

# **HYDRAULIC AND GEOMORPHOLOGIC EVALUATION**

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## **Analysis of Wood Loading in the Ozette River and Its Effect on Water Levels in Lake Ozette, Clallam County, Washington**

Prepared for

Makah Indian Tribe  
Makah Fisheries Management

September 2005

**Note:**

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Prepared for

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Makah Fisheries Management  
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September 9, 2005





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## Executive Summary

Lake Ozette is located on the Olympic Peninsula, in Clallam County Washington. Historic salmon harvest data for Lake Ozette indicate that sockeye salmon (*Oncorhynchus nerka*) likely numbered over ten thousand fish per year. In the 1950s, the Lake Ozette sockeye salmon harvest data indicate a precipitous decline in sockeye abundance for both harvest and presumably escapement. Sockeye harvest and escapement have remained at low levels throughout the last fifty years (Haggerty et al. in preparation). On March 25, 1999, the Lake Ozette sockeye salmon population was listed as threatened under the Endangered Species Act. Many factors likely contributed to the decline or continued depression of Ozette sockeye. One of the contributing hypotheses for the decline or continued depression of the population is the removal of wood from the Ozette River in the 1950s (and before) and the subsequent alteration of water levels and spawning habitat in Lake Ozette and its tributaries.

The Makah Tribe is interested in restoring the Lake Ozette sockeye salmon population. Makah Fisheries Management hired Herrera Environmental Consultants (Herrera) to study the impact of large woody debris in the Ozette River on water levels in Lake Ozette and the availability of spawning habitat along the Lake Ozette shoreline. Thus, the primary objective of this study was to assess the effect of logjams in the Ozette River on the magnitude and duration of water levels in Lake Ozette during salmon spawning and incubation periods. This study also included an evaluation of historical changes in the Lake Ozette shoreline due to vegetation encroachment after the removal of wood from the river.

The results of this study indicate that logjams in the Ozette River significantly affect the magnitude and duration of lake levels in Lake Ozette during spawning and incubation seasons for Lake Ozette sockeye. The results also show that wood loading in this upper region of the Ozette River influence low and moderate lake levels, but to a smaller degree than for higher lake levels. However, the potential change in summer, or low, lake level due to wood loading, even if only moderate, could have a significant influence on the ability of vegetation to colonize shorelines during the summer. Likewise, associated winter lake levels under a wood-rich regime, coupled with increased wave energy, could help remove or prevent winter dormant shrub vegetation from persisting through the winter, as currently exists.

Given that the Lake Ozette sockeye salmon are currently listed as threatened, a proactive restoration approach is recommended to promote more rapid habitat recovery than the rate that would result from natural processes. A proactive approach using constructed logjams could also improve local habitat in the Ozette River, which was directly impacted by historic wood removal. The results of this study also indicate that vegetation has encroached significantly around the Lake Ozette shoreline. Therefore, restoration projects would be needed at selected sites along the shoreline to reestablish high-quality spawning habitat. Finally, an assessment of flood protection is warranted to evaluate potential flood inundation, identify risk areas, and recommend appropriate measures to provide needed protection that is compatible with environmental restoration.



## **Introduction**

Lake Ozette is located entirely within Olympic National Park in the northwest corner of the Olympic Peninsula, in Clallam County, Washington (Figure 1). It is the third largest natural lake in Washington State. Historic salmon harvest data for Lake Ozette indicate that sockeye salmon (*Oncorhynchus nerka*) likely numbered over ten thousand fish per year. In the 1950s, the Lake Ozette sockeye salmon harvest data indicate a precipitous decline in sockeye abundance for both harvest and presumably escapement. Sockeye harvest and escapement have remained at low levels throughout the last fifty years (Haggerty et al. in preparation). On March 25, 1999, the Lake Ozette sockeye salmon population was listed as threatened under the Endangered Species Act.

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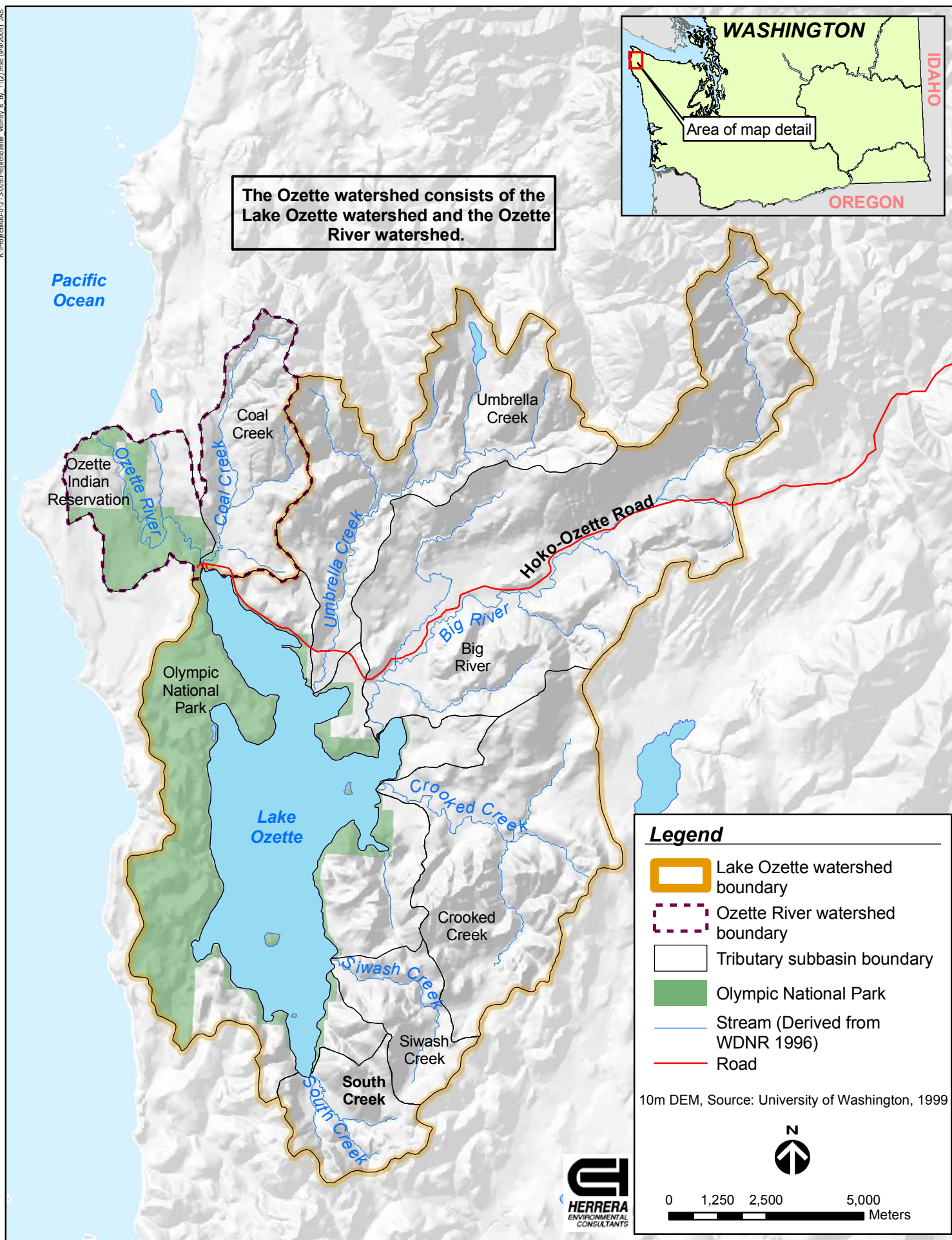
Many factors likely contributed to the decline or continued depression of Ozette sockeye (Haggerty et al. in preparation). One of the contributing hypotheses for the decline or continued depression of the population is the removal of wood from the Ozette River and the subsequent alteration of water levels and spawning habitat in Lake Ozette. Twenty six (26) large logjams were removed from the Ozette River in 1952 by the Washington Department of Fisheries (Kramer 1953), under the presumption that they blocked fish migration. In addition, an unknown amount of wood was removed from Ozette River prior to 1952 by settlers of the Ozette region. A subsequent change in water levels in Lake Ozette has been attributed to the removal of these logjams, as evidenced by widespread channel incision in the lower portion of tributary channels (Herrera 2005) and vegetation encroachment along the Lake Ozette shoreline since at least 1952. These direct and indirect consequences of wood removal may have degraded habitat conditions for sockeye and other depressed salmonids, such as chinook and chum in the Ozette River and all salmonids in the lake tributaries.

The primary objective of this study was to assess the role that large woody debris in Ozette River plays on controlling water levels in Lake Ozette, particularly during spawning and incubation periods of sockeye. Understanding the link between wood loading in the Ozette River and water levels in the lake is vitally important to developing a restoration strategy for Lake Ozette sockeye salmon. This study also included an evaluation of historical aerial photographs to quantify the degree of vegetation encroachment on the lake shoreline after the wood removal from the river. A companion study of the Ozette watershed performed by Herrera in 2005 for the National Park Service (Olympic National Park) assessed the role that watershed land management may have played in increasing sediment production, degrading tributary conditions, and potentially also influencing the decline (and precluding the recovery) of Lake Ozette sockeye salmon (Herrera 2005).

This report includes a discussion of the study findings and their implications for the recovery of Lake Ozette sockeye salmon. It is divided into six sections:

- Background Information
- Historical Changes in Lake Ozette Shoreline
- Hydraulic Modeling to Assess the Role of Logjams on Lake Levels
- Discussion and Conclusions
- Recommendations
- References.





**Figure 1. Vicinity map of the Ozette watershed and tributary subbasins, Lake Ozette and Ozette River watersheds, northwest Olympic Peninsula, Washington.**



## Background Information

This section provides a description of the physical attributes of the Lake Ozette system, including Lake Ozette, the Ozette River, and the six tributaries to Lake Ozette and Ozette River.

### General Description of Lake Ozette

Lake Ozette lies entirely within Olympic National Park, in the northwest corner of the Olympic Peninsula (Figure 1). Lake Ozette extends approximately 6 miles (10 km) from north to south and 2 miles (3 km) wide. With a surface area of 12.2 square miles (31.5 km<sup>2</sup>), Lake Ozette is the largest lake on the Olympic Peninsula and the third largest natural lake in Washington state. The mean surface elevation of the lake is approximately 34 feet (10.5 meters) above mean sea level (NGVD 1929) and annual lake level fluctuations range from 30.8 to 41.0 feet (9.4 to 12.5 meters) above mean sea level. The entire Lake Ozette watershed covers approximately 90.0 square miles (233 km<sup>2</sup>) and the area draining to Lake Ozette covers approximately 69.1 square miles (179 km<sup>2</sup>). The major tributaries that drain the watershed include Umbrella Creek, Big River, Crooked Creek, Siwash Creek and South Creek. A number of smaller tributaries drain slopes directly adjacent to the lakeshore. A sixth major tributary, Coal Creek, flows towards Lake Ozette at the north end of the lake. Instead of flowing into the lake, however, Coal Creek discharges to the Ozette River approximately 656 feet (200 meters) downstream from its head at the outlet of the lake.

The Ozette River is the largest river in the Lake Ozette watershed and is the only outflow from the lake. It begins at the northwest tip of the lake and flows approximately 4.7 miles (7.6 kilometers) to the northwest to its mouth in the Pacific Ocean at Cape Alava. Because of the low relief between the lake and the ocean the Ozette River has a very low gradient (0.0014) and a sinuous channel alignment. The Ozette River provides the conduit for anadromous sockeye salmon that travel from the Pacific Ocean to Lake Ozette in order to spawn. Much of the Lake Ozette shoreline consists of gently sloping beaches, portions of which are critical habitat for these threatened salmonids.

### Sockeye Habitat Utilization

The populations of sockeye salmon (*Oncorhynchus nerka*) in Lake Ozette have declined dramatically over the last half century, along with other salmonids in the Ozette watershed (i.e., chinook and chum) (Haggerty et al. in preparation). National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) has determined that the Lake Ozette sockeye represent an evolutionarily significant unit (ESU), and the population is listed as “threatened” as defined by the Endangered Species Act.

Beach spawning Lake Ozette sockeye spawn in unconsolidated mixtures of cobble, gravel and coarse sand along the lake’s perimeter. The lake depth at spawning sites ranges from 1.0 to 9.2

feet (0.3 to 2.8 meters) with a majority of redds placed in 3.3 to 9.2 feet (1.0 to 2.8 meters) of water (Dlugokenski et al. 1981). Occasional redds may be found at depths up to 20 to 30 feet (6.1 to 9.1 meters) (Peterschmidt 2005 personal communication). Eggs and alevins at redd sites are extremely sensitive to fluctuations in water surface. If they are exposed they can be desiccated; but in too much water the eggs can receive too little aeration to survive (Bortleson and Dion 1979; Jacobs et al. 1996). Spawning typically occurs between early November and mid-January, with peak spawning occurring from mid-December to early January. Incubation occurs from November through March. Emergence occurs between February and April. From April to June emerged juveniles will emigrate to the pelagic zone of the lake and rear for one year before they become smolt and migrate to the Pacific in April or May of the following year (Peterschmidt 2005 personal communication).

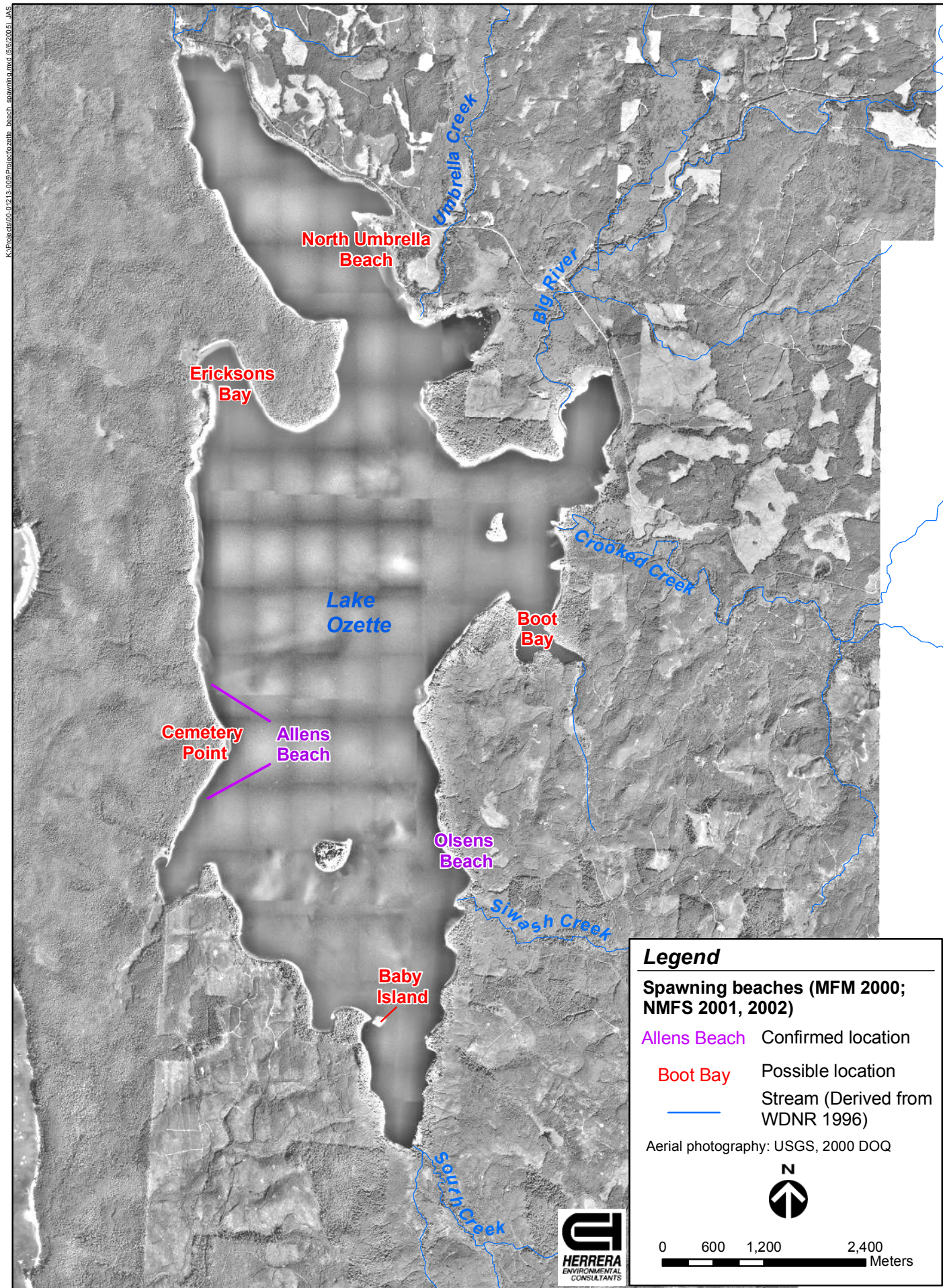
In Lake Ozette, sockeye spawn at two primary beaches: 1) Olsens Beach, located on the lake's eastern shore north of Siwash Creek, and 2) Allens Beach, located on the lake's western shore north of Allens Bay (Figure 2). Spawning has been observed at these two beaches every year since 1976 (Haggerty et al. in preparation). Secondary beach spawning also has or does occur around the lake, but these locations have been poorly investigated or documented beyond what is summarized in Table 1. In addition, other apparently suitable spawning habitat exists around the lake, but is not utilized for unknown reasons. It is also likely that Lake Ozette sockeye historically spawned in tributaries to Lake Ozette, possibly including Big River, Umbrella Creek, and Crooked Creek, as well as in the Ozette River. Currently, sockeye spawn in Big River, Umbrella Creek, and Crooked Creek, which is largely a result of the Makah Fisheries Management hatchery program derived from local Lake Ozette native brood stock (Peterschmidt 2005 personal communication).

**Table 1. Details of confirmed and potential sockeye spawning locations in Lake Ozette.**

| Spawning Locations                                                          | Details                                                                                               |
|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| <b>Confirmed Primary Spawning</b>                                           |                                                                                                       |
| Allens Bay                                                                  | Confirmed redds 1976 to 2005, located along the southwest shore of Lake Ozette.                       |
| Olsens Beach                                                                | Confirmed redds 1976 to 2005, located along the southeast shore of Lake Ozette north of Siwash Creek. |
| <b>Historical Primary Spawning</b>                                          |                                                                                                       |
| North Umbrella Beach                                                        | Confirmed spawning January 1979 (30 spawning sockeye); no observations since then.                    |
| Cemetery Point                                                              | Confirmed redds during several years, secondary spawning extension of Allens Beach.                   |
| North Olsens Beach                                                          | Confirmed redds during several years, secondary spawning extension of Olsens Beach.                   |
| Baby Island                                                                 | One time observation of spawning sockeye and at least one redd.                                       |
| <b>Potential Spawning Locations</b>                                         |                                                                                                       |
| Historic and current gravel beaches around the lake (e.g., Erickson's Bay). |                                                                                                       |
| <b>Live Adult Sockeye Observed</b>                                          |                                                                                                       |
| Boot Bay                                                                    | Several ripe fish captured in gill nets in 1979, no evidence of spawning.                             |

Source: MFM (2000); NMFS (2001); Meyer and Brenkerman (2001); NMFS (2002); Haggerty et al. (in preparation); Peterschmidt (2005).





**Figure 2. Locations of confirmed and potential spawning beaches in Lake Ozette.**



## Subbasin Descriptions

The Lake Ozette watershed is located at the north-west corner of the Olympic Peninsula, in Clallam County, Washington (Figure 1). The watershed covers approximately 90 square miles (233 km<sup>2</sup>) with relief from 1,903 feet (580 meters) to sea level. Six major tributaries drain the Lake Ozette watershed; Umbrella Creek, Big River, Crooked Creek, Siwash Creek, and South Creek flow into Lake Ozette (Figure 2), whereas Coal Creek flows out of the north-west part of the basin into the Ozette River. Big River is the largest tributary to Lake Ozette and the tributary subbasins range in size from 22.8 to 3.0 square miles (59.1 to 7.9 km<sup>2</sup>). Dunham Creek, Trout Creek, Solberg Creek, and Boe Creek are tributaries to Big River. Flows to Umbrella Creek originate at Elk Lake at the northern end of the basin. Low relief rounded hills dominate the topography of the Lake Ozette watershed. Almost 83 percent of the tributary subbasins have hillslope gradients less than 30 percent (Table 2).

**Table 2. Characteristics of major tributary subbasins in the Lake Ozette watershed.**

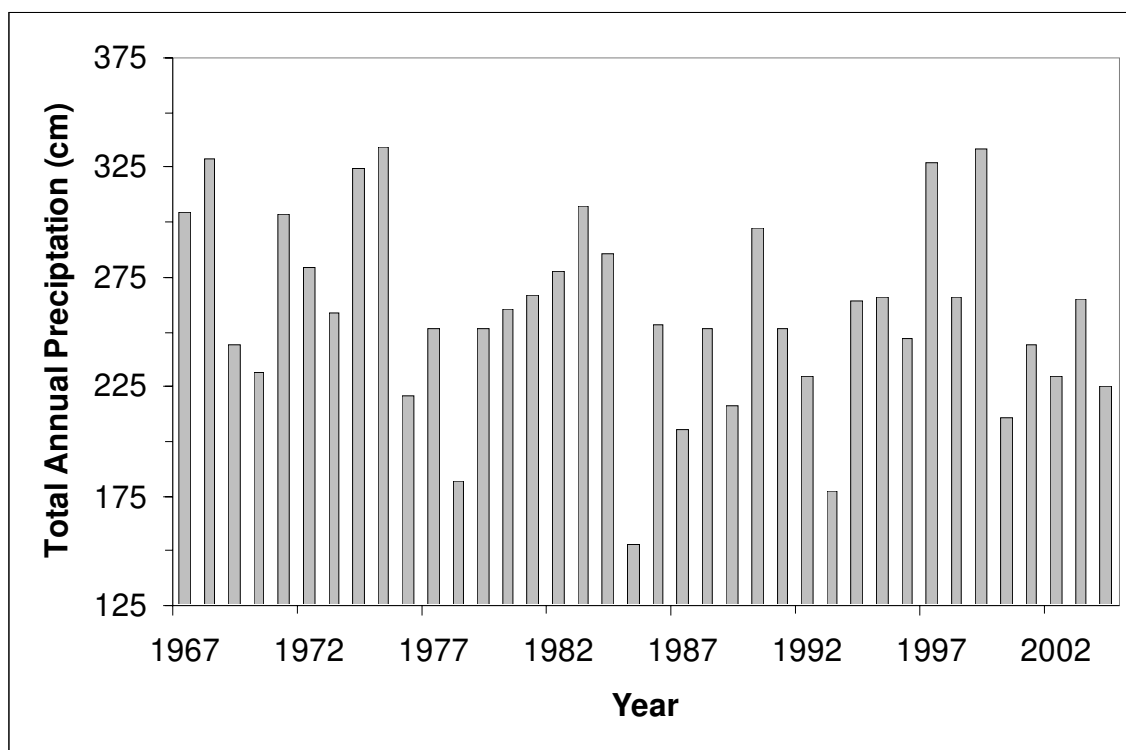
| Subbasin       | Area           |                    | Percentage of Subbasin by Hillslope Gradient Categories |                           |                         |
|----------------|----------------|--------------------|---------------------------------------------------------|---------------------------|-------------------------|
|                | (square miles) | (km <sup>2</sup> ) | Less than 30 Percent                                    | Between 30 and 65 Percent | Steeper than 65 Percent |
| Coal Creek     | 5.1            | 13.2               | 85                                                      | 15                        | <1                      |
| Umbrella Creek | 11.5           | 29.9               | 85                                                      | 14                        | <1                      |
| Big River      | 22.8           | 59.1               | 77                                                      | 20                        | 3                       |
| Crooked Creek  | 11.9           | 30.9               | 92                                                      | 8                         | <1                      |
| Siwash Creek   | 3.1            | 7.9                | 78                                                      | 21                        | <1                      |
| South Creek    | 3.4            | 8.7                | 78                                                      | 21                        | <1                      |

## Climate

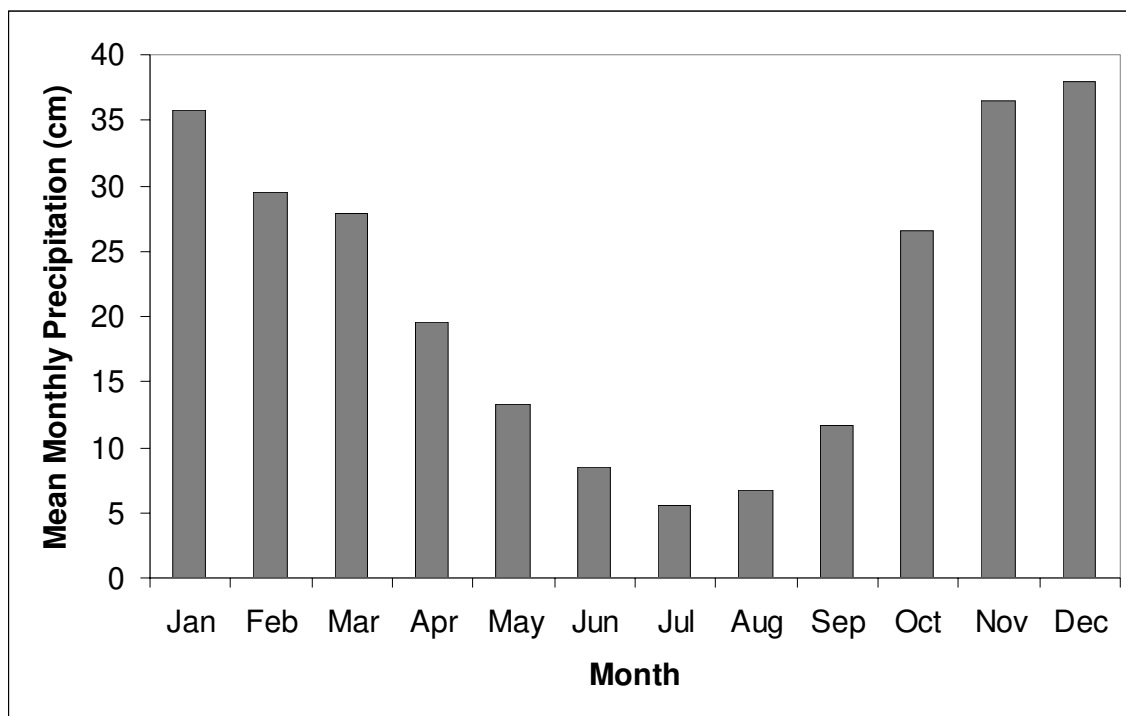
The Lake Ozette watershed lies within the temperate rainforest between the Pacific Ocean and the Olympic Mountains. The nearest weather station to the watershed with a long-term record is located at Quillayute Airport, approximately 11 kilometers to the south. With an annual precipitation ranging from 60.2 to 131 inches (153 to 334 cm) during the period from 1967 to 2004, average annual precipitation at Quillayute Airport was 102 inches (259 cm) (Figure 3). October through March marks the period of heaviest precipitation and monthly rainfall totals average over 10 inches (25 cm) during these months (Figure 4).

## Geology

The geology of the Lake Ozette watershed influences the morphology of stream channels and the supply and transport of sediment through the channel network. Uplift and accretion of marine



**Figure 3. Annual rainfall totals at the Quillayute Airport weather station from 1967 through 2004.**



**Figure 4. Mean monthly rainfall at the Quillayute Airport weather station from 1967 through 2004.**



sedimentary and volcanic rocks have resulted in highly deformed and faulted bedrock units in the Lake Ozette watershed. The majority of bedrock units exposed in the Lake Ozette watershed consist of Eocene and Oligocene marine sedimentary rocks that are between 15 and 60 million years old. Additional bedrock geology is made up of volcanic rocks of the Crescent Formation, which consists primarily of basalt with minor exposures of flow breccia and volcanoclastic deposits. The volcanic rocks of the Crescent Formation, which formed 50 to 60 million years ago on the ocean floor during the Eocene, are exposed exclusively in the upper portion of the Big River subbasin.

Glacial sediments from the Fraser glaciation, which persisted regionally from 29,000 to 11,000 years bp (before present), mantle the bedrock geology and cover the majority of the basin (Thackary 1996). The glacial units are relatively unconsolidated and consist of glacial drift, glacial outwash, glacial till, and glaciolacustrine deposits. Alluvial sediments, deposited by rivers and streams since the retreat of the last glacier advance, occupy some floodplains and delta environments in the lower portion of the larger tributaries within the basin. Figure 5 shows the arrangement of geologic units in the Lake Ozette watershed.

The weak character of marine sedimentary and volcanic bedrock units, and the relatively unconsolidated condition of glacial units, make the exposed geology in the Lake Ozette watershed susceptible to erosion and mass wasting. In order for these units to generate significant sediment to the channel network and to Lake Ozette, however, the conditions of slope, precipitation, and vegetative cover must combine to promote erosion and slope instability.

## **Ownership and Land Use History**

Current land ownership within the Ozette watershed is distributed among private timber companies, the National Park Service (NPS), Washington State Department of Natural Resources (WDNR), and the Makah Indian Tribe (Figure 6). Private timber companies own 72 percent of the land within the watershed (Table 3). All lands draining to Lake Ozette and currently under private ownership are located east of Lake Ozette. State and local government-owned land (WDNR) constitutes 11 percent of the Ozette watershed and is dispersed throughout the privately owned portion of the basin east of the lake. Over 90 percent of Coal Creek, Umbrella Creek, and Big River subbasins are privately owned with less than 10 percent being WDNR land. Over 80 percent of Crooked Creek and South Creek subbasins are privately owned, with less than 20 percent being WDNR land. Land ownership in Siwash Creek subbasin is split between WDNR (49 percent) and private ownership (51 percent). Federal ownership administered through the Olympic National Park constitutes 16 percent of the land within the watershed. Land within the Olympic National Park owned by the NPS is located west of Lake Ozette and around the perimeter of the lake. The Ozette Indian Reservation, which is included in the Makah Tribal land ownership, covers approximately 1 percent of the watershed and is located west of the Ozette River.

**Table 3. Distribution of land ownership within the Ozette River watershed.**

|                    | Land Ownership    |                      |                  |
|--------------------|-------------------|----------------------|------------------|
|                    | WDNR<br>(percent) | Private<br>(percent) | NPS<br>(percent) |
| Coal Creek         | 5                 | 95                   | 0                |
| Umbrella Creek     | 6                 | 94                   | 0                |
| Big River          | 10                | 90                   | 0                |
| Crooked Creek      | 20                | 80                   | 0                |
| Siwash Creek       | 49                | 51                   | 0                |
| South Creek        | 14                | 86                   | 0                |
| Other              | 5                 | 39                   | 56               |
| Total Ozette basin | 11                | 72                   | 16               |

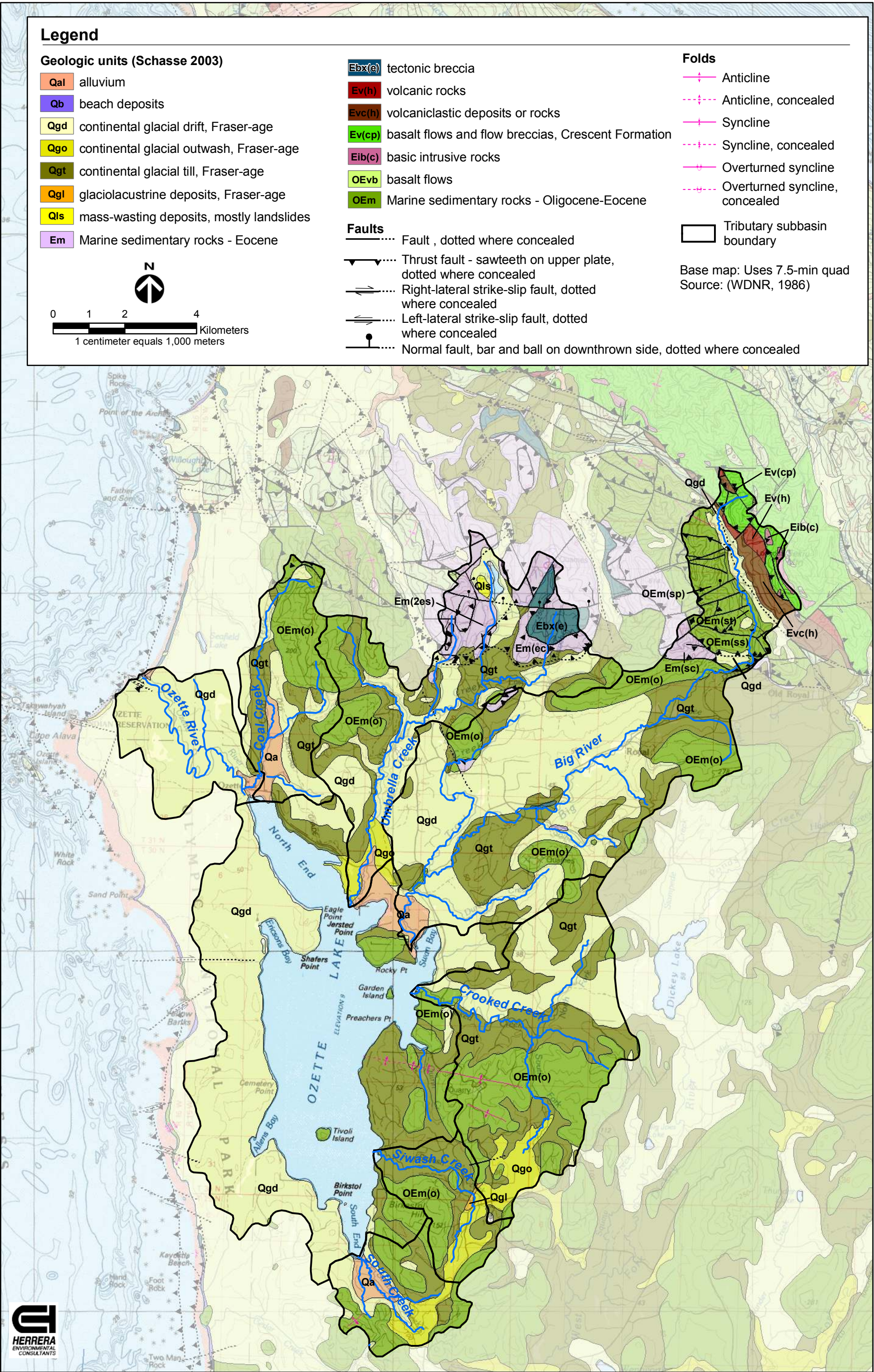
## Historical Lake Levels

The water surface elevation (WSE) of Lake Ozette fluctuates seasonally, rising as precipitation increases in October and typically peaking during periods of intense precipitation during the months of November through March. The WSE begins to drop in March or April as precipitation declines, and generally falls to its lowest elevation of about 31.1 feet (9.5 meters) ASL in the months of September or October.

Figure 7 shows the full period of available daily lake level data based on the lake level gauge operated by Olympic National Park (ONP) at the Ozette ranger station. ONP recorded lake levels at this location from 1981 to 1994 and 1998 to 2003. Since 2003, the Makah Indian Tribe has been recording Lake Ozette water levels at this same location as well as at Tivoli Island at the south end of the lake (Figure 8). The available lake level data were acquired from ONP and the Makah Indian Tribe and was evaluated to determine the magnitude and seasonality of variations in lake level.

The Lake Ozette WSE ranges between 30.8 and 41.5 feet (9.4 and 12.6 meters) above mean sea level (NAGD 27). The average annual WSE is 33.9 feet (10.3 meters) above mean sea level (NAGD 27). The average range between maximum and minimum WSE during the water years (WY) from 1982 to 1994 and 1998 through 2003 is 7.4 feet (2.3 meters) with a maximum range of 10.2 feet (3.1 meters) and a minimum range of 2.7 feet (0.8 meters). The standard deviation of the annual variability is 1.9 feet (0.6 meters). Figure 9 shows the Lake Ozette WSE for water year 1982 to 1994 and 1998 to 2004.









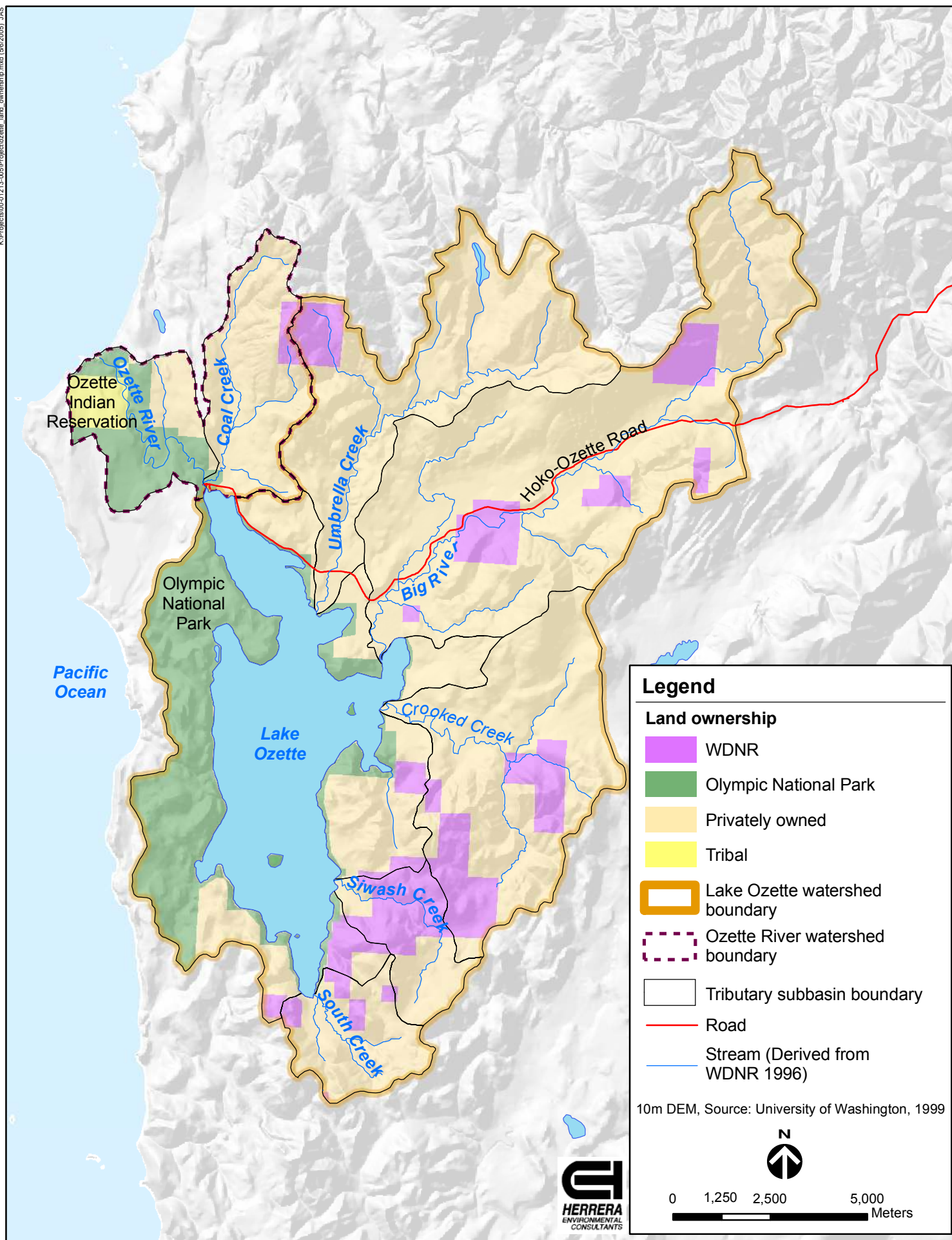
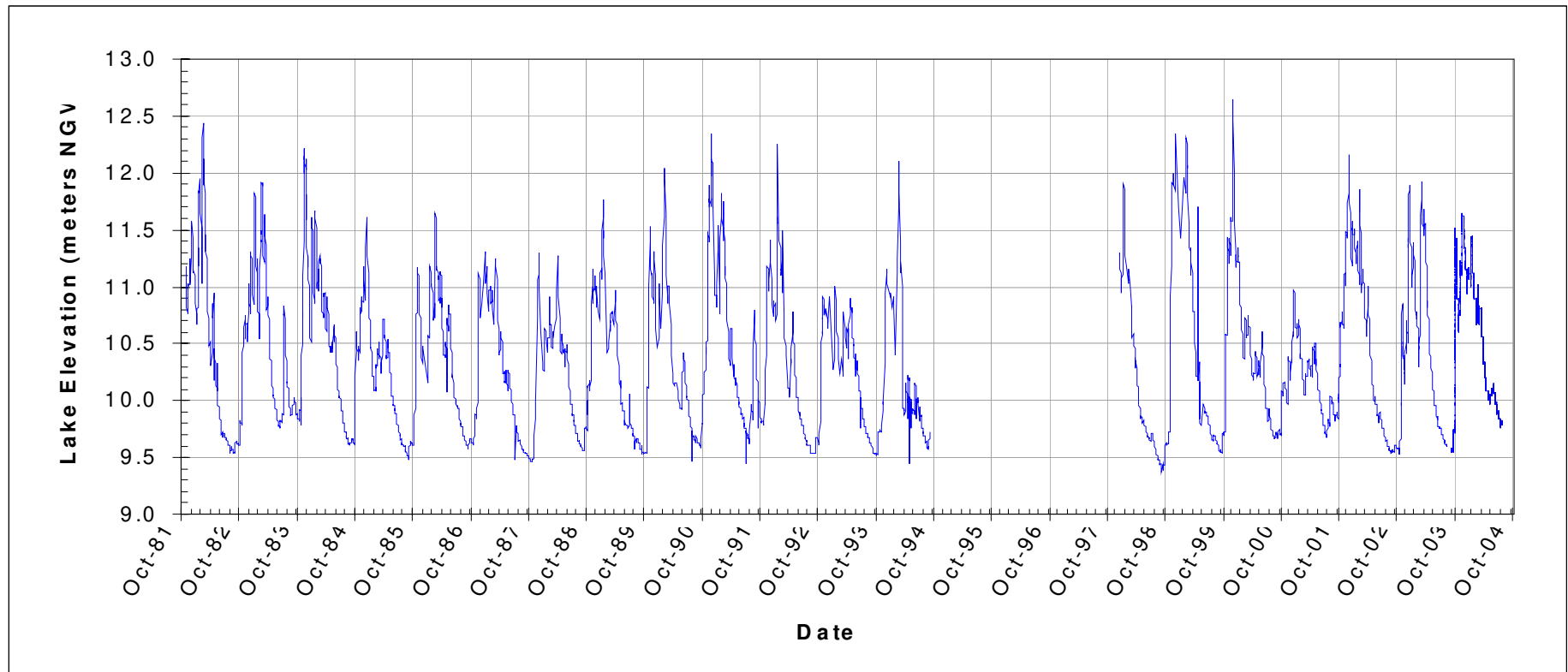


Figure 6. Land ownership within the Ozette watershed.

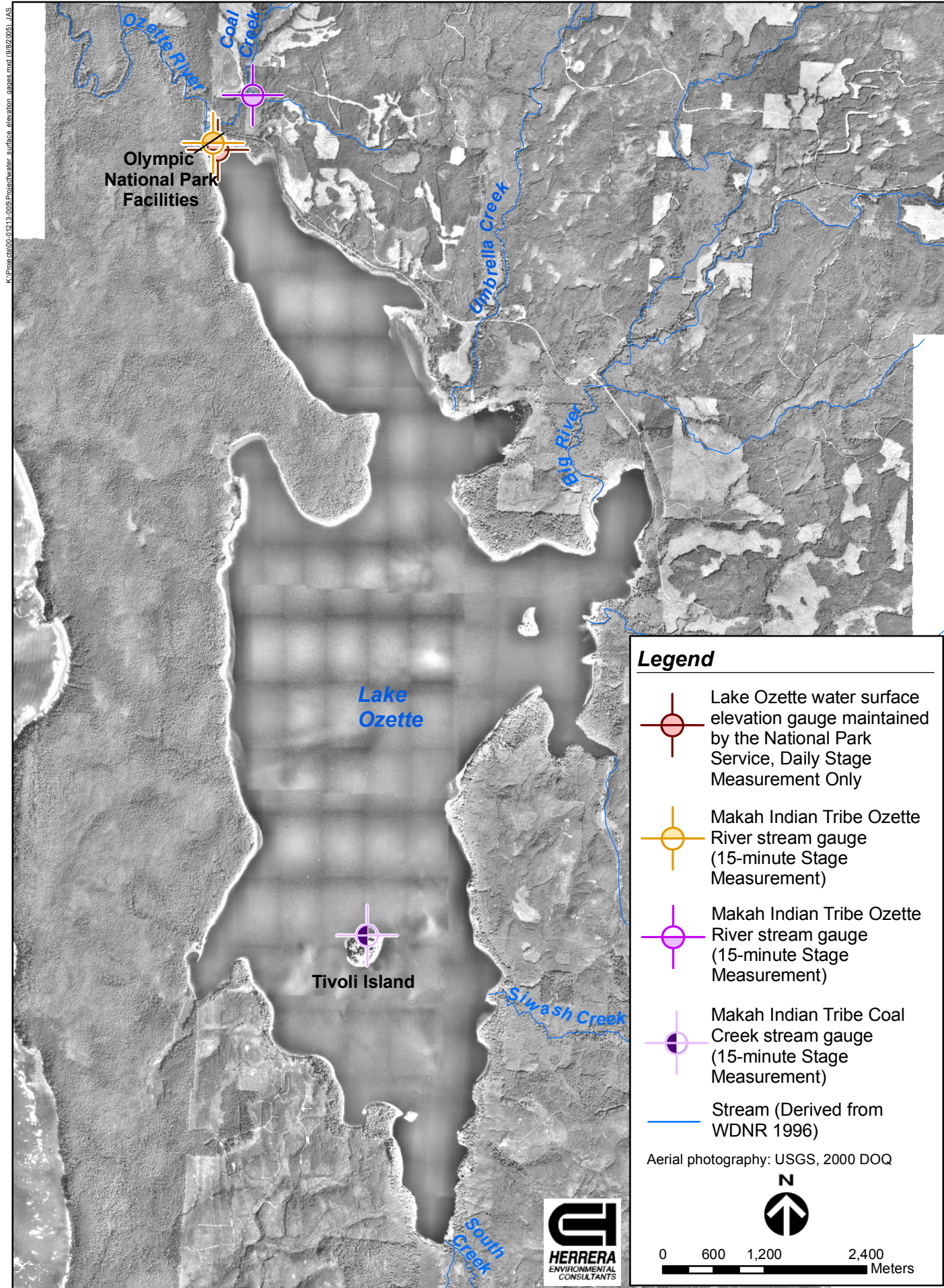




**Figure 7. Lake Ozette water surface elevations for water years 1982 to 1994 and 1998 to 2004 collected from gauge located at the national park facility at the north end of the lake. Lake levels for water years 1982 to 1994 and 1998 to 2003 are mean daily values; water year 2004 data were collected at 15-minute intervals.**

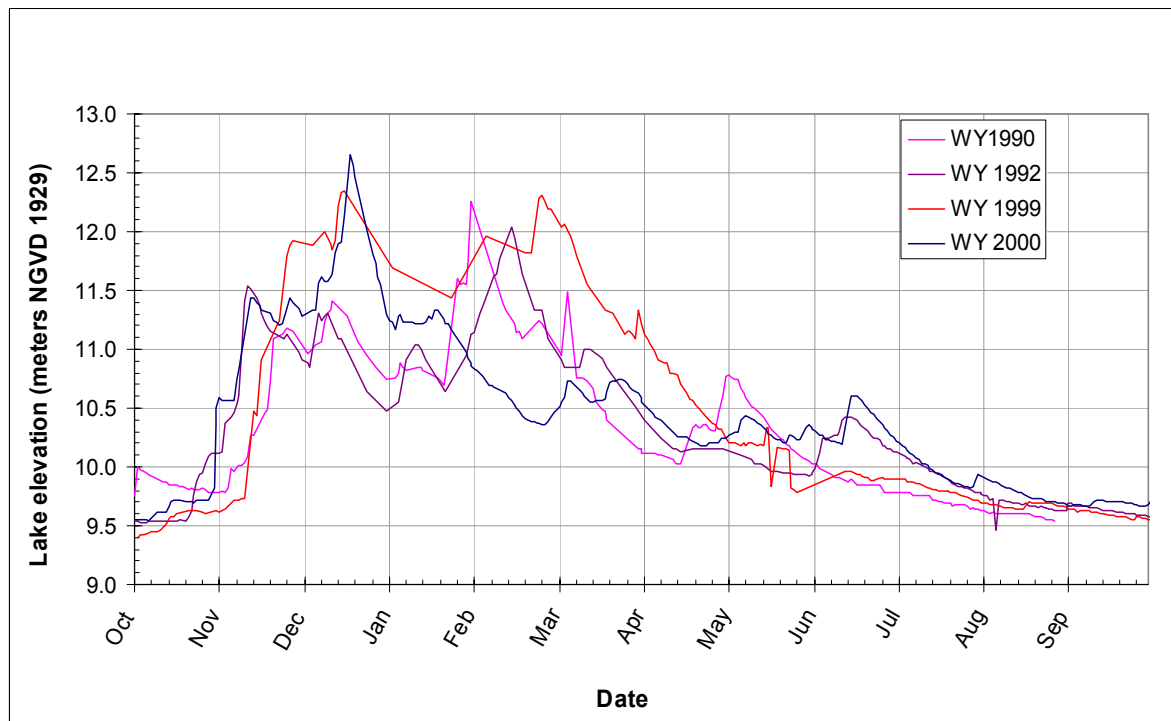






**Figure 8. Locations of Lake Ozette water surface elevation gauges and Ozette River flow gauge.**





**Figure 9. Lake Ozette water surface elevations for water years 1990, 1992, 1999, and 2000, illustrating the annual variability in lake levels**



## **Historical Changes in the Lake Ozette Shoreline**

### **Methods**

An analysis of historical aerial photographs of Lake Ozette shoreline was performed to determine the magnitude of change in shoreline position over time, and the extent to which vegetation has encroached towards the lake. Available aerial photographs for this analysis include: 1953 (limited), 1964 (limited), 1994, 2000, 2002/2003 (limited), and 2003 lidar (2003L). The resolution of the 1964 aerial photo are adequate to compare with the modern photosets, but the water surface elevation (WSE) of the lake appeared to be higher than in any other photoset, which caused the edge of vegetation to be inundated in several locations but did not significantly influence delineations. The majority of high resolution 1953 aerial photos were not rectified at the time of the analysis, but were used to qualitatively verify the edge of vegetation in the 1964 photosets. The quality of the 2000 photoset is poor, therefore the 2002/2003 and 2003L photos were used to compare shoreline and vegetative character with the 1963 photosets. The edge of vegetation is defined as the shrubby edge.

Considering the limited coverage of Lake Ozette in the 1953 and 1964 photosets, specific sites for analysis were chosen based on non-delta beaches and Lake Ozette tributary deltas (Figure 10). Delineations of the edge of vegetation are clearly displayed on aerial photos and Figures 11 through 19.

The non-delta sites include:

- Allens Beach and Cemetery Point
- Olsens Beach
- Preachers Point (Boot Bay)
- Deer Bay Spit
- Baby Island (south side).

The delta sites include:

- Umbrella Creek delta
- Big River delta
- Crooked Creek delta
- Siwash Creek delta
- South Creek delta.

Two of the non-delta beach locations, Allens and Olsens Beach, are known fish spawning locations. An understanding of the changes to these sites is extremely important for the recovery of ESA-listed Lake Ozette spawning salmon. Two other non-delta locations are spits in the northern portion of the lake, Preachers Point and Deer Bay Spit. These areas have potential to reveal longshore transport and depositional processes occurring in the lake. The south side of Baby Island was chosen because of its potential spawning habitat and steeper slopes, compared

to the other sites. The shoreline features at each location were evaluated in detail by delineating the edge of vegetation in the 1964 and 2002/2003 or 2003L aerial photographs.

The changes to five Lake Ozette tributary deltas were evaluated in order to better understand the potential impacts to lake sediments from upstream land-use practices. The shoreline features of each tributary delta were evaluated similar to the non-delta sites, but the edge of delta formation was also delineated where considerable growth had occurred between 1964 and 2003.

The slope of the beach at the non-delta sites was determined from the 1-foot (0.3-meter) water level contours created from the 2003 lidar data (Optimal Geomatics 2003) and was used to assess the impact of water elevation change on the length of horizontal beach inundation.

## **Results**

Results of the shoreline characterization show a significant trend in vegetative encroachment at many locations around the perimeter of the lake. These findings are consistent with a similar ongoing study being performed by A. Ritchie (2005). Ritchie classified approximately 88 percent of Lake Ozette shoreline for changes in vegetation and sedimentation. The initial results from his study reveal that over 40 percent of the surveyed shoreline has shown evidence of increased vegetative cover between 1953 and 2003; and approximately 17 percent of the surveyed shoreline has shown evidence of sediment deposition.

### **Non-delta Sites**

Allens Beach (south) and Cemetery Point has shown evidence of significant vegetative encroachment between 1953 and 2003 (Figure 11). At Cemetery Point there is an upper beach between the woody vegetation line and a shrubby vegetation patch. This upper beach is slightly evident in the 1953 photo, with only a few shrubs above the water line. By 2003, the shrub patch has grown significantly. South of Cemetery Point in 1964 was exposed beach, but in 2003 patchy shrubs have encroached onto the beach. South Allens Beach had patchy shrubs in 1964 and by 2003 the shrubs had populated the majority of the beach. The slope of Cemetery Point and Allens Beach is approximately 10 to 12 percent, therefore, a 1 meter drop in WSE would result in an approximate 33- to 39-foot (10- to 12-meter) decrease in beach inundation.

Olsens Beach has shown evidence of vegetative encroachment between 1964 and 2003 (Figure 12). The areas of non-vegetated beach in the 1964 photos are difficult to distinguish, but referring to the unrectified 1953 photos (Appendix A) reveal areas of exposed beach to the north of the point. These areas of beach had been completely vegetated by 2003. The average slope of Olsens Beach is approximately 9 percent; therefore, a 3.3-foot (1-meter) drop in WSE would result in an approximate 33-foot (10-meter) decrease in beach inundation.

Preachers Point, which is located just west of Boot Bay, has shown evidence of vegetative encroachment, and potential beach growth between 1964 and 2002/2003 (Figure 13). The quality of the 1964 aerial photograph in this location is poor; therefore, the 1953 photoset



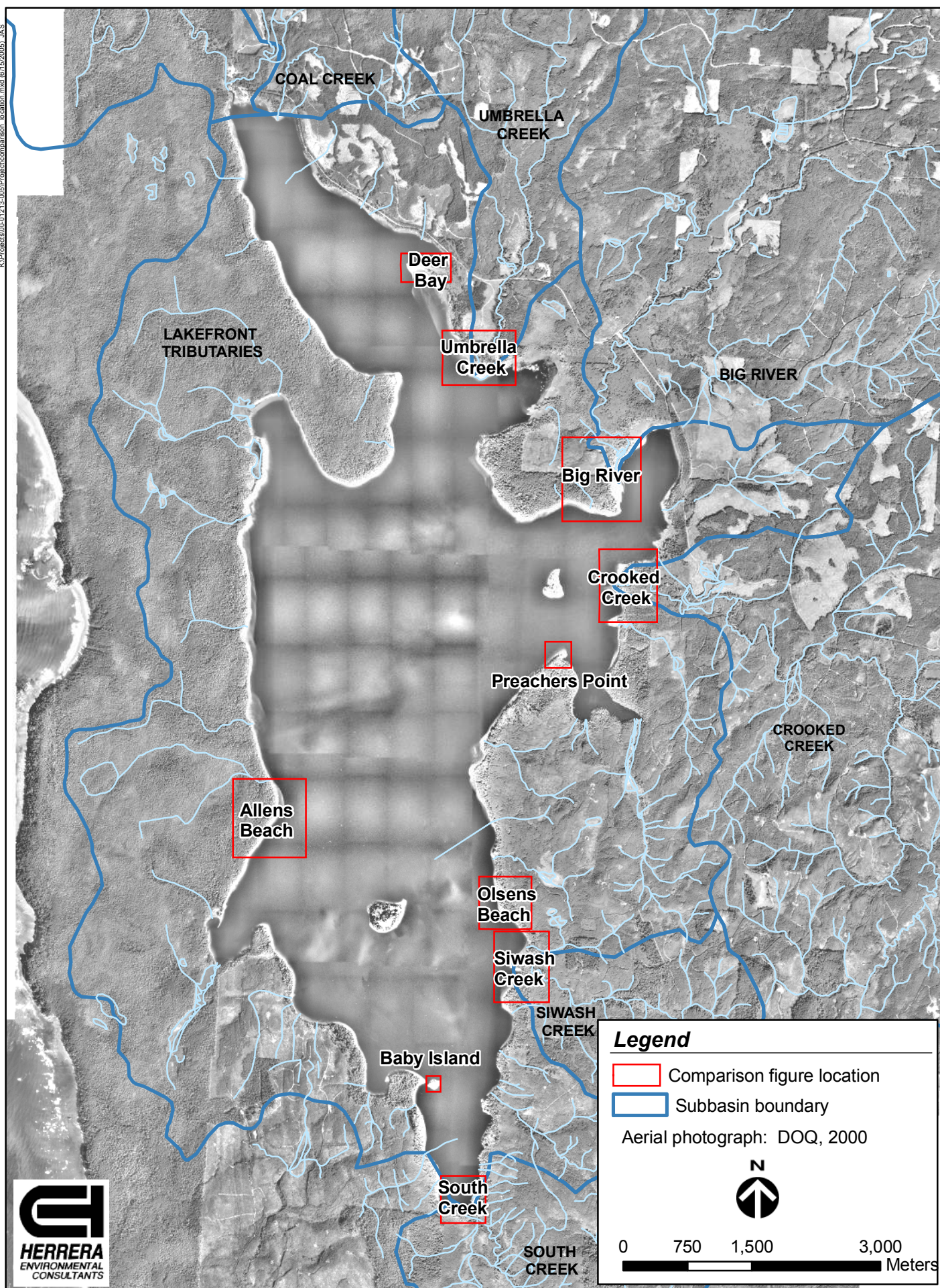


Figure 10. Location and extent of shoreline characterization sites, Lake Ozette, Washington.







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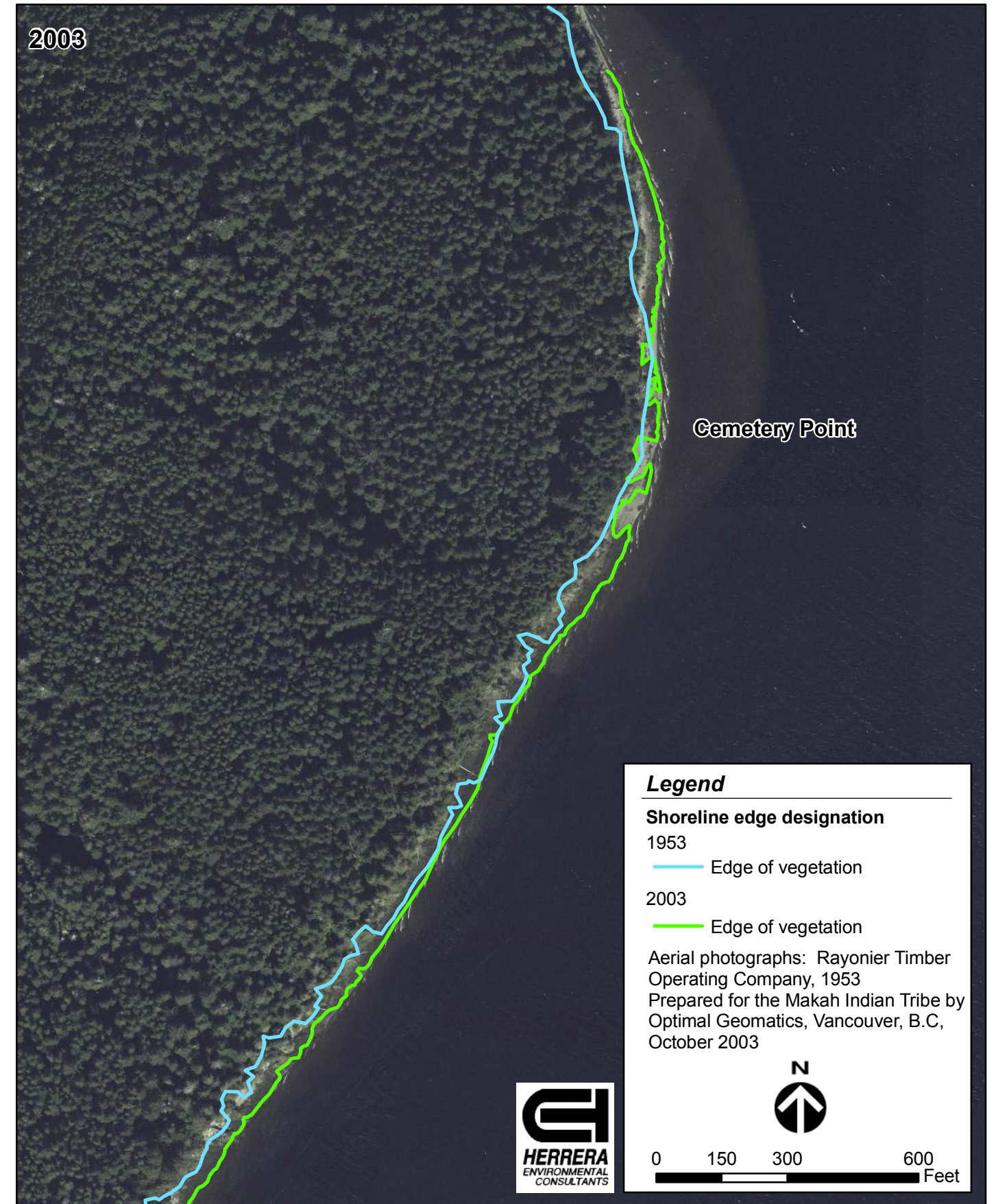
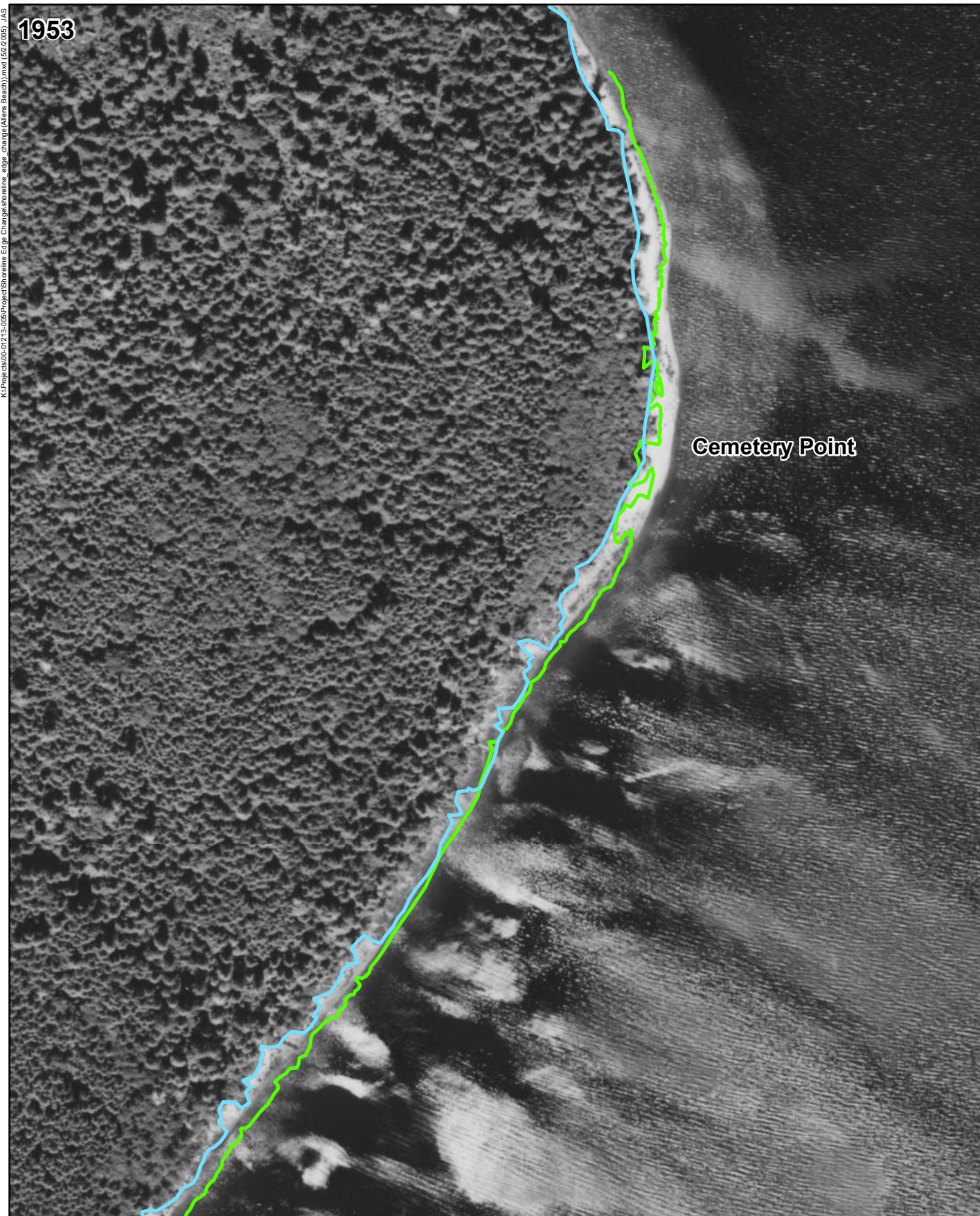


Figure 11. Shoreline changes at Allens Beach and Cemetery Point between 1953 and 2003, Lake Ozette, Washington.







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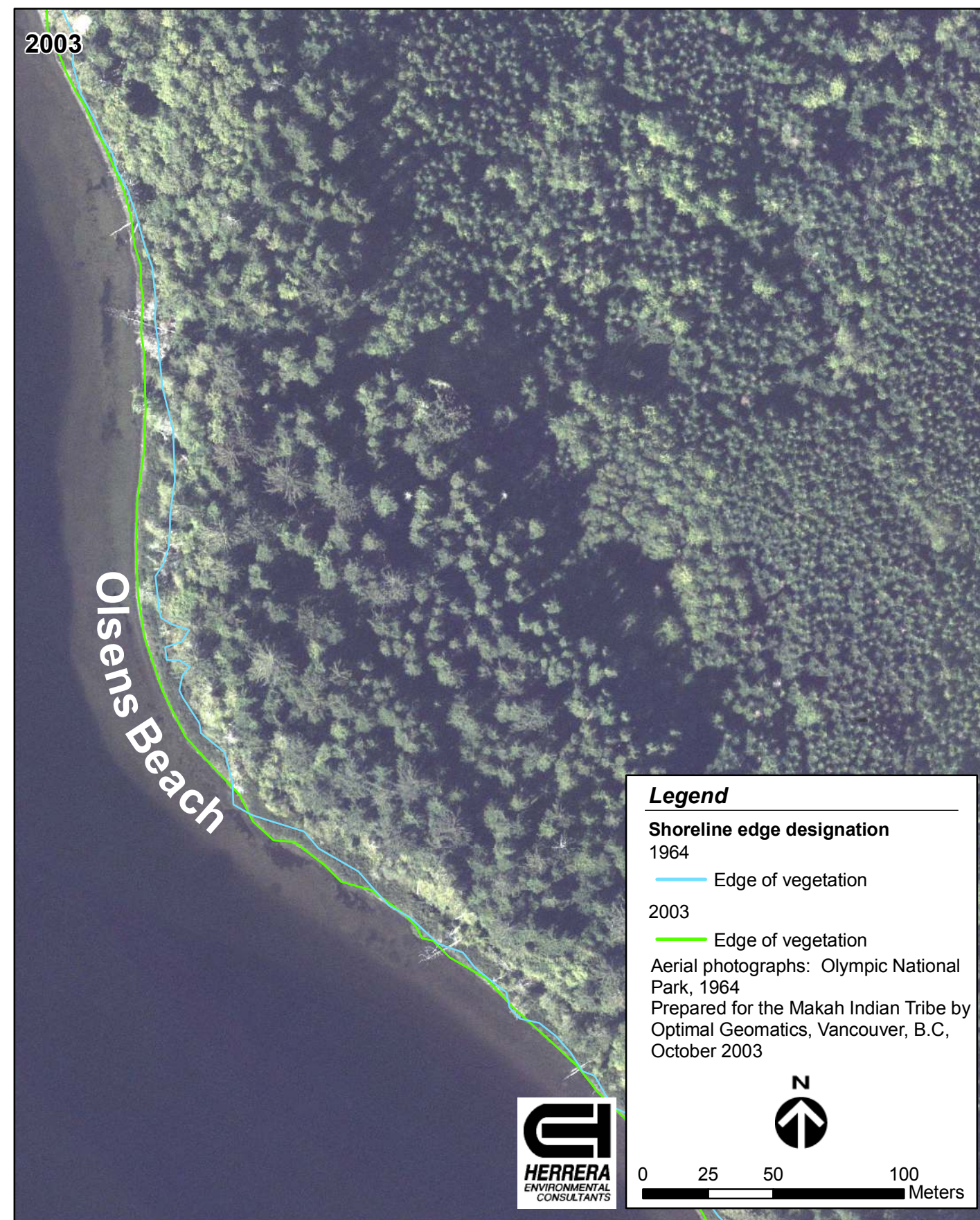


Figure 12. Shoreline changes at Olsens Beach between 1964 and 2003, Lake Ozette, Washington .







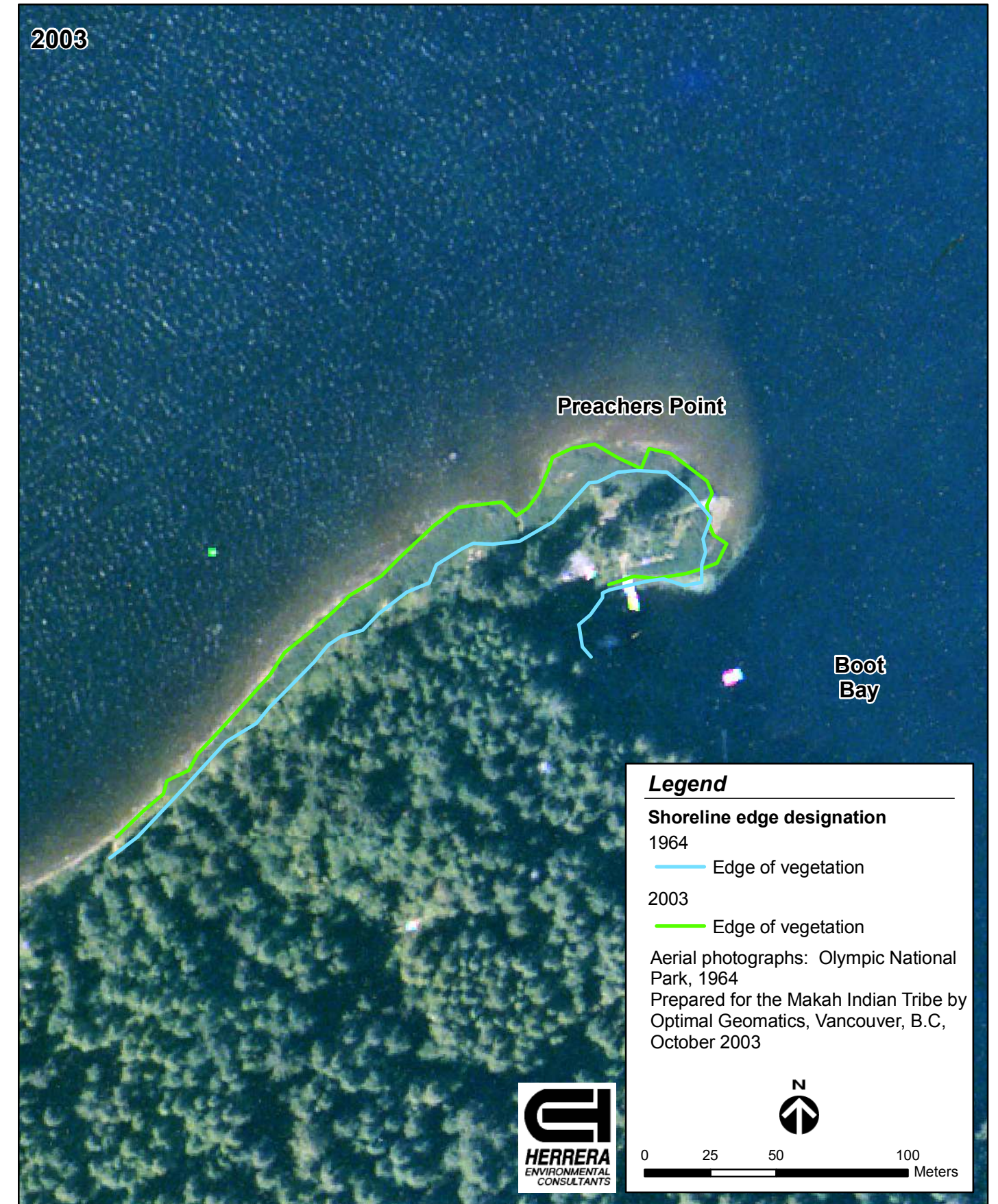
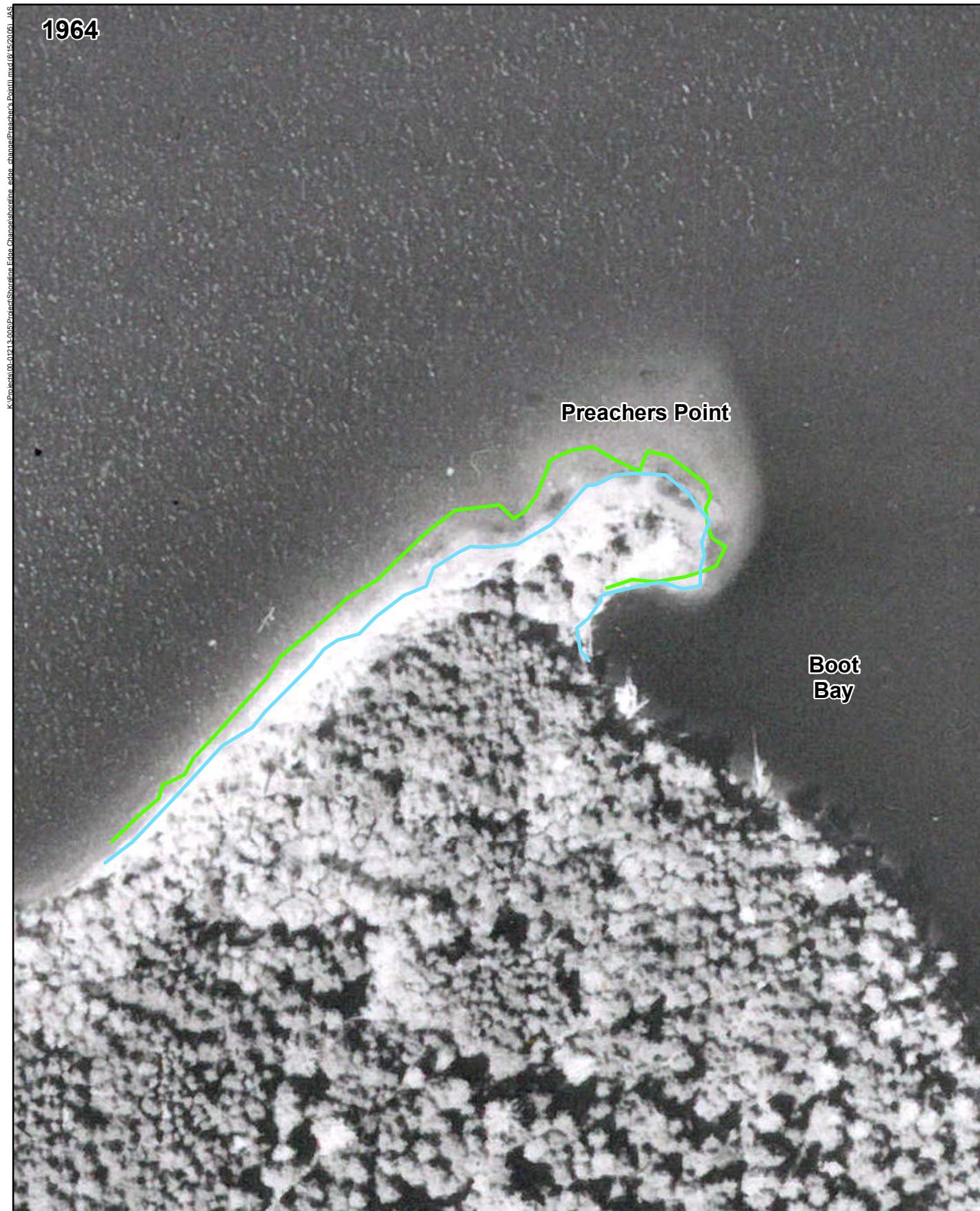


Figure 13. Shoreline changes at Preachers Point between 1964 and 2003, Lake Ozette, Washington.







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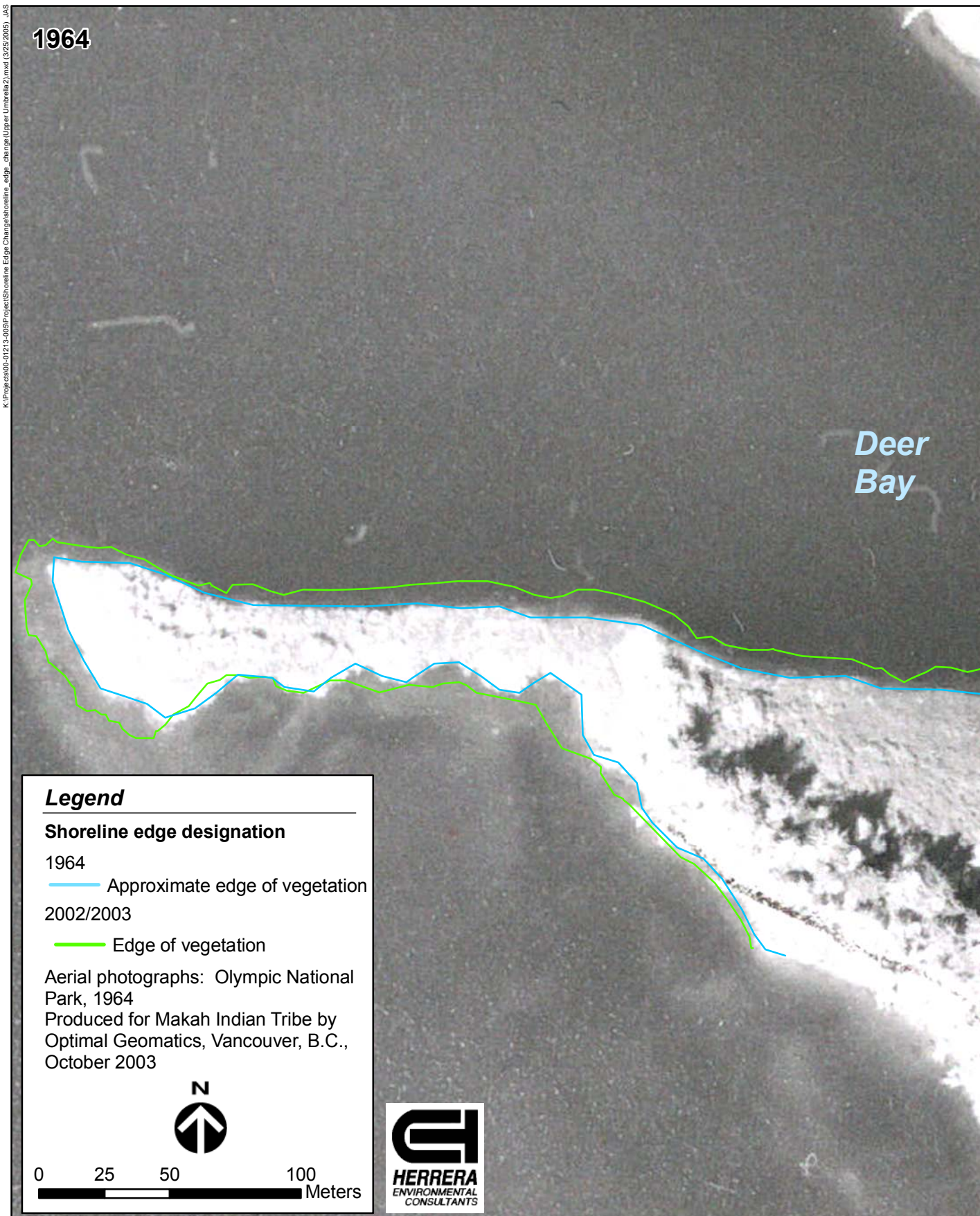


Figure 14. Shoreline changes at Deer Bay Spit between 1964 and 2003, Lake Ozette, Washington .







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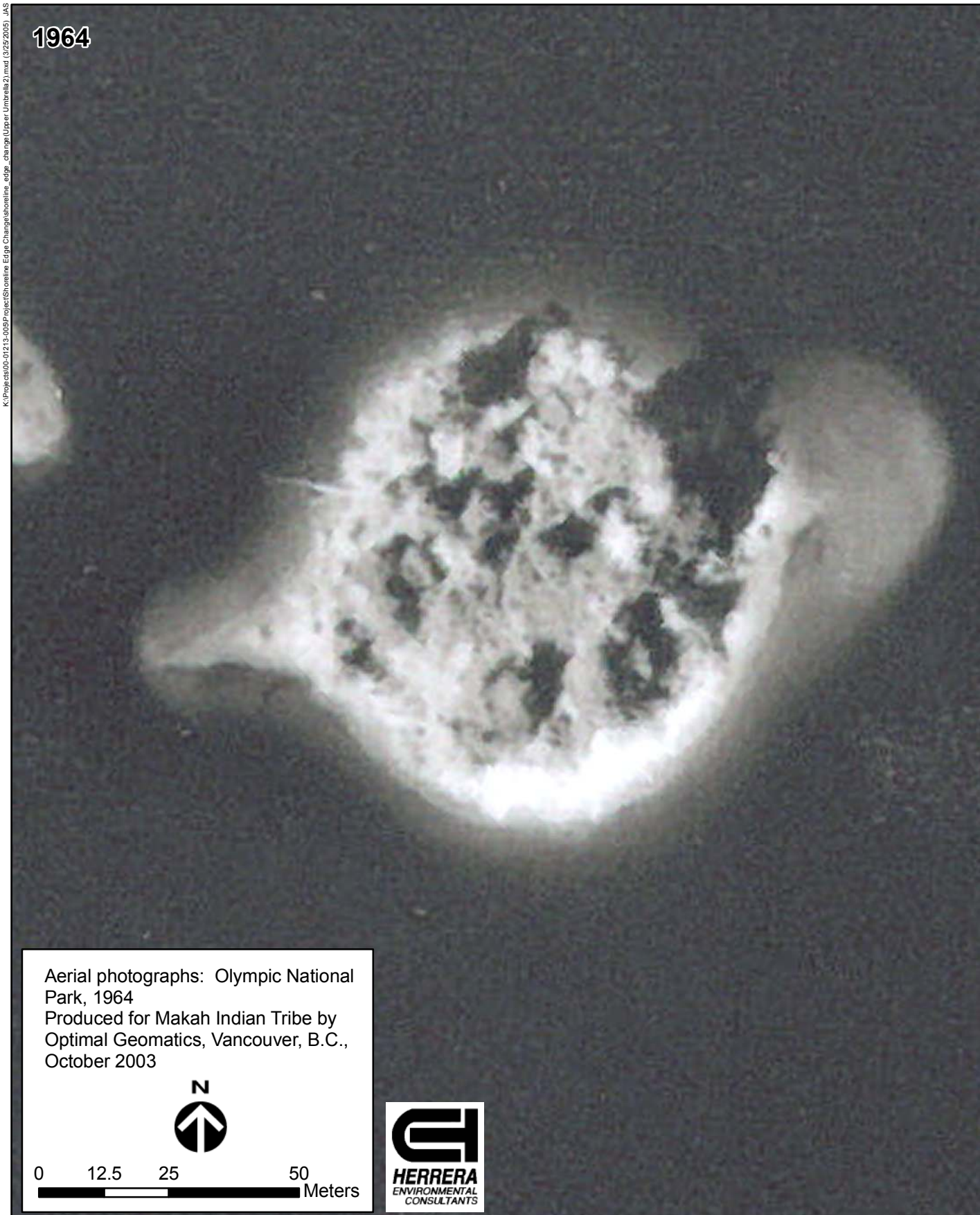


Figure 15. Shoreline changes at Baby Island between 1964 and 2003, Lake Ozette, Washington.







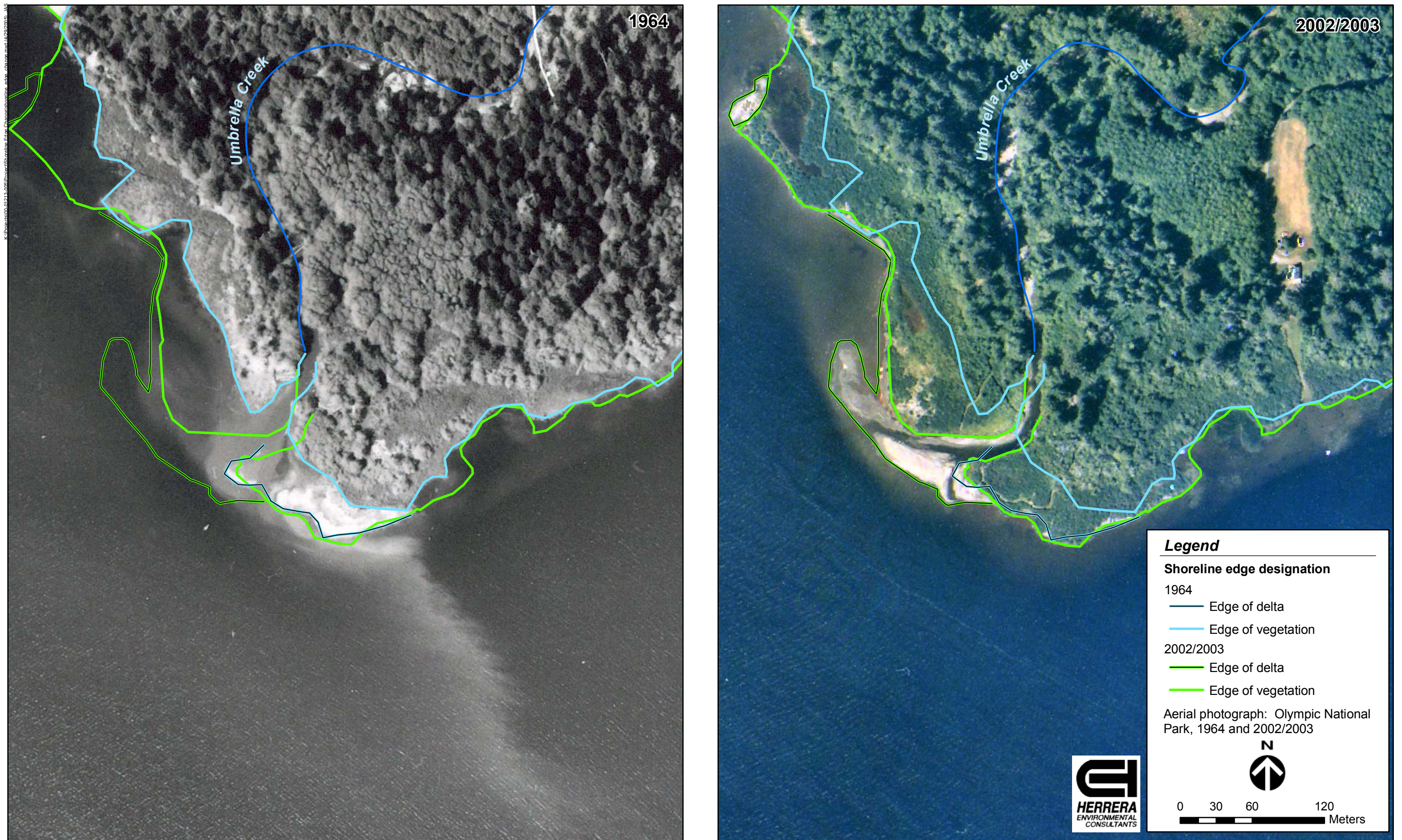


Figure 16. Shoreline changes and delta growth at the mouth of Umbrella Creek between 1964 and 2002/2003, Lake Ozette, Washington.







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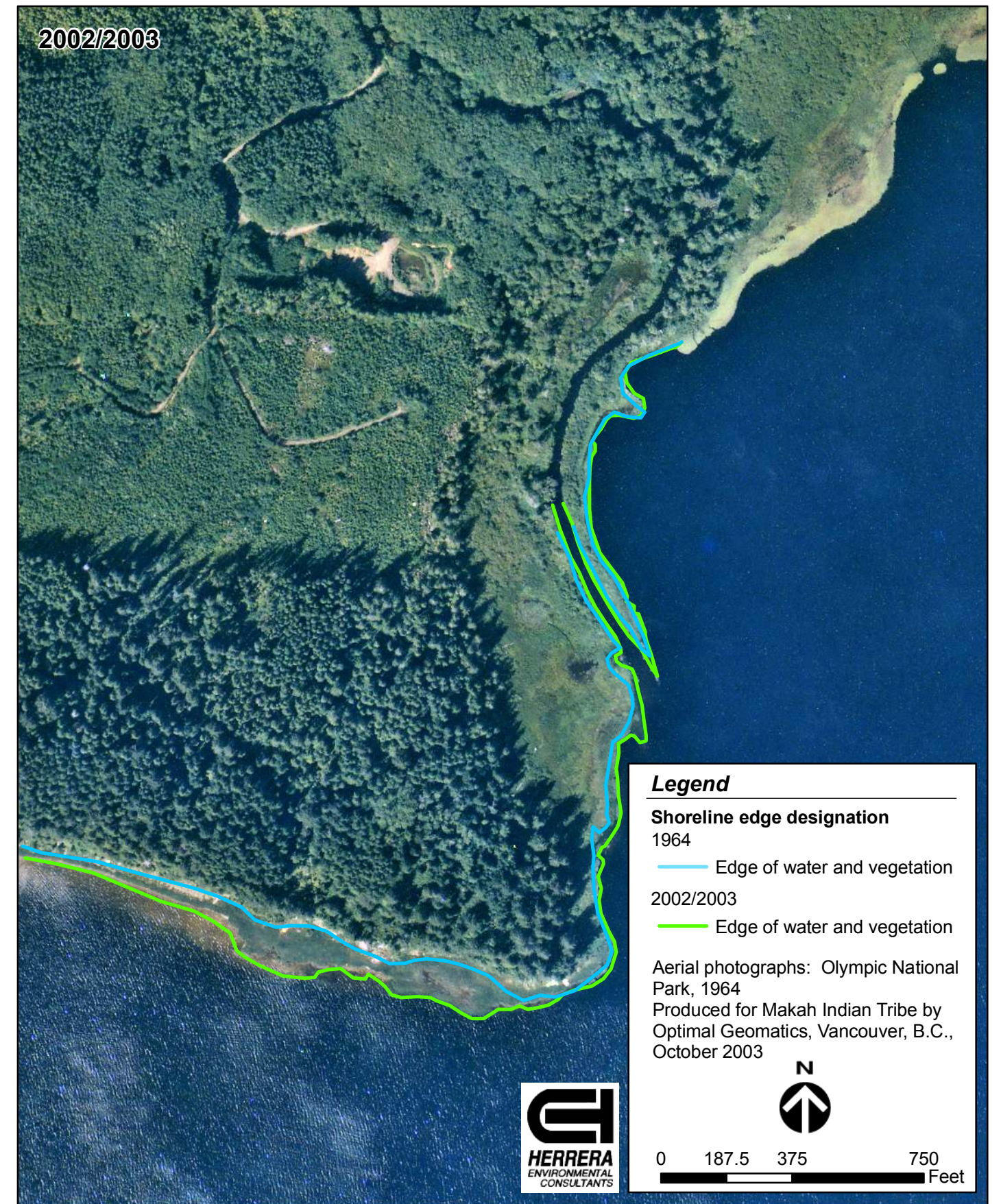


Figure 17. Shoreline changes at the mouth of Big River, Lake Ozette, Washington between 1964 and 2002/2003.









Figure 18. Shoreline changes and delta growth at the mouth of Crooked Creek between 1964 and 2002/2003, Lake Ozette, Washington .







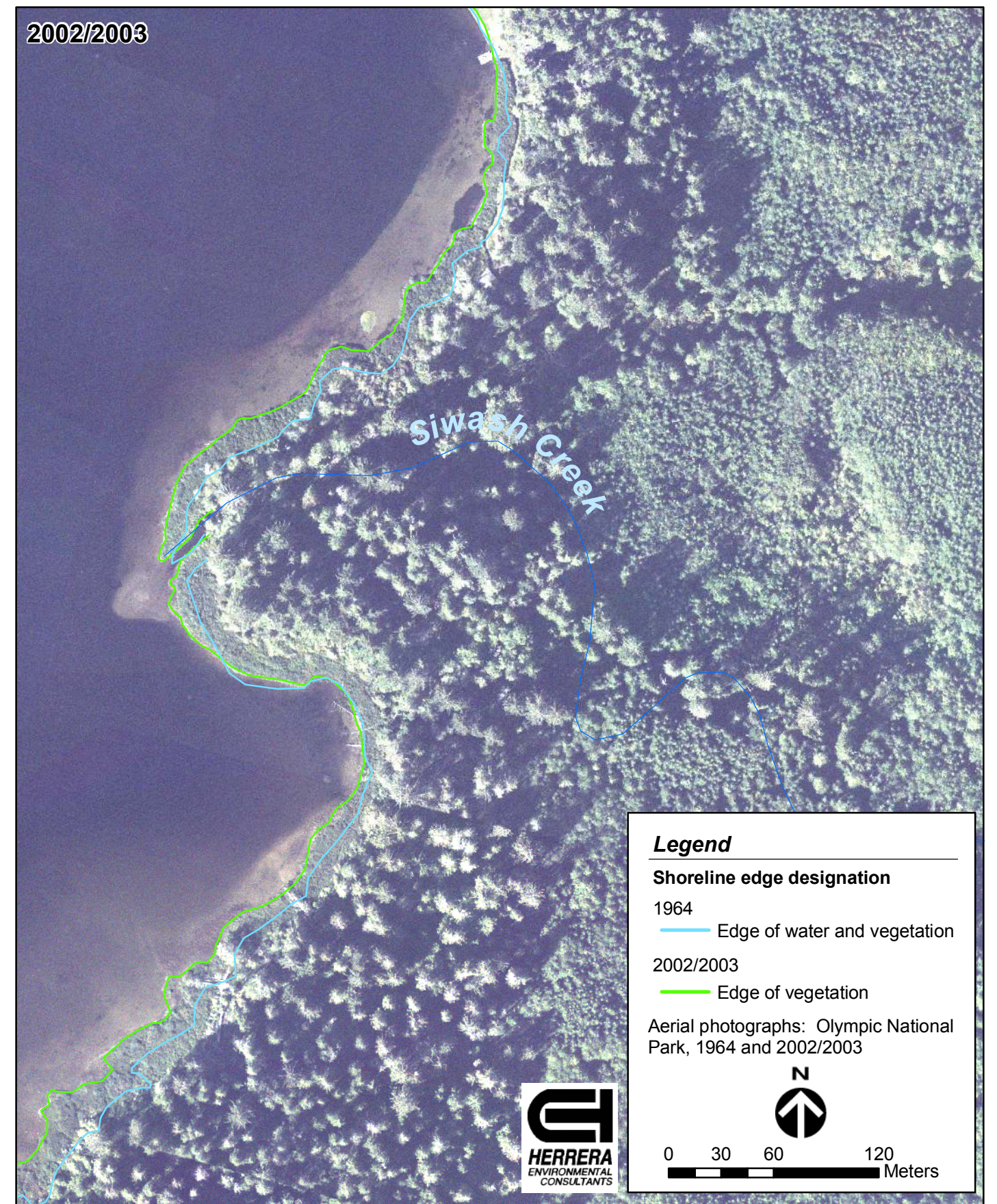
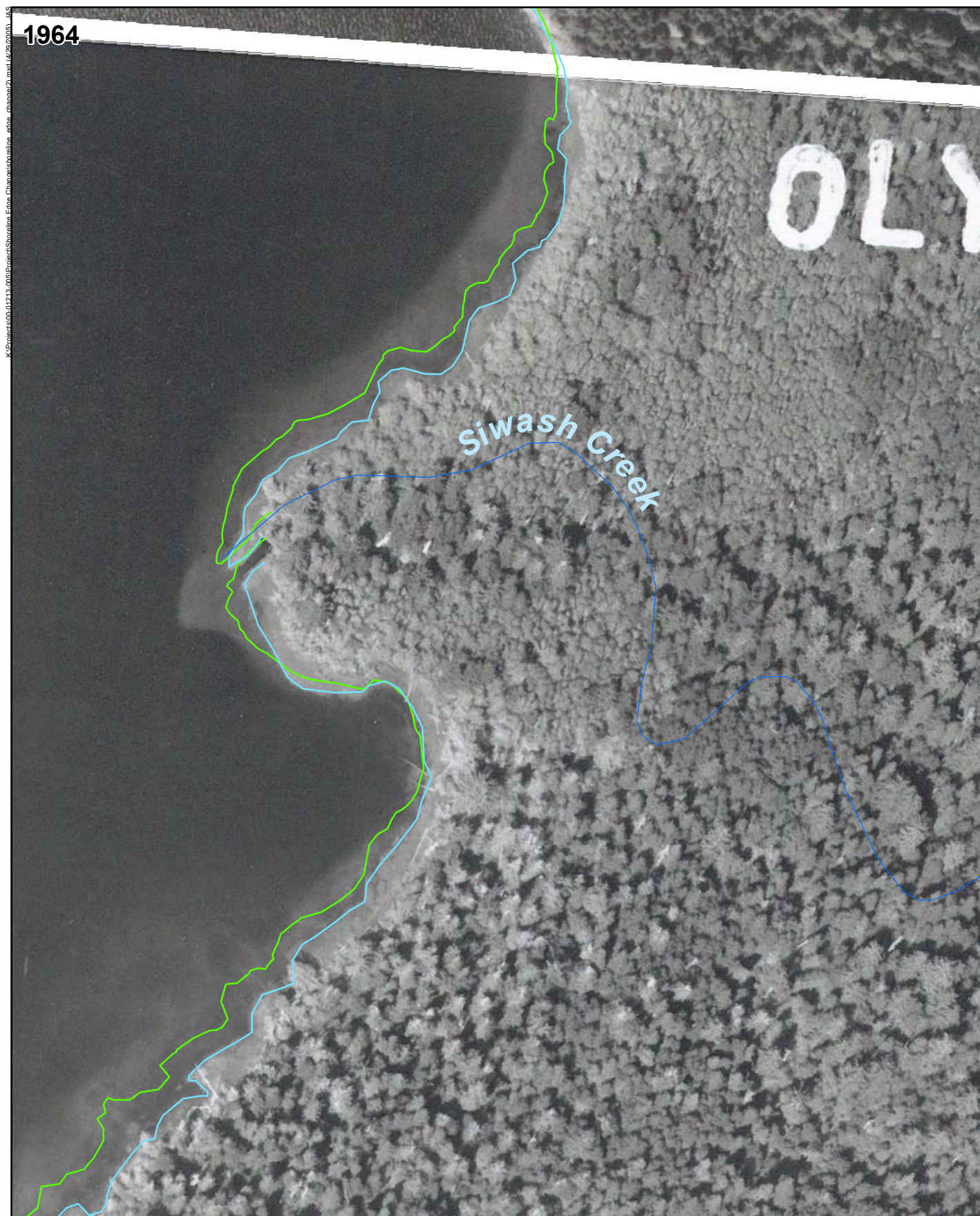


Figure 19. Shoreline changes at the mouth of Siwash Creek between 1964 and 2003, Lake Ozette, Washington.





(Appendix A) was utilized to verify the edge of vegetation in the 1964 photo. In the 2002/2003 photoset, the west side of Preachers Point shows significant vegetative growth compared to the 1953/1964 beach that is devoid of vegetation. The slope of the northern portion of the point is approximately 6 percent and the slope of the southwestern section of the beach is approximately 11 percent; therefore, a 3.3-foot (1-meter) drop in WSE would result in decreased beach inundation of approximately 27.8 to 52.5 feet (8.5 to 16 meters).

Deer Bay Spit has had potential deposition and vegetative encroachment between 1953 and 2003. The most distinguishable change occurred on the north and west side of the spit. The poor quality of the 1964 photo and higher WSE in the 1953 photoset make it difficult to distinguish the edge of vegetation in the 1964 photoset (Figure 14). Delineations of edge of vegetation in 1964 may include unvegetated gravel areas and are thus conservative in their representation of vegetation encroachment. The slope of the spit is approximately 11 to 20 percent; therefore, a 3.3-foot (1-meter) drop in WSE would result in decreased beach inundation of approximately 16.4 to 27.8 feet (5.0 to 8.5 meters). While the exact amount of change in vegetation is difficult to precisely quantify, all of our analyses clearly indicate encroachment consistent with a lowering of lake elevations.

Vegetative encroachment on the south side of Baby Island is difficult to verify in Figure 15 due to poor image quality in the 1964 photo. Referring to the 1953 unrectified photo (Appendix A) does not clarify vegetative change because of a higher WSE than in the 2003 photo. The 1953 aerial photo shows some vegetation already present at the south end of the island. An upper beach is also present in the 1953 and 2003 photos located above the patch of shrubby vegetation. The slope of the south side of Baby Island is steeper than any other site analyzed in this report, 17 percent; therefore, a 3.3-foot (1-meter) drop in WSE would only result in decreased beach inundation of approximately 19.7 feet (6 meters).

The slope of beach and average width of vegetative encroachment for each site is presented in Table 4. These values were used to calculate an estimated vertical change that could potentially be related to a WSE change in Lake Ozette. Average slope of the analyzed sites is 11 percent, average width of vegetative encroachment is 40 feet (12 meters), and the estimated vertical change is 3.8 feet (1.2 meters). Ritchie (2005) found that of the 35.4 miles (57,000 meters) of shoreline, approximately 11.2 miles (18,000 meters) showed evidence of increased vegetative cover; therefore using the approximate width of vegetative encroachment found in the present study, the approximate area of beach vegetated between 1953/1964 and 2002/2003 is 55 acres (0.22 km<sup>2</sup>).

### **Lake Ozette Tributary Deltas**

Aerial photo analysis of tributary deltas in 1964 and 2002/2003 indicates evidence for variable delta growth at each tributary mouth. It is evident that lake water surface elevations may have been higher in the 1964 photo set than in the more recent photos and absolute WSE could not be determined for each photo set. Because of this, measurements of delta growth can only provide an order of magnitude estimate in terms of sediment accumulation, though they are sufficiently accurate to qualitatively portray depositional trends over the 40 year analysis period. The



Umbrella Creek delta appears to have grown most significantly over the analysis period, followed by the Crooked Creek delta. There is evidence of moderate delta growth at the South Creek delta, and evidence of little delta growth at the mouth of Big River and Siwash Creek.

**Table 4. Summary of shoreline characteristics for non-delta sites, Lake Ozette, Washington.**

| Shoreline Location              | Slope of Beach <sup>a</sup> | Average Width of Vegetative Encroachment (m) | Estimated Vertical Change (m) |
|---------------------------------|-----------------------------|----------------------------------------------|-------------------------------|
| Allens Beach and Cemetery Point | 7-11%                       | 12-21                                        | 1.4-1.5                       |
| Olsens Beach                    | 9-10%                       | 8-15                                         | 0.8-1.3                       |
| Preachers Point (Boot Bay)      | 6-11%                       | 9-14                                         | 0.9-1.0                       |
| Deer Bay Spit                   | 11-20%                      | 6-11                                         | 1.2                           |
| Baby Island (south side)        | 17%                         | —                                            | —                             |
| <b>Average</b>                  | <b>11%</b>                  | <b>12</b>                                    | <b>1.2</b>                    |

<sup>a</sup> Derived from 1-foot lidar elevation contours (Optimal Geomatics 2003).

Umbrella Creek has had considerable delta growth between 1964 and 2003. Figure 16 shows the northwest delta growth and subsequent vegetative encroachment. On the south side of the mouth, the edge of vegetation in 2003 is approximately the same as the edge of delta in 1964 with approximately 247,572 square feet (23,000 m<sup>2</sup>) of delta growth to the north-northwest. Little change was observed on the west side of Umbrella Creek towards Umbrella Bay.

Very little delta growth occurred at the mouth of Big River. Between 1964 and 2002/2003, there may have been minor amounts of deposition directly south of the mouth as well as around the shoreline to the south west; however the differences in water surface elevation between 1964 and 2002/2003 photos make this growth difficult to evaluate even qualitatively (Figure 17).

Crooked Creek has experienced approximately 129,168 square feet (12,000 m<sup>2</sup>) of delta growth between 1964 and 2002/2003. Figure 18 shows the majority of deposition occurring to the north of the mouth, as well as subsequent vegetative encroachment.

Siwash Creek has not had major delta growth between 1964 and 2003, but has had distinctive vegetative encroachment on the north side of mouth (Figure 19). Vegetation in 2003L photos has extended beyond the edge of vegetation line of 1964 photos and the edge of vegetation in 1964 photo matches a shrubby line of vegetation (older than new vegetation but younger than woody vegetation) in the 2003L photos. The slope of the beach to the north of Siwash Creek mouth is approximately 6 percent; therefore, a 3.3-foot (1-meter) drop in WSE would result in decreased beach inundation of approximately 52.5 feet (16 meters).

South Creek has had potentially delta growth (up to 86,112 square feet [8,000 m<sup>2</sup>]) and definite vegetative encroachment between 1964 and 2003 (Figure 20).



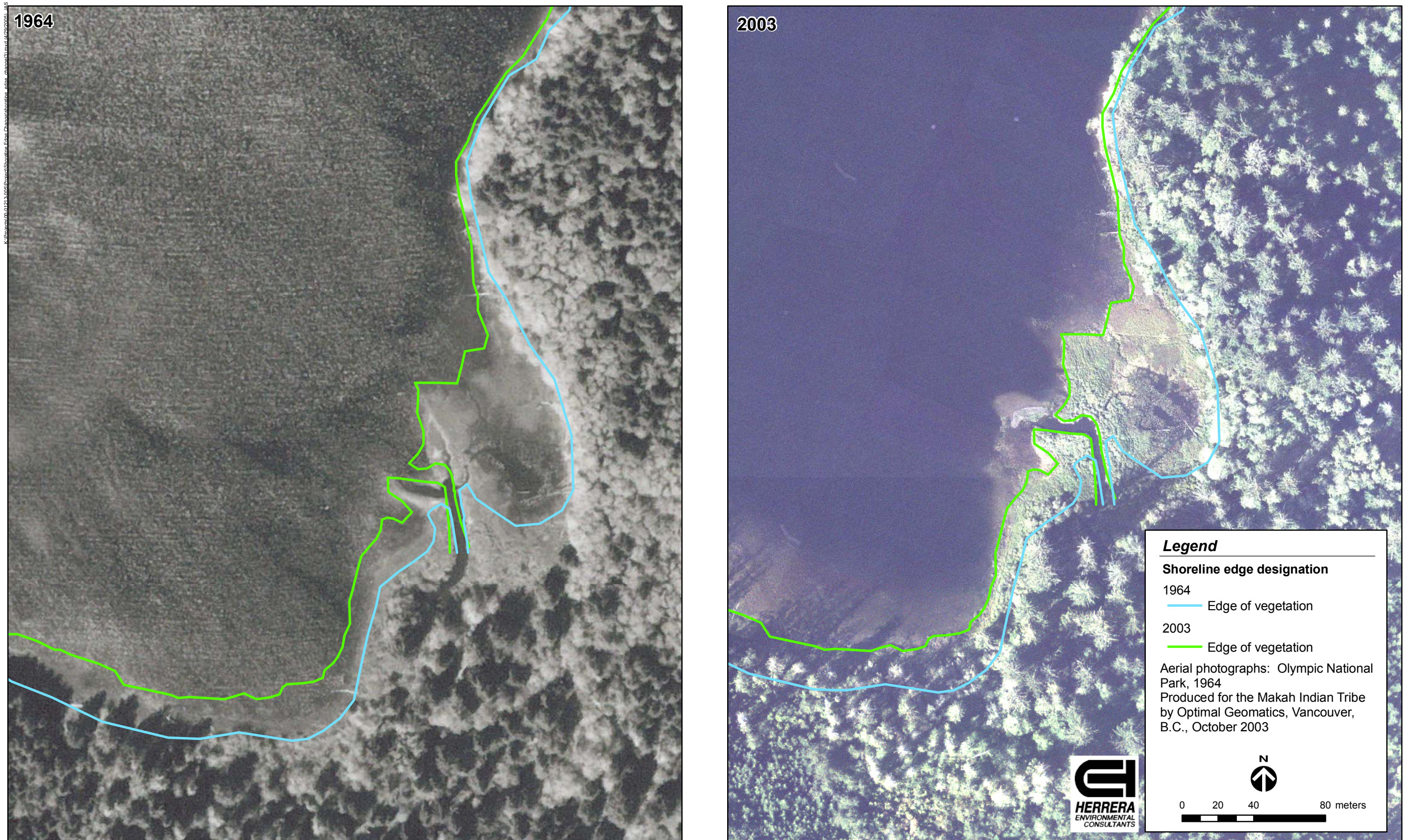


Figure 20. Shoreline changes and delta growth at the mouth of South Creek between 1964 and 2003, Lake Ozette, Washington.





## **Hydraulic Modeling to Assess Effects of Logjams on Lake Levels**

This section provides a description of hydraulic modeling performed to investigate the relationship between 1) wood loading in Ozette River, 2) resultant water surface profiles in the Ozette River, and 3) lake levels and availability of spawning habitat in Lake Ozette. A continuous hydraulic model of the Ozette River using the unsteady version of HEC-RAS was developed for this study. The objective of the modeling was to analyze the effects of current, historical, and assumed variations in wood loading in the Ozette River on lake levels in Lake Ozette. The model reach extends approximately 3,199 feet (975 meters), with an upstream boundary at the lake outlet, near the upstream side of the bridge near the National Park Service ranger house (Figure 21). Detailed discussion of model inputs, assumptions, methods, and results is provided below.

### **Model Inputs**

Required inputs to the HEC-RAS model include geometry, or topographic inputs, description of channel and overbank conditions, and flow hydrographs at each boundary location of the model. This section provides a detailed description of all of the inputs developed for modeling.

#### **Geometry**

CTS Engineers performed preliminary survey of the Ozette River in October, 2003. Due to high flows in the river at that time, control was only set and the water surface profile surveyed for the left and right edges of water. A complete survey in the main part of the river was not performed at that time. CTS returned in July 2004 to complete the survey. They performed another water surface profile survey and surveyed a total of 11 cross-sections, spaced roughly every 492 feet (150 meters) apart.

The Makah Indian Tribe provided additional topographic survey for one cross-section upstream of the bridge near the National Parks Service ranger house on October 26, 2004 and several additional water surface profiles for October 2004, November 2004, and December 2004. Figure 21 shows the cross-section locations. Appendix B provides graphical plots of each cross-section used in the model.

#### **Channel and Wood Loading Conditions**

On July 16 and 17, 2004, Herrera surveyed channel conditions and 15 logjams found within the model reach. The channel survey included notes and photographs to document changes in vegetation, substrate, channel gradient, and roughness type and magnitude within the model reach. The existing conditions wood load survey documented the length, width, and height of each major logjam (e.g., any jam that appeared relatively stable and large enough to exert an



appreciable influence on water surface profiles), the number of key pieces, and the estimated percentage of bankfull width being blocked by the jam. Table 5 provides a summary of wood load survey findings. Figure 21 shows the approximate location of each logjam at the time the survey was conducted and Appendix C provides a photograph of each surveyed logjam.

## **Flow**

In addition to the topographic inputs discussed above, the unsteady version of HEC-RAS requires continuous flow data inputs, or hydrographs, for the simulation period. Hydrographs are needed for each boundary location within the model reach. The boundary locations for the study reach include the Lake Ozette spillway, or headwaters to the Ozette River, and Coal Creek near the confluence with Ozette River (Figure 8). The model period selected was based on the longest period of available data for both locations, which was December 2003 to January 2005. Figure 22 shows the hydrographs for each location for this period. Note that this period of time covers one complete spawning cycle (October 15, 2004 to January 15, 2005), but does not cover the entire incubation period, which could last until March 15, 2005. Therefore, modeling results represent the complete spawning cycle and a portion of the incubation period for 2004/2005.

The model has a limited number of time steps (10,000) allowed for a given simulation. To meet the long simulation period with the limited number of time steps allowed, the flow hydrographs were averaged from their native 15-minute time step to an hourly time step. A check was performed to verify that this averaging was acceptable given the study objectives. To perform this check, the model was run using the native time step, but with the input data broken into four contiguous, roughly evenly split blocks. Results from these runs were compared with results from a continuous run for the simulation period using the hourly time step. As could be expected, the run with the 15-minute time step produced slightly higher peaks, but differences in daily peaks were within 5 percent during the simulation period. Thus, the hourly time step was used, since this study is not seeking to predict daily or hourly peaks, but rather to predict the magnitude and duration of lake levels over the duration of the salmon spawning and incubation period.

## **Stage-Area-Volume Relationship for Lake Ozette**

A stage-area-volume relationship for Lake Ozette was needed to understand how the lake surface area and volume of storage vary with fluctuations in lake levels. This relationship provides the linkage between modeled water surface elevations in Ozette River, particularly at the upstream boundary (or lake spillway) with lake elevation.

The stage-area-volume relationship was developed using a digital topographic model (DTM) of the Lake Ozette shoreline. The DTM was produced by Optimal Geomatics (Optimal) using light detection and ranging (lidar). Optimal collected data using a fixed-wing aircraft in October of 2003 and subsequently delivered unprocessed XYZ data and processed bare-earth DTM data (a data set that attempts to approximate only ground surface elevations). Due to heavy vegetation cover and improper processing techniques, the processed DTM data contained areas with no



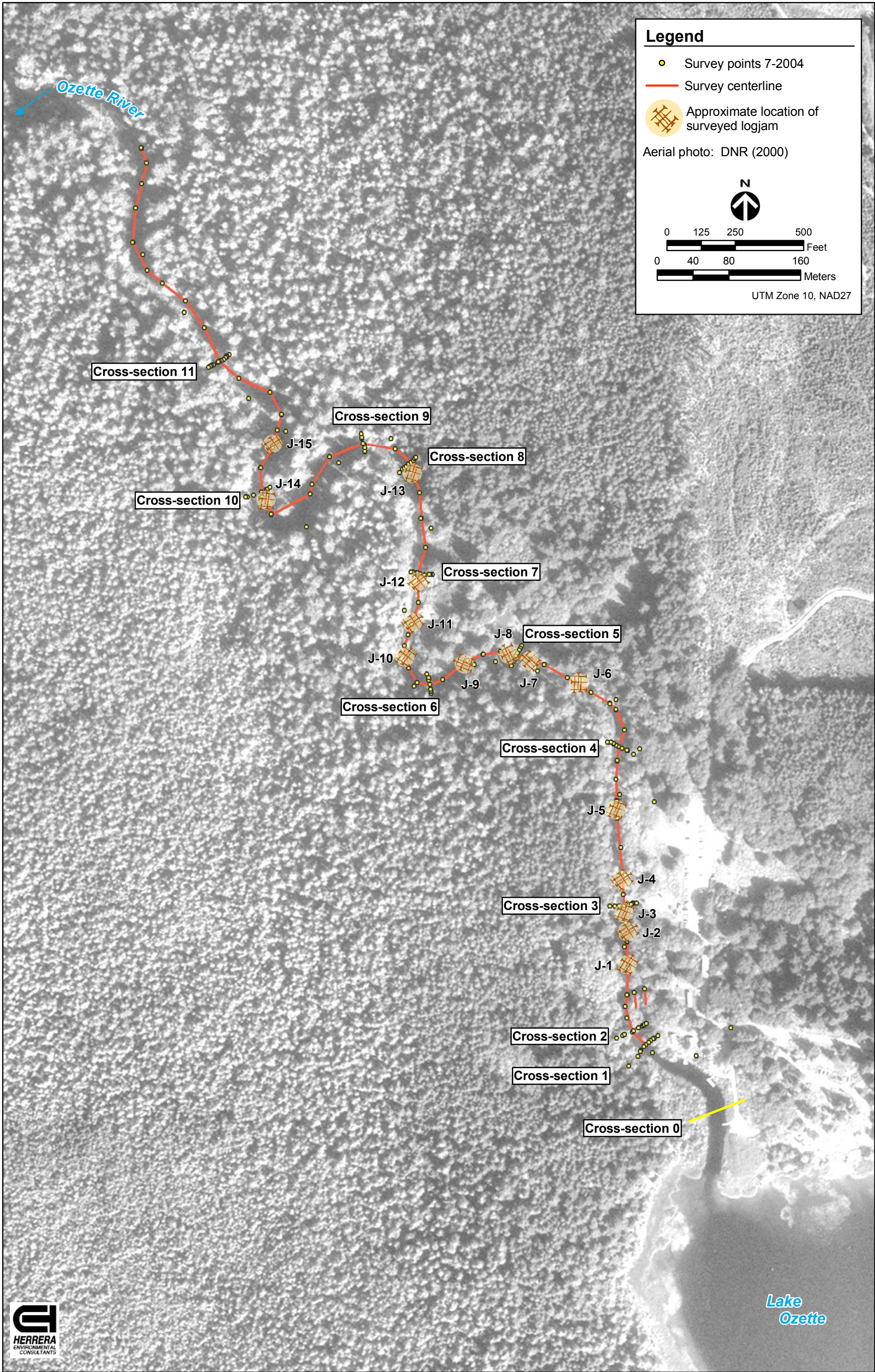
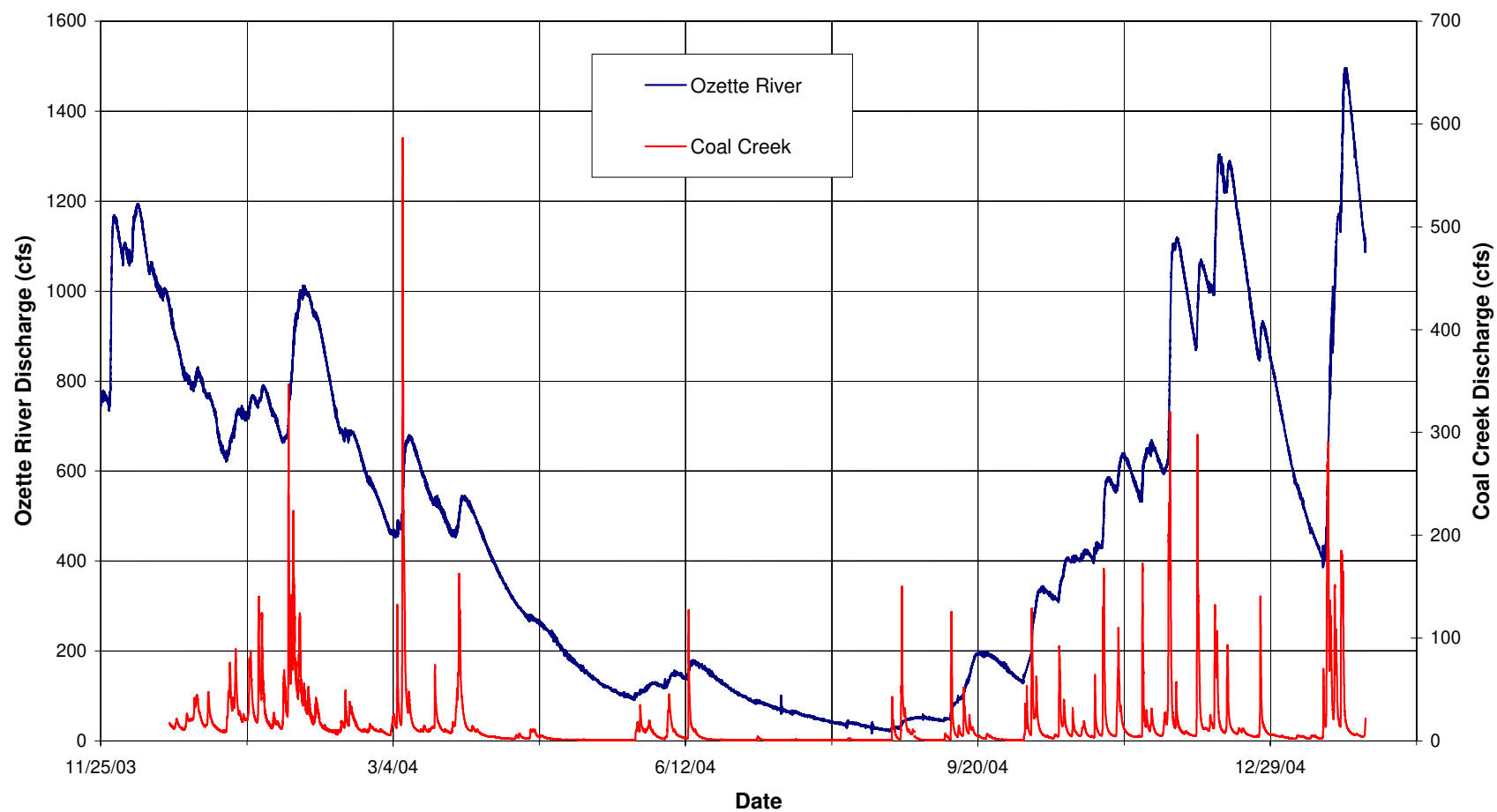


Figure 21. Cross-section locations for the Ozette River.







**Figure 22. HEC-RAS model input hydrographs for the Ozette River and Coal Creek.**





**Table 5. Summary of existing conditions during the wood survey for Ozette River.**

| ID  | Approx. Location (mile) <sup>a</sup> | Jam Length (m) | Jam Width (m) | Jam Height (m) | Key Members (#) | Key Member DBH (m) | Key Member Rootwad dia. (m) | Key Member Length (m) | Key Member Species (-) | Max. Age Trees on Top (yrs) | Est. Bkf Width (m) | Est. Bkf Depth (m) | Bankfull Obstructed (%) |
|-----|--------------------------------------|----------------|---------------|----------------|-----------------|--------------------|-----------------------------|-----------------------|------------------------|-----------------------------|--------------------|--------------------|-------------------------|
| J1  | 0.1                                  | 2              | 17            | 1              | 3               | 0.25               | 2                           | 19                    | Alder                  | 0                           | 20                 | 1.8                | 10                      |
| J2  | 0.12                                 | 20             | 4             | 0.5            | 3               | 0.3                | 0.75                        | 15                    | Alder                  | 0                           | 20                 | 2                  | 2                       |
| J2  | 0.12                                 | 20             | 5             | 0.5            | 5               | 0.3                | 0.75                        | 15                    | Alder                  | 0                           | 20                 | 2                  | 3                       |
| J3  | 0.2                                  | 2              | 10            | 1              | 1               | 0.5                | in bank                     | 10                    | Alder                  | 1-2                         | 20                 | 2                  | 5                       |
| J3  | 0.2                                  | 0.5            | 15            | 0.75           | 1               | 0.25               | in bank                     | 15                    | Alder                  | 1-2                         | 20                 | 2                  | 5                       |
| J4  | 0.21                                 | 1.5            | 15            | 1              | 1               | 0.25               | in bank                     | 15                    | Alder                  | 1                           | 22                 | 2.2                | 10                      |
| J5  | 0.3                                  |                | 15            | 1              | 2               | 0.25               | in bank                     | 18                    | Alder                  | 0                           | 22                 | 2.2                | 1                       |
| J6  | 0.4                                  | 2              | 10            | 1.5            | 3               | 0.25               | in bank                     | 10                    | Alder                  | 0                           | 18                 | 2.4                | 1-2                     |
| J7  | 0.48                                 | 3              | 5             | 1.75           | 1               | 0.3                | in bank                     | 10                    | Spruce                 | 0                           | 19                 | 2.5                | 3                       |
| J8  | 0.5                                  |                | 18            | 2              | 1               | 0.25               | in bank                     | 17                    | Alder                  | 0                           | 18                 | 2.5                | 10                      |
| J9  | 0.55                                 | 16             | 20            | 2.2            | 2               | 1                  | 1                           | 22                    | Alder/spruce           |                             | 20                 | 2.6                | 60+                     |
| J10 | 0.6                                  | 2              | 17            | 2              | 1               | 2                  | 2.3                         | 20                    | Red cedar              | 3                           | 22                 | 2.8                | 15-20                   |
| J11 | 0.66                                 | 1              | 18            | 1.75           | 1               | 0.5                | N/A                         | 18                    | Spruce                 | 1                           | 23                 | 2.6                | 2-5                     |
| J12 | 0.67                                 | 1              | 13            | 1.5            | 1               | 0.25               | 2                           | 10                    | Alder                  | 0                           | 28                 | 2.5                | 2-5                     |
| J13 | 0.7                                  | 27             | 25            | 1.75           | 5               | 2                  | 3                           | 25                    | Cedar/spruce           |                             | 25                 | 2.8                | 60+                     |
| J14 | 0.9                                  | 3              | 25            | 1.5            | 2               | 1                  | 2                           | 30                    | Spruce                 | 3                           | 25                 | 2.8                | 50                      |
| J15 | 1                                    | 1              | 25            | 1              | 1               | 0.75               | N/A                         | 25                    | Spruce                 | 1                           | 23                 | 2.6                | 5                       |

Notes:

<sup>a</sup> Approximate location for each surveyed logjam was estimated in GIS. Values reported represent distances in miles from the lake outlet, or Ozette River headwaters.



elevation data and, in vegetated areas, incorrectly modeled hill surfaces as being terraced. Due to holes in the data set and the low accuracy of the data set, the original DTM was unusable for modeling changes in lake levels and for slopes.

The Makah Indian Tribe reprocessed the raw XYZ data to generate a continuous, smoother DTM by creating a triangulated irregular surface (TIN) with ERSI ArcInfo and converting the TIN into a DTM raster. The resulting DTM contains approximate elevations in a one meter pixel size grid, but shows artifacts of heavy vegetation cover such as an uneven and “mottled” ground surface in most vegetated areas. The water surface of Lake Ozette appears to have been approximately 30.0 to 31.3 feet (9.1 to 9.5 meters) above sea level over the time period the data set was generated. The lidar was optimized to collect ground surface data for this project, so no sub-water-surface data are available in this area. The vertical datum of the lidar data is NAVD88.

In order to estimate the lake surface area for lake levels above 31 feet (9.4 meters) above sea level, 1-foot contours were generated from the bare earth DTM using ESRI Spatial Analyst between 32 feet (9.8 meters) above sea level and 44 feet (13.4 meters) above sea level. For each lake level, the contour around the lake area was converted into a polygon. The area of the resulting polygon corresponded to the projected area of lake surface at a given lake level.

The additional volume of water stored in the lake for each 1 foot (0.31 meters) increase in lake level was calculated by modeling the area of the lake surface as a pyramidal frustum:

$$V = \frac{1}{3}h(A_1 + A_2 + \sqrt{A_1A_2})$$

Where  $V$  = change in volume,  $h$  is the change in elevation (1 foot),  $A_1$  is the area of the lower lake surface and  $A_2$  is the area of the increased lake surface.

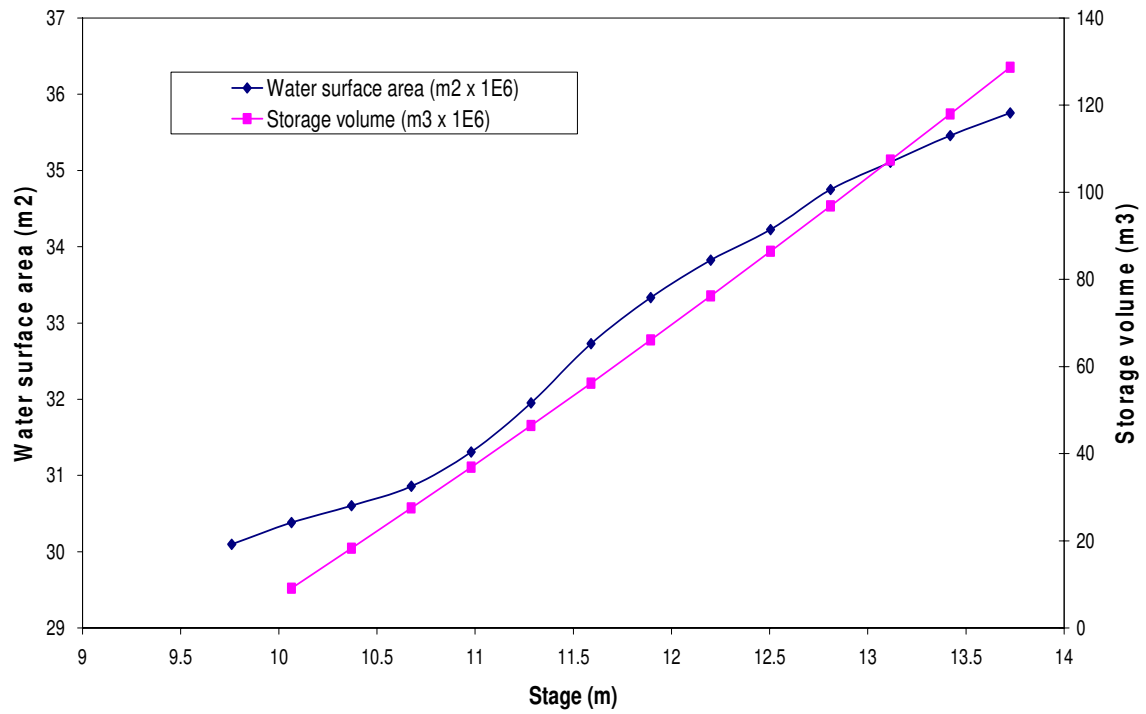
The lidar data are not continuous above 37 feet (11.3 meters) above sea level around the Ozette lake shoreline. The edge of the lidar data was treated as a vertical wall for lake surface area calculations; lake surface area is likely larger than reported for elevations above 37 feet (11.3 meters) above sea level. As elevation increases above 37 feet (11.3 meters) above sea level, an increasing percentage of the projected water surface area abuts the “vertical wall” at the edge of the DTM. Figure 23 shows the stage-area-volume relationship.

## **Methods**

This section provides detailed description of model calibration, approaches for modeling logjams in Ozette River, and development and modeling of alternative wood loading scenarios.

### **Model Calibration/Existing Conditions**

The unsteady model was calibrated for existing wood load conditions based on the presence of existing logjams, as discussed above, and using the obstructions feature of HEC-RAS to model



**Figure 23. Stage-area-volume relationship for Lake Ozette based on lidar data.**





each major jam. Several calibration parameters were adjusted until modeled water surface profiles reasonably matched observed water surface profiles for October 2003, July 2004, November 2004, and December 2004. The primary parameters that were subject to adjustment included Manning's roughness ( $n$ ) for channel and overbank areas and percent blockage at the three major jam locations (cross-sections 6.5 [interpolated between survey cross-sections 5 and 6], 3.5 [interpolated between survey cross-sections 3 and 4], and 2.5 [interpolated between survey cross-sections 2 and 3]; Figure 21). Manning's  $n$  is a model input parameter that provides an index of the roughness characteristics of the stream channel for purposes of flow and velocity calculation. The percent blockage for each major jam was defined in the model for low and high flow portions of the channel, based on the recorded blockage at bankfull conditions and graphical inspection of photographs taken during the wood survey (Appendix C).

Table 6 provides a summary of calibration parameters for each surveyed logjam. In addition to the information summarized below, it should be noted that  $n$  values for the remaining cross-sections (e.g., not in the vicinity of logjams) was 0.065 for overbank and 0.043 for channel. Figures 24 through 27 show simulated versus observed water surface profiles for October 2003, July 2004, November 2004, and December 2004, respectively. Figure 28 shows calibration results as a continuous time series throughout the model period at the upstream boundary location.

**Table 6. Summary of model calibration parameters at surveyed logjam locations.**

| Logjam | Recorded % Blockage at Bankfull Flow | Modeling Method                                                                                     | Overbank $n$ Values | Main Channel $n$ Values |
|--------|--------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------|-------------------------|
| J1     | 10                                   | Increased roughness at cross section (X-S) 9.6                                                      | 0.085               | 0.043                   |
| J2     | 2                                    | Increased roughness at X-S 9                                                                        | 0.085               | 0.043                   |
| J3     | 5                                    |                                                                                                     |                     |                         |
| J4     | 10                                   |                                                                                                     |                     |                         |
| J5     | 1                                    | Increased roughness at X-S 8                                                                        | 0.085               | 0.043                   |
| J6     | 2                                    |                                                                                                     |                     |                         |
| J7     | 3                                    | Increased roughness at X-S 7                                                                        | 0.085               | 0.043                   |
| J8     | 10                                   |                                                                                                     |                     |                         |
| J9     | 60+                                  | Obstruction at X-S 6.5, with approx. 34% low flow channel blocked and 36% high flow channel blocked | 0.12                | 0.055                   |
| J10    | 15-20                                | Increased roughness at X-S 6                                                                        | 0.09                | 0.043                   |
| J11    | 5                                    | Increased roughness at X-S 5                                                                        | 0.085               | 0.043                   |
| J12    | 5                                    |                                                                                                     |                     |                         |
| J13    | 60+                                  | Obstruction at X-S 3.5, with approx. 70% low flow channel blocked and 46% high flow channel blocked | 0.12                | 0.055                   |
| J14    | 50                                   | Obstruction at X-S 2.5, with approx. 56% low flow channel blocked and 26% high flow channel blocked | 0.12                | 0.055                   |
| J15    | 5                                    | Increased roughness at X-S 2                                                                        | 0.085               | 0.043                   |

The water surface profiles (Figures 24 through 27) showed excellent agreement between modeled and observed conditions for a point in time, along the length of the model reach, and for low flow as well as for high flows; however, water surface elevations over the simulation period at the upstream boundary (Figure 28) were not in as close agreement. The modeled time series at the upstream boundary show artificial blips in water surface elevation that can be up to 2 feet (0.61 meters) in magnitude, but only persist for an hour or so. This may be attributed to the need for better floodplain definition in several upper reach cross-sections. Because of the short duration of these spikes, however, and since this study is seeking to investigate changes in lake levels over the entire spawning season, the calibration results were deemed suitable for this application. Further calibration may be needed if the model were to be used for other purposes, such as flood risk analysis.

### **Approach for Modeling Logjams**

HEC-RAS does not contain model elements for explicitly modeling logjams. Several indirect methods were therefore investigated to try to determine the best approach for this study, including:

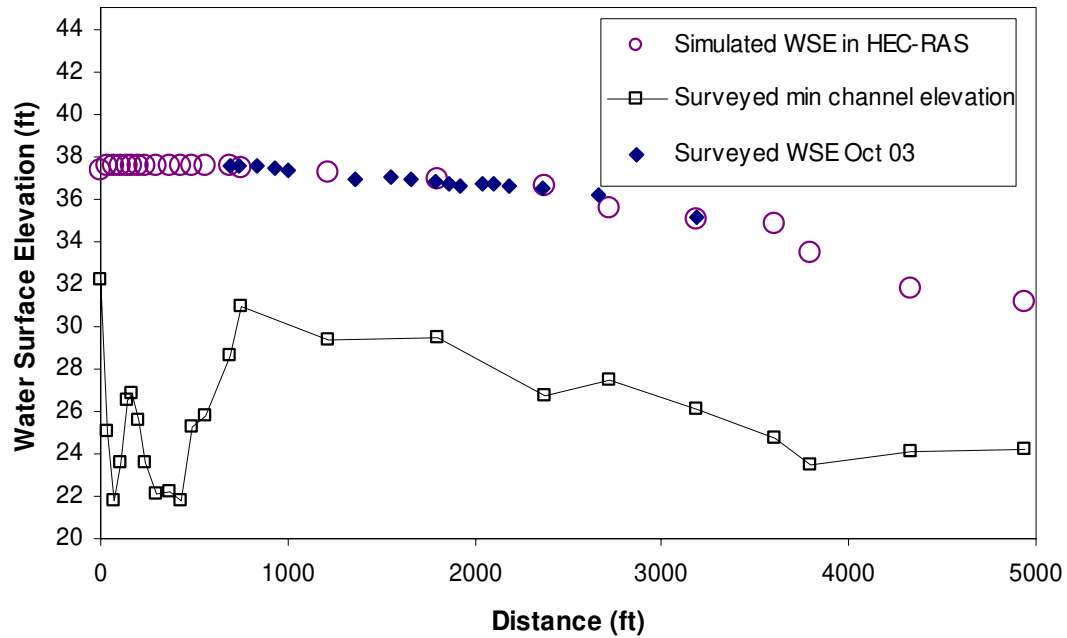
- Adjusting Manning's roughness ( $n$ ) in the vicinity of each jam
- Modeling each major jam (bankfull blockage equal to or greater than 50 percent) as an obstruction; modeling each smaller jam as an increase in Manning's  $n$
- Modeling each major jam (bankfull blockage equal to or greater than 50 percent) as a bridge deck with multiple culverts to represent openings in the logjams; modeling each smaller jam as an increase in Manning's  $n$ .

For each candidate method, a steady version of the HEC-RAS model was roughly calibrated to the observed water surface profiles for October 2003 and July 2004. The additional water surface profile data provided by the Makah Indian Tribe mentioned above were not available during execution of this task. Each candidate method was compared in terms of opportunity to represent the most important physical features of the jams, ability to reproduce observed high flow (October) and low flow (July) water surface profiles, and ease of implementation.

The first method, adjusting Manning's roughness coefficient in the vicinity of each jam, is the simplest to implement. While this method is the easiest to implement, it was considered least desirable, because it does not provide enough flexibility to distinguish the major physical characteristics of each jam. For example, this method would not allow for describing the bed slope of a given jam, or gradients in wood density with cross-section elevation.

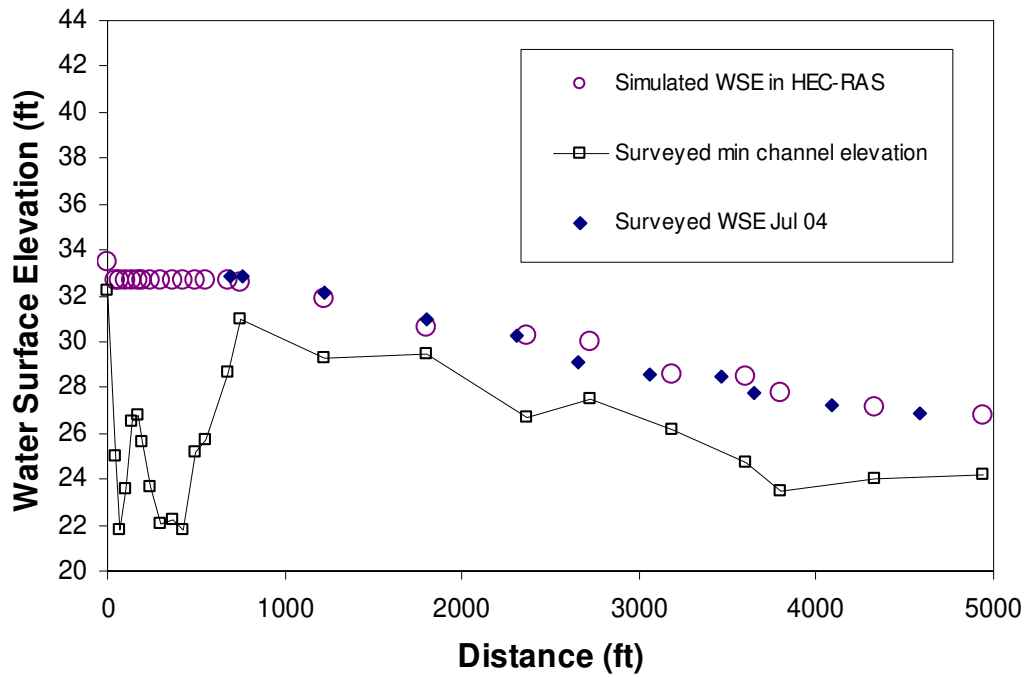
The third method is more time consuming to implement, but provides excellent opportunities for specifying the physical attributes of each jam. The modeler can define the length of the jam (measured in the direction of flow), bed slope, and gradients in wood load density as a function of elevation. The disadvantage of this method is that there are many parameters needing to be





**Figure 24. HEC-RAS unsteady model calibration results for the Ozette River, showing the simulated versus observed water surface profile for October 2003.**

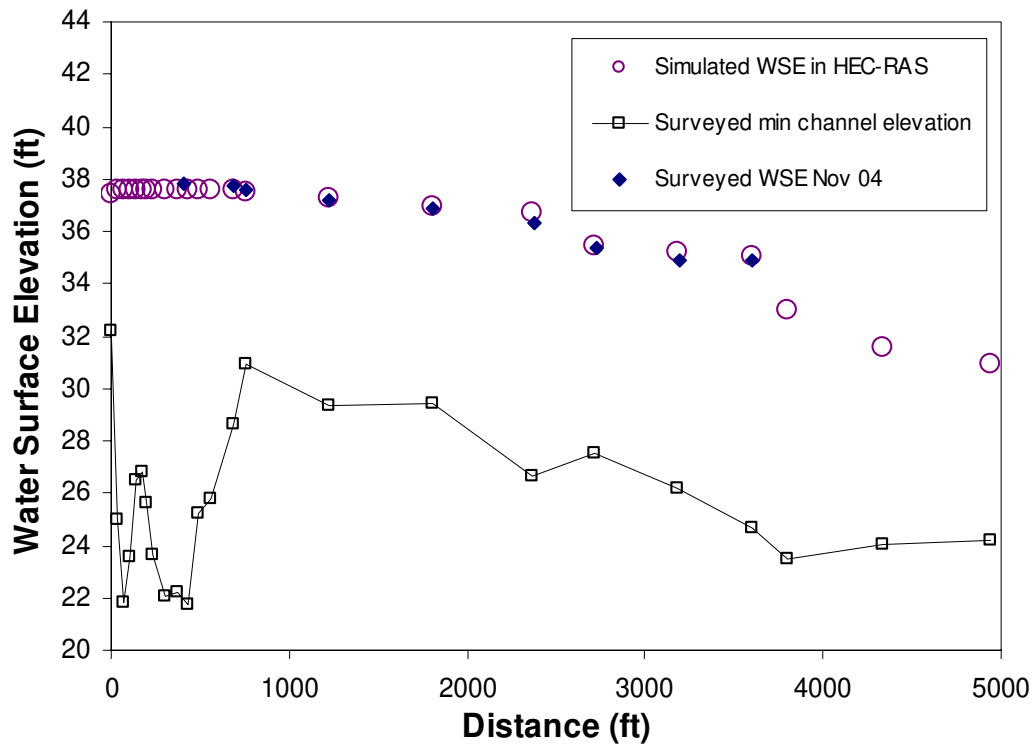




**Figure 25. HEC-RAS unsteady model calibration results for the Ozette River, showing the simulated versus observed water surface profile for July 2004.**



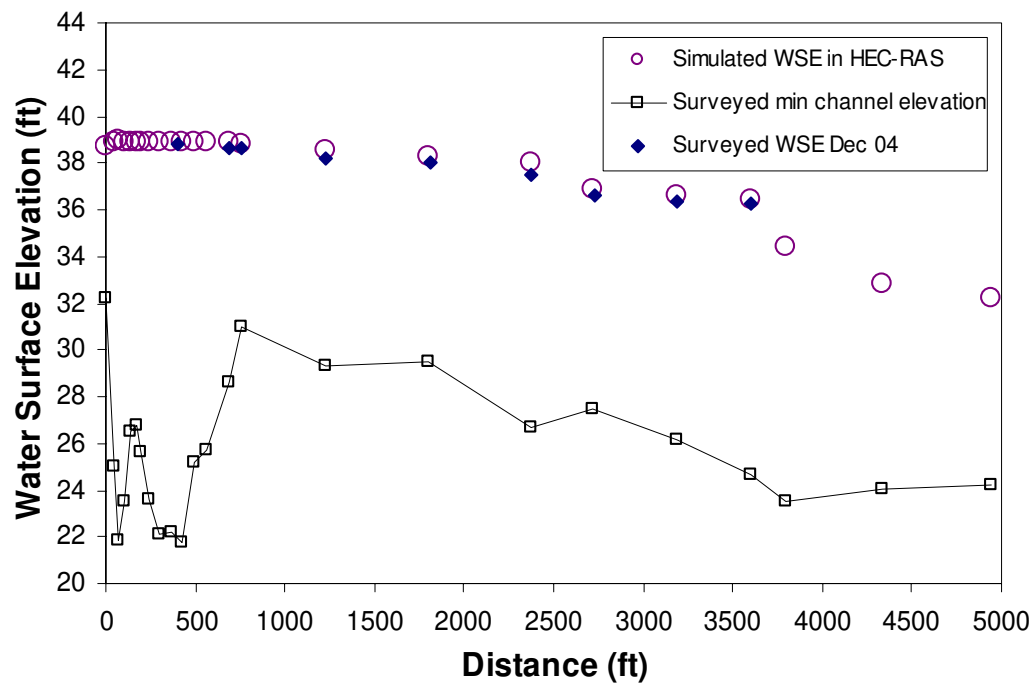




**Figure 26. HEC-RAS unsteady model calibration results for the Ozette River, showing the simulated versus observed water surface profile for November 2004.**

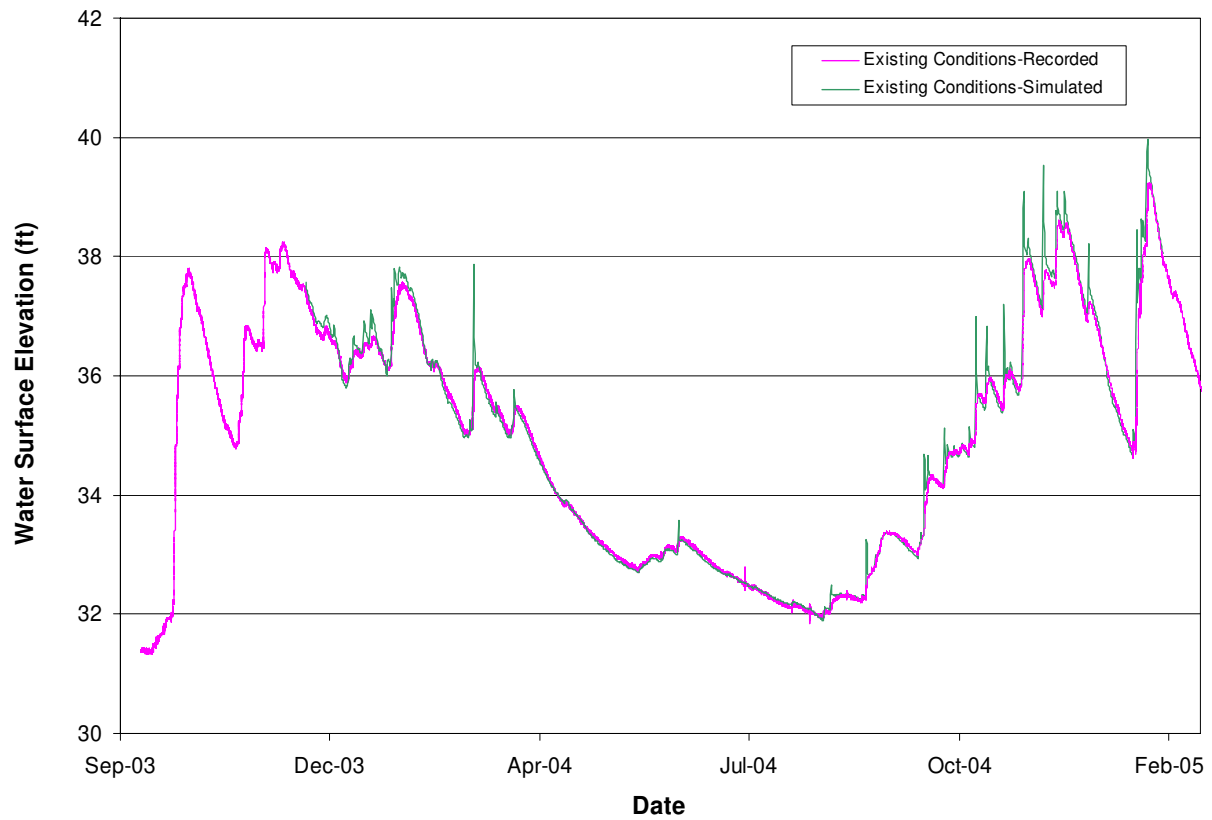






**Figure 27. HEC-RAS unsteady model calibration results for the Ozette River, showing the simulated versus observed water surface profile for December 2004.**





**Figure 28. HEC-RAS unsteady model calibration results for the Ozette River, showing the simulated versus observed water surface elevations at upstream HEC-RAS model boundary, near the Lake Ozette spillway, for entire simulation period.**





specified, with not enough data for calibration/validation of such a large number of parameters. For instance, the user must specify entrance loss and exit loss coefficients as well as Manning's  $n$  (top and bottom) for each culvert through the bridge deck that would represent an opening in the logjam. In the end, it was believed that such a high level of model parameterization would not be worth pursuing, especially in the absence of sufficient data to fully calibrate and validate this approach.

The second method of modeling the major jams as blockages, or obstructions, was ultimately used for this study. This method allows for specifying some of the most important physical features of each jam (e.g., height, length, width, and percentage of cross-sectional area blocked), and shows good ability to simulate the effects of major jams on the water surface profile during high and low flow. The following section provides more detailed description of the actual model calibration to existing conditions using this approach.

### **Alternative Wood Loading Scenarios**

Once the model was calibrated to existing conditions, several alternative wood loading scenarios were defined and evaluated to assess the effects of wood loading on lake levels and availability of spawning habitat. Two classes of scenarios were defined. The first class included one scenario to evaluate how lake levels would respond to the existing three large jams staying in place and accumulating more wood. This was modeled by increasing the percent bankfull blockage by 20 percent at each location. This scenario was developed to represent a condition that may be expected to occur naturally over time, without any human intervention. As was noted above, percent bankfull blockage for both the low flow and high flow portions of the channel were defined for each of the three major logjams based on model calibration (Table 6). Thus, for this scenario, the low flow and high flow portions of the channel were both increased by 20 percent over the values reported in Table 6 in order to roughly maintain the shape, as well as location of each major logjam.

The second class included a total of 12 scenarios developed in order to more fully understand the relationship among logjam spacing frequency (average distance between jams), logjam size (percent bankfull blockage), and magnitude and duration of lake levels. The relationship among these variables is important to understanding the potential beneficial effects on spawning habitat, as well as potential flood risks associated with restoration activity involving logjam construction in the Ozette River. For this study, spacing frequency was varied as one jam per every 200 feet (61 meters), one jam per every 500 feet (152.4 meters), and one jam per every 1,000 feet (304.8 meters). Logjam size was varied as 0 (or no logjam), 20, 40, 60, and 80 percent bankfull blockage. As mentioned above, percent bankfull blockage was defined separately for the low flow and high flow portions of the channel based on model calibration. Thus, for these scenarios, a 20 percent blockage, for instance, was represented as a cross-section in which 20 percent of the low flow portion of the channel was blocked and 20 percent of the high flow portion of the channel was blocked.

Photos depicting logjams in Ozette River prior to the wood clearing activities by the Washington State Department of Fisheries indicate that the historical jams were extremely large and

relatively evenly and densely spaced (Kramer 1953). Thus, the 200-foot spacing/60 percent blockage scenario is deemed most closely representative of historical conditions. Appendix D includes images of logjams removed from the Ozette River at 2¾ miles, 3 miles, and 4 miles below the lake outlet (Kramer 1953).

## **Results**

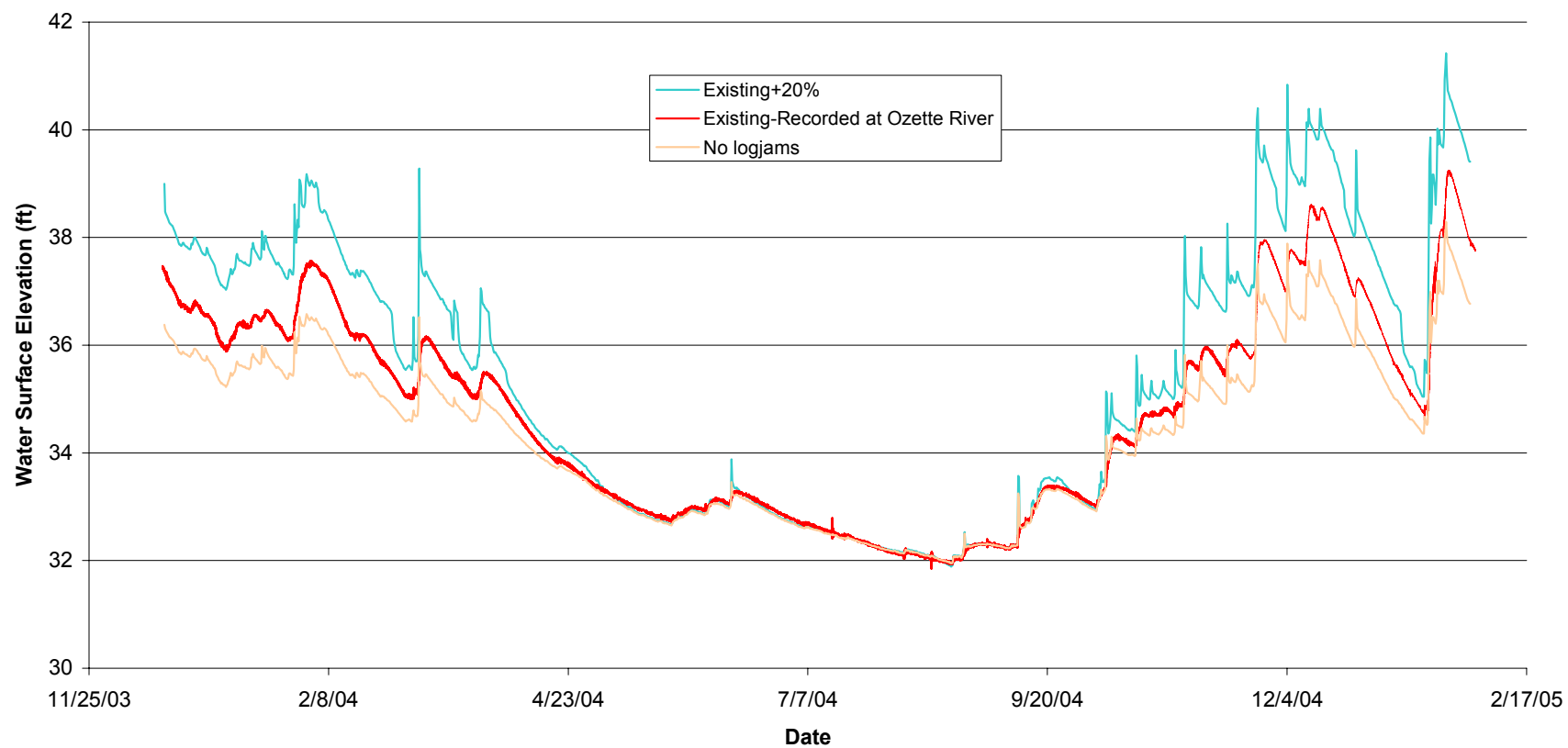
Results from the modeling indicate that the conditions of wood loading in the Ozette River can exert a significant influence on lake elevations and on the duration of high lake levels during the spawning and incubation period. The remainder of this section provides detailed discussion of modeling results in terms of magnitude, timing, and duration of lake levels as a result of logjams in the Ozette River.

### **Magnitude and Timing**

Figure 29 illustrates Lake Ozette water surface elevations for the first alternative wood loading scenario, which consists of the three existing major logjams that stay in place but increase in size (e.g., percent blockage) by 20 percent. This figure also shows existing conditions (e.g., recorded lake levels at the ONP gauge near the outlet) and a “No Wood,” or zero percent blockage scenario, for comparison. The results show that increases in lake levels due to increases in jam size is greatest during high lake stages that occur in the late fall, winter, and early spring and is less significant during the lower lake stages that occur over the remainder of the year. This result may be attributed to the fact that the major jams contain a fairly high density of wood in the high flow portion of the channel (see wood survey photos in Appendix C). While the results show a significant influence on magnitude and duration of high lake levels, the timing of high lake levels appears essentially unaffected by the variations in wood loading.

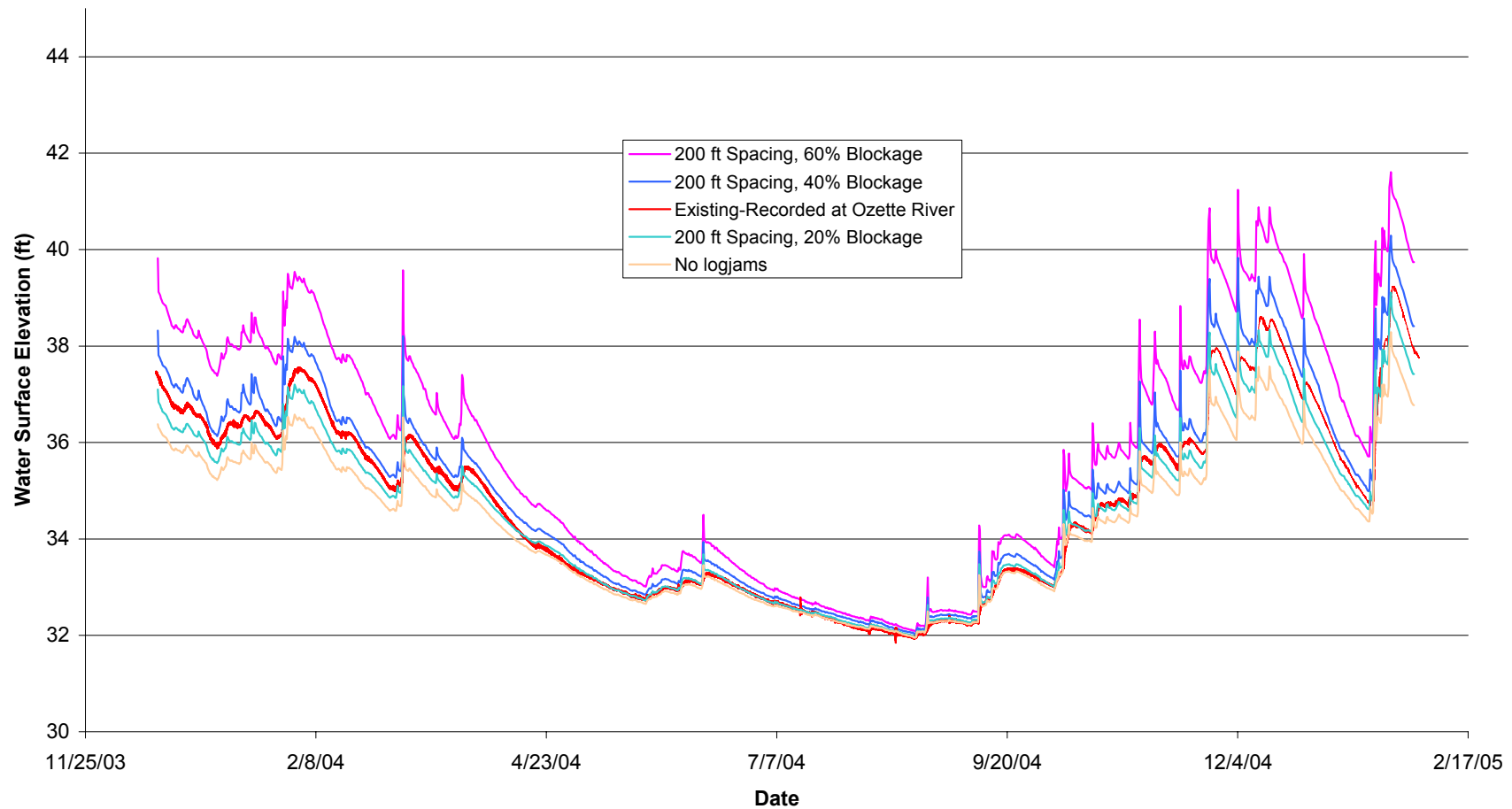
Figures 30 through 32 illustrate similar results for the second class of alternative wood loading scenarios, in which jam size and spacing frequency were varied uniformly to investigate the effects of multiple combinations of these variables on lake levels. Figure 30 shows results for 200-foot spacing frequency, with jam size ranging from 0 percent (no jams) to 80 percent in intervals of 20 percent. A 200-foot spacing, 80 percent blockage scenario was attempted, but did not run stably throughout the simulation period. This instability may be attributed to the extreme density of wood, which could cause abrupt changes in the stage-discharge relationship at major logjam locations. Figures 31 and 32 provide plots similar to those in Figure 30, but with a 500-foot and 1,000-foot spacing frequency, respectively. The results from these scenarios behave similarly as described above, with lake levels increasing as a function of increased wood loading. Since the 200-foot, 80 percent blockage scenario did not run, the scenario with the highest lake levels throughout the simulation period was the 500-foot, 80 percent blockage scenario. This scenario produced high lake stages that were up to approximately 4 feet (1.2 meters) higher than existing conditions for the maxima on record and approximately 1 foot (0.3 meters) higher on average during the simulation period. Again, the timing of high lake levels appears unaffected by the different wood loading scenarios.





**Figure 29. Comparison of simulated lake elevations for existing conditions, existing logjam placement with assumed 20 percent increase in bankfull blockage, and no logjams.**

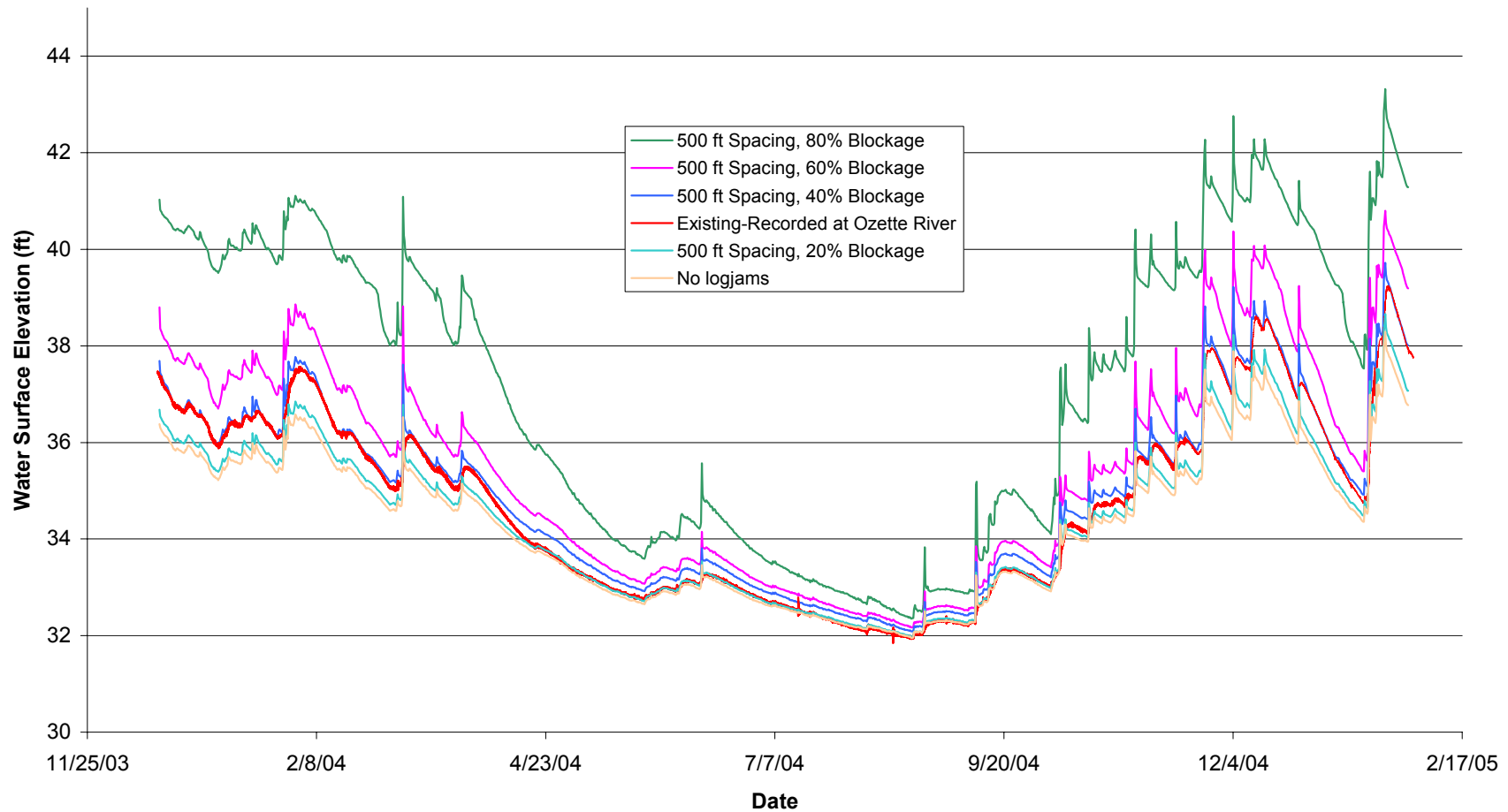




**Figure 30. Comparison of simulated lake elevations for various assumed bankfull blockage levels, assuming logjams are spaced roughly every 200 feet in the Ozette River reach.**



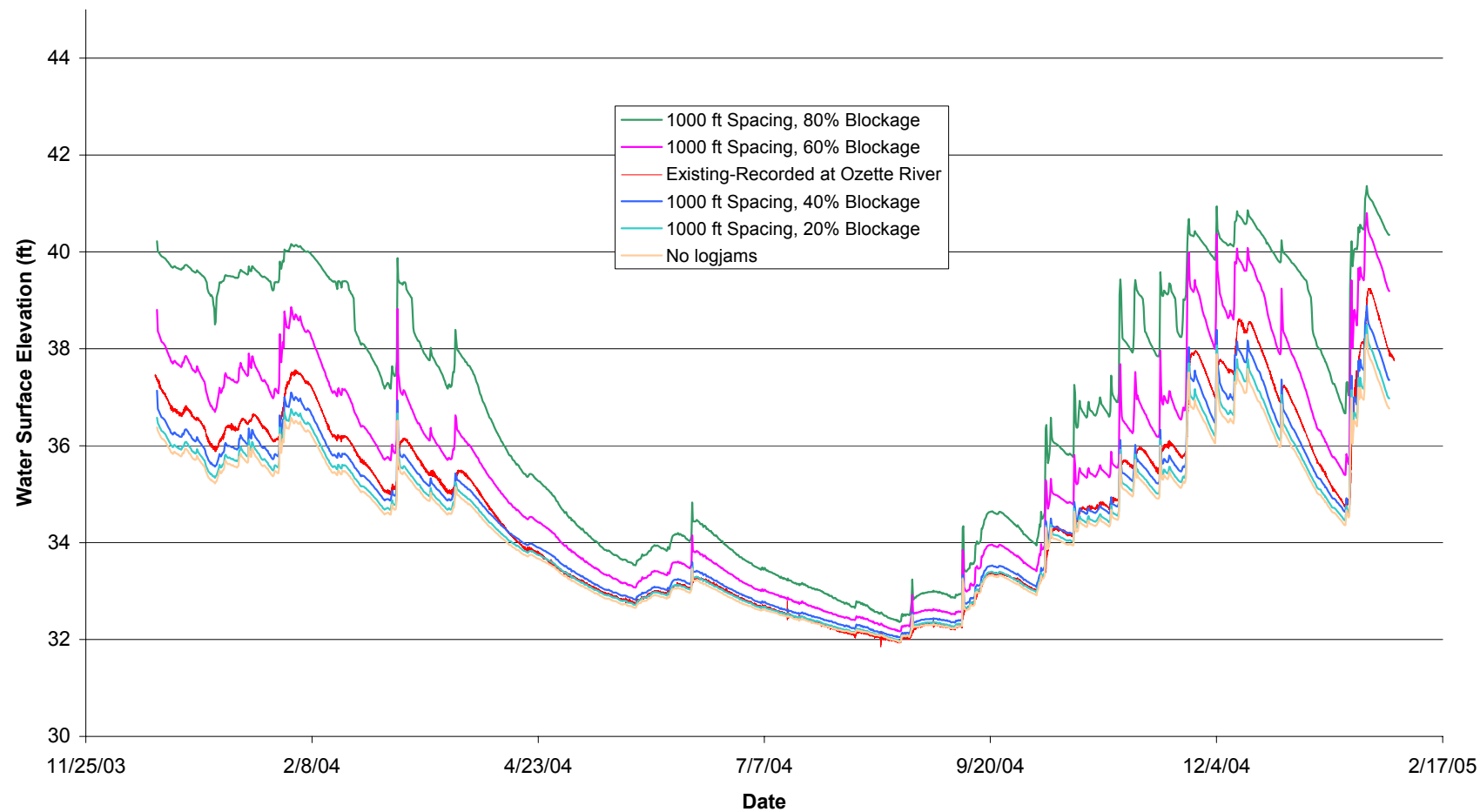




**Figure 31. Comparison of simulated lake elevations for various assumed bankfull blockage levels, assuming logjams are spaced roughly every 500 feet in the Ozette River reach.**







**Figure 32. Comparison of simulated lake elevations for various assumed bankfull blockage levels, assuming logjams are spaced roughly every 1000 feet in the Ozette River reach.**



Figure 33 provides a summary of modeling results for the second class of scenarios, showing mean lake level during the spawning and a portion of the incubation window (October 15 to January 15) with varying percent blockage on the x-axis, and different curves representing various spatial frequencies (e.g., every 200 feet, 500 feet, and 1,000 feet). The existing condition mean lake level is also shown on this plot as a horizontal line with value 36.61 feet (11.16 meters) for purposes of comparison. This plot suggests an exponential trend between mean lake level during spawning season and size of logjams. The plot also suggests that a given mean lake level during spawning season can be achieved through restoration of wood in the Ozette River by either adding many smaller jams or fewer larger jams. For example, if a mean lake level of 37 feet (11.3 meters) during spawning season were the target, this could be achieved either by placing jams with roughly 40 percent cross-sectional blockage spaced every 500 feet, or by placing larger jams with roughly 60 percent cross-sectional blockage spaced every 1,000 feet. In order to substantially increase the mean lake level during spawning and incubation periods (e.g., to elevation 39 feet or greater), very large logjams with at least 80 percent cross-sectional blockage and spaced at a minimum frequency of 1,000 feet would be needed. Table 7 provides a summary of mean lake levels during the spawning and incubation period for all of the second class scenario results.

**Table 7. Summary of model results for various wood load scenarios.**

|               | Existing Condition <sup>a</sup> | 200-foot spacing |       |       | 500-foot spacing |       |       |       | 1,000-foot spacing |       |       |       |
|---------------|---------------------------------|------------------|-------|-------|------------------|-------|-------|-------|--------------------|-------|-------|-------|
|               |                                 | 20%              | 40%   | 60%   | 20%              | 40%   | 60%   | 80%   | 20%                | 40%   | 60%   | 80%   |
| Oct 15-Jan 30 | 36.61                           | 36.21            | 36.95 | 38.10 | 35.96            | 36.66 | 37.52 | 39.93 | 35.90              | 36.16 | 36.67 | 38.99 |

Note: Values represent mean lake levels for the given scenario during spawning season and a portion of the incubation period (October 15 to January 30). Values are reported in feet.

<sup>a</sup> Existing condition based on recorded stage for the period of analysis (October 15, 2004 – January 30, 2005) at Ozette River gauge.

## Duration

This section provides analysis on the duration, or number of hours during the spawning and incubation period (October 15, 2004 to January 30, 2005) that various lake levels were exceeded. Figure 34 provides a plot of stage-duration for existing conditions and for each of the second class of wood load scenarios analyzed. The trends shown in Figure 34 are very similar to those described above for magnitude and timing of high lake levels in that scenarios with greater density of wood result in longer periods of high lake stage throughout the spawning and incubation period. Using the 37-foot (11.3-meter) stage as an example again, Lake Ozette currently maintains stage at 37 feet or greater roughly 45 percent of the time during the spawning and incubation period. With 80 percent blockage jams spaced every 500 feet, this duration more than doubles. Comparing duration results for a higher stage such as 39 feet, logjams with 80 percent blockage spaced every 500 feet could increase the duration from approximately 5 percent of the time under existing conditions to approximately 75 percent of the time during the spawning and incubation period. Table 8 provides a summary of duration analysis results.



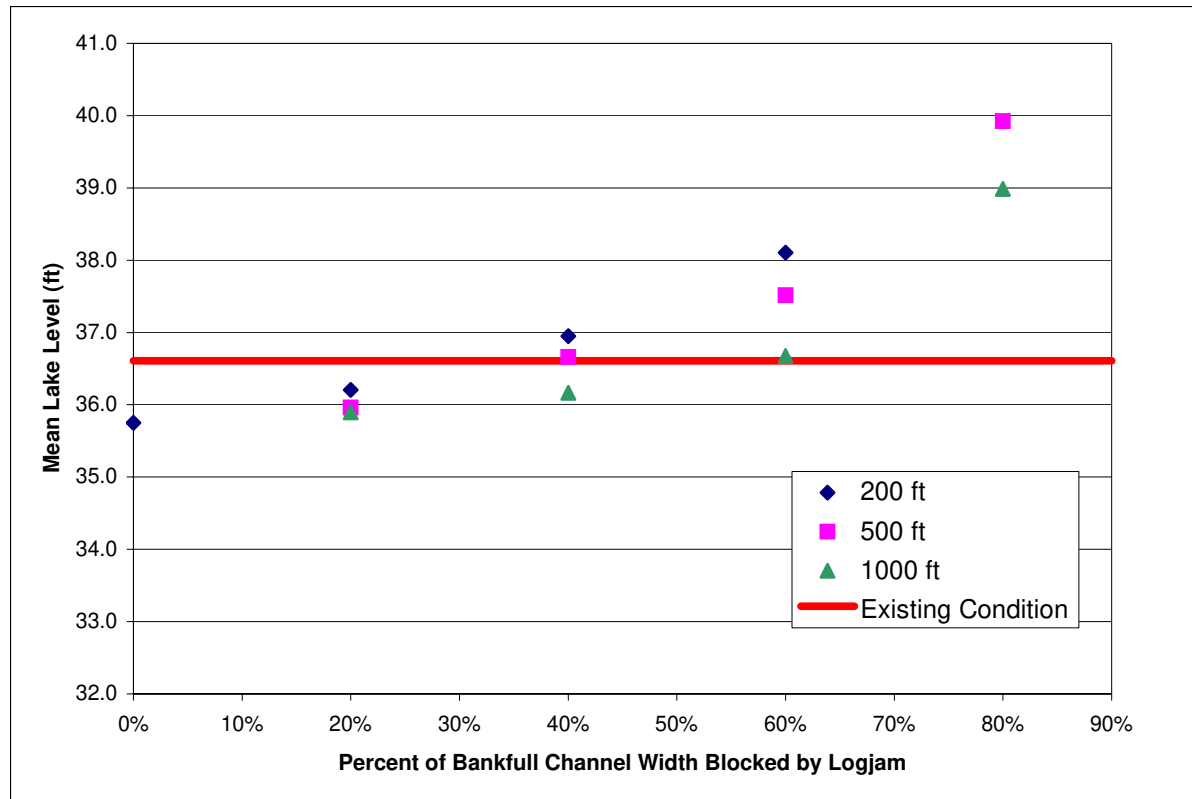
**Table 8. Summary of results of stage-duration analysis.**

| Stage Level Number | Stage (ft) | Volume (acre-ft) | Existing Condition <sup>a</sup> | 200-foot spacing <sup>b</sup> |              |              | 500-foot spacing |              |              |              | 1,000-foot spacing |              |              |              |
|--------------------|------------|------------------|---------------------------------|-------------------------------|--------------|--------------|------------------|--------------|--------------|--------------|--------------------|--------------|--------------|--------------|
|                    |            |                  |                                 | 20% blockage                  | 40% blockage | 60% blockage | 20% blockage     | 40% blockage | 60% blockage | 80% blockage | 20% blockage       | 40% blockage | 60% blockage | 80% blockage |
|                    |            |                  |                                 | (% of time)                   | (% of time)  | (% of time)  | (% of time)      | (% of time)  | (% of time)  | (% of time)  | (% of time)        | (% of time)  | (% of time)  | (% of time)  |
| 1                  | 32         | 0                | 100.0                           | 100.0                         | 100.0        | 100.0        | 100.0            | 100.0        | 100.0        | 100.0        | 100.0              | 100.0        | 100.0        | 100.0        |
| 2                  | 32.5       | 4.55             | 100.0                           | 100.0                         | 100.0        | 100.0        | 100.0            | 100.0        | 100.0        | 100.0        | 100.0              | 100.0        | 100.0        | 100.0        |
| 3                  | 33         | 9.1              | 100.0                           | 100.0                         | 100.0        | 100.0        | 100.0            | 100.0        | 100.0        | 100.0        | 100.0              | 100.0        | 100.0        | 100.0        |
| 4                  | 33.5       | 13.69            | 100.0                           | 100.0                         | 100.0        | 100.0        | 100.0            | 100.0        | 100.0        | 100.0        | 100.0              | 100.0        | 100.0        | 100.0        |
| 5                  | 34         | 18.28            | 100.0                           | 100.0                         | 100.0        | 100.0        | 100.0            | 100.0        | 100.0        | 100.0        | 100.0              | 100.0        | 100.0        | 100.0        |
| 6                  | 34.5       | 22.91            | 97.4                            | 96.7                          | 97.4         | 100.0        | 90.9             | 97.4         | 100.0        | 100.0        | 88.1               | 96.5         | 97.4         | 100.0        |
| 7                  | 35         | 27.54            | 79.1                            | 77.2                          | 92.3         | 100.0        | 75.8             | 86.7         | 97.4         | 100.0        | 75.3               | 77.4         | 87.2         | 100.0        |
| 8                  | 35.5       | 32.22            | 70.2                            | 63.5                          | 76.7         | 97.4         | 54.2             | 75.8         | 87.0         | 100.0        | 52.3               | 63.3         | 76.0         | 100.0        |
| 9                  | 36         | 36.89            | 54.4                            | 48.8                          | 65.6         | 81.9         | 46.5             | 58.6         | 76.5         | 100.0        | 46.0               | 48.4         | 59.3         | 97.4         |
| 10                 | 36.5       | 41.66            | 48.6                            | 43.3                          | 50.2         | 76.3         | 37.4             | 48.1         | 66.3         | 97.4         | 35.8               | 41.9         | 48.1         | 96.5         |
| 11                 | 37         | 46.42            | 45.3                            | 34.4                          | 47.2         | 68.6         | 24.2             | 43.3         | 52.6         | 97.4         | 21.2               | 31.2         | 43.7         | 83.0         |
| 12                 | 37.5       | 51.29            | 35.8                            | 19.8                          | 42.1         | 57.7         | 10.7             | 35.8         | 47.9         | 94.9         | 8.1                | 18.1         | 35.8         | 77.4         |
| 13                 | 38         | 56.15            | 24.0                            | 7.7                           | 34.0         | 48.8         | 2.8              | 22.8         | 42.3         | 80.9         | 2.1                | 5.3          | 22.6         | 70.7         |
| 14                 | 38.5       | 61.13            | 11.6                            | 2.3                           | 20.0         | 45.8         | 0.2              | 9.8          | 34.9         | 76.7         | –                  | 1.2          | 9.5          | 61.6         |
| 15                 | 39         | 66.1             | 4.2                             | 0.2                           | 9.5          | 38.4         | –                | 3.0          | 25.6         | 75.8         | –                  | –            | 3.5          | 60.0         |
| 16                 | 39.5       | 71.15            | 1.2                             | –                             | 2.8          | 28.1         | –                | 0.5          | 14.7         | 61.2         | –                  | –            | 0.7          | 48.1         |
| 17                 | 40         | 76.21            | –                               | –                             | 0.5          | 16.3         | –                | –            | 4.2          | 49.1         | –                  | –            | –            | 36.0         |
| 18                 | 40.5       | 81.33            | –                               | –                             | –            | 7.2          | –                | –            | 0.7          | 44.7         | –                  | –            | –            | 14.4         |
| 19                 | 41         | 86.45            | –                               | –                             | –            | 2.3          | –                | –            | –            | 32.1         | –                  | –            | –            | 2.6          |
| 20                 | 41.5       | 96.84            | –                               | –                             | –            | 0.2          | –                | –            | –            | 15.8         | –                  | –            | –            | –            |

Note: Values represent percentage of time during the spawning and a portion of the incubation period (October 15, 2004 – January 30, 2005) that stage is exceeded during the spawning season and a portion of the incubation period (October 15 to January 30).

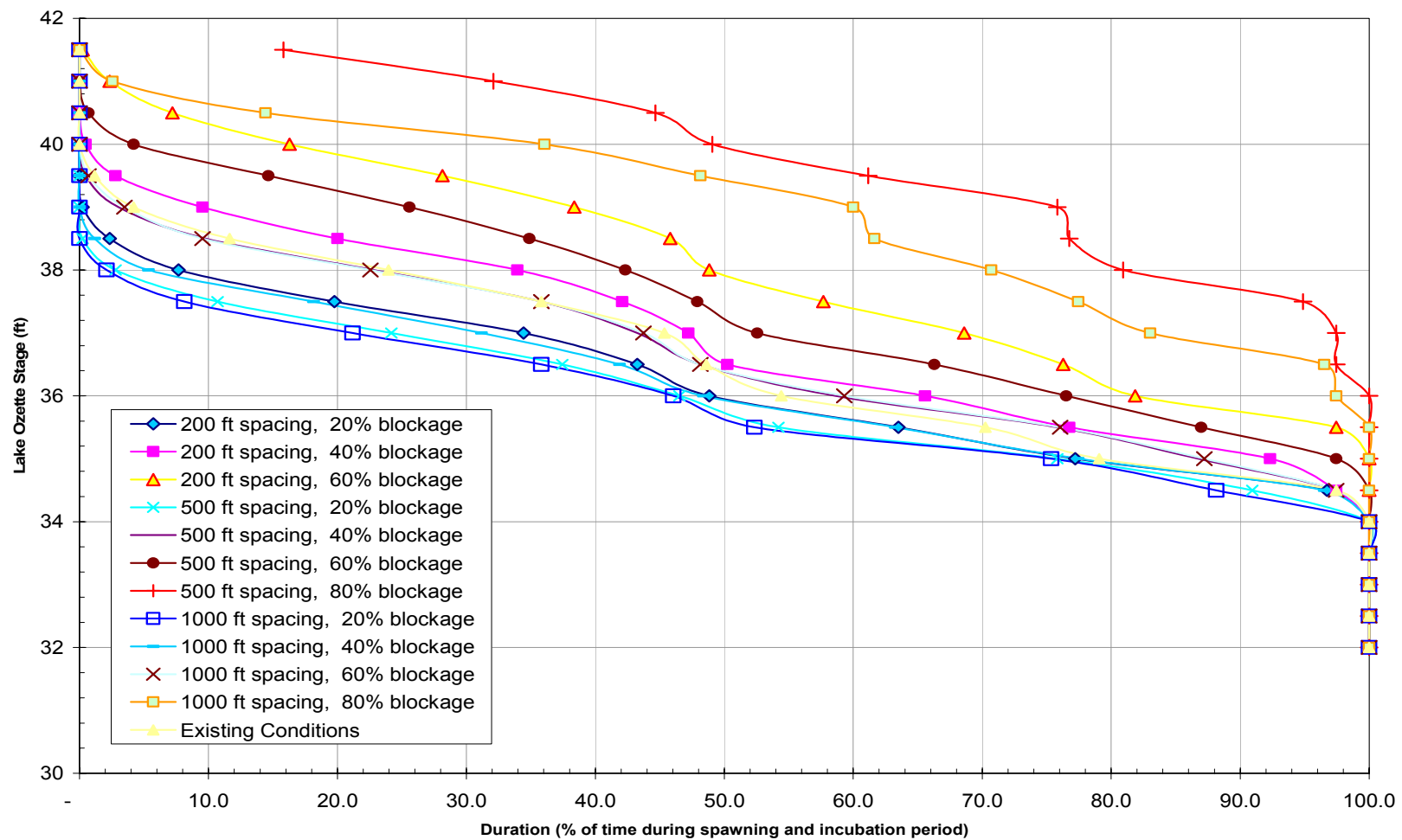
<sup>a</sup> Existing condition duration analysis based on recorded stage for the period at Ozette River gauge.

<sup>b</sup> The 200 foot, 80% blockage scenario did not produce stable model results.



**Figure 33. Comparison of mean lake level over the entire simulation period for different combinations of logjam spacing and magnitude (e.g. percent blockage).**





**Figure 34. Comparison of lake level durations during the spawning and incubation (October 15, 2004 to January 30, 2005) period for different combinations of logjam spacing and magnitude (e.g., percent blockage).**





## **Discussion and Conclusions**

The modeling results show that wood loading in the upper 3,000 feet of the Ozette River exerts a major influence on the magnitude and duration of high water levels in Lake Ozette. For example, a lake level of 39 feet (11.9 meters) is estimated to occur approximately 5 percent of the time during salmon spawning and incubation periods under existing conditions. With the addition of large logjams that occupy roughly 80 percent of the bankfull cross-sectional area spaced roughly every 500 feet, the duration of this high stage is predicted to increase to approximately 75 percent of the time during the spawning and incubation period. Accordingly, the mean lake level during this same period of time is estimated to increase from approximately 36.6 feet under existing conditions to approximately 39.9 feet under the 80 percent blockage, 500-foot spacing scenario.

The modeling results also show that wood loading in this upper region of the Ozette River influence low and moderate lake levels, but to a smaller degree than for higher lake levels. However, the potential change in summer, or low, lake level due to wood loading, even if only moderate, could have a significant influence on the ability of vegetation to colonize shorelines during the summer. Associated winter lake levels under a wood-rich regime, coupled with increased wave energy, would help remove or prevent winter dormant shrub vegetation from persisting through the winter, as currently exists.

The results of the modeling are consistent with previous studies that found that the drop in Lake Ozette water levels was related to the removal of logjams from the Ozette River in the early 1950s and earlier (Abbe et al. 2001). Analysis of historical changes in the Lake Ozette shoreline performed as part of this study showed that vegetation has encroached substantially along the shoreline due to the lowering of both winter and summer lake levels following the same wood removal activities. Finally, a companion study performed for Olympic National Park showed that channel incision in the lower portion of the major tributaries of Lake Ozette has increased due to the lowering of lake levels following wood removal (Herrera 2005). Therefore, these studies, each with slightly different purposes and methodologies, provide strong corroboration of the linkage between wood loading in the Ozette River, water levels in Lake Ozette, and habitat degradation in tributaries.

As discussed previously, the model calibration showed close agreement of observed versus simulated water surface profiles for the entire model reach for October 2003, July 2004, November 2004, and December 2004. However, observed versus simulated water surface elevations over the entire simulation period at the upstream boundary were not in as close agreement. The modeled time series at this location shows short-duration spikes in water surface elevation that can be up to 2 feet (0.61 meters) in magnitude but persist only for an hour or so. Because of the short duration of these spikes and the goal of this study to investigate longer term responsiveness of lake levels to logjams in the Ozette River, the calibration was deemed acceptable for this study. Further refinement would be needed if the model were to be used for more detailed analysis, such as final logjam design or flood prediction studies.

Recovery of the threatened Lake Ozette sockeye population will require reestablishment of favorable lake level or hydraulic regimes to ensure the proper function of the beach spawning habitat and the maintenance of stable base levels to minimize tributary degradation. This restoration could occur naturally as wood falls from the banks into the Ozette River and accumulates on existing jams or new jams form. However, this natural process could take decades to centuries. Since the Lake Ozette sockeye salmon are listed as threatened and beach spawning populations are not recovering at a substantial rate, a more proactive approach for restoring hydraulic processes and habitat using constructed logjams is recommended. A proactive approach could also provide valuable local habitat for sockeye salmon and other aquatic species such as chinook and chum in the Ozette River.

In addition to reestablishing favorable lake level regimes, beach habitat restoration would also be needed at selected sites since vegetation has encroached on so much of the beach area and reduced the availability of spawning sites. This restoration could occur naturally as lake levels rise, wave action increases, and vegetation dies off. As with logjam restoration, however, this natural process is likely to be too slow to support the recovery of Lake Ozette sockeye salmon given that they are currently listed as threatened. Thus, recommendations for selecting priority sites and implementing spawning habitat restoration are also provided in the following recommendations. While beach restoration is highly recommended for selected sites as part of the overall restoration effort, beach restoration would not be recommended as a stand-alone measure, without also restoring the underlying hydraulic regime for Lake Ozette and the upper portion of the Ozette River, including the Lake Ozette outlet. More detailed recommendations for coordinating potential beach restoration with restoration of favorable lake level regimes using engineered logjams are provided below.

## Recommendations

This section provides recommendations for proactive restoration measures for Lake Ozette shoreline and outlet habitat that Lake Ozette sockeye salmon utilize. The recommendations include the construction of logjams in the Ozette River to raise water levels in the lake and restore inundation durations during the beach spawning season. Recommendations are also provided for identifying areas that will be at risk of increased flooding due to restoration activities and providing flood mitigation where needed. Following is a list of activities for prioritizing, planning, and engineering potential habitat restoration projects. The recommendations are presented in sequential order.

1. **Refine model.** Improve the hydraulic model for design of in-stream structures and evaluating potential flood hazards around the lake. To correct for the artificial spikiness shown in calibration results, better floodplain definition may be needed, especially in cross-sections in the upper reach. Although the model calibration was deemed suitable for purposes of this study, it should be refined for the final design and for detailed flood prediction purposes.
2. **Establish reference spawning areas.** Survey actual spawning locations and elevation zones; beach slope; substrate types; vegetation types, elevation zones, and conditions; and ordinary high water mark. This information will be used to further analyze the existing results from the hydraulic modeling to make more detailed site-specific estimates of impacts on the existing spawning habitat that are associated with changes in lake levels and to determine design criteria and goals for future enhancement and restoration efforts.
3. **Evaluate and select restoration sites.** Evaluate the existing, historically active, and potential spawning area locations to develop a prioritized list of spawning areas (existing and potential) to be targeted during restoration. This assessment will also define the favorable hydraulic regime in these target locations. Survey potential spawning area locations and elevation zones; beach slope; substrate types; groundwater/hyporheic conditions; vegetation types, elevation zones, and conditions; and ordinary high water mark.
4. **Develop shoreline vegetation plan.** Assess passive versus proactive plan for removal of shoreline vegetation that has encroached on lake shore, focusing on substrate cohesion and impacts on spawning. Experiments in vegetation removal would be done to better understand the difference between sediment mobility with and without vegetation. A timeline for beach recovery would be developed for either scenario.



5. **Develop a logjam restoration plan for the Ozette River.** The logjam restoration plan should be based on creating a favorable hydraulic regime in target restoration locations around the Lake Ozette shoreline.
6. **Determine the effect of increased lake levels on property and infrastructure.** Perform a topographic survey of flood-prone areas around Lake Ozette and the Ozette River, such as the ONP ranger station facilities and individual residences along the lake. Reprocessing the lidar data should greatly assist in this analysis. Additional surveys should be tied into the control established by CTS Engineers in October 2003. The results of the topographic survey will be compared with simulated lake elevations and durations to estimate the degree of potential flood risks at flood-prone locations.
7. **Prepare construction plans and specifications for logjams and habitat restoration.** Develop engineering plans for engineered logjams in the Ozette River, shoreline habitat restoration projects, vegetation clearing/beach restoration at the shoreline project sites, and flood protection in areas that were identified as flood-prone. Engineering plans may also be needed for the mitigation of temporary and long-term water quality problems that may arise during or after construction.

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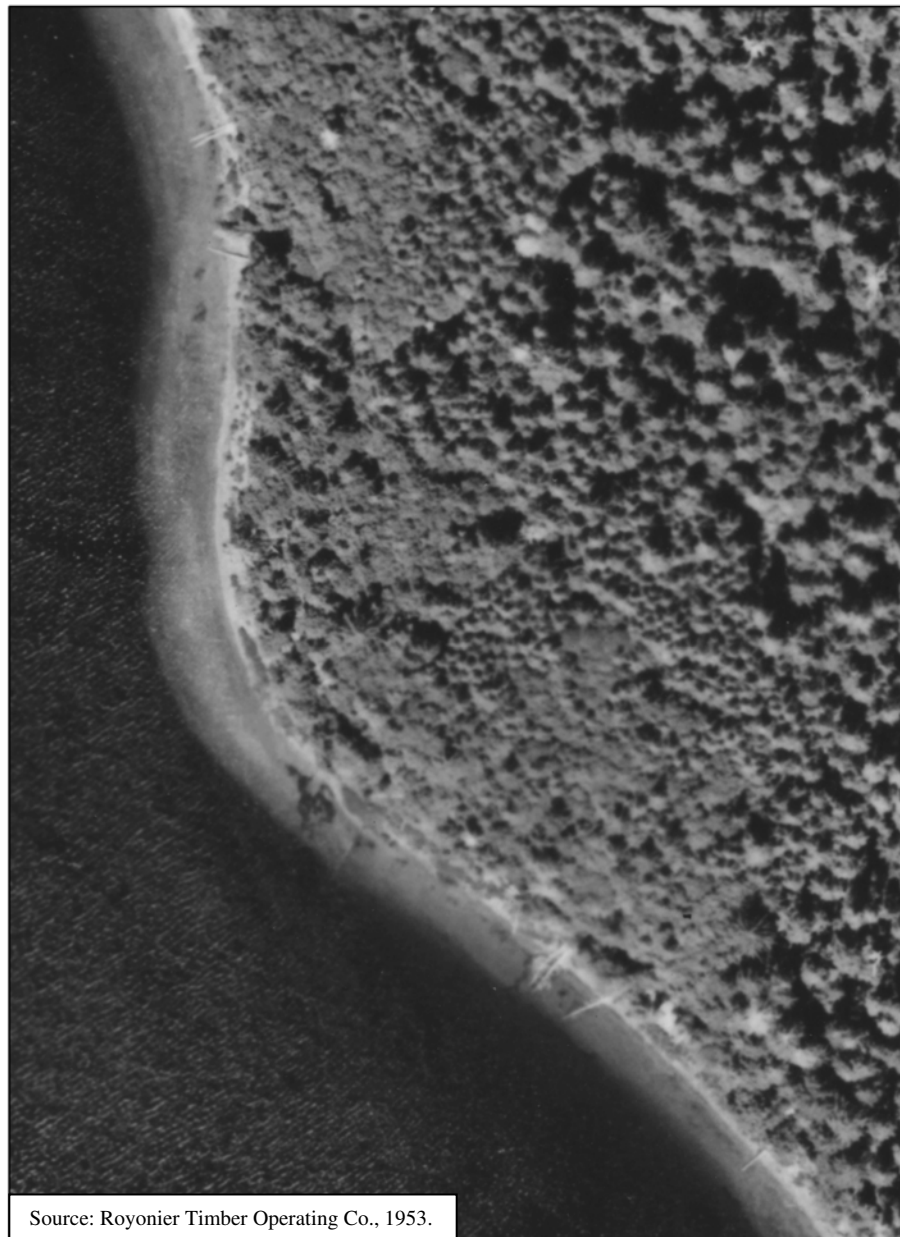
## **APPENDIX A**

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# **Intermediate GIS Analysis to Support Shoreline Characterization Analysis and Unrectified Aerial Photos from 1953**

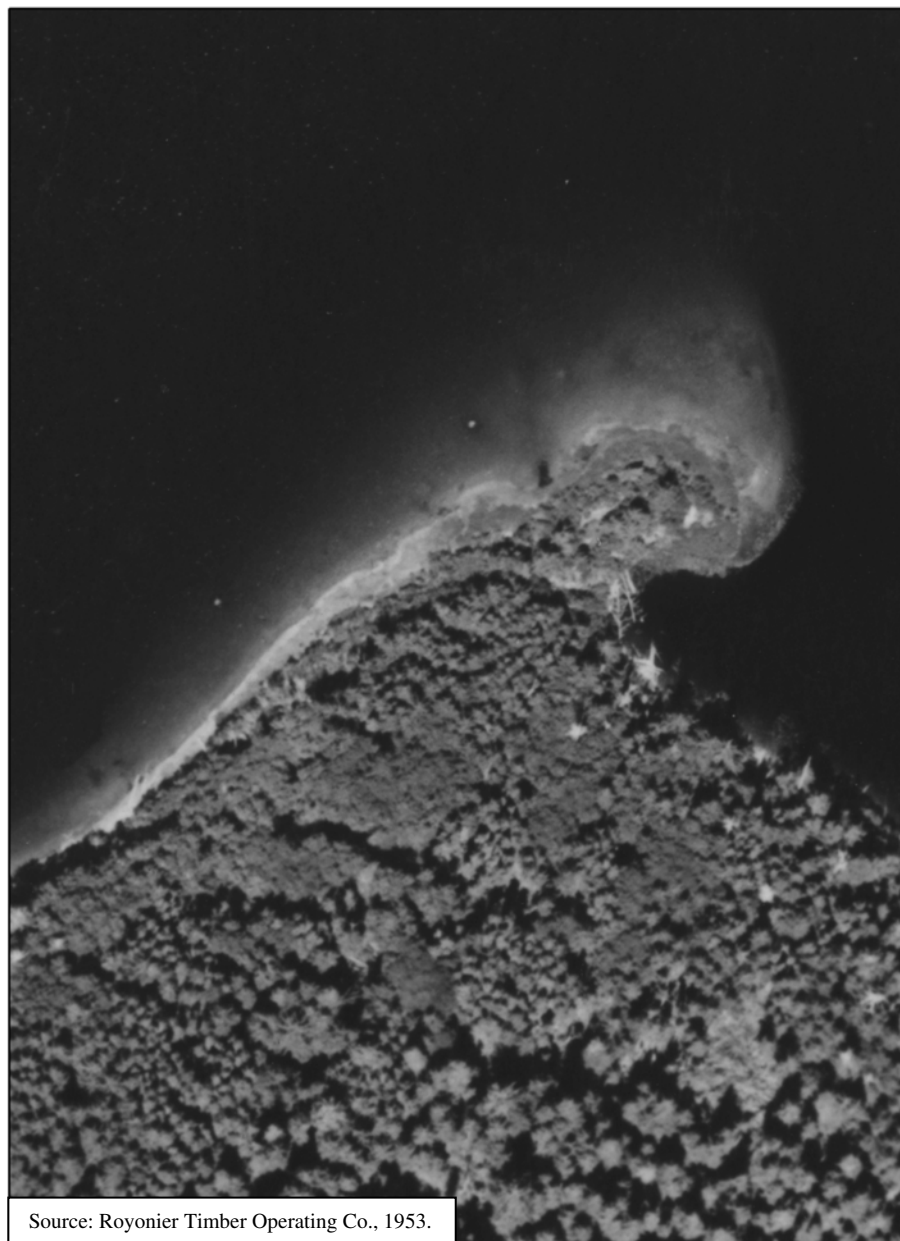






Source: Royonier Timber Operating Co., 1953.

**Figure A-1. Unrectified 1953 aerial photograph of Olsen's Beach, Lake Ozette, Washington.**



**Figure A-2. Unrectified 1953 aerial photo of Preacher's Point, Lake Ozette, Washington.**



**Figure A-3. Unrectified 1953 aerial photo of Deer Bay spit, Lake Ozette, Washington.**



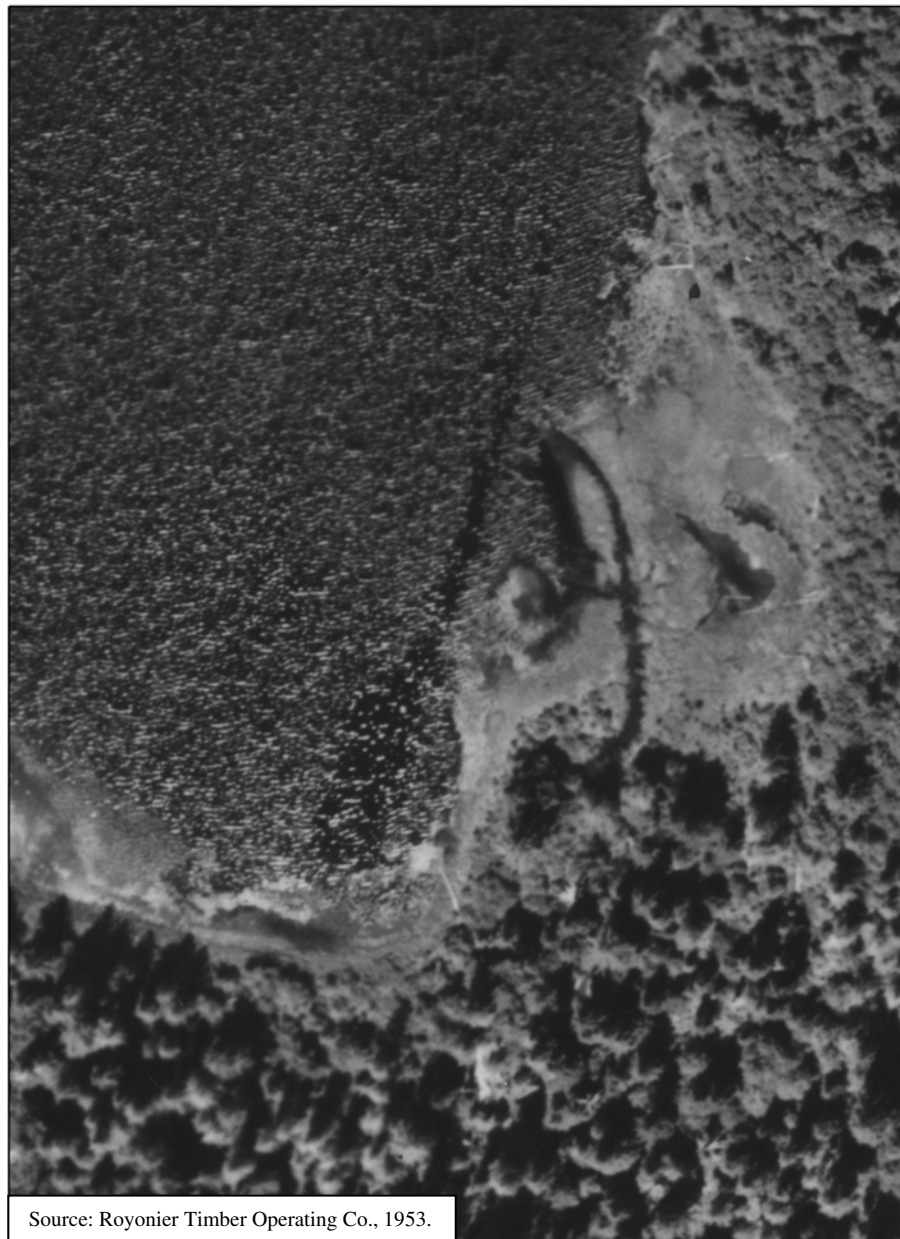


**Figure A-4. Unrectified 1953 aerial photo of Baby Island, Lake Ozette, Washington.**



Source: Royonier Timber Operating Co., 1953.

**Figure A-5. Unrectified 1953 aerial photo of the mouth of Siwash Creek, Lake Ozette, Washington.**



**Figure A-6. Unrectified 1953 aerial photo of the mouth of South Creek, Lake Ozette, Washington.**

## **APPENDIX B**

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### **Graphical Plots of Model Cross-Sections**







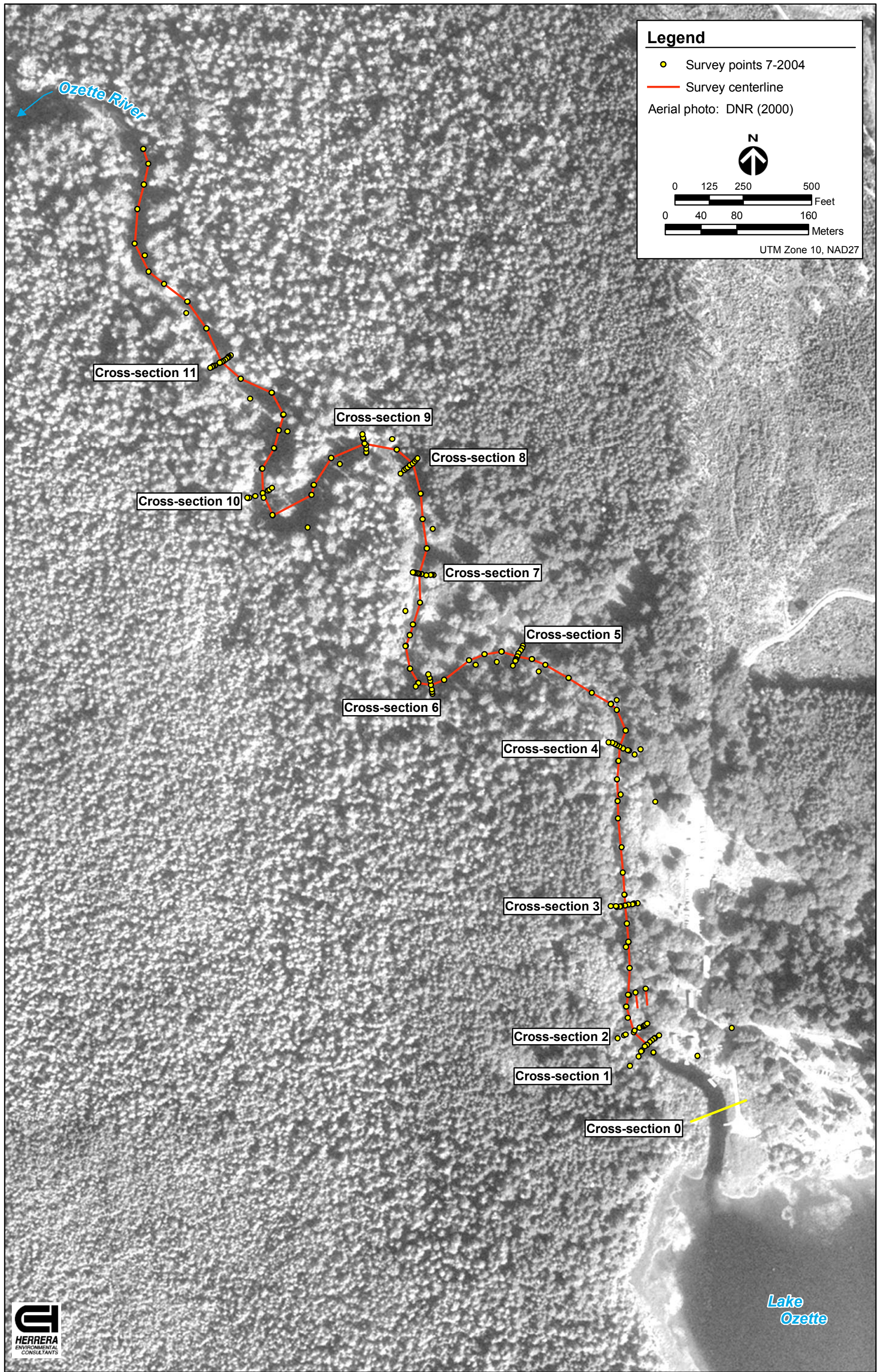
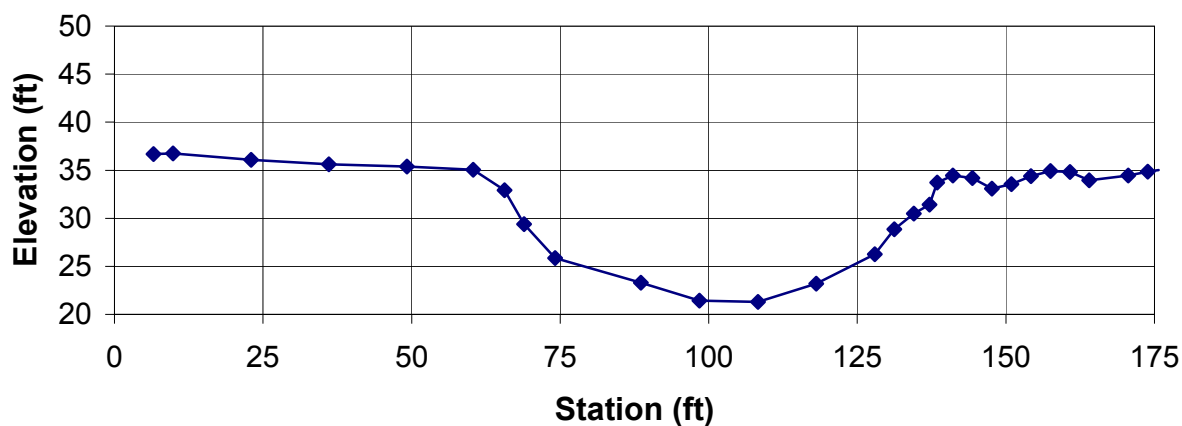


Figure B-1. Cross-section locations for the Ozette River.

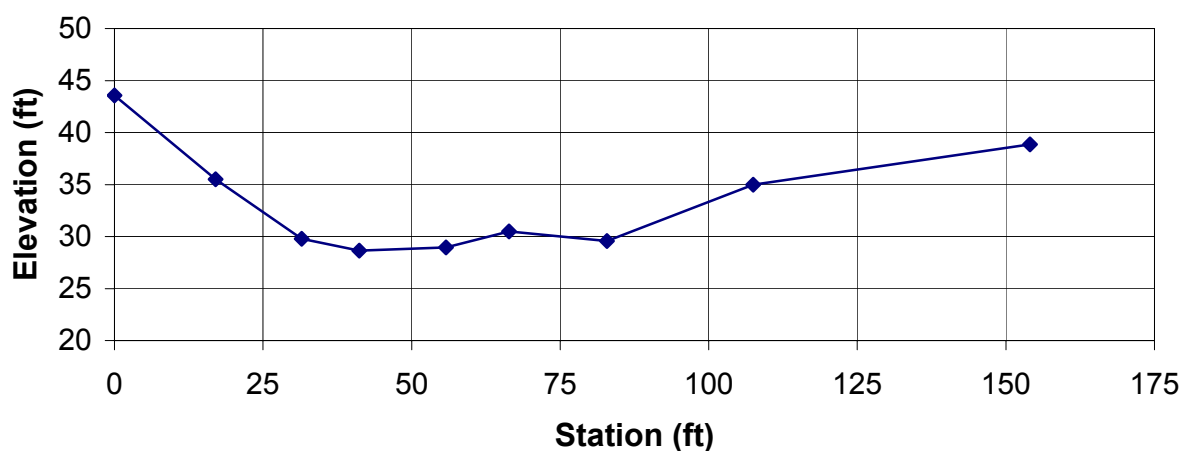




### Survey Cross-Section 0 October, 2004 - Independent Survey by Makah Tribe

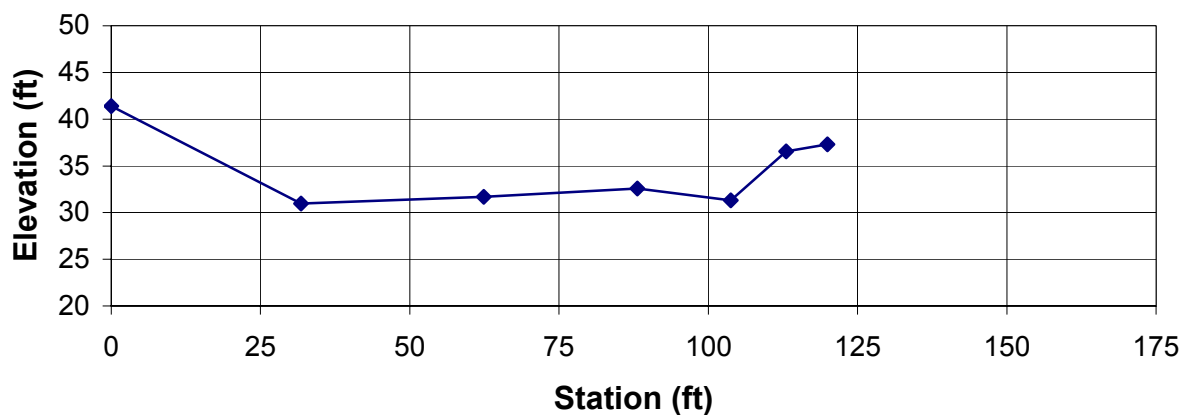


### Survey Cross-Section 1 July, 2004 - CTS Engineers

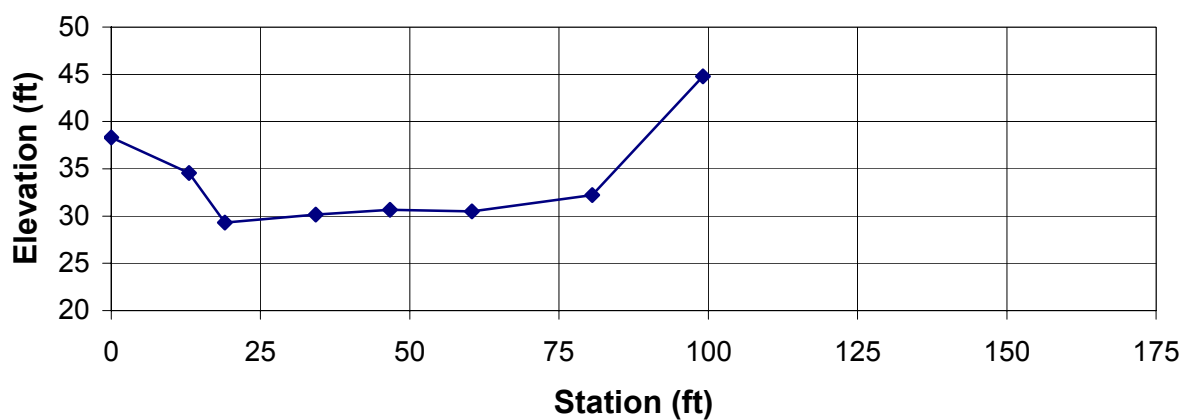




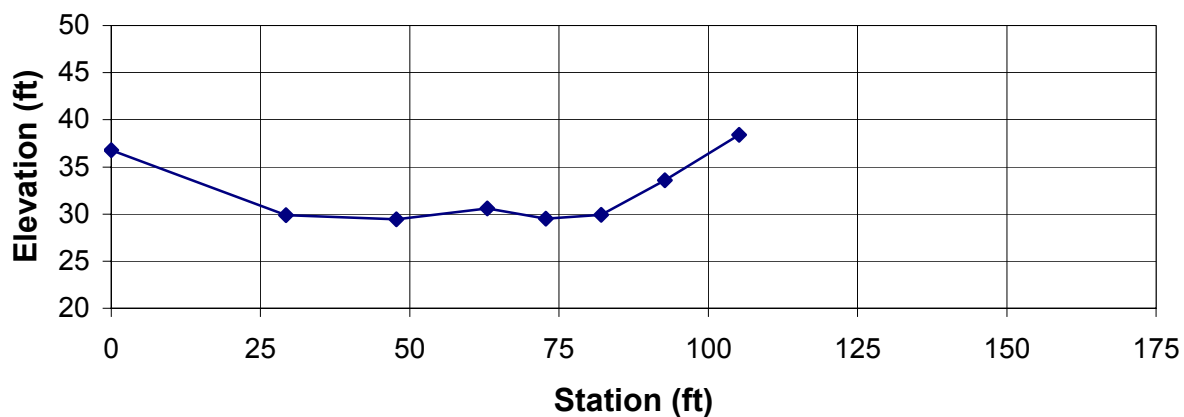
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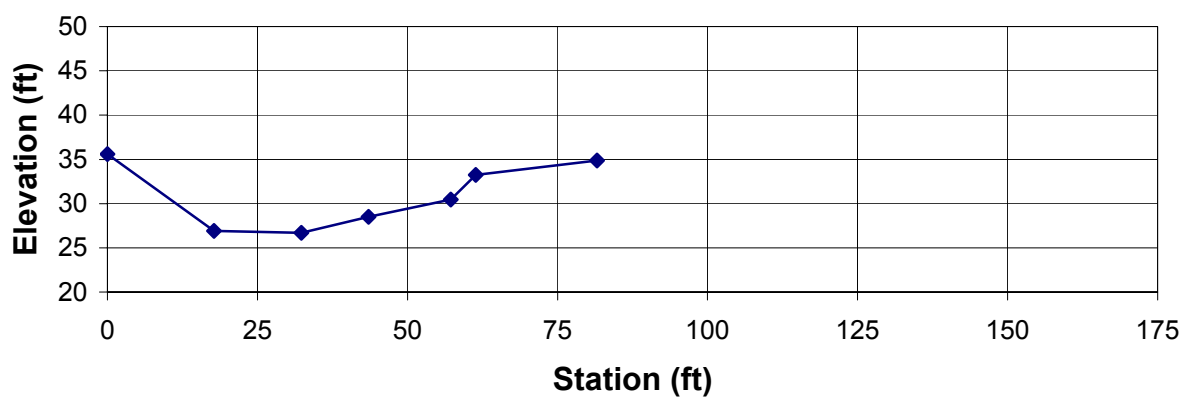
### Survey Cross-Section 3 July, 2004 - CTS Engineers



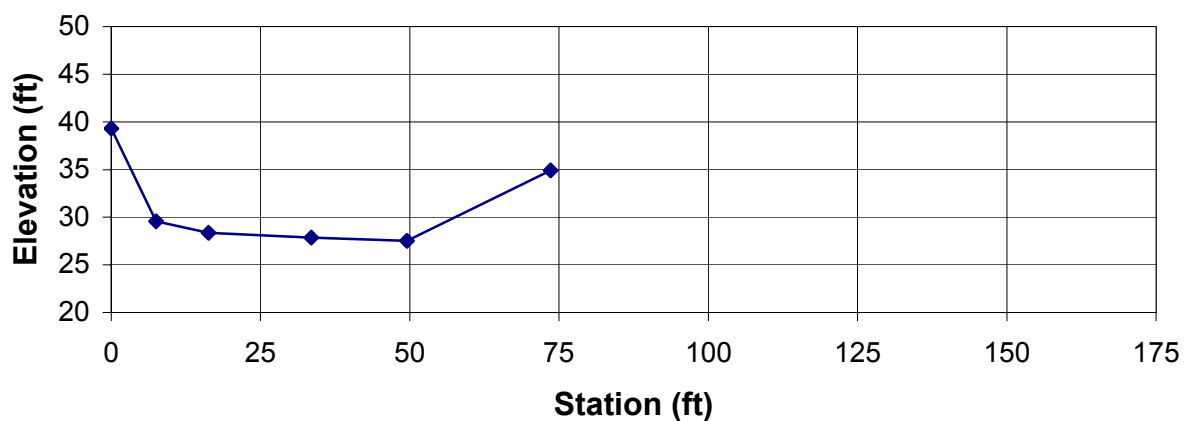
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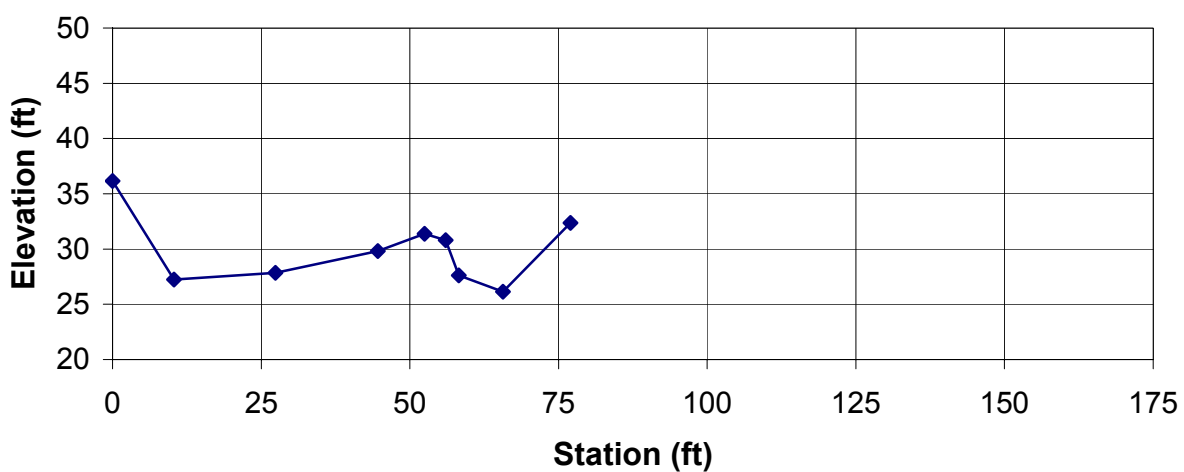
### Survey Cross-Section 5 July, 2004 - CTS Engineers



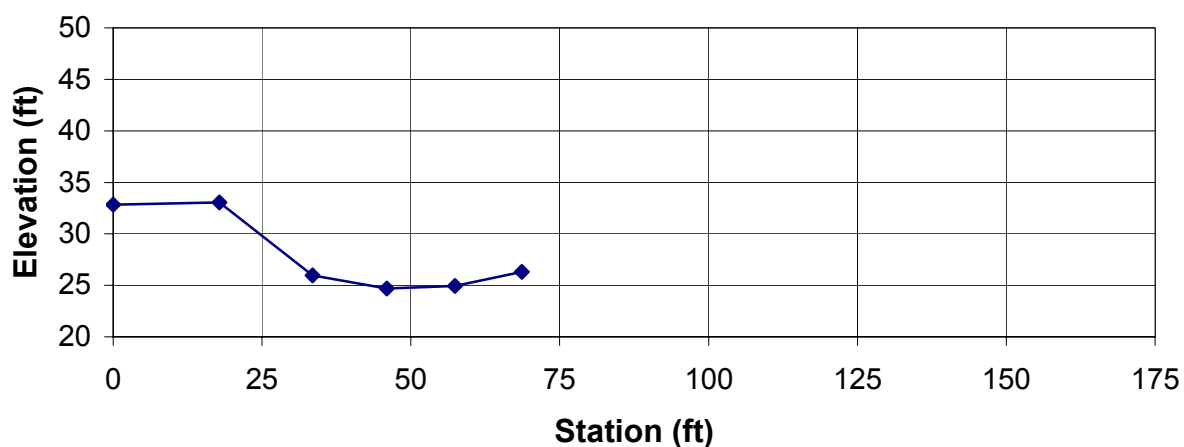
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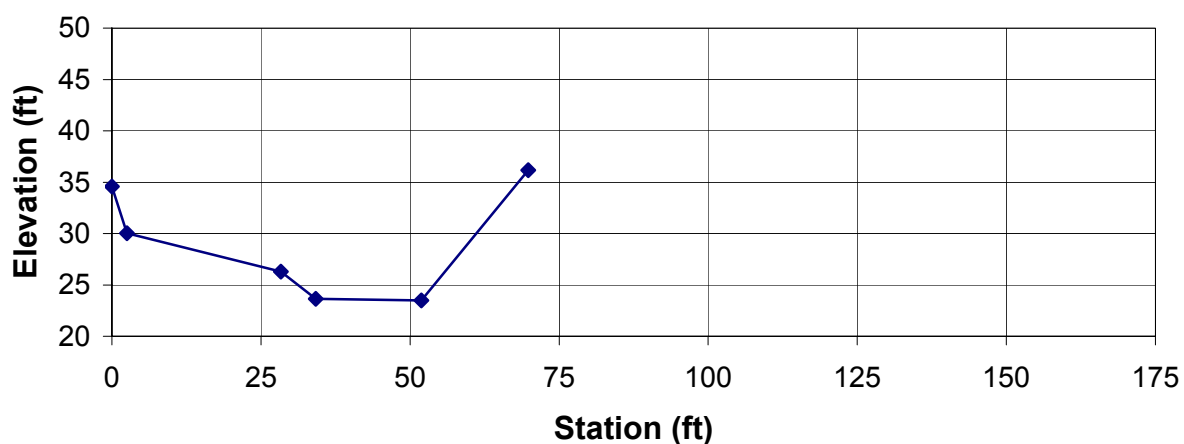
### Survey Cross-Section 7 July, 2004 - CTS Engineers



### Survey Cross-Section 8 July, 2004 - CTS Engineers

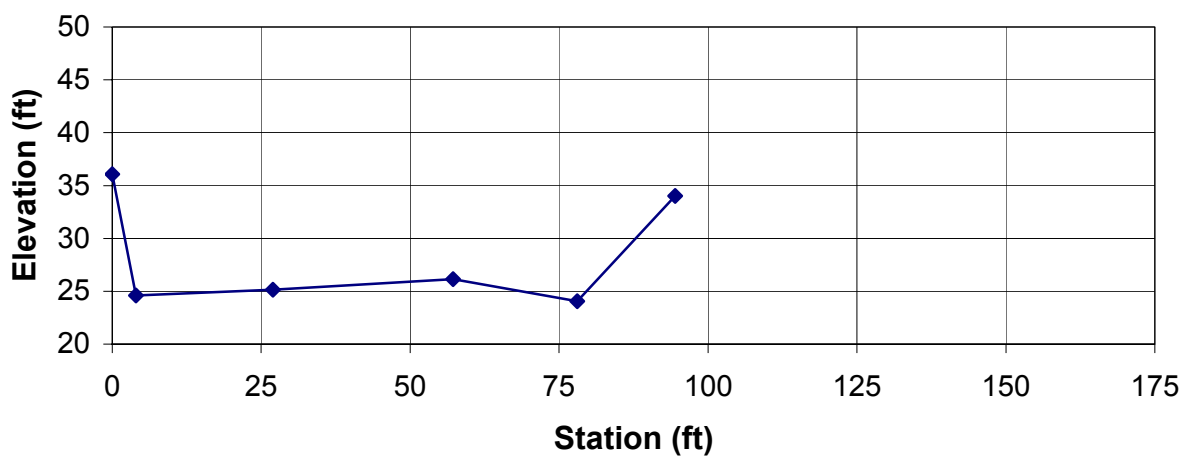


### Survey Cross-Section 9 July, 2004 - CTS Engineers

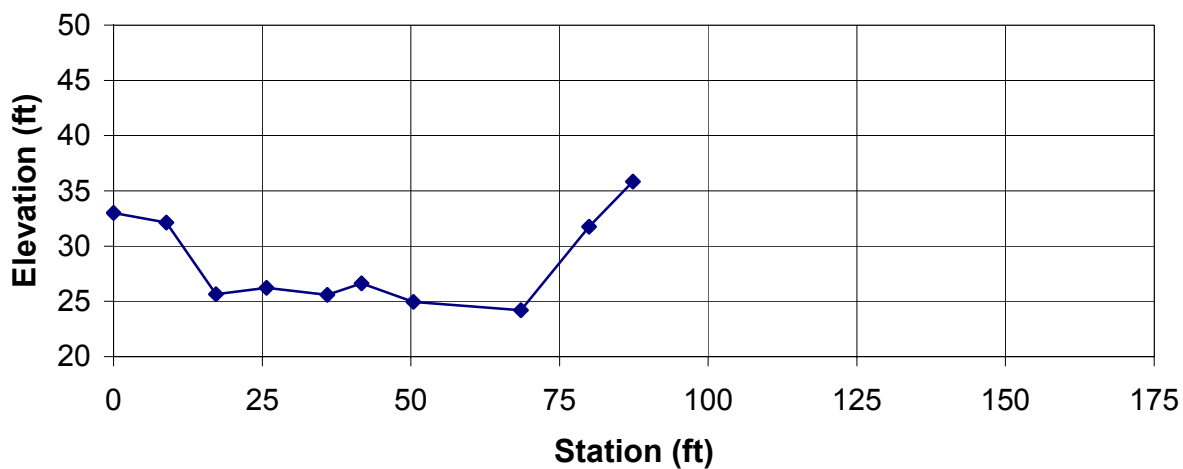




### Survey Cross-Section 10 July, 2004 - CTS Engineers



### Survey Cross-Section 11 July, 2004 - CTS Engineers



## **APPENDIX C**

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# Photographic Documentation



**Hydraulic and Geomorphologic Evaluation  
Analysis of Wood Loading in the Ozette River and Its Effect on Water  
Levels in Lake Ozette  
Photographic Log**

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| Photo Number | Photo Description                                                                                                                                            |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1            | Looking upstream at J1.                                                                                                                                      |
| 2            | Standing on gravel bar downstream from bridge, looking downstream at J1.                                                                                     |
| 3            | Looking downstream at J2. J2 consists of 2 jams, one on the left and one on the right bank. J3 is also visible in this photograph, located downstream of J2. |
| 4            | Looking downstream at J2 (left).                                                                                                                             |
| 5            | Looking downstream at J2 (right).                                                                                                                            |
| 6            | Looking downstream at J3.                                                                                                                                    |
| 7            | Looking downstream at J4.                                                                                                                                    |
| 8            | Looking downstream at J5.                                                                                                                                    |
| 9            | Looking downstream at J6.                                                                                                                                    |
| 10           | Looking downstream at J7. Note that the thin alder in the foreground is not a part of J7.                                                                    |
| 11           | Looking downstream at J7 and J8.                                                                                                                             |
| 12           | Panorama of J9.                                                                                                                                              |
| 13           | Standing on left bank, looking downstream at J9.                                                                                                             |
| 14           | Looking upstream at J9.                                                                                                                                      |
| 15           | Looking upstream at J11.                                                                                                                                     |
| 16           | Looking downstream at J12.                                                                                                                                   |
| 17           | Looking downstream at J13.                                                                                                                                   |
| 18           | Looking downstream at J13.                                                                                                                                   |
| 19           | Standing on left bank, looking downstream at J13.                                                                                                            |
| 20           | Looking upstream at J13.                                                                                                                                     |
| 21           | Standing on left bank, looking downstream at J14.                                                                                                            |
| 22           | Standing on left bank, looking downstream at J15.                                                                                                            |

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## **APPENDIX D**

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# Historical Photographs of Logjams Removed from the Ozette River





Typical view of log jam removed from Ozette River 2 miles below lake. Kramer 1953 report



Log and trash jam removed from Ozette River at three mile point below lake. Kramer 1953 report.



Log jam removed from Ozette River at 2 3/4 mile point below lake. Kramer 1953 report.



