

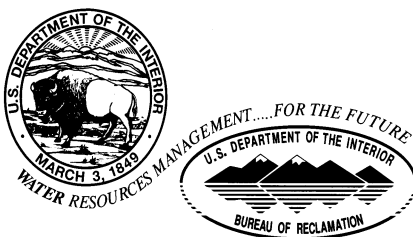
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The file "appendix" contains the title pages for the three appendices and the caption pages for the photographs. The material in appendices a and b are not available electronically. The drawings in appendix c are located in the geology drawing directory.

ELWHA RIVER
ECOSYSTEM AND FISHERIES RESTORATION PROJECT,
Washington

Elwha Technical Series
PN-95-6

GEOLOGIC DESIGN DATA REPORT
FOR
REMOVAL OF ELWHA DAM



U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region

Boise, Idaho

May 1996

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering wise use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

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ECOSYSTEM AND FISHERIES
RESTORATION PROJECT
Washington

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SUMMARY

This report presents the results of a Bureau of Reclamation geologic mapping, drilling investigation, and documentation of an underwater examination 1994–95 at the Elwha Project on the Elwha River in northwest Washington. This is part of a Federal program to remove two private hydroelectric projects and restore the Elwha River ecosystem for anadromous fish.

The Elwha Project consists of Elwha Dam and powerplant, and Lake Aldwell, the reservoir impounded by that dam. The purposes of this study were to determine the thickness and engineering properties of fill materials placed in the forebay immediately upstream of the dam and to determine the depth to and engineering properties of bedrock materials underlying the dam and forebay. Additional consideration is given to a submerged landslide mass upstream of the dam (identified in forebay bathymetry) and stability concerns for the reservoir rim of Lake Aldwell.

The geologic investigation of Elwha Dam consisted of drilling two holes in the left forebay area from a floating drilling platform. The depths of the holes ranged from 36.5–91.0 feet, as measured from the lake surface. Bedrock consisted of variably cemented, moderately to slightly fractured, gravel conglomerate that was encountered at depths of 23.0–47.2 feet in the holes. The conglomerate appeared to be massively bedded, but displayed a faint foliation resulting from a preferential orientation of flat and/or elongate particles.

The conglomerate bedrock beneath the left (north) spillway appears to be a suitable foundation for the temporary diversion channel. Excavation through the conglomerate will require controlled blasting techniques and should be expected to produce stable, nearly vertical cut slopes. The temporary diversion channel is the only viable rock source identified for production of rockfill and riprap needed for the dam removal project, as commercial sources of rock do not exist within the local area.

Restoration of the Elwha River to its original channel will require the excavation of shot rock and earthfill to a depth of nearly 100 feet. These were placed in the forebay of Elwha Dam during efforts to restore the reservoir after the foundation failure of 1912 and subsequent efforts to reduce seepage through the foundation. The shot rock has commercial value as riprap and rockfill and could be stockpiled for later resale. The earth materials could be salvaged and stockpiled for later processing and sale as aggregate or various types of sand and gravel products. However, handling and processing costs may preclude resale due to competition from commercial suppliers in the Port Angeles-Sequim area. Present cost estimates prepared for dam removal list the fill materials as waste scheduled for disposal.

Reclamation bathymetric surveys of the Lake Aldwell forebay indicated the presence of an irregular, hummocky landslide mass that completely blocked the channel of the Elwha River about 700 feet upstream from Elwha Dam. An apparent lack of surface erosion by the Elwha River suggests that the landslide is relatively young in age and likely dates from the construction period for Elwha Dam or later. An examination of the slope above the landslide did not find any indication of continuing slope movement in the area.

The forebay landslide forms a natural dam that would prevent migration of sediments from Lake Aldwell until the Elwha River has eroded a channel through the slide. Mechanical excavation of the landslide may be required to ensure timely sediment migration, reduce impacts to downstream fish habitat, and maintain project schedules. The forebay landslide represents a source of long-term sediment contribution into the Elwha River and may require stabilization to minimize impacts to downstream habitat and water quality. Additional geotechnical concerns for the forebay landslide are the rate of natural river erosion through the forebay landslide, the stability of the slide mass under static loads applied by a remnant reservoir remaining during dam removal, and possible limitations to reservoir drawdown rates during removal of Elwha Dam to prevent additional sliding.

A reconnaissance-level review of Lake Aldwell conducted in March 1995 did not locate other areas of significant active or potential landsliding. Both the forebay landslide and a larger, upstream bathymetric feature appear to be localized in extent. A small, active landslide was noted near the mouth of Indian Creek where it enters the delta area at the head of Lake Aldwell, although impacts to the project are considered to be minimal.

CHAPTER I. INTRODUCTION

A. PURPOSE

The Bureau of Reclamation (Reclamation) conducted an integrated geologic mapping, sampling, and drilling investigation in northwest Washington as part of a Federal program to remove two private hydroelectric projects and restore the Elwha River ecosystem for anadromous fish. The Glines Project consists of Glines Canyon Dam and its reservoir, Lake Mills. The Elwha Project consists of Elwha Dam and Lake Aldwell, the reservoir impounded by that dam. Both projects are located on the Elwha River, which flows north from the Olympic Peninsula into the Strait of Juan de Fuca near the City of Port Angeles (Figure 1).

This report presents the results of geologic mapping and drilling at Elwha Dam. The purposes of this study were to determine the thickness and engineering properties of fill materials placed in the forebay immediately upstream from the dam and to determine the depth to and engineering properties of bedrock materials underlying the dam and forebay. The data presented in this report will be used to develop designs and cost estimates for removal of Elwha Dam. A separate geologic report (Reclamation, 1995) presents estimated post-dam sediment distribution, grain-size gradations, and sediment volumes in each of the reservoir basins. Reclamation (1996) presents baseline geologic descriptions of the Elwha River at 34 surveyed profile locations downstream from Glines Canyon Dam to the Strait of Juan de Fuca and documents the present sediment regime of the river system. The data from these two reports will be used to model migration of the sediment from the reservoirs during and after removal of the dams.

Field work for the Lake Mills portion of the study was done April 18–26, 1994. Field mapping and sampling of the Elwha River cross sections was conducted September 8–21, 1994. Geologic mapping and surface sampling for the Lake Aldwell portion of the study was performed September 12–16, 1994, and subsurface sampling October 3–21, 1994. A landslide reconnaissance evaluation of the Lake Aldwell reservoir was conducted March 13–16, 1995.

The 1994–95 geologic mapping and sampling investigations were conducted by the Geology, Exploration and Instrumentation staff of Reclamation's Pacific Northwest Regional Office. During the Lake Mills investigation, concurrent sedimentation profiling investigations were conducted by the Sedimentation Section of Reclamation's Technical Service Center and stream gauging investigations were conducted by the U.S. Geological Survey (USGS). The Sedimentation Section personnel also obtained detailed bathymetric data from Lake Aldwell during the 1994 portion of the study. Logistic support during both investigations was provided by the Lower Elwha Klallam Tribe.

B. LOCATION

Lake Aldwell is located on the Elwha River about 5.7 miles downstream from Lake Mills and about 5 miles southwest of Port Angeles, Washington. Lake Aldwell, about 2 miles long with a storage capacity of about 8,000 acre-feet, is impounded by Elwha Dam, a 105-foot-high concrete gravity dam. The dam was constructed near river mile (RM) 4.9 in the period 1908–12. Structures at the dam include gated spillways on each abutment and a powerhouse left of the main gravity section of the dam. The foundation of the dam experienced a catastrophic failure that resulted in a total loss of the reservoir during initial filling in October 1912. The reservoir was restored following heavy blasting of the canyon rim in 1913 and efforts to reduce seepage beneath the dam continued intermittently until about 1922.

In the 84 years since dam completion, the Elwha River has constructed a narrow, 2,500-foot-long delta of post-dam sediments at the head of Lake Aldwell adjacent to older river terrace deposits. Most of the delta is below water when the reservoir is at normal elevation of 197 feet. The older terrace deposits are thickly covered by brush, alders, and cottonwoods.

C. PREVIOUS EXPLORATIONS

A number of explorations were conducted at Elwha Dam prior to and immediately after construction. Records of these investigations were apparently destroyed in a warehouse fire and very little site-specific records from those investigations have survived. Accounts of the foundation failure appear in the *Engineering Record* (1912) and the *Engineering News* (1912). Reineking (1914) provides a description of the successful efforts to repair the dam foundation and restore the reservoir.

A number of previous geotechnical investigations have been performed at Elwha Dam for Crown Zellerbach, Inc. and James River II, Inc. in efforts to obtain Federal Energy Regulatory Commission (FERC) licensing of the Elwha powerplant. Initial investigation of the dam was conducted under contract in 1967 by Shannon & Wilson, Inc. (1968) and included the drilling of four holes through the gravity section of the dam. In 1978, CH2M Hill conducted an inspection under contract with the government (Army Corps of Engineers, 1978).[‡] There were subsequent modifications. A series of anchor tendons were installed through the dam and penstocks in two stages to improve static stability under reservoir loads. The final stage of anchor installation was performed around 1986, under the direction of Harza Engineering, Inc (Harza, 1987).

Complete copies of these reports are maintained in the files of James River II, Inc., in Port Angeles. Copies of the geotechnical reports documenting these investigations were not received by the Reclamation in time for consideration for this report. However, the inclusion of this geotechnical data is not considered critical to the geologic discussions in this report and primarily would have been used to better define top-of-bedrock contours in the immediate vicinity of Elwha Dam.

[‡] This was a "Phase I Inspection" under authority of the National Dam Safety Act (P. L. 92–367).

D. PRESENT EXPLORATIONS

1. Drilling, Lake Aldwell and Elwha Dam — Five holes were drilled on Lake Aldwell for a combined footage of 245.1 feet. All holes were drilled using an Ingersoll-Rand A200 rotary drill mounted on a floating drilling platform. Three of the holes were drilled in the delta area near the upstream end of the lake to determine the thickness of post-dam sediment accumulation in that area. Data from these holes are discussed in greater detail in Reclamation (1995). Two holes were drilled in the forebay area upstream of Elwha Dam as part of the data collection program for removal of the dam. The purposes of the forebay drilling program were to determine the thickness and physical properties of hydraulic fill in the forebay behind Elwha Dam and to determine the depth to and characteristics of bedrock materials on the left side of the forebay, which is being considered as the site for a temporary diversion channel during removal of Elwha Dam.

Two holes (DH-A4 and DH-A5) were drilled in the forebay upstream from the left spillway of Elwha Dam along the approximate alignment of a proposed temporary diversion channel (Figure 2). The holes were drilled using a 4-inch casing advancer that was seated into the top of bedrock. Samples of the overlying hydraulic fill were obtained on approximate 5-foot intervals using a nominal 3-inch-outside-diameter, split-tube, sample barrel driven by a 140-pound safety hammer dropped from a height of 30 inches. Four of 5 field samples taken from the fill were laboratory tested to determine standard physical properties. The bedrock was cored using a Nw split-tube core barrel and clear water. Both holes experienced total fluid losses short distances into bedrock. Geologic logs and laboratory test results for holes DH-A4 and DH-A5 are located in Appendix A.

Locations for the two forebay drill holes were obtained by Brunton compass and tape triangulation from surveyed monuments located on the north shore of the forebay.

2. Topographic and Bathymetric Data, Lake Aldwell — Topography for Elwha Dam and bathymetry for the Lake Aldwell forebay (Figure C2 in the appendix ; drawing 1440-100-9) were developed from 1994 Reclamation surveys conducted for this study. Preconstruction topography for Elwha Dam is very limited and topographic maps of the dam generated by previous studies did not have sufficient coverage for use in preparing design estimates for dam removal. Forebay bathymetry prepared by Shannon & Wilson (1968) was incomplete and did not cover the left (north) side of the forebay in the vicinity of the proposed temporary diversion channel.

The local project datum coordinate system used on Figure C2 is based on “NAD (North American Datum) 1983,” state plane zone 4601. Elevations are based on “NGVD (National Geodetic Vertical Datum) 1929.” The 1994 Reclamation survey conducted for Elwha Dam indicated that the NGVD 1929 vertical datum is 9.48 feet higher than the local project datum. A factor of 10 feet was used to convert project datum contours on archival drawings to the 1929 NGVD vertical datum used in this report.

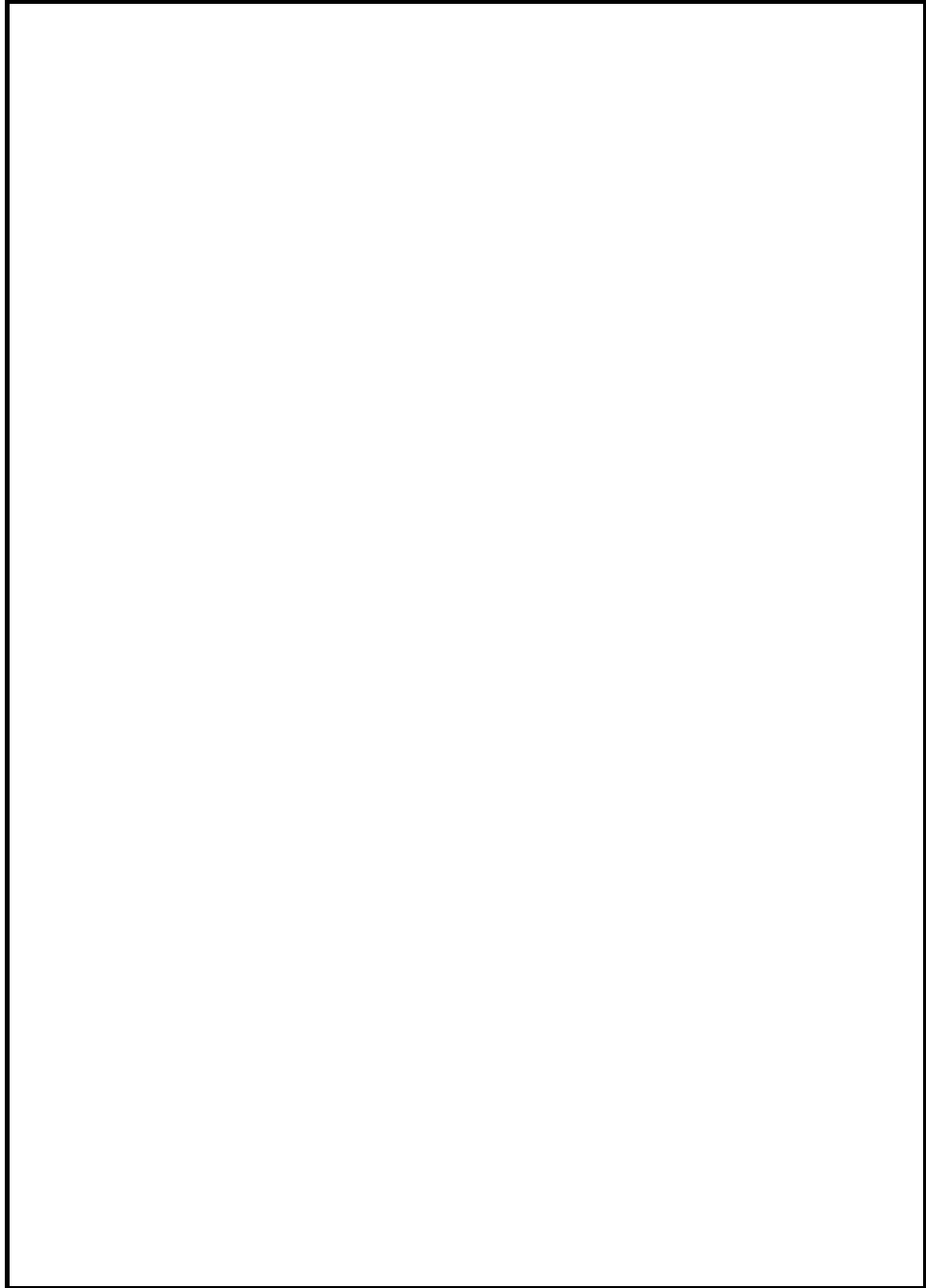
3. Underwater Dive Examination — An underwater examination of the left side (north) of the Elwha Dam forebay was performed on October 20, 1994 by members of the Reclamation Pacific Northwest Region Dive Team. This examination was done in conjunction with underwater geologic mapping of the delta area at the upstream end of Lake Aldwell. The purposes of the forebay examination were to determine the presence of bedrock outcrops along the left (north) shore of the forebay and to visually observe the hydraulic fill materials exposed upstream of the dam. An earlier review of archival photographs in the Daishowa America-James River II, Inc., files had identified apparent rock outcrops in a series of photographs dating from installation of a gunite cap about 1922.

Appendix C of this document is the dive examination report documenting the findings of the underwater exam.

Also included in the underwater dive examination report is a discussion of a remotely operated vehicle inspection of the forebay at Glines Canyon Dam conducted October 21, 1994. The purpose of this inspection was to determine the height of post-dam sediment fill upstream of the dam and the amount of sediment and woody debris accumulation around the intake structure for the low-level outlet.

4. Borrow and Disposal Site Reconnaissance — A reconnaissance survey of borrow sources and disposal sites was done concurrently with the October 1994 Lake Aldwell drilling investigation. Contacts were made with the Clallam County Road Department, the Washington Department of Transportation, and many of the commercial suppliers of granular materials and aggregate in the Port Angeles-Sequim area. The survey located multiple commercial sources of granular materials within the project area, but did not find any viable sources of rock or impervious material, or any disposal sites for waste material.

The Lower Elwha Klallam Tribe has indicated a desire to salvage shot rock and concrete during dam removal and has assumed responsibility for locating suitable disposal and stock pile areas. Disposal site information obtained during the Reclamation reconnaissance survey has been furnished to tribal staff members.



CHAPTER II. GEOLOGY

A. INTRODUCTION

A number of investigators have examined the complex geology of the Olympic Peninsula and its implications to the development of the North American continent. A large number of technical references have resulted from these studies and provide the framework for the discussions presented in this report. A detailed presentation of these studies is beyond the scope of this report, which focuses on the local geology as it pertains to sediment management and dam removal issues for the Elwha River restoration project. A brief summary of the regional geology is presented to provide context for site-specific discussions of geologic considerations. Tabor (1987) presents an excellent, nontechnical discussion of the geology of Olympic National Park.

B. REGIONAL GEOLOGY

The central portion of the Olympic Peninsula, termed the Olympic core complex (USGS, 1978a; USGS, 1978b; Eckerlin, 1989; USGS and WDMG, 1978), consists principally of early Tertiary marine sedimentary and volcanic rocks (Figure 1). These core rocks have been intensely deformed through folding and thrust faulting, and are slightly metamorphosed. A series of peripheral Tertiary marine sedimentary and oceanic basaltic units (the Crescent, Lyre, and Aldwell Formations, and the Twin River Group) are in high-angle thrust-fault contact with the central core complex (USGS, 1978b; Babcock, et al., 1994). These units comprise most of the rock exposed in the Elwha River drainage from Lake Mills north to the Strait of Juan de Fuca (USGS, 1978a). The peripheral rocks are faulted and folded, but still retain much of their original bedding and fabric.

Most of the present topography in the Olympic Peninsula resulted from multiple alpine and continental glaciations that extensively sculpted the older bedrock units. Alpine glaciers originating high in the Olympic Mountains moved downslope along the major drainages, carving broad, U-shaped valleys such as the one now occupied by the Elwha River. The latest Cordilleran continental ice sheet moved south out of Canada during the Vashon stage, about 14,500 years ago (Galster and Coombs, 1989). This ice sheet extended south to the northern range front of the Olympic Mountains, where it split into two lobes. The Juan de Fuca lobe moved west along the coast line to the Pacific Ocean; the Puget Sound lobe moved east and south as far as the Chehalis River, south of Olympia, Washington. The Elwha River alpine glacier likely merged into the Juan de Fuca lobe at maximum ice extent.

Extensive till deposits were laid down on the lowlands between the Olympic Mountains and the Strait of Juan de Fuca during glacial maximum and large sheets of outwash were subsequently deposited during ice retreat. Thick blankets of till and outwash remain adjacent to major river valleys and on the lowlands adjacent to the Strait of Juan de Fuca. Major streams flowing north from the Olympic Mountains, including the Elwha River, have become deeply entrenched within these deposits and have formed deep, steep-sided valleys. Continental glacial deposits, consisting mostly of sand, gravel, cobbles, and boulders in a matrix of fine rock flour, are commonly found high up on the walls of the Elwha River canyon.

C. SITE GEOLOGY

Basaltic flows of the Crescent Formation underlie the Elwha riverbed between Glines Canyon Dam and the upper end of Lake Aldwell (Figure 1). In the Lake Aldwell basin, the bedrock transitions from the Crescent Formation at the upper end of the basin through the marine siltstones and sandstones of the Aldwell and Lyre Formations near the center portion of the basin, to the basal conglomerate of the Twin Rivers Group at Elwha Dam (USGS, 1978a). The dam was constructed near the upstream end of a 100-foot-deep gorge cut by the Elwha River into the Twin Rivers conglomerate. Bedrock outcrops are common along the eastern shore of the upper half of the lake, often forming prominent bluffs or cliffs overlooking the lake. More discontinuous exposures of rock are observed on the lower half of the west side of the reservoir.

The upland above the Lake Aldwell basin is composed chiefly of glacial till and outwash of the Juan de Fuca lobe of the continental ice sheet. This upland, which slopes gently down to the north from the range front of the Olympic Mountains to the Strait of Juan de Fuca, has been deeply dissected by the Elwha River and other north-flowing streams. Continental glacial sediments comprise much of the shoreline along Lake Aldwell and thinly mantle bedrock units on the west and lower half of the east side of the reservoir.

Pre-dam alluvium distribution in the Lake Aldwell basin is not known, as pre-dam topography is not available. Sketches from a 1913 timber cruise of the reservoir area show extensive gravel terraces and bars alternating with marshy bottom land.

CHAPTER III. GEOLOGIC CONSIDERATIONS

The results of geologic design data investigations related to the removal of Elwha Dam are presented below. Figure C2 is a topographic map and site plan of the dam and combines both ground survey of the area around the dam with sonar-based bathymetric survey of the submerged reservoir bottom in the forebay immediately upstream of the dam. Geologic section D-D' (figure C3 in the appendix; drawing 1440-100-10) generally parallels the original Elwha River valley and illustrates the site geology and fill materials placed upstream of the dam. Geologic logs of explorations and core photographs are included in Appendix A of this report.

A. ENGINEERING GEOLOGY

Design data requirements for analysis of dam removal options for Elwha Dam included determination of: (1) the thickness and physical properties of fill materials placed in the forebay upstream of the dam; and (2) the physical and engineering properties of the bedrock foundation, including the depth to top of bedrock in the upstream forebay. Other dam removal considerations include excavation requirements and material suitability for disposal. The results of the geologic investigations are presented in the following sections. Descriptors of physical properties used below conform to standard definitions given in the *Engineering Geology Field Manual* (Reclamation, 1988).

1. Bedrock — The foundation of Elwha Dam consists of a variably cemented, gravel conglomerate bedrock that directly underlies the entire structure, except for the main gravity section in the old river channel that is founded on Elwha River alluvium. Two vertical exploration holes (DH-A4 and DH-A5) were drilled in the forebay upstream of the left (north) spillway along the approximate alignment of a proposed temporary diversion channel. This channel would be excavated through the left spillway to an approximate elevation of 135 feet and would serve to temporarily divert the Elwha River while the dam and fill materials blocking the original river channel are removed. The diversion channel would be backfilled and restored to original contours upon completion of dam removal. Drill hole DH-A4 was located about 220 feet upstream of Elwha Dam and penetrated about 13.5 feet into bedrock. Hole DH-A5 was sited approximately 320 feet upstream of the dam and examined a total of 43.8 feet of the conglomerate. The locations of the drill holes are shown on the site plan of Elwha Dam (figure C2).

The following description of the conglomerate is based on core samples retrieved from the two drill holes and on geologic mapping of bedrock outcrops in the immediate vicinity of the dam. These drill cores and exposures are considered representative of the bedrock materials forming the foundation of Elwha Dam.

1a. Physical Properties — USGS (1978a) mapped the conglomerate bedrock at Elwha Dam as a basal conglomerate of the lower member of the Twin Rivers Group (figure 3). The conglomerate consisted of chiefly subangular to rounded particles of predominantly fine gravel and fine to coarse sand in a matrix of carbonate cement in core samples obtained from the forebay. Individual particles were composed chiefly of basalt and volcanic tuff with minor rhyolite and quartzite constituents. The maximum individual particle size observed in the core measured 100 millimeters (mm) by 40 mm. The conglomerate appeared to be massively bedded, as no bedding planes were observed in the core, although Bliton (1989) reports a bedding plane strike of N. 50° W. and a dip of 20° NE. The core

displayed a faint foliation resulting from a preferential orientation of flat and/or elongate particles that generally dipped from 20° to 40°. This foliation appears to be subparallel to the bedding plane attitudes reported by Bliton.

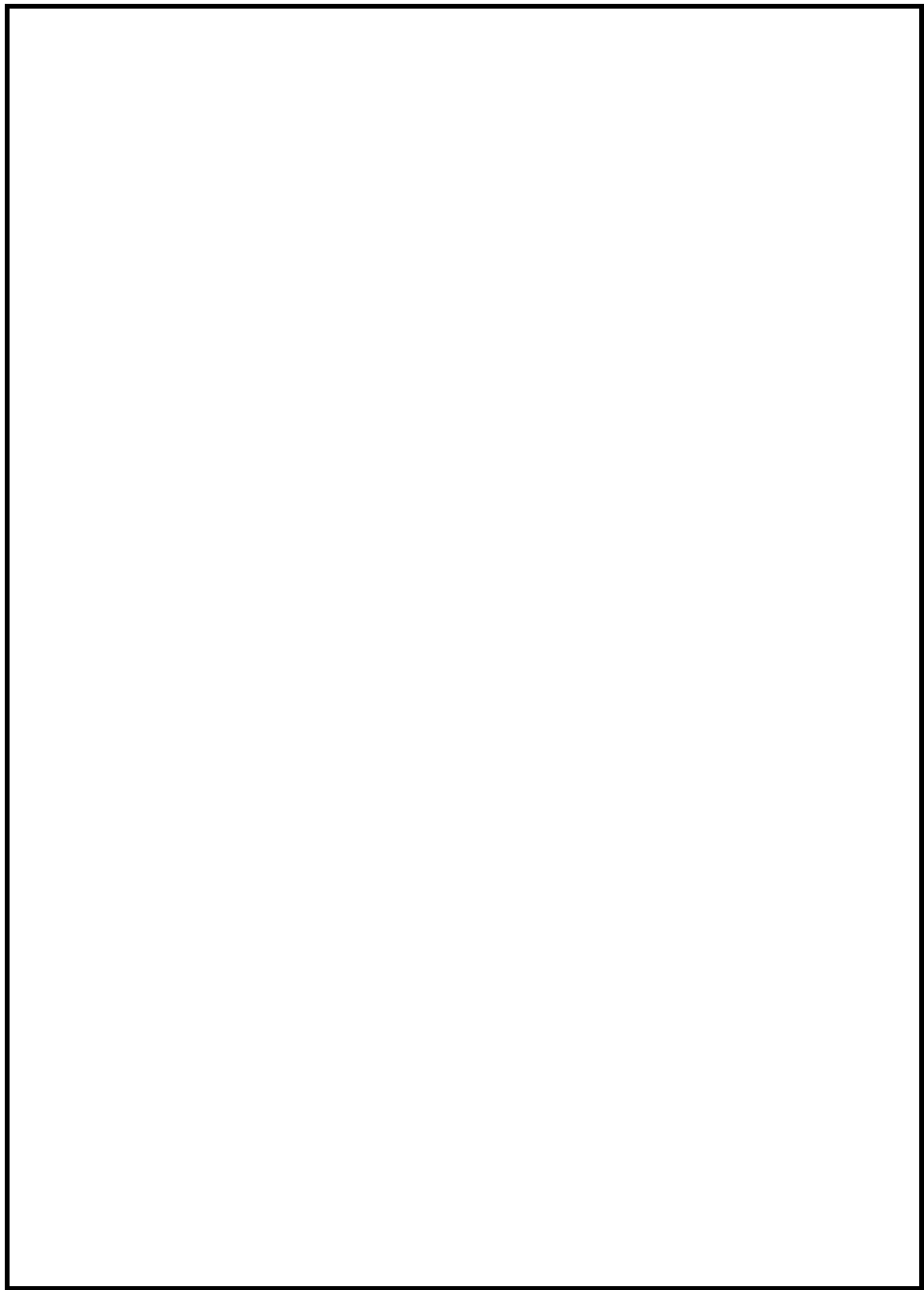
1b. Cementation — The dominant factor controlling the engineering and physical properties of the conglomerate was the degree of carbonate cementation observed in the matrix. Cementation varied widely in the core. Samples ranged from poorly to strongly cemented with generally gradational transitions between distinct cementation zones.

Poorly cemented zones were typically located near the top of DH-A4 and were likely related to surficial weathering of the conglomerate. The core samples were recovered chiefly as chips and fragments that were oxidized throughout. These fragments broke with heavy manual pressure to a light to moderate hammer blow. Breakage occurred in the matrix along the edges or boundaries of individual particles rather than through the particles.

Moderately cemented zones were noted primarily in DH-A5, but occurred throughout the length of bedrock section cored in the hole. The moderately cemented zones were characterized by tight bonding of the cement to individual particles. Iron staining was observed on all fracture surfaces within the moderately cemented zones, but generally dissipated to a faint, pervasive oxidation with distance into the main body of the core. Core samples from moderately cemented zones scratched with a knife and broke with a moderate hammer blow. These breaks usually occurred in the cemented matrix along the edges of individual particles.

Strongly cemented zones were observed in both drill holes. Cementation in these strongly cemented zones was tightly bonded to individual particles with oxidation limited to iron staining of fracture surfaces only. Core samples did not scratch with a knife, but broke with a heavy hammer blow. These breaks in the core occurred through individual particles rather than in the matrix material.

1c. Fracturing — The conglomerate is moderately to slightly fractured with the core generally recovered in lengths ranging from 0.2 to 2.7 feet; a maximum core length of 4.0 feet was obtained in DH-A5. Three sets of joints were observed in the core. The first joint set consisted of generally rough and planar surfaces spaced from 2–10 feet apart that dipped 5° to 15°. These joint surfaces were lightly stained with iron oxide minerals. The second joint set was composed of generally rough and planar surfaces spaced from 1–2 feet apart, but as wide as 11–13 feet. These surfaces were variably stained with iron oxides and dipped 20° to 35°, generally parallel to the faint foliation noted above. The third set of joints comprised typically rough and planar to irregular surfaces spaced from 1–8 feet apart. These joint surfaces were variably stained to coated with iron oxides and dipped from 50° to 65°.



1d. Permeability — The permeability of the gravel conglomerate cannot be quantified, as borehole permeability tests were not performed. A fair degree of permeability is inferred from drilling conditions and field observations. Complete loss of the circulating water was experienced while core-drilling in the conglomerate, except for a short run in DH-A5 (from 49.1 feet to 53.8 feet, measured from the water surface). The volume of circulating fluid used when core drilling is dependent on the character of the material being drilled, but is typically kept low to prevent flotation of the drill bit, erosion of the core sample, and wear of the water ports on the drill bit itself. Volumes used in the core drilling at Elwha were on the order of 5 gallons per minute or less.

A further indication of seepage through the conglomerate is the prevalence of oxide staining on the vast majority of fracture surfaces recovered in the core. Thicker accumulations of oxide either partially or completely coating the fracture surfaces were noted in several instances. The presence of oxide stains and coatings is another indicator of seepage through fractures and joints in the conglomerate.

1e. Top-of-bedrock Contour Map — Appendix figure C5 (drawing 1440-100-12) is a top-of-bedrock contour map of Elwha Dam and its immediate vicinity. This drawing was prepared to aid in estimating fill quantities to be excavated from the original Elwha River channel upstream of the dam and in laying out final alignment for the temporary diversion channel. Bedrock contours adjacent to and downstream of the dam have been developed primarily from rock outcrops. Contours in the forebay have been prepared using construction-era written accounts, drawings and photographs supplemented by drill hole data obtained in 1994 from DH-A4 and DH-A5 and by underwater documentation. Principal construction-era sources include: (1) a sketch map in Reineking (1914) that shows the upstream river canyon configuration, limited topographic contours, and blast hole locations; and (2) a generalized cross section through the forebay showing the distribution of fill components and foundation materials, based in part on drill hole data obtained 1912–13. This latter drawing consists of a tracing of the original sketch by V. H. Reineking (Crown Zellerbach, 1940). Two cross sections located on the upstream and downstream faces of the dam were used to better define bedrock contours beneath the gravity section of Elwha Dam (Reineking, 1913).

The contour map shows the bedrock configuration of the Elwha River canyon after the 1913 blasting to restore reservoir integrity following failure of the foundation of the gravity section of the dam in 1912. A series of blast holes were drilled to depths of 30 feet along the canyon rim both upstream and immediately downstream of the dam. Two small tunnels, one in each canyon wall, were excavated upstream of the dam to augment the blast holes (Reineking, 1914). Contours shown for the buried canyon upstream of the dam have been estimated based on the effect of blasting observed in the downstream rock outcrops. The large rock promontory immediately to the right (southeast) of the powerplant was particularly useful in estimating the effectiveness of the 1913 blasting.

The interpretation of the bedrock configuration shown on figure C5 is based on available data. Additional definition of the top of bedrock within the forebay may be required to prepare final volume estimates of fill excavations in the forebay and for final slope restoration and revegetation plans following removal of the dam. Definition of the canyon profile could be obtained through a series of three or four underwater seismic surveys. These surveys should readily define the top of bedrock and are relatively inexpensive compared to drilling investigations.

1f. Construction Considerations — Rock outcrops in the vicinity of Elwha Dam and drill hole data obtained from the forebay suggest that the conglomerate bedrock will provide a satisfactory foundation for the temporary diversion channel. Excavation of the conglomerate will require controlled blasting techniques. Excavations in the generally moderately to strongly cemented conglomerate are expected to produce stable, nearly vertical cut slopes. Localized zones of more intense fracturing may be encountered where the excavation approaches the locations of the 1913 blast holes. Bedrock fracturing noted in DH-A4 may have been due to its location within 10 feet of two of the 1913 blast holes. Fractures produced by the 1913 blasting may locally inhibit the effectiveness of shots for the temporary diversion channel and could also result in local over-excavation outside the lines and grades designed for the diversion.

The temporary diversion channel excavation is the only viable rock source identified for production of rockfill needed as a stability berm at the downstream toe of the gravity dam section. The rockfill would be placed prior to removal of the dam itself. No commercial sources of rock exist within the local area and investigations for viable sources by the Washington Department of Transportation have not located any potential sources capable of meeting size or durability requirements. The rockfill has commercial value and could be stockpiled at an offsite storage area pending future sale. Alternately, the rockfill could be wasted back into the temporary diversion channel to aid in restoration of that area to original ground surface contours.

2. Forebay Fill Materials — Following the failure of the dam foundation and loss of the reservoir in October 1912, the forebay area immediately upstream of Elwha Dam was backfilled in stages to restore the reservoir and reduce seepage losses through the foundation. Reconstruction efforts began in 1913 and were completed in 1922. Restoration of the Elwha River to its original channel will require excavation of these fill materials in addition to removal of the dam itself.

The following descriptions of the various materials placed in the forebay are based on descriptions of the backfill operations by Reineking (1914), a construction-era cross section of the forebay (Crown Zellerbach, 1940), and a series of photographs dating from the final stages of construction in about 1922. The geologic cross section D-D' (figure C3) shows the distribution of the fill materials based on the construction-era cross section. These data are supplemented by limited drilling and sampling of hydraulic fill in the forebay behind the left (north) spillway by Reclamation in October 1994.

2a. Shot Rock and Earthfill (1913) — The initial backfill effort in the Elwha Dam forebay consisted of heavy blasting of both canyon walls in 1913 to produce material to plug an open gap beneath the dam left by failure of the foundation materials (Reineking, 1914). The intent of the blasting was to create a wide gradation of material to minimize the occurrence of voids in the fill. An undetermined amount of earthfill was placed on top of the canyon rim under the assumption that mixing of the earthfill and the rock would occur during the blast. Descriptions of the blasting indicate that the majority of the rock shot from the canyon walls ranged in size from 2–40 tons, although considerably smaller size material would likely have been generated during the explosion. The reported volume of material placed into the Elwha River canyon during the blast was about 50,000 cubic yards (yd³). An additional 6,000 yd³ of rock was excavated from the approach to the right or south spillway and dumped into the river channel upstream of the dam prior to the blast.

The shot rock has commercial value as riprap and rockfill due to the lack of viable rock sources in the local area. Present estimates call for stock-piling the shot rock for later resale rather than disposal as

waste. Some processing of the rock may be required to remove earthfill components or to reduce large blocks into more manageable sizes.

2b. Fir Mattresses (1913) — A blanket of fir mattresses was placed on top of the shot rock in 1913 to reduce the volume of seepage moving beneath the dam. The mattresses consisted of pine boughs tied up with wire into bundles about 15 inches in diameter and about 30 feet long. The bundles were then wired to pole frames constructed from 6-inch-diameter wooden poles spaced on approximately 6-foot centers. Each mat measured 30 feet wide by 50 feet long and consisted of three individual layers of pine-bough bundles oriented 90° to each other. All bundles were securely wired to the underlying pole frame and a second frame was then placed on top of the mat for additional support. The fir mattresses were then towed into position in the forebay and loaded with about 5 yd³ of loose rock, sinking the mats at the desired location. The fir-mattress blanket was constructed across the entire river channel and extended as far as 150 feet upstream from the face of the dam (Reineking, 1914).

The fir mattresses are considered waste material and have no commercial value. Disposal would likely include temporary stockpiling to permit drying of the pine boughs. The mattresses could then be burned and the remaining wire ties could be collected and hauled for disposal at an approved site.

2c. Fill (1913) — The fill material overlying the fir mattresses was described as loose rock and earth on the construction-era cross section (Crown Zellerbach, 1940). This fill material likely consists of silt, sand, and gravel, with cobbles and minor boulders. This additional fill was added to the forebay after the fir mattresses were loaded and sunk. This material was hauled to the dam in rail cars and dumped onto the mattresses to further reduce seepage flows through the foundation (Reineking, 1914).

The 1913 fill and the other fill materials described in the following paragraphs could be salvaged and stockpiled for later processing and sale as aggregate or various types of sand and gravel products. The commercial value of these types of materials may not be high enough to justify handling and processing costs due to competition from the large number of commercial suppliers of these materials present in the Port Angeles-Sequim area. Design cost estimates prepared for the removal of Elwha Dam list the fill materials as waste scheduled for disposal. The fill is anticipated to be free of contaminants, but could include some woody debris.

2d. Stone, Gravel, and Sand Fill (1914) — Very little information is available for this fill unit, which appears on a construction-era cross section of Elwha Dam and forebay (Crown Zellerbach, 1940). The unit likely represents a continuation of fill placement begun in 1913, but halted due to winter flooding, as described by Reineking (1914). The 1914 stone, gravel, and sand fill is probably similar to the earlier 1913 fill material.

2e. Hydraulic Fill (1918–22) — The hydraulic fill was placed in a series of stages beginning in about 1918 and ending in 1922. The following description of the fill is based on a number of photographs dating from the later stages of construction in 1922, augmented by additional photographs of the forebay taken in 1934, and from five borehole samples of the hydraulic fill obtained from the forebay upstream of the left (north) spillway October 1994.

The hydraulic fill was mined from glacial deposits located on the right abutment high above the dam. These materials were excavated using a high-pressure water jet (monitor) and transported to the forebay through a network of flumes and pipelines. This type of extraction and placement system likely separated clayey fines from the fill and limited the size of material that could be placed in the

fill. Laboratory testing of drill hole samples indicates that the hydraulic fill consists chiefly of “poorly graded sand with silt and gravel” with an average gradation of 66 percent sand, 24 percent gravel, and 10 percent nonplastic, silty fines. Considerable variation was observed in the hydraulic fill with soil classifications of “poorly graded gravel with sand” (66 percent gravel, 32 percent sand, and 2 percent fines; laboratory classification) and “poorly graded gravel” (95 percent gravel, 5 percent sand, and a trace of fines; visual classification) being obtained for two of the samples. The maximum particle size of the drill hole samples was 75 mm, the diameter of the sample barrel. A review of construction photographs indicates that cobble-size particles ranging up to 8 inches in diameter are present in the fill and may comprise 5–15 percent of the fill by volume. Scattered boulders may be present along the groin areas, but are not expected within the main body of the hydraulic fill to any great extent due to the method of placement.

As with the 1913 fill, the hydraulic fill could be salvaged and stockpiled for later processing and sale. Photographs of the forebay in 1934 and visual observations made in the field in 1994 indicate that wooden planks and timbers from the old flume system remain in the fill and would need to be removed during processing.

2f. Gunite (1922) — The surface of the hydraulic fill was capped with a reinforced-gunite layer in about 1922 to prevent erosion of the hydraulic fill during spillway releases. The reinforcement consists of square steel rebar set in a 12-inch grid. The thickness of the cement cap is estimated to be 2–3 inches. The approximate lateral extent of the gunite cap is shown on the Elwha Dam plan map (figure C2) and is based to a large extent on field mapping in 1994, visual observations of the forebay made by boat, and supplemented by 1934 photographs taken when the forebay had been dewatered. The 1934 photographs show that a considerable amount of erosion had taken place in the hydraulic fill beneath the gunite cap along its upstream margin. This undercutting resulted in the failure of several sections of the gunite. The present condition of the gunite cap in the central portion of the forebay has not been verified by recent observation.

The gunite cap, including reinforcement, is considered waste and is scheduled for disposal.

2g. Construction Considerations — The fill units placed in the forebay behind Elwha Dam consist largely of granular earth materials and are considered common excavation, with the exception of the shot rock material and possibly the fir mattresses. No compaction was done during placement of these materials, which were primarily dumped from cars or placed by hydraulic methods. In-place densities of these materials are expected to be low. Densities ranging from 70 to 90 pounds per cubic foot could be expected, based on previous experience with similar materials placed by hydraulic processes. Present dam removal designs envision excavation of most of the fill materials in the dry while the Elwha is diverted through a temporary channel cut through the present left (north) spillway. Excavations through the granular materials will likely have to be slopes of 2 to 1 (horizontal to vertical) or flatter to ensure stability of the fill materials in open cuts.

The shot rock placed on the bottom of the forebay is reported to contain blocks as large as 40 tons (Reineking, 1914). Removal of material of this size will require special excavation techniques. Larger blocks may have to be reduced in size through blasting or other mechanical means before they can be removed. A significant portion of the shot rock lies below the bottom elevation of the temporary diversion channel (approximately elevation 135 feet) and may have to be excavated largely in the wet, depending on seepage inflow through the adjacent bedrock and upstream hydraulic fill materials.

B. LAKE ALDWELL LANDSLIDES

The following section discusses a landslide observed in 1994 sonar-generated bathymetry of the forebay and associated concerns regarding stability of the reservoir shoreline materials during the drawdown of Lake Aldwell that would occur during removal of Elwha Dam. An examination of the area upslope of the forebay landslide and a reconnaissance-level review of the lake shoreline were performed March 14–16, 1995 to determine the extent of landsliding in and around Lake Aldwell. Field observations made during those examinations are included in the discussion which follows.

1. Forebay Landslide — The site plan of Elwha Dam (figure C2) includes topography of the forebay bottom upstream of the dam generated from sonar-based bathymetric surveys performed by Reclamation in September 1994. Examination of the bathymetric topography indicates the presence of a landslide mass about 700 feet upstream of the dam that extends south from the left (north) shoreline of the Lake Aldwell. This landslide appears to completely block the submerged channel of the Elwha River. An 1989 bathymetric survey by Hosey and Associates (1989) did not extend far enough downstream to cover the forebay of Elwha Dam. Geologic cross section D-D' (figure C3) roughly parallels the original channel of the Elwha River and shows the landslide in relation to the dam and the upstream mass of fill materials. Section E-E' (figure C3) profiles the landslide from north to south across the river canyon.

1a. Description — The forebay landslide is an irregular, hummocky lobe of material with a minimum crest length about 125 feet and a maximum width about 110 feet. The surface elevation of the slide mass ranges from an elevation of 165 feet on the left abutment to an elevation of 150 feet over much of the length of the lobe. The lowest point on the surface of the landslide occurs at its downslope toe where it drops to about an elevation of 144 feet near the south (right) valley wall. The thickness of the slide mass ranges from about 70 feet on the left abutment to a minimum thickness of about 43 feet near the toe (figure C3). The extent of the slide upslope in the left abutment is poorly defined above the elevation 165 feet contour due to relatively flat slopes. The volume of the landslide (lobe only) is estimated at about 15,000 yd³.

Examination of the area immediately upslope of the forebay landslide on March 14, 1995 revealed minimal evidence of previous sliding in the slope above the lake. No direct evidence for landsliding, such as surface fissuring or tilted trees was noted. However, a shallow, bowl-shaped depression observed in the face of the steep slope may represent the detachment surface at the head of the landslide. This bowl-shaped depression ranged from about 50–75 feet wide, forming an extremely steep-sided chute that was choked with deciduous trees, underbrush, and deadfall. If this chute marks the upslope limit of the forebay landslide, the amount of material that would have been involved at this location would have been small, possibly on the order of a few feet in thickness. This type of topographic feature is not uncommon where slope failures occur on steep slopes and involve thin soil horizons and/or weathered bedrock. A number of large tree stumps three to four feet in diameter were observed on the slope adjacent to the chute, indicating long-term stability of the adjacent slopes.

1b. Composition — Materials comprising the forebay landslide were not sampled, but are likely derived from the glacial sediments exposed upslope from the slide mass, although local variations of material should be expected. The entire west shore of Lake Aldwell has been logged and several excellent exposures were observed in logging road cuts upslope from the landslide area. These road cuts typically measured 5 to 6 feet in height. The materials exposed in the road cuts consisted of compact glacial deposits. These materials are likely underlain by conglomerate bedrock at shallow

depth, based on the close proximity of bedrock outcrops both upstream and downstream of the landslide area. Representative exposures of the glacial sediments were logged using procedures outlined in Reclamation (1990). The visual soil classification was “poorly graded sand with silt, gravel, cobbles, and boulders.” The material had about 50 percent fine to coarse, subrounded sand; about 35 percent fine to coarse, subrounded gravel; about 10 percent nonplastic fines; about 5 percent 3- to 12-inch cobbles; and a trace of plus 12-inch boulders. The maximum-size boulder observed in outcrop was about 18 inches in diameter. Glacial deposits were tan in color, grading to dark brown, and were typically compact, requiring heavy blows with a rock hammer to dislodge the material from outcrops.

Further inferences about the materials present in the landslide can be deduced from the configuration of the slide mass, based on the bathymetric survey. The irregular, hummocky, lobate configuration of the forebay landslide is commonly associated with failures of earth or soil materials, such as the glacial sediments, rather than bedrock. Large blocks of underlying bedrock could have been displaced and incorporated into the slide mass during the failure process. The toe of the forebay landslide appears to run up the opposite (right) valley wall, forming an elongate, linear ridge crest about 15 feet higher in elevation than the adjacent right abutment wall. This feature also suggests that the landslide involves primarily earth materials. The toe ridge further indicates that the failure may have been a sudden, rapid event that generated sufficient energy to force the material at the toe to move upslope when it encountered the right valley wall.

1c. Age — The forebay landslide appears to be a very young feature, as topographic evidence for river erosion of the slide is very limited. The apparent lack of erosion indicates that the landslide developed sometime after the construction of Elwha Dam. The landslide may have developed in response to the failure of the dam foundation in 1912. Reineking (1914) reports that the reservoir surface was at project datum elevation of 163 feet (about an elevation of 173 feet in the NGVD 1929 datum) when the failure occurred and the lake was drained in 1.5 hours. The rapid drawdown of the reservoir could have resulted in high pore pressures in the glacial sediments along the reservoir rim, which may have induced the subsequent failure of the forebay landslide. The Elwha River was returned to free-flowing conditions for about 1 year until drilling and blasting of the river canyon was completed in 1913 and the reservoir was restored. Erosion or scouring of the landslide would have been limited to that one-year period of free flowing river.

Failure of the forebay landslide may have resulted from heavy blasting of the canyon rim in 1913 during efforts to plug the failed foundation of the dam and restore the reservoir. Reineking (1914) reports that about 25,000 pounds of black powder and 20,000 pounds of gelatin explosives were used in the blast centered about 110 feet upstream of the dam. Another possibility is the forebay landslide could have developed at some time after restoration of the reservoir in 1913. The left (west) shoreline of Lake Aldwell is in a relatively remote area and a slope failure could have occurred at this location without much notice. The lack of erosion noted in the bathymetry of the forebay landslide would be consistent with a slope failure late in the reservoir restoration process or at a date subsequent to the restoration of Lake Aldwell.

2. Reservoir Rim Stability — Bathymetric surveys of Lake Aldwell conducted by Hosey and Associates (1990) and conducted by Reclamation (1996) suggest the presence of another large landslide about 1,200 feet upstream of Elwha Dam. This potential slide area does not dam the river, but restricts the channel to an approximate width of 100 feet or less. Another area of concern is the narrow “gooseneck” area near the midpoint of the reservoir where Lake Aldwell makes a radical turn to the west around a large rock promontory and through a narrow constriction (see figure 4). This “gooseneck” area has been mapped as a landslide by USGS (1960, 1978a). A field reconnaissance of Lake Aldwell was performed March 14–16, 1995 to assess the landslide potential of the reservoir rim and to examine suspect areas for indications of past or continuing landslide activity.

2a. Landslide Reconnaissance — The slope on the west side of Lake Aldwell was examined on the ground from Elwha Dam upstream to the large rock promontory or “gooseneck” (figure 4). The terrain in this area is relatively steep along the reservoir rim, rising to a gently sloping terrace about 100 feet or more above the lake surface. Older, higher terraces occur further to the west, based on aerial photographs and topography shown on the *Elwha, Washington* map (USGS, 1985). Measured slope angles along the lake margin ranged from 34° to 36° from the edge of the lower terrace down to the lake shore. The entire west shore of Lake Aldwell has been logged and several excellent exposures were observed in logging-road cuts. These cuts generally measured 5–6 feet in height, although larger exposures exceeding 20-feet high were observed further upstream of the forebay landslide location. The materials exposed along the old logging roads consisted of compact glacial deposits similar in composition to that described previously for the forebay landslide area. The glacial sediments extended upstream of the dam for a distance of about 2,000 feet or more and appeared to comprise the majority of materials present west of the reservoir. Bedrock crops out on the left abutment of the dam, at lake level about 1,200 feet upstream of the dam, and in nearly continuous lake-level exposures beginning about 2,000 feet upstream. These outcrops indicate that bedrock likely occurs at shallow depths beneath the glacial deposits along this portion of the reservoir rim.

The west reservoir rim, about 1,200 feet upstream of Elwha Dam, was examined for evidence of the landslide noted in the two sets of bathymetry for Lake Aldwell. No evidence for active landsliding or soil creep was noted. The ground surface was free of cracking or fissuring, indicative of distress in the subsurface materials. Regrowth of the forest has progressed well since the last phase of logging (approximately 1930) and no evidence for toppling trees was observed in the several stands of large timber examined. The assumption that the forebay landslide may have developed in response to loss of the reservoir in 1912 would mean that none of the present stands of trees would have existed at the time of slope failure. A photograph (dated November 10, 1934) in the James River II, Inc. files shows the west slopes of Lake Aldwell were extensively clear cut, as does a later but undated photograph. Large tree stumps, 3 feet or more in diameter, are scattered throughout the west slope of the lake, indicating long-term stability of the rim materials.

2b. The “Gooseneck” Area — During the landslide reconnaissance, the large rock promontory that projects out into Lake Aldwell from the west shore near the midpoint of the lake was also examined (see figure 4). The “gooseneck” portion of the reservoir is cut into massive bedrock with precipitous, nearly vertical cliffs lining much of the shoreline. The main body of the promontory is connected to the west shoreline by a steep, narrow saddle forming a knife-like ridge 10-feet-or-less wide at its crest. This saddle area is heavily overgrown and variably mantled with a veneer of soil. No evidence of fissuring was observed in either the bedrock outcrops or in the soil mantle, nor were any tilted trees observed to indicate that any landslide movement has occurred in the “gooseneck” area in the recent past.

The rock promontory appears to be in-place bedrock. The trend of the rock outcrop generally parallels the bedrock promontory on which Elwha Dam is sited and could represent a structurally controlled bedrock feature. If the “gooseneck” is a landslide, it must be a large glide-block that would have detached from the west slope and moved down into the Elwha River virtually intact. Evidence for such large-scale movement is not readily discernable in the heavily timbered slope above the promontory. If this feature is a glide-block failure, it is most probably an ancient feature that may have been triggered by a large-magnitude earthquake. Such a mechanism has been postulated for a series of massive landslides that have naturally dammed Indian Creek and formed Lake Sutherland and Lake Crescent, both located a few miles west of Lake Aldwell (Logan and Schuster, 1991).

2c. Lake Aldwell Perimeter — The entire perimeter of Lake Aldwell, with the exception of the area immediately adjacent to the delta, was examined by boat to identify existing or potential landslide areas. Several suspect areas were examined in further detail on foot to determine geologic conditions. No active or potential landslide areas were identified during this reconnaissance. The west (left) shore of the lake from the boat launch at the upstream end to the “gooseneck” area is composed almost entirely of compact glacial sediments that appeared to be stable and shows no evidence of movement. The west shore from the “gooseneck” to Elwha Dam is also free of any evidence for landsliding, as discussed above. The east shore from the dam upstream to the “gooseneck” consists of more gently sloping topography than observed on the west side. The east shore is heavily timbered, overgrown, and outcrops of any kind are few. No evidence of landslide movement or potential for movement was noted in this reach. The rest of the east shoreline from the “gooseneck” upstream to the delta is comprised of rock outcrops with occasional areas obscured by vegetation.

2d. Indian Creek Landslide — A small, active landslide was noted along the county road to the Lake Aldwell boat launch from U.S. Highway 101. The slide area is located about 1,000 feet upstream from the boat launch. A stand of young deciduous trees ranging from 15-30 feet in height marks the location of this slide. Continuing movement has impacted the county road and caused subsidence in the outside lane immediately above the Indian Creek slough. This slide area does not appear to involve a large volume of material, but does represent a source of ongoing maintenance for the county road.

3. Landslide Considerations — The presence of a landslide in the upstream of Elwha Dam raises a number of issues meriting further discussion in relation to the dam removal project. These considerations may affect both short-term impacts related to construction activities during the dam removal process and longer-term impacts to sediment management and water quality control.

3a. Reservoir Sediment Removal — The forebay landslide forms a natural dam approximately one-half the height of Elwha Dam and will prevent downstream migration of reservoir sediments from both Lake Aldwell and Lake Mills. Migration of sand and coarser-grained sediments from Lake Aldwell could only take place once erosion has cut through the landslide to the elevation of the sediments. The rate of natural erosion is contingent on the composition of the landslide material and discharge rates for the Elwha River. Depending on the size of material present in the landslide and inflow rates into Lake Aldwell, natural erosion of the slide debris could extend the period needed to move the coarse sediments out of the reservoir basin by several years. An examination of the slope above the landslide area and analysis of the topography of the landslide mass suggest that the slide is composed of chiefly granular glacial sediments. These sediments would be expected to erode naturally under free-flowing river conditions.

Mechanical excavation of the landslide may be required to ensure that coarse sediment migration from Lake Aldwell occurs within desired time constraints in order to minimize impacts to downstream fisheries and water users. Mechanical excavation would likely require a barge equipped with a clamshell or dragline excavator. Site access via land would require lowering the reservoir level and allowing drying of the lakebed sediments followed by temporary access road construction from the dam site. These activities would be expected to require a significant block of time and could extend the construction schedule for dam removal. The materials comprising the landslide are expected to be saturated and are likely to run into the excavation area, especially sand and fines. A considerable amount of excavation may be needed to reach a stable angle of repose for the landslide debris. Slope stability is difficult to estimate without subsurface data on the composition, engineering properties, and in-place condition of the landslide materials. The limited data presently available suggest that the landslide would likely attain some degree of stability at a slope of 3 to 1 (horizontal to vertical) or flatter. Additional investigation of the landslide is required before geotechnical analyses of the slide can be completed.

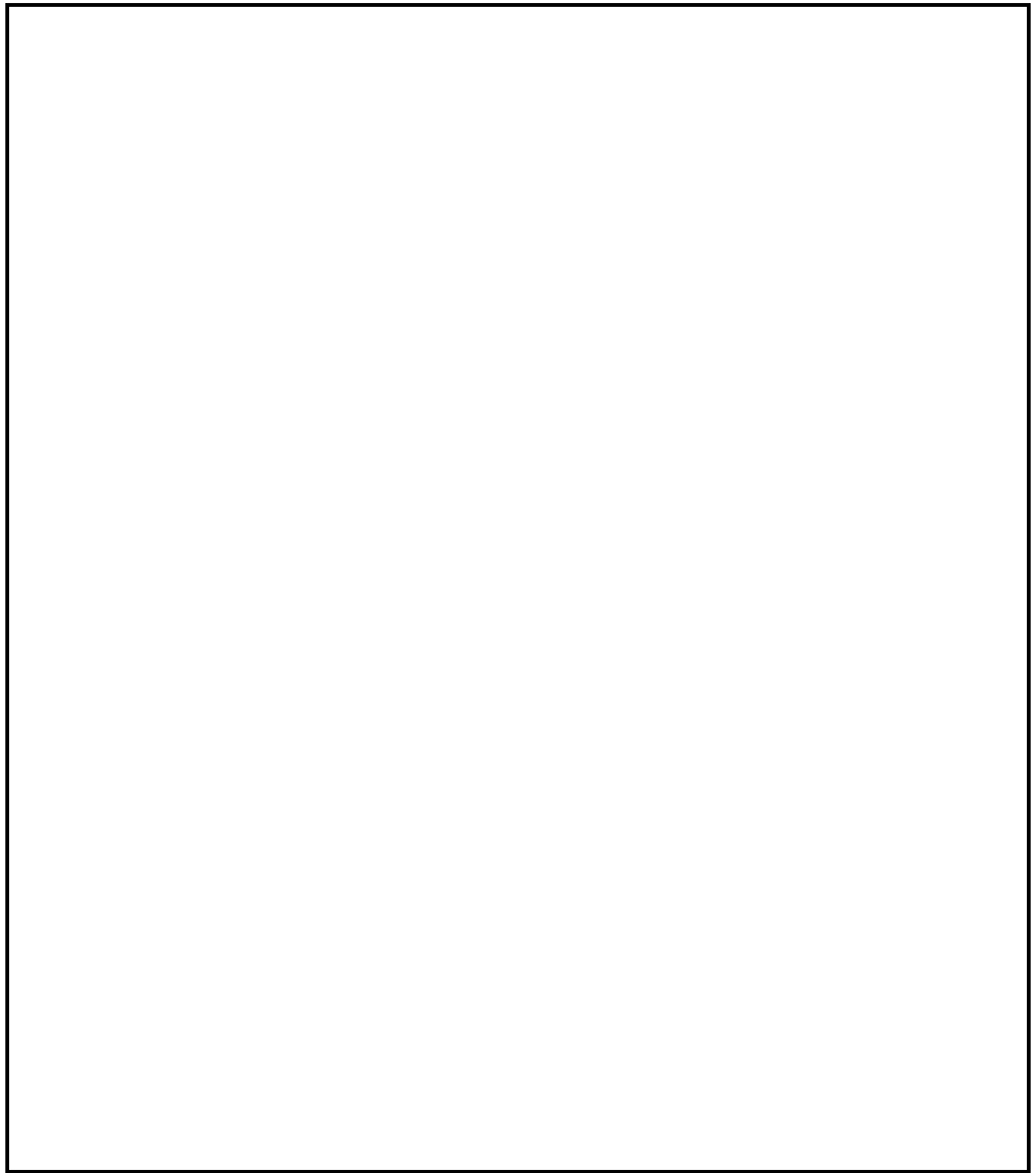
3b. Stability of Natural Dam — A potential exists for a failure of the forebay landslide dam under the static load of the Lake Aldwell remnant either during latter stages of dam removal or shortly thereafter. The size of the lake remnant that would be impounded by the landslide is largely dependent on the rate at which the slide material can be eroded and the volume of inflow through the lake basin. Under rapid erosion and/or high inflow conditions, the Elwha River would be expected to downcut rapidly through the slide mass and any resulting lake remnant should be fairly small in extent. A relatively large remnant of Lake Aldwell may impound against the landslide dam under conditions of slow erosion, low inflow, or both. Present understanding of the landslide indicates it is a young feature and probably has experienced reservoir loading for at most one year, if the landslide resulted from draining of the reservoir during the foundation failure in 1912. The stability of the landslide could be further jeopardized during a large flood event which would almost instantaneously increase the static load on the landslide dam. The stability of the landslide is difficult to assess at present due to the lack of quantitative data about the materials comprising the slide mass and their engineering properties. Impacts to construction at Elwha Dam and downstream interests could be large depending on the stage of construction activity and the level of the remnant lake.

3c. Reservoir Drawdown Rate — It may be prudent to limit the drawdown rate for Lake Aldwell during dam removal to reduce the potential for reactivation of existing landslides and prevent

development of new sliding at other locations along the reservoir rim. Lack of detailed information on the composition of the materials comprising the forebay landslide makes it difficult to evaluate the drawdown rate of the reservoir at the present time. A criteria of 1.5 feet-per-day maximum drawdown has been developed by Reclamation where landslides are present on a number of reservoirs that are drafted for power generation. This drawdown rate has been very effective in reducing landslide risks. Additional geotechnical investigation of the forebay landslide and other high-risk areas may be required before an acceptable reservoir drawdown rate can be identified. The need for geotechnical investigations should be considered as part of any final data collection studies that may be needed prior to completion of construction designs. Other factors should be considered when establishing a reservoir drawdown criteria, including flooding potential for property adjacent to the existing river channel downstream of the dam. Also, impacts to the downstream infrastructure need to be considered, such as the Elwha Road bridge, the intake to the City of Port Angeles-Daishowa America water supply, and the proposed water treatment plant.

3d. Long-term Stability/Sediment Source — Long-term resource management of the Lake Aldwell lands should recognize the potential for continuing slope failures at the forebay landslide due to downcutting across the landslide's toe by the Elwha River. Erosion of the landslide would contribute to downstream sediment aggradation and impact water quality of the river. Episodic failures of the landslide would be expected to produce higher concentrations of suspended and bedload sediment than normal background levels and could impact downstream water treatment facilities. Considerable erosion may be required until the slide area attains some degree of stability.

Stabilization of the landslide may be possible by constructing a buttress across the toe area. Such a buttress would also reduce the effect of river erosion and could be used as a disposal area for concrete and shot rock excavated at the dam, reducing the size of off-site disposal areas required for the project.



CHAPTER IV. CONCLUSIONS AND RECOMMENDATIONS

A. ELWHA DAM FOREBAY

The gravel conglomerate bedrock beneath the left (north) spillway appears to be a suitable foundation for the temporary diversion channel, as indicated by rock outcrops in the vicinity of the dam and drill hole data obtained from the forebay explorations. Excavation through the conglomerate will require controlled blasting techniques and should be expected to produce stable, nearly vertical cut slopes. The fractured bedrock produced by the 1913 blasting may locally inhibit the effectiveness of shots for the temporary diversion channel excavation and could also result in local overexcavation outside the lines and grades designed for the channel.

The configuration of the original Elwha River Canyon may need to be further defined in order to prepare final volume estimates of fill excavations in the forebay and to layout final slope restoration and revegetation plans once the dam has been removed. The most cost-effective means to define the canyon profile would be through a number of seismic surveys throughout the forebay area. These surveys should readily define the top of bedrock due to the relatively low density of the fill materials in comparison to the conglomerate bedrock. Seismic surveys are relatively inexpensive when compared to drilling investigations.

The only viable source identified for production of the rockfill needed to make a stability berm at the downstream toe of the gravity dam section is the temporary diversion channel excavation in the left spillway area. Commercial sources of rock do not exist within the local area. The rockfill has commercial value and, after removal of Elwha Dam, could be stockpiled offsite pending future sale to local customers.

The forebay upstream from Elwha Dam was backfilled with material nearly 100 feet deep in efforts to restore the reservoir after the foundation failure of 1912 and subsequent efforts to reduce seepage through the foundation. The bottom of this fill section consists of about 56,000 yd³ of shot rock 2 to 40 tons in size that is reported to be mixed with an unspecified volume of earthfill. The shot rock has commercial value as riprap and rockfill due to the lack of viable rock sources in the local area and could be stockpiled for later resale. Some processing of the shot rock may be needed to remove earthfill components or to reduce large blocks into more manageable sizes.

The fill materials overlying the shot rock consist largely of various types of granular earth materials and should be readily removed using common excavation techniques. These fill materials could be salvaged and stockpiled for later processing and sale as aggregate or various types of sand and gravel products. Handling and processing costs may preclude resale due to competition from the large number of commercial suppliers of these materials already present in the Port Angeles-Sequim area. Present cost estimates prepared for dam removal list the fill materials as waste scheduled for disposal. The fill is known to include woody debris, including the 1913 fir mattresses, which could be segregated and burned prior to disposal of the fill.

B. LAKE ALDWELL LANDSLIDES

Bathymetry of the Lake Aldwell forebay obtained by Reclamation in September 1994 indicated the presence of an irregular, hummocky landslide mass that completely blocks the channel of the Elwha River about 700 feet upstream from Elwha Dam. The forebay landslide had a minimum length of about 125 feet with a maximum width of about 110 feet. The thickness of the slide mass ranged from 43–70 feet. The volume of the landslide has been estimated at 15,000 yd³. The landslide is likely composed of granular sand, gravel, and cobbles with silt and boulders derived from continental glacial deposits upslope of the submerged slide mass. An apparent lack of surface erosion by the Elwha River suggests that the landslide is relatively young and likely dates from the construction period for Elwha Dam or later. An examination of the slope above the forebay landslide did not find any indication of continuing slope movement in the area.

The forebay landslide is a natural dam about one-half the height of Elwha Dam. Migration of sediments from Lake Aldwell cannot occur until the Elwha River has re-established its channel through the landslide mass. Mechanical excavation of the landslide may be required to ensure timely sediment migration, reduce impacts to downstream fish habitat, and maintain project schedules.

After the draining of Lake Aldwell, continuing slope failures at the forebay landslide should be expected as the Elwha River downcuts the toe of the landslide. Long-term resource management of the river should recognize that the contribution of landslide materials to sediment loads could impact downstream habitat and water quality. Stabilization of the landslide may be required to minimize these impacts. Construction of a buttress across the landslide toe would reduce erosion and could provide a disposal area for concrete and shot rock removed at Elwha Dam, reducing requirements for off-site disposal areas.

Additional geotechnical investigations may be required as part of final design data collection for the project. This is necessary to evaluate the rate of natural erosion through the forebay landslide, the stability of the slide mass under static loads applied by a remnant reservoir remaining during dam removal, and possible limitations to reservoir drawdown rates during removal of Elwha Dam.

A reconnaissance-level review of Lake Aldwell did not locate other areas of significant active or potential landsliding. A landslide-like feature observed about 1,200 feet upstream of Elwha Dam does not have topographic expression upslope of the lake. Both the forebay landslide and this larger, upstream feature appear to be localized in extent. A large rock promontory forming a “gooseneck” in Lake Aldwell near its midpoint appears to be in-place bedrock or possibly an ancient, glide-block landslide that now appears to be stable. A small, active landslide was noted about 1,000 feet upstream of the Lake Aldwell boat launch along the county access road. Impacts to the project from this landslide are minimal and relate primarily to maintenance of the county road to the Lake Aldwell boat ramp.

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