Klamath Settlement Process
Sediment Management in the Reservoirs

Klamath Settlement

Prepared by CDM

February 2011

This page intentionally left blank

Table of Contents

Tables

Figures

Abbreviations and Acronyms

BLM	Bureau of Land Management
CEQA	California Environmental Quality Act
DFG	California Department of Fish and Game
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GEC	Gathard Engineering Consulting
KBRA	Klamath Basin Restoration Agreement
KHSA	Klamath Hydroelectric Settlement Agreement
NEPA	National Environmental Policy Act
TEQ	Total toxic equivalent
TSS	Total Suspended Solids
yd^3	Cubic yards

This page intentionally left blank

Chapter 1 Introduction

The United States Department of the Interior (DOI), as the National Environmental Policy Act (NEPA) lead agency, and the California Department of Fish and Game (DFG), as the California Environmental Quality Act (CEQA) lead agency, are currently developing an Environmental Impact Statement/ Environmental Impact Report (EIS/EIR) for the Klamath Hydroelectric Settlement Agreement (KHSA) and the Klamath Basin Restoration Agreement (KBRA). The EIS/EIR will evaluate the environmental and social effects of a set of alternatives that may include removing all or portions of four dams on the Klamath River providing volitional fish passage to aid in restoring salmonid fisheries.

The KHSA stipulates that a determination must be made by the U.S. Secretary of the Interior regarding whether removal of four PacifiCorp dams will enhance salmonid fisheries and will be in the public interest. The four dams are J.C. Boyle, Copco 1, Copco 2, and Iron Gate Dams (see Figure 1-1). Three of the reservoirs created by the dams (J.C. Boyle, Copco 1, and Iron Gate) have accumulated sediment over time that would be released to the lower Klamath River with dam removal, under the provisions of the KHSA. The EIS/EIR will address the effects to Klamath River aquatic resources from the release of this sediment.

The removal of sediment from the reservoirs, prior to or during dam decommissioning, could aid in reducing the downstream effects to aquatic resources in the Klamath River. This paper evaluates the methodologies that might be undertaken to remove sediment from the three reservoirs, consistent with the dam removal and reservoir drawdown scenarios developed by the Bureau of Reclamation's (Reclamation) Technical Services Center. These drawdown scenarios are more fully described in Section 1.1 below.

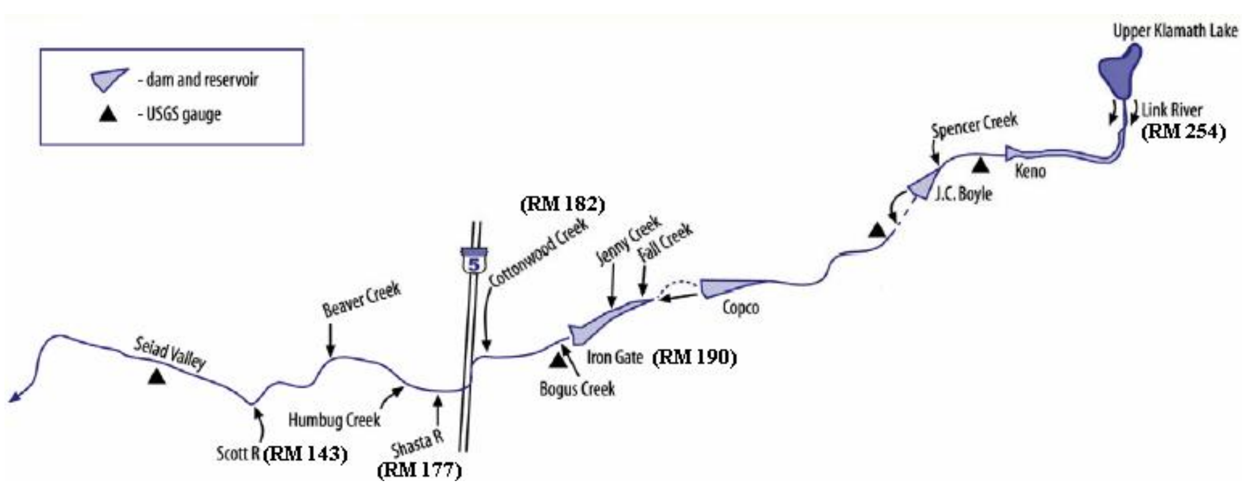

Figure 1-1. Klamath River Dams and Reservoirs

1.1 KHSA Dam Removal and Reservoir Drawdown Scenario

In the KHSA, reservoir drawdown and dam removal is scheduled to occur during a single year, with the construction beginning in year 2020. This 12-month time constraint was specified to limit temporal downstream impacts to aquatic resources from a sediment release event. Studies conducted by Stillwater Sciences (Stillwater 2009) have demonstrated that the release of sediment will have a deleterious effect on salmonid fisheries, primarily due to increased turbidity. Limiting the effect to aquatic resources by passing reservoir sediment in a single fall and winter period when river flows are the greatest and when there are the fewest number of migrating salmonids has been identified as the ideal strategy to remove the dams. (Stillwater 2009)

A single event of short duration would allow many of the resident fish and any migratory salmonids to seek temporary refuge in tributary rivers and streams. Although the studies conducted by Stillwater indicated there would likely be fish mortality, due to dam removal and sediment release, limiting the impact to the fewest cohorts of a species resulted in the a more rapid recovery of the species' population. If the dam removal and sediment release occurred over a longer period of time or multiple years, affects to multiple cohorts (adults in fall, juveniles in winter, fry in spring, and smolts in spring or multi-year classes) would occur and the species' population would have a more difficult time recovering than if impacts could be limited to a single fall and winter, thus affecting only one or two cohorts.

To reduce the impacts to aquatic resources and meet the terms of the KHSA, Reclamation identified and evaluated several potential reservoir drawdown and dam removal scenarios over a single fall and winter season (Reclamation 2010). The ideal reservoir drawdown scenario identified by Reclamation that facilitates dam removal and reduced effects to aquatic resources is presented in Table 1-1. This scenario is included in the proposed project action of the EIS/EIR and will be evaluated in detail to determine its environmental impacts.

Table 1-1. Summary of Reservoir Drawdown Rates

	J.C. Boyle	Copco			Iron Gate
		Phase I	Phase II	Phase III	
Start Date	1/1/2020	11/1/2019	1/1/2020	2/5/2020	1/1/2020
Starting Elevation (feet)	3793	2606	2590	2529	2328
End Date	2/1/2020	11/17/2019	2/4/2020	2/24/2020	2/11/2020
Ending Elevation (feet)	3762	2590	2529	2484	2202
Elevation Difference (feet)	31	16	61	45	126
Average Drawdown (feet/day)	1	1	1.75	2.25	3

Drawdown would occur during the coldest winter months in northern California and Southern Oregon. The cold weather, precipitation, and possible snow could affect sediment removal operations and strategies. Provisions would be required to deal with inclement weather that otherwise could result in project delays. Prior to the start of operations, a detailed plan and schedule would need to be created to account for these possible events.

Sediment removal from the three reservoirs was evaluated within the framework and constrains presented with the drawdown scenario defined above. Alternative drawdown scenarios over different time periods, multiple years, or those inconsistent with the KHSA, were deemed speculative and not analyzed in this paper.

1.2 Document Content

This paper presents a cursory analysis of sediment removal and disposal (sediment management) feasibility from each of the reservoirs, consistent with the drawdown scenarios, as defined in Section 1.1.

- Chapter 2 – Provides background information on the Klamath River Basin and the reservoirs.
- Chapter 3 - Discusses the volumes, characteristics, and erodibility of the sediment found in the reservoirs.
- Chapter 4 – Describes the applicable sediment management technologies.
- Chapter 5 – Discusses sediment disposal options for the dredged reservoir sediment.
- Chapter 6 – Describes methodologies and quantities of sediment that would be removed under the KHSA dam removal process.
- Chapter 7 – Includes document references

This page intentionally left blank

Chapter 2
Reservoirs and Surrounding Environs

The following section presents general roadway access into and around the reservoirs and specifics regarding the area surrounding each reservoir that potentially influence sediment removal options.

2.1 Local Roads and Transportation Options

The three reservoirs are remotely located with access through narrow, curvy rural roads. The closest highway to both Iron Gate and Copco Reservoirs is Interstate 5, while J.C. Boyle Reservoir is accessed through Oregon State Highway 66, a two-lane road (Figure 2-1). Union Pacific Railroad (UPRR) has a mainline that serves Klamath Falls and is located northeast of J.C. Boyle Reservoir.

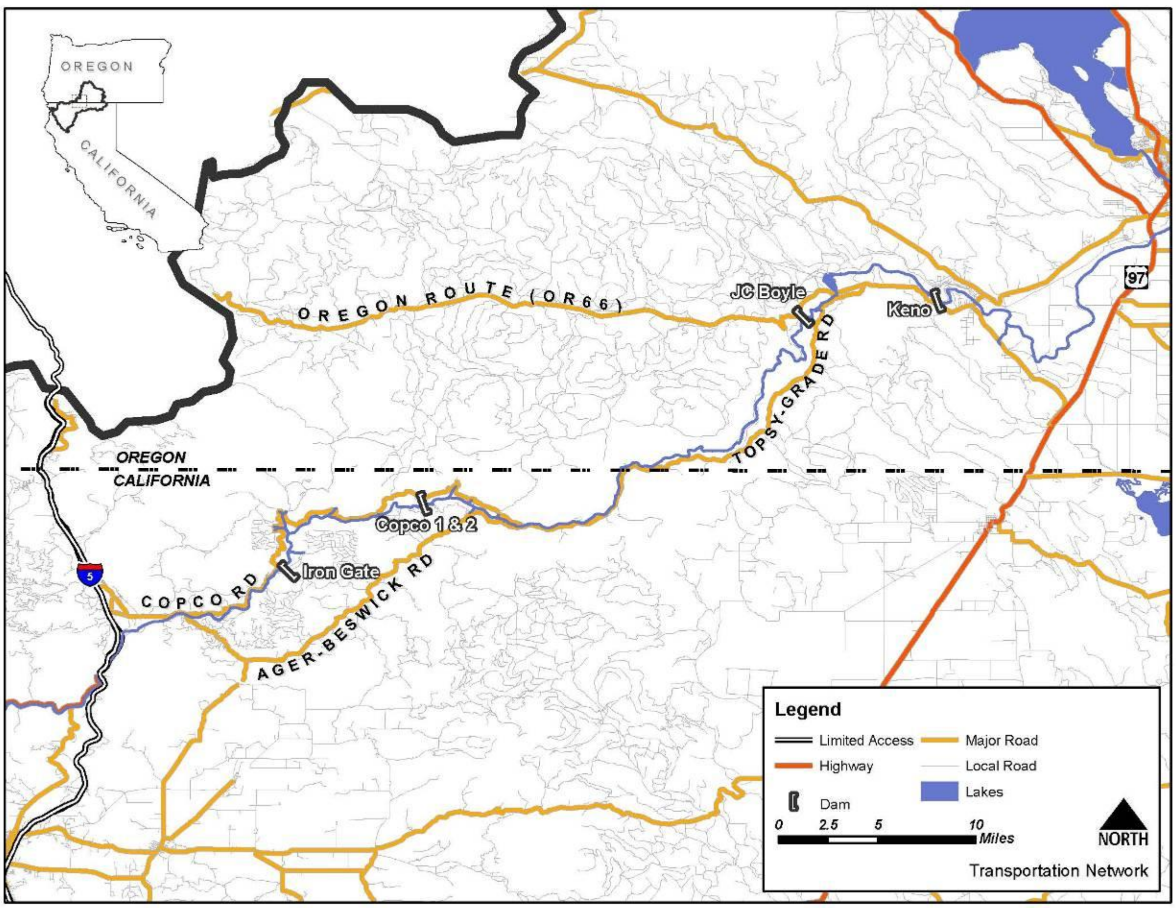

Figure 2-1. Local Roads around the Reservoirs

The remote location of the reservoirs and rural roads influence the types of equipment that can be used to remove sediment from the reservoirs. Large dredging equipment, typically used in US ports and harbors, have lengths in excess of 90 feet and weigh more than 100 tons.

In California and Oregon, the maximum legal gross weight limit on roadways is 40 tons. In Oregon, trucks with a total gross weight over 40 tons and up to 53 tons must obtain a special Extended Weight permit. The maximum continuous length truck allowed on Oregon roads is 53 feet and in California the limit is 48 feet. (ORS 818.080, ORS 818.090, and CA§35550-35558). No additional restrictions for local rural roadways were found.

Another option for potential transportation would be the UPRR mainline that serves Klamath Falls. This mainline has a maximum gross weight per car of 158 tons with a maximum-coupled length of 53 feet.

2.2 J.C Boyle Reservoir

J.C. Boyle Reservoir, located in Southern Oregon, is approximately three miles long and 350 to 2,500 feet wide, with water depths of up to about 40 feet and sediment thicknesses ranging from one foot in the upper reservoir to 20 feet near the dam (Figure 2-2). Bathymetric figures are presented in Attachment A.

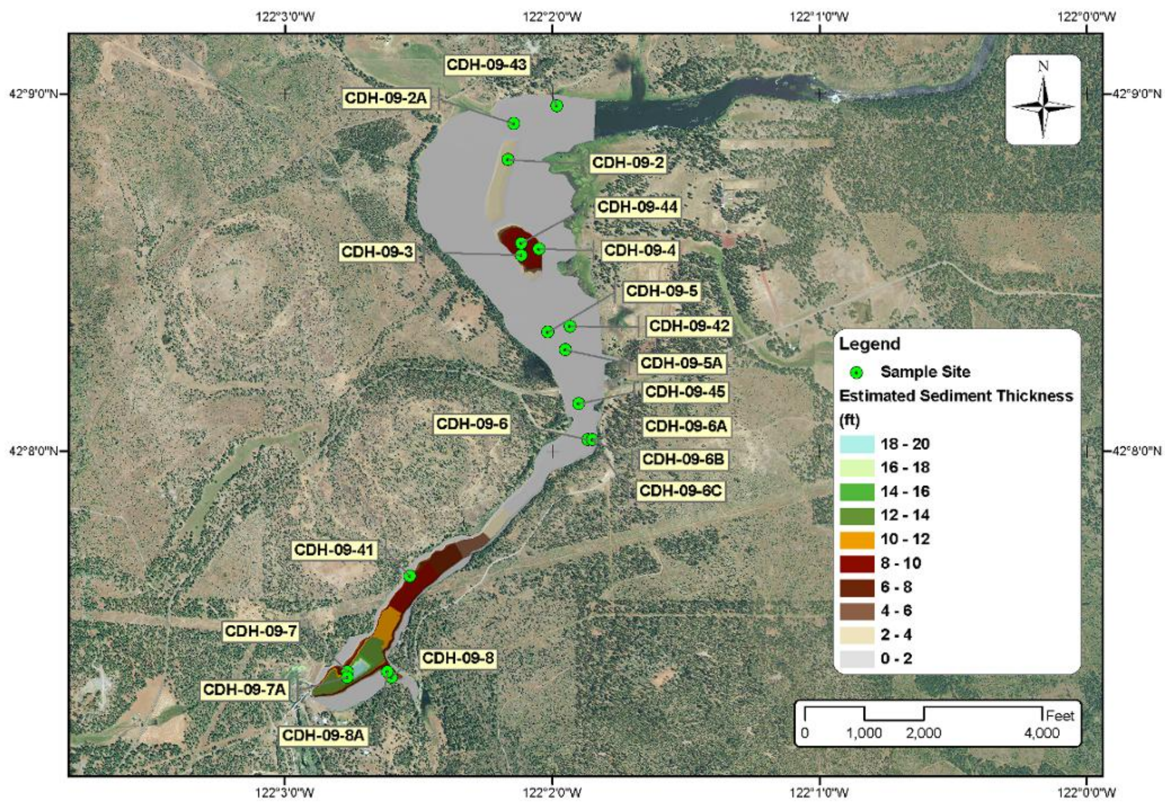

Figure 2-2. Estimated Sediment Thickness in J.C. Boyle Reservoir (Source: Reclamation 2010c)

Land surrounding J.C. Boyle reservoir is gently sloping and is mainly covered by forests and open lands. The land immediately surrounding the reservoir is primarily owned by PacifiCorp (Figure 2-3). Other landowners include Bureau of Land Management (BLM) and private entities.

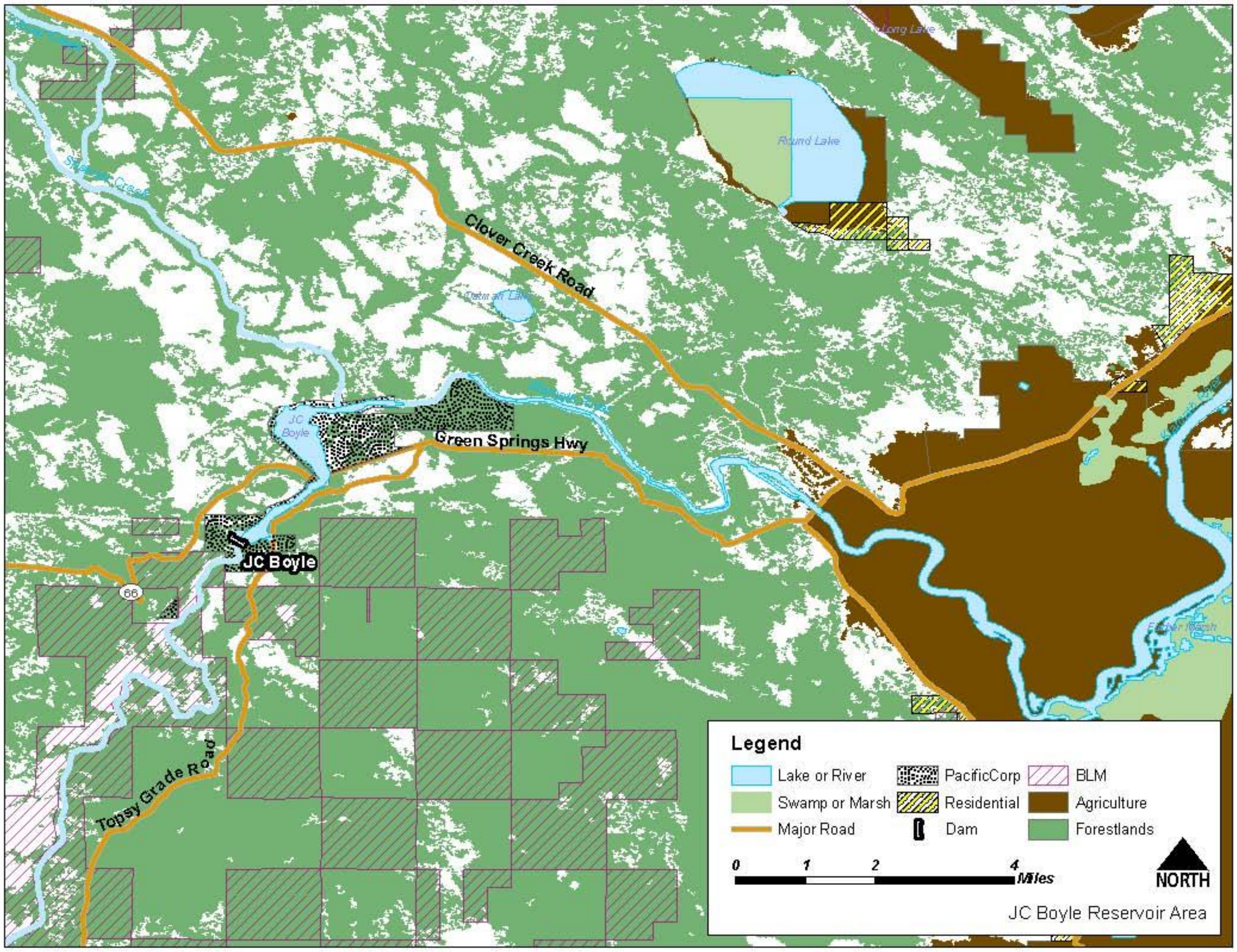

Figure 2-3. Land Use near J.C. Boyle Reservoir

2.2.1 Cultural Sites

There are numerous sites throughout the Klamath Basin of cultural significance to Indian tribes, including several sites around or in close proximity to the reservoirs.

Several cultural sites are located around the perimeter of the J.C. Boyle reservoir and one site has been identified within the reservoir. Any sediment removal operations at this reservoir would be designed to avoid these areas and would also likely result in the removal of less sediment in the vicinity of cultural sites.

2.3 Copco Reservoir

Copco Reservoir, located in Northern California, is approximately 4.2 miles long and up to 3,300 feet wide in the main reservoir. The reservoir's maximum water depth at normal pool is approximately 110 feet, but averages approximately 47 feet deep. Bathymetric figures of the reservoir are presented in Attachment A. Sediment in the reservoir is thickest towards the dam (up to 10 feet) where the deepest water is also present (Figure 2-4).

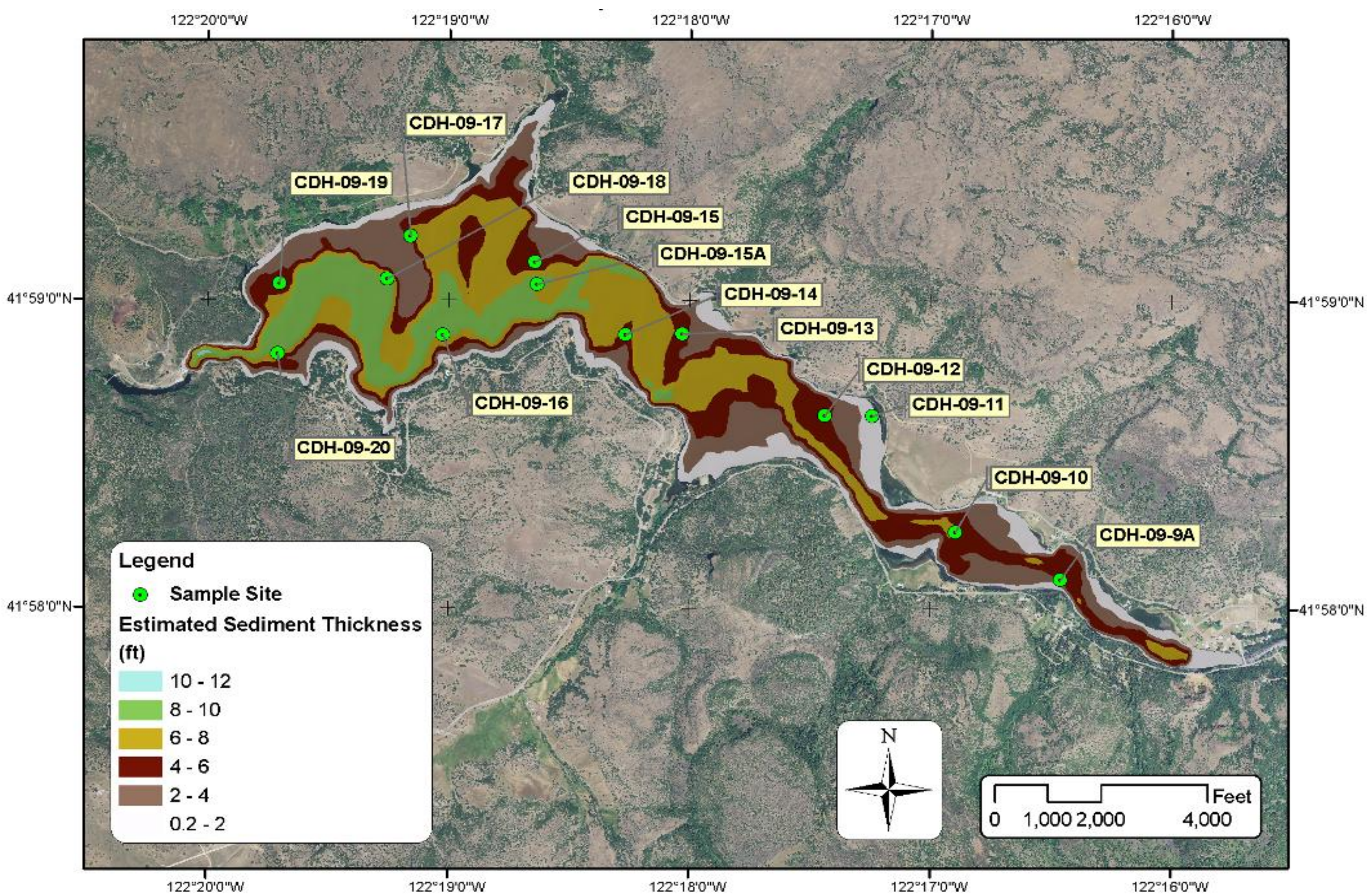

Figure 2-4. Copco Reservoir Sediment Distribution (Source: Reclamation 2010c)

The perimeter of Copco Reservoir consists primarily of private residences. Beyond these residences is scrub forest, owned primarily by PacifiCorp, private entities and the BLM (Figure 2-5).

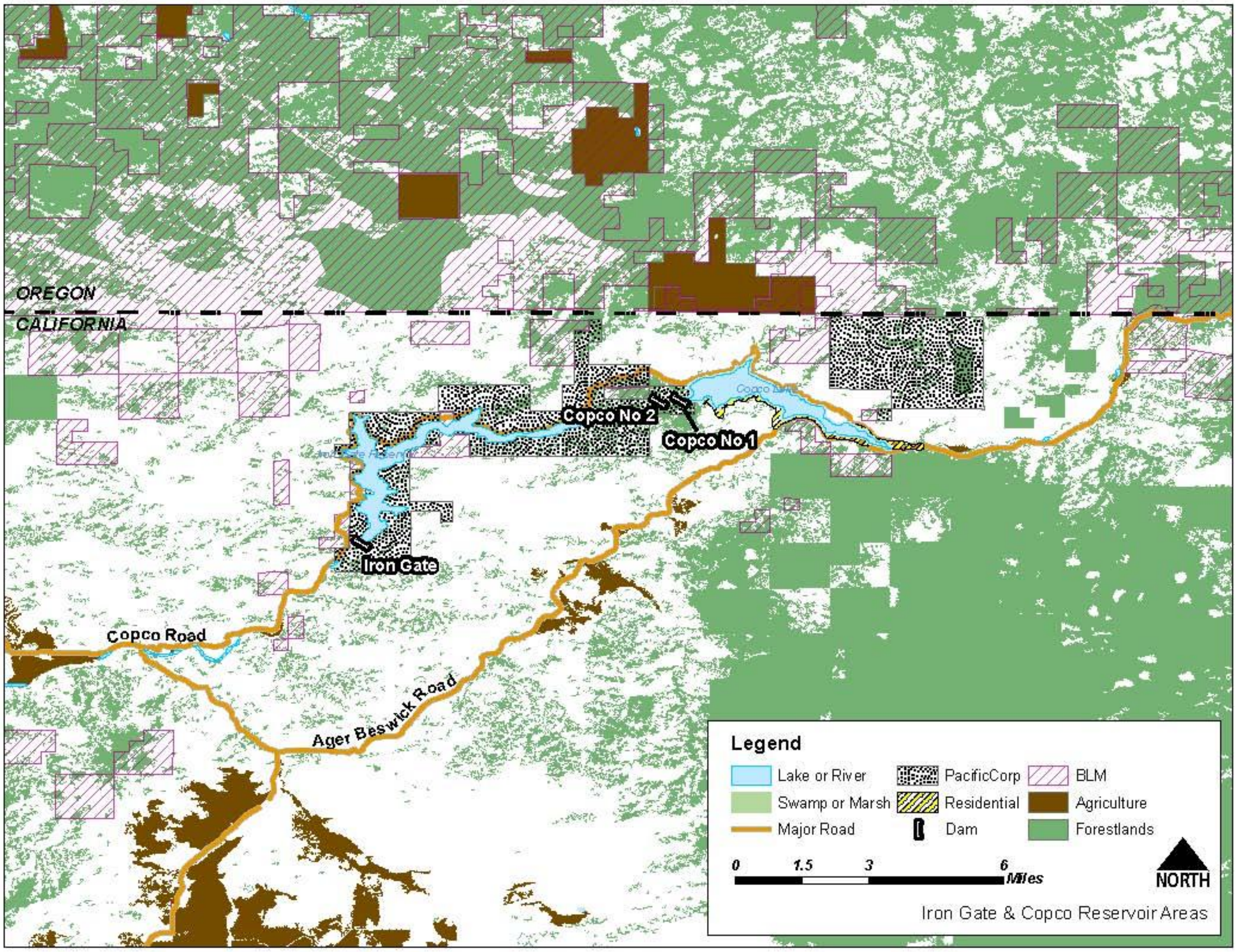

Figure 2-5. Land Use near Copco and Iron Gate Reservoirs

2.3.1 Cultural Sites

Like J.C. Boyle, several cultural sites are located around the perimeter of Copco Reservoir. No cultural sites have been identified within the reservoir proper. As with J.C. Boyle, any sediment removal operations at this reservoir would be designed to avoid the cultural site areas.

2.4 Iron Gate Reservoir

Iron Gate Reservoir, located in Northern California, is approximately 5.7 miles long and is narrow, with numerous embayments and side channels. The upstream two thirds of the reservoir ranges in width from about 400 to 1,000 feet, and the downstream third is generally 1,500 to

2,000 feet wide. Mirror Cove is a major side channel, extending northward from the main stem of the reservoir for about one mile. The reservoir's maximum water depth is approximately 160 feet, near the location of the dam, and averages 62 feet deep. Bathymetric figures can be found in Attachment A. Figure 2-6 illustrates the average reservoir sediment thicknesses. Sediment thickness in the reservoir ranges from one to five feet thick in the main stem of the reservoir but the Jenny Creek arm has sediment depths in excess of 10 feet and an average of 6 feet.

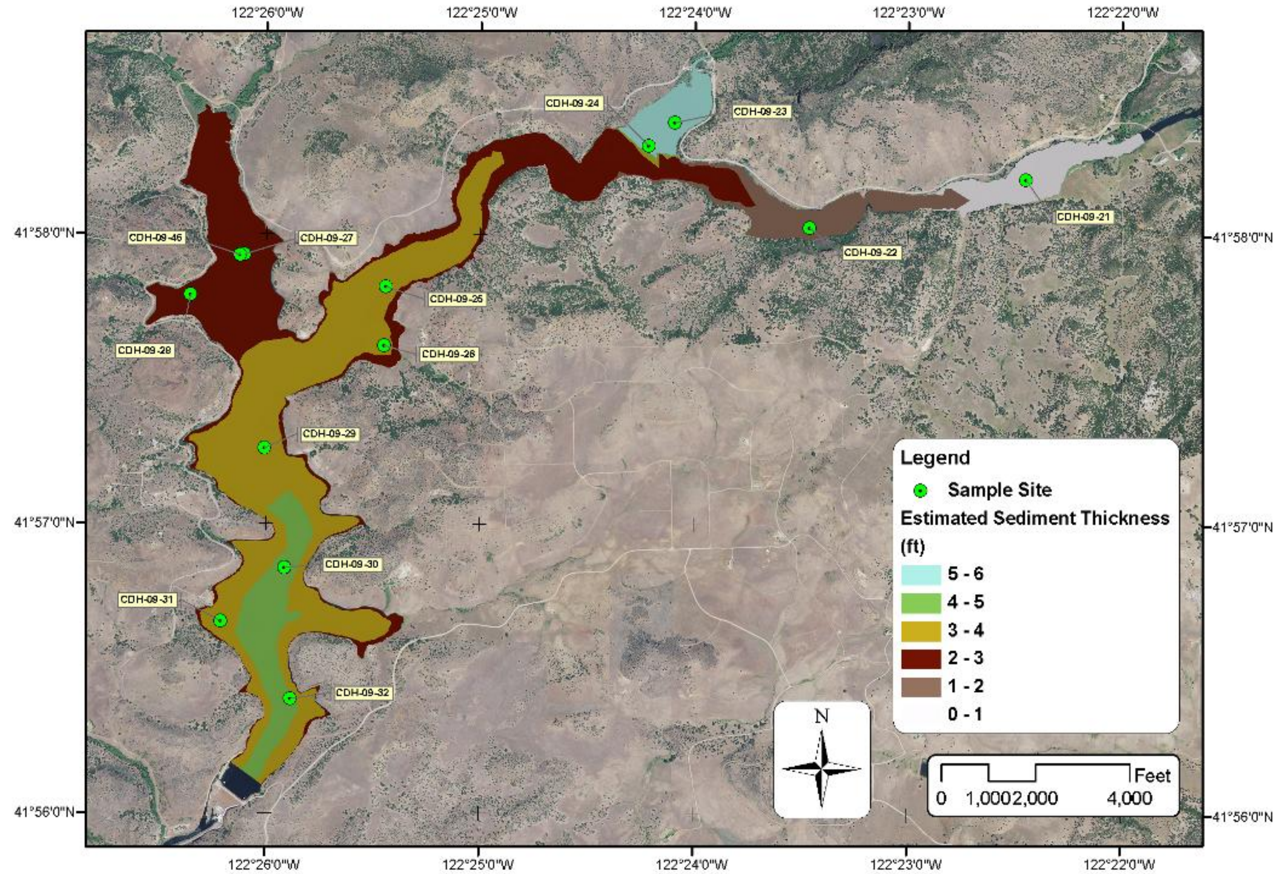

Figure 2-6. Sediment Distribution in Iron Gate Reservoir (Source: Reclamation 2010c)

Iron Gate Reservoir has relatively steep topographic side-slopes and a narrow channel with numerous side drainages. Three of these side drainages are large, and two of the side drainages (Camp Creek at Mirror Cove, in the upper left portion of Figure 2-6, and Jenny Creek, indicated in the figure by the light blue sediment thickness classification) likely contribute significant amounts of sediment to the reservoir. Except for the three principal side drainages, Iron Gate Reservoir has a relatively similar depositional environment throughout its length.

The area around Iron Gate Reservoir consists primarily of open scrub forest, as shown in Figure 2-5. The land immediately surrounding the reservoir is primarily owned by PacifiCorp. Other landowners include BLM and private entities.

2.4.1 Cultural Sites

Similar to J.C. Boyle and Copco Reservoirs, several cultural sites are located around the perimeter of the Iron Gate Reservoir. No cultural sites have been identified within the reservoir proper. Any sediment removal operations at Iron Gate Reservoir would be designed to avoid the cultural site areas.

This page intentionally left blank

Chapter 3
Overview of Reservoir Sediment

This section presents an overview, by reservoir, of the total sediment volume, estimated erodible sediment volume resulting from dam decommissioning, and the physical and chemical characteristics of the sediment.

3.1 Estimates of Total Reservoir Sediment Volume

Three separate estimates of the reservoir sediment volumes have been made in the past 10 years. In 2002, J C Headwaters, Inc. (Headwaters) performed a bathymetric survey of J.C. Boyle, Copco, and Iron Gate reservoirs and computed the relationships between reservoir storage volume and reservoir surface elevation. These relationships were compared to the historical pre-dam survey of each reservoir to obtain an estimate of total accumulated sediment volume.

In 2006, Gathard Engineering Consulting (GEC) utilized the same process as Headwaters' bathymetric survey and calculated a different reservoir sediment volume. The estimated sediment volumes were similar for the Copco Reservoir but significantly different for J.C. Boyle and Iron Gate Reservoirs (see Table 3-1).

Given the general discrepancy between the Headwater and GEC estimates, Reclamation conducted a field investigation in each of the reservoirs in 2009 to more accurately determine sediment thickness. The fieldwork entailed coring 55 holes in reservoir sediment by barge to directly measure sediment thickness and to collect geotechnical and chemical properties of the sediment. Reclamation used data from the 2009 cores and previous sediment thickness measurements (Shannon and Wilson 2006)[1] to extrapolate these measurements into sediment volumes in each reservoir.

Table 3-1 shows the results of the three approaches. Given the completeness of the Reclamation 2010 study, these calculations are assumed to be the most accurate estimate of the total sediment volumes. However, there is some uncertainty regarding the total volume in each of the reservoirs and the uncertainty of the volume estimate is expected to be between 20 to 30 percent.

Table 3-1. Comparison of Different Sediment Volume Estimates by Reservoir

Study	Volume of Sediment (yd^3)		
	J.C. Boyle	Copco 1	Iron Gate
JC Headwaters, Inc. (2002)	22,222	9,629,000	4,818,000
GEC (2006)	636,000	10,870,000	8,767,000
Reclamation (2010)[1]	1,000,000	7,440,000	4,710,000

[1]Reclamation published their report on their analysis from their 2009 geological study

[1] Shannon and Wilson (2006) collected 26 sediment samples in the three reservoirs and characterized both the physical and chemical properties of the sediment. Depths were recorded, but no volume estimates were made.

3.2 Sediment Characteristics

3.2.1 Sediment Composition

Investigations conducted by Reclamation (Reclamation 2010) and Shannon and Wilson (Shannon and Wilson 2006) show sediments in the three reservoirs are primarily composed of silt and clay with lesser amounts of sand and gravel.

Table 2-2 shows estimated volumes of reservoir sediment and the estimated percent of fine-grained reservoir sediment found in the upper and lower reaches of the reservoirs.

Table 3-2. Reservoir Sediment Volumes and Characteristics

Reservoir	Location	Volume (yd^3)	Silt & clay (%)
J.C. Boyle	Upper	380,000	44
	Lower	620,000	88
Copco No. 1	Upper	810,000	73
	Lower	6,630,000	88
Iron Gate	Upper	830,000	78
	Lower	2,780,000	86
	Jenny Creek Tributary	300,000	75
	Mirror Cove Tributary	800,000	94

(Source: Reclamation 2010c)

3.2.2 Sediment Distribution

Distribution of sediment within each of the reservoirs varies, as shown in Figures 2-1, 2-2, and 2-3. In J.C. Boyle, sediment primarily resides in the area nearest to the dam, with thicknesses up to 20 feet. Both Copco and Iron Gate Reservoirs have generally even distributions of sediment with thicknesses increasing towards the dams. Iron Gate has two tributary streams, Camp Creek and Jenny Creek that likely contribute significant amounts of course grained sediment to the reservoir.

3.2.3 Sediment Moisture Content and Erodibility

Field moisture of sediment samples collected by Reclamation were frequently 200 percent to 300 percent of the sample's dry weight, and ranged up to 700 percent moisture (Reclamation 2010c).

Reservoir sediment fine-grained nature and high water content, in general, make these sediments highly erodible. Sediment critical shear stress is one quantitative measure of the sediment's susceptibility to erosion. Critical shear stress is measured in units of pressure, (pounds per square inch or metric Pascals [Pa]). The higher the critical shear stress value, the lower the susceptibility to erosion. The critical shear stress for reservoir samples was on the order of 0.1 Pa. For comparison, the critical shear stress of clay is on the order of 1.0 Pa, while the critical shear stress of sand is 10.0 Pa (100 times greater than that of the reservoir sediments). (Reclamation 2010c)

3.2.4 Sediment Quality

As part of the Secretarial Determination studies, reservoir sediment cores are being analyzed for a suite of inorganic and organic contaminants to assess the potential environmental and human health impacts of sediment release. Sediment contaminant levels in samples from the Klamath River were collected at multiple sites and at various sediment depths per site in J.C. Boyle Reservoir, Copco Reservoir, Iron Gate Reservoir, and the Klamath River Estuary, for a total of 77 samples (USBR 2010). To date, the sediment evaluation process has followed screening protocols of the Sediment Evaluation Framework (SEF)[2] for the Pacific Northwest, issued in 2009 by the interagency Regional Sediment Evaluation Team (RSET).

Thus far, the SEF sediment chemistry screening process indicates that the sediment deposits in the Klamath River reservoirs are not contaminated. There are few positive exceedances of relevant screening values, and therefore little positive indication that significant aquatic toxicity, or ecological or human health risk, would likely result from exposure to the sediments. For the few compounds that positively exceeded relevant screening levels, as well as the greater number of compounds for which it could not be determined whether screening levels were exceeded, further evaluations must be conducted before conclusions about the potential for contaminant-related impacts and risks can be reached. This includes direct laboratory testing of the sediments to assess their toxicity to sensitive aquatic organisms (i.e., toxicity bioassays), and direct laboratory testing of the sediments for the bioavailability of the contaminants present (i.e., whether contaminants are available to be taken up by organisms directly exposed to the sediments for extended periods of time, or bioaccumulation assays). Each of these biological testing approaches have been conducted on the same reservoir sediment samples evaluated in the chemistry screening described above. The results of this biological testing are expected during spring 2011.

Sediment removal options in the following sections do not include special removal, handling, or disposal requirement that would result from the presence of contaminants exceeding acceptable regulatory standards. If the results of biological testing described above identify any sediments requiring special management requirements, the assumption behind this evaluation will be revisited.

3.3 Estimate of Erodible Sediment Volume

Under the provisions of the KHSA, sediment in the reservoirs would be naturally eroded by the river's action with the removal of the four dams. This section estimates the percentage of sediment, from the entire sediment volume presented in Table 2-2 for each reservoir that would potentially erode with dam removal.

To help with estimating the percent of erodible sediment it is important to reflect on the sediment depositional process in the reservoirs. Sediment accumulation has occurred primarily because the reservoirs provide a low velocity pool, which allows the settling of fine and course sediment that would have otherwise migrated downriver in the absence of dams. This sediment has been

[2] The SEF is a regional guidance document that provides a framework for the assessment and characterization of freshwater and marine sediments in Idaho, Oregon, and Washington (RSET 2009).

distributed throughout the reservoirs, including the historic river channel and side slopes, which are now inundated.

As the reservoir water elevations are lowered during decommissioning, the river channel will incise (down cut) into the erodible sediments as water velocity increases. In addition to sediment scoured though river down cutting, some proportion of the sediment on the side slopes will slump and enter the river due to its low critical shear stress (see Section 3.2.3).

The Reclamation 2010 study modeled sediment transport under the KHSA to estimate the amount of sediment that would be released to downstream reaches of the river. The estimates are presented in a range for each reservoir and are included in Table 3-3. The estimates assume that sediment in the historic channel would be mobilized in addition to side slope sediments where the material's critical shear stress was exceeded. This was estimated to occur on slopes exceeding 5 to 15 degrees (approximately a slope ratio of 10 horizontal to 1 vertical [10H:1V] and 4H:1V, respectively). A range of values was simulated because of the uncertainty regarding the stable slope. The flows will also affect the amount of sediment eroded. A wet water year will result in a significant amount of more sediment eroded from the reservoir than a dry year. The sediment amounts presented by Reclamation also include the deposition of material from upstream reservoirs during the drawdown process, so they are net erosion volumes from the reservoir. The Reclamation estimate also ignored the erosion that could occur from flow of tributaries during the drawdown process. Furthermore, the Reclamation estimate of volume erosion was based upon a cross section based model that idealizes the reservoir as a series of distinct cross sections. Bathymetry information between the cross sections is lost and therefore may be less accurate than a volumetric calculation. The main purpose of the Reclamation 2010 study was to estimate the range of potential response from dam removal. The purpose of the present study is to identify the volume of sediment that will most probably be eroded so that the dredging operation will be as efficient as possible. These are slightly different purposes and therefore require different analysis techniques. It will not be practical to remove all the sediment from behind the dams and therefore we need to identify the amount and location of the sediment most likely to erode.

Table 3-3. Estimate of Erodible Sediment Volume by Reservoir

Source		Volume of Eroded Sediment (yd^3)		
		J.C. Boyle	Copco	Iron Gate
Reclamation (2010)[1]	Range	300,000-600,000	3,600,000-6,500,000	1,200,000-2,200,000
	Average	450,000	5,050,000	1,700,000
	Percentage of Total Sediment Volume[2]	45%	68%	36%
CDM	Estimated Amount	940,000	2,700,000	2,830,000
	Percentage of Total Sediment Volume[2]	94%	36%	60%

[1]Numbers assuming an angle of repose between 5 to 15 degrees and the variation between a wet and dry water year.
[2]Uses Reclamation's estimates from Table 3-1

This paper, therefore, includes an additional estimate of erodible sediment volumes (CDM Estimate), which are also presented in Table 3-3. The additional estimate was developed using the following process.

Maps of each of the three reservoirs (depicted in Figures 3-1 through 3-3) were created to show the pre-dam topography and river channel layered with data on current sediment thicknesses, as described in Section 2.1. The sediment thicknesses were divided and mapped in each reservoir (e.g. 0-1 feet, 1-3 feet, 3-4 feet, 4-5 feet, and 5-6 feet) and each map was then sub-divided into either polygon shapes or lengths and quantified through a summing exercise using the following assumptions:

- Historical river channel would be eroded to its pre-dam elevation
- Historical tributaries would be eroded to their pre-dam course and elevation
- Narrow and steep canyons would erode
- The reservoir side slopes erode at a slope of 10H:1V.

Calculation tables that corresponded to Figures 3-1 through 3-3 are presented in Attachment B.

While Reclamation provided a range of erodible sediment volume, CDM attempted to provide a more rigorous assessment of the sediment most likely to erode by performing a volumetric estimate. For J.C. Boyle, the CDM estimate of the amount of sediment most likely to erode is significantly higher than the estimate from Reclamation. The Reclamation estimate may have missed some of the sediment located in a relatively small region of the reservoir near the dam because the estimate is based upon a few cross sections through this region.

For Copco, the CDM estimate is significantly lower than that provided by Reclamation. Reclamation's estimate accounted for the fact that hydraulic forces can also eroded some of the sediment and allowed erosion to occur over the entire reservoir cross section. There was therefore significant erosion of material in the terrace locations. The amount of erosion in the terrace locations is relatively uncertain and depends upon the specific flow velocities in the overbank locations. One-dimensional models such as the one employed by Reclamation cannot simulate overbank flow velocities in detail and therefore the erosion estimates in the overbanks are relatively uncertain. Because CDM estimate targets the sediment most likely to erode, the terrace deposits with slopes less than 10H:1V were not included.

For Iron Gate, the CDM estimate is slightly higher than the Reclamation estimate. This is most likely due to the fact that Reclamation did not include the potential erosion due to flows from Camp, Scotch, or Jenny Creek tributaries which flow into the Reservoir.

Overall, the averaged total quantity of erodible sediment estimated by Reclamation is between 5.1 and 9.3 million cubic yards. Total estimated erodible sediment estimated by CDM is 6.47 million cubic yards. This paper goes on to use the CDM estimated erodible sediment volumes.

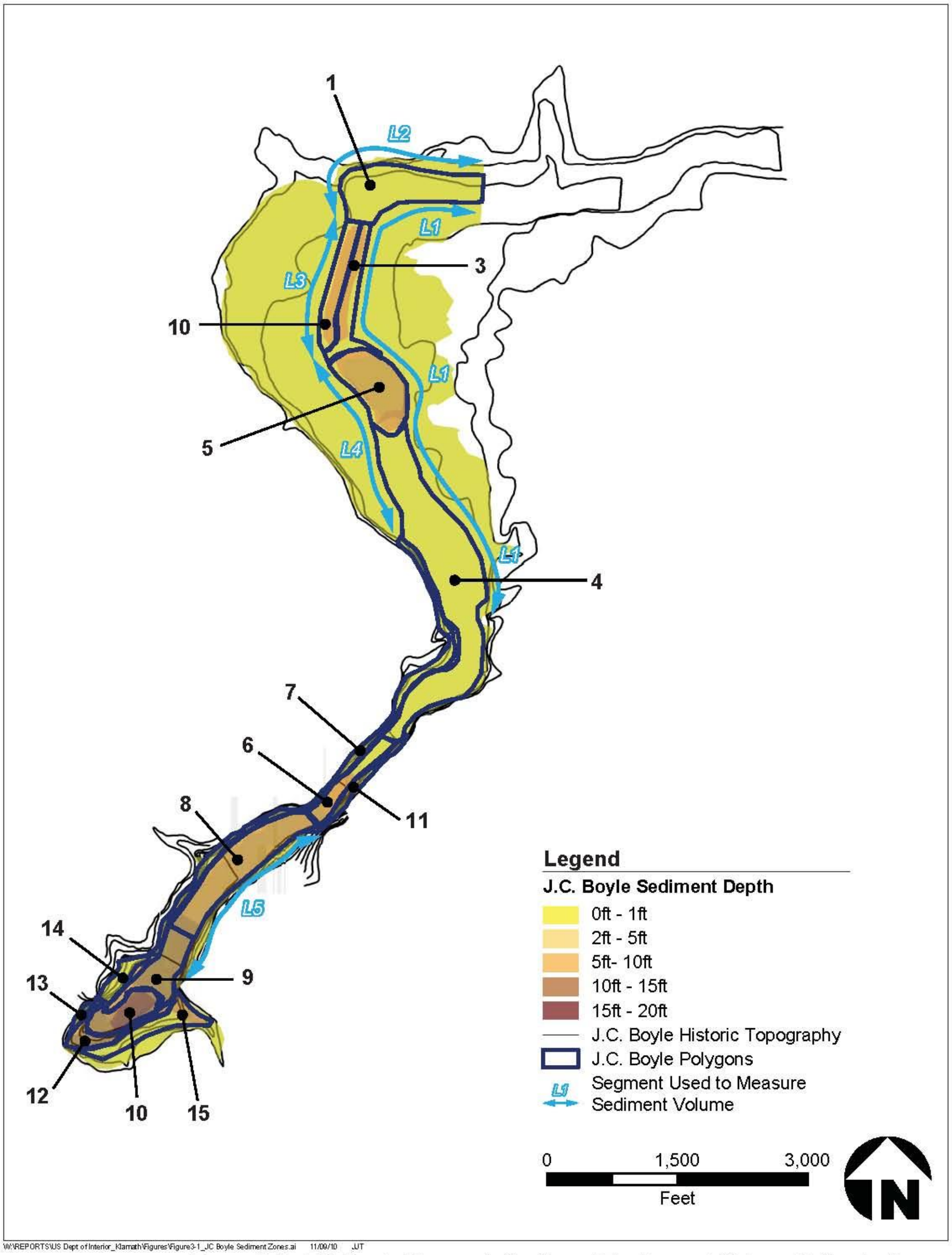

Figure 3-1: J.C. Boyle Reservoir Sediment Depths and Volume Estimate Zones

Figure 3-1. J.C. Boyle Reservoir Sediment Depths and Volume Estimate Zones

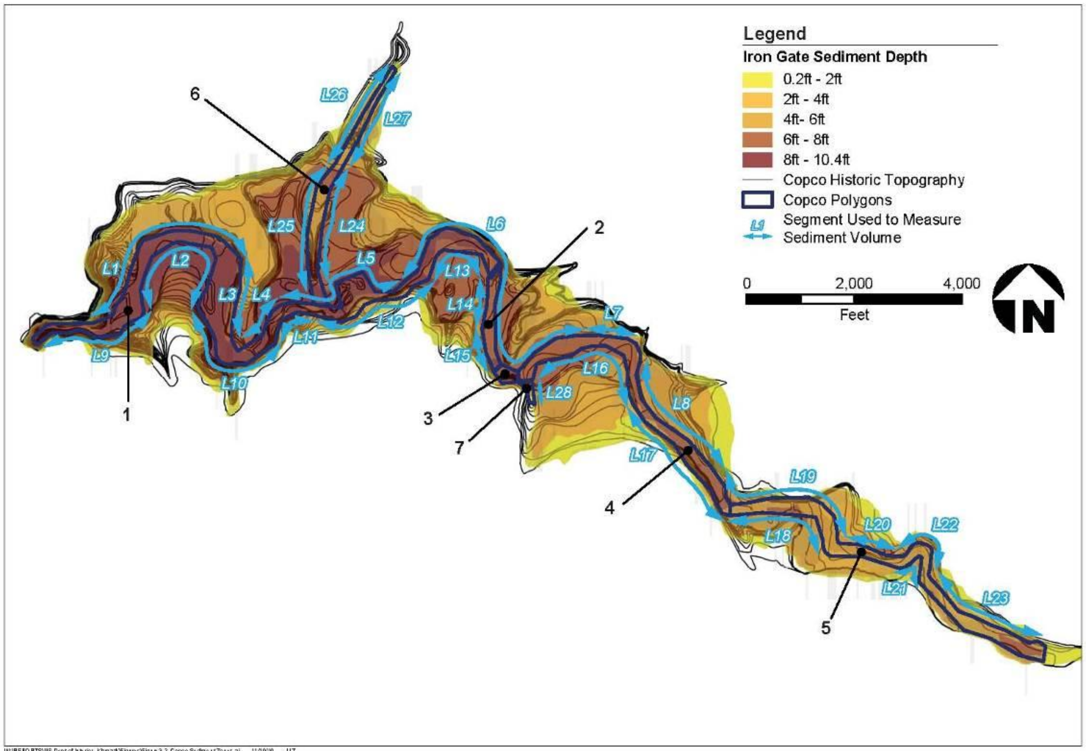

Figure 3-2. Copco Reservoir Sediment Depths and Volume Estimate Zones

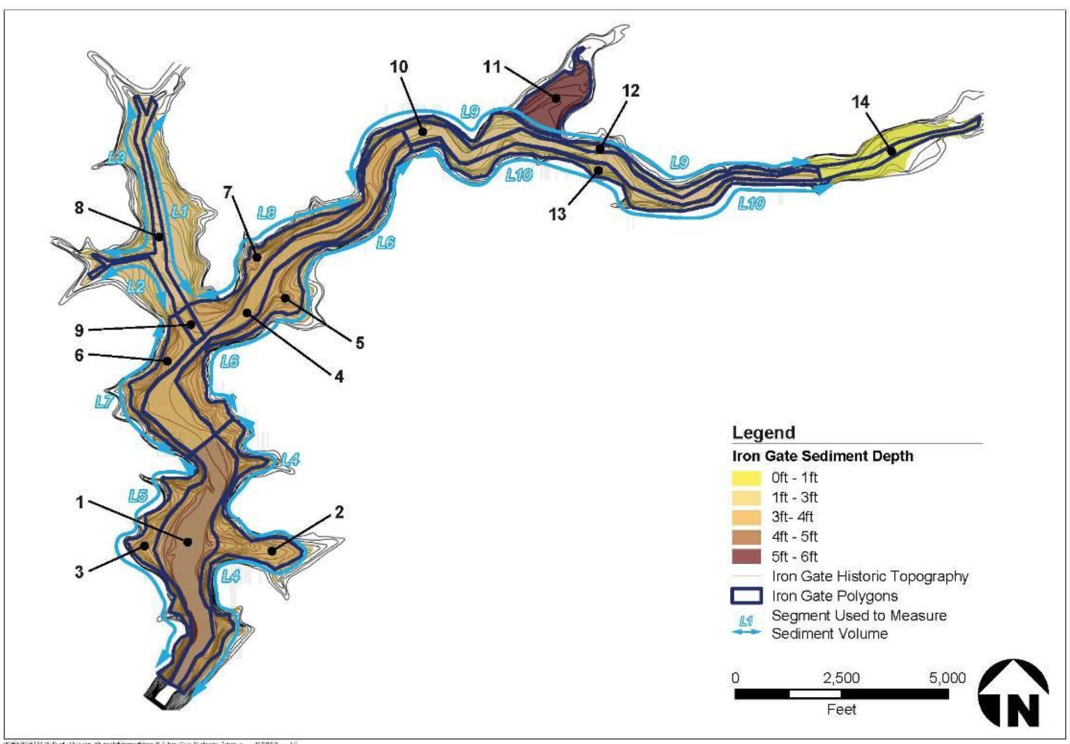

Figure 3-3. Iron Gate Reservoir Sediment Depths and Volume Estimate Zones

Chapter 4
Potential Sediment Management Technologies

Managing sediments at the three reservoir sites includes removal, dewatering, conveyance and disposal. The chosen method, or methods, of dredging sediment are dependent on factors such as the type of sediment and their location in the reservoir. This chapter describes potential sediment removal and conveyance technologies that may be applicable to the three reservoirs. Sediment disposal is addressed in Chapter 5.

4.1 Conventional Excavation

Conventional excavation (heavy mechanical equipment) requires that the reservoir be lowered or the river rerouted around each reservoir to dry the reservoir sediments and allow for conventional equipment access. The sediment could then be excavated by tracked excavation equipment and front-end loaders and hauled by truck to an appropriate disposal site.

4.1.1 Constraints

Conventional excavation methods will remove little to none of the erodible sediment defined in Chapter 3. Under this scenario, as the reservoirs are lowered, river down cutting and slope failures will occur that will mobilize the erodible sediment.

Rerouting of the Klamath River around any of the reservoirs is possible (although highly impracticable) given the steep topography, reservoir lengths, and the high river flows. Conventional excavation is therefore not considered further in this document as a practical means for sediment removal.

4.2 Hydraulic Dredging

Hydraulic dredges work by sucking a mixture of dredged material and water from the reservoir bottom. Hydraulic dredging is typically the preferred approach for removing large amounts of sediment, particularly if the sediments are fine-grained. Sediment is removed as slurry, approximately 10 to 20 percent solids by weight (USACE 1983).

Hydraulic dredging is normally conducted from a barge capable of accessing shallow areas (approximately five feet in depth) of the water body being dredged.

Although there are various styles of hydraulic dredges, the most applicable for the three reservoirs would be a hydraulic pipeline cutterhead dredge (cutterhead dredges). Cutterhead dredges draw sediment through an intake pipe and then discharge the slurry directly to the decant and settling site. The cutterhead on the suction end of the dredge has a mechanical device with rotating blades or teeth to break up or loosen the bottom material allowing it to be sucked through the dredge. Two stern spuds hold the dredge in working position. Cables attached to anchors on each side of the dredge control lateral movement. Figure 4-1 presents a schematic of a typical pipeline cutterhead dredge. The suction operation of the dredge minimizes turbidity events of the dredge action.

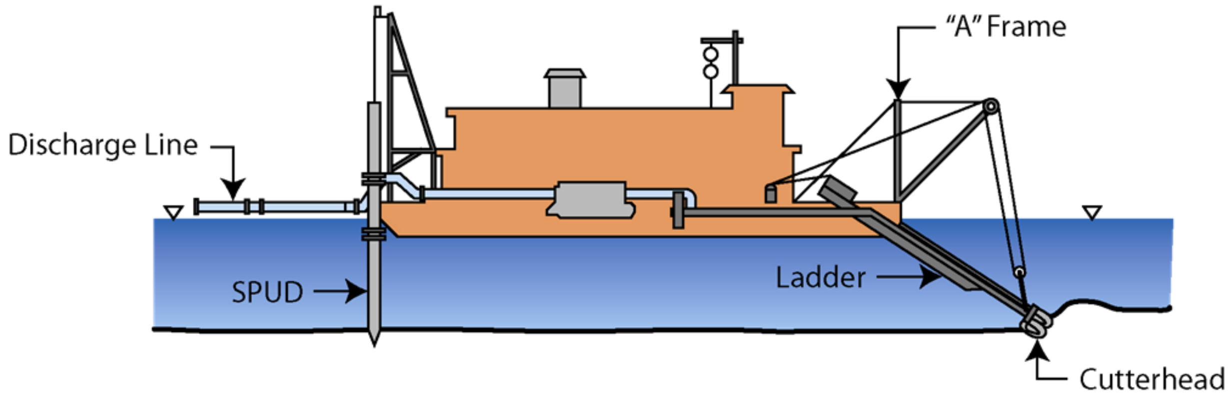

Figure 4-1. Hydraulic Pipeline Cutterhead Dredge (Source: USACE 1983)

4.2.1 Constraints

Hydraulic dredges, depending upon their size, have depth limitations. To accommodate for the drawdown scenarios presented for each reservoir in Section 1.1, hydraulic dredging would access shallower areas of the reservoir, prior to drawdown, and follow the drawdown to deeper areas of the reservoir.

Woody debris can inhibit the operability of hydraulic dredging, if present in the reservoirs. However, it is unknown at this time whether the presence of woody debris will affect dredging.

Given the local transportation constraints identified in Chapter 2, it is reasonable to assume that the maximum cutterhead dredge that could reasonably be transported to the reservoirs would have an optimal dredge depth capability of approximately 25 feet, with a maximum depth of 33 feet (See Table 4-1).

A dredge capable of reaching greater reservoir depth could be used to remove sediment prior to reservoir drawdown but this approach would present other limitations. A typical dredge capable of reaching a depth of 50 feet can exceed 150 tons and could pose a transportation challenge. The larger, deeper dredge would also have more difficulty operating within the narrow confines of the reservoirs and the precision of the cutterhead would be reduced at greater depths potentially disturbing cultural sites or removing sediment classified as non-erodible. Operating suction dredge(s) in the reservoirs for an extended period prior to reservoir drawdown may also contribute to Klamath River water quality impacts during the coho and Chinook migration period (March 15 through December) from suspended sediment entering the river because the reservoirs do not have sufficient resonance time to settle fine particles.

Table 4-1. Hydraulic Dredge Physical Specifications

Pipeline Diameter (in)	Weight (tons)	Length (ft)	Width (ft)	Height (ft)	Draft (in)	Dredge Pumps		Production Rate[3] (yd^3/hr)	Dredging Depth
						hp	Drive		
8[1]	19	44	11	20	35	175	Diesel	45-105	12
14[1]	87	70-95	20	33	43	520	Diesel	160-700	25
16[2]	90	97	23	55	34	855	Diesel	150 – 700	10-33
20[1]	316	180	32	70	54	1700	Diesel	310-1,365	50

([1]Source: USACE 1983; [2]Source: Ellicot Dredges, No Date)

[3] Production rates are defined as the amount of sediment (**not slurry**) removed per hour.

The 25 foot dredge depth would limit the quantity of reservoir sediment that could be removed, prior to and during dam removal and reservoir drawdown. Only a portion of the remainder of the sediment (that was initially located at depths greater than 25 feet before drawdown) would be removed as the reservoir is drawn down.

The proposed drawdown rates exceed the capacity of the dredge to remove all of the sediment material. At some point during the drawdown, the dredge would become stranded in the lower reach of the reservoir, towards the dam. Operational provisions would be required to plan for the removal of the dredge from a predetermined reservoir location.

Transporting a single dredge, pipeline and support equipment, would require several tractor truck loads, in addition to a large crane to assemble and launch the dredge. To meet the requirement of the drawdown scenarios it would be necessary to stage individual or multiple dredges at each of the three reservoir sites.

4.2.2 Hydraulic Sediment Conveyance and Decanting

The hydraulic dredges would convey the sediment-slurry through a pipeline, where the route and distance to the disposal site are important design considerations. An alignment along the downstream river channel may allow for gravity flow and avoid pumping. If gravity flow is not possible, then a pumping station and/or booster pumps would be needed. Silt- and clay-sized sediment slurries, similar to the reservoir sediments, are ideal for gravity or pumping through a slurry pipeline.

The cutterhead dredge has the capability of pumping dredged material distances of several miles with booster pumps. The sediment-water mixture is conveyed and discharged into a diked containment area ideally at the disposal facility. The diked containment areas are used to retain dredged material solids while allowing the carrier water to decant from the sediment.

A typical diked containment area is shown schematically in Figure 4-2. A tract of land is surrounded by dikes to form a confined surface area into which hydraulically dredged sediments are pumped. The containment area is designed to allow for both coarse- and fine-grained materials to settle out of suspension and thereby occupy a given storage volume. The decant water is discharged from the containment area over a weir. The fine grained clay and silts identified in the reservoirs would require large settling areas or potentially secondary treatment after decant water leaves the containment area to adequately remove suspended sediment. Depending upon the quality, the decant water could be returned to the river, or land applied in a manner to minimize any runoff.

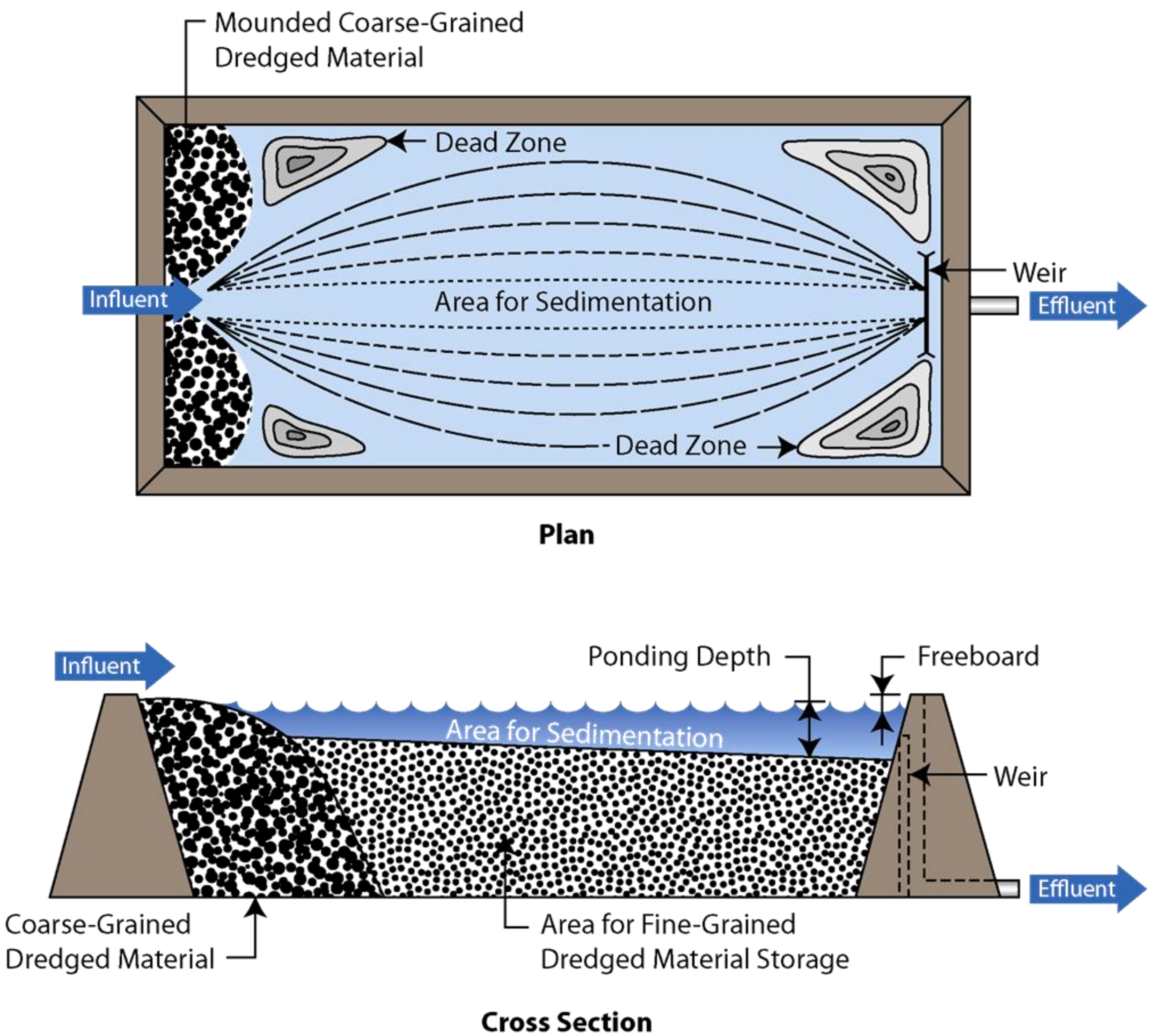

Figure 4-2. Conceptual Sediment Disposal and Dewatering Facility (Source: USACE 1983)

Reservoir sediment volumes at the disposal sites, including the dredged volume of water, will require large land areas. For example, disposal of the total estimated 6.47 million cubic yards of erodible reservoir sediments, assuming an 85 percent water content (which increases the sediment/slurry volume to approximately 43.1 million cubic yards), would require an estimated 1,336 acres, assuming a 20-foot depth for the diked containment area. If the slurry were decanted prior to disposal of the sediment, the area required for storage could be on order of 50 percent less. Additional detailed studies evaluating sediment settling rates and discharge requirements would be needed to appropriately design and size sediment disposal sites that provide decanting.

Dikes for retaining or confining dredged material are normally earthen embankments and designs generally parallel those required for design of flood protection levees or earth-filled dams. These structures would likely require permitting as a dam structure in Oregon and California.

4.3 Mechanical Dredging

Mechanical dredging is generally done with a barge-mounted crane using a clam bucket or dragline bucket (Figure 4-3). The material is excavated and placed in a barge. Buckets range in size up to 26 cubic yards and can operate at depths of up to 100 feet, although deeper operations result in less removal accuracy. Mechanical dredging is ideal for coarse-grained sediments or where sediment can be dredged from a channel bottom and directly placed on land. For the three reservoirs, a barge would be required to convey sediment to shore and sediment would be unloaded with a crane using a clam bucket. Ideally, the sediment would be placed directly in dump trucks, and hauled to a disposal site. However, the high water content of the reservoir sediments would likely require decanting of the materials prior to truck transportation. Decanting would take place in a temporary settling basin similar to that described in Section 4.2.1.

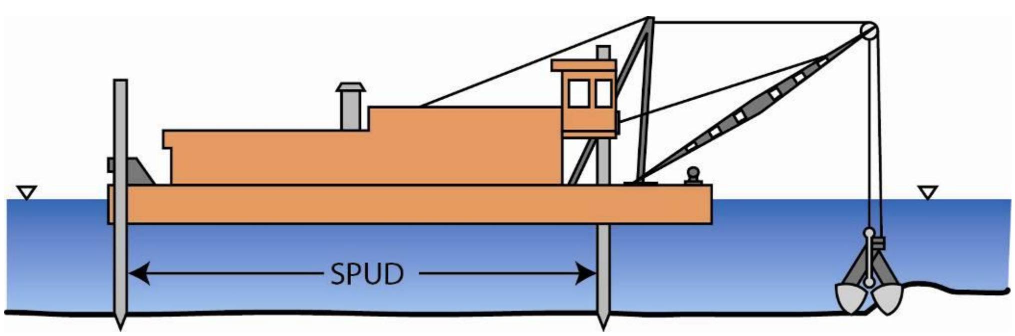

Figure 4-3. Mechanical Bucket Dredge (Source: USACE 1983)

4.3.1 Constraints

There are several constraints to mechanical dredging that render its application less advantageous than hydraulic dredging for the three reservoirs, the most important being effect to water quality. The mechanical dredging bucket once it clears the water surface will experience sediment loss through rapid drainage of water and slumping of the material heaped above the rim. Given the fine-grained nature of the reservoir sediments and high water content, it is anticipated that substantial losses of sediments will occur and enter suspension in the reservoir. The mechanical nature of the bucket on the reservoir bottom will also contribute to increased sediment suspension in the reservoir. The operation would likely need to operate with a silt curtain to minimize the extent of suspended sediment in the reservoirs or operate over longer periods of time with imposed operational water quality criteria. Both approaches add cost and time to the operation.

Other constraints include its lack of operational precision, relatively slow speed of operation and potential need to dewater sediment prior to transporting, as noted above.

4.3.2 Truck Conveyance

Trucking is required with mechanical bucket dredging. Under this scenario, barges with estimated capacities up to 160 cubic yards would convey sediment to a transfer site along the shoreline. At the transfer site, haul trucks with haul capacities up to 15 cubic yards would be staged. Ideally, assuming that no decanting of water would be required, the dredged sediment would be transferred from the barge to the haul trucks using an excavator and transported to a disposal site.

Based on a mechanical dredge capacity of around 325 cubic yards per hour, a barge will be filled in 25-30 minutes or two barges per hour. A single barge would require approximately 11 haul trucks to be fully unloaded. For the smallest of the reservoirs J.C. Boyle, this equates to approximately, 264 trucks per hour, 12 hours per day for a period of eight months to remove the estimated 940,000 cubic yards of erodible materials from the reservoir.

4.4 Summary of Technology Alternatives

Although limited by the drawdown scenarios proposed for dam removal, hydraulic dredging appears to be the best and potentially only acceptable method for sediment removal in the reservoirs.

Conventional methods of sediment removal have been proposed at other dam removal programs (San Clemente Dam on the Carmel River) where the river can be rerouted, allowing conventional equipment access. Rerouting of the Klamath River around any of the reservoirs is not feasible given their size, topography, and river flows.

Mechanical removal of sediments although technically feasible, creates water quality and truck transportation impacts that would likely not be acceptable to the local community or regulatory agencies.

Hydraulic dredging could be accomplished while maintaining acceptable water quality conditions in the reservoirs and large-scale transportation impacts can be avoided by hydraulically piping the sediment material to nearby decant and disposal sites.

However, this process is not without challenges. Large areas of land would be required to decant and dispose of the sediment in the vicinity of the reservoirs and methods would be required to manage decant water to avoid water quality impacts to surface waters. This process would be permitted as a Clean Water Act 404 activity for the discharge of dredged or fill material into the navigable waters at specified disposal sites. Chapter 5 reviews the available land and disposal options in and around the reservoirs to accommodate sediment disposal.

This page intentionally left blank

Chapter 5
Sediment Disposal

This section evaluates the sediment management and disposal sites that could be reasonably considered for disposal of the reservoir sediment. Given the large quantity of material involved, it is important that potential sites be located in close proximity to the reservoirs to reduce conveyance costs.

As indicated in Section 4, hydraulic dredging appears to be the best method to remove reservoir sediments. Hydraulic dredging would result in hydraulically pumping a sediment and water mixture to a management and disposal site. Given the very large quantity of sediment that could potentially be pumped and the generally hilly topography that would require booster pumping to move sediment over long distances increasing costs, this paper analyzed potential disposal facilities within approximately two miles of the reservoirs.

Three types of disposal sites were reviewed including land use/application, landfills, and engineered facilities in the vicinity of the reservoirs.

5.1 Land Use/Application

Land use application would directly apply the sediments to agricultural lands. Land use is an accepted practice for the use of wastewater treatment sludge that contain high organics and nitrogen compounds that can augment the quality of agricultural soil. Reservoir sediments do contain organics and thus there could be some benefit to agriculture through land application.

Land surrounding the three reservoirs is primarily wooded or upland sage with range cattle, and hay being the primary agricultural activity. There are designated agricultural lands within two miles of Copco Reservoir on the Oregon side of the border with California. There are no agricultural lands within two miles of J.C. Boyle or Iron Gate (See Figures 2-3 and 2-5). Review of aerial photos of the designated agriculture lands, located north of Copco Reservoir, do not show any cultivated agriculture, indicating likely range cattle operations.

Reuse of reservoir sediment on open range land would provide limited to no agricultural benefit. There is extensive cultivated agriculture in the Klamath Basin approximately 10 miles from J.C. Boyle reservoir, however, these lands are considered too far away to cost effectively convey sediment from the three reservoirs.

5.2 Landfills

A search of regional landfills was conducted to determine if any were in close proximity to the reservoirs. Landfills could have the designated space to manage the sediments and once dried the materials could be used for daily cover. Table 5-1 is a summary of area landfills. The nearest landfill to any of the reservoir sites is 19 miles away and is considered too far to convey sediments.

Table 5-1. Locations of Local Landfills

Landfill	Location	Approximate Distance
Klamath County Landfill	Klamath Falls, OR	19.5 Miles from J.C. Boyle
Hornbrook	Henley, CA	19.0 Miles from Iron Gate
Dorris	Dorris, CA	19.7 Miles from J.C Boyle
Yreka Med. Vol. Transfer Station	Yreka, CA	27 Miles from Iron Gate

5.3 Engineered Vicinity Disposal Sites

Another potential sediment disposal approach reviewed was the use of land in the vicinity of each reservoir that could accommodate the construction of an engineered containment and disposal site. As discussed in Section 4.2.1, this type of facility would require engineered dikes similar to levee construction to contain the 15 percent sediment and 85 percent water slurry. The sites could be oversized to accommodate sediment and water or designed to provide for the decanting of water from the sediment. For the purposes of assessing land requirements, it is assumed that the sediment slurry will be decanted and would result in approximately 50 percent less land requirement. This assumption would be subject to further engineering design as discussed in Section 4.2.2. The disposal sites would remain in place and once the sediment settled and the water decanted, the area would be re-vegetated and stabilized to conform with the natural landscape.

A preliminary search was conducted for potential disposal locations near each of the reservoirs. Land use, land ownership, and topographic information was reviewed to assess potential sediment disposal sites. The primary engineering factor reviewed was slopes of less than 20 percent with ideal slopes of less than 10 percent. Other considerations included land currently owned by PacifiCorp, state, of federal agencies. Private properties were not considered as viable for disposal sites. This initial analysis did not include an investigation of soils types, which could further limit land disposal options. Land ownership and land use maps were then overlain on slope maps for the three reservoirs. Results of land use and slopes are depicted in (Figures 5-1, 5-2, and 5-3).

For the J.C. Boyle Reservoir, there are several small areas that could accommodate disposal sites (See Figure 5-1). The largest of these areas are either on private property or designated as the Sportsman's Park. Although the Sportsman's Park is owned by PacifiCorp it was not considered as a viable disposal location given its recreational value to the local community.

For both Copco and Iron Gate Reservoirs, there are limited large areas with topographic slopes of less than 10 percent located in the immediate vicinity of the reservoirs. When the search is broadened to include lands with slopes of less than 15 percent and 20 percent, there are several sites around Copco on PacifiCorp or BLM lands that could accommodate a large sediment disposal site.

Engineering on these steeper slopes would be more challenging and increase overall containment design and construction costs. Iron Gate Reservoir has more limited land disposal opportunities. Two are shared with Copco and three others, in the central reservoir area, are on private land with current residential development (See Figures 5-2 and 5-3). Private lands were not considered as viable disposal sites.

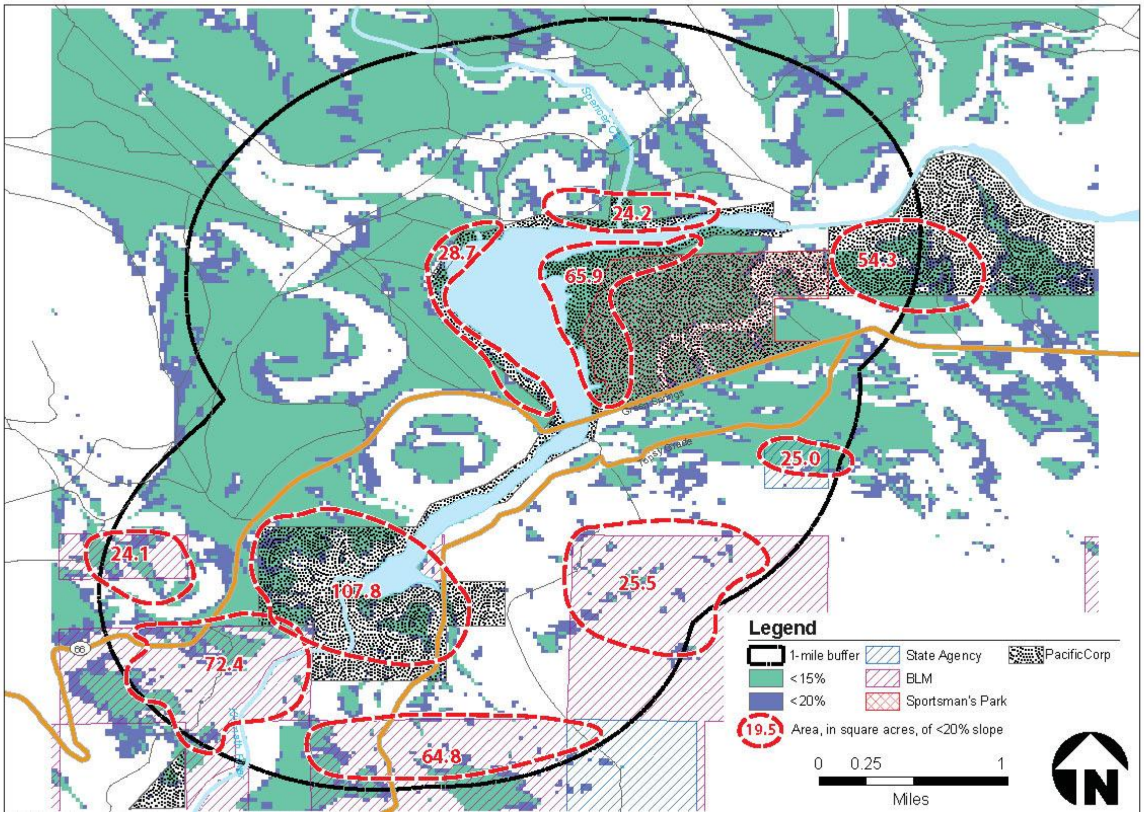

Figure 5-1. J.C. Boyle Reservoir Area (Slopes <10%)

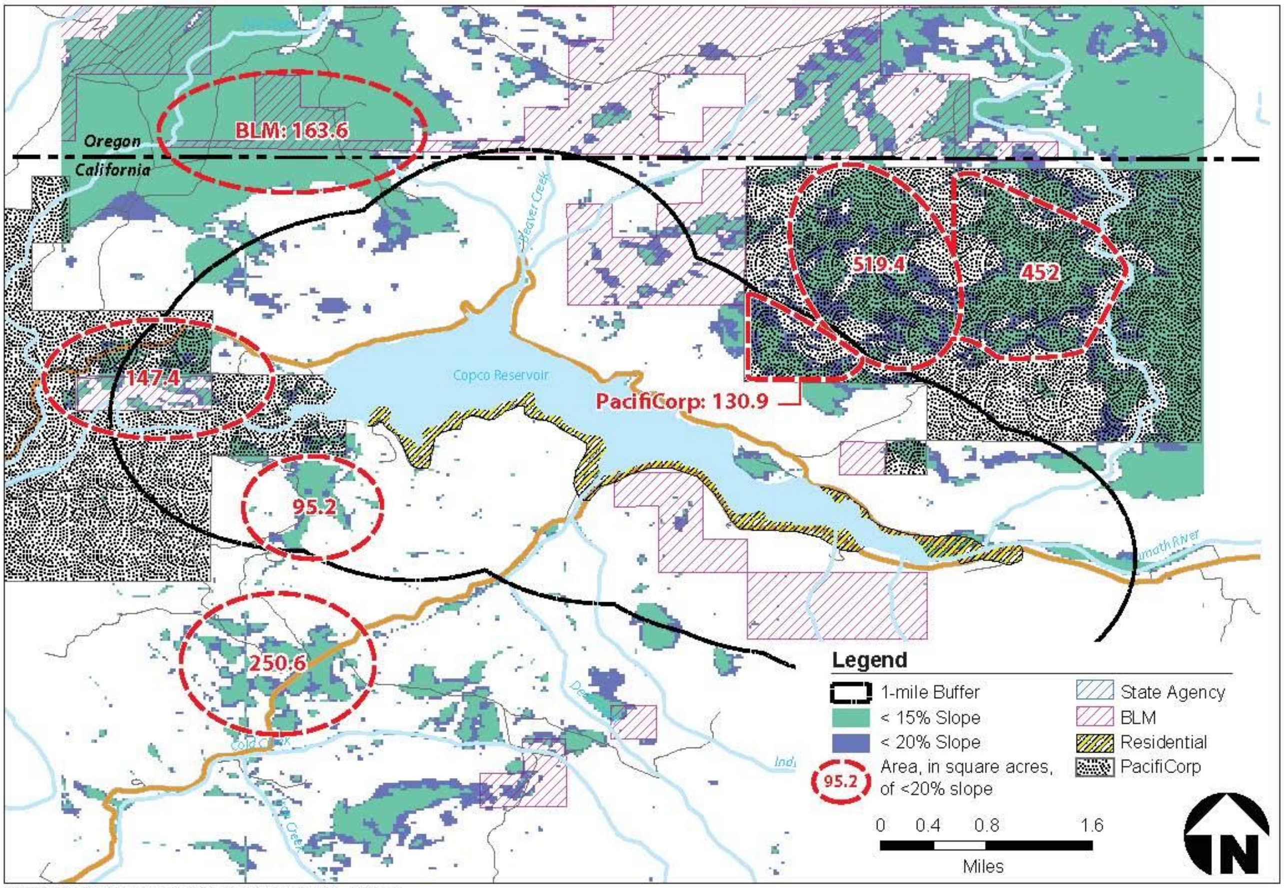

Figure 5-2. Copco Reservoir Area (Slopes <15% and <20%)

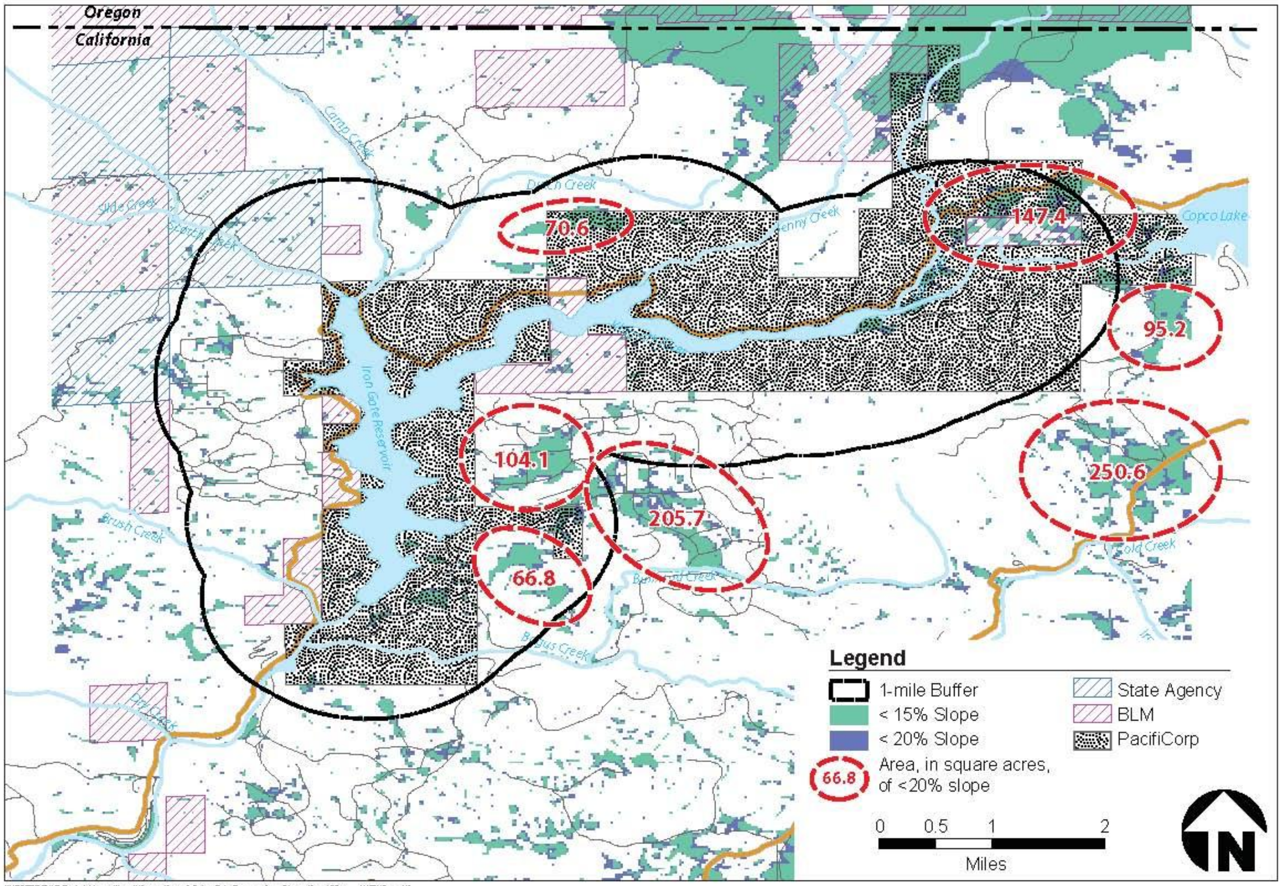

Figure 5-3. Iron Gate Reservoir Area (Slopes <15% and <20%)

5.4 Summary of Sediment Disposal Sites

Engineered disposal sites appear to be the best option for disposal of hydraulically removed reservoir sediments. These facilities would ideally be placed within 2 miles of the reservoirs, on slopes of less than 10 percent. However large sites meeting this criterion are not present at J.C. Boyle, Copco or Iron Gate. Steeper sloped sites are available at all of the reservoir sites, but these sites may present challenges for engineering and containment design. The compatibility of these sites for sediment disposal was not explored beyond ownership and current land use. For the purposes of this analysis, only land owned by PacifiCorp or another State or Federal agency is considered as feasible for sediment disposal.

This page intentionally left blank

Chapter 6
Sediment Management During Dam Removal

6.1 Summary of Feasible Sediment Management Measures

As presented in Sections 4 and 5 the best option for managing reservoir sediment would utilize hydraulic dredging with designated disposal sites in close proximity (within 2 miles) to the reservoirs. Hydraulic dredging would occur simultaneously at the three reservoirs in two stages. The first stage would occur prior to reservoir drawdown. The hydraulic dredges would remove sediment in the reservoirs up to the optimal depth of the dredge (estimated at 25 feet). During the second stage, dredging in each reservoir would progress with reservoir draw down removing the greatest quantity of sediment possible in the time available.

The sediment would be hydraulically pumped in a pipeline to the potential disposal site. Disposal sites would be designed to either retain the total quantity of sediment and water (ratio of 15 percent sediment to 85 percent water) or a percentage of the water could be decanted and returned to the river or applied to land. Decanting the sediment slurry would ultimately reduce the land requirement for sediment disposal. There are potential locations for disposal facilities around the reservoirs on public land or land belonging PacifiCorp. Most of the potential disposal facilities sites would be constructed on land slopes exceeding 10 percent. Disposal site containment embankments would be engineered structures estimated at a height of 20 feet, similar to levees and would likely require dam safety inspection and permitting.

The following section estimates the maximum quantity of sediment that could reasonably be expected to be removed from the three reservoirs given the drawdown scenarios for the KHSA alternative. Several important assumptions were used for sediment removal estimates:

- Hydraulic dredges can be transported to the reservoir sites with operational depths of at least 25 feet. Achieving greater dredge depth presents potential operational, logistical, and environmental constraints that may not be acceptable.
- A high-end dredge production rate of 700 cubic yards per hour can be maintained during the dredging process. Although this is the maximum stated capacity, personal correspondence with a dredging company indicated that 700 cubic yards per hour could be maintained for this project using a 16-inch diameter cutterhead dredge and discharge pipeline. (Queral 2010)
- Dredging operations can occur in each reservoir simultaneously with reservoir drawdown.
- Siting and construction of disposal facilities on land surrounding reservoirs is feasible and will not limit sediment removal rates.
- Hydraulic pumping of sediments will meet dredge production rates for distances up to two miles using pipelines and booster station pumping.

- Sediments are suitable to be dredged and placed without special handling or management (from a contaminant perspective).
- Production rates in and around cultural or archeological sites will be the same as production rates in open reservoir areas.
- Sediment removal would occur during the winter months. It is assumed that cold weather, heavy precipitation, snow, or ice will not slow production or affect the containment structure sizes.
- A one foot depth of reservoir sediment will be left to prevent disturbance of any cultural or archeological sites.

6.2 J.C. Boyle Reservoir

J.C. Boyle Reservoir has an estimated 940,000 cubic yards of erodible sediment. The sediment thickness is relatively thin in the upper portions of the reservoir and increasingly thickens to 20 feet, towards J.C. Boyle Dam (see Figure 2-1). Water depths range from two feet up to 40 feet. As described in Chapter 4.2, the largest hydraulic dredge that could be used for sediment removal has an effective dredge depth of 25 feet. This dredge has an ability to access a fairly large proportion of the reservoir sediments prior to drawdown.

To remove the sediment, it is assumed that one dredge would be needed with a 16-inch diameter cutterhead and discharge pipeline. This dredge would work two shifts (16 hours per day), 6 days a week, at a maximum production capacity of 700 cubic yards per hour (See Table 4-1). The production efficiency, based on dredge length, depth, dredge swing angle, thickness of the sediment, and depth of the cut, is assumed to be 75 percent (Johnson, No Date). This results in an approximate production rate of 7,200 cubic yards per calendar day.

The dredge would access the water on the west shore of the reservoir on Highway 66, near the Topsy Recreation Site at the Route 66 Bridge (see Figure 6-1). Equipment would most likely access this site using the Highway 66 Bridge crossing the reservoir. Currently the bridge is a one-lane bridge with an unknown weight capacity, although it is known that the maximum limit on Highway 66 is 40 tons of gross weight (see Section 2.1). The access site would provide an area for equipment staging.

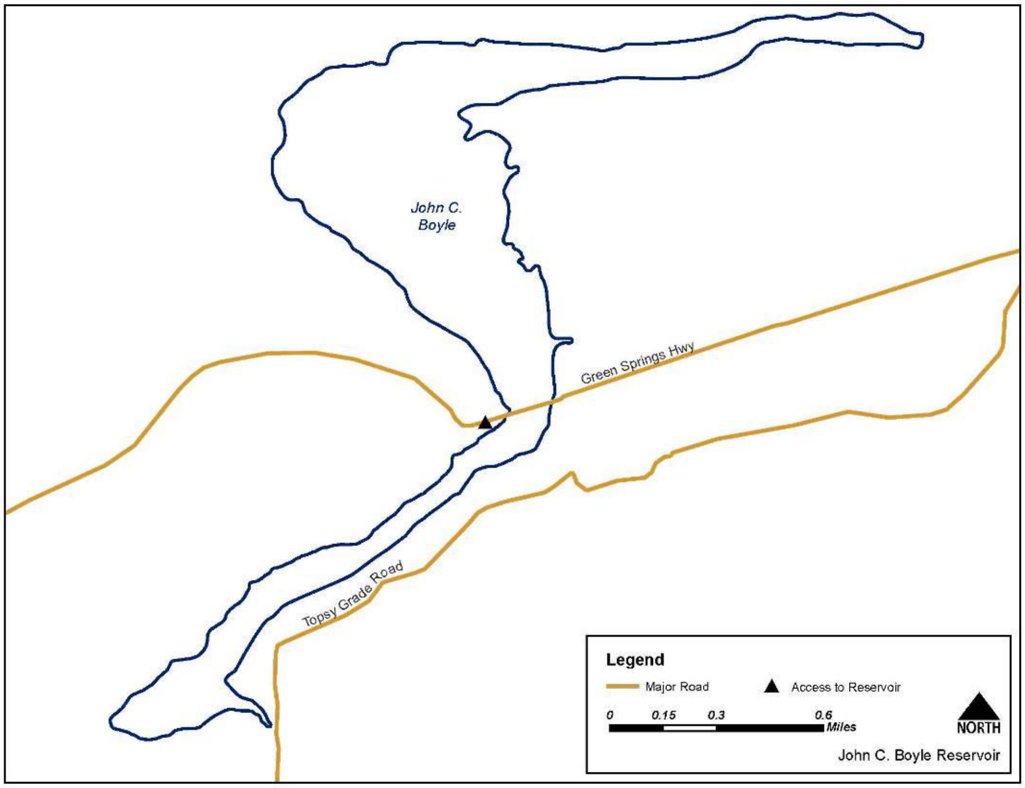

Figure 6-1. J.C. Boyle Reservoir Access (42.1341 N, 122.0328 W)

The start of hydraulic dredging operations would occur prior to the start of reservoir drawdown. This would allow dredging equipment to remove the accessible sediment in water less than 25 feet in depth. It is estimated that approximately 335,600 cubic yards[3] of sediment could be removed prior to drawdown in approximately 47 days, based on the 7,200 cubic yards per calendar day production rate.

Dredging operations would continue simultaneously with reservoir drawdown, removing the sediment as reservoir areas became available in water shallower than 25 feet. Assuming a starting reservoir elevation of 3793.0 feet and ending at elevation 3762.0 feet, complete drawdown is expected to take 30 days, under a normal water year. In a dry water year drawdown would take less time and in a wet year it would take more time.

Approximately 219,800 cubic yards of additional reservoir sediment could be removed from the reservoir during 31 days of drawdown and continuing dredging operations until February 1, 2020. Table 6-1 summarizes the maximum amount of sediment that could be removed before and during reservoir drawdown. This approach would strand the dredge in the reservoir near the J.C. Boyle dam. It is assumed that during the dam removal process, the dredge could be removed at Topsy Grade Road with cranes and other means, as work progressed on dam removal.

[3] Estimated to be the amount of sediment above a water depth of 25 feet.

Table 6-1. J.C. Boyle Reservoir Maximum Sediment Removal under KHSA Drawdown Scenario

Assumptions	
Drawdown Rate	Average of 1 foot/day
Total Amount of Eroded Sediment	940,000 yd^3
Reservoir Elevation Prior to Drawdown	3793.0 feet
Calculated Quantities	
Pre-Drawdown Duration[1]	47 Days
Number of Dredges for Pre-drawdown Dredging	1
Pre-Drawdown Sediment Removal Volume	335,600 yd^3
Drawdown Duration	31 days
Number of Dredges for Dredging	1
Sediment Removal during Drawdown Volume	219,800 yd^3
Total Sediment Removal under Drawdown Scenario	**555,400** yd^3
Percentage of Erodible Sediment Removed	**59.1%**

[1]The amount of time that dredging would occur prior to the start of drawdown. This number is rounded to the nearest whole day.

Given the constraints of the drawdown scenario, an estimated 555,400 cubic yards, or approximately 59.1 percent of erodible sediment could be removed as slurry by hydraulic dredging. The slurry would contain approximately 15 percent solids (by weight) as described in Section 4.2. The total volume of slurry requiring management and disposal is estimated at approximately 3,702,667 cubic yards.

As discussed in Section 4.2.1, a diked containment area would be required to hold the sediment slurry, allowing the sediment to settle out and the water to either decant or evaporate. Assuming that the water would be decanted, a parcel of land of approximately 57.4 acres, utilizing 20-foot height containment dikes, would be required. Publicly owned land directly around J.C. Boyle could potentially accommodate sediment management and disposal by developing multiple sites. (See Figure 5-1). However, these lands have slopes exceeding 10 percent and would present additional design considerations. The Sportsman's Park recreation area, owned by PacifiCorp, is an ideal location but not considered as a viable option, as the land will stay a recreational park.

6.3 Copco Reservoir

Copco Reservoir has an estimated 2,700,000 cubic yards of erodible sediment. The sediment thickness is relatively uniform throughout the reservoir, ranging from 0.2 to 10.4 feet (see Figure 2-2). Water depths in Copco range from 5 feet up to 110 feet. As described in Chapter 4.2, the hydraulic dredges that could be used in the reservoirs have an effective depth of 25 feet. The dredge has an ability to access only a relatively small area of the reservoir sediments without drawdown.

It is assumed that there would be two dredges on the reservoir with a 16-inch diameter cutterhead and pipeline, with an approximate production rate of 7,200 cubic yards per calendar day per dredge. The dredges would access the water on the north shore of the reservoir on Copco Road (Figure 6-2). The site would provide an area for equipment staging.

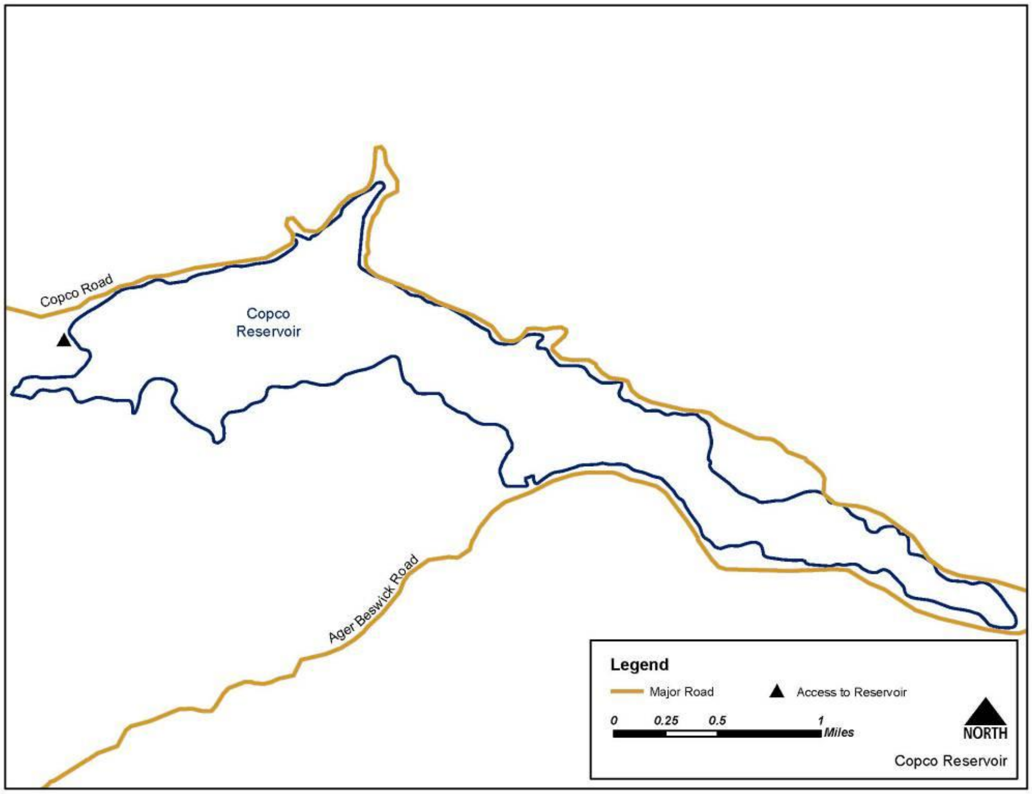

Figure 6-2. Copco Reservoir Access (41.9834 N, 122.3310 W)

The start of hydraulic dredging operations would occur prior to the start of reservoir drawdown. This would allow dredging equipment to remove the sediment in water shallower than 25 feet. It is estimated that approximately 176,700 cubic yards[4] of sediment could be removed prior to drawdown in approximately 13 days using 2 dredges, based upon the 7,200 cubic yards per day per dredge production rate.

Dredging operations would continue simultaneously with reservoir drawdown, removing the sediment as areas became available. The drawdown scenario assumes a starting reservoir elevation of 2606.0 feet and ending at 2484.0 feet, taking approximately 108 days, under a normal water year. This approach would strand the dredges in the reservoir near the Copco dam.

[4] Estimated to be the amount of sediment above a water depth of 25 feet.

It is assumed that during the dam removal process, the dredges could be removed along Copco Road with cranes and other means.

Approximately 1,277,100 cubic yards of additional reservoir sediment could be removed from the reservoir during the drawdown period. Table 6-2 summarizes the maximum amount of sediment that could be removed before and during drawdown from Copco Reservoir.

Table 6-2. Copco Reservoir Maximum Sediment Removal under KHSA Drawdown Scenario

Assumptions	
Drawdown Rate	Varies between 1 – 2.25 feet/day. See Table 1-1.
Total Amount of Eroded Sediment	2,700,000 yd^3
Reservoir Elevation Prior to Drawdown	2606.0 feet
Calculated Quantities	
Pre-Drawdown Duration[1,2]	13 Days
Number of Dredges for Pre-drawdown Dredging	2
Pre-Drawdown Sediment Removal Volume	176,700 yd^3
Drawdown Duration	108 days
Number of Dredges for Dredging	2 to 3
Sediment Removal during Drawdown Volume	1,277,100 yd^3
Total Sediment Removal under Drawdown Scenario	**1,453,800 yd^3**
Percentage of Eroded Sediment Removed	**53.8%**

[1]The amount of time that dredging would occur prior to the start of drawdown. This number is rounded to the nearest whole day.

[2] Pre-drawdown dredging would occur using only two dredges.

Approximately 1,453,800 cubic yards of sediment could be removed as slurry with the hydraulic dredge. The slurry would contain approximately 15 percent solids (by weight), as described in Section 4.2, which would be approximately 9,692,000 cubic yards. Assuming water had been decanted, a parcel of land of approximately 150.2 acres, utilizing 20-foot height containment dikes, would be required.

As shown in Figure 5-2, the lands around Copco Reservoir are relatively steep sloped, with few areas with less than a 20 percent slope. Two potential sites located north of the reservoir owned by PacifiCorp and the BLM cover areas of 519.4 acres and 163.6 acres, respectively.

6.4 Iron Gate Reservoir

Iron Gate Reservoir has an estimated 2,830,000 cubic yards of erodible sediment. The sediment thickness is relatively uniform throughout the reservoir, ranging from 1 to 6 feet (see Figure 2-3) in water depths up to 160 feet. As described in Chapter 4.2, the hydraulic dredges that could be used for the Klamath reservoirs have a effective depth of 25 feet. As with Copco, the dredge has an ability to access only a relatively small area of the reservoir sediments without drawdown.

Similar to Copco, it is assumed that there would be two dredges on the reservoir with a 16-inch diameter pipeline, with an approximate production rate of 7,200 cubic yards per calendar day per dredge. The dredges would access the water on the south shore of the reservoir by an access road off of Lake View Road (which is not depicted). (Figure 6-3) The site would provide an area for equipment staging.

The start of hydraulic dredging operations would occur prior to the start of reservoir drawdown. This would allow dredging equipment to remove the sediment in water depths less than 25 feet. It is estimated that approximately 106,000 cubic yards[5] could be removed prior to drawdown in approximately 8 days, based on the 14,400 cubic yards per day production rate for two dredges. This approach would strand the dredges in the reservoir near the Iron Gate dam.

[5] Estimated to be the amount of sediment above a water depth of 25 feet.

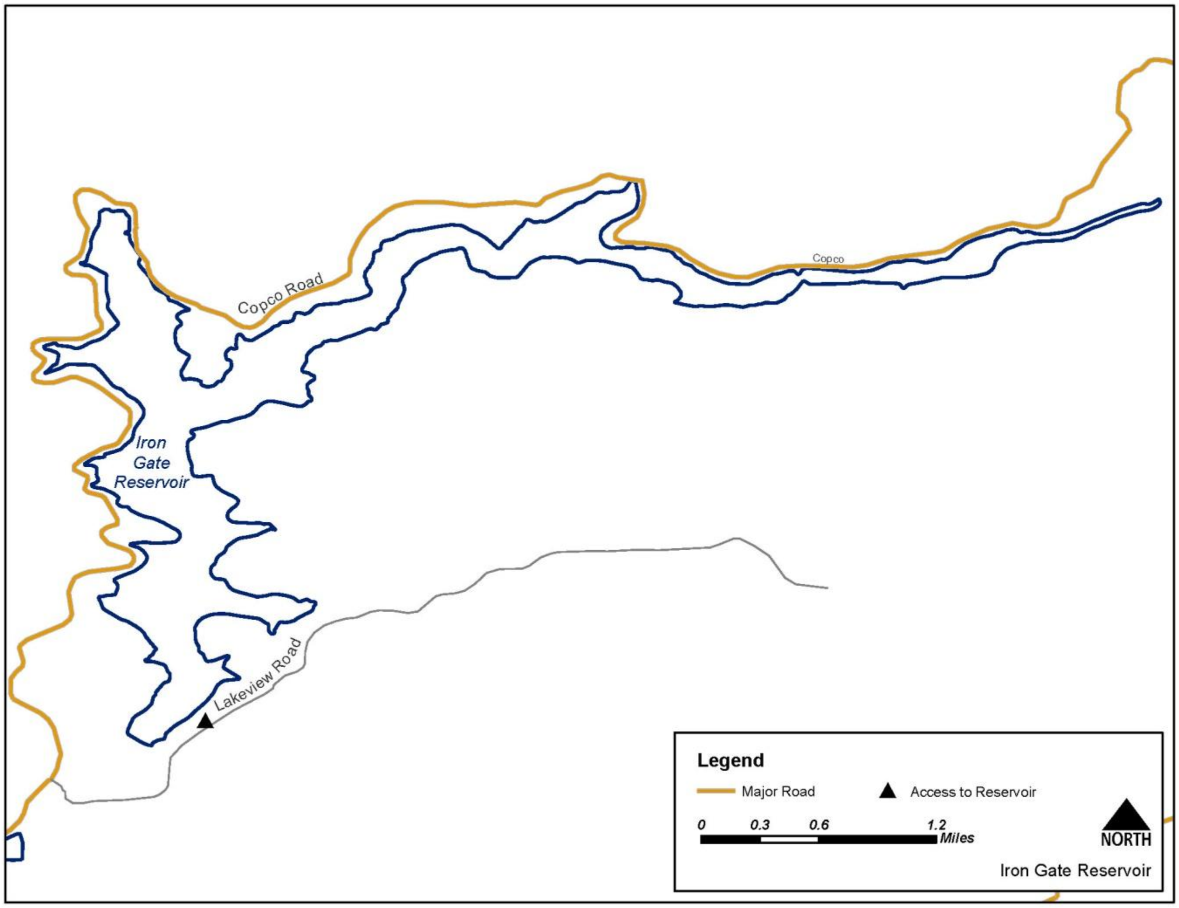

Figure 6-3. Iron Gate Reservoir Access (41.93756 N, 122.4303 W)

Dredging operations would continue simultaneously with reservoir drawdown, removing the sediment as areas became available. Assuming a starting elevation of 2328.0 feet and an ending elevation of 2202.0 feet, complete drawdown is expected to take 42 days, assuming a normal water year. Approximately 733,100 cubic yards of additional reservoir sediment could be removed as areas became available. It is assumed that during the dam removal process, the dredges could be removed with cranes and other mean at the dam site. Table 6-3 summarizes the maximum amount of sediment that could be removed before and during drawdown.

Table 6-3. Iron Gate Reservoir Maximum Sediment Removal under KHSA Drawdown Scenario

Assumptions	
Drawdown Rate	Average of 3 feet/day
Total Amount of Eroded Sediment	2,830,000 yd^3
Reservoir Elevation Prior to Drawdown	2328.0 feet
Calculated Quantities	
Pre-Drawdown Duration[1, 2]	8 Days
Pre-Drawdown Sediment Removal Volume[2]	106,000 yd^3
Number of Dredges for Pre-drawdown Dredging	2
Drawdown Duration	42 days
Number of Dredges for Dredging	3
Sediment Removal during Drawdown Volume	733,100 yd^3
Total Sediment Removal under Drawdown Scenario	**839,100 yd^3**
Percentage of Eroded Sediment Removed	**29.7%**

[1]The amount of time that dredging would occur prior to the start of drawdown. This number is rounded to the nearest whole day.
[2] Pre-drawdown dredging would occur using only two dredges.

Given the constraints of the drawdown scenario, an estimated 839,100 cubic yards, or approximately 29.7 percent of erodible sediment, could be removed as slurry by the hydraulic dredges. The slurry would contain approximately 15 percent solids (by weight), as described in Section 4.2. The volume of the sediment slurry requiring containment is estimated at 5,594,000 cubic yards.

As shown in Figure 5-3, the lands around Iron Gate Reservoir are relatively steep sloped, with few areas that are less than a 20 percent slope. Assuming the slurry has been decanted to approximately half of the volume and a 20 foot containment height, a parcel of land that is approximately 86.7 acres would be needed. There is a 147.4 acre area with sites owned by either PacifiCorp or the BLM on the far eastern side of the reservoir and another site of approximately 70 acres north of the reservoir, as shown in Figure 5-3. Both of areas could be used as disposal sites.

6.5 Sediment Removal Summary

This paper identifies hydraulic dredging with designated disposal sites in close proximity to the reservoirs as the ideal, and potentially only acceptable process for removal of sediments trapped behind the JC Boyle, Copco, and Iron Gate reservoirs for the KHSA dam removal alternatives. The large quantity of erodible sediment and the speed with which it's removed under the KHSA alternative essentially eliminates any form of truck transportation. During the drawdown scenario, thousands of tractor trailer trucks trips would be required daily to move sediments on local roads for several months. Although technically feasible, this alternative was deemed as unacceptable to the local community. Further, mechanical dredging of sediment using a clam shell was deemed as unacceptable due to prolonged water quality impacts that would likely occur during the dredging process.

Hydraulic dredging would occur simultaneously at the three reservoirs in two stages. The first stage would occur prior to reservoir drawdown with removal of sediment up to 25 feet deep, the projected operational limit of the dredge. During the second stage, dredging in each reservoir would progress with reservoir draw down removing the greatest quantity of sediment possible in the time available. Table 6-4 summarizes the maximum quantities of erodible sediment that could potentially be removed from each reservoir under the KHSA drawdown scenarios. The total sediment removal for all reservoirs is approximately 2.8 million cubic yards of an estimated 6.47 million cubic yards of erodible sediment (43 percent).

Table 6-4. Maximum Sediment Removal under KHSA Drawdown Scenarios

Reservoir	J.C. Boyle	Copco	Iron Gate
Drawdown Rate	1 foot/day	Varies between 1 – 2.25 feet/day. See Table 1-1.	3 feet/day
Total Amount of Erodible Sediment	940,000 yd^3	2,700,000 yd^3	2,830,000 yd^3
Pre-Drawdown Sediment Removal Volume	335,600 yd^3	176,700 yd^3	106,000 yd^3
Sediment Removal during Drawdown Volume	219,800 yd^3	1,277,100 yd^3	733,100 yd^3
Total Sediment Removal under Drawdown Scenario	555,400 yd^3	1,453,800 yd^3	839,100 yd^3
Percentage of Eroded Sediment Removed	59.1%	53.8%	29.7%

The sediment would be hydraulically pumped by pipeline to disposal sites in the vicinity of the reservoirs. Table 6-5 identifies the total amount of sediment slurry (ratio of 15 percent sediment to 85 percent water) that would need to be retained. With 20 foot engineered embankments, the total acres of land needed for sediment disposal is approximately 590 acres. If disposal sites were designed to decant and return carrier water to the river or apply it to land, the amount of land needed for disposal sites could potentially be reduced by an estimated 50 percent (286 acres). There are potential locations for disposal facilities around the reservoirs on land belonging to the BLM, PacifiCorp, or state agencies. Disposal site containment embankments would be engineered structures similar to levees.

Table 6-5. Total Sediment Slurry Conveyed and Disposal Area Requirements

Reservoir	J.C. Boyle	Copco	Iron Gate
Drawdown Rate	1 foot/day	Varies between 1 – 2.25 feet/day. See Table 1-1.	3 feet/day
Total Sediment Removal under Drawdown Scenario	555,400 yd^3	1,453,800 yd^3	839,100 yd^3
Total volume of sediment slurry removed	3,702,667 yd^3	9,692,000 yd^3	5,594,000 yd^3
Land containment requirements (Assuming water has been decanted from the slurry)	57.38 acres	150.19 acres	86.68 acres

This paper presents potential maximum sediment removal volumes for the KHSA alternatives. Several factors could reduce these quantities and are presented as limitations to the set of assumption as presented below:

- A hydraulic dredge capable of dredging to an optimal depth of 25 feet is a large piece of equipment potentially exceeding 50 tons and 70 feet (see Table 4-1). It is assumed that there are dredges of this size available that can be transported to the reservoirs without exceeding rail or road size and weight limits. Site assembly would be required.

- The dredge production rate used to calculate sediment removal (700 cubic yards per hour) is the upper end of dredge rate production (see Table 4-1). Several factors could significantly reduce this production rate including presence of reservoir bottom debris, cultural resource sites, required winter operations and coordinating concurrent dredging and drawdown operations.

- Although there is potential land around the reservoirs for disposal sites, most locations are less than ideal. Surrounding land is hilly and most sites would need to be constructed on land slopes exceeding 15 percent increasing engineering and construction efforts. The compatibility and acceptability of using Federal land for sediment disposal was not explored in great detail. The acquisition or condemnation of privately owned land was not considered as a viable option. Insufficient land disposal sites could be the critical factor limiting the quantity of sediment removed from the reservoirs.

- Hydraulic dredge operations will result in large quantities of carrier water. Large disposal sites containing this water and sediment mix will likely require dam safety inspection and permitting from the state in which it’s located (California or Oregon). Decanting the slurry is possible but discharge or disposal of this water would require Clean Water Act 404 permitting to protect surface water resources. The construction of large reservoir structures will have its own set of environment effects that may further limit sediment disposal options and the quantity of material that can be removed.

- Sediments contaminant studies are ongoing. The presence of contaminants exceeding regulatory thresholds could significantly change disposal options if additional special handling or management is required.

Chapter 7 References

Ellicott Dredges, No Date. Accessed on 12/27/2010, Available at: http://www.dredge.com/dredge-equipment-models/specs-1170-dragon-dredge.html

GEC (2006), Klamath River - Dam and Sediment Investigation, Technical Report, Seattle, Washington.

GEC. 2007. *Evaluation of Alternatives to Reservoir Lowering Start Date from Those Proposed in November 2006 Federal Energy Regulatory Commission Report.*

J.C. Headwaters, Inc. (2003). Bathymetry and Sediment Classification of the Klamath Hydropower Project Impoundments. Prepared for PacifiCorp By J.C. Headwaters, Inc.

Johnson, Charles H. (Dredging Supply Company, Inc.) (No Date) *Maximizing Profits By Understanding Hydraulic Dredge Efficiency.*

Klamath Basin Restoration Agreement. Feb 2010. Klamath Basin Restoration Agreement for the Sustainability of Public and Trust Resources and Affected Communities. Sacramento, California.

Queral, Andrew. 23 December 2010. (Ellicott Dredges, LLC) Telephone conversation with W. Friers of CDM, Albany, NY.

Reclamation (2008). "Klamath River Salmon Redd Scour Study, 2007 – 2008," Technical Memorandum No. 86-68290-08-02, Technical Service Center, Denver, CO.

Reclamation (2010a). "Klamath River Sediment Sampling Program Phase 1-Geologic Investigations," Mid-Pacific Region, MP-230, Sacramento, CA.

Reclamation (2010b). "Klamath Dam Removal Engineering Analysis," Technical Service Center, Bureau of Reclamation, Denver, CO.

Reclamation (2010c). Hydrology, Hydraulics and Sediment Transport Studies for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration Klamath River, Technical Service Center, Bureau of Reclamation, Denver, CO.

Stillwater Sciences (2008) Klamath River dam removal study: sediment transport DREAM-1 simulation. Technical Report, Prepared for California Coastal Conservancy, 1330 Broadway, 13th Floor, Oakland, CA 94612, 73 pages, October

Stillwater Sciences (2009b). Effects of sediment release following dam removal on the aquatic biota of the Klamath River. Technical report. Prepared by Stillwater Sciences, Arcata, California for State Coastal Conservancy, Oakland, California. January. 185 pp.

Stillwater Sciences (2010). Anticipated sediment release from Klamath River dam removal within the context of basin sediment delivery. Prepared by Stillwater Sciences, Arcata, California for California Coastal Conservancy, Oakland, California.

U.S. Army Corp of Engineers (USACE). Engineering and Design – Dredging and Dredged