Klamath River Dam Removal Investigation

J. C. Boyle Dam
Copco 1 Dam
Copco 2 Dam and
Iron Gate Dam

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by G&G Associates

Table of Contents

Table of Figures

List of Tables

Executive Summary

An investigation was conducted by G&G Associates for American Rivers, to determine the feasibility and cost of removing Iron Gate, Copco 2, Copco 1, and J.C. Boyle dams on Klamath River. The study was based on public information available to American Rivers and limited information available from PacifiCorp. Review of available information regarding the dams, trapped sediment, and river characteristics indicates that removing the dams is feasible and that the cost would be approximately $40 million. Based on assumptions stated in this report, the cost for removal would be $19.2, $1.9, $8.5, and $6.2 million respectively for Iron Gate, Copco 2, Copco 1, and J.C. Boyle dams.

Dams would be removed using a combination of well-established blasting, excavating, and hauling techniques. Removing the structures would require river flow to be diverted away from the work site. Approximately 1.5 million cubic yards of concrete, rock and earth would need to be removed from the dam sites and relocated to nearby spoils sites.

Studies conducted as part of the hydropower relicensing proceeding indicate that cumulatively, all four dams trap approximately 14.4 million cubic yards of sediment, of which approximately 87% is silt and clay and 13% is sand or larger material. Cost estimates developed for this study are based on the assumption that sediment trapped behind the dams would be naturally eroded downstream. Information regarding the volume of sediment trapped appears to be well developed but information regarding grain size distribution of trapped sediment appears to be insufficient to determine how quickly the eroded sediment would move through and out of the river system.

To remove the structures, reservoir water and river flow must be temporarily diverted away from demolition activities. Several approaches to diversion of river flow are presented. Two approaches, notching structures to allow flow through the top and using existing low-level outlet structures were found to be feasible and least cost approaches to river diversion.

Additional studies required to fully evaluate all required actions for dam removal are also discussed.

Introduction

PacifiCorp is currently in the process of preparing a license application for their Klamath River hydroelectric project (FERC Project No. 2082). Mitigation measures that PacifiCorp and the relicensing proceeding stakeholders are investigating include various means of providing or improving fish passage at the five dams located on the mainstem Klamath River. As an alternative to constructing or upgrading fish passage facilities, this report investigates decommissioning all or any of the four lower dams. These four dams, Iron Gate, Copco 1 and Copco 2, and J. C. Boyle are located from river mile (RM) 190 to 224.7. Removal of the four dams would return approximately 40 miles of river to natural processes and allow unrestricted access to migrating fish in this reach.

This report develops a feasibility level analysis of the costs and feasibility of completely removing the four dams and all the sediment trapped behind the dams. Existing information sources were used to develop this report. No additional testing or measurement was conducted for the report. Information used came from PacifiCorp and public sources such as U.S.G.S. for flow and topographic information, state agencies, and studies conducted as part of the relicensing proceeding.

Authorization and Scope

G&G Associates has developed this report for American Rivers, Trout Unlimited, California Trout, Friends of the River, and the Klamath River Intertribal Fish and Water Commission. The scope of this investigation is feasibility level only. Specific information regarding volume, location, and size of trapped sediment, specific dimensions of structures, nature and extent of water use downstream of the dams, and location of spoils sites was either not available or developing such information was beyond the scope of this report. Numerous issues require more investigation before final costs estimates can be completed. The objective of this report is to determine whether removal of the four lower Klamath River dams is feasible from a construction and cost perspective.

The sources of information used to analyze dam removal options were limited to published information and information supplied in documents meant for purposes other than analyzing details of the dam and associated structures. As a result, the accuracy of the analysis is limited to the accuracy of the source information. A compilation of additional information required to further investigate removal is included at the end of this report.

Project Description

The Klamath River flows generally southwesterly from Lake Euwana, near Klamath Falls, Oregon to the Pacific Ocean near Requa, California. The four lower dams on the river, J. C. Boyle, Copco 1 and 2, and Iron Gate, were studied for removal. Details of these four dams are provided in Table 1. J.C. Boyle is located on the Klamath River in Oregon, while the other three are located in northern California.

Table 1 Dam Details[1]

Item	Iron Gate	Copco 2	Copco 1	J.C. Boyle
Purpose	Hydropower and Flow Regulation	Hydropower	Hydropower	Hydropower
Date of Construction	1962	1925	1918	1958
Location	190	198.3	198.6	224.7
Generating Capacity (MW)	18	27	20	80
Head (ft)	158	152	123	463
Turbine Hydraulic Capacity (cfs)	1,735	3,200	3,200	3,000
Dam Type	Rockfill	Concrete	Concrete	Earthfill
Spillway Length (ft)	685	130	182	115
Spillway Gate Type	Ungated	Taintor	Taintor	Taintor
Spillway Crest Elevation (ft msl)	2328.0	2454.0	2593.5	3781.5
Head at Spillway	164	21	111	18
Upstream Fish Passage	No	No	No	Yes
Downstream Fish Passage	No	No	No	Yes
Reservoir Length (miles)	6.8	.3	4.54	3.6
Reservoir Surface Area (acres)	944	40	1000	420
Reservoir Max. Depth (ft)	167	28	108	53
Normal Pool Elevation (ft msl)	2324		2601	3788
Storage Capacity (ac-ft)	58,794	73.5	46,867	3,495
Average Annual Daily Flow (cfs)	1,852	1,885	1,885	1,511

[1] Information shown was taken from *First Stage Consultation Document*, Klamath Hydroelectric Project, FERC No. 2082, submitted by PacifiCorp, 2000

Structure Removal

As shown in Table 1, the structures to be removed include concrete construction and earth and rock fill structures. The total quantity of material contained in all four dams is approximately 1.4 million cubic yards. Most of this material is contained in Iron Gate Dam. Both Iron Gate and J.C. Boyle dams are earthen dams that also include concrete appurtenant structures. Copco 1 and 2 are concrete structures.

The type of dam involved will determine removal requirements. The two concrete dams can be removed using drilling and blasting demolition techniques. Earth and Rock fill dams will require the use of excavating and hauling equipment. As shown in Figure 1, river flow is continuous in the river channel during all months of the year. Due to this continuous flow, access to the dam for demolition purposes will require some type of river diversion during demolition activities for each dam.

Cost and feasibility analyses assume that all structures restricting flow in the Klamath River will be removed down to the pre-dam riverbed elevation. Portions of structures below the streambed would remain in place except where they are considered unstable. The approach to structure removal for each site will depend on conditions at that site including access for construction and demolition equipment, access requirements, extent and need for road upgrades, and spoils site location.

Investigation of the availability of spoils sites for materials from the dams is beyond the scope of this report. However, a review of the topographic maps of the area suggests that appropriate sites located near each facility may be available. An estimate of the space required to contain the demolished dam materials, and assumptions regarding haul distances, are provided in the discussion for each dam.

Dam Removal Approaches

Dam removal generally involves demolishing and removing structural flow impediments in the path of the river. Removal strategies such as opening a flow path through the bottom of the dam were not considered in this report. For efficiency, demolition generally requires that work activities be conducted in dry conditions. Rivers that exhibit continuous flow throughout the year require some means to temporarily divert the river flow away from the location of work during dam demolition activities. The following sections describe several dam demolition and river diversion techniques. Actual demolition projects may combine several of the following techniques to suit site constraints or opportunities.

Assumptions and Criteria

Removal Approaches described below are based on the following assumptions.

1. The least expensive approach to demolition of high strength concrete structure is, generally, drilling and blasting.
    a. Concrete strength of the structures is unknown.
    b. Low strength concrete can be economically removed at a price competitive with blasting using impact devices such as a hoe-ram.

   c. Drilling and blasting involves pre-drilling holes in the concrete structure, packing the holes with explosive material, and blasting sections of the structure in a controlled fashion.

2. Several options for river diversion are possible when removing a concrete dam structure including;
   a. allowing river flow through a notch constructed in a portion of the structure while other sections are demolished,
   b. low-level outlets, and
   c. tunnels.

   The approach used will depend on the economics, flow conditions, safety, structural integrity, and water quality considerations.

3. Earthfill and rockfill dam structures, such as Iron Gate and J.C. Boyle, can be removed using standard construction excavation equipment such as dozers, graders, scrapers, excavators, loaders, conveyors, and trucks.
   a. Unlike concrete structures, the material used to construct the dam is erodible. Water and river flow must be diverted away from the dam to accomplish excavation.
   b. Iron Gate Dam has a low-level outlet that would be used to lower water level elevations during demolition
   c. The availability of a low-level outlet at J.C. Boyle is unknown.
   d. Heavy construction equipment would be used to excavate the material and haul it to a disposal site where the material would be stabilized.
   e. Local haul roads may require some upgrading. Public highways will be adequate for all vehicles used.
4. Structures in the river will be removed to the pre-dam riverbed elevation.
   a. Tunnels will be unaltered.
   b. Concrete structures that present a possible hazard will be removed.
   c. Otherwise, concrete structures that do not affect river flow conditions will remain in place.
   d. Wood support buildings would be removed.
   e. Concrete buildings would remain as long as exposure would not represent a safety hazard.
5. Electrical tower and line removal is not part of this investigation. Power plants and turbines would be removed and salvaged as possible.

Spoils Sites

Sites will be required for placement of all materials taken from each demolished dam. A review of topographic maps suggests that appropriate sites might exist. This report assumes that a site is available within 10 miles of each structure dam. However, no specific sites were identified as a part of this study.

Disposal site preparation would include clearing and grading. The assumption was made that ground water would not be adversely affected by permanent storage of material on the sites. Cost estimates assume that some site preparation would be necessary and that surface and groundwater impacts at the site would need to be addressed. The cost estimates include a line item for environmental mitigation at the disposal site to cover the costs of these issues.

Table 2 provides approximate dimensions of spoils site requirements for each dam. Iron Gate contains a much greater quantity of material than the other projects. The height of the material will depend on local conditions and material characteristics, neither of which is available for this report. Side slopes on material placed at the spoils site were assumed to be formed at 2 horizontal to 1 vertical ratio.

Table 2 Estimated Spoils Site Requirements

Structure	Volume – CY	Area - acres	Height - feet
J.C. Boyle	150,000	15.5	6
Copco 1	38,500[2]	4	6
Copco 2	5,500	1.2	3
Iron Gate	1,320,000	41	20

Access

Access by large construction equipment was assumed possible since access was available during the construction of the project. Since the condition or necessity to improve road access was unknown, an allowance in the cost estimate for road upgrades was included to account for heavy equipment access.

Hydrology

Precipitation in the basin is seasonal, with 60 percent of the total annual precipitation falling from November to March. December and January are the wettest months; the driest months are between June and September. Annual precipitation patterns historically define distinct dry and wet cycles that are closely related to runoff and the river's flow regime. The most recent climatic trends include wet periods from 1885 to 1915 and 1940

[2] Volume increased by 10% for concrete structures, Copco 1 and 2

to 1975, and dry periods from 1915 to 1940 and 1975 to 1994. General decreases in runoff and discharge over the last 20 years also coincide with a generally decreasing trend in precipitation patterns and increasing consumptive diversions upstream of the project.

Some accretion of flow occurs over the 64 miles of river where the Project facilities are located. Natural springs contribute an assumed relatively constant flow to the Klamath River channel between the J.C. Boyle dam and its powerhouse between about RM 220 and RM 225. These springs contribute about 350 cfs. Tributaries to the Klamath River in the Project area between Link River dam and Iron Gate dam are relatively small. The largest include Spencer Creek (approximately 20 to 200 cfs, which flows into J.C. Boyle reservoir, Shovel Creek (10 to100 cfs), which enters the river just upstream from Copco reservoir, and Fall (30 to100 cfs) and Jenny creeks (30 to 500 cfs), which flow into Iron Gate reservoir. Spencer Creek, Shovel Creek, and Jenny Creek all have irrigation diversions that remove some water from them.

River Flow

Figure 1 shows the average daily flow rate of the Klamath River downstream from Iron Gate dam, USGS gage no. 11506530, measured in cubic feet per second. The figure shows the average flow for each calendar day over the period 1960 to 1999. Peak flow usually occurs during March while the lowest flows are typically in July. During July average daily flows are lower downstream of the Keno and J.C. Boyle facilities than they are in the Link River. This is primarily due to irrigation diversions between the Link River staff gage and Keno.

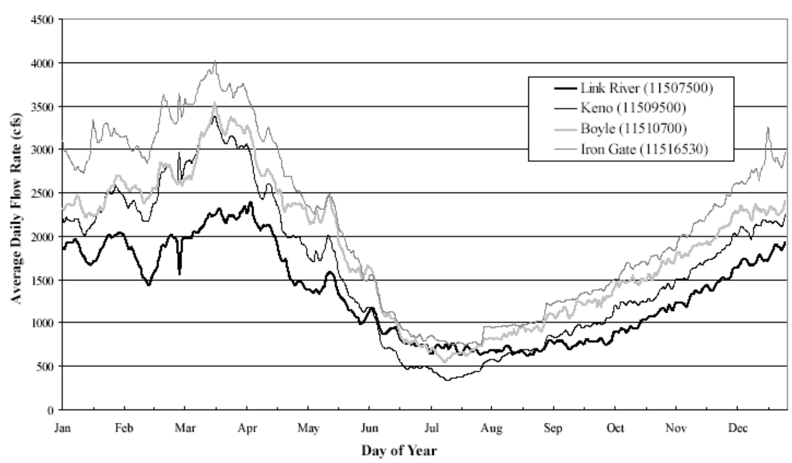

Figure 1 Average Daily Flow on the Klamath River

River Diversion Options

Diversion of water away from the back of the dam structure allows the structure to be removed in dry rather than wet conditions, aiding demolition efficiency. The river can be diverted over, under, around or through the dam.

Notch Approach

Concrete Structures

The “notch” approach diverts the river over the dam through a notch constructed in the top of the dam. A rectangular section is constructed at the top of the dam to create an opening or notch large enough to allow slightly greater than average daily river flow to pass through. The elevation of the notch is constructed to allow the reservoir to drop with each new notch is construction. When the reservoir elevation is lowered the remaining portion of the dam is above the water elevation and can be removed in the dry using any of the methods described above. The advantage to this approach is that no low-level outlet or diversion tunnel is required to divert the river. The river is diverted through a notch in the top of the dam as the dam is removed.

After the exposed concrete is removed down to the elevation of the reservoir water, a new notch is created and the reservoir is lowered again. This pattern is repeated until the dam structure is removed. This approach can greatly reduce the cost of demolition by eliminating the cost of diversion tunnel or outlet construction. It may, however, slow construction because storm events can raise water elevations, temporarily shutting down demolition.

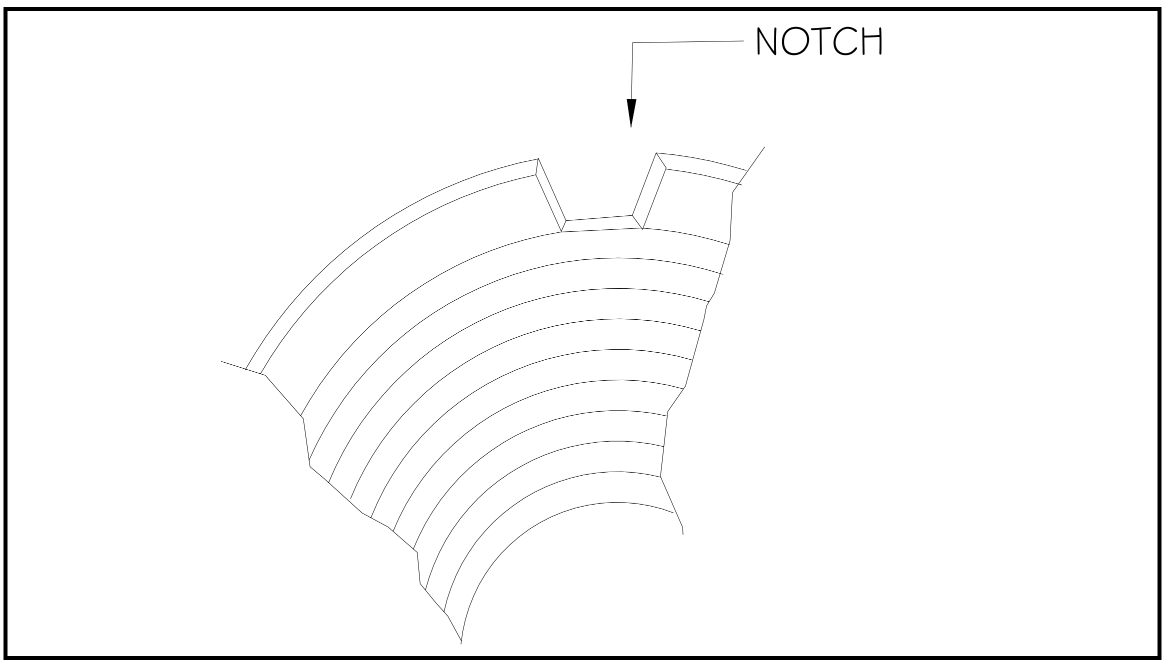

Figure 2 Notch Approach

Earthfill or Rockfill Structures

Both earthfill and rockfill structures are constructed of erodible material. Creating a channel to allow flow over the top of these structures could cause severe vertical erosion of the notch, breaching of the dam. However, if dam material properties are similar to river materials and quantities are small, this complete breach of the dam may be an appropriate option. This approach has been used on many smaller eastern United States dams.

An alternative to notching through dam material would notch through harder material adjacent to the dam structure, creating notches similar to the approach for a concrete dam.

Tunnel Diversion

Many dams are constructed using tunnels to divert the river flow while the structure is constructed. Many times the tunnel is constructed around the construction site through a rock abutment. Tunnels are, many times, plugged with concrete after construction. In a similar manner, it is possible to construct a tunnel to divert the river flow during demolition. If the original tunnel is capable of use for diversion, costs for demolition can be reduced. However, construction of a new tunnel can be a major portion of the cost of dam removal. Tunnel construction usually is the most expensive approach to river diversion and, as a result, is not generally used.

Low-level Outlet

Many dams have low-level outlets built into them. These outlet structures are used for reservoir elevation control or sluicing of sediment to keep reservoirs from filling with sediment. In larger reservoirs they may never have been used because sedimentation issues are not of concern until many years after the dam is constructed. Outlet structures may or may not be low enough to use for complete dam demolition. Many dam owners are not sure of the safety or control of the outlet if it has not been used frequently.

Using the outlet in conjunction with the penstock intake to lower the reservoir may also be possible. Most intake ports for power generation are not constructed at an elevation that allows the reservoir to be completely emptied.

J. C. Boyle Dam

J.C. Boyle development consists of a reservoir, dam, diversion canal, and powerhouse between about RM 228 and 220. Construction was completed in 1958. J.C. Boyle dam is an earthfill dam with a crest length of 692.6 feet and a top width of 15 feet. The upstream to downstream length at the base of the dam is 413.5 feet.

The dam is 68 feet tall, impounding a narrow reservoir of 420 surface acres[3]. According to facility drawings, the impoundment formed upstream of the dam stores about 3,495 acre-feet of water with 1,724 acre-feet of active storage capacity. The dam has three spill gates and can divert up to roughly 3,000 cfs, which is the hydraulic capacity of the powerhouse. The intake invert elevation is 3768 msl.

State highway 66 provides access to the site. An access road runs along the downstream face of the dam. Below that the face is covered with riprap. The pre-dam river elevation at the downstream toe of the dam is approximately elevation 3715. The crest of the dam is at elevation 3800 msl and 117 feet wide. A drawing of the cross section of the dam shows the length to be approximately 430 feet while documents list the length as 730 feet. The former was used in volume calculations. The structure height at the center of the dam is 68 feet.

A weir with cleaning orifice fish ladder approximately 569 feet long with 57 pools is located at the dam. The concrete-walled canal extends just over 2 miles along a cliff face before entering a tunnel and steel penstocks. The powerhouse is located about 4.3 RM downstream of the dam. Each penstock serves a separate 40-MW unit. The next downstream facility is Copco No. 1 reservoir, approximately17 miles away. Other elements of the project are listed below in Table 3

Table 3 J. C. Boyle Appurtenances

Item	Quantity	Description
Tunnel	74.5 feet	Diversion tunnel for dam construction
Tunnel	1587 feet	Penstock tunnel
Intake Structure		Concrete
Water Delivery System	10761 feet	Concrete Flume
Power Plant and Turbines	2	GE Generators
Substation	2	Transformers
Transmission Lines	70 miles	
Penstock	2 @ 958 feet each	Approximately 10 feet in diameter

[3] First Stage Consultation Document, Klamath Hydroelectric Project, FERC No. 2082, pg. 2-5

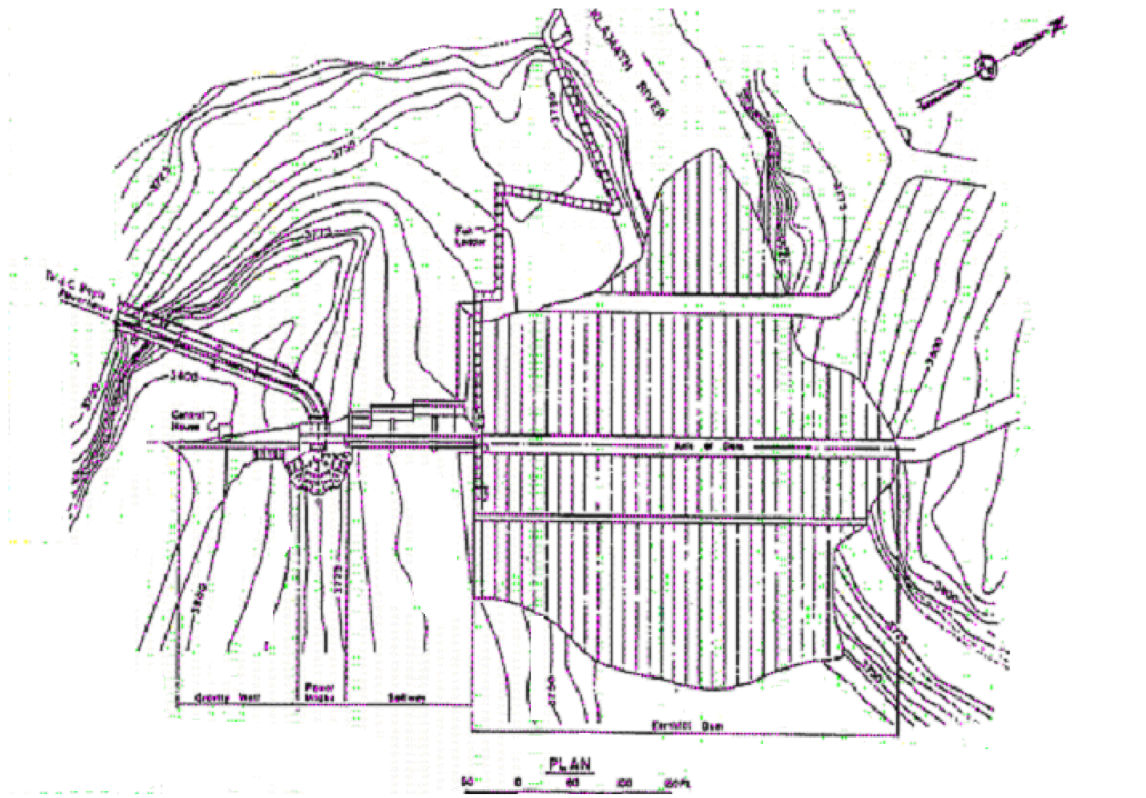

Figure 3 Plan View of J. C. Boyle Dam

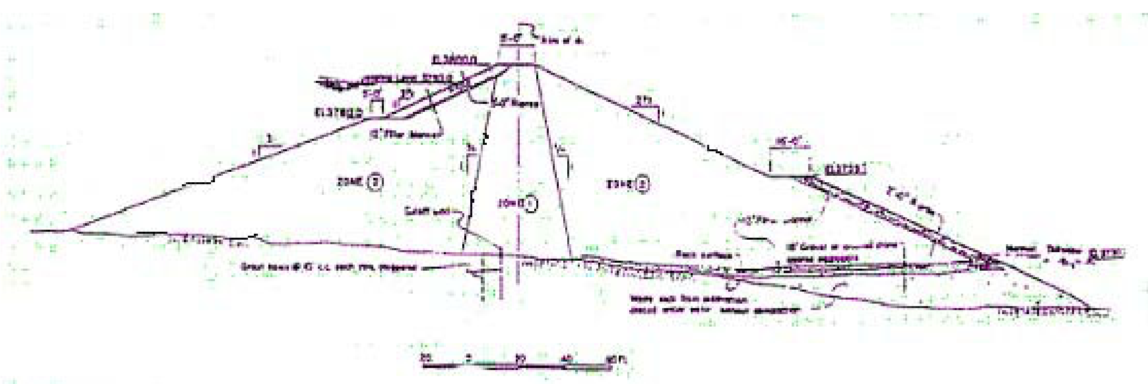

Figure 4 Section through J. C. Boyle Dam

Removal Approach

Because this structure is an earth-fill structure the construction materials are likely to be highly erodible. Approximately 150,000 cubic yards of material were placed to form the dam. The approach discussed in this report removes dam material using mechanical equipment to excavate and haul the material to an upland location for permanent placement.

Cost estimates were conducted for two approaches to river diversion. The first approach would use sheet piles driven through the dam to the riverbed in the direction of river flow to create a controlled channel. The reservoir would be lowered to approximately elevation 3770 through the existing diversion canal during summer low flows. Approximately 25,000 cubic yards of material could be removed down to this elevation.

Sheet piles would be driven prior to lowering the reservoir and a channel excavated between the piles down to elevation 3760. A row of sheet piles perpendicular to these piles would be constructed upstream of the crest of the dam to control flow. A downstream row of sheet piles would also be constructed to control erosion. See **Figure 5**.

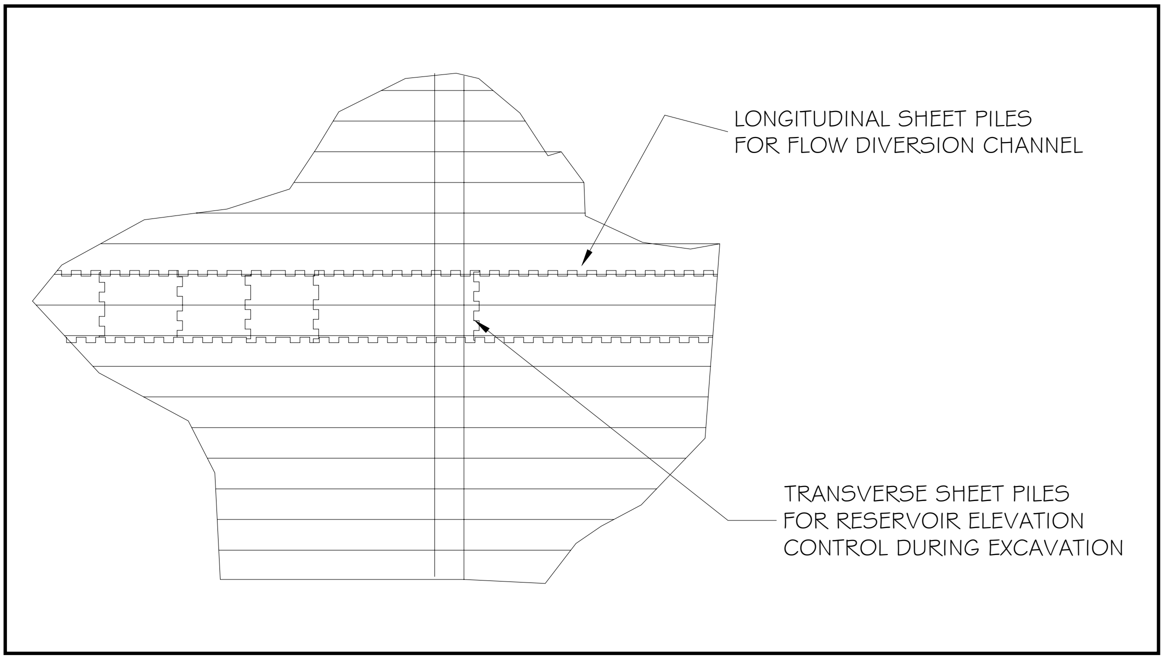

Figure 5 Plan View of J.C. Boyle Dam

Alternate methods of river diversion would be to construct a notch in the rock abutment adjacent to the dam or open the river diversion tunnel used for construction of the dam. However, because no information was available about the tunnel the rock excavation approach was investigated.

The elevation of the notch would be constructed incrementally to allow excavation of dam material in the dry. A channel in the rock abutment at the location of the existing spillway would be constructed approximately 20 feet wide and up to approximately 40 deep. Drilling and blasting techniques would be used to excavate the rock.

Approximately 10,00 cubic yards of rock would be removed during river diversion and replaced after dam removal. The channel would be excavated prior to excavation of dam material except for the upstream-most section of the channel. This section would be removed as required to control the rate of reservoir lowering. The river would be diverted through the channel during excavation of the dam. Rock would be blasted into rubble and removed using standard excavating equipment or a crane with a clamshell bucket erected on site for use in material excavation. Rock would be stored on site for replacement after dam removal.

Cost Estimate

The cost estimate for removing J.C. Boyle Dam, shown in Table 8, assumed that all material in the dam above the streambed was removed. The sheet pile incremental removal method proved to be less expensive and is used for this estimate. The cost estimate did not include costs for removing all canal concrete. Canal concrete removal shown in the cost estimate includes only the freestanding wall sections. Canal concrete against rock was not removed. Transmission line removal was not included. Insufficient information was available to determine detailed costs for removal of most of the appurtenance items such as the penstock, powerhouse, out buildings, and substations. Cost for these items should be considered order of magnitude only. Line items are included to show consideration of the requirement to conduct this work only. See Table 8 for more details regarding costs.

Copco 1

Copco No. 1 project faculties include a reservoir, dam, and powerhouse located between about RM 204 and RM 199 near the Oregon-California border. Construction was complete and generation at unit 1 began in 1918. Copco No. 1 dam is a concrete arch dam 126 feet high; approximately 250 wide at the top, with 13 spill gates across the top. Normal full pool elevation is 2607.5. The bottom of the dam extends well beneath the predam riverbed and is approximately 110 feet wide at the predam riverbed elevation.

The crest of the spillway section is shown at elevation 2593.6 and predam riverbed elevation just downstream of the dam was approximately 2480. About 100 feet of concrete is buried beneath the riverbed. A concrete cutoff wall was constructed upstream of the dam to aid in the construction of the foundation.

The impoundment formed upstream of the dam is approximately 1,000 surface acres containing about 45,500 acre-feet of total storage capacity and 6,235 acre-feet of active storage capacity. The Copco No. 1 powerhouse is located at the base of dam and has two Double Runner Horizontal Francis turbines, each 10 MW. Combined hydraulic capacity of the turbines is roughly 3,200 cfs. Water diverted through the Copco No. 1 powerhouse is directed to the Copco No. 2 powerhouse intake (described below) through the approximately 1-mile-long reservoir.

Removal Approaches

Based on available drawings the estimated concrete contained in the arch dam structure is approximately 52,000 cubic yards of concrete. However, reported concrete quantity[4] placed in the dam was only 35,000 cubic yards. The lower volume was used for this report. Several methods of removing the concrete are possible including using a mechanical impact hammer, drilling and blasting, expansion cracking, and combinations of these methods.

Several methods of river diversion are described in the previous discussions. A low-level outlet would provide the least cost and best control over reservoir elevations. Because information regarding the low-level outlet was not available the “notch” diversion approach was used in cost and construction feasibility analysis. Discussions of the construction of Copco 1 indicate that a diversion tunnel was used to divert flow during the construction of the dam. A tunnel outlet is visible at the base of the dam. The condition of the tunnel is unknown and assumed to be unusable for deconstruction purposes. Should this tunnel be usable it may offer a more convenient and less expensive option for removal.

The penstock can be used during low flows to draw the elevation of the water below the demolition work up to 20 feet below the spillway crest. The water cannot be lowered below that elevation without use of a low-level outlet. An alternate method would

[4] *50 Years on the Klamath River*, John C. Boyle, Klocker Printery, Medford, Or, 1976

construct notches in one section of the dam to allow river flow to pass leaving the remaining portion of the structure to be removed in the dry.

Depending on the allowable sediment release requirements downstream of the dams, control of coarse sediment releases can be accomplished using either the notch or low-level outlet approach. Since Iron Gate Dam is downstream of Copco 1, sediment release criteria may not be an issue.

Cost Estimate

The estimated costs for removal of Copco 1 are shown in Table 9. Cost estimates are based on the assumption that Copco 1 would be removed using the notch approach. However, more control of sediment release and turbidity may be possible using a low-level outlet approach.

The cost estimate assumed that all concrete would be removed down to the pre-dam riverbed. Turbine, penstock, powerhouse, and other appurtenance removal could happen either before or after dam removal. Table 9 provides more detailed cost information.

Copco 2

The Copco No. 2 development consists of a concrete diversion dam, small impoundment, and powerhouse located just downstream of Copco No. 1 dam between about RM 198.3 and RM 196.8. Copco 2 has a normal pool level of 2,483.0 feet and a tailwater elevation of 2,461.0 feet, resulting in a total gross head of 22 feet. The reservoir created by the dam has minimal storage capacity (73 acre-feet). Completed in 1925, the dam is only 33 feet high by approximately 140 feet wide. Taintor gates control pond elevation in 5 bays.

The conduit to the powerhouse consists of portions of wood-stave, rock tunnel, and steel penstock. Two Vertical Francis (13.5 MW each) units with a combined hydraulic capacity of 3,200 cfs reside in the powerhouse

Removal Approaches

Based on description and very limited sketches, the concrete volume contained in the dam is estimated to be approximately 3,000 cubic yards. Access to the site is reported to be constrained. For this analysis the assumption was made that only one vehicle could travel on the access road but that a standard over the road 10 to 12 yard truck could pass. We also assumed that demolition equipment large enough to conduct the demolition process could be transported to the site.

Dam demolition would most likely be conducted using a hoe-ram and several 10-yard trucks to haul material away from the site. Water level would be lowered using the gate as far as possible. Penstock capacity significantly exceeds low average flows in summer months and would be used to lower water elevation to near the invert of the penstock.

Preceding concrete demolition, spillway gates and stanchions would be removed. Due to lack of sufficient details regarding the configuration of the structure we could not determine if water elevations could be drawn down sufficiently to remove all concrete in dry conditions. Generally, hoe-ram demolition can proceed in wet conditions if flow velocity around the hammer does not exceed about 6 feet per second. We have assumed that all demolition would occur using backhoe mounted hydraulic impact hammers. Should further investigation show that water velocities become excessive, a small section of the dam could be blasted out to allow river flow to pass around the dam while the remaining portion was demolished in the dry.

Using a hoe ram, a 24-foot section would be demolished 10 feet deep in wet conditions. Equipment would be located on both sides of the demolition area to allow sufficient reach to conduct the demolition. Once demolition in this section was finished, the portion of the dam above water would be demolished down to water elevation. This approach would be used to remove the concrete in steps down to the riverbed elevation. When the notched portion bottom elevation reaches the riverbed elevation the notching can proceed no lower. At that point temporary cofferdams would be placed in the river to divert water to the notch away from the demolition areas. The temporary cofferdam would be approximately 5 feet high and constructed of individual concrete blocks that could be set and removed using a crane.

Cost Estimate

The cost estimate, presented in Table 10, included removing the dam, wood stave pipe, surge tank, penstock, and powerhouse. A review of the condition of access roads was not included in this report. However, access road improvement is included in the cost estimate. Tunnels would be capped but otherwise unaltered. Capping tunnels was considered incidental to the overall construction cost and is part of the contingency factor. Cost for removal of the surge tank was included in powerhouse removal costs. The cost estimate, Table 10, provides more details

Iron Gate Dam

Existing Conditions

Iron Gate Dam is the last dam on the river, located approximately 7 miles downstream of Copco 2 powerhouse. The project consists of a reservoir, dam, and powerhouse located between about RM 196.8 and RM 190. This facility is located about 20 miles northeast of Yreka, California.

The dam is earth and rock fill construction with a compacted clay core and concrete cutoff wall with a grout curtain at the base of the dam. The dimensions of the grout curtain and clay core were not available for this investigation.

Iron Gate dam was completed in 1962. Iron Gate Dam is 173 feet high and has a crest length of approximately 685 feet. The spillway is a free overflow, side channel with a capacity of 32,000 cfs. A 969 foot long horseshoe shaped tunnel served as a river diversion during construction of the dam and currently serves as a sluiceway.

Access for demolition activities would be along an existing road along the Klamath River. The dam is about 7 miles from Interstate Highway 5. The condition of the road along the Klamath River is unknown. It was assumed that the road would need to be upgraded due to the relatively large volume of traffic that would be required to remove dam material.

The impoundment formed upstream of the dam is approximately 944 surface acres and contains about 58,794 acre-feet of total storage capacity and 3,790 acre-feet of active storage capacity. An ungated spillway, 730 feet long, leads to a large canal, allowing the transport of high flows past the structure. The powerhouse is located at the base of the dam and consists of a single Vertical Francis unit (18 MW) with a hydraulic capacity of 1,735-cfs. Normal tailwater elevation is 2,171 feet.

No construction drawings were available for this investigation. Based on photographs and sketches of the facility from previous reports, removal volumes tabulated in Table 4, were calculated.

Table 4 Estimated Material Volumes at Iron Gate Dam

Item	**Volume - cubic yards**
Rockfill	1,100,000
Core Material [5]	220,000
Estimated Concrete	3,000

[5] Assumed. Dimensions – no drawings were available.

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Table 5 Additional Iron Gate Dam Project Structures

Item	Quantity	Description
Tunnel	969.2 feet	Horseshoe shaped 16 feet - Assumed to be gated and operational
Penstock	681 feet long	12 foot diameter
Side channel diversion	730 feet	Diversion intake withdraws water from about the top (surface) 35 feet of reservoir.
Power plant	1 Turbine	
Substation	1 Transformer	
Fish rearing facilities and ladder	40,000 Square Feet	Approximate area occupies by fish facilities
Transmission lines	Unknown	

Removal Approach

Iron Gate Dam contains the largest quantity of material of all the dams included in this report, and is the most expensive to remove. Although information regarding the condition of the low-level diversion tunnel used to divert the river during original construction was not available, it is assumed that the tunnel can be made operational since it is listed as a sluice tunnel. It is also assumed that a diversion structure or cofferdam was constructed across the river upstream of the tunnel and left in place during the original construction. This would have been essential for high flow contingencies during the construction to avoid overtopping of the tunnel and erosion of the partially constructed dam.

The first stage of construction would lower the reservoir approximately 10 feet below the existing elevation using the existing diversion tunnel. It is assumed that Iron Gate Reservoir could be completely drained, and the trapped sediment could be sluiced out, using the low-level tunnel because the material for the dam was placed using the same tunnel. The demolition process, then, would simply reverse the activities of the construction process. Reservoir water elevations would be kept below construction activities to ensure adequate safety in the event of high flows so that equipment and personnel would have time to evacuate the site.

Details of the dam material characteristics were not available for development of this report. The removal approach assumed that demolition would be conducted using standard excavation techniques and equipment. Approximately 130,000 round trips of a standard 12-yard truck would be necessary from the dam site to an unspecified disposal site to remove all dam material.

The removal approach assumed that a diversion dam was constructed across the upstream channel just below the tunnel upstream opening. After all removal activities were complete for the main dam structure, the diversion dam would be breached. Nothing is known of this diversion dam. An estimate based on the assumption that the diversion dam was approximately 20-feet high was used in the cost estimate.

The spillway structure appears to be constructed on bedrock. Most of the higher portion of the structure would not be demolished. The cost estimate reflects removing the lower section adjacent to the river.

Cost Estimate

The estimated cost for removing Iron Gate is presented in Table 11. For Iron Gate only, the contingency is 20% instead of 25% used on all other cost estimates. This lower contingency reflects the lower uncertainty associated with a repetitive process such as removing large quantities of material.

The cost estimate includes removal of the dam, concrete appurtenant structures including the spillway, right bank channel, powerhouse, and fish facilities. Concrete in the existing tunnel would be removed after the dam was successfully removed. Since the condition of the existing tunnel is unknown, cost for refurbishing the outlet are included. This cost should be considered a placeholder for this item until better information is available.

Because such large quantities of material were used to construct the dam, cost for removal of Iron Gate Dam is dominated by the length of the haul, the size of truck used to conduct hauling activities, and requirements of the disposal site. The cost estimate included in this investigation assumes that material removed from the dam would be hauled to a site within 5 miles of the dam. Developing a disposal site near the dam would greatly reduce removal costs. Using off road trucks would also reduce the costs.

Removal of the substation was not included in the cost estimate. The appurtenant structures would be removed after dam removal. Table 11 provides details of the items included in the cost estimate.

Sediment Management

Existing Conditions

A thorough investigation of the characteristics of the sediment trapped behind the four dams has not been conducted at this time. Before dam removal could occur, the chemical and physical characteristics of trapped sediment would need to be determined. Limited chemical testing has been conducted. Regulatory requirements for chemical testing of sediments for dam removal have not been clearly defined. Other similar projects have used the Puget Sound Dredge Disposal Analysis techniques and drinking water chemical testing requirements as guidelines.

Physical parameters that will need to be investigated include material grain size distribution and location, particle fall velocities and particle shape, and geotechnical characteristics of the material. Grain size distribution and location is important for analyzing the ability to excavate or erode the material. Fall velocity and material shapes would be used to analyze the erosion, deposition, and transport of the material by flowing water. Geotechnical properties are needed to analyze stable slopes through eroded sediment and embankment slopes for relocated sediment.

Sediment Removal Options

Of the four reservoirs created by the dams, only two have significant amounts of trapped sediment, Iron Gate and Copco 1. Most of the sediment naturally carried by a river is trapped when a dam is constructed across the river. Water velocities slow when the river enters the reservoir and most sediment settles out of the water and stays in the reservoir. Upstream dams have captured much of the sediment transported by the river in the upper reaches and have restricted the volume of trapped sediment in the downstream reservoirs. Still, the estimated cumulative trapped sediment volume is over 14 million cubic yards. See Table 6.

The upstream reservoirs may also have affected the size of material trapped in the lower reservoirs. Approximately 87% of the trapped sediment is fine-grained material. A typical distribution between fine and coarse-grained material found in west coast reservoirs is 65% fine-grained and 35% coarse-grained. Fine-grained material is transported in the water column in suspension and moves downstream essentially at the velocity of the water. Larger coarse-grained material, generally larger than approximately 0.1mm in size, is transported more slowly along the riverbed. The estimated distribution between volumes of fine and course grained sediment in each reservoir are shown in Table 7.

Two approaches to managing the sediment are possible; remove the sediment from the reservoirs before removing the dams or allow the river to naturally erode the material downstream. Several factors favor the latter approach. Costs for removing the sediment from the river are much greater than allowing the material to naturally erode. Because the trapped material is sediment naturally transported by the river, the downstream environment may benefit from allowing it to move downstream.

There are, however, numerous issues associated with transporting many years of accumulated sediment in a short period of time that must be investigated. Most of these issues are beyond the scope of this document primarily because adequate information relating to water use downstream of the dams has not yet been assembled.

There would, most likely be some costs associated with implementing the natural erosion approach. These costs could be for temporary flood or erosion protection, water quality maintenance, or water rights issues. Further study would be necessary before these issues could be resolved.

Mechanical Excavation

Mechanical excavation would involve using large construction equipment to mechanically excavate trapped sediment. Techniques would involve using a large backhoe, scrappers, clamshell dredges, barges, and other excavation and transportation equipment. Roads, bridges and docking facilities may need to be constructed or upgraded to load and haul material. Excavated material would be transported to a new location and compacted.

Trucks used to remove the material would be limited to approximately 10 cubic yards of material if transported to a remote upland site. If a nearby site were found that did not involve transport over public thoroughfares, larger transport vehicles could be used.

Two approaches to mechanically removing sediment are possible; 1) dewater the reservoir and remove material using standard excavation methods and 2) excavate material using floating dredges and use barges and trucks to transport the excavated material. Both methods are expensive. Preliminary information indicates that material trapped in the reservoirs is primarily fine-grained material, which is more difficult to excavate and transport. Mechanically excavating and relocating trapped sediments could add over $150 million to removal costs. Mechanical excavation was not investigated.

Hydraulic Dredging

Hydraulic dredging, a variation of the mechanical excavation approach, would use large suction dredges to remove sediment trapped in the reservoirs. Cost for large-scale operations of this type usually range between $7.50 and $15.00 per cubic yard of material for removal only. Costs increase if multiple pumping stations are required to move the material. Dredging was not investigated. Dredging could be expected to add over $100 million to removal costs.

Natural Erosion

As shown in Table 7 most of the trapped material is fine material.

Natural erosion of trapped sediments would simply involve lowering the reservoir water elevation so that the river erodes through the material. Several approaches to naturally eroding trapped sediments have been investigated on other dam removal projects.

The least complex approach would be to simply lower the reservoir rapidly without regard to adjacent lands. This approach is desirable if the canyon in which the sediment is trapped is narrow. Rapidly lowering the water levels causes water laden side slopes of the river path cut through the sediment to fail and cause sediment to slide into the river to be transported downstream. In a narrow canyon the river is constrained by the canyon walls and will not meander. Conditions in the upstream delta area of the reservoirs for Copco 1 and Iron Gate are unknown but the general topology of the river canyon in these reaches appears to fit this description.

In delta areas that are much wider than the river, lowering the reservoir in increments and holding the water elevation steady for several days or weeks allows the river to meander and erode through the delta. This process will relocate much of the material downstream in an area across the width of the remaining reservoir. As the reservoir is lowered the sediment is distributed across the reservoir. At the same time a new river channel is cut through the redistributed sediment. Much of the trapped material can be flushed out of the reservoir and moves downstream. The remaining sediment would be perched on riverbanks along the side of the newly formed river.

Sediment Characterization

If mining activities occurred upstream of the dams it is possible that the reservoirs have trapped some heavier metals. However, testing information reviewed for this report does not suggest that heavy metals are present in the sediment.

Grain size analysis shown in Figure 6 below, was taken from a report by JC Headwaters, Inc. (Bathymetry Study) conducted for PacifiCorp in April 2003. Based on that report sediment volumes and grain size distributions were developed, shown in Table 6 and Table 7. Unfortunately, because of the sampling techniques used, the grain size distribution shown in Table 7 is unlikely to be very accurate since sediment samples were taken only on the surface. Sampling must be conducted at vertical and horizontal locations distributed throughout the sediment to provide adequate knowledge of the characteristics of the sediment.

Table 6 Reservoir Sediment Volumes

Reservoir	Volume of Sediment	% of Total Reservoir Volume
Boyle	22,222	.06
Copco	9,630,000	3.17
Iron Gate	4,810,000	3.55

As shown in Table 6, approximately 14.4 million cubic yards of sediment are trapped behind the dams. Based on the Bathymetry Study, approximately 87% of the material is fine material that is easily erodible and would present no significant short or long-term aggredation or flooding impacts downstream. Eroding sediments will dramatically increase suspended sediment concentrations and turbidity for certain periods.

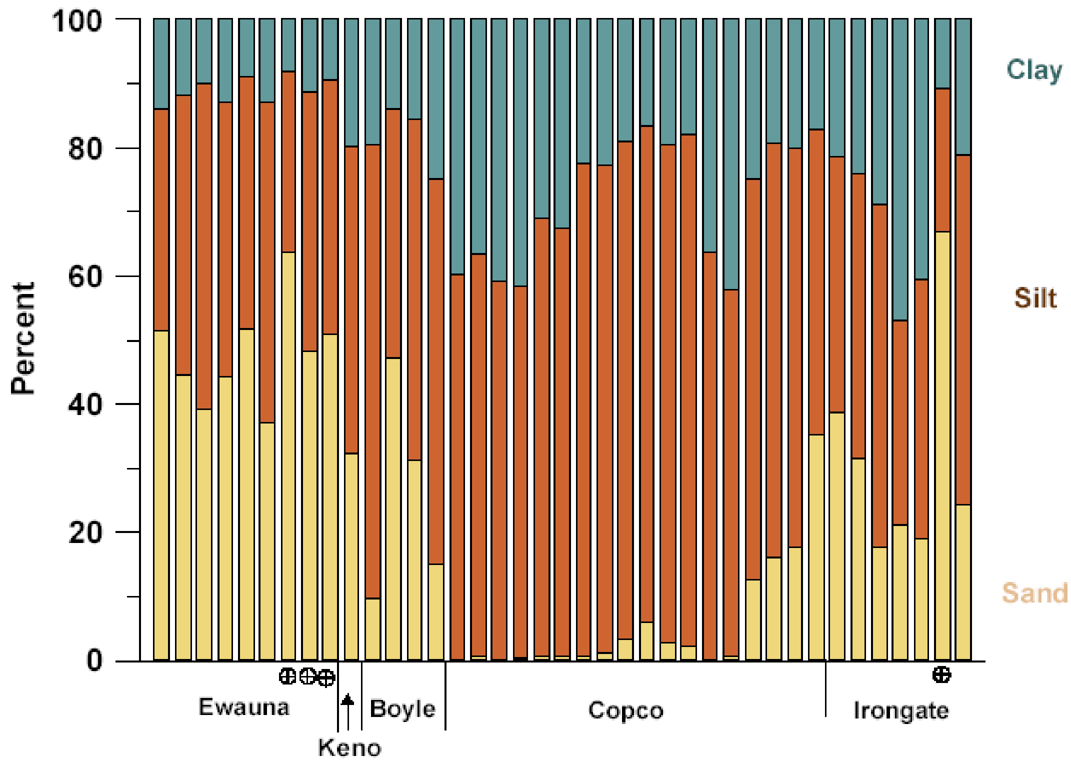

Figure 6 Approximate Grain Size Distributions for Klamath River Dams[6]

Using the sediment grain size distribution shown in Figure 6 and assuming that each reading represents an equal volume of sediment, the distribution between suspended sediment and bedload sediment, shown in Table 7, would result.

Typically all material classified as silt and clay (fine material) would be immediately eroded and remain suspended in the river the entire length of the downstream reach. This is a simplification of what might actually occur if river erosion were used to remove the sediment. Some temporary deposition of fine-grained particles would probably occur in slow-moving and deeper reaches. Also some of the finer sands would be suspended except for in the low-gradient, slower reaches. A more complete geomorphic study is required to assess the response of the downstream river to erosion of this volume of fine sediment. However, before such a study is undertaken, a more complete analysis of sediment will need to be conducted to better determine grain size characteristics.

The results presented in the Bathymetry Study are, generally, consistent with the characteristics of sediment found in similar reservoirs in western North America; that is the reservoir contains a greater amount of fine sediment than coarse sediment. However,

[6] Bathymetry and Sediment Classification of the Klamath Hydropower Project Impoundments, for PacifiCorp by JC Headwaters, Inc., April 2003

it seems likely that Copco 1 reservoir contains more sand and larger sized material than estimated in Table 7 because it was the first dam to be constructed and would have captured virtually all sediment coming into the reservoir. Analysis based on the Bathymetry Study shows only about 4% coarse material in Copco 1.

According to the data shown, Iron Gate Dam, the most downstream in the group has a larger percentage and amount of coarse material than the upstream dams. However, Copco 1 has a greater free flowing upstream reach length and has been in place longer than Iron Gate. Copco 1 would, therefore, be expected to trap a similar or greater amount and proportion of coarse sediment.   This inconsistency suggests further analysis of the sediment should be conducted to confirm the Bathymetry Study results.

Table 7 Estimated Quantities of Suspended and Bed Load Material Trapped behind Copco, Iron Gate, and J. C Boyle Dams

Dam	Suspended Load Volume CY Fine Grained Material - Silt and Clay	Bed Load Volume CY Coarse Material - Sand, Gravel, and Larger
J. C. Boyle	16,330	5,890
Copco 1	9,208,688	421,313
Iron Gate	3,391,050	1,418,950
Total	12,601,371	1,840,851

Downstream Issues

Allowing sediment to erode downstream has several effects. It dramatically increases the turbidity for the short term. It may increase the riverbed elevation in low-gradient reaches. It may temporarily cause higher deposition in pools, and it may cause some riverbed degradation in steeper areas if extremely high flows occur during the erosion process.

Examination of specific effects of river erosion downstream of the dams is beyond the scope of this document. However, based on past projects of a similar nature, it is possible to identify a number of issues that require examination to ensure downstream movement of sediment does not severely impact water users or habitat. These issues are listed below.

1. Affects to aquatic life including fish and their food sources such as invertebrates.
2. Changes in riverbed elevations especially near structures. Changes can be either aggredation or degradation of the riverbed. Structures over the river, such as bridges, might be impacted in the short-term due to changes in foundation support. Structures along the river may be impacted by a rise in flood levels due to short and long term changes.
3. Changes in the course of the river. Most of the sediment that previously came down the river has been trapped since the early part of the 20^{th} century. This loss of sediment may have caused the river to be straighter than other wise would be the case. Adding high sediment loads in the short term can cause the river to change course as new zones of deposition or erosion are created in response to the changed sediment regime.
4. Changes in river water quality. Users of river water may experience changes in turbidity, temperature, organic content, and dissolved oxygen. Depending on the use and the method of withdrawal, these changes may need to be mitigated.

Generally, effects would be most pronounced within the reach immediately downstream of the dams. Because of the relatively large distance between the dams and the river mouth, impacts would be attenuated by tributary inflows and distribution of coarse sediment over a great length of river. Spikes in turbidity from eroded fine sediment would reach the mouth of the river in approximately three days. Coarse sediment, depending on grain size, would require weeks to months to reach the mouth of the river, depending on flows. An analysis of the expected response of the river to the release of sediment from the dams would be required to evaluate the potential impacts to structures, water quality, habitat and other resources.

Combination Approaches

Numerous approaches using both mechanical, hydraulic, and erosion methods of moving the sediment out of the reservoirs are possible. It is beyond the scope of this document to analyze these approaches.

Sequence and Timing

The timing and sequence of removal of the dams may require consideration of downstream water users primarily for fisheries and water withdrawal issues. Flooding considerations will also need to be considered. For this investigation it was assumed that the three upstream dams were removed before Iron Gate Dam was removed. Iron Gate would act as a sediment trap and allow some control over sediment release rates and downstream conditions.

Release of sediment through the low-level outlet at Iron Gate would allow some measure of control over turbidity and flooding issues downstream of the dam. As stated previously, functionality of the outlet is unknown. However, based on drawings of the dam, the capacity and elevation of the outlet would appear to be sufficient to control the release of most of the fine sediment and about half of the coarse sediment.

Removing Iron Gate Dam would require the greatest amount of time. Scheduling would depend on requirements of sediment removal. This report assumes that cost, feasibility, and environmental constraints (noise, air, and traffic considerations) would make removal of trapped sediment impractical and the sediment would be allowed to naturally erode downstream.

Timing of eroding sediment may be important to water users and migrating fish and other aquatic organisms. This investigation assumes that erosion would be initiated in high flow months of November through December. The schedule assumes that all sediment is eroded in a single year. At a minimum, further investigation of the sediment characteristics and development of sediment release criteria will be required before this assumption can be confirmed. Because Iron Gate Dam is the last dam on the river and it has a working low-level outlet, eroding the sediment over several years would be also feasible. However, this strategy might not be desired because the period of high turbidity would be extended. Further investigation of water issues will be required to determine the optimum approach for sediment erosion.

shows fish activity in the Klamath River.

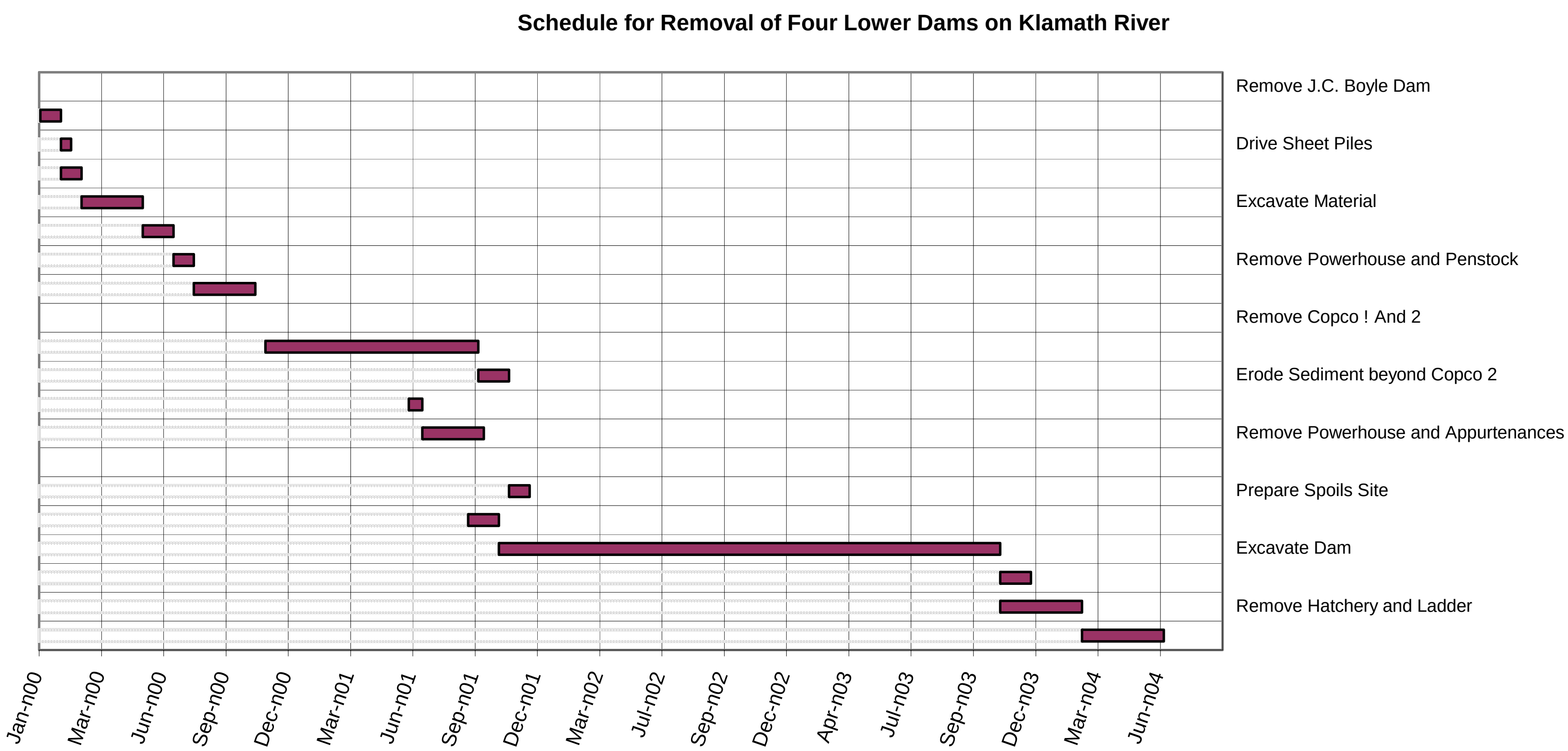

Figure 7 Construction Timing and Sequence

Species/ Life stage	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Spring Chinook Type I												
Adult migration	xx	xx							xx	xx	xx	xx
Adult spawning			x**x**	**x**								
Incubation			xx	xx	**xx**	**xx**	**xx**	**xx**	**xx**	xx	x	
Fry emergence						xx	xx	**xx**	**xx**	**xx**	xx	
Rearing	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Juv. outmigration							x	xx	xx	xx	**xx**	xx
Spring Chinook Type II												
Adult migration		x	xx	x								
Adult spawning			xx	xx								
Incubation			xx	xx	xx	xx	xx	xx	xx			
Fry emergence								xx	xx	x		
Rearing	xx	xx						xx	xx	xx	xx	xx
Juv. outmigration			xx	xx	x							
Fall Chinook Type II (fall juvenile migrant)												
Adult migration		xx	**xx**	**xx**								
Adult spawning				**xx**	x							
Incubation				xx	xx	xx	xx	xx	xx			
Fry emergence								xx	**xx**	**xx**		
Rearing	xx	xx						xx	xx	xx	xx	xx
Juv. outmigration			xx	xx	xx							
Fall Chinook Type I (ocean type)												
Adult migration		xx	**xx**	**xx**								
Adult spawning				**xx**	x							
Incubation				xx	xx	xx	xx	xx	xx			
Fry emergence							xx	**xx**	**xx**	**xx**		
Rearing							xx	**xx**	**xx**	**xx**	**xx**	**x**
Juv. outmigration	**xx**	x								xx	**xx**	**xx**
Coho												
Adult migration				xx	**xx**	**xx**	xx					
Adult spawning					xx	**xx**	xx					
Incubation					xx	xx	xx	xx	xx			
Fry emergence								**x x**	**xx**	x		
Rearing	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Juv. outmigration	xx							xx	**xx**	**xx**	xx	xx
Steelhead Fall/Winter[1]												
Adult migration			xx	xx	xx							
Adult spawning						xx	xx	xx	**xx**	xx		
Incubation						xx	xx	xx	xx	xx		
Fry emergence									xx	xx	**xx**	xx
Rearing	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Juv. outmigration	x								xx	xx	xx	xx
Redband/ Rainbow Trout[2]												
Adult migration				xx	xx			x	**xx**	**x**x	x	
Adult spawning								x	xx	xx	x	
Incubation									xx	xx	xx	xx
Fry emergence	x									xx	xx	xx
Rearing	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Juv. Emigration[3]	xx	xx	xx	xx						xx	xx	xx

Lamprey[4]	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Adult migration	x[5]	x[5]	x[5]			xx	xx	xx	xx	xx	xx	xx
Adult spawning	x								x	xx	xx	xx
Incubation	xx								x	xx	xx	xx
Rearing	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Juv. Emigration[6]	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Suckers[7]												
Adult migration								x	xx	xx	x	
Adult spawning									xx	xx	xx	
Incubation									xx	xx	xx	x
larval emergence										xx	xx	xx
Rearing	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx

Figure 8 Timing of Fish Runs[7]

1. The mainstem Klamath River tributaries have the highest incidence of a half-pounder life history within the Klamath –Trinity system. Approximately 90 to 100percent of steelhead juveniles from Iron Gate Hatchery and nearby tributaries return to fresh water four to five months later as half-pounders (Shaw et al 1998).
2. Limited trout spawning has been observed in the mainstem Klamath River within the Project area (J.C. Boyle bypass reach). Spawning does occur in Shovel and Spencer Creeks.
3. The resident trout juvenile emigration indicates when fish are leaving their natal streams and entering the mainstem Klamath River.
4. The information in this table is for the anadromous Pacific lamprey (*Lamptera tridentata*) which occurs below Iron Gate Dam (IGD). Above IGD, potentially five lamprey species reside in the upper Klamath Basin (Kostow 2002). The nonparasitic Pit-Klamath brook lamprey (*Lampetra lethophaga*) and the parasitic Klamath River lamprey (*Lampetra similis*) are considered sister species of the Pacific lamprey. The Pit-Klamath brook lamprey is found in the upper Klamath Basin upstream of the Keno vicinity while the Klamath River lamprey distribution is from upper Klamath Basin down to the vicinity of Happy Camp, CA. The Miller Lake lamprey (*Lampetra minima*) was thought to be endemic to Miller Lake (upper Klamath Basin), was extirpated from Miller Lake by ODFW in 1958 and declared extinct in 1973. However, this species was rediscovered in the 1990's and the expanded distribution includes Miller Lake basin, upper Klamath Marsh, the Williamson River system upstream of the marsh, and throughout the upper Sycan River system. The other two recognized species in the upper Klamath Basin include the nonparasitic lamprey (*Lamptera folletti*) and a parasitic species currently called *Lamptera tridentata. L. folletti* was described in 1976 with a distribution in Lost River and the Klamath Basin around the lower Klamath Marsh near Klamath Falls. However, it is not known whether *L. folletti* is present, or ever was present. The other species is called *L. tridentata* as it was once considered to be a landlocked population of *L. tridentata*. Evidence now suggests that this is an entirely separate species that never exhibited anadromy; it does, however, have a migratory life history pattern, moving between various freshwater habitats to spawn and rear. For the purposes of this table, the life history of the Pacific lamprey is a surrogate for the other lamprey species since very little is known about their life history.
5. The river lamprey (*L ayresi*) has not been found in the Klamath Basin but its range is reported to be Sacramento River to SE Alaska. The extension of adult lamprey migration will cover this species if it is present.
6. This includes both ammocoetes and eyed lamprey migration.
7. The Klamath Basin contains four recognized species of catostomids: Klamath smallscale sucker, Klamath largescale sucker, the shortnose sucker, and the Lost River sucker. Both the shortnose sucker and the Lost River sucker are federally listed endangered species and this table represents their life history strategies (USFWS 1993).

[7] First Stage Consultation Document, Klamath Hydroelectric Project, FERC No. 2082, pg. 5-3

Cost Estimates

Cost estimates presented below include costs for removal of dams and certain appurtenant structures only. Only structures that might present future safety hazards or could affect the free flows of the river were removed. The following cost estimates attempt to identify the major cost items involved in removal of the dams. However, the line item costs and total costs should be considered to be feasibility level cost estimates.

Costs associated with sediment removal and management are not included due to lack of information regarding sediment characteristics, downstream structure locations, and downstream water user information.

Removal costs analysis did not identify a location for the disposal of dam material. Most likely some improvement of the site and the access to the site or sites will be required. Costs shown for site work are order of magnitude placeholders for these items. Further analysis will be required to determine disposal site costs.

The largest cost items are concrete and earth/rock fill removal. Concrete demolition and removal costs were taken from similar dam removal projects on the White Salmon and Elwha rivers in Washington State. Earth and rock removal costs for Iron Gate and J.C. Boyle dams were taken from *Heavy Construction Cost Data*, published by RS Means. Adjustments were made to account for the size of the project and access considerations.

Most of the material removal quantities were based on relatively rough drawings of the dam sites and should be taken as approximate only. Quantities for structures such as fish facilities, shops, and other buildings especially should be considered accurate only in order of magnitude.

Requirements for environmental cleanup at the site are also completely unknown, but estimates have been provided. Typically, oil used in transformers will require some cleanup. The line items for cleanup should also be considered order of magnitude placeholders only until better information can be developed.

Cost Estimate J. C. Boyle				
Item	**Quantity**	**Unit**	**Unit Cost**	**Total**
Mobilization	1	LS	$ 300,000.00	$ 300,000
Sheet Piles - Place, Cut and Extract	300	Tons	$ 2,000.00	$ 600,000
Disposal Site Preparation	1	LS	$ 50,000.00	$ 50,000
Upgrade Roads	1	LS	$ 50,000.00	$ 50,000
Excavate Material	150,000	CY	$ 3.50	$ 525,000
Haul Material	150,000	CY	$ 10.00	$ 1,500,000
Compact and Grade Material	150,000	CY	$ 1.00	$ 150,000
Environmental Mitigation at Disposal Site	16	Acres	$ 25,000.00	$ 400,000
Remove Fish Ladder	500	CY	$ 75.00	$ 37,500
Remove Spillway and Gates	1	LS	$ 50,000.00	$ 50,000
Remove Intake Structure	1	LS	$ 50,000.00	$ 50,000
Subtotal				$ 3,712,500
Remove Canal Concrete	7,500	CY	$ 150.00	$ 1,125,000
Substation Removal	1	LS	$ 150,000.00	$ 150,000
Environmental Cleanup	1	LS	$ 150,000.00	$ 150,000
Remove Powerhouse and Generation Facilities	1	LS	$ 150,000.00	$ 150,000
Subtotal				**$ 4,987,500**
Contingencies		25%		$ 1,246,875
Total				**$ 6,234,375**

Table 8 J.C Boyle Cost Estimate

Cost Estimate Copco 1				
Item	**Quantity**	**Unit**	**Unit Cost**	**Total**
Mobilization	1	LS	$ 600,000.00	$ 600,000
Upgrade Roads	1	LS	$ 50,000.00	$ 50,000
Drill and Blast Concrete	35,000	CY	$ 150.00	$ 5,250,000
Disposal Site Preparation	1	LS	$ 50,000.00	$ 50,000
Haul Material	35,000	CY	$ 10.00	$ 350,000
Compact and Grade Material	35,000	CY	$ 3.00	$ 105,000
Environmental Mitigation at Disposal Site	4	Acres	$ 25,000.00	$ 100,000
Remove Spillway and Gates	1	LS	$ 50,000.00	$ 50,000
Remove Intake Structure	1	LS	$ 50,000.00	$ 50,000
Subtotal				**$ 6,605,000**
Remove Penstock	1	LS	$ 25,000.00	$ 25,000
Substation Removal	1	LS	$ 150,000.00	$ 150,000
Environmental Cleanup	1	LS	$ 150,000.00	$ 150,000
Remove Powerhouse and Generation Facilities	1	LS	$ 150,000.00	$ 150,000
Subtotal				$ 6,780,000
Contingencies		25%		$ 1,695,000
Total				**$ 8,475,000**

Table 9 Copco 1 Cost Estimate

Cost Estimate Copco 2				
Item	**Quantity**	**Unit**	**Unit Cost**	**Total**
Mobilization	1	LS	$ 75,000.00	$ 75,000
Upgrade Roads	1	LS	$ 10,000.00	$ 10,000
Drill and Blast Concrete	5,000	CY	$ 150.00	$ 750,000
Disposal Site Preparation	1	LS	$ 10,000.00	$ 10,000
Haul Material	5,000	CY	$ 10.00	$ 50,000
Environmental Mitigation at Disposal Site	1	Acres	$ 25,000.00	$ 25,000
Compact and Grade Material	5,000	CY	$ 2.00	$ 10,000
Remove Spillway and Gates	1	LS	$ 15,000.00	$ 15,000
Remove Intake Structure	1	LS	$ 50,000.00	$ 50,000
Subtotal				**$ 995,000**
Substation Removal	1	LS	$ 150,000.00	$ 150,000
Environmental Cleanup	1	LS	$ 150,000.00	$ 150,000
Remove Penstock	1,400	FT	$ 35.00	$ 49,000
Remove Powerhouse and Generation Facilities	1	LS	$ 150,000.00	$ 150,000
Subtotal				$ 1,494,000
Contingencies		25%		$ 373,500
Total				**$ 1,867,500**

Table 10 Copco 2 Cost Estimate

Cost Estimate Iron Gate Dam				
Item	**Quantity**	**Unit**	**Unit Cost**	**Total**
Mobilization	1	LS	$ 300,000.00	$ 300,000
Refurbish Tunnel Outlet	1	LS	$ 350,000.00	$ 350,000
Disposal Site Preparation	1	LS	$ 50,000.00	$ 50,000
Upgrade Roads	1	LS	$ 50,000.00	$ 50,000
Excavate Material	1,100,000	CY	$ 2.50	$ 2,750,000
Excavate Core Material	220,000	CY	$ 3.00	$ 660,000
Haul Material 12CY Truck 10 Mile Haul	1,320,000	CY	$ 7.00	$ 9,240,000
Compact and Grade Material	1,320,000	CY	$ 0.50	$ 660,000
Environmental Mitigation at Disposal Site	41	Acres	$ 25,000.00	$ 1,025,000
Remove Fish Ladder and Facility	750	CY	$ 75.00	$ 56,250
Remove Spillway and Other Concrete	4,000	CY	$ 150.00	$ 600,000
Remove Penstock	1	LS	$ 50,000.00	$ 50,000
Remove Intake Structure	1	LS	$ 50,000.00	$ 50,000
Subtotal				$ 15,841,250
Environmental Cleanup	1	LS	$ 25,000.00	$ 25,000
Remove Powerhouse and Generation Facilities	1	LS	$ 150,000.00	$ 150,000
Subtotal				**$ 16,016,250**
Contingencies		20%		$ 3,203,250
Total				**$ 19,219,500**

Table 11 Iron Gate Cost Estimate

Dam	Structure Removal Cost	
Iron Gate	$	19,219,500
Cocpo 2	$	1,867,500
Copco 1	$	8,475,000
J. C. Boyle	$	6,234,375
Total Structure Removal Cost	**$**	**35,796,375**

Table 12 Summary of Cost Estimates Including All Costs

Dam	Structure Removal Cost	
Iron Gate	$	19,009,500
Cocpo 2	$	1,243,750
Copco 1	$	8,256,250
J. C. Boyle	$	4,640,625
Total Structure Removal Cost	**$**	**33,150,125**

Table 13 Total w/o Power House Removal Costs

Additional Information Required

Appraisal of the cost and approach for removal of the four lower dams on the Klamath River was based on very limited information regarding the nature of the dams, structures, and river. No information was available regarding spoils sites, details of structures, and many other aspects of the projects that will need to be developed if the removal is to proceed.

It was also based on the assumption that sediment trapped behind the dams would be eroded downstream and eventually be washed into the Pacific Ocean. Effects on the river, structures in and over the river, and water users will depend on the details of the approach to sediment management. Analysis of mitigation requirements is beyond the scope of this document.

The following is a partial list of general information required to fully assess removal options. The single most important piece of information not available for this study was an accurate characterization of trapped sediment grain sizes. Assessment of the ability of the river to erode trapped material cannot be completed until this information is determined in some manner. Equally important is determining all uses of Klamath River water downstream of Iron Gate Dam. With this information an assessment of the feasibility of the natural erosion approach can be conducted.

An alternative approach to attaining core samples from the reservoirs would be to conduct an analysis using conservative estimates of the volume of sediment that is comprised of the larger grain sizes. This would determine an upper limit on the time for sediment to move downstream and could be used to place an upper limit on potential flooding issues downstream of Iron Gate Dam. It would not adequately address water quality issues, however. Should high concentrations of heavy metals be present in the sediment, eroding them may have unacceptable impacts to water users.

List of Additional General Information Required

- Contamination at transformer sites – Sites may have had PCBs
- Criteria for structure removal - Are all structures to be removed or can inert structures such as concrete remain?
- Spoils site locations, preparation and mitigation required.
- Road conditions, upgrades required.
- Accurate details of the dimensions and construction materials of the structures to be removed.
- Type of materials used to construct dams
- Conditions of any diversion facilities used for construction or presently in use
- Dimension, construction type, and existence of upstream cofferdam used to divert river during construction of dam

Additional Informal Required For Individual Dams

J.C. Boyle

- Quantity of sediment in reservoir
- Availability tunnel used for original diversion for lowering dam
- Exact dimensions and elevations of structures
- Nature and type of materials used in dam construction
- Site topography and access conditions at dam and powerhouse

Copco 1

- Dimensions and type of materials for dam and appurtenances
- Availability of tunnel used for original diversion for lowering dam
- Exact dimensions and elevations of structures
- Strength of dam concrete

Iron Gate

- Capacity, dimensions, and elevation of outlet tunnel
- Volume and type of material contained in dam structure
- Condition of roads to haul site
- Dimensions of concrete in structures to be removed
- Existence, size, location, and composition of upstream diversion dam for tunnel
- Mechanical nature, source location, and volume of material in dam
- Availability and operational condition of tunnel used for original diversion for lowering dam
- Dimension, construction type, and existence of upstream cofferdam used to divert river during construction of the dam

Findings and Conclusions

An investigation of removal of the four lower Klamath River Dams was conducted for American Rivers, Trout Unlimited, California Trout, Friends of the River, and the Klamath River Intertribal Fish and Water Commission. The study was based on public information available to American Rivers and limited information provided by PacifiCorp. Additional information is required to fully assess the approach for dam removal and removal of trapped sediment in the reservoirs.

Review of dam characteristics indicates that removing the dams is feasible and that the cost would be approximately $40 million based on assumptions stated in this report. Dams would be removed using a combination of well-established blasting, excavating, and hauling techniques. Removing the structures would require that river flow be diverted away from the work site. Approximately 1.5 million cubic yards of concrete, rock and earth would need to be removed from the dam sites and relocated to spoils sites.

Several approaches for river diversion are possible. More information is required to determine the optimum approach for river diversion. The approach can affect costs of dam removal. Using a low-level controlled outlet would allow the most flexibility and would presumably allow for the least cost for structure removal.

A low-level outlet is available at Iron Gate Dam. The sequence of dam removal presented would be to remove upstream dams before removing Iron Gate Dam and allow all trapped sediment to be eroded into Iron Gate reservoir. Using the low-level outlet at Iron Gate would allow some control over the rate and timing of downstream releases of sediment trapped in the reservoir. Approximately 14.4 million cubic yards of sediment are trapped in the reservoirs of the four dams. Of this, approximately 87% is fine sediment, which is highly erodible.

To restore the river to approximately predam conditions the sediment would need to be moved from its present location in the inundated river. Several methods are possible to remove or relocate the sediment. Potentially, the least expensive option would be to allow the river to simply erode the sediment downstream. The river flow appears to be sufficient to quickly erode the trapped material and move it to the mouth of the river. Additional sediment characteristic, water user information, structure location, and fish usage information will be needed before a full evaluation of the potential for and associated cost of allowing the river to erode the sediment can be made.

Recommendations for Further Study

As stated above, more detailed information will be required to completely assess the feasibility and cost of the proposed dam removal methods discussed. Further studies should include the following:

1. A study of all water use downstream of the dam will be required to determine dam removal impacts to water users, regardless of the methods used to remove the sediment. Using erosive stream power to move sediment downstream may be the least expensive approach if concerns to water users can be adequately addressed. Information regarding downstream water use was not available for this report.

   As part of the study of water use, developing mitigation measures for impacts to water users may be necessary.

2. A thorough investigation of existing information regarding trapped sediment should be conducted. It is possible that some information on the chemical and grain size characteristics, beyond sources cited in this report, is available. If no additional information is available, some means will need to be developed to bracket the potential affects of river erosion will need to be developed.

   This could include estimating the potential range of grain sizes and chemical characteristics based on similar projects or in situ sediment sampling and analysis.

3. A study of potential flooding risks will need to be conducted downstream of Iron Gate Dam. This study should be in conjunction with and subsequent to developing information about trapped sediment. For this study to be meaningful, a review of all structures that may potentially be affected by higher water elevations related to dam removal must be conducted.

   Water level changes might be expected regardless of the removal approach for sediment used. Removing the dams will allow future sediment moved into the river to travel past the sites. This sediment, which is currently trapped in the dam reservoirs, will have some impact on riverbed elevations.

4. More detailed information regarding structures on the river should be conducted to develop more accurate cost estimates for structure removal.

5. A review of potential spoils sites location should be conducted to determine costs for land acquisition, road improvements, environmental impacts to the sites, and costs for transportation of material to the sites.