Chapter 1

Coastal and Lower Elwha River, Washington, Prior to Dam Removal—History, Status, and Defining Characteristics

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Abstract

Characterizing the physical and biological characteristics of the lower Elwha River, its estuary, and adjacent nearshore habitats prior to dam removal is essential to monitor changes to these areas during and following the historic dam-removal project set to begin in September 2011. Based on the size of the two hydroelectric projects and the amount of sediment that will be released, the Elwha River in Washington State will be home to the largest river restoration through dam removal attempted in the United States. Built in 1912 and 1927, respectively, the Elwha and Glines Canyon Dams have altered key physical and biological characteristics of the Elwha River. Once abundant salmon populations, consisting of all five species of Pacific salmon, are restricted to the lower 7.8 river kilometers downstream of Elwha Dam and are currently in low numbers. Dam removal will reopen access to more than 140 km of mainstem, flood plain, and tributary habitat, most of which is protected within Olympic National Park. The high capture rate of river-borne sediments by the two reservoirs has changed the geomorphology of the riverbed downstream of the dams. Mobilization and downstream transport of these accumulated reservoir sediments during and following dam removal will significantly change downstream river reaches, the estuary complex, and the nearshore environment. To introduce the more detailed studies that follow in this report, we summarize many of the key aspects of the Elwha River ecosystem including a regional and historical context for this unprecedented project.

Introduction

Coastal environments are among the most important ecological components of Puget Sound, a large fjord-estuary in northwestern Washington State. The more than 3,000 km of Puget Sound shoreline is classified into a diverse array of forms according to geologic, oceanographic, and anthropogenic features (Shipman, 2008). Common forms include rocky coasts, beaches, bluffs, embayments, and deltas. Puget Sound and the Georgia Basin are part of the Salish Sea (fig. 1.1), which is fed by rivers in the Cascade Range and Olympic Mountains. These rivers carry melt water from glaciers, snowmelt, and local rainfall. This inland marine water body is connected to the Pacific Ocean by the Strait of Juan de Fuca to the west and the Strait of Georgia to the north. Characterized by a relatively young tectonic- and glacier-influenced geology, spatially variable oceanography, and unevenly distributed levels of urban and anthropogenic impacts, Puget Sound is home to a diverse array of biological communities and charismatic species (Buchanan, 2006; Dethier, 2006; Kriete, 2007; Mumford, 2007; Penttila, 2007; Strickland, 1983). The regions where rivers flowing into Puget Sound meet salt water (sub-estuaries within the greater Puget Sound fjord-estuary) are an especially important habitat type, particularly for salmon, an iconic natural, cultural, and economic symbol for the region (Simenstad and others, 1982).

As an interface between fresh and salt waters, river-mouth estuaries and their surrounding habitats are among the most productive and biologically rich ecosystems on Earth (Goldman and Horne, 1983; Keddy, 2000). The river-mouth estuaries of Puget sound are both dynamic and complex because they are influenced by physical forcings from the Pacific Ocean (such as wave action, currents, and upwelling of nutrients), seasonally and annually varying levels of river inputs (such as sediment, nutrients, and freshwater), and local and large-scale climatological forcings (Moore and others, 2008). The diverse biological communities present in these areas also have complex responses, interactions, and feedbacks with these physical factors. Added to this natural physical and biological variability are human influences that have dramatically altered the amount, quality, and distribution of estuarine habitats throughout the region (Collins and Sheikh, 2005; Todd and others, 2006). Reconstructions of the distribution and size of historical coastal habitats, compared with their current condition, show a dramatic reduction in the amount of river-mouth estuarine and wetland habitat, approaching more than 95 percent loss in some areas. A suite of human drivers, which include industrial and non-point source pollution, resource extraction, recreation, and development affect the remaining estuarine wetlands. Nevertheless, the intact estuarine habitats play an important role in the life history of many species, especially juvenile salmonids, because these young fish reside in river-mouth estuaries during their migration from freshwater rearing areas to the sea (Beamer and others, 2003; Fresh, 2006). Estuarine habitats are believed to offer more protection from predation and higher growth potential compared to alternative nearshore habitats. Exposure of the juvenile salmonids to estuarine salinity gradients also facilitates their physiological transition from freshwater to salt water.

Recently, there has been increased focus on restoring Puget Sound ecosystems and these efforts have highlighted the estuarine ecosystems' capacity to support biodiversity, commerce, and recreational opportunities, despite various impacts and threats to overall system health (Puget Sound Partnership, 2009). The U.S. Geological Survey (USGS) multi-disciplinary Coastal Habitats in Puget Sound (MD-CHIPS) initiative was developed to promote interdisciplinary collaboration among scientists studying Puget Sound ecosystems, with the goal of developing research efforts focused on priorities identified by stakeholders, management agencies, and the public for the restoration and preservation of Puget Sound (Gelfenbaum and others, 2006). To date, MD-CHIPS science has focused on three areas: (1) the effects of urbanization on nearshore ecosystems, (2) restoration of large river deltas, and (3) the recovery of nearshore ecosystems (U.S. Geological Survey, 2006). This report summarizes the research and monitoring activities of MD-CHIPS scientists and partners relating to the Elwha River restoration project.

The Elwha River flows northward from the heart of the Olympic Mountains to the Strait of Juan de Fuca west of Port Angeles, Washington. The Elwha River restoration involves the largest dam removal project to date in the United States and provides the unprecedented opportunity to study the ecological effects of dams and the removal of these dams as an ecosystem restoration technique (Hart and others, 2002; Duda and others, 2008). Although characterized as a restoration project, many of the ecosystem responses and trajectories following dam removal may be novel and precisely predicting ecological outcomes is challenging. Thus, it is imperative that this restoration project is monitored and studied closely, so that ecosystem responses can be characterized and predictive techniques can be advanced. The MD-CHIPS project was developed to characterize the physical and biological characteristics of the Lower Elwha River, its estuary, and nearshore habitats prior to dam removal with the understanding that these characteristics would provide important baseline conditions for comparisons following dam removal. To introduce the more detailed studies that follow in this report, many of the key aspects of the Elwha River ecosystem are summarized here including a regional and historical context for this unprecedented project.

Figure 1.1. The Salish Sea, which includes the Strait of Juan de Fuca, Strait of Georgia, Puget Sound, and the Olympic Peninsula, Washington and British Columbia, Canada. (Used with permission [Freelan, 2009])

Elwha River Dam Removal and River Restoration Project

The Elwha River, on the Olympic Peninsula of Washington State, offers a unique opportunity for restoration because 83 percent of the watershed lies within Olympic National Park (ONP), a World Heritage site (accessed March 12, 2011, at http://whc.unesco.org/en/list) and International Biosphere Reserve (United Nations Educational, Scientific and Cultural Organization, 2010; fig. 1.2). Restoration of the Elwha River was congressionally mandated by The Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495) and represents the single largest river-restoration project currently (2011) planned for the greater Puget Sound region. Moreover, the Elwha River restoration project will be the largest dam-decommissioning project in the history of the United States in terms of the projected release of sediment and the size of the existing hydroelectric projects. Decommissioning will involve simultaneous removal of the Elwha Dam (32 m high, constructed from 1910 to 1913 at river kilometer [RKm] 7.9; fig. 1.3) and Glines Canyon Dam (64 m high, completed in 1927 at RKm 21.6; fig. 1.4). These actions offer the unique opportunity to assess the effectiveness of a large dam removal in restoring the watershed and recovering and salmon populations. The upper Glines Canyon Dam and its reservoir Lake Mills are in the National Park, whereas the lower Elwha Dam and its reservoir Lake Aldwell are in an area of mixed ownership and land use (fig. 1.5).

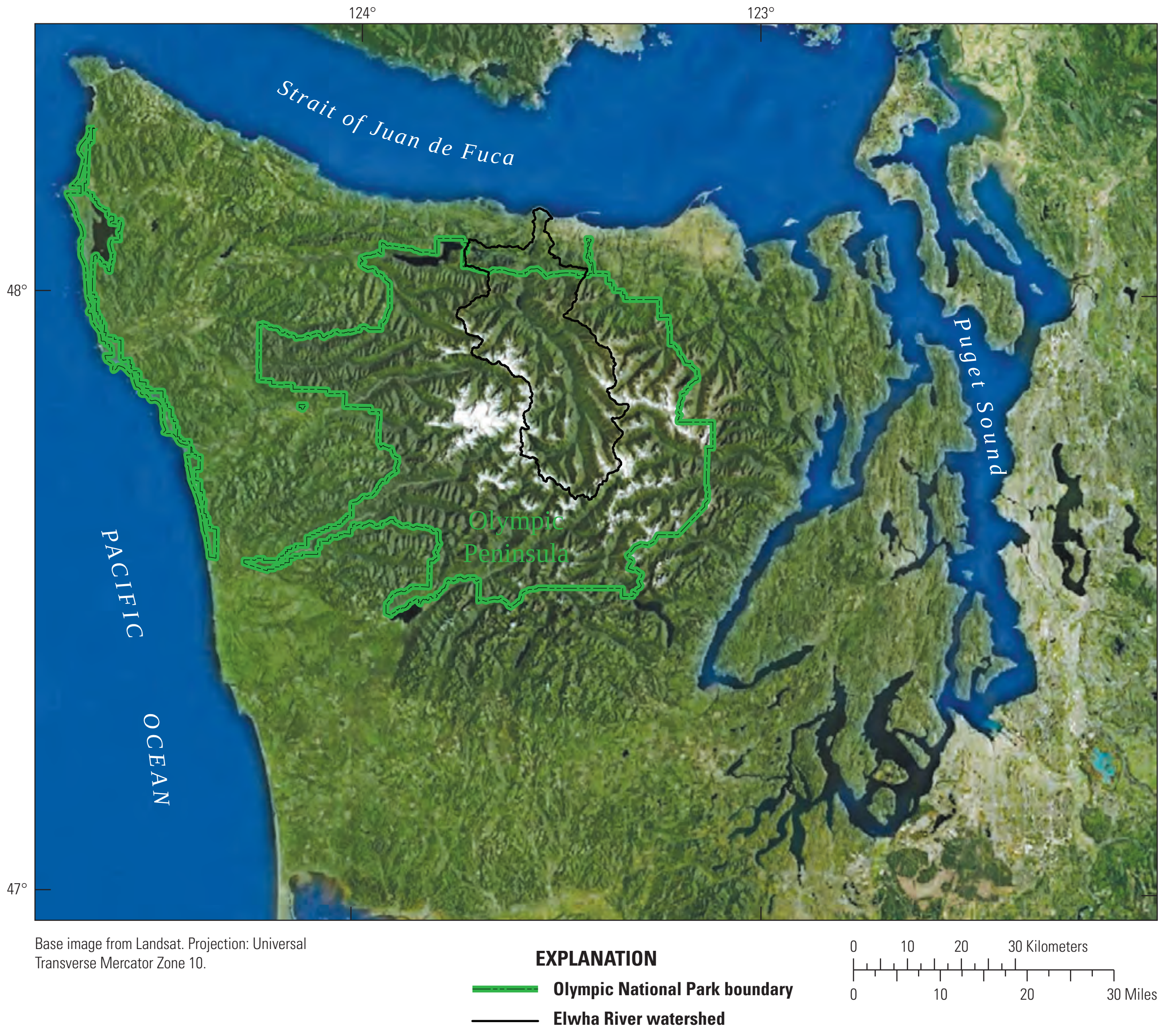


Figure 1.2. Aerial photograph showing view of the Olympic Peninsula and Puget Sound, Washington, showing the Elwha River watershed and the boundaries of Olympic National Park.

Figure 1.3. Diagram and photographs showing the Elwha Dam, Washington, completed in 1913. (*A*) Elwha Dam is a concrete gravity dam with adjacent buttress-type intake sections flanked by spillways. (*B*) The dam measures 32 meters high and is 137 meters wide at its crest. (*C*) The dam creates the Lake Aldwell reservoir. (*D*) A large delta of sediment deposits has formed at the head of the reservoir.

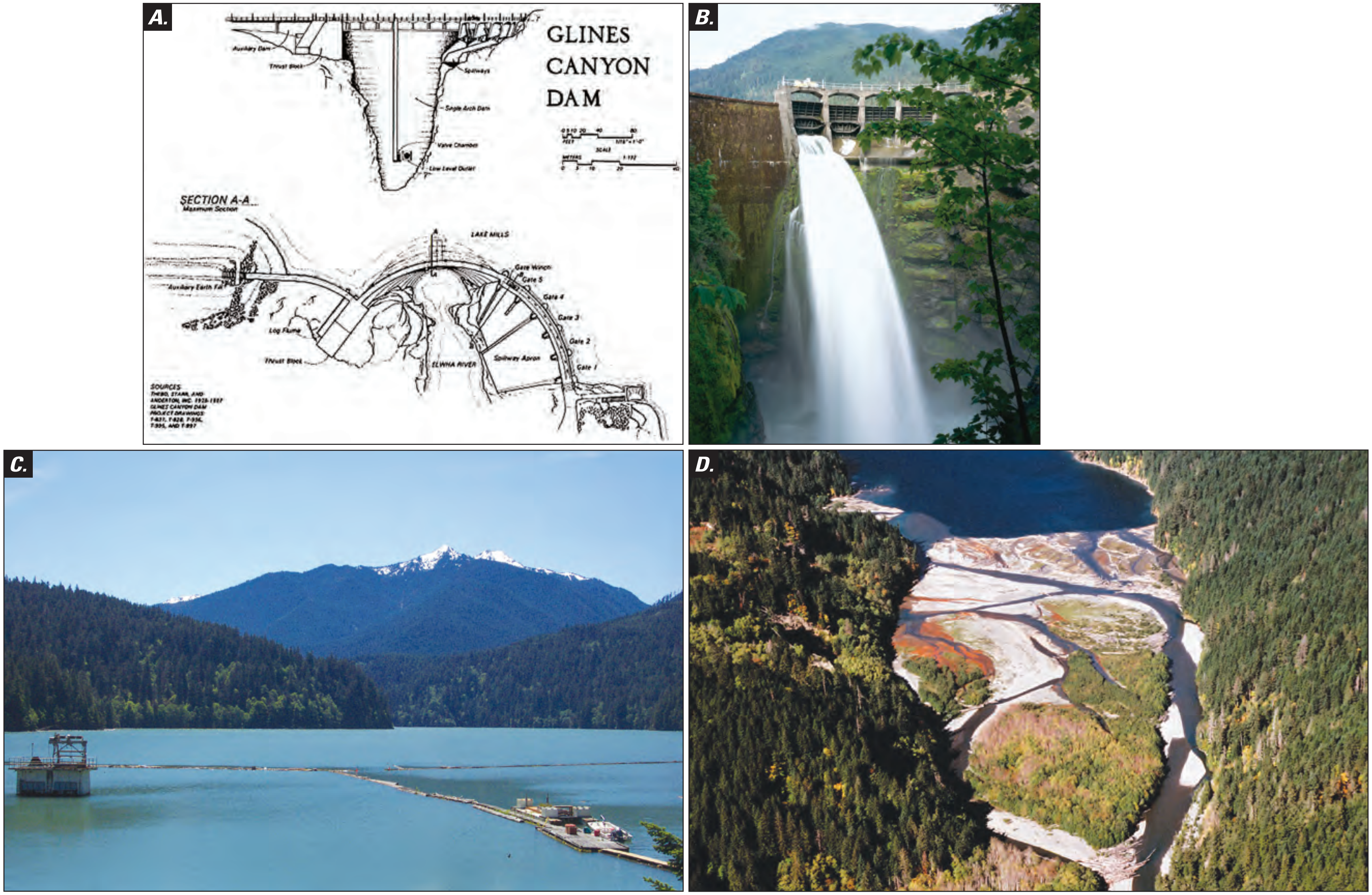


Figure 1.4. Diagram and photographs showing the Glines Canyon Dam, Washington, completed in 1927. (*A*) Glines Canyon Dam is a varied radius, single arch concrete dam. (*B*) The dam measures 64 meters high and width varies from 15.8 meters at its base to 82.3 meters at its crest. The dam is currently (2011) operated as run-of-the-river (equivalent flows entering the reservoir from the Elwha River are released from spillways). (*C*) The dam creates the Lake Mills reservoir. (*D*) A large delta of sediment deposits has formed at the head of the reservoir. (Photograph *B* by Scott Church, private citizen, used with permission, date unknown.)

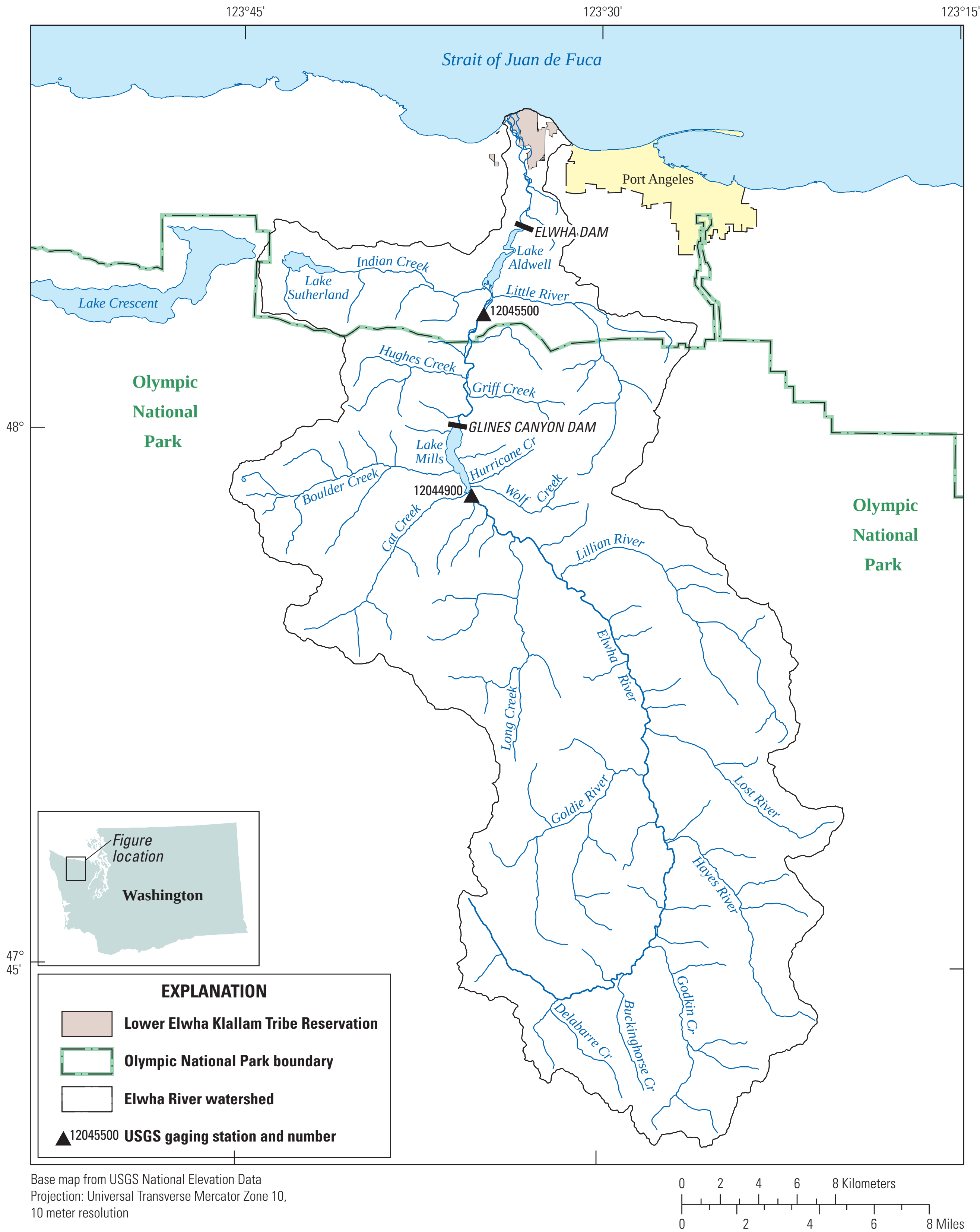


Figure 1.5. Elwha River watershed, northern boundary of Olympic National Park, major tributaries, Lower Elwha Klallam Tribe Reservation, Elwha Dam (Lake Aldwell), Glines Canyon Dam (Lake Mills), and City of Port Angeles, Washington.

Constructed without fish-passage structures, the dams have altered the size and composition of salmon populations in a river that once produced 10 distinct runs, comprised of steelhead trout (*Oncorhynchus mykiss*) and all 5 species of Pacific salmon—Chinook (*O. tshawytscha*), coho (*O. kitsutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye (*O. nerka*). Also affected were sea-run cutthroat trout (*O. clarki*), anadromous bull trout (*Salvelinus confluentus*), eulachon (*Thaleichthys pacificus*), and lamprey (*Lampetra tridentata*), which have life cycles that also require migration to or from freshwater. Salmon populations downstream of Elwha Dam currently are estimated at about 1 percent of their pre-dam numbers (U.S. Department of the Interior, 1995a); the amount of spawning habitat has steadily decreased during the decades following dam construction (Pess and others, 2008). This degradation of spawning habitat has been caused by a massive reduction in the supplies of sand and gravel to the lower river from the sediment trapping effects of the two reservoirs, which in turn has resulted in a coarsening of the riverbed with time. Two fish hatcheries operated by the State of Washington Department of Fish and Wildlife (Chinook salmon) and the Lower Elwha Klallam Tribe (coho, steelhead, and chum) supplement salmon populations. Four fish species (Puget Sound Chinook, steelhead, eulachon, and bull trout) in the Elwha are federally listed as threatened under the U.S. Endangered Species Act.

Construction of the Elwha and Glines Canyon Dams fundamentally changed the Elwha River ecosystem, including its estuarine and nearshore components. Similar changes due to dam construction have occured in other rivers around the world (Baxter, 1977; Petts, 1984). Because of a high sediment trapping capacity (Curran and others, 2009), most of the sediment load transported by the upper Elwha River has accumulated in the two reservoirs. Surveys conducted in 1994–95 determined that approximately 11 million m^3 of sediment had accumulated in Lake Mills (upper dam) and had accumulated behind the lower dam in Lake Aldwell (Randle and others, 1996). The latest estimate (2010) of combined sediment volume in both reservoirs is about 19 million m^3 (Bountry and others, 2010; Czuba and others, 2011, chapter 2, this report). Other changes caused by the dams include increased armoring and channelization in parts of the river downstream of each dam; increased in median particle size (Pohl, 2004; Morley and others, 2008, Draut and others, 2011); increased average age of riparian flood plain forests (Kloehn and others, 2008); and some decreased flood plain complexity and lateral migration of the main channel (Draut and others, 2008; 2011). Geomorphic changes have affected instream benthic invertebrate assemblages and patterns of periphyton standing crop (Morley and others, 2008), as well as salmon populations (Wunderlich and others, 1994; Brenkman and others, 2008; Connolly and Brenkman, 2008; Pess and others, 2008). Another component of functioning flood plain river systems, large woody debris (Abbe and Montgomery, 1996; Latterell and others, 2006), also has been intercepted by the reservoirs (although dam operators regularly pass rafted logs through the dams), further changing flood plain dynamics and fish habitat downstream of each reservoir. However, efforts by the Lower Elwha Klallam Tribe to place engineered log jams in the lower Elwha River has helped rehabilitate some areas (Coe and others, 2006, 2009; see also side bar in Warrick and others, 2011a, chapter 3, this report).

Dam Removal and Release of Sediment Stored in Reservoirs

Mobilization and downstream transport of sediments currently (2011) accumulated in the reservoirs (figs. 1.3*D*, 1.4*D*) during and following dam removal is expected to significantly change downstream river reaches, the estuary complex, and the nearshore environment to the west (Freshwater Bay) and east (Ediz Hook) of the river mouth (fig. 1.6). Studies of the reservoir sediment composition (U.S. Department of the Interior, 1995b; Randle and others, 1996; Childers and others, 2000) indicated that 85 percent and 95 percent (in Lake Mills and Lake Aldwell, respectively) was sand, silt, and clay. A portion of this fine sediment will be readily transported during and immediately after dam removal (Randle and Bountry, 2008). Based on numerical model studies (Randle and others, 1996) and a 1995 reservoir draw down experiment in Lake Mills (Childers and others, 2000), extremely high suspended-sediment concentrations could occur in the Elwha River following dam removal. A simulation model by Konrad (2009) suggests that during the 2- to 3-year deconstruction period, the suspended-sediment concentration in the river could exceed 10,000 mg/L for several weeks each year, with periodically high concentrations for as much as 3–5 years following dam removal, depending upon hydrological conditions (Randle and others, 1996). Anticipation of high-suspended sediment concentrations led to development of unprecedented mitigation measures for the restoration project, including construction of two new water-treatment facilities, the planned suspension of reservoir

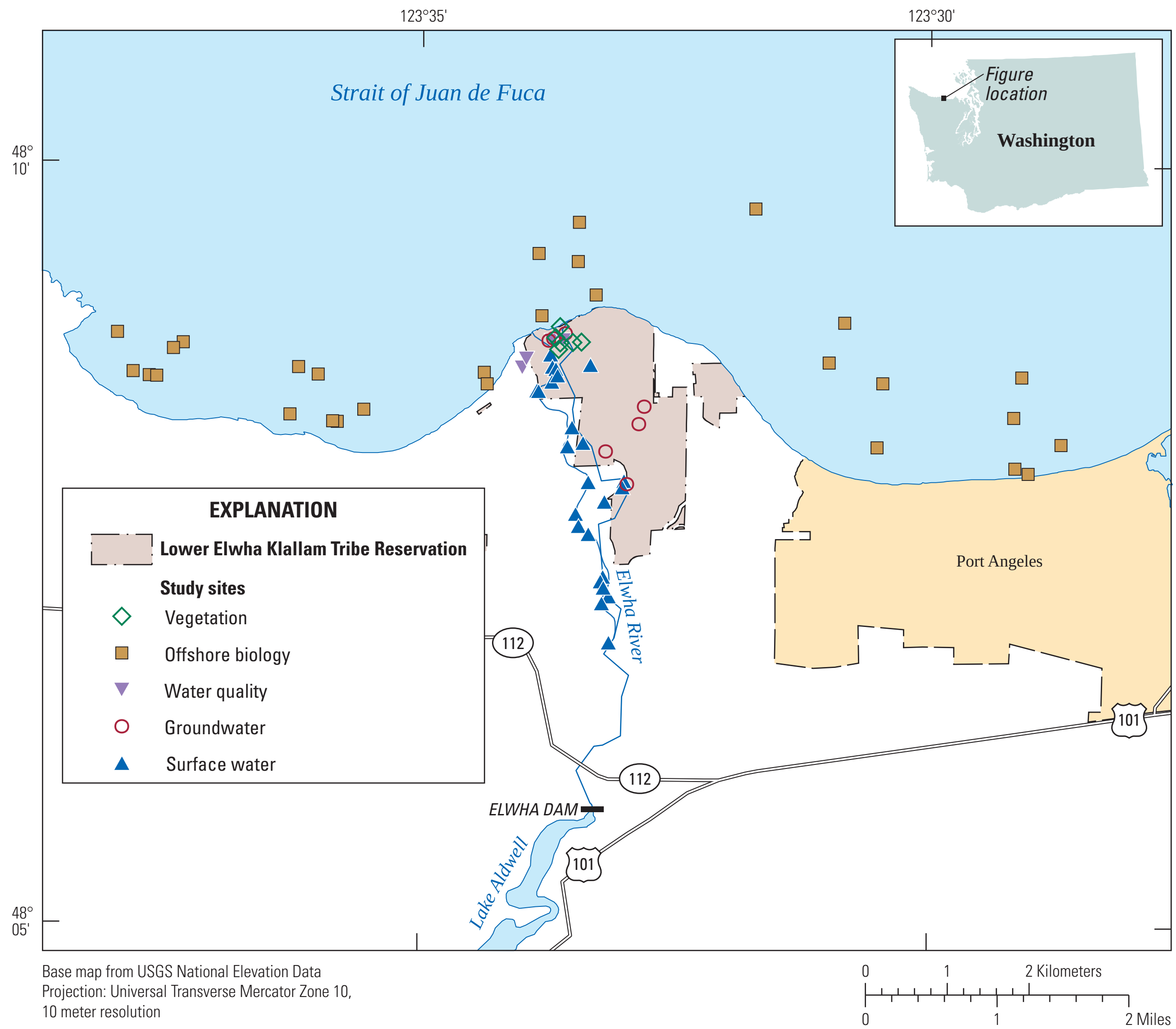


Figure 1.6. Estuary and nearshore study sites, lower Elwha River, Washington. Samples were collected by the U.S. Geological Survey multi-disciplinary Coastal Habitats in Puget Sound team and the Lower Elwha Klallam Tribe.

drawdown when salmon would be affected ("fish windows"), and operation of conservation hatcheries to protect native fish stocks. Over the long-term, the Elwha River bed downstream of the dams is expected to aggrade by as much as 1 m in some areas (U.S. Department of the Interior, 1996; Konrad, 2009), requiring additional mitigation measures such as raising existing flood-protection levees, construction of new levees, and transitioning sewage treatment on the Elwha Klallam Tribal reservation from septic to municipal (City of Port Angeles). Additional details of sediment delivery are provided by Czuba and others (2011), in chapter 2 of this report.

Upon entering the Strait of Juan de Fuca, sediment will be dispersed by waves and tidal currents and deposited on the sediment-starved beaches and seafloor of the Elwha delta (see Warrick and others, 2011, chapter 5, this report). After decades of sediment reduction due to the dams, the nearshore seafloor has coarsened (Warrick and others, 2008) and appears to have developed benthic communities characteristic of coarse sediment and hard bottom substrate (Rubin and others, 2011, chapter 6, this report). Release of massive amounts of fine sediment during and following dam removal will have unknown affects on bottom communities in the nearshore and deep water habitats off the river mouth. The ultimate fate of these sediments depends on complex interactions among waves, currents, and the freshwater plume of the Elwha River (Gelfenbaum and others, 2009; Warrick and Stevens, 2011). Once sediment supply is restored and a long-term equilibrium is reached, the coastal environment will still be affected by other anthropogenic features. For example, coastal bluff armoring that results in a reduced coastal sediment supply (Shaffer and others, 2008) still will be present following dam removal.

The development of key monitoring needs, hypotheses, and the appropriate spatial and temporal scales for data collection and analysis benefited from a series of scientific workshops (Clallam County Marine Resources Committee, 2004; Stolnack and Naiman, 2005; Stolnack and others, 2005; Randle and others, 2006; see also summary in Woodward and others, [2008]). Among the many study designs available for evaluating restoration actions (Roni and others, 2005), the most common study design for the various Elwha River related projects is an intensive "before and after" (BA) approach, although others are using a, "before-after control-impact" (BACI) approach where appropriate control sites exist. The former approach relies on replicating data collection through time from multiple sites over multiple years before dam removal, subsequently returning to these sites for multiple years following removal to measure responses. Strictly speaking, an ideal experimental design would require replication of the treatment (dam removal) in multiple locations. Practically speaking, the Elwha River dam removal is the only such project of its kind in the greater Puget Sound region. Thus, replication is available only within the treatment (termed pseudoreplication by Hurlburt [1984]) and results must be assessed through multiple lines of evidence.

The other approach, a BACI design, incorporates experimental and control treatments (sites). This allows the researcher to account for natural variability in a parameter of interest that is occurring at both sites, which allows a differentiation of these effects from treatment effects. Because there are numerous parameters of interest in the Elwha River restoration project, ranging from terrestrial to aquatic and biological to physical (each of these operating at different spatial scales), there is no single effective "control" site for the Elwha River. For some studies, the Quinault River has been used (Kloehn and others, 2008; Morley and others, 2008) due to its similar watershed area, slope, and discharge (McHenry and Pess, 2008). Others have used the Elwha River upstream of Lake Mills as a reference section (Draut and others, 2008, 2011; Kloehn and others, 2008) for physical processes. Overall, these design constraints necessarily limit the statistical power available to assess the effects of dam removal. However, as Roni and others (2005) point out, valuable knowledge can result from unreplicated BA and BACI designs couched in the framework of a case study, combining multiple lines of inquiry.

Comparison of Regional Estuaries

Estuaries are semi-enclosed water bodies with a connection to the ocean, where freshwater from a river mixes with seawater. In western North America, these estuaries can be highly variable in their size, origin, and functions. Although Puget Sound is the second largest estuary in the United States, most estuaries on the U.S. Pacific coast are relatively small (less than 100 km^2 in area), especially those that drain the steep mountainous terrain in coastal ranges (Emmett and others, 2000). On the Olympic Peninsula, river mouth estuaries and their wetland complexes typically are less than 1–2 km^2 (Todd and others, 2006).

Comparing the river-mouth estuaries of the coastal Olympic Peninsula, the Strait of Juan de Fuca, and the Puget Sound (fig. 1.7) is instructive to highlight the differences in sizes, geomorphologies, and hydrologic conditions. These differences influence the biological conditions among these sites, which can vary considerably. For visual comparisons of these estuaries, we used 2009 aerial imagery from the U.S. Department of Agriculture National Agriculture Imagery Program (NAIP), displayed at 1:24,000 or 1:85,000 scales. The side-by-side comparisons of the river mouth estuaries on the Olympic Peninsula (Hoh, Queets, Quinault, Elwha, and Dungeness Rivers) show that they each cover a relatively small area, with limited off-channel aquatic habitat and virtually non-existent tidal flats (fig. 1.8). The widths of river mouths along the Pacific coast are generally larger than those within the Strait of Juan de Fuca and differences in wave energy are also apparent from the size and extent of breaking waves in the photographs (fig. 1.8; see also Warrick and others, 2011b, chapter 5, this report). The Puget Sound river mouth estuaries, however, are somewhat larger than their coastal counterparts. The Skagit River estuary (fig. 1.9) is the largest of the eight presented in fig. 1.7. In addition to its larger size, a higher diversity of estuarine habitat types is apparent, with complex assemblages of tidal flats, tidal marshes, and tidally influenced distributary channels. Likewise, the Snohomish and Nisqually river mouth estuaries (fig. 1.10) are larger and more diverse than the estuaries of the Olympic Peninsula, although both are smaller than the Skagit.

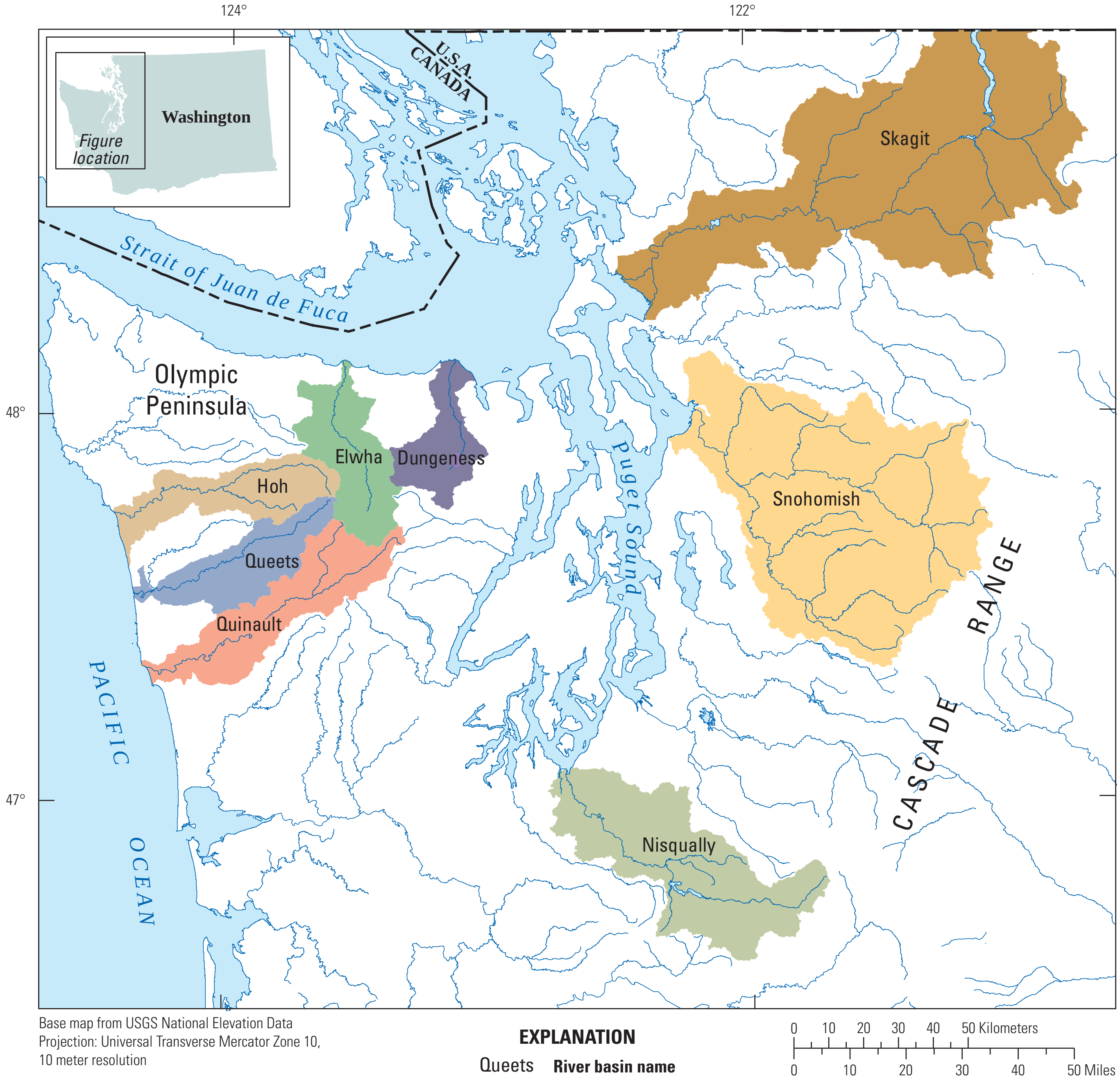
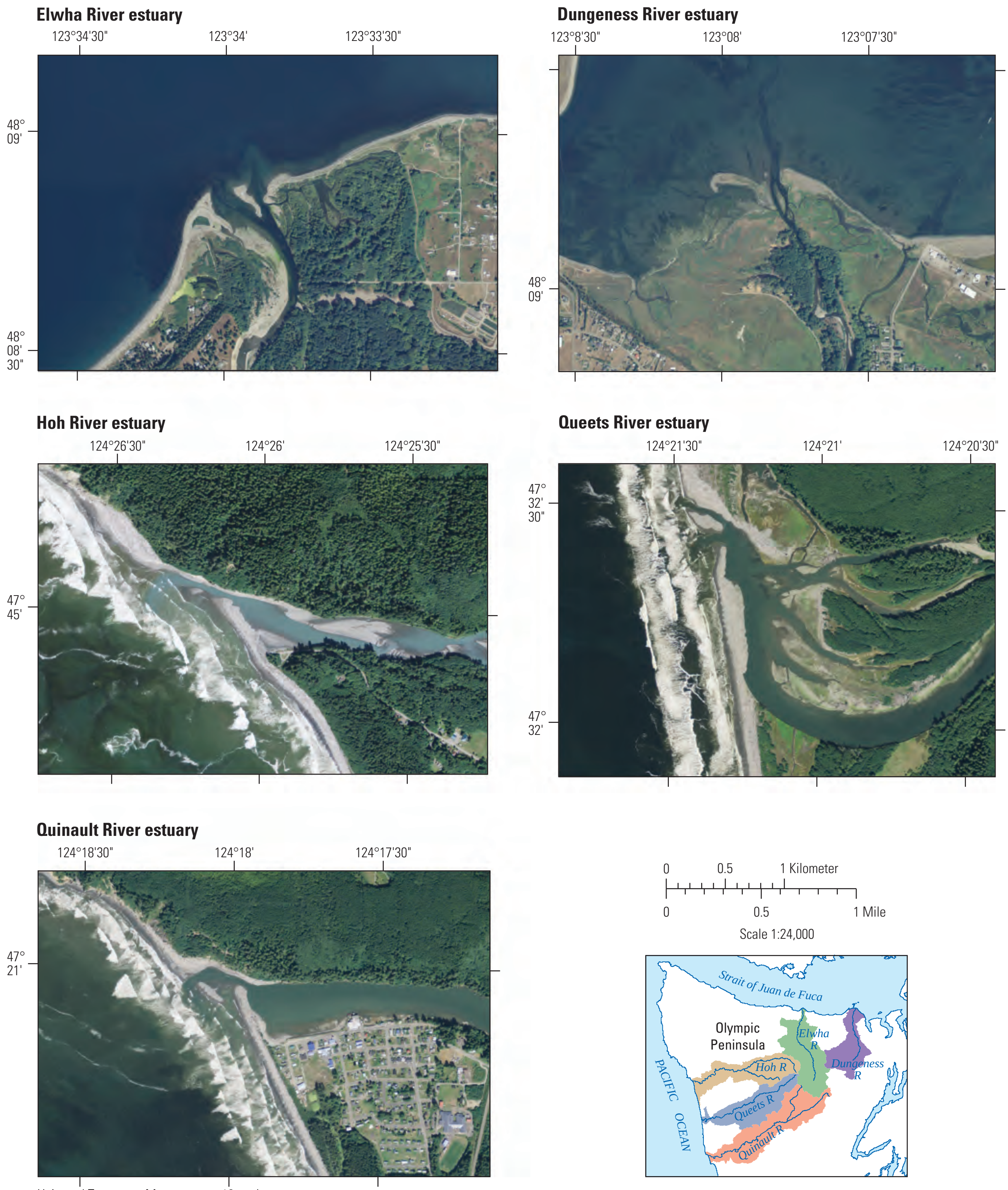


Figure 1.7. Location of eight river watersheds used to compare the size of river mouth estuaries in the Puget Sound and Olympic Peninsula, Washington.



Universal Transverse Mercator zone 10, and U.S. Department of Agriculture NAIP (National Agricultural Imagery Program) 2009 imagery

Figure 1.8. Aerial images showing five river mouth estuaries of the Olympic Peninsula, Washington.

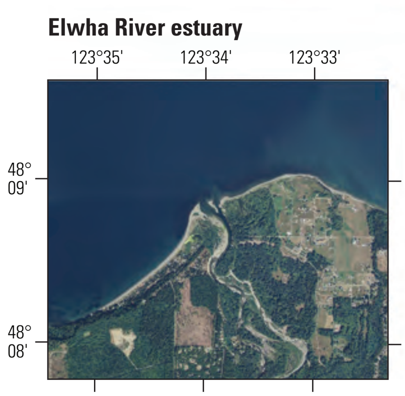


Figure 1.9. Aerial images comparing the size of the Skagit River and the Elwha River estuaries, Washington.

Figure 1.10. Aerial images of the Snohomish River and Nisqually River estuaries, Washington.

The Elwha River Estuary: History and Definitions

The mouth of the Elwha River has undergone substantial change over the historical record as sediment sources were curtailed by the dams. Further change resulted from human modification and natural river processes, such as channel meandering and avulsion. The earliest written accounts of the lower Elwha River are from the late 19th and early 20th centuries. Todd and others (2006) suggested that the Elwha River had previously discharged into the Strait of Juan de Fuca through several distributary channels. For example, the General Land Office survey of 1874 noted at least three distributary channels, and an 1891 U.S. Army map and the 1908 U.S. Coast and Geodetic Survey topographic maps showed two channels (Todd and others, 2006).

The number of distributary channels of the Elwha River mouth was reduced to a single channel for most of the 20th century (Todd and others, 2006; Draut and others, 2008). Humans are largely responsible for these changes, due to active modification of the flood plain and channel between the 1940s and 1980s (Draut and others, 2008), as well as from the reduced sediment supply from damming. Human modifications included physical movement of the channel and levee building on both sides of the flood plain. The effects of these modifications can be seen, as an example, in the formation and persistence of Dudley Pond on the west side of the river mouth (fig. 1.11), which was created through the construction of a flood-control levee in 1964 through the middle of the active river mouth (Draut and others, 2008).

A. Western Elwha River estuary

B. Dudley Pond

Figure 1.11. (*A*) West Elwha River estuary and (*B*) the northern shore of Dudley Pond showing bloom of green algae common for this location during summer, near Port Angeles, Washington. ([*A*] Aerial photograph taken by Ian M. Miller, University of California, Santa Cruz, January 14, 2009; [*B*] photograph taken by Jeffrey J. Duda, U.S. Geological Survey October 10, 2007.)

Throughout the 20th century, the Elwha River channel continued to change its position in response to lateral meander migration and episodic avulsion. These natural processes resulted in annualized rates of channel movement of approximately 2–10 m/yr. Some of the highest rates of channel movement were along the lowest 3 km of the river, including the river mouth, an area characterized by low stream gradient and a broad flood plain (Draut and others, 2008; 2011). These historical changes to the lower Elwha River (discussed in detail in Warrick and others, 2011a, chapter 3, this report) are central to the formation and evolution of the river mouth estuary, the coastal wetlands, and the habitats and ecosystem functions they support. For example, most of the coastal lakes along the Elwha River delta, which serve as important rearing habitat for salmon, are former river channels cut off from the current channel by avulsions. The dynamic history of the Elwha River and its flood plain plays an important role in the formation and evolution of the lower river and estuary ecosystem.

The total wetland complex at the mouth of the Elwha River is approximately 0.35 km^2 (table 1.1). The western area of this complex (0.10 km^2) is comprised of two main wetland components (referred to herein as the west estuary). The 0.028 km^2 remnant of the historical estuary—known locally as Dudley Pond (fig. 1.11B)—is contained by the 275 m levee discussed above. The other major feature of the west estuary is a 0.068 km^2 off-channel habitat on the eastern side of the levee that is influenced by river stage and tides. Although groundwater exchange and tidally influenced seepage maintain some degree of connectivity between this habitat and the river channel, the impounded Dudley Pond appears to have limited hydrological connectivity to the Elwha River or the ocean.

Table 1-1. Study areas and descriptions for coastal areas and lower Elwha River, Washington.

Study area name	Description
Elwha River	
Lower Elwha River	The tidally influenced part of the Elwha River near its mouth.
East estuary	
ES1	A part of the eastern estuary complex nearest to the river's mouth. This area was a larger, lentic water body, prior to winter storms in November, 2006 that eroded much of the habitat.
ES2	A large lentic waterbody east of ES1. This is a former river mouth channel that is tidally influenced standing water.
Intraestuarine Channel	A channel that connects ES1 and ES2 that is tidally influenced and flows to the east on a rising tide and to the west on an ebbing tide.
Bosco Creek	A spring-fed perennial water source flowing into the eastern side of ES2. This water source is connected to the Lower Elwha Klallam Tribal Hatchery and receives outflow from rearing ponds.
Western Estuary	
Dudley Pond	A disconnected water body west of a privately constructed dike on the western part of the estuary.
West Estuary Channel (WESC)	A slough (secondary distributary channel) bordered to the west by the dike that is confining Dudley Pond
Nearshore	
Freshwater Bay	The nearshore west of the Elwha River mouth
Ediz Hook	The eastern boundary of the Elwha River nearshore east of the river mouth
West Beach	The beach west of the Elwha River mouth
East Beach	The beach east of the Elwha River mouth

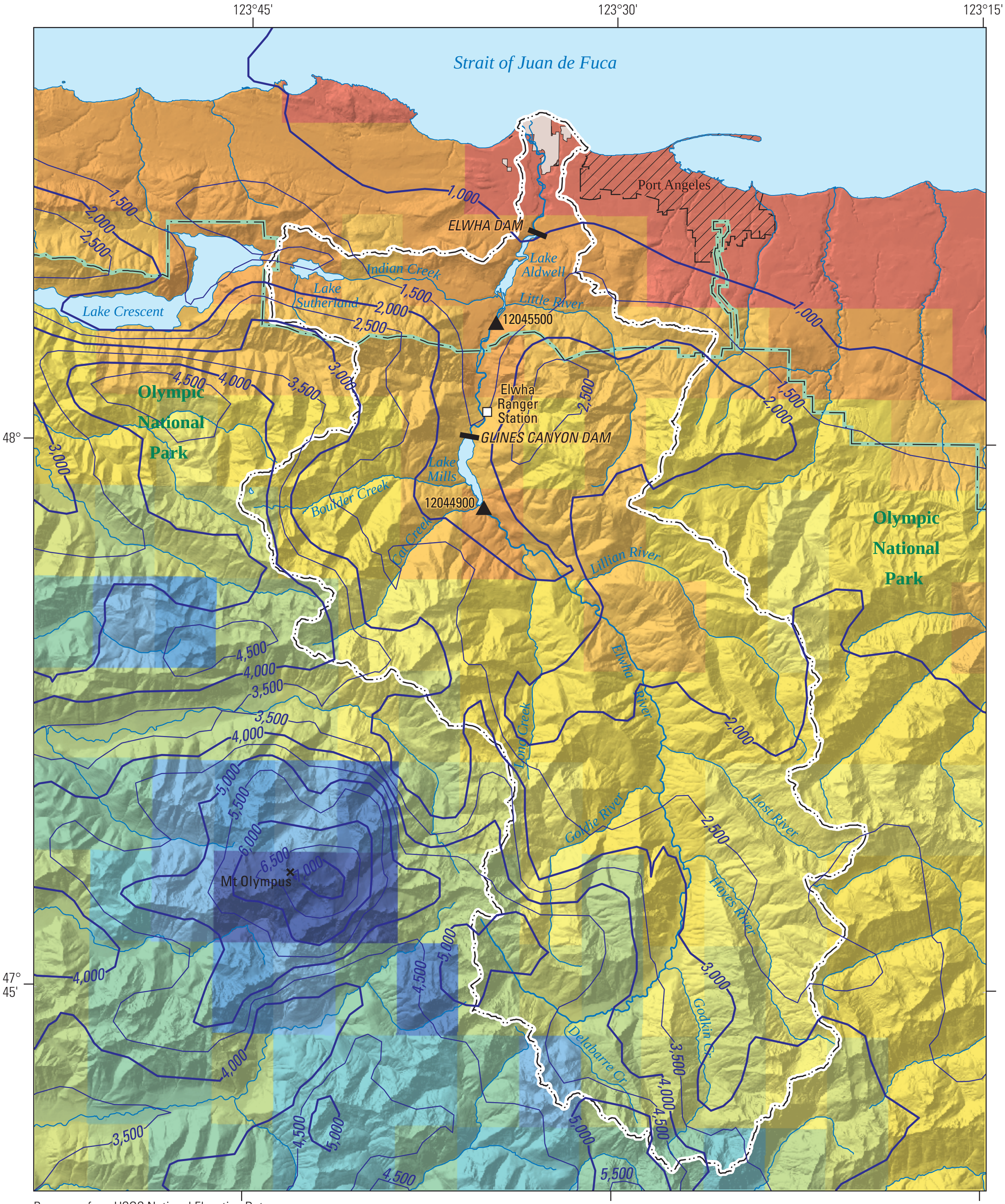
The levee eliminates access to the pond by migrating fish. Resident fish consist largely of a single species, the threespine stickleback (*Gasterosteus aculeatus*) (Shaffer and others, 2009). The east estuary is 0.25 km^2 and is composed of interconnected lagoons and interestuarine channels (fig. 1.12). An important source of freshwater to the east estuary is from Bosco Creek, a spring-fed freshwater source that also serves as the supply and outflow of the Lower Elwha Klallam Tribe's fish hatchery. A mosaic of vegetation south of the beach includes mixed hardwood forests and willow thickets. Vegetation communities of the Elwha River estuary are described by Shafroth and others (2011), chapter 8 of this report.

Figure 1.12. (*A*) East Elwha River estuary and (*B*) beach berm looking south. ([*A*] Aerial photograph taken by Ian M. Miller, University of California, Santa Cruz, March 28, 2008; [*B*] photograph taken by Jeffrey J. Duda, U.S. Geological Survey, October 20, 2007.)

Hydrology of the Elwha River and its Estuary

The climate of the Elwha River basin is characterized by warm, dry summers and cool, wet winters. Most precipitation at upper elevations falls as snow with rain predominating below elevations of about 1,200 m. Because the Elwha River watershed spans the rain shadow created by Mount Olympus and the Bailey Range, the drainage contains the steepest precipitation gradient on the Olympic Peninsula (fig. 1.13). Mean annual precipitation is more than 6,000 mm on Mount Olympus near the headwaters of the Elwha River and about 1,000 mm at the river mouth. Long-term weather records (1948–2005) from the Elwha Ranger Station (approximately RKm 18.2, 110 m elevation) indicate an average annual precipitation of 1,430 mm (Western Regional Climate Center, 2007); most precipitation falls from October through March (fig. 1.14).

Discharge of the Elwha River has been monitored continuously by the USGS since 1918 at McDonald Bridge (streamflow-gaging station 12045500, Elwha River at McDonald Bridge near Port Angeles, WA); the site also was monitored from 1897 to 1901. The gaging site, 7.9 km downstream of Glines Canyon Dam and 13.8 km upstream of the river mouth, has a total drainage area of 697 km^2, 84 percent of the total Elwha River drainage area. Prior to 1975, the discharge at McDonald Bridge was strongly influenced by, "...frequent, rapid, and dramatic stream flow fluctuations for power generation purposes" (U.S. Department of the Interior and others, 1994, p. 8). Between 1975 and 2000, as part of a settlement agreement with the Washington Department of Fisheries, Glines Canyon Dam and Elwha Dam were operated largely as run-of-river by managing discharge at the dams to equal river flow entering the reservoir. Since March 2000, the Bureau of Reclamation, with National Park Service oversight, has operated both projects as run-of-river, except during September and October when lower river flows have been augmented by drafting Lake Mills at the request of the Washington Department of Fish and Wildlife and Lower Elwha Klallam Tribe (Brian Winter, Olympic National Park, written commun., 2010).



Base map from USGS National Elevation Data
Projection: Universal Transverse Mercator Zone 10,
10 meter resolution

0 2 4 6 8 Kilometers
0 2 4 6 8 Miles

EXPLANATION

- Lower Elwha Klallam Tribe Reservation
- Olympic National Park boundary
- Elwha River watershed
- ▲12045500 USGS gaging station and number
- 1,000 **Precipitation contour**—Index contour at 1,000 feet, interval is 500 feet

Annual precipitation, in millimeters

- 250 to 1,000
- 1,000 to 1,500
- 1,500 to 2,000
- 2,000 to 2,500
- 2,500 to 3,000
- 3,000 to 3,500
- 3,500 to 4,000
- 4,000 to 4,500
- 4,500 to 5,000
- 5,000 to 5,500
- 5,500 to 6,000
- 6,000 to 6,500
- 6,500 to 7,000
- 7,000 to 7,500

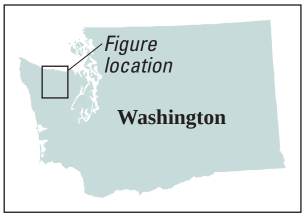
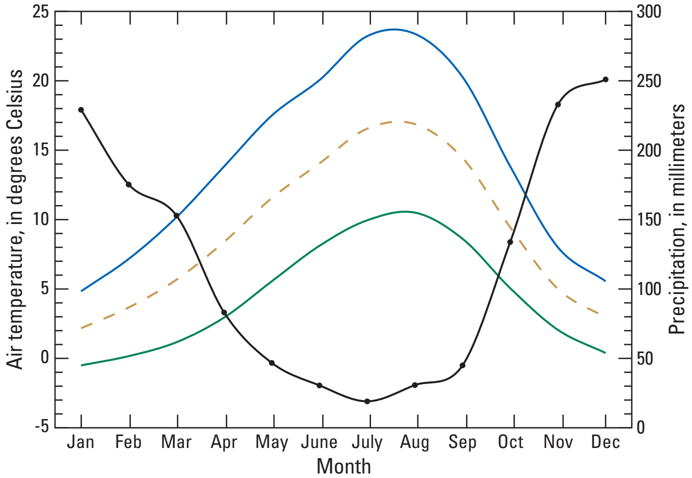


Figure 1.13. Map showing isohyetal contours of annual precipitation across the Elwha River watershed, Washington. Estimated precipitation data from PRISM Climate Group (2010).



EXPLANATION

- Air temperature
- **Precipitation**
  - Maximum
  - Average
  - Minimum

Figure 1.14. Graph showing annual trends in air temperature and precipitation in the Elwha River watershed, Washington, June 1948–December 2005. Long-term monthly averages, maximum and minimum air temperatures, and precipitation recorded at the Elwha Ranger Station (RKm 18.2) at an elevation of 110 m. Modified from Duda and others (2008).

The mean annual discharge for the river at the McDonald Bridge gaging station (12045500) is 43 m^3/s (1,520 ft^3/s) based on 95 years of discharge data. Elwha River discharge is bimodal with a peak discharge in the wet winter months due to rainfall and a peak discharge in the late spring and early summer due to snowpack melt (fig. 1.15). The two months with the largest mean monthly discharge are June with 63 m^3/s (2,230 ft^3/s) and December with 60 m^3/s (2,120 ft^3/s). Typically, the smallest flow is in September, with a mean monthly discharge of 11 m^3/s (388 ft^3/s). Extreme low flows often are calculated using a log Pearson Type III approach (Hann, 1977) to determine statistical limits of minimum discharge. For the Elwha River, the 10-year recurrence-interval 7-day low discharge is 7 m^3/s (247 ft^3/s).

The maximum recorded discharge of 1,180 m^3/s (41,600 ft^3/s) occurred November 18, 1897, and seven annual peak discharges in the record were greater than 800 m^3/s (28,300 ft^3/s) (fig. 1.16). The second largest peak of 1,020 m^3/s (35,900 ft^3/s) occurred December 3, 2007, affording researchers the opportunity to observe the Elwha River response to a significant discharge event. All the recorded annual peak discharges have occurred between October and April, and 78 percent of the peak discharges occurred between November and January, consistent with climatology of rivers throughout western Washington (Mass, 2008).

Annual exceedance probabilities (AEP) of peak discharge (also known as flood recurrence intervals) were calculated using the annual peak-discharge record of the Elwha River at McDonald Bridge weighted according to variance (Tim Cohn, U.S. Geological Survey, written commun., 2010) using a regional regression equation for the Elwha River (Sumioka and others, 1998) (table 1.2). The size of the 0.50 AEP event (2-year flood) is 400 m^3/s (14,100 ft^3/s), the size of the 0.04 AEP event (25-year flood) is 948 m^3/s (33,500 ft^3/s), and the size of the 0.01 AEP event (100-year flood) is 1,240 m^3/s (43,700 ft^3/s) (fig. 1.17). These flood-frequency calculations included the peak discharges in 1897 and 2007 as well as the influence of retention capacity of Lake Mills. After the Glines Canyon Dam is removed and the capacity to attenuate the flood hydrograph is lost, peak flows are expected to be slightly larger. Using the watershed regression estimates of Sumioka and others (1998), the 0.01 AEP event (100-year flood) for the Elwha River at McDonald Bridge without the presence of the dam would be about 1,400 m^3/s (49,100 ft^3/s), 10–15 percent greater than peak discharges moderated by the reservoir capacity.

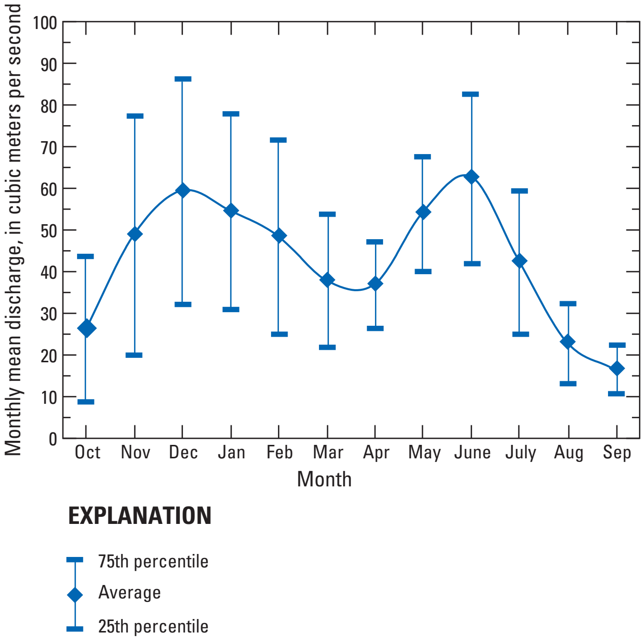


Figure 1.15. The 25th percentile (lower bars), median (50th percentile, diamonds), and 75th percentile (upper bars) of monthly mean discharge as measured at U.S. Geological Survey streamflow-gaging station 12045500, Elwha River at McDonald Bridge near Port Angeles, Washington.

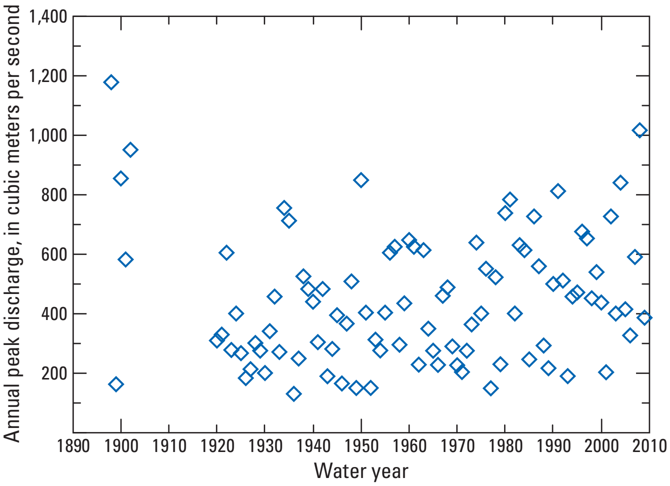


Figure 1.16. Annual peak discharges measured at U.S. Geological Survey streamflow-gaging station 12045500, Elwha River at McDonald Bridge near Port Angeles, Washington.

Table 1.2. Flood-frequency discharge magnitudes calculated for the Elwha River at USGS streamflow-gaging station 12045500, Elwha River at McDonald Bridge near Port Angeles, Washington.

[**Abbreviations:** m^3/s, cubic meter per second; ft^3/s, cubic foot per second]

Annual exceedance probability	Recurrence Interval (years)	Discharge (m^3/s)	Discharge (ft^3/s)
0.5	2	400	14,100
0.1	10	752	26,600
0.04	25	948	33,500
0.02	50	1,090	38,500
0.01	100	1,240	43,700

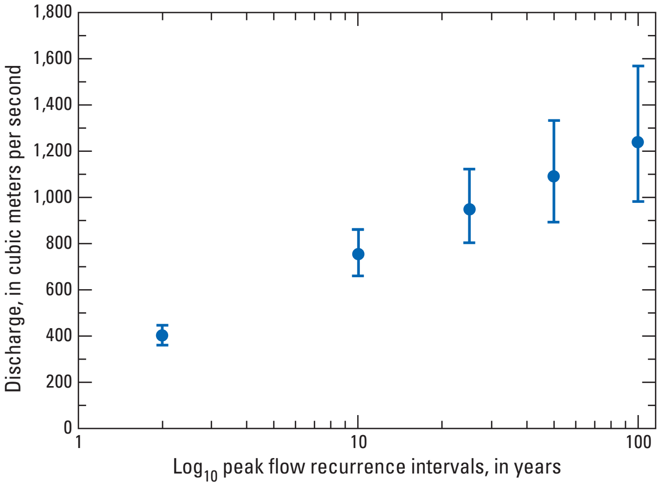


Figure 1.17. Weighted recurrence-interval peak flows calculated for the Elwha River at U.S. Geological Survey streamflow-gaging station 12045500, Elwha River at McDonald Bridge near Port Angeles, Washington, with the upper and lower 95 percent confidence intervals.

Summary

Over the past century, the Elwha River ecosystem has undergone substantial changes due to the presence of the Elwha and Glines Canyon Dams. Dam removal will cause the Elwha River and its coastal environments to change once again as sediments are released from the reservoirs following dam removal and salmon recolonize the watershed. Recent scientific studies conducted in anticipation of dam removal have described the current condition of the river and coastal ecosystems. This report provides a scientific snapshot of the lower Elwha River, its estuary, and adjacent nearshore ecosystems prior to dam removal, serving as a document that can be used to measure and evaluate the responses and dynamics of various ecosystem components following dam removal.

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