ERDC/GSL TR-19-21

Geotechnical and Structures Laboratory

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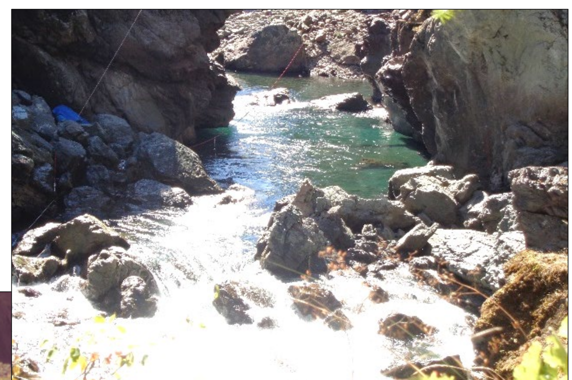
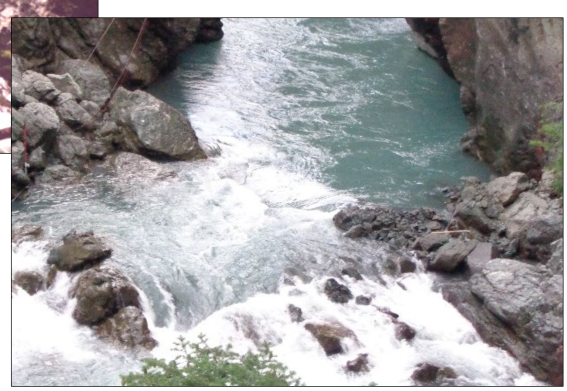
May 2019





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Final report

Prepared for National Park Service
Olympic National Park
Port Angeles, WA 98362

Under Project Number 460474

Abstract

The Elwha River is a unique river system located on Washington's Olympic Peninsula and was dammed in the early 20th century for hydroelectric power. Approximately one century later, these dams, the Elwha Dam and Glines Canyon Dam, were removed to restore the river's natural ecosystem. In 2015, the National Park Service (NPS) engaged with the U.S. Army Engineer Research and Development Center (ERDC) to provide subject matter expert support to the final stages of the restoration project.

In September 2016, ERDC conducted a project for removal of hazardous rebar that was remaining in the river bed at the Elwha Dam site. The rebar was protruding from the dam foundation and created a safety hazard for the public. The project also included explosive demolition of numerous large boulders in the vicinity of the former dam sites that created flow constrictions with large velocity gradients and hydraulic jumps. The demolition objective was to improve passage conditions for the numerous species of trout and salmon that migrate up the Elwha River. This report documents the rebar removal and boulder demolition and provides recommendations for techniques to remove the remaining Elwha Dam foundation in the future if desired by NPS.

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Preface

This project was conducted for the Department of the Interior, National Park Service (NPS) under Project Number 460474 at Olympic National Park (ONP), WA. The NPS Technical Monitor was Mr. Andrew Ritchie. Project coordination was performed with Mr. Brian Winter (NPS-ONP) and Mr. Mark Baker, NPS Project Service Center in Denver, CO.

The work was performed by the Survivability Engineering Branch (SvEB) and the Structural Engineering Branch (StEB), Geosciences and Structures Division (GSD), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Mr. Omar G. Flores was Chief, SvEB; Dr. Jay Shannon was Acting Chief, StEB; Mr. James L. Davis was Chief, GSD; and Ms. Pamela G. Kinnebrew was Technical Director for Survivability and Protective Structures. The Deputy Director of ERDC-GSL was Mr. Charles W. Ertle, and the Director was Mr. Bartley P. Durst.

COL Ivan P. Beckman was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms

1 Introduction

1.1 Background

The Elwha River is located in northwest Washington and flows 45 miles from the Olympic Mountains in Olympic National Park to the Strait of Juan de Fuca and the Pacific Ocean. The Elwha and Glines Canyon dams were constructed on the Elwha River for hydroelectric power generation in 1911 and 1926, respectively. The Elwha Dam (ELD) was 108 ft tall and formed Lake Aldwell approximately 5 miles upstream from the river mouth. The Glines Canyon Dam (GLI) was constructed further upstream in a large canyon and was 210 ft tall; the lake impounded at Glines was known as Lake Mills. With its connection to the ocean, the Elwha River is a unique ecological resource and a major fishery for 11 species of salmon and trout. However, construction of the Elwha and Glines Canyon Dams significantly disrupted the river's ecology by blocking fish passage and sediment flow (National Park Service 2016).

In 1992, the U.S. Congress passed the Elwha River Ecosystem and Fisheries Restoration Act, which authorized removal of both dams in order to restore the Elwha to its natural conditions. In 2012, the ELD removal project was completed, which was followed by completion of the GLI removal project in 2014. The dam removal and ecosystem restoration is led by the Department of Interior's National Park Service Olympic National Park (NPS-ONP) along with major partners such as the Lower Elwha Klallam Tribe, the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the Washington Department of Fish and Wildlife, and the Coastal Watershed Institute. Removal of the Elwha and Glines Canyon dams is the largest dam removal project in U.S. history (National Park Service 2016). Pre- and post-demolition pictures from both sites are shown in Figure 1 through Figure 4.

The demolition projects successfully removed the dam superstructures at both sites. However, the concrete foundation and a large concrete caisson at ELD were left, which was blocking river regrading and created hydraulic jumps detrimental to fish passage. Furthermore, it was discovered that a large quantity of rebar that was embedded in the ELD foundation had become exposed and created life safety hazards for the river's recreational users. In addition to the foundation, numerous large boulders at both locations were restricting river flow and creating large hydraulic gradients that impact fish passage. The boulders were likely the result of movement during large winter/spring flows as the river is regrading during the post-dam removal processes. During the 2015 low-flow period (August-September), the NPS utilized commercial blasters to remove a portion of the boulder restrictions at Glines. However, following the 2016 winter/spring high flows, it was observed that several restrictions remained at both sites.

1.2 Purpose and objectives

In the Spring of 2016, the NPS-ONP engaged the U.S. Army Engineer Research and Development Center (ERDC) to assist with removal of the exposed rebar at ELD, demolish select boulders that were creating fish passage restrictions, and provide subject matter expertise to the U.S. Army Corps of Engineers (USACE), Seattle District, on techniques for potential removal of the remaining ELD foundation and caisson. The purpose was for ERDC to provide government subject matter expertise and execution capabilities for explosive demolition to assist with the final restoration at both sites.

USACE support was divided into two phases. Phase 1 focused on ERDC removal of the ELD rebar and boulder demolition, and Phase 2 focused on potential Seattle District removal of the remaining ELD foundation and caisson (USACE-NPS Interagency Agreement 2016). A multistep approach was developed for ERDC's Phase 1 work, which included Task 1: Project Initiation and Management, Task 2: Site Survey and Technical Plan Development, and Task 3: Execution of Debris Removal. After successful debris removal, ERDC will provide subject matter expert support to NPS-ONP and the Seattle District as required for Phase 2 foundation demolition. Phase 2, if conducted, will be led by the Seattle District in 2017. The site survey required under Task 2 was conducted July 25-28, 2016. Results from the survey and the proposed technical plan were reported to NPS-ONP in August 2016 (ERDC 2016); the plan is included in Appendix A for reference.

Task 3 of ERDC's Phase 1 work was executed September 11-21, 2016. More than 100 pieces of metal/rebar were removed from the ELD site, and 17 large boulders were demolished. The remainder of this report documents the rebar removal, boulder demolition, and technical recommendations for demolition of the remaining ELD foundation and caisson.

Figure 1. Elwha Dam before dam removal.

Figure 2. Elwha Dam after dam removal.

Figure 3. Glines Canyon dam before dam removal.

Figure 4. Glines Canyon dam after dam removal.

2 River Flow Conditions

Flow conditions on the Elwha River vary significantly through the course of a year. Low flows occur during the August-September period when flow rates can be as low as 200 cfs to 300 cfs. The beginning of October typically marks the onset of winter storms, so flow rates begin to increase as the result of intermittent rain systems moving through the region. Peak flow rates on the river can be as high as 20,000 cfs to 30,000 cfs; at these conditions, the hydraulic forces are tremendous, and the river is able to move large objects (boulders, debris, etc.) in the river channel.

For both the rebar removal and the rock demolition, it was important to capitalize on river flow conditions that provided optimum accessibility. Accordingly, ERDC worked with NPS-ONP during July and August to monitor flow predictions and make the best selection for the project execution window. The objective was to wait as long as possible to allow flows to reach minimum condition while ensuring that sufficient time was available to execute work before the October storms. Through this coordination, the project execution window was determined to be September 11 through September 21. A hydrograph from the USGS monitoring station at the McDonald Bridge (downstream of the ELD site) is shown in Figure 5, where flow data are plotted for the period of May 1 through October 31, 2016. A second hydrograph from the same monitoring station showing flow data from September 10 through September 26 is shown in Figure 6. The lowest flows for the year were observed in the last third of September, with significant jumps beginning in the first week of October. These data indicate that the project was executed under the most favorable flow conditions for the 2016 calendar year.

Figure 5. Elwha River, McDonald Bridge hydrograph.

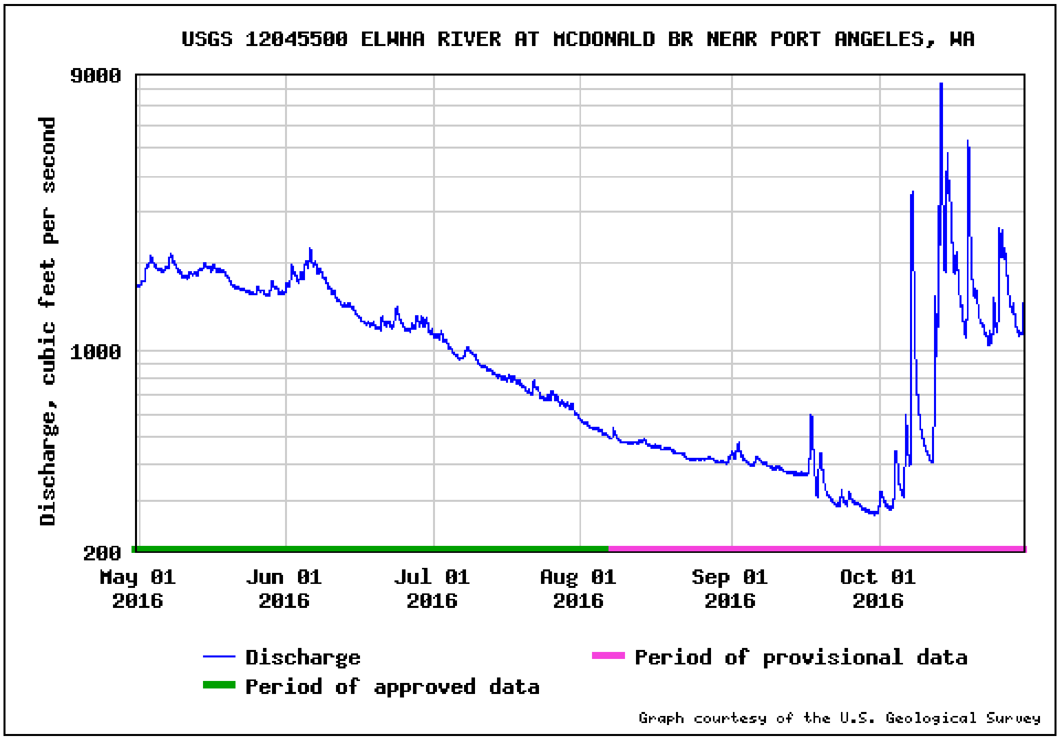
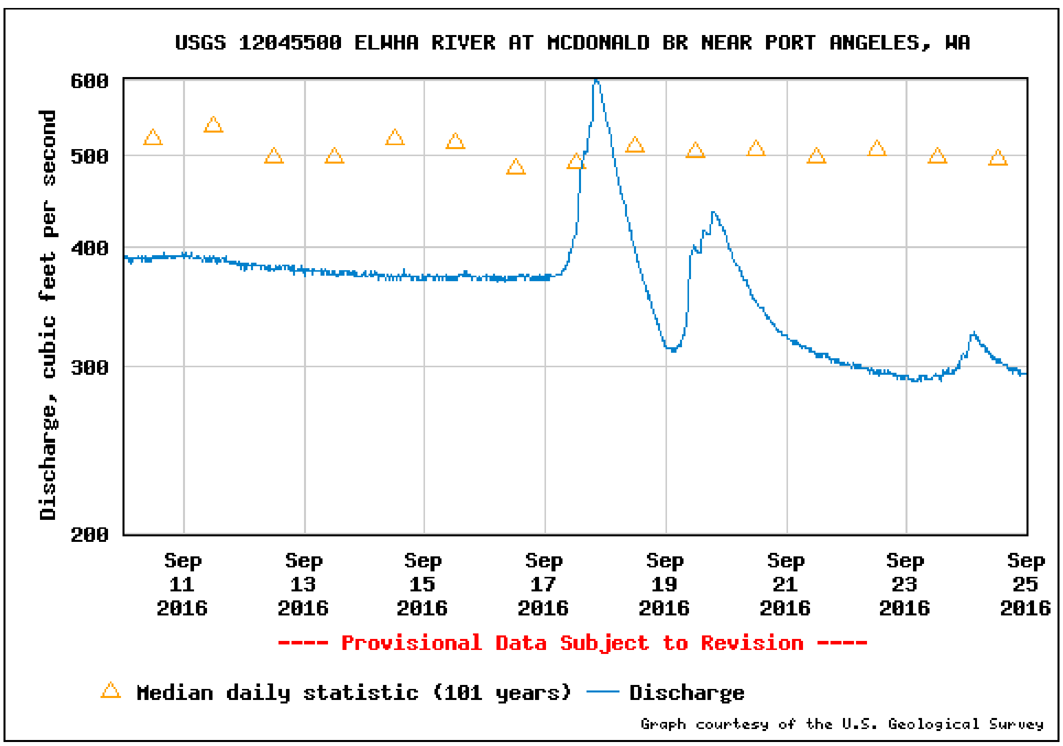


Figure 6. Flow conditions during execution window.



3 Elwha Dam Site

The Elwha Dam site is located in a small canyon just above a sharp bend in the Elwha River, approximately 5 miles upstream of the river mouth. The dam was designed as a concrete gravity dam that was wedged into the canyon walls (Louter 1995; Reineking 1914). Limited engineering details are available on the dam design, although it is well documented that significant problems occurred with construction, failure, and repair of the dam foundation (Louter 1995; Reineking 1914). The foundation problems largely stemmed from lack of bedding into the river bedrock; as a consequence, the dam failed by seepage and blowout of the base (Louter 1995; Reineking 1914). Repair of the blowout was performed by constructing a sheet piling system coupled with a reported 50-ft by 20-ft concrete-filled caisson downstream of the dam (Louter 1995; Reineking 1914). This system was designed to reduce seepage through the gravel layer underlying the dam and to provide a retaining block (the caisson) for rock fill that would be used to plug the base failure (Louter 1995; Reineking 1914). The rock fill was obtained by detonating approximately 45,000 lb of black powder and gelatin explosive upstream of the dam, which deposited a gradation of rock and earth into the river channel (Reineking 1914). The river washed the fill into the blown-out void beneath the dam, which largely sealed the breach (Reineking 1914). Plans from Reineking (1914) of the dam repair are shown in Figure 7 and Figure 8.

After the 2012 demolition, remnants of the dam that remained in the channel included a part of the foundation and the 20-ft by 50-ft concrete-filled caisson. It is assumed that some or all of the sheet piling curtain walls (reference Figure 8) are still in place, although this was not confirmed by ERDC. From a historical article (Anonymous 1912), it was reported that the dam base was approximately 100 ft thick by 40 ft wide. This is consistent with dimensions measured by ERDC while on site. A panoramic view of the dam site area in 2015 is shown in Figure 9; the dam and caisson locations are noted in the picture. A picture looking upstream from the dam site is shown in Figure 10, and a downstream picture is shown in Figure 11.

From NPS-ONP, the naturally occurring rock at the ELD site is weakly cemented sandstone-pebble conglomerate of the Hoko River Formation. This material was expected to be drilled and blasted with relative ease.

Figure 7. Elwha Dam repair, plan view (Reineking 1914).

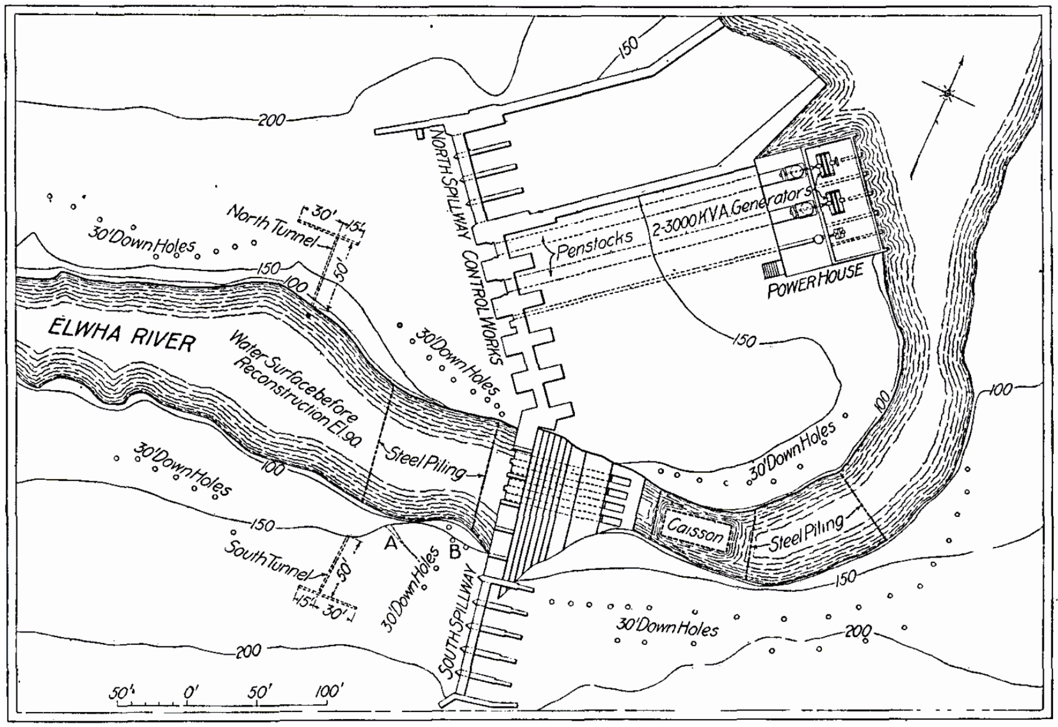


Figure 8. Elwha Dam repair, section view (Reineking 1914).

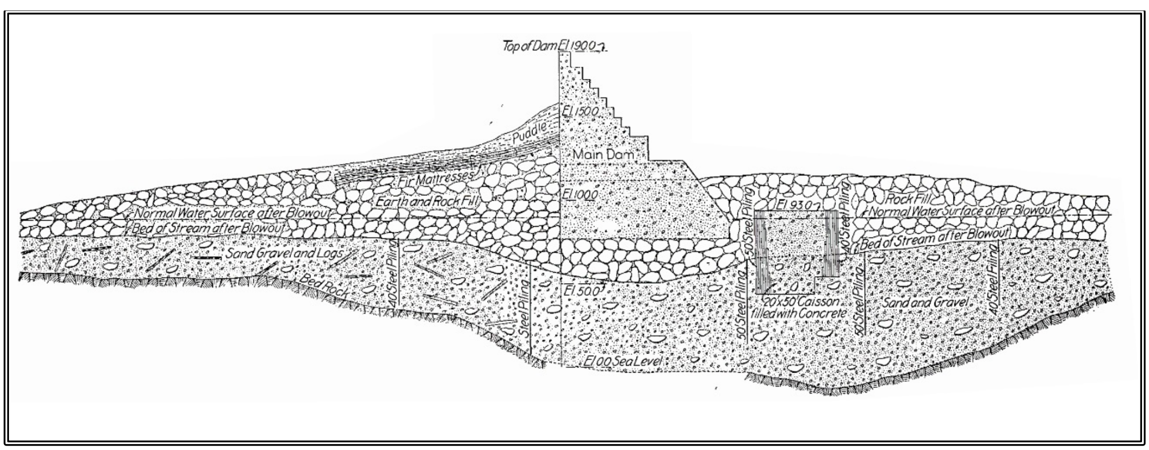


Figure 9. Elwha Dam site panoramic view, 2015 (photo courtesy A. Ritchie).

Figure 10. Upstream view at Elwha Dam site, September 2016.

Figure 11. Downstream view at Elwha Dam site, September 2016.

Access to the site for equipment and materials was established by constructing a cabling system from the south bank (river-right side) that ran from a tripod on the top bank down to an anchor approximately 6 ft above the water on the north bank (river-left side). The canyon walls were too steep on the south bank to traverse by foot, so personnel access was established on the north bank side. North bank access required crossing Washington Department of Natural Resources (DNR) land by means of an established foot trail. NPS-ONP obtained permission from DNR for access by light equipment, i.e., utility vehicles, for this project. A picture of the tripod and cabling system are shown in Figure 12 and Figure 13, respectively.

Figure 12. Tripod on ELD south bank.

Figure 13. ELD cable system for equipment access.

3.1 Rebar removal

Rebar and metal debris removal at the ELD site were focused on the remaining dam foundation area. To remove the debris, ERDC personnel considered several options following the completion of Task 2: Site Survey and Technical Plan Development. It was decided that using a cutting torch system, such as a Broco BR-22 underwater cutting torch, was the best approach and would require less logistical support than other removal options. The cutting torch uses an oxygen feed and electrical current to ignite exothermic cutting rods and produce temperatures in excess of 10,000°F at the tip to quickly cut or melt through almost any type of material (Broco-Rankin 2016). For underwater cutting support, ERDC contacted personnel in the USACE Vicksburg District, Operations Division, which manages a specialized group of trained divers that conduct underwater cutting activities. For this project, ERDC and the Vicksburg District dive team agreed to collaborate on Task 3: Execution of Debris Removal.

The Vicksburg District dive team performed all underwater cutting activities at ELD. Underwater cutting operations were conducted in accordance with standard USACE requirements and standard operating procedures of the Vicksburg District Operations Division dive team. ERDC personnel supervised the removal methods, assisted divers with positioning and staging all necessary dive equipment, and documented the results and locations of all metal debris as it was removed from the river.

Low-flow conditions allowed divers to safely wade across the majority of the foundation section without the use of Self Contained Underwater Breathing Apparatus (SCUBA) or Surface Supplied Air (SSA) equipment. Water depth in the foundation area varied from approximately 1 ft to 4 ft. The low-flow rates also significantly reduced the amount of whitewater compared to what was witnessed during the initial site survey in July 2016. As a result, water clarity in a large portion of the river was clear, and metal debris in the foundation could be easily identified from the surface. A picture of the divers wading near the river-left bank is shown in Figure 14.

Figure 14. Vicksburg District divers at river-left bank.

The dive team utilized a two-man search approach while operating in the river. Beginning at the north bank (river-left side), both divers traversed across the foundation section in an effective left-to-right scan pattern to ensure that all metal/rebar was identified and removed in the accessible areas. The primary diver served as the operator of the underwater cutting torch, while the secondary diver relayed instructions and communicated any issues to support personnel. A picture of two dive team members working in the Elwha River is shown in Figure 15. When a piece of metal debris was located, proper grounding was established by attaching a ground clamp to the metal object. The secondary diver notified support personnel to engage a single throw 400-amp knife switch and allow current to flow from the DC welding power source to the cutting torch. Constant oxygen flow was provided and monitored by support personnel using a Broco oxygen regulator. Video of the debris removal was recorded using an underwater camera and captured the cutting methods to ensure complete removal. Figure 16 is a screen capture taken from an underwater video recording. Once a piece of metal debris was cut, the secondary diver notified support personnel to disengage the knife switch and then hand-carried the metal debris to the north bank for documentation and removal. ERDC personnel collected photos of the debris and recorded its location, type, and dimensions.

Figure 15. Dive team members removing hazardous debris.

Figure 16. Underwater metal cutting.

Approximately 80-90 percent of the river channel was safely accessible for the underwater cutting operations. However, flow conditions and a trench that was discovered by the divers created an area near mid-channel that could not be safely accessed. Just upstream of the dam site, several boulders created a restriction that funneled the majority of flow towards the middle of the channel. This created a whitewater jet with significantly higher water velocity, as shown in Figure 17 through Figure 19. Divers were able to work to the left and right of the whitewater area, but velocity and loss of water clarity made cutting in the whitewater area impossible.

Further complicating the midchannel access was the divers discovering a trench in the concrete foundation that ran underneath the whitewater area. The trench appeared to be manmade and was formed into the concrete. It was approximately 2 ft to 3 ft wide and ran parallel with the riverbanks, i.e., it ran with the direction of water flow. The trench extended into the whitewater area in the upstream direction, so the divers could not see the upstream end of it. Towards the downstream edge of the foundation, the trench widened into a box-type depression that also appeared to be manmade. Rebars were protruding from the edges of the box and were cut by the divers. The divers also observed additional rebar in the box and below the top surface of the concrete foundation. That rebar could not be safely reached, but it was not considered a significant issue, since it was depressed below the foundation surface. A picture of the trench area is shown in Figure 20.

Figure 17. Whitewater area at ELD site.

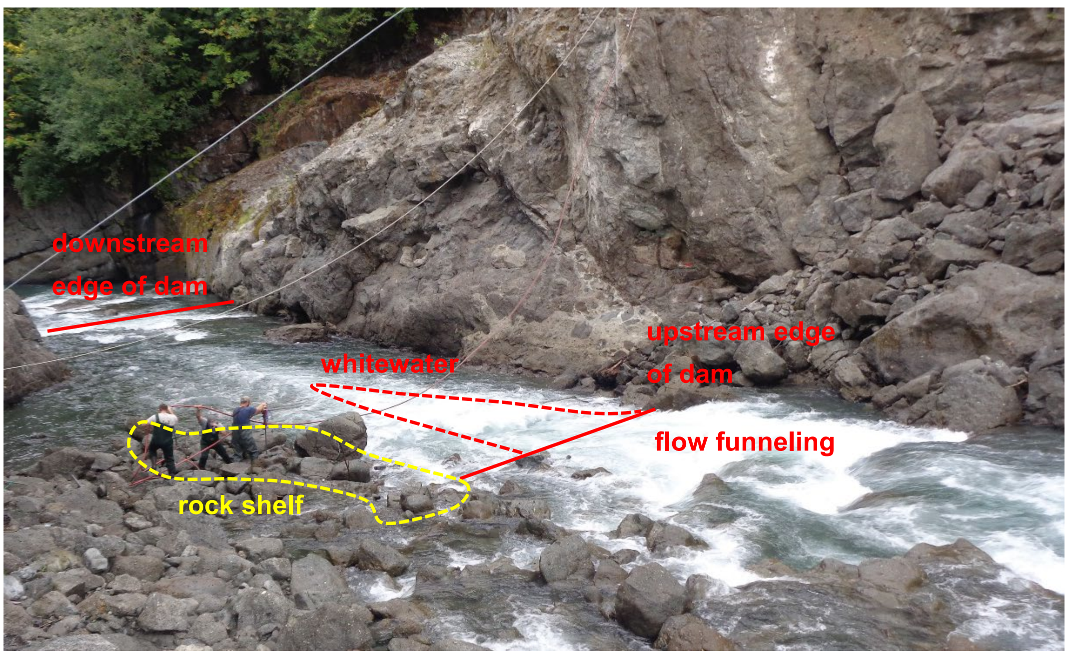
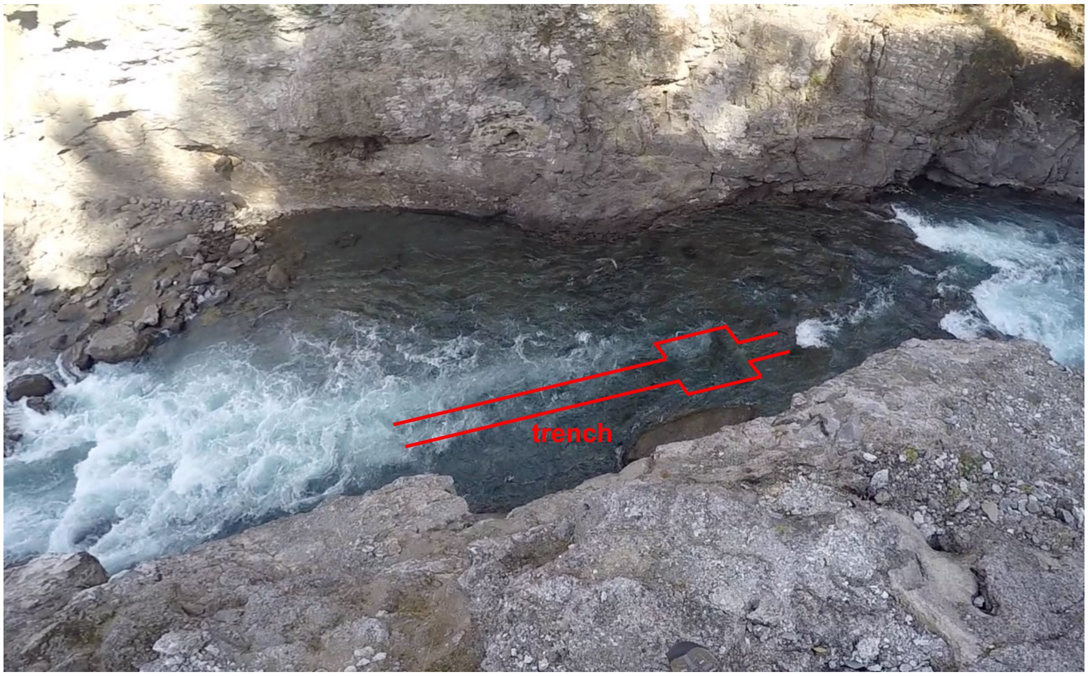


Figure 18. Whitewater area at ELD site, close-up view.

Figure 19. Flow funneling at upstream edge of dam.

Figure 20. Approximate location of trench in ELD foundation.



A total of 104 pieces of metal debris ranging from 6 in. to 161 in. in length were removed from the accessible areas. The metal debris consisted of twisted rebar, round stock, flat bar, square stock, and concrete anchors; typical debris is shown in Figure 21. A picture of all of the debris removed from the river is shown in Figure 22. The debris was collected in 9 main locations along the river channel with large concentrated areas of debris (5 or more pieces of debris) found in locations 2, 4, 5, 6, and 9 (see Figure 23). Figure 23 shows a panoramic view of the dam site with the inaccessible area shaded in red and the numbered areas where metal debris was identified and removed outlined in yellow. Table 1 lists all of the debris removed by type, length, diameter, and location.

Figure 21. Typical metal debris from ELD site.

Figure 22. Metal debris removed from ELD site.

Figure 23. Panoramic view of ELD site with hazardous debris locations.

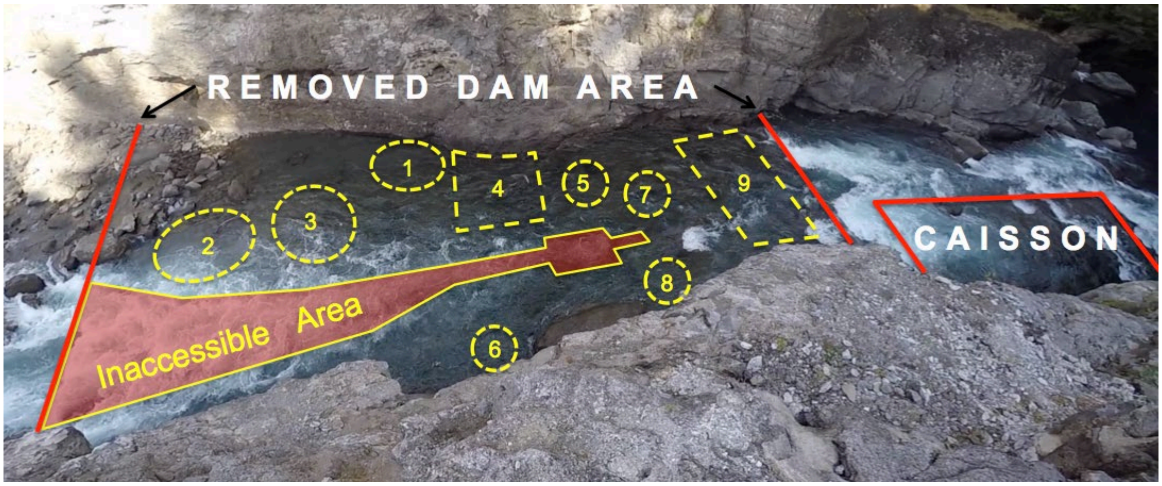


Table 1. List of all hazardous debris removed.

Debris Count	Approximate Location	Type of Object Removed	Length (in.)	Diameter (in.)
1	1	rebar	24	1
2	1	rebar	14	1
3	2	rebar	16	1
4	2	rebar	32	1
5	2	rebar	31	1
6	2	rebar	32	1
7	2	rebar	36	1
8	2	rebar	27	1
9	2	rebar	24	1
10	2	rebar	10	1
11	2	rebar	18	1
12	3	rebar	29	1
13	3	rebar	23	1
14	3	rebar	54	1
15	3	rebar	50	1
16	4	rebar	32	1
17	4	rebar	19	1
18	4	rebar	7	1
19	4	rebar	12	1
20	4	rebar	27	1
21	4	rebar	12	1
22	4	rebar	15	1
23	5	rebar	8	1
24	5	rebar	8	1
25	5	rebar	16	1
26	5	rebar	6	1
27	5	rebar	36	1

Debris Count	Approximate Location	Type of Object Removed	Length (in.)	Diameter (in.)
28	5	rebar	38	1
29	5	rebar	12	1
30	6	rebar	58	1
31	6	round stock	24	1.5
32	6	round stock	36	1.5
33	6	round stock	30	1.5
34	6	concrete anchor	13	0.5
35	6	round stock	34	1.5
36	7	rebar	36	1
37	7	rebar	45	1
38	8	rebar	129	1
39	9	rebar	156	1
40	9	round stock	21	1.5
41	9	rebar	72	1
42	9	rebar	58	1
43	9	rebar	12	1
44	9	rebar	48	1
45	9	concrete anchor	11	0.5
46	9	round stock	12	0.75
47	9	round stock	13	0.75
48	9	rebar	16	1
49	9	round stock	18	0.75
50	9	rebar	6	1
51	9	concrete anchor	10	0.5
52	9	flat bar	26	0.5
53	9	concrete anchor	8	0.5
54	9	round stock	42	1.75
55	9	rebar	80	1
56	9	rebar	56	1
57	9	rebar	72	1
58	9	rebar	41	1
59	9	round stock	9	1.5
60	9	rebar	54	1
61	9	round stock	45	1.5
62	9	concrete anchor	15	0.5
63	9	rebar	9	1
64	9	concrete anchor	7	0.5
65	9	rebar	15	1
66	9	round stock	27	1.5
67	9	turnbuckle + round stock	32	1.5
68	9	rebar	48	1
69	9	rebar	10	1

Debris Count	Approximate Location	Type of Object Removed	Length (in.)	Diameter (in.)
70	9	rebar	24	1
71	9	round stock	13	0.5
72	9	round stock	15	0.5
73	9	concrete anchor	10	0.5
74	9	concrete anchor	11	0.5
75	9	round stock	6	1.5
76	9	round stock	14	1.5
77	9	rebar	18	1
78	9	rebar	27	1
79	9	rebar	35	1
80	9	round stock	18	0.5
81	9	rebar	42	1
82	9	rebar	11	1
83	9	concrete anchor	10	0.5
84	9	rebar	12	1
85	9	rebar	13	1
86	9	rebar	6	1
87	9	round stock	36	1.5
88	9	square stock	15	1
89	9	round stock	10	1.5
90	9	round stock	21	1.5
91	9	concrete anchor	15	0.5
92	9	round stock	26	0.5
93	9	round stock	12	1.5
94	9	round stock	52	1.5
95	9	round stock	24	1.5
96	9	round stock	42	1.5
97	9	rebar	20	1
98	9	rebar	38	1
99	9	rebar	161	1
100	9	rebar	36	1
101	9	rebar	35	1
102	9	rebar	34	1
103	9	rebar	32	1
104	9	rebar	24	1

3.2 Boulder demolition

Boulder demolition at the ELD site focused on two areas. One was a group of boulders located upstream of the remaining foundation and the other was two large boulders located downstream of the caisson. The upstream boulders were located along a shelf that extended into the river from the river-left bank (see Figure 17). The shelf caused flows to concentrate towards the right half of the channel and form a jetting area and a large hydraulic jump. As discussed in Section 3.1, this area could not be accessed by the dive team for rebar removal. Therefore, the expectation for demolition along this shelf was to reduce the flow restriction and increase boater access towards the river-left bank, which was more accessible for rebar clearing. The two large boulders downstream of the caisson were positioned side by side and constricted approximately half of the river's flow path. This created a hydraulic jump in the vicinity of the boulders and also created a location to catch smaller boulders from upstream. According to NPS-ONP, removal of these two boulders would reduce the velocity gradient and the potential for more significant blockage in the future as rocks wash downstream through the dam site.

All demolition was conducted using a drilling-and-blasting approach. Explosive charges were 1.5-in.-diam by 16 in. long Dynomax Pro dynamite (1.5-lb net explosive weight); each dynamite stick was initiated with a Dyno Noble Primaline SMS detonator. Multiple charges were simultaneously detonated in a single blast by bringing the Primaline leads together to a single point and initiating with an FS-17/RP-83/non-el firing system configuration. The dynamite was placed into the rock by drilling 1.75-in.-diam holes with an AIRREX Panther S55-B rock drill. This is a pneumatic drill that can be fit with different length shafts and different size bits for drilling. A 1.75-in.-diam button bit was used in this project. Charge depths (measured to bottom of the hole) varied from 2 ft to 4 ft depending on specific rock geometry. Charges were placed on a 2-ft to 4-ft spacing according to geometry and accessibility, which resulted in powder factors between 0.25 lb/cy and 0.4 lb/cy. All charges were placed in the bottom of the drilled holes and were stemmed with small gravel from the river bed. Where 4-ft-deep holes were drilled, two charges were typically stacked in the hole to achieve the desired powder factor. Pictures of the drill and a typical drilled hole pattern are shown in Figure 24 and Figure 25, respectively.

Figure 24. AIRREX Panther rock drill with 4-ft shaft.

Figure 25. Typical drilled hole pattern (prior to charge placement).

Eight large boulders were demolished at the upstream shelf in two detonations on the afternoon of September 16. The total charge weight for the first shot was 3 lb; the second shot was also 3 lb. Flow rate at the time of demolition was 375 cfs. The charges were successfully detonated and fractured all of the target boulders to the water line. A picture of the rock shelf prior to demolition at a river flow rate of 360 cfs is shown in Figure 26. A picture of the rock shelf after demolition at a flow rate of 375 cfs is shown in Figure 27. It is expected that the high winter and spring flows will clear the demolition debris, which was characterized by 2-ft to 3-ft sized rubble.

Figure 26. Rock shelf upstream of ELD site, pre-demolition.

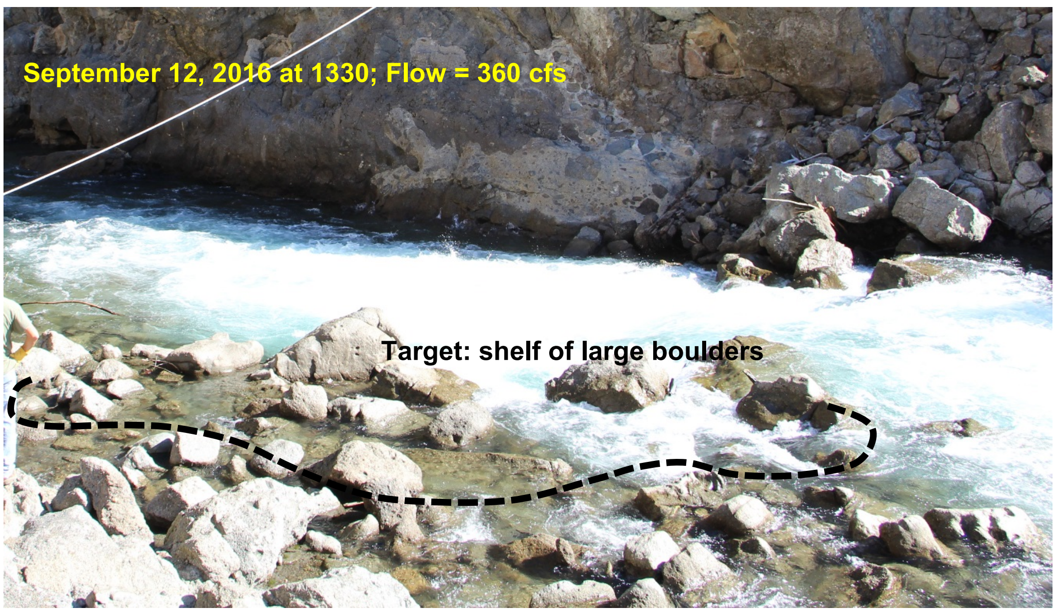


Figure 27. Rock shelf upstream of ELD site, post-demolition.

The two large boulders downstream of the caisson were demolished in a single detonation on September 18. The total charge weight was 18 lb. Flow rate at the time of detonation was 350 cfs. The charges were successfully detonated and fractured both of the target boulders to the water line. A picture of the boulders prior to demolition at a river flow rate of 650 cfs is shown in Figure 28. A picture of the boulders after demolition at a river flow rate of 320 cfs is shown in Figure 29. A close-up view of the boulders from river-right bank after demolition is shown in Figure 30. As seen, the boulders were generally reduced to 2-ft to 4-ft rubble, which is expected to be moved downstream during winter and spring flows. The detonation process recorded on high-speed video is shown in Figure 31.

Figure 28. Boulders downstream of ELD caisson, pre-demolition.

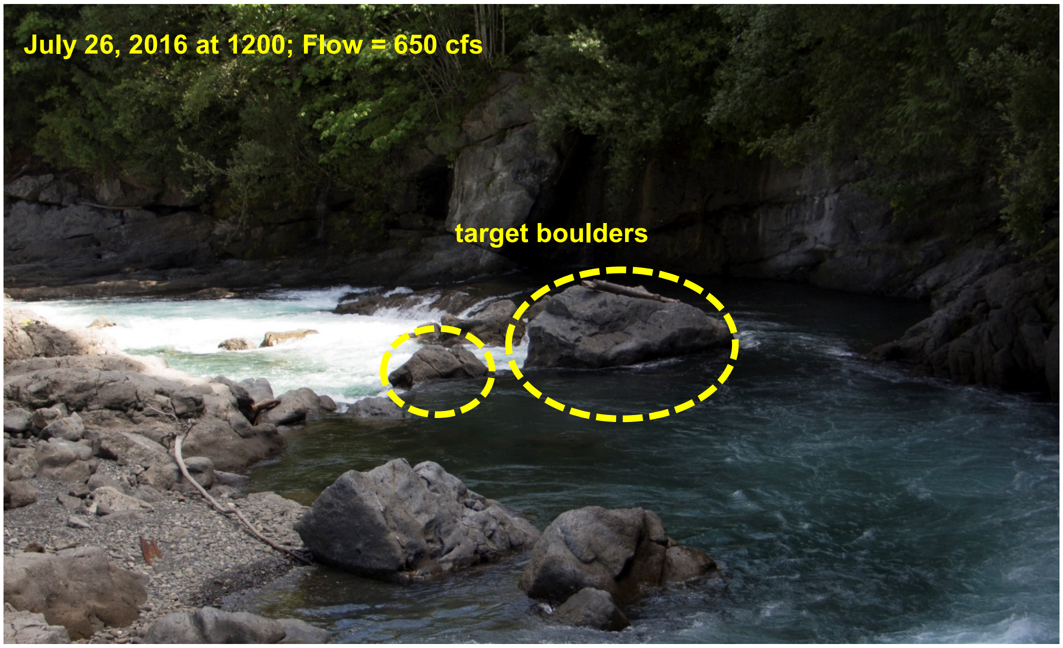


Figure 29. Boulders downstream of ELD caisson, post-demolition.

Figure 30. Post-demolition conditions at boulders downstream of ELD caisson.

Figure 31. ELD boulder demolition from high-speed video.

Blast effects from the detonations were documented using a Miniseis seismograph, which is equipped with a microphone for measuring acoustic overpressure and a triaxial geophone for measuring ground vibration. The Miniseis units are stand-alone devices that are deployed in a monitoring mode and record events based on user-defined acoustic or ground vibration triggers. A picture of a typical Miniseis unit is shown in Figure 32. Blast effects for all shots at ELD were monitored with a single unit (SN 2885) placed at the gated entrance near Highway 12. At this location, the unit was approximately 1,500 ft from the blast sites. For acoustic effects, the unit was configured with a 128-dB trigger and 160-dB maximum range. For ground vibration, the unit was configured with a 0.03 in./sec trigger and 2.5 in./sec maximum range. The unit did not trigger in any of the blast events, indicating that the acoustic effects did not exceed 128 dB (0.007 psi) nor did the ground vibration exceed 0.03 in./sec. These limits are both well below thresholds for any type of damage to buildings or structures (ERDC 2016).

Figure 32. Typical Miniseis unit deployed for blast monitoring.

4 Glines Canyon Site

The Glines Canyon Dam is located upstream of the Elwha Dam in a deep, narrow canyon where access is limited to a river approach from upstream or downstream of the work area. The dam was designed as a concrete arch dam and was constructed without the major problems that were encountered with the Elwha Dam (Louter 1995). At GLI, one of the key issues that accompanied dam demolition was the presence of logjams and large boulder obstructions downstream of the site. These obstructions created potential obstacles to sediment transport and river regrading after dam removal.* A view of the river downstream of the dam prior to dam removal is shown in Figure 33; a large boulder obstruction in the middle of the channel is seen in the picture foreground. These downriver obstructions were addressed during demolition and with follow-on blasting by a commercial company in 2015. Pictures before and after the 2015 blasting are shown in Figure 34 and Figure 35, respectively.

Figure 33. Obstruction downstream of GLI prior to dam demolition (courtesy of A. Ritchie).

* Ritchie, A. 2012. Memo on Wood and boulders below Glines Canyon Dam – current and historic conditions and Sediment Team recommendations for optimal sediment management. August 3, 2012.

Figure 34. Channel downstream of GLI prior to 2015 blasting (courtesy of A. Ritchie).

Figure 35. Channel downstream of GLI after 2015 blasting (courtesy of A. Ritchie).

Although a large portion of the channel obstructions were addressed during construction and the follow-on blasting, several large boulders remained that created potential hindrance to fish passage. Channel conditions in July 2016 are shown in Figure 36. Boulders at the river-left bank that are seen in the 2015 photo (Figure 35) are circled in yellow.

Figure 36. Channel downstream of GLI in July 2016.

To address the river constriction and hydraulic jumps caused by the remaining boulders, NPS-ONP requested that several large boulders at river-left and -right banks be demolished as part of this project. Rock formation at the Glines Canyon site differed from the Elwha geology. At GLI, the rock was reported to be Crescent Basalt that is heavily folded and faulted. The Crescent formation was reported to be weak, but during drilling operations, it was observed to be stronger than the rock at ELD.

Demolition at the GLI site focused on seven boulders located near the July 2015 blasting area. Six of the boulders were located at the river-left bank, and one was located at river-right. These boulders obstructed approximately half of the channel flow path, which resulted in a large hydraulic jump near the middle of the channel. Consequently, the demolition objective was to widen the flow path and lower the velocity gradient to improve fish passage conditions.

All demolition was conducted using the same drilling and blasting approach that was used at ELD. Charge spacing was 2 ft to 4 ft on center depending on the boulder geometry and accessibility; powder factors were similar to that used at ELD. The six boulders located at the river-left bank were demolished in three detonations. The first and second detonations were conducted on September 15 with total charge weights of 21 lb and 24 lb, respectively. Flow rate at the time of demolition was 375 cfs. A picture of the boulders prior to demolition is shown in Figure 37; a close-up view of the left bank boulders is shown in Figure 38. The charges were successfully detonated, and it was found that the explosive loading was effective at rubblizing the basalt rock. The material was heavily fractured down to the water line; most of the rubble was less than 2 ft in size. It is expected that high winter and spring flows will clear the demolition debris from the area. A picture of the left bank area after the first two detonations is shown Figure 39. The third and final detonation at GLI was conducted on September 19 to complete demolition of the left bank boulders and to fracture the single right bank boulder. The total charge weight was 18 lb. The charges were successfully detonated and the resulting rock fracture was similar to results achieved in the first two shots. The final channel conditions at the GLI site are shown in Figure 40 and Figure 41. Compared to the July 2016 conditions in Figure 36, the channel restrictions were significantly diminished. A flow path with much lower velocity gradient was created near the river-left bank, which is expected to improve fish passage through the area. Rubble from the demolition will be mobile during high flows so it is expected that further channel clearing will occur during the 2016/2017 winter and spring seasons. The detonation process recorded on high-speed video is shown in Figure 42.

Figure 37. Boulders at GLI prior to demolition.

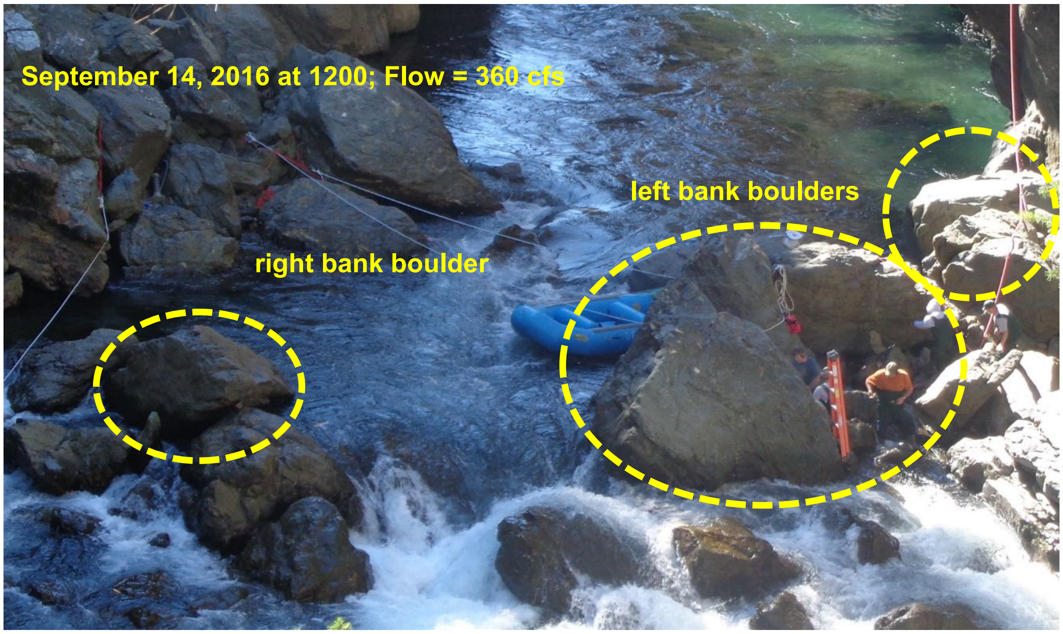


Figure 38. GLI left bank boulders prior to demolition.

Figure 39. GLI left bank boulders after first two detonations.

Figure 40. GLI after completion of demolition.

September 19, 2016 at 1800;

Figure 41. Improved fish passage conditions at GLI following demolition.

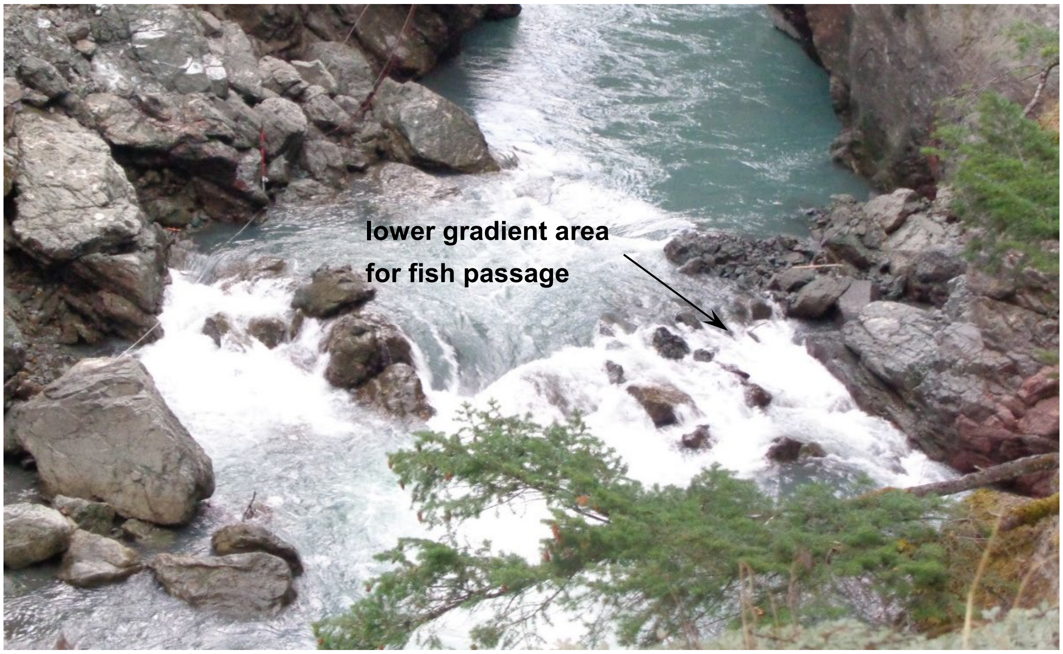


Figure 42. GLI boulder demolition from high-speed video.

Similar to ELD, blast effects from the detonations were documented using Miniseis seismographs. Three Miniseis units were deployed during the first two shots on September 15; locations and settings are summarized in Table 2. None of the units triggered to the detonation events, indicating that acoustic and ground vibration effects did not exceed the trigger thresholds shown in Table 2. For the September 19 detonation, only unit 1487 was deployed at the ranger station. As with the September 15 detonations, the unit did not trigger due to the rock demolition, indicating that the acoustic and ground vibration limits did not exceed the conservative triggering thresholds. According to these data, demolition blast effects at all monitoring locations were well below published thresholds for damage to any building or structure.

Table 2. Miniseis locations and settings for GLI demolition.

SN	Location	Range from Blast Site, ft	Acoustic Trigger, dB	Max Acoustic Range, dB	Ground Vibration Trigger, ips	Max Ground Vibration Range, ips
2885	Top of boat ramp road	1750	128	160	0.03	2.5
1487	Ranger station	5280	112	148	0.02	2.5
1486	Entrance gate	12,670	106	142	0.02	2.5
ips = inches per second						

5 Recommendations for ELD Foundation Removal

The two main factors influencing successful removal of the remaining dam foundation are (1) the ability to accomplish work within the short window of opportunity that typically presents itself under low-flow conditions, and (2) the volume of material to be removed. Flow conditions vary significantly from year to year, but generally, the ideal timeframe is about 6 weeks that occurs between the middle of August and the first of October. The remaining dam foundation at the ELD site is believed to be approximately 15 ft thick. With approximate planimetric dimensions of 100 ft long by 40 ft wide, the approximate yield of concrete to be removed is 2,200 cubic yards. Using a bulking factor of 1.4 for the rubblized material, this yields approximately 3,300 cubic yards of dam foundation material to be hauled from the site. If the caisson is also demolished, an additional 1,500 cubic yards of material would need to be removed. Based on rebar and other steel removed from the surface of the dam foundation, the remaining steel in the foundation appears to be scattered with little uniformity in positioning; in most cases, it does not appear tightly matted. There does not appear to be any steel in the caisson (Reineking 1914) but rather loosely placed concrete similar to that found in the dam foundation with an expected unconfined compressive strength less than 3,000 psi.

The volume of material to be removed from the river channel dictates the use of heavy equipment. Heavy equipment such as a large tracked excavator fitted with a hydraulic hammer and an additional excavator fitted with a large bucket and hydraulic “thumb” attachment should be sufficient to break up and move the concrete. Typical equipment and attachments are shown in Figure 43 and Figure 44, respectively.

Figure 43. Typical large excavator.

Figure 44. Thumb and hammer attachments.

These large excavators can easily traverse the terrain in and around the river, and native materials (rocks, boulders, and other loose fill material) can be used to direct flow around the equipment and provide a stable working position. Typical horizontal reach for large excavators is 30 ft;

reach in the vertical direction is similar. With these reach capabilities, it is recommended that work commence on the downstream end of the dam foundation and work upriver. This will provide a stable position from which to work as the dam foundation is removed. Due to the large volume of material to be removed and in an effort to cut down on material to be transported away from the site, considerations should be made to relocate excavated rubble to an area near the river channel where the steel and concrete can be separated. Using this approach, the steel can be hauled away, and the concrete remnants, if acceptable to NPS, can be left behind to be carried downstream. A large dozer, as shown in Figure 45, should be readily available to assist in movement of materials and equipment in and out of the river channel.

Figure 45. Typical large dozer.

The use of explosives is a viable approach to assist in breaking up the dam foundation and aiding in the decoupling of reinforcing steel from the concrete. However, the application and placement of explosives becomes increasingly more difficult as flow rates and water depths increase. The explosives would aid in breaking up the dam foundation but would not completely separate the steel and concrete. Past experience with similar concrete demolition work indicates that the result will be entangled rebar and concrete that has to be further demolished with the aid of torches and hydraulic impact hammers. Based on flow conditions, the window of opportunity for using heavy equipment is much larger than the window of opportunity to safely emplace explosives. Likewise, the heavy equipment to be used for excavating is less susceptible to varying water conditions than for drill rigs. A typical drill rig that could be used for this application is shown in Figure 46.

Figure 46. Drill rig for explosive placement.

Temporary weirs constructed of rocks, super sacks filled with materials, or some combination thereof would be necessary to aid in dewatering a portion of the dam foundation where explosives would be used. Since the likelihood of being able to place explosives in a previously blasted area would be small, the entire thickness (depth) of the dam foundation in a particular area would need to be blasted at one time. This area should remain within the reach of the excavators to be used for moving the blasted material. It should be expected that some portion of the temporary weirs would need to be repaired after a series of detonations. Explosive type, placement/spacing, drill-hole diameter, and drill depths can be provided by ERDC as needed. Considering the time efficiency of a blasting approach, it may be found that the benefit of pre-fracturing the foundation with explosives is offset by the excavator downtime while charges are being prepared and placed. In other words, the same amount of work might be accomplished, if the large excavators are able to continuously hammer and excavate without the interruption of explosive emplacement. If the caisson is to be demolished and does not contain any reinforcing steel, explosives can be strategically placed to reduce the caisson to rubble and allow the river to carry the remnants downstream. This action would require the use of a drill similar to that shown in Figure 46 since the thickness of the caisson is on the order of 30 ft (Reineking 1914). If the caisson is removed, it will need to be demolished first, since it is the furthest downstream.

In order to completely remove the dam foundation and caisson within the typical window of opportunity, work to improve the DNR access road will need to be completed by July. An access ramp with provisions for moving materials from the river basin to the top of the hill along with moving rocks and boulders around to gain access to the dam foundation would need to be completed by August. The time requirement for completely separating steel and concrete (5,000 psi) in a typical reinforced concrete structure with similar thickness and 2 percent steel (volumetric) is on the order of 5 cubic yards per hour. The steel percentage in the dam foundation appears to be much less than this, and the desired end state is to break up and remove the steel from the river. The final separation of steel and concrete can take place out of the river and continue later even if flow rates and water levels increase. Even though recommendations are to use mechanical means to break up the remaining foundation and caisson, the use of explosives should remain as a contingency and be available for use as needed.

6 Summary and Conclusions

The primary objectives of removing exposed rebar and demolition of select boulders that were creating fish passage restrictions were accomplished. In total, 104 pieces of metal debris were removed from the surface of the ELD dam foundation. The metal debris was primarily composed of rebar with additional pieces of round stock, concrete anchors, and a turnbuckle. Approximately 80 percent of the surface of the dam foundation was cleared. The other portion was inaccessible due to safety concerns associated with high flow rate conditions and lack of underwater visibility. All steel was transported to the top of the south bank using the cable and pulley system and then disposed offsite.

All boulders identified by the NPS-ONP were successfully demolished. Remaining rubble is expected to be cleared during high-flow rate events in the 2016/2017 high-flow season. An immediate reduction in hydraulic jumps at each of the targeted areas was observed. A portion of the rock shelf above the ELD site was demolished in order to reduce the hydraulic jump near midchannel above the dam foundation. It is anticipated that after several high flow events, the portion of the dam foundation that was inaccessible will become more accessible for future dive work if needed. The shelf demolition will also increase boater access towards the river-left bank, which was cleared of metal debris.

The third project objective was to identify techniques for removal of the remaining ELD foundation and caisson and provide guidance and subject matter expertise to the USACE Seattle District. Two key factors influence and aid in the decision process for removal of the remaining foundation and caisson. These are the volume of concrete to be removed from the river bed and the short time window to remove the material. Recommendations are to use mechanical means to break up and remove the foundation and caisson from the riverbed. The use of explosives to help break up the materials should remain as a contingency. It is anticipated that, with the use of large excavators and a dozer, the demolition of the foundation/caisson and removal of material from the riverbed can be completed within a 4-week timeframe. Additional time would be needed to completely break up materials and dispose of them offsite. If the caisson is void of reinforcing steel, the best option may be to rubblize using explosives and let the remnants be carried downstream.

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Appendix: Technical Plan for Debris Removal

TECHNICAL PLAN FOR DEBRIS REMOVAL

Elwha River Restoration Project
Olympic National Park, WA

U.S. Army Engineer Research and Development Center
Vicksburg, MS 39180
August 15, 2016

The U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), is providing support to the National Park Service (NPS) for removal of dam debris on the Elwha River as described in the scope of work[1] developed between GSL, NPS, and the USACE Seattle District. A multi-step approach was proposed for ERDC's removal activities, which includes Task 1: Project Initiation and Management, Task 2: Site Survey and Technical Plan Development, and Task 3: Execution of Debris Removal. After successful debris removal, ERDC will provide subject matter expert support to NPS and the Seattle District as required for foundation demolition at the Elwha Dam (ELD) site, which is anticipated for execution by Seattle District in FY17.

ERDC conducted the Task 2 site survey from July 26 to 28, 2016. Personnel from GSL and the USACE Vicksburg District met with Andy Ritchie, Elwha River Restoration Project Hydrologist, to identify approaches for access to the ELD site and to conduct an underwater survey of metal debris at ELD. During the survey, possible demolition of several boulders at the ELD and Glines Canyon (GLI) sites was also discussed to remove potential fish passage restrictions that are currently present; the most critical was identified at GLI. The scope of this work is focused on metal debris removal at ELD. However, after completion of the ELD metal debris removal if time and project funds allow then boulder demolition might be executed under Task 3 as an additional river restoration activity. It is not assured that this demolition will be performed; it is dependent on river conditions and any unforeseen complexities that might be encountered during the metal debris removal. However, demolition will be conducted if and to the extent possible with any remaining funds and time.

The metal debris survey at ELD was conducted on July 27. Flow rates reported by the U.S. Geological Survey (USGS) at the McDonald Bridge station for that day were 700-800 cfs. It is noted that the river flow conditions will be the single most important factor in execution of the metal debris removal; the flows must subside a sufficient amount to allow divers to safely work in the river reach. The approach for tracking and monitoring flow conditions is discussed in Section 2.1.

Findings from the site survey, recommended approaches for debris removal and boulder demolition, site access requirements, and estimated schedule for Task 3 execution are provided in the following sections.

1.0 SITE SURVEY RESULTS

1.1 METAL DEBRIS AT ELD SITE

The metal debris survey at the ELD site was conducted on July 27. The survey was conducted by tethering a raft in the river and using an underwater camera with feed to an above water monitor to identify debris locations. When a piece of debris was identified, underwater video was recorded and the coordinate position was recorded using a total station operated by Andy Ritchie.

Flow rates on the Elwha River at the time of survey were between 700 cfs and 800 cfs, as reported by the USGS. For comparison, low flow rates during the month of August in 2015 were in the range of 200-300 cfs. With the comparatively higher flow rates at the time of survey, water velocity and whitewater

[1] Statement of Work for USACE Technical Support to "Elwha River Restoration – Demolition and Removal of Elwha Dam Debris"

conditions on the right side of the channel significantly restricted visibility conditions. Therefore, the survey coverage was limited to approximately 30-40 percent of the channel at the river-left side. For the purpose of planning debris removal work in Task 3, conditions identified along river-left are assumed representative of the entire channel. Flow conditions in the river at the time of survey are shown in Figure 1. For comparison, flow conditions at 210 cfs on August 27, 2015 are shown in Figure 2.

Approximately 25 pieces of debris were identified during the underwater survey, which were located in 11 spots along the river channel. Several of the locations had groups of rebar protruding from the dam foundation, as indicated by the number of pieces identified versus the number of locations. The surveyed debris locations are shown in Figure 3; debris identified during a 2015 snorkel survey by NPS are circled in red and yellow in Figure 2. At most all of the locations, the debris consisted of single pieces of twisted rebar; the rebar was generally between 1-ft and 3-ft-long. From a piece collected at the river's edge, the rebar is approximately 1-in. in diameter. Pictures of the rebar taken by the underwater camera are given in Appendix 1 to this report.

Based on the number of debris pieces identified in the area of the channel that could be surveyed, it is estimated that 75 to 100 pieces may be present over the entire dam foundation.

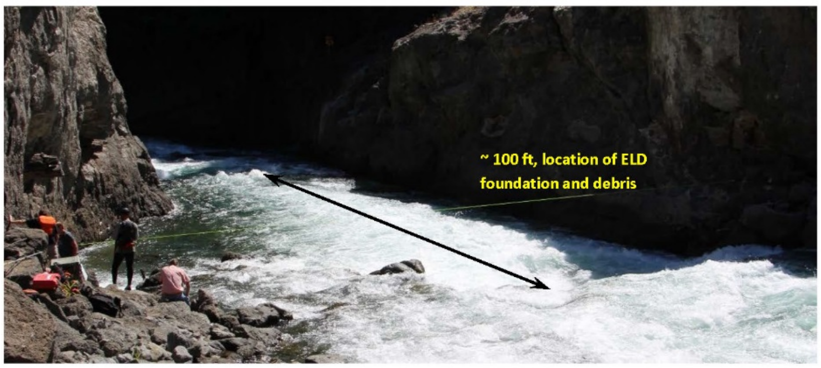

Figure 1. Flow conditions at ELD site during ERDC metal debris survey (July 2016).

Figure 2. Flow conditions at ELD site during NPS metal debris survey (August 2015)[2].

[2] Ritchie, Andy. Sept. 2, 2015. Memo on "Former Elwha Dam site visit and reach survey 8/27/2015 @~ 200 cfs."

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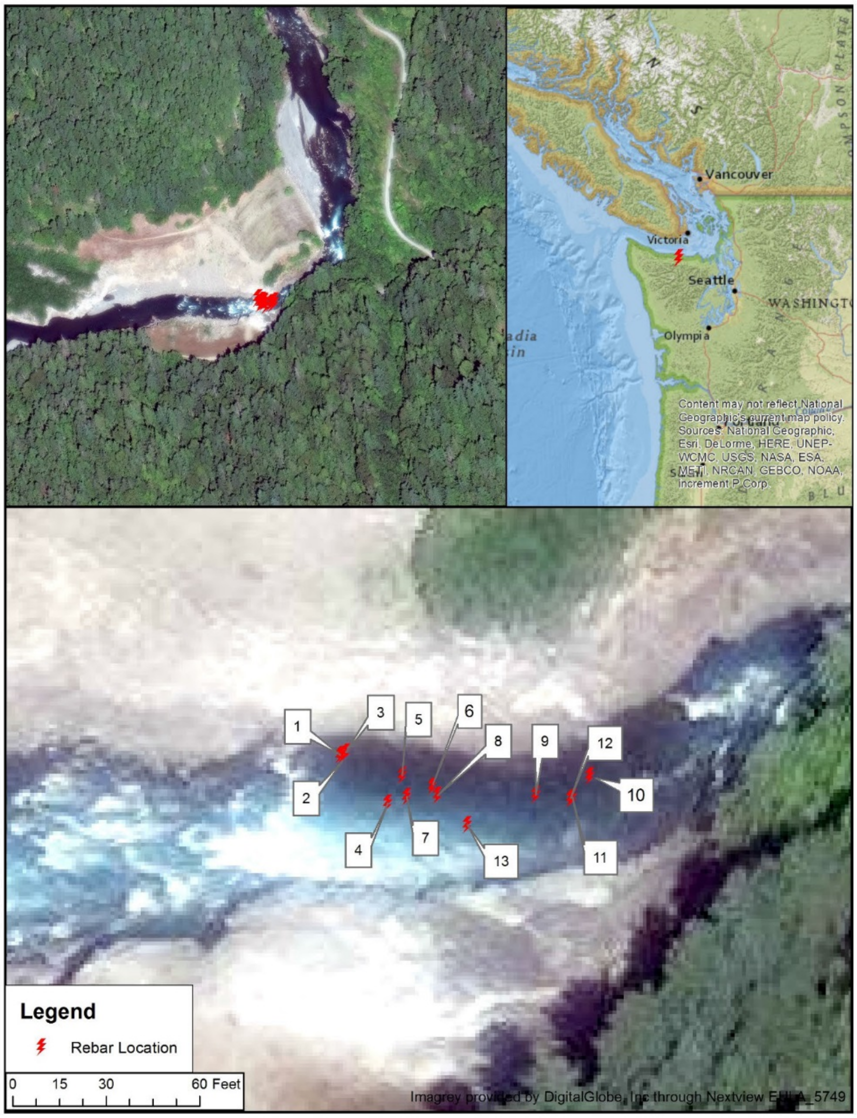

Figure 3. Surveyed metal debris locations at ELD site (survey limited to left portion of channel).

1.2 ELD and GLI BOULDERS

The boulders that are creating potential fish passage restrictions at Glines Canyon and Elwha Dam are shown in Figure 4 and Figure 5, respectively. Four boulders were identified at the GLI site. From visual observation, each of the GLI boulders are 8 ft to 10 ft in largest dimension. Three of the boulders – GLI-1, GLI-2 and GLI-3 – are located on the river-left bank and are constricting 30-50 percent of the channel width. The fourth boulder, GLI-4, is located closer to the river-right bank and is a part of several rocks that are restricting the right side of the flow path. All four of these rocks are positioned in close proximity to each other, so that the channel width is restricted by over 50 percent at flows present during the site visit. A large hydraulic jump is also present between the rock groups, which is expected to diminish with demolition of the four rocks.

A single boulder was identified as the ELD site for possible demolition to improve fish passage. This rock, labeled ELD-1 in Figure 5, is similar in size to the larger rocks at GLI. ELD-1 appears to be restricting approximately 25 percent of the flow path, so the conditions at this location are not as critical as at Glines Canyon. However, a hydraulic jump is located adjacent to the rock, so demolition is expected to create flow conditions that are more favorable for passage.

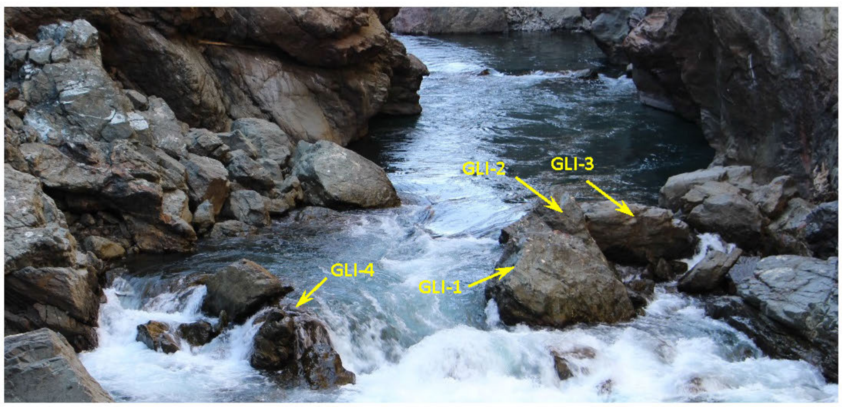

Figure 4. Boulders at Glines Canyon site.

Figure 5. Boulder at Elwha Dam site.

2.0 RECOMMENDED APPROACH FOR DEBRIS REMOVAL

2.1 HAZARDOUS METAL DEBRIS AT ELD SITE

Based on results of this survey and the nature of the metal debris, it is recommended that removal be performed with an exothermic cutting torch system such as the Broco BR-22 underwater cutting torch. This torch is specifically designed for underwater cutting, and uses an oxygen feed and electrical current to create an exothermic cutting tip that is maintained under the water. The size of rebar identified in the survey is within the cutting capacity of the torch system. Explosive methods were also considered and could be used for the debris removal; underwater linear cutting charges produced by Accurate Energetic Systems were identified as an explosive technology that could be used in this project. However, the cutting torch approach is expected to have lower logistical requirements compared to explosive methods, i.e., alleviate explosive transport, handling, placement, etc., so that the torch is recommended as the first choice approach.

For underwater cutting support, GSL contacted personnel in the USACE Vicksburg District (MVK), Operations Division; GSL and the Operations Division have worked together on previous projects and have prior experience with collaborative project execution. For this project, GSL will collaborate with an MVK dive team that regularly conducts underwater cutting activities. The dive team uses a Broco BR-22 underwater torch by liquid O2 and welding machine. This equipment is capable of cutting the embedded rebar flush with the surface of the embedment material. Prior to project execution, the MVK team will assess flow conditions for feasibility and prepare a dive plan, according to their standard operating procedures. This dive plan will include the Safe Practices Manual, equipment and diver certifications, diver training and physical information, dive plan, evacuation plans, and emergency care notification procedures. Activity Hazard Analysis, and all other pre-dive requirements and documentation required under ER 385-1-86 and EM 385-1-1, will be addressed.

From observations during the survey, the key issue for executing the debris cutting portion of the project will be flow conditions in the river. At the flow rate of 700-800 cfs, the water velocity was too high to conduct cutting activities in the majority of the channel. However, conversation with Andy Ritchie indicated that water velocities will drop off significantly as the flow rate falls during the August and September months. In the previous year the entire river channel could be snorkeled at a flow rate of around 200-300 cfs. Therefore, it will be important for GSL and the dive team to stay in communication with Andy Ritchie et al. to predict flow conditions and identify a time period(s) that will allow diver access to as much of the dam foundation as possible.

2.2 BOULDER DEMOLITION: ELD AND GLINES CANYON SITES

In addition to removal of the hazardous steel material that is exposed in the ELD foundation, NPS has identified several large boulders downstream of the ELD site and in Glines Canyon that are of concern. The boulders are restricting flow conditions, affecting fish passage, and impacting other natural sediment and regrading processes. Accordingly, the objective of demolition activities, if they are able to be conducted, is to reduce the overall size of the boulders so that the normal high flows of the river can move the remaining material downstream. The NPS considers rock sizes in the range of 8 cubic feet to be easily manageable by the river.

The most feasible method of removing the boulder flow restrictions is to reduce their size using explosives. Five large boulders have been identified for possible demolition, as shown in Figure 4 and Figure 5. All blasting will be limited to the locations of these boulders within the GLI and ELD site footprints; NPS has previously indicated that all required permits and right-of-way access to these sites are in place and will be verified by NPS prior to blasting in this project.

With respect to the blasting plan, a drill and blast method will be utilized to fracture the large boulders. Pneumatic rock drills will be used to drill 1.5-inch to 2-inch diameter holes into the rock. The holes will be filled with either a 1.5D booster sensitive water-gel type explosive or a 1.1D detonator sensitive gel explosive. The explosive material is expected to be either a nitroglycerin or ammonium nitrate based product, such as DYNOMAX PRO (nitroglycerin dynamite) or BLASTEX (ammonium nitrate based emulsion). Densities will be in the range of 1.2 g/cc to 1.7 g/cc with relative equivalency factors of between 0.9 and 1.3 (ANFO=1.0 at 0.82 g/cc). Detonation velocities are in the range of 14,000 to 20,000 ft/sec. The final determination of explosive type, amount, and drill patterns will vary for each blast in order to maximize effectiveness and minimize the chance of hole-to-hole propagation. Using practical assumptions for number of holes in a single shot, the anticipated maximum net explosive weight per detonation is 30 lb, which is based on a 12-hole pattern with 1.5-in.-diameter holes at 24-in. o.c.

The initiation system will vary depending on location, accessibility, and other factors specifically associated with blasting, such as explosive type and patterns for each shot. The two main options will be either an RP-83 exploding bridge wire detonator fired with a Reynolds FS-17 firing system or a non-electric shock-tube initiated system. A combination of the two systems might be used. Once explosives are placed, each hole will be stemmed with #89 crushed stone or a similar material to maximize performance and minimize flyrock. Each shot will be documented to capture before and after characteristics of the boulders, hole pattern layout, explosives, and explosive quantity used. High-speed video will be the primary means of documenting initiation and complete detonation.

In consideration of the relatively small maximum charge weight and remote nature of the blasting location, explosive effects on surrounding structures is not anticipated to be a significant issue. In terms of ground motion, charge coupling with the surrounding ground will be poor since the charges are placed directly in the boulders, which are not well coupled with the ground. Using vibration data from USBM RI 8507[3] and a peak particle velocity of 0.5 in./sec as a limit for threshold structural damage[3], the safe standoff distance for a 30-lb charge is estimated to be in the range of 175 ft to 275 ft. Using data from USBM RI 9226[4], a safe standoff for 0.5 in./sec vibration is estimated to be around 450 ft. Accordingly, using a safe standoff of 400 ft to 500 ft for ground vibration impact on surrounding structures is a conservative approach. Blast overpressure will be complex as a result of the reflections that will take place inside the canyon(s). As an estimate of the overpressure effects, Roth et al. measured long range blast pressures from a surface-laid ammonium nitrate-fuel oil emulsion line charge[5]. Using a threshold of 0.15 psi for glass breakage[6], the estimated safe standoff is around 500 ft. Considering the

[3] Siskind, Stagg, Kopp and Dowding. 1980. Structure response and damage produced by ground vibration from surface mine blasting, U.S. Bureau of Mines Report of Investigation 8507.
[4] Siskind, Crum, Otterness and Kopp. 1989. Comparative study of blasting vibrations from Indiana surface coal mines, U.S. Bureau of Mines Report of Investigation 9226.
[5] Roth, Ertle, Boone, Guynes, Jackson, Magee and Senior. 2016. Birds Point-New Madrid floodway alternate explosive breaching system, ERDC/GSL TR-16-3.
[6] Wheeler. 2011. Report on seismic and overpressure monitoring, Birds Point New Madrid Floodway project.

reflections that may occur and enhance the blast effects inside the canyon, this safe standoff might be increased to 1000 ft. A conservative safe standoff estimate from ETL 1110-1-142 for an embedded charge in rock is 500 ft[7]. Explosive effects will be documented using up to three remote sensing seismographs (White Seismology Miniseis units). The seismographs are equipped with triaxial velocity geophones and microphones to record ground vibration and blast overpressure, respectively.

Considering secondary debris hazards, the estimated safe standoff distance is 670 ft[8]. This is a conservative value based on open air detonation with straight-line distances from the detonation. Any attempt at shielding personnel from fragmentation reduces the safe standoff distance to only the hazards associated with overpressure exposure on personnel. Generally, anything less than 3.5 psi is considered safe. The safe standoff for reflected pressure of 3.5 psi generated from a 30-lb charge is 83 ft (generated with a conservative calculation using an explosive with a relative equivalency factor of 1.4). For flyrock consideration, using reasonable estimates for powder factor indicate a safe standoff distance of 1000-1250 ft[7]. Using these estimates of safe standoff for debris/flyrock in conjunction with the standoff estimates for ground vibration and window breakage, the conservatively estimated safe standoff distance for non-blasting personnel is 1000-1250 ft, depending on the specific charge configuration used. The safe standoff distance for essential blasting personnel will be 670 ft if no shielding is used. Standoff distances of 1,000 ft and 1,250 ft at the GLI site are shown in Figure 6. Road closures at GLI on Olympic Hot Springs Road and Whiskey Bend Road will be coordinated with NPS during the shot times. Similar coordination will be conduct at ELD if blasting is conducted there.

It is not anticipated that overnight storage of explosives will be necessary. All storage and transportation will be coordinated with local law enforcement agencies.

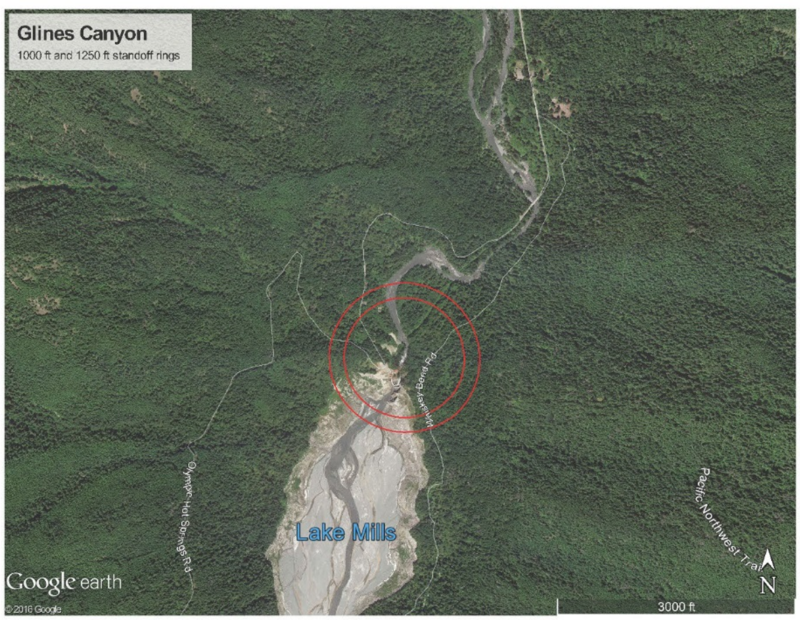

Figure 6. Safe standoff distances at GLI site.

[7] Engineering and design, Blasting damage and noise prediction and control. ETL 1110-1-142, 1 September 1989.
[8] Department of the Army Pamphlet 385-64, Ammunition and Explosive Safety Standards, 28 November 1997.

3.0 SITE ACCESS REQUIREMENTS

Work at the ELD site will require access from both the right and left sides of the Elwha River. Two main access roads are identified to provide sufficient site access for personnel and equipment: 1) the current Elwha Dam Restoration Project Road/Lower Dam Road that is accessible from Highway 112 (reference Figure 7), and 2) a trail on the North side of the dam that is accessible from Dan Kelly Road (reference Figure 8). The Lower Dam Rd is accessed through an NPS controlled gate; this will be the primary access to the site, especially for equipment and materials. The trail on the North side is near the end of a service road that runs parallel with and in the right-of-way of a powerline; this trail is envisioned for personnel access due to a more accessible bank grade on the river-left side. Access to this trail is also controlled by a gate, which is understood to be placed by the Department of Natural Resources (DNR). Since this North trail will primarily be used for personnel access, it is anticipated that UTV/ATV (Utility or All-Terrain Vehicle) traffic is all that is needed. The current trail will facilitate this requirement without the need for major disturbance of soil or vegetation. NPS has indicated that since the North trail is on DNR land, they will coordinate access prior to project execution.

Figure 7. ELD site access via Lower Dam Road.

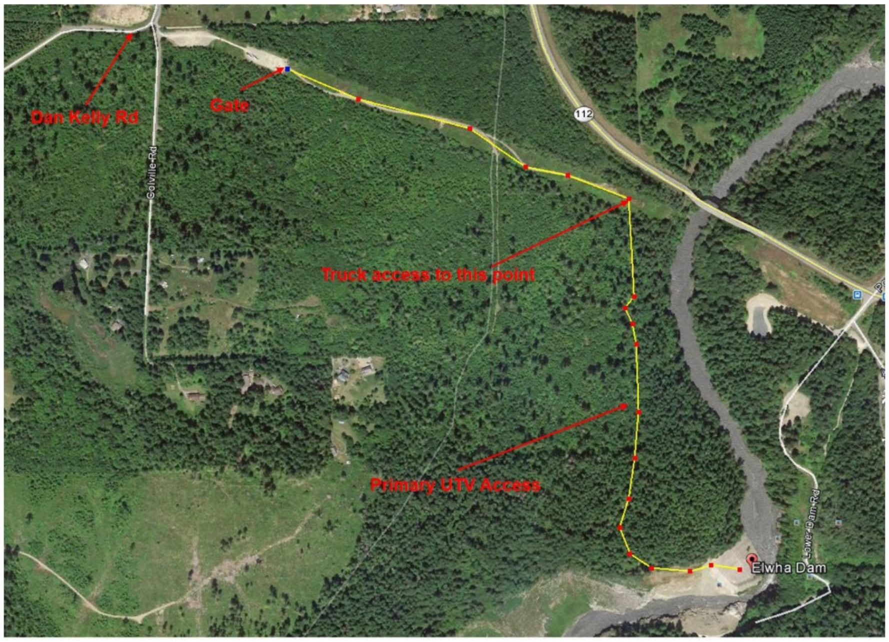

Figure 8. ELD site access via Dan Kelly Road and UTV trail.

4.0 RECOMMENDED SCHEDULE

Execution of Task 3, Demolition and Removal of Debris, according to this proposed plan will be executed at some time between August 29 and October 15. On-site execution of the metal debris cutting and boulder demolition (if conducted) is anticipated to take approximately 3 weeks. This includes an estimated time of several days for site setup, 1 week for metal debris removal at ELD, and 1 to 2 weeks for boulder demolition at GLI and/or ELD. There is a strong potential that multiple teams will be working at the ELD and GLI sites, so that the activities will not necessarily be sequential. The actual time on site will be preceded by approximately 2 weeks of gear preparation and travel; a minimum of 1 week will be required post-execution for travel back to the ERDC station.

As previously indicated, the key issue for execution at both locations is sufficient reduction of the river flow/velocity to allow for the demolition activities. USGS flow rate data from the McDonald Bridge gage is shown in Figure 9 for the period of July through October 2015. The minimum low flow condition was approximately 200 cfs near the end of August with periods of 200-300 cfs in September and early October. For reference, the flow rate on August 15, 2016 was reported to be approximately 460 cfs. Per communication with NPS, GSL and MVK will utilize this stream gage data to track river conditions and estimate the execution windows/feasibility accordingly. In this process of assessing river conditions, GSL/MVK will also communicate with NPS directly to obtain an on-site assessment of flow conditions based on their visual observation of the river.

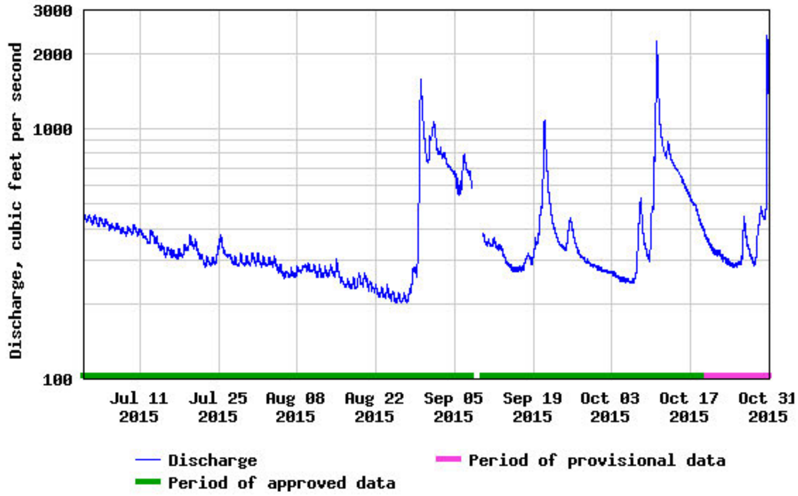

Figure 9. Elwha River hydrograph, July through October 2015.

5.0 OTHER CONSIDERATIONS

All diving and underwater cutting activities will be conducted in accordance with standard USACE requirements and standard operating procedures of the MVK Operations Division dive team. Similarly, all blasting operations will be in accordance with GSL's standard operating procedures for explosive activities, as described in Appendix 2.

After completion of all debris removal activities, GSL and MVK will conduct a post-event site survey with NPS to confirm that all required debris has been satisfactorily addressed.

APPENDIX 1, UNDERWATER DEBRIS PICTURES

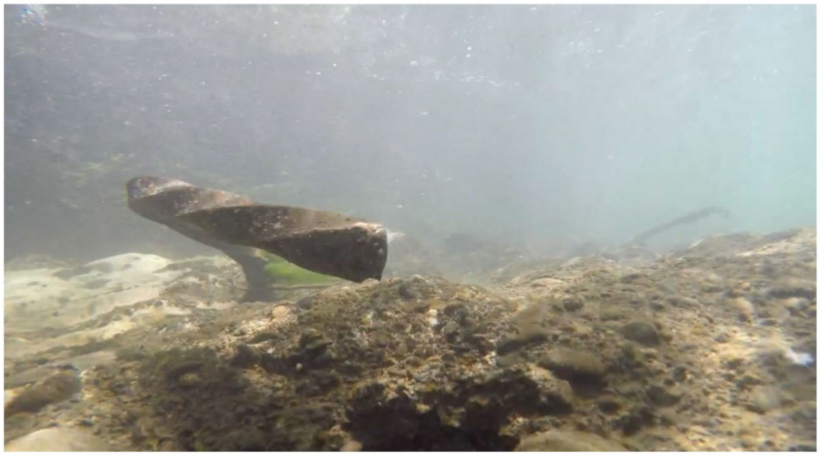

Figure 10. Metal debris, location 1.

Figure 11. Metal debris, location 2.

Figure 12. Metal debris, location 3.

Figure 13. Metal debris, location 4.

Figure 14. Metal debris, location 5.

Figure 15. Metal debris, location 6.

Figure 16. Metal debris, location 8.

Figure 17. Metal debris, location 9

Figure 18. Metal debris, location 11

APPENDIX 2, EXPLOSIVES SAFETY

Regulations

- CR 385-1-4 (formally SR 385-1-7)
- Department of the Army Pamphlet 385-64, Ammunition and Explosives Safety Standards
- Army Material Command (AMC) Regulation 350-4, Training and Certification Program for Personnel Working in Ammunition Operations
- AMC Regulation 385-100, AMC Safety Manual
- Engineer Manual 385-1-1, Safety and Health Requirements
- Army Regulation (AR) 190-11, Physical Security of Arms Ammunition and Explosives
- DoD Ammunition and Explosives Safety Standards

General Regulations

Only authorized and qualified personnel shall handle explosives and shall always be under the direct supervision of a certified ERDC blaster.

No flame, heat, or spark-producing device shall be permitted in or near explosives during handling, transport or use.

Explosives shall be accounted for at all times. Explosives not in use shall be kept in locked storage magazines. A running inventory shall be maintained at all times.

Appropriate authorities shall be notified of any loss, theft or unauthorized entry into a magazine.

No explosives shall be abandoned.

No fires shall be fought where contact with explosives is imminent. All personnel shall be cleared and area guarded against other intruders.

When blasting in areas of congestion or in close proximity of other structures or services, special precaution will be taken to avoid damage or personal injury.

Every reasonable precaution shall be used to notify others of use of explosives (visual, audible, flags, barricades, etc.). No onlookers or unauthorized personnel will be permitted within 1000 feet during loading or blasting. Available personnel that are non-essential to blasting operations shall be stationed on roadways that pass through the danger zone to stop traffic during blasting operations.

All blasting operations shall be suspended and all persons shall be removed from the blasting areas during the approach and progression of any storm containing lightning. The following rules must be followed:

A system for lightning detection should be used to monitor the proximity of lightning to the shot. When the storm is 10 miles distant as identified by the detection system, all persons in the blasting crew will be notified of approaching storm. All loading of holes will cease and personnel will be evacuated except blaster and assistant, to the established safe standoff distance. If the blast cannot be initiated before the storm arrives (within 10 miles as indicated by the detection system), the blaster and assistant shall evacuate the site to a safe distance. Personnel may return to worksite when the storm has passed and is 10 miles distant or after the completion of blast which allows for inspection of site and/or misfire.

No loaded holes shall be left unattended, abandoned, or unprotected. Explosives shall not be primed until immediately before use and shall not be allowed to lay overnight in drilled holes.

An audible blasting signal (air-horn or siren) shall be used. The following blast signals will be used during blasting.

- Warning Signal – 30 minutes prior to the blast, a series of long horn or siren sounds will be made.
- Blast Signal – 1 minute prior to charge priming (attachment of detonator to charge), a series of short horn or siren sounds will be made.
- All Clear Signal – A prolonged horn or siren sound will be made following the inspection of the blast area once it is deemed all clear.

Misfires will be handled in accordance with ERDC policy and regulations. In general, a second attempt will be made to detonate the explosive. If the result of this is no detonation of the main charge, a minimum of a 30 minute wait period will begin. After this period, the blaster will disconnect the detonator from the main charge (adhering to policy and procedures associated with appropriate firing system for safe arm and shunting procedures). A second detonator will be attached and another attempt will be made to detonate the explosives. In the event of a partial detonation, additional booster material will be used to initiate remaining material.

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14. ABSTRACT
The Elwha River is a unique river system located on Washington's Olympic Peninsula and was dammed in the early 20th century for hydroelectric power. Approximately one century later, these dams, the Elwha Dam and Glines Canyon Dam, were removed to restore the river's natural ecosystem. In 2015, the National Park Service (NPS) engaged with the U.S. Army Engineer Research and Development Center (ERDC) to provide subject matter expert support to the final stages of the restoration project. In September 2016, ERDC conducted a project for removal of hazardous rebar that was remaining in the river bed at the Elwha Dam site. The rebar was protruding from the dam foundation and created a safety hazard for the public. The project also included explosive demolition of numerous large boulders in the vicinity of the former dam sites that created flow constrictions with large velocity gradients and hydraulic jumps. The demolition objective was to improve passage conditions for the numerous species of trout and salmon that migrate up the Elwha River. This report documents the rebar removal and boulder demolition and provides recommendations for techniques to remove the remaining Elwha Dam foundation in the future if desired by NPS.

15. SUBJECT TERMS

Elwha River	Elwha Dam	Rock demolition
Ecosystem restoration	Glines Dam	
	Debris removal	

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