroding delta sediments have reached each dam (Randle, et al., 1996).

a. b.

Figure 5. Photographs of Lake Mills during the 1994 drawdown experiment: Eroded delta sediments re-deposited across the width of the receded reservoir (a) and sediment terraces were deposited along the margins of the reservoir (b).

The predicted reservoir sediment erosion volumes are presented in table 2 under four separate hydrologic scenarios (Randle, et al., 1996). Between one-quarter and one-third of the sand and gravel-sized sediments (1.7 million to 2.4 million m^3) are expected to erode from the reservoirs and be transported downstream to the sea as bed-material load. Between one-half and two-thirds of the silt and clay-sized sediments (4.1 million to 5.0 million m^3) are expected to erode from the reservoirs and be transported downstream to the sea as suspended load (Randle et al., 1996). The remaining reservoir sediments are expected to stabilize and become covered with woody vegetation over the long term.

The reservoir sediment erosion model results are based on the simulation of four historic hydrologic periods:

(1) 1950 to 1963 begins with one year of relatively high annual peak discharge, followed a year of relatively low peak discharge, and then a year of moderate peak discharge.

(2) 1968 to 1981 begins with the lowest peak discharge for any three consecutive water years of record.

(3) 1971 to 1984 begins with progressively higher annual peak discharges in each of the three years.

(4) 1989 to 2002 begins with the highest peak discharge for any three consecutive water years of record.

Reservoir drawdown and Elwha River flows are expected to be the primary causes of reservoir sediment erosion, but tributary streams that enter the reservoirs are also expected to erode gullies through the reservoir sediments. In addition, rainfall runoff is expected to cause some additional erosion of sediment deposits along the reservoir margins.

Table 2. Reservoir Sediment Erosion Summary

Reservoir Sediment Volumes expected by the year 2012 (m^3)		Sediment erosion volumes (m^3) under four historic hydrologic periods: 1950 to 1963	1968 to 1981	1971 to 1984	1989 to 2002
Lake Mills Sediment	**13,400,000**	**4,700,000**	**5,300,000**	**5,000,000**	**4,600,000**
Silt and Clay	6,420,000	3,700,000	3,900,000	3,900,000	3,000,000
Sand	4,980,000	700,000	1,000,000	800,000	1,100,000
Gravel	2,020,000	280,000	400,000	320,000	460,000
Lake Aldwell Sediment	**2,970,000**	**1,900,000**	**1,900,000**	**1,900,000**	**1,900,000**
Silt and Clay	1,980,000	1,200,000	1,200,000	1,200,000	1,200,000
Sand	837,000	590,000	590,000	600,000	610,000
Gravel	149,000	110,000	110,000	110,000	110,000
Total Reservoir Sediment	**16,400,000**	**6,600,000**	**7,100,000**	**6,900,000**	**6,500,000**
Silt and Clay	8,400,000	4,900,000	5,000,000	5,000,000	4,100,000
Sand	5,810,000	1,300,000	1,600,000	1,400,000	1,800,000
Gravel	2,170,000	390,000	510,000	430,000	570,000

Downstream Sediment Transport and Geomorphic Effects

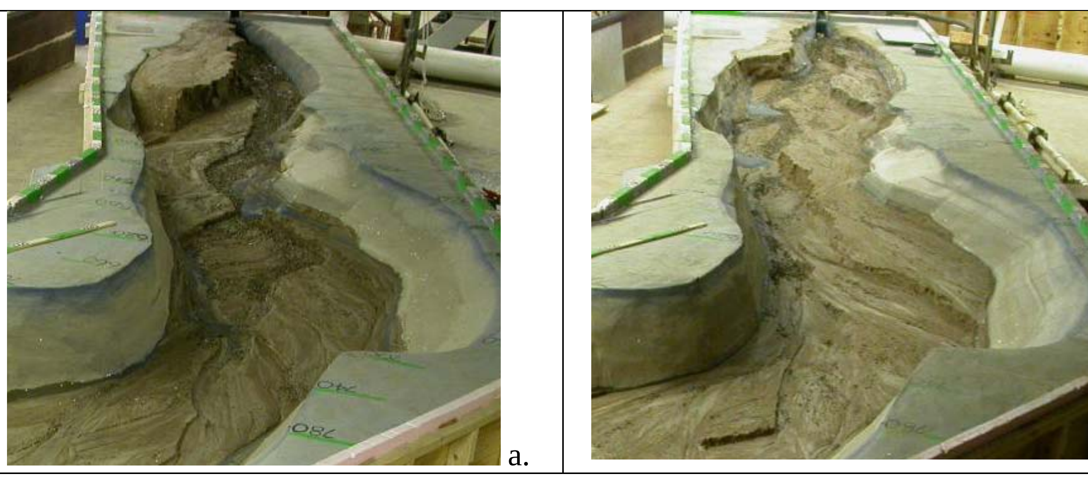
Depending on the hydrologic regime and the rate of reservoir sediment erosion, turbidity is expected to exceed water quality standards (greater than 5 NTU's or 10 percent of the natural turbidity upstream from the reservoirs) during three-quarters of the three-year dam removal period. Peak suspended sediment concentrations during dam removal are predicted to be between 10,000 and 40,000 ppm. General riverbed aggradation could increase the 100-year flood stage by up to 1 m in response to reservoir sediment erosion and by allowing the natural sediment supply from the upstream watershed to reach the lower river (Randle et al., 1996).

The erosion and release of coarse sediment from the reservoirs is expected to successively aggrade river pools in a downstream progression over the short term. The water surface profile would only significantly increase if there were significant aggradation on the riffles, which have steeper slope, higher river velocity, and higher sediment transport capacity than river pools. If coarse sediment did aggrade the riffles, then river flows would begin to enter and widen secondary river channels. Thus, the river channel would tend to migrate laterally by occupying and eroding the banks and vegetation of old river channels. This means that the river channel would move laterally if the amount of aggradation became too much in any one location. As the sediment loads increase and the channel bed aggrades, the river channel would tend to flow in a straighter and more braided pattern. Over the long-term, the Elwha River would likely reach a new equilibrium similar to that of the pre-dam river.

Adaptive Management

An adaptive management monitoring plan will be used to determine if actual sediment impacts agree with predictions and if the new water treatment plants and flood control levees can accommodate the increases in suspended sediment concentration and river-bed aggradation. Initially, monitoring will focus on the erosion and redistribution of reservoir sediments. Once sediments are released from the reservoirs, downstream monitoring will focus on turbidity and suspended sediment concentration and on aggradation of the channel bed. Early detection of significant channel-bed aggradation will trigger additional monitoring. Detection of system-wide aggradation or high sediment concentrations that begin to approach flood-control or water-treatment capacities will trigger a slower rate of dam removal or a temporarily halt to dam removal. If localized problems are identified through monitoring, then attempts will be made to treat the problem locally.

Physical modeling (Bromley, et al., 2005) and field evidence suggest that the reservoir deltas are most like to naturally erode along their reservoir margins. Even though multiple channels may initially erode the deltas, a single erosion channel in each reservoir may eventually capture Elwha River flow from other erosion channels. If a single erosion channel incises the delta along the reservoir margin, then a substantial portion of the delta could be left in place immediately after dam removal (Figure 6a). These delta sediments would be vulnerable to uncontrolled erosion after dam removal is complete. Physical modeling has demonstrated that the initial formation of a pilot channel along the delta centre was effective at eventually eroding and redistributing a substantial portion of the reservoir delta (Figure 6b).



a. b.

Figure 6. Physical Model Experiments of Lake Mills sediment erosion by Chris Bromley without a pilot channel (a) and with a pilot channel (b).

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Appendix B: Matilija Dam

Written by Blair Greimann, Sedimentation and River Hydraulics Group, Bureau of Reclamation, Denver, Colorado.

Introduction

Matilija Dam was built in 1947 with an initial reservoir capacity of 7,018 ac-ft. It is located on Matilija Creek, which joins with North Fork Matilija Creek approximately 0.6 miles downstream to form the Ventura River (Figure 7). It was original constructed as a 160 ft sill height, but a 30 foot notch was cut in 1965 in the dam and approximately 2600 ac-ft was lost. The upper part of the dam had alkali-aggregate reaction that caused the concrete in the upper section of the dam to be weakened. The original purpose of the dam was water storage for the local community. However, the dam is now practically full of sediment and its usefulness is lost. The dam is an impediment to southern steelhead trout passage, and the trout is an endangered species. Under the authority of the Endangered Species Act, the US Army Corp of Engineers and the County of Ventura are now funding studies to design the removal of the dam.

Hydrology

The flows in the Ventura River basin are highly variable. The historic peak flows are shown in Figure 8. The annual peak flow has varied between essentially zero and 20,000 ft^3/s. The flows with a specific return period are given in Table 3. The large flows events are very short lived and the flow can quickly recede after the rain stops (Figure 9). The annual flow volumes at Matilija Dam are shown in Figure 10. The average annual flow is about 30,000 ac-ft, but is highly variable from year to year and the average flow is not a good indicator of an average year. It is more likely that the flow at the dam will be significantly higher or lower than this value.

River Characteristics

Just downstream of the dam, Matilija Creek is confined in a canyon for approximately 1 mile. The river has then joined with North Fork Matilija Creek and is called the Ventura River. The Ventura River is primarily a braided river channel downstream (see Figure 11). The river slope is approximately 1.5% at its beginning and gradually decreases to about 0.5 % just upstream from its mouth (Figure 12). The river width varies between about 150 feet for the first 2 miles downstream of the dam, to about 350 feet in the flatter downstream sections. Because of its steep slope and high flow rates, it has a high sediment transport capacity during flood events. The suspended sediment loads are very high during floods and commonly exceed 10,000 mg/l. The representative surface bed material in the river is given in Figure 13.

Reservoir Sedimentation

Sedimentation in the Matilija Reservoir has been a concern since its construction and a photograph of the current reservoir is shown in Figure 14. Matilija Reservoir currently has less than 500 ac-ft of capacity remaining and its usefulness as a water storage facility is significantly decreased. There is currently about 6 million yd^3 of sediment deposited behind the dam, at a maximum depth of about 80 ft against the face of the dam. The dam currently traps all sand-sized and larger material. It is estimated that most of the silts and clays pass over the dam during flood flows. An extensive drilling program was performed on the reservoir sediment and the physical properties of the sediment are given in Table 4. Eighteen drill holes were collected in the reservoir deposit. The sediment collected from these holes was analyzed for its physical and chemical properties. No significant contamination was found in the reservoir sediment.

The sediment deposit was broken in to three sections. The reservoir area is the area currently still under water and it primarily silts and clays. The delta region is above water and is dominated by sands, but has silts, clays, and some gravels. The upstream channel area is just upstream of the delta and has few fines and is a mixture of sands, gravels, and cobbles. The reservoir width is approximately 3 times greater than the river width. The reservoir delta extends about 7,000 ft upstream from the dam.

Sediment Impact Concerns

There is considerable development adjacent to the Ventura River. The aggradation that will result from the release of the stored sediment and resupply of the natural sediment load will increase the flood risk to several residences downstream of the dam. These residences must be purchased or protected as part of the project. There is also a major diversion approximately 2 miles downstream of the dam (Robles Diversion). Robles Diversion feeds the only major water storage facility in the Ventura Basin and the water supply needs to be protected.

Dam Removal Plans

The dam removal study is currently in the design phase. There are several mitigation measures that will be constructed as part of the dam removal. The general are to mitigate the impacts caused by the release of the sediment to the downstream reach. They are:

1. One new levee is being constructed and another is being raised.
2. Additional radial gates are being constructed at Robles Diversion downstream of the dam. This will allow more sediment to be sluiced downstream and not deposit behind the diversion dam.
3. Several private properties that cannot be protected from the increase in flood risk will be purchased.
4. A desilting basin will be constructed on the canal leading from the diversion.

5. A smaller surface water diversion approximately 10 miles downstream of the dam is being replace with a groundwater well. This will allow the water treatment plant to withdraw cleaner water.

To remove the dam and prevent sediment from overwhelming Robles Diversion, much of the fine sediment in the reservoir area will be excavated or transported by slurry line from behind the dam. It is estimated that up to 2.1million yd^3 of material will be moved. The disposal site for this material is still being discussed. Because of the development and steep environment, there is little available space for a disposal site. One likely alternative is that most of the fine material will be stabilized in place upstream of the dam. The coarse sediment in the delta and upstream channel areas will be naturally transported downstream.

Figure 7. Overview of Ventura Watershed.

Table 3. Flow rate at various return periods on Matilija Creek and Ventura River.

	Flood Flows at Selected Locations (ft³/s)					
Return Period (yr)	**Upstream of Confluence with N. Fork Matilija Creek**	**Downstream of Confluence with N. Fork Matilija Creek**	**Baldwin Rd.**	**Casitas Springs**	**Casitas Road Bridge**	**Shell Chemical Plant**
2	3,060	3,250	3,380	4,130	4,520	5,080
5	7,090	7,580	7,910	9,820	11,060	12,250
10	12,500	15,000	16,000	35,200	36,400	41,300
20	15,200	18,800	19,800	44,400	46,400	52,700
50	18,800	24,000	24,800	56,600	59,700	67,900
100	21,600	27,100	28,300	66,600	69,700	78,900
500	27,900	35,200	36,700	89,000	93,100	105,500

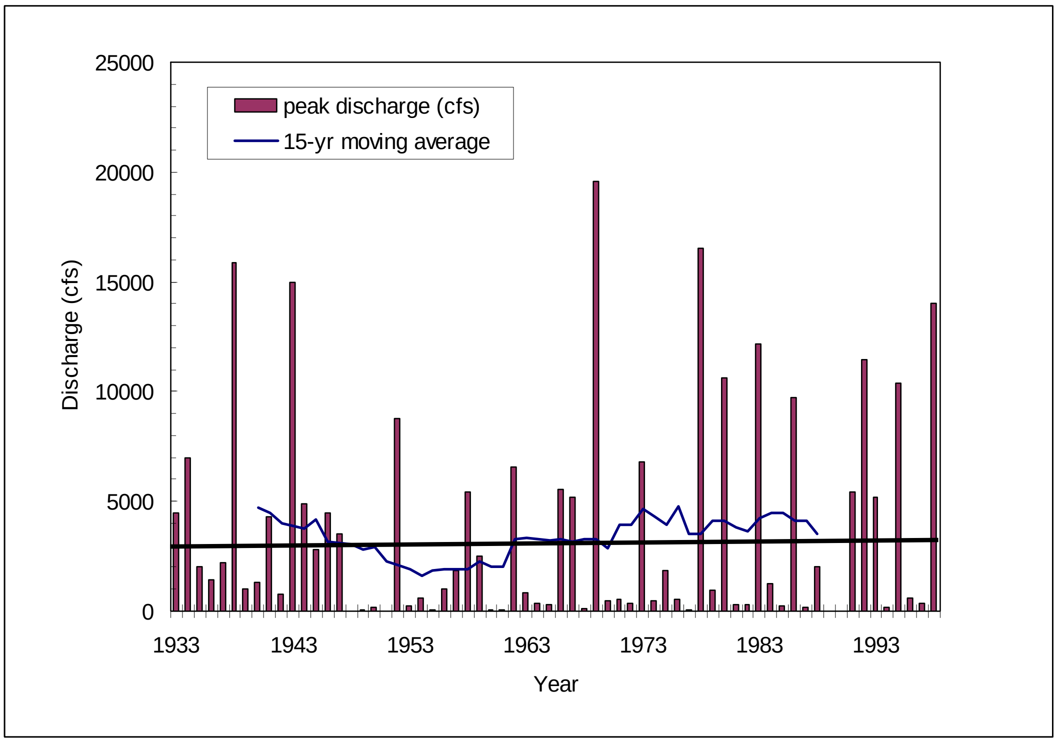

Figure 8. Peak Discharge at USGS gage 11115500, downstream of Matilija Dam on Matilija Creek. Flows between Oct 1 1988 and Sept 30 1990 were not available at this gage.

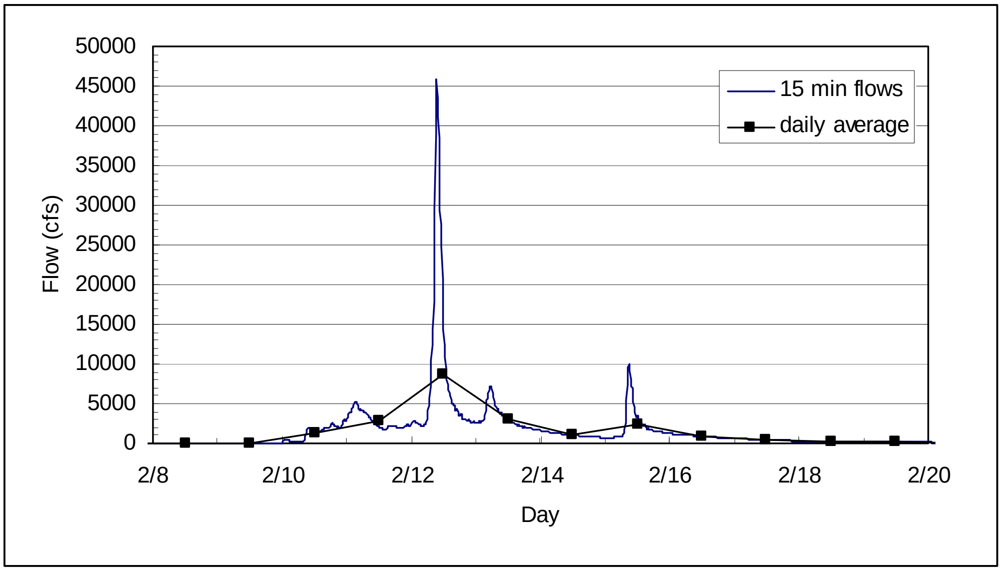

Figure 9. Comparison of 15-minute instantaneous hydrographs and daily average hydrographs for the 1992 flood at Foster Park gage on the Ventura River (USGS gage 11118500).

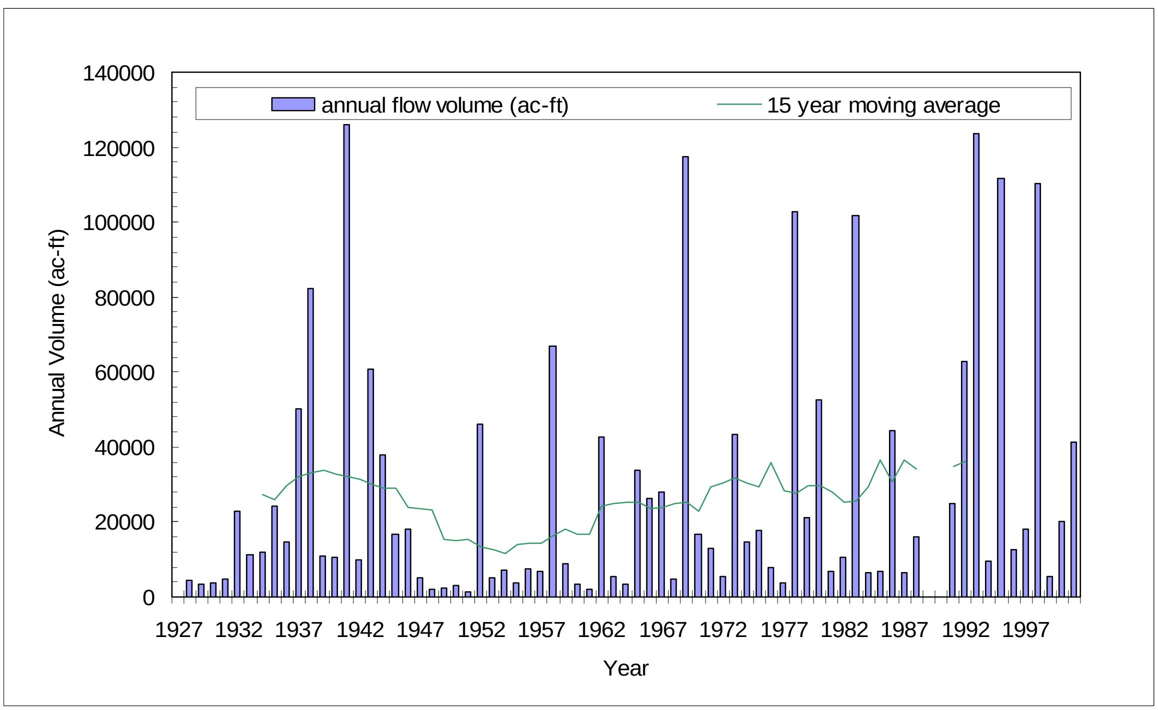

Figure 10. Annual flow volume at USGS gage 11115500, downstream of Matilija Dam on Matilija Creek.

Figure 11. Overview of site.

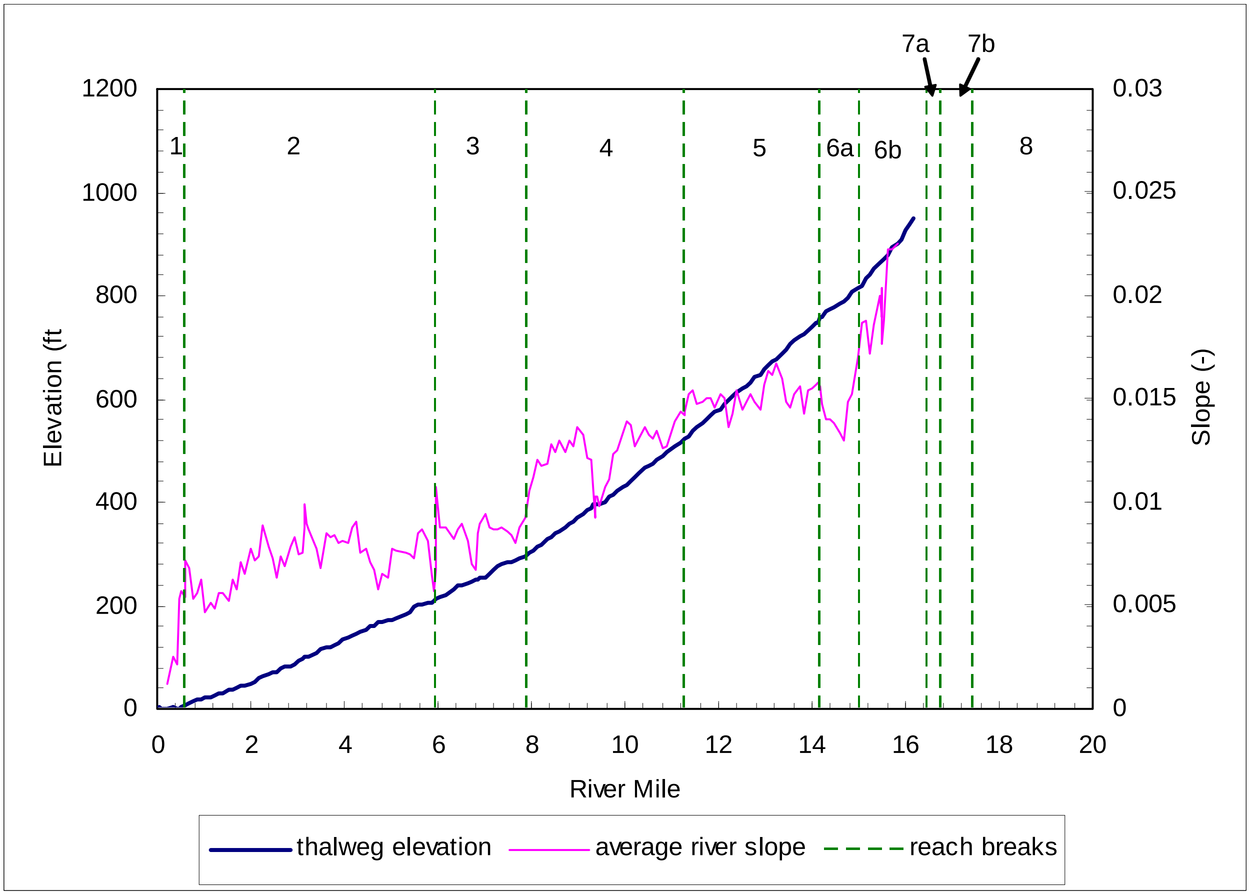

Figure 12. River profile downstream of Matilija Dam. Matilija Dam is at RM 16.3.

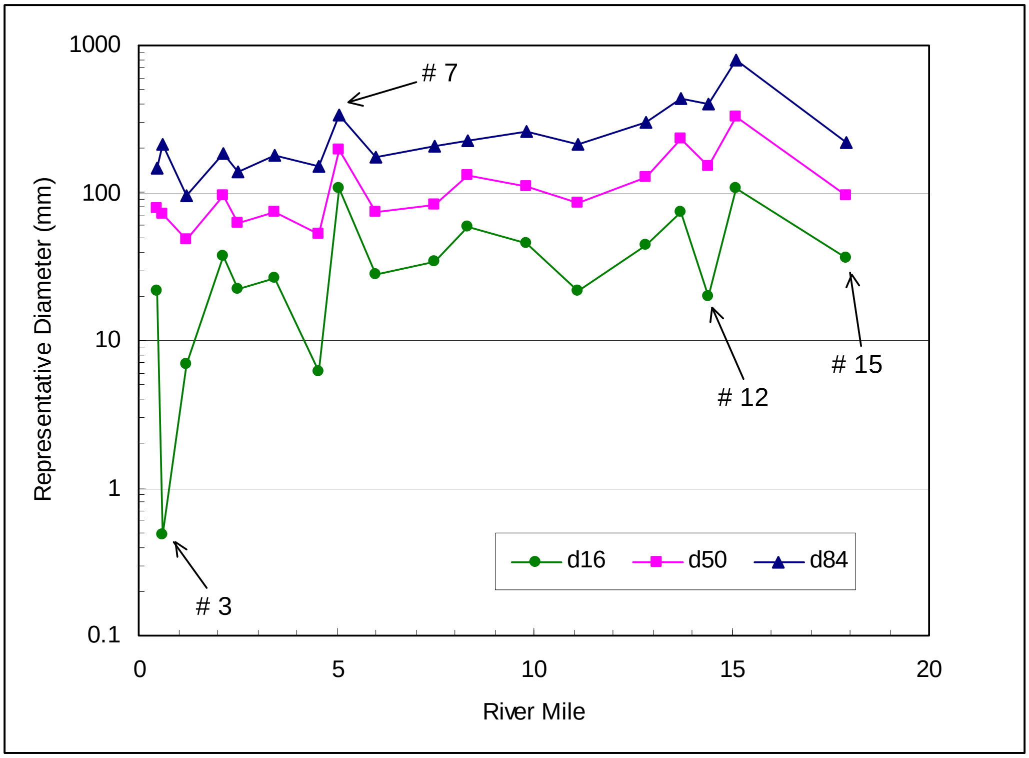

Figure 13. Surface bed material in Ventura River.

Figure 14. Picture of sediment trapped behind Matilija Dam while the reservoir was drawn down. Picture was taken in July 2003 by Paul Jenkin of the Surfrider Foundation.

Table 4. Gradations and Sediment Volume Determined from Drill Data.

	% finer than		
Grain Diameter (mm)	**Reservoir**	**Delta**	**Upstream Channel**
512	100.0	100.0	100.0
256	100.0	100.0	87.9
128	100.0	100.0	75.9
64	100.0	99.8	60.9
32	100.0	98.4	48.9
16	99.9	95.1	36.9
8	99.8	92.5	29.9
4	99.7	89.9	24.9
2	99.7	87.3	21.9
1	99.5	83.7	18.4
0.5	99.0	77.5	15.0
0.25	97.2	66.5	12.0
0.125	92.2	50.8	9.0
0.0625	82.8	33.2	6.0
0.031	70.9	21.9	4.0
0.016	57.3	14.5	2.0
0.008	43.1	9.7	1.0
0.004	30.1	5.3	0.0
0.002	18.0	0.0	0.0
Total Volume (yd^3)	2,100,000	2,800,000	1,000,000

Study References

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Appendix C: Savage Rapids Dam

Written by Jennifer Bountry, Sedimentation and River Hydraulics Group, Bureau of Reclamation, Denver, Colorado.

History

When was the reservoir constructed and by who?

Savage Rapids Dam was built in 1921 to divert river flows for irrigation (Figure 15). The dam is operated by the Grants Pass Irrigation District (GPID). Modifications were made to the dam in the 1950s that included installation of two radial gates and excavation of a channel in bedrock that allow the reservoir to be partially drawn down and sluice sediment for purposes of installing or removing stop logs.

Figure 15. View of Savage Rapids Dam, located on the Rogue River in southwestern Oregon, U.S.A. on February 23, 1999 when the mean-daily flow was 7400 ft^3/s (210 cms).

What is the purpose of the dam and reservoir?

The dam is utilized to divert water for irrigation customers during the months of April through October. The reservoir is also utilized for recreational boating and fishing, mostly during the irrigation season when the pool is extended from ½ mile to 2 ½ miles (0.8 to 4.0 km).

What is the size of the dam?

The dam is a combination gravity and multiple arch concrete dam with a crest length of 464 feet (141 m) and a structural height (total height of the dam from the foundation to the top of the crest, including the stop logs) of 39 feet (12 m) (Reclamation, 1997). The hydraulic height of the dam (height of the structure from the original channel bed elevation to the crest of the dam) is 30 feet (9 m). The crest elevation of the dam is 957.6 feet (291.9 m) in the 1988 North American Vertical Datum (NAVD) (elevation 953.0 feet (290.5 m) in the 1929 National Geodetic Vertical Datum [NGVD]). Fish ladders are present on both ends of the structure, with the north ladder located on the right abutment of the dam and the south ladder located on the left, adjacent to the headworks for the Gravity Canal.

What are the reservoir pool normal operations?

The dam creates a backwater pool that extends ½ mile (0.8 km) upstream during the non-irrigation season (November through April) and 2-½ miles (4.0 km) upstream during the irrigation season (May through October) (Figure 16). The upstream 2-miles are largely riverine conditions during non-irrigation periods (Figure 17).

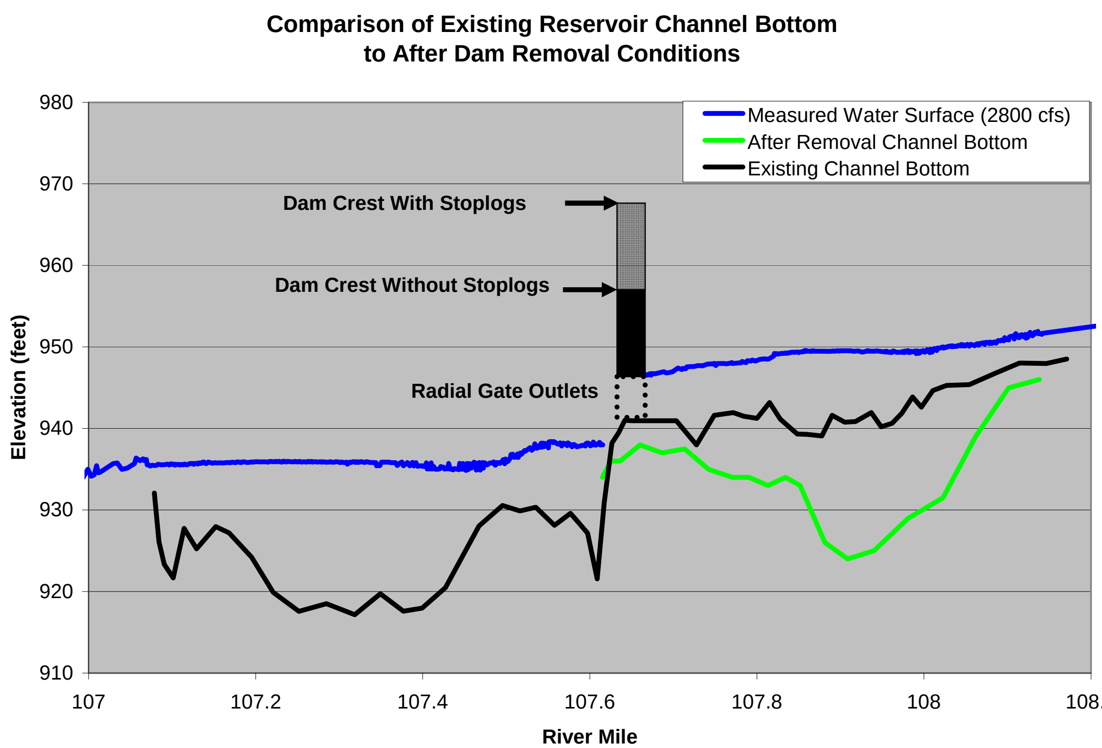

Figure 16. Illustration of pre-dam and existing reservoir bottom and elevation influence of stop logs.

Figure 17. Looking upstream at Savage Rapids reservoir in upstream areas during riverine conditions in the non-irrigation season.

Does the dam have a sediment sluiceway and, if so, has it been used?

The river outlet for the dam consists of two 7- by-16- foot (2.1 by 4.9 m) radial gates with a combined capacity of 6,000 ft^3/s (169 m^3/s). The radial gates are used in the spring and fall to lower the reservoir and either place or remove stop logs that raise the reservoir 11 feet (3.4 m). The radial gate operation causes a partial sluicing of sediment during the multi-day operation twice a year.

Setting

Where is reservoir located within watershed?

- Savage Rapids Dam is located in southwestern Oregon at approximately river mile (RM) 107.6 on the Rogue River, just 5 miles upstream from the town of Grants Pass.
- Savage Rapids Dam and the GPID service area are within the lower part of the middle Rogue River basin, which includes most of Josephine County and a large part of Jackson County.
- The middle Rogue is surrounded by mountains, and more than three-fourths of the basin is forest or timberland.

- The Rogue River is a designated wild and scenic waterway from its junction with the Applegate River, just west of Grants Pass, Oregon, downstream to Lobster Creek Bridge, about 10 miles upstream from the mouth of the river.

What is the controlling geology?

Surficial deposits at Savage Rapids Dam and upstream along the reservoir consist of several distinct units of alluvium that are Quaternary in age. The alluvium is dominated by older terraces that flank both sides of the reservoir and underlie the north end of the dam. Younger alluvium within the channel of the Rogue River is largely submerged by the reservoir impounded by Savage Rapids Dam. Included in the surficial deposits are the reservoir sediments that have accumulated behind the dam since completion of construction in 1922. Bedrock is present at the dam site.

What is the dominant hydrology?

- The annual mean flow of the Rogue River is 3,372 cubic feet per second (ft^3/s). The total drainage area is 2,459 square miles.
- The mean annual runoff is 19 inches, the highest recorded peak flow was 152,000 ft^3/s on December 23, 1962, and the lowest mean-daily flow recorded was 744 ft^3/s.
- Flood peaks on the Rogue River typically occur from November to March, with most occurring in December and January. Rainstorms occur during spring and summer months that also result in higher flows.

Are there any upstream or downstream tributaries and dams that impact sediment storage?

- Of the total drainage area upstream from Savage Rapids Dam, 30 percent (686 square miles) is regulated by Lost Creek Reservoir, primarily a flood control reservoir built and maintained by the U.S. Army Corps of Engineers (Corps). Lost Creek Dam also traps virtually all of the sediment transported into the reservoir by the Rogue River during these peak flows.
- A few other reservoirs, such as Emigrant Lake, may also trap a small amount of sediment that would otherwise be delivered to the Rogue River. However, these drainage areas are small relative to that of the Rogue River, and they were not within the scope of this study. Lost Creek Reservoir, which began storage in February 1977, reduces flood peaks at Savage Rapids Dam by storing water during high flood peaks.
- The Applegate River enters the Rogue River 12.5 miles downstream from Savage Rapids Dam. This tributary contributes large quantities of sediment (sand and gravel) to the Rogue River.
- Just downstream from the confluence with the Applegate River, the Rogue River enters Hellgate Canyon, a steep, narrow, bedrock canyon that is 65 miles long. The Rogue River exits the canyon approximately 30 miles from the ocean, and the slope of the river flattens out.

- The Illinois River enters the Rogue River just downstream from the canyon mouth and contributes additional water and sediment to the river.

Reason for Removal

Although the dam has fish ladders, these ladders are old, do not meet current fisheries criteria, and allow only limited fish passage. Dam removal is occurring to restore fish passage to natural conditions. The dam would be replaced with two pumping plants that would deliver water to the irrigation canals to continue to meet water delivery needs.

Project Challenges

What were the main concerns from stakeholders and/or managers?

Among the many significant concerns with this project are the volume, particle size gradation, and spatial distribution of sediment accumulated within the reservoir, the chemical composition of the reservoir sediment, and the rate at which the reservoir sediment would be eroded if the dam is removed. Specifically, stakeholders identified the following sediment issues that needed to be addressed before dam removal could be considered:

1. The sediment may contain hazardous contaminants from upstream mining and other human activities.
2. The sediment might plug pumps or cause elevated maintenance costs for pumps proposed for construction immediately downstream from the dam to supply water to the GPID.
3. Release of the sediment could affect fisheries and fish habitat downstream from the dam.
4. Release of sediment might possibly affect the municipal water supply system of the City of Grants Pass, which is located 5 miles downstream from the dam.
5. Release of the sediment could cause barriers to safe navigation of the Rogue River downstream from the dam.
6. Landowners along the reservoir shoreline were concerned regarding how the new riverine conditions would change the property value and aesthetics at their homes.

Reservoir Sediment Characteristics

What is the distribution of reservoir sediment?

The majority of sediment is deposited in the permanent reservoir pool upstream from Savage Rapids Dam in the reach extending about 3,000 feet upstream from the dam to just above Savage Rapids Park, near RM 107.95. The maximum sediment thickness occurs just upstream of the dam and is about 25 ft in height.

What is the volume of the reservoir sediment?

Initially, the volume of reservoir sediment was estimated to range between half a million yds^3 up to perhaps as much as 1,000,000 yds^3. These estimates were based on the assumption that sediments had deposited along the entire 2.5-mile-long reservoir. Pre-dam topographic maps of the reservoir basin do not exist, and the original estimates did not have the benefit of any measured sediment thicknesses to determine the elevation of the pre-dam river bed. Another limitation was that sediment sampling was only done at five locations along the rim of the reservoir. Therefore, the original estimates assumed a pre-dam river bottom by making a constant slope through the entire reservoir (2.5 miles) based solely on the lowest elevations among 17 surveyed cross sections. The original methods did not account for the pool and riffle complex that existed before the reservoir filling. Assuming a constant slope for the original river bottom overestimated sediment deposition in areas that are actually bedrock or riffles and underestimated areas, which were actually pools that had filled with sediment. Additionally, because the reservoir has actually only trapped sediments in the ½-mile reach upstream from the dam, the original volume estimate within the upper portion of the reservoir overestimated the actual sediment volume.

To refine the estimate, a bathymetric survey of the reservoir was conducted and dive inspections were performed to determine where the reservoir sediment had deposited (downstream portion of the reservoir, 3,000 feet upstream from the dam). A drill rig from a barge was used to measure the actual reservoir sediment thickness. Based on these new data, the volume of reservoir sediments was computed to be 200,000 yds^3. This sediment volume is also roughly equivalent to one or two years of sediment load transported by the Rogue River at Grants Pass, Oregon.

What is the size gradation of reservoir sediment?

In 1999, 32 reservoir sediment samples were collected and 25 of these were deemed acceptable and utilized. Reservoir sediment consists mostly of sand and gravel. Increases in turbidity are primarily caused by silt and clay-sized sediments that make up a very small portion (2 percent) of the reservoir sediment volume. Cobbles ranging in size from 3 to 5 inches in diameter and composing an estimated 5 to 20 percent by volume of the deposit were observed during geologic mapping of sediment exposures along the north shore of the reservoir.

Are there any contaminants in the reservoir sediment?

Historical mining activities occurred upstream in the Rogue River Basin that could potentially have resulted in contaminated reservoir sediments. However, a large amount of contamination was not expected in Savage Rapids Reservoir sediment because contaminants typically attach to finer-sized sediments, and these make up only 2 percent of the sediment behind the dam. Testing of reservoir sediment showed that there were no contaminants found with concentrations significantly higher than naturally occurring background levels. The chemical composition of reservoir sediment would not pose any hazard to water quality, fish and wildlife, or human uses if released from the reservoir.

Sediment samples were tested for arsenic, cadmium, mercury, copper, lead, mercury, iron, and zinc.

What is the ratio of reservoir volume to mean annual river flow?

- 0.01 percent

What is the ratio of reservoir width to river width?

- The reservoir is relatively narrow, only two to three times wider than the river.

What is the ratio of maximum reservoir depth to maximum river pool depth?

- River pool depths generally range from 10 to 20 ft; the maximum original reservoir depth is approximately 20 to 25 ft. Therefore, the ratio is between 1 to 2.

What is the reservoir sediment size gradation relative to the upstream river channel?

- The upstream channel is armored with gravels and cobbles. The reservoir sediment is finer grained sand and gravel with limited cobbles.

If the reservoir is already filled with sediment, over what period of time did the filling take place?

- The reservoir is full with sediment and this likely occurred within the first few floods following construction in the 1920s (Figure 18).

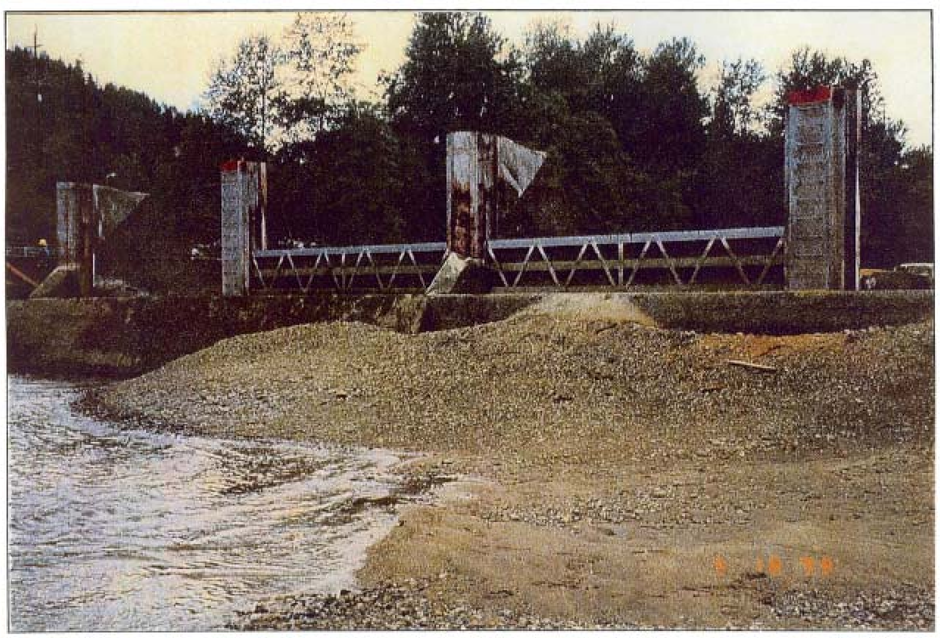

Figure 18. Upstream face of Savage Rapids Dam - During a reservoir drawdown in May 1999, gravel-sized sediment was observed on the crest of the dam, indicating that sediment is transported past the dam during spillway releases.

Pre-Removal Evaluation

What data was collected?

Reservoir Sediment Sampling

Exploratory drilling was conducted using an Ingersoll-Rand A200 skid-mounted drill, operating from a custom-built drilling platform floating on pontoons (Figure 19). The assembled platform measured approximately 21 feet wide by 20 feet long by 3.5 feet high. Field samples were evaluated on the basis of percent recovery and mass of retained material in the sample tube. Then, 25 samples were submitted for laboratory testing to determine standard physical and engineering properties. Included in the laboratory testing program were (1) particle size distribution, including hydrometer for the minus No. 200 sieve fraction (0.075 mm); (2) soil plasticity, or Atterberg limits; (3) fall diameter of sand-size and finer material; and (4) specific gravity of the minus No. 4 fraction (4.75 mm). Initial testing of the sediment samples showed extremely low concentrations of the silt and clay fractions, and the requirement for the hydrometer, Atterberg limits, and fall diameter were canceled because sample mass was insufficient to perform these tests.

Figure 19. View downstream showing Reclamation's custom built, floating drilling platform in operation on drill hole AP-99-10. The spillway and pumping plant portions of Savage Rapids Dam are present in the background of this photograph. (Reclamation photograph by Richard Link; September 30, 1999.)

Channel and Reservoir Surveys

A 2-foot contour map of Savage Rapids Reservoir was developed based on a sonar survey of the reservoir completed in July 1999 by Reclamation. The survey was performed from a raft equipped with a high precision global positioning system and depth-sounding equipment (Figure 20). Using the same equipment, data were also collected along the river bottom downstream from the dam to the confluence with the Applegate River, approximately 12 miles downstream. These data were used to develop river cross sections for computer modeling purposes.

Figure 20. View of survey boat configuration equipped with global positioning software (GPS) equipment, depth sounder, and laptop to document channel bathymetry.

What modeling of sediment transport was accomplished?

- To address flooding, water quality, fish passage, and infrastructure concerns a one-dimensional hydraulic and sediment transport model was utilized.

What were the sediment predictions?

An initial flushing of reservoir sediment would occur immediately following removal of the dam. This flushing occurs because, as the dam is removed, the river would seek a lower base level and begin incising through the sediment deposits behind the dam. This incision process and sediment flushing would continue until a stable longitudinal slope is reached upstream from the dam site. This flushing would cause sediment concentrations downstream from the dam site to significantly increase for a hours to a few days immediately following dam removal. After the initial flushing, successively higher flows would be required to erode more sediment from the reservoir deposits immediately upstream from the dam and again increase the sediment load to the downstream river channel. Sediment concentrations will be much higher than natural conditions during the first flood following dam removal. These high concentrations will tend to decrease toward natural levels with each subsequent flood. Between floods, sediment concentrations will be relatively low.

Nearly all reservoir sediment is expected to be eroded from the reservoir over time, but some sediment may remain along the reservoir margins. About three-fourths of the sediment would be eroded from the area immediately upstream of the dam within the first year. The reservoir sediment would be transported past the Applegate River (12 miles downstream) within a 1- to 10-year period depending on the magnitude and frequency of high-flow events following dam removal. Sediment would temporarily deposit downstream in pools if the dam is removed during low-flow (Figure 21). The sediment would then be expected to be flushed during floods as occurs now. No flooding is expected to occur in the downstream river channel due to deposition in river pools. No deposition is expected to occur on riffles, which provide the hydraulic controls of the water surface profile.

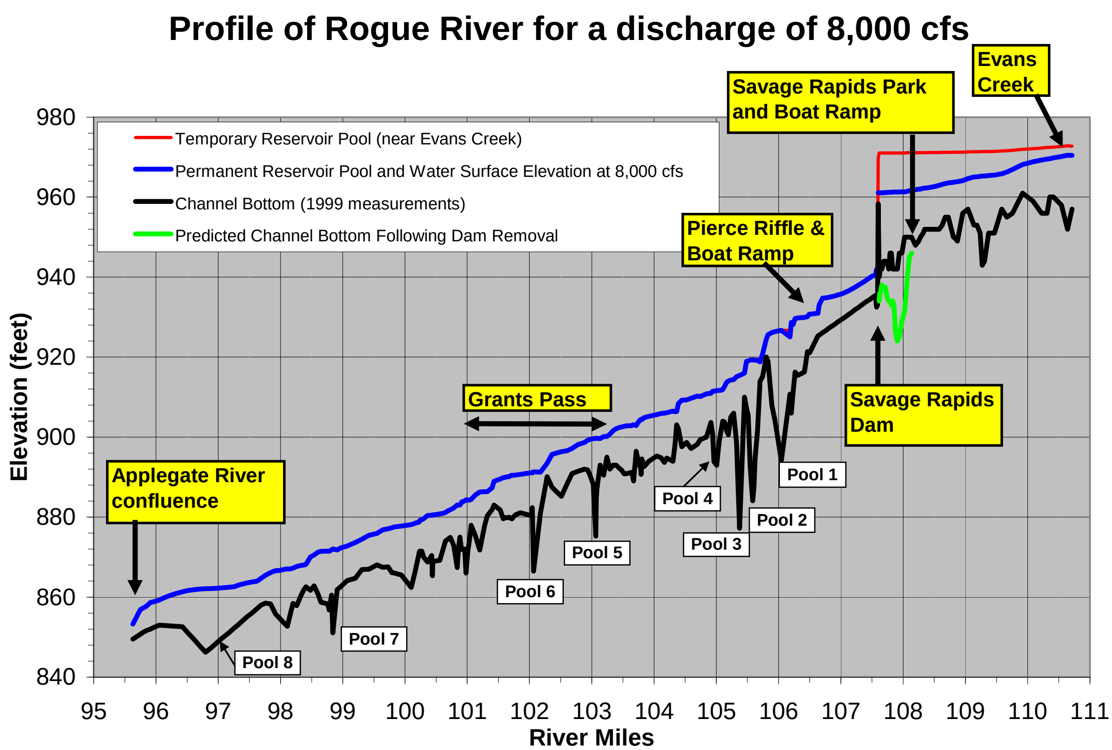

Figure 21. Longitudinal profile showing downstream pool-riffle morphology.

Dam Removal Plan

- A partial dam removal plan was selected and is planned for October 2009 during a low-flow period. October was recommended because this will be just after the end of the irrigation season so the new pumping plant located downstream will not need to be operating. Additionally, this will provide an entire winter flood season to erode and transport reservoir sediments before the next irrigation season in the following spring.
- The portion of the dam extending across the pre-dam river channel will be entirely removed. The remaining dam section is located on top of bedrock that will cause a small amount of ponding at the 5-year flood but be largely drowned out during the 100-year flood.
- The dam will be removed in two phases. The portion of the dam on the pre-dam river bed will be blocked off with a cofferdam and removed in the dry. During this period all flow will be passed over the left (south) side of the dam to maintain

fish passage. The new pumping plant intake located downstream of the dam will be operational during this period.

- A small pilot channel is planned to be excavated in the sediment deposit upstream of Savage Rapids Dam to initiate the breaching of the sediment and help speed up the reservoir sediment erosion process. This is desired to ensure the river is restored as fast as possible to its original pre-dam location to limit impacts to fish migration through the former dam site.

Monitoring Accomplished

What monitoring questions were important to study team?

- Ensuring that the river was restored to its pre-dam position, fish passage was adequately restored, and sediment impacts did not exceed predictions.

What data was collected and over what time period?

- Turbidity data upstream and downstream of the dam site before, during, and after dam removal.
- Time-lapse photography of dam removal construction and post-dam removal river changes.
- Topographic survey of pre-dam removal and planned post-dam removal reservoir topography to verify volume and locations of reservoir sediment erosion.
- Topographic survey of pre-dam downstream river channel elevations and planned post-dam survey to validate deposition locations and magnitude from release of reservoir sediment.

Lessons Learned

What were the most valuable data and analysis that helped guide the dam removal process?

- Getting additional reservoir sediment data to improve the volume estimate was very helpful and improved predictions and reduced potential estimates of sediment impacts.
- Hydraulic modeling and geologic investigations of bedrock at the site were very useful to determine how much of the dam needed to be removed in order to provide the most benefit for restoring fish passage balanced with cost.
- Two-dimensional hydraulic modeling was very helpful to determine how to construct cofferdams during dam removal and to meet fish passage requirements during and post-dam removal.
- Unique to this project, several iterations of the two-dimension model were important to assist with design of a new, downstream pumping plant intake to replace the dam's diversion capabilities.

What steps would be done differently in future projects?

- For initial modeling, previously collected cross-section data in the downstream river channel for a flood insurance study were made available, but these cross-section data were not adequate. A longitudinal profile was measured by Reclamation and had to be post-processed to generate cross-sections for modeling. In the future, it would be recommended that new cross sections and a longitudinal profile be measured to more accurately determine locations of hydraulic controls (riffles and rapids) and areas of potential sediment storage (eddies and pools).

Study References

Bureau of Reclamation, 2001, Savage Rapids Dam Sediment Evaluation Study, prepared by the Pacific Northwest Regional Office and the Denver Technical Service Center.

Appendix D: Gold Hill Dam

Written by Jennifer Bountry, Sedimentation and River Hydraulics Group, Bureau of Reclamation, Denver, Colorado.

History

When was the reservoir constructed and by who?

The Gold Hill Diversion Dam has existed in various forms for over 80 years. The Pacific Oregon Power Company originally built the dam and used stop logs to divert water into the canal. In the mid-1940s, the left dam crest was built perpendicular to the river's flow and all stop logs were replaced with concrete (Figure 22). The power plant, canal, and diversion facilities were transferred to various owners, mostly cement companies, until the city of Gold Hill took title in 1968.

Figure 22. Looking upstream at Gold Hill Dam on the Rogue River in Oregon, U.S.A..

What is the purpose of the dam and reservoir?

The Pacific Oregon Power Company built the dam to provide a water diversion to a power plant located approximately 2,000 feet downstream from the head works. Though the power plant is not operational, the City uses the diversion canal as its municipal and industrial water supply intake.

What is the size of the dam and how is it operated?

The existing diversion dam is a 1,000-foot-long L-shaped concrete gravity structure. The dam's crest varies in elevation from 1 to 8 feet above the downstream water surface elevation. The dam's uncontrolled crest elevation is approximately 1077.0 feet, and the depth of flow over the crest for low to normal flows (1,500 cfs to 3,000 cfs) is 3 to 6 inches. The diversion dam backs water approximately 1 mile upstream near the base of Gold Nugget Rapids. The backwater effect from the dam does not extend past the base of this rapid. The dam is located at the top of a bedrock rapid.

The Gold Hill Diversion Dam diverts water from the Rogue River into a 2,000-foot-long canal where the city of Gold Hill draws its municipal and industrial water supply.

Setting

Where is the reservoir located within the watershed?

The Gold Hill Diversion Dam is 121 river miles (RM) upstream from the mouth of the Rogue River at the Pacific Ocean. The Rogue River is a relatively steep gravel and cobble-bed river with several pools, riffles, and rapids (Figure 23). In the vicinity of Gold Hill the river channel slope has a 0.0040 gradient.

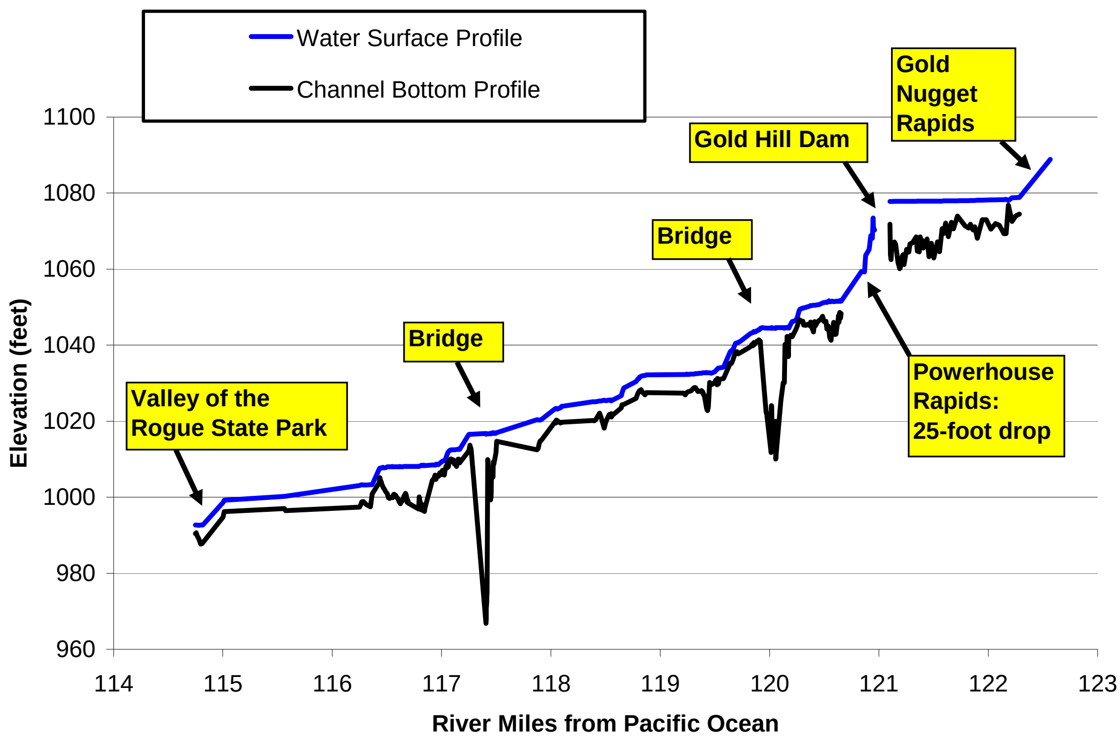

Figure 23. Longitudinal profile of Gold Hill resevoir and downstream river channel.

What is the controlling geology?

As flow approaches the dam, several large bedrock outcrops constrict the river channel width to approximately 100 feet at low flow. The average channel width in the Rogue River upstream from the influence of Gold Hill Diversion Dam ranges from 150 to 400 feet, depending on the magnitude of flow. This upstream constriction causes high velocities and very minimal sediment deposition.

What is the dominant hydrology?

Major floods occur during winter months with occasional rain storms throughout the rest of the year (Figure 24).

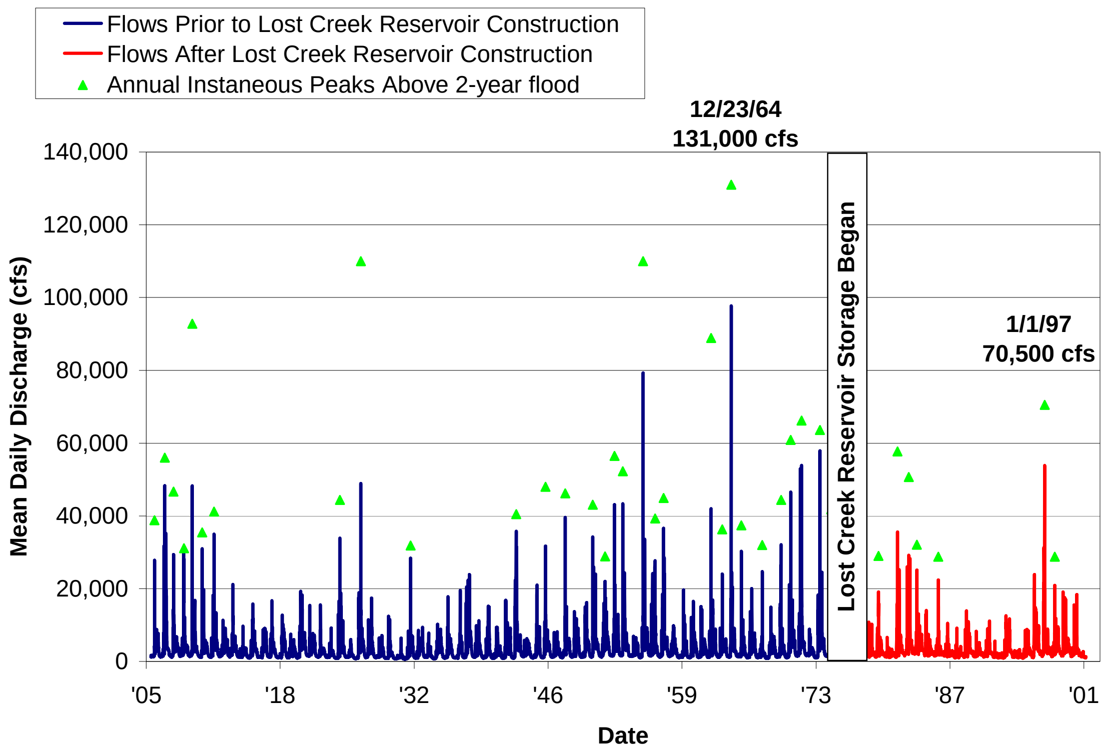

Figure 24. Historical river flows at a U.S. Geological Survey stream gage located slightly upstream of the Gold Hill Dam.

Are there any upstream or downstream dams?

Savage Rapids Dam is located downstream of Gold Hill Dam. Gold Ray Dam and Lost Creek Dam are located upstream of Gold Hill Dam. The United States Geological Survey Rogue River at Raygold gage, located 5 miles upstream from Gold Hill Diversion Dam, has measured river flow since 1905. The river's peak flows substantially changed in 1977 when the Army Corps of Engineers built Lost Creek Dam and began regulating flow out of Lost Creek Lake. Though flooding peaks have decreased, the additional regulation did not affect the average daily flow of 2,927 cfs. Gold Ray Dam is a run–of-the river dam that is no longer operational and is being considered for potential removal.

Reason for Removal

The diversion dam does not meet National Marine Fisheries Service criteria for effective fish passage and protection because it impedes migration of anadromous fish listed under the Endangered Species Act. The existing diversion dam and associated facilities impact migration for adult and juvenile spring and fall chinook salmon, coho salmon, and summer and winter steelhead. The large drop at the diversion dam does not meet current fish passage criteria and can delay upstream fish migration. The dam's fish ladder is overgrown with vegetation and blocked by debris. Because fish passage criteria have changed since the fish ladder's construction, additional maintenance will not put the ladder in compliance with current National Marine Fisheries Service criteria. Further, the 140 cubic feet per second (cfs) of diverted water reduces the main stem flows over the dam and delays upstream fish migration. The facilities also pose significant entrapment and descaling dangers for fish.

Past water diversions have also exceeded the City's legal water right. In 1999, the City expressed a willingness to modify its municipal water intake system to correct fish passage problems by relocating the pump intake structure, adding compliant fish screens to the intake facilities, and modifying the diversion dam. Because these modifications will impact the City's current bike path and greenbelt area, the City also took measures to preserve the area's aesthetic, recreational, and historical nature.

Project Challenges

What were main concerns from stakeholders and/or managers?

The stakeholders identified the following objectives to be addressed:

- Identify a pump intake location to give the City a reliable municipal water supply
- Provide adequate and permanent fish passage and protection to adult and juvenile anadromous fish
- Reduce the City's water diversion to their legal water right of 3 cfs
- Keep all formerly-diverted water in the Rogue River main stem
- Retain or mitigate, as much as possible, the aesthetic, historic, and recreational values associated with the site

Reservoir Sediment Characteristics

<u>General characteristics</u>

What is the distribution, volume, and size gradation of reservoir sediment?

In March 2001, divers from Reclamation's Pacific Northwest Region dive team visually inspected the stored sediment upstream from the diversion dam. The divers cataloged the locations of accumulated sediment and provided volume estimates. A very small volume of fine-grained sediments, estimated at approximately 456 cubic yards, lines the river bottom immediately upstream of the dam. This sediment consists of mostly sands and gravels, deposited primarily along the right channel margins downstream of the elbow in the dam crest alignment and against the dam and headgate. The remaining reservoir does not contain any significant sediment deposits.

Are there any contaminants in the reservoir sediment above background levels?

The divers also collected two sediment samples from the upstream side of the diversion dam and two samples from the diversion canal. The sediment samples were tested for major and trace element concentrations to determine if the sediment had been contaminated by upstream activities such as mining. The sediments were also evaluated using existing information, grain size, and total volatile solids. Existing information includes historic mining activities in southwestern Oregon and within the Rogue River basin. The grain size and total volatile solids analyses tested if any metals present in the sediments exceeded screening levels. These tests confirmed that if the diversion dam is removed and sediments along the channel margins are eroded, the discharge of the sediments is not expected to have any secondary toxic effects on aquatic life in the Rogue River.

<u>Relative characteristics</u>

- What is the ratio of reservoir volume to mean annual river flow?
  - 0.005 percent
- What is the ratio of reservoir width to river width?
  - 2.3
- What is the ratio of maximum reservoir depth to maximum river pool depth?
  - Maximum reservoir depth is 18 ft and downstream pools can typically range between 8 to 10 ft but can be as deep as a few tens of feet in areas confined by bedrock; this provides a ratio of about 2 for typical river pools but less than or equal to 1 for larger pools
- Does the reservoir have a sediment delta?
  - No reservoir delta is present
- What is the estimated sediment trap efficiency of the reservoir for both fine and coarse sediment?
  - The reservoir does not trap fine or coarse sediment
- What is the reservoir sediment size gradation relative to the upstream river channel?
  - The very small amount of reservoir sediment is of similar material size present in upstream gravel and cobble bars

Pre-Removal Evaluation

Evaluation was done in three phases as follows:

Phase 1 appraisal-level review developed from October 6, 1999, through May 17, 2000. This review included identifying specific fish passage problems and examining concepts for resolving these problems. After reviewing the options, the City of Gold Hill and the a group of local stakeholders agreed to relocate the water pump intake outside of the canal.

Phase II, feasibility-level evaluation included analysis of removing all or parts of the diversion dam and relocating and screening the pump intake structure. Major tasks of this evaluation are listed below:

- Data Collection and Analysis
- Engineering and Design
- City and Committee Review
- Study Documentation
- Canal Area Enhancement Concepts

Phase III activities included preparing final engineering drawings and specifications suitable for bidding, constructing, screening the pump intake structure, and breaching the diversion dam.

Data used in determining the feasibility of dam removal include bathymetric surveys, hydraulic modeling, geologic investigations, underwater inspections, and a sediment contamination analysis.

The one-dimensional hydraulic model indicated that a pool about 150 feet upstream from the dam would have sufficient depths at a minimum design flow of 662 ft^3/s for a pump intake structure. This area has sufficient sweeping velocities to prevent sediment from depositing around the pump intake structure.

If the diversion dam did not exist, the high bedrock elevations at the top of the Powerhouse Rapids (where the dam is located) would still have a backwater influence upstream. Without the dam in place, small pools would form upstream of each currently submerged riffle and rapid, rather than one large reservoir pool as now exists.

A U.S. Army Corps of Engineers river hydraulics model, HEC-RAS 3.0, was applied to the study reach. HEC-RAS is a one-dimensional, steady flow backwater model that computes hydraulic parameters for any given cross section at any discharge. The model was calibrated to measured water surface elevation data to accurately predict hydraulic parameters. Model results were used to compare water surface elevation, average velocity, and water depth for existing river and reservoir conditions for various dam removal options.

An additional 6 miles of river downstream were evaluated with a conceptual model to determine the available sediment storage capacity.

Dam Removal Plan

The various dam removal options were evaluated and are listed below:

- Removing the entire dam
- Removing the left dam crest
- Removing all or portions of the right dam crest

The entire Gold Hill Dam was removed in summer 2008. Total dam removal costs were not significantly more than removing the right diversion crest. Further, total removal eliminated aesthetic and safety concerns associated with leaving a portion of the dam within the river channel.

The one-third and two-thirds right dam crest removal options were eliminated because they could not guarantee satisfactory fish passage velocities. These notching options also leave significant amounts of concrete within the river channel that present aesthetic and safety issues. Evaluations recommended removing the entire dam, relocating the pump intake structure 150 feet upstream from the alignment of the main dam, installing a drum screen, and closing the diversion canal.

Because of the limited sediment deposited in the reservoir, no sediment management was necessary.

Monitoring Accomplished

Time lapse photography was collected during the construction period of July to September 2008 to visually document day to day river responses during construction activities and post-dam removal (Figure 25). Four pictures were taken per day, or once every 6 hours.

Turbidity measurements were collected upstream and downstream of Gold Hill Dam to measure and document sediment impacts related to construction activities during July to September 2008. No turbidity impacts were detected during the dam removal above upstream (background) levels.

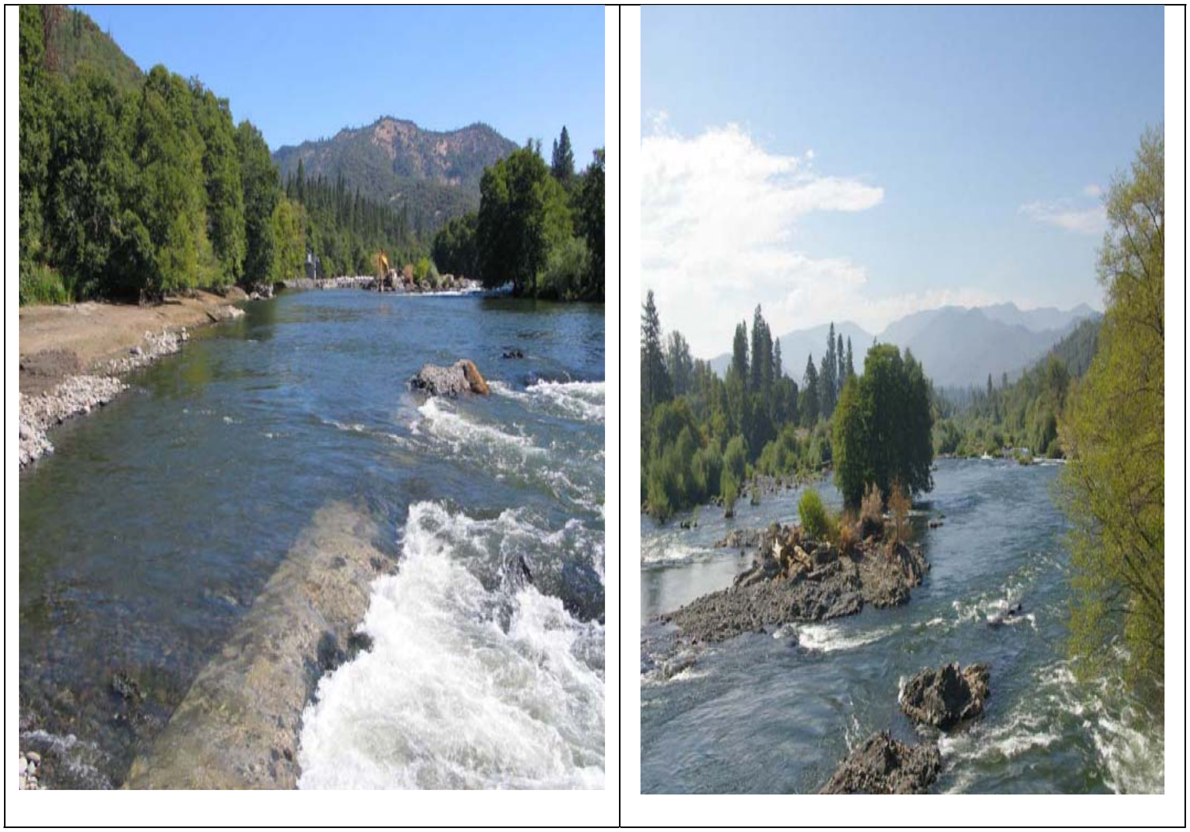

Figure 25. Looking at Gold Hill Dam in August 2009 after removal from an upstream view (left photo) and a downstream view (right photo).

Lessons Learned

What management or collaboration steps were helpful in navigating the dam removal discussion?

Collaboration throughout the project among technical staff, resource managers, landowners, and stakeholders helped make the dam removal a success. Parties involved included the following:

- City of Gold Hill
- Jackson Soil and Water Conservation District
- Little Butte Creek and Bear Creek Watershed Councils
- National Marine Fisheries Service (NMFS)
- Oregon Department of Fish and Wildlife (ODFW)
- Oregon Watershed Enhancement Board
- Oregon Water Resources Department (OWRD)
- Rogue Valley Council of Governments (RVCOG)
- U.S. Army Corps of Engineers (Corps)
- U.S. Bureau of Reclamation (Reclamation)
- U.S. Fish and Wildlife Service (USFWS)
- Several local irrigation districts

What was most valuable data and analysis done up front that helped guide dam removal process?

Bathymetric surveys and hydraulic modeling results were used to eliminate several potential pump intake locations and identified the preferred location along the bank's right side (looking downstream) upstream from the alignment of the main dam. The modeling analysis also showed that because the river's thalweg travels along the right bank, sufficient water flow and depths near this location would occur if the right dam crest or the entire dam were removed. Modeling indicated that full dam removal would guarantee successful fish passage. Project cost comparisons concluded that removing the entire dam versus only a portion increased total project costs by only 4%.

Any surprises from dam removal that resulted in new needs for construction, analysis, or monitoring?

- No

Did reservoir sediment and river conditions behave as expected from predictions?

- Yes

Study References

Bureau of Reclamation, September 2001, City of Gold Hill Fish Passage Improvements at the Municipal Water Supply Diversion: Phase II, prepared for Rogue River Basin Fish Passage Technical Committee.

Appendix E: Chiloquin Dam

Written by Travis Bauer, Sedimentation and River Hydraulics Group, Bureau of Reclamation, Denver, Colorado.

History

- When was the reservoir constructed and by who?
    - The dam was constructed in 1914 by the United States Indian Service (Figure 26).
- What is the purpose of the dam and reservoir?
    - Irrigation diversion
- What is the size of the dam?
    - 11 feet high and 220 feet long with a reservoir of 60 acre-feet
- What are the reservoir pool normal operations?
    - Run of the river (constant pool elevation) for river diversion or hydropower
- Does the dam have a sediment sluiceway and, if so, has it been used?
    - No

Figure 26. Looking upstream at Chiloquin Dam prior to removal.

Setting

- Where is reservoir located within watershed?
    - The dam was located on the Sprague River about 0.87 miles upstream from the confluence with the Williamson River. Downstream from this point the Williamson River enters Upper Klamath Lake

- What is the controlling geology?
    - The dam was located in a bedrock canyon with volcanically derived rock
- What is the dominant hydrology?
- Are there any upstream or downstream dams?
    - There are no upstream dams but Upper Klamath Lake has been raised by a dam and the further downstream on the Klamath River there are 4 more dams.

Reason for Removal

- Note reason (objectives) and timing (if known) of removal decision
    - The purpose of the project is to improve fish passage at Chiloquin Dam on the Sprague River and contribute to recovery of endangered shortnose and Lost River suckers while continuing to deliver water to the Modoc Point Irrigation District.
    - The quality of the concrete used in the dam was also questionable so there were some safety concerns.

Project Challenges

- What were main concerns from stakeholders and/or managers?
    - Fish mortality during and after the dam removal was the greatest concern. Many of the biologists involved in the project were concerned that any disturbance to spawning areas even for a short time would push the suckers even closer to extinction.

Reservoir Sediment Characteristics

General characteristics

- What is the distribution of reservoir sediment?
    - Delta
        - There isn't a delta
    - Lake bed deposit
        - There are deposits along the channel margins and there is more sediment and thicker deposits closer to the dam. The upper part of the reservoir is river gravel and boulders.
- What is the volume of the reservoir sediment?
    - The reservoir sediment was estimated between 49,000 and 61,000 tons
- What is the size gradation of reservoir sediment?
    - 39% silt and clay, 52% sand, and 9% gravel
- Are there any contaminants in the reservoir sediment above background levels?
    - No

Relative characteristics

- What is the ratio of reservoir volume to mean annual river flow?
    - 0.000142
- What is the ratio of reservoir width to river width?
    - 315/170 (1.8) at the widest location

- What is the ratio of maximum reservoir depth to maximum river pool depth?
    - They are about the same
- Does the reservoir have a sediment delta?
    - No
- What is the reservoir sediment size gradation relative to the upstream river channel?
    - 0.145mm / 78mm (0.00186)
- If the reservoir is already filled with sediment, over what period of time did the filling take place?
    - The reservoir most likely filled with sediment to the extent possible within one or two years of operation.

Pre-Removal Evaluation

- Reason for evaluation
    - Permitting and concerns about burial of spawning areas were the primary reasons for evaluation.
- Predictions
    - We predicted that all the sand and silt sized sediment in the reservoir would move downstream very quickly (in as little as a single flood) if flows were large enough, but we also predicted that after 2 years there would only be a trace amount of reservoir sand left in the Williamson River if large flows did not occur. We also predicted that there would not be deposition in sucker spawning areas as these locations have fast moving water with higher sediment transport capacity.

Dam Removal Plan

- The dam was completely removed.

Monitoring Accomplished

What monitoring questions were important to study team?

- How would reservoir sediment be redistributed downstream and how long would it take?

What data was collected and over what time period?

- Time-lapse photography was collected during the dam removal period using two solar powered cameras in weather proof boxes (note that one camera was stolen during monitoring) (Figure 27).
- Profiles and cross sections and bed material samples were collected in 2006 and 2007 before the dam was removed and again in 2008 and 2009 following dam removal.
- Low elevation aerial photography was also collected in 2008 and 2009 following dam removal to address issues with large amounts of timber in the reservoir.

Figure 27. Looking at time-lapse photography setup utilized on Chiloquin Dam removal project.

Was monitoring adequate to address questions or were there limitations due to funding, access, logistics, etc?

Overall the level of monitoring was appropriate and maybe even excessive. One of the difficulties on this project was that much of the river downstream from the dam is either very swift with boulders or deep making wading difficult if not impossible. In steeper and faster sections sediment deposition would likely be limited to the channel margins where a boat based survey was not possible due to shallow depths and fast moving water. In the pools the challenge is that small amounts of deposition may not be detectable due to limitations in the accuracy of survey equipment. Deposition amounts of 6 inches or less may be difficult to separate from equipment noise while larger amounts of deposition are easily detectable.

Lessons Learned

What was the most valuable data and analysis done up front that helped guide the dam removal process?

Sediment samples from the reservoir showed that there were a large percentage of fines in the bed. We also used a probabilistic approach with the sediment transport analysis to consider different hydrologic scenarios. This approach prepared us for the possibility of a longer adjustment period if water levels were low following dam removal.

Any surprises from dam removal that resulted in new needs for construction, analysis, or monitoring?

There were reports of logs in the reservoir, but when the dam was removed in August 2008, we were surprised by the large number of logs. Initial log counts showed that there were well over 1,000 logs (historically cut for timber) in the reservoir pool (Figure 28). After aerial photography was conducted in October 2008 and July 2009 the number of logs has been estimated at over 1,600 in the first half mile upstream from the dam.

Figure 28. Looking at Chiloquin reservoir following removal showing the large number of logs that were uncovered.

Did reservoir sediment and river conditions behave as expected from predictions?

Except for all the logs in the reservoir pool, the reservoir sediment and river response has been predictable. The largest factor in the response has been the lack of high flows to mobilize and redistribute reservoir sediment. It is taking longer to move sediment downstream and it is only moving short distances. High flows should quickly remove any remaining sediment in the reservoir and move it from the Sprague River to the Williamson River.

Another important consideration for this project is that the data collected in 2007 prior to dam removal showed that there might only be a small amount of sediment in the reservoir and that the original estimate of sediment might be very high. Surveys of the reservoir pool in 2007 showed that the water was nearly as deep as the dam was high. Visual inspection of the reservoir bottom showed that there was only a small section of the reservoir actually covered with fine grained sediment. Further upstream in the reservoir much of the bed was covered with cobbles and boulders. Much of the fine grained sediments were confined to areas on the inside of bends. After the dam was removed this was confirmed as much of the riverbed was filled with boulders and cobble and a pool riffle sequence was clearly present in the reservoir pool. In addition, the areas on the inside of the bends were identified as point bars that had additional fine grained sediment deposits on them. There were cut stumps on these surfaces clearly identifying them as surfaces prior to dam construction.

Study References

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