Lake Ozette Sockeye Limiting Factors Analysis

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DISCLAIMER:

The Lake Ozette Sockeye Salmon Limiting Factors Analysis (LFA) describes and evaluates limiting factors affecting the survival and productivity of Lake Ozette sockeye salmon. Current habitat conditions and limiting factors in the Ozette River, the lake, and tributaries are a function of the cumulative effects of <u>all</u> past activities. Where the LFA describes habitat impacts from forestry-related activities, this description refers to past activities and not to future activities conducted under the Washington State Forest Practices Habitat Conservation Plan (FPHCP). The effects of implementation of the FPHCP on sockeye habitat and population levels can only be determined from an intensive future monitoring program. It is the goal of the LFA to provide guidance as to where and how this monitoring could be most informative.

Many hypotheses presented within the Ozette LFA are supported by substantial data. Others require additional investigation. A scientific hypothesis must be reasonable, have a definable null hypothesis, and be testable. It is not necessary, nor is it possible, to have sufficient data to confirm or refute the hypothesis at the time that it is formulated.

The authors are committed to the recovery of Lake Ozette sockeye, and we believe that this is possible only with a thorough and accurate understanding of all of the factors limiting sockeye productivity and their interrelationships. The LFA establishes a reasonable set of hypotheses based upon available information and promotes the concept of future research aimed at testing these hypotheses. We firmly believe that this approach is consistent with the best available science, and, at the same time, we welcome and will carefully consider all substantive comments.

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EXECUTIVE SUMMARY

PURPOSE

This report summarizes previously available information relating to factors limiting the survival and productivity of Lake Ozette sockeye salmon (*Oncorhynchus nerka*), presents and summarizes new information and data, and comprehensively analyzes factors potentially limiting sockeye salmon productivity and recovery. Lake Ozette sockeye salmon were listed as threatened under the Endangered Species Act (ESA) in 1999. This report represents an important step in identifying factors that need to be addressed to rebuild the sockeye salmon population to a healthy level, helping to fulfill a local management goal that has stood for many decades. In addition, the report provides critical information on factors limiting sockeye productivity and viability that the National Marine Fisheries Service (NMFS) has used to complete a recovery plan for the Lake Ozette sockeye, as required by the ESA.

BACKGROUND

Historically, Lake Ozette, the Ozette River, and tributaries draining into the lake were important sources of salmon available for harvest in tribal fisheries (Swindell 1941; Gustafson et al. 1997). The salmon resources of the Lake Ozette watershed were also used by homesteaders. Within the greater Lake Ozette ecosystem and Olympic National Park (ONP), Lake Ozette sockeye salmon are a critical component of biological integrity, linking freshwater, marine, and terrestrial ecosystems.

The decline in harvest of Lake Ozette sockeye salmon from a high of more than 17,500 fish in 1949 (Washington Department of Fisheries 1955) to a low of 0 in 1974 and 1975 (Jacobs et al. 1996) catalyzed research into the limiting factors affecting Lake Ozette sockeye salmon. In 1976, the Makah Tribe requested assistance from the U.S. Geological Survey (USGS) to determine the preferred and observed freshwater habitat conditions of Lake Ozette sockeye, and assistance from the U.S. Fish and Wildlife Service (USFWS) to determine the sockeye's habitat status and limiting factors. These requests resulted in studies by Bortleson and Dion (1979) and Dlugokenski et al. (1981), studies that provided a tremendous amount of baseline data but did little to determine the primary factors affecting the decline and/or recovery of the sockeye population.

In 1981, the first meeting of the Lake Ozette Sockeye Steering Committee was convened. Initial participants included the Makah Tribe, ONP, USFWS, Washington Department of Fisheries, the University of Washington, and Crown-Zellerbach Corporation. The initial focus was on hatchery supplementation as a potential means to quickly bolster sockeye abundance from depressed levels. The committee met over the next two years and helped to establish the Umbrella Creek hatchery. However, multi-agency recovery efforts waned. Between 1983 and 1993, few meetings were held and only a few independent studies were conducted on Lake Ozette sockeye salmon (Blum 1988; Beauchamp and LaRiviere 1993). In 1994, ONP funded a study to compile existing data on Lake Ozette sockeye and assemble a panel of experts to make recommendations on monitoring and management. Despite being the most comprehensive document of the time, the resulting report by Jacobs et al. (1996) was unable to specifically define the population limiting factors and concluded that the population decline was likely the result of a series of cumulative impacts including (in no order of priority): 1) introduced species, 2) predation, 3) loss of tributary spawning populations, 4) decline in the quality of beach spawning habitat, 5) short-term unfavorable ocean conditions, 6) historical over-fishing, 7) introduced disease, and 8) a combination of factors.

In 1999, the NMFS listed Lake Ozette sockeye salmon as threatened under the Endangered Species Act (64 FR 14528; 70 FR 37160). Lake Ozette Chinook (*Oncorhynchus tshawytscha*) and chum (*Oncorhynchus keta*) salmon populations are not currently ESA-listed, but both populations are nearly extinct or functionally extinct. Bull trout (*Salvelinus confluentus*) are historically absent from the Lake Ozette watershed. Largely as a result of the 1999 ESA listing, multi-agency efforts to coordinate research and recovery planning resumed, and the Lake Ozette Sockeye Steering Committee was reorganized and expanded to include NMFS, as well as local landowners and other interested parties. The Lake Ozette Steering Committee initiated the development of a Hatchery and Genetic Management Plan (HGMP)/Joint Resource Management Plan (JRMP) for Lake Ozette Sockeye Salmon (Makah Fisheries Management 2000). Work also began on the Limiting Factors Analysis (LFA) report in 1999. NMFS approved the HGMP in 2004.

The HGMP and draft LFA have been used as guides for interim research and monitoring until the Final LFA and the NMFS Lake Ozette Sockeye Salmon Recovery Plan could be completed. The Makah Tribe, Olympic National Park, and NMFS have recently implemented over a dozen detailed field investigations designed to increase understanding of the spatial distribution of anadromous fish and the habitat limiting factors in Lake Ozette and its tributaries. Additional funding made it possible to complete the LFA report in late 2004.

ORGANIZATION OF LIMITING FACTORS ANALYSIS

Within the context of this report, limiting factors are defined as physical, biological, or chemical conditions (e.g., inadequate spawning habitat, insufficient prey resources, or deleterious suspended sediment concentrations) experienced by sockeye at the spawning aggregation scale that result in a reduction in viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity). Key limiting factors are those with the greatest adverse impacts on a population’s ability to reach its desired status. Factors responsible for the decline of the population (factors for decline) may or may not be current limiting factors, since certain activities that may have contributed to decline may no longer be operating (e.g. commercial sockeye harvest). This report is not intended to be a review of previous factors for decline, but instead represents a thorough investigation of factors currently limiting VSP parameters.

The report is divided into seven main sections:

- Introduction (Chapter 1)
- Fish Populations of the Lake Ozette Watershed (Chapter 2)
- The Sockeye Salmon Population (Chapter 3)
- Habitat Conditions Affecting Lake Ozette Sockeye (Chapter 4)
- Limiting Factors Affecting Lake Ozette Sockeye (Chapter 5)
- Analysis of Limiting Factors (Chapter 6)
- Research, Monitoring, and Evaluation Needs (Chapter 7)

Limiting factors affecting sockeye salmon are discussed by geographical area and life history stage. Factors are rated for degree of impact and presented as a series of hypotheses and sub-hypotheses. These hypotheses are intended to serve as the scientific foundation for identifying recovery actions in the Lake Ozette sockeye recovery plan.

WATERSHED SETTING

The Lake Ozette watershed (88.4mi^2) is located along the coastal plain of the northwest tip of the Olympic Peninsula in Washington State. Lake Ozette is a monomictic and oligotrophic-to-mesotrophic lake, which drains to the Pacific Ocean through the very low gradient, sinuous, 5.3-mile-long Ozette River. Lake Ozette is the third largest (7,550 acres) natural lake in Washington State. It has average and maximum depths of 130 feet and 320 feet, respectively, and the observed water surface elevation fluctuates from 30.8 to 41.5 feet above mean sea level. The tributary drainage basin area is 77 mi^2, drained by several large tributaries and numerous smaller tributaries.

Lake Ozette watershed geology is a mix of gently sloping glacial deposits, hilly sedimentary rock, and steep volcanic flows and breccias. The temperate coastal-marine climate is characterized by cool summers, mild wet winters, and an average annual precipitation of 102.6 inches. The watershed is predominantly forested by coastal temperate rain forest conifer and hardwood species. Tributary streamflow is highly variable, similar to other perennial rain-dominated streams in the region with little snow storage.

Land use in the watershed has ranged from traditional Native American management of old-growth forest, to European settler homesteading along the lake and stream valleys, to commercial timber production and National Park management. Currently, land ownership in the watershed is 73% private land, 15% Olympic National Park, 11% Washington State, and 1% Tribal. Private timber companies own approximately 93% of the four largest tributaries to Lake Ozette. Timber harvest levels accelerated over the period of record, with 8.7% of the watershed area clear-cut by 1953, increasing to 83.6% of the watershed area clear-cut by 2003. Natural disturbance in the watershed was dominated by wind and hydrogeomorphic events, while contemporary disturbance additionally includes timber harvest, road construction and maintenance, residential and agricultural development, channelization and direct and indirect stream wood clearance.

FISH POPULATIONS IN THE LAKE OZETTE WATERSHED

The Lake Ozette fish community includes a rich array of approximately 26 species of fishes. There are seven species of salmonids present in the lake system and 18 non-salmonid fish species, of which six are exotic. In addition to sockeye, these other species are important indicators of ecosystem health, and thus this report includes summary information and data for many of them. For species that are potential competitors with or predators of sockeye salmon, additional information on habitat utilization, diets, and relationships to sockeye salmon are included. Of these species, the most important competitors are kokanee salmon (non-anadromous *Oncorhynchus nerka*) and threespine stickleback (*Gasterosteus aculeatus*), while the most important predators are coho salmon juveniles (*O. kisutch*), cutthroat trout (*O. clarki*), sculpin (*Cottus Spp*), northern pike minnow (*Ptychocheilus oregonensis*) and largemouth bass (*Micropterus salmoides*). While few data are available regarding non-salmonid population integrity, data on other salmonid populations inhabiting the basin over the past century indicate either generally decreasing population trends over time (*O. tshawytscha; O. keta; O. kisutch*) similar to sockeye, or static or unknown trends (non-anadromous *O. nerka, O. mykiss*). Coho salmon have shown small but significant population increases during recent years but are still well below historical abundance levels.

SOCKEYE SALMON POPULATION LIFE HISTORY AND STATUS

Ozette sockeye life histories are described and evaluated assuming a single population divided into seven life history phases:

1. Adult sockeye entering the system (April-July)
2. Adult holding in the lake (April-January)
3. Spawning (October-January) and incubation (October-March)
4. Fry emergence and dispersal (March-April)
5. Juvenile freshwater rearing (Multi-year)
6. Seaward migration (March-June)
7. Marine/ocean phase (Multi-year)

Two spawning groups (i.e., beach-spawning and tributary-spawning) are discussed independently during their spawning, incubation, emergence and dispersal phases. Sockeye immigration into and through the Ozette River typically peaks in early June, with short residence times in the river (average transit time equal to ~65 hours). Nighttime migration predominates during low lake/river levels, while higher lake/river levels result in increased daylight migration. Extensive lake holding occurs below the thermocline at minimum depths ranging from 30 to 100 ft for about six months, until the lake turns over and de-stratifies at the onset of the wet season.

The timing of sockeye salmon adult entrance and holding in tributaries is largely controlled by streamflow increases during the onset of the wet season (generally in October). A majority of tributary spawners use Umbrella Creek, with additional fish spawning in Big River and Crooked Creek. Fish typically spawn in late November in gravel riffles and glides and less commonly in pools, alcoves, and side channels. Average female fecundity is 3,050 eggs with fish size ranging from 430 to 690 mm, which is similar to beach spawning sockeye. Tributary incubation temperatures typically range from 3-8°C, with fry emergence occurring 100-130 days after fertilization.

There are two known active beach spawning sites along the shores of Lake Ozette: Allen's Beach and Olsen's Beach. Historically, the beach just north of the confluence with Umbrella Creek (i.e., Umbrella Beach) was also used for spawning. Other locations around the lake are hypothesized to have provided spawning habitat. Beach staging begins in mid- to late October, with spawning beginning as early as November and ending in late January or early February. Habitat usage varies considerably between and within the two beaches, with core, concentrated, and dispersed spawning sites. At Olsen's Beach, competition is intense for the small core spawning area where upwelling groundwater occurs through small gravel and sand. Concentrated sites surround the core site in substrate lacking upwelling and ranging from cobble/large gravel to coarse sand and silt. Substrate and spawning sites are often surrounded by or found within large patches of submerged shrub vegetation. Dispersed sites are scattered along long stretches of beach, and are at a remove from core and concentrated spawning areas. Beach slopes used for sockeye salmon spawning range from 2% to 15%. Spawning is concentrated in the middle elevation beach in 2 to 6 ft of water, with redds observed at depths up to 20 ft in concentrated sites. Spawning along Allen's Beach is significantly more dispersed than on Olsen's Beach, with at least one area of concentrated spawning. Substrate varies from silt and sand at the south beach to gravel and cobble-gravel mix in the north. Spawning depths range from 1 to 33 ft, with several spawning sites associated with seeps and springs. Incubation temperatures are warmer on the beaches than the tributaries (6-10°C), especially in groundwater upwelling sites, resulting in shortened incubation periods to time of fry swim up (~100 days).

Beach fry dispersal after emergence is assumed to consist of a rapid migration to the limnetic zone; however, additional data are needed on sockeye fry behavior during this life phase. Downstream tributary fry dispersal and movement after emergence corresponds with streamflow and appears to occur predominantly at night soon after emergence. Immediate limnetic rearing is assumed, but littoral data are lacking. In offshore rearing areas sockeye salmon mix with kokanee salmon, and the two *O. nerka* races become morphologically indistinguishable.

The year-round primary prey of juvenile sockeye/kokanee salmon is *Daphnia pulicaria*, with additional consumption of benthic invertebrates, adult insects, and copepods. Juvenile sockeye and all year classes of kokanee consume less than 1% of the monthly standing stock of *Daphnia pulicaria* > 1.0 mm in size, suggesting that food available for rearing fish is not limiting *O. nerka* productivity.

At the onset of their spring-time seaward migration, sockeye smolts migrate along the nearshore lake environment and emigrate down the Ozette River predominantly at night. More than 99% of the juvenile sockeye salmon emigrating from the lake to ocean are age 1+, indicating that few juvenile sockeye rear in the lake for more than one summer. Lake

Ozette sockeye salmon smolts are large, averaging between 11.3 to 13.0 cm fork length, making them the third largest yearling sockeye smolts in the world. Little is known about the behavior of Lake Ozette sockeye immediately after smolt emigration to sea. The Lake Ozette system does not include a sizeable estuary, but the nearshore region surrounding the mouth of the Ozette River is an extensive, complex, and shallow sub-tidal environment, with high apparent productivity for sockeye salmon, despite the presence of many marine piscine predators. Few data are available regarding Lake Ozette sockeye salmon ocean distribution, and their distribution and behavior during this life history phase must be extrapolated from studies of other sockeye salmon populations.

Generally, juvenile sockeye are present close to shore from Cape Flattery to Yakutat in July and August, and scarce to absent in areas farther offshore. Juvenile sockeye remain primarily inshore through October, before moving offshore in late autumn or winter. In Bristol Bay where inner coastal waters are less productive than offshore waters, juvenile sockeye migrate to the outer Bay within 2 to 6 weeks. They remain in the outer bay for an undetermined length of time, staying near the coast during migration. Average marine survival rates for Lake Ozette sockeye are thought to be relatively high (15-17%). The vast majority of Lake Ozette sockeye spend 2 to 2.25 years at sea before returning to the lake, but some return after only one year, and others remain at sea for as many as three years.

Out-of-basin origin hatchery sockeye were released into Lake Ozette episodically between 1936 and 1983 through transplants derived from Baker Lake and Lake Quinault broodstocks. All subsequent hatchery stocking efforts have relied on within-basin broodstock sources. Based partially on recommendations of Dlugokenski et al. (1981), the Umbrella Creek Hatchery was established in 1983 as a tool to reintroduce and rebuild the sockeye population in the Lake Ozette watershed. Broodstock were collected from Olsen's Beach almost every year between 1983 and 1999. Spawners collected from Allen's Beach were also occasionally used as broodstock during this span. On average, 100 adults were collected for spawning each year. Eyed eggs and fry grown from these egg sources were released into Lake Ozette and major tributaries to the lake during this time.

After the ESA listing of sockeye in 1999, the Makah Tribe and WDFW worked with NMFS to assemble a Hatchery and Genetic Management Plan that would adequately protect the listed population and would be used to guide all hatchery-based sockeye salmon restoration actions. The HGMP stipulated that, beginning in 2000, the collection of broodstock from spawning beaches for hatchery production would cease, and broodstock for the supplementation program would be collected from adult sockeye salmon returns to Umbrella Creek. Juvenile fish were only to be released into Umbrella Creek and Big River.

However, implementation of the HGMP alone will not result in recovery of Lake Ozette sockeye salmon. The HGMP is part of the overall comprehensive recovery plan/process that integrates hatchery supplementation and reintroduction efforts with habitat protection, assessment, and restoration so that hatchery and habitat components can work in concert to promote sockeye recovery. NMFS (2004) concluded that the hatchery program was not likely to increase the spatial structure of the beach spawning aggregations within Lake Ozette, but that the tributary-based hatchery program was likely to increase the spatial structure of the ESU as a whole and increase life history diversity and the resiliency of the population. Determinations of whether and how to supplement or reintroduce lake spawning aggregations will be made after further research in this area.

The Lake Ozette sockeye salmon ESU is believed to have been historically composed of a single population with substantial sub-structuring of individuals into multiple spawning aggregations (BRT 2003). Gustafson et al. (1997) described the Lake Ozette sockeye salmon population as genetically distinct from all other sockeye salmon stocks in the Northwest. Hawkins (2004) found that there was very little genetic difference among the sockeye spawning aggregations at Olsen's Beach, Allen's Beach, and Umbrella Creek. However, the author found significant genetic differences between cohort lineages along the predominant 4-year brood cycle and found that those lineages were most closely related among common brood years, independent of sampling locations. Hawkins (2004) described the Lake Ozette kokanee population structure as likely one panmictic group, having found no genetic differences among the sample collections (between locations or brood years) within the study. Sockeye and kokanee-sized *O. nerka* are known to interact during the spawning phase on both beaches and in the tributaries; however, visual observations may confuse kokanee and residual, jack, or hybrid sockeye salmon. Hawkins (2004) indicated that hybridization between sockeye and kokanee is persistent but of low enough frequency to maintain the large genetic differences observed between these two *O. nerka* races.

Only marginal data are available for estimating historical escapement levels for Lake Ozette sockeye. Partial weir counts, lacking any harvest data, exist for the period from 1924 to 1926, making it impossible to estimate total run size for this period (Kemmerich 1945). Between 1948 and 1976, harvest data were collected (WDF 1955), but no escapement data were collected for the same period, creating substantial uncertainty regarding run sizes during this period. Blum (1988) speculated that the Lake Ozette sockeye run size exceeded 50,000 fish prior to the 1940s. Over a 20-year period, Lake Ozette sockeye harvests went from several thousand per year to zero, with insignificant (<100) to no fish harvested annually between 1973 to present.

Contemporary (1977 to present) run size estimating methods as fish enter the lake from the Ozette River have varied significantly from nighttime weir counts (1977-1981); 24-hour counts with a river-spanning picket weir with live trap attached (1982, 1984, 1986); visual nighttime counts and daytime/weekend closures using a river-spanning picket weir (1988-1992; 1994-1997); 24-hour counts with a river-spanning picket weir with an underwater video camera and time-lapse VCR and backup visual observations (1998-2001); and 24-hour counts with a river-spanning picket weir with an underwater video camera, time-lapse VCR, and backup computer hard drive digital images (2002-present). Substantial differences in older methods limited the quality of data collected and therefore likely underestimated run sizes.

Total annual lake entry run-size estimates from 1977 to present have ranged from 385 to 5,075 adult sockeye. The annual run size, considered over three periods reflecting differing census methods, has averaged 1,132 fish for 1977-1995, 2,590 fish for 1996-1999, and 4,600 fish for 2000-2003. While these run-size estimates represent the best available data, they should be used with extreme caution since the quality of estimates for many early years is poor at best (see Section 3.4). Independent estimates of the minimum number of fish spawning on Ozette beaches has increased from a low of six spawning sockeye after extensive surveys in 1989, to 32 fish in 1993, 236 fish in 1997, and 466 fish in 2002.

Much of the increase in total Ozette River run size is likely a result of increased adult returns from Umbrella Creek Hatchery releases and increased natural production in Umbrella Creek. For example, nearly 210,000 brood year (BY) 1996 fed fry and fingerlings were released into Umbrella Creek in 1997, which subsequently comprised a large portion of the brood year 2000 adult run. In addition, the estimated numbers of smolts emigrating from the lake in 2002, 2003, and 2004 from the smolt trap were dramatically higher than any past year's estimates.

Sockeye spawning ground surveys in Umbrella Creek initially recorded low numbers of fish (<50) from 1988 to 1994, with recent peak adult counts ranging from 44 to 1,709 adults from 1995 to 2004. Total run-size estimates in Umbrella Creek have recently ranged from 1,709 to 4,442 adults from 2000 through 2004, which represented 34 to 68% or more of the total estimated Lake Ozette sockeye adult run size. Estimates of adult sockeye run size for Big River and Crooked Creek are not as accurate due to less survey effort and no tag and recapture program. Pending the onset of supplementation program origin adult returns to Big River, numbers of returning fish to these tributaries have remained at low levels.

Sockeye productivity estimates are limited by the quantity and quality of the population data described above. For 1988 and 1990, Jacobs et al. (1996) estimated marine survival at 27% and 18%, spawner-recruit ratios at 0.99 and 1.89, and smolts-per-spawner ratios at 3.6 and 10.5, respectively. From recent data at Umbrella Creek, natural origin recruits per spawner estimates ranged from 0.9 to 3.3 from 2000 through 2002, averaging 1.9. Total survival from hatchery fingerling release to adult return to Umbrella Creek for return years 1999, 2000, 2002, and 2004 was estimated to be 2.03%, 1.47%, 0.81% and 0.49% respectively. Total survival from smolt to spawner for 2004 Umbrella Creek marked hatchery sockeye was estimated to be 15.5%.

HABITAT CONDITIONS AFFECTING LAKE OZETTE SOCKEYE

This report describes in detail the habitat conditions encountered by Lake Ozette sockeye salmon spawning aggregations at different life history stages in marine, estuary, and freshwater habitats. Known habitat conditions and data are described, while data gaps are highlighted.

NEARSHORE HABITAT

Nearshore physical habitat in the vicinity of the Ozette River is characterized by a gently sloping marine shore platform with abundant boulders and outcrops of resistant rock intermixed by beaches (sand to cobble) fed by bluffs and tributaries. The remote and relatively pristine condition of the shoreline in the vicinity of the Ozette River is reflected by a complex nearshore habitat that supports a wide diversity and abundance of marine life. The Ozette River estuary is small relative to nearby estuaries (<4,600 feet long by 120 feet wide), and is currently partially constricted by a gravel spit. Beyond photo evidence of significant growth of this spit over the last 50 years, little documentation of current and/or historical estuary conditions exist to allow for an assessment of effects on sockeye salmon growth and survival.

OZETTE RIVER HABITAT

The Ozette River is unique relative to other rivers on the Olympic Peninsula due to its very low gradient (0.1%) over its 5.3 mile journey, dropping only 32 feet in elevation from the outlet of Lake Ozette to the Pacific Ocean. The lake moderates the seasonal flow regime of the Ozette River dramatically, with flows ranging from less than 4 cfs to 2,000 cfs. Lake Ozette traps and prevents entrance of nearly all lake tributary sediment into the Ozette River, making bank and bed erosion, a handful of small tributaries, and Coal Creek (largest tributary) the only contemporary sources of sediment. The active river channel averages approximately 100 feet in width, with varying depths and wetted widths controlled by the water elevation of its source, Lake Ozette. The river maintains a semi-rhythmic sequence of riffles and pools, with the latter often controlled by large wood jams and the former often covered with two species of native mussels, freshwater sponges, and aquatic insects. Floodplains are relatively narrow with steep banks for much of the length. Floodplains are covered by dense conifer forest, various shrubs and wetland plants. Wetland plants include reed canary grass, an invasive plant which colonizes disturbed areas.

Besides tributaries to Ozette River, the river's entire length is now protected by either the ONP or the Makah Tribe's wilderness designation. Historically, human disturbances along the Ozette River were limited to homesteading, and later, tourist development near the lake outlet, cedar salvage along the lower river, and direct removal of instream large wood debris (LWD) along much of the river but concentrated near the lake outlet. Wood removal from Ozette River began in the late 1800s at a small scale, with most wood removed from the upper homestead area by the early 1900s. In 1952, the Washington Department of Fisheries (Kramer 1953) conducted wholesale clearing of wood from the river and removed 26 separate log concentrations. Local residents continued to clear wood from the river until the mid-1980s, when the practice was banned.

As a consequence of wood removal, pool conditions in Ozette River are impaired, with large stretches devoid of functional LWD, and with an associated loss of fish holding, rearing, and spawning habitat. The river is incapable of moving most large wood, but it will take decades to centuries for wood loads to fully recover. As a less apparent consequence, wood removal has resulted in less hydraulic roughness, reduced instream water depths, and reduced backwater effects on Lake Ozette, which has thus altered the entire hydraulic control on Lake Ozette levels and changed the in-river stage-discharge relationship. More recently, deposition of sediment originating from Coal Creek at the lake outlet has further altered lake and river levels.

Water quality conditions in Ozette River are good, except for sediment and temperature, which are affected by tributaries and the lake itself, respectively. Large amounts of fine (sand and silt) and coarse sediment are delivered to Ozette River by Coal Creek during floods, altering the local lake outlet control and substrate conditions, as well as downstream habitat conditions. Peak and 7-day average temperatures in the river regularly exceed 22 to 23°C respectively. High water temperatures observed in the Ozette River appear to be a natural condition caused by solar heating of Lake Ozette surface waters and climatic variability. Downstream cooling is minimal (less than 2°C).

LAKE OZETTE HABITAT

Lake Ozette habitat conditions are important to numerous life history stages of sockeye. Beyond providing key habitat for juvenile sockeye rearing, the lake's habitat is an integration of all cumulative upstream watershed conditions. The lake environment also controls habitat conditions downstream through the Ozette River to the ocean.

Lake productivity, and more specifically production of abundant phytoplankton and zooplankton, varies seasonally in the oligotrophic to mesotrophic lake and is a critical component of the overall sockeye smolt production because of the smolts' reliance on zooplankton. Limnological research indicates that abundant food supplies are available for juvenile sockeye salmon during their rearing period. Studies completed in the 1980s indicated that consumption demand by kokanee and juvenile sockeye rearing in the lake is satisfied by less than one percent of the instantaneous production of their preferred prey, large Daphnia (*Daphnia sp*.) throughout the growing season. In addition, Ozette sockeye smolts are the third largest (by length and weight) yearling sockeye smolts documented in the recorded literature, providing additional evidence that zooplankton populations are not limiting sockeye productivity.

The beach spawning sockeye salmon aggregations are a key component of the Ozette sockeye population. Shoreline conditions and potential sockeye spawning habitat vary greatly, both spatially and temporally, around the 36.5 mile lake perimeter, as determined by beach topography and slope, substrate size distribution, groundwater and hyporheic flow paths into beach gravel, wind fetch, fine sediment concentrations, tributary position, shoreline vegetation, riparian condition, lake level and hydroperiod, shoreline development, and other factors. The habitat review focuses on the two remaining sockeye spawning beaches (Olsen's Beach and Allen's Beach), in addition to known historical spawning locations (Baby Island and Umbrella Beach). However, it is important to note that current and recent spawning locations, as well as vegetation and substrate conditions along the lake shoreline, may not be representative of past spawning distribution and shoreline conditions. Historically, high quality spawning habitat was likely provided by numerous hydrogeomorphic situations around the lake:

- Beach spawning habitat maintained by wind- and wave-driven currents.
- Beach spawning habitat maintained by upwelling hyporheic- or groundwater in gravel or sand substrate.
- Beach spawning at or near tributary inlet deltas maintained by upwelling hyporheic flow or groundwater, and clean gravel with minimal fine sediment inputs from tributaries.

Currently, lake spawners use beach spawning habitat irrigated by wave-driven currents and/or upwelling hyporheic flows or groundwater. Seeps and springs have been mapped on both Olsen's and Allen's beaches, and appear to be areas where spawning activity is concentrated, with dispersed areas of spawning in non-upwelling areas. Zones of upwelling are warmer than non-upwelling areas during sockeye incubation and significantly cooler during summer months.

Substrate along Olsen's and Allen's beaches is a heterogeneous mixture of organic detritus, clay mud, silt, fine sand, coarse sand, pebbles, gravel, cobble, and rubble. Core spawning areas are typically located in a framework of gravel, with various levels of matrix finer sediment. Dozens of bulk gravel samples from each beach indicate that fine (<0.85mm in diameter) sediment concentrations in gravels are high, ranging from 7.0% to 72.7% of the total substrate composition. Fine sediment concentrations averaged 27.0% at Olsen's Beach, ranging from 4.6% to 44.3% in areas sampled. Allen's Beach fine sediment averaged 24.6% of total substrate composition. Fine sediment concentrations at the Umbrella Beach delta currently exceed 50%.

Due to seasonal fluctuations in lake level, vegetation (e.g., sweet gale, sedges, grass) often occupies the mid- to upper-elevations of both main spawning beaches and other lake margins. This vegetation is very effective at trapping fine sediment. Sockeye may spawn in and around this vegetation when it is submerged by high lake levels during the dormant season. Aerial photography analysis has estimated a 56% average decrease in unvegetated (bare substrate) shoreline around the lake from 1953 to 2003. At Olsen's and Allen's beaches, the decrease bare substrate shoreline was measured to be higher than average for other shoreline areas, at 66 % and 67%, respectively. Potential causal mechanisms for decreases in unvegetated shoreline include a reduction in elk shoreline grazing pressure early in the twentieth century and alterations in lake level regime and hydroperiod because of modifications in lake outlet hydraulics (e.g., Ozette River LWD removal) and lake inflow hydrology.

Riparian conditions (above typical high lake levels) around the lake are generally good to excellent, because of the retention of primary forest on the western shoreline and forest management measures providing a narrow buffer of mature trees on the eastern shoreline between the lake and adjacent clear-cuts. However, exceptions exist where the county road parallels the shoreline, where development (cabins, ranger station) has occurred, where old railroad grades exist, and where old homesteading cleared large conifer trees.

The hydrology of Lake Ozette has been poorly studied over the contemporary settlement period, but an assortment of lake level, climate, and hydrology data have been collected at various locations in the watershed and coastal region, which have been massed together to highlight major physical patterns. A stage gage at the lake outlet has been maintained semi-consistently from 1976 to 2006. Similar to regional precipitation patterns, Lake Ozette stage (which has a range of 12 ft) is typically at a maximum between December and February and at a minimum in September annually. The average peak-lake-stage timing typically lags behind average tributary-peak-discharge timing by several weeks. Annually, climatic variability has a strong effect on lake stage variability, similar to rainfall. Peak lake stages are highly correlated with total winter rainfall, while minimum lake stages are highly correlated with total summer rainfall and evaporation. During windy periods, lake stage can vary by up to 0.5 feet from north to south due to wind seiche, which is a wave oscillation lasting several hours to days following water displacement. Lake Ozette stage levels are also considerably influenced by both the hydraulic roughness conditions (e.g., LWD) in the lake outlet (Ozette River), and by vegetation and land surface disturbance condition influence on tributary inflow hydrology.

TRIBUTARY HABITAT

Lake Ozette tributary conditions are described in detail for the individual streams used directly by sockeye for spawning (Big River, Umbrella Creek, and Crooked Creek), for the streams that have a strong indirect impact on sockeye habitat (e.g., Coal Creek impacts on Ozette River and Lake Ozette) and for those tributaries that support healthy runs of kokanee (Siwash Creek). For each tributary, the floodplain, riparian, pool and LWD habitat, streambed substrate, water quality, and hydrology and streamflow conditions are described in detail. Data gaps pertaining to the status of these habitat parameters are highlighted.

Floodplain conditions for Lake Ozette tributaries vary considerably. The lower sections of most tributaries are partially disconnected from their floodplains due to incision (by approximately one meter) caused by changes in base level and lake level regime, in addition to local indirect and direct removal of LWD. Furthermore, roads located in the riparian zone have degraded floodplain conditions severely in Big River (county road and agricultural roads) and Umbrella Creek (logging roads). Road densities are less in riparian areas adjacent to Crooked and Siwash Creeks, which retain good floodplain habitat. Siwash Creek riparian habitat remains good because of remnant old growth conditions and high instream wood loads. The lower Coal Creek floodplain has been modified in contemporary times through channel incision caused by base level change (e.g., LWD removal), and by human development modifications of the confluence configuration and deltaic distributary locations.

As a consequence of its standing as the main transportation and settlement corridor in the Lake Ozette watershed, the Big River floodplain has been uniquely and significantly modified by roads, agriculture pastures, residences, channelization, LWD removal, and overall channel incision (by one to two meters). Channel incision in lower Big River has resulted partially because of base and lake level changes associated with logjam removal from the Ozette River. In addition, direct and indirect removal of LWD from Big River has contributed to incision and bed instability. Kramer (1953) describes clearing 3.5 miles of the river of logs and debris between approximately RM 2 and RM 6. Wood removal, insufficient LWD recruitment, and channel incision have reduced floodplain connectivity in Big River.

The Hoko-Ozette Road roughly follows the original wagon trail to Lake Ozette from Clallam Bay. Big River was correctly named, as for most of the year it was a small, slow-flowing stream, but during storm events, it often flooded out of its channel and occupied a large part of the floodplain valley, which encompassed parts of the trail (road), making passage on the trail (road) impossible. More recently, base level incision, road construction, channelization (rock and cars), and repeated "lifts" (which raise the level of the road to prevent flooding) have restricted channel migration, LWD recruitment, and stream-floodplain interactions. In 2003, 6.1 miles of roads were within 200 feet of the river's bankfull edge. There is an average of 8.8 miles of road per square mile of riparian area within 200 feet of the river's bankfull edge (range by channel segment of 6.5 to 17.8 miles per square mile), which equals or exceeds suburban or urban road densities. Rip-rap can be found along the banks of Big River in at least eight locations, preventing the river from migrating across its floodplain, and in some cases, preventing flood waters from accessing the floodplain. Several bridge crossings constrict the river and block flood flows from traveling on the floodplain (e.g., Swan Bay Road).

Agricultural development along the floodplain of Big River began in the late 19th century, when pioneer families cleared virgin forest into workable pasture. Floodplain and riparian encroachment by pastures and residences into the Big River riparian zone area (defined as the area extending 200 feet from each river bank) ranges from 0 to 15% by area. On average, 20% of the length of the river has pastures or residences within 200 feet of the bankfull edge (ranging from 0 to 36%). The lowest quality habitat segments (based on pool quality and LWD abundance) in Big River were located adjacent to pastures and/or residences.

Similar to floodplain conditions, riparian conditions along Big River are severely degraded. Nearly all (exceeding 95%) of the old growth riparian forest historically vegetating the riparian zone has been clear-cut or converted to pasture land. Extensive stands of medium-aged red alders (*Alnus rubra*) dominate the riparian forest where it remains, replacing conifers. However, some residual, large conifer trees are still present in patches, as are some continuous stream reaches of relatively young conifers. In addition, disturbed stream banks in many portions of Big River are infested with reed canary grass (*Phalaris arundinacea*). Japanese knotweed (*Polygonum cuspidatum*) and giant knotweed (*Polygonum sachalinense*) are also rapidly colonizing portions of the lower mainstem of Big River.

Riparian conditions in other Lake Ozette tributaries are also degraded. In contrast to the Big River, logging, rather than agricultural and rural development, has been the major causative factor of degradation in these other tributaries. Nearly all (exceeding 95%) of the old growth riparian forest has been harvested along most tributaries. The majority of riparian forests have been converted to stands dominated by red alder, but in scattered areas, relatively young conifers are the predominant species. Residual in-channel LWD and standing trees provide evidence of the massive trees that once existed. Small exceptions of good riparian conditions remain in portions of the Siwash and Crooked Creek watersheds, where residual in-channel LWD and intact mature riparian areas represent riparian conditions that historically existed throughout the watershed (i.e. large Sitka spruce and western red cedar).

Pool and LWD habitat quantity and quality mirror riparian conditions throughout the watershed. Beyond riparian timber harvesting, WDNR implemented stream clearing policies after 1952 and forest landowners were required to clear wood from streams when logging in adjacent riparian areas, which continued into the early 1990s as an integral part of forest practices.

Comprehensive instream pool and LWD condition data has been collected in the anadromous zone of all major tributaries. Habitat quality was rated and mapped in detail based on observations of instream wood load, large key piece frequency, and pool size and frequency. In most stream reaches with degraded riparian condition, the quantity and quality of LWD were low and below properly functioning levels, especially for the frequency of key conifer pieces (LWD greater than 50 cm in diameter). Conifer dominated the LWD piece count (69 to 83%), despite the standing of alder as the dominant species in many riparian zones. Key pieces ranged from one to four percent of the total piece count. Where present, pools formed by key-piece-sized LWD averaged nearly 1.5 to 1.8 times deeper than pools formed by medium or small LWD or free-formed pools without LWD. Recent recruitment of small and medium sized LWD appears incapable of producing the same habitat quality and complexity as those habitats formed by LWD greater than 50 cm in diameter. Pool habitat features associated with small and medium sized LWD had essentially the same attributes as free-formed pools independent of LWD. Future conifer recruitment will be minimal in many stands that are currently dominated by alder. However, the functionality of large alder recruitment in the future is unknown, as alders represented a smaller portion of past recruitment and current LWD loads. Large alder tree recruitment and LWD placement may be essential to maintain wood loads through the upcoming LWD deficit, until conifers can be planted and mature in the riparian zone.

Spawning substrate quality and quantity varies throughout the main tributaries to Lake Ozette. Past data indicate that the percent fine sediment (particles less than 0.85 mm in diameter) in spawning gravel is high in many Lake Ozette tributaries, averaging 16.1%

(wet-sieve equivalent) of the total substrate composition in Umbrella Creek, 15.7% to 17.3% in Big River, 14.0% to 23.9% in Crooked Creek, and 24.0% in Siwash Creek. Salmonid egg to alevin survival decreases when fine sediment concentrations exceed 13% (McHenry et al. 1994). In undisturbed drainage basins with geology similar to the Lake Ozette watershed, fine sediment levels rarely exceed 10% (McHenry et al. 1996). High levels of fine sediment in Lake Ozette tributaries are a partial result of naturally erosive geology. However, anthropogenic watershed disturbance, notably high road densities (5.5 to 7.5 mi/mi^2), lack of adequate road surfacing material, high road to stream connectivity, and gullying and mass-wasting associated with vegetation clearing have contributed to observed high fine sediment concentrations.

The quantity of spawning habitat available for salmon in Lake Ozette tributaries has also changed relative to historical levels. The loss of LWD in some streams has reduced the stream's ability to trap and store gravel, with bed coarsening occurring in many tributaries (e.g., Umbrella Creek). In other situations, fine sediment deposition from watershed disturbance has buried previous gravel bed reaches (e.g., lower Big River as described by Kramer 1953).

Water quality conditions in Lake Ozette tributaries vary by season and location. While winter water temperatures are within the preferred range for spawning and incubating salmonids, summer temperatures in most major tributaries regularly exceed the standard environmental temperatures preferred by salmon (10-12°C) and trout (15°C) for many weeks each summer. Water temperatures in Umbrella Creek, Big River, and Crooked Creek regularly exceed 18°C for several days to weeks each summer along lower reaches. These relatively high stream temperatures are thought to be partially a function of riparian forest disturbance and shade loss (mostly from logging during the last 50 years) and partly due to naturally elevated stream temperatures. Low dissolved oxygen conditions often accompany these higher temperatures. In addition, fecal coliform bacteria samples collected during summer months adjacent to agricultural sections of Big River have regularly exceeded Washington State Water Quality Standards (greater than 10% of samples exceed 100 colonies per 100 ml).

Turbidity measurements in Lake Ozette tributaries indicate that turbidity levels regularly exceed 100 nephelometric turbidity units (NTU) during storm events in most tributaries, with extremely high levels (greater than 500 NTU) measured in Umbrella Creek and Big River. In Coal Creek, paired measurements indicate that suspended sediment concentration (SSC) can exceed 1000 mg/L at turbidity values of 300 NTU. Peaks in turbidity and SSC closely follow the patterns of water discharge in each tributary. There is abundant sediment available in the channel network and turbidity is limited by flow-related transport capacity.

The flow regime of Lake Ozette tributaries can be defined as rain-dominated and flashy, with low and high flows commonly being separated by three orders of magnitude. While high discharge, turbidity, and SSC values last only for several hours to days for each event, over a dozen events can occur each year creating cumulatively poor conditions for salmonids.

LIMITING FACTORS AFFECTING LAKE OZETTE SOCKEYE

Limiting factors affecting Lake Ozette sockeye are identified by geographic area: estuary and nearshore environment; Ozette River; Lake Ozette; Lake Ozette tributaries; off-shore marine environment. Within each geographical area, limiting factors are further described by sockeye salmon life history stage.

ESTUARY AND NEARSHORE ENVIRONMENT

Physical changes to the nearshore environment have not been documented. The region is remote and relatively pristine. The effect of climatic forces on ocean temperatures and water current patterns can result in seasonal variations in nearshore productivity, which can alter the nutrients available to juvenile and adult sockeye. However, the effects of changes in the early marine juvenile rearing conditions and late-stage marine life history of Lake Ozette sockeye are unknown. Available marine survival estimates for Lake Ozette sockeye are relatively high compared to survival estimates for other Northwest sockeye salmon populations. Changes in the tidal prism and estuarine habitat conditions appear to have occurred during the last 50 years, but the cause is poorly understood, as are the potential effects of the apparent changes on Lake Ozette sockeye salmon.

Predation on sockeye salmon in the Ozette River estuary and nearshore environment is not well documented. It is suspected that juvenile sockeye are preyed upon by avian, fish, and marine mammal predators during their migration through the estuary and nearshore, but the degree to which this occurs remains unknown. A substantial proportion (33%) of adult sockeye entering the Ozette River from the nearshore environment have scars associated with predation events, with 77% of these scarred fish having old scars and 52% with new scars. Of the identifiable scars on sockeye captured in the lower river, 25% were from wounds inflicted by California and Steller sea lions, while 60% were inflicted by harbor seals. Direct visual observations of predation by pinnipeds have been made, but are limited in quantity and quality. The current number of pinnipeds interacting with Lake Ozette sockeye in the estuary and nearshore environment has increased significantly in the last 50 years, consistent with upward population trends for these animals observed across the Washington coastal and Puget Sound regions. The abandonment of the Ozette Village (one of five Makah villages) near the mouth of the Ozette River over the last 100 years has decreased traditional native hunting of pinnipeds in the nearshore area, Ozette River and Lake Ozette, and has likely increased the local number of these sockeye predators.

Healthy populations of prey species (e.g., salmon) often overwhelm predators (e.g., pinnipeds) by migrating in mass past interaction points, reducing the total number and percentage of predator-prey interactions. Decreases in the number of adult sockeye returning and juveniles emigrating from Lake Ozette in the past are thought to have increased the percentage of the annual juvenile and adult populations preyed upon.

Currently there is no directed sockeye harvest by humans occurring in the nearshore marine environment or the Ozette River estuary. Commercial tribal sockeye harvest was discontinued in 1977. A tribal ceremonial and subsistence fishery took place in the river from 1978 to 1982, with no directed sockeye harvest since. Past over-exploitation in fisheries has been described as a factor for the decline of Ozette sockeye, but fisheries harvest is not currently limiting sockeye salmon viability.

OZETTE RIVER

Compared to other mainstem rivers of the region, the Ozette River retains much of its natural integrity, despite numerous anthropogenic modifications. Instream habitat conditions have been degraded by repeated LWD removal operations (1890s to 1980s) and patchy riparian forest removal, resulting in reduced LWD size, frequency, and functionality. However, a mostly intact riparian corridor along the Ozette River ensures a supply of future LWD. Degraded LWD and riparian conditions have altered migration and rearing conditions for juvenile and adult sockeye, specifically, pool depth and volume, cover availability, and refugia from predators.

Wood in the Ozette River plays an important role in channel roughness, creating a backwater effect that increases floodplain connectivity. In addition, LWD in at least the upper 3,000 feet of the Ozette River exerts a significant influence on lake level regimes, as well as a positive feedback on river discharge. Herrera (2005) modeled various wood loading scenarios in the upper Ozette River and determined that under historical wood loading conditions, the mean lake level during the beach sockeye spawning period was 1.5 to 3.3 feet higher than current conditions. More recently (1979 through 2003), sedimentation at the lake outlet from Coal Creek has further altered lake and river levels, slightly raising summer lake levels but reducing (blocking) low stream discharges for a given lake stage.

The impact of high water temperatures in the Ozette River on migrating Lake Ozette sockeye depends upon specific temperatures and exposure times of both individuals and the entire run. For return years 2002 to 2004, 16.3%, 21.3%, and 55.9%, respectively, of the adult sockeye runs migrating in the Ozette River were exposed to daily average temperatures greater than 18°C. The average duration of migration from the estuary to lake is approximately 65 hours (ranging from 17-154 hours). Direct en-route mortality due to exposure to water temperatures greater than 18°C during river migration has not been investigated for Lake Ozette sockeye salmon. Studies from other areas (e.g., the Fraser River) indicate that exposure to temperatures at or above 18°C could make the sockeye more susceptible to disease and infection (especially considering their extensive [up to 6-month] lake holding period), resulting in elevated pre-spawning mortality levels and/or decreased spawning success

Sources of turbidity and high suspended sediment concentrations (SSC) in the Ozette River are limited to inputs from Coal Creek and a few small tributaries. Modeled impacts of the high SSC recorded in the Ozette River on sockeye adults range from moderate physiological stress to major indications of physiological stress for 6% (May), 4.8%

(June), 1% (July), and much less than 1% (August) of the adult population, respectively. Cumulatively, approximately 12% of the migrating sockeye salmon population on average would be exposed to SSC that would be expected to result in moderate physiological stress.

Juvenile sockeye smolts are preyed upon by a host of predators in the Ozette River, including river otters, harbor seals, northern pikeminnow, cutthroat trout, birds, and terrestrial mammals. While no detailed studies have exclusively focused upon smolt predation during emigration, smolt trap data indicate that northern pikeminnow are significant predators of sockeye smolts in the Ozette River. Adult sockeye are preyed upon mainly by seals and river otters in the Ozette River, where both species have been observed to frequently transit the entire length of the river. Research has shown that the incidence of scarring on adult sockeye increased by 11% along the length of Ozette River, with a significant portion of upstream-bound fish tagged in the estuary being lost (unrecovered) in transit. Predator scarring rates on sockeye in the Ozette River are among the highest rates observed in the Pacific Northwest. Predator abundance and predation rates in the Ozette River are hypothesized to have been altered by the removal of LWD, which in turn resulted in less availability of refugia for sockeye and easier transit for seals; changes in discharge regime; increases in aquatic mammal abundance; abandonment of the Ozette Village and traditional hunting; decreases in sockeye abundance (resulting in less predator swamping); and fisheries management practices (regulations, monitoring), which have synergistically interacted to unbalance predator-prey interactions, causing an increase in the ratio of predators relative to numbers of remaining Lake Ozette sockeye salmon.

LAKE OZETTE

Spawning habitat availability around the perimeter of Lake Ozette is largely controlled by lake level regime, which is influenced by the hydraulic (backwater) conditions of the Ozette River outlet, in addition to the hydrologic conditions of tributary inflow. Under historical wood loading conditions in the Ozette River, the mean lake level during the beach sockeye spawning period was 1.5 to 3.3 feet higher than current conditions. It is hypothesized that reduced mean lake levels have reduced the available area of sockeye beach spawning habitat and increased the ability of vegetation to colonize the lake shorelines in spring and summer months. Tributary inflow hydrology and outlet hydraulics together control how rapidly lake levels rise and fall and how they are sustained at preferred spawning levels, thus influencing the probability of redds (eggs) becoming desiccated and dewatered (e.g., three percent of the redd surface area on Olsen's Beach was estimated [based on measurements or redds and lake level] to be dewatered during the sockeye egg incubation period in return year 2000). Known alterations to lake outlet hydraulics and known land use changes in tributary watersheds, with hypothesized hydrologic impacts, have altered lake level regimes beyond levels attributable to natural climatic variability to an unquantified degree.

The quantity and quality of beach spawning gravels in Lake Ozette have declined significantly from their historical conditions to present. Reduced spawning gravel quantity and quality are ***key*** limiting factors affecting the success of beach spawning sockeye in Lake Ozette. The degree to which habitat quantity and quality has been reduced has not been quantified for the entire lake shoreline. Habitat quality reduction varies by site. For example, the entire Umbrella Beach spawning area historically used for sockeye spawning has been covered by several acres of fine sediment originating from Umbrella Creek and no longer provides suitable habitat. Other potential spawning areas have been reduced by vegetation colonization. The degree of colonization varies from small scale increases in vegetation, to entire beach segments colonized by shrubs and grasses (adjacent to areas currently used by spawning sockeye).

Measured levels of fine sediment collected in spawning gravels on Olsen's and Allen's beaches average 25% fines (particles less than < 0.85mm; n=56; gravimetric method), but with high spatial variability. Egg basket studies indicate that the total green egg-to-emergence survival rate was extremely low (averaging less than 1%; ranging from 0 to 45%). Over 21 day eyed-egg survival trials, median survival in cleaned gravel (8%) was higher than in uncleaned gravel (2%). Concurrent hatchery incubated eggs in cleaned and un-cleaned gravel had survivals of 99% and 61%, respectively. Reduced sockeye egg survival measured in uncleaned Olsen's Beach gravel under optimal incubation conditions at the hatchery and devoid of other confounding factors present in the lake suggest that fine sediment plays a significant role in egg mortality. However, these data also strongly suggest that other factors also contribute to reduced survival (e.g. encroachment by vegetation, deleterious changes in upwelling characteristics, and deleterious changes in inter-gravel flow).

Delivery of fine sediment to the lake from tributaries has increased three-fold during the last 50 to 100 years (Herrera 2006), largely due to increased sediment production from forest roads, clear-cutting, channel incision, and agricultural development. Historically utilized beaches, such as Umbrella Beach, have a clear link between sediment source, delivery, and the elimination of beach spawning habitat (5.7 acres of delta growth 1964-2003). However, it is not fully understood to what degree these increases have affected the remaining utilized beach spawning habitats located at Olsen's and Allen's beaches. Sediment delivery from local tributaries and shore slopes, combined with lateral lake shore transport from winds from the south-southwest, are the likely primary mechanisms for fine sediment delivery to sockeye spawning habitat at these extant spawning locations. In addition, the reduction in the abundance of the sockeye population in Lake Ozette during the last 30 years may have reduced the population's effectiveness in cleaning and maintaining spawning gravels that are free from fine sediment and vegetation through the act of mass spawning.

Furthermore, colonization and encroachment of native and non-native vegetation on the lake shoreline influences the habitat quality, sediment particle size distribution, and sediment trapping efficiency of Lake Ozette spawning beaches. There has been a substantial increase in shoreline vegetation (shrubs and grasses) during the last 50 years, hypothesized to be a result of long-term wood removal from Ozette River, lower lake levels during the growing season, reduced elk shoreline grazing, and vegetation colonization of newly delivered fine sediment from tributaries. In some locations, vegetation has completely blocked or smothered access to traditional spawning sites, while in other areas vegetation has decreased wave energy, promoting sediment deposition and reducing wind-driven currents needed to oxygenate eggs. The cumulative effects of vegetation colonization, sedimentation, and altered lake levels are hypothesized to have altered local hyporheic or groundwater flow paths and rates through spawning gravel, adversely affecting the quality of the incubation environment (i.e., egg oxygenation, waste removal).

In addition to degradation of habitat quality, the quantity of potential beach spawning habitat has also been reduced. While the number of beach spawning aggregations that have been extirpated is unknown, the strategy of spawning at creek mouths is no longer observed for Lake Ozette sockeye (e.g., Umbrella Creek and other tributaries). Colonization by native and non-native plants in spawning gravel decreased the extent of unvegetated (bare substrate) shoreline by an average of 56% from 1953 to 2003, directly reducing the quantity of spawning habitat available for sockeye. At Olsen's and Allen's beaches, the decrease in unvegetated shoreline area was higher than average, at 66 % and 67%, respectively.

Altered lake level regimes resulting from changes in outlet hydraulics and inflow hydrology have also reduced the amount of spawning gravel habitat inundated, and therefore available for sockeye salmon use, during the spawning and incubation period. The average reduction (1.5 to 3.3 feet) of lake levels during spawning and incubation period because of removal of wood at the Ozette River outlet has decreased the available spawning habitat area at Olsen's Beach by 11% to 33%. The cumulative effects of changes in lake level, increased vegetation colonization, and elevated sediment deposition levels have reduced the suitable spawning habitat (above 31.5 ft MSL) area by greater than 70% at Olsen's and Allen's beaches.

Predation on sockeye salmon occurs during all life history phases within the lake. Juvenile sockeye and smolts are preyed upon by a host of predators in Lake Ozette including northern pikeminnow, cutthroat trout, sculpin, other native and non-native fishes, and birds. In the limnetic (open water) zone of Lake Ozette, cutthroat trout have been documented to be the major predator of juvenile *O. nerka*, whereas northern pikeminnow are less significant predators because they feed less in the limnetic zone. However, northern pikeminnow, sculpin, cutthroat trout, juvenile steelhead trout, juvenile coho salmon, yellow perch, and largemouth bass may be significant predators where they interact with juvenile sockeye along lake margins and near tributary confluences.

Adult sockeye are preyed upon mainly by harbor seals and river otters in Lake Ozette. Harbor seals are most commonly observed in the lake during fall and winter months during adult spawning, but seals are also encountered during spring or early summer during sockeye migration. Seals were not observed in the lake until the late 1980s. The number of harbor seals that frequent Lake Ozette appears to be low (two to four animals), but spawning sockeye are extremely vulnerable to predation, and the limited number of beach spawners in the lake could be significantly negatively impacted by only a handful of seals. Beach carcass studies also indicate that river otters are a major predator of adult sockeye in the lake. However, there is the potential that river otters scavenge the remains of sockeye that were captured and killed by harbor seals, implicating the wrong animal.

Disease is believed to have a low impact on the survival and abundance of adult sockeye holding in Lake Ozette. There is no direct evidence of significant disease mortality of free swimming adult sockeye in the lake during the up to six-month holding period. However, little is known about this life stage of Lake Ozette sockeye, and fish losses to disease cannot be entirely discounted as a potential limiting factor. In some years, only a fraction of the adult fish enumerated at the weir have been accounted for during lake and tributary spawning ground surveys, suggesting the potential for significant mortality from disease, secondary infections due to lacerations, direct predation, or unknown factors.

Hatchery practices implemented through the Hatchery Genetic Management Plan include measures to minimize potential disease and genetic impacts to beach spawning aggregations. The Umbrella Creek Hatchery “stock” poses limited genetic risk from breeding with beach spawning sockeye, since Umbrella Creek sockeye are essentially the same genetically as Olsen’s Beach sockeye. Mark and recapture data collected at Olsen’s and Allen’s beaches indicate that few, if any Umbrella Creek hatchery releases return to spawn on Lake Ozette beaches.

LAKE OZETTE TRIBUTARIES

Lack of long-term hydrologic data sets in the Ozette watershed preclude precise quantification of any potential changes to hydrology and flow regimes from land use and channel modifications. However, forest harvest data (showing that greater than 90% of the watershed has been logged once and 33% to 60% has consistently remained hydrologically immature), road density data (averaging 5.5 miles/mi^2) in the Lake Ozette basin, and loss of floodplain connectivity and water storage (loss of LWD), along with a thorough literature review of forest hydrological processes, strongly suggest that these anthropogenic perturbations may have resulted in alterations in common peak flows (0.5- to 2-year recurrence intervals) and baseflows (i.e., historically higher progressing toward chronically lower).

Natural or anthropogenically modified variability in streamflow can affect salmonid habitat availability via velocity and depth or gravel area covered by water. Low flows and delayed seasonal high flows can alter adult migration timing, influencing predation rates or overall fitness. Highly variable discharge during spawning can force fish to spawn high in the channel cross-section, increasing the probability of later redd desiccation, or it may force fish to spawn low in the channel, increasing the probability of redd scour.

Summer temperatures in most major tributaries regularly exceed the standard environmental temperatures preferred by salmon (10-12°C) and trout (15°C); however, there is very little overlap between natural-origin sockeye and stream temperatures exceeding 16°C. In contrast, low ph values during low and high discharges can inhibit successful spawning and incubation, as hypothesized for Crooked and Coal Creeks.

Past and recent turbidity measurements in Lake Ozette tributaries indicate that turbidity levels regularly exceed 100 NTU during storm events in most tributaries, with extremely high levels (exceeding 500 NTU) measured in Umbrella Creek and Big River. In Coal Creek, paired turbidity and SSC measurements indicate that SSC values can exceed 1,000 mg/L at turbidity values of 300 NTU. Peaks in turbidity and SSC closely follow the patterns of water discharge in each tributary, indicating that the abundant fine sediment is transport limited. Elevated turbidity and SSC levels can directly and indirectly affect fish survival through altered behavior, physiology, and habitat quantity and quality. While high discharge, turbidity, and SSC values are limited in duration (only lasting for several hours to days for each storm event), the high frequency of such events (over a dozen events each year) can create cumulatively poor conditions for salmonids. In all tributaries, on average the duration of turbidity and SSC exposure is greater during fall and winter (adult spawning and incubation) than spring (juvenile emigration from tributaries). Modeled impacts of SSC on sockeye adults and smolts during spring floods in Coal Creek range from moderate physiological stress to major physiological stress. Because of the significantly higher turbidity and SSC values in Big River and Umbrella Creek, it is likely that the impacts on sockeye behavior, physiology, and habitat are greater there.

Channel-floodplain-riparian connectivity plays an important role in sediment transport and storage dynamics, as well as in regulating hydraulic and hydrologic processes. Cumulatively, altered floodplain processes coupled with other changes in watershed processes, such as increased sediment and water production and delivery to the channel network, can result in increased fine sediment levels, decreased bed stability, and increased sediment delivery to the lake. Loss of large riparian conifer vegetation because of floodplain development or logging has resulted in a decrease in LWD in most tributaries. In the habitat segments of major Lake Ozette tributaries defined for research purposes, the number of LWD pieces per 100 meters of stream length rated good in 25% of the segments; LWD greater than 50cm in diameter per 100 meters of stream length rated good in 23%; but key pieces/BFW rated good in only one percent of segments. A high frequency of large-diameter pieces of LWD is highly correlated with reaches with undisturbed riparian zones. In Ozette stream channels and floodplains, “key piece LWD” is an important roughness component that dissipates energy, promotes channel stability, creates complex aquatic habitat, increases floodplain connectivity, stores spawning sediment, and filters fine sediment.

In many Lake Ozette tributaries, the quantity of suitable spawning habitat has been reduced as a result of LWD removal, reduced LWD recruitment, increased fine sediment inputs and abundance, channelization and bank armoring, gravel mining, and colonization of bar deposits by non-native vegetation. In some reaches of Big River and Umbrella Creek, spawning gravel beds have been completely converted to sand bed or cobble bed, respectively. However, current sockeye salmon run sizes in the tributaries (less than 5,000 adult sockeye) occupy a small fraction of available habitat and thus are not currently limited by habitat quantity.

Spawning habitat quality in Lake Ozette tributaries is affected by channel stability and, more specifically, by redd scour. Channel stability and scour is influenced by many factors, including peak streamflow, sediment inputs, sediment transport imbalances, bed and bank material, size and density of LWD, and channel-floodplain connectivity. It is hypothesized that the combined influence of increased common peak flood magnitude, increased sedimentation of spawning reaches, reduced wood loads, and/or channelization and floodplain disconnection have synergistically destabilized relative bed stability and reduced sockeye egg-to-fry survival. Numerous observations have been made of highly mobile stream beds in tributary spawning areas, but no direct monitoring of scour depth has been conducted. Identification of the effects of gravel movement and redd scour on Lake Ozette sockeye salmon survival and productivity remains a data gap.

Reduced spawning gravel quality and the accumulation of fine sediment in spawning gravels during egg incubation appear to be *key* limiting factors affecting the success of tributary spawning sockeye. High levels of fine sediment in spawning gravels can reduce or block water exchange, oxygen delivery, waste removal, and fry emergence. It is hypothesized that fine sediment production has increased in the Lake Ozette watershed following European-American settlement by a factor of three, due to changes in land use (vegetation clearing, logging, road building). While no pre-disturbance fine sediment data are available for Ozette tributaries, in nearby undisturbed drainage basins with similar geology, fine sediment levels rarely exceed 10%. Under current, post-disturbance conditions, Lake Ozette tributaries have some of the highest levels of fine sediment (18.7% volumetric) measured in spawning gravels on the north Olympic Peninsula. Salmonid egg-to-alevin survival has been shown to decrease drastically when fine sediment concentrations exceed 13% (volumetric method).

Predation on juvenile and adult sockeye in Lake Ozette tributaries is poorly documented. During the period that adult sockeye enter, migrate, and hold in lake tributaries, they are primarily susceptible to predation by river otters, harbor seals, terrestrial mammals and birds (bald eagles, osprey). During spawning and egg incubation, sockeye eggs are susceptible to predation by sculpin, cutthroat trout, river otters, and birds (merganser, belted kingfisher). No studies of sockeye egg predation in the tributaries have been conducted nor has it been suggested that significant levels of egg predation are occurring. Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in tributaries by sculpin (sp), cutthroat trout, juvenile steelhead trout, juvenile coho salmon, and northern pikeminnow. Predator abundance and predation efficiencies in Ozette tributaries have been altered by LWD removal, which influences availability of refugia for sockeye, and loss of substrate refugia due to fine sediment deposition and embeddedness.

Within Lake Ozette tributaries, competition effects are limited primarily to impacts that may occur during spawning. Emergent sockeye fry quickly migrate to the lake upon emergence from the gravel, and food resource competition is not likely. Both intraspecific and interspecific competition exists in Lake Ozette tributaries: sockeye competing with one another for spawning habitat, sockeye competing and/or spawning with kokanee for spawning habitat, and sockeye competition with coho salmon for spawning habitat. The degree and type of competition thought to occur in tributaries varies by stream system, species population abundance, and habitat quality and availability. Within certain reaches with modest numbers of sockeye (Umbrella Creek), competition can be intense and redd superimposition can play a significant role in egg-to-fry survival. Spawning competition with coho salmon also occurs, since both species spawn at the same time and in similar habitat, but coho populations will need to increase before their competition with sockeye for spawning sites becomes a significant factor. Competition and interaction with kokanee is thought to be minimal in Umbrella Creek, since few kokanee spawn in this stream system. Interactions between the two *O. nerka* races are more common in other streams (Crooked Creek) where sockeye numbers are low but kokanee numbers are moderate. Tributary spawning ground surveys during the last 10 years have provided no evidence of pre-spawning disease-induced mortality in the tributaries.

OFF SHORE MARINE ENVIRONMENT

Limited marine survival data indicate that *total* marine survival rates appear good, averaging 15 to 27%. Data for other Pacific Northwest sockeye salmon populations indicates that average marine survival for large sockeye smolts (>115mm) in the southern range of the ocean where Lake Ozette likely rear (latitude <55°N) averages 17.1%. While marine survival is a critical component in determining the ultimate abundance of Lake Ozette sockeye, broad-scale, regional studies of decadal-scale productivity suggest that changes in marine survival have played a limited role in the decline of Lake Ozette sockeye.

Since the discontinued tribal sockeye fishery in late 1970s, there have been no known directed sockeye fisheries that substantially affect Lake Ozette sockeye in the marine environment. No past or recent marine harvest data for Lake Ozette sockeye exist. Marine area migration timing for Lake Ozette sockeye salmon was estimated for Southeast Alaska and West Coast Vancouver Island marine areas. Ozette sockeye migration timing was charted relative to the timing of fisheries in recent years to determine whether the fisheries could be intercepting Lake Ozette sockeye. Alaskan fisheries appear to occur too late in the season to pose a threat of intercepting Ozette sockeye. West Coast Vancouver Island sockeye fisheries have been virtually closed since 1996, and less than 10% of Ozette sockeye could be subject to harvest if/when these fisheries operate. A small (one to two gill net boat) test fishery in Canadian Area 20 (one day's travel north from the mouth of the Ozette River) that is conducted to assess Fraser River sockeye salmon run strength and timing overlaps in timing with approximately 25% of the Lake Ozette sockeye return. This test fishery could intercept some Lake Ozette sockeye (Pacific Salmon Commission staff estimated that one Lake Ozette adult was encountered two years ago). However, DNA analysis has shown that the vast majority of fish caught originate from Lake Washington and the Fraser River during the period when Lake Ozette sockeye might be present in the test fishery. The Pacific Fishery Management Council states that southern U.S. coastal sport, commercial, and tribal fisheries have no measurable impact on sockeye salmon.

ANALYSIS OF LIMITING FACTORS BY LIFE STAGE

This report presents a series of limiting factors hypotheses by life stage, supported by a narrative describing reasoning and evidence. Each limiting factor hypothesis was evaluated based on the following definition of a limiting factor: physical, biological, or chemical conditions (e.g., inadequate spawning habitat, insufficient prey resources, and deleterious suspended sediment concentration) experienced by sockeye at the spawning aggregation scale resulting in reductions in viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity).

The Lake Ozette Sockeye Steering Committee's Technical Workgroup evaluated and rated each of the limiting factors hypotheses based upon the degree of impact on the population or sub-population during each life stage. The degree of impact of each limiting factor was categorized as one of the following: unknown, negligible, low, moderate, or high.

In addition, a narrative describing the rationale for determining a specific degree of impact and certainty of impact (low, medium, high, N/A) was characterized by the group for each limiting factor hypothesis. Sub-hypotheses were developed for some complex limiting factors, which include linkage between each limiting factor and the processes and/or threats that may influence the limiting factor. Most sub-hypotheses include a link to the sub-section of the report where detailed supporting evidence can be found. Key limiting factors are those with the greatest (highest) impacts on a population's ability to reach its desired status.

LIMITING FACTORS AFFECTING ALL POPULATION SEGMENTS

High Level of Impact
- Predation on juvenile sockeye in the Lake Ozette pelagic zone
- Marine survival

Moderate Level of Impact
- Predation during adult migration
- Predation during juvenile emigration
- Water quality during adult migration

Low Level of Impact
- Ozette River habitat during adult migration
- Ozette River habitat during juvenile emigration
- Research and monitoring during adult migration
- Research and monitoring during juvenile emigration

Unknown Level of Impact
- Disease: all life stages
- Estuary alterations: adult and juvenile stages
- Streamflow alterations: adult and juvenile stages
- Water quality during adult holding
- Predation during adult holding

LIMITING FACTORS AFFECTING BEACH SPAWNERS

High Level of Impact
- Predation during adult spawning
- Reduced suitable spawning substrate during incubation
- Fine sediment in gravel during incubation
- Vegetation encroachment during incubation

Moderate Level of Impact
- Fine sediment in gravel during fry emergence
- Seasonal lake level change during incubation and emergence

Low Level of Impact
- Predation during adult staging near beaches
- Redd superimposition during spawning/incubation

Unknown Level of Impact
- Predation during incubation and emergence
- Water quality during adult staging and spawning
- Low population size (habitat maintenance) during incubation

LIMITING FACTORS AFFECTING TRIBUTARY SPAWNERS

High Level of Impact
- Fine sediment in gravel during incubation
- Water quality during incubation

Moderate Level of Impact
- Predation during fry emergence and emigration

Low Level of Impact
- Predation during adult migration, spawning and incubation
- Pool habitat during adult migration and spawning
- Streamflow during adult migration, spawning, and fry emigration
- Water quality during adult migration, spawning, and fry emigration
- Research and monitoring during egg incubation

Unknown Level of Impact
- Streamflow during egg incubation

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LIST OF ACRONYMS/ABBREVIATIONS USED

ATU Accumulated Thermal Unit
BFD Bankfull Depth
BFW Bankfull Width
BIA Bureau of Indian Affairs
BMP Best Management Practice
BRT Biological Review Team
BY Brood Year
CART Combined Acoustic Radio Tag
CCNWCB Clallam County Noxious Weed Control Board
cfs Cubic Feet per Second
cfs/Mi^2 Cubic Feet per Second per Square Mile
CMZ Channel Migration Zone
CW Channel Width
DBH Diameter at Breast Height
DEM Digital Elevation Model
DFO Department of Fisheries and Oceans Canada
DHVSM Distributed Hydrologic Vegetation Simulation Model
ESA Endangered Species Act
ESU Evolutionarily Significant Unit
FL Fork Length
GLO Government Land Office
HCP Habitat Conservation Plan
HEC-RAS Hydraulic Engineering Centers River Analysis System
HGMP Hatchery and Genetic Management Plan
HOF Hortonian Overland Flow
HORs Hatchery Origin Recruits
IHN Infectious Hematopoietic Necrosis
IMST Independent Multidisciplinary Science Team
IPCC Intergovernmental Panel on Climate Change
JRMP Joint Resource Management Plan
LBT Left Bank Tributary
LFA Limiting Factors Analysis
LWD Large Woody Debris
MDN Marine Derived Nutrients
MFM Makah Fisheries Management
MMPA Marine Mammal Protection Act
MSL Mean Sea Level
NCDC National Climate Data Center
NGVD 1929 National Geodetic Vertical Datum of 1929
NMFS National Marine Fisheries Service
NMML National Marine Mammal Laboratory
NOAA National Oceanic and Atmospheric Administration

NORs	Natural Origin Recruits
NPS	National Park Service
NWS	National Weather Service
ONF	Olympic National Forest
ONP	Olympic National Park
PFMC	Pacific Fishery Management Council
PNW	Pacific Northwest
POT	Peaks Over Threshold
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PSC	Pacific Salmon Commission
RBT	Right Bank Tributary
QIN	Quinault Indian Nation
QNR	Quileute Natural Resources
RI	Recurrence Interval
RM	River Mile
RMIS	Regional Mark Information System
RMP	Resource Management Plan
RY	Return Year
SASSI	Salmon and Steelhead Stock Inventory
SCAS	Spatial Climate Analysis Service
SEAK	Southeast Alaska
SL	Standard Length
SSC	Suspended Sediment Concentration
SSHIAP	Salmon Steelhead Habitat Inventory and Assessment Project
TE	Trap efficiency
TFW	Timber, Fish, and Wildlife
TL	Total length
TRT	Technical Recovery Team
UJNR	United States and Japan Natural Resources
USBOR	United States Bureau of Reclamation
USCG	United States Coast Guard
USFS	United States Forest Service
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service
VSP	Viable Salmonid Population
WAU	Watershed Administrative Unit
WSVI	West Coast Vancouver Island
WDF	Washington Department of Fisheries (now WDFW)
WDFW	Washington State Department of Fish and Wildlife
WDNR	Washington State Department of Natural Resources
WDOE	Washington State Department of Ecology
WFPB	Washington State Forest Practice Board
WRIA	Water Resource Inventory Area

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1 INTRODUCTION

The purpose of this report is to describe and evaluate limiting factors currently and cumulatively affecting the survival and productivity of Lake Ozette sockeye salmon (*Oncorhynchus nerka*). A thorough analysis of Lake Ozette sockeye limiting factors has been a goal of those involved with the management and restoration of Lake Ozette sockeye for decades (see background below). In addition, the National Marine Fisheries Service (NMFS) is required under the Endangered Species Act (ESA) to develop recovery plans for each species under NMFS jurisdiction listed as threatened or endangered. This report provides critical information regarding factors limiting the survival and productivity of Lake Ozette sockeye for future incorporation into the Lake Ozette sockeye salmon recovery plan.

Within the context of this report, limiting factors are defined as physical, biological, or chemical conditions (e.g., inadequate spawning habitat, insufficient prey resources, or suspended sediment concentration) experienced by sockeye at the spawning aggregation scale that result in a reduction in viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity). Limiting factors that affect sockeye at the spawning aggregation scale may threaten the viability of the evolutionarily significant unit (ESU). Key limiting factors are those with the greatest impacts on a population's ability to reach its desired status.

It is important to distinguish between factors responsible for the decline of the population (factors for decline), and factors that currently limit sockeye abundance, productivity, spatial structure, and diversity (limiting factors). Certain activities that may have contributed to the decline of Ozette sockeye may no longer operate to limit abundance or productivity (e.g. commercial sockeye harvest).

Both the factors for decline and the limiting factors affecting the productivity and survival of Lake Ozette sockeye have been previously investigated and documented in detail in several reports and studies (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; Jacobs et al. 1996; Gustafson et al. 1997; Makah Fisheries Management [MFM] 2000). Several hypotheses were developed regarding factors for decline of the Ozette sockeye population. MFM (2000) summarized the commonly presented factors for decline as follows: (1) loss of adequate quality and quantity of beach spawning habitat, (2) loss of tributary spawning sockeye populations, (3) past over-exploitation, (4) predation and disruption of natural predator-prey relationships, (5) introduction of non-native fish and plant species, (6) temporarily poor ocean conditions, and (7) interactions of these factors. The collective effects of these factors may have further influenced spawning habitat quality by reducing the population size to a threshold where lower densities of fish could not adequately maintain clean, vegetation-free spawning gravels.

This report is not intended to be a review of factors for decline, however, but instead a thorough investigation of factors currently limiting VSP parameters.

1.1 BACKGROUND

Historically Lake Ozette, the Ozette River, and tributaries draining into the lake were important components of tribal fisheries (Swindell 1941; Gustafson et al. 1997). The Ozette watershed also provided an important subsistence fishery for early settlers within the watershed.

Olympic National Park (ONP) is the only national park in the lower 48 states that contains significant numbers of all species of Eastern Pacific salmon. Lake Ozette sockeye salmon represent a critical component of biological integrity of ONP from both ecosystem and public interest perspectives. Lake Ozette sockeye are critical to ecosystem function in ONP; they link freshwater, marine, and terrestrial ecosystems. Three fish species in ONP are listed as threatened under the Endangered Species Act: Ozette sockeye salmon, Puget Sound Chinook (*Oncorhynchus tshawytscha*), and Puget Sound/Coastal bull trout (*Salvelinus confluentus*). In the Lake Ozette watershed only sockeye salmon are listed under the ESA. Ozette Chinook are not listed but are nearly extinct, if not functionally extinct. Bull trout are historically absent from the Lake Ozette watershed. Ozette sockeye are one of only two populations of sockeye that inhabit the approximately 1 million acres of land managed by ONP.

The decline in harvest of Lake Ozette sockeye salmon from a high of more than 17,500 fish in 1949 (Washington Department of Fisheries [WDF] 1955) to a low of 0 in 1974 and 1975 (Jacobs et al. 1996) acted as the catalyst to prompt research into the limiting factors affecting Lake Ozette sockeye. In 1976, the Makah Tribe requested assistance from the U.S. Geological Survey (USGS) and U.S. Fish and Wildlife Service (USFWS) to determine the limiting factors and status of Lake Ozette sockeye. The result of the Makah Tribe's request was two joint studies. One addressed the abundance and limiting factors of Lake Ozette sockeye (Dlugokenski et al. 1981), and the other focused on the preferred and observed conditions of sockeye habitat within the Ozette watershed (Bortleson and Dion 1979). These studies provided a tremendous amount of baseline data on abundance, distribution, and habitat conditions but did little to determine the primary limiting factors affecting Lake Ozette sockeye or the factors causing the population decline.

On April 1, 1981 the first meeting of the Lake Ozette Steering Committee was convened (MFM 1981). Initially the steering committee focused on hatchery supplementation plans. It included the following participants: the Makah Tribe, ONP, USFWS, Washington State Department of Fisheries (WDF), University of Washington, and Crown-Zellerbach Corporation (MFM 1981). The committee met over the next two years and helped to establish the Umbrella Creek hatchery. However, multi-agency recovery efforts waned from 1983 to 1987. Population monitoring efforts also diminished over this period. Another multi-agency planning meeting was held in July 1987, made up of representatives from the Makah Tribe and state and federal entities (Jacobs et al. 1996). As a result of the 1987 meeting, the team recommended compiling all existing information on Lake Ozette sockeye, increasing spawning ground surveys to determine the status of tributary spawners, and re-forming the Lake Ozette Steering

Committee. However, the Makah Tribe was unable to rally the multi-agency support needed to reestablish the steering committee (Jacobs et al. 1996), and little or no coordinated multi-agency efforts occurred after the 1987 meeting.

Two important independent studies were conducted between 1983 and 1993. The first was John Blum's Master's thesis, *Assessment of Factors Affecting Sockeye Salmon (Oncorhynchus nerka) Production in Ozette Lake, USA* (Blum 1988). The second was an evaluation of predation and competition limits on juvenile sockeye salmon (Beauchamp and LaRiviere 1993). In 1994, the National Park Service (NPS) funded the National Biological Service's Forest and Rangeland Ecosystem Science Center to compile existing data on Lake Ozette sockeye and assemble a panel of experts to make recommendations on future monitoring and management efforts (Jacobs et al. 1996). This effort focused on the same priorities recommended by the 1987 watershed planning team. The result was *The Sockeye Salmon (Oncorhynchus nerka) Population in Lake Ozette, Washington, USA* (Jacobs et al. 1996), known as the "Jacobs Report," which, at the time, was the most comprehensive document related to Lake Ozette sockeye.

The Jacobs Report was unable to specifically define the population limiting factors and concluded that the population decline was likely the result of a series of cumulative impacts, including the effects of the following: 1) introduced species, 2) predation, 3) loss of tributary spawning populations, 4) decline in the quality of beach spawning habitat, 5) short-term unfavorable ocean conditions, 6) historical over-fishing, 7) introduced disease, and 8) a combination of factors (Jacobs et al. 1996). The panel of experts concluded that the highest priority monitoring effort was to continue and improve weir counts on the Ozette River. Three of the four panel members recommended monitoring the fate of hatchery fish as the second highest priority.

On March 25, 1999, NMFS listed Lake Ozette sockeye salmon as threatened under the Endangered Species Act (64 FR 14528). The threatened status under the ESA was reaffirmed in 2005 (70 FR 37160). Largely as a result of the ESA 1999 listing, multi-agency efforts to coordinate research and recovery planning resumed, and the Lake Ozette Steering Committee was reorganized and expanded to include NMFS as well as local landowners and other interests. In 1999 and 2000, the Steering Committee formed a hatchery working group to coordinate issues relating to development of a Hatchery and Genetic Management Plan (HGMP)/Joint Resource Management Plan (JRMP) for Lake Ozette sockeye salmon. A habitat working group was also formed to develop a ranked list of potential limiting factors, as well as a ranked list of research and monitoring priorities.

The ESA requires the federal government to designate "critical habitat" for any species it lists under the ESA. Critical habitat is defined as: 1) specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and 2) specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation. NMFS formally designated the following areas within the Lake Ozette watershed as critical habitat that is necessary for the survival and recovery of the Ozette Lake sockeye salmon ESU (70 FR 52630, September 2, 2005): Ozette Lake and the Ozette Lake Watershed, including the Ozette River (Lat 48.1818, Long -124.7076) upstream to endpoints in: Big River (48.1844, -124.4987); Coal Creek (48.1631,-124.6612); the East Branch of Umbrella Creek (48.1835, -124.5659); North Fork Crooked Creek (48.1020, -124.5507); Ozette River (48.0370, -124.6218); South Fork Crooked Creek (48.0897, -124.5597); Umbrella Creek (48.2127, -124.5787); and three unnamed Ozette Lake tributaries (48.1771, -124.5967); (48.1740, -124.6005); and, (48.1649, -124.5208). See Figure 1.1 for watershed overview map and Figure 1.2 for detailed map depicting designated Critical Habitat within the Lake Ozette Sockeye ESU.

The Lake Ozette Sockeye HGMP (MFM 2000) and the ranked research and limiting factors lists were completed in 2000 and have guided recent and ongoing research and monitoring in the Ozette watershed. The Makah Tribe, ONP, and co-managers have recently implemented a series of detailed field investigations designed to increase understanding of the spatial distribution of anadromous fish and the habitat limiting factors in Lake Ozette and its tributaries. These include:

- A baseline inventory of tributary habitat conditions (Haggerty and Ritchie 2004)
- Increased quantity and quality of adult abundance monitoring from 1998 to present (Haggerty 2004A, 2005A, 2005B, 2005C, 2005D)
- Increased spawning ground survey effort along the spawning beaches and tributaries (data presented in this report)
- Adult weir, trapping, and tagging in lower Umbrella Creek (Hinton et al. 2002; Crewson 2003; Peterschmidt and Hinton 2005)
- Increased hatchery monitoring
- Smolt and fry migration studies
- Ozette River streamflow monitoring (Shellberg 2003)
- Egg-to-emergence survival studies on the lake beaches
- Fine sediment in spawning gravel study on lake beaches
- Combined radio-acoustic tagging study (Hughes et al. 2002)
- Genetic monitoring studies (Crewson et al. 2001; Hawkins 2004)
- pinniped predation studies (Gearin et al. 1999; Gearin et al. 2002)
- Hydrologic and hydraulic investigations in Lake Ozette (Herrera 2005)
- Reconnaissance survey of Lake Ozette geomorphic conditions (Herrera 2006)

The current report was conceived during the habitat and hatchery workgroup meetings that took place in 1999 and 2000. A lack of dedicated funding hindered progress until late 2004, when renewed interest by the Steering Committee and dedicated funding from the Makah Tribe and NMFS pulled the necessary resources together to complete the assessment. This report summarizes past information relating to factors limiting the productivity of Lake Ozette sockeye salmon (e.g. information found in the Jacobs Report), presents new information and data (bulleted list above), and analyzes factors limiting sockeye productivity and recovery.

1.2 ORGANIZATION OF REPORT

The report is divided into seven main chapters:

- Introduction (Chapter 1)
- Fish Populations of the Lake Ozette Watershed (Chapter 2)
- The Sockeye Salmon Population (Chapter 3)
- Habitat Conditions Affecting Lake Ozette Sockeye (Chapter 4)
- Limiting Factors Affecting Lake Ozette Sockeye (Chapter 5)
- Analysis of Limiting Factors (Chapter 6)
- Research, Monitoring, and Evaluation Needs (Chapter 7)

Chapters 1 through 4 include a review of the most up-to-date information related to the physical setting (Section 1.3), ecological setting (Section 1.4), watershed disturbance history (Section 1.5), non-sockeye fish species present and their interaction and relationship with sockeye salmon (Chapter 2), the sockeye salmon population (Chapter 3), and habitat conditions affecting sockeye salmon (Chapter 4). In addition, the report summarizes population trends, dynamics, and interactions for all non-sockeye fish species in the watershed (Chapter 2), and provides a thorough review of the Lake Ozette sockeye life history and spawning distribution (Section 3.1), sockeye hatchery practices (Section 3.2), population structure and diversity (Section 3.3), population trends (recent and historic; Section 3.4), and stock productivity (Section 3.5). These data are then integrated with habitat conditions (Section 4) and factors affecting the species productivity across the watershed (Section 5), to build an understanding of the current limiting factors affecting Lake Ozette Sockeye.

Limiting factors affecting sockeye salmon are discussed by geographical area and life history stage in Chapter 5. Limiting factors are then rated for degree of impact and synthesized in Chapter 6. Chapter 6 includes an analysis of limiting factors by life stage and presents a series of limiting factors hypotheses and sub-hypotheses. These hypotheses are intended to serve as the scientific foundation for identifying recovery actions in the Lake Ozette sockeye recovery plan. Chapter 7 includes a summary of recommended research, monitoring, and evaluation needs across the watershed.

1.3 PHYSICAL SETTING

Lake Ozette watershed is located along the northwest tip of the Olympic Peninsula in Washington State (Figure 1.1). Lake Ozette is situated on the coastal plain between the Pacific Ocean and the Olympic Mountains. The terrain of the Ozette watershed is slightly rolling to steep with a gradual increase in elevation from zero at sea level at the Ozette River mouth, to 40 feet at the Ozette Ranger Station, to just under 2000 feet at the watersheds highest point in the upper Big River watershed. Most of the watershed ranges from 200 to 800 feet elevation.

Lake Ozette is approximately 8 miles (12.9 km) from north to south and 2 miles (3.2 km) wide. The lake is irregularly shaped and contains 36.5 miles of shoreline (Ritchie 2005). It includes several bays (North End, Deer, Umbrella, Swan, Ericson's, Boat, Allen's, and South End), distinct points (Deer, Eagle, Shafer's, Rocky, Cemetery, and Birkestol) and three islands (Garden, Tivoli, and Baby). With a surface area of 11.8 mi^2 (30.6 km^2; 7,550 acres; 3,056 ha), Lake Ozette is the third largest natural lake in Washington State. The lake has a drainage basin area of 77 mi^2 (199.4 km^2), an average depth of approximately 130 feet (40 m), and a maximum depth of 320 feet (98 meters) (Dlugokenski et al. 1981). The average water surface elevation of the lake is 34 feet above mean sea level (10.4 meters; National Geodetic Vertical Datum of 1929 [NGVD 1929]). Extreme low and high water surface elevations of the lake range from 30.8 feet (9.4 m) to 41.5 feet (12.6 m) above mean sea level.

The Ozette River drains the lake from its north end, and there are no other outlet streams. The river travels approximately 5.3 miles (8.5 km) along a sinuous course to the Pacific Ocean. The total drainage area of the Ozette watershed at the confluence with the Pacific Ocean is 88.4 mi^2 (229 km^2). Coal Creek, which enters just downstream from the lake's outlet, is the largest tributary to the Ozette River. Several significant tributaries drain into Lake Ozette. The largest are Umbrella Creek, Big River, Crooked Creek, Siwash Creek, and South Creek (Table 1.1). Several smaller streams also feed the lake and include: Palmquist, Quinn, Elk, and Lost Net Creek, as well as several other unnamed streams.

Table 1.1. Lake Ozette and tributary drainage basin areas.

Watershed/Subbasin	Watershed/Subbasin Description	Basin Area (sq. mi.)	Basin Area (sq. km.)
Palmquist Creek	Entire Palmquist Creek Watershed	1.1	2.8
Umbrella Creek	Entire Umbrella Creek Watershed	10.6	27.6
Big River	Entire Big River Watershed	22.8	59.0
Lake Ozette Tributary	Unnamed Trib. between Crooked and Dunham Creeks	0.9	2.3
Crooked Creek	Entire Crooked Creek Watershed	12.2	31.6
Lake Ozette Tributary	Unnamed Tributary between Crooked and Quinn	0.7	1.7
Quinn Creek	Entire Quinn Creek Watershed	0.9	2.3
Unnamed Tributary 20.0073	Entire 20.0073 Watershed	0.4	0.9
Elk Creek	Entire Elk Creek Watershed	0.3	0.8
Siwash Creek	Entire Siwash Creek Watershed	2.9	7.4
Lake Ozette Tributary	Unnamed Tributary between Siwash and South Creeks	0.5	1.2
South Creek	Entire South Creek Watershed	3.3	8.4
Lake Ozette Watershed	**Entire Lake Ozette Watershed**	**77**	**199**
Coal Creek	Entire Coal Creek Watershed	4.6	11.8
Ozette River at Pacific Ocean	**Entire Lake Ozette and Ozette River Watershed**	**88.4**	**229**

1.3.1 Watershed Geology

The geology of the Ozette watershed (Figure 1.3) is an interesting mix of flat and gently sloping glacial and glacio-fluvial deposits situated between resistant knobs and small hills composed of Tertiary marine sedimentary rock units (mechanically weak silt- and sand-stones). Some glacial landforms extend for several square miles while others only occupy small valleys. Much of the land within the watershed is low-relief and contains numerous swamps, bogs, and wetlands. Other portions of the watershed (e.g. upper Big River) are steep and rugged and are underlain by Eocene age volcanic flows and breccias.

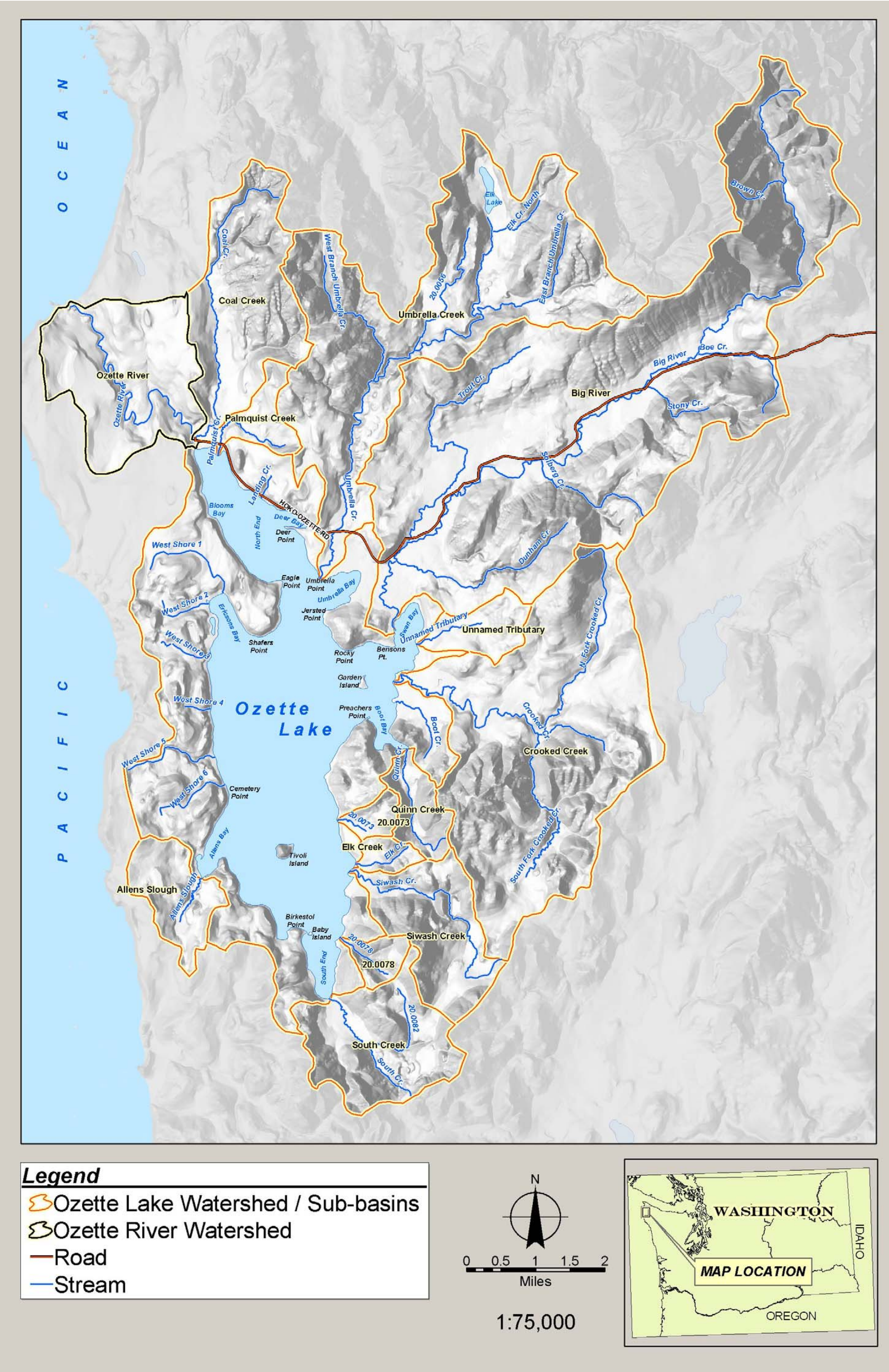

Figure 1.1. Lake Ozette watershed overview map (source: original hydrography from DNR Hydro GIS layer).

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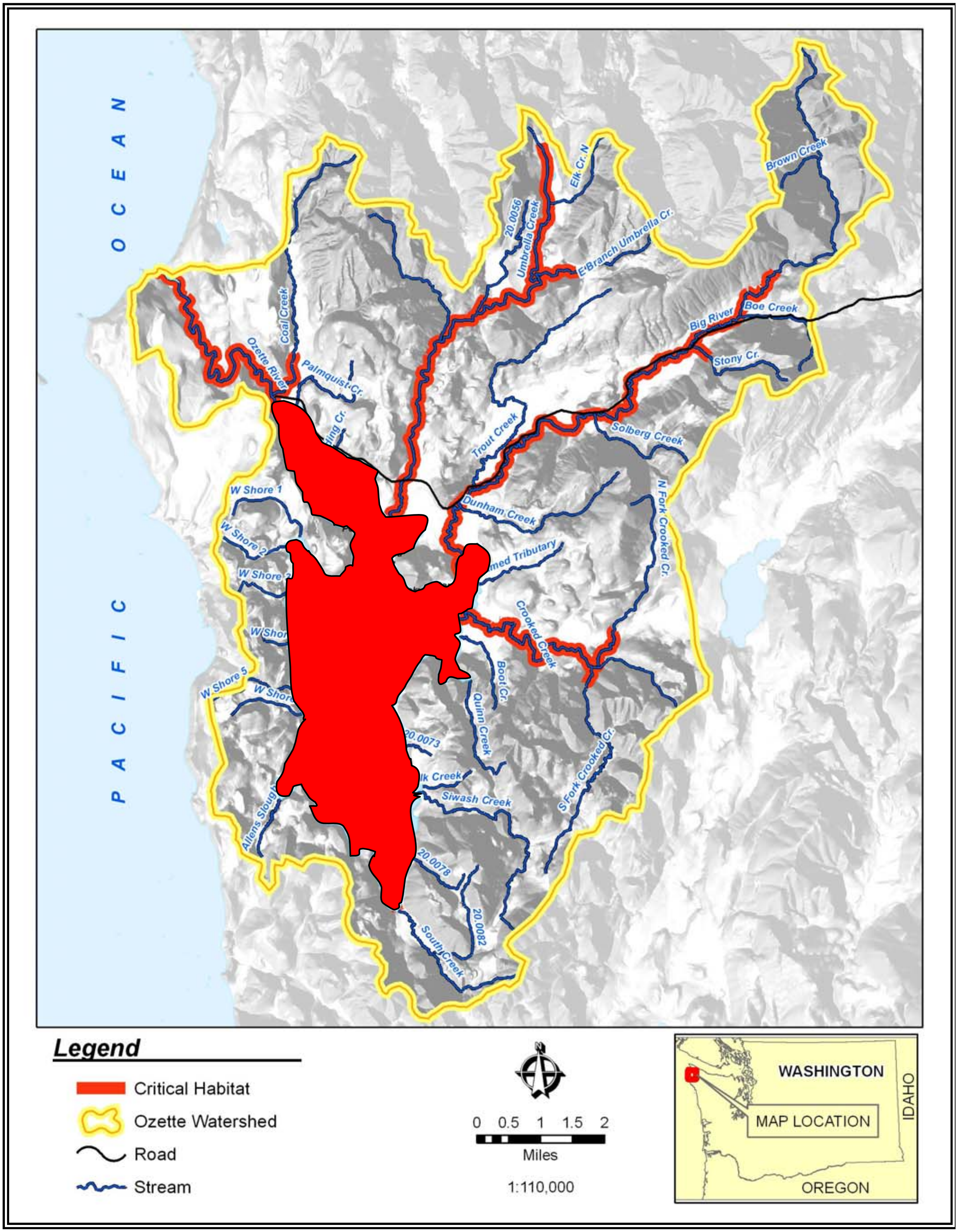

Figure 1.2. Designated critical habitat for Lake Ozette sockeye salmon. Note: the entire lake is designated critical habitat. (source data: 70 FR 52630).

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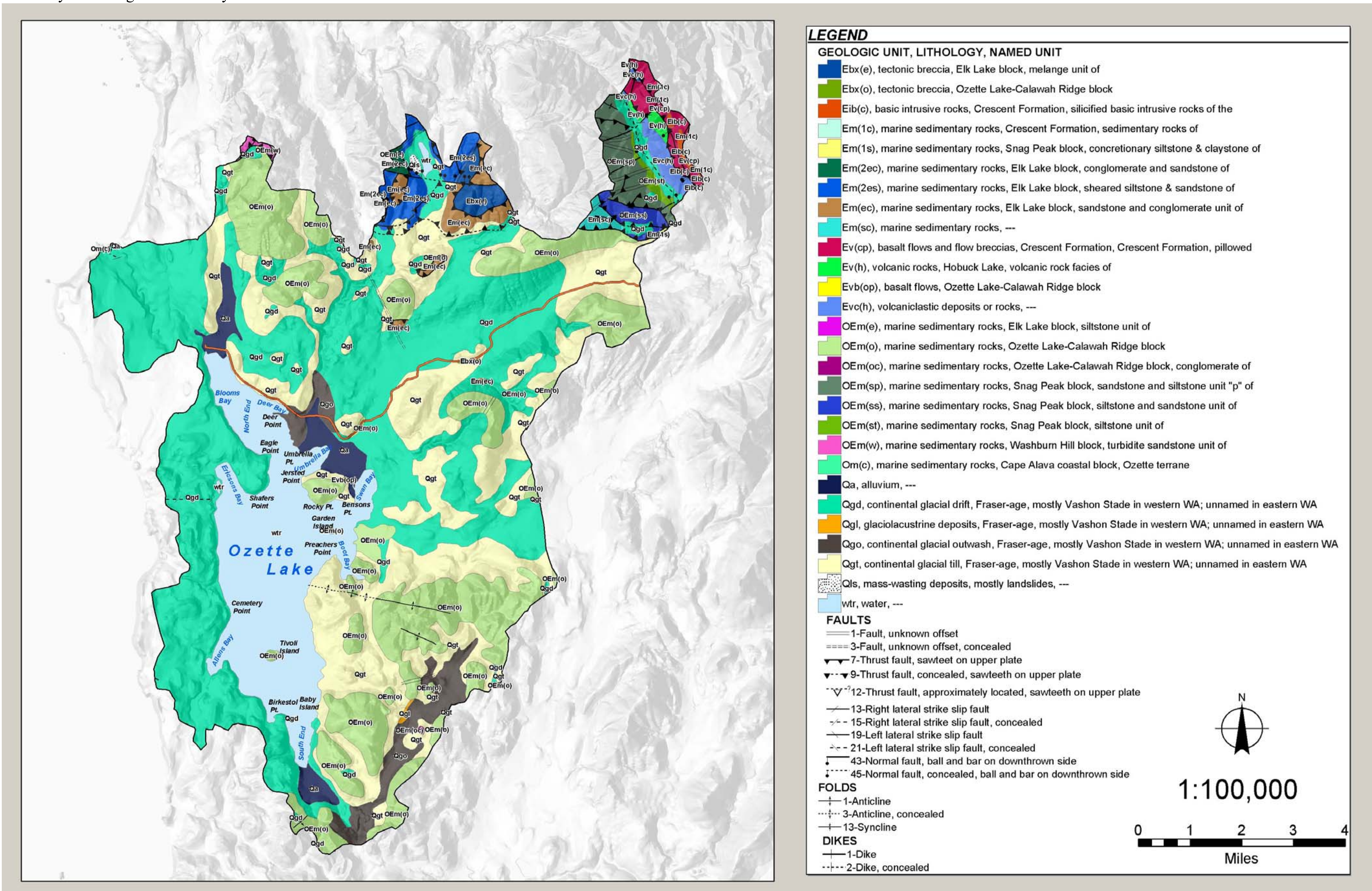

Figure 1.3. Ozette watershed geology (source: Schasse2003)

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1.3.2 Climate

The climate of the northwest Olympic Peninsula can be characterized as temperate coastal-marine, with mild winters and cool summers. The closest climate station to Lake Ozette is located at the Quillayute State Airport, approximately 12 miles to the south from the center of Lake Ozette (ranging from 6 to 22 miles from various points in the watershed). No long-term weather stations are located in the Ozette watershed (a new weather station was recently installed at the Ozette Ranger Station). The Quillayute climate station is the most representative of long-term conditions in the Ozette watershed, as compared to stations in Neah Bay, Tatoosh Island, or Forks. Most researchers (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; Jacobs et al. 1996) have used Quillayute, Washington climate data when describing Ozette climate patterns.

The following text was directly taken from the station description of the National Weather Service (NWS) climate station at the Quillayute State Airport (NOAA-National Climate Data Center [NCDC] 2005).

"Maritime air from over the Pacific has an influence on the climate [at Lake Ozette] throughout the year. In the late fall and winter, the low pressure center in the Gulf of Alaska intensifies and is of major importance in controlling weather systems entering the Pacific Northwest. At this season of the year, storm systems crossing the Pacific follow a more southerly path striking the coast at frequent intervals. The prevailing flow of air is from the southwest and west. Air reaching this area is moist and near the temperature of the ocean water along the coast which ranges from 45 degrees in February to 57 degrees in August. The wet season begins in September or October. From October through January, rain may be expected on about 26 days per month, from February through March, on 20 days, from April to June, on l5 days, and from July to September, on l0 days.

As the weather systems move inland, rainfall is usually of moderate intensity and continuous, rather than heavy downpours for brief periods. Gale force winds are not unusual. Most of the winter precipitation over the coastal plains falls as rain, however, snow can be expected each year [especially in the foothills surrounding Lake Ozette]. Snow seldom reaches depths in excess of l0 inches or remains on the ground longer than two weeks. Annual precipitation increases from approximately 90 inches near the coast, to amounts in excess of l20 inches over the coastal plains [and foothills surrounding Lake Ozette]. During the rainy season, temperatures show little diurnal or day-to-day change. Maximums are in the 40s and minimums in the mid-30s. A few brief outbreaks of cold air from the interior of Canada can be expected each winter. Clear, dry, cold weather generally prevails during periods of easterly winds. In the late spring and summer, a clockwise circulation of air around the large high pressure center over the north Pacific brings a prevailing northwesterly and westerly flow of cool, comparatively dry, stable air into the northwest Olympic Peninsula.

The dry season begins in May with the driest period between mid-July and mid-August. The total rainfall for July is less than .5 inch in one summer out of ten. It also exceeds 5 inches in one summer out of ten. During the warmest months, afternoon temperatures are in the upper 60s and lower 70s, reaching the upper 70s and the lower 80s on a few days. Occasionally, hot, dry air from the east of the Cascade Mountains, [funneled through the straits of Juan de Fuca], reaches this area and temperatures are in the mid- or upper-90s for one to three days. In summer and *early fall, fog or low clouds form over the ocean and frequently move inland at night, but generally disappear by midday [inland, but often persist throughout the day within a mile or three from the coast]. In winter, under the influence of a surface high pressure system, centered off the coast, fog, low clouds, and drizzle are a daily occurrence as long as this type of pressure continues."*

Average annual precipitation (by Water Year [WY]; October-September) at the Quillayute State Airport was 102.6 inches (260 cm) between 1967 and 2005, and ranged between 72.2 inches and 139.9 inches (183.4 and 355.3 cm; Figure 1.4). The bulk of this precipitation fell between October and April each year (i.e., the wet season) between 1967 and 2005, averaging 84 inches (231.4 cm) and ranging from 52.6 to 120 inches (133.6 to 304.8 cm; Figure 1.4). Summer precipitation (May – September; i.e., the dry season) during the same period averaged 18.1 inches (46 cm), ranging from 7.5 to 33.2 inches (19.1 to 84.3 cm; Figure 1.4). Average monthly precipitation ranges from a maximum of 29.1 inches (73.9 cm) in November to 2.2 inches (5.6 cm) in July (Figure 1.5). For the period of record at Quillayute on an annual basis, there are 209 days of the year with greater than 0.01 inches of precipitation, 148 days greater than 0.10 precipitation, 70 days greater than 0.50 precipitation, and 30 days with precipitation greater than 1.0 inches (0.03, 0.3, 1.3, and 2.5 cm).

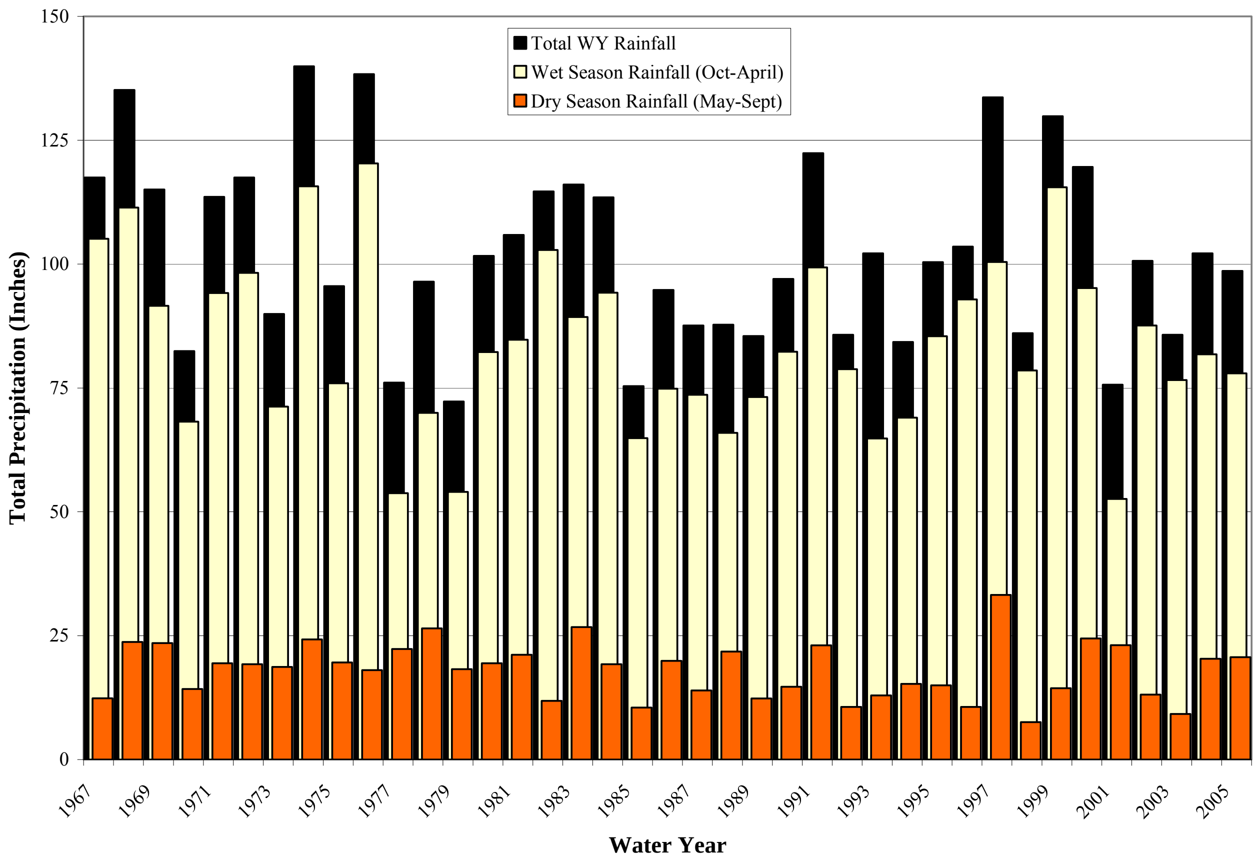

Figure 1.4. Total wet season, dry season, and annual precipitation by water year for Quillayute Airport weather station WY 1967 to WY 2005 (source: NOAA-NCDC 2005).

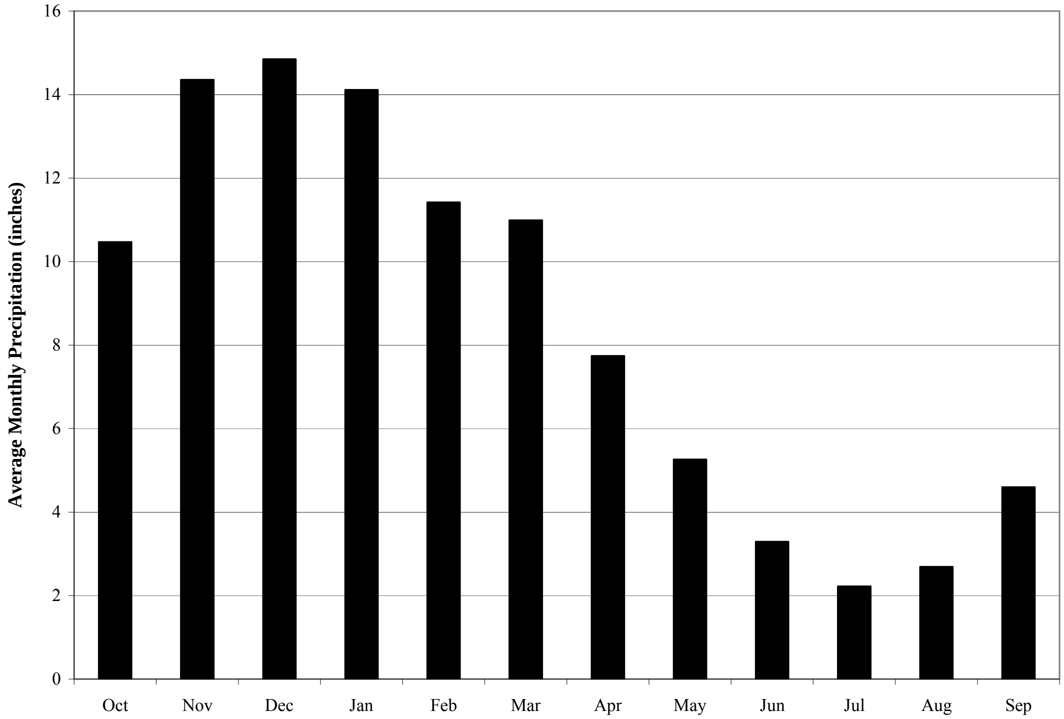

Figure 1.5. Average monthly precipitation for Quillayute Airport weather station WY 1967 to WY 2005 (source: NOAA-NCDC 2005)

While the data from the Quillayute State Airport are reliable and generally representative of the Lake Ozette watershed 12 miles (19.3 km) to the north, they do not define the existing north to south, west to east and elevational gradients of climate and precipitation on the northwest end of the Olympic Peninsula, and thus the high spatial heterogeneity of precipitation at the instantaneous to annual time steps. To shed some light on this heterogeneity, modeled precipitation data were acquired from the Spatial Climate Analysis Service (SCAS) at Oregon State University for the period 1967 to 2004. The PRISM (the Parameter-elevation Regressions on Independent Slopes Model) model was used to estimate annual precipitation (note: January to December) at various points in the Ozette watershed. This model uses point data, a digital elevation model, and other spatial data sets (including expert knowledge of rain shadows, temperature inversions, coastal effects, etc.) to generate gridded (4km) estimates of precipitation.

These data suggest that average annual precipitation at the Quillayute Airport is generally similar to low elevation points around the Lake Ozette watershed, such as the Ozette Ranger Station at the north end of Lake Ozette (Table 1.2 and Figure 1.6). However, annual precipitation gradually increases toward the east from Lake Ozette (e.g., Ozette Ranger Station to Coal Creek to Umbrella Creek to Big River at Royal), which is partially a result of elevational increases and orographic effects. Sharp increases in precipitation exist where large elevational gradients occur, such as in the headwaters of Big River above 1000 feet, where average precipitation is greater than 120 inches (Table 1.2 and Figure 1.6).

Table 1.2. PRISM modeled precipitation for various locations in the Ozette watershed for the period of 1967 through 2004.

ANNUAL PRECIPITATION 1967 TO 2004					
	Quil. Recorded	Quil. Modeled	South Creek	Siwash Creek	Crooked Creek
Elevation (feet)	192	192	80	200	120
Annual Avg (inches)	102.7	104.3	102.7	112.4	111.7
Annual Min (inches)	72.2	62.1	60.3	65.8	66.3
Annual Max (inches)	139.9	136.1	134.8	141.4	144.9
	Ranger Station	Coal Creek	Umbrella Crk.	Big at Royal	Big at Sekiu Mt.
Elevation (feet)	40	200	400	143	1788
Annual Avg (inches)	100.6	103.7	106.4	107.8	129.2
Annual Min (inches)	59.7	61.1	61.6	62.8	77.8
Annual Max (inches)	135.1	142.7	142.0	145.3	158.0

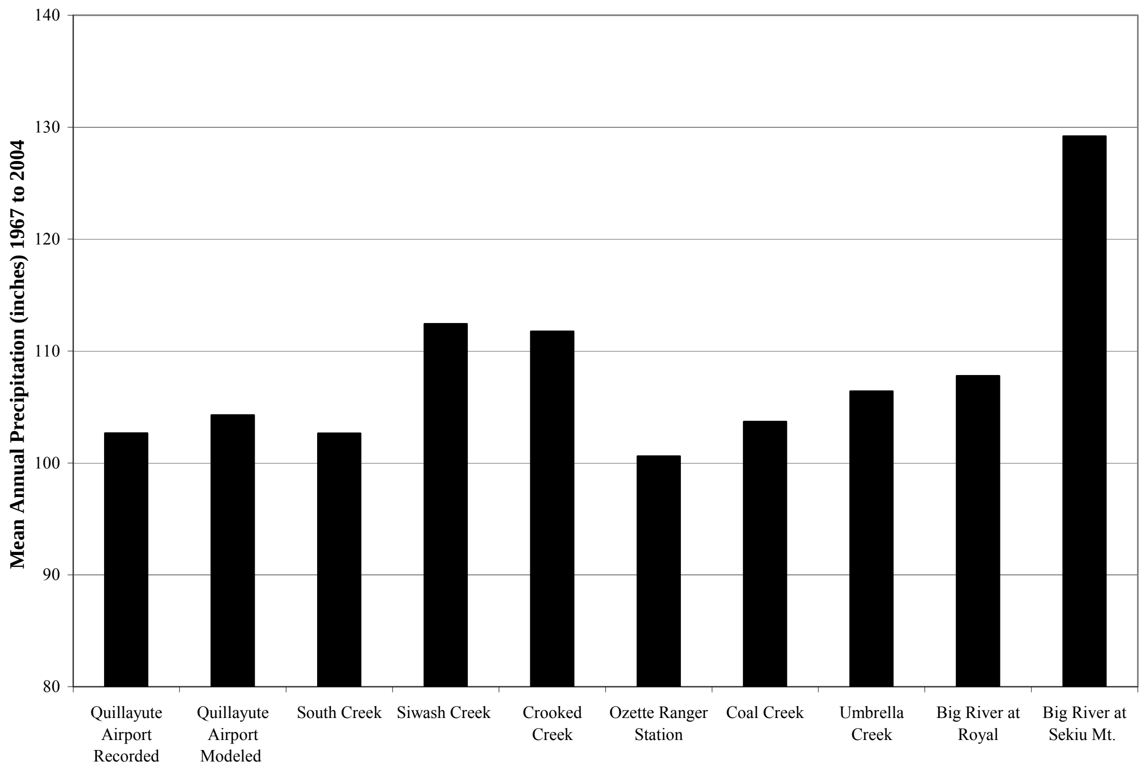

Figure 1.6. PRISM modeled mean annual precipitation (January through December) for various locations in the Ozette watershed for the period of 1967 through 2004.

Only one reliable precipitation data set inside the Lake Ozette watershed helps test the accuracy of these PRISM data. The National Park Service installed a continuous weather station at the Ozette Ranger Station in September 2003, which continuously records precipitation and records temperature, humidity, and solar radiation at the hourly time interval. This station allows for the direct comparison of annual precipitation for the two stations (Quillayute and Ozette) during Water Years (WY) 2004 and 2005. The annual precipitation total at Quillayute for WY 2004 was 102.15, while at Ozette the annual total was 89.54, a difference of 12.61 inches. For WY 2005, the annual precipitation total at

Quillayute was 98.61, while at Ozette was 91.68, a difference of 6.93 inches. Therefore, for at least these two water years, annual precipitation at Quillayute would over estimate precipitation at the Ozette Ranger Station. Modeled PRISM data indicates that on average Quillayute receives 2.1 more inches annually than Ozette Ranger Station.

At the regional scale, these annual data at Quillayute and Ozette initially suggest the presence of a south to north gradient in annual precipitation. However, rainfall data from Neah Bay 2E (average annual rainfall = 104.34 inches, 1948 to 1987) and the Quillayute Airport (average annual rainfall = 101.80 inches, 1966 to 2005) indicate that there is not a strong south to north gradient in annual or monthly precipitation. Differences in precipitation totals between Quillayute and Ozette were also present at monthly time scale over 2004 and 2005. Monthly total precipitation at Quillayute was generally higher than at Ozette, but exceptions did occur, especially during wet months (Figure 1.7). These data indicate that overall, Quillayute might receive slightly more precipitation than the Ozette Ranger Station, but that depending on differing weather patterns, storm tracks and physiographic positions, spatial variability in precipitation may be high enough to restrict development of consistent relationships without significant additional data.

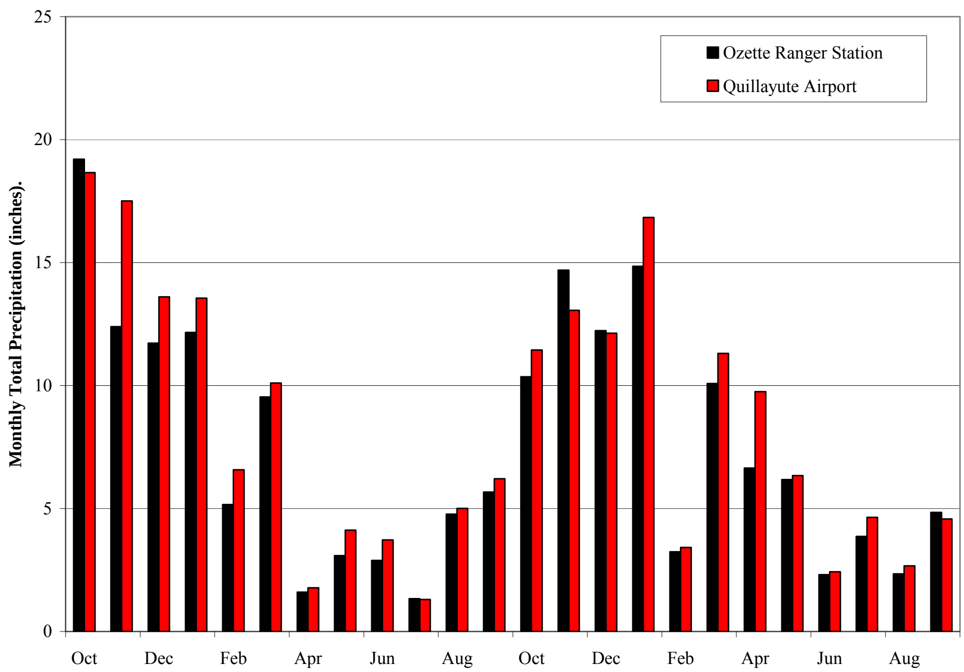

Figure 1.7. Monthly rainfall comparison, Quillayute versus Ozette for WY 2004 and 2005 (source: NOAA-NCDC 2005; ONP, unpublished data).

Regardless of specific comparisons that can be made between existing data in the region, there is obviously a lack of site-specific rainfall or climate data within the Lake Ozette watershed. While there are general trends that hold true for the region, such as similar patterns of monthly precipitation distribution, moderate variations in precipitation depths and intensities undoubtedly occur at the hourly and daily time scales on up to annual precipitation totals. This is especially true when factoring orographic effects on precipitation totals and intensity, wind effects on precipitation actually reaching the ground surface, and the effects of distance to coast and forest condition on moisture retention and fog drip. Due to the watershed's proximity to the coast, fog drip is likely a significant, but locally unquantified, contributor to overall ground surface precipitation. Vegetation cover and land use can significantly influence the magnitude of the fog drip component of the water cycle. The recently installed continuous weather station at the Ozette Ranger Station allows for a more local view of the weather parameters that may influence climate, local water balances, and lake levels, especially during the summer months. Figure 1.8 displays air temperature, relative humidity and shortwave radiation data for the summer 2004. Distinct diurnal patterns exist with temperature directly corresponding to radiation at the ground surface and humidity inversely relating to radiation level. On clear summer days, shortwave radiation is high, resulting in high day time temperatures near the ground and low relative humidity. Evaporation from Lake Ozette is presumed to be very high during these daytime conditions.

Following these clear summer days, summer nights bring lower temperatures and increased relative humidity, often as the marine layer and fog temporarily move inland. By the next day, often the fog burns off and the marine layer pushes back offshore. However, during other days, the marine layer fails to move off shore, which is often the case when temperatures are very hot inland pulling the cooler air in to replace hot rising air. During these foggy days, daytime temperatures are moderated by reduced shortwave radiation penetrating the low cloud surface and reaching the ground surface. Moderate temperatures and high humidity on these foggy days results in reduced potential for evaporation from Lake Ozette. Each summer at Lake Ozette varies in the degree that the coastal marine layer dominates local weather conditions over the lake. It is hypothesized that during typical summers with periodic precipitation events (Figure 1.4), moderately warm inland temperatures, and a general easterly flow of wind and pacific moisture (fog), evaporation from Lake Ozette is moderated by fog and periodic precipitation and runoff maintain the lake level at or above average summer lake levels. During drier summers dominated by more frequent winds from the east and northeast (westerly) and reduced precipitation, evaporation from Lake Ozette is enhanced and lake levels are not moderated by periodic precipitation and runoff, such as occurred during 2002 and 2003.

During a majority of the year at Quillayute (and Lake Ozette), but especially during the wet season, "*the prevailing flow of air is from the southwest and west. In the late spring and summer, a clockwise circulation of air around the large high pressure center over the north Pacific brings a prevailing northwesterly and westerly flow of cool, comparatively dry, stable air into the northwest Olympic Peninsula. Occasionally, hot, dry air from the east of the Cascade Mountains, [funneled through the Strait of Juan de Fuca], reaches this area*" (National Oceanic and Atmospheric Administration, National Climate Data Center 2005). Figure 1.9 displays a polar plot of average daily wind speed and <u>source</u> direction at the Quillayute Airport for the period 1966 to 2003. This wind rose indicates the percent of time the wind blew <u>from</u> a given direction over a range of wind velocities. The graph displays the overall general trend of wind and air flow from the west and southwest, with a counter trend of wind from the northeast, predominantly during periods of east/southeast wind through the Strait of Juan de Fuca. 41% of the time the average wind speed was calm between 1966 to 2003. Note units are in knots.

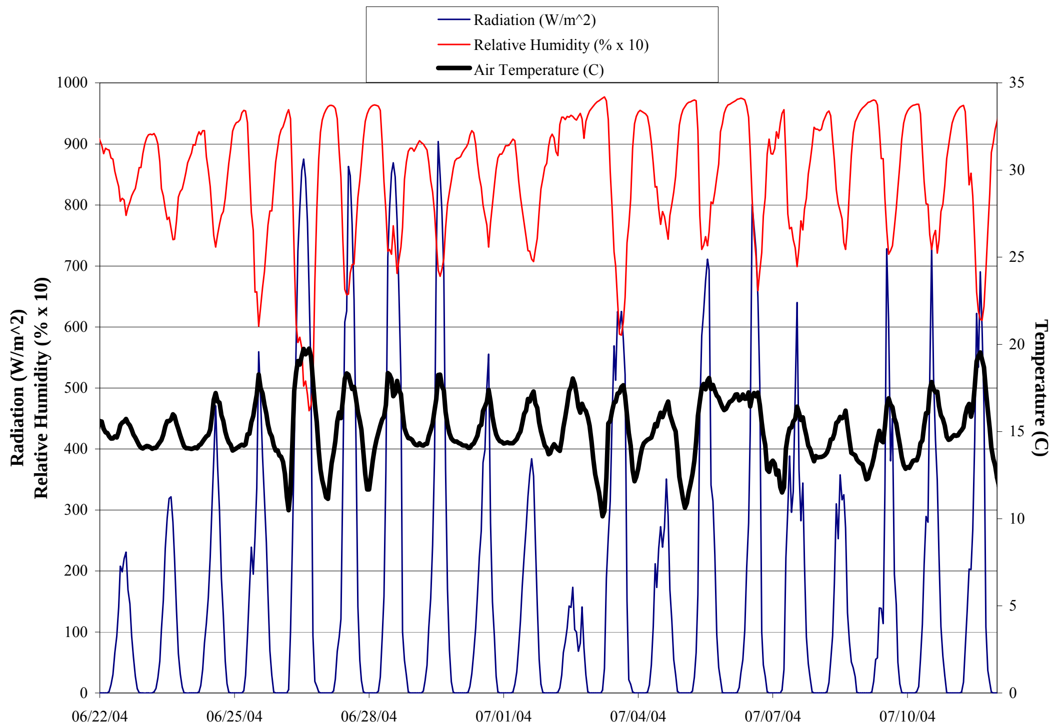

Figure 1.8. Ozette Ranger Station weather data for the early summer, 2004 (source: ONP, unpublished data).

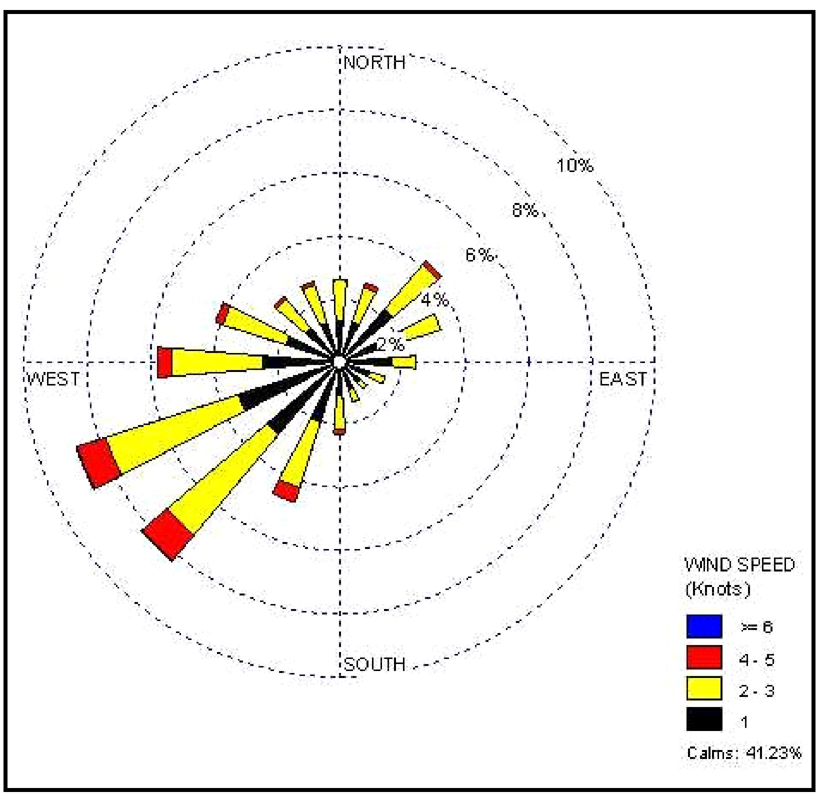

Figure 1.9. Rose plot of daily average wind speed and <u>source</u> wind direction at the Quillayute Airport 1966 to 2003 (adapted from Herrera 2005).

1.4 LAKE OZETTE ECOLOGICAL SETTING

Lake Ozette is a monomictic, mesotrophic lake, and is thermally stratified from April/May through October (Beauchamp and LaRiviere 1993). Summer time epilimnetic temperatures average 21°C. Dissolved oxygen levels remain greater than 8 mg/L above 70 m but were found to drop to approximately 4 mg/L at a depth of 80 m in September (Beauchamp and LaRiviere 1993; Bortleson and Dion 1979). The following is a summary of Meyer and Brenkman (2001) findings:

- pH levels ranged from 6.7 to 7.7
- Specific conductivity was relatively low and uniform throughout the water column
- Turbidity levels within the lake vary significantly depending upon time of year, sample location, and depth
- The highest chlorophyll concentrations are near the lake surface
- The lake's zooplankton community is comprised of nine crustacean and 15 rotifer taxa with the highest densities occurring in July

Meyer and Brenkman (2001) concluded that the water chemistry, nutrients, and zooplankton densities were within ranges documented for other sockeye lakes in Washington, British Columbia, and Alaska. Shoreline vegetation was surveyed in 1993 and 1994 and included approximately 24 plant taxa.

The Lake Ozette fish community includes a rich array of approximately 26 species of fishes presumed to be present (see Chapter 2). There are seven "species" of salmonids present in the lake system including: sockeye salmon (*Oncorhynchus nerka*), kokanee salmon (*Oncorhynchus nerka kennerlyi*), coho salmon (*Oncorhynchus kisutch*), chum salmon (*Oncorhynchus keta*), Chinook salmon (*Oncorhynchus tshawytscha*), rainbow/steelhead trout (*Oncorhynchus mykiss*), and cutthroat trout (*Oncorhynchus clarki*). Approximately 18 non-salmonid fish species are also thought or known to be present within the Lake Ozette watershed and they include the following: speckled dace (*Rhinichthys osculus*), coastrange sculpin (*Cottus aleuticus*), prickly sculpin (*Cottus asper*), reticulate sculpin (*Cottus perplexus*), riffle sculpin (*Cottus gulosus*), torrent sculpin (*Cottus rhotheus*), brook lamprey (*Lampetra richardsoni*), pacific lamprey (*Lampetra tridentata*), three-spine stickleback (*Gasterosteus aculeatus*), Olympic mudminnow (*Novumbra hubbsi*), peamouth (*Mylocheilus caurinus*), Tui chub[1] (*Gila bicolor*), northern pikeminnow (*Ptychocheilus oregonensis*), redside shiner (*Richardsonius balteatus*), American shad[2] (*Alosa sapidissma*), yellow perch[3] (*Perca

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[1] Tui chub have been documented but no specimen samples have been collected; presumed present and introduced.

[2] Introduced species: American shad were not directly introduced into the Lake Ozette watershed. American shad were introduced into the Sacramento River system in 1871 and since that time their range has expanded north and they have recently been found in the Ozette watershed; although their numbers currently remain low.

[3] Introduced species: both yellow perch and largemouth bass were introduced to Lake Ozette in the 1920s

flavenscens), largemouth bass[3] (*Micropterus salmoides*), yellow bullhead[4] (*Ictalurus natalis*), and brown bullhead (*Ictalurus nebulosus*)[5] (MFM 2000; Gustafson 1997; Mongillo and Hallock 1997; Jacobs et al. 1996; MFM unpublished fish captures). Several other species of fish use the estuarine portion of the lower Ozette River and likely include sturgeon (*Acipenser spp.*), marine cottids, marine flatfish, and surf smelt (*Hypomesus pretiosus*).

The Lake Ozette watershed is predominantly forested. Lake Ozette and Elk Lake are the largest unforested areas within the watershed. Other unforested areas also occur where bogs and open water wetlands naturally exist. The forest contained within the Ozette watershed can be characterized as a coastal temperate rainforest ecosystem. Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*), are the dominant conifer species, followed by western redcedar (*Calocedrus decurrens*) pacific silver fir (*Abies amabilis*), Douglas fir (*Psuedotsuga mensiezii*), and western yew (*Taxus brevifolia*). Red alder (*Alnus rubra*) is the most prevalent deciduous tree, and is common along streams and disturbed sites. Vine maple (*Acer circinatum*) and bigleaf maple (*Acer macrophylla*) are also common in riparian areas, wetlands, and meadows. Schoonmaker et al. (1997) define this section of the Pacific coastal temperate rainforest as seasonal temperate rainforest, as compared to warm temperate rainforest to the south and perhumid temperate rainforest and sub-polar temperate rain forest zones to the north. It has been classified as seasonal due to less than 10% of the total rainfall occurring during summer months.

Understory vegetation in mature temperate rainforests is complex. In the Ozette watershed there are approximately 363 vascular plant species (Buckingham et al. 1995). Fungi and lichen are ubiquitous in areas of primary forest. They compose a significant fraction of the forest biomass and play an important role in nutrient cycling within the forest ecosystem. The lake and watershed contain a diverse assemblage of terrestrial and aquatic mammals, birds, and amphibians.

1.5 WATERSHED DISTURBANCE AND LAND USE

Natural disturbance in the Ozette watershed is primarily driven by winter storms. Wind and geomorphic events are considered the primary disturbance agents in coastal temperature rainforests (Alaback 1996). The size and age of the long-lived trees present when Europeans first began to settle the area is a testament to the pre-settlement disturbance regime in the watershed. Forest fires were infrequent, and mature spruce and cedar trees easily achieved ages of 400 years and older. Strong winter storms are common on the Pacific coast, and are the primary natural disturbance mechanism in coastal areas, frequently causing windthrow and toppling shallow-rooted trees (Alaback 1996). The “21 Blow” of January 29, 1921 toppled more than 8 billion board feet of

[4] Included in the ONP non-native fish species database, their presence has not been reconfirmed since their original observation by ONP in 1992.
[5] First documented individual captured in the Ozette River on June 1, 2001, brown bullhead are assumed to have been introduced but no documentation of the date or nature of releases has been found.

timber. In addition, large magnitude (~magnitude 9) great earthquakes have been shown to recur at a 400-600 year frequency along this region of the Pacific Coast (Atwater and Hemphill-Haley 1997).

Prior to European settlement, the area around Lake Ozette was occupied by Native Americans for thousands of years. The population of the Ozette Village, near the mouth of the Ozette River, decreased when natives were forced to move to Neah Bay so that their children could attend school in 1896 (Wray 1997). By 1914 there were only 17 natives remaining at Ozette and by 1932 there were only two (Wray 1997). Several prairies west of Lake Ozette were regularly burned by Native Americans to maintain open areas that attracted and fed game such as deer and elk. Swan (1869), who may have been the first white man to see Lake Ozette, describes journeying to the lake by trail with a group of natives from the Ozette village. In interviews in 1935 (Swindell 1941), Makah fishermen described fishing in the Ozette River, the lake, and the tributaries, using a variety of methods. Native American people undoubtedly affected their environment. However there is no evidence to indicate that significant anthropogenic watershed disturbance took place prior to European settlement.

Modern disturbance in the Ozette watershed is primarily driven by timber harvest, road construction and maintenance, residential and agricultural development, and stream clearing, including "stream improvement" projects and policies implemented by WDF and later WDNR.

1.5.1 Landownership

Each land parcel's ownership in the Ozette watershed can be classified into one of the following categories: industrial forest, Washington Department of Natural Resources (WDNR), National Park Service (NPS), Ozette Reservation, Clallam County, small private (small forest, residential, and agriculture land owners), or undefined (no data or multiple landowners). Figure 1.10 depicts land ownership categories for the Lake Ozette watershed. Private lands including industrial forest and small private ownership types comprise about 74% of the basin. The NPS owns 15% of the basin, WDNR owns 10%, and the Makah Tribe owns about 1%. Clallam county and undefined land ownership comprises less than 1% of the watershed. Over 81% of the watershed's land surface is zoned as commercial forest land.

Private timber companies and small private landowners own an average of 90% of the four largest tributaries to Lake Ozette and the Ozette River (Big River, Crooked Creek, Umbrella Creek, and Coal Creek). Ownership patterns vary between the four largest tributaries. Table 1.3 depicts the land ownership categories within the four largest Ozette watershed sub-basins. Private land ownership within the Coal Creek, Umbrella Creek, Big River, and Crooked Creek sub-basins comprises 92%, 93%, 92%, and 82% of the land area respectively. With the exception of Big River, zoning within these four sub-basins is 99 to 100% commercial forest.

Table 1.3. Land ownership types as a percentage of watershed area for the four largest Lake Ozette watershed sub-basins.

Sub-Basin	Clallam County	WDNR	Federal	Industrial Forest	Small Private	Undefined
Coal Creek	0.2%	6.3%	1.5%	91.8%	0.2%	0.0%
Umbrella Creek	0.3%	6.3%	0.2%	93.2%	0.1%	0.1%
Big River	0.2%	6.6%	0.3%	82.4%	9.7%	0.7%
Crooked Creek	0.0%	18.0%	0.2%	80.8%	1.0%	0.0%
TOTAL	**0.2%**	**9.1%**	**0.4%**	**85.3%**	**4.7%**	**0.3%**

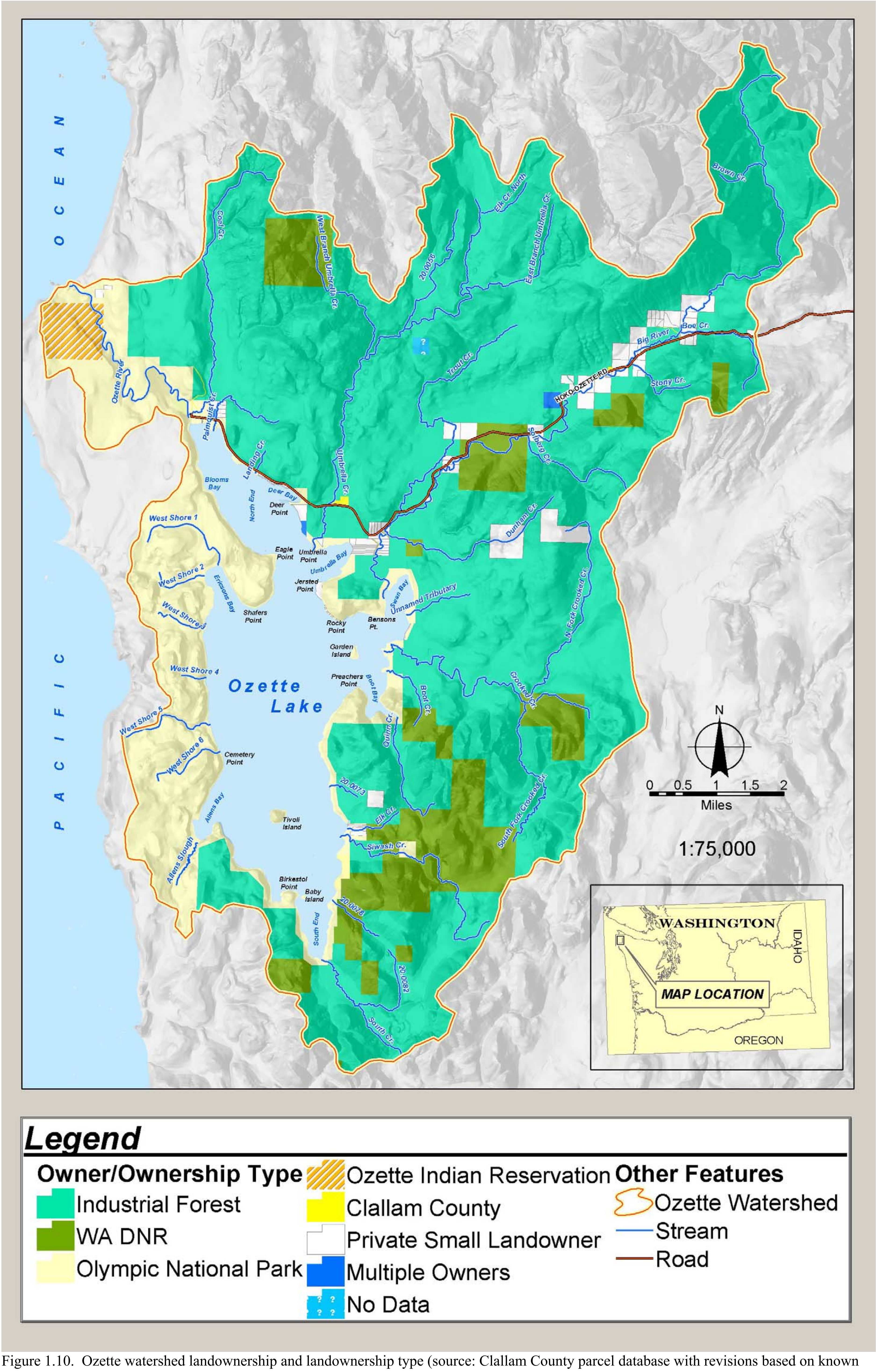

Figure 1.10. Ozette watershed landownership and landownership type (source: Clallam County parcel database with revisions based on known errors).

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1.5.2 Settlement and Agricultural Development

The Lake Ozette watershed was ceded to the United States in the Treaty of Neah Bay (1855) and the Treaty of Olympia (1856). European settlement in the Ozette watershed began soon after the Treaty was signed. The Ozette area was opened to homesteading from 1890 to 1897. By 1892, 33 families occupied homesteads in the area (Jacobs et al. 1996). In 1893, the Ozette Reservation was established by Congress to protect the rights of 64 Makah villagers living there (Wray 1997).

Settlement was concentrated along the shoreline of the lake and the gentle bottomlands of lower Big River, which was the primary route to civilization. Government Land Office (GLO) surveys conducted from 1892 to 1897 showed 39 homesteads along the lake and 29 additional homestead sites scattered throughout the watershed. Settlers cleared timber around their homes, and a wagon trail extended from Ozette to Clallam Bay. Settlement peaked near the turn of the century and declined after the creation of the Olympic Forest Reserve by President Cleveland in 1897. This caused an exodus of settlers, who had hoped for a road to bring development. By the time the land was reopened to settlement in 1907, timber companies rapidly consolidated their holdings, and very little additional settlement occurred. Big River has continued to slowly develop, while the lake shoreline has returned to forest, with the exception of a few parcels of private property within the boundaries of ONP. While the GLO maps at the turn of the century show 39 buildings around the lake, the 1935 USGS map shows only 10. Subsequent USGS maps show 11 buildings in 1956 and 21 in 1987.

In 1953, a portion of the Pacific coast (including the western shore of Lake Ozette) was transferred to the National Park Service (Truman 1953, Presidential Proclamation). The lake and a thin strip along the eastern shoreline were added to Olympic National Park in 1976 (PL 94-578). Currently, the most developed portion of the shoreline of Lake Ozette is the area immediately surrounding the lake outlet. In addition to the ONP ranger facilities at the lake's outlet, there are 15 cabins/homes on lakefront parcels surrounding the lake. Starting in 1942, the area from the mouth of Coal Creek south to the current ONP campground was occupied by the U.S. Coast Guard, which performed beach patrols along the coastline. This area was developed into a resort in the 1950s, and was redeveloped into the ONP Ozette visitor center, ranger station, campground, and parking area in the 1980s. In addition to development at the lake outlet, there are two other vehicle access points to the lake at Swan Bay and Rayonier Landing, along the east side of the North End. Other developed private properties within the boundaries of ONP are reachable by boat or trail. The developed length of shoreline comprises approximately 1-2% of the total shoreline length.

Along Big River, agricultural and residential development have been confined to the lower 10 miles of the river. Most residential development along Big River is near the original wagon trail, which is now the only public road to Lake Ozette. GLO maps showed 8 developed homesteads along Big River in 1897. The 1935 USGS map shows

13 settlements, with 32 homes and other buildings, and about 288 acres of cleared land (~2% of watershed area). The 1956 USGS map shows 12 settlements with 19 homes and other buildings, and 483 acres of cleared land (~3.3% of watershed area). The 1987 USGS map shows 34 homes or other buildings and 176 acres of cleared land (~1.2% of watershed area). Currently, about 245 acres of land (~1.7% of the watershed area) are cleared for residential or agricultural use, and there are approximately 62 houses and other buildings within the Big River valley. (Based on 2006 ortho photos, 42 tax parcels contain at least a home, building, or other improvement.) In agricultural areas, the riparian area and floodplain of the river were cleared of vegetation and converted to pasture. Currently, approximately 9,900 feet of Big River are adjacent to developed residential or agricultural land. Bank destabilization through these reaches has led to attempts to armor the river with automobiles, riprap, and wood, and in at least one location, an old side channel of the river has been filled in to create additional pasture (Emil Person, personal communication, verified with USGS maps and aerial photos).

1.5.3 Commercial Timber Harvest

Commercial timber harvest in the Ozette watershed began in the 1930s (Jacobs et al. 1996). Table 1.4, below, summarizes the percent of the watershed harvested, as reported in Herrera (2005) and Good et al. (2005). Values from Herrera have been adjusted to include the Ozette River and Coal Creek as part of the Ozette basin.

Table 1.4. Reported percent of Ozette basin clear-cut at least once since 1953 (source: Jacobs et al. 1996; Herrera 2006).

YEAR	1953	1964	1981	2003
Percent of basin logged	8.7%[1]	22.2%[2]	60%[1]	83.6%[2]

[1] It is not clear whether this calculation included the lake surface area in the basin area (Meier 1998).
[2] This calculation does not include lake surface in basin area calculations (Herrera 2005).

As part of this limiting factors analysis, a thorough review of aerial photos through time was conducted to accurately depict the logging history of the Ozette watershed, as well as major sub-basins within the watershed. Figure 1.11 depicts the percentage of old growth forest clear-cut through time for the Ozette watershed, as well as the Umbrella Creek, Big River, and Crooked Creek sub-basins. An additional analysis was conducted to determine the cumulative percentage of the forested watershed area where second growth forest has been clear-cut. As of 2006, within the Umbrella Creek, Big River, and Crooked Creek sub-basins, approximately 11.8%, 18.2%, and 11.2% of the second growth forests had been clear-cut, respectively, totaling approximately 14.4% of the second growth forest within the Ozette watershed as a whole.

Until the 1970s there were few regulations governing timber harvest. Streams were used for yarding corridors, riparian trees were removed, and sediment and slash inputs to streams were not regulated. Habitat degradation in Lake Ozette tributaries from commercial forest operations have long been implicated as major limiting factors affecting salmonid survival (USFWS 1965; Phinney and Bucknell 1975; Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; WDF et al. 1994; Jacobs et al. 1996; Lestelle 1996; McHenry et al. 1996; MFM 2000; Smith 2000). Dlugokenski et al. (1981) noted that during their habitat surveys, trees were felled across Umbrella Creek and yarded through the channel; they also noted in one location in the mainstem where heavy equipment had been operating in the channel.

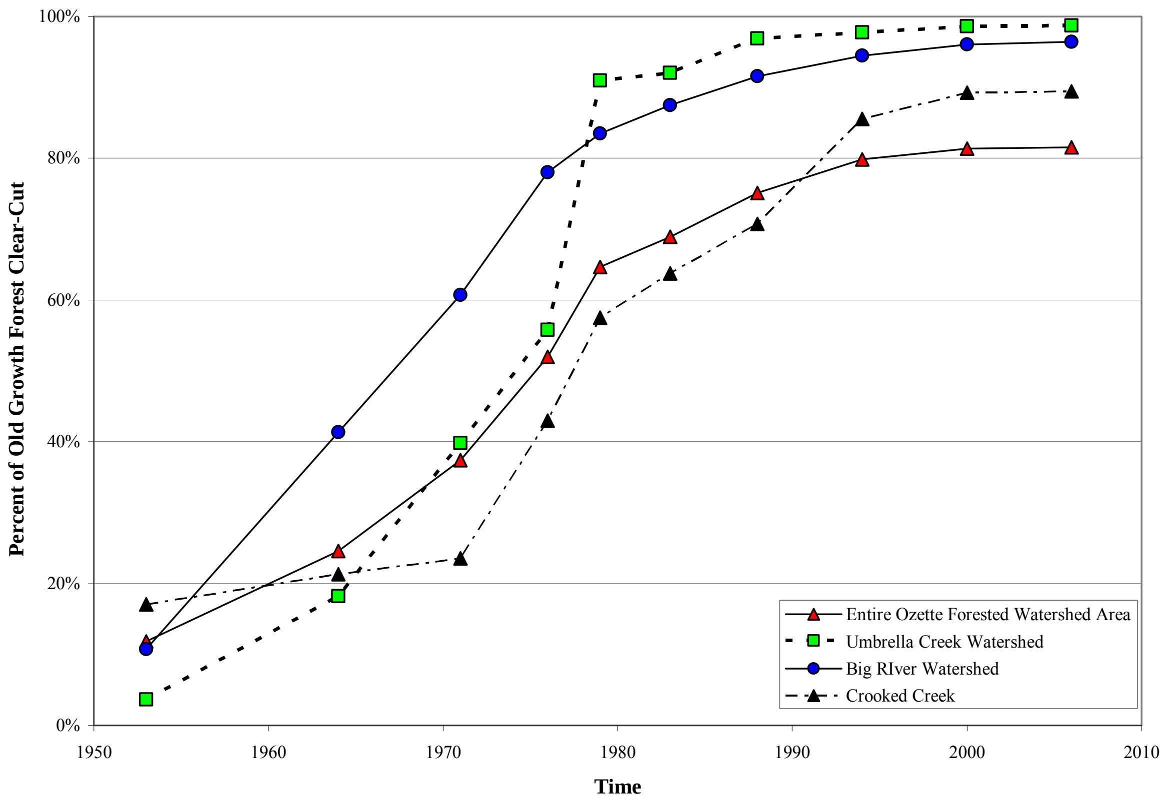

Figure 1.11. Percentage of old growth forest clear-cut through time for the entire forested portion of the Ozette watershed, as well as the Umbrella Creek, Big River, and Crooked Creek sub-basins.

1.5.4 Road and Railroad Construction

Lake Ozette in 1923 was described as being "*isolated*" by its location "*25 miles from Clallam Bay over an almost impassable road*" by Kemmerich (1926). The first road to Lake Ozette was completed in 1926 (Jacobs et al. 1996). Road and railroad building kept pace with timber harvest in the watershed, and road density continued to increase. In 1935, approximately 12.8 miles of road or railroad grade are shown on the USGS map. This increased to 25 miles in 1956, and by 1987 the USGS maps show 258.5 miles of road. Currently, there are about 341.3 miles of road and railroad grade identified on the WDNR GIS transportation coverage in the Ozette watershed, or about 4.4 miles of road per square mile (mi/mi^2) of land (Herrera 2006; note lake surface area not included in road density calculation).

A thorough review of aerial photos indicates that road densities are significantly higher than those depicted on USGS maps and the WDNR GIS transportation coverage, as well as recent estimates included in Herrera (2005; 2006). Road delineation using aerial photos and mapping in GIS resulted in the estimates of road length and road densities for major sub-basins depicted in Figure 1.12. In 2006, the total length of roads within the Ozette watershed was 417 miles. This road length results in an overall watershed road density of 5.5 mi/mi^2 (excluding the surface area of the lake). The 2006 ortho photo coverage indicates that road densities on non-federal land exceed 6 mi/mi^2 within the Ozette watershed.

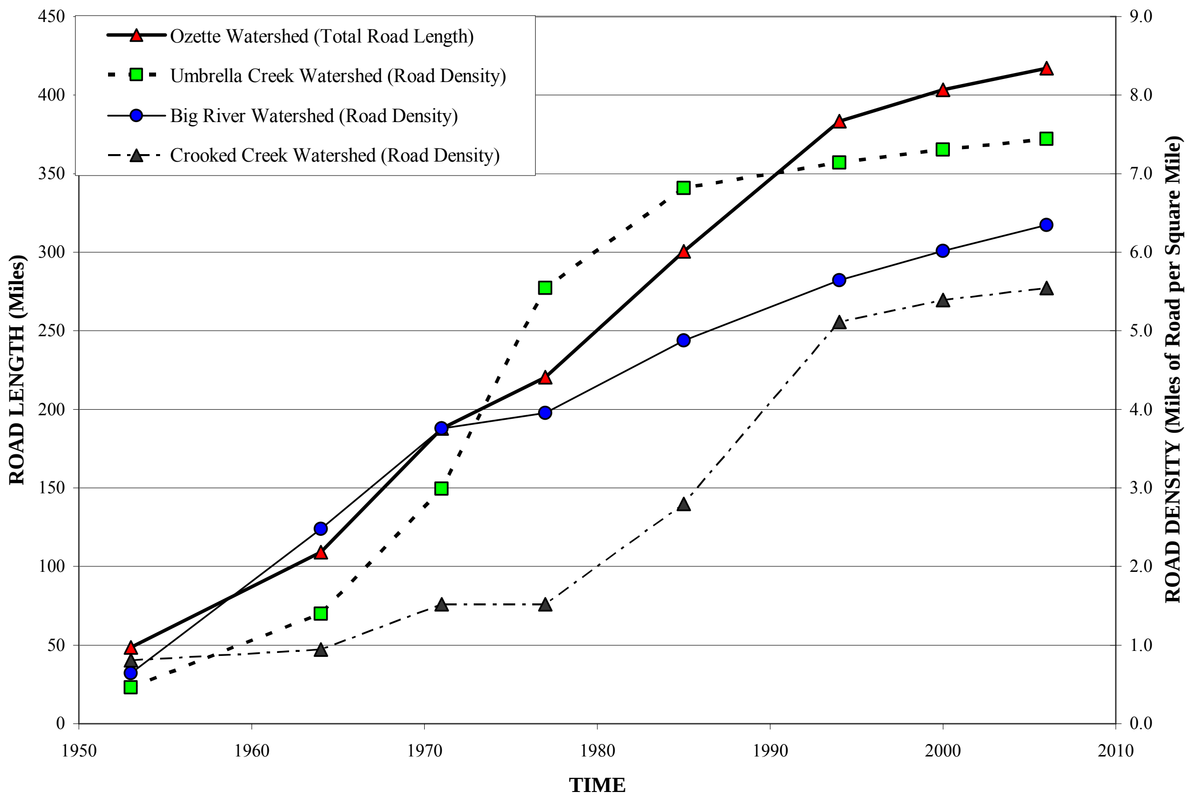

Figure 1.12. Ozette watershed road lengths and road densities for major sub-basins through time (road lengths based on aerial photo coverage; basin areas used in road density calculations were generated using a digital elevation model).

The Hoko-Ozette Road is the only significant public road in the area. It follows the original wagon trail to Ozette from Clallam Bay, and parallels Big River for approximately 7.8 river miles (Swan Bay Road to Nicolas Road). Within this reach, the road prism is frequently within the floodplain and channel migration zone of Big River. Kramer (1953) reported the road to be "*at times covered with flood waters*" during stream clearing activities in December 1952. Since then, the road has been raised repeatedly, but it still floods periodically. The road functions as a dike or levee during high water in some locations. Approximately 4,100 feet (1,250 meters) of bank hardening occurs along the county road and private property. Approximately 3.06 miles of riparian area are impacted by the road (road length within 200 feet of the bankfull edge of Big River; source: preliminary review of 2003 color aerial photos).

1.5.5 Stream Clearing History

It is unknown to what extent Native Americans cleared wood in the Ozette River prior to European settlement in the late-1800s. James G. Swan, possibly the first non-native to see Lake Ozette, was brought in by trail from the Ozette Village, near the mouth of the Ozette River. However, canoes were used on the lake, and may have been used on the Ozette River as well. Some historical accounts of homesteading describe the Ozette Indians ferrying settlers and goods to and from the mouth of the Ozette River. Stream clearing occurred, at least at a small scale, as early as the late-1800s in the Ozette and Big Rivers. Photos of the upper Ozette River from the late 1800's show no evidence of large wood above the Nylund homestead. One photo taken in the early 1900s shows cut logs in the river downstream of the ONP footbridge across Ozette River. In the lower Ozette River, a cedar logging operation was active in 1920s. By far the most significant directed stream clearing effort in the watershed took place in 1952, and was conducted by the Washington Department of Fisheries (Kramer 1953). A crew of eight men spent 63 operational days clearing log jams from the Ozette River, beginning August 7, 1952, and continuing through late October of the same year. A cat road was built along the river, and 26 separate log concentrations (Figure 1.13) were cleared or made passable (Kramer 1953). Many of the jams were described as being formed by erosion and blow-down of "*large over-ripe timber*" (Figure 1.14 and Figure 1.15). A 1964 aerial survey of the Ozette River from the mouth to the lake found that no log jams were present (USFWS 1965).

Immediately upon completing work in the Ozette River, the crew moved to Big River, where stream clearing took place from November 1 through December 19 (Figure 1.16) Heavy logging debris was reported to obstruct the river in the lower mile, which was not cleared because clearance equipment was "*not large enough to handle the heavy water-soaked logs*". Before stopping work due to flooding on December 19, the crew completed clearing about 3½ miles of stream between RM 2 and RM 6 of Big River (Kramer 1953). Umbrella Creek and Coal Creek were surveyed, and the need for clearance activities on Umbrella Creek was identified, however no work was completed at the time. It is not known if WDF conducted additional stream clearing activities in the Ozette watershed. Kramer's 1953 report does state though, that "*People of the area, especially the Lions Club of Sekiu, Neah Bay, and Clallam Bay, were very interested in this clearance project. They have assured us that they will assist us in keeping the river open after completion of clearance work*".

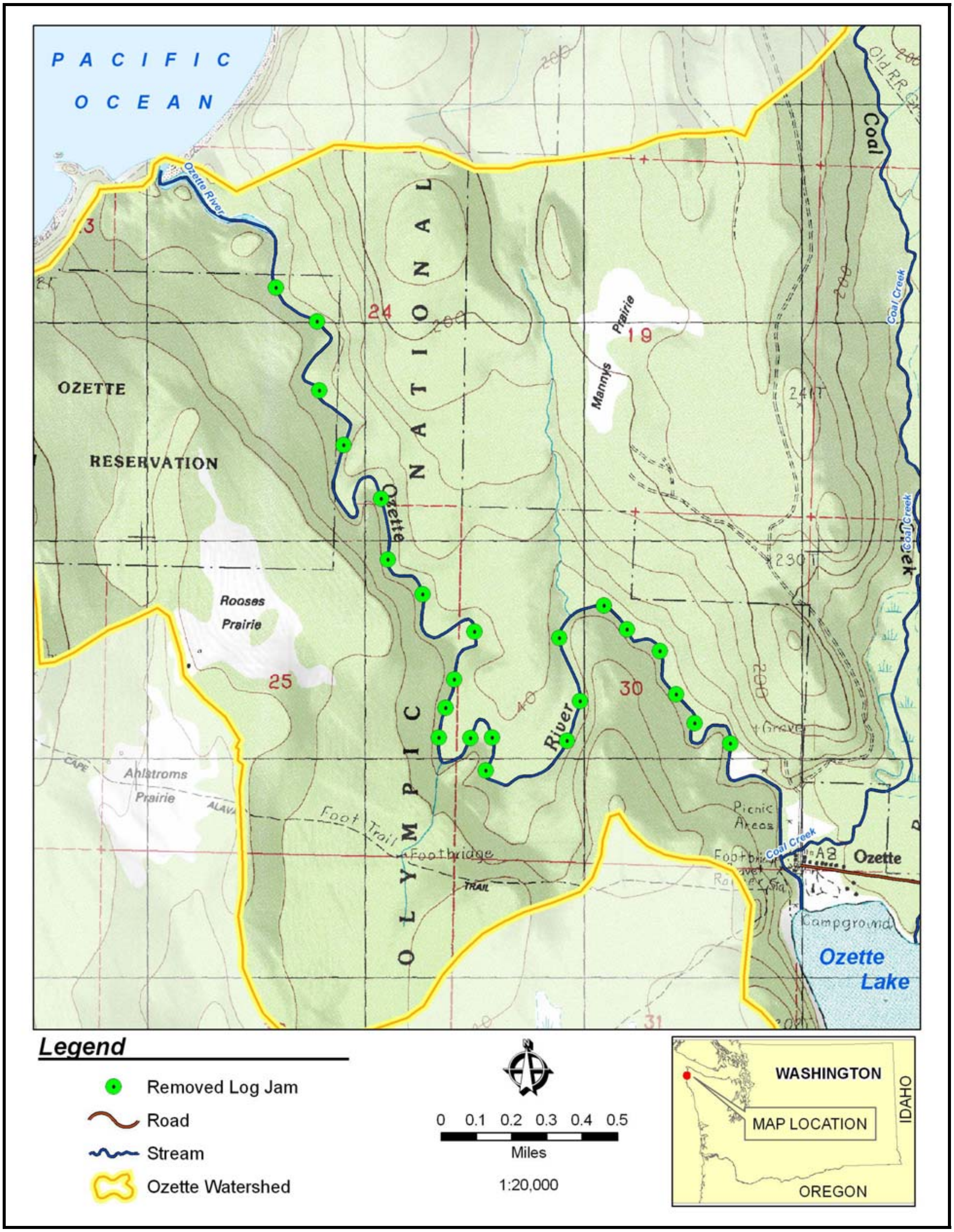

Figure 1.13. Map depicting the sites that logjams were cleared from the Ozette River (modified from Kramer 1953).

Figure 1.14. Example of typical logjam removed from Ozette River (source: Kramer 1953).

Figure 1.15. Debris racking on jam removed from the Ozette River (source: Kramer 1953).

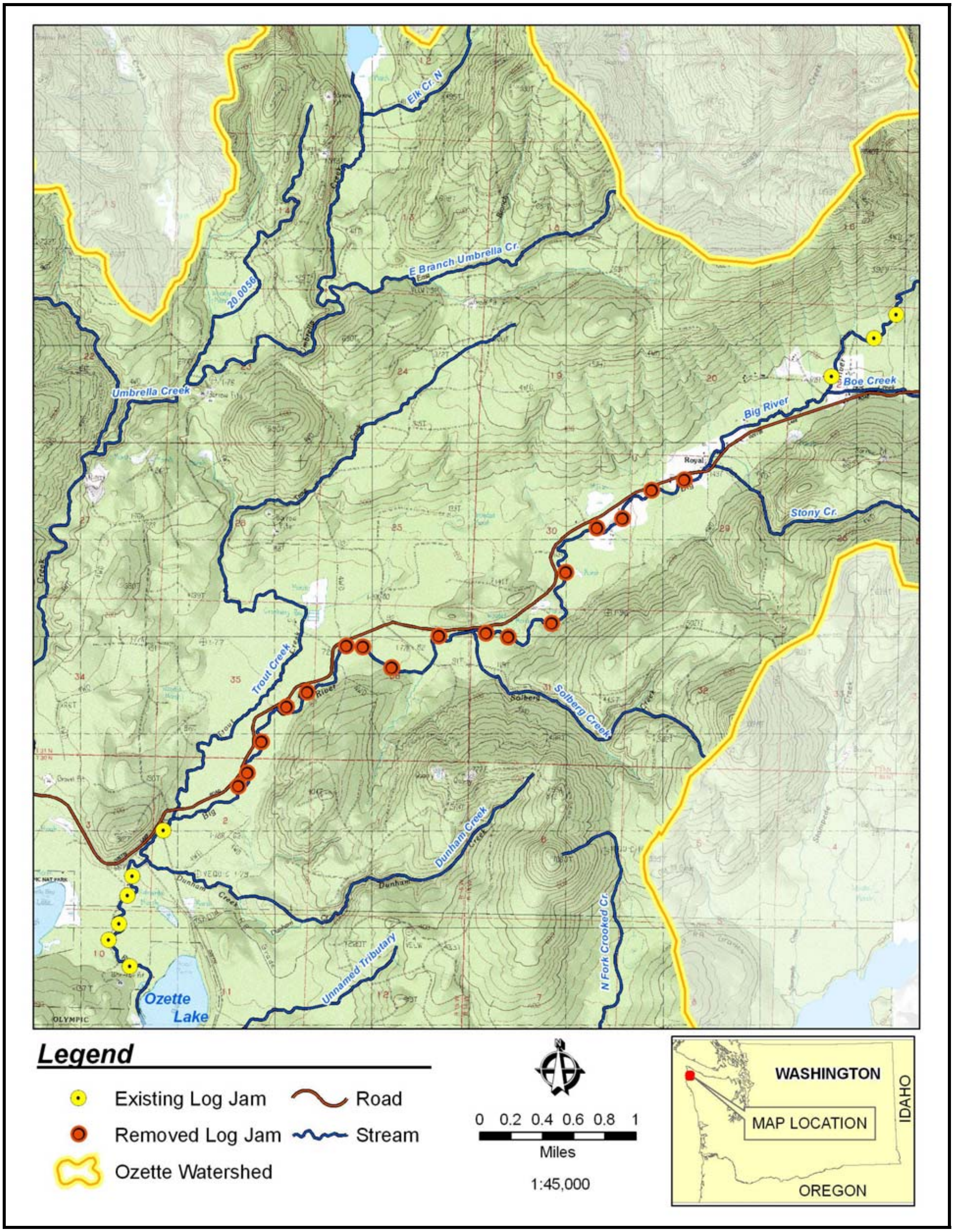

Figure 1.16. Map depicting existing and removed logjams in Big River in 1952 (modified from Kramer 1953).

Local residents continued to clear wood from the Ozette River sufficient to allow a small skiff to travel from the lake to the river mouth in the 1970s and 80s (Larry Sears, personal communication, 2005). ONP and the Makah Tribe continued to discuss a perceived need to remove wood from the river to improve fish passage through 1982 (Blum 1982, Contor 1982), but after surveying the river in 1985, they determined that fish passage was not obstructed by wood. Around the same time, the park stopped local residents from clearing wood in the Ozette River (Larry Sears, personal communication 2005).

After 1952, WDNR implemented stream clearing policies, and forest landowners were required to clear wood from streams when logging in the area. As with many Pacific Northwest watersheds, stream clearing became an integral part of forest practices, and was continued through the 1980s. Through much of the 1990's, cedar salvage and timber harvest operations continued to remove wood from channels, off-channel habitat, and riparian areas, although the rate declined steadily as regulations protecting instream and riparian areas developed.

2 FISH POPULATIONS OF THE LAKE OZETTE WATERSHED

As described above, there are thought to be at least 26 species of fish within the Lake Ozette watershed, making it one of the most species-rich lakes in Washington State. This chapter presents a brief review of the fish species present within the watershed and the locations of available information relating to the distribution, abundance, current and past harvest (where applicable), and trends in abundance for as many species for which data exist. In addition, for species that are potential competitors with, or predators of, sockeye salmon, general information on habitat utilization, diet, and relationship to sockeye salmon is included. Note that sockeye salmon biology is summarized in Chapter 3.

2.1 SALMONID POPULATIONS

Salmonid populations in the Lake Ozette watershed (in addition to sockeye salmon) are kokanee (non-anadromous) salmon, coho salmon, chum salmon, Chinook salmon, steelhead, and coastal cutthroat trout.

2.1.1 Kokanee Salmon (Oncorhynchus nerka kennerlyi)

Kokanee salmon in Lake Ozette are classified as an independent population of resident (non-anadromous) sockeye (Gustafson et al. 1997). No official stock designation has been given to the kokanee population(s) in the Ozette watershed, but they are considered native and are sustained through natural production. Lake Ozette kokanee are *NOT* part of the Lake Ozette sockeye salmon ESU. The West Coast Sockeye Biological Review Team (BRT) concluded that, "*Based on the very large genetic distance between Ozette Lake kokanee that spawn in tributaries and Ozette Lake sockeye salmon that spawn on shoreline beaches, the BRT excluded Ozette Lake kokanee from this sockeye salmon ESU.*"

2.1.1.1 Current and Historical Abundance

No historical (pre-1975) data exist for kokanee salmon spawning aggregations in the Ozette system. Population estimates for kokanee are poorly documented. Beauchamp et al. (1995) concluded that from 1980 through 1992, tributary spawning kokanee numbered between 5,000 and 10,000 spawners per year. However, the methods used to make this estimate are not described. From a review of spawning ground data and other documented descriptions of survey efforts during this time period, it was impossible to accurately estimate the annual total number of spawning kokanee. Spawning ground surveys in the fall of 1987 detected several thousand kokanee spawning or holding in lower Siwash Creek (MFM 1987). Recent survey efforts have not been designed to quantify the total abundance of spawning kokanee, and therefore no estimates of recent population abundance are available.

2.1.1.2 Kokanee Salmon Life History

2.1.1.2.1 Adult and Sub-Adult Kokanee Rearing in Lake Ozette

Anadromous sockeye and kokanee early life histories and freshwater rearing in the lake overlap. During their rearing phase, kokanee mix extensively in the lake with juvenile sockeye salmon (Jacobs et al. 1996). No attempt to differentiate the two populations during the lake rearing phase of their life-history has been attempted. Beauchamp and LaRiviere (1993) collected data on the age of *O. nerka* individuals captured in vertical gillnets. No age 4 sockeye/kokanee were captured during their study. This indicates that all kokanee spawn by the age 4. It was assumed that the majority of kokanee rear in lake for four springs and summers, and then spawn during their fourth fall. Jacobs et al. (1996) concluded that there are several lines of evidence indicating that sockeye salmon abundance is not suppressed by competition for food by kokanee.

2.1.1.2.2 Adult Kokanee Migration and Spawning

Little is known with respect to kokanee pre-spawning holding and migration patterns. Large numbers (~50) of kokanee-sized *O. nerka* have been observed holding adjacent to Allen’s Beach during the sockeye spawning season. A similar behavior has been observed with large numbers of coho salmon (~100) at Olsen’s Beach. In fact, even chum salmon have been observed holding and potentially spawning on the beaches. Kokanee spawning primarily occurs in tributaries, but to a much lesser degree kokanee-sized *O. nerka* also spawn on both Allen’s and Olsen’s beaches (MFM unpublished spawning ground surveys; Dlugokenski et al. 1981; Crewson et al. 2001; Hawkins 2004). Kokanee spawning ground survey data and genetic tissue sampling data indicate that kokanee spawn in all low-gradient streams with suitable substrate entering the lake, with the exception of the mainstem Big River. Kokanee spawning typically occurs from early November until mid-December (MFM, unpublished spawning ground survey data). Spawning kokanee are quite small. During genetic tissue sampling in 2000 and 2001, a total of 444 individuals were sampled for length (streams sampled: Crooked, Siwash, Elk, Rayonier Landing, and Cedar creeks, as well as an unnamed tributary to Crooked Creek and unnamed tributary 20.0073). Females averaged 22.4 cm fork length (FL) and males averaged 23.3 cm FL (Table 2.1). Fecundity data collected in 1990 found 402 eggs/female (n=81; MFM unpublished broodstock data).

Table 2.1. Summary of spawning kokanee length data collected during genetic tissue sampling in several Lake Ozette tributaries (source: MFM, unpublished genetic tissue database).

Sex	n	Maximum Length (cm FL)	Minimum Length (cm FL)	Average (cm FL)
Females	178	25.5	18.0	22.4
Males	235	27.0	19.0	23.3
Unknown	31	26.0	21.0	23.6
Total	444	27.0	18.0	22.9

With the exception of Crooked Creek, kokanee appear to prefer smaller tributaries for spawning. A thorough review of over 1,500 spawning ground surveys conducted between 1970 and 2004 indicates that Umbrella Creek and Big River do not have kokanee spawning aggregations as seen in the primary spawning grounds. A review of over 300 spawning ground surveys only revealed one observation of two kokanee size *O. nerka* in Big River. Kokanee have been observed spawning in Solberg Creek and Boe Creek, tributaries to Big River. Kokanee-sized *O. nerka* in Umbrella Creek are observed in low numbers on most years. Between 1970 and 2004 the peak Umbrella Creek kokanee count was 49 fish per mile in 1987, however, this survey appears to be an anomaly. During the same period over 300 surveys have been conducted and the next highest peak count was less than 6 fish per mile, during several years no kokanee or kokanee sized *O. nerka* have been observed in Umbrella Creek. Figure 2.1 depicts the annual peak kokanee counts per mile for all streams with multiple years of kokanee spawning ground surveys.

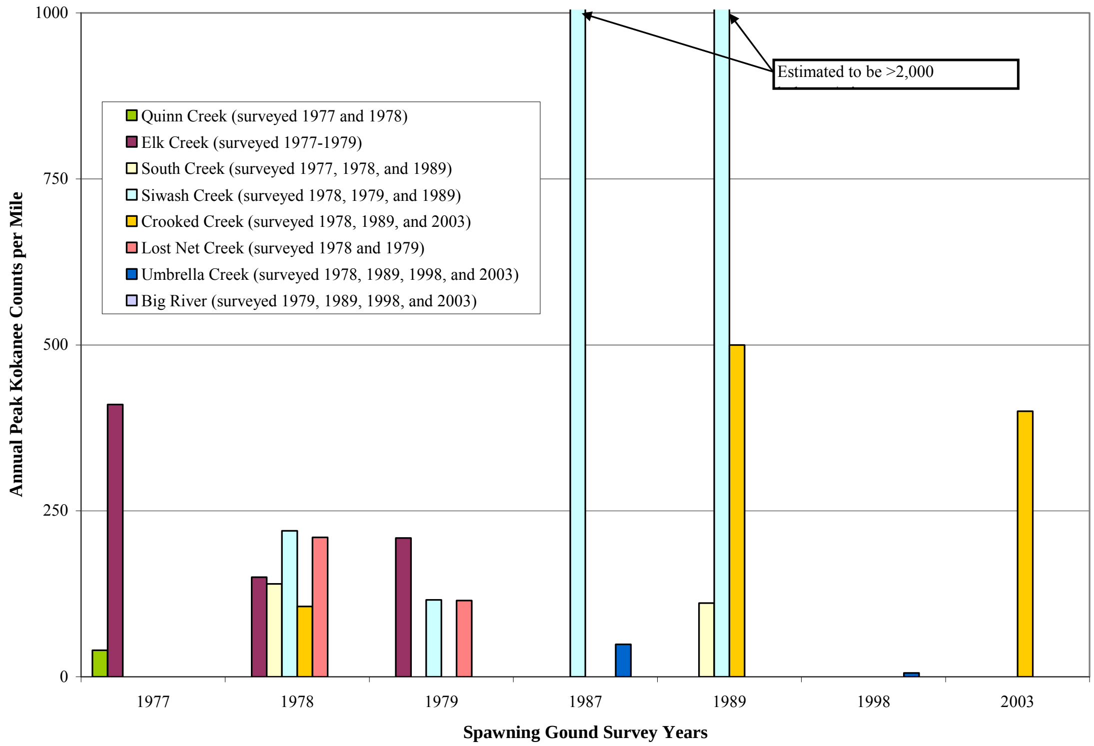

Figure 2.1. Annual peak kokanee counts per mile for select streams during spawning years 1977, 1978, 1979, 1989, 1998, and 2003 (source: Dlugokenski et al. 1981; MFM spawning ground survey database).

2.1.1.2.3 Kokanee Fry Emergence, Dispersal, and Early-Rearing

No direct data has been collected regarding kokanee fry emergence, dispersal, and early-rearing. It is assumed that since spawn timing is similar to that of tributary spawning sockeye that emergence timing is also similar. See Section 3.1.8.

2.1.1.3 Hatchery Practices and Planting History

Currently there are no hatchery releases of kokanee or kokanee- sockeye hybrids in the Ozette system. Past stocking efforts have been relatively limited. In 1940 over 108,000 kokanee fry from the Lake Crescent Trout Hatchery were released into Lake Ozette (Kloempken 1996 *in* Gustafson et al. 1997). Dlugokenski et al. (1981) also reports a kokanee release of an unknown quantity and origin into Lake Ozette in 1958. The most recent kokanee releases in the Ozette watershed occurred with brood year 1990 and 1991 sockeye x Siwash Creek kokanee hybrids. A total of 2,915 and 11,483 sockeye x kokanee hybrids were released into Lake Ozette July 1991 and 1992 respectively. In 1990, 81 Siwash Creek female sockeye were spawned with five male sockeye captured at Olsen's Beach (MFM, unpublished hatchery records) . In 1992, 94 Siwash Creek females were spawned with 12 male sockeye from either Allen's or Olsen's Beach or a mix from both beaches (MFM, unpublished hatchery records).

2.1.1.4 Kokanee Salmon Genetics

The genetics of Lake Ozette sockeye and kokanee are examined in detail in Gustafson et al. (1997), Crewson et al. (2001), and Hawkins (2004). Gustafson et al. (1997) concluded that Lake Ozette kokanee were genetically dissimilar from Lake Ozette sockeye, as well as all other anadromous sockeye populations examined in Washington State. Lake Ozette kokanee proved to be the most genetically distinct *O. nerka* population examined in a genetic comparison between different kokanee/sockeye salmon populations from the contiguous United States (Gustafson et al. 1997). Lake Ozette kokanee clustered most closely with Vancouver Island sockeye populations. Hawkins (2004) compared Lake Ozette kokanee genetic samples to test whether the Ozette kokanee stock contained multiple populations. Hawkins (2004) concluded that the Lake Ozette kokanee populations probably comprise one panmictic group. There were no genetic differences among the collections analyzed by Hawkins (2004).

2.1.2 Coho Salmon (*Oncorhynchus kisutch*)

Coho salmon are native to the Ozette watershed and are sustained through wild production (WDF et al. 1994; WDFW 2002). Coho salmon in the Ozette watershed have been identified as a distinct stock in recent stock assessments (Nehlsen et al. 1991; WDF et al. 1994; McHenry et al. 1996; WDFW 2002).

2.1.2.1 Current and Historical Abundance

Historically coho salmon were particularly abundant in Lake Ozette, potentially the most abundant anadromous salmonid in the watershed. Kemmerich (1945) reported counting 9,611 coho salmon passing the weir in the Ozette River between September 24 and October 16, 1924. In the same year, Kemmerich (1945) reported counts of 3,241[6] sockeye transiting the weir between May 27 and August 8. In 1925, a partial check of the coho salmon run was conducted by Kemmerich (1945) and in excess of 10,000 coho salmon were counted through the weir in a two-day period. In this same year, 6,343 sockeye were counted transiting the weir between June 8 and September 15 (it is unclear whether this is a complete count of the sockeye run or not). No data on coho abundance could be found for the years between 1926 and 1947. Starting in 1948, there are coho salmon harvest data for the Ozette River. Figure 2.2 depicts coho harvest data and weir data from the Ozette. Harvest of Lake Ozette coho between 1948 and 1957 averaged approximately 1,600 fish per year. Harvest declined precipitously during the next 10 years, averaging only 300 to 400 coho per year. Harvest from 1968 to 1972 averaged less than 300 coho per year. Lestelle (1996) suggests that the decline of Lake Ozette coho is

[6] The weir was undermined during the sockeye enumeration period and several days passed prior to repairing the weir, so the 3,241 sockeye counted were only a partial count of the run.

an indicator of how coho salmon habitat was changing in the watershed during this time period. Dlugokenski et al. (1981) suggest that the decline in harvest may have been a result of decreased effort after most of the individuals living at Ozette moved to Neah Bay in the 1950s. Nonetheless, it seems reasonable that Lake Ozette coho run sizes were much greater than 10,000 fish per year in the 1920s (after the in-river fisheries had harvested an unknown number of fish) and that harvest declined sharply in the late 1950s and 1960s to a point that a terminal fishery could no longer be supported.

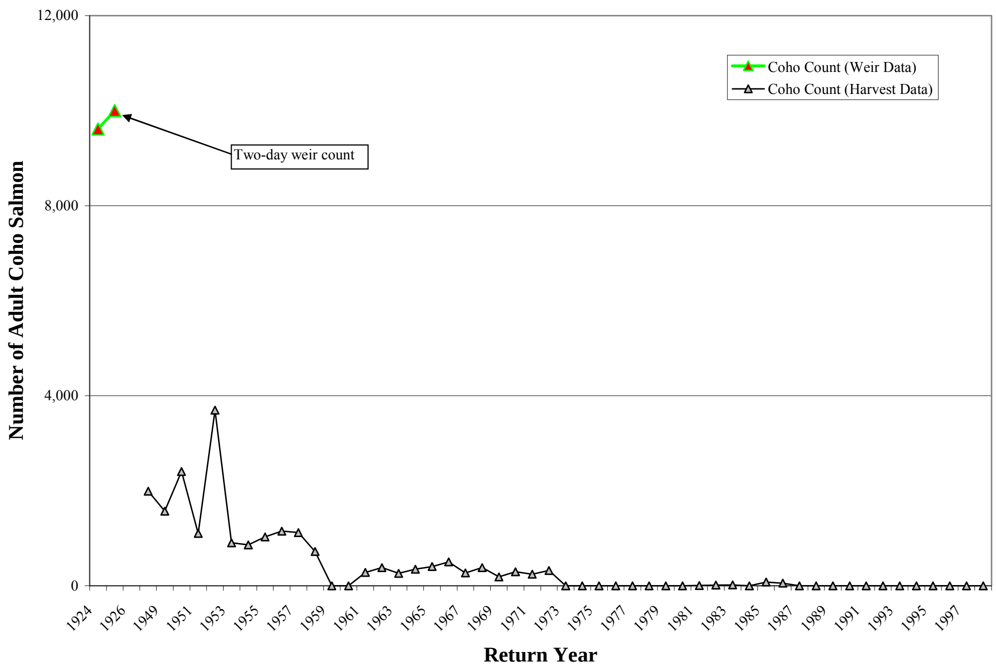

Figure 2.2. Coho salmon weir counts and harvest trends for available data from 1924 through 1999 (source: Kemmerich 1945; Jacobs et al. 1996, MFM 2000).

Currently there are no spawning escapement estimates for Lake Ozette coho; therefore no trend analysis could be conducted for this stock. Long-term spawning ground survey data are available for only two streams. The dataset contains 19 years of surveys which took place from return year 1974 to 2004. WDFW conducted spawning ground surveys in an index reach of Big River[7] (from the 7402 Rd Bridge to Boe Creek) from 1974 through 1985 (excluding 1984) and in the lower 0.6 miles of Boe Creek (from 1974 through 1986, excluding 1984). The Makah Tribe began conducting coho spawning ground surveys in 1998 in these same stream reaches. However, the Tribe's index reach in Big River extends downstream from the 7402 Bridge past Boe Creek, to the Hoko-Ozette Road Bridge and in Boe Creek the survey is 1.0 miles in length versus of the 0.6 miles surveyed in the WDFW index reach. Figure 2.3 depicts the annual number of surveys conducted within each of the spawning ground survey reaches, as well as the annual peak coho counts per mile. While the overall quantity and quality of Lake Ozette

[7] WDFW surveys are recorded in their database as taking place between RM 9.4 and 8.3, however, these river miles are based on river miles depicted in Phinney and Bucknell (1975). These river miles correspond to RM 10.81 to RM 9.4 in Haggerty and Ritchie (2004). Stream lengths in Haggerty and Ritchie (2004) are the basis for all river miles described in this report, as well as river miles used in MFM spawning ground surveys from 1998-2004.

coho abundance data are quite limited some general inferences can be made regarding the number of coho salmon on the spawning grounds. Peak coho counts in Big River and Boe Creek from 1974 to 1986 averaged 15 and 26 coho per mile respectively and from 1998 through 2004 peak counts averaged 40 and 196 coho per mile; equating to a 2.5 and 7.5 fold increase respectively.

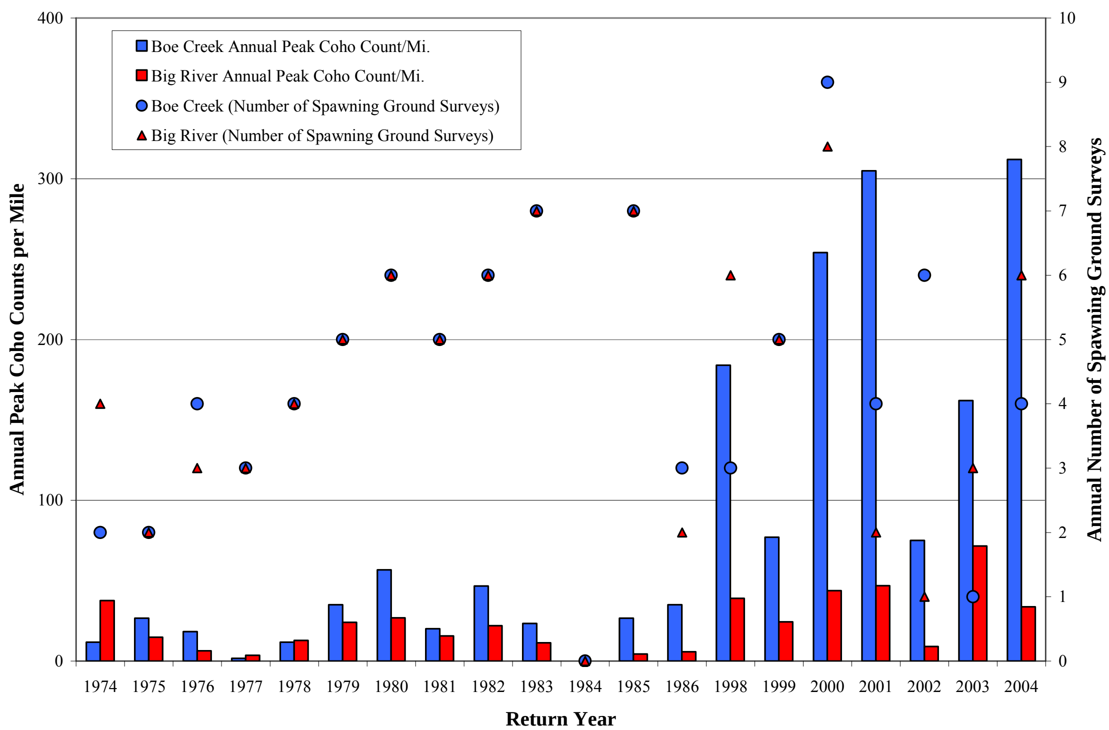

Figure 2.3. Summary of the annual number of spawning ground surveys conducted within index survey reaches and annual peak coho counts per mile in Big River and Boe Creek spawning ground index reaches from 1974 to 1986 and 1998 to 2004 (source: WDFW spawning ground survey database; MFM spawning ground survey database).

2.1.2.2 Coho Salmon Life History

2.1.2.2.1 Adult Coho Entering System

Very little data have been collected related to adult coho salmon migration and entry into Lake Ozette. Kemmerich (1926) describes entry timing into the lake starting in mid-September with peak counts corresponding to the first initial rise of the lake in early fall. In 1999 the sockeye counting weir was fished in the Ozette River until October 1, approximately 45 days later than in other years. On August 27, 1999 the first coho salmon was observed transiting the weir (MFM unpublished weir counts). Coho salmon continued to trickle into the lake averaging from 1 to 7 fish per day throughout the duration of the monitoring period. Rainfall during this period was low; only 2.04 inches (51.8 mm) of rainfall were measured between August 17 and October 1 (ONP unpublished rainfall data collected at the Ozette Ranger Station), and subsequently there was no rise in lake or river levels. WDF (1955) reports that the greatest abundance of coho salmon in the Ozette River occurs during the months of September through November.

2.1.2.2.2 Adult Coho Holding in Lake Ozette

Little is known regarding adult coho holding in Lake Ozette. Adult coho salmon have been observed milling and jumping in Swan Bay in September and early October, as well as other areas of the lake. It is assumed that fish holding in the lake are waiting for streamflows to increase so they can ascend tributaries and reach the spawning grounds. In 2000, fall rains were later than normal, and streamflows and lake levels did not rise until late November. In the fall of 2000, a few hundred coho salmon were observed holding just offshore of Olsen's Beach, apparently waiting for rain so they could ascend nearby tributaries to spawn.

2.1.2.2.3 Adult Coho Migration and Spawning in Tributaries

Coho salmon distribution in the Ozette watershed is depicted in Figure 2.4. Coho salmon have been found to spawn in all accessible low-gradient streams where suitable spawning gravel exists. In general spawning coho salmon have a preference for small tributaries where bankfull width is typically less than 30-40 feet (9-12 meters). In larger streams such as Big River, Umbrella Creek, and Crooked Creek coho spawning is typically limited in the lower, wider sections. The number of spawners per mile increases towards the upper watersheds of these stream systems and in smaller side tributaries. The timing of coho salmon migration into Ozette tributaries remains relatively unstudied. Weir data collected at the Umbrella Creek weir from 2001 through 2004 suggests that coho salmon migrate upstream soon after the first significant rise in streamflow in October or early-November. Figure 2.5 illustrates the relationship between streamflow and coho entry into Umbrella Creek. The earliest coho entry during this period was on October 14, 2001 and the latest first entry occurred on November 8, 2002 after a prolonged period of unseasonably low flows.

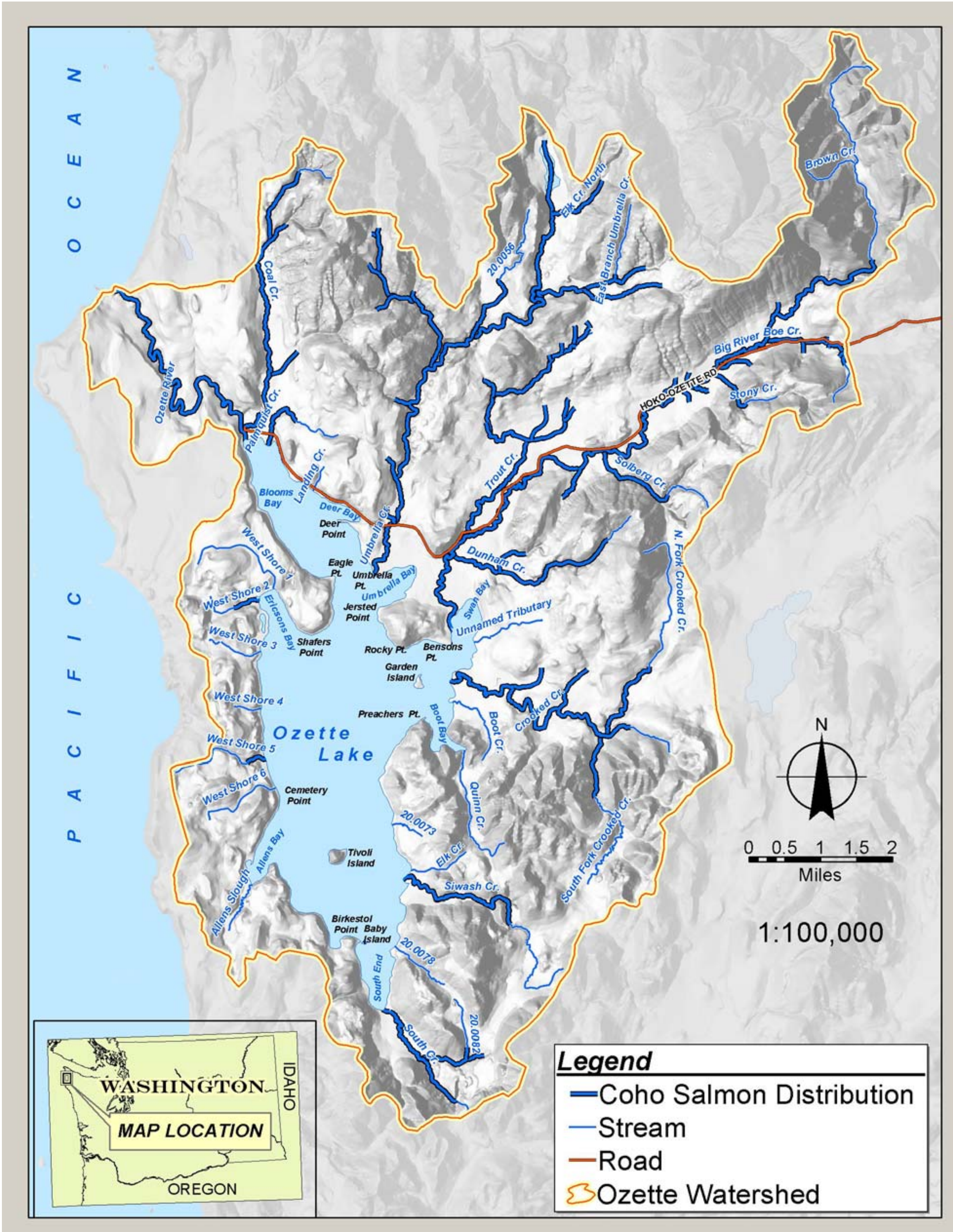

Figure 2.4. Known and presumed coho distribution in the Lake Ozette Watershed (source: MFM, unpublished fish distribution data).

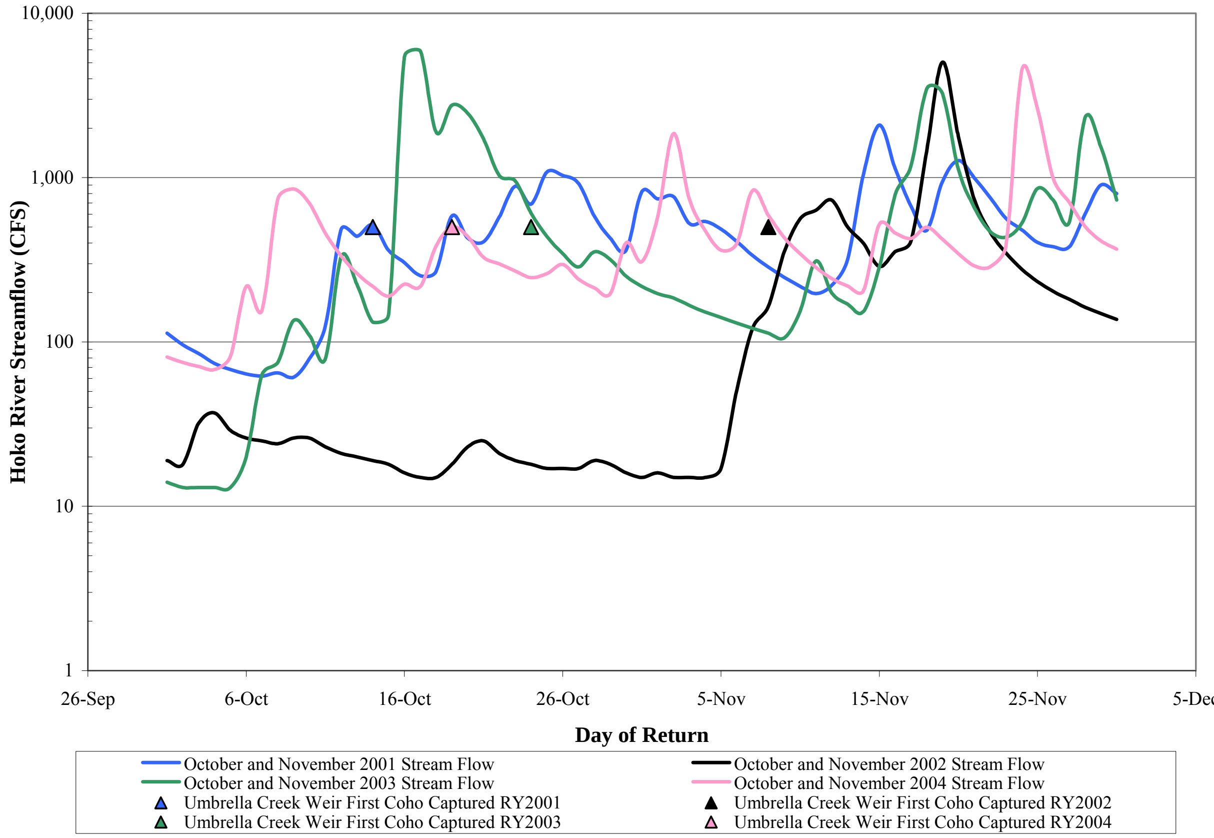

Figure 2.5. Relationship between streamflow[8] and the first coho salmon captured in the Umbrella Creek weir for return years 2001 through 2004 (source: hydrologic data from USGS gage 12043300; biological data from MFM, unpublished weir records).

Coho spawning in Ozette tributaries begins in early to mid-November and extends through mid- to late January. The earliest seasonal records of coho spawning in Ozette tributaries occurred on October 27, 1998 when one coho redd was observed in Big River (MFM unpublished spawning ground data). The latest seasonal observation of coho spawning in Ozette tributaries was observed on January 28, 1983 when 2 spawning coho were observed in Big River between RM 10.81 and 9.4 (MFM spawning ground database, survey conducted by WDFW). The timing of peak coho spawning varies between years. The earliest peak coho counts in Big River occurred on November 25, 1981; the latest peak counts were recorded December 20, 2004. The earliest peak coho counts in Boe Creek occurred on November 25, 1980; the latest peak counts were recorded January 6, 1986. Average peak coho counts for the period of survey record in Big River and Boe Creek occur on December 8 and 14, respectively.

[8]Streamflow data used is from the Hoko River stream gage, which is the nearest long-term stream gage to Umbrella Creek. Complete stream gage data for Umbrella Creek is not available for the entire period of 2001 through 2004. . Umbrella Creek streamflows are significantly lower than Hoko River streamflows, but the relationship between the two streams' relative streamflows is good.

2.1.2.2.4 Coho Salmon Fry Emergence and Dispersal

Only limited monitoring of coho salmon fry emergence and dispersal has occurred in the Ozette watershed. In 1999 and 2001 salmon fry and smolt trapping was conducted in Umbrella Creek. Results of trapping from 1999 suggest that coho salmon emerge from the gravel in March and April (based on egg sacs still attached to fish in late April). There are likely several life history strategies employed by emergent fry. In Umbrella Creek large numbers of fish have been observed rearing in secondary channels or along the margins of the main channel in early spring. Others rapidly migrate downstream from the spawning grounds into the lake or lower reaches of Umbrella Creek. In a period of 24 days from April 14 to May 7, 1999 almost 49,000 age 0 coho were observed moving downstream from RM 1.0 towards the lake (Figure 2.6). Based on sampling on April 20, 2001 at RM 0.7 (Umbrella Creek) it was estimated that 9,300 age 0 coho moved downstream towards the lake in a single day. Snorkel surveys of along the shoreline of the lake near the mouth of Umbrella Creek indicate that numerous coho disperse into the nearshore environment upon entering the lake. Surveys in Swan Bay also detected nearshore dispersal of age 0 coho. Sockeye smolt trapping near the lake outlet routinely detects age 0 coho moving down the Ozette River. In 2001 over 2000 age 0 coho were counted through the smolt trap. Age 0 coho have been observed in spring and early-summer near the lake's outlet and along banks of the Ozette River.

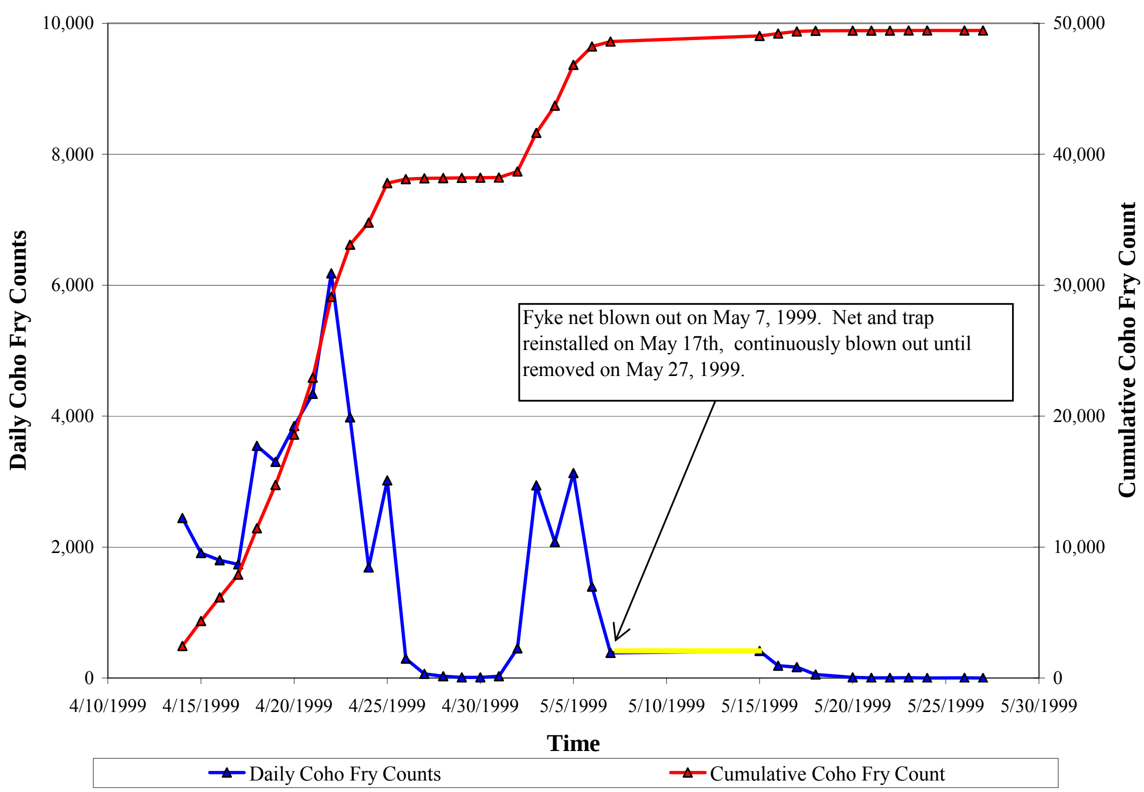

Figure 2.6. Daily and cumulative coho fry counts conducted near RM 1.0 in Umbrella Creek using a winged fyke net during the spring of 1999 (source: MFM, unpublished trap data).

2.1.2.2.5 Juvenile Coho Salmon Freshwater Rearing

Juvenile coho salmon are known to rear in tributaries to Lake Ozette, the Ozette River, tributaries to the Ozette River, and the lake. The degree or proportion of the population that rears in each habitat type is unknown. Seine surveys conducted in Umbrella Creek during early fall 1999 revealed high numbers of age 0 coho rearing pools. In one pool, more than 180 age 0 coho were captured in three passes with a seine net (MFM unpublished juvenile trapping data). Smolt counts from trapping efforts during the spring of 1999 only enumerated 88 age 1+ coho, suggesting that the majority of stream rearing juvenile coho migrate into the lake sometime between fall and early spring and then rear for two to several months before their migration to the Pacific Ocean. Very little data exist on the timing of tributary rearing coho migration into the lake. However, coho have been observed in off-channel habitats throughout the watershed during the winter months, suggesting that at least a component of the population exhibits the more common stream rearing life history traits observed in other coastal watersheds, with downstream migrations beginning in spring.

The life history of age 0 lake-rearing coho salmon remains poorly understood in the Ozette watershed. Wydoski and Whitney (2003) found that lake [reservoir] rearing juvenile coho salmon fed primarily on zooplankton (57-75%), such as *Daphnia*. Jacobs et al. (1996) concluded that there was some potential competition for food with sockeye salmon. In British Columbia, lake dwelling coho stomach contents contained less than 11% (by prey items, 5% by weight) zooplankton (Mason 1974 *in* Sandercock 1991). This may suggest less potential for competition with sockeye, but the diets of Lake Ozette lake-rearing coho have not been investigated. Predation on juvenile sockeye by lake-rearing coho may be a more important interaction than potential competition for food. In Cultus Lake (B.C.), age 0 sockeye were the primary food item for juvenile lake-rearing coho (Sandercock 1991). In Chignik Lake (Alaska) it was estimated that juvenile coho consumed 59% of the average population of sockeye salmon fry during a three-year period (Ruggerone and Rogers 1992). During trapping studies in Umbrella Creek, juvenile coho as small as 1.5 inches (38 mm) were observed preying on emergent sockeye fry (MFM unpublished trapping data).

2.1.2.2.6 Coho Salmon Seaward Migration

No direct attempts to enumerate coho smolt production in the Ozette watershed have been made. Coho smolts are captured during sockeye smolt trapping, but sockeye emigrate earlier than coho, and therefore only partial datasets for coho smolt production are available. Jacobs et al. (1996) provide an estimate of smolt production from trapping conducted in 1992. In 1992, estimated smolt production was 2,562 (95% CI 1,317-3,807) using the standard mark and recapture techniques, or 2,913 (95% 1,736-5,372) using a bootstrap estimation method (Conrad 1993). However, in 1992, smolts were trapped only during nighttime hours and the period of sampling was only from March 31 to May 14. Thus, these smolt estimates do not reflect total smolt production from the system.

In recent years (2001-2004), peak coho smolt counts have occurred from mid-May to early June. Coho smolts have been captured as early as April 10 (2002) and as late as July 1 (2001). Coho smolt size has averaged 119 mm FL (n=314) during this time period. Since no years contain a full dataset of the emigration time window, it is not possible to accurately produce smolt production estimates. All smolt monitoring periods do contain at least one period of record that overlaps with each of the other years of smolt trapping data. This makes it possible to compare relative proportions of smolts that migrated outside of the monitoring time frame for years where the trap was either pulled early or put in place late in the season. These periods were used to produce emigration proportions for each of the datasets from 2001 through 2004 and to produce general estimates of seasonal smolt production (Table 2.2).

Table 2.2. Ozette River coho smolt trapping periods, total coho smolts counted, expanded counts (based on trap efficiency [TE]), and estimated total coho smolt production (based on estimates for missing periods of the emigration period) (source: MFM, unpublished data).

Year	Start of Trapping	End of Trapping	Total Coho Smolts Counted	Expanded Count for Trap Efficiency	Estimated Coho Smolt Production
2001	5/24/2001	7/1/2001	4,029	13,714	48,782
2002	3/19/2002	5/30/2002	3,609	24,387	35,431
2003	5/13/2003	6/11/2003	2,858	52,899	81,281
2004	4/7/2004	6/1/2004	11,720	78,524	90,602

2.1.2.2.7 Coho Salmon Marine/Ocean Phase

No direct studies have been conducted of Ozette coho salmon marine life histories. It is assumed that Ozette coho behave similarly to other Washington northern coastal coho stocks.

2.1.2.3 Coho Salmon Hatchery Practices and Planting History

Several stock assessment reviews of Ozette coho indicate either no or very limited hatchery releases have occurred (WDF et al. 1994; McHenry et al. 1996; WDFW 2002). However, a query of the Regional Mark Information System (RMIS) reveals this is not the case. Between 1959 and 1980, over 1.6 million juvenile coho salmon were released into the Ozette watershed. Table 2.3 depicts the recorded hatchery releases of coho salmon in the Ozette watershed. Slightly more than 93% of all releases were fry less than 1 gram in weight. In fact only 2% of all coho released were yearling smolts. All coho hatchery releases were discontinued in this watershed in 1980.

Table 2.3. Summary of Ozette Watershed coho hatchery releases (source: RMIS database query 2005)

Brood Year	Release Date	Agency	Hatchery	Broodstock Source	Weight at Release (grams)	Release Site	Number Released
1958	8/4/1959	WDFW	Dungeness	Dungeness	0.68	Big River	139,650
1958	9/18/1959	WDFW	Dungeness	Dungeness	0.75	Big River	152,306
1958	9/27/1959	WDFW	Dungeness	Dungeness	0.8	Big River	124,865
1958	10/6/1959	WDFW	Dungeness	Dungeness	0.75	Big River	159,874
1958	12/29/1959	WDFW	Dungeness	Dungeness	1.53	Big River	74,000
1965	6/7/1967	WDFW	Dungeness	Dungeness	11.94	Big River	28,082
1975	5/7/1976	WDFW	Sol Duc	George Adams	0.5	Siwash Creek	180,000
1976	3/1/1977	WDFW	Sol Duc	George Adams	0.36	Umbrella Creek	200,000
1976	3/1/1977	WDFW	Sol Duc	George Adams	0.36	Big River	200,000
1976	3/2/1977	WDFW	Sol Duc	George Adams	0.36	NF Crooked Creek	100,000
1976	3/3/1977	WDFW	Sol Duc	George Adams	0.36	Siwash Creek	100,000
1976	3/3/1977	WDFW	Sol Duc	George Adams	0.36	Ozette Lake	200,000
1977	4/27/1979	USFWS	Quilcene	Big Quilcene	23.84	Ozette River	2,000
1978	4/29/1980	USFWS	Quilcene	Big Quilcene	22.7	Ozette River	4,500

2.1.2.4 Coho Salmon Genetics

No information is available on this subject.

2.1.3 Chum Salmon (*Oncorhynchus keta*)

Chum salmon are native to the Ozette watershed and are sustained through wild production (WDF et al. 1994). Fall chum salmon in the Ozette watershed have been identified as a distinct stock in recent stock assessments (Nehlsen et al. 1991; WDF et al. 1994; McHenry et al. 1996; WDFW 2002).

2.1.3.1 Current and Historical Abundance

Chum salmon were fairly abundant in the Ozette watershed according to historical catch records. The historical data available for Ozette chum salmon is limited. Figure 2.7 illustrates the trend in chum salmon harvest in the Ozette River between 1948 and 1955. After 1955, chum salmon harvest only appears in the catch records during two years, with a total of three fish landed. The harvest trend data for Ozette gives only a short snapshot of the historical population size, but clearly shows that the number of chum salmon harvested declined in the Ozette River while chum harvest remained stable or increased in the other nearby watersheds. Since the 1950s, observations of chum salmon in the Ozette system are very limited.

A few chum salmon have been observed transiting the weir in mid- or late August. Spawning ground surveys in the watershed detect chum salmon only on some years. Factors contributing to the decline of the Ozette fall chum stock remain poorly understood. Recent stock assessment reports describe the stock status as either critical, threatened, or unknown (WDF et al. 1994; WDFW 2002; Nehlsen et al. 1991; McHenry et al. 1996). Nehlsen et al. 1991 describe the Ozette chum population as potentially extinct. The Lake Ozette chum run was once at least a thousand or more fish, while current run sizes are most likely less than 25 or 50 fish.

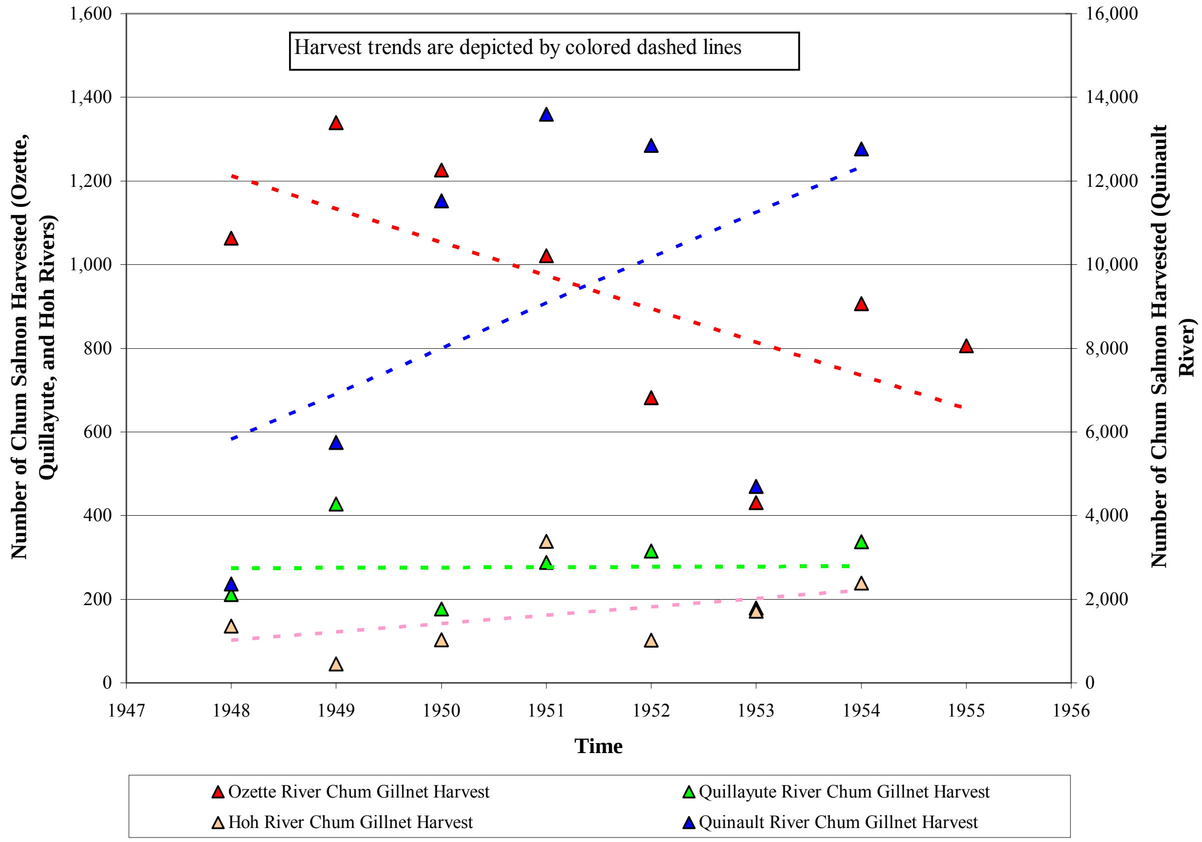

Figure 2.7. Chum salmon harvest from gillnets fishing Ozette River (1948-1955) contrasted with chum salmon harvest from nearby Olympic Peninsula rivers (source: WDF 1955; Dlugokenski et al. 1981).

2.1.3.2 Chum Salmon Life History

2.1.3.2.1 Adult Chum Entering System

Adult chum salmon enter the Ozette system between October and early December (WDF et al. 1994). Historically, peak harvest occurred between October and December (WDF 1955). Occasionally chum salmon are observed transiting the weir in mid- or late

August. Little else is known about the historical and/or current migration pattern of chum salmon in the Ozette watershed.

2.1.3.2.2 Adult Chum Holding in Lake Ozette

No information is available on this subject. It is assumed that some chum salmon that enter the system spawn downstream of the lake and therefore do not hold in the lake. Chum salmon have been observed on Allen's Beach (1988 and 2002), but records are not available for all years. It is assumed that most chum salmon spawning in the tributaries have a brief holding period in the lake prior to migrating to the spawning grounds. Chum salmon observed entering the lake in August (RY 1999, 2001, and 2003) must hold for at least a few months in the lake prior to spawning.

2.1.3.2.3 Adult Chum Migration and Spawning

Very little is known about the historical spawning distribution of chum salmon in the Ozette watershed. WDF et al. (1994) describe the spawning distribution as the Ozette River, Big River, Umbrella Creek, and Crooked Creek. Very limited spawning ground surveys have been conducted in the Ozette River. The Ozette River is inaccessible from late fall through winter for spawning ground surveys because of high streamflows and is nearly impossible to survey from the banks due to the size and depth of the river, dense riparian vegetation, and the lack of a trail (Jacobs et al. 1996). Fairly detailed data from spawning ground surveys are available for Ozette tributaries for return year (RY) 1974-1990 and limited data from RY 1991 through 1997, and more detailed data for Ozette tributaries from RY 1998 to present. A review of approximately 1,150 spawning ground surveys conducted from 1970-2004 included only 8 observations of chum salmon. There have been 6 observations in Umbrella Creek occurring in return years 1996, 1999, 2000, and 2004. In 1993 there was one observation in Crooked Creek and one in the South Fork Crooked Creek. A total of six chum were captured in the Umbrella Creek weir in return years 2002 (3), 2003 (1), and 2004 (2). One spawned-out chum carcass was found on Allen's Beach on December 5, 2001. Chum salmon were also observed on Allen's Beach in 1988.

2.1.3.2.4 Chum Salmon Fry Emergence and Dispersal

Very little information is available on this subject. The limited number of spawners makes encounters infrequent in the watershed. No juvenile salmonid monitoring has occurred downstream of spawning habitat in the Ozette River, limiting smolt and fry trapping to the tributary spawning component of the run. During fry trapping in Umbrella Creek in 1999, a total of 13 chum salmon fry were captured in early May, apparently migrating to the lake.

2.1.3.2.5 Juvenile Chum Salmon Freshwater Rearing

No information is available on this subject. It is assumed that chum fry rapidly migrate from the spawning grounds to the lake and then to the river. Some feeding may occur in the lake and tributaries.

2.1.3.2.6 Chum Salmon Seaward Migration

Very little information is available on this subject. In recent years juvenile chum salmon have regularly been caught in the Ozette River smolt trap. The sockeye smolt trap is not designed to enumerate emigrating Age 0 salmonids, and counting methods have varied between and within monitoring seasons. During trapping in 2001 through 2004, juvenile chum counts ranged from 1 (2002) to 445 (2004. Note: chum and Chinook not differentiated in all counts, but the majority of fish were juvenile chum salmon). Peak counts have been observed from mid-April to mid-May. Juvenile chum have been captured in the smolt trap into late June.

2.1.3.2.7 Chum Salmon Marine/Ocean Phase

It is assumed that chum salmon in the Ozette system have similar migrations and feeding patterns as other nearby stocks.

2.1.3.3 Chum Salmon Hatchery Practices and Planting History

No records of chum salmon hatchery plants were found for the Ozette drainage. It is therefore assumed that no stocking has occurred within the basin.

2.1.3.4 Chum Salmon Genetics

No information is available on this subject.

2.1.4 Chinook Salmon (*Oncorhynchus tshawytscha*)

Chinook salmon are native to the Ozette watershed (WDF 1955; Nehlsen et al. 1991; McHenry et al. 1996) and were historically sustained through wild production. Fall Chinook salmon in the Ozette watershed have not been identified as a distinct stock in recent stock assessments conducted by WDFW (WDF et al. 1994; WDFW 2002).

2.1.4.1 Current and Historical Abundance

Chinook salmon were abundant in the Ozette watershed according to historical catch records. The historical data available for Ozette Chinook salmon are limited. Figure 2.8, illustrates the trend in Chinook salmon harvest in the Ozette River between 1948 and 1958. After 1958, Chinook salmon harvest appears in the catch records only during 6 years, with a total of 40 fish landed. The harvest trend data for Ozette give only a short snapshot of the historical population size but clearly shows that the number of Chinook salmon harvested declined in the Ozette River while Chinook harvest remained stable or increased in the other nearby watersheds. Reported harvest from 1948 to 1951 in the Ozette River is slightly higher than the harvest during the same years in the Hoh River, suggesting that the run was fairly sizable before the population collapse. Since the 1950s, observations of Chinook salmon in the Ozette system are very limited. No Chinook salmon have been observed transiting the adult weir in the Ozette River. Spawning ground surveys in the watershed have not detected Chinook salmon in recent times (1977-2004). Factors contributing to the decline of the Ozette fall Chinook stock remain poorly understood.

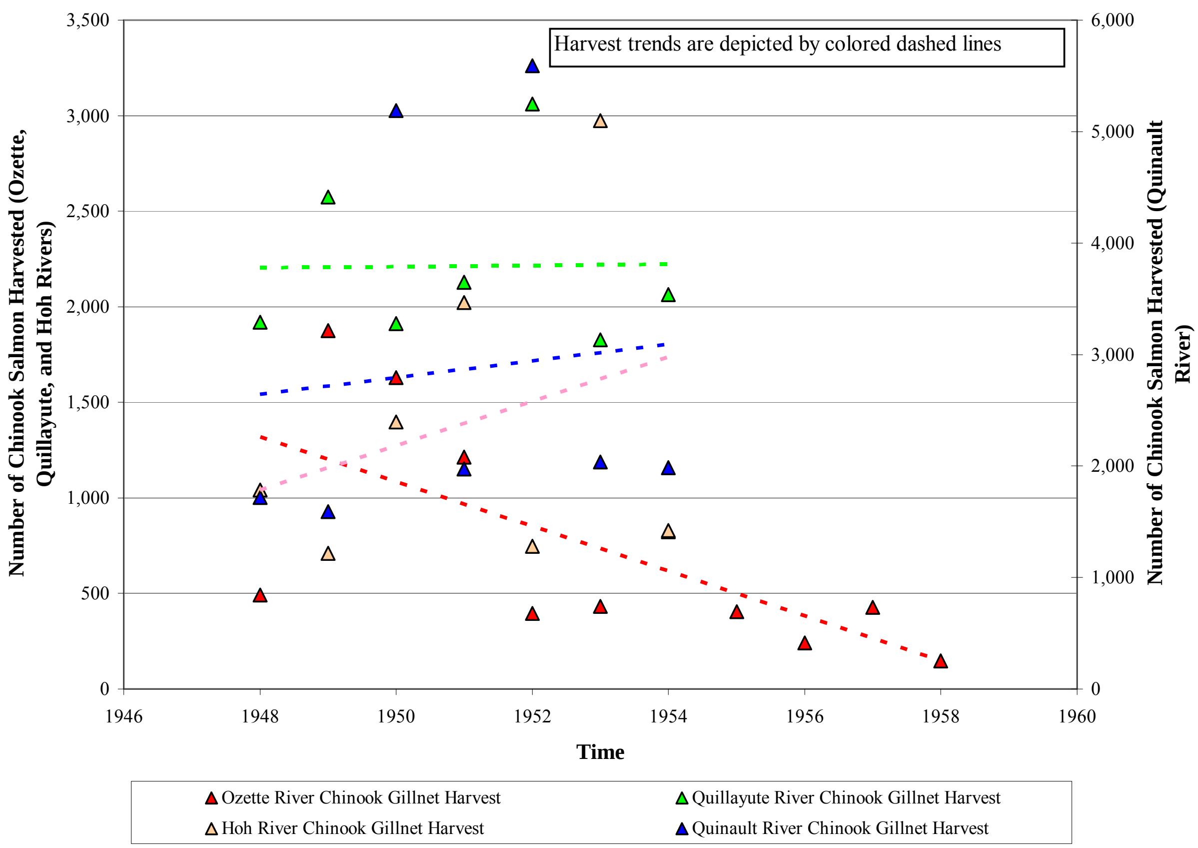

Figure 2.8. Chinook salmon harvest from gillnets fishing the Ozette River (1948-1958) contrasted with Chinook salmon harvest data from nearby Olympic Peninsula rivers (source: WDF 1955; Dlugokenski et al. 1981).

Recent stock assessment reports describe the stock status as either critical or extinct (WDF et al. 1994; Nehlsen et al. 1991; McHenry et al. 1996). Nehlsen et al. (1991) describe the Ozette Chinook population as potentially extinct. WDF et al. (1994) describe the stock as extinct or not currently verifiable within the system. The Lake Ozette Chinook run was once at least 2,000 or more fish; current run sizes are most likely less than 10 to 20 Chinook.

2.1.4.2 Chinook Salmon Life History

2.1.4.2.1 Adult Chinook Entering System

The current abundance of Chinook salmon is so low in the Ozette watershed that information on run timing is nonexistent. Historically, peak harvest occurred between September and October (WDF 1955). Little else is known about the historical and/or current migration pattern of Chinook salmon in the Ozette watershed.

2.1.4.2.2 Adult Chinook Holding in Lake Ozette

No information is available on this subject. It is assumed that some Chinook salmon that enter(ed) the system spawn downstream of the lake and therefore do not hold in the lake. In recent years only one observation of adult Chinook salmon holding in the lake could be found. One adult Chinook was electro-fished from the lake on October 7, 2004 but information on the location within the lake is not available (WOE 2005). It is assumed that most Chinook salmon spawning in the tributaries have a brief holding period in the lake prior to migrating to the spawning grounds.

2.1.4.2.3 Adult Chinook Migration and Spawning

As discussed earlier, no Chinook have been observed spawning in Lake Ozette tributaries in recent years (1977-2004). Phinney and Bucknell (1975) report that Chinook spawning occurs in the Ozette River and in Big River.

2.1.4.2.4 Chinook Salmon Fry Emergence and Dispersal

Very little information is available on this subject. The lack of spawners makes encounters infrequent in the watershed. No juvenile salmonid monitoring has occurred downstream of spawning habitat in the Ozette River, limiting smolt and fry trapping to the tributary spawning component of the run. During fry trapping in Umbrella Creek in 1999 no Chinook salmon fry were captured.

2.1.4.2.5 Juvenile Chinook Salmon Freshwater Rearing

No information is available on this subject. It is assumed that Chinook fry rapidly migrate from the spawning grounds to the lake and then to the river. Some feeding may occur in lake and tributaries.

2.1.4.2.6 Chinook Salmon Seaward Migration

Very little information is available on this subject. In recent years juvenile Chinook salmon have been captured in the Ozette River smolt trap. The sockeye smolt trap is not designed to enumerate emigrating Age 0 salmonids and counting methods have varied between and within monitoring seasons. During trapping in 2001 through 2004, juvenile Chinook were observed only in 2003 and 2004, and only in low numbers (less than 50 fish). It is possible that low numbers of Chinook were captured in 2001 and 2002 but not correctly identified and/or recorded.

2.1.4.2.7 Chinook Salmon Marine/Ocean Phase

It is assumed that Chinook salmon in the Ozette system have/had similar migrations and feeding patterns as other Washington northern coastal stocks.

2.1.4.3 Chinook Salmon Hatchery Practices and Planting History

The relatively high numbers of Chinook salmon in the reported gillnet catch followed by a complete collapse in the fishery warrants discussion of the potential influence of hatchery stocking in the watershed. Extensive hatchery releases occurred in the nearby Hoko River in the years following the highest Chinook catches reported for the Ozette River. A review of hatchery release records was conducted to determine whether hatchery stocking may have affected the peak Chinook harvests reported for the Ozette River. However, there are no records of Chinook salmon being released into the Ozette watershed and therefore it is unlikely that hatchery releases influenced harvest of Chinook salmon in the Ozette River.

2.1.4.4 Chinook Salmon Genetics

No information is available on this subject.

2.1.5 Steelhead/Rainbow Trout (*Oncorhynchus mykiss*)

Steelhead trout are native to the Ozette watershed and are sustained through wild production (WDF et al. 1994; McHenry et al. 1996; WDFW 2002). Steelhead/rainbow trout primarily occur in the form of winter-run steelhead, but non-anadromous forms of the species may also be present. Winter-run steelhead in the Ozette watershed have been identified as a distinct stock in recent stock assessments conducted by WDFW (WDF et al. 1994; WDFW 2002). Within the context of this report, the term steelhead will be used when describing the species *O. mykiss*.

2.1.5.1 Current and Historical Abundance

No current or historical abundance data are available for this stock. The status and trend of this stock are unknown (WDF et al. 1994; McHenry et al. 1996; WDFW 2002). Only anecdotal evidence of their historical abundance exists. Kemmerich (1926) reports that old-time residents of the lake informed him that steelhead enter the lake system in considerable numbers. A review of sport harvest data (1993-2002) indicates that fewer than 20 steelhead are harvested annually in the Ozette system (WDFW 1994; WDFW 1997; WDFW 1999a; WDFW 1999b; WDFW 1999c; WDFW 1999d; WDFW 2004a; WDFW 2004b). The majority of harvest occurs in the Big River and the majority of fish reported on catch record cards are of hatchery origin[9] (WDFW 1994; WDFW 1997; WDFW 1999a; WDFW 1999b; WDFW 1999c; WDFW 1999d; WDFW 2004a; WDFW 2004b).

2.1.5.2 Steelhead Trout Life History

2.1.5.2.1 Adult Steelhead Trout Entering System

Data regarding adult steelhead entry timing into watershed are limited. Steelhead captures in the adult weir in Umbrella Creek indicate that adult steelhead must begin entering the Ozette River in early-November and potentially earlier.

2.1.5.2.2 Adult Steelhead Trout Holding in Lake Ozette

Very little information is available regarding adult holding in the lake. Adult steelhead are sometimes caught by sport fishers in the lake.

[9] Hatchery-origin steelhead reported as harvested from Big River are assumed to be hatchery strays from nearby hatcheries (Quillayute, Sooes, Hoko).

2.1.5.2.3 Adult Steelhead Trout Migration and Spawning

Steelhead have been observed entering Ozette tributaries as early as late October (Umbrella Creek) and increase in abundance as the spawning season progresses. Weir operations at Umbrella Creek from 2001 to 2004 have enumerated a total of 8 steelhead migrating upstream before December. Steelhead have been observed spawning as early as late November in Big River and as late as mid-June in Coal Creek. However, less than 2% of all redds detected in the watershed are detected in the months of November, December, and June. Just over 95% of all redds detected have been detected in February (12.5%), March (24.6%), April (44.4%), and May (13.5%). Based on data collected from 1987 to 2001, peak spawning was determined to take place between late March and mid-April. The primary streams used for spawning include the Ozette River, Umbrella Creek, Big River, and Crooked Creek. Additional spawning also occurs in other accessible tributaries such as the North and South Forks Crooked Creek, Coal Creek, West Branch Umbrella Creek, and Boe Creek. Spawning ground survey data are somewhat limited in the Ozette watershed; a total of 216 steelhead surveys were reviewed as part of this assessment. Redds per mile surveyed averaged 0.56 redds/mi in the smaller streams (60 surveys) and 1.32 in the larger streams (156 surveys). Big River contains the largest spawning aggregation in the watershed as well as the highest number of steelhead spawning ground surveys. A summary of Big River spawning ground survey data for the period of record is shown in Figure 2.9.

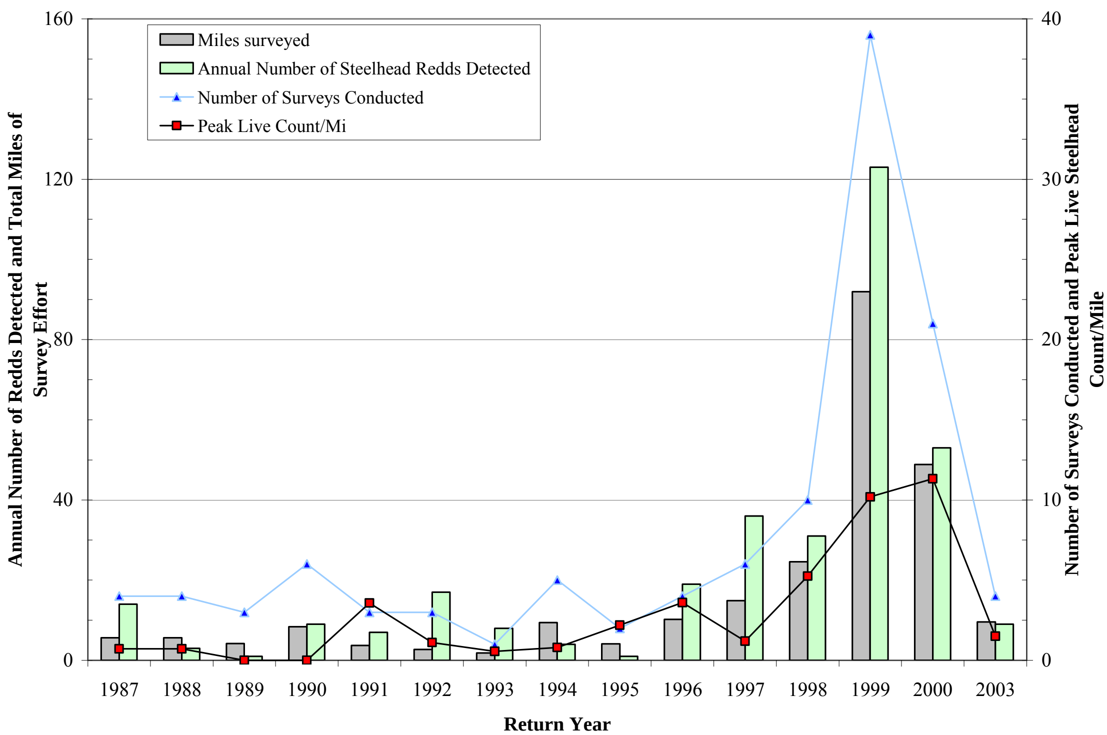

Figure 2.9. Summary of mainstem Big River steelhead spawning ground survey data from RYs 1987 through 2003, excluding RYs 2001 and 2002, when no data were collected (source: MFM, unpublished spawning ground survey data).

2.1.5.2.4 Steelhead Trout Fry Emergence and Dispersal

Winter-run steelhead have a protracted spawning season, and therefore their emergence timing also extends across several months. Emergence likely begins in mid-March for some individuals and extends into August for others. The first age 0 steelhead encountered during trapping studies in Umbrella Creek in 1999 was on April 20. Less than 100 age 0 steelhead were encountered between April 15 and May 27, when the trap was destroyed. The trap was repaired and reinstalled on June 22, 1999. Based upon data collected during the second round of trapping in 1999, it is thought that peak emergence timing and dispersal occurred from mid-June to mid-July. Over 8,200 age 0 steelhead were enumerated migrating downstream of the Hoko-Ozette Road Bridge towards Lake Ozette.

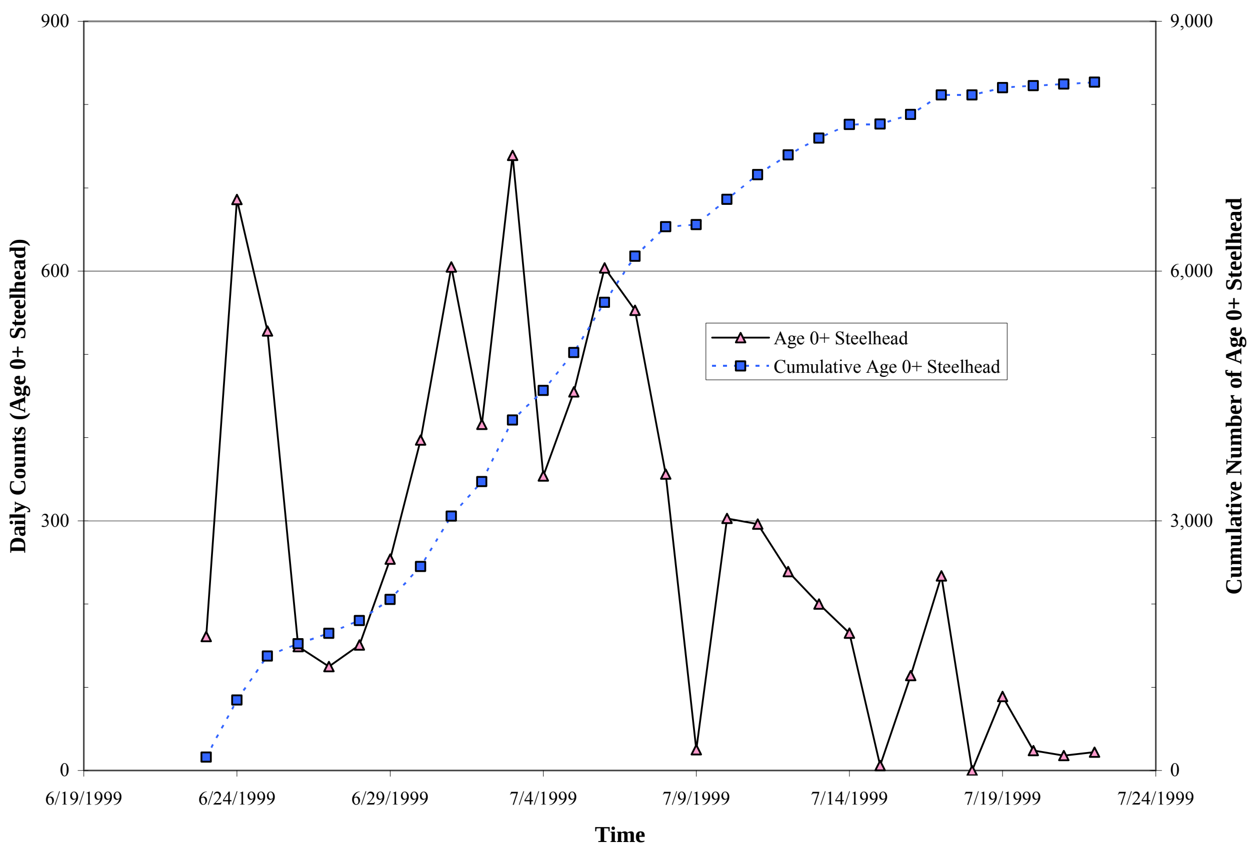

Figure 2.10. Daily and cumulative steelhead fry counts conducted near RM 0.8 in Umbrella Creek using a winged fyke net during the summer of 1999 (source: MFM, unpublished trap data).

2.1.5.2.5 Juvenile Steelhead Trout Freshwater Rearing

Very few data are available regarding juvenile steelhead freshwater rearing. Based upon trapping studies conducted in Umbrella Creek, it is possible that some juvenile rearing occurs in the lake. All other rearing occurs in accessible tributaries to the lake, or Ozette River. It is assumed that steelhead typically rear for one to three years prior to emigration. The majority of Washington steelhead smolts migrate at age 2 (Wydoski and Whitney 2003).

2.1.5.2.6 Steelhead Trout Seaward Migration

No directed attempts to enumerate steelhead smolt production in the Ozette watershed have been made. Steelhead smolts are captured during sockeye smolt trapping, but the period of the sockeye emigration is much shorter than the steelhead migration period and therefore only partial datasets for steelhead smolt production are available. In recent years (2001-2004), peak steelhead smolt counts have occurred from mid-April to early June. Steelhead smolts have been captured as early as April 13 (2002) and as late as July 1 (2001). No length or age data were collected for steelhead smolts during this period. Since no years contain a full dataset of the emigration time window, it is not possible to accurately produce smolt production estimates. All smolt monitoring periods do contain at least one period of record that overlaps with each of the other years of smolt trapping data. This makes it possible to compare relative proportions of smolts that migrated outside of the monitoring time frame for years where the trap was either pulled early or put in place late in the season. These periods were used to produce emigration proportions for each of the datasets from 2001 through 2004 and to produce general estimates of seasonal smolt production (Table 2.4).

Table 2.4. Ozette River steelhead smolt trapping periods, total steelhead smolts counted, expanded counts (based on trap efficiency), and estimated total steelhead smolt production (based on estimates for missing parts of the emigration period) (source: MFM, unpublished trap data).

Year	Start of Trapping	End of Trapping	Total Steelhead Smolts Counted	Expanded Count for Trap Efficiency	Estimated Steelhead Smolt Production
2001	5/24/2001	7/1/2001	170	543	4,784
2002	3/19/2002	5/30/2002	255	1,720	2,117
2003	5/13/2003	6/11/2003	87	1,652	6,667
2004	4/7/2004	6/1/2004	395	2,647	2,852

Unlike salmon, steelhead trout are iteroparous and may make several migrations from salt to freshwater to spawn. Upon spawning, some steelhead die but many survive. Those that survive spawning must then migrate back to the ocean. During this life history phase, steelhead are called kelts. Kelts are routinely observed transiting the adult sockeye weir and have also been captured during smolt trapping activities. There have been no attempts to quantify the total number of kelts migrating down the Ozette River, but most observations during smolt trapping and adult sockeye enumeration are recorded. A review of these records indicates that most kelts move down from the lake during the month of May. Smolt trapping in 2001, 2002, 2003, and 2004 captured 4, 2, 0, and 0 kelts respectively. All kelts captured during smolt trapping occurred between April 20 (2002) and June 7 (2001). Steelhead observations at the adult sockeye weir have been far more numerous then captures. From 1999 through 2002, a total of 648 steelhead observations were made at the weir. Table 2.5 depicts a summary of all adult steelhead observations at the weir. Note that some of the observations included are adults migrating upstream, but most are kelts migrating downstream.

Table 2.5. Summary of adult steelhead observations at the Ozette River counting weir from 1999 through 2002 (source: MFM, unpublished sockeye weir data).

Year	Start of Weir Operations	End of Weir Observations	Number of Steelhead Observations	First Steelhead Observation	Last Steelhead Observation
1999	4/30/1999	8/6/1999	34	5/3/1999	5/27/1999
2000	4/19/2000	8/12/2000	112	4/19/1999	7/14/2000
2001	4/30/2001	8/18/2001	50	5/1/2001	5/24/2001
2002	4/11/2002	8/14/2002	452	4/11/2002	6/21/2002

2.1.5.2.7 Steelhead Trout Marine/Ocean Phase

No information is available on this subject.

2.1.5.3 Steelhead Trout Hatchery Practices and Planting History

A query of the RMIS (2005) database indicates that no steelhead hatchery releases have occurred in this watershed. No release history is included in any of the stock assessment documents pertaining to the Ozette watershed (see WDF et al. 1994; McHenry et al. 1996; WDFW 2002).

2.1.5.4 Steelhead Trout Genetics

No information is available on this subject. No genetic analysis was been conducted on this stock (WDFW 2002).

2.1.6 Coastal Cutthroat Trout (*Oncorhynchus clarki*)

Coastal cutthroat trout are native to the Ozette watershed and are sustained through wild production (WDFW 2000). Coastal cutthroat trout in the Ozette watershed have been identified as a distinct stock complex based upon the geographic distribution of their spawning grounds (WDFW 2000).

2.1.6.1 Current and Historical Abundance

There are no current or historical abundance data for Ozette coastal cutthroat. The status of the stock complex is unknown (WDFW 2000). Beauchamp et al. (1995) speculated that 5,000 to 10,000 large (>300mm) cutthroat trout might reside in Lake Ozette. There are limited data regarding incidental captures of coastal cutthroat in Section 2.1.6.2.

2.1.6.2 Coastal Cutthroat Trout Life History

In general, coastal cutthroat trout exhibit four discrete life history forms: sea-run/anadromous, adfluvial, fluvial, and resident (Johnson et al. 1999). Little is known about the life histories displayed by coastal cutthroat trout in the Ozette watershed. WDFW (2000) speculated that the life history in Ozette is likely similar to that observed in Bear Creek (a tributary to the nearby Bogachiel River). While this is likely true for some segments of the population, it is likely not the case for the most significant component of the cutthroat population. Major differences exist between habitat types in the Bogachiel/Quillayute watershed and Lake Ozette. Lake Ozette, being the third largest natural lake in Washington State, provides a different habitat than the Bogachiel/Quillayute watershed. Fish within the watershed surely have adapted to take advantage of the unique lake habitat. Dlugokenski et al. (1981) captured a total of 209 cutthroat trout in Lake Ozette and stated that both resident and sea-run cutthroat were present within their sample. Dlugokenski et al. (1981) identified the adfluvial form of cutthroat trout as resident cutthroat trout (likely just a difference in terminology). It seems likely that the Ozette coastal cutthroat stock consists of three discrete life history types: sea-run/anadromous, adfluvial, and resident. The fluvial life history type of cutthroat trout may also exist in Ozette, but the small tributaries feeding the lake may not provide the habitat types required by this form of coastal cutthroat trout.

2.1.6.2.1 Sea-Run/Anadromous Cutthroat Trout

Emigrating and resident cutthroat trout are commonly captured during smolt trapping operations in the Ozette River (including cutthroat kelts). During spring sockeye smolt trapping from 2001 through 2004, a total of 207 cutthroat juvenile emigrants/kelts were captured (in approximately 209 days trapping effort). Based upon this very limited data, the number of emigrants appears higher in June than in April and May, although trapping efficiency varied by year and month. In S.E. Alaska streams, most emigrants move to salt water from mid-April to September (Wydoski and Whitney 2003). In Sand Creek (Oregon) cutthroat trout emigrate from January through June, but the majority (87%), migrate between April and June (Wydoski and Whitney 2003). Kelts return to salt water between March and early-April in Oregon and Washington streams, typically about 1 month prior to peak smolt emigration (Trotter 1989). Age at smolt emigration for cutthroat trout in tributaries to the Clearwater River (Olympic Peninsula) mostly appears to be 3 and 4 years, based on scale analysis of spawning fish (Fuss 1984).

Time spent in the estuary or at sea is highly variable for sea-run cutthroat trout, some spending as little as seven days or as many as 158 days (Petersburg Creek, S.E. Alaska; Wydoski and Whitney 2003). On average, sea-run cutthroat spend about 90 days at sea. While at sea, fish typically stay close to shore and do not make the extensive migrations seen with other anadromous salmonids (Trotter 1989). There are no records of sea-run cutthroat over-wintering at sea (Wydoski and Whitney 2003). Some cutthroat trout have been observed over-wintering in non-natal streams, but apparently these entries are not associated with spawning.

Adult sea-run cutthroat trout have been observed entering the Hoh and Clearwater Rivers as early as July, but most fish probably enter freshwater in September and October (Fuss 1984). Upon entering the Ozette River, fish may hold in the mainstem of the Ozette River or directly enter the lake or tributaries. Spawn timing of sea-run cutthroat trout on the Olympic Peninsula is typically between February and March (Fuss 1984). In an unnamed tributary to Nolan Creek (Hoh River, Olympic Peninsula) sea-run cutthroat have been observed spawning during the first week of January (Haggerty 2004B). The spawning distribution of sea-run cutthroat is not documented in the Ozette watershed but is likely similar to that observed in other nearby watersheds where cutthroat seek out small headwater tributaries for spawning.

2.1.6.2.2 Adfluvial Cutthroat Trout

Little is known about the adfluvial cutthroat trout population in Lake Ozette. Trotter (1989) describes this life history type of cutthroat trout to behave similarly to that of sea-run cutthroat trout, spending 1 to 3 years rearing in tributaries before migrating to the lake. Little research has been conducted on the tributary portion of the lives of adfluvial cutthroat populations (Trotter 1989). In food web studies conducted by Dlugokenski et al. (1981) and Beauchamp and LaRiviere (1993), no attempt to distinguish between sea-run and adfluvial cutthroat trout was made. For the purpose of this summary, their findings with respect to life history, feeding, and population structure will be considered to be for the adfluvial type of cutthroat trout. Dlugokenski et al. (1981) examined the stomach contents of 98 cutthroat trout captured and determined that the diet consisted of terrestrial insects (76%), aquatic insects (13%), fish (8%), and benthic invertebrates (4%). The fish consumed by cutthroat trout consisted of equal portions of yellow perch, sculpin, peamouth, and sockeye/kokanee. Northern pike minnow and coho salmon were eaten at a frequency of about one-half of the other three species. Nearly half of the fish remains found in stomach contents were unidentified fish. Dlugokenski et al. (1981) assumed a maximum of 4% of the cutthroat trout diet consisted of sockeye/kokanee salmon. However, the sampling design focused on the near-shore environment; thus, cutthroat trout in the limnetic zone were not included in the study. Beauchamp and LaRiviere (1993) found significantly different diets in the cutthroat they captured and examined. The authors did not clearly describe the actual stomach contents they examined, but stated that during spring, nearly 40% of the diet of cutthroat trout > 300mm FL was age-0 and age-1 O. *nerka*, while juvenile coho salmon made up 0% of the diet. The total number of fish sampled is also not clearly indicated, but in the methods section the authors describe sampling 15 fish <300 and >300 mm FL of each species. As with sea-run cutthroats, the spawning distribution of adfluvial cutthroat is not documented in the Ozette watershed but is likely similar to that observed in other nearby watersheds where cutthroat seek out small headwater tributaries for spawning

2.1.6.2.3 Resident (Non-Migratory) Cutthroat Trout

The resident life history form does not typically undertake significant migrations but simply maintains a small home territory (Johnson et al. 1999). The resident life history form differs significantly from the anadromous form. Most importantly, resident cutthroat populations are typically isolated from one another spatially. In WDFW (2000), the authors speculate that the later spawn timing (April-May) of resident cutthroat further isolates them from the anadromous form. Little is known about the specifics of this life history type within the Ozette watershed other than that it can be found in most perennial streams with gradients less than about 20%. Little interaction between resident non-migratory cutthroat trout and anadromous salmonids is thought to occur within the watershed.

2.1.6.3 Coastal Cutthroat Trout Hatchery Practices and Planting History

There are no hatchery plants of anadromous or resident cutthroat trout in the Ozette watershed (WDFW 2000). No records of past hatchery plants into Lake Ozette have been found.

2.1.6.4 Coast Cutthroat Trout Genetics

The number of genetically distinct stocks within the Ozette stock complex is unknown; genetic sampling and analysis are needed in order to determine the genetic composition of the stock complex (WDFW 2000).

2.2 NATIVE NON-SALMONID FISH POPULATIONS

Native non-salmonid fish populations in the Lake Ozette watershed are speckled dace, four types of sculpins, Western and Pacific lamprey, threespine stickleback, Olympic mudminnow, peamouth, northern pikeminnow, and redside shiner.

2.2.1 Speckled Dace (*Rhinichthys osculus*)

Little is known about the presence and distribution of speckled dace in the Ozette watershed. Mongillo and Hallock (1997) concluded that they are likely present within the watershed and include them in the map depicting the range of speckled dace on the Olympic Peninsula. Mongillo and Hallock (1997) did not capture speckled dace at their sample sites within the Ozette watershed but concluded that they were likely present based upon captures in the nearby Dickey River watershed. Speckled dace are primarily associated with stream bottoms. Their food sources are typically of benthic origin (Wydoski and Whitney 2003). They are not considered to be competitors with sockeye in the Lake Ozette watershed and are only presumed to be present.

2.2.2 Sculpins (*Cottus Spp*)

Little is known about the presence, distribution, or abundance of sculpins in the Ozette watershed. To date only three species of sculpin have been positively identified in the Ozette watershed; prickly, riffle, and reticulate sculpin. However, there has not been a systematic search including species identification conducted. Mongillo and Hallock (1997) did not capture coastrange, riffle, or torrent sculpins at their sample sites within the Ozette watershed but concluded that they were potentially present based upon captures in the nearby Dickey River and Hoko River watersheds. Wydoski and Whitney (2003) include the Lake Ozette watershed within the range of prickly, reticulate, riffle, coastrange, and torrent sculpins. Additional complexities in the identification of species within the watershed also exist. Reticulate and riffle sculpins are not clearly separated by existing taxonomic descriptions (Wydoski and Whitney 2003), further hindering obtaining conclusive evidence of the existence of one or both of these species in the Ozette watershed. During sockeye fry trapping in Umbrella Creek in the spring of 1999, sculpins of undermined species (any of the 5 potentially present species) were observed preying upon juvenile sockeye and coho in the trap. Sockeye were preyed upon in much higher numbers than other species present in the trap, even though coho salmon fry outnumbered sockeye at a ratio of up to 10:1.

2.2.2.1 Prickly Sculpin (Cottus asper)

Mongillo and Hallock (1997) captured this sculpin species at two sampling locations along the shoreline of Lake Ozette but none in the tributaries to the lake. Dlugokenski et al. (1981) captured and examined the stomach contents of 74 prickly sculpins and found that 1/3 of the stomach contents were fish eggs. No fish species were present in any of the stomach contents examined, but this is could be a function of sample timing and location. Prickly sculpin are known to feed on small fishes, including redside shiner, threespine stickleback, longfin smelt, yellow perch, lamprey, and juvenile salmonids (Wydoski and Whitney 2003). Wydoski and Whitney (2003) suggest that prickly sculpin may eat more fish than other species of sculpin because they grow larger than other species of sculpin, allowing them to capture and swallow fish more easily. During the fall of 1998 in Lake Washington, 53% of the diet of prickly sculpin > 150 mm TL were sockeye salmon pre-smolt (Warren personal communication 2000 *in* Wydoski and Whitney 2003). Beauchamp and LaRiviere (1993) concluded that prickly sculpin were an important prey food for both cutthroat trout and northern pikeminnows in Lake Ozette.

2.2.2.2 Reticulate and Riffle Sculpin (C. perplexus; gulosus)

As described above, information on the distribution and abundance of these sculpin species is not available for the Ozette watershed. Mongillo and Hallock (1997) captured reticulate sculpin at two sampling locations in Big River but not at any of the other sampling locations in the watershed. Reticulate and riffle sculpins are not clearly separated by existing taxonomic descriptions (Wydoski and Whitney 2003). However, a riffle sculpin was collected from Allen's Bay in 1991 and is part of the University of Washington fish collection. Riffle sculpin feed primarily on crustaceans, aquatic insect larvae, and snails (Wydoski and Whitney 2003). In the Cedar River, riffle/reticulate sculpins as small as 45mm TL consumed sockeye fry (Tabor and Chan 1996). Reticulate sculpin feed primarily on immature aquatic insects and larvae of other insects, such as midges, beetles, and caddisflies (Wydoski and Whitney 2003). Reticulate sculpin are also known to feed on other sculpin, salmon eggs, and fry (Wydoski and Whitney 2003). Reticulate sculpin can burrow into gravel and cobble substrates quite deeply; sculpin 50-75 mm can penetrate substrate to depths of 175mm (Wydoski and Whitney 2003).

2.2.2.3 Coastrange Sculpin (Cottus aleuticus)

Wydoski and Whitney (2003) describe the coastrange sculpin as inhabiting medium- to large-size rivers with moderate current and being distributed along the entire Olympic Peninsula. Coastrange sculpins in Olympic Peninsula streams have been documented to prefer habitats with current, which segregates them from habitat types used by coastrange and prickly sculpins (Wydoski and Whitney 2003). Coastrange sculpin feed primarily on stoneflies and other aquatic insects, but may also feed on salmon eggs and fry (Wydoski and Whitney 2003). Foote and Brown (1998) found that the largest sculpins could consume 50 fresh sockeye eggs per day (130/week). They found sculpin densities in sockeye nests as high as 100 sculpins per m^2 in Lake Iliamna, Alaska. Coastrange sculpin as small as 50mm TL have been found to feed on sockeye fry in the Cedar River, Washington (Wydoski and Whitney 2003).

2.2.2.4 Torrent Sculpin (Cottus rhotheus)

As described above, information on the distribution and abundance of torrent sculpin are not available for the Ozette watershed. Mongillo and Hallock (1997) did not capture this sculpin species at any of their sampling sites within the watershed. Lake Ozette is within the reported range of torrent sculpins by Wydoski and Whitney (2003). Torrent sculpin feed primarily on similar prey items to prickly sculpin but frequent higher velocity habitats in streams (Wydoski and Whitney 2003).

2.2.3 Western Brook Lamprey (*Lampetra richardsoni*)

There is some confusion with respect to the presence of western brook lamprey in the Ozette watershed. Spawning lampreys of undetermined species approximately 6 inches (150 mm) long have been observed above falls and/or culverts that were thought to be anadromous barriers (Mike Haggerty, personal communication, 2004). Two spawning lampreys approximately 6 inches (150 mm) long were also observed in late June 2004 in Crooked Creek (Andy Ritchie, personal communication, 2004). It was assumed that these individuals were brook lamprey. However, MFM (2000) and NMFS (2003) both state that river lamprey (*Lampetra ayresi*) are present within the watershed. Mongillo and Hallock (1997) found no river lamprey at any of their sampling sites on the Olympic Peninsula. Only one documented occurrence of river lamprey on the Olympic Peninsula was found by Mongillo and Hallock (1997) and that occurred in Lake Cushman in 1931. Since brook lamprey are non-anadromous, and given the size of observed spawning lampreys, it is probable that western brook lamprey were the species found above what were believed to be anadromous barriers in the Ozette watershed. Mongillo and Hallock (1997) found no western brook lamprey at any of the sampling sites within the watershed and did not include this species as being potentially present even though it is found just a few miles away in the Quillayute River.

2.2.4 Pacific Lamprey (*Lampetra tridentata*)

Little is known about the abundance of Pacific lamprey within the Ozette watershed. They are relatively common in most of the larger streams, including Ozette River, Umbrella Creek, Big River, and Crooked Creek. They may be common in small streams as well, but very limited data are available. Meyer and Brenkman (2001) found at least three lamprey in Siwash Creek but did not identify the species. Lamprey have been observed transiting the sockeye weir between mid-April and July but only in very low numbers, likely because they are able to pass through the pickets and are not forced to transit through the weir opening where the camera is positioned. Several lamprey were captured during adult sockeye trapping in the spring and early summer of 2000. A total of 909 sockeye were captured but not handled. Only visual observation of these fish occurred, and it was determined that at least 3.9% of the sockeye either had attached lamprey or lamprey scars (both fresh and old).

Lamprey have also been captured during smolt trapping activities in the Ozette River. These have included both adults (spawning size) and small lamprey in adult form (presumed to be juveniles migrating to sea). Lamprey have been found in the stomach contents of large northern pikeminnows captured from the Ozette River. Between 2001 and 2004, an average of 5-10 lamprey have been captured during smolt trapping activities in the Ozette River. More quantitative data are available for Pacific lamprey abundance in Umbrella Creek from sockeye fry trapping during the spring of 1999. A total of 82 lamprey were captured; 9 were adults and 73 were juveniles (adult form but small size < 20cm) apparently in the process of migrating to sea.

2.2.5 Threespine Stickleback (*Gasterosteus aculeatus*)

Threespine stickleback are thought to occur in low numbers in the Ozette watershed (Beauchamp and LaRiviere 1993). They have been captured in low numbers (6 and 7 individuals in 2003 and 2004, respectively) in the Ozette River smolt trap. Miscellaneous observations have also occurred in different areas of the lake. No threespine stickleback were captured during sockeye fry trapping in Umbrella Creek in 1999 and 2001. No threespine stickleback were captured by Meyer and Brenkman (2001) or Mongillo and Hallock (1997) in efforts to determine species composition at several sites in tributaries to Lake Ozette. They have been observed in Trout Creek, a tributary to Big River. Beauchamp and LaRiviere (1993) attempted to capture threespine stickleback in vertical gill nets and baited minnow traps in the lake but were unsuccessful. Typically, threespine stickleback make up a major component of coastal cutthroat trout diets; however, they were absent in the diet of cutthroat trout in examined in Lake Ozette (Beauchamp and LaRiviere 1993). These are important observations, because threespine stickleback can compete with sockeye and reduce the quantity and quality of food available for sockeye fry/parr consumption (Burgner 1991). This does not appear to be the case in Lake Ozette (Dlugokenski et al. 1981; Beauchamp et al. 1995). Ruggerone (1991) found that threespine stickleback aggregations can potentially create predation refuge for sockeye salmon fry from predatory juvenile coho salmon.

2.2.6 Olympic Mudminnow (*Novumbra hubbsi*)

Little is known about the abundance and distribution of Olympic mudminnows in the Ozette watershed. Jacobs et al. (1996) reported that the question of mudminnows being native to the Ozette watershed remained unresolved. However, Mongillo and Hallock (1999) concluded that Olympic mudminnows were indeed native to Ozette. They hypothesized that because Ozette remained ice free during the last glaciation, the basin provided refugia to Olympic mudminnows, as well as many other species. Olympic mudminnows have been documented in at least 6 sites in the Ozette watershed, including Ericson’s Bay, Allen’s Bay, Boot Bay, and Swan Bay. Mudminnows require three habitat characteristics, and if any one of these characteristics is missing, no mudminnows will be present: 1) several centimeters of soft mud bottom substrate, 2) little or no water flow, and 3) an abundance of aquatic vegetation (Mongillo and Hallock 1999). Statewide population trends are considered stable, but mudminnows are extremely sensitive to habitat alterations. Mudminnows are not considered competitors with sockeye, since there is little if any overlap in habitats utilized and food consumed.

2.2.7 Peamouth (*Mylocheilus caurinus*)

Peamouth are a species of chub that occur throughout the lake. Dlugokenski et al. (1981) noted that peamouth were the most abundant fish captured during their gillnetting study. They found fish in spawning condition in all of their sampling locations from mid-April to mid-June, with the highest concentrations occurring in May. Peamouth are known to spawn in the Ozette River and Umbrella Creek. Peak entry and spawning activity in Umbrella Creek occurs around Memorial Day, when black clouds of peamouth can be observed spawning just downstream of the Hoko-Ozette Road. They likely spawn in other tributaries to Lake Ozette, but no data are available regarding their use of other tributaries. Peamouth are captured in the Ozette River smolt trap in relatively high numbers; in 2001, 2003, and 2004 there were 928, 174, and 418 peamouth captured, respectively.

Within the lake it was concluded that peamouth have minimal spatial overlap with sockeye salmon because of the observed nearshore distribution of the species (Dlugokenski et al. 1981). Gillnet captures indicate that small peamouth occur in Lake Ozette offshore areas at depths of 1-40 meters (in low numbers) and that large individuals tend to occur in nearshore areas (Beauchamp and LaRiviere 1993; Jacobs et al. 1996). Peamouth diets are dominated by benthic prey items for all size classes of fish throughout the entire year (Beauchamp et al. 1993). Jacobs et al. (1996) reported that peamouth ate sockeye salmon eggs but that the extent of this behavior was unknown. Dlugokenski et al. (1981) concluded that peamouth were likely not significant competitors with sockeye salmon in Lake Ozette.

2.2.8 Northern Pikeminnow (*Ptychocheilus oregonensis*)

In the past, some have speculated that northern pikeminnows may have been introduced to Lake Ozette (e.g. Jacobs et al. 1996); however, Kemmerich (1926) describes homesteaders stating in 1923 that the lake is "*full of squaw fish [northern pikeminnow]*." These early observations should dispel any suggestion that northern pikeminnow were introduced to lake. They are present in the nearby Dickey Lake and Dickey River and were considered native in Lake Ozette in a recent review of non-game fishes conducted by Mongillo and Hallock (1997). Pikeminnows are quite abundant in Lake Ozette. Dlugokenski et al. (1981) state that northern pikeminnows were the second most abundant fish species captured in gillnet samples taken from Lake Ozette during randomized monthly sampling from 1977 to 1979. Beauchamp et al. (1995) speculated that the population of large (>300mm), northern pikeminnows numbered 5,000 to 15,000 based upon nearshore gillnet sampling. The distribution within the Ozette watershed appears limited to the lake and upper Ozette River. Large schools of northern pikeminnow congregate at the lake's outlet as early as mid-April and peak in late May through June. Most individuals are ripe and in spawning condition. While in the upper river these fish feed primarily on juvenile salmonids, mostly sockeye and coho smolts, but they have been observed eating other species present in the Ozette River, including yellow perch and redside shiners. During the spring of 2001, approximately 1,108 northern pikeminnows were captured in the smolt trap and in 2002, 2003, and 2004 an additional 366, 31, and 403 fish were captured, respectively.

The lake's outlet and upper-river area appears to be a major spawning site for northern pikeminnows from Lake Ozette. The area adjacent to Garden Island also is known to be a significant spawning site for northern pikeminnows in Lake Ozette. The diet of northern pikeminnows has been examined in detail. Dlugokenski et al. (1981) determined that terrestrial insects composed 37% of the year-round diet and benthic invertebrates 21%. The remaining diet was 21% fish, 14% aquatic insects, and 7% plant matter. However, the sampling design did not incorporate the off-shore component of the northern pikeminnow population. Beauchamp and LaRiviere (1993) sampled the off-shore environment and determined that only 2-29% of the northern pikeminnow population used the off-shore environment (depending upon the season). However, in the summer, 100% of the limnetic northern pikeminnow's diet was composed of sockeye/kokanee (Beauchamp and LaRiviere 1993). In the winter, up to 90% of their diet was composed of sockeye/kokanee (Beauchamp and LaRiviere 1993). All northern pikeminnows greater than 450 mm in length captured in the limnetic zone fed exclusively on sockeye/kokanee (Beauchamp and LaRiviere 1993). No studies have been conducted exclusively focusing upon potential impacts of northern pikeminnows feeding at the lake's outlet or in the Ozette River during the smolt emigration period.

2.2.9 Redside Shiner (*Richardsonius balteatus*)

The abundance, distribution, and life history of redside shiners in the Ozette watershed is poorly documented and understood. Redside shiners are present throughout the lake and the Ozette River. They have been captured in the Ozette River smolt trap in moderate numbers. A total of 51, 1, 18, and 8 redside shiners were captured in 2001, 2002, 2003, and 2004 respectively. No captures were indicated in studies conducted by Dlugokenski et al. (1981) or Beauchamp and LaRiviere (1993). Redside shiners did not appear in the diets of any of the piscivorous fish species in these studies, which is surprising since they compose a portion of coastal cutthroat diets in other Olympic Peninsula lakes (e.g. Lake Sutherland). The degree to which they compete and interact with sockeye in Ozette is not understood. Juvenile redside shiners feed on zooplankton and algae (Jacobs et al. 1996). Adults feed on insects and snails and zooplankton when in the pelagic zone (Jacobs et al. 1996) and may compete with sockeye for zooplankton in the pelagic zone (NMFS 2003).

2.3 EXOTIC FISH POPULATIONS

Exotic fish populations within the Lake Ozette watershed include: tui chub, American shad, yellow perch, largemouth bass, yellow bullhead, and brown bullhead. A brief description of each species present is included below in sections 2.3.1 through 2.3.5.

2.3.1 Tui Chub (*Gila bicolor*)

The presence of tui chub was not documented in Lake Ozette until the spring of 2002. Mongillo and Hallock (1997) do not include tui chub as a species native to the Olympic Peninsula. Wydoski and Whitney (2003) do not include the Ozette watershed as part of the range of this species. Fish identified as tui chub have been captured in the Ozette River smolt trap. A total of 30, 1, and 3 tui chub were captured in the smolt trap in 2002, 2003, and 2004. Upon hatching, young tui chub feed on diatoms, rotifers, desmids, and other microscopic food (Wydoski and Whitney 2003). Juveniles feed on zooplankton, including copepods and cladocerans, while adults feed on plankton, insects, crustaceans, fish larvae, and fry (Wydoski and Whitney 2003). Wydoski and Whitney (2003) noted that tui chub often become overpopulated and compete with young trout. This does not appear to be the case in Lake Ozette. Further research is needed to understand the abundance and distribution of this species, as well as the species' origin and history in Ozette. It seems peculiar that it is present in Lake Ozette and not in any other nearby habitats.

2.3.2 American Shad (*Alosa sapidissma*)

American shad were first observed and captured in the Ozette watershed on June 16, 2000 during adult sockeye trapping operations. A single fish was collected and transferred to ONP for archiving in their fish collection. Little is known about shad abundance and distribution in the watershed. American shad have been observed entering the lake in relatively low numbers. A total of 6 adult shad were captured in the Ozette River during smolt trapping operations between 2000 and 2004. It is thought that the shad observed in Ozette are dip-ins and that they do not spawn in the lake or its tributaries. No juvenile shad have ever been captured in the lake or any of its tributaries. Much higher numbers of shad have been observed in the lower Ozette River. Groups of shad including 20-40 individuals were observed in the inter-tidal reaches and reaches just upstream from the zone of tidal influence during a snorkel survey conducted in the summer of 2000.

2.3.3 Yellow Perch (*Perca flavenscens*)

Yellow perch are not native to Lake Ozette. The earliest documentation of yellow perch introductions into the lake comes from a Port Angeles Evening News article (August 17, 1929). This article describes volunteers from the Izaak Walton League transporting yellow perch from Lake Pleasant to Lake Ozette in live boxes. Dlugokenski et al. (1981) concluded that yellow perch were the third most abundant fish species in Lake Ozette based upon gillnet captures in the nearshore environment. They found that yellow perch were in advanced stages of sexual maturity for eight months out of the year (February through May, and October to December). Beauchamp and LaRiviere (1993) found that low numbers of perch used the pelagic portions of the lake and that all pelagic perch were <200mm FL. In the pelagic zone, fish were captured at depths of only 2-3 m in April, but were much deeper (19-38 m) in autumn. Pelagic perch captured in the lake did not consume zooplankton; they fed primarily on insects and benthic invertebrates. However, the smallest perch (<125mm) were not susceptible to capture in the vertical gillnets used and therefore no prey analysis could be performed on these fish.

In other lakes, young perch feed on zooplankton, particularly cladocerans and copepods (Wydoski and Whitney 2003). In Lake Ozette, larger perch (>150 mm) were captured almost exclusively in the nearshore environment, where they fed primarily on insects, invertebrates, sculpin, and unidentified fish species (Beauchamp and LaRiviere 1993). The largest perch (>250 mm) became cannibalistic during winter and spring (Beauchamp and LaRiviere 1993). Yellow perch were not found to prey on sockeye salmon in Lake Ozette in studies conducted by Dlugokenski et al. (1981) or Beauchamp and LaRiviere (1993). Tabor and Chan (1996) found that yellow perch did not prey upon juvenile salmonids in Lake Washington. Little spatial overlap exists between piscivorous perch (>200 mm) and juvenile sockeye, making yellow perch an unlikely predator of juvenile sockeye. However, yellow perch compete for zooplankton resources in Lake Ozette. Dlugokenski et al. (1981) concluded that yellow perch <119mm FL fed primarily on zooplankters and thus were directly competing with juvenile sockeye salmon. Beauchamp and LaRiviere (1993) concluded that young yellow perch could represent a significant source of competition for the zooplankton resource in Lake Ozette during early spring.

2.3.4 Largemouth Bass (*Micropterus salmoides*)

Largemouth bass are not native to Lake Ozette. The history and timing of the introduction of this species is currently unknown. Little is known about the distribution and abundance of largemouth bass in Lake Ozette. Dlugokenski et al. (1981) report the presence of largemouth bass in the lake but do not include data on catch in the nearshore gillnets used for fish sampling. Beauchamp and LaRiviere (1993) caught only six largemouth bass during their vertical and nearshore gillnet sampling in the lake. They concluded that largemouth bass are not very vulnerable to gillnets. Other largemouth bass captures in the lake have typically occurred in shallow bays. In general, largemouth bass prefer clear water with bottoms composed of mud, sand, and organic material, which provide optimal substrates for rooted aquatic vegetation (Wydoski and Whitney 2003). Largemouth bass are seldom encountered at depths > 10 to 20 feet (Wydoski and Whitney 2003). The only identifiable fish remains in largemouth bass captured by Beauchamp and LaRiviere (1993) were yellow perch. Beauchamp and LaRiviere (1993) concluded that largemouth bass and juvenile sockeye were spatially segregated during the growing season but a combination of conditions in spring could draw the bass nearshore earlier while fry and smolts pass through the littoral zone, making juvenile sockeye susceptible to predation by largemouth bass. Largemouth bass fry in Lake Washington primarily feed on copepods, cladocerans, and midge larvae (Wydoski and Whitney 2003). In Lake Sammamish, largemouth bass feed extensively on fish, with 42% of their diet composed of salmonids (Wydoski and Whitney 2003).

2.3.5 Brown Bullhead (*Ictalurus nebulosus*) and Yellow Bullhead (*Ictalurus natalis*)

Brown and yellow bullhead are not native to Lake Ozette. The history and timing of the introduction of these bullhead species is currently unknown. Little is known about the distribution and abundance of brown and yellow bullhead in Lake Ozette. These species were first identified as present within the lake by ONP in the early 1990s. Additional bullhead captures have occurred on at least five occasions during sockeye trapping operations in the Ozette River. Based upon the low number of encounters of this species, it is difficult to summarize its potential range and feeding patterns within the lake. However, it is unlikely that either bullhead species would have been susceptible to the gear types used in the food web investigations conducted by Dlugokenski et al. (1981) and Beauchamp and LaRiviere (1993).

Yellow bullhead prefer clear water habitat in slow moving streams, ponds, and lakes where abundant vegetation exists (Wydoski and Whitney 2003). Brown bullhead prefer warm water habitats within lakes, sloughs, and sluggish areas in streams. In tagging studies conducted in Lake Washington, brown bullhead were recaptured only near the location where they were tagged (Wydoski and Whitney 2003). In another tagging study conducted in Folsom Lake (CA), tagged brown bullhead moved an average of 1.7 miles prior to being recaptured, with a maximum movement of 16.2 miles (Wydoski and Whitney 2003).

Yellow bullhead primarily feed at night. Their diet consists of insects, crustaceans, molluscs, plant matter, and fishes (Wydoski and Whitney 2003). Young brown bullhead feed primarily on zooplankton (including cladocerans, such as *Daphnia*) and midge larvae, while larger fish feed on midges, mayflies, worms, and crustaceans (Wydoski and Whitney 2003). Stomach contents of brown bullhead captured in Lake Washington contained primarily fish eggs (94% by weight) and benthic invertebrates; no fish remains were observed (Tabor and Chan 1996). Tabor and Chan (1996) captured one brown bullhead in the Cedar River (Lake Washington, WA) and examined its stomach contents, which contained the remains of one coho smolt.

3 THE SOCKEYE SALMON POPULATION

This chapter presents detailed biological information that sets the context for the investigation of factors currently limiting the Lake Ozette sockeye salmon population's survival and recovery. Sockeye life history, hatchery practices, population structure, abundance, trends, and productivity are reviewed.

3.1 LAKE OZETTE SOCKEYE LIFE HISTORY

Information regarding Lake Ozette sockeye life history forms the foundation for subsequent discussions addressing limiting factors and potential threats to population recovery. The limiting factors affecting Lake Ozette sockeye are evaluated by life stage in Chapter 5. In this section, Ozette sockeye life histories are described and evaluated assuming a single population divided into seven life history phases: 1) adult sockeye entering system, 2) adult holding in the lake, 3) spawning and incubation, 4) fry emergence and dispersal, 5) juvenile freshwater rearing, 6) seaward migration, and 7) marine/ocean phase. Beach and tributary spawning aggregations differ in the spawning, incubation, emergence and dispersal phases, and tributary spawners have a brief extra phase of migration to the lake as fry. The general timing of each life history phase of Lake Ozette sockeye is depicted in Figure 3.1.

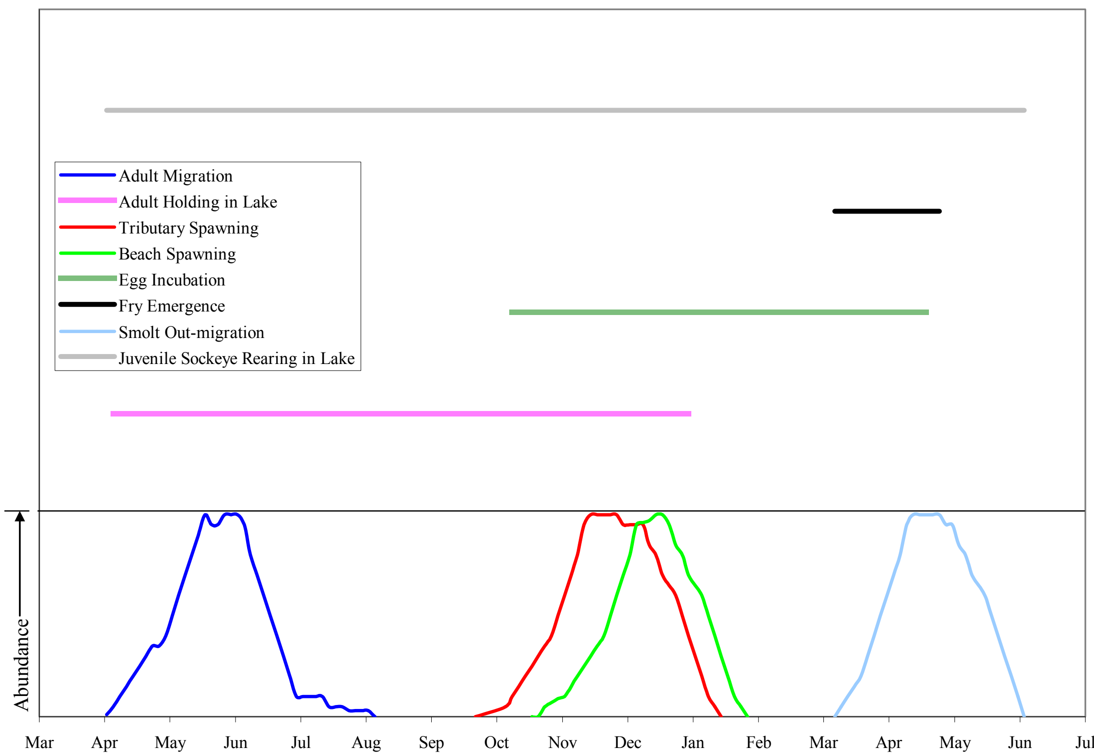

Figure 3.1. Conceptualization of Lake Ozette sockeye life history and timing (modified from Jacobs et al. 1996). (Note that migration, tributary spawning, beach spawning, and smolt emigration are scaled to the estimated relative abundance of animals displaying a life history trait through time, whereas holding, incubation, emergence, and rearing are plotted without a scale of relative abundance.)

3.1.1 Adult Sockeye Entering System

Lake Ozette sockeye begin entering the Ozette River and arriving at the lake in mid-April. In recent years the run typically peaked between late May and mid-June, ending in early to mid-August (recent run-size estimates have used a run-time window of April 15 to August 15). Kemmerich (1926) reported that the sockeye runs in 1924, 1925, and 1926 ended on August 8, September 15, and September 8, respectively. Figure 3.2 illustrates the average daily proportion of sockeye that enter the lake for each day of the run-time window (based on 1998-2003 weir data and run-size estimates). In recent years (1998-2003), 50% of the sockeye run has entered the lake as early as May 27 (2000), and no later than June 14 (1998; Figure 3.3). Data collected and presented by Dlugokenski et al. (1981) found that peak run timing during return years (RY) 1977 through 1980 was between June 5 and June 24. Dlugokenski et al. (1981) estimated that 63.3% of the sockeye run entered during that period. Weir data from RY 1998-2003 indicate that only 34.6% of the sockeye run entered the lake during this same time period (range: 19.8-48.8%; Haggerty 2005d). These differences in run timing may be a function of a shift in run timing, or more likely the consequence of the quality of weir data collected in the past, coupled with the lack of monitoring during the early portion of the run.

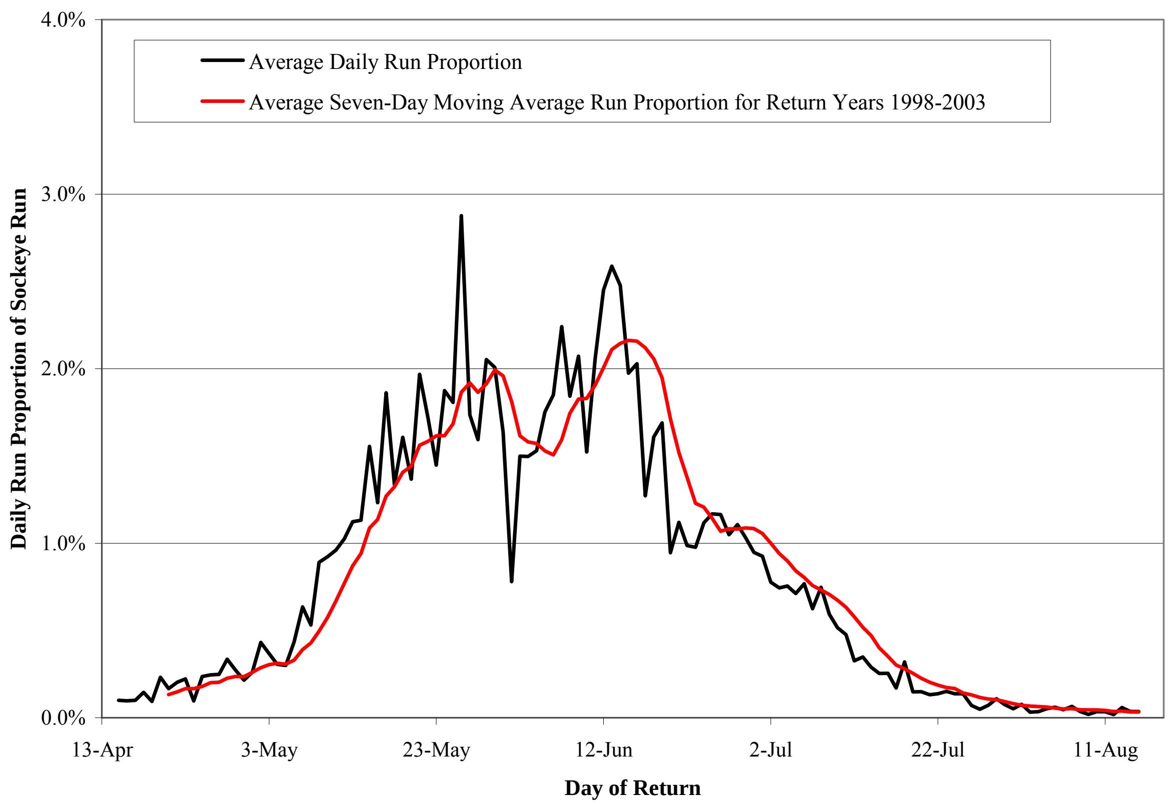

Figure 3.2. Mean daily run proportion and the mean 7-day moving average for return years 1998-2003 (source: Haggerty 2005d).

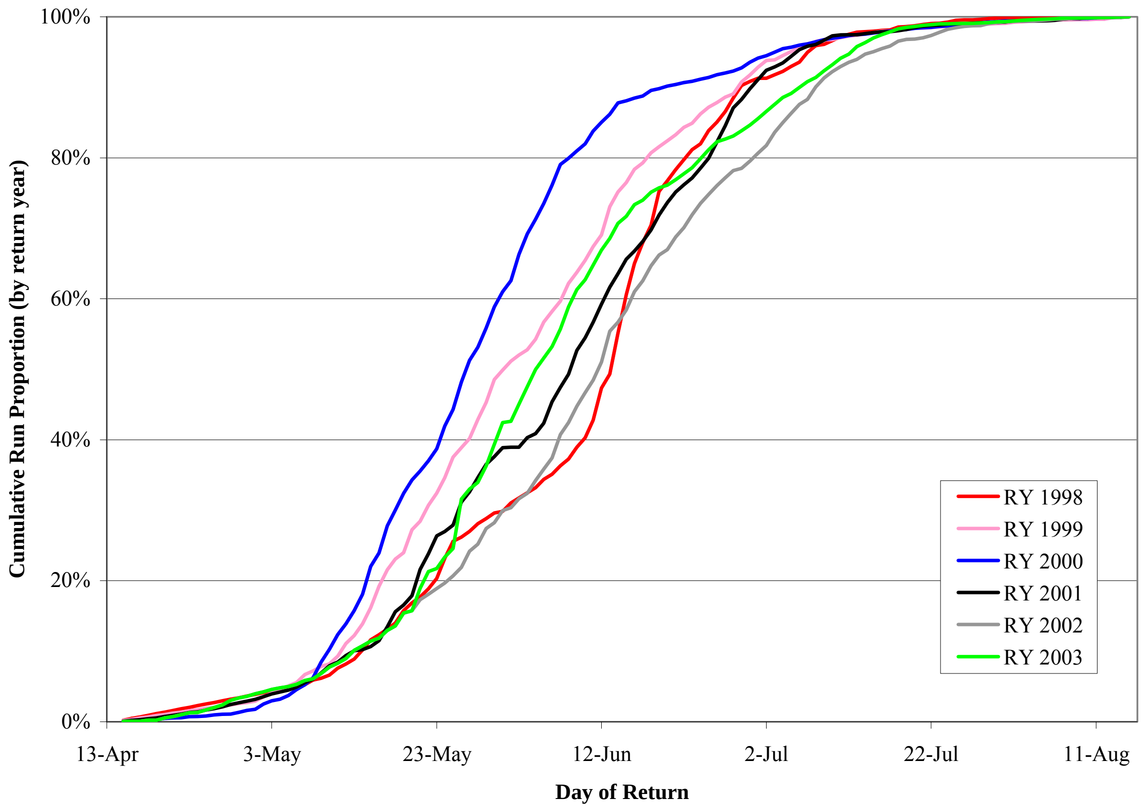

Figure 3.3. Observed and estimated cumulative run proportion by return year for years 1998 through 2003 (source: Haggerty 2005d).

Sockeye residence time in the Ozette River has been reported to be short (~48h) based on observations of sockeye transiting the weir with sea lice attached (Dlugokenski et al. 1981; MFM 2000). The life span of sea lice in freshwater can range from a few days up to 21 days (Pike and Wadsworth 1999). Gearin et al. (2002) reported that the mean transit time for adult sockeye from ocean to lake entry in RY 2000 was 65.2 hours (Figure 3.4; range=17-154hrs).

Past studies and reports have indicated that the majority of the run transits the counting weir at the lake's outlet between dusk and dawn (Dlugokenski et al. 1981; LaRiviere 1991; MFM 1992). Monitoring at the weir in past years (pre-1998) typically occurred at "nighttime," between 22:00 and 07:00. However, recent (1998-2003) 24-hour time-lapse camera counts indicate that lake level[10] is the most important factor in determining the proportion of the run that transits the weir during daylight hours. In most years, the peak

[10] Lake level has been used as a surrogate for streamflow in Ozette weir studies mainly because no stream gage has been operated during the majority of years when weir data has been collected. ONP has maintained a staff gage and has compiled an extensive dataset on lake level just downstream of the lake's outlet. Stage at this gage has a direct relationship with stream discharge at the weir; for the sake of consistency and ease of interpretation "lake level" will be used throughout this document instead of streamflow.

of the sockeye run coincides with periods of “low” lake level, typically resulting in a low percentage of sockeye transiting the weir during daylight hours (Figure 3.5). However, in years when the lake level is higher during the peak of the run, as much as 65% of the run appears to transit the weir between 07:00 and 22:00 (Haggerty 2005c). Although tidally influenced migration patterns have not been identified, they are thought to exist as well.

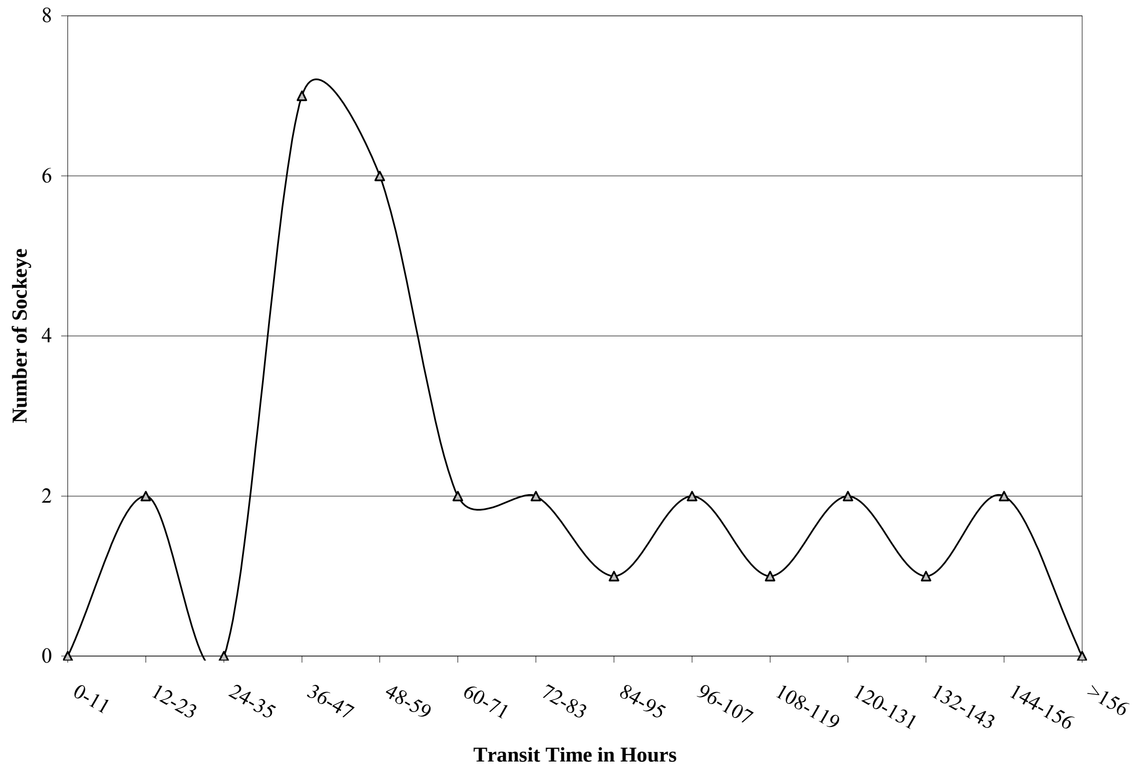

Figure 3.4. RY 2000 transit times from estuary to weir for 28 tagged sockeye (source: Gearin et al. 2002).

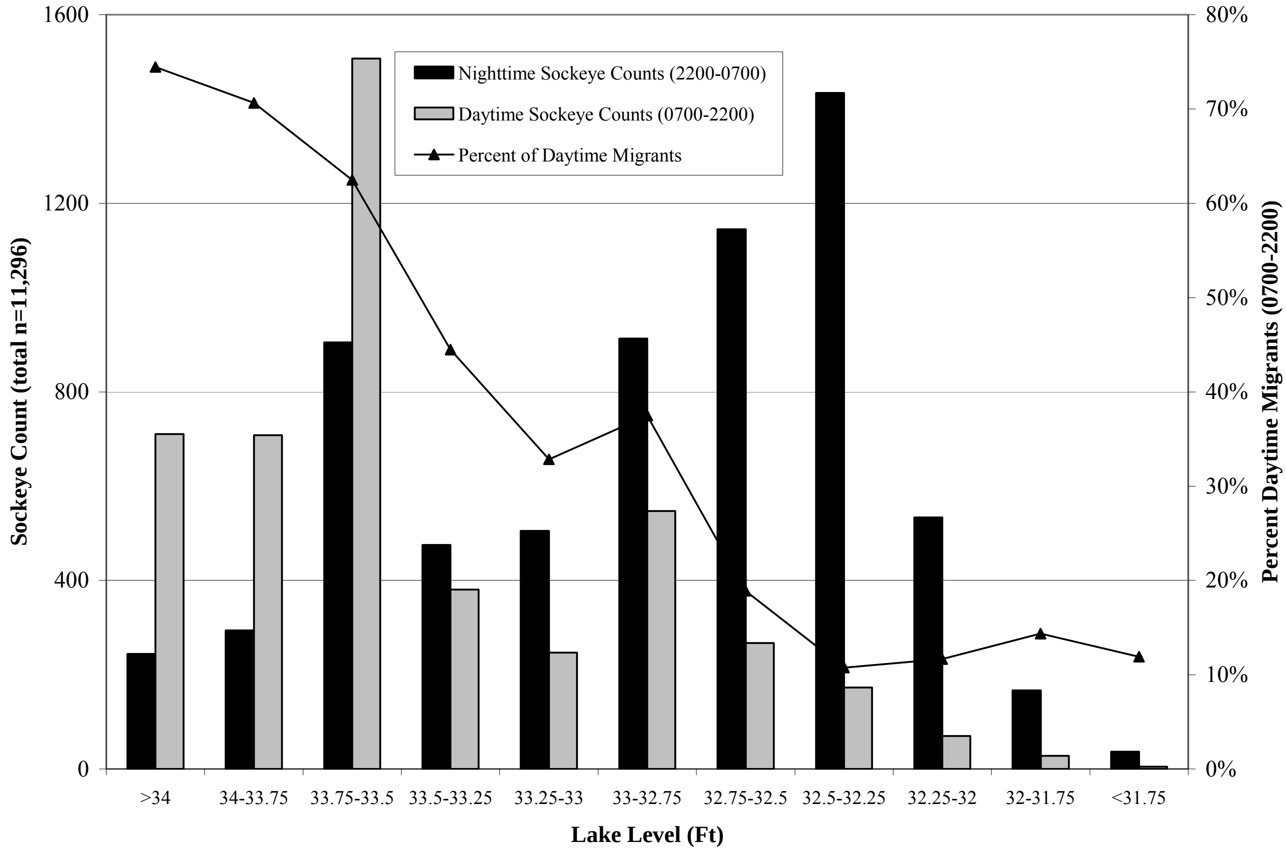

Figure 3.5. A comparison of day- and night-time sockeye transits through the weir relative to lake level for combined sockeye counts from return years 1999, 2000, 2002, and 2003 (source: Haggerty 2005d).

3.1.2 Adult Sockeye Holding in Lake Ozette

Sockeye hold for an extended period in Lake Ozette. Adult sockeye begin entering the lake in mid-April and have been observed spawning through late February. Peak spawning in recent years has been observed in December, while peak immigration occurs from late May to mid-June. This indicates an average holding time of roughly 6 months, although individual fish may hold for as little as 3 months, or as long as 9 months.

Combined acoustic-radio tag (CART) studies in 2000 and 2001 indicated that adult sockeye holding distribution was mostly restricted to the eastern half of the lake (Hughes et al. 2002). The majority of tagged fish occupied the northern and eastern portions of the lake through the month of September. Tagged fish were only detected in the western portion of the lake after spawning had started. The majority of holding sockeye stayed at depths greater than 32 feet (10 m), as evidenced only by hydrophone detection. Sockeye did not appear to hold in any particular habitat types or locations, but were uniformly distributed in the eastern half of the lake during the holding period. The only habitat preference that could potentially be concluded was that sockeye appeared to concentrate in the deepest parts of the lake (Hughes et al. 2002).

The metalimnion in Lake Ozette extends from 32 to 98 feet (10-30 m) during the holding period, and shows a rapid decrease in dissolved oxygen (D.O.) by depth, while D.O. concentration increases rapidly in the hypolimnion (Meyer and Brenkman 2001). Since sockeye hold below 10 m, and D.O. decreases to a minimum from 32 to 98 feet (10-30 m), it is likely that holding sockeye remain below 98 feet (30 m) in the hypolimnion to avoid the low D.O. region that extends throughout the thermocline. Temperatures in the hypolimnion during this period range from 8-10ºC (Meyer and Brenkman 2001).

3.1.3 Adult Sockeye Entering, Migrating, and Holding in Tributaries

Adult sockeye are known to spawn in the three largest tributaries to Lake Ozette (Big River, Umbrella Creek, and Crooked Creek), where supplementation programs have established returns. Very few data were available regarding sockeye entering, migrating, and holding in Big River and Crooked Creek. The majority of data collected to date has been in Umbrella Creek. Sockeye typically enter Umbrella Creek in mid- to late October depending on fall precipitation patterns. One sockeye was captured as early as August 31, in 2001, when above-normal streamflows occurred in late summer. In 2001, more than 350 adult sockeye (~10% of the total estimated Umbrella Creek run) were trapped at the weir before October 15. December 20 was the last day sockeye were trapped in Umbrella Creek in RY 2001. Unadjusted RY 2001 daily trap counts from the Umbrella Creek weir are shown in Figure 3.6.

In drier years such as 2002, sockeye migration into Umbrella Creek is delayed. The first sockeye trapped in 2002 was on November 13. Delayed migration may make sockeye more prone to predation, since sockeye are known to congregate near the mouth of Umbrella Creek before beginning their upstream migration. Harbor seals (*Phoca vitulina*) were observed on three occasions at the mouth of Umbrella Creek and were also observed chasing fish. On one occasion, a seal was observed transiting up Umbrella Creek (Gearin et al. 2002). Upon entering Umbrella Creek, sockeye rapidly migrate 2-5 miles upstream, where large numbers of fish hold in deep pools while others initiate spawning. Early in the spawning season, holding sockeye will congregate in large pools typically near their primary spawning grounds and may hold for up to several weeks.

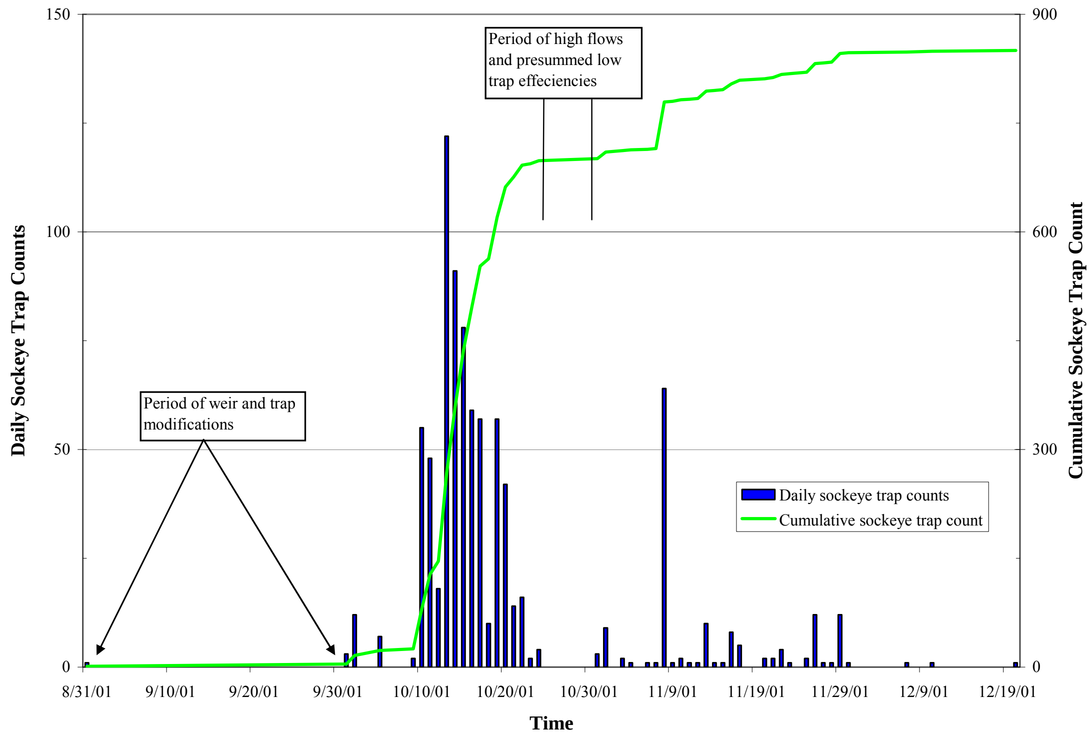

Figure 3.6. Unadjusted daily and cumulative sockeye trap counts from the Umbrella Creek weir located at RM 0.8 (modified from Hinton et al. 2002).

3.1.4 Adult Sockeye Spawning and Egg Incubation on Beaches

There are two known active beach spawning sites along the shores of Lake Ozette: Allen's Beach and Olsen's Beach (Figure 3.7). Spawning ground surveys conducted in 1978 and 1979 also found about 30 sockeye spawning just north of the confluence with Umbrella Creek (Umbrella Beach) (Dlugokenski et al. 1981). The only other record of beach spawning sockeye locations is a one-time observation of a pair of sockeye spawning on the southwest shoreline of Baby Island (Meyer and Brenkman 2001).

Recent data indicate that beach spawning sockeye stage offshore of the spawning beaches in mid- to late October and begin spawning as early as November 1 (MFM unpublished spawning ground surveys). Unripe fish continue to aggregate in deeper water just off-shore until maturation, then move onto the beaches to commence spawning. Physical and environmental conditions at the two primary spawning beaches (Olsen's and Allen's) vary considerably, as does utilization by spawning sockeye salmon.

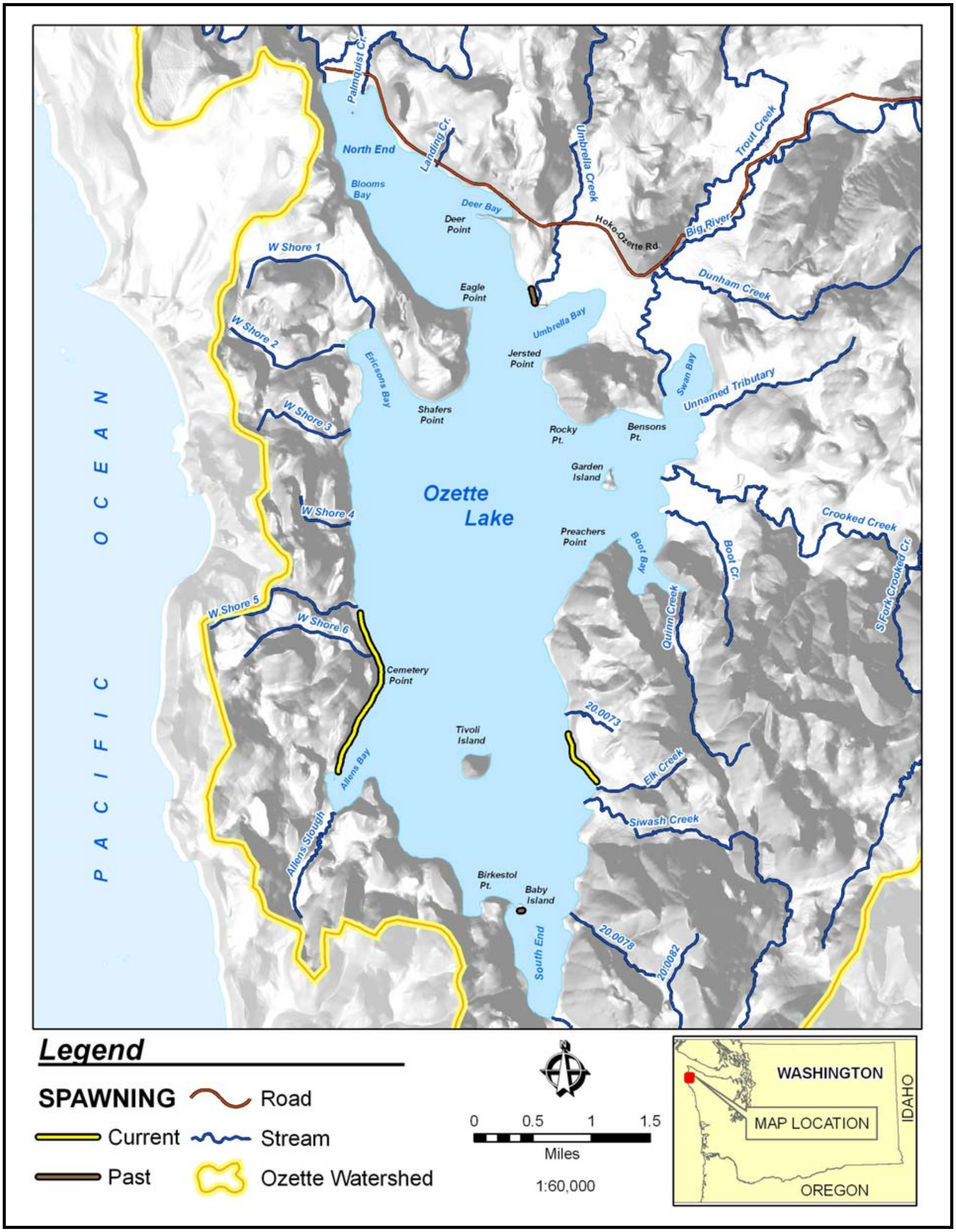

Figure 3.7. Current and historical Lake Ozette sockeye beach spawning locations (source: MFM, unpublished spawning ground survey data; Dlugokenski et al. 1981; Meyer and Brenkman 2001).

At Olsen's Beach, the core spawning area is a relatively small upwelling zone (spring), encompassing approximately 6,400 ft^2 (600 m^2) of beach. Substrate conditions along the entire spawning beach grade from small cobble/large gravel to coarse sand and silt. Competition for optimal spawning sites is intense and extensive redd superimposition has been observed during most years that surveys have been conducted (MFM, unpublished spawning ground surveys; Dlugokenski et al. 1981). Suitable spawning habitat consists of three utilization categories: core, concentrated, and dispersed (Figure 3.8). The core habitat is approximately 100 feet (30 m) in length and 66 feet (20 m) in width. The area categorized as having concentrated spawning use consists of about 115 feet (35 m) on either side of the core area, as well as a zone approximately 425 feet (130 m) long at the northern tip of Olsen's Beach. In total, approximately 656 feet (200 m) of beach is classified as having concentrated sockeye spawning. Dispersed utilization occurs along a 1,886 foot (575 m) stretch of beach between the concentrated area north of the core area and the concentrated area at the north end of Olsen's, as well as along about 130 feet (40 m) of shoreline south of the spawning ground survey lead line identified in Figure 3.8.

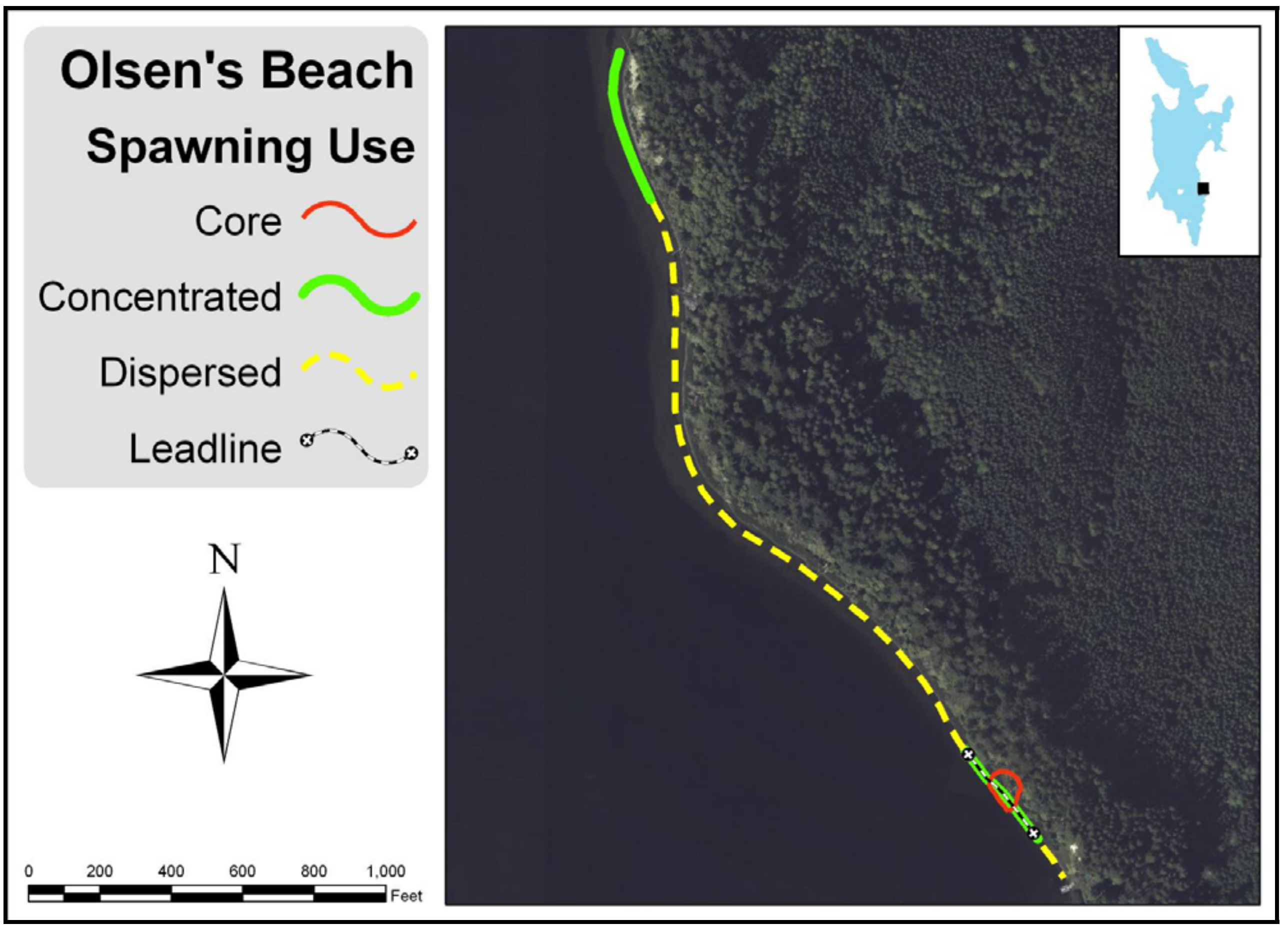

Figure 3.8. Depiction of current Olsen's Beach sockeye spawning use categorized as concentrated, core, and dispersed, as well as the relative position of the spawning ground survey lead line used for data collection in 1999, 2000, and 2001 (source: map was generated using a collection of unpublished spawning ground survey and GPS datasets provided by MFM).

Within the core spawning area at Olsen's Beach, there are three discrete beach zones: the upper beach, middle beach, and lower beach. Beach slope, substrate, and vegetation conditions vary between and in some cases within each zone. The middle beach is the most heavily utilized for spawning. Redds deposited in this zone are not vulnerable to dewatering, unlike redds deposited in the upper beach. The core area middle beach is approximately 26 feet (8 m) wide and 100 feet (30 m) in length, and has a slope of 2.7% (Figure 3.9). The core area upper and lower beaches have slopes of 11% and 12% gradient respectively. Areas utilized by spawning sockeye to the south of the core area have a more uniform beach slope, while areas to the north have a slope structure similar to the core area, with the exception being that the low gradient beach sections occur at an elevation 3.3 feet (1 m) higher.

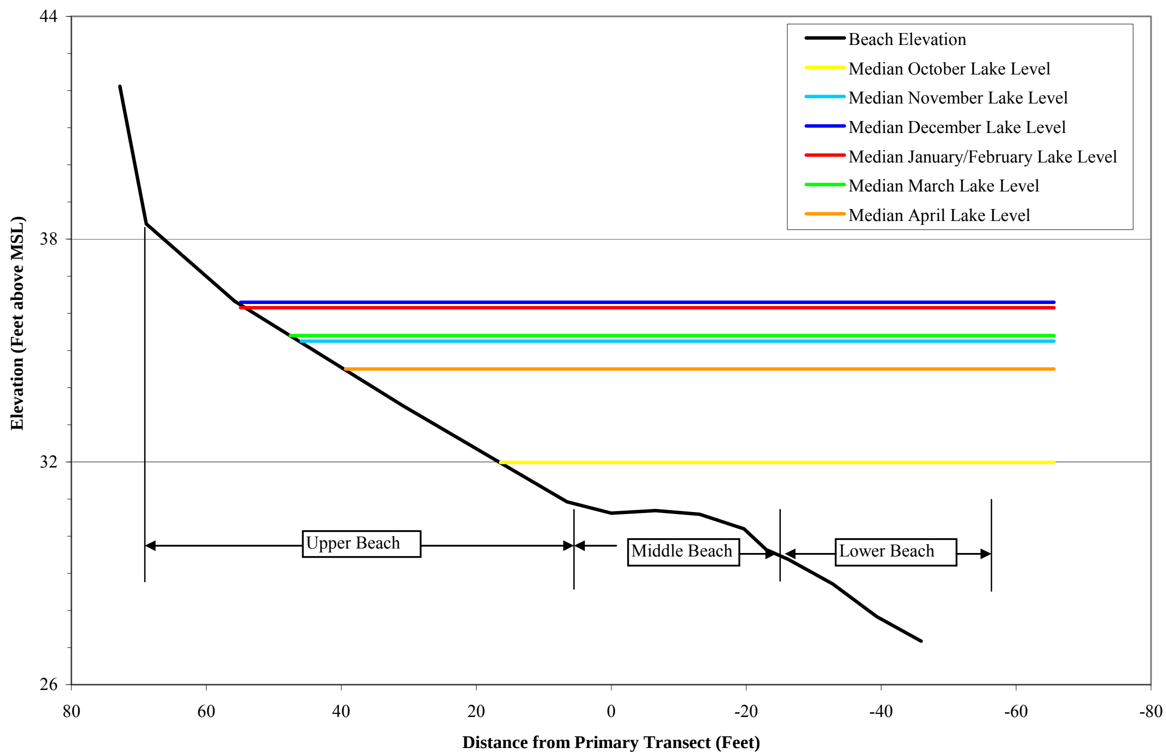

Figure 3.9. Cross-section through the middle of the core spawning area of Olsen's Beach depicting the three spawning zones contrasted with median monthly lake level data from WY 1981 through 2004 (source: ONP and MFM, unpublished data).

During the fall and winter of 2000/01, detailed spawning ground surveys were conducted at Olsen's Beach every 5 to 14 days from early November to mid-February. During this time, carcass recovery, pinniped surveys, and an egg basket study were also conducted. Beaches were surveyed in detail on 10 separate days and a total of 18 days were spent observing sockeye spawning, counting fish, collecting genetic tissue samples, and conducting the egg basket study. Spawning ground surveys were conducted along the entire 2,772 feet (845 m) of utilized habitat. Intensive monitoring was focused around the core spawning area along approximately 394 feet (120 m) of shoreline. A 328 foot (100 m) lead line fixed to permanent reference points driven into the lake bottom was used to aid mapping of redd construction throughout the spawning season (along with several additional reference points throughout the spawning area). Redd positions were recorded using an XY-coordinate system based upon the lead line and then converted into the coordinate system developed during the 1999 beach mapping project, so that redd positions relative to other habitat attributes and measurements could be compared. Other attributes were also recorded, such as orientation, length, width, elevation above mean sea level (MSL), and depth (of redd depression). These data were then summarized based upon redd type, which was defined for Ozette beaches as the following: individual redd; individual redd with secondary spawning events; small redd complexes; large redd complexes; and individual redds along the fringe of redd complexes.

Results from the RY 2000 spawning ground surveys at Olsen's Beach are depicted in Table 3.1. It was not possible to collect high resolution spawning ground survey data for the entire length of the Olsen's Beach spawning area in 2000. Additional spawning was observed to the north of the intensively monitored section, and is not included in Table 3.1. No spawning had been documented in this area prior to the onset of the surveys, so it was not possible to quantify the total area utilized by the Olsen's Beach spawning aggregation for RY 2000. However, data do provide valuable insight into, and quantifiable measurements of, utilization in the core spawning area and the southern concentrated zone. Just over 87% of the beach area containing sockeye redds was within a single large redd complex. This site was utilized by spawning sockeye for a total of 89 days, and sockeye were observed spawning there during 90% of the visits to the beach in 2000/01. Over 90% of the redd area identified was within the core spawning area. Eight individual redds were identified along the fringe of the large redd complex.

Table 3.1. Summary of Olsen's Beach RY 2000 spawning ground survey redd data (source: MFM, unpublished spawning ground survey data).

Redd Type	Number of Redd Features Identified	Redd Area (sq. ft)	Redd Area (sq. meters)	Avg. Number of Surveys with Active or New Disturbance	Average Spawning Duration (Days)	Percent of Total Redd Area Identified
Large Redd Complexes	1	3,013	280	9	89	87.2%
Small Redd Complexes	2	185	17.2	4	65.5	5.3%
Single Redds along fringe of Complex	8	109	10.1	1	1	3.1%
Single Redds with Multiple Spawning Events	4	55	5.1	2.6	35.60	1.6%
Single Redds	7	96	8.9	1	1	2.8%
Total	**22**	**3,458**	**321.3**	**na**	**na**	**100.0%**

Interestingly, redds constructed along the fringe of the large redd complex were all identified during the January 11, 2001 survey when lake level was near its annual peak height. Redds were constructed at an average elevation of 34.2 feet (10.4 m; range 35.27

to 31.98 ft), approximately 0.5 feet (0.15 m) above the lake level projected at the time of fry emergence. All but one redd in this area was constructed above the lake stage at projected fry emergence. Less than 3% of the area identified as redds consisted of single redds. The winter of 2000 was unusually dry, and most spawning (~95%) occurred approximately 3.3 feet (1 m) below the lake level at projected fry emergence. Dlugokenski et al. (1981) made similar observations during the winter of 1979 when they identified an area approximately 25 meters long that was extensively utilized by spawning sockeye. They also noted that two redds were constructed high on the beach at elevations resulting in redd desiccation prior to emergence when lake level dropped. Depth of spawning observed by Dlugokenski et al. (1981) was 1 to 9 feet (0.3 to 2.8 m), although they were limited to a maximum viewing depth of 10 feet [3 m]). Recent surveys (2000-2004) used boat-based teams with SCUBA divers, and indicate that areas adjacent to the core spawning site are utilized by spawning sockeye to depths of at least 18 feet (5 m). Recent observations of spawning on the beach to the north indicate that area needs further attention, as over half of the peak sockeye count was observed in the concentrated area to the north of the core area in RY 2004 and up to one-third in RYs 2002 and 2003.

Spawning along Allen's Beach is significantly more dispersed than on Olsen's Beach (Figure 3.10). One area was categorized as having concentrated spawning use based on spawning ground surveys conducted from 1999 through 2004. However, spawning ground surveys outside of the concentrated spawning area are somewhat limited and there may be other small areas with concentrated spawning use that have not yet been detected by surveys (such as Cemetery Point). The spawning area is approximately 1.4 miles long (2.2 km). Substrate size and condition is quite variable along the beach. The southern section of shoreline is composed chiefly of silt and sand, coarsening to gravel and cobble-gravel mix to the north. Detailed substrate characterization is depicted in Figure 3.10. Sockeye salmon at Allen's Beach have been observed by SCUBA teams spawning at depths up to 10 m (33 ft) and as shallow as 0.3 m (1 ft).). At least some spawning site selection appears to be associated with numerous seeps and springs along the shoreline, which were mapped during the summer of 1999 (See Section 4.2.1). During the summer of 1998, thermographs were deployed in and adjacent to a seep/spring. The first redd constructed in both 1998 and 1999 was built in and adjacent to this seep. Spawning sockeye salmon have been observed as early as November 2 (MFM, unpublished spawning ground surveys) and as late as April (Dlugokenski et al. 1981; note the April spawning date is not supported by their data-see Figure 3.11).

During the late 1970s, peak sockeye spawning on Allen's Beach was documented in January. In recent years the latest spawning observed at Allen's Beach occurred in late January, and peak spawning occurred in early January (MFM, unpublished spawning ground surveys). Currently Olsen's and Allen's beaches appear to have very similar peak spawn timing (Figure 3.12). In recent years, the latest spawning activity observed at Olsen's and Allen's Beach occurred on February 6, 2001 and January 31, 2001 respectively. Kokanee have been observed in spawning colors on both Olsen's and Allen's beaches during the spawning season (the extent to which this is occurring will be discussed in Section 3.3).

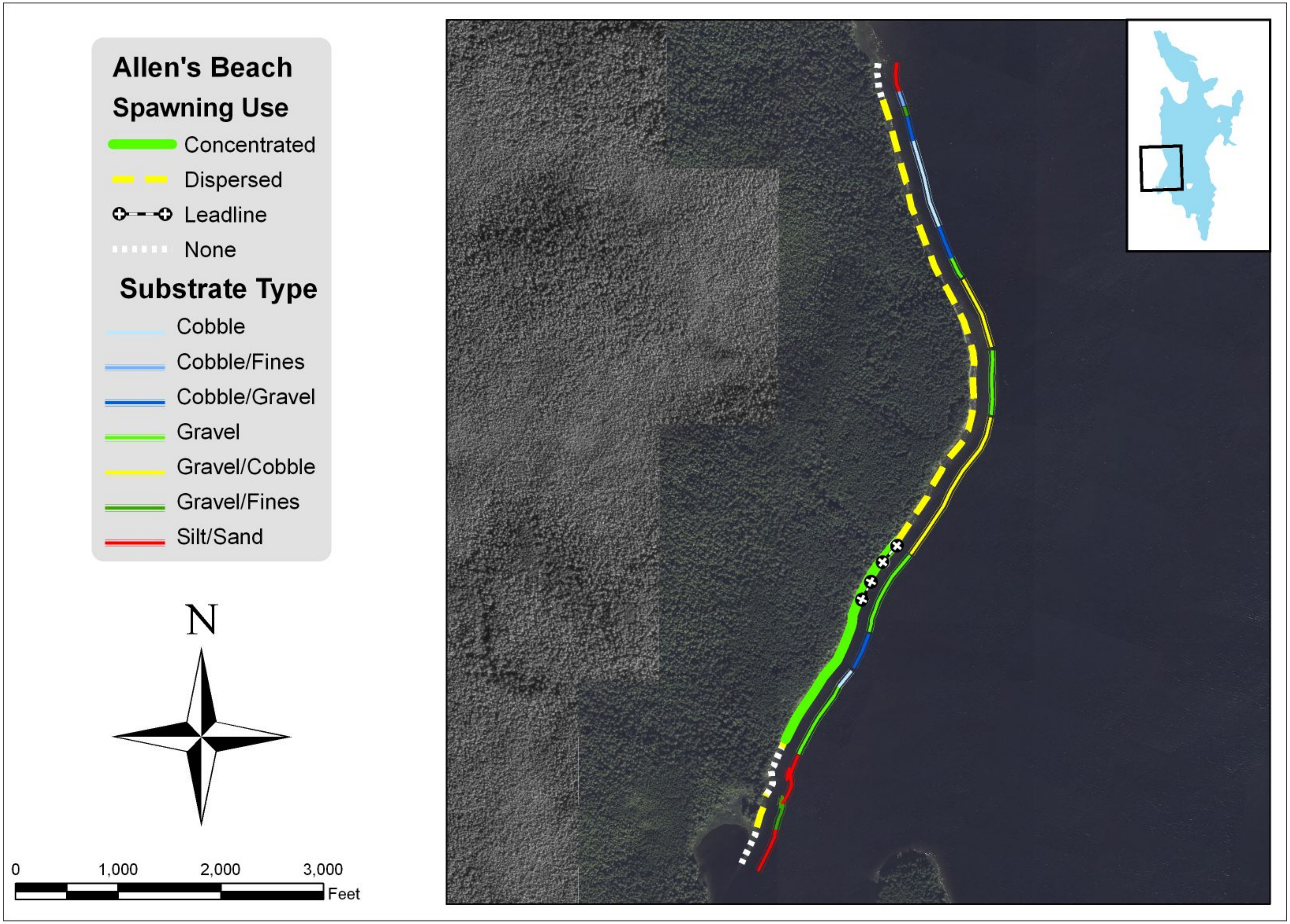

Figure 3.10. Map depicting Allen's Beach spawning use and dominant substrate types (MFM, unpublished habitat data).

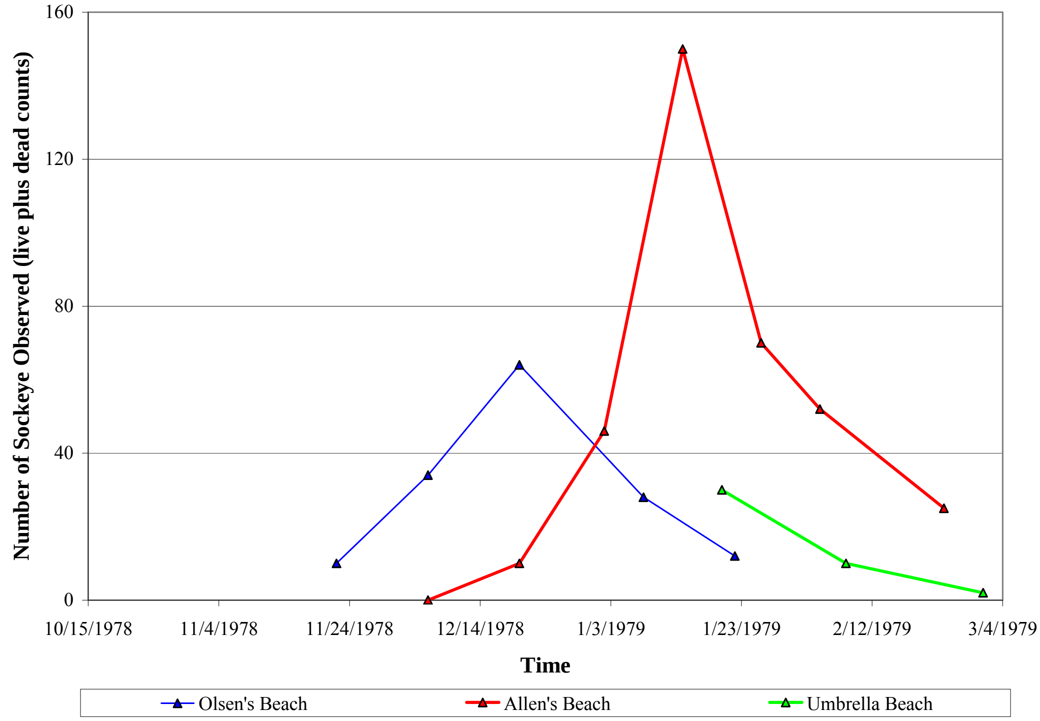

Figure 3.11. Timing and abundance of brood year 1978 beach spawners (modified from Dlugokenski et al. 1981).

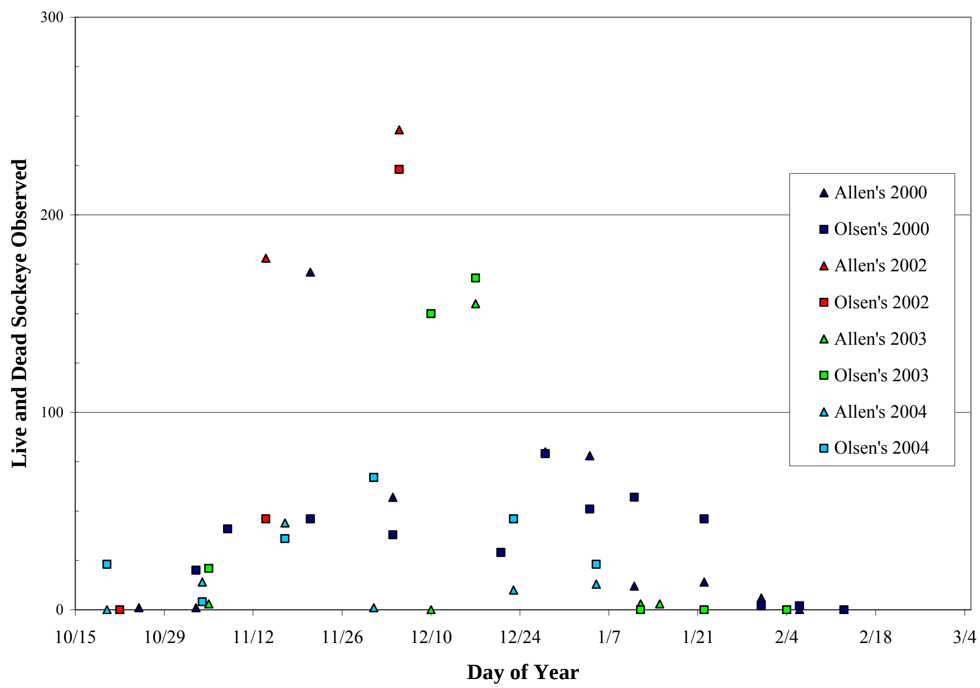

Figure 3.12. Combined live and dead sockeye counts for Allen's and Olsen's beaches (RY 2000-2004; source: MFM, unpublished spawning ground survey data).

The number of eggs deposited by each sockeye at Lake Ozette spawning beaches is not well documented (Jacobs et al. 1996). However, average female fecundity is approximately 3,050 eggs (size=0.107cc/egg; MFM 2000). In return years 2000 and 2001, female sockeye length averaged 523 mm FL and males averaged 567 mm FL. The time required for egg incubation is directly dependent on water temperature. Water temperatures from the brood year (BY) 1998 spawning and incubation period at the beach spawning grounds are depicted in Figure 3.13. Average temperature during the incubation of BY 1998 sockeye eggs on Allen's (7.3°C; 45.1°F) and Olsen's (8.2°C; 46.8°F) beaches was 7.9°C (46.1°F; MFM 2000). No direct data are available for the length of egg incubation at the spawning beaches. Based on hatchery data, MFM (2000) estimated that at an average temperature of 46.1°F, 99 days are required for fish to progress from egg fertilization to the fry swim-up stage. Dlugokenski et al. (1981) studied an individual redd on Olsen's Beach and found that it took 103 days from egg deposition until the first fry emerged from the redd, which closely matches the MFM estimate (99 days) for BY 1998 sockeye eggs on lake beaches.

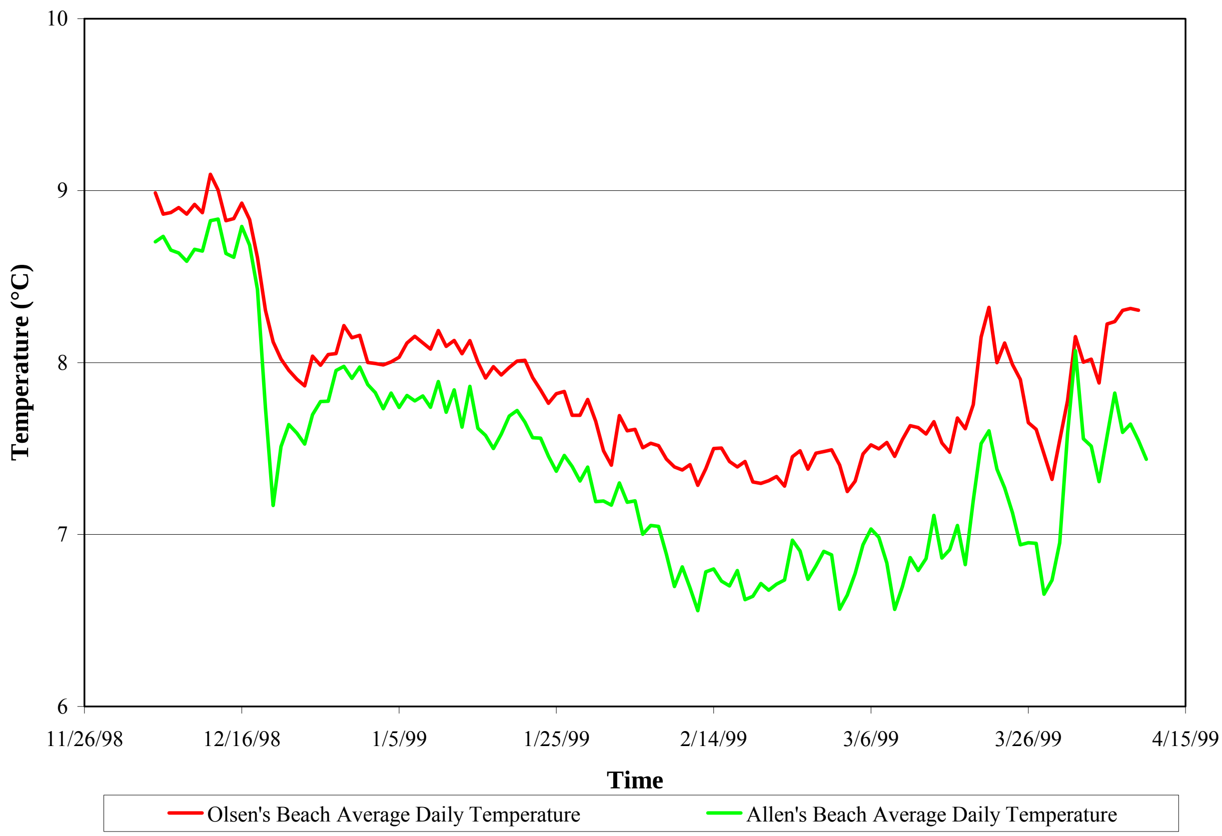

Figure 3.13 Average daily temperature at Olsen's and Allen's beaches during BY 1998 spawning and incubation periods. Note: Average daily temperature is the mean of the average daily surface, bottom, and sub-gravel water temperature. The actual sub-gravel temperatures may be slightly warmer. (source: MFM, unpublished water temperature data).

Additional temperature data were collected during the RY 1999 spawning season at both primary spawning beaches. Data collected in 1999 were measured within and directly above the spawning gravel at three sites on each beach. These data suggest that above-gravel water temperatures are essentially the same at both beaches (Figure 3.14). However, within-gravel temperatures varied between sites and position within the water column on Olsen's Beach. The temperature unit deployed in the spawning substrate within the center of the core spawning area at Olsen's Beach (near the RY 1998 thermograph location) recorded a different thermal signature than all other thermographs deployed on Olsen's Beach. Before thermograph deployment, this area was identified as a potential sub-surface spring and targeted for thermograph placement in an attempt to detect temperature differences.

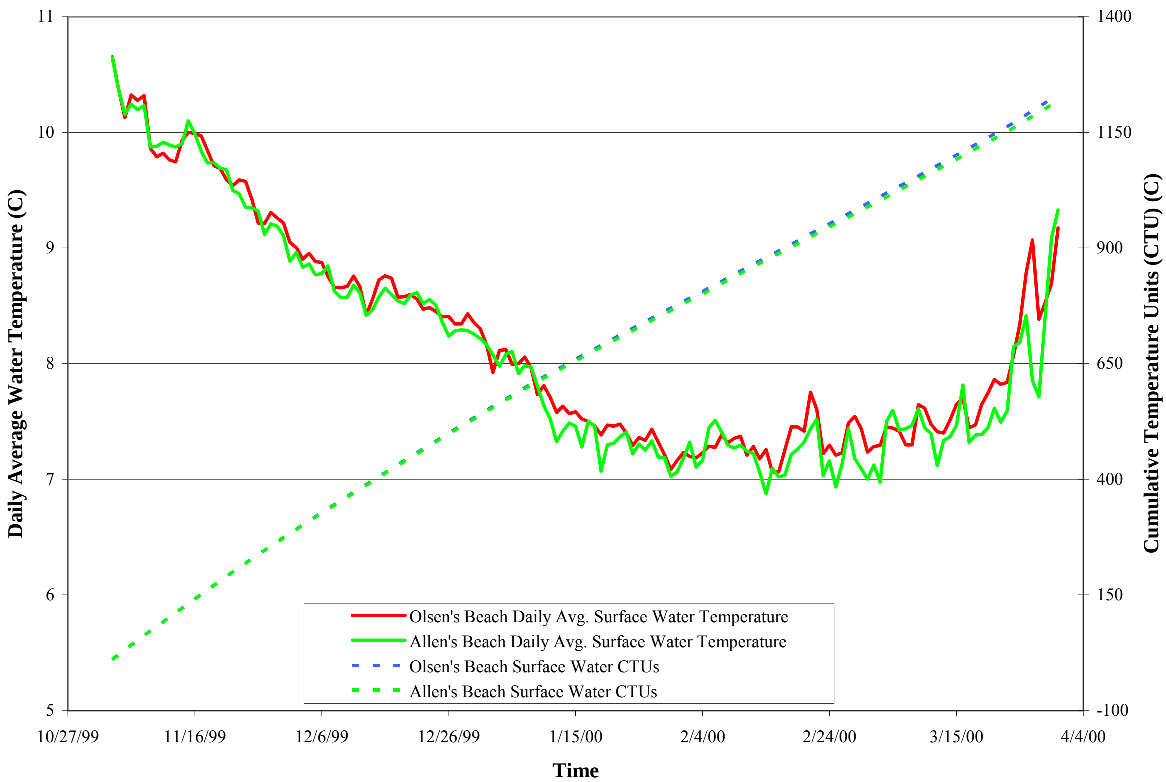

Figure 3.14. Comparison of average daily surface water temperature and cumulative temperature units during the sockeye incubation period on Olsen's and Allen's beaches based upon the average daily temperature of three sites on each beach (source: MFM unpublished water temperature data).

3.1.5 Adult Sockeye Spawning and Egg Incubation in Tributaries

Currently the majority of tributary spawners use Umbrella Creek. Recent observations of spawning sockeye have also been documented in Big River (1998, 2003, and 2004) and Crooked Creek (2002, 2003, and 2004). The most recent observations in Big River and

Crooked Creek have corresponded to hatchery plants, but a group of 20-30 sockeye were known to have spawned in Big River (just downstream from the confluence with Solberg Creek) in December 1998, before any hatchery out planting in Big River (see Section 3.2). In Umbrella Creek, the highest density of spawning occurs from RM 2.5 to 4.8. The physical habitat used by spawning sockeye varies widely, but the primary habitat types used are gravel-bottomed riffles and glides (Figure 3.15). Spawning also occurs in lower densities downstream and upstream of the highest density stream reach, as well as in at least a few tributaries (see Figure 3.16). High density spawning areas are often used by large groups of sockeye (10-60 individuals), creating massive redds that can be 100 square feet in size. Sockeye have also been observed spawning in pools, alcoves, side channels, and other habitat types not commonly recognized as stream spawning habitat. These areas are not expected to be productive spawning areas, and spawning site selection is thought to be somewhat a function of the fact that the majority of stream spawning sockeye are the descendents of lake spawning sockeye; only a few generations removed. No attempts have been made to determine whether sockeye salmon spawning in tributaries is associated with upwelling sites. The currently known spawning distribution of tributary spawning sockeye is depicted in Figure 3.16.

Figure 3.15. Typical spawning site in Umbrella Creek.

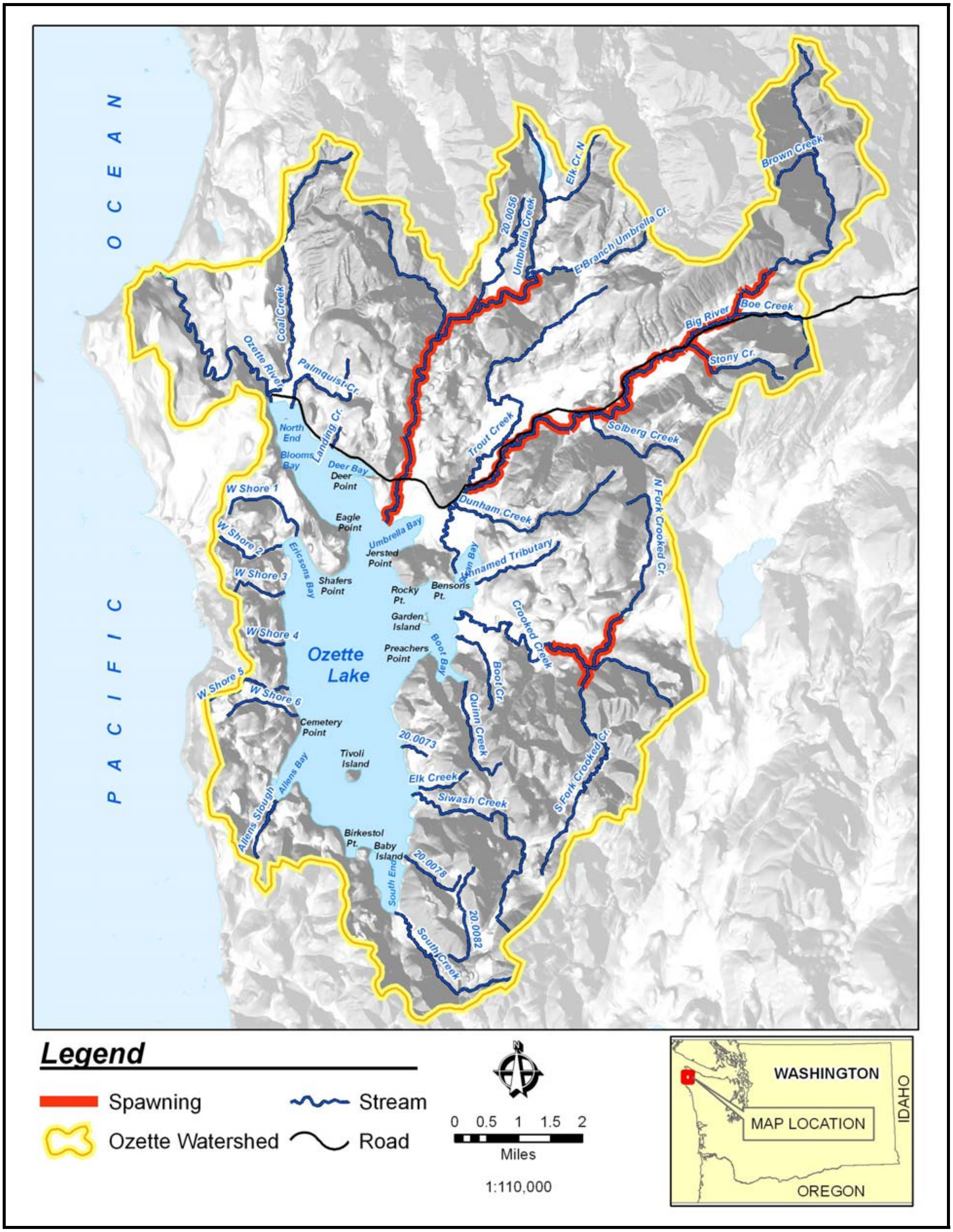

Figure 3.16. Known spawning distribution of Lake Ozette sockeye tributary spawners (source: MFM, unpublished spawning ground survey data).

Spawning in Umbrella Creek has been documented as early as October 8 and as late as January 8. Peak spawning typically occurs in late November but has been observed as early as November 13 and as late as January 9 (2003). Kokanee or jack sockeye salmon have been observed spawning with adult sockeye in numbers similar to those observed on the lake beaches. The number of eggs deposited by each sockeye in the tributaries is not documented. However, average female fecundity is approximately 3,050 eggs (size=0.107cc/egg; MFM 2000). In Umbrella Creek during the 1999 and 2000 spawning season the average length of male sockeye was 567 mm FL (range 505-690 mm, n=125; MFM, unpublished spawning ground and broodstock sampling data). Females averaged 523 mm FL (range 430-660 mm, n=138; MFM, unpublished spawning ground and broodstock sampling data).

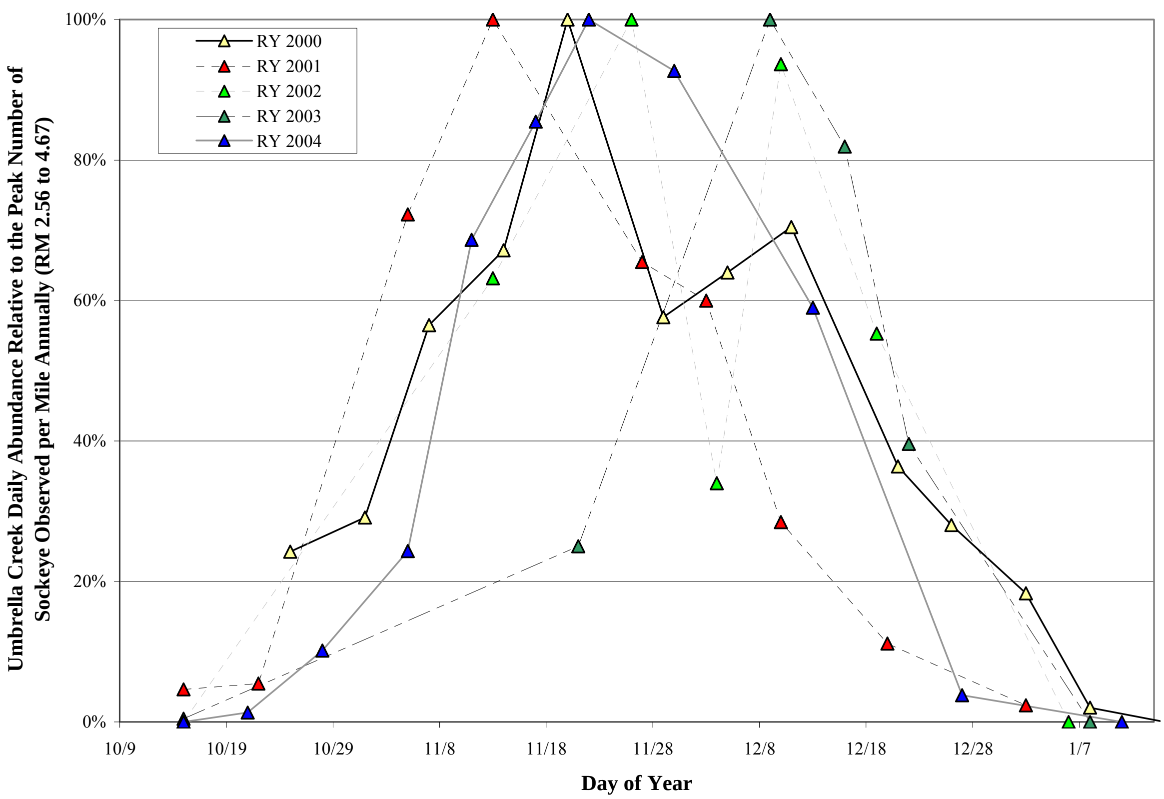

Figure 3.17. Umbrella Creek daily abundance relative to the peak number of sockeye observed per mile for return years 2000-2004 (RM 2.52-4.78) (source: MFM, unpublished spawning ground survey data).

The time required for egg incubation is directly dependent upon water temperature. Average daily water temperature from the BY 1998 spawning and incubation period in Umbrella Creek is depicted in Figure 3.18. Average temperature during the incubation of BY 1998 sockeye eggs in Umbrella Creek was 5.8 °C (42.5°F). No direct data are available for the length of egg incubation in the tributaries. MFM (2000) estimated that based on an average incubation temperature of 42.3°F, fry swim up would occur 136 days after egg fertilization.

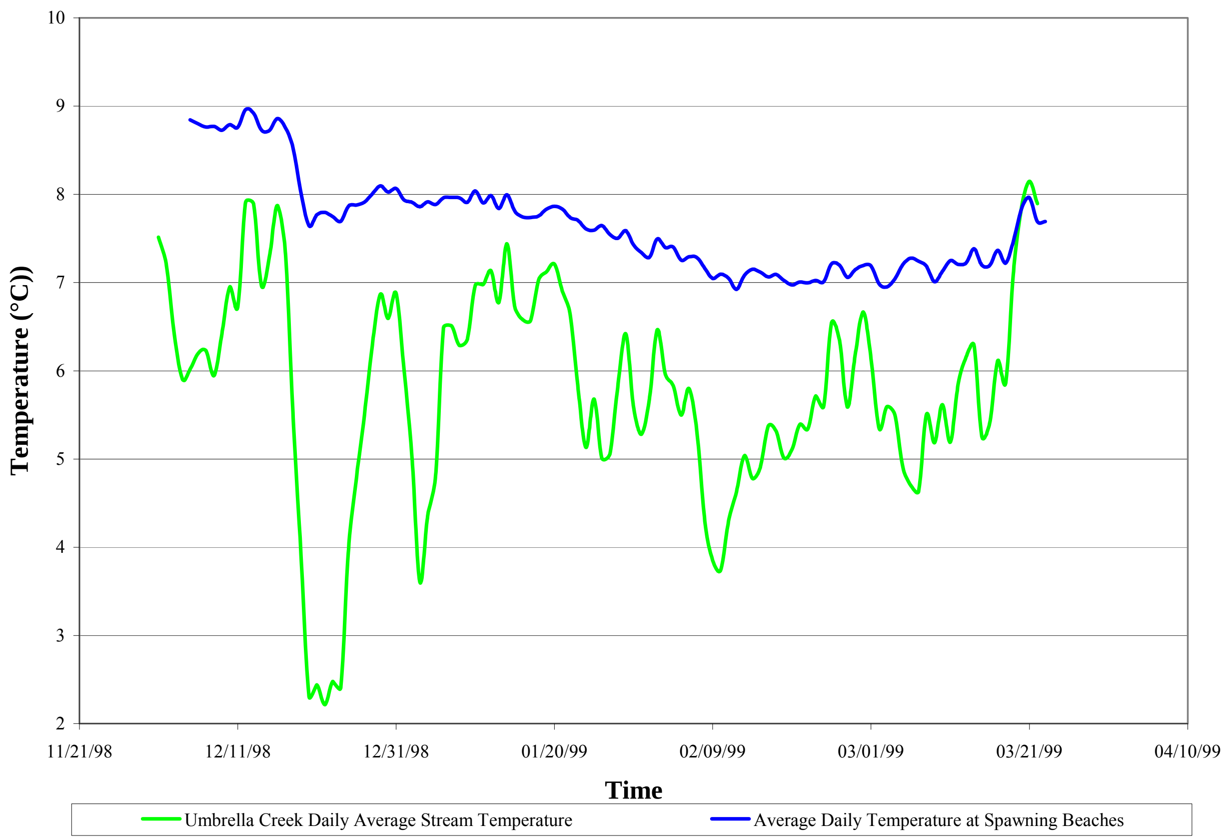

Figure 3.18. Comparison of average daily water temperature in Umbrella Creek and Lake Ozette spawning beaches for brood year 1998 (source: MFM 2000).

3.1.6 Lake Beach Fry Emergence and Dispersal

Few, if any, direct observations of beach fry emergence and dispersal have been documented in the Ozette watershed. Based upon the estimated 99 days it takes for beach spawned fertilized eggs to emerge as swim-up fry, it is believed that peak fry emergence is between late March and late April. Snorkel surveys along the spawning beaches have been unable to detect emergent fry in or around the spawning beaches, although no night-time snorkel surveys have been conducted. It is assumed that emergent fry move rapidly to offshore rearing areas upon emergence from the spawning gravel (Jacobs et al. 1996). However, this life history phase of Lake Ozette sockeye salmon remains a data gap. In other sockeye systems a wide range of different behaviors occur after emergence, including littoral rearing, rapid migrations to the limnetic zone, and behaviors between delayed and rapid pelagic dispersal. The lack of sockeye fry in the diets of littoral zone captured predators by Beauchamp et al. (1995) suggests that rapid migration may be the dominant behavior.

3.1.7 Tributary Fry Emergence and Dispersal

A limited amount of direct observations of tributary fry emergence and dispersal have been documented in the Ozette watershed. On April 14, 1999, a winged fyke net was placed at RM 1.0 to monitor the daily number of sockeye fry transiting to the lake (MFM 2000). Before this time no direct measurements of spawning success in Umbrella Creek had been conducted. During the BY 1998 incubation period, mean stream temperature was approximately 5.8°C (42.5°F), yielding a predicted spawning to swim-up period of 136 days.

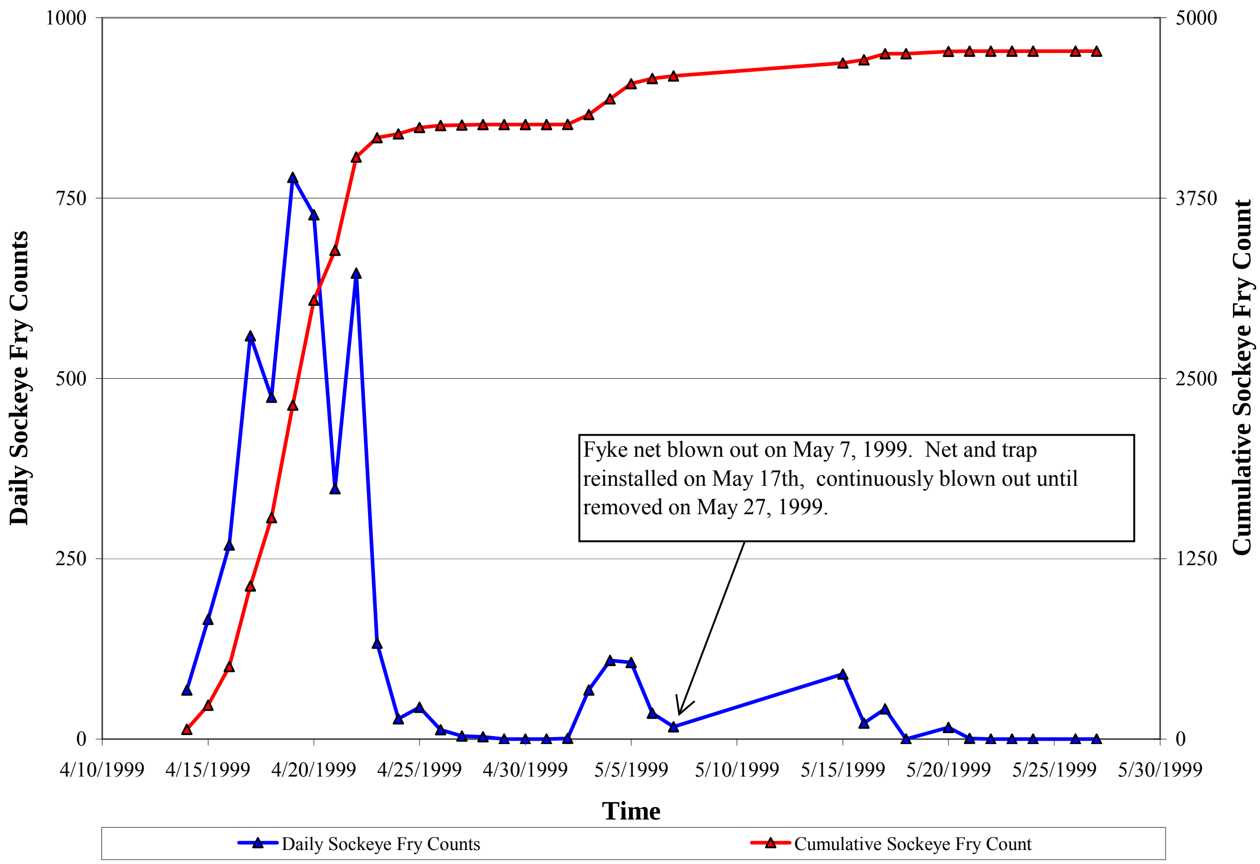

Figure 3.19. Spring 1999 daily and cumulative sockeye fry count (modified from MFM 2000).

Peak spawning in Umbrella Creek during BY 1998 was between November 23, 1998 and December 3, 1998. Assuming 136 days required to progress from fertilized egg to swim-up fry, peak emergence would have occurred in mid-April 1999. Placement of the fyke net is presumed to have occurred close to the peak emergence and dispersal period. Downstream fry movement may correspond with streamflow. After moderate rainfall and subsequent increases in streamflow, sockeye fry counts increased while trap efficiency (TE) decreased. Increased streamflow and algae production prohibited good data collection after May 7, 1999. No attempt was made to estimate the total number of fry produced in Umbrella Creek for BY 1998 because the early portion of the run was not monitored and there is no way to estimate trap efficiency (trap efficiency was assumed to be less than 50%).

The trap was redeployed downstream in June 1999 to study the movement of hatchery released fingerlings, and at least one natural-origin age 0 sockeye fry was caught on June 23, 1999. The trap was again deployed during spring 2001 so that an idea of survival during the winter could be made. Only two days of data were collected, April 20 and May 4. It was estimated based upon trap efficiency that over 5,000 fry migrated downstream on April 20, 2001. In general it is assumed that fry emigration from Umbrella Creek starts in late March or early April and ends in late June. Peak emigration appears to occur around mid- to late April. The majority of sockeye fry captured appeared to have recently emerged from the gravel, as evidenced by incomplete egg sac absorption. All sockeye fry migration appears to occur at night, based upon trapping conducted during spring 1999 and 2001. Several daylight surveys in Umbrella Creek failed to detect a single fry. Seine netting conducted during daylight hours in pools was unable to detect migrating sockeye fry. Based on these observations, it is assumed that during daylight hours sockeye fry burrow into the stream substrate to conserve energy and avoid predation. Upon entering the lake it is unclear whether sockeye immediately move to the limnetic zone or whether littoral rearing occurs for a short period (see Section 3.1.6)

3.1.8 Juvenile Freshwater Rearing

Juvenile Lake Ozette sockeye salmon are thought to rapidly migrate to the pelagic zone of the lake upon emerging from the spawning gravel, although the exact timing and rate of movement from the shoreline spawning sites have not been documented (Jacobs et al. 1996). Beauchamp et al. (1995) found that sockeye salmon utilized the nearshore environment only during fry and smolt migrations. Upon entering the offshore rearing areas of the lake, sockeye salmon mix with kokanee salmon and become morphologically indistinguishable (Jacobs et al. 1996). Approximately 94% of the fish >100 mm (FL) caught in vertical gill nets in April 1991 were sockeye salmon pre-smolts or kokanee (Beauchamp et al 1995). In the summer months only 54% of the gill net catch was composed of kokanee salmon, but age 0 sockeye/kokanee salmon were not susceptible to gill net capture (Beauchamp et al. 1995).

The primary prey of juvenile sockeye/kokanee salmon is *Daphnia pulicaria,* which dominate the diet of juvenile sockeye/kokanee salmon throughout the year (Beauchamp et al. 1995). Benthic invertebrates, adult insects, and copepods comprised 7-46% of the adult kokanee salmon diets from late summer through early spring. Beauchamp et al (1995) estimated that juvenile sockeye and all year classes of kokanee consumed less than 1% of the monthly standing stock of *Daphnia pulicaria* > 1.0 mm in size, suggesting that food available for rearing fish was not limiting *O. nerka* productivity. More than 99% of the juvenile sockeye emigrating from the lake to ocean are age 1+, indicating that few juvenile sockeye rear in the lake for more than one summer (Jacobs et al. 1996).

3.1.9 Seaward Migration

Lake Ozette sockeye smolts emigrate from the lake to the Pacific Ocean by means of the Ozette River. Dlugokenski et al. (1981) observed (or assumed) that sockeye smolts only migrate at night. Dlugokenski et al. (1981) sampled only four 24-hour periods to determine daily migration timing. In recent years a minimum of 10% of sockeye smolts emigrated during daylight hours, and this number may be an underestimate because trap avoidance during daylight appears to be higher than during darkness, further complicating the estimate of daylight emigrants. LaRiviere (1990) found that peak smolt emigration consistently occurred in early May and was essentially over by late May. These emigration timing patterns appear still to be the case, as only 5% of the smolts captured in 2003 were captured after May 30, 2003 (although the peak emigration period was not sampled, and therefore the proportion after May 30th is likely an overestimate; MFM unpublished smolt trapping data).

Sockeye smolt trapping has occurred intermittently in the Ozette River from the spring of 1979 to the present. Trapping between 1978 and 1992 was conducted using a fyke net and holding box just downstream of the confluence with Coal Creek (Jacobs et al. 1996). Smolt enumeration data were collected in 1979, 1982, 1984, 1988, 1989, 1990, 1991, and 1992, but the quantity and quality of data collected were only good enough to produce expanded count estimates for 1979, 1990, and 1992. The quality of these estimates is questionable at best. During spring 2001, experiments were conducted to improve the methods for smolt trapping in the Ozette River. A 5-foot rotary screw trap, fixed to the adult picket weir (partially covered in *Vexar*) with an adjustable 5-foot tubular interface, was determined to yield the highest trap efficiencies (up to 46% for coho smolts). Only limited sockeye smolt data were collected in 2001 because by the time trapping techniques were developed and implemented, the sockeye emigration had ceased. This method was used for the majority of data collection in 2002, 2003, and 2004. Table 3.2 summarizes data for all smolt trapping conducted on the Ozette River from 1979 through 2004.

The estimated numbers of smolts emigrating from the lake in 2002, 2003, and 2004 were dramatically higher than any past year's estimates. Peak counts were observed on April 25, 2002 and on May 7, 2004, very close to the May 4, 1979 peak observed by Dlugokenski et al. (1981). It is assumed that the peak of the emigration was missed in 2003, since the smolt trap did not begin fishing properly until May 24, 2003. Figure 3.20 depicts the daily smolt counts from the spring of 2004, which is considered the most complete dataset collected for Lake Ozette sockeye smolts. Even though the dataset is the most complete, variation in trap efficiency (TE) still makes it difficult to accurately estimate the total smolt production for the watershed. Note that the shape of the curve produced by the 2004 sockeye smolt daily counts is quite different from the curve presented by Dlugokenski et al. (1981), which depicted the shape as a perfect bell curve, versus the bi-modal distribution observed in 2004.

Table 3.2. Summary of Ozette River sockeye smolt trapping (modified from Jacobs et al. 1996; includes recent MFM unpublished smolt trapping data).

Year	Trapping Period	Total Sockeye Smolts Counted	Expanded Count for Trap Efficiency	Estimated Sockeye Smolt Production	Comments
1979	4/3-5/29/1978	NA	9,600	Insufficient Data (9,600)	Full count- but only 4 days of 24 hr data collection. (Dlugokenski et al. 1981)
1982	May 11-June 1, 1982	NA	5,400	NA	Source Blum (1988)
1984	April 19-May 14, 1984	400	11,400	NA	Approximately 400 smolts captured, estimate source: Blum 1988.
1988	One day in mid-May	NA	NA	NA	NA
1989	April 10-May 26, 1989	255	NA	NA	255 sockeye smolts captured
1990	April 1-June 11, 1990	NA	7,942	NA	Minimum estimate based on 4/22-5/18 expansion, only days sampled expanded, sampled 5 days/week.
1991	April 17-May 30, 1991	NA	NA	Insufficient Data	Only fished 2-3 nights/week
1992	March 31-May 14, 1992	263	2,752	Insufficient Data	Partial count: n=263
2001	May 10-July 1, 2001	30	NA	Insufficient Data	Trap efficiency very poor from May 10 to May 24. Trap efficiency increased as modifications were made to system but the sockeye emigration had peaked before trap was working properly.
2002	March 18–May 30, 2002	6,710	55,238	55,238	Full count, 6,710 sockeye smolts captured expanded trap efficiency trials, 6,152 of the total estimated number of sockeye were of hatchery origin (Crewson 2003)
2003	May 13-June 12, 2003	1,412	26,245	Insufficient Data (145,598)	Measured trap efficiency was low (5.38%). Only a portion of the out migration period was monitored (estimated to be 16.0%) resulting in a high level of uncertainty with respect to the expanded counts and estimated smolt production.
2004	April 7-June 1, 2004	5,759	31,504 - 51,941	31,504 - 51,941	The 31,504 estimate was derived by applying a fixed trap efficiency rate of 18.28%. The 51,941 estimate was generated using a measured time differential efficiency rate.

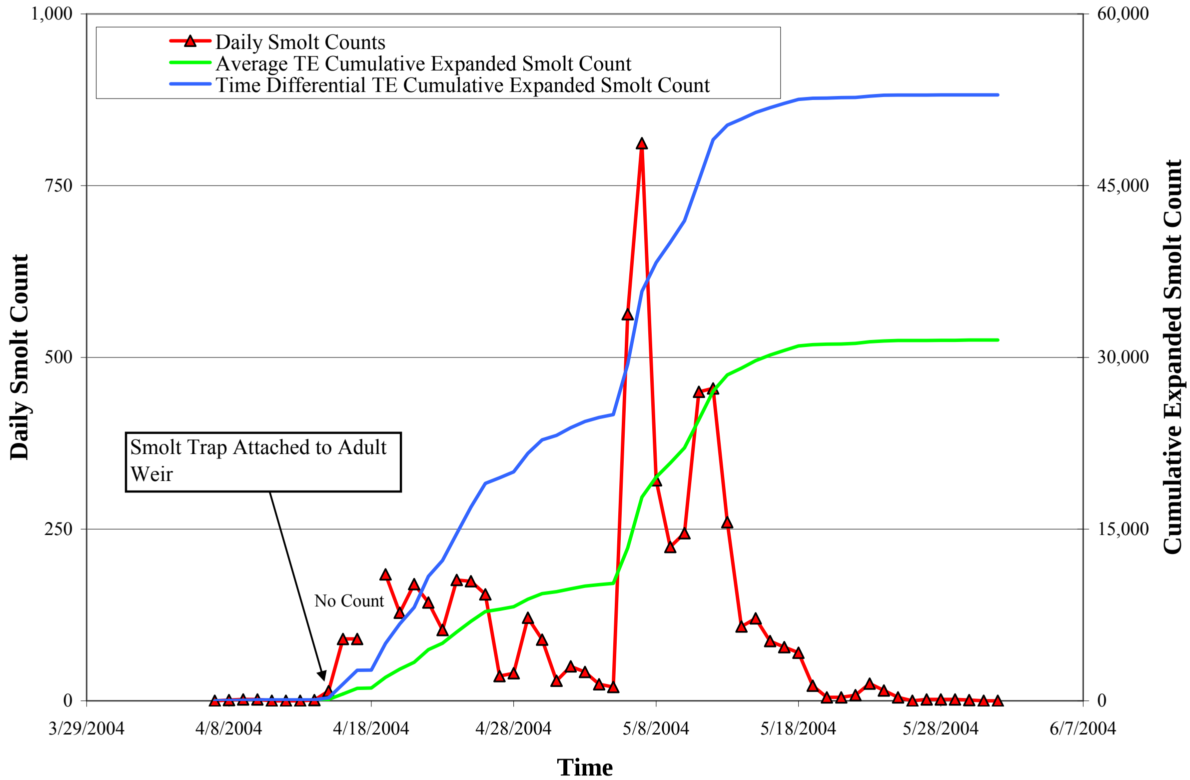

Figure 3.20. Ozette River daily sockeye smolt counts, average trap efficiency expanded cumulative sockeye smolt counts, and time differential trap efficiency expanded cumulative smolt counts, spring 2004 (source: Peterschmidt 2005)

Lake Ozette sockeye predominantly emigrate as age 1+ smolts (LaRiviere 1990; MFM 1991; Jacobs et al. 1996). Recently collected otolith data (BY 2000, 2001, and 2002) indicate that less than 1% of sockeye emigrate as Age 2+ smolts (n=981; MFM, unpublished otolith age data). Age 1+ smolt emigration is a common life history strategy employed by sockeye salmon within the southern range of the species. Lake Ozette sockeye salmon smolts are large in size, averaging between 11.3 to 13.0 cm (FL) for years 1978, 1984, 1989, 1990, 1991, and 1992 (Blum 1988; Jacobs et al 1996). Dlugokenski et al. (1981) evaluated the length and weight of Ozette sockeye smolts and concluded that they were the third largest yearling sockeye smolts documented in the recorded literature. Recently collected smolt size data measured only total length; smolts averaged 14 cm (TL; n=107) in 2003 and 14.4 cm (TL; n=231) in 2004. The size of emigrating smolts increased by 2.3 cm over the course of the 2004 emigration period. Initially, on April 21, 2004, the average smolt length was 11.9 cm (TL; n=143), by April 28, 2004 the average length increased to 13.1 cm (TL; n=40), and from May 6 through May 14, 2004, smolt length averaged 14.4 cm (TL; n=230) (MFM unpublished smolt trap data). This trend was not apparent in the 1984 (n=375) and 1989 (n=255) smolt data. In fact, data from these years show a slight decrease in smolt length at the end of the sampling seasons (LaRiviere 1990; Blum 1988).

3.1.10 Marine/Ocean Phase

Sockeye salmon exhibit a wide variety of behaviors following emigration from their natal watersheds; however, little is known about this phase of juvenile Ozette sockeye life history. At least some populations of sockeye are known to rear in the estuarine environment for extended periods, in systems with sizable estuaries. Many populations of sockeye use the nearshore for at least 2-6 weeks following emigration from their natal stream (Burgner 1991). The Ozette system does not include a sizeable estuary, but the nearshore region surrounding the mouth of the Ozette river is an extensive, complex, and productive shallow sub-tidal environment.

It is unknown to what degree Ozette sockeye use this environment before migrating to northern inshore or offshore marine rearing environments. Juvenile sockeye are present close to shore from Cape Flattery to Yakutat in July and August, and scarce to absent in areas further offshore (Burgner 1991). Limited sampling in the North Pacific Ocean indicates that juvenile sockeye remain primarily inshore through October before moving offshore in late autumn or winter (Burgner 1991).

Most Fraser River sockeye remain within the Strait of Georgia or closer to their natal stream from April until late June or July before moving north into Johnstone Strait and the Gulf Islands (Burgner 1991). In Bristol Bay, where inner coastal waters are less productive than offshore waters, juvenile sockeye migrate to the outer Bay within 2 to 6 weeks. They remain in the outer bay for an undetermined length of time, staying near the coast during migration (Burgner 1991). Sockeye in the Ozernaya River in Kamchatka feed for several months close to their natal stream, and juvenile sockeye are captured further offshore by September or October in the Sea of Okhotsk and north of the Kamchatka River (Burgner 1991).

High densities of marine mammals and marine piscine predators can be found near the mouth of the Ozette River, and predation at this life stage may be significant. However, marine survival rates for Lake Ozette sockeye are thought to be relatively high. Jacobs et al. (1996) report estimated marine survival rates of 27% and 18% for BY 1988 and 1990 respectively. It is known that the vast majority of Lake Ozette sockeye spend 2 to 2.25 years at sea before returning to the lake, but some return after as little as one year or as many as three years at sea. No data are available regarding their ocean distribution.

3.2 HATCHERY PRACTICES and PLANTING HISTORY

NMFS (Gustafson et al. 1997) identified three major concerns that led to the findings that if current conditions continued into the future, Lake Ozette sockeye were likely to become in danger of extinction in the foreseeable future. One of the primary concerns related to the potential genetic effects of hatchery practices that were occurring at the time of the NMFS ESA Status Review, as well as past practices that included interbreeding sockeye and genetically dissimilar kokanee salmon. Gustafson et al. (1997) estimated that approximately 24% of the sockeye fry entering the lake rearing environment between 1988 and 1995 were of hatchery origin. These concerns were addressed in detail during the development of the Makah Tribe's Lake Ozette Sockeye Hatchery and Genetic Management Plan (HGMP). The following subsections (3.2.1 through 3.2.3) include a brief history and description of hatchery practices and stocking efforts in the Lake Ozette watershed. For additional details see MFM (2000).

The first sockeye releases into Lake Ozette were from out-of-basin broodstock sources and are described in Section 3.2.1. The last out-of-basin sockeye stocking in Lake Ozette occurred in 1983 (BY 1982 releases). All subsequent hatchery stocking efforts in the watershed relied only on sockeye salmon returning to the spawning grounds within the Lake Ozette watershed as the broodstock source. A detailed description and summary of recent hatchery stocking is included in Section 3.2.2. Hatchery production and stocking efforts occurring since the inception of the Lake Ozette Sockeye HGMP are described in Section 3.2.3.

3.2.1 Non-Native Sockeye Salmon Stocking (1937-1983)

Adult returns resulting from past out-of-basin hatchery plants of non-native sockeye had the potential to interbreed with the native Lake Ozette sockeye, although the extent of non-native sockeye stocking was relatively low and their success was unknown. The first documented releases of non-native juvenile sockeye into Lake Ozette occurred with a brood year 1936 plant of approximately 450,000 sockeye fingerlings from the U.S. Bureau of Fisheries Birdsview Station at Baker Lake (Kemmerich 1945). Kemmerich (1945) states that additional transfers of sockeye juveniles from Quilcene and Quinault stations occurred after 1937, but the numbers and dates of those releases were not available. The only other documented out-of-basin sockeye releases were in 1983, when 120,000 (BY 1982) Lake Quinault sockeye fingerlings were released into Lake Ozette (MFM, unpublished hatchery out-planting records). Releases of non-native kokanee into Lake Ozette have also been documented, in addition to non-native sockeye releases. In 1940, over 108,000 kokanee fry from the Lake Crescent Trout Hatchery were released into Lake Ozette (Kloempken 1996 *in* Gustafson et al. 1997). Dlugokenski et al. (1981) also reports a kokanee release of an unknown quantity and origin into Lake Ozette in 1958.

3.2.2 Recent Sockeye Salmon Artificial Propagation Efforts (1984-1999)

The Makah Tribe's Umbrella Creek Hatchery facility operated without a concise operation plan from 1982 through 1998. That is to say that there was no overall plan for integrating the hatchery operations with the overall recovery and restoration of the Lake Ozette sockeye population. Initially, hatchery operations and planning attempted to follow the recommendations set forth in Dlugokenski et al. (1981). Dlugokenski et al. (1981) developed three management alternatives for rebuilding Lake Ozette sockeye abundances: 1) no action, 2) rehabilitation of existing beach spawning population and habitat, and 3) import an out-of-basin sockeye stock. Dlugokenski et al. (1981) recommended management alternative 3 as the preferred alternative and suggested that 3-5 million sockeye eggs per year should be imported, hatched, and reared in Umbrella Creek over an 8-year period. Dlugokenski et al. (1981) recommended importing sockeye from another watershed mainly because they believed that in order to increase the number of sockeye in Lake Ozette, utilization of tributaries for spawning was required. At the time it was believed that the remaining beach spawning sockeye aggregation could not adapt to the tributary spawning environment.

Preparation for hatchery supplementation in Lake Ozette started in earnest during the spring and summer of 1981 (MFM 1981). The Lake Ozette Sockeye Steering Committee formed and met for the first time on April 1, 1981 (MFM 1981). Stream surveys were conducted in Big River, Umbrella, Crooked, Siwash, and South Creeks between July 14 and September 21, 1981, in an attempt to locate a suitable egg incubation site (MFM 1981). It was concluded that the best site was an unnamed tributary to Umbrella Creek (WRIA 20.0056), based upon hydraulic head, water quality, and accessibility (MFM 1981). The site was prepared for egg incubation during the fall of 1982.

In order for the project to be successful it was determined that a local stock with tributary spawners was needed. In fall 1982, the Lake Ozette Steering Committee met and decided that their efforts should focus on obtaining broodstock from Lake Quinault (MFM 1983b). The steering committee, WDFW, USFWS, and ONP all wrote letters of support declaring their preference for the Lake Quinault broodstock, in an attempt to secure eggs for hatching and rearing during the spring of 1983 (MFM 1983b). The low run size in 1983 prevented the Tribe from obtaining eggs from Lake Quinault. With a recently constructed incubation facility and no sockeye eggs, the effort to get eggs shifted to the Lake Ozette spawning beaches in the fall of 1983. Broodstock was collected from Olsen's Beach and eggs fertilized from spawners were then incubated at the Umbrella Creek facility. Resultant fry were released at the Hoko-Ozette Road Bridge into Umbrella Creek. In the end, eggs from Lake Quinault were obtained for only one year (By 1982) and in numbers well below the recommendations set forth by Dlugokenski et al. (1981). Efforts to obtain eggs from Lake Quinault slowly waned, and attention focused on collecting beach spawning sockeye from Lake Ozette as the primary broodstock source.

Broodstock were collected from Olsen's Beach every year between 1983 and 1999, except for 1984 and 1989. Additional broodstock were collected from Allen's Beach in 1987, 1988, 1991, 1992, 1994, 1995, and 1996. Additional broodstock were collected from Umbrella Creek in 1997. It is not possible to quantify the number of broodstock collected from the two beach spawning aggregations for all years collections were made, but the vast majority of broodstock were collected from Olsen's Beach during this period. The number of fish collected and the resulting releases varied significantly between years. From 1986 to 1999, a total of 1,415 sockeye salmon were collected from the spawning beaches and used as broodstock. Table 3.3 lists the total number of fingerlings or fry and eggs produced from broodstock collected at Lake Ozette sockeye spawning beaches and released at various locations in the watershed from 1984 through 2000. Figure 3.21 depicts the number of fish or eggs released for each year during this period, for each release site.

Table 3.3. Total number of fingerlings or fry and eggs produced from broodstock collected at Lake Ozette sockeye spawning beaches released at various locations in the watershed from 1984 through 2000 (modified from MFM 2000).

Release Site	Number of Years	Total Number of Fry or Fingerlings Released	Total Number of Eggs Planted	Total Number of Released Fry and Eggs
Umbrella Creek	8	691,748	0	691,748
Lake Ozette	8	242,599	16,628	259,227
Big River	1	0	14,299	14,299
Crooked Creek Mainstem	1	0	34,530	34,530
N.F. Crooked Creek	3	34,500	67,589	102,089
TOTAL		**968,847**	**133,046**	**1,101,893**

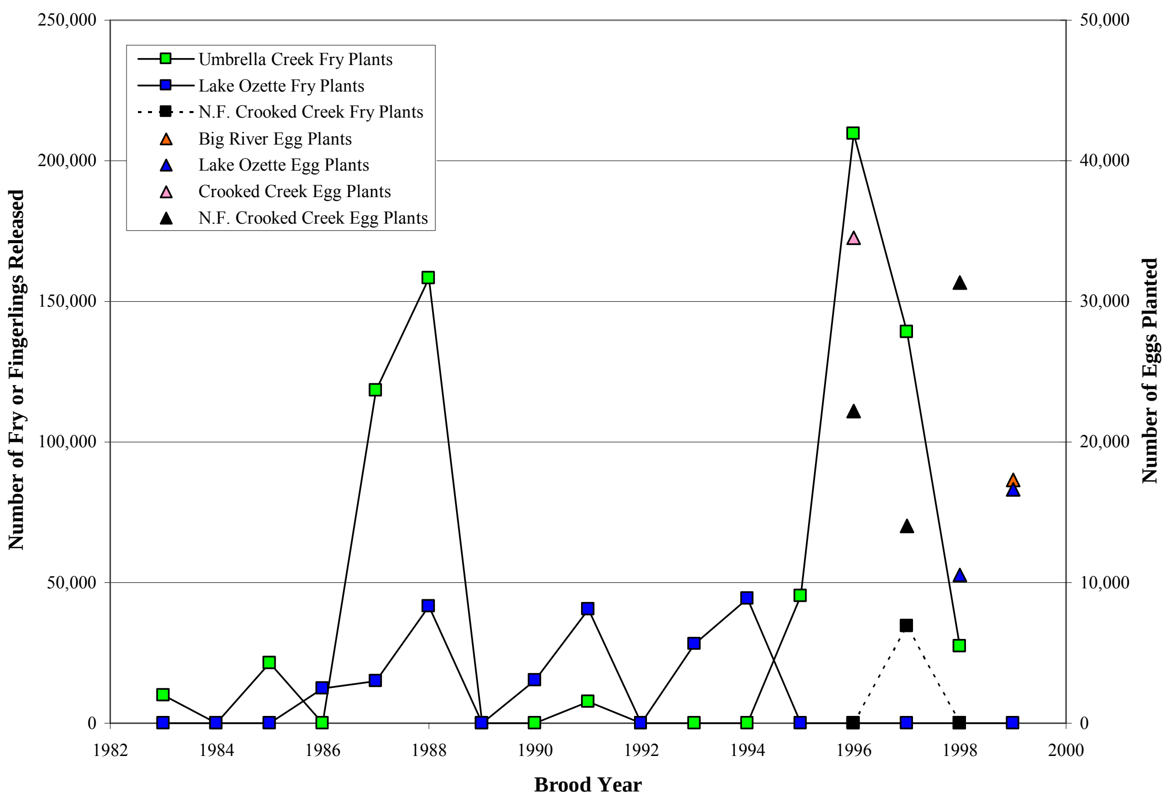

Figure 3.21. Total number of sockeye fry or fingerlings and eggs produced from broodstock collected at Lake Ozette beach spawning grounds released into various areas of the Lake Ozette watershed from 1984 through 2000 (BY 1983 to BY 1999) (source: MFM, unpublished hatchery release data).

3.2.3 Hatchery and Genetic Management Plan (HGMP)

On March 25, 1999, the National Marine Fisheries Service (NMFS) listed Lake Ozette sockeye as Threatened under the ESA (64 FR 14528). The listing necessitated the development of an HGMP (MFM 2000) in order for the program to receive federal authorization under the ESA. Actions that may affect listed species can be reviewed by NMFS through ESA section 7, section 10, or the 4(d) Rule, which can limit application of take prohibitions under section 9 of the ESA for actions considered sufficiently conservative (NMFS 2003). The NMFS opted to evaluate the HGMP through the 4(d) rule process (65 FR 42422). The HGMP was later submitted to NMFS as a joint Makah Tribe and WDFW Resource Management Plan (RMP- http://www.nwr.noaa.gov/Salmon-Harvest-Hatcheries/State-Tribal-Management/Ozette-Sockeye-RMP.cfm) for consideration under Limit 6 of the 4(d) Rule. NMFS issued a final determination for the HGMP in July 2003, finding that the plan adequately addressed criteria under limit 6 of the 4(d) rule, exempting the plan from the ESA section 9 take prohibitions (69 FR 18874). The joint RMP evaluated by NMFS is the HGMP and will be referred to in this document as the HGMP.

The HGMP is part of the overall recovery planning process for Lake Ozette sockeye. The HGMP contains a complex set of recovery goals and a well-defined strategy for supporting recovery and preserving the genetic diversity of Lake Ozette sockeye. The HGMP contains measures and actions exclusively needed to maintain the operation of the hatchery component of Lake Ozette sockeye recovery, as well as population and habitat monitoring components not normally associated with hatchery activities. The HGMP clearly states that the HGMP alone will not result in recovery of Lake Ozette sockeye, but a comprehensive approach to habitat protection, habitat assessment, and habitat restoration is needed so that hatchery and habitat components can work in concert with one another to promote species recovery.

The HGMP contains the following recovery goals:

1. Prevent further decline of the ESU population.
2. Increase abundance of naturally spawning Lake Ozette sockeye salmon to self-sustaining levels that meet future estimated escapement goals and enable sustainable Tribal and non-Tribal commercial, Ceremonial and Subsistence (C&S), and sport fisheries.
3. Conserve the genetic and ecological characteristics of Lake Ozette sockeye salmon.
4. Increase distribution and diversity of Lake Ozette sockeye salmon in their present and historical localities along the lakeshore of Lake Ozette and its tributaries using supplementation, reintroduction, and natural colonization.
5. Rebuild naturally spawning aggregations of sockeye in the Ozette watershed and restore their role in ecological processes, including nutrient recycling, serving as a source of prey for other species of fish and wildlife, and for traditional native uses (MFM 2000)

The plan of how to achieve these goals is through an innovative approach to adaptive management in which "restoration activities" are treated as experiments used to develop knowledge of how to change or refine future actions. The adaptive management component of the HGMP contains four steps:

1. Identify recovery strategies that test hypotheses about the limiting factors or causes for decline of the population.
2. Design recovery activities as experiments to collect information from which we can learn.
3. Analyze the responses to recovery activities.
4. Implement changes based on synthesis of information and adaptive management.

The initial strategy of the HGMP included two main components:

1. Reintroduction and supplementation efforts were directed in Big River and Umbrella Creek using tributary returns for broodstock, with intensive monitoring of the experimental introductions to clearly understand their outcome. The intent is that reintroduction into these tributaries will increase viability (abundance, productivity, spatial structure, and diversity) of Lake Ozette sockeye, which should be of long-term benefit to the recovery of the population.
2. Limit artificial production activities for beach spawning fish to studies of limiting factors, genetic composition, and life history, using methods described in the HGMP. Determinations of whether and how to supplement or reintroduce lake spawning aggregations will be made pending results of the research.

Implementation of the HGMP started with BY 2000 returns to the lake. Since implementation of the HGMP, no broodstock have been collected from the beaches and no planting in the Crooked Creek watershed has occurred. Hatchery efforts have focused on refining broodstock capture, incubation, and release methods within Umbrella Creek, in addition to incubation and releases strategies within Big River, as well as small scale limiting factor studies at the spawning beaches. Much of the new population status, life history, ecological interaction, and habitat limiting factors data presented in this analysis were collected as part of the HGMP monitoring effort. Since the implementation of the HGMP began in BY 2000, a total of 746 (379 females and 367 males) sockeye have been collected for broodstock from Umbrella Creek (less than 10% of the total return to Umbrella Creek between 2000 and 2003; MFM unpublished broodstock collection data). A total of 783,617 fry and fingerlings have been released into the Umbrella Creek (36%) and Big River (74%) watersheds (MFM unpublished sockeye release data). A simplified summary of sockeye hatchery releases in the Lake Ozette watershed is included in Table 3.4.

Table 3.4. Summary of HGMP sockeye fry and fingerling releases in the Ozette watershed for brood years 2000 through 2003 (source: MFM, unpublished hatchery release data).

Brood Year	Release Date	Size (Grams)	Number of Fry or Fingerlings Released	Release Site	Broodstock Source
2000	April/May 2001	0.13	63,201	Big River (Stony Creek)	Umbrella Creek
2000	7/29/2001	1.01	50,168	Big River (Stony Creek)	Umbrella Creek
2000	7/27/2001	1.17	48,379	Umbrella Creek	Umbrella Creek
2000	7/27/2001	0.8	32,328	Umbrella Creek	Umbrella Creek
2001	April/May 2002	0.13	75,900	Big River (Stony Creek)	Umbrella Creek
2001	6/28/2002	0.86	75,352	Big River (Stony Creek)	Umbrella Creek
2001	July 2002	1.0-1.57	94,958	Umbrella Creek	Umbrella Creek
2002	6/5/2003	0.32	74,377	Big River (Stony Creek)	Umbrella Creek
2002	6/5/2003	0.91	47,990	Big River (Stony Creek)	Umbrella Creek
2002	6/26/2003	0.74	79,325	Umbrella Creek	Umbrella Creek
2002	June 2003	0.4	24,568	Umbrella Creek	Umbrella Creek
2003	May 2004	0.16	102,779	Big River (Stony Creek)	Umbrella Creek
2003	7/2/2004	0.6	12,792	Big River (Stony Creek)	Umbrella Creek
2003	5/25/2004	0.57	1,500	Umbrella Creek	Umbrella Creek

The HGMP includes a pre-specified duration of 12 years, or three sockeye salmon generations, per release site. After 12 years (2012), the program will be evaluated. If it has been successful in establishing self-sustaining sockeye runs that meet determined escapement goals for release areas after 12 years of operation, it will be terminated. The HGMP also includes an extensive monitoring plan that allows for many of the program performance indicators to be monitored and evaluated annually. Monitoring and annual program evaluation allow for terminating specific program elements that are determined to be ineffective. NMFS (2003) determined that,

"*If, after 12 years, the program is meeting performance standards, and is expected to achieve, but has not yet fully accomplished, program goals, continuation of specific components of the program will be proposed and reevaluated. Similarly, if aspects of the program are not meeting goals or standards, but alternative adaptive management measures are available that are likely to achieve goals and standards providing a net benefit to the ESU, program elements may be changed and continued upon evaluation and reassessment before or after the 12-year evaluation. The co-managers' overall goals and objectives for the program will also be reevaluated over the duration of the hatchery programs to incorporate new findings. Tributary escapement goals and population abundance thresholds are yet to be developed by the co-managers and the TRT. The ability to meet minimum escapement and spawner distribution goals for release streams for each brood year will be considered in defining success or failure of the tributary program and its subsequent continuance or termination.*"

In 2003 NMFS conducted an assessment of the Lake Ozette hatchery program's relative contribution to the conservation of the listed species. This assessment included a detailed evaluation of the hatchery program's effects on ESU viability, based on the viable salmonid population (VSP) parameters of abundance, productivity, spatial structure, and diversity. NMFS (2004) concluded that the hatchery program is increasing the abundance of natural spawning sockeye in the ESU, but that tributary spawners from the program are isolated from the beach spawning aggregations (by design), and are unlikely to benefit the abundance of the natural-origin beach spawning sockeye population. Neither was the productivity of the beach spawning aggregations expected to be increased by the tributary hatchery programs in Umbrella Creek and Big River.

NMFS (2004) concluded that the hatchery program was not likely to increase the spatial structure of the *beach spawning aggregations* within Lake Ozette, but that the hatchery program is likely to increase the spatial structure of the ESU as a whole. NMFS also determined that the ESU's diversity may potentially benefit from the hatchery program. The hatchery program is expected to affect ESU diversity by extending the range of the species' distribution, which may contribute to life history diversity and increase the resiliency of the population (NMFS 2004).

3.3 POPULATION STRUCTURE and DIVERSITY

The Lake Ozette sockeye ESU is believed to have been historically composed of a single population with substantial sub-structuring of individuals into multiple spawning aggregations (BRT 2003). Presently Lake Ozette sockeye spawn on two lake beaches, Olsen's Beach and Allen's Beach (Figure 3.7) and in three tributary streams, Umbrella Creek, Crooked Creek, and Big River (MFM 2000; Figure 3.16). During the late 1970s and early 1980s, only beach spawning sockeye were documented during a series of intense basin-wide spawning ground surveys. A few documented occurrences of spawning outside of the currently known spawning sites have been recorded in the past 25 years. Dlugokenski et al. (1981) observed sockeye spawning along the shoreline just north of the confluence with Umbrella Creek during the BY 1978 spawning period. During 1994 spawning ground surveys, sockeye redds were observed by ONP divers along the shoreline of Baby Island (Meyer and Brenkman 2001). Indirect evidence of spawning in or around Boot Bay was documented by Dlugokenski et al. (1981) based on gillnet captures of ripe sockeye, although no actual spawning was documented.

The historical presence of tributary spawning sockeye is somewhat controversial. Blum (1988) concluded that loss of tributary spawners was a primary factor for the sockeye population decline, although his hypothesis is not widely accepted. Others have argued that no tributary spawners existed prior to the Makah Tribe's hatchery (re)introductions. Dlugokenski et al. (1981) cites Pete Ward (former MFM biologist), Emil Pearson (Ozette resident and direct descendant of an Ozette settler), and J. Ayerst (WDFW biologist) as stating that sockeye historically utilized Lake Ozette tributaries, and Pete Ward specifically is cited as stating that sockeye spawned in Umbrella Creek. Blum (personal communication 2004) states that in interviews with William Parker Sr. (now deceased), Mr. Parker stated that sockeye spawned in the tributaries and that historically tribal fisherman harvested sockeye directly from the tributaries. In interviews in 1941 with the Bureau of Indian Affairs, Makah fishermen described taking salmon by net and spear in the Ozette River, and by a net strung between two canoes in the lake, but salmon species was not specifically identified in the transcript of the interview (Swindell 1941). Kemmerich (1945) stated that there was no evidence that sockeye ascended any of the tributaries to Lake Ozette, but they spawned along several lake beaches and at the mouths of tributary streams[11].

The Umbrella Creek spawning aggregation was established using a combination of broodstock collected at Olsen's and Allen's beaches (MFM 2000). The first direct release into Umbrella Creek occurred with BY 1983 releases into Umbrella Creek at RM 1. The first documented adult sockeye return to Umbrella Creek occurred during the BY 1988 spawning season. The origin of these fish is unclear but may have been the result of BY 1983 or 1985 releases that occurred in Umbrella Creek (MFM unpublished hatchery release data; no releases were associated with BY 1984). Blum (former MFM biologist) reported approximately 10 adult sockeye spawning in a tributary to Lake Ozette during the fall/winter of 1982, but the specifics of the report are unclear (Jacobs et al. 1996). Hatchery objectives have changed significantly over the course of the last 20 years, and a strategy of specifically building/rebuilding tributary spawning aggregations began in the 1990s. Objectives were refined again in 2000 (see MFM 2000 for specifics on hatchery strategies and history). Brood year 1994 was the last year juveniles were released in the lake; since then, hatchery efforts have primarily focused on tributary releases.

Observations of sockeye spawning in Big River during the winter of 1998 before any hatchery out-planting may provide evidence that some Ozette sockeye stray into new habitats, possibly in an attempt to colonize new environments. This could be what has occurred in the past when sockeye have been observed in numbers of 10-30 fish in an area in a single year and then not observed again at the same site (Boot Bay, Baby Island, Umbrella Beach, Big River, unknown tributary in 1982).

3.3.1 Genetics

Lake Ozette sockeye genetics have been studied and summarized in past work done by Hershberger et al. (1982), Gustafson et al. (1997), and Crewson et al. (2001); and more recently by Hawkins (2004). Gustafson et al. (1997) described Lake Ozette sockeye as genetically distinct from all other sockeye salmon stocks in the Northwest. Past analyses of Lake Ozette sockeye genetics and life histories have suggested that two within-basin populations may exist in Lake Ozette (Dlugokenski et al. 1981; Hershberger et al. 1982). Dlugokenski et al. (1981) suggested that the beach spawning aggregations may be separate populations based upon variations in peak spawn timing between Olsen's and

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[11] Kemmerich (1939) states in a letter to Dr. Foerster, "We made no special investigation of the spawning beds during the years covered in the report (referring to the 1926 report on the history and operations conducted at Lake Ozette, later included in Kemmerich 1945) but merely observed that from time to time that most of the spawning seemed to be along the lake shore …"

Allen's beaches. Hershberger et al. (1982) suggested that there may be two populations based upon genetic differences observed between samples collected in June and July in the Ozette River. However, they cautioned that sample sizes were small and a more detailed analysis including increased sample sizes and increased duration of sampling would be needed in order to gain greater certainty on whether multiple populations exist. Gustafson et al. (1997) indirectly suggested that two populations may exist, based upon samples collected from Olsen's and Allen's beaches that were statistically different at seven loci (BY 1995).

Crewson et al. (2001) used adult sockeye tissue samples collected from Olsen's Beach (BY 1996, 1999, 2000), Allen's Beach (BY 2000), and Umbrella Creek (BY 2000), as well as kokanee tissue samples collected in Siwash and Crooked Creeks to examine genetic differences between and among these spawning aggregations. They concluded that the data revealed large genetic differences between the kokanee and sockeye populations within Lake Ozette. Crewson et al. (2001) determined that there were significant genetic differences between cohort lineages within the Olsen's Beach spawning aggregation. The brood year 1999 and 2000 genetic samples were significantly different from one another, while the 1996 and 2000 (BY 1996 were parents to the BY 2000 spawners) samples were not significantly different. Crewson et al. (2001) also found that samples collected in 2000 at Olsen's and Allen's beaches were significantly different from one another, but were unable to determine whether this pattern was consistent between years, since only one brood year was sampled.

Hawkins (2004) genetically characterized over 1,800 sockeye and kokanee tissue samples collected over a 14-year period (1988-2002) from seven different spawning locations within the watershed, at 17 microsatellite DNA loci. All samples analyzed by Hawkins were collected from adult sockeye and kokanee salmon. Hawkins (2004) found that there was very little genetic structure among the sockeye spawning aggregations at Olsen's Beach, Allen's Beach, and Umbrella Creek. However, there were genetic differences between cohort lineages along the predominant 4-year brood cycle, and these lineages were found to be most closely related independent of sampling locations (Hawkins 2004). Hawkins (2004) determined that the genetics of Umbrella Creek sockeye are more closely aligned to sockeye spawning aggregations at Olsen's Beach than those spawning at Allen's Beach. Hawkins (2004) described the Lake Ozette kokanee population structure as likely one panmictic group with no genetic differences among the sample collections within the study. However, not all streams and spawning sites used by kokanee were sampled.

3.3.2 Sockeye-Kokanee Genetic Interactions

Sockeye and kokanee salmon are known to interact during the freshwater rearing phase of the sockeye salmon, which coincides with nearly the entire rearing life history phase of kokanee salmon. Of most importance here is the interaction of sockeye and kokanee salmon during the spawning phase. Dlugokenski et al. (1981) described kokanee as being interspersed with sockeye salmon on the both of the spawning beaches during the months of November and December. Recent spawning ground surveys of the beaches have also included observations of kokanee-sized O. *nerka* among spawning sockeye salmon. It has not been possible to positively determine whether visual observations of kokanee-sized fish are kokanee or whether they may be residual, jack, or hybrid sockeye salmon. Kokanee-sized *O. nerka* have also been observed spawning with sockeye salmon in Umbrella Creek. Genetic evidence analyzed by Hawkins (2004) indicates that hybridization between sockeye and kokanee salmon appears to have been occurring prior to 1991 and continues to be persistent between the two populations. However, the genetic mixing between sockeye and kokanee salmon is of low enough frequency to maintain the large genetic differences observed between the two populations (Hawkins 2004).

3.4 POPULATION SIZE AND TRENDS

The purpose of the population size and trends section is to provide the most up to date information regarding Lake Ozette sockeye run sizes, spawning aggregation sizes, and recent and long-term trends in both total run sizes and spawning aggregation sizes. This best available information will serve as the baseline for the analysis of limiting factors, and consideration of recovery actions. In addition, this section of the report will describe in detail the methods used to enumerate and estimate the Lake Ozette sockeye run sizes, how these methods have changed through time, and how changes in counting and estimation methods may affect the accuracy of past and recent sockeye run-size estimates.

3.4.1 Methods Used to Estimate Run Sizes

The first attempt to quantify the size of the Lake Ozette sockeye run occurred in 1924 when the U.S. Fish and Wildlife Service (USFWS) installed and operated a counting weir approximately 660 feet (200 m) downstream from the lake's outlet in the Ozette River. Sockeye weir counts were conducted between 1924 and 1926 at this site; the methods used were poorly described in Kemmerich (1945). However, Kemmerich (1945) does describe the use of a trap in the last half of the 1926 run which likely increased the accuracy of those counts. It is important to note that run-size estimates produced for RY 1924-1926 do not include the number of sockeye harvested. Also, the weir was not deployed during the early part of the run during all years and therefore the numbers reported in Kemmerich (1945) only represent a fraction of the actual number of sockeye entering the Ozette system. The weir was operated from May 27, 1924 to August 8, 1924, between June 8, 1925 and September 15, 1925, and between June 10, 1926 and September 8, 1926. From 1927 to 1976 no attempt was made to accurately quantify the number of sockeye salmon entering the lake. Past analyses (Bortleson and Dion 1979; Dlugokenski et al. 1981; Jacobs et al. 1996; Gustafson et al. 1997; MFM 2000) used salmon harvest records reported in Ward et al. (1976) as an indicator of the historical abundance of Lake Ozette salmon stocks.

The first contemporary attempt to quantify the size of the Lake Ozette sockeye run occurred between 1977 and 1980 when a joint study between the USFWS, U.S. Geological Survey (USGS), and the Makah Tribe operated a counting weir in the Ozette River, near the lake's outlet (200 m downstream). Lake Ozette sockeye run sizes from 1977 to present are considered "recent" estimates within the context of this discussion. The methods used to estimate sockeye run sizes in the Ozette River and spawning aggregation sizes have varied over the course of the last 25 years. Initially, from 1977 to 1981, weir counts were made based upon nighttime counts of sockeye passing over an illuminated counting board. Observers were stationed on the Olympic National Park's footbridge crossing the Ozette River (the same location where the counting weir is currently deployed) for fish observation. In 1977, bi-weekly daytime counts were conducted, but no daytime migrants were observed (Dlugokenski et al. 1981). Only nighttime counts appear to have been used in return years 1978-1981 (Dlugokenski et al. 1981; MFM 1981B). The weir used during RY 1977 through 1981 was made of seine netting attached to a lead line and chain. The lead line and chain were used to weight the net to the stream bottom. However, the use of a net made the weir susceptible to sockeye burrowing under the lead line and chain (complete details of methods for each year of weir counts are included in Appendix A).

In 1982, a river-spanning picket weir with a live trap attached was used to enumerate sockeye entering the lake. This allowed for a more "fish tight" structure than the previously employed net weir. The MFM FY 1982 annual report states (MFM 1982A): "*A different sampling design was installed this year due to problems encountered with the previously used methodology.*" It is assumed that one of the problems with the sampling design of past weir counts (1977-1981) was related to the lack of 24-hour monitoring. In RY 1982, just over 24% (512 of 2123) of the sockeye transiting the weir passed during daylight hours. The picket weir and trap were again used in 1984, but due to high water the weir and trap could not be deployed until June 19 (MFM 1984A). The weir was not operated during 1985 and 1987 (LaRiviere 1991). The weir was reportedly operated during RY 1986, but no records could be found regarding weir operations for that year.

In 1988, the picket weir was deployed just upstream from the ONP footbridge and operated between 2000 hr and 0600 hr (LaRiviere 1991). The weir was closed during non-observer time periods (LaRiviere 1991). Fish were enumerated as they crossed a white, illuminated, counting board from an observation platform (LaRiviere 1991). In 1989, the weir was deployed and operated in the same manner as in 1988 with the exception that for one night a trap was attached to the weir so that sockeye could be captured and measured (LaRiviere 1991). In 1990, the weir was deployed in the same location and operated in a similar manner as in 1988 and 1989 (LaRiviere 1991), but the weir was blocked off during weekends. A trap was attached to the weir and fished sporadically throughout the run (LaRiviere 1991). Approximately 17% of the fish transiting the weir were trapped and manually passed through the weir. In 1990 the weir was fished a total of 31 nights over a 66-day period (June 7 through August 11, 1990).

In 1991 the picket weir was again fished at the same location as in 1988-1990. Weir observation and trapping times fluctuated radically throughout the monitoring period, but overall methods were similar to those used in RY 1988-1990 (see Appendix A for complete details). Weir counts encompassed a greater portion of the run time in 1992, as the weir was fished from May 29 through July 9. Methods used were similar to those employed between 1988 and 1991. No reliable documentation of 1993 weir counts exists; the field notes were lost. From RY 1994 through RY 1997 the same methods were used as in RY 1988 through 1993. No written reports describing these years could be found, but field notes indicate that operations were conducted in the same manner as in previous years. No significant differences in methods occurred until 1998.

Return year 1998 was the first year in which 24-hour per day monitoring was conducted using an underwater video camera and time-lapse VCR. The picket weir was assembled in the same location as in RY 1989-1997. Visual observers were stationed at the weir from 2200 to 0700 starting May 7 and ending July 2. The video system was operated from June 16 through August 6. The setup and operation of the weir were the same in 1999 as in 1998. In 1999, the video system operated from May 1 until September 30. In addition to the video system, observers were stationed at the weir opening between 2200 and 0700 beginning April 30 and ending August 6 (for more details see Haggerty 2005d). Weir operations in 2000 and 2001 predominantly used the video system to enumerate the sockeye run size. A trap was also used in both of the years to monitor a portion of the run (see Appendix A; Haggerty 2005c). In 2000, the weir was operated from April 19 through August 12. In 2001, the weir was operated from April 30 through August 18. Both years encompassed a larger portion of the run-entry timing than in any other two years.

Weir operations during return years 2002 and 2003 used the video system to enumerate sockeye transiting the weir. The weir was set up in the same location as in past years (1989-2001) and minor adjustments were made to increase the quality of data collected at the weir. In addition to the standard time-lapse VCR data, video images were also recorded on a computer hard drive (HD) to evaluate the efficiency and accuracy of using computers to help process the time-consuming videos. Paired imagery of VCR and HD were compared to calculate the proportion of sockeye transiting that was detected using both methods. This method provided a relatively accurate estimate of the overall sockeye run sizes for these years. The weir and video systems were operated from April 11, 2002 through August 14, 2002. In 2003, the weir and video system was used to monitor adult migration into Lake Ozette between May 12 and August 12.

The methods used to enumerate and estimate Lake Ozette sockeye run sizes have changed significantly between 1977 and the present. Significant differences in older methods limited the quality of data collected and therefore likely underestimated run sizes. Return years with incomplete datasets were used to develop the Dlugokenski Model, which estimates the sockeye run size based upon the assumption that 63.3% of the sockeye run enters the lake between June 5 and June 24 (Equation 1).

Equation 1

$$N = \left(\frac{n}{p}\right)$$

Where,
n= the number of sockeye transiting the weir between June 5 and June 24.
p= the proportion of sockeye assumed to have transited the weir between June 5 and June 24 in the base years (1977-1979; 0.633).

Recently, data collected at the weir have shown that several of the basic assumptions used by Dlugokenski et al. (1981) are now invalid and were also likely invalid at the time of their study. In order for the Dlugokenski Model to yield reliable estimates, at least five assumptions must be valid: 1) the proportion of sockeye that transit the weir between June 5 and June 24 must be normally distributed between years, 2) sockeye must not transit the weir during daylight hours, 3) all fish that enter the lake must pass through the weir, 4) visual observers stationed at the weir must count every sockeye passing through the weir, and 5) all fish entering the lake between 1977 and 1979 (model base years) must have been enumerated (MFM 2000).

Most of the five assumptions above have not been valid in the most recent years of weir operations and were no more valid between 1977 and 1979 when the model was developed. Unfortunately, only one of the base year datasets still exists and the degree to which these assumptions were violated will remain a mystery. The most recent data collected at the weir (1998-2003) has enabled a much clearer depiction of errors associated with sockeye enumeration in the system. Much of the new perspective on sockeye enumeration at the weir comes from having robust datasets that encompass all or the majority of the sockeye run-entry timing. It has been found that peak migration into the lake varies by 20-30 days dependent upon the return year. Daytime sockeye passage into the lake is highly influenced by lake level and streamflow; when the lake level is high the proportion of daytime migrants is also high (Figure 3.5). The number of fish detected by visual observers stationed at the weir is consistently lower than the number detected by video systems. However, the proportion of sockeye detected by video tape review is also significantly less than 100% of the total number of sockeye transiting the weir. For RY 1996 through 2003 several new adjustment and expansion factors have been added to the methods used for estimating the total sockeye run sizes.

3.4.2 Historical (pre-1977) Ozette Sockeye Run Sizes

As reported earlier, there are only marginal data available for estimating historical escapement levels for Lake Ozette sockeye. A weir was used to enumerate sockeye entering Lake Ozette in 1924, 1925, and 1926, but no harvest data for interceptor fisheries are available for these years, so it is not possible to estimate the total run sizes for these years (Figure 3.22). It is assumed that fisheries would have been conducted downstream of the weir in RY 1924 through RY 1926 (see WDF 1955). In addition, these weir counts are only partial counts that do not incorporate the entire run-time window for Lake Ozette sockeye. Between 1948 and 1976, harvest data are available but no escapement data were collected, creating substantial uncertainty regarding run sizes during this period. MFM (2000) questioned the accuracy and reliability of the reported harvest numbers, since they come from verbal reports of fish bought by local fish buyers, although WDF (1955) cites the source of the catch data along with the numbers of nets used in the Ozette River fishery. It can still be argued that in some years the harvest may have been significantly less and in other years, much of the harvest may not have been sold and consequently not reported. Blum (1988) speculated that the Lake Ozette sockeye run size exceeded 50,000 fish prior to the 1940s. Over a 20-year period, Lake Ozette sockeye harvests went from several thousand per year to zero. For the last 25-plus years (1982-present) no harvest of sockeye salmon has taken place in tribal fisheries. From 1973 to 1977, tribal regulations strictly limited harvest of sockeye salmon. Reported catch during this period was 133 fish. From 1978 through 1982, tribal regulations limited the harvest to 30 fish per year for ceremonial purposes.

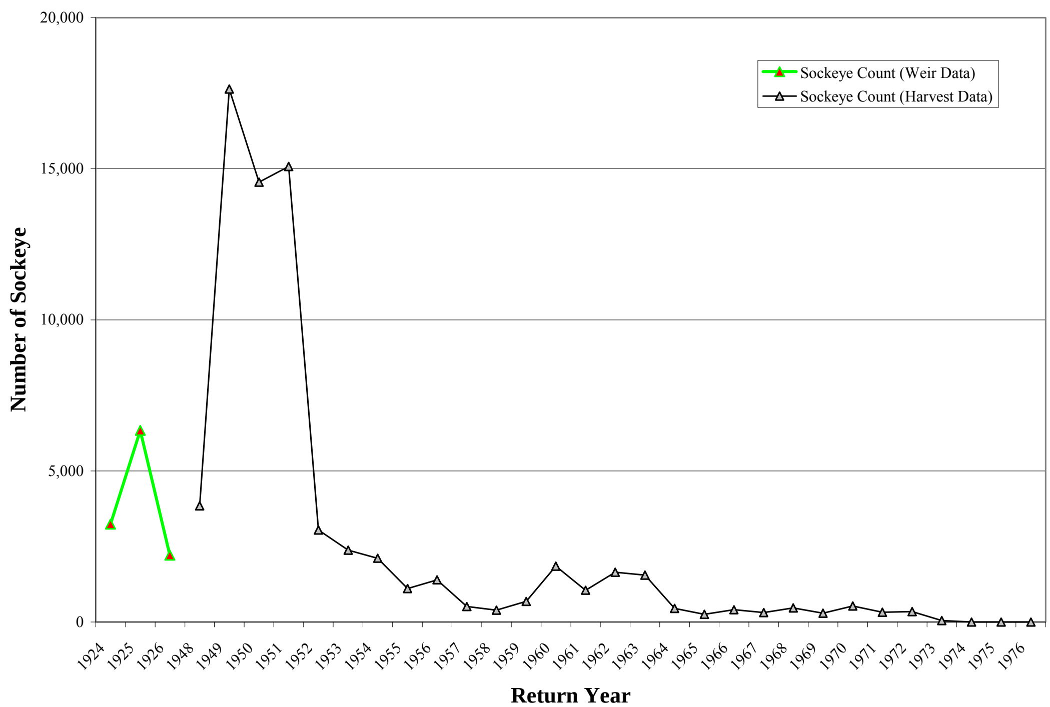

Figure 3.22. Historical abundance of Lake Ozette sockeye (RY1924-1926 and RY1948-1976) based on Kemmerich (1945) and Jacobs et al. (1996).

3.4.3 Recent (1977-2003) Lake Ozette Sockeye Run Sizes

As described in Section 3.4.1. sockeye have been counted using a weir located near the lake's outlet from 1977 to present. Estimated run sizes presented in Jacobs et al. (1996) and MFM (2000) are shown in Table 3.5. The most recent (1996-2003) run-size estimates are presented later in this section in Table 3.6. MFM (2000) used information and data collected in 1998 and 1999 to adjust run-size estimates between 1988 and 1997. Upon summarizing and analyzing recent datasets (1996-2003) additional insights were gained and adjustments to recent run-size estimates (pre-1996) were made in an attempt to generate run-size estimates that are adjusted and expanded based on the same general assumptions.

Table 3.5. Estimated Lake Ozette sockeye run sizes, monitoring periods, and methods (Modified from Jacobs et al. 1996; MFM 2000).

YEAR	Weir Operations Start	Weir Operations End	No. Adults Observed	Estimated Run Size (Jacobs et al. 1996)	Estimated Run Size (MFM 2000)	Method of Estimate	Citations
1977	~5/14/1977	~8/10/1977	920 + 84 harvested	1,004	1,004	N = n + Harvest	Dlugokenski *et al.* (1981)
1978	~5/24/1978	~8/8/1978	890 + 30 harvested	920	920	N = n + Harvest	Dlugokenski *et al.* (1981)
1979	~5/20/1979	~8/8/1979	510 + 30 harvested	540	540	N = n + Harvest	Dlugokenski *et al.* (1981)
1980	?	?	255 + 30 harvested	432	432	N = n/p + Harvest	Dlugokenski *et al.* (1981)
1981	6/8/1981	7/8/1981	239		350	N = n/p	MFM 1981A
1982	6/9/1982	8/17/1982	2,061 + 29 harvested	2,147	2,152	N = n + Harvest	Blum 1988
1983	NA	NA	NA	350	NA	NA	No Data Collected
1984	6/19/1984	8/7/1984	804	2,170	2,170	N = n/p	Blum 1988
1985	NA	NA	NA	NA	NA	NA	NA
1986	?	?	NA	691	691	N = n/p	LaRiviere 1991;
1987	NA	NA	NA	NA	NA	NA	NA
1988	6/27/1988	6/29/1988	218	2,191	3,599	N = n/p	LaRiviere 1991
1989	6/19/1989	6/30/1989	143	588	603	N = n/p	LaRiviere 1991
1990	6/7/1990	8/11/1990	175	263	385	N = n/p	LaRiviere 1991
1991	5/23/1991	7/12/1991	NA	684	684	N = n/p	Drange and LaRiviere 1991
1992	5/29/1992	7/9/1992	1,175	2,166	2,548	N = n/p	MFM 2000
1993	?	?	69	≤267	NA	N = n/p	MFM 2000
1994	6/6/1994	7/15/1994	NA	498	585	N = n/p	MFM 2000
1995	?	?	NA	314	314	N = n/p	MFM 2000
1996	6/18/1996	6/29/1996	NA	NA	1,778	N = n/p	MFM 2000
1997	6/9/1997	7/1/1997	280	NA	1,133	N = n/p	MFM 2000
1998	5/7/1998	7/2/1998	980	NA	1,406	MFM 2000	MFM 2000
1999	5/1/1999	9/30/1999	1,945	NA	2,076	MFM 2000	MFM 2000

The methods used to derive the most recent (1996-2003) run-size estimates for sockeye entering Lake Ozette are described in detail by Haggerty (2004a; 2005a; 2005b; 2005c; and 2005d). Sockeye run-size estimates from 1996 to 2003 ranged from a low of 1,609 (1997) to a high 5,075 (2003), averaging approximately 3,600 sockeye per year. The quality of annual run-size estimates varies depending on the methods used to collect data, data quality, and days of data collection. In some years, such as 1996, very few data were collected and their quality was some what questionable. The range of reasonable run-size estimates for 1996 is broad. Consistent run-size estimate methodology was applied to datasets from 1996 through 2003. For example, the run size in each year is calculated based upon a return window starting April 15 and ending August 15. Where small data gaps were present within a given dataset, a two-sided, hourly 7-day moving average method (see Haggerty 2004A) was used to expand for missing time periods. Where bigger blocks of missing data were present (such as in 1996 and 1997), sockeye counts were adjusted based upon the mean proportion of sockeye detected by visual observers from the 1998 and 1999 weir datasets (two years when full counts were made by visual observers). Upon adjusting the visual observer counts, the run-size estimate was then expanded based upon the average proportion of sockeye transiting the weir during RY 1998-2003 for the days when visual observer data were collected. Run-size estimates for return years 1996 through 2003 are provided in Table 3.6.

Table 3.6. Estimated sockeye run sizes entering Lake Ozette for return year 1996 through 2003 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d).

Year	Estimated Run Size	Confidence in Estimate	Low End Estimate	High End Estimate	Days of Weir Operation	Number of Sockeye Counted	No. of Sockeye Counted to Derive Run-Size Estimate
1996	4,131	Low	1,924	18,117	12	429	429
1997	1,609	Mod-Low	na	na	21	258	236
1998	1,970	Moderate	na	na	91	980	965
1999	2,649	Moderate-High	na	na	106	2,282	2,282
2000	5,064	Moderate-High	na	na	116	4,423	4,423
2001	4,315	Mod-Low	3,768	na	98	2,288	2,288
2002	3,990	High	na	na	125	3,223	3,223
2003	5,075	Moderate	na	na	83	2,342	2,342
Mean	**3,600**	**Moderate**	**na**	**na**	**82**	**2,028**	**2,024**

Lake Ozette sockeye exhibit a four-year brood cycle, and for this reason trends were evaluated in four-year groups (Brood Years A, B, C, and D). The mean run size over the last four years can be compared to the previous four years. Between 1996 and 1999 the run size averaged 2,590 sockeye; from 2000 to 2003 the run size averaged just over 4,600 sockeye. Within these two four-year cycles the average return increased by approximately 78%. Much of the increased production is likely a result of increased adult returns from Umbrella Creek Hatchery releases, and increased natural production in Umbrella Creek. Nearly 210,000 BY 1996 fed fry and fingerlings were released in 1997 and these releases composed a large portion of the RY 2000 run. Figure 3.23 depicts the estimated run sizes for 1996 through 2003 and compares the proportion of the run-size estimates that are based upon expansion, as well as the percentage (in days) of the run in which the weir was deployed.

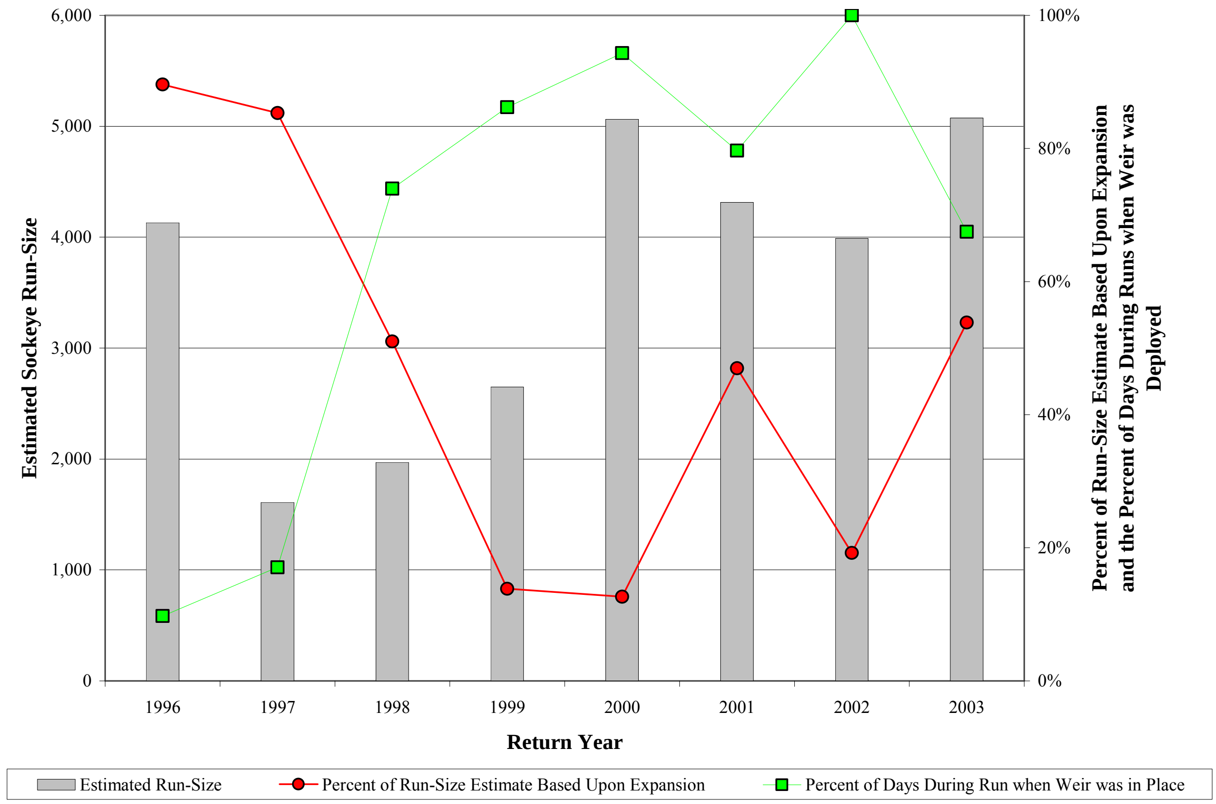

Figure 3.23. Estimated Lake Ozette sockeye run sizes for return years 1996 to 2003 contrasted with the proportion of the run-size estimates that were based upon expansion and the percentage of run-days in which the weir was deployed (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d).

The most significant finding in reworking the 1996 through 2003 weir datasets was a better understanding of what proportion of the sockeye transiting the weir were actually being detected. The proportion of sockeye detected varied by method, visual observer, VCR tape reviewer, and, potentially, environmental conditions (lighting, turbidity, bio-disturbance). MFM (2000) calculated that approximately 1.72 sockeye transited the weir for every sockeye detected by visual observers based upon "paired" video and visual observer weir datasets. Run-size estimates based upon visual observer datasets were then adjusted based upon this factor by MFM. However, there was an assumption that time-lapse video review detected all sockeye transiting the weir. Replicate tape review, paired visual observer/time-lapse video review, and paired computer hard drive/time-lapse video review have all revealed that this assumption was false. In fact sockeye detection using time-lapse video was quite poor in some years, such as 2001, when only 48% of the detectable sockeye were actually detected in the first view dataset (Haggerty 2005b). The highest proportion of sockeye detected by time-lapse video review was in 2002 when approximately 87% of all detectable sockeye were detected by first view video review. It was found that nearly all of the error associated with video review was related to the speed at which the time-lapse videos were played. When videos were viewed at the "normal" play speed, approximately 98% of all detectable sockeye were detected. But when tapes were initially reviewed they were played at a viewable fast forward speed during periods of decreased weir activity. This resulted in numerous occasions when sockeye were undetected in the first view dataset.

Additional important factors revealed by reviewing weir datasets from 1998-2003 showed that the Dlugokenski Model consistently failed to adequately describe and estimate run sizes based upon the June 5 to June 24 entry window. Dlugokenski et al. (1981) projected that approximately 63.3% of the run entered during this time period. However, their weir counts were incomplete; they didn't enumerate sockeye during the entire run window, and they claimed that no sockeye transited the weir during daylight hours. Contrary to this assertion, sockeye are known to transit the weir during daylight hours. In fact in 1982, just over 24% of the sockeye transiting the weir did so during daylight hours. In 2000, higher than average lake levels persisted throughout most of the run-time window. Nearly 65% of the sockeye counted transited the weir between 0700 and 2200, and it was calculated that 76% of the sockeye transited during daylight hours (defined as civil twilight; Haggerty 2005c).

It has been suggested that increased daytime entry may be influenced by increased numbers of hatchery sockeye making up the run. A comparison of daytime sockeye weir transit and hatchery clip status has shown that there was no proportional difference in the number of hatchery-clipped fish transiting the weir between day and night (Haggerty 2005C). Lake level appears to be the main factor controlling day and nighttime entry at the weir. The "apparent" shift in run timing from the late 1970s to what is currently being observed has also been attributed to the influence of hatchery practices. A comparison of the cumulative number of clipped sockeye versus the cumulative number of sockeye transiting the weir in return years 2000-2003 indicated that clipped and unclipped sockeye transit the weir proportionally throughout the entire length of the run. Between 1998 and 2003, an average of only 34.6% of the sockeye transiting the weir passed within the Dlugokenski window (range 19.9%-48.9%).

The above factors may have worked collectively to bias abundance estimates toward underestimating sockeye run sizes in the past. In order to compare the most recent run-size estimates with those made in the past, common factors such as run timing and visual sockeye detection rates were used to "adjust" previous run-size estimates. This was done so that all run-size estimates were based upon the same basic assumptions (day and night transit, run timing, observer error). This resulted in run-size estimates that lack the desired precision and statistical certainty, but these estimates are based upon the best available data for Lake Ozette Sockeye. Appendix B contains a table summarizing run-size estimates for Lake Ozette sockeye from 1977 through 1995. Data from each year were evaluated based on the number of days of weir operation, total number of sockeye counted, and the mean daily proportion of sockeye estimated to have transited the weir during RY 1998 through 2003, as well as the extreme years of inter-annual variation in daily run proportions for the period of 1998 through 2003. The average daily proportion of sockeye for each day of observation within each dataset (1977-1995) was summed to estimate the proportion of the run represented by the data based upon the average run timing observed from 1998 to 2003. The same calculation was performed on the extreme years of inter-annual variation from 1998-2003. This allowed for an estimate for each year based upon the earliest, "normal," and latest entry timing into the lake. The proportion of sockeye assumed to be detected by observers during RY 1977 through 1995 were grouped into three broad categories: high detection (90%), moderate detection (70%), and low detection (50%). This allowed for a simple calculation of run-size estimates for each year of data. Where specifics are known regarding sockeye detection, such as in 1982 and 1984 (when all fish were trapped and handled during the weir monitoring period), detection was assigned a high rating.

The median value of the nine run-size estimates was then defined as the run-size estimate for a given year. This method of back calculating leaves much to be desired but is the only reasonable method which allows for older run-size estimates to be scaled to the most recent estimates. It is clear from a review of weir data, field notes, and experience operating the weir, that counts have become progressively more accurate, and that older counts should typically be considered less accurate. Figure 3.24 depicts the newly constructed run-size estimates for return years 1977 through 2003 grouped by brood year.

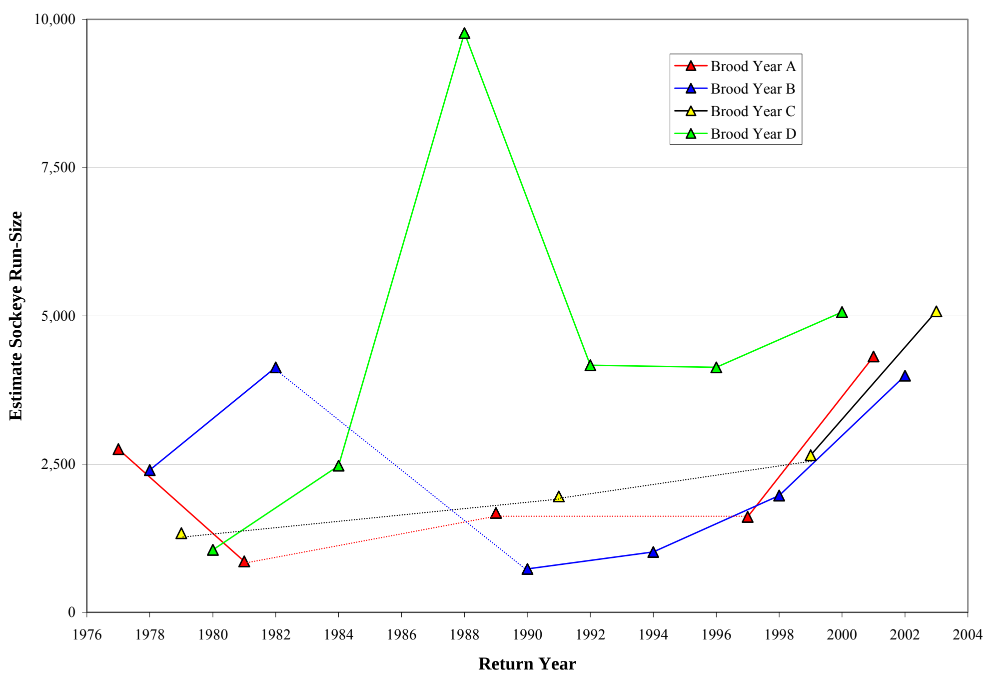

Figure 3.24. Lake Ozette Sockeye run-size estimates adjusted based on sockeye detection rates and new run-timing curves for RY 1977-1995, grouped by brood year with run-size estimates for 1996-2003 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d).

Weir data from 1977 through 1997 generally lack sockeye counts for more than 50% of the sockeye run time period and the quality of the daily sockeye counts is questionable for most years. Weir observers enumerating sockeye in return years 1998 and 1999 were only able to detect an average of 59% of the detectable sockeye transiting the weir. The accuracy of visual observers in the past may or may not have been significantly better than crews used in recent years, but several other factors likely affected the quality of weir counts in either case, such as the use of a net weir and the lack of daytime counting. Run-size estimates for return years 1977-1997 should be used with extreme caution, since the quality of estimates for most years is poor at best. It should also be noted that on years of low abundance it is likely that run timing may be truncated, making the average run-timing curves used to adjust the 1977-1997 run-size estimates relatively meaningless. Compressed run timing in years of low abundance would cause significantly higher run-size estimates than the actual run sizes using this method of run-size estimation. Furthermore, run timing may have significantly shifted between time periods, making these estimates obsolete.

3.4.3.1 Current Spawning Distribution and Number of Spawners

The current spawning distribution of Lake Ozette sockeye is described in detail in Sections 3.1.4 and 3.1.5. Spawning sockeye can be divided into two main groups: beach spawners and tributary spawners. Currently, sockeye use two beaches for spawning, Olsen's Beach and Allen's Beach (Figure 3.7). Sockeye use three main tributary systems for spawning: Big River, Umbrella Creek, and Crooked Creek (Figure 3.16). Accurate census data for most spawning aggregations is nonexistent. Recently a weir has been operated in Umbrella Creek to measure the number of spawners entering that system.

3.4.3.1.1 Lake Ozette Sockeye Beach Spawning Aggregations

The earliest documented beach spawning ground surveys were conducted in BY 1973. Between 1973 and 2004, various methods have been used to count the number of spawning sockeye along the shorelines. Unfortunately, systematic counts do not exist for the beach spawning grounds. Methods used to count spawning sockeye have included: seine and gill netting (mostly for broodstock collection, but also used to retrieve tissue samples for various genetic collections), foot, snorkel, SCUBA, and boat surveys. Appendix C contains a comprehensive summary of broodstock collections, genetic tissue collections, and sockeye spawning ground survey efforts from 1973 to 2004. For most years broodstock collection data contains a start and end date and the total number of sockeye collected. Most of the genetic tissue sampling data contains the same attributes as the broodstock collection datasets but also includes the number of fish captured and sampled for each day. The spawning ground survey data contains the most variability. Some years contain few surveys. Others contain descriptive details about each redd, the number of sockeye observed, and live and dead counts, while yet other years contain only narrative descriptions. Because of the general randomness of the data collected for the beach spawning component of the sockeye population, we were forced to illustrate trends within the beach spawning aggregation by describing survey effort and the minimum number of sockeye that used a beach or beaches for each year where data were available.

Although this analysis has no statistical merit, it does provide insight regarding the trend in beach spawning sockeye abundance. Survey effort was defined as "low" if three or fewer surveys were conducted within the survey season. Survey effort was defined as "moderate" for years with four to six surveys and "high" for years with more than six surveys. Defining the "minimum" number of sockeye on the beaches was more complex because some years contained both broodstock collection and spawning ground survey data. The minimum number of sockeye in most years was defined as the peak sockeye count or the number of broodstock collected plus peak sockeye numbers observed after broodstock collection. In other years, the minimum number of beach spawning sockeye was defined as the peak count plus the cumulative number of dead sockeye observed prior to the peak count (in these years all carcasses were sampled so that on subsequent surveys previously sampled dead sockeye were not re-counted). It is also important to note that the minimum number of beach spawners does not equate to the beach spawning escapement, because in some years most of the fish captured were retained for hatchery broodstock; in other years large numbers of sockeye were counted that were determined to be pre-spawning predation mortalities; and, most importantly, only a fraction of the fish on the spawning beaches are counted or captured during any given sampling event.

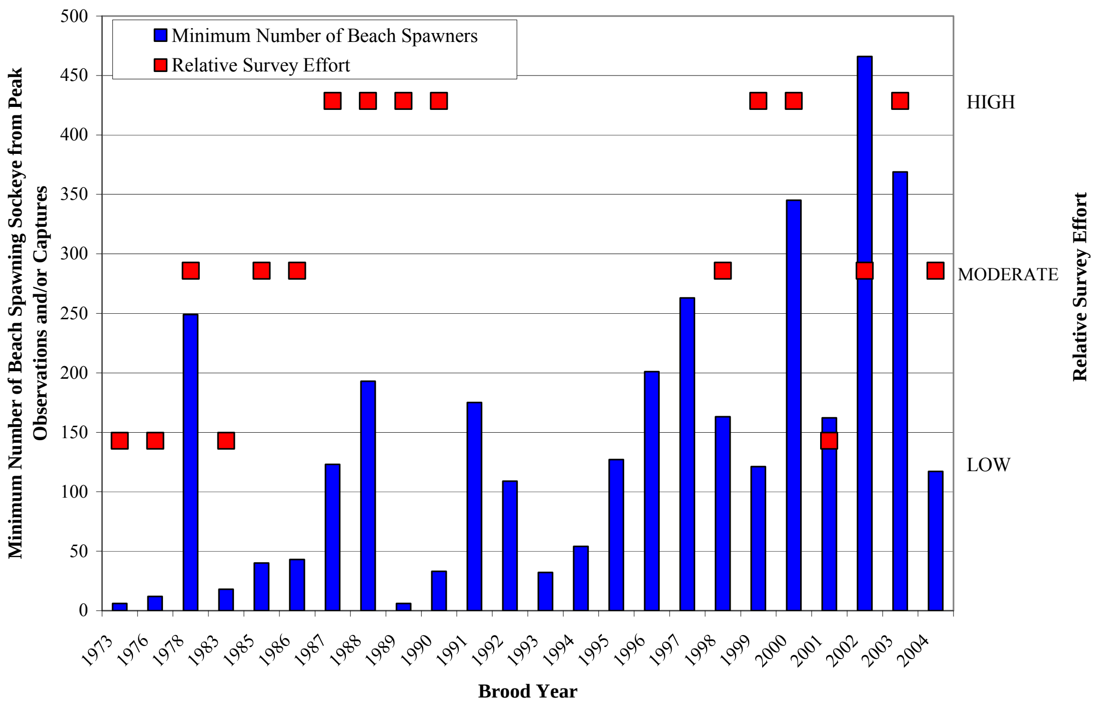

Figure 3.25. Minimum number of beach spawning sockeye from peak observations and/or captures by brood year contrasted with spawning ground survey effort. For years with no relative survey effort values, effort is unknown. Note that only a few of the survey cards for 2001 have been located; this is a minimum estimate and may change when the data are located. Also note that 2004 survey data does not include dive survey data (source: Dlugokenski et al. 1981; Jacobs et al. 1996; MFM, unpublished spawning ground survey data).

Sockeye observation data at the primary spawning beaches of Lake Ozette were collected using several different techniques and did not always specifically attempt to count the number of sockeye on each beach. In some years, the data collected were pooled into the number of fish captured or observed on both beaches; other years contain only the observations and collections from one beach or one portion of a beach. Collectively it is impossible to fully reconstruct these data for the entire period of record for each beach. One fact that has become particularly clear is that sockeye no longer utilize creek mouths for spawning. The most comprehensive spawning ground survey records are for Olsen's Beach. Allen's Beach has the next most comprehensive dataset. Other beaches where sockeye have been observed have far much less data associated with them. Nonetheless, the only non-primary beach spawning sockeye observation other than the spawning observed at Umbrella Beach (1978) is a one-time observation of two spawning sockeye along the south side of Baby Island. Since >97% of all Lake Ozette beach spawning sockeye spawn at age 4, annual observation data were pooled by brood year for comparisons between cohorts. Figure 3.26 depicts the minimum number of beach spawning sockeye from peak observations and/or captures at Allen's and Olsen's beaches from 1973 through 2004 by brood year.

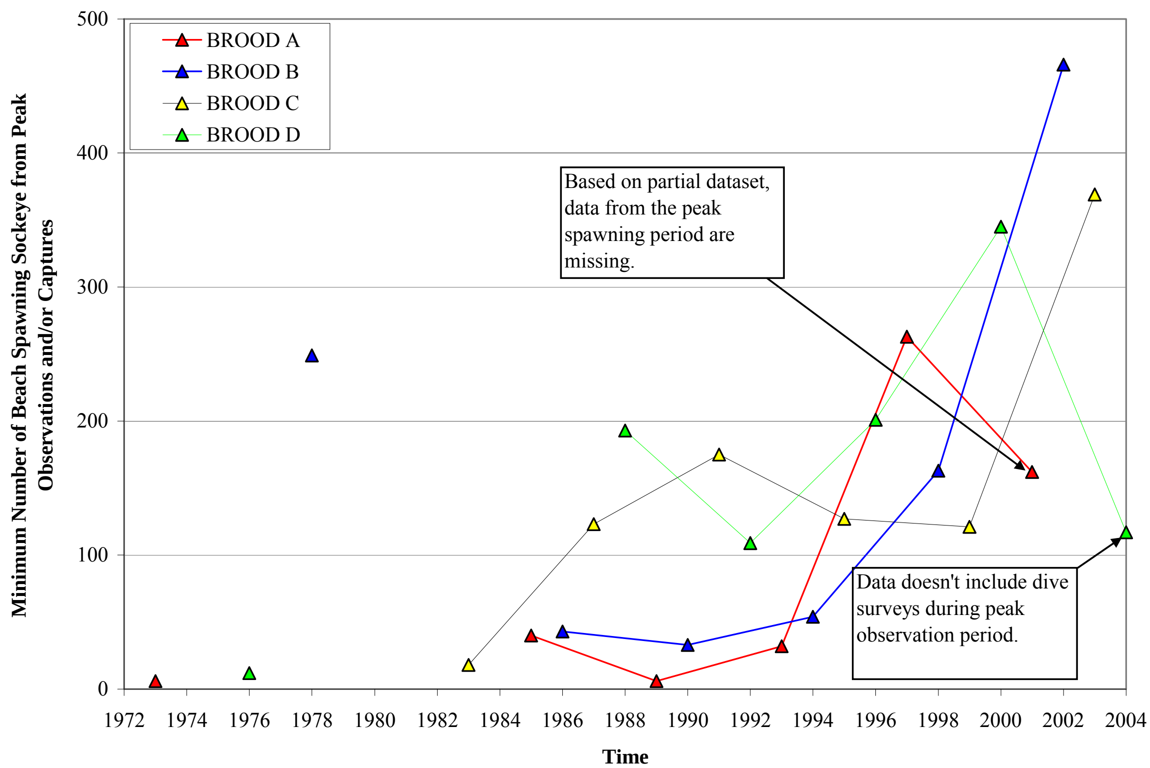

Figure 3.26. Minimum number of beach spawning sockeye from peak observations and/or captures from Allen's and Olsen's beaches. Note that only a few of the survey cards for 2001 have been located; this is a minimum estimate and it may change when the data are located. Also note that 2004 survey data do not include dive survey data (source: Dlugokenski et al. 1981; Jacobs et al. 1996; MFM, unpublished spawning ground survey data).

While it is not possible to accurately quantify increases and/or decreases in the number of beach spawning sockeye through time for the primary spawning beaches, there are some interesting facts regarding brood years A and B. In 1989, extensive surveys (26 combined) using visual observation, gillnets, and seine nets were able to positively detect a total of only 6 spawning sockeye on Olsen's and Allen's beaches combined. In the subsequent brood return years (1993 and 1997), a total of 32 and 236 sockeye were detected on the spawning beaches, respectively. This strongly suggests that this portion of the population has increased significantly from the low abundance observed in 1989. Brood year B experienced a similar increase in numbers captured and/or observed. In 1990, extensive survey and capture effort detected a total of only 33 sockeye. In 1994, 54 fish were captured for broodstock, in 1998, 163 fish were captured (88 for broodstock and 77 for genetic sampling), and in 2002, a minimum of 466 sockeye were observed on the beaches.

3.4.3.1.2 Lake Ozette Sockeye Tributary Spawning Aggregations

As described earlier, historical reports of tributary spawning sockeye are contradictory. Several sources were cited in Dlugokenski et al. (1981), Blum (1988), and Jacobs et al. (1996) as evidence of historical tributary spawning sockeye. Other sources such as Kemmerich (1945) provide evidence of only beach spawning sockeye. Currently not all biologists agree on the historical presence of tributary spawning sockeye in the Ozette watershed (Smith 2000). The first tributary sockeye spawning ground surveys were conducted in 1973 and were unable to detect sockeye salmon using the tributaries (J. Meyer personal communication, 1995 *in* Jacobs et al. 1996). However, the extent of these surveys is undocumented. Dlugokenski et al. (1981) conducted spawning ground surveys in Ozette tributaries for return years 1977, 1978, and 1979, specifically targeting sockeye spawning. The same team surveyed several of the small tributaries to Lake Ozette, including Quinn, Siwash, Lost Net, South, and Coal Creeks. A total of 16 surveys were conducted in return years 1977 and 1978. No sockeye salmon were observed in these surveys. Additional surveys in tributaries to Umbrella Creek and Big River during the same time period yielded no sockeye observations. Table 3.7 shows sockeye spawning ground surveys in the three largest tributaries to Lake Ozette.

Table 3.7. Tributary sockeye spawning ground surveys for BY 1977 and 1978 (source: Dlugokenski et al. 1981).

Stream Name	Date		Stream Reach		Number of Surveys	Species Observed
	Start	End	Lower (RM)	Upper (RM)		
Big River	12/1/1979	1/6/1980	7.2	9.5	3	Coho
Crooked Creek	10/30/1977	na	0	1.5	1	None
Crooked Creek	11/24/1978	na	0	1.4	1	Coho
Umbrella Creek	11/28/1978	na	0	0.9	1	Coho
Umbrella Creek	11/28/1978	1/1/1979	0.9	3.5	2	Coho
Umbrella Creek	11/28/1978	na	3.5	7	1	Coho

These nine surveys, along with surveys conducted in smaller tributaries, make up the bulk of evidence used by Dlugokenski et al. (1981) and Jacobs et al. (1996) to conclude that no tributary spawning sockeye were present in Lake Ozette tributaries in the 1970s. However, drawing any conclusion based on the limited quantity of surveys conducted relative to the current known spawning distribution of tributary spawning sockeye is not reasonable. Interestingly, an additional 100 spawning ground surveys (mostly directed at coho) were conducted by WDFW and MFM from 1970 to 1980, of which none are included in any of the Lake Ozette sockeye literature. None of these surveys detected sockeye salmon spawning in tributaries. Most of these surveys were conducted in Big River and Boe Creek. These surveys were just recently put into the MFM spawning ground survey database.

This more strongly supports the argument that no tributary spawning sockeye were present during the 1970s and early 1980s. In 1998, 10 coho spawning ground surveys were conducted in Big River and no sockeye salmon were detected, but on December 20, 1998, an MFM employee steelhead fishing on Big River observed 6 sockeye spawning in Big River and found evidence of 20-30 sockeye spawning in the preceding week. The subject section of river is not normally surveyed. This suggests at minimum that small isolated pockets of tributary spawning sockeye may have gone undetected, independent of the number of spawning ground surveys conducted. Jacobs et al. (1996) provide a personal citation from J. Blum (1995; former MFM biologist) stating that, "*around 10 adults [sockeye] were observed in [the] lower reaches of a tributary in December, 1982.*" Currently, Lake Ozette sockeye are known to spawn in the three largest tributaries, Umbrella Creek, Big River, and Crooked Creek, as well as in tributaries to these streams.

3.4.3.1.2.1 Umbrella Creek

The first contemporary written documentation of tributary sockeye spawning pertains to one dead sockeye found in Umbrella Creek on December 9, 1988 (MFM unpublished spawning ground data). Interestingly, no BY 1984 hatchery fish were released in the watershed, but in BY 1983 10,000 fry were planted in Umbrella Creek and in BY 1985, 21,400 fry, also into Umbrella Creek. The sockeye observed in 1988 may have been a 3-

or 5-year-old fish associated with one of these releases, a stray from one of the beaches, or an Umbrella Creek natural-origin recruit (NOR). From 1988 through 1990, sockeye were observed in low numbers. Peak sockeye counts increased to 50 fish in Umbrella Creek in 1991. No counts are available for BY 1992 through 1994.

In RY 1995, sockeye spawning ground surveys in Umbrella Creek were reinitiated and have been continuous since then. Spawning ground index reaches were developed and incorporated into the survey sampling protocol, as was increased survey effort. Data for this period is considered fair to good. Nonetheless, several problems exist with comparing sockeye spawning ground surveys from the early 1970s to 1994 with the most recent dataset (RY1995-2003). In those years, survey frequency was usually low and the stream reaches surveyed often do not correspond to the core spawning grounds that sockeye are currently using. Therefore, in this assessment of the Umbrella Creek spawning aggregation no numerical comparisons of pre-1995 survey data to post-1995 survey data were made. Before 1991, the Umbrella Creek sockeye spawning aggregation was considered small, less than 50 fish, some of which may or may not have been a remnant sub-population of tributary spawning sockeye. Spawning ground survey data from 1995 through 2004 typically consists of four or more surveys over the course of the spawning season within the index reach (RM 2.5-4.8) for the 10 years of data. Survey data are summarized by return year, number of surveys, peak number of adult sockeye observed, stream length surveyed, and peak sockeye count per mile (Table 3.8).

Table 3.8. Summary of Umbrella Creek sockeye spawning ground surveys for return years 1995 through 2004 (source: MFM, unpublished spawning ground survey data).

Return Year	Number of Surveys	Peak No. of Adults Observed	Stream Length Surveyed (mi)	Peak Sockeye Count per Mile
1995[1]	2	44	2.26	19.5
1996[1]	2-3	79	2.26	35.0
1997	4	135	2.26	59.7
1998[2]	3-4	96	2.26	42.5
1999	7	312	2.26	138.1
2000	12	1,419[3]	2.26	627.9
2001	11	840	2.26	371.7
2002[4]	8	513	3.98	128.9
2003[4]	6	387	3.98	97.2
2004	9	1,121	2.26	496.0

[1] Low survey frequency.
[2] RY 1998 peak counts occurred during a period of low visibility; under good viewing conditions peak counts would likely be higher.
[3] In RY 2000 a total of 1,718 sockeye were counted between river mile 0.8 and 5.34 in a single day. For comparison it should be noted that in 2000, peak counts were made before broodstock removal, while in 2004, peak counts occurred after broodstock removal.
[4] In RY 2002 and 2003, peak counts were made from river mile 0.8 to 4.78.

Annual peak sockeye count per mile is the preferred abundance indicator for comparisons among the data collected from 1995 through 2004. Redd counts were also made in all years data were collected, but in years of moderate and high abundance, redd counting was generally abandoned because sockeye spawning occurred in large groups, and there was no way to accurately quantify the number of fish per redd. It is important to note that the peak sockeye count per mile escapement estimation method has limited accuracy. Viewing conditions vary between years and within each season. Some years have lower counts because the surveyor's ability to count sockeye during the peak spawning period was limited by higher flows and turbidity.

The increasing numbers of sockeye spawning in Umbrella Creek and the difficulty in accurately quantifying the run size prompted the installation of a floating, resistance board counting weir and adult trap in 2001. Mark and recapture methods have been used to estimate Umbrella Creek spawning ground escapement since RY 2001. Estimated escapement to Umbrella Creek including broodstock collected has ranged from 4,442 (2004) to 1,709 (2002), averaging 2,333. Figure 3.27 depicts the Umbrella Creek annual peak sockeye count/mile and hatchery releases from the corresponding brood years.

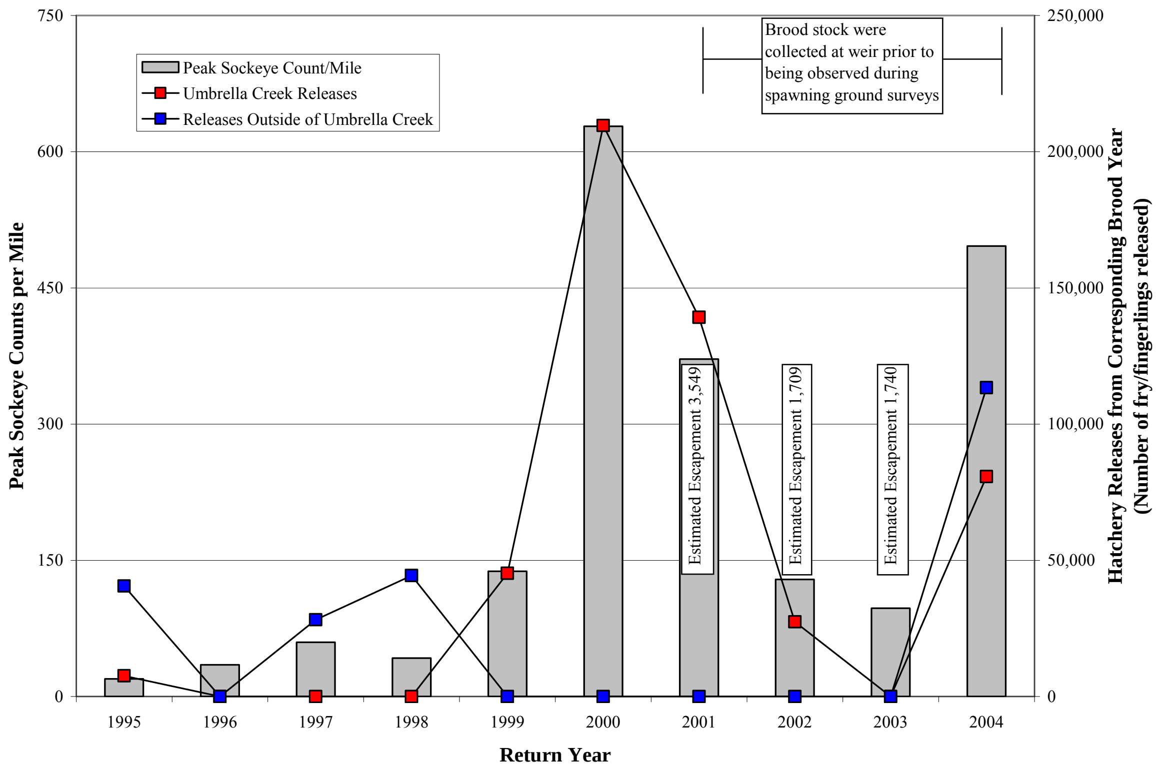

Figure 3.27. Umbrella Creek annual peak sockeye counts from spawning ground surveys compared with hatchery releases within Umbrella Creek and releases outside of Umbrella Creek. Estimated run sizes for Umbrella Creek (for 2001-2004) are from a weir and trap using mark and recapture techniques (source: Hinton et al. 2002; Peterschmidt and Hinton 2005; MFM, unpublished spawning ground surveys).

Hatchery releases into Umbrella Creek make it difficult to accurately define trends in production for naturally spawning sockeye in Umbrella Creek. While it is true that the vast majority of spawners are age 4, some 3- and 5-year-old fish also make up a component of the spawning escapement. Spawning ground surveys before RY 1999 did not include data collection on hatchery marks. This, combined with a lack of Umbrella Creek escapement estimates, makes it nearly impossible to quantify the number of hatchery versus natural-origin spawners in Umbrella Creek before RY 2001. Umbrella Creek escapement in 1996, 1997, and 1998 is assumed to have been primarily composed of NORs, although strays from lake releases likely make up a component of the 1997 and 1998 Umbrella Creek escapement. MFM (2000) suggested that approximately 37% (range 21-53%) of the sockeye returning to Umbrella Creek in 1999 were NORs. MFM (2000) tentatively established a spawning escapement estimate for the 1999 Umbrella Creek return of 400 fish. Based upon recent Umbrella Creek weir counts and mark and recapture techniques, this estimate is likely much lower than the actual escapement in 1999. The peak sockeye count per mile in 1999 was very similar to the peak counts observed in 2001 and 2002, when an average of 1,541 sockeye were estimated to have spawned in Umbrella Creek.

A portion of the BY 1996 hatchery fingerling release (RY 2000) were adipose fin clipped. However, additional unfed and unmarked fry were also released, making it difficult to develop an estimate of hatchery-origin sockeyes' contribution to escapement. Based upon fin clip sampling from carcass recovery and broodstock collection activities, approximately 0-10% of the Umbrella Creek 2000 return were estimated to be NORs. One method for estimating the Umbrella Creek escapement for RY 2000 is to compare the incidence of adipose fin clips at the weir versus Umbrella Creek recoveries of fin clipped fish. Approximately 23% of the fish observed at the Ozette weir were adipose fin clipped. This proportion increased to 34% in Umbrella Creek broodstocking and carcass recovery collections (n=734). Assuming that 5,064 fish entered the lake and 1,165 (23%) were adipose fin clipped, that all adipose fin clipped returned to Umbrella Creek, and that 34% of the sockeye were clipped in Umbrella Creek, the estimated RY 2000 run size in Umbrella Creek was 3,426 sockeye.

Breakdowns for hatchery origin recruits (HORs), NORs, broodstock collected, and estimated sockeye escapement for Umbrella Creek are included in Table 3.9. Releases from BY 1997 were unmarked and therefore no estimate of the number of NORs was possible for RY 2001. The actual number of NORs is dependent upon several assumptions, but age structure is critically important. All estimates made in Table 3.9 assume that all sockeye spawning were age-4, although preliminary otolith aging data indicate that up to 9% of the broodstock taken in 2002 were age 3 or 5.

Table 3.9. Summary of Umbrella Creek run-size estimates, broodstock collected, and the estimated number of NORs within the run (source: Hinton et al. 2002; Peterschmidt and Hinton 2005; MFM, unpublished spawning ground surveys).

Return Year	Umbrella Creek Run Size	Broodstock Retained	Umbrella Creek Estimated Escapement	Percent Adipose Fin Clipped	Estimated Percent HOR	Estimated Number of NORs
2000	3,426	213	3,213	34%	90%	0-343
2001	3,549	164	3,385	3%	na	na
2002	1,709	168	1,541	13%	13%	1,487
2003	1,740	199	1,541	1%	1%	1,723
2004	4,442	218	4,224	9%	9%	4,047

3.4.3.1.2.2 Big River

As described in Section 3.4.3.1.2, sockeye spawning was not observed in Big River during spawning ground surveys conducted in the 1970s and 1980s. Spawning ground surveys occurred intermittently in Big River between the late 1970s and the mid-1990s. A spawning ground dataset for Ozette was constructed, which included the WDFW historical spawning ground database, the WDFW coastal survey database, USFWS data, and MFM datasets to determine survey effort by species in the Ozette watershed. A query of this dataset indicated that a total of 81 spawning ground surveys (>110 miles of survey effort) in the mainstem of Big River and 65 surveys (>37 miles of survey effort) in Boe Creek were conducted between return years 1970 and 1997. All surveys included in the query were during the time period sockeye would be expected to be observed if present. No sockeye were detected in any of 146 surveys during this time period. However, all of these surveys were upstream of where sockeye were first detected in 1998. No sockeye were observed in surveys conducted until December 1998, when it was estimated that 20-30 sockeye spawned in Big River. Sockeye spawning in Big River during the fall and winter of 1998 does not correspond to hatchery releases into Big River (the first release into Big River occurred with BY 1999 releases). It is assumed that these fish were strays from other spawning aggregations within the watershed or from hatchery releases outside of Big River. The first hatchery release into Big River occurred in February 2000. Approximately 17,000 eyed eggs procured from BY 1999 Olsen's Beach broodstock were hatched resulting in the release of unfed fry in 2000. All subsequent hatchery sockeye releases into Big River were progeny of sockeye broodstock collected from Umbrella Creek (Table 3.9).

Table 3.10. Big River hatchery releases for BY 1999-2003 (source: MFM, unpublished hatchery release data).

Brood Year	RELEASE DATE Start	End	Number of Sockeye Released	Release Type	Broodstock Source
1999	2/15/2000	2/29/2000	17,200	Eyed Eggs	Olsen's Beach
2000	4/1/2001	5/13/2001	63,201	Unfed Fry (0.13g)	Umbrella Creek
2000	7/29/2001	7/29/2001	50,168	Fingerling (1.01g)	Umbrella Creek
2001	4/1/2002	5/10/2002	75,900	Unfed Fry (0.13g)	Umbrella Creek
2001	6/27/2002	6/28/2002	75,352	Fingerling (0.86g)	Umbrella Creek
2002	5/29/2003	6/5/2003	74,377	Fry (0.32g)	Umbrella Creek
2002	5/29/2003	6/5/2003	47,990	Fingerling (0.91g)	Umbrella Creek
2003	5/2/2004	5/24/2004	102,779	Unfed Fry (0.16g)	Umbrella Creek
2003	7/2/2004	7/2/2004	12,792	Fingerling (0.61g)	Umbrella Creek

Spawning ground survey effort increased in Big River from 1998 to present (with the exception of 2002, when only five surveys covering 9 miles were conducted). No sockeye or sockeye redds were detected in RY 1999-2001. Two sockeye redds but no sockeye were detected in RY2002; however, data from this survey are questionable. During RY 2003, sockeye surveys were conducted in Big River from river mile 10.8 to 3.9. Four surveys were conducted between October 15, 2003 and December 18, 2003. The first sockeye were observed on November 5, 2003 between RM 3.9 and 5.5. The peak sockeye count occurred on December 11, 2003, when 62 sockeye were counted between RM 10.8 and 5.5 (12 sockeye/mile). During RY 2004, seven surveys were conducted between October 21, 2004 and December 20, 2004. The first sockeye were observed on November 9, 2004, and peak sockeye counts were recorded between November 29 and 30 from RM 10.8 to RM 5.5, when 58 sockeye were counted (11 sockeye/mile). It is not possible to estimate the total Big River run size for return years 2003 and 2004 with the data available.

3.4.3.1.2.3 Crooked Creek

As described in Section 3.4.3.1.2, sockeye spawning was not observed in Crooked Creek during spawning ground surveys conducted in the 1970s or 1980s. Spawning ground surveys occurred intermittently in Crooked Creek between 1974 and 1999. Starting in RY 2000, more intensive survey efforts were made due to expected returns from hatchery releases that were initiated with BY 1996. Adult sockeye were observed during surveys conducted in RY 2002. Five separate surveys were conducted in RY 2000, and no sockeye were observed. Lack of personnel combined with difficult surveying conditions have limited the amount of survey effort available for the Crooked Creek system. Peak sockeye counts per mile in the mainstem of Crooked Creek in RY2002 were 42 sockeye per mile. In RY 2003, only three surveys in the mainstem were conducted; peak counts were 14 sockeye per mile. Three surveys were conducted in the North Fork and one survey was conducted in the South Fork. Results from these surveys showed a peak count of 6 and 4 sockeye per mile in the North and South forks, respectively. In RY 04 only one survey was conducted during the sockeye spawning season in both the mainstem and North Fork. The peak count in the mainstem was 6 sockeye per mile and no sockeye were observed in the North Fork. Increased monitoring effort is needed within the Crooked Creek sub-basin in order to estimate sockeye spawning numbers. The lack of data from 2000 through 2004 prevents any sockeye escapement estimates for the Crooked Creek watershed. The presence of sockeye in 2003 and 2004 suggests that the BY 1996 and BY 1997 hatchery releases were successful and sockeye were undetected in 2000 and 2001, or that Umbrella Creek Hatchery strays or NOR or beach spawners strayed into Crooked Creek, and/or that BY 1998 releases resulted in a few age-5 spawners. A complete record of all hatchery releases into the Crooked Creek sub-basin is included in Table 3.11.

Table 3.11. Crooked Creek hatchery releases for BY 1996-1998 (source: MFM, unpublished hatchery release data).

Brood Year	RELEASE DATE		Number of Sockeye Released	Release Type	Broodstock Source
	Start	End			
1996	4/7/1997	4/15/1997	56,733	Eyed Eggs	Olsen's and Allen's beaches
1997	2/18/1998	2/18/1998	14,036	Eyed Eggs	Olsen's X Umbrella Creek
1997	4/16/1998	4/16/1998	34,500	Fed Fry	Olsen's Beach
1998	2/19/1999	3/9/1999	31,350	Eyed Eggs	Olsen's Beach

3.5 LAKE OZETTE SOCKEYE SALMON PRODUCTIVITY

3.5.1 Past Estimates

Lake Ozette sockeye salmon population data lack the desired accuracy and long-term time frame required for deriving precise estimates of stock productivity at various life stages. Jacobs et al. (1996) used parent year run-size estimates and resulting smolt emigration estimates to generate estimates of marine survival for brood years 1988 and 1990, which were 27% and 18% respectively. However, both the adult return estimates and smolt emigration estimates used to make these estimates are considered very crude and should only be regarded as indicators of marine survival. Jacobs et al. (1996) used these same population estimates to generate estimates of recruits per spawner and estimated that brood year 1988 and 1990 spawner recruit ratios were 0.99 and 1.89 respectively. Smolts per spawner production for brood year 1988 and 1990 are 3.6 and 10.5 using these same population estimates. It is critical to recognize that these estimates are poor at best, due to the extreme uncertainties regarding both adult run size and smolt emigration estimates.

3.5.2 Recent Estimates

Recent population productivity estimates using adult return (post-1997) and resultant smolt emigration abundance data are considered much better than older estimates, but they still lack the desired accuracy and long-term time frame for developing sound estimates of stock productivity. In addition, the influences of hatchery releases on the population complicate estimates of natural production. In recent years all hatchery efforts have focused on producing fish that return to spawn naturally in tributaries to the lake and therefore the most significant influence of hatchery releases on sockeye productivity estimates is in the tributaries. The lack of long-term sockeye spawning escapement estimates further hinder production estimates. Spawning ground survey datasets for Umbrella Creek report sockeye as peak counts per mile for years before the installation of the counting weir in 2001. For years before 2001, Umbrella Creek escapement can be estimated based on the average ratio of peak sockeye counted per mile to spawning escapement (based on weir counts for RY 2001-2004). The ratios of peak sockeye per mile to spawning escapement for RY 2001 through 2004, were 0.110, 0.084, 0.063, and 0.117. The average annual peak count/mile during these 4 years was 9.3% of the estimated run size after broodstock collection. Combining this value with peak counts/mile for RYs 1995 through 1999 produces the estimated escapements shown in Table 3.12.

Table 3.12. Summary of Umbrella Creek sockeye returns, their origin, and estimates of natural origin recruits per spawner for return years 1995-2004 (source: MFM 2000; Hinton et al. 2002; Peterschmidt and Hinton 2005; MFM, unpublished spawning ground surveys).

Return Year	Peak Sockeye Count per Mile	Estimated Umbrella Run Size	Estimated Umbrella Creek Spawning Escapement	Natural Origin Recruits	Hatchery Origin Recruits	NORs per Parent Year Spawners
1995	19.5	208	208	na	na	na
1996	35.0	374	374	374	0	na
1997	59.7	639	639	na	na	na
1998	42.5	454	454	na	na	na
1999	138.1	1,477	1,477	556	920	2.7
2000	627.9	3,426	3,213	343	3,083	0.9
2001	371.7	3,549	3,385	na	na	na
2002	128.9	1,709	1,541	1,487	222	3.3
2003	97.2	1,740	1,541	1,740	0	1.2
2004	496.0	4,442	4,224	4,047	395	1.3

Note: Either no hatchery marks or no hatchery mark sampling occurred with RY 1995, 1997, 1998, and 2001; therefore, there was no way to differentiate NORs from HORs for these years.

Umbrella Creek data were further analyzed to develop an estimate of the spawner to spawner recruit relationship. This assessment could only be conducted for return years 1999-2004, with the exception of RY 2001 (no hatchery fish released from BY 1997 were marked). Natural origin recruits per spawner estimates ranged from 0.9 (RY 2000) to 3.3 (RY 2002), averaging 1.9 (Table 3.12). Age distribution of returning fish was not considered when estimating the NORs/spawner due to a lack of age data for each return year. Otolith age data collected in 2000, 2001, and 2002 indicate that 93% (n=963) of sockeye salmon returning to Ozette during these years were age 4 (Peterschmidt 2005). This would primarily affect the RY 2002 estimate. Age data are available and indicate 5% of the RY 2002 Umbrella Creek run were age-5 sockeye. Adjusting for age 5 requires producing an estimate of RY 2002 spawners/RY 1998 natural spawners returning only in RY 2002; this yields an estimate of 3.1 age-4 recruits for every RY 1998 spawner. (This value does not include total spawner recruitment for BY 2002. No BY 1998 sockeye were detected in RY 2001 based on age sampling, but RY 2003 age data are not available and it is expected that some of the spawners were age 5 sockeye.)

Since smolt trapping was not reinitiated until the spring of 2002, other estimates of stock productivity are still lacking. Hatchery fingerling survival to smolt estimates were calculated for BY 2000 through 2002 using data from marked releases and marked recoveries at the smolt trap and then applying total smolt production estimates made from trapping efficiency trials in the Ozette River. Fingerling survival to smolt estimates range widely depending upon the methods used to estimate the total number of marked smolts emigrating (Table 3.13).

Table 3.13. Estimated fingerling to smolt survival for brood years 2000-2003 ad-marked hatchery fingerlings released into Big River and Umbrella Creek (source: Peterschmidt and Hinton 2005; MFM, unpublished data).

Brood Year	BY2000	BY2001	BY2002
Smolt Capture Year	2002	2003	2004
Ad-Marked Fingerling Releases	130,875	167,410	54,758
Ad-Mark Smolt Captures (unexpanded)	531	528	53
% of Ad-Marked Releases Recaptured	0.41%	0.32%	0.10%
Expanded Ad-Mark Smolt Estimate[1]	4,149	9,814	290
% Survival Fingerling-Smolt	3.17%	5.86%	0.53%
Expanded Ad-Mark Smolt Estimate[2]	na	51,517	482
% Survival Fingerling-Smolt	na	30.77%	0.88%

[1] In this estimate the ad-mark smolt emigration estimate for BY 2001 is calculated for only the period when the trap was deployed and does not represent the entire smolt emigration; for BY 2002 the smolt estimate is based on seasonal average trap efficiency.
[2] In this estimate the ad-mark smolt emigration estimate for BY 2001 is calculated for the entire smolt emigration period by using a ratio of the average number of smolts observed during periods where data where collected for BY 2000 and 2001 (see Peterschmidt 2005 and/or Section 3.1.9). For BY 2002 the smolt estimate is based on time weighted trap efficiency.

Brood year 2000 and 2001 releases appear to have survived at a much higher level than the BY 2002 release. This may be a function of release site used for BY 2002 and/or streamflow conditions. Flow conditions were approximately 25% lower during the BY 2002 release than during the BY 2000 and 2001 releases. Umbrella Creek population size estimates also allow for estimation of the percent of total survival from fingerling release to adult return in Umbrella Creek. These data are only available for return years 1999, 2000, 2002, and 2004, and survivals were estimated to be 2.03%, 1.47%, 0.81% and 0.49% respectively. Total survival from smolt to spawner can only be calculated for RY 2004 Umbrella Creek marked hatchery sockeye since total escapement estimates have not been determined for RY 2004. Survival from smolt to spawner was estimated to be 15.5%.

A general understanding of sockeye life histories and trajectories are documented for Lake Ozette sockeye (Sections 3.1.1 through 3.1.10). However, empirical measurements of survival by life history stage are generally lacking. In order to develop a comprehensive understanding of life cycle productivity, further research and monitoring is required. The major data gaps that currently exist are: 1)green egg to fry survival rates for beach and tributary spawning aggregations, 2)fry-to-smolt survival, and 3) freshwater adult survival. Continuation of the current population monitoring program should provide additional marine survival estimates, as well as fry-to-smolt survival estimates for marked hatchery fingerlings released in Umbrella Creek and Big River. Increased population monitoring will be required to fully assess survival at different life stages, and it should be a high priority for Lake Ozette sockeye.

4 HABITAT CONDITIONS AFFECTING LAKE OZETTE SOCKEYE

This chapter contains a summary of sockeye salmon habitat conditions within the Lake Ozette watershed, focusing on estuary and near-shore, Lake Ozette, the Ozette River, and the Lake Ozette tributaries. While most of the information presented here was compiled from past reports and studies, a considerable amount of it also comes from firsthand fieldwork in the watershed by the contributing authors. Throughout development of this report, the authors and contributors spent numerous days in the field to "ground truth" and document habitat conditions. These new findings are included in the following discussion.

4.1 ESTUARY AND NEAR-SHORE

The Ozette River estuary is small relative to the estuaries of other similar sized, nearby river systems (e.g. Sooes River). Currently, a spit composed primarily of gravel and cobble constricts the mouth, forcing the river's outlet to the south side of the narrow valley. The Ozette River estuary extends upstream from the spit for approximately 4,300 to 4,600 feet (1,300-1,400 m) to where a steep riffle serves as the divide between the estuarine and riverine environments. The tidally influenced section of the Ozette River is deep, averaging about 3 meters, with depths of over 5 meters in some locations.

Little documentation of current and/or historical estuary conditions exists. However, a cursory review of historical aerial photos reveals that the mouth of the Ozette River has changed noticeably since the 1950s. Aerial photos from the 1957 flight depict greater tidal energy entering the river system than under current conditions. The spit that currently exists along the tidal interface of the river did not exist in 1957, although a submerged island can be observed at the mouth of the river. By 1971, a spit has developed; in aerial photos the spit appears un-vegetated and more transitory in nature than in the present day (Figure 4.1). In photos from 1997, the top of the bar is vegetated and appears to have stable driftwood accumulation (Figure 4.1; Smith 2000). In field visits during the summer of 2000, healthy stands of beach rye, stable accumulations of LWD, and young conifer trees were present on the surface of the spit.

The conditions and processes that formed and maintain the channel depths observed in the lower river are not well understood. Photo evidence from 1953-2003 (Figure 4.1 supports the idea that tidal flux and storm surge energies expressed upon the estuarine channel may have been greater in the past, if the bar at the mouth represents a recent phenomenon. There has been speculation that the bar formed after wood removal in 1952, and has reduced tidal flux (Smith 2000). While it is possible that wood removal in 1952 and/or cedar logging/salvaging in the lower river in the 1920s (see Section 1.5.5) caused changes in water surface elevation at the mouth, timing and magnitude of low discharge, or estuary sediment dynamics, the relationship between current estuary conditions and past conditions remains unclear.

Nearshore physical habitat in the vicinity of the Ozette River is characterized by a gently sloping marine shore platform with abundant boulders and outcrops of resistant rock. To the north of the estuary, this platform is bounded on the shore by a long (~3.1 mi, 5 km) sand, gravel, and cobble beach backed by an eroding bluff. To the south of the river, at Cape Alava, about 1.5 miles distant, the shore platform slope decreases, and widens considerably after a series of closely spaced rocky headlands separated by short sand and gravel beaches. The seaward boundary of the shore platform can be roughly demarcated by sea stacks, which dot the coastline in the vicinity. The remote and relatively pristine nature of the shoreline in the vicinity of the Ozette River is reflected in the diversity and abundance of marine life in the area. Pinnipeds are seasonally abundant (See Sections 5.2.2.1.1 and 5.2.2.1.2) and number in the thousands within a few miles of the mouth of the Ozette River (Gearin et al. 1998). Nearshore habitat complexity is high, and both predator and prey species are believed to be abundant.

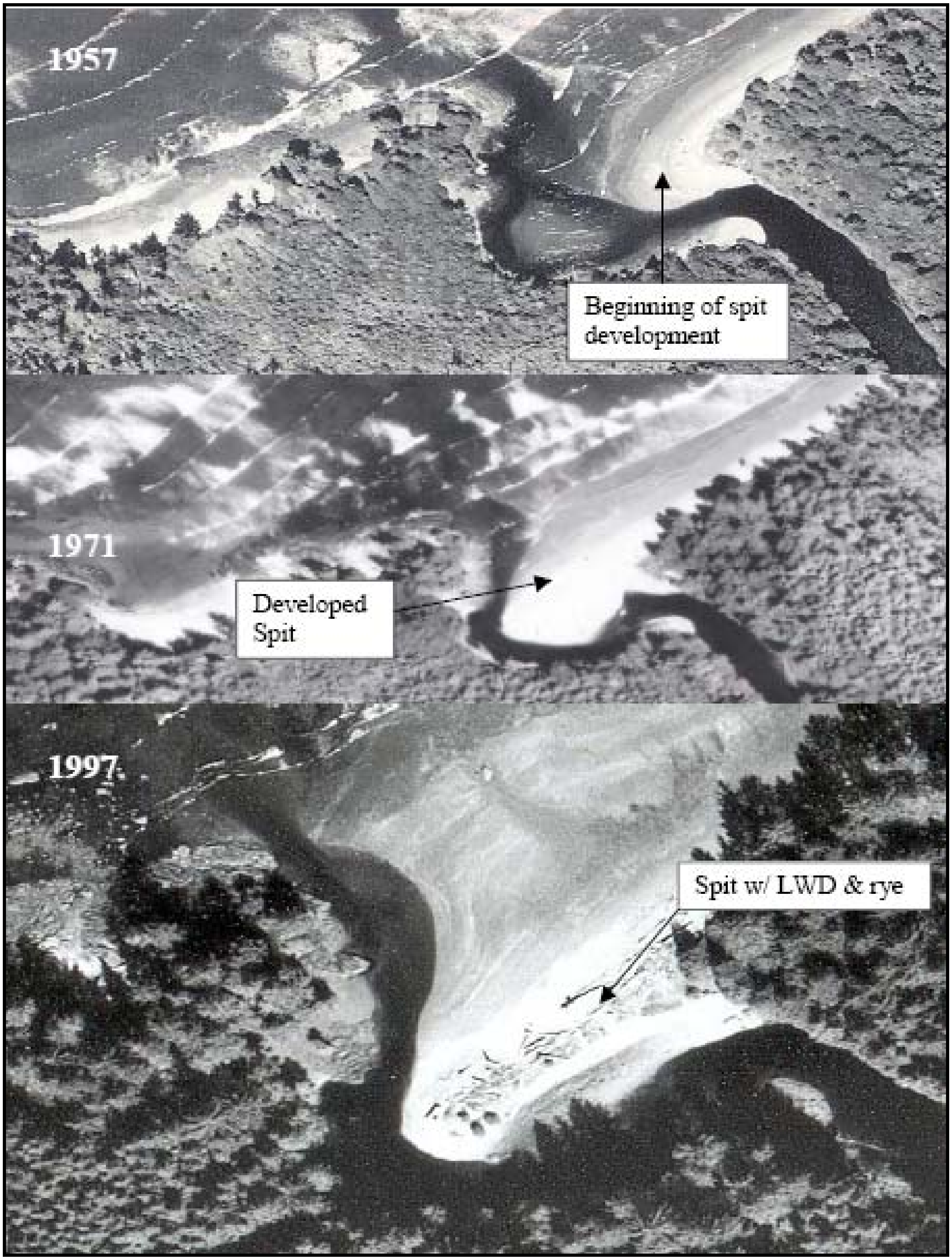

Figure 4.1. Ozette River spit evolution from 1957 to 1997 (source: Smith 2000).

4.2 LAKE OZETTE

4.2.1 Shoreline and Beach Conditions

Lake Ozette's shoreline is 36.5 miles (57 km) long (Ritchie 2005). Shoreline vegetation, substrate, and topography vary widely around the lake, with additional variations according to time of year and lake level. Where the beaches and shorelines are very gently sloping, lake level may fluctuate by as much as 8 to 12 feet (2.4 to 3.6 meters) between summer low and winter high.

Lake Ozette shoreline conditions were first described by Bortleson and Dion (1979), based upon shore surveys conducted in August 1976. They observed beach and lakebed substrates that were most commonly a mixture of silt, sand, gravel, and cobbles. Bortleson and Dion (1979) also observed that much of the beach was exposed during the summer months, allowing for the growth of grasses, shrubs, and other vegetation. Meyer and Brenkman (2001) conducted surveys of the lakeshore during the summer of 1994 and determined that much of the shoreline substrate was composed of fine sediment. Coarser sediment including gravel and cobble can be found at several locations around the lake (Figure 4.2).

Olsen's and Allen's beaches are a primary focus because they are the only two remaining beach spawning locations. Baby Island and Umbrella Beach are also of considerable interest because of historical observations of sockeye spawning at these locations. Factors that may affect beach and shoreline sediment conditions at both spawning beaches are not well understood, but include alterations of the lake's hydro-period, colonization of native and non-native vegetation, and reduced numbers of sockeye spawning on the beach. In the case of Olsen's Beach, potential additional factors include increased sediment delivery from nearby tributaries and shoreline development.

At mid- to upper elevations of both spawning beaches, sedges, sweet gale, and other vegetation occupy much of the beach area. Meyer and Brenkman (2001) noted that sweet gale, grasses, and sedges were observed at depths of up to 2m in December 1994, in the vicinity of where sockeye salmon were spawning. Seeps and springs have been mapped on both Olsen's and Allen's beaches, and appear to be areas where spawning activity is concentrated (see below). To date no comprehensive inventory of seeps and springs has been completed for Lake Ozette.

Olsen's Beach (see Figure 3.7 and Figure 3.8) extends from the southeast end of a shallow bay near the inlet of Elk Creek northwest for approximately 845 meters. Substrate along the southeast end of the beach is composed primarily of fine sand, silt, mud, and organic detritus. Substrate size grades into a matrix of coarse sand, pebbles, and gravel in a northwest direction; this is the core sockeye spawning site at Olsen's Beach (see Section 3.1.4). The core spawning area is focused around a small, approximately 6,400ft^2 (600m^2) spring. During winter 1999-2000, a thermograph deployed in the spring measured subsurface water temperature significantly warmer than ten other thermographs deployed at Olsen's and Allen's beaches (Figure 4.3).

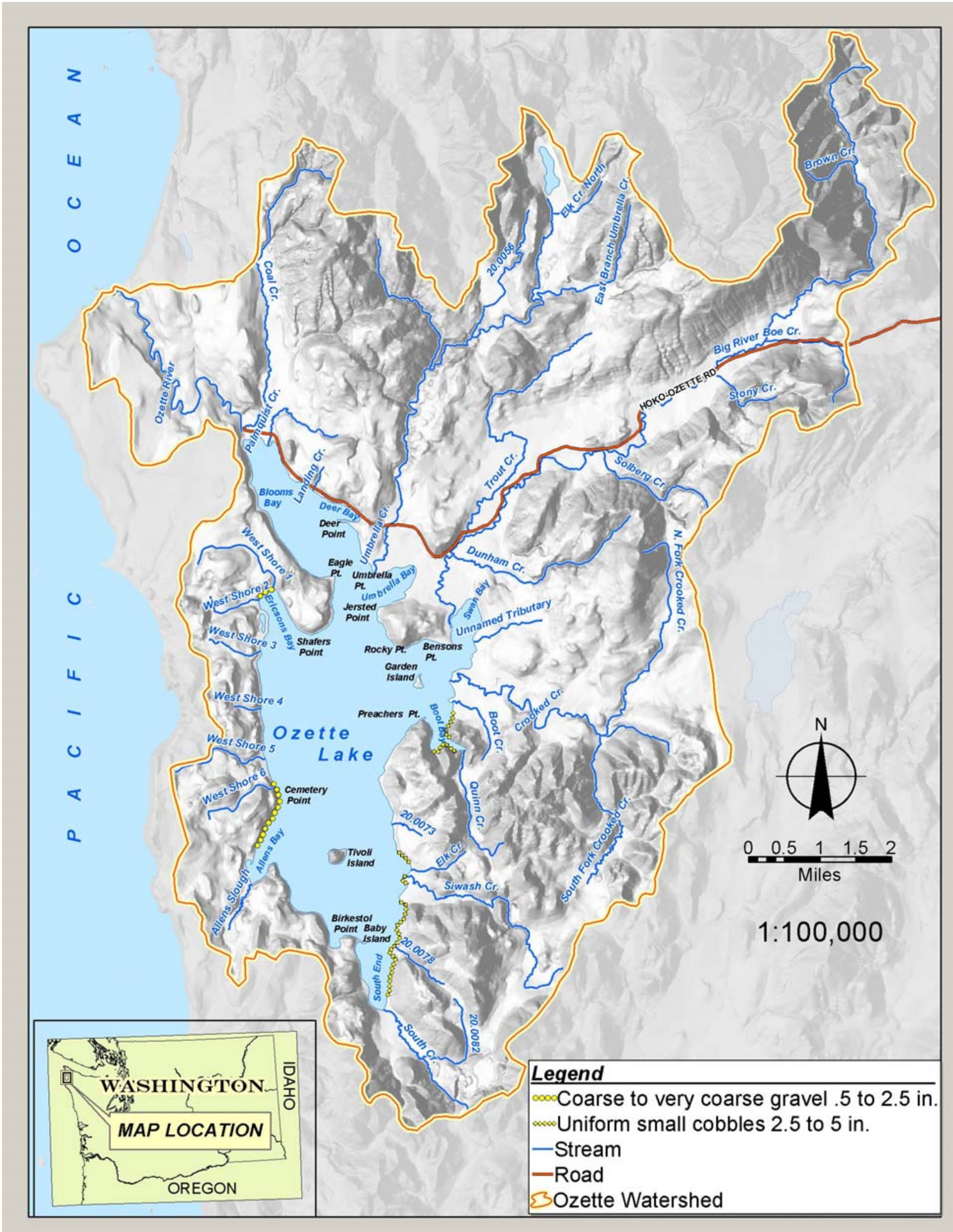

Figure 4.2. Generalized locations of beach substrate conditions suitable for sockeye salmon spawning (modified from Bortleson and Dion 1979).

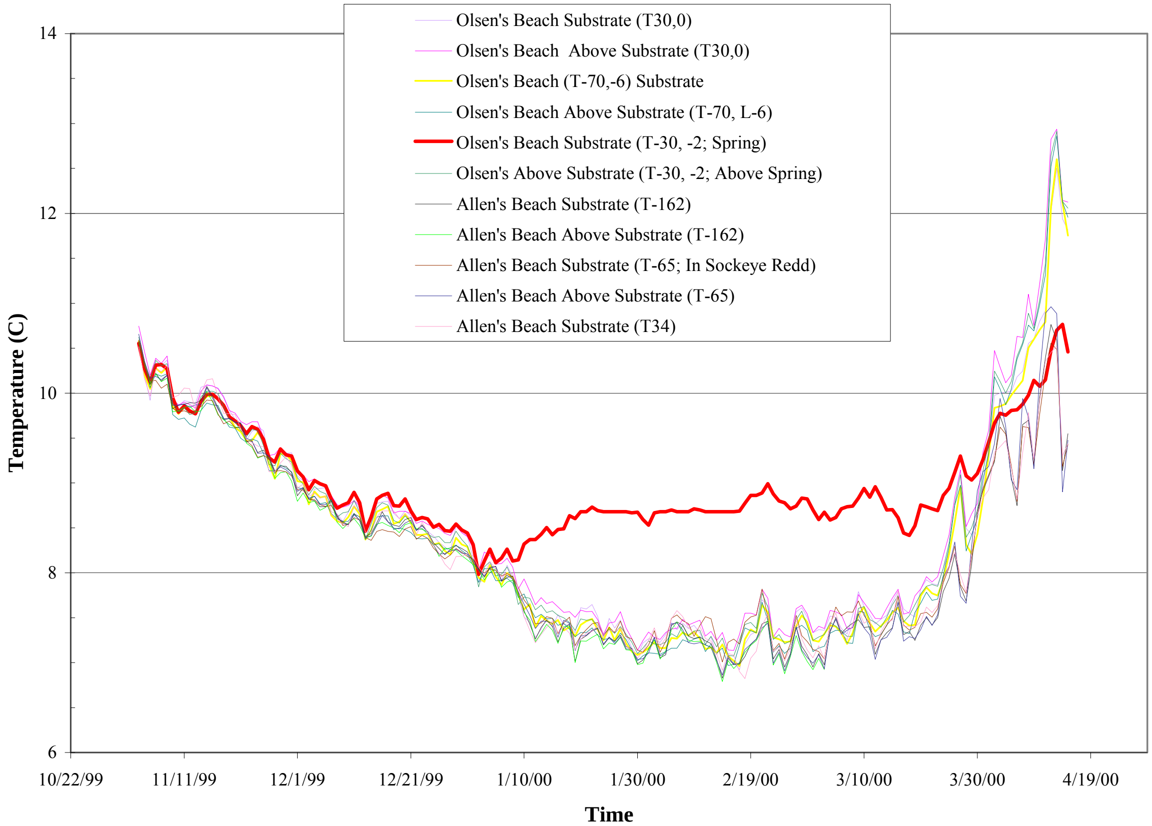

Figure 4.3. Comparison of water temperatures in substrate and directly above substrate at three sites on both Olsen's and Allen's beaches during the 1999/2000 sockeye spawning and incubation period (source: MFM, unpublished water temperature data).

Moving perpendicular to the beach along the primary spawning area, gravel quickly grades to sand (at a depth of about 3 m). Moving south from the primary spawning area, the slope of the bay floor is gentle, and substrate becomes fine and mucky, but to the north, the shoreline slope remains sandy and steeply sloping to an unknown depth (>5 m). Sockeye have been observed spawning in unusual depressions on these slopes at about 5 meters depth (MFM unpublished spawning ground survey data). Suitable substrate size extends along the shoreline northwest to an unnamed point where sockeye have been observed spawning in recent years. Gravel samples were collected along a 460-foot (140 m) transect that extended through the primary spawning area in 1999. A total of 13 samples were collected using a McNeil core sampler and processed using gravimetric sediment processing methods. It was found that levels of fine sediment within the spawning gravel ranged widely throughout the primary spawning area at Olsen's Beach. The percent "fines" (sediment particles less than 0.85 mm in diameter) ranged from 9.1% to 54.1%, averaging 25.2%. Additionally, 30 gravel samples were collected in September 2000, along the same transect as samples collected in 1999. Again highly variable percent fines were found in the spawning gravel samples. The percent fines ranged from 7.0% to 72.7%, averaging 27.0% (median=23.7%). Figure 4.4 depicts the results from spawning gravel samples and the sample proximity to sockeye spawning use categories for Olsen's Beach.

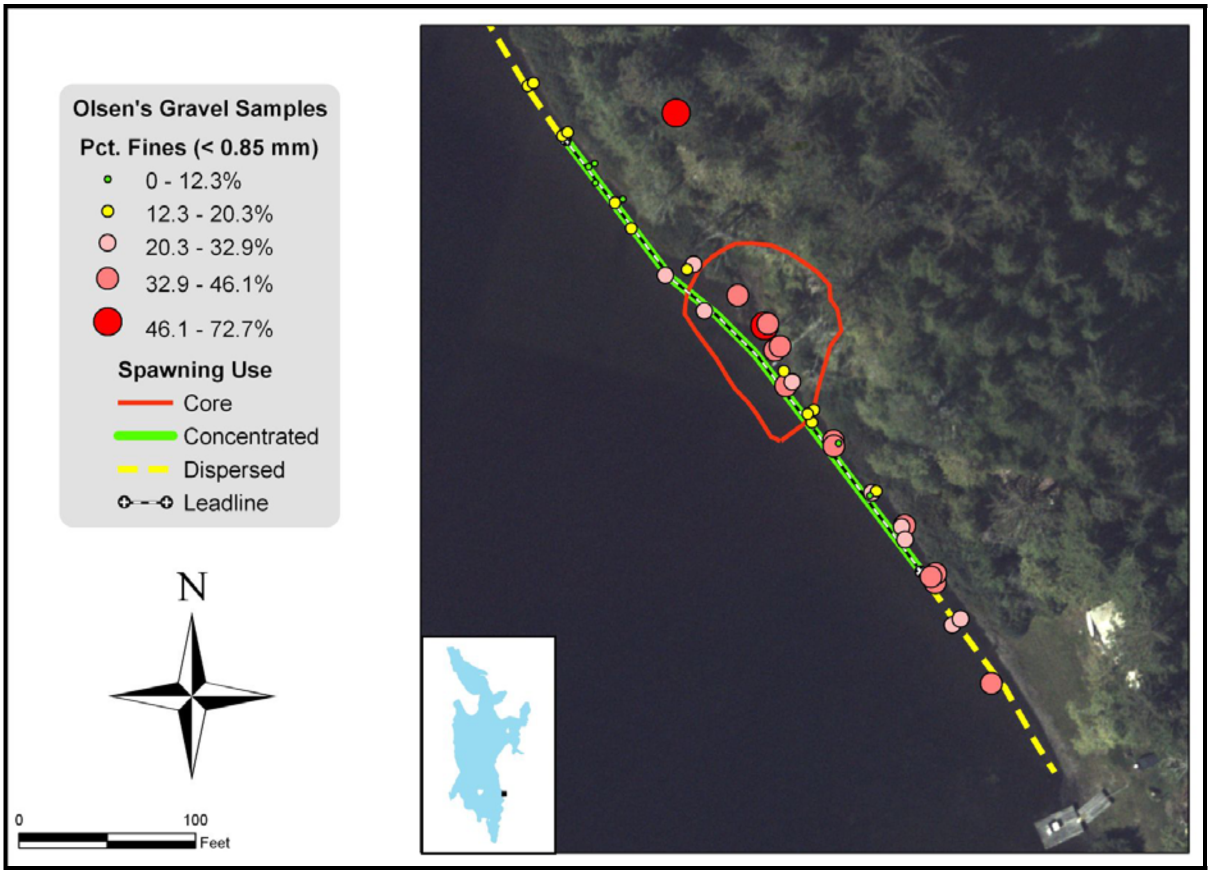

Figure 4.4. Olsen's Beach gravel sampling results for 1999 and 2000 and sample proximity to different categories of spawning use. (Note: The lead line corresponds to concentrated spawning use outside of the core use area.) (source: MFM, unpublished data.)

The area previously described as Allen's Beach (e.g. MFM 2000) is generally a stretch of beach 100-200 meters (328-656 ft) north of Allen's Slough extending 200-300 meters (656-984 ft) northward. Spawning occurs along Allen's Beach (see Figure 3.7 and Figure 3.10) from the northwest end of Allen's Slough, north-northeast to Cemetery Point. Substrate along the southwest end of the beach is composed primarily of fine sand, silt, mud, and organic detritus. Substrate size quickly grades into a matrix of coarse sand, pebbles, and gravel in northwest direction. This area is sometimes referred to as South Allen's. Moving north-northeast from South Allen's Beach, substrate size generally increases, with cobbles becoming a dominant component near Cemetery Point. Moving in the offshore direction, the beach grades to sand and gently slopes to a depth of about 4 meters (13 ft) (relative to winter lake levels), where a distinct slope break occurs between about 4 and 6 meters (13 to 20 ft). Below about 6 meters (20 ft), the slope decreases again, and in some areas gravel can be found. Sockeye salmon have been observed spawning on this lower "shelf" at Allen's Beach to depths of approximately 10 meters (32 ft).

During the summer of 2005, lower and middle beach surfaces were classified into seven categories based upon dominant substrate types: cobble, cobble/gravel, cobble/fines, gravel/cobble, gravel, gravel/fines, and fines. A total of 1.6 miles (2.6 km) of shoreline substrate were mapped and classified (see Figure 3.10) from the south end of the spit in Allen's Bay to an unnamed tributary approximately 1 km northwest of Cemetery Point. Approximately 85% of the shoreline length contained substrate types used by spawning sockeye but only 26% of the shoreline was classified as containing concentrated spawning usage. Gravel was the dominant shoreline substrate (30%) by length followed by fines (14%) and cobbles (13%). The remainder of the shoreline length was a mixture of cobble, gravel, and fines (43%;Table 4.1).

Table 4.1. Allen's Beach area dominant substrate categories, number of segments, length of substrate categories, and percentage of beach length within specified length categories (source: MFM, unpublished shoreline survey data).

Dominant Substrate Category (lower and middle beach surfaces)	Number of Beach Segments	Total Length (Ft)	Total Length (m)	Percent of Beach within Specified Substrate Category
Cobble	2	1,096	334	12.6%
Cobble/Gravel	3	934	285	10.8%
Cobble/Fines	1	151	46	1.7%
Gravel/Cobble	2	2,194	669	25.3%
Gravel	4	2,604	794	30.0%
Gravel/Fines	2	439	134	5.1%
Fines	3	1,249	381	14.4%
Totals	**17**	**8,667**	**2,642**	**100.0%**

Mapping surveys conducted during the summer of 1999, when much of the beach was exposed during low lake level, identified numerous small seeps and springs in portions of the area used for spawning. A total of approximately 180 meters of beach were mapped during the summer of 1999. Attempts to measure thermal gradients around the springs during winter of 1999 and 2000 were unsuccessful (MFM unpublished data). Based upon the lack of thermal gradient around the seeps it was assumed that either: 1) the groundwater and lake water temperatures were the same, or 2) that the quantity of water emerging from the seeps was insufficient to be detected using the methods employed.

Utilization of Allen's Beach by spawning sockeye is less concentrated than Olsen's Beach. There is no core spawning area at Allen's Beach, unlike Olsen's Beach. MFM established a lead line transect for monitoring sockeye spawning along Allen's Beach in 1999 (along the mapped transect). This area (middle Allen's Beach) at the time was thought to have the highest density of spawners. Gravel samples were collected along a 170 meter (558 ft) transect that extended through the spawning area in 1999 (MFM unpublished data). It was later found that higher spawning density was actually to the south and another lead line transect was deployed in that area during the fall in 2000. A total of 11 gravel samples were collected using a McNeil core sampler and processed using gravimetric sediment processing methods. It was found that levels of fine sediment within the spawning gravel ranged widely along the transect. Percent fines (<0.85mm) ranged from 4.6% to 44.3%, averaging 24.6%. Figure 4.5 depicts location and percent fine sediment calculated for each of the 13 sediment samples collected in 1999.

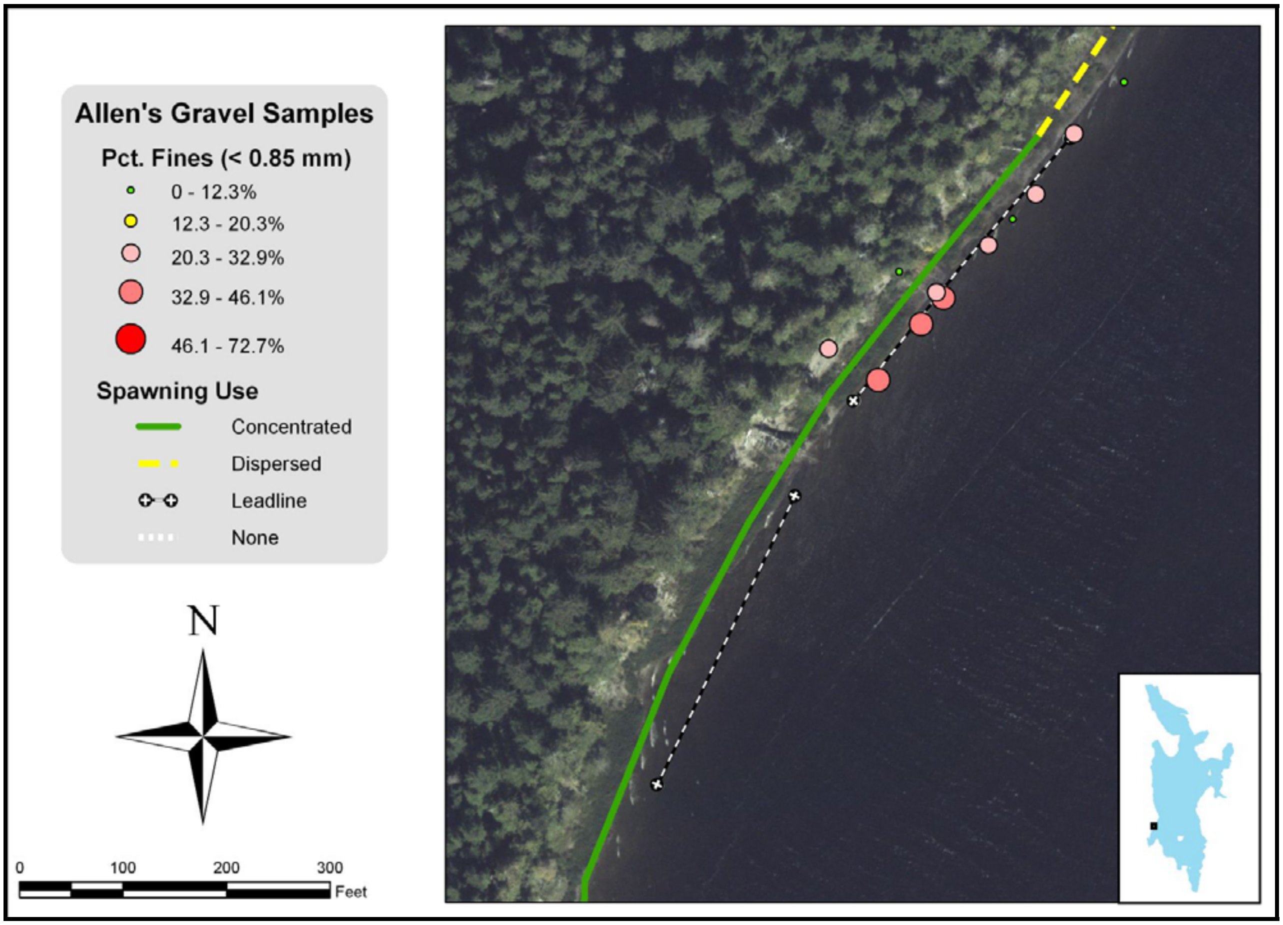

Figure 4.5. Allen’s Beach gravel sampling results from 1999 and sample proximity to different categories of spawning use. (Note: There are two lead lines at Allen’s Beach: Allen’s and South Allen’s. Note: Two gravel samples were located in the dispersed spawning use category.) (source: MFM, unpublished shoreline survey data.)

There are additional differences between Olsen’s and Allen’s beaches. One factor that has been examined is difference in beach slope. The slope of Olsen’s Beach where it is most heavily used by spawning sockeye is approximately 30% steeper than areas of concentrated spawning use at Allen’s Beach. Beach slope at Olsen’s Beach ranges from 10-12% gradient, whereas the slope at Allen’s Beach ranges from 8% to 9% gradient. These differences may be a function of increased wave energy at Olsen’s Beach. Figure 4.6 illustrates the differences in beach slope between Olsen’s and Allen’s beaches based upon typical cross-sections from the core and concentrated spawning areas.

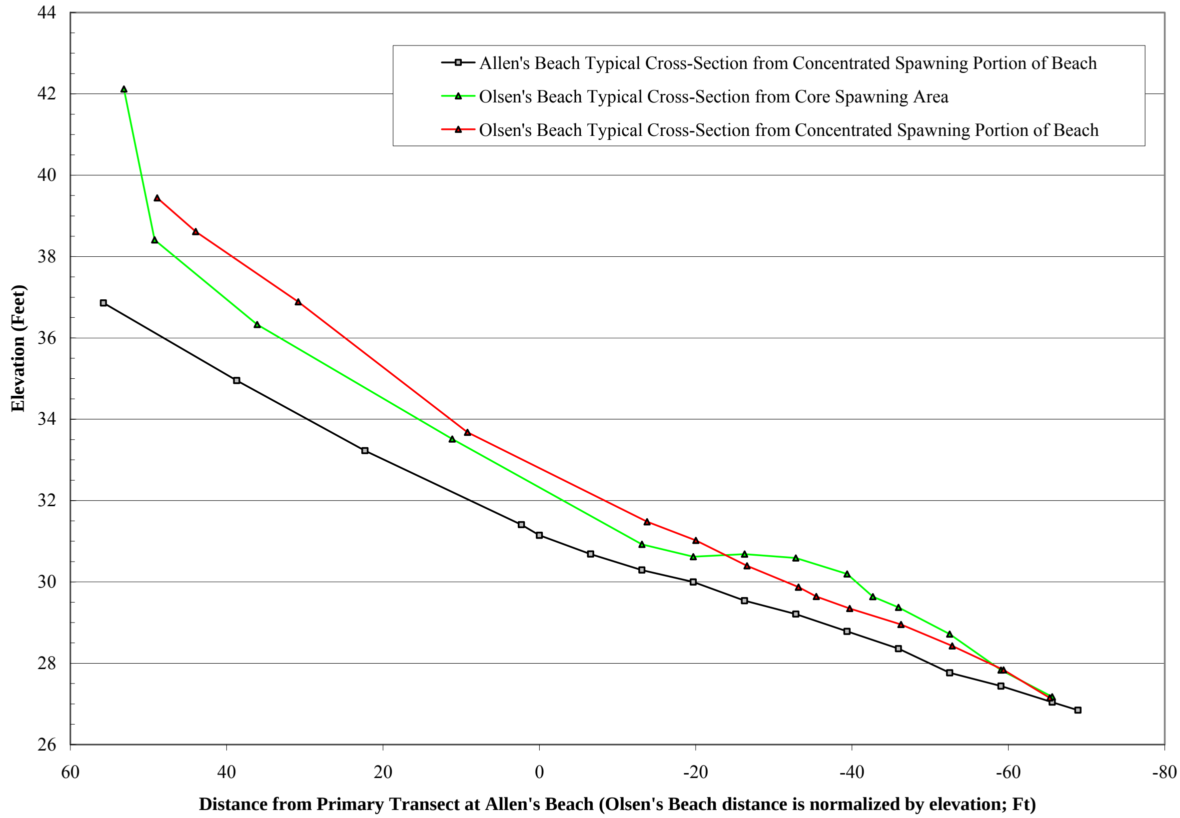

Figure 4.6. Comparison of beach slopes using typical cross-sections from Olsen's Beach core and concentrated spawning areas and Allen's Beach concentrated spawning use area. (source: MFM, unpublished beach topography data.)

In addition to Olsen's and Allen's beaches, sockeye have been reported to spawn at Umbrella Beach, Ericson's Bay, and Baby Island, although a thorough review of Ozette literature, reports, and spawning ground survey data could not verify spawning in Ericson's Bay. Bortleson and Dion (1979) described the substrate in Ericson's Bay as suitable for sockeye spawning but did not document any spawning there. Meyer and Brenkman (2001) observed sockeye spawning at Baby Island during the winter of 1994. Field investigations and spawning ground surveys conducted by MFM and ONP during the winters of 1999 and 2000 revealed that very little spawning gravel is present along the shores of Baby Island. Besides Olsen's and Allen's beaches, Umbrella Beach has the best-documented account of beach spawning sockeye. Shoreline and delta conditions are significantly different now from what they were in 1964 (Figure 4.7). Herrera (2006) estimated that delta growth between 1964 and 2003 was approximately 5.7 acres (23,000 m^2). Much of the delta growth described by Herrera (2006) was just north of the mouth of Umbrella Creek. This is the area where spawning sockeye salmon were observed by Dlugokenski et al. (1981). Much of the new (post-1964) delta is now vegetated in shrubs, as is much of the older (pre-1964) delta, which contained little vegetation along the lake margins in 1964.

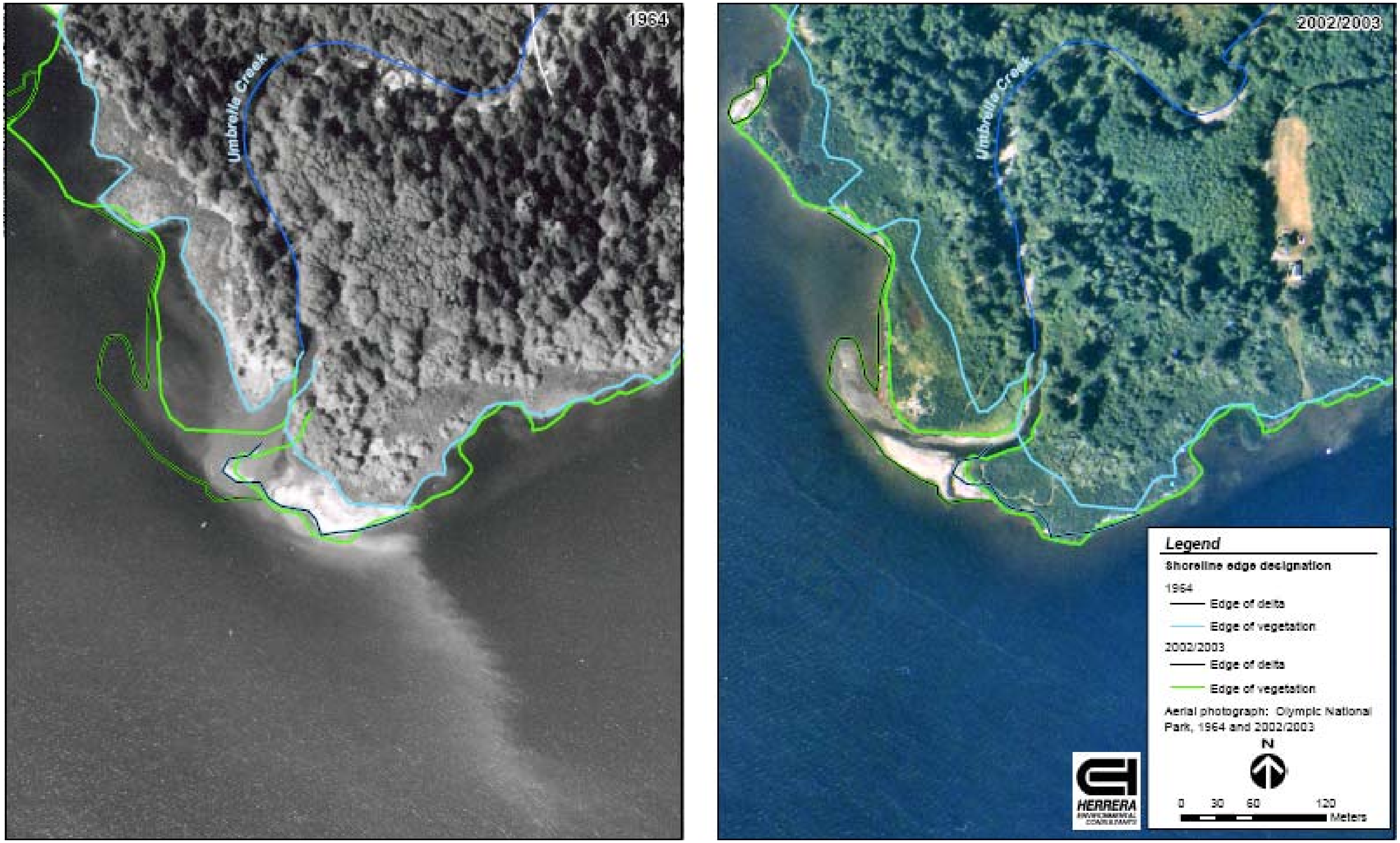

Figure 4.7. Comparison of 1964 and 2002 shoreline and delta conditions at the mouth of Umbrella Creek (source: Herrera 2005)

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A preliminary comparison of shoreline vegetation and sediment dynamics based on aerial photography in 1953 and 2003 (Ritchie 2005) found that significant increases in vegetation cover along the Ozette shoreline likely occurred in the last 50 years. About 28.3 miles (45.6 km) of shoreline were analyzed for vegetation changes between 1953 and 2003, and classified linearly as increase, decrease, or no change. Of this length, about 11.4 miles (18.4 km) showed an increase in vegetation cover, 0.1 miles (0.16 km) showed a decrease, and 16.8 miles (27.0 km) showed no change. Much of the shoreline classified as unchanged was completely vegetated prior to 1953. Changes were particularly noticeable along the north end of the lake and near the mouth of Umbrella Creek.

Ritchie (2005) detected increases in vegetation colonization along a fraction of the shoreline lengths at both Allen's and Olsen's beaches. Vegetation colonization at Allen's Beach was primarily to the south of the zone categorized as concentrated spawning use and to the north near Cemetery Point. At Olsen's Beach, vegetation encroachment was limited to areas just south of the northern concentrated spawning area and a zone 100 meters (328 ft) north of the core spawning area. Ritchie (2006) completed a second, higher resolution analysis motivated by results of the preliminary comparison. The second analysis delineated patches of unvegetated shoreline that could be resolved in photos from 1953 to 2003 at a scale of 1:300 or better, for the entire length of shoreline visible in 1953 and 2003 photos.

Ritchie's second analysis (2006) also found that the area of unvegetated shoreline decreased from 1953 to 2003. Ritchie identified 1,034,887 ft^2 (96,144 m^2) of unvegetated shoreline around the lake in 1953, and only 451,561 ft^2 (41,951 m^2) of unvegetated shoreline in 2003, a decrease of 56%. Ritchie found that unvegetated area at Allen's Beach dropped by 67%, from 125,645 ft^2 (11,673 m^2) in 1953, to 41,716ft^2 (3,876 m^2) in 2003 (Figure 4.8). The length of shoreline analyzed was 8,670 ft (2,643 m). Unvegetated area at Olsen's Beach declined from 27,322 ft^2 (2,538 m^2) in 1953, to 9,343 ft^2 (868 m^2) in 2003, a decrease of 66% over 2,804 ft (855 m) of shoreline assessed (Figure 4.9).

Many protected embayments were fully vegetated in the 1953 photos and remained so in 2003. Negligible change occurred in Deer Bay, Swan Bay, Allen's Slough, and the South End. The greatest decreases in unvegetated shoreline occurred on the east side of the North End north of Blooms Bay, at Shafer's point, at and near Cemetery Point, on the east shore opposite Cemetery Point, and between Jersted Point and Benson's Point (Figure 4.10). A region with a notable increase in unvegetated shoreline was identified at the Umbrella Creek delta, where Herrera (2006) estimated that delta growth between 1964 and 2002 was approximately 5.7 acres (23,000 m^2). However, virtually all of the area of unvegetated beach in 1953 was covered with vegetation in 2003. The current unvegetated shoreline at this locale consists entirely of sediment delivered to the lake from Umbrella Creek since 1953. A second area with a small increase in unvegetated shoreline was identified at the delta of a small, steep tributary (20.0078) east of Baby Island.

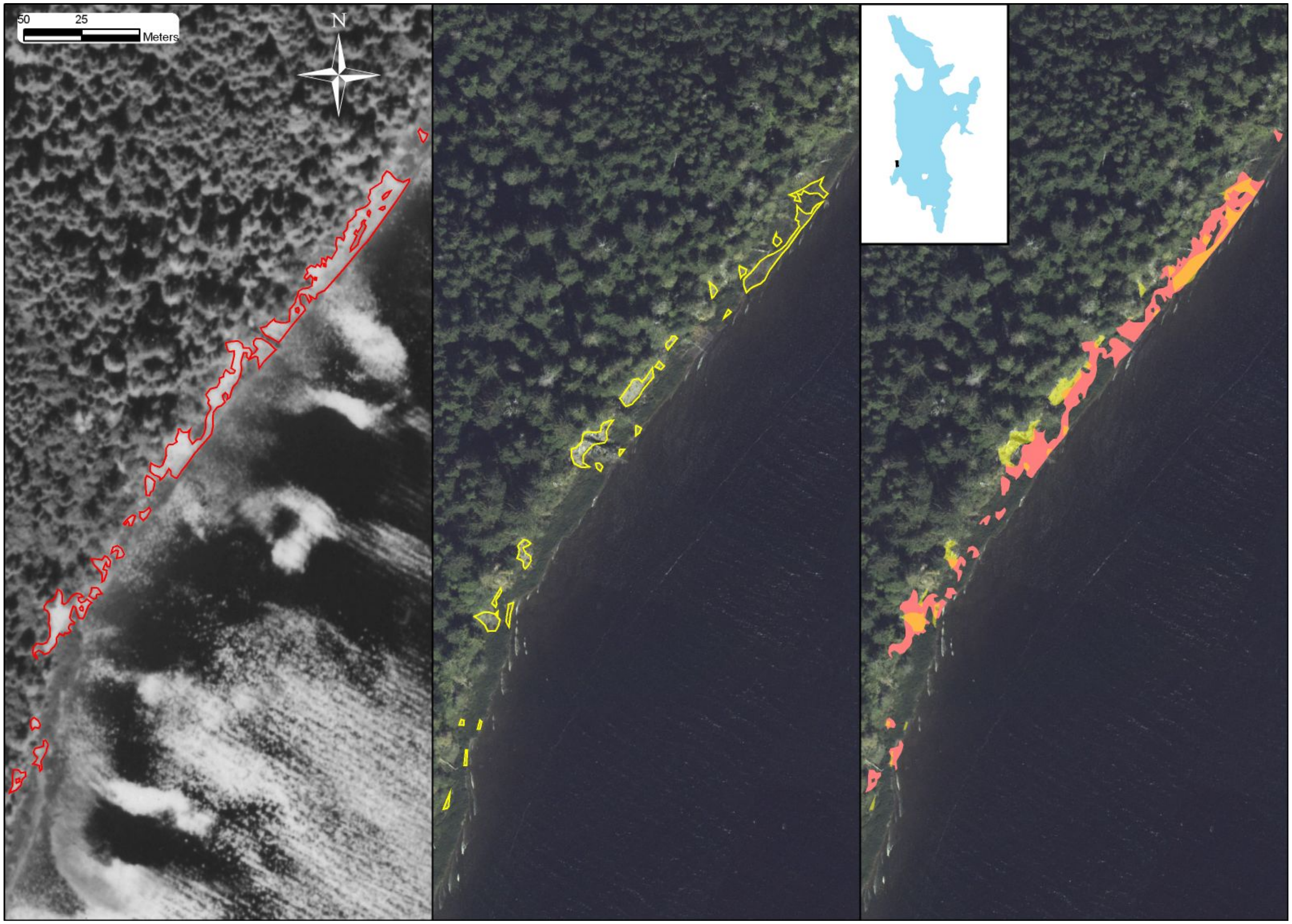

Figure 4.8. Comparison of a portion of Allen's Beach from 1953 to 2003. Red polygons delineate unvegetated shoreline in 1953 (left image) and yellow polygons delineate unvegetated area in 2003 (middle and right images).

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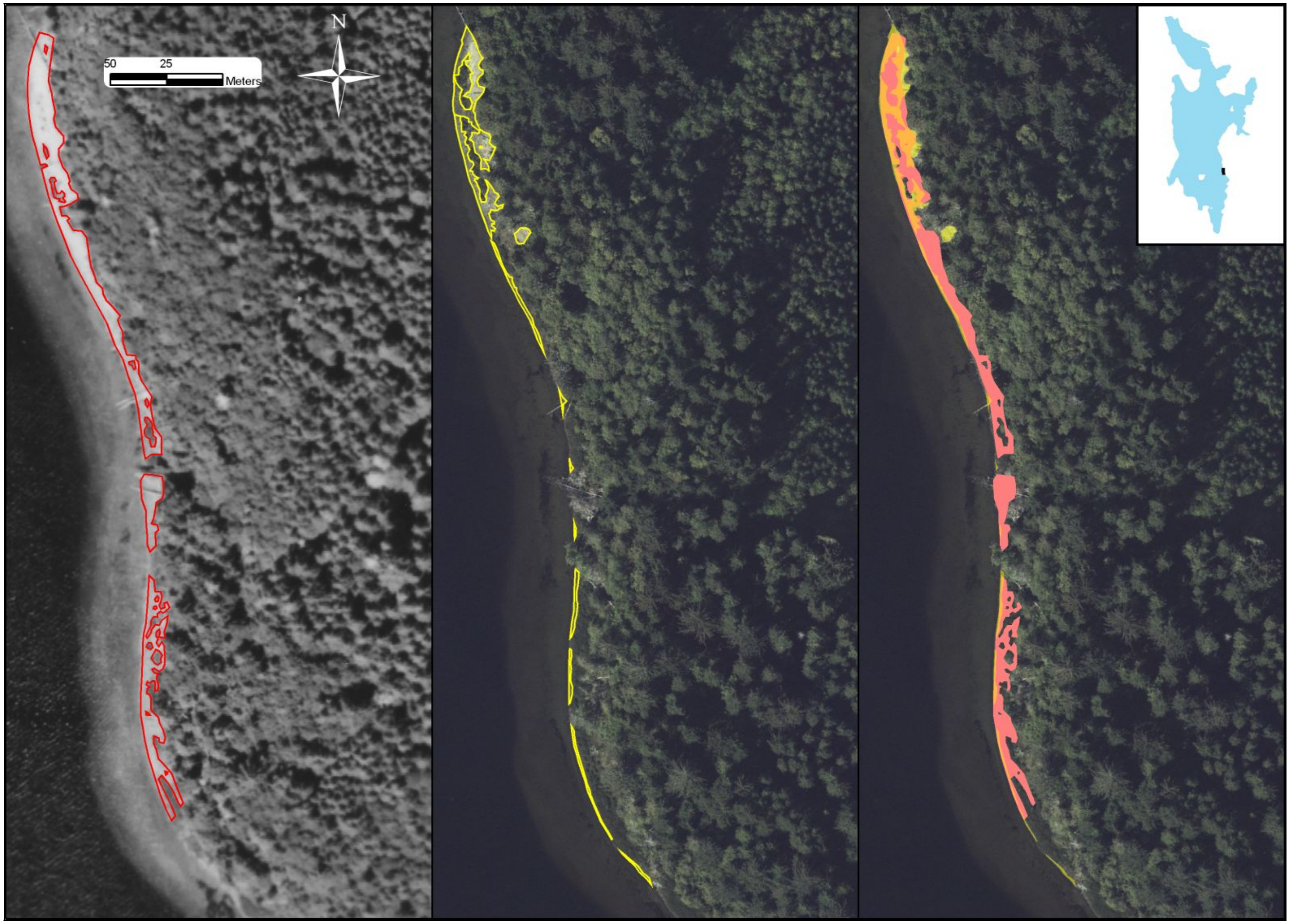

Figure 4.9. Comparison of a portion of Olsen's Beach from 1953 to 2003. Red polygons delineate unvegetated shoreline in 1953 (left image) and yellow polygons delineate unvegetated area in 2003 (middle and right images).

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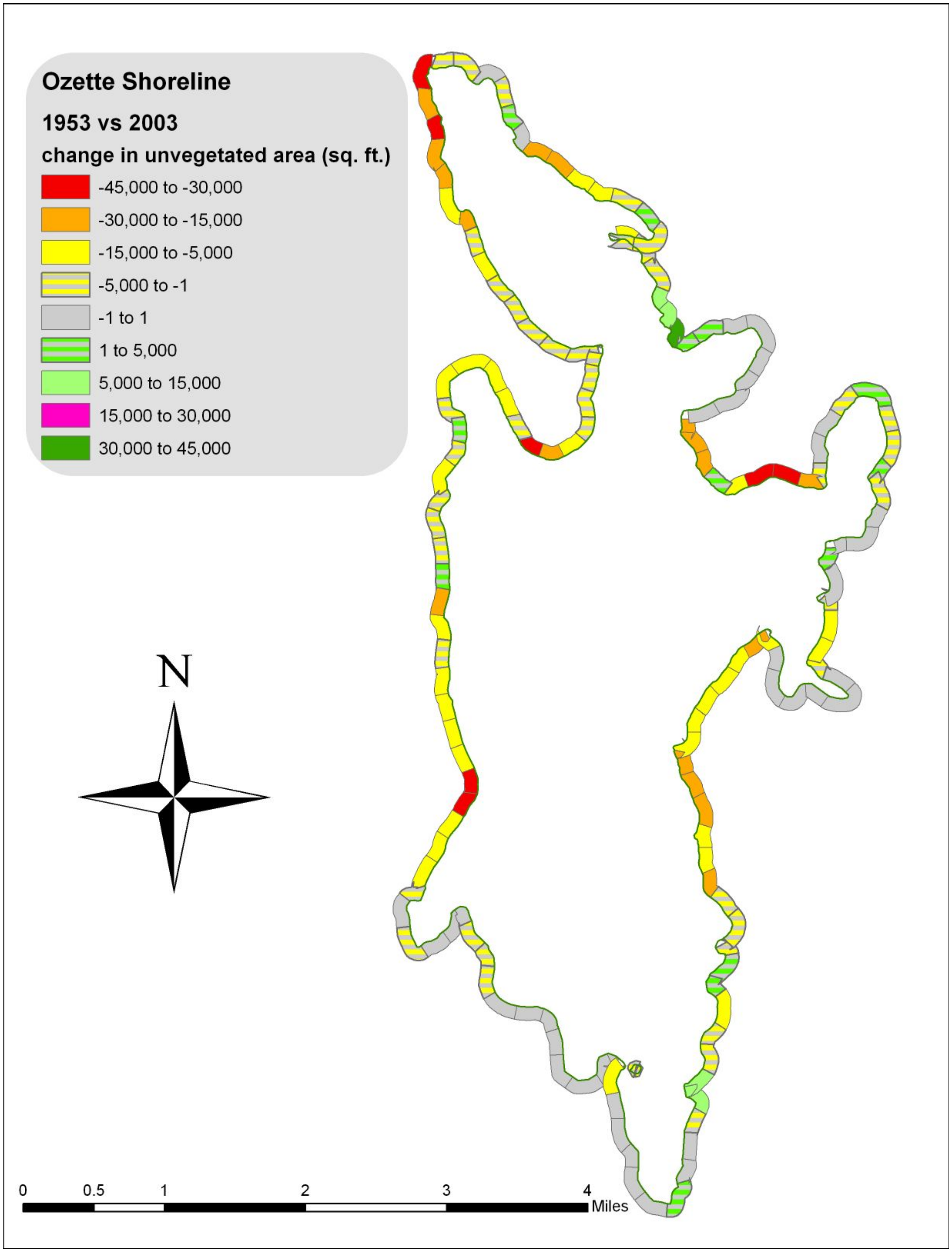

Figure 4.10. Change in unvegetetated area from 1953 to 2003 along overlapping 1,000 ft. segments of Lake Ozette shoreline.

Ritchie (2005) analyzed changes in vegetation only from 1953 to 2003. Significant changes to shoreline vegetation prior to 1953 may also have occurred. A news story from 1940 (Port Angeles Evening News, February 15, 1940) states, "*After the first big slaughter… [of elk] half a century ago the area that had been over-browsed started to grow up again, it was contended, and now all the lake [Ozette] shore and the adjacent country is a complete thicket…*". While aerial photos were taken in the 1930s to produce a topographic map for the War Department, an exhaustive search has failed to locate them. These photos, if found, will add valuable information about the evolution of shoreline vegetation, as well as sediment flux rates.

It is important to note that current and recent spawning locations, as well as vegetation and substrate conditions along the lake shoreline, may not be representative of past spawning distribution and shoreline conditions. The historical spawning distribution of beach spawning sockeye is not fully understood. Kemmerich (1926) stated that "*The shores of the lake afford many ideal spawning beds and over a large area, also numerous small streams of gravel bottom empty into the lake which are ideal spawning beds*". Kemmerich (1939) also recalled that, "*We made no special investigations of spawning beds during the years [1923-1926] but merely observed from time to time that most of the spawning seemed to be along the lake shore in suitable places and especially at the mouths of the several creeks*." Dlugokenski et al. (1981) observed sockeye spawning to the north Umbrella Creek during surveys in the late 1970s, but no sockeye have been observed spawning there since, despite exhaustive surveys. The spawning at the mouths of creeks described by Kemmerich (1939) is no longer observed. Meyer and Brenkman (2001) also observed sockeye spawning at Baby Island during the winter of 1994, but no sockeye have been observed spawning there since, also despite exhaustive surveys. The number of beach spawning aggregations that have been entirely eliminated remains unknown. Currently used spawning habitat at extant beaches (Olsen's and Allen's) and remaining available spawning habitat along the beaches appears able to produce only a small fraction of the population abundance that is thought to have once occupied the lake.

From the above historical observations and known habitat use by sockeye throughout their range, a larger picture of spawning habitat potentially used by sockeye in Ozette can be developed. Beach spawning habitat quality is controlled by substrate size and composition (i.e., gravel with interstitial spaces, low percentage fines), and intergravel circulation from lake current patterns (Blair and Quinn 1991; Hendry et al. 1995; Leonetti 1997) or upwelling hyporheic[12]- and/or groundwater (Blair et al. 1993; Burger et al. 1995; Young 2004). Historically, high quality spawning habitat was likely provided by numerous hydrogeomorphic situations:

1. Spawning on shallow non-vegetated beaches with suitable clean substrate exposed to wind-driven currents and wave action (Leonetti 1997).

[12] Note that for all text in the LFA, "hyporheic" is used to refer to water of mixed origin with no less than 10 percent and no more than 90 percent of either surface water or groundwater. The hyporheic zone is the surface/groundwater mixing zone. Groundwater does not = hyporheic water. Both can exist and differentially create seeps and springs.

2. Spawning at or near upwelling springs or seeps (hyporheic water or groundwater), regardless of water depth, where temperature regimes and intergravel flow are maintained. This reduces mortality during redd dewatering in shallow areas (Burger et al. 1995) or during times of little or no wind-driven current in deeper waters (Leonetti 1997).
3. Spawning at or near tributary inlet (deltas) with suitable substrate (deltaic gravel deposits), good intergravel circulation (upwelling hyporheic water and/or groundwater), and stable hyporheic temperature regimes (e.g., Umbrella Beach: Dlugokenski et al. 1981). Hyporheic water temperature regimes in tributary deltas would likely be slightly warmer and more stable than tributary temperatures, but cooler than warmer ambient lake temperatures or groundwater (White 1993; Edwards 1998).
4. Spawning in tributaries above deltaic zones.

4.2.2 Riparian Conditions

Riparian conditions around the lake are generally good to excellent, with the exception of the east portion of the North End where the county road parallels the shoreline, the north tip of the North End where most development has occurred, and a few parcels of private property where owners have constructed cabins or houses. Aerial photo analyses indicate that the area of vegetated shoreline below the winter high water level has increased since 1952 (Section 4.2.1). Increased shoreline vegetation may be limiting available spawning habitat, although the mechanisms responsible for this are not well understood.

Primary forest is the dominant riparian condition for most of the western half of the shoreline. Although abandoned homestead locations are known to exist in this area, they are virtually indistinguishable from undisturbed shoreline. Non-native vegetation (primarily reed canary grass) is generally limited to the mouth of Big River, some areas of Swan Bay, and near the lake outlet. Along the eastern half of the shoreline, a narrow buffer of mature trees exists between the lake and areas that have been clear-cut. On the North End, Rayonier Landing has remained unvegetated since at least the 1950s, and the current site of the ONP Ranger Station and campground has been subjected to ongoing disturbance since the USCG Life Saving Station was established at Lake Ozette in the 1940s. South of Swan Bay, an old railroad grade parallels the shore for some distance. Along the grade, shoreline conifers are mostly <50 years old, and the riparian area has a high proportion of mature red alder. This grade was constructed before 1952.

4.2.3 Water Quality

During the past 30 years several water quality attributes have been studied in Lake Ozette. In 1976, Bortleson and Dion (1979) examined several water quality attributes in the lake, including water temperature, dissolved oxygen, water transparency, and nutrients. Since then, others (Blum 1988; Beauchamp and LaRiviere 1993; Jacobs et al. 1996; Meyer and Brenkman 2001) have either collected water quality data or attempted to summarize data for Lake Ozette. Meyer and Brenkman (2001) and Beauchamp and LaRiviere (1993) both found that the lake begins to stratify in April and begins to mix in October. Isothermal conditions were found from December through February (Figure 4.11).

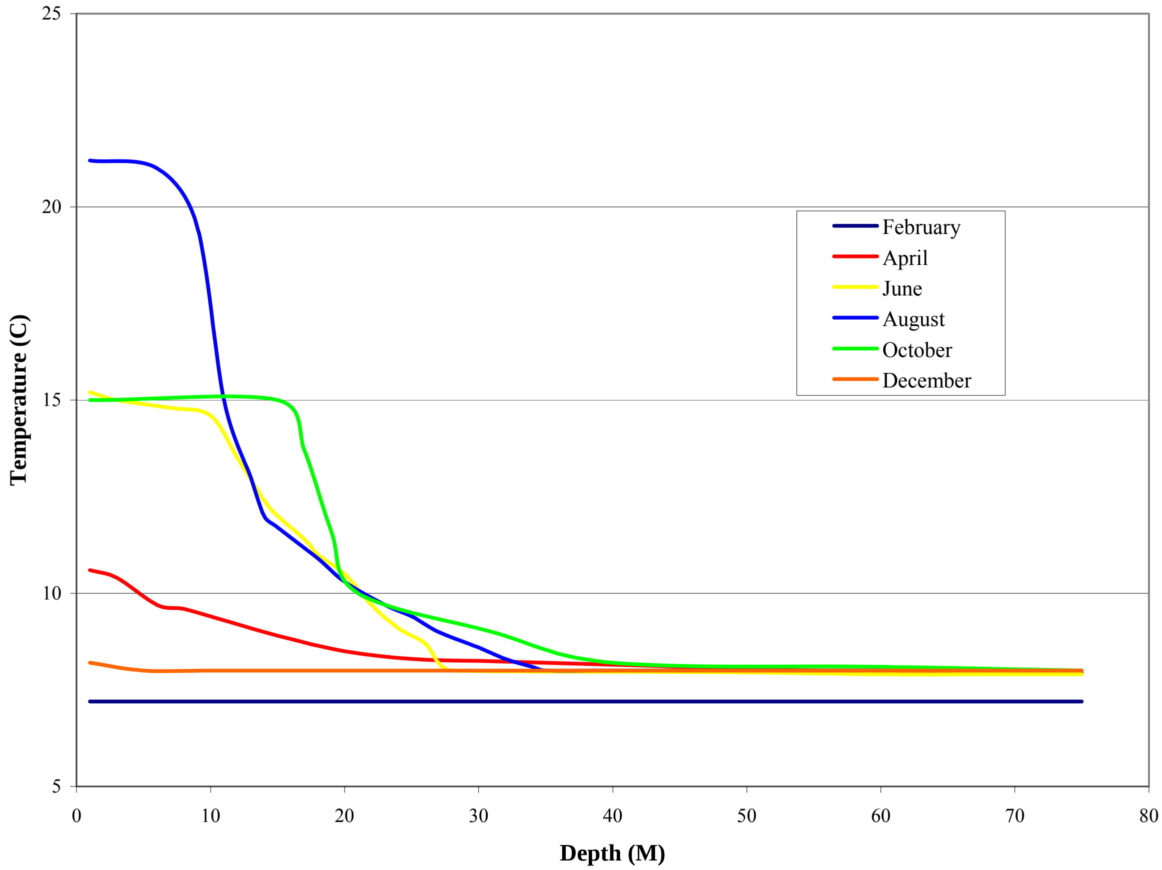

Figure 4.11. Seasonal variation in temperature-depth profiles for Lake Ozette (modified from Jacobs et al. 1996; source data: Meyer and Brenkman 2001).

Meyer and Brenkman (2001) reported dissolved oxygen levels ranging from 12.4 to 6.2 mg/l. Data collected by Meyer and Brenkman (2001) show a rapid decrease in dissolved oxygen in the lake's metalimnion from August through October. They found that dissolved oxygen levels rapidly increased in the hypolimnion. Jacobs et al. (1996) concluded that temperature and dissolved oxygen conditions do not appear to be a threat to sockeye salmon. Meyer and Brenkman (2001) concluded that temperature and dissolved oxygen conditions were well within the range preferred by sockeye salmon. Meyer and Brenkman (2001) also collected pH data during the summer of 1994. They found that pH levels ranged from 7.7 to 6.1 and that pH gradually decreased with depth throughout the monitoring period.

Water clarity has also been thoroughly examined in Lake Ozette. Water clarity can be divided into two main constituents: suspended materials and dissolved materials.

Turbidity is a measure of suspended materials, such as silt and algae. Color values are a measure of materials dissolved in water. Slightly different methods have been employed by different researchers attempting to describe water clarity in Ozette. Bortleson and Dion (1979) used water color and secchi-disk depth readings to describe Lake Ozette water clarity. They reported secchi-disk readings ranging from 2 to 4 meters, averaging 3 meters. Color reading ranged from 20-45 on Pt-Co scale. Meyer and Brenkman (2001) measured secchi-disk depths and turbidity in their study of water clarity. Meyer and Brenkman (2001) reported mean (from the four lake monitoring stations) secchi disk readings ranging from 3.7 to 6.5 meters. Meyer and Brenkman (2001) speculated on the higher clarity observed in 1994 as compared to 1976 and thought that at least in part it was due to the lower zooplankton densities observed in 1994. Meyer and Brenkman (2001) also monitored turbidity levels in Lake Ozette and reported a range of 1.4 to 18 NTUs at their four monitoring stations in the lake. They concluded that turbidity levels tend to be low in the lake with two exceptions: during May and June when plankton blooms are occurring and after storm events. The highest turbidities recorded in the lake were made a few days after a storm event. Turbidity levels of 35 NTUs were measured in the middle of Swan Bay. During this sampling period they found turbidity decreased with depth. Turbidity levels at 13 meters were 14 NTUs.

Nutrients were also sampled by Bortleson and Dion (1979) and Meyer and Brenkman (2001). Meyer and Brenkman found that Kjeldahl-N, total dissolved phosphorus, orthophosphate-P, and ammonia-N did not demonstrate any consistent patterns in concentration with increased depth. They also found that concentrations of nitrate did not change with increased depth in January, but the lowest concentrations occurred near the lake surface in samples collected in May, July and August. Table 4.2 is a comparison of average winter/spring and summer/fall values for organic and inorganic nitrogen, total phosphorus, and orthophosphate phosphorus collected in 1976 and 1994. Based upon data collected in 1976 and 1994, Lake Ozette can be described as an oligotrophic to mesotrophic system (low to moderate levels of nutrients; Jacobs et al. 1996). Meyer and Brenkman concluded that Lake Ozette is likely phosphorus limited.

Table 4.2. Comparison of inorganic nitrogen, organic nitrogen, total phosphorus, and orthophosphate from samples collected in 1976 and 1994 for three separate depth zones (source: Bortleson and Dion 1979; Meyer and Brenkman 2001).

	Winter-Spring (1976)			**Winter-Spring (1994)**		
	0-25m	**10-50m**	**22-80m**	**1m**	**18m**	**22-64m**
Inorganic Nitrogen (mg/l)	0.150	0.140	0.160	0.137	0.156	0.169
Organic Nitrogen (mg/l)	0.110	0.110	0.120	0.115	0.101	0.103
Total Phosphorus(mg/l)	0.008	0.007	0.008	0.006	0.006	0.005
Orthophosphate (mg/l)	0.004	0.003	0.004	0.002	0.001	0.002
	Summer-Fall (1976)			**Summer-Fall (1994)**		
	0-25m	**10-50m**	**22-80m**	**1m**	**18m**	**22-64m**
Inorganic Nitrogen (mg/l)	0.060	0.110	0.130	0.059	0.168	0.171
Organic Nitrogen (mg/l)	0.130	0.140	0.120	0.110	0.098	0.105
Total Phosphorus(mg/l)	0.008	0.008	0.007	0.008	0.009	0.010
Orthophosphate (mg/l)	0.003	0.003	0.004	0.001	0.001	0.001

4.2.4 Lake Productivity

Healthy and abundant zooplankton communities are a critical component of the overall sockeye smolt production in any lake. Zooplankton communities are dependent upon phytoplankton communities. Bortleson and Dion (1979) used chlorophyll α concentrations measured in Lake Ozette to estimate algae concentrations in the lake, and algae growth potential was tested using algal bioassay tests. They found that chlorophyll α concentrations were highest in the summer (averaging 3.5μg/l) and lowest (1.2-0.3μg/l) in the winter. Meyer and Brenkman (2001) report chlorophyll concentrations of 7.6 to 11.5 mg/m^3 in the upper five meters of the lake during April and May and concentrations of 0.4 to 0.6 mg/m^3 at 20 meters depth during the same period. Samples collected in 1976 indicated that the algal population in Lake Ozette is dominated by *Botryococcus* during all months except May (Bortleson and Dion 1979). Meyer and Brenkman (2001) concluded that Lake Ozette can be classified as oligotrophic based upon concentrations of chlorophyll.

Meyer and Brenkman (2001) concluded that most of the chlorophyll in Lake Ozette is in the upper water column. Copepod and cladoceran densities from surveys conducted by Meyer and Brenkman (2001) indicate that densities are 3 times higher in the upper 5 meters than in the zone from 5 to 30 meters. Dlugokenski et al. (1981) calculated an average density of 7.4 copepods and cladocerans per liter of water. Densities reported by Meyer and Brenkman were much lower. Meyer and Brenkman (2001) described the Lake Ozette zooplankton community as composed of nine crustacean and 15 rotifer taxa. Several other researchers have studied and described the Lake Ozette zooplankton community. Dlugokenski et al. (1981) found the copepods and cladocerans made up 57 to 99.8% of the organisms in monthly samples.

They found that *Diaptomus sp*., *Epischura sp*., and copepods of the genius cyclopoida were present in all samples, as were *Bosmina sp*., *Daphnia sp*., *Holopedium sp*., and *Leptodora kindtii*. Bortleson and Dion (1979) found similar zooplankton assemblages and that densities were highest from May to November and lowest from February to April. Jacobs et al. (1996) found through an extensive review of Ozette literature that all researchers who have studied zooplankton communities in Lake Ozette have concluded that sufficient food supplies are available for juvenile sockeye salmon during their period of lake residence. Beauchamp and LaRiviere (1993) used bioenergetic simulations and cladocerans egg-ratio analysis to predict that consumption demand by kokanee and juvenile sockeye could be satisfied by less than 1% of the instantaneous production of the preferred large Daphnia throughout the growing season. Dlugokenski et al. (1981) evaluated the length and weight of Ozette sockeye smolts and concluded that they were the third largest yearling sockeye smolts in the world, providing additional evidence that zooplankton populations are not limiting sockeye productivity.

4.2.5 Hydrology and Lake Level

The hydrology of the Ozette Watershed has been poorly studied over the contemporary settlement period of the Ozette region. However, an assortment of lake level, climate, and hydrology data has been collected at various places in the watershed and coastal region, for different reasons, that can be massed together to highlight the major physical patterns of the lake's hydrology. The USGS made several miscellaneous measurements of instantaneous stage discharge in the watershed's tributaries in the 1960s and 1970s (Bortleson and Dion 1979) and maintained a continuous stream gage on Ozette River at the outlet of Lake Ozette between 8/1/1976 and 9/30/1979 (Figure 4.12). The stream gage station consisted of a continuous stage (level) recorder and periodic discharge measurements (using a current meter) to develop a stage-discharge rating curve. The stage recorder and backup stage plate were located approximately 100 feet upstream of the new footbridge (circa 1976) that crosses Ozette River. The stream gage effectively measured both lake and river stage, as the gage was located at the transition zone between lake and river, where lake water converges into the river. These data will be described in more detail in Section 4.3.6.

In 1981, the Olympic National Park (ONP) partially continued previous efforts by the USGS and began recordings of manual daily lake stage at the same USGS stage plate at the head of the Ozette River and outlet of the lake (Figure 4.12). The ONP personnel recorded stage at this location manually every day from 11/1/1981 to present (or 9/30/2002 used here). A gap in the data exists between 9/20/1994 and 12/31/1997, and daily records are missing for other parts of the record, with gaps ranging from a day to several weeks. ONP personnel recorded stage only once daily at random or convenient time periods. Time of day was not recorded in their database. Lake Ozette does fluctuate on a daily basis, especially during windy periods, because of wind seiche. However, due to the large volume of the lake and partial storage and attenuation of inflows, the lake does not experience dramatic level fluctuations at the daily time scale, except during extremely high discharge (flow) input events or large wind seiches. Daily ranges of stage change are less than 0.5 feet. While these data from this ONP gage do not represent daily averages, the data, in mass, can be assumed to be a reasonable surrogate for mean daily stage. Gaps in the stage record were filled in through linear interpolation between adjacent data points by Makah Tribe Fisheries personnel. Gaps larger than 10 days were not interpolated and left blank. Thus, the long but discontinuous stage record was recovered for the period 1982-2002.

In March 2002, MFM personnel installed a continuous stage gage near the same location as the historical USGS gage. This gage is located 30 feet above the footbridge and 70 feet below the USGS/ONP manual stage plate. This gage automatically measures and records lake (or river) stage every 15 minutes. These data were averaged to create mean daily lake stage, comparable to the ONP daily stage recordings. Thus daily lake stage data are available from 1976 to 2005 (Figure 4.13).

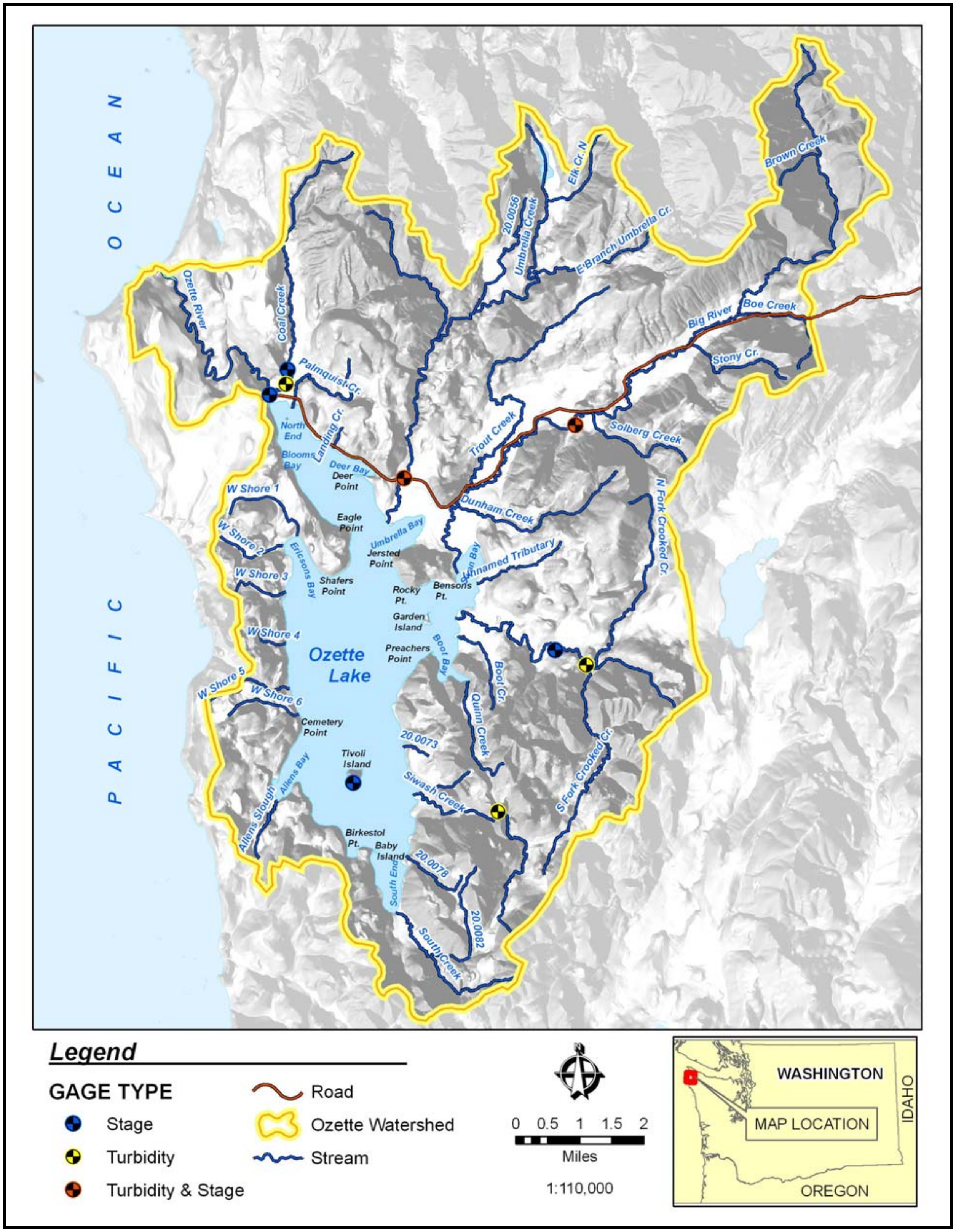

Figure 4.12. Locations of Lake Ozette watershed stream and turbidity gages operated by MFM.

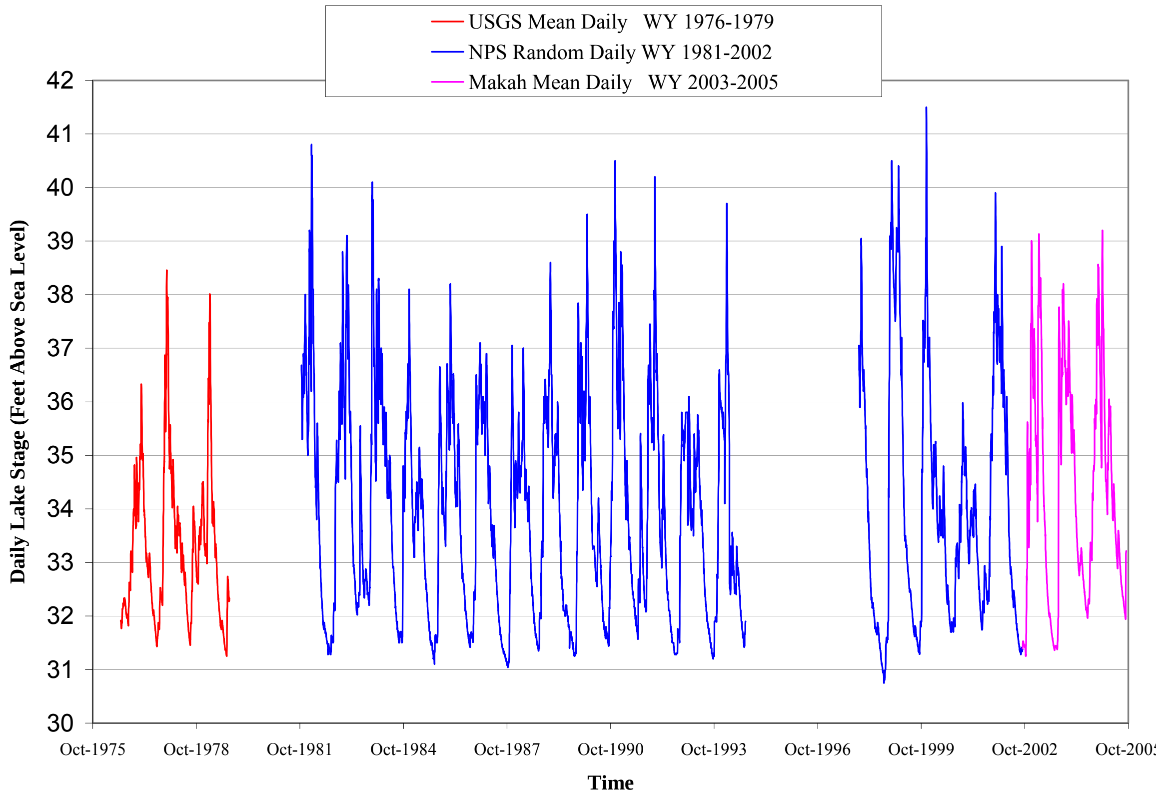

Figure 4.13. Lake Ozette stage hydrograph, 1976-2005 (source: USGS, ONP, and MFM lake stage data).

The mean surface elevation of the lake for the period of record (1976-2005) was 33.98 feet above mean sea level (National Geodetic Vertical Datum of 1929). Annual lake level fluctuations ranged from an average minimum of 31.3 feet (30.75 lowest recorded) to an average maximum of 38.6 feet (41.5 highest recorded) above mean sea level (Figure 4.13). Hydrographs of the lake stage (level) generally follow the same seasonal patterns as average monthly rainfall displayed in Figure 1.5. Peak lake levels occur during the wettest months between November and April, while low lake levels occur during the dry season between July and September (Figure 4.14 and Figure 4.15). Figure 4.14 displays the level regime of Lake Ozette and different percentiles that the lake has achieved between 1976 and 2005. Example lake hydrographs for various wet, average, and dry precipitation years are displayed in Figure 4.15, while Figure 4.16 displays level duration curves for those same years.

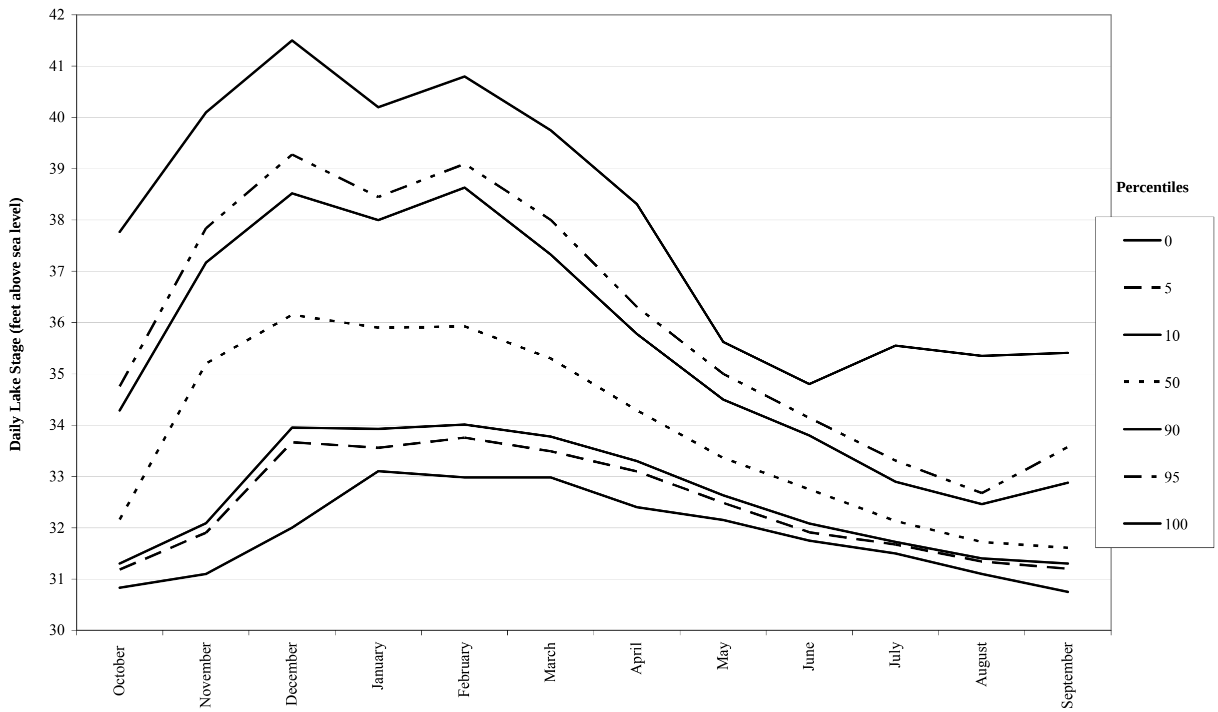

Figure 4.14. Lake Ozette water level duration curves for the period 1976 through 2005 (source: USGS, ONP, and MFM lake stage data).

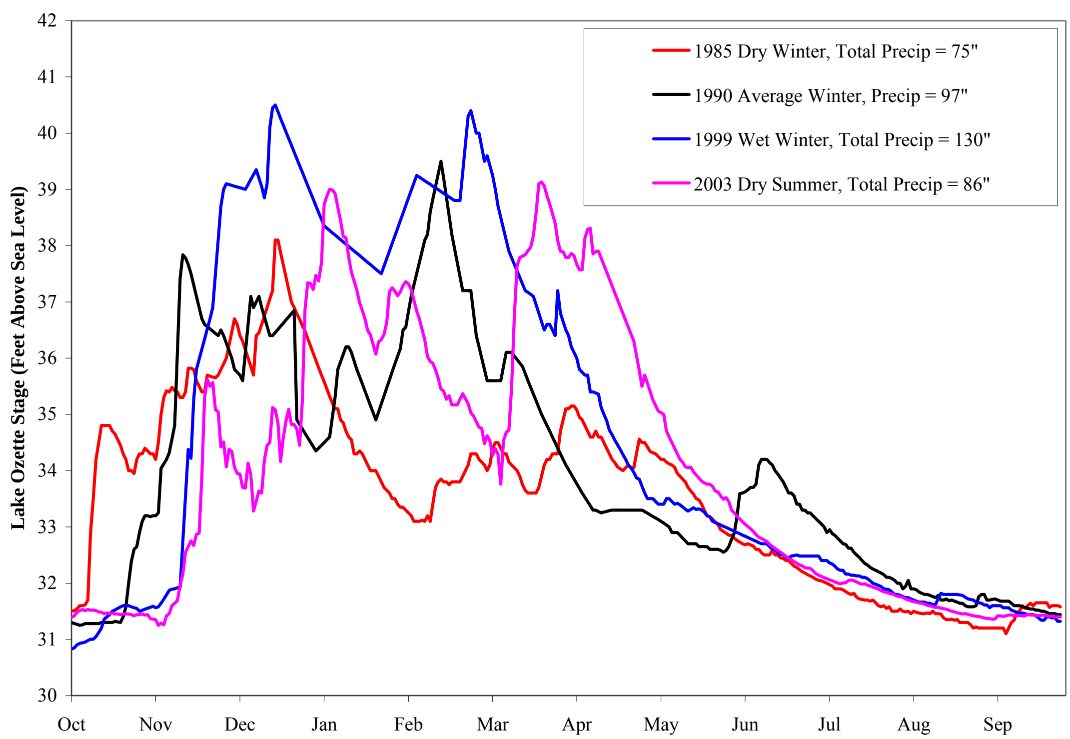

Figure 4.15. Sample Lake Ozette hydrographs for 1985 (dry winter), 1990 (avg. winter), 1999 (wet winter), and 2003 (dry summer) (source: USGS, ONP, MFM).

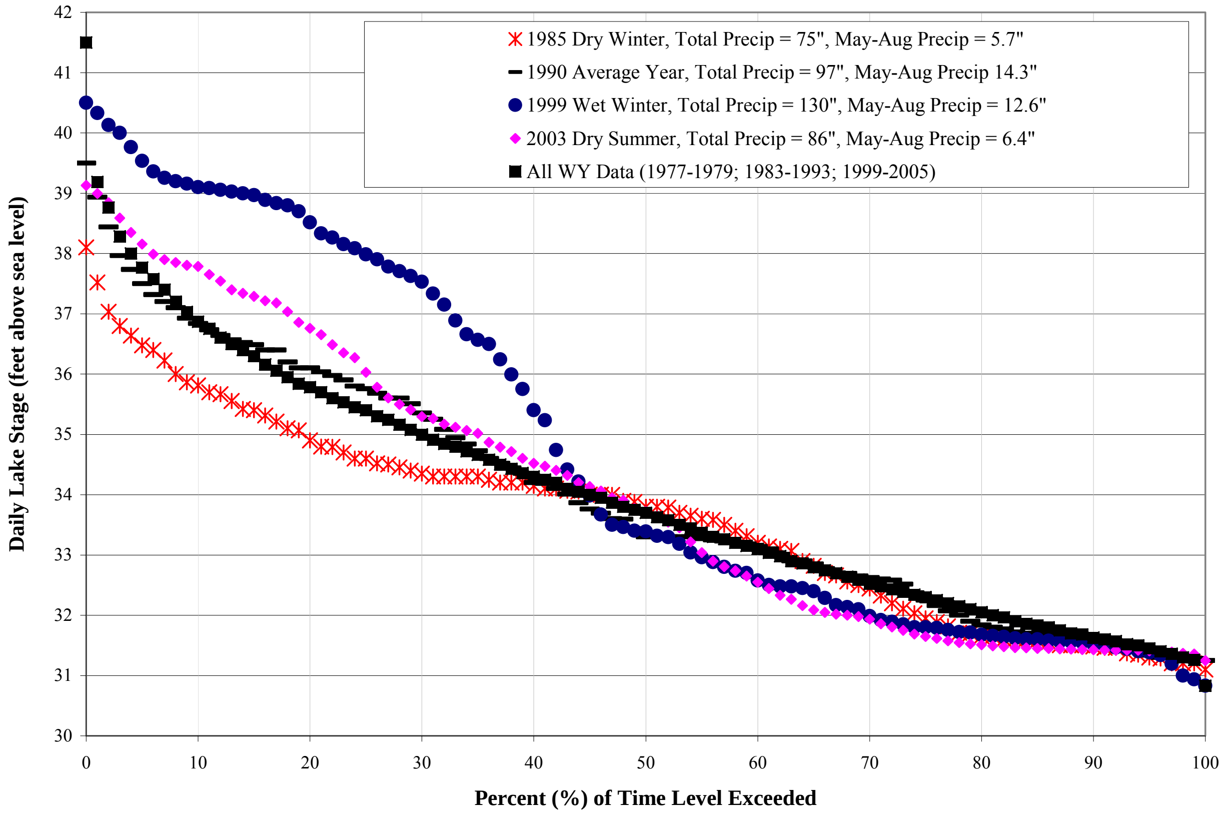

Figure 4.16. Lake Ozette level duration curves for 1985 (dry winter), 1990 (average winter), 1999 (wet winter), 2003 (dry summer), and all water years (1983-1993; 1999-2005) (source: USGS, ONP, and MFM).

Stage (flood) frequencies of both annual maximum and minimum lake stages from values depicted in Figure 4.17 and Figure 4.19 were calculated using a Log-Pearson Type III distribution and other standard techniques outlined by the U.S. Water Resources Council (1981). Estimates based on these data are outlined in Table 4.3. However, it is very important to note that these data represent stage frequency conditions under varied lake outlet (Ozette River) hydraulic conditions throughout the period of record (1976-2005). Historically, LWD was removed extensively from the Ozette River by early settlers and by the WDF (Kramer 1953), and to a lesser extent by local citizens post 1953. Wood removal from the Ozette River has likely affected the lake level regime (stage magnitude, frequency, duration and timing) of Lake Ozette (PWA 2002; Herrera 2005). Thus, these frequency estimates can be used only to understand conditions within the period of record.

Stage or flood frequency predictions *outside this period of record*, into the past or future, should be conducted with caution, especially as wood loads and channel boundary conditions in Ozette River recover toward pre-disturbance conditions. In addition, sediment deposition at the mouth of Coal Creek within Ozette River, between 1979 and

2003, has likely altered stage magnitude, frequency, duration and timing conditions of Lake Ozette stage *within the period of record* 1976 to 2003. However, the exact effect of these sedimentation changes on the lake level regime is unanalyzed, and is likely much less than the effects of wood removal historically.

Table 4.3. Lake Ozette stage frequencies for the period of 1976-2005, using weighted skew coefficients (source: Shellberg 2003).

Return Interval (Years)	Frequency	Annual Maximum Stage (Feet)	Annual Minimum Stage (Feet)
1.01	0.99	35.21	32.1
2	0.5	38.84	31.43
5	0.2	40.1	31.19
10	0.1	40.74	31.07
20	0.05	41.27	30.97
25	0.04	41.42	30.94
50	0.02	41.85	30.86
100	0.01	42.24	30.78
	Station Skew	-0.40	-0.06
	General Skew	0.2	0.20
	Weighted Skew	-0.17	0.05

Maximum annual lake stage (Figure 4.17) is strongly correlated with total wet season precipitation during the period October through April (Figure 4.18). This trend is also evident in the level duration curves in Figure 4.16, which shows that the duration of time water exceeds a given level is higher than average during a very high (wet) precipitation year (1999). However, during this same wet year (1999), high-exceedence low lake levels were below average, indicating a summer precipitation control on low lake levels and a limit on winter storage carryover into summer.

Minimum annual lake stage (Figure 4.19) is very weakly correlated ($r^2 = 0.018$) with total precipitation during the preceding water year and winter wet season, largely due to the limit of water storage following the winter mass of precipitation and discharge input to the lake. In contrast, late summer Lake Ozette stages are more strongly correlated to total precipitation ($r^2 = 0.635$) during the summer months (July to September) (Figure 4.20). This indicates that summer rain, along with the associated mild weather and reduced evaporation and transpiration, control the recession of the lake stage and ultimately the low lake and river discharge levels. Furthermore, the transient fog belt along the coast during the summer also likely has a strong but unquantified effect on evaporation losses and thus ultimate summer lake level (see Figure 4.16 and Section 1.3.2). While long-term lake storage and carryover of water from the winter wet season into the summer dry season is weak, the relatively large Lake Ozette basin (7,550 acres) still has an enormous impact on water storage and release up to the seasonal (3 month) time step, creating a unique hydrologic signature for both Lake Ozette water levels and Ozette River discharge.

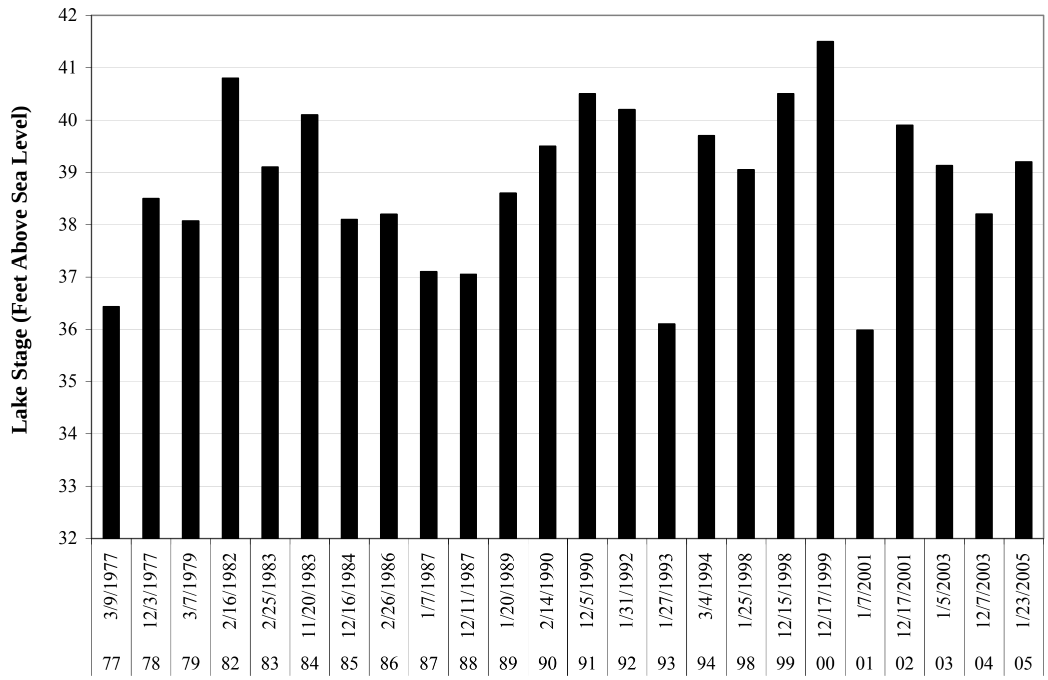

Figure 4.17. Lake Ozette annual maximum lake level for the period of record (source: USGS, ONP, and MFM lake level data).

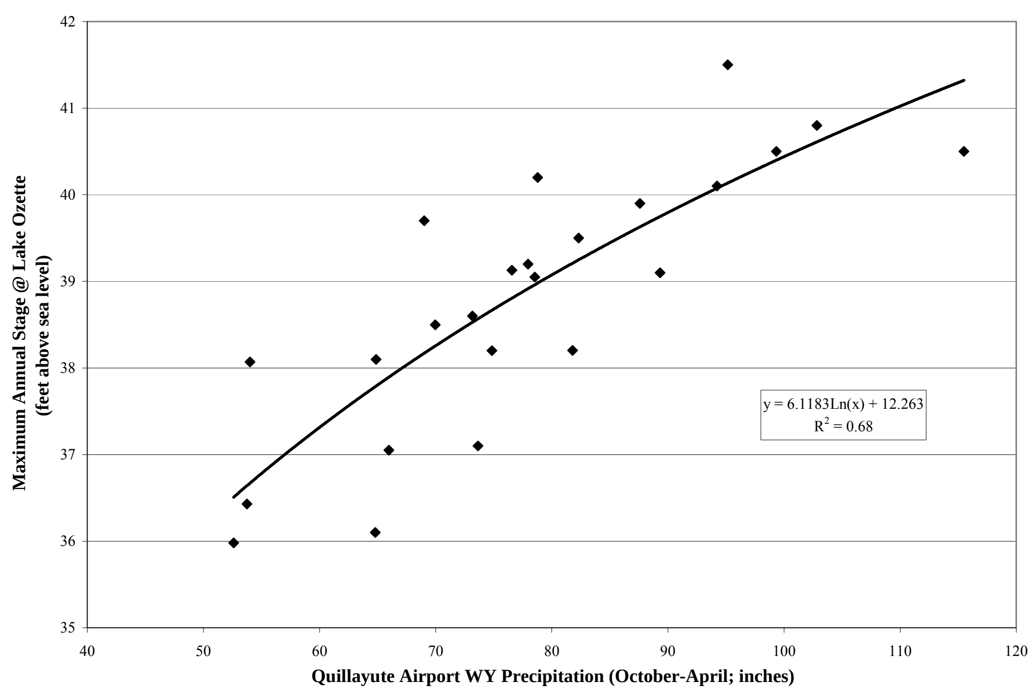

Figure 4.18. Regression of maximum annual stage and winter precipitation (October through April) (source: USGS, ONP, and MFM lake level data).

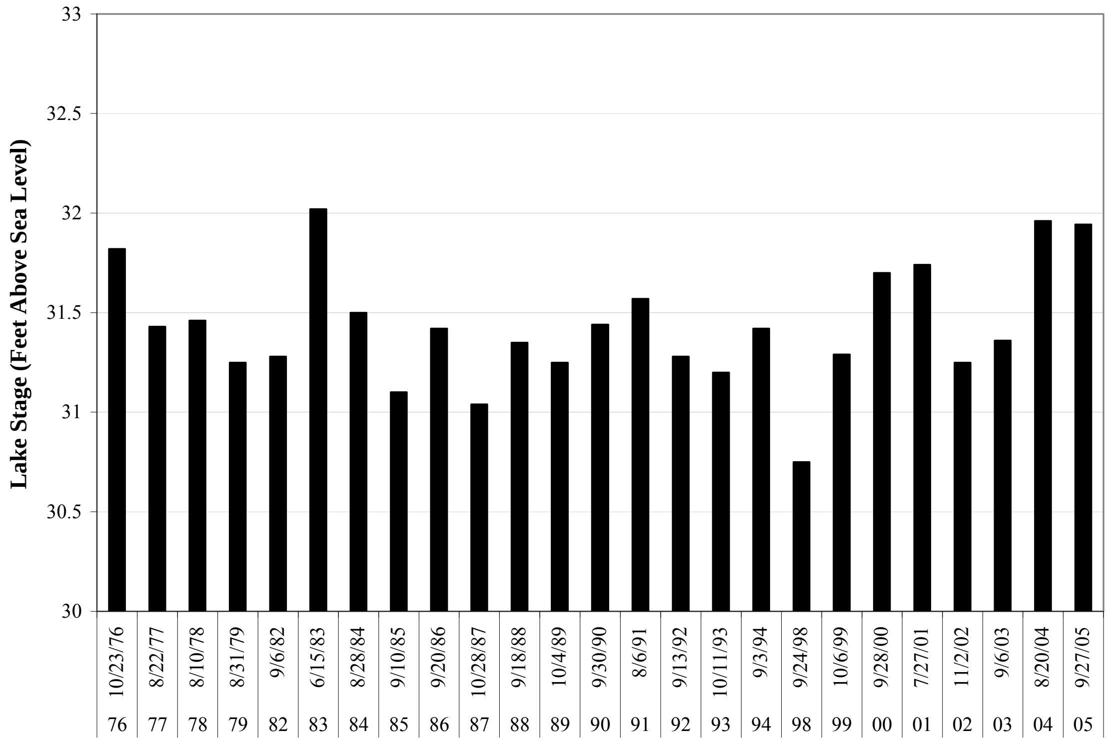

Figure 4.19. Lake Ozette annual minimum lake level for the period of record (source: USGS, ONP, and MFM lake level data).

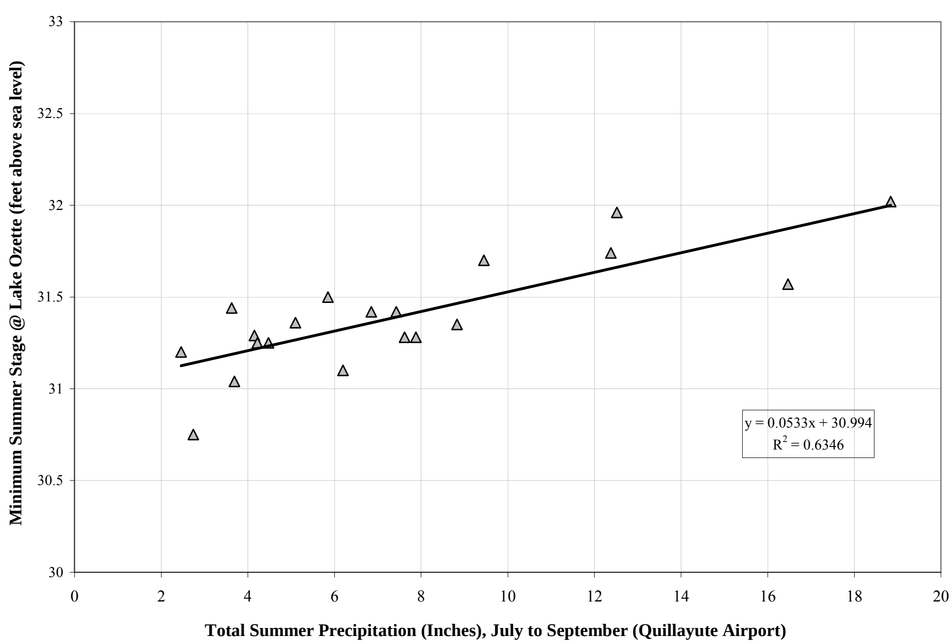

Figure 4.20. Regression of minimum annual stage and summer precipitation (July through September) (source: USGS, ONP, and MFM lake level data).

To display the storage effect of Lake Ozette, the average timing (mean date) of peak discharge and lake stage events was calculated and plotted in polar coordinates (Figure 4.21), following methods outlined in Castellerin et al. (2001) and Shellberg (2002). Stream gaging data from watersheds around the Olympic Peninsula were selected to compare to Lake Ozette. For all watersheds except Lake Ozette, the peaks over threshold (POT) data were obtained from the USGS, which contains all major flood peaks above the "base discharge" calculated by the USGS (Novak 1985). To insure independence, peaks within ten days of each other were filtered out of the data set, leaving only the largest of numerous close peaks. For Lake Ozette, the dates for the annual maximum lake stage were used to calculate the average timing of peak lake levels, since a base discharge (or stage) was not available. In addition, this allows for the analysis of response and timing delay of the highest annual Lake Ozette peak stages from multiple discharge input events.

For Figure 4.21, the distance around the circumference of the polar plot, θ_t, is the average timing or date of n distinct peak events. The distance from the center of the polar circle, r_t, is the vector magnitude associated with that average. The magnitude of r_t is a measure of the regularity or variability of the distinct events. Values range from zero to one, with high values indicating a strong seasonality (low variability around the mean date) and low values indicating weak seasonality (high variability around the mean date)

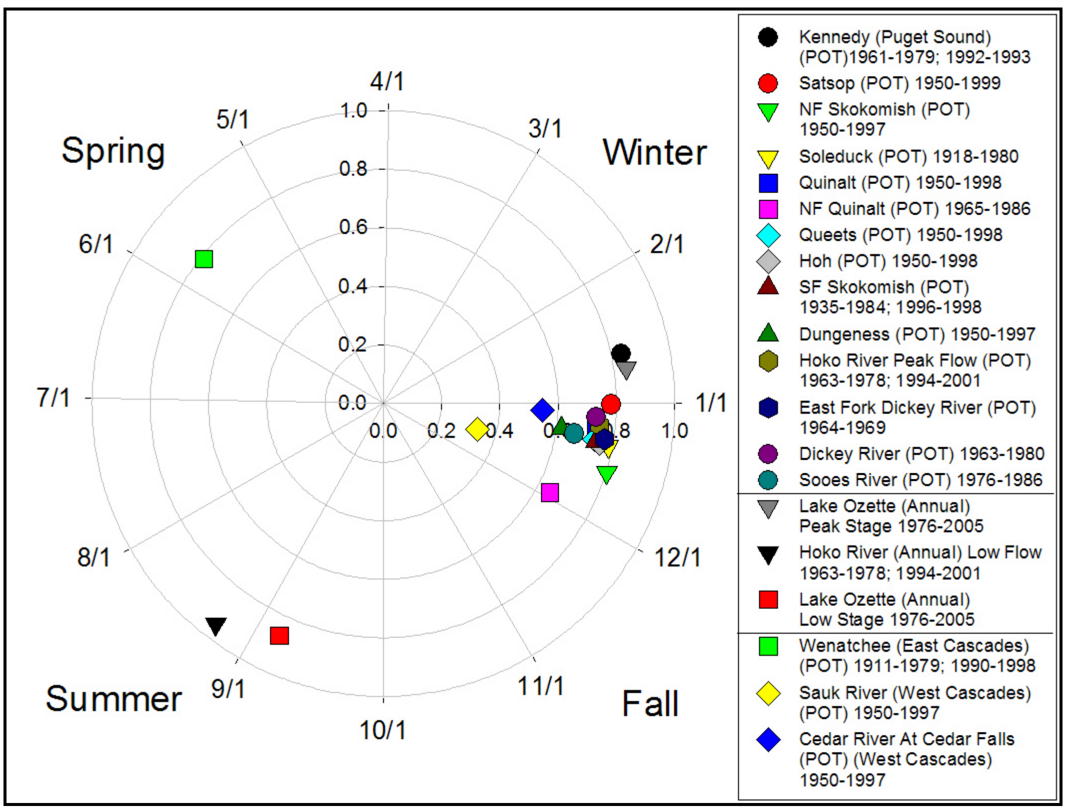

Figure 4.21. Average timing of distinct flood or low flow events for Washington State streams (sources: USGS, ONP, and MFM).

The average peak stage date for Lake Ozette is January 13 with r_t= 0.84, indicating a strong seasonality to winter peak events. The closest long-term USGS gage to Ozette is located on the Hoko River, which has an average peak discharge date of December 21 with r_t = 0.74, also a strong seasonal signal. The Hoko River is a decent surrogate for inflow conditions to Lake Ozette, since the Hoko River shares similar headwaters with the largest Ozette tributary, Big River. On average, there is a 22-day delay between average peak events in the Hoko vs. Lake Ozette. However, this is not to say that there is an average 22-day delay between a given peak flood and a given peak response in Lake Ozette, but rather that it takes roughly 22 days longer for Ozette to ramp up to its full annual peak level compared to when typical peak river levels occur in the nearby Hoko River. Lake Ozette peak levels are a response of 1) peak inflow water volume, 2) recession and base flow contributions following (or between) a given event, 3) multiple input events of various size that can interact because of antecedent conditions, and 4) lake outlet conditions that change infrequently. Thus, peak levels in the lake are a response of multiple flow events of various size and spacing, which build up to the peak lake level, on average, 22 days after the average peak inflow timing.

A stage-area-volume relationship for Lake Ozette was developed to understand how the lake surface area and volume of storage vary with fluctuations in lake levels (Figure 4.22). This relationship provides the linkage between modeled water surface elevations in Ozette River, particularly at the upstream boundary (or lake spillway) with lake elevation. Figure 4.23 illustrates the modeled relationship between lake stage and surface area.

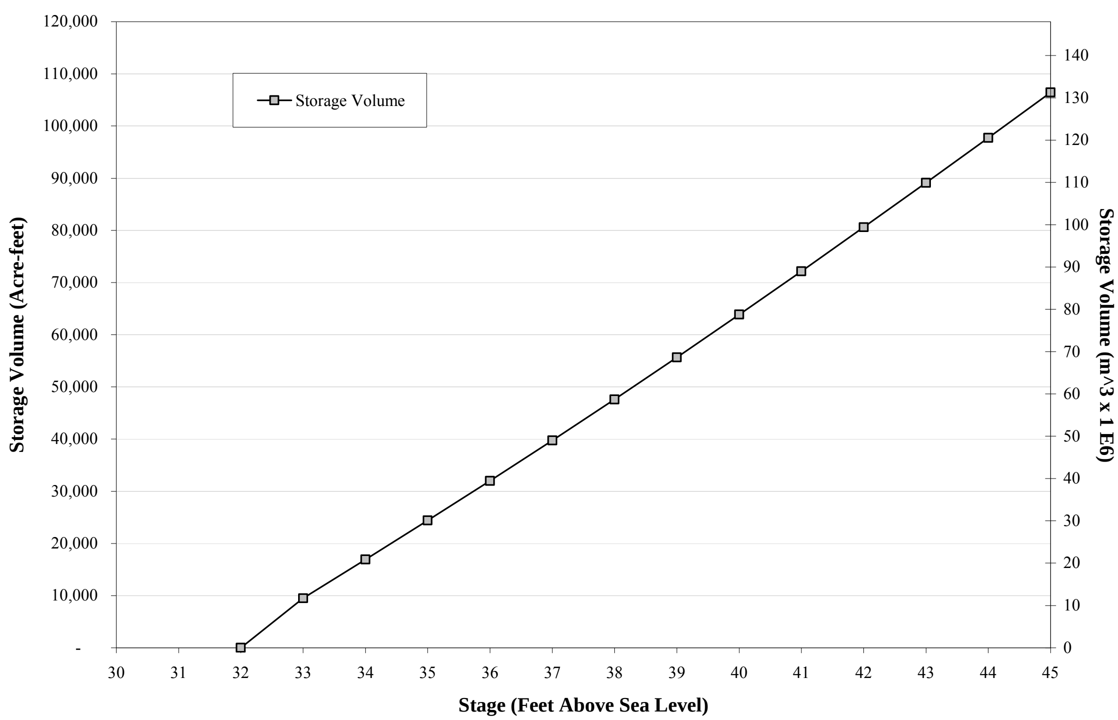

Figure 4.22. Stage-area-volume relationship for Lake Ozette based upon LiDAR data and modeled shoreline (modified from Herrera 2005).

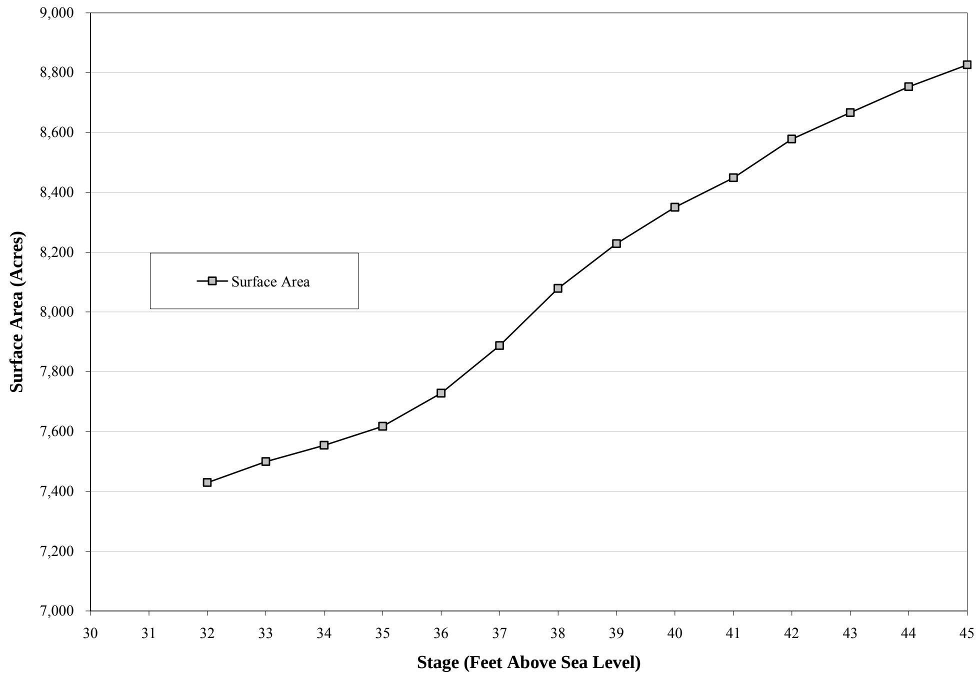

Figure 4.23. Lake Ozette surface area versus stage relationship (modified from Herrera 2005).

Finally, the knowledge of the dynamics of the water surface elevation of Lake Ozette cannot be complete without a brief discussion of the wind seiches that are known to occur at Lake Ozette. A wind seiche is a wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours to a few days (maximum) as a result of seismic or atmospheric disturbances. The initial displacement of water from a level surface can arise from a variety of causes, and the restoring force is gravity, which always tends to maintain a level surface. At Lake Ozette, it is the strong southwest wind blowing over the enclosed basin that produces a displacement of the surface elevation. Surface waters are pushed to the downwind lakeshore, typically the north and northeast shores. When the winds diminish, the accumulated water along the downwind shoreline flows back across the lake to the south and begins oscillating. This causes rising and falling water levels on both sides of the basin. With each circuit across the lake, the seiche diminishes in height, eventually damping out into background lake motions. Like the striking of a bell, it takes only one disturbance event to begin the wave action of a seiche. Once formed, the oscillations are characteristic only of the geometry of the basin itself and may persist for many cycles before decaying under the influence of friction.

In the fall of 2003, MFM installed a lake stage (level) gage at the south face of Tivoli Island near the south end of the lake (Figure 4.12). Since historical lake levels were always taken at the north end of the lake within the converging Ozette River head, a true lake recorder was installed at the south end to both validate existing data at the north end of the lake and uncover additional lake level dynamics that may influence such factors as shoreline erosion and sockeye beach spawning habitat. Figure 4.24 displays the hydrographs for both the North Lake Ozette stage recorder and South Lake Ozette stage recorder at Tivoli Island. At the daily time step, these gages are virtually identical. However, at the hourly or instantaneous time step, significant deviation is observed between the gages, as indicated by the stage "noise" associated with the hydrograph. This noise is a reflection of the wind seiche. By subtracting stage data at the north end of the lake from data at the south end of the lake (Tivoli minus Ozette River), at the 15-minute time step, the instantaneous wind seiche patterns become apparent (Figure 4.25). Within Figure 4.25, negative values of "Tivoli minus Ozette River Stage" indicate that water is displaced toward the north end of the lake as compared to the south. The opposite is true for positive values, when the seiche wave propagates back toward the south end of the lake. These differences are denoted by sharp spikes and usually last less than several hours. Absolute differences up to 0.5 feet are observed as seiche heights, but common values typically range between 0.1 and 0.2 feet. Wind seiche magnitudes are stronger in the negative direction to the north, as the initial water surface elevation disturbance is typically from a strong southwest wind pushing water northward. This north-south wind seiche relationship is slightly affected by changing hydraulic conditions at the head of Ozette River, since the stage gage there is located in the transition zone between the lake and river. During periods of high river discharge, the relative average stage at the Ozette River gage drops up to 0.1 feet below the average stage at Tivoli, as displayed by the changing zero equilibrium line between the north and south gages (Figure 4.25). This is an artifact of increases in water surface slope through the gage reach as discharge increases, which decreases the absolute stage as compared to Tivoli Island.

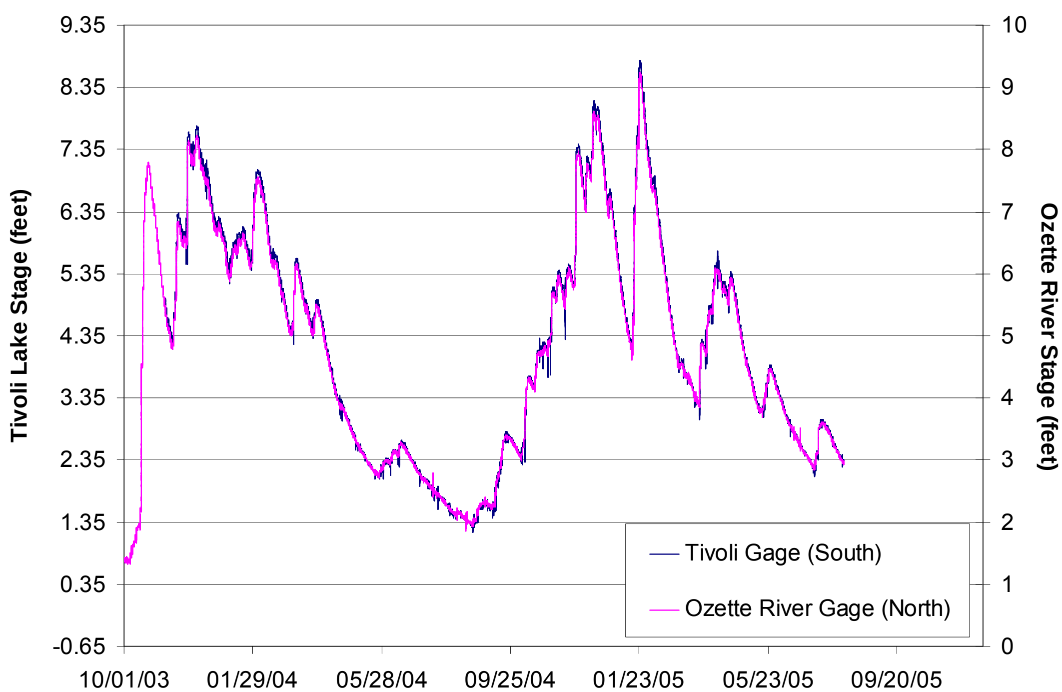

Figure 4.24. Lake Ozette stage at North Ozette (River) and South Ozette (Tivoli Island) (source: MFM unpublished lake level data).

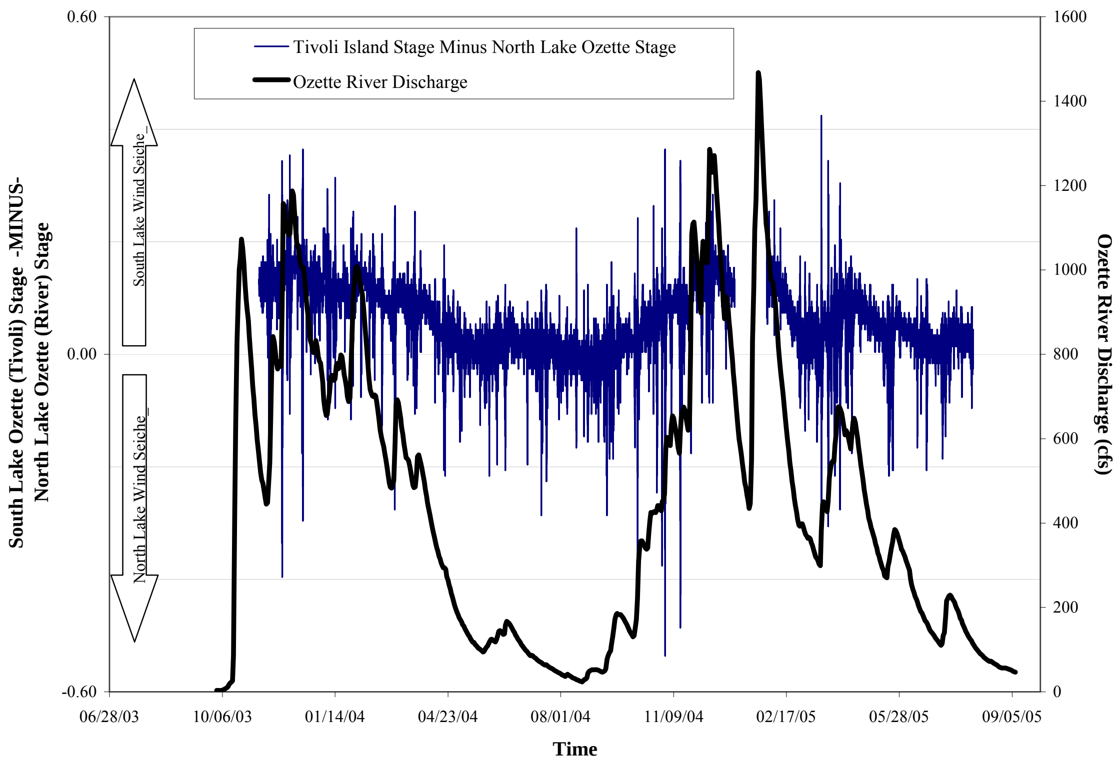

Figure 4.25. Instantaneous (15-minute) wind seiche differences contrasted with Ozette River discharge (source: MFM lake and river stage data).

4.3 OZETTE RIVER

The Ozette River is unique compared to other Olympic Peninsula rivers. The river is very low gradient (0.1%), dropping approximately 32 feet (10 m) in elevation over a distance of 5.3 miles (8.5 km) from the lake to the ocean. Minimum stream bed elevations and water surface elevations for various lake stages are depicted in Figure 4.26. Lake Ozette forms an efficient sediment trap, trapping all but minor amounts of suspended sediment entering the lake from tributaries. The topographic low in the channel of the extreme upper Ozette River, between the lake's outlet and Coal Creek, indicates that coarse sediment from the lake is not being transported downstream into the river (Herrera 2006). Therefore, the only sources of coarse sediment to the Ozette River are a handful of small tributaries, bank erosion, and Coal Creek (the river's largest tributary). The outlet is quite interesting; the river maintains an average depth of 3 to 4 meters (10-13.3 ft) during low flow for a distance of almost 200 meters (650 ft). The overall very low gradient and low energy of the lake outlet influence channel processes and fish habitat conditions to a large extent. Figure 4.27 depicts a typical channel cross-section from the upper Ozette River that is typical of the lake-to-river transition zone at the lake outlet, but not of the fluvial portions of Ozette River.

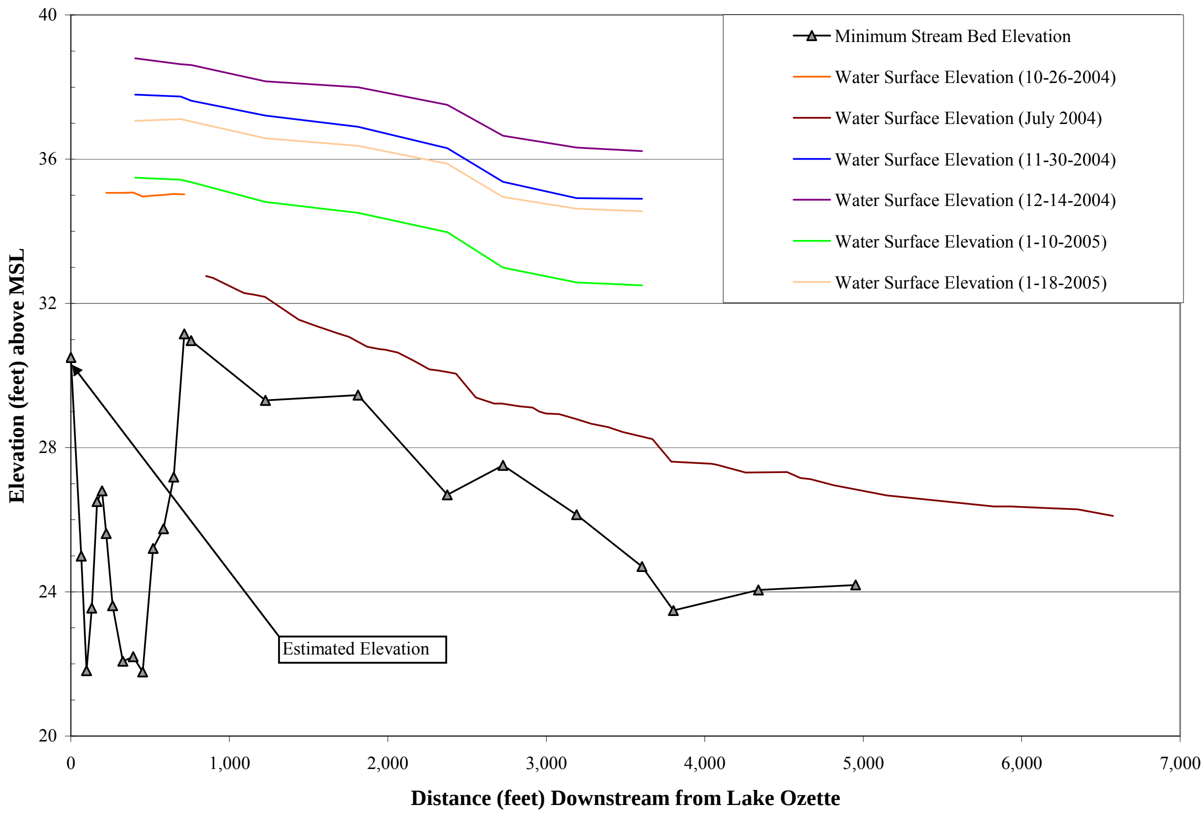

Figure 4.26. Longitudinal profile of Ozette River depicting both minimum stream bed elevation and water surface elevations at various lake stages (source: MFM, unpublished survey data; Herrera 2005).

The bankfull width of the Ozette River averages approximately 30 meters (98 ft) and depth varies by location and season. Shallow faster flowing reaches and slow, deep reaches intermingle throughout the river. Shallow reaches are typically <1 to a few feet deep during July-August flows. At many shallow riffles, several species of aquatic plants and two species of freshwater mussels, western river pearl mussel (*Margaritifera falcata*) and western floater mussel (*Anodonta kennerlyi*) are common. Upstream of logjams and at meander bends, the river becomes deep, often 2 to 3 meters (6.5-10 ft) during low summer flows (July through September). In these areas, submerged wood, boulders, and undercut banks provide important cover and holding areas for salmonids. Sculpin and crayfish reach large sizes and are common throughout much of the river. River otter (*Lutra canadensis*) sign is abundant along most of the river as well.

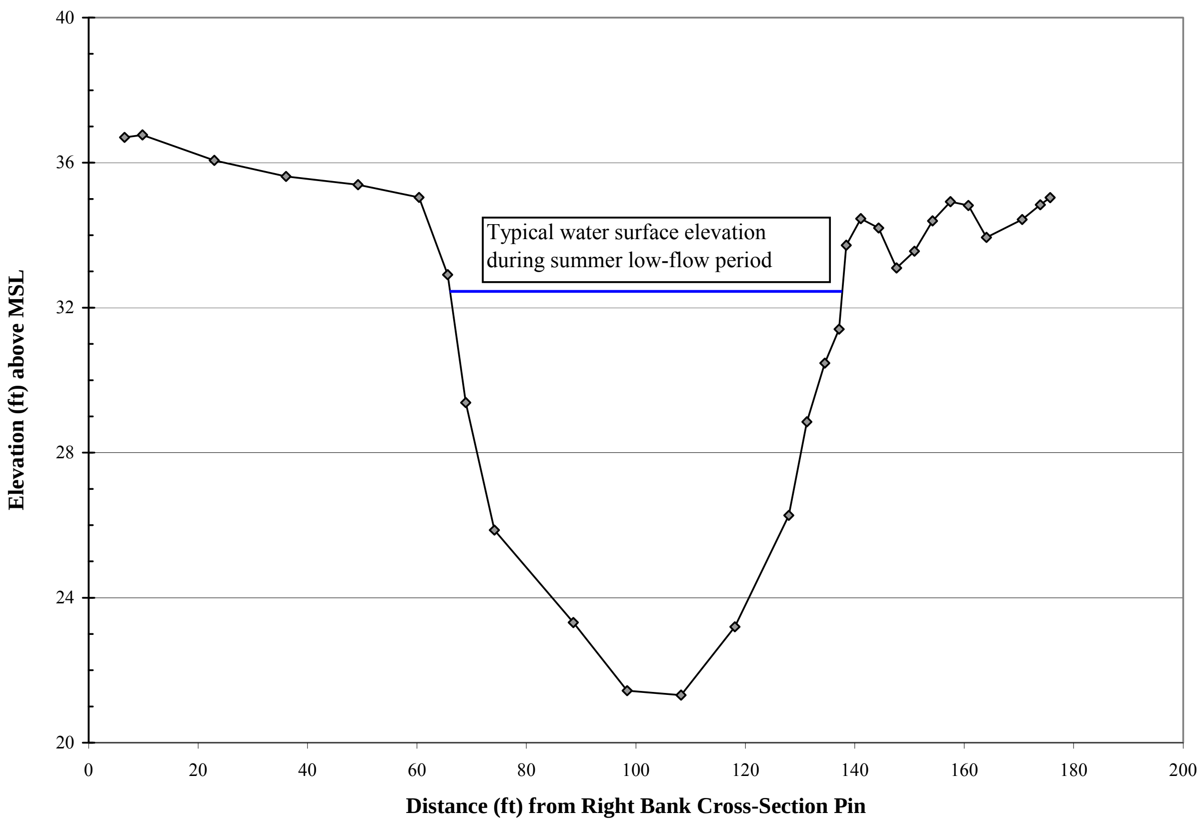

Figure 4.27. Ozette River channel cross-section mid-way between the ONP footbridge and the lake's outlet (source: MFM unpublished stream survey data). Note this cross-section is typical of the lake-to-river transition zone at the lake outlet, but not of the fluvial portions of the Ozette River.

4.3.1 Ozette River Floodplain Conditions

No formal analysis of floodplain conditions for the Ozette River has been conducted. There has been little if any floodplain disturbance in the past 50 years, although there is a record of disturbance prior to 1953. No roads parallel or cross the river. The river's entire length is now protected by either the ONP or the Makah Tribe's wilderness designation. The most significant floodplain impacts that have been identified for the Ozette River are associated with historical wood removal (see Sections 1.5; 1.5.3; 1.5.5).

The floodplain appears high and relatively narrow with steep banks for much of the length of the Ozette River. Kramer (1953) describes the area along both sides of the river (which may or may not be the floodplain) as "*marshy, covered with a thick growth of salal bushes.*" Currently, along much of its length the floodplain-channel margin is almost entirely vegetated with reed canary grass (*Phalaris arundinaceae*), believed to be introduced to the Pacific Northwest in the 1800s. Reed canary grass is generally considered to be a non-native invasive plant that colonizes disturbed areas, and it is likely that the grass has spread along the Ozette River since the 1950s.

4.3.2 Ozette River Riparian Conditions

Smith (2000) concluded that riparian conditions along the Ozette River were good. For the most part, riparian trees are at least several hundred years old, and they represent the characteristics of mature temperate rainforest. At the turn of the century, at least two homesteads were established along the Ozette River. In these areas, land was cleared, and the riparian area is characterized by younger trees, brushy areas, and less ground structure. The most degraded riparian conditions along the Ozette River occur near the lake's outlet. National Park Service infrastructure and maintenance of deforested areas along the upper quarter mile of the Ozette River have resulted in degraded riparian conditions along the right bank. Reed canary grass grows on gravel bars and exposed banks along much of the Ozette River below the bankfull width. The effects of this non-native grass on river processes have not been evaluated.

A cedar salvage operation in the lower river in the 1920s likely impacted the riparian zone locally. In 1952, riparian disturbance occurred in conjunction with wood removal from the Ozette River. However, even in 1952, it is likely that attempts were made to minimize damage to standing trees. Kramer (1953) reported that, "*All removal work was done by ground logging, as the National Park Service would allow no rigging of block or spar trees to be used in conjunction with jam removals.*"

4.3.3 Ozette River Pool and LWD Habitat Conditions

Pool and LWD habitat conditions are believed to be impaired from their historical conditions. Stream clearing occurred in the Ozette River, at least on a small scale, as early as the late 1800s. Photos of the upper Ozette River from the late 1800s to early 1900s show no evidence of large wood above the Nylund homestead, and one photo taken in the early 1900s shows cut logs in the river downstream of the ONP footbridge across Ozette River. Extensive LWD removal occurred in the Ozette River during the summer of 1952 (Kramer 1953; see Figure 1.13). Kramer (1953) reports that some of the logs removed from the Ozette River were 6 to 8 feet in diameter. Bortleson and Dion (1979) cite Patrick Bucknell (WDFW, oral communication, February 21, 1977) as stating that logjams were also removed from the Ozette River in 1956 and 1964. ONP and the Makah Tribe discussed removing wood from the river for fish passage as recently as 1982 (Blum 1982; Contor 1982), and conversations between some of the authors of this paper and local residents indicate that wood removal to pass small skiffs and canoes continued until about 1985.

LWD removal in the Ozette River is presumed to have significantly impacted habitat conditions within the river. Currently large stretches of the river are devoid of functional LWD. The low energy of the river suggests that LWD was not removed by floods, but only by deliberate human action. Pool frequency and refuge cover is low or nonexistent in these areas. The availability of pools that provide cover for holding fish is quite limited in some areas. LWD remnants from the removal projects, and the small amount of existing functional LWD, exemplify the habitat-forming qualities of LWD in the Ozette River. The majority of the large (>50 cm diameter) wood in the channel occurs as full-spanning logs with branches extending to or into the bed of the river (see Figure 4.28). These features are very efficient at capturing small pieces of organic debris such as branches, leaves, or other small pieces of wood. This results in excellent cover where effectively sized LWD accumulations remain. The full-spanning logs are also very efficient at creating associated under-scour pools that create pool tailouts that are important spawning habitat for some salmonids (e.g. Chinook). A small number of lateral scour pools are present in the Ozette River along bedrock faces, as well as two pools formed at confluences with minor tributaries that enter the river from the south. Virtually all of the habitat units that contain deep pools have large wood (often full spanning jams) as well. In the future decades to centuries, sizable conifer LWD would be expected to naturally recruit to the river.

While no detailed survey of wood and associated pool characteristics has taken place in the Ozette River, there is an obvious association between wood, pool frequency, and pool habitat complexity. Herrera (2005) conducted an LWD inventory of the upper 1 mile of the Ozette River during July 2004. They found a total of 17 LWD accumulations consisting of 1 or more pieces of LWD. However, within the upper half mile of the river all LWD accumulations (n=10) inventoried consisted of LWD <0.5 meters diameter and all but one piece was alder. All LWD obstructions in the upper 0.5 miles of the river were quite small and obstructed 10% or less of the BFW. In the lower 0.5 miles of the inventoried reach LWD key members in obstructions were much larger (3.7 times greater diameter on average) than those inventoried upstream. More than half of these jams obstructed 15-60% of the channel cross-section in the lower 0.5 miles.

Figure 4.28. Photo illustrating large trees spanning the Ozette River (photo looking upstream; source: MFM photo archive).

4.3.4 Ozette River Streambed-Substrate Conditions

Since the river receives no coarse sediment load from the lake, the low-energy bed is composed of a limited amount of glacially derived granites, and dominated by easily fractured/weakly cemented sedimentary rocks, which remain angular within the stream (this could also be the result of blasting to remove logjams). These sedimentary rocks apparently break down rather rapidly from the mechanical action of the stream and generate some silts and coarse sands as a result of this process. In many locations, freshwater mussels appear to be the dominant particle in riffles, particularly in the upper reaches of the river (Figure 4.29). Large amounts of fine, glacially derived sediments, input by Coal Creek during flood events, can be found initially near the upstream end of the Ozette River and then decreasing gradually downstream.

Herrera (2006) found that bulk sediment sample values were nearly identical in the Ozette River just upstream of Coal Creek (D_{50}=7.8mm) and in Coal Creek just upstream of the confluence with the Ozette River (D_{50}=10.1mm). No fine sediment sampling of spawning gravels has been conducted in the Ozette River. Kramer (1953) noted that "*Numerous gravel areas exist throughout the stream bed, being mainly in the upstream* *areas*." He further noted that "*Much of the stream bottom is covered with mud and silt*." Several contributing authors of this paper snorkeled the entire Ozette River during the summers of 2000, 2002, and/or 2004. The authors observed that river substrate varied by location along the river, but that spawnable gravel deposits appeared to contain moderate to high levels of fine sediment. The outlet of Lake Ozette as it transitions to the Ozette River is controlled by a shallow (~0.5 m)[13] vegetated bar of fine sediment, followed by a 3- to 4-meter (10-13 ft) deep pool with a cobble and boulder bed in the area of the ONP dock and boat launch, and a sand and gravel riffle just upstream of the confluence with Coal Creek (see Figure 4.26).

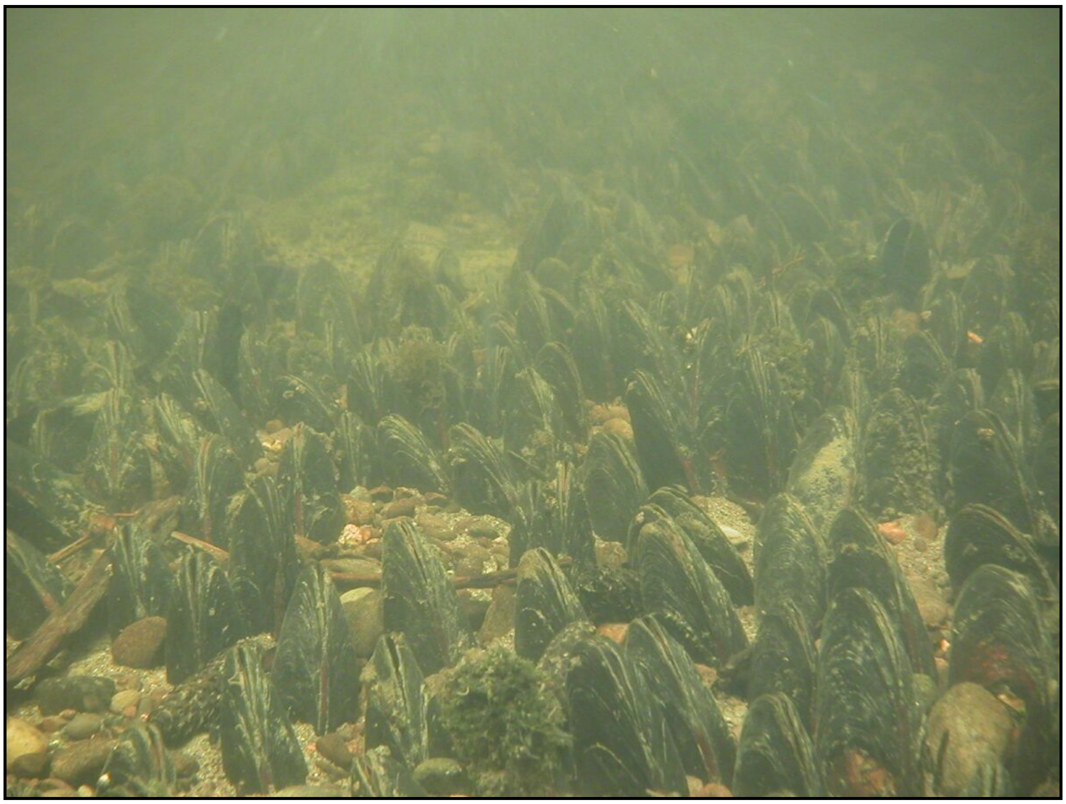

Figure 4.29. Typical Ozette River bottom conditions where freshwater mussel beds are present (source: Andy Ritchie).

Downstream of Coal Creek, the river bed is composed largely of gravel, pebble, sand, and silt. Much of this material is or has been derived from Coal Creek. Shallow, wide riffles and glides exist where wood is absent, and deep, sluggish pools and glides exist where wood is present and at the outside of many of the meander bends. Weak native siltstone outcrops in a few places along the upper river, and boulders, cobbles and gravel are locally present at these locations. Fine sediment (silt and sand) covers much of the bed of the Ozette River, since pools and sluggish glides dominate the river. However, low

[13] Depths in this section are reported relative to summer low flows corresponding to typical July and August discharge (Section 4.3.6), when data on these features have been collected.

flow riffles are composed of gravel and sometimes cobble, with varying levels of finer sand and silt mixed within the substrate interstices.

Fine sediment in potential spawning gravels appears relatively high for as least the upper 1/3 of the Ozette River, and not confined to the area immediately downstream from Coal Creek. Riffles along the lower 2/3 of the Ozette River appear to be coarser than upstream due to inputs from local bedrock outcrops and the relatively steeper gradient of riffles towards the mouth. However, fine sand and silt still dominate much of the bed area in the lower Ozette River.

4.3.5 Ozette River Water Quality

Water quality data for the Ozette River was first collected by Bortleson and Dion (1979) from 1976 through 1977. Unfortunately, the methods used are not clearly described and only graphical data are presented in the report. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 25, 1993 through November 30, 1994. Table 4.4 contains a summary of water quality sampling data for Ozette River reported by Meyer and Brenkman (2001). They concluded that other water quality variables in the Ozette River are not in the range that would prevent salmonids from migrating, spawning, or rearing in the river. Smith (2000) rated the water quality “poor” for Ozette River based on water temperature.

Table 4.4. Summary of water quality data collected in the Ozette River from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	pH	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/l)	Turbidity (NTU)
Minimum	6.7	6.4	31.3	8.1	0.4
Maximum	19.0	7.4	47.4	11.8	14.2
Mean	12.1	6.9	38.1	10.1	3.1
Number Months Sampled	n=21	n=15	n=20	n=17	n=15

In recent years additional water quality data have been collected from the Ozette River. MFM began collecting water quality data in February 2004. Data are typically collected monthly, but sampling frequency increases to approximately twice per month during the adult sockeye migration. Table 4.5 depicts a summary of the results of water quality sampling by MFM in the Ozette River. Water quality conditions measured by MFM are roughly within the range of conditions measured by Meyer and Brenkman (2001). The minor differences between data are likely a function of increased sample frequency during May, June, and July in the MFM dataset.

Table 4.5. Summary of water quality data collected in the Ozette River from January 15, 2004 through October 7, 2005 (source: MFM unpublished data).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	6.7	6.1	29.0	8.8	0
Maximum	20.76	7.6	48.5	16.0	5.7
Mean	13.62	6.8	40.5	11.22	<1
Number Months Sampled	n=29	n=29	n=29	n=29	n=29

Additional stream temperature data have been collected during seven summers from 1993 through 2005. Temperature data were collected at roughly the same location (near the confluence with Coal Creek) during all years with the exception of 1999 when data were collected near the confluence with the Pacific Ocean. Temperature data were collected on a total of 769 days between June 1st and September 30 (1993-2005). Maximum annual temperatures were recorded between July 22 (2002) and August 21 (1999; Table 4.6). Maximum temperature excluding 1999 data occurred between July 22 and August 9 (2004).

Table 4.6. Summary of maximum daily stream temperature observations from the Ozette River during temperature monitoring from 1993 through 2005 (source MFM unpublished data, Meyer and Brenkman 2001).

Year	**Number of Days Sampled (6/1 to 9/30)**	**Date of Peak Temperature**	**Peak Temp (C)**	**Date of Peak 7-Day Moving Average Daily Maximum Temp.**	**Peak 7-Day Mov. Avg. Daily Max. Temp. (C)**
1993	72	8/3/1993	22.2	8/8/1993	21.5
1994	108	8/5/1994	23.7	8/21/1994	23.2
1999	122	8/21/1999	19.8	8/25/99	19
2002	116	7/22 to 7/24/02;	22.4	7/28/02	21.9
2003	120	7/29/2003	23.8	8/14/2003	22.3
2004	114	8/9/2004	23.8	7/24/2004; 7/28/2004	23.0
2005	117	7/31/2005	22.6	8/05/2005	21.7

The 7-day moving average maximum daily temperatures observed from 1993 through 2005 are depicted in Figure 4.30. Figure 4.31 shows the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C. Maximum daily stream temperatures exceeded 16°C on 736 days (95% of the days sampled) between June 1 and September 30 (1993-2005). Maximum daily stream temperature exceeded 18°C on 562 days (73% of the days sampled) and exceeded 20°C on 292 days (38% of the days sampled). When the 1999 data are excluded from the analysis, 16, 18, and >20°C were observed 98%, 81%, and 45% of the time respectively. The peak temperature measured during the 7 years of sampling was 23.8°C (recorded on 7/29/2003 and 8/9/2004). A temperature of 23.7°C degrees was also recorded on August 21, 1994. During the warmest period of summer, July 15 through August 15, data were collected on 218 days. Maximum daily stream temperatures exceeded 16°C on all days. Stream temperatures exceeded 18°C on 203 days (93% of the days sampled) and exceeded 20°C on 153 days (70% of the days sampled). The relatively high stream temperatures documented from 1993-2005 are thought to be primarily a function of natural conditions. Kemmerich (1945) reported that stream temperatures near the lake's outlet were between 19 and 21°C in late June 1926.

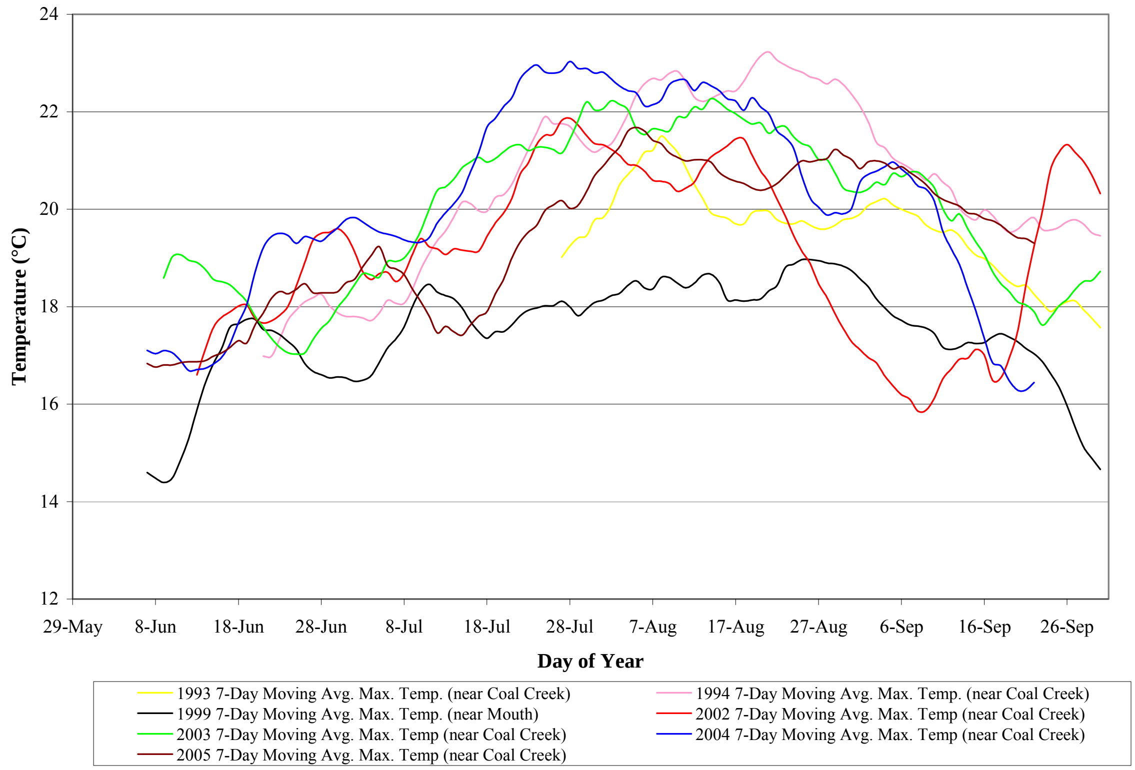

Figure 4.30. Ozette River 7-day moving average maximum stream temperature near Coal Creek from 1993-2005 (source: MFM unpublished stream temperature data; Meyer and Brenkman 2001).

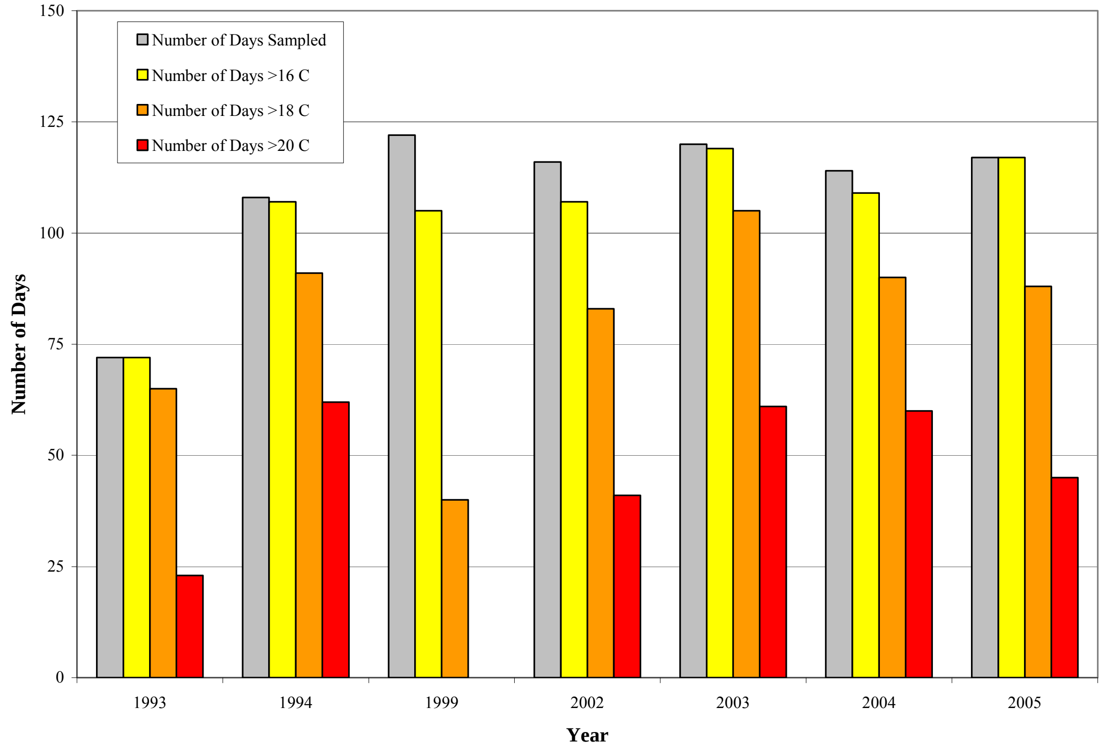

Figure 4.31. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20 °C in the Ozette River from 1993 through 2005 (source: MFM unpublished stream temperature data; Meyer and Brenkman 2001).

High water temperatures observed in the Ozette River appear to be a natural condition caused by solar heating of Lake Ozette surface waters (Meyer and Brenkman 2001). The extent to which watershed alterations have influenced Ozette River surface water temperatures has not been thoroughly studied, but based upon the lake summertime thermocline pattern (uniform temperatures in the upper 15 feet) it is unlikely that alterations affecting the lake outlet or the river depth could influence water temperatures in the vicinity that data were collected (i.e. upper Ozette River). Water temperatures observed near the river's confluence with the Pacific Ocean were generally lower than those observed upstream near the lake. In 1999, water temperatures near the mouth of the Ozette River never exceeded 20°C but did exceed 18°C on 40 separate days during the summer (MFM unpublished stream temperature data). However, 1999 was one of the cooler summers occurring during the past several years. Temperature data for Umbrella Creek collected during nine summers from 1993-2005 indicate that maximum stream temperature in 1999 was 2.6°C lower than the average annual peak temperature recorded during this period. Stream temperature data collected during the summer of 2005 showed little temperature moderation in the first 3.5 miles downstream from the lake during the sockeye migration period (Figure 4.32). This suggests that temperatures observed near the lake outlet are an excellent indicator of downstream temperatures and the overall temperatures experienced by migrating sockeye salmon.

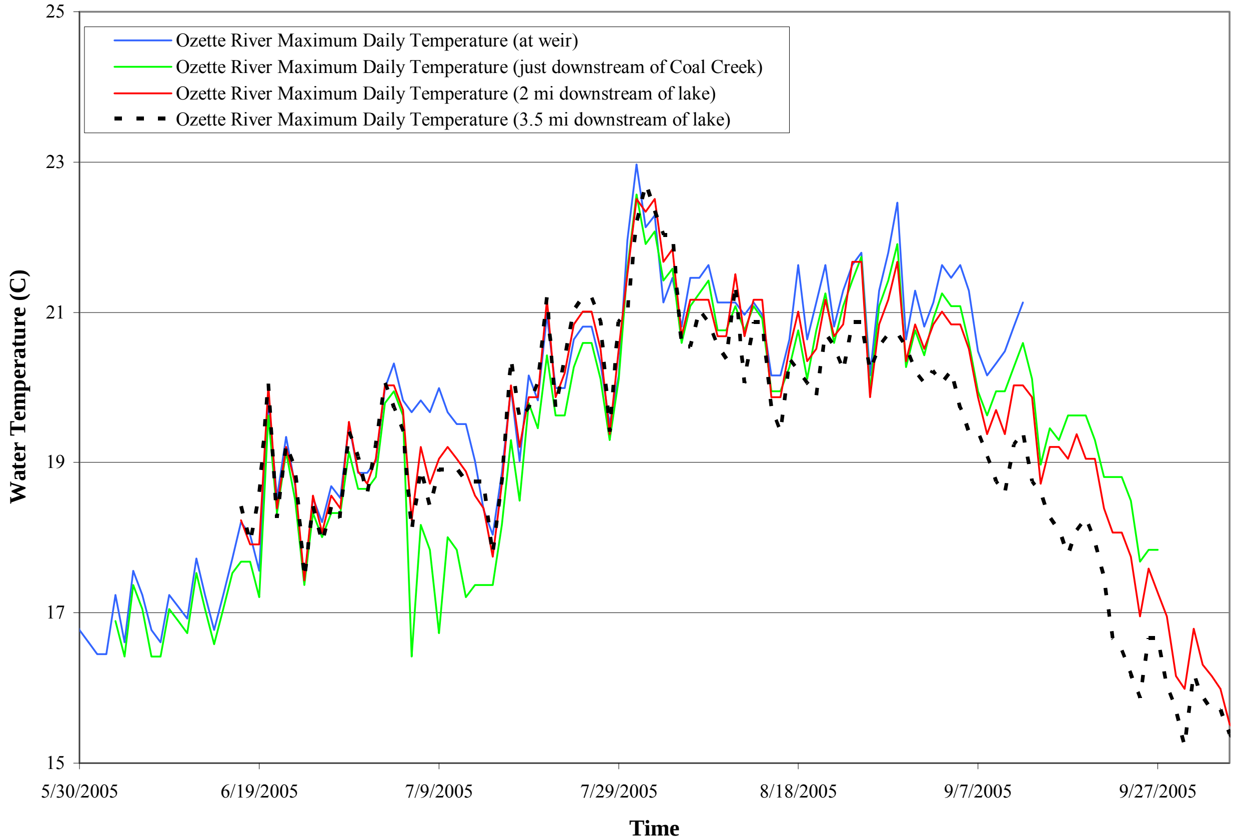

Figure 4.32. Ozette River daily maximum temperature at the Ozette counting weir, just downstream of Coal Creek, 2 miles downstream of lake, and 3.5 miles downstream of lake (source: MFM unpublished data).

In recent years Coal Creek has been observed to contribute sediment plumes to the Ozette River and Lake Ozette. From June 12 through June 14, 2000, approximately 3.7 inches (94 mm) of rainfall occurred while sockeye mark and recapture studies were being conducted in the Ozette River. Coal Creek was carrying excessive quantities of suspended sediment into the Ozette River; the water was extremely turbid, and flow reversal was observed where Coal Creek flowed up the Ozette River into the lake. Sockeye weir operators noted that several sockeye were observed covered in silt and some were observed bleeding from the gills. Several days after the storm, the river cleared and the entire river bottom in the vicinity of the weir and Coal Creek were covered in a mantle of silt and fine sand. A tour of the Coal Creek road network later that same summer revealed that much of the road network was contributing sediment to Coal Creek and its tributaries. Ditch erosion of up to 3 feet (1m) was observed along the mainline and many of the road ditches were connected to live streams. Water quality impacts to the Ozette River from Coal Creek sediment and turbidity have not been quantified, but observations suggest that they may be significant (see Section 4.4.4.5).

4.3.6 Ozette River Hydrology

The USGS made several miscellaneous measurements of instantaneous discharge in the watershed's streams in the 1960s and 1970s (Bortleson and Dion 1979), including the Ozette River and various tributaries to Lake Ozette. This started a series of four efforts to measure stream discharge in the Ozette watershed, with additional stream gaging by the USGS 1976-1979, by the ONP 1993-1994, and by the Makah Indian Tribe 2003-2005. All of the discharge measurements made in the Ozette Watershed between 1962 and 2005 are displayed in Figure 4.33.

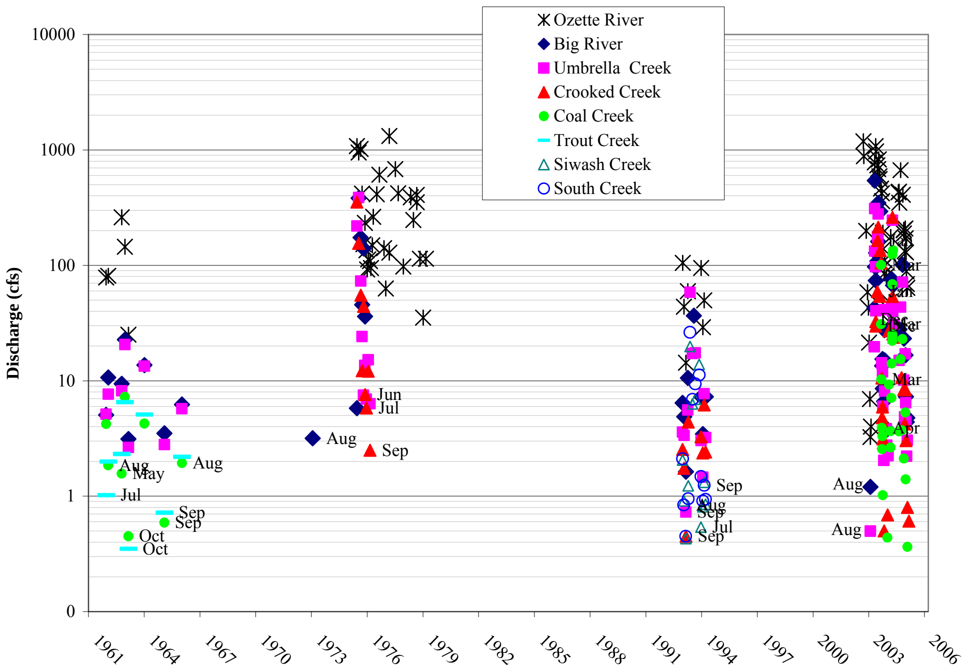

Figure 4.33. Instantaneous stream discharge measurements (source: USGS, Meyer and Brenkman 2001; MFM, unpublished discharge data).

While these data do not define the hydrologic regime of Ozette tributaries and Ozette River, they do help indicate the relative magnitude of discharges during different seasons, the water-producing abilities of each sub-watershed and Ozette River, and potential changes over time. The USGS maintained a continuous streamflow (discharge) gaging station at the outlet of Lake Ozette in the Ozette River from 8/1/1976 to 9/30/1979 (Figure 4.12) covering three complete Water Years (WY 1977, 1978, 1979). This station consisted of a continuous stage (stream level) recorder and periodic discharge measurements to develop a stage-discharge rating curve. This station was discontinued after water year 1979. The USGS has not collected additional hydrological data since this period.

In March 2002, Makah Fisheries Management installed a continuous stage gage at the same location as the historical USGS gage. This gage is located 30 feet above the footbridge and approximately 70 feet below the ONP manual stage plate (Figure 4.12). This gage automatically measures and records lake (or river) stage every 15 minutes.

Since early 2003, Makah Fisheries Management also has been measuring discharge (ft^3/s) at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve (correlation between stage and discharge; Figure 4.34).

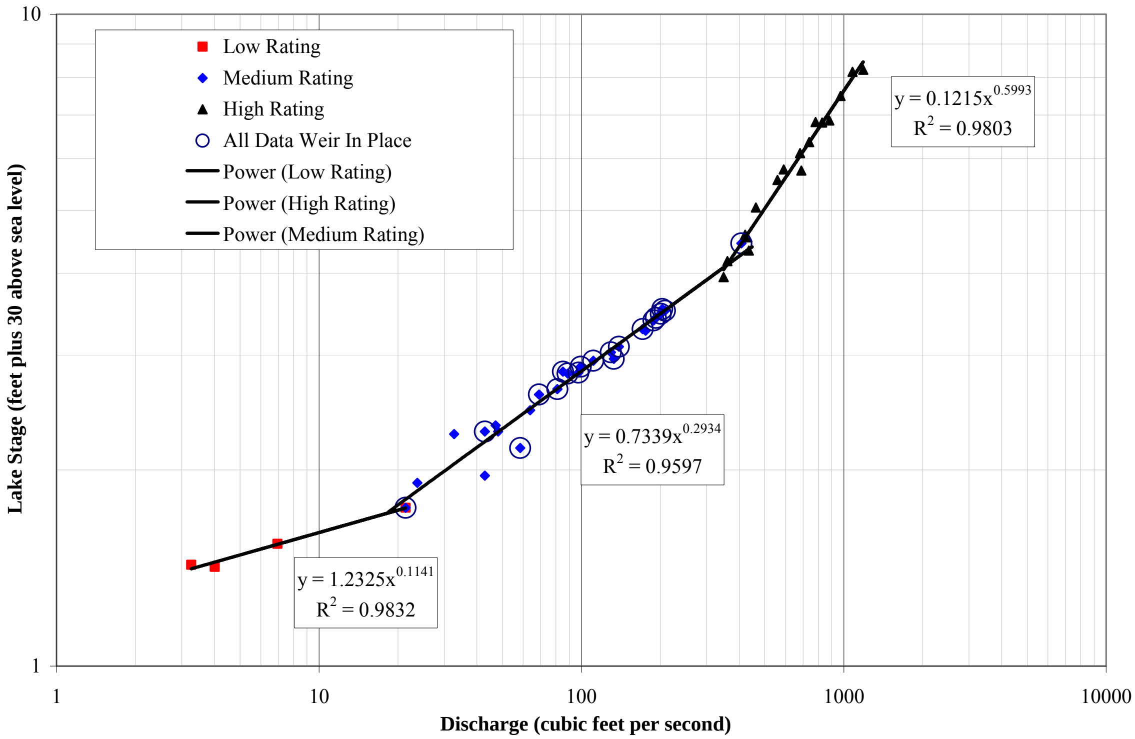

Figure 4.34. Ozette River rating curve developed by MFM (source: MFM unpublished data).

The Makah continuous stage recorder was installed using the same elevation datum used by both the previous USGS gage and ONP stage plate. The gage was installed with its zero elevation equal to a true elevation of 30 feet above mean sea level (MSL). The current correlation between the Makah gage and ONP stage plate is excellent (Figure 4.35). This close relationship is also assumed for the historical USGS gage recorder that was referenced to the same datum as the stage plate also used by the ONP.

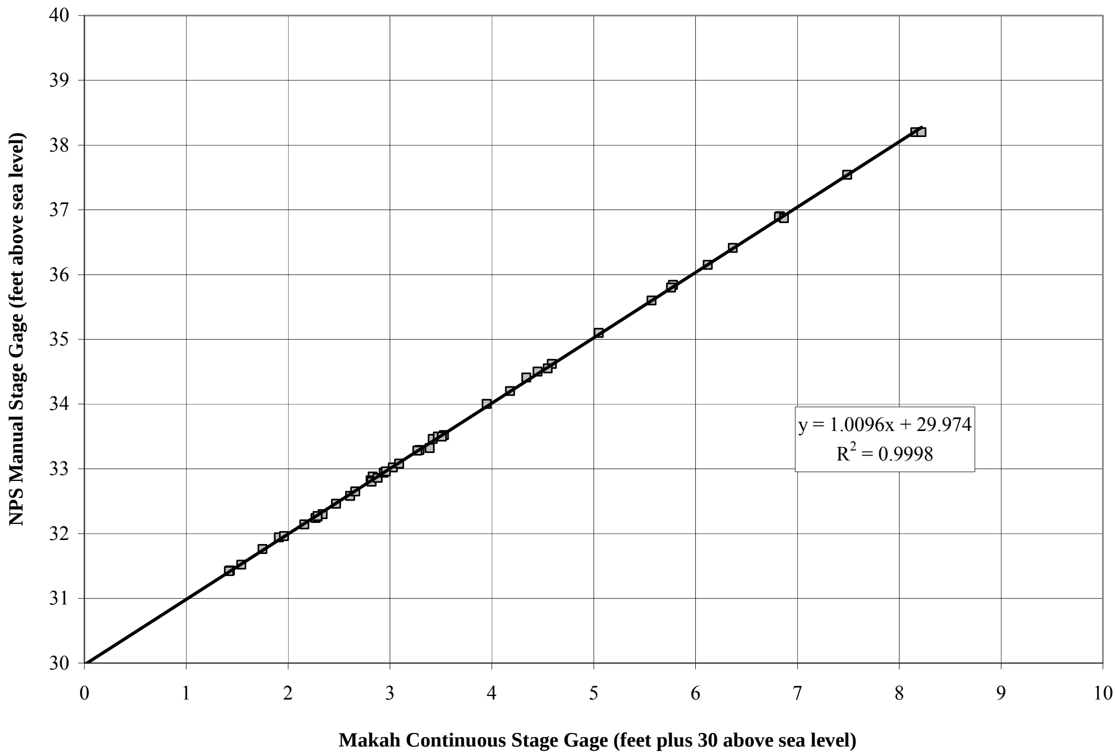

Figure 4.35. Correlation between MFM stage readings and ONP staff gage (source: MFM unpublished data; ONP unpublished data).

4.3.6.1 Lake and River Hydraulic Controls

Since the ONP did not collect discharge data along with its daily stage data, a complete discharge record does not exist to match the almost continuous stage record from 1976 to 2005. Ideally, if the channel configuration of the lake's outlet and Ozette River was constant, either the USGS or MFM stage-discharge rating curves could be used to estimate discharge from the 1981 to 2002 ONP stage data. At first this seems like a plausible assumption, since the locations of these stream gages are at the outlet of a very large lake that effectively traps all bedload and most suspended sediment, which is responsible for most channel morphology changes that might alter a rating curve. Furthermore, no obvious major trends are apparent in the historical ONP stage data that might indicate a changing elevation control on river/lake stage at this location. Indeed, the channel configuration in the immediate vicinity of these gages appears to be generally stable according to both local observations and historical artifacts (30- to 50-year-old bottles) found on the bed while snorkeling.

Shoreline erosion does occur along the lake margins on the north end of the lake. Deposition of longshore transported bar sediment in relatively small quantities has been observed near the outlet of the lake approximately 600 feet upstream of the ONP gage. This fine sediment is periodically colonized by vegetation, aiding further sedimentation, but is episodically flushed out by high lake levels via erosion of the low sill. However, both the ONP gage and MFM gage are located downstream of this minimally dynamic lake zone and appear to be relatively unaffected by any major sedimentation from upstream. The hydraulic control of the lake outlet into the Ozette River is not located at this upstream shoreline location or low sill, above the boat docks, launch ramp, and stream gages. The ultimate hydraulic control of the lake is located at the riffle downstream of the stream gages, just downstream of the bridge and just upstream of Coal Creek. This riffle is the highest bed or substrate elevation point before water spills into Ozette River (Figure 4.36).

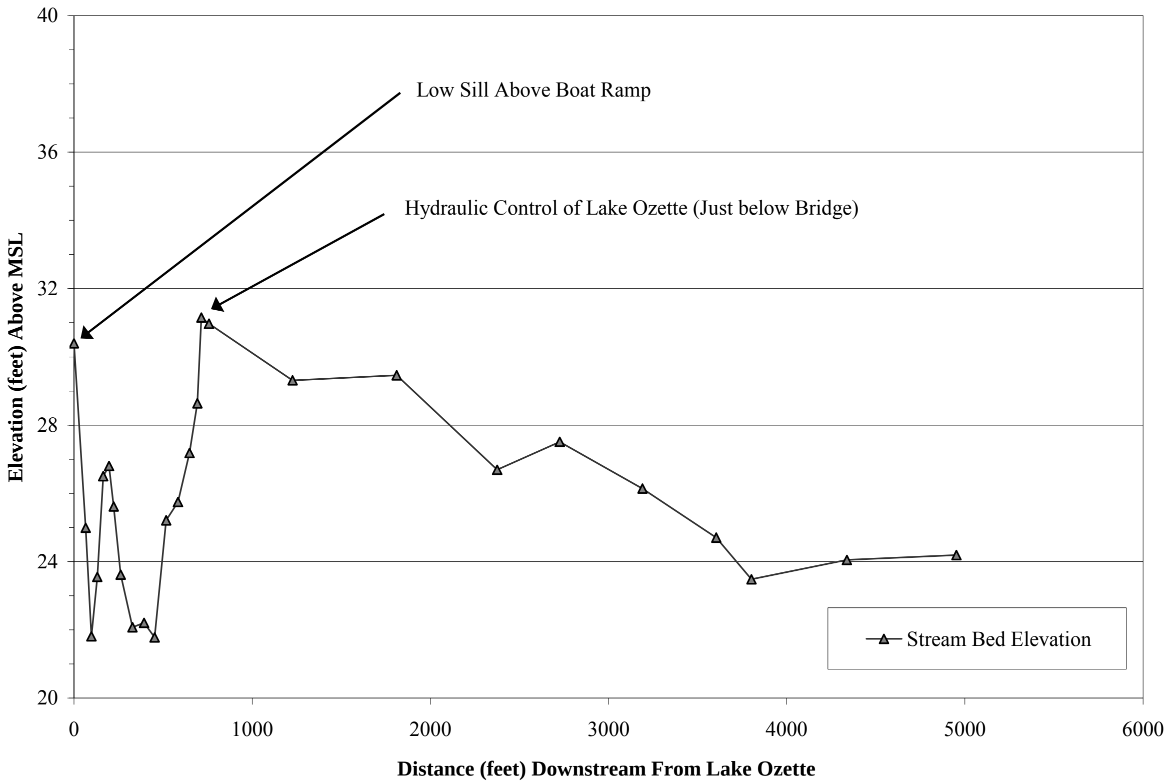

Figure 4.36. Longitudinal bed elevation profile of Ozette River depicting the hydraulic control point (source: MFM unpublished data; Herrera 2005).

This riffle controls lake outlet stage and river discharge at low to moderate flows. At higher flows, stage and discharge are regulated by the overall reach channel configuration, such as reach width, depth, slope, floodplain access, and roughness conditions. Channel roughness in the form of large woody debris (LWD) has been shown to have a significant influence on lake and river stage relative to discharge (PWA 2002; Herrera 2005). LWD in Ozette River has changed dramatically between 1953 and earlier to present (e.g., Kramer 1953). Over the last 30 years, LWD has been very slowly accumulating and recovering from past removal but is still assumed to be only a fraction of its historical abundance. Minor wood accumulations in the immediate vicinity of the stream gage and reach downstream of Coal Creek are fairly minor.

In order to quantify the potential changes in local riffle and channel hydraulic control at the lake outlet, the historical USGS stage-discharge rating curve was compared to the current MFM rating curve (Figure 4.37). In addition, stage and discharge data collected by the National Park Service in 1993 and 1994 are plotted in Figure 4.37. These data indicate that there are significant differences between the USGS and MFM ratings, as well as ONP data. At all stages, but especially at the lowest stages, the current MFM rating has shifted positively upward, approximately 0.4 to 1.0 feet between 1979 and 2003. The ONP data indicate that this positive shift occurred gradually, as the ONP data lie intermediate between the USGS and Makah data. This positive shift indicates that over the last 25 years, either: 1) significant channel aggradation has occurred, and/or 2) channel roughness has increased, thus affecting the hydraulic control(s) that regulate water release out of the lake. In other words, at the same discharge, the lake stage is higher in 2003 than in 1979. And conversely, at the same stage, the lake releases less water (discharge) into the Ozette River.

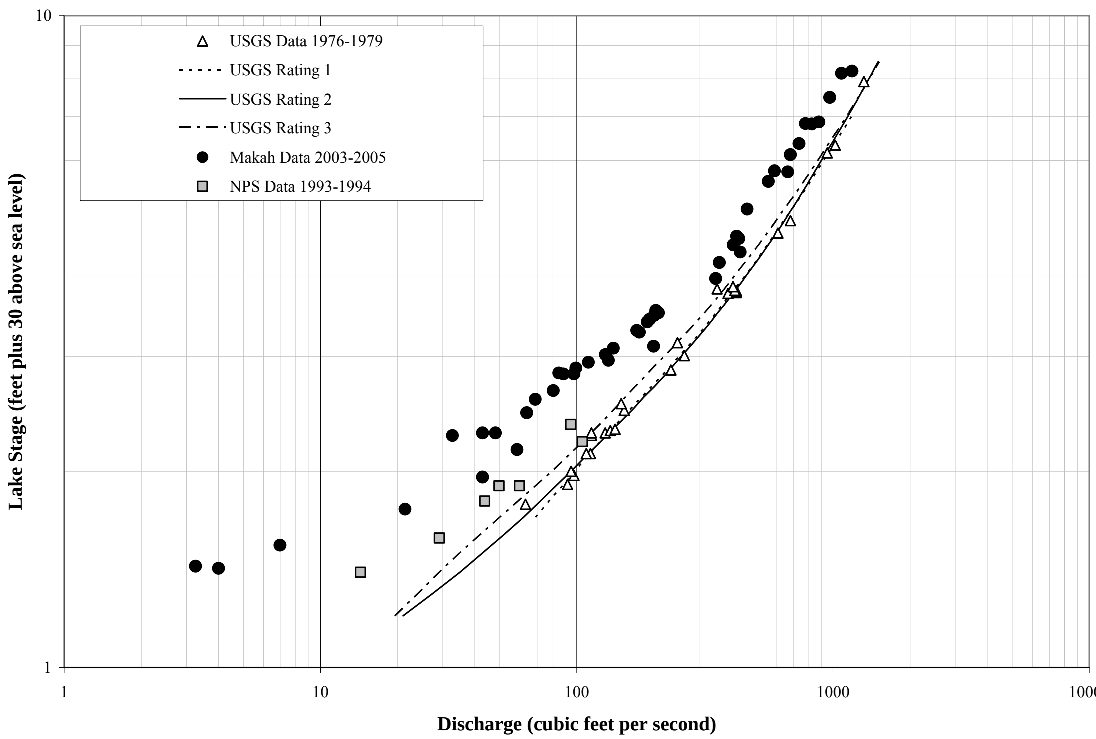

Figure 4.37. Comparison of USGS, ONP, and MFM stage-discharge relationships for the Ozette River.

In order to further quantify and document changes in hydraulic control at the lake outlet, cross-section data were extracted from both the USGS and MFM stream measurement notes. Since both gages used a common datum, the data were directly comparable. In addition, the current footbridge across Ozette River was constructed initially in 1974 and finished in summer of 1976, and has not changed in configuration to date, railings included (Dave Easton, NPS Personal Communication after review of construction drawings and photos). Thus, this bridge was the location of all medium and high discharge measurements by both the USGS and MFM, who both used portable bridge board and cable equipment to measure depth. Cross-section data were only extracted from measurements from the bridge, so that all measurements were along the same transect under the bridge. All USGS bridge measurements were taken from the upstream face of the bridge. Only some of the Makah measurements were taken on the upstream face, while most were taken on the downstream side. Therefore, some of the Makah measurements are located along the exact same transect as the USGS (upstream bridge railing; Figure 4.38), while others are taken eight (8) feet downstream on the downstream face (Figure 4.39). All depth (and thus elevation) measurements were accurate to the nearest 0.1 feet.

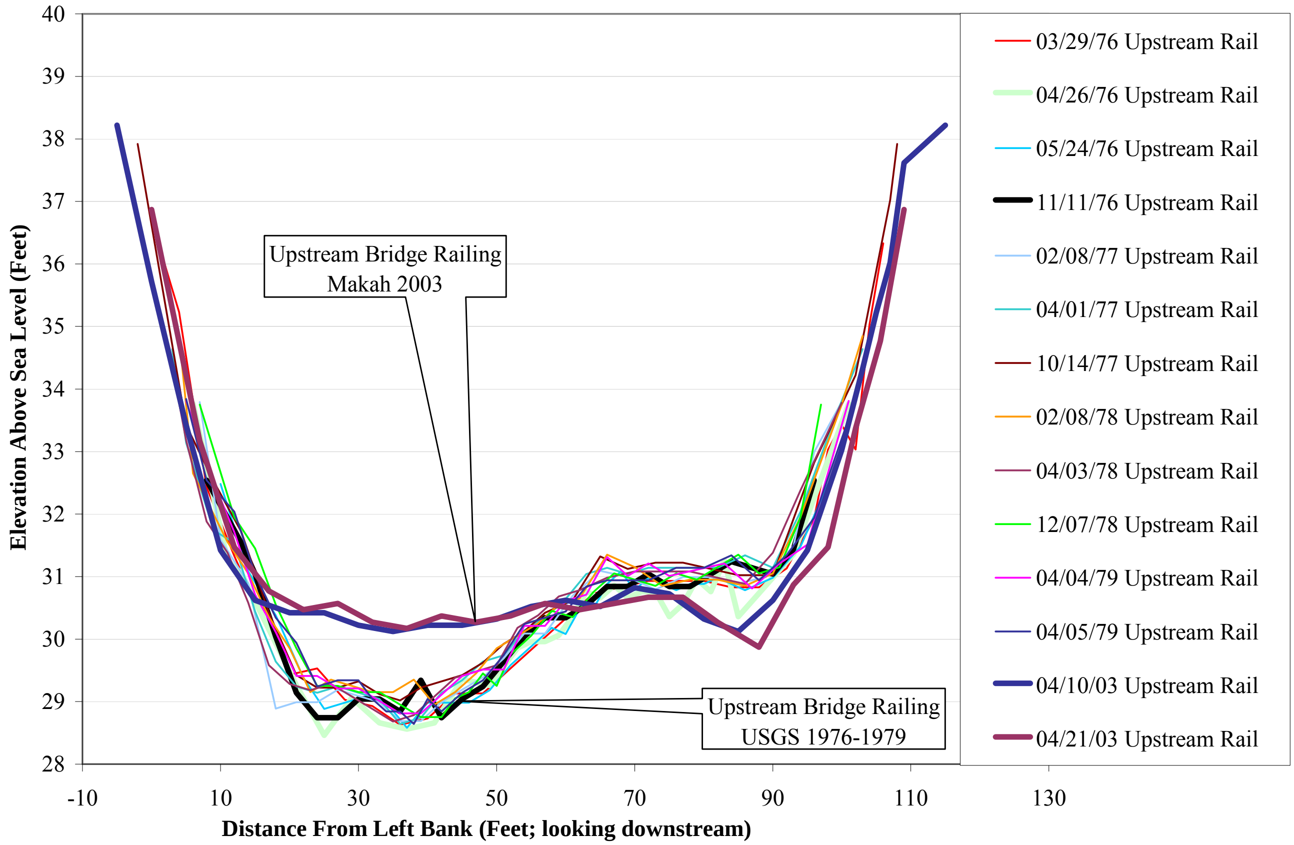

Figure 4.38. Cross-section elevation data collected from the upstream bridge railing on the Ozette River (source: USGS; MFM, unpublished data).

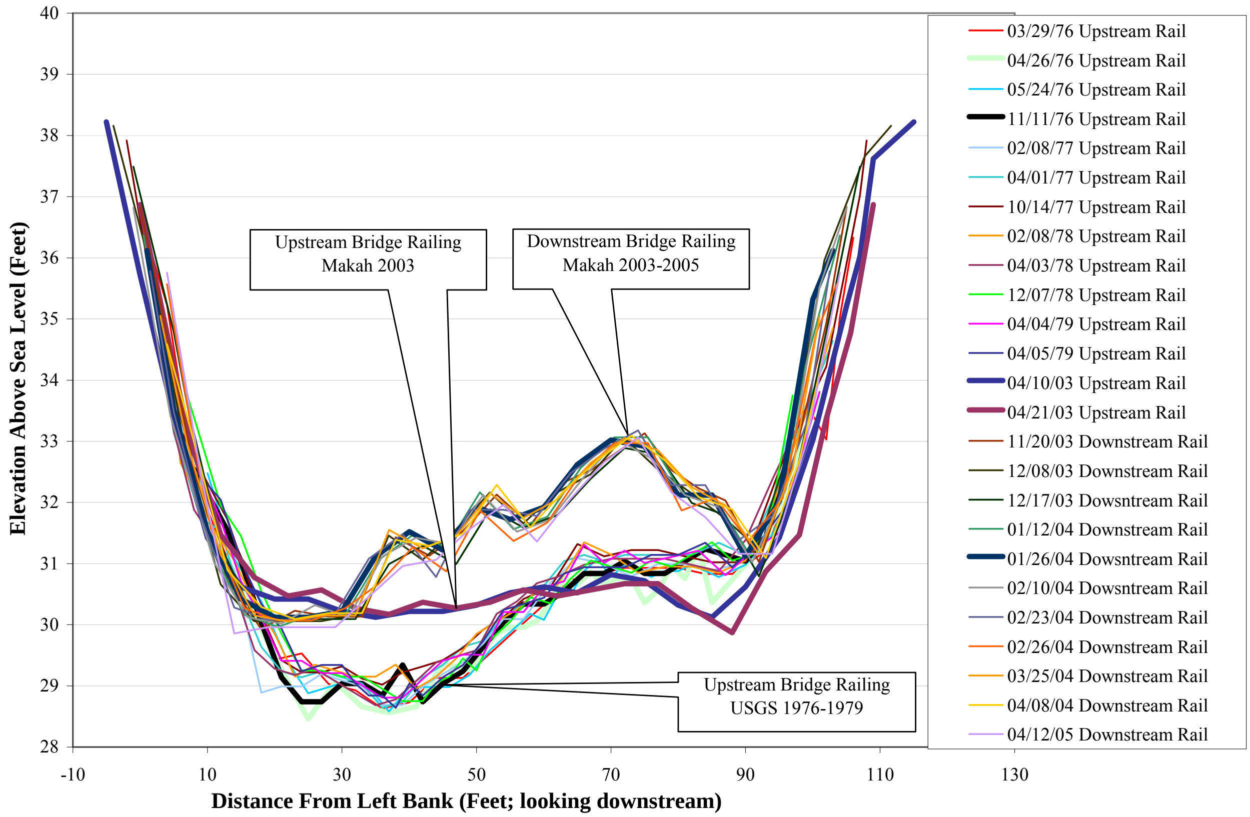

Figure 4.39. Cross-section elevation data collected from both the upstream and downstream bridge railings on the Ozette River (source: USGS; MFM, unpublished data).

The cross-sectional data displayed in Figure 4.38 and Figure 4.39 complement the stage-discharge and rating curve data. Between 1979 and 2003, the Ozette River channel thalweg (deepest point) under the bridge has aggraded approximately 1 vertical foot. This value also correlates to the average 1 foot upward shift in the rating curve between 1979 and 2003. Therefore, it is likely that sediment aggradation at the hydraulic control of the lake outlet is the dominant factor altering the river and lake stage/discharge relationship over the last 25 years.

Local observations at the bridge location and hydraulic control provide additional qualitative data that sedimentation has occurred at the controlling riffle. USGS water year summary description (WY 1976-1979) and measurement notes describe the controlling riffle downstream of the bridge as a "*cobble [and gravel] riffle about 100 feet downstream of gage.*" "*Channel control is probable at extremely high stages*" (USGS, unpublished discharge measurement notes 1976-1979). Currently the riffle contains very few cobble particles and is dominated by sand and small gravel. Particle size in the riffle is nearly the exact same size as the substrate size in Coal Creek (Herrera 2006). In addition, a mid-channel bar has developed just downstream of the bridge. Looking downstream from the bridge, significant deposition is observable in the middle of the channel and especially along the right bank. This right bank sediment deposit is formed in the eddy that develops upstream of the confluence of Coal Creek, and is readily observable in Figure 4.39 as an increase in bed elevation along the right bank progressing from the cross-sections upstream of the bridge to downstream.

Coal Creek in its present channel location (compared to its historical distributary channels) undoubtedly has a periodic influence on the stage-discharge relationship at the stream gage and hydraulic control just upstream of the confluence. This hydraulic influence consists of both 1) sediment deposition at the Ozette River confluence and 2) backwater effects of Coal Creek stage or discharge on the stage and flow dynamics of Ozette River upstream of the confluence, through the bridge opening and over the hydraulic control. This backwater effect occurs when the relative stage (or discharge) in Coal Creek is equal or greater than the stage (or discharge) upstream in the Ozette River. This backwater effect was first noted on October 14, 1977 in the USGS discharge measurement notes and has been periodically observed by NPS and MFM personnel since then. During most of the time or duration of most discharge situations, Coal Creek has a minimal to negligible backwater influence on Ozette River. Indeed, over six water years of stream gaging and 66 discharge measurements, this influence has not been quantified with current meters, but only visually observed.

The typical observed situation of backwater influence occurs when Lake Ozette and Ozette River are relatively low, typically below 34 or 35 feet, which can be the case during late spring, summer, or early fall. While not common, intense precipitation events can occur during these seasons, which can cause Coal Creek to quickly rise to flood stage after several inches of rain. Due to the low relative stage of Lake Ozette during these situations, response to these “dry season” events is minimal due to the large storage capacity of Lake Ozette. Thus, the relative stage of Coal Creek is temporarily elevated above Lake Ozette and Ozette River, overwhelming the stage-discharge patterns of Ozette River. Typically, during these events Coal Creek rises and falls quickly due to a lack of sustained multi-day precipitation (Figure 4.40). During these events, local observers have witnessed a variety of changes in hydraulic flow conditions, including 1) backwater without reverse flow in Ozette River, 2) backwater with partial reverse flow (east bank) through the bridge span (Figure 4.41), and 3) full reverse flow through the bridge cross-section into Lake Ozette.

During an event, the hydraulic conditions and flow directions become readily apparent because of the relatively high suspended sediment yields of Coal Creek compared to clear water exiting the lake. However, it is often the case that while sediment plumes and velocities are observed to move upstream, the Ozette River stream gage does not register extreme anomalous stage (and thus discharge) readings, even though Ozette discharge estimates (via the rating curve) through the bridge cross-section during these short Coal Creek spikes (less than one day rise to fall) are obviously incorrect, especially during the highest part of the Coal Creek flood wave. However, as compared to lake stage data at Tivoli Island, Ozette River Stage data does show a slightly elevated stage during high Coal Creek discharge events when Lake Ozette stage is relatively low (Figure 4.40).

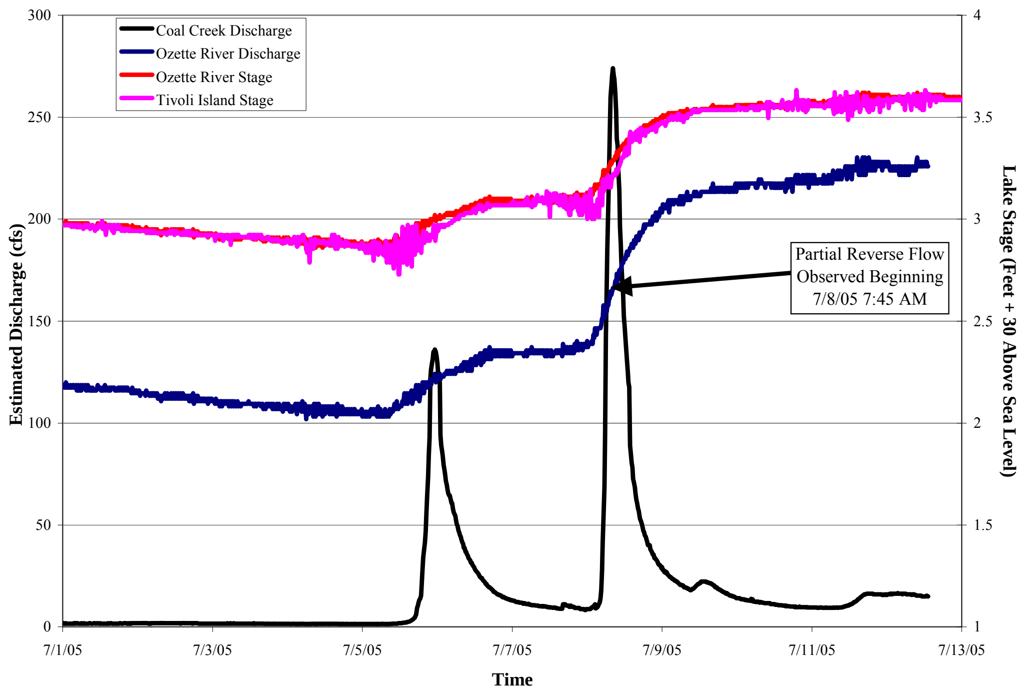

Figure 4.40. Comparison of discharge and stage of Coal Creek, Ozette River, and Lake Ozette during partial flow reversal at Ozette River stream gage (source: MFM unpublished data).

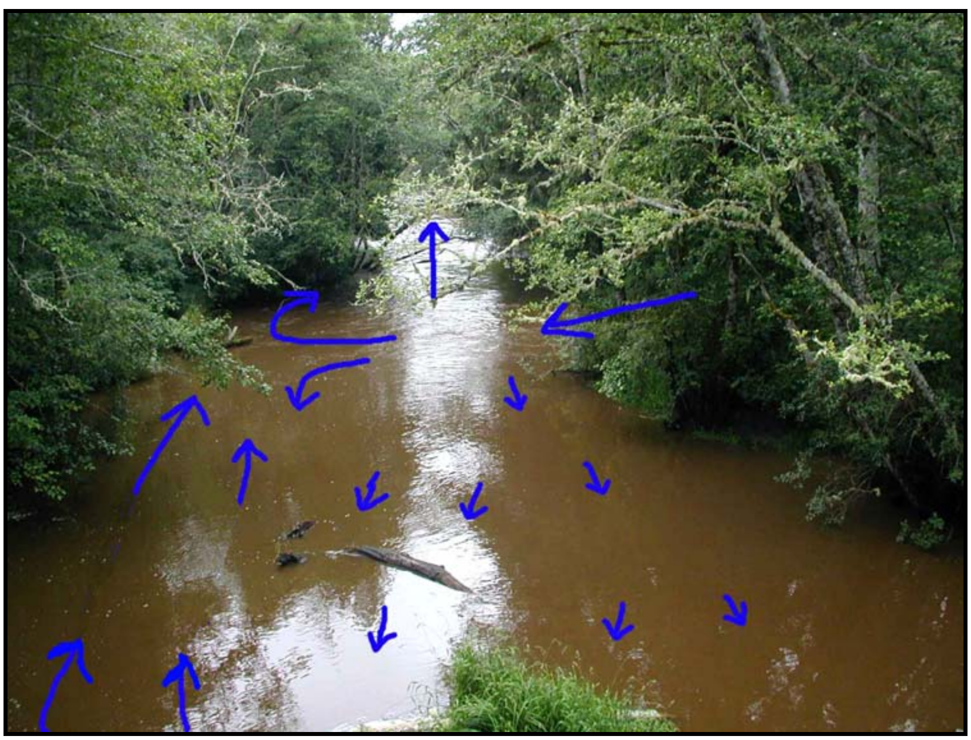

Figure 4.41. Photo depicting partial flow reversal of the Ozette River on July 8, 2005, blue arrows represent approximate velocity vectors (source: MFM).

Sediment deposition at and upstream of the mouth of Coal Creek is most pronounced during these backwater conditions. At moderate to high lake stages when Ozette River and Coal Creek discharges are moderate to high, Ozette River dominates the flow pattern at the confluence and quickly pushes Coal Creek discharge and sediment loads downstream, forming an abrupt right turn of the sediment plume at the confluence. This situation limits the ability of Coal Creek sediment to migrate upstream. However, this situation reverses during high Coal Creek and low Ozette River discharges. During these conditions, sediment first begins to migrate upstream along the east (right) bank of Ozette River via the large hydraulic eddy that forms following the displacement of Ozette River flow patterns toward the opposite west (left) bank (Figure 4.41). During large anomalies, sediment and velocities can reverse upstream across the entire river cross-section. These observations match the quantified aggradation patterns at the Ozette/Coal confluence (Figure 4.38 and Figure 4.39), where bar growth over the last 25 years has been concentrated toward the east (right) bank of Ozette River.

As a final influence on the Lake Ozette stage and Ozette River discharge relationship, MFM operates a seasonal salmon counting weir at the outlet of the lake. This weir is installed and removed seasonally from approximately April 15 to August 15. It is installed just below the footbridge across Ozette River, above Coal Creek, 30 feet below the Makah stage gage, and 100 feet below the NPS stage gage. The porous weir consists of one-inch circular metal tubes placed approximately ½ inch apart, so as to alter upstream salmon migration and force fish to migrate through a viewing chamber. In addition, on some years *Vexar* mesh is place across the face of the weir to increase smolt trapping efficiency while smolt trapping operations are underway (April-May). The weir and trapping operations have varying backwater effect on Lake Ozette, depending largely on the amount of leaf litter buildup on the face of the weir. Maximum backwater observed at the weir (upstream versus downstream stage), is 0.3 feet, but is typically less. Lake stages during weir operation typically range from 32 to 35 feet. At the lower end of the rating curve near 32 feet, considerable scatter exists in the rating data depending on whether the weir is in place or not (see Figure 4.34). More discharge data are needed below a stage of 32.5 feet to better define the stage discharge relationship and exact effect of the weir on this relationship.

4.3.6.2 Measured and Reconstructed Ozette River Discharge

Following the analysis of the Ozette River rating curves and changes in the hydraulic control over the last 25 years, it became clear that the assumption of a stable rating curve over time was incorrect. The date(s) of these rating shifts are unknown; however, NPS discharge data from 1993 and 1994 suggest that the change was gradual. Therefore, it becomes impossible to accurately transform all the NPS stage data between 1981 and 2003 into discharge data and reconstruct a mostly full period of record for discharge between 1976 and 2005. However, a more generalized approach was used that brackets the two rating curve extremes, assuming that the actual rating curve between 1981 and 2003 was between (above) the USGS curve in 1979 and (below) the Makah curve in 2004 (see Figure 4.37). Using both the USGS and Makah rating curves, this approach provides the potential range of discharges (maximum and minimum) between 1981 and 2002, using the NPS stage data. These hydrographs are shown in Figure 4.42, and display a more detailed picture of the hydrology as compared to the extremely short USGS and Makah records. NPS discharge data in 1993 and 1994 confirm that during the mid-1990s, discharge was less than predicted by the USGS rating curve, but greater than the Makah rating curves (Figure 4.37 and Figure 4.42).

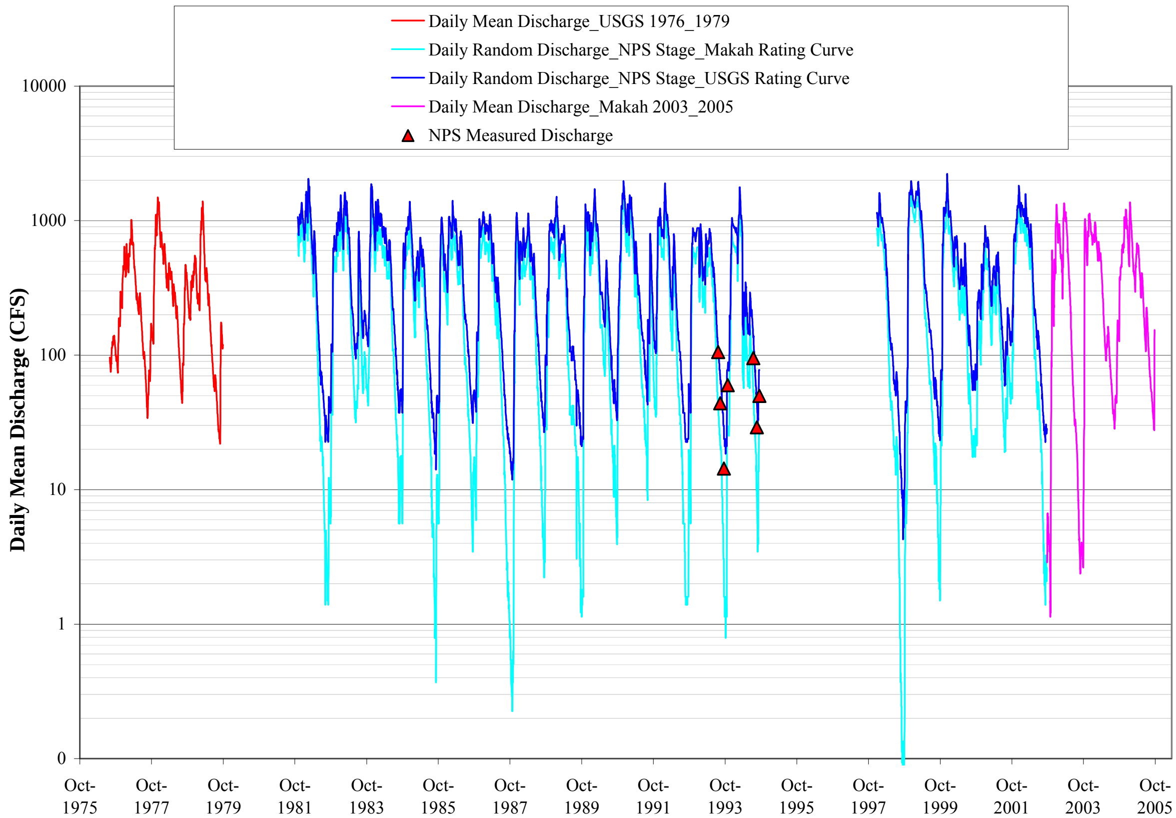

Figure 4.42. Reconstructed Ozette River discharge contrasted by estimates produced by USGS and MFM rating curves.

While this bracketed dataset is not robust enough for detailed analyses, several significant observations and trends can be gleaned from the dataset. Two datasets were created using the two different rating curves that represent the two extreme (maximum and minimum) discharge scenarios. The first dataset consists of measured USGS discharge data (1976-1979), NPS stage data and the 1979 USGS rating curve (1981-2002), and measured MFM discharge data (2003-2005). The second dataset consists of measured USGS discharge data (1976- 1979), NPS stage data and the 2004 MFM rating curve (1981-2002), and measured MFM discharge data (2003-2005). Both datasets use the 1993 low flow discharge measured by the NPS. Annual maximum (peak flow) and minimum (low flow) extremes were extracted from these two datasets. Each dataset for the period of record was plotted to detect potential trends in high or low flow discharge over time (Figure 4.43 and Figure 4.44).

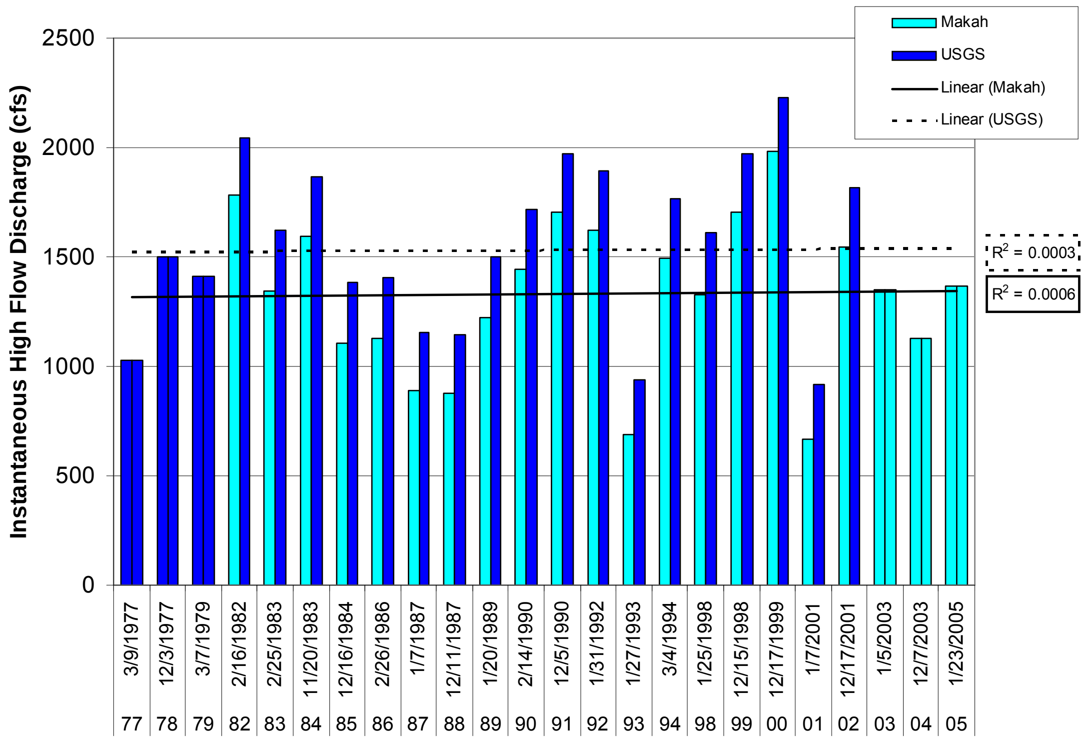

Figure 4.43. Ozette River bracketed annual peak flow discharges for water years 1977 through 2005 (source: USGS, ONP, and MFM stage data).

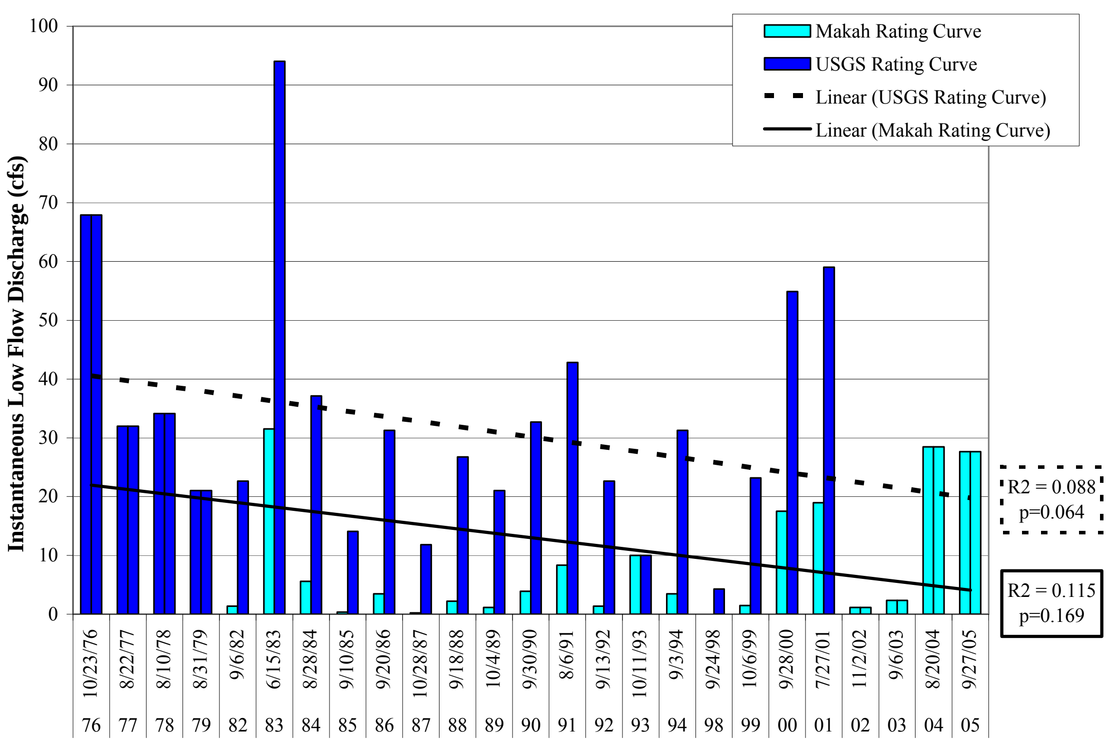

Figure 4.44. Ozette River bracketed annual low flow discharges for water years 1977 through 2005 (source: USGS, ONP, and MFM stage data).

Using either the USGS or MFM rating curves, no obvious trends were observed over time for peak flow discharges (Figure 4.43). Annual peak discharges range from a minimum potential low of 666 cfs (WY01, drought winter) to a maximum potential high of 2,229 cfs (WY 00, a wet winter). For annual low flow discharges, weakly significant decreasing trends exist for both data sets (Figure 4.44). Probability values were calculated using the non-parametric, rank-based, Mann-Kendall test (Kendall's tau) (Helsel and Hirsch 2002).

The extreme nature of the low flow hydrology at the Ozette River was not known until summer 2003. Before then, the USGS from 1976-1979 indicated fairly high sustained base flows in the river as compared to other regional rain-fed rivers. However, after the reinstallation of a gaging station in 2002 and better examination of the climate and precipitation records at Quillayute and NPS stage data, it appeared that winter and summer precipitation during the USGS record was average or above average and did not fully represent the range of variability of low lake stages and river discharges. While the extreme minimum discharge values calculated using the NPS stage data and Makah rating curve Figure 4.42) are likely not accurate (i.e. it is unlikely that the river went almost dry in 1985, 1987, and 1998), subsequent measured discharges indicate that the Ozette River can regularly drop below 20 cfs in the summer, and periodically get down to 1 to 4 cfs during extremely dry summers. Measured summer discharge data (June-November) for both the USGS (1976-1979) and Makah (2002-2005) data sets are graphed in Figure 4.45, along with the total summer precipitation (inches July-Sept) at the Quillayute Airport. These discharge and rainfall data indicate how average or above average the USGS data years were compared to the more extreme dry years during 2002 and 2003 measured by Makah.

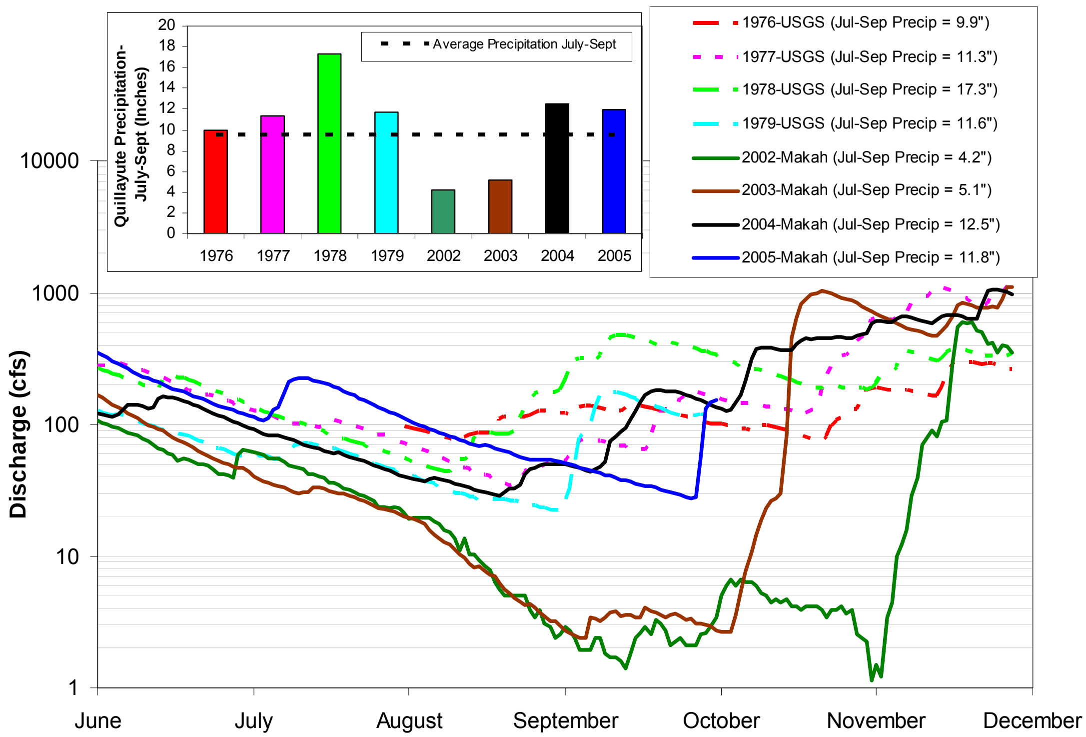

Figure 4.45. Ozette River discharge, summers 1976-1979 and 2002-2005 (source: USGS and MFM streamflow data).

During the summers of 2002 and 2003, discharge in the Ozette River above Coal Creek dropped to between 1 and 4 cfs of flowing water on the surface of the channel (Figure 4.45). For example, during summer 2003, measured discharge ranged from 58.4 cfs on 7/2/03, 42.9 cfs on 7/21/03, 21.4 cfs on 8/1/03, 7.0 cfs on 8/19/03, 3.3 cfs on 8/28/03, and 4.0 cfs on 9/7/03 after one inch of rain on 9/6/03. The dry season summer rainfall, lake stage and river discharge levels during the summers of 2002 and 2003 do not appear to be rare or uncommon events. Dry season summer rainfall, lake stage, and presumably river discharge were also comparably low during the summers of 1967, 1982, 1985, 1992, 1996, and 1998 (Figure 1.4; Figure 4.13). It is unknown whether the dry summer periods of 2002 and 2003 are just part of the overall hydro-climatic variability of the Lake Ozette watershed, or are partially influenced by trends in climate change (IPCC 2001) and the global trend of the hottest years on record recently (2000 to 2005), or whether anthropogenic land use has partially influenced the water balance of the Ozette Watershed and Ozette River.

Of particular local interest is the potential effect of sedimentation at the mouth of Coal Creek on the release of water from Lake Ozette. Due to the raise of the hydraulic control of Lake Ozette over the last 25 years (Figure 4.35), lake storage between 29 and 30 feet above MSL may be unavailable for release into Ozette River. However, the nature and extent of low flow changes in the Ozette River is still poorly understood and is likely a result of multiple factors acting cumulatively. Hyporheic flow [or shallow subsurface flow (e.g., Harvey and Bencala 1993; White 1993; Boulton et al. 1998; Edwards 1998; Bencala 2000)] through the recently deposited sediments above Coal Creek may mask the surface expression of water release from the lake. An unknown portion of the total outflow of water from Lake Ozette may be contained in hyporheic flow. Undoubtedly, hyporheic flow was still a component of the lake's outflow in the late 1970s and before, but the percentage of hyporheic flow to total flow may have changed over time due to sedimentation.

Only two sets of measurements shed light on the potential significance of hyporheic flow through the outlet of Lake Ozette into Ozette River. On August 28, 2003 at 11:00 a.m., the discharge of Ozette River above Coal Creek was measured at 3.26 cfs on the surface. The discharge was measured to be 4.65 cfs approximately 200 feet below Coal Creek on the same day at 12:30 p.m., showing a relative increase of 1.39 cfs potentially the result either of hyporheic flow through the bar upstream of Coal Creek, or the Coal Creek contribution. Surface flow of Coal Creek at this time was likely under 0.5 cfs. However, the accuracy of these low flow discharge measurements is approximately 8%, indicating a potential maximum increase of discharge below Coal Creek of 2.02 cfs and minimum increase of 0.75 cfs. If the surface flow of Coal Creek was less than 0.5 cfs, then the hyporheic contribution to Ozette River flow below Coal Creek was between 0.25 and 1.5 cfs. On September 28, 2005 at 9:45 a.m., the Ozette River above Coal Creek was measured at 23.72 cfs, while on the same day at 10:15 a.m. the Ozette River below Coal Creek was measured at 24.49 cfs. At the same time (9/28/05 9:00) the Coal Creek stream gage upstream calculated Coal Creek discharge as 0.41 cfs. The remaining flow would indicate 0.37 cfs of hyporheic flow through the bar upstream of Coal Creek. However, this difference is within the potential 8% error of the discharge measurements. Better quantification of the nature of hyporheic flow through the outlet of Lake Ozette could be fairly easily conducted using standard techniques (Bencala et al. 1983; Harvey et al. 1996; Harvey and Wagner 2000; Packman and Bencala 2000) or by more detailed longitudinal measurements of surface discharge along the upper end of Ozette River to document and quantify the extent of losing and gaining reaches.

4.3.6.3 Synthesized Ozette River Hydrographs

Due to the significant changes in the stage/discharge rating curve at the lake outlet between the 1979 and 2003, the NPS stage data could not be precisely and accurately transformed into discharge data, leaving an uncompleted discharge record for Ozette River. To compensate for this lack of data, discharge data for Ozette River have been synthesized from data in adjacent watersheds. As part of water resource investigations for the Water Resource Inventory Area (WRIA) 20 Watershed Planning Process, the U.S. Bureau of Reclamation (USBOR) gathered all available stage and discharge data for synthetic data construction (see Lieb and Perry 2004 for additional detail). Due to the high variability and poor correlation of instantaneous discharge between Ozette River and adjacent rivers (a partial result of the high water storage effect of Lake Ozette at the daily time step), all discharge data were summed into monthly total streamflow volumes (acre-feet per month or average cubic feet per second, per month). Regression equations were developed between monthly total streamflow for the Ozette River and monthly total streamflow at nearby gages including Hoko River (USGS 12043300), Sooes River

(USGS 12043163), and Dickey River (12043100). The measured Ozette River data (i.e., USGS and Makah data) were used to calibrate application of the equations. Data were synthesized for two locations on Ozette River for the period 1962 and 1999: Ozette River below Coal Creek and Ozette River at ocean mouth.

These synthesized data only represent monthly averaged flows (cubic feet per second), but are very useful for defining both the general flow regime (hydrograph magnitude, duration, timing) and variability over time (1962 to 1999). These data are displayed in Figure 4.46 and Figure 4.47, as annually dispersed flow duration probabilities (% of time average flow is less than [<] a given discharge). Note that at any given point in time, the instantaneous discharge could be much higher or lower than the average monthly flow. These data are not useful for defining extreme instantaneous discharges such as extreme low summer flows or peak flows. As another note of caution, several sources of data for the Ozette River were not available to the USBOR at the time of their synthesis calculations, resulting in several omissions or errors in their results. For example, the USBOR did not have the USGS and Makah data that indicate a significant rating shift (sediment aggradation) at the Lake outlet above Coal Creek. Thus, their calculations did not take into account changes in outlet conditions over time that would control water release from the lake. These changes include changes in large woody debris roughness following removal in 1953 and slow recovery over time (PWA 2002; Herrera 2005). Lastly, they made an incorrect assumption regarding where the USGS measured discharge during the period 1976 to 1979. The USGS made discharge measurements upstream of Coal Creek at the footbridge, similar to Makah data. Perceived changes in discharge out of Lake Ozette between 1979 and 2003 were partially a result of sediment aggradation and a rating shift, not changes in discharge measurement location.

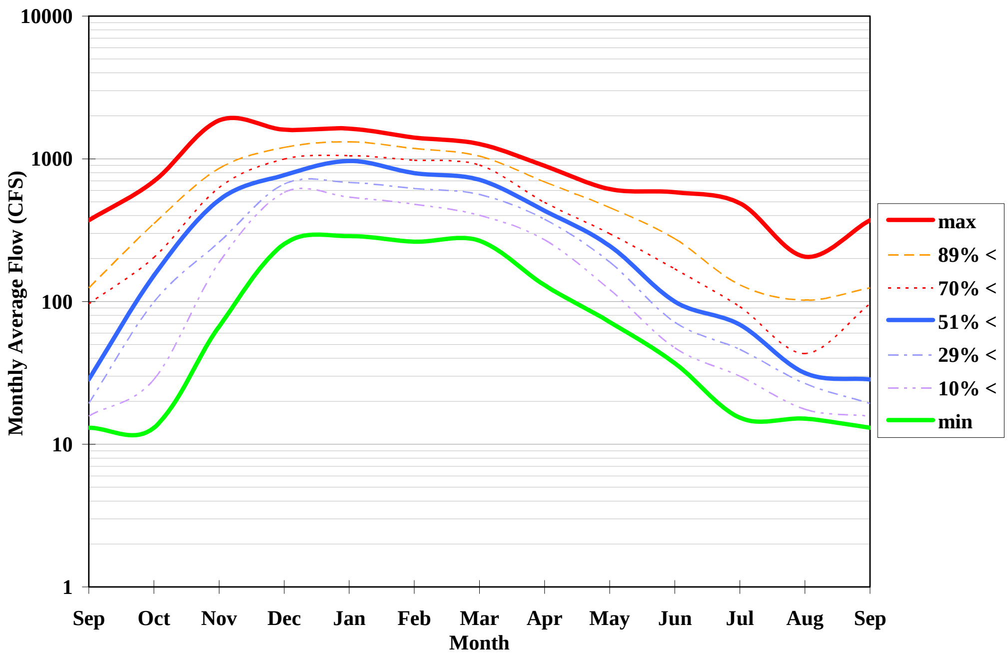

Figure 4.46. Ozette River below Coal Creek, annually (1962-1999) dispersed flow duration curve (source: data synthesized by USBOR).

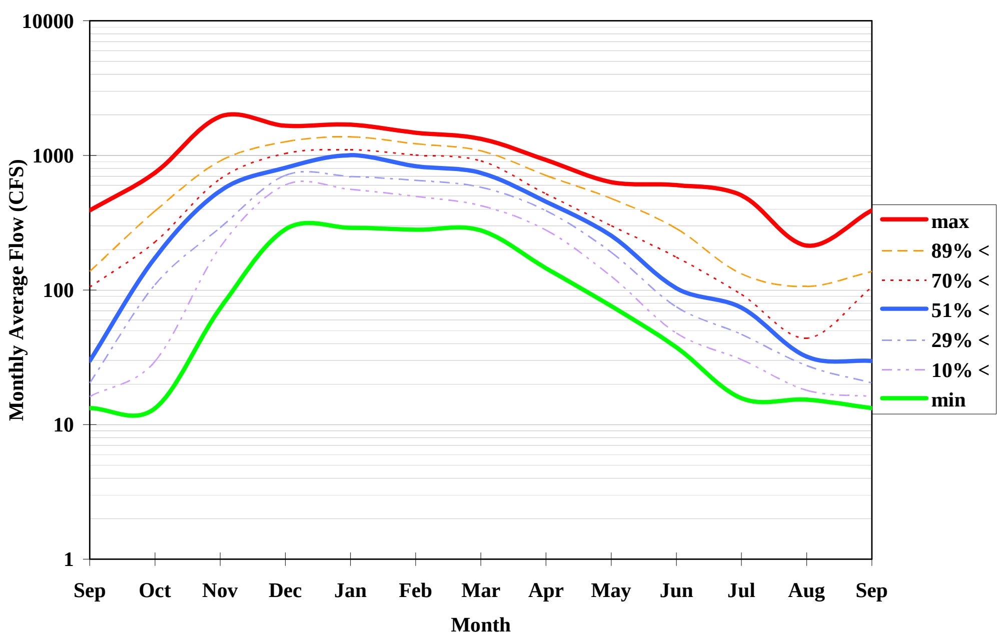

Figure 4.47. Ozette River at confluence with Pacific Ocean, annually (1962-1999) dispersed flow duration curve (source: data synthesized by USBOR).

4.4 LAKE OZETTE TRIBUTARIES

Sockeye salmon spawn in the three largest tributaries to Lake Ozette, i.e., Umbrella Creek, Big River, and Crooked Creek. Habitat conditions in these streams are discussed in detail in this section. Similar information is provided for Coal Creek mainly because of its size, its sediment and hydrologic influence on the Ozette River and Lake Ozette, and its potential for future colonization by sockeye. Detailed information for Siwash Creek is included because it has a large population of kokanee; documenting and understanding habitat elements that are capable of sustaining a healthy population of kokanee may provide critical insight into factors affecting tributary spawning sockeye salmon in the watershed.

4.4.1 Umbrella Creek

Umbrella Creek is the third largest tributary to Lake Ozette. Umbrella Creek enters the lake at the northwest edge of Umbrella Bay (Figure 3.16). The Umbrella Creek watershed drains approximately 10.6 mi^2 (27.5km^2) and has several significant tributaries. The two largest tributaries are the East and West Branches of Umbrella Creek, followed by Hatchery Creek (WRIA# 20.0056) and Elk Creek. The mainstem flows predominately south-southwest from its headwaters at Elk Lake. The course of the mainstem is almost exclusively underlain by Pleistocene age glacial till, drift, and outwash deposits. The majority of the main channel sections of large tributaries to Umbrella Creek are associated with broad, low relief glacial deposits.

4.4.1.1 Umbrella Creek Floodplain Conditions

Smith (2000) rated the overall floodplain condition in Umbrella Creek as good. But Smith (2000) also cites J. Freudenthal as stating that channel incision is a problem in Umbrella Creek. Herrera (2006) reports that the lower 0.75 mile (1.2 km) of Umbrella Creek has undergone approximately 3.3 feet (1m) of channel incision over the last 50 years. No formal field-based assessment of Umbrella Creek floodplain conditions has been conducted. Short reaches of Umbrella Creek were identified by Smith (2000) as having riparian adjacent roads (RM 6.0-6.3, RM 8.0-8.2). Floodplain conditions in two of the largest tributaries to Umbrella Creek (West Branch and Hatchery Creek) were rated as poor by Smith (2000), based upon riparian-adjacent roads.

4.4.1.2 Umbrella Creek Riparian Conditions

Riparian conditions in Umbrella Creek vary considerably depending on location. Nearly all (>95%) of the old growth riparian forest has been harvested along the mainstem of Umbrella Creek. Meyer and Brenkman (2001) reported that 93% of forest within the Umbrella Creek watershed was 40 years old or less. Less than 0.1% of the forest within the watershed was classified as >80 years old (Meyer and Brenkman 2001). Smith (2000) rated the riparian conditions along Umbrella Creek as poor. However, the data used by Smith (2000) were limited to the lower mile of Umbrella Creek. Orthophotos taken in the summer of 2000 show that while it is true that the majority of riparian forests have been converted to stands dominated by red alder (*Alnus rubra*), some residual large conifer trees are still present in small patches. These patches are mostly along the west side of the lower 2 miles of the creek. Stands dominated by red alder or mixed alder/conifer predominate in the riparian areas from the Hoko-Ozette Road upstream past the confluence with the East Branch of Umbrella Creek. Prior to timber harvest, riparian forests here were composed primarily of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). Residual in-channel LWD and standing trees provide evidence of the massive trees that once grew along Umbrella Creek. Riparian conditions in the primary tributaries to Umbrella Creek are also highly degraded from the pre-disturbance condition. Extensive stands of young to medium-aged red alders dominate the riparian composition of both the East and West Branches of Umbrella Creek.

4.4.1.3 Umbrella Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 in Umbrella Creek and are summarized in detail by Haggerty and Ritchie (2004). Field data were collected for almost 11,000 meters of channel within the mainstem of Umbrella Creek and several thousand meters in tributaries. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 20 habitat segments encompassing the 11,000 meters of channel in the mainstem. A total of 4,734 pieces of LWD were inventoried, of which 77%, 21%, and 2% were categorized as conifer, deciduous, and unknown respectively. Only 1% of the pieces inventoried were classified as key pieces[14]. Approximately 81% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.48 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in Umbrella Creek watershed.

Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables including: pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.49 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments

[14] Key piece is defined as a log and/or rootwad that is: (1) independently stable in the stream bankfull width (not functionally held by another factor, i.e., pinned by another log, buried, trapped against a rock or bedform, etc.), and (2) is retaining (or has the potential to retain) other pieces of organic debris. Without the Key Piece, the retained organic debris will likely become mobilized in a high flow (approximately equal to or greater than a 10 year event). (From WDNR 1997)

surveyed in the Umbrella Creek watershed. A total of 279 pools were documented in the mainstem of Umbrella Creek. The highest quality pools were most often associated with the largest LWD pieces. Pools formed by key-piece-sized LWD averaged nearly 1.8 times deeper than pools formed by medium or small LWD, or free-formed pools without LWD.

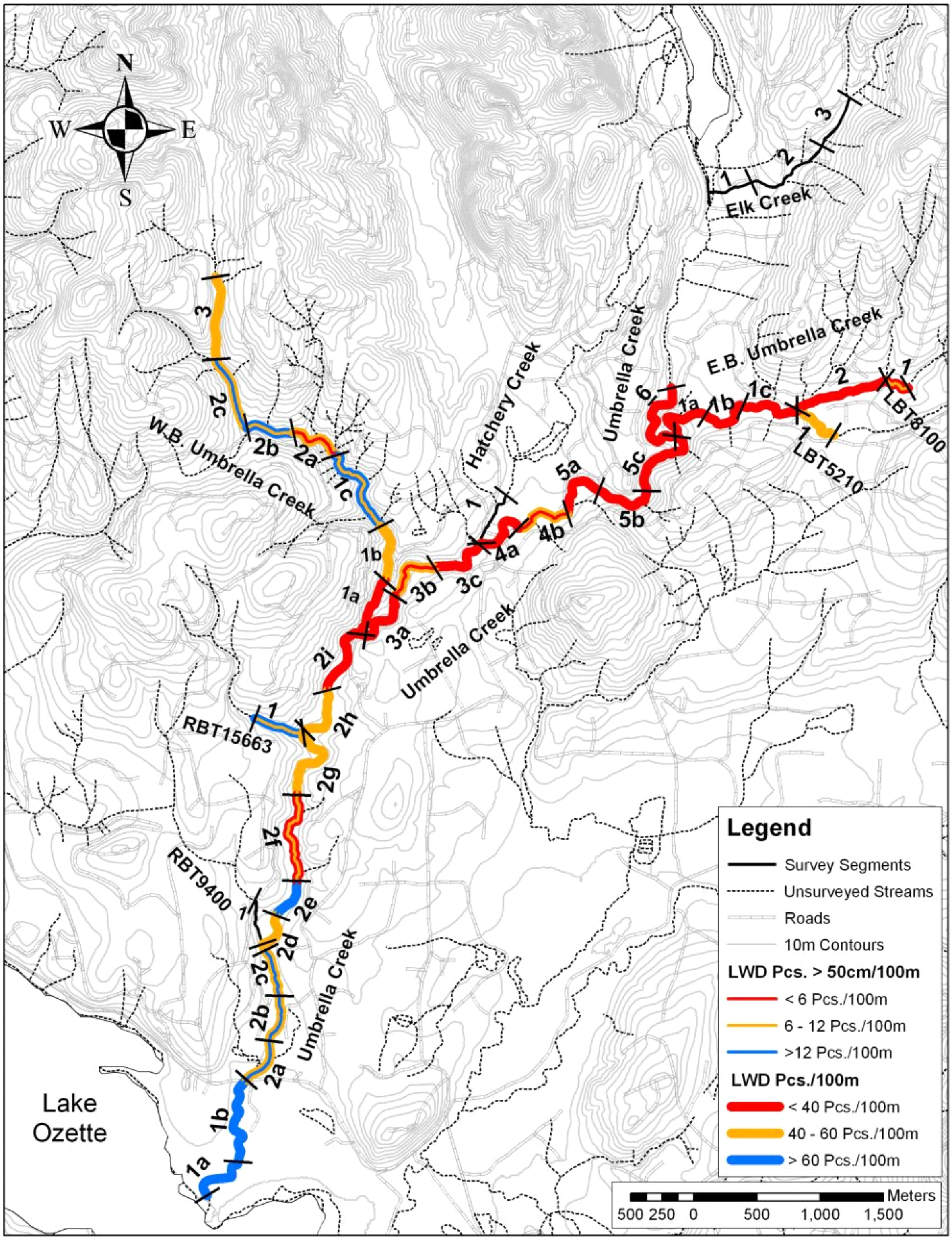

Figure 4.48. Umbrella Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

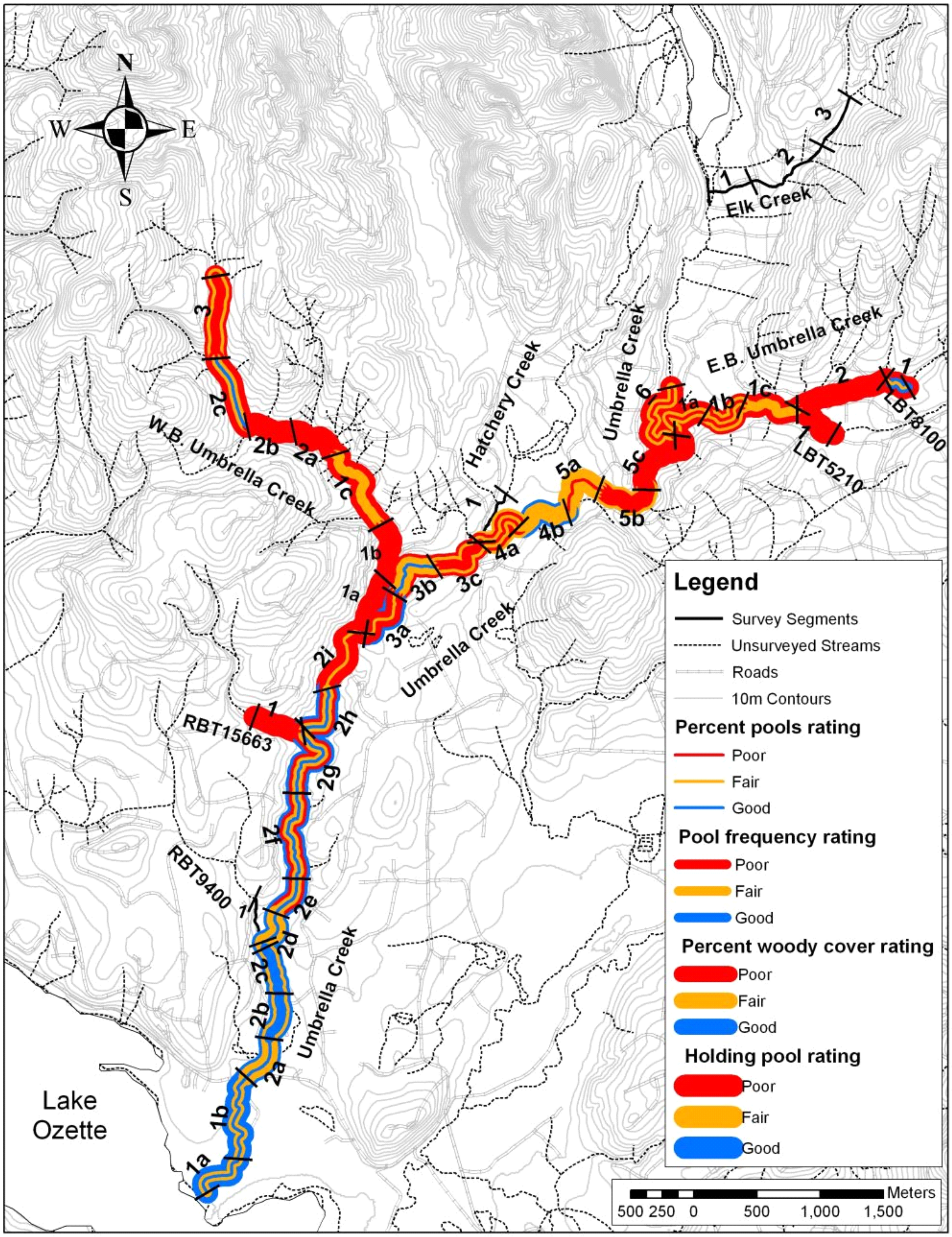

Figure 4.49. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Umbrella Creek watershed (source: Haggerty and Ritchie 2004).

Riparian forest removal has dramatically decreased the quantity and quality of trees available for recruitment into Umbrella Creek. Habitat and LWD data collected in Umbrella Creek illustrate the importance of large and key-piece-sized LWD in forming high quality habitat features. Recent recruitment of small and medium size LWD appears incapable of producing the same habitat quality and complexity as seen in those habitats formed by LWD > 50 cm diameter. Pool habitat features associated with small and medium size LWD had essentially the same attributes as free-formed pools independent of LWD (with the exception of percent woody cover).

4.4.1.4 Umbrella Creek Streambed and Substrate Conditions

No recent data are available regarding Umbrella Creek substrate conditions. However, McHenry et al. (1994) sampled substrate conditions in three Umbrella Creek stream reaches (lower, middle, and upper). McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in Umbrella Creek averaged 16.1% (wet-sieve equivalent; actual dry-sieve method equal to 9.1%). Fine sediment levels were uniform between lower, middle, and upper sampling sites. Dlugokenski et al. (1981) sampled Umbrella Creek in 1979 and found that fine sediment in spawning gravel (<0.6mm) ranged from 7% to 25%, averaging ~18%. Dlugokenski et al. (1981) suggest that the "high" levels of fines in spawning gravels are associated with the high road density and lack of adequate road surfacing material. Smith (2000) rated Umbrella Creek "poor" for fine sediment levels in spawning gravel. Current (2006) estimates of road density in Umbrella Creek are high, 7.4 mi/ mi^2 (4.6 km/km^2; Ritchie, unpublished data).

The loss of both quantity and quality of LWD in Umbrella Creek has also likely affected spawning gravel availability, stability, and quality. Significant correlations between the surface area of sediment accumulations and LWD volume have been shown for streams draining old-growth forests in western Washington (Bilby and Ward 1989). Martin (2001) studied streams flowing through old-growth forests in Alaska and found that gravel dominance within habitat units increased with both increased LWD frequency and volume. Bilby and Ward (1991) found that streams draining old-growth forests had larger areas of LWD-associated sediment accumulations than those found in streams draining second-growth forests. Some reaches of Umbrella Creek with low LWD abundance also appear to have coarser sediments (mainly cobble) and a lower frequency of suitable spawning gravels, although no quantitative data have been collected in Umbrella Creek correlating low LWD abundance with decreased quantities of suitable spawning gravel. The marine-sediment geology, moderate gradient, and moderate confinement of most of the Umbrella Creek channel suggests that bedload deposition of gravels and smaller-sized sediments would be expected to occur next to stable wood accumulations.

4.4.1.5 Umbrella Creek Water Quality

Water quality data have been collected in Umbrella Creek intermittently from the mid-1970s to present. Early data collected by Bortleson and Dion (1979) are quite limited for Umbrella Creek. Until recently the most comprehensive water quality dataset had been summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 21, 1993 through November 30, 1994. Table 4.7 contains a summary of water quality sampling data for Umbrella Creek from Meyer and Brenkman (2001).

Table 4.7. Summary of water quality data collected in Umbrella Creek from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	2.7	6.2	24.2	8.3	0.3
Maximum	16.0	7.4	100.5	12.3	161.0
Mean	10.0	6.9	59.0	10.2	19.1
Number Months Sampled	n=21	n=16	n=21	n=17	n=20

In recent years additional water quality data have been collected in Umbrella Creek just downstream from the Hoko-Ozette Road Bridge (near the Umbrella Creek stream gage). Makah Fisheries Management began collecting water quality data in Umbrella Creek in January 2004. Data collection is ongoing and is typically collected monthly, but sampling frequency increases to approximately twice per month during spring and summer months. Table 4.8 summarizes the results of water quality sampling by MFM in Umbrella Creek. Water quality conditions measured by MFM are roughly within the same range of conditions measured by Meyer and Brenkman (2001). Some of the minor differences between datasets can be attributed to increased sample frequency during May, June, and July in the MFM dataset.

Table 4.8. Summary of water quality data collected in Umbrella Creek from January 15, 2004 through October 7, 2005 (source: MFM unpublished water quality data).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	5.1	6.1	23.7	8.8	0.0
Maximum	16.3	7.3	90.8	15.2	330.2
Mean	10.1	6.8	59.4	11.6	14.7
Number Sample Points	n=31	n=31	n=31	n=31	n=31

Additional stream temperature monitoring was also conducted using thermographs and data loggers during the summer of 1993 and 1994 near the ONP boundary (MFM unpublished data; Meyer and Brenkman 2001). A review of available temperature data for lower Umbrella Creek indicates that data were collected during nine summers from 1993 through 2005. Stream temperature data from 1998 and 1999 were collected by Green Crow approximately 0.8 mile upstream of the Hoko-Ozette Road Bridge. All other data were collected by MFM at or very near the bridge. Temperature data were collected on a total of 798 days between June 1st and September 30 (1993-2005). Maximum annual temperatures were recorded between July 21 (2003) and August 18 (1994; Table 4.9). The 7-day moving average maximum daily temperatures observed from 1993 through 2005 are depicted in Figure 4.50. Figure 4.51 depicts the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C.

Table 4.9. Summary of maximum daily stream temperature observations from lower Umbrella Creek during temperature monitoring from 1993 through 2005 (source: MFM unpublished data, Meyer and Brenkman 2001; Green Crow, unpublished data).

Year	Number of Days Sampled (June 1 to September 30)	Date(s) of Peak Temperature	Peak Temperature (C)	Date of Peak 7-Day Moving Average Daily Maximum Temp.	Peak 7-Day Moving Average Daily Maximum Temperature (C)
1993	72	8/4/1993	21.8	8/6/1993	19.9
1994	107	8/18/1944	19.1	8/18/1944	18.2
1997	36	8/5/1997	18.5	8/10 to 8/16/1997	17.9
1998	64	7/27-28; 8/13/1998	19.4	8/1/1998	18.0
1999	64	8/10/1999	16.3	8/11/9999	15.5
2002	104	07/22/02	19	7/25/2002	17.9
2003	120	7/21/2003	18.7	7/30/2003	17.6
2004	114	7/23/2004	19.8	7/24 to 7/26/2004	18.8
2005	117	7/27/2005	17.6	8/2; 8/4-6/2005	17

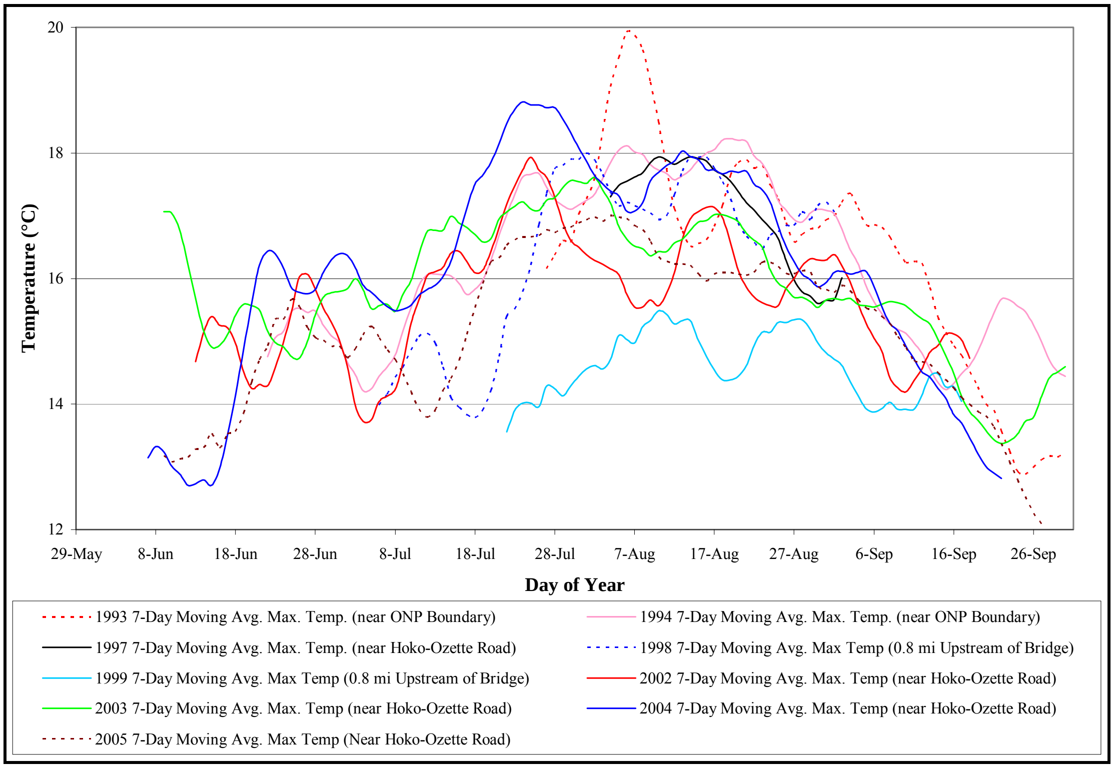

Figure 4.50. Umbrella Creek 7-day moving average maximum stream temperature near Hoko-Ozette Road from 1993-2005 (source: MFM, unpublished stream temperature data; Meyer and Brenkman 2001).

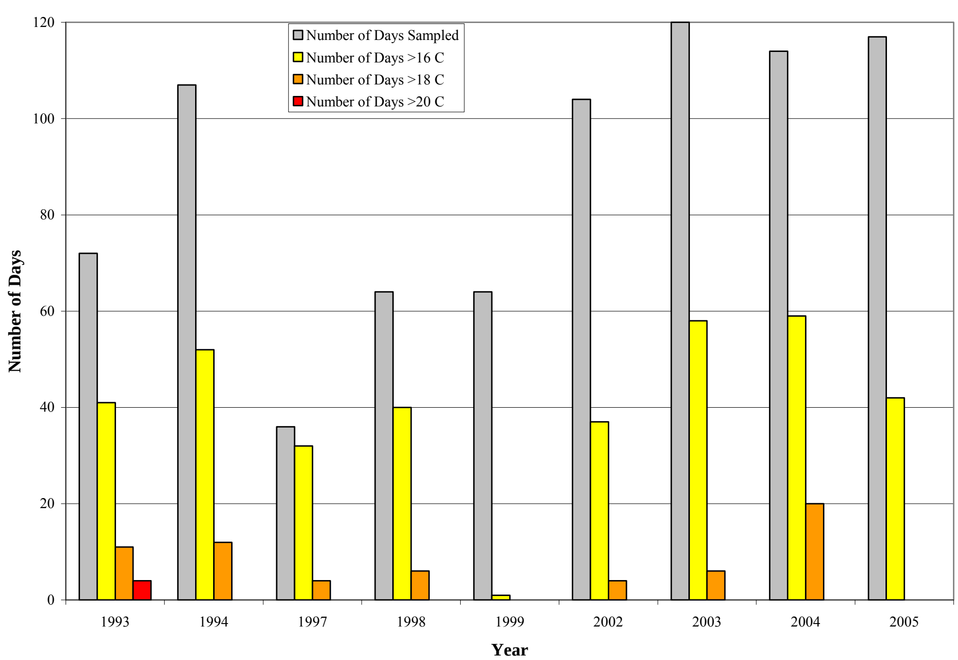

Figure 4.51. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20 °C in Lower Umbrella Creek (1993-2005) (source: MFM, unpublished stream temperature data; Meyer and Brenkman 2001).

Maximum daily stream temperatures exceeded 16°C on 362 days (45% of the days sampled) between June 1 and September 30 (1993-2005). During the warmest period of summer, July 15 through August 15, data were collected on 267 days. Stream temperatures exceeded 16°C on 203 days (76% of the days sampled). Stream temperatures exceeded 18°C on 51 days (19% of the days sampled). Figure 4.52 includes a summary of the number of days data were collected July 15 through August 15, as well as the number of days when the maximum temperature exceeded 16, 18, and 20°C. The relatively high stream temperatures documented from 1993-2004 are thought to be partially a function of riparian forest disturbance and shade loss (mostly from logging during the last 50 years) and naturally elevated stream temperatures. Kemmerich (1926) reported that the stream temperature in lower Umbrella Creek was 14.5°C on July 1, 1926 and increased each day until it reached 17.8°C on July 12, 1926[15].

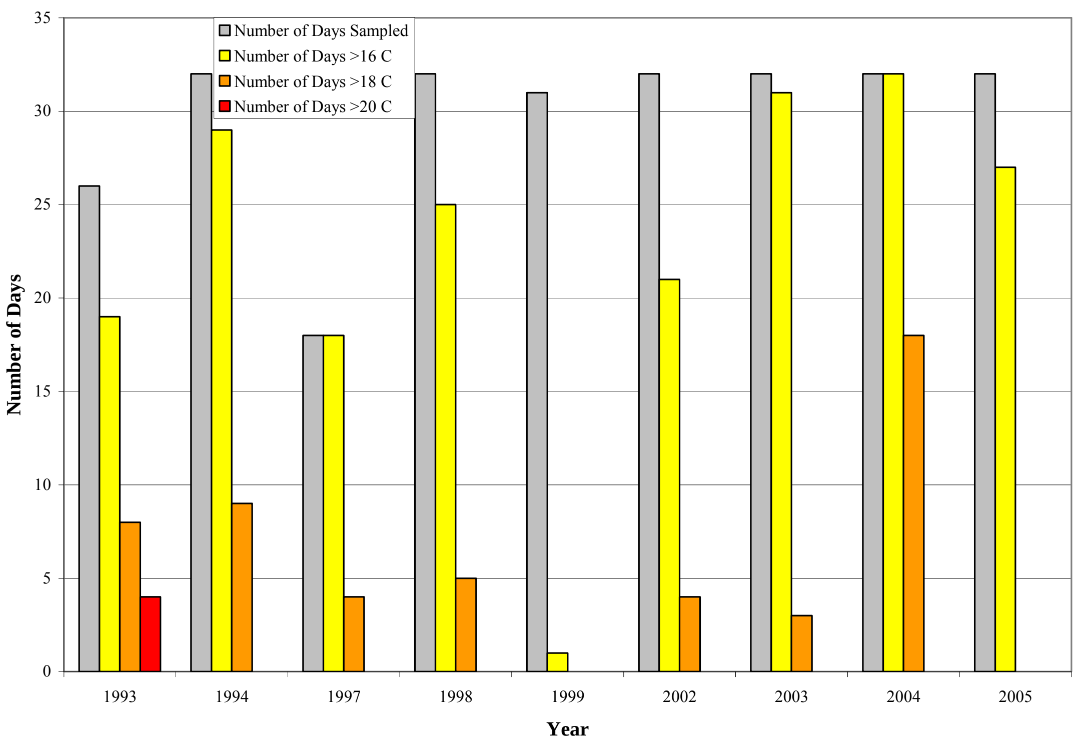

Figure 4.52. Summary of lower Umbrella Creek maximum daily stream temperature data for the period July 15 through August 15 (1993-2004) (source: MFM, unpublished stream temperature data; Meyer and Brenkman 2001).

Other water quality investigators within the watershed have described water quality concerns in addition to stream temperature. Meyer and Brenkman (2001) voiced concern regarding pH, dissolved oxygen, and turbidity levels in Umbrella Creek. They concluded

[15] Kemmerich's observations from 1926 occurred during a period of very low rainfall (4th lowest recorded June-July rainfall in 90 years of record at the Quillayute weather station).

that water quality conditions for fish were marginal. Smith (2000) rated the water quality "poor" for Umbrella Creek based upon stream temperatures consistently exceeding the Washington State Water Quality Standards. Jacobs et al. (1996) suggested that turbidity levels exceeded the threshold at which feeding juvenile salmonids are negatively affected but expressed no concern over the dissolved oxygen, pH, and conductivity levels recorded by in 1993 and 1994 by Meyer and Brenkman (2001)

Makah Fisheries Management installed a continuous submersible turbidity sensor on Umbrella Creek at the County Bridge on 2/17/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and SSC. The sensor is deployed down an open-bottom, vertically porous pipe attached to the bridge structure in well-mixed water. The sensor is attached to floats within the pipe, allowing the sensor to adjust vertically with stage changes, assuring the sensor viewing area is off the channel bed during high flows. The sensor (Forest Technology Systems DTS-12 turbidimeter) measures in Nephelometric Turbidity Units (NTU), is factory calibrated annually in Formazin standards of known NTU, has a built-in wiping mechanism to self clean the sensor before every measurement, and measures 100 turbidity samples every 15 minutes and returns the median, mean, minimum, maximum, BES, and variance, in addition to water temperature. Field maintenance consists of periodic equipment checks that consist of cleaning the sensor with soap and water, removing any major debris from the sensor, wiper, boom, or pipe, and flushing the structural components. Point samples of turbidity and SSC are taken periodically at the continuous sensor for correlation purposes and to detect any instrument drift, which is extremely rare

Median turbidity values (15-minute) are plotted in Figure 4.53, along with discharge. In Umbrella Creek turbidity and suspended sediment concentration peaks usually last for less than a day, depending on the length of the flood pulse event. During small discharge events, turbidity rises sharply on the rising limb of the discharge hydrograph and falls more rapidly than discharge on the recession limb. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). At these moderate discharges, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources. However, during large flood events in Umbrella Creek, the relationship between discharge and turbidity remains more constant on both the rising and falling limbs of the hydrograph, indicating that for large discharge events, turbidity and SSC are not supply limited, but rather that there is abundant sediment available in the channel network that is limited by transport by available flows (Hicks and Gomez 2003; Nistor and Church 2005).

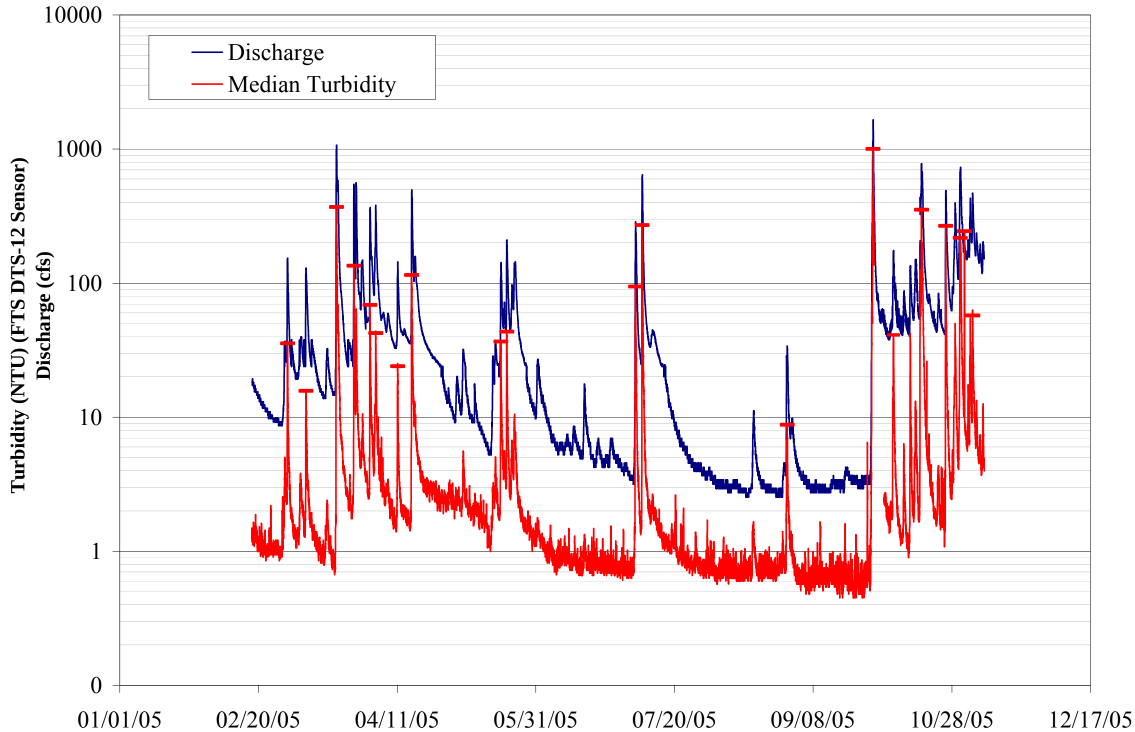

Figure 4.53. Preliminary results from continuous turbidity readings and provisional stream discharge data for Umbrella Creek (source: MFM, unpublished data).

4.4.1.6 Umbrella Creek Hydrology and Streamflow

Makah Fisheries Management installed a continuous stream gage on Umbrella Creek at the Hoko-Ozette Road County Bridge on 12/18/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s-cfs) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional).

Instantaneous discharge at Umbrella Creek for water years 2004 and 2005 are plotted in Figure 4.54. In addition to these data, exceedence probabilities (% of time average flow exceeds a given discharge) are displayed that define the 89%, 49%, and 10% exceedence values. These values were calculated by the U.S. Bureau of Reclamation (USBOR) as part of water resource investigations for the Water Resource Inventory Area (WRIA) 20 Watershed Planning Process (Lieb and Perry 2004). Regression equations were developed using monthly total streamflow at Umbrella Creek and monthly total streamflow at the nearby Hoko River gage (USGS 12043300). These synthesized data only represent monthly averaged flows (cubic feet per second) and exceedence of those average flows, but are very useful for defining both the general flow regime (hydrograph magnitude, duration, timing) and variability over time (1962 to 1999). Note that at any given point in time, the instantaneous discharge is much higher or lower than the average monthly flow.

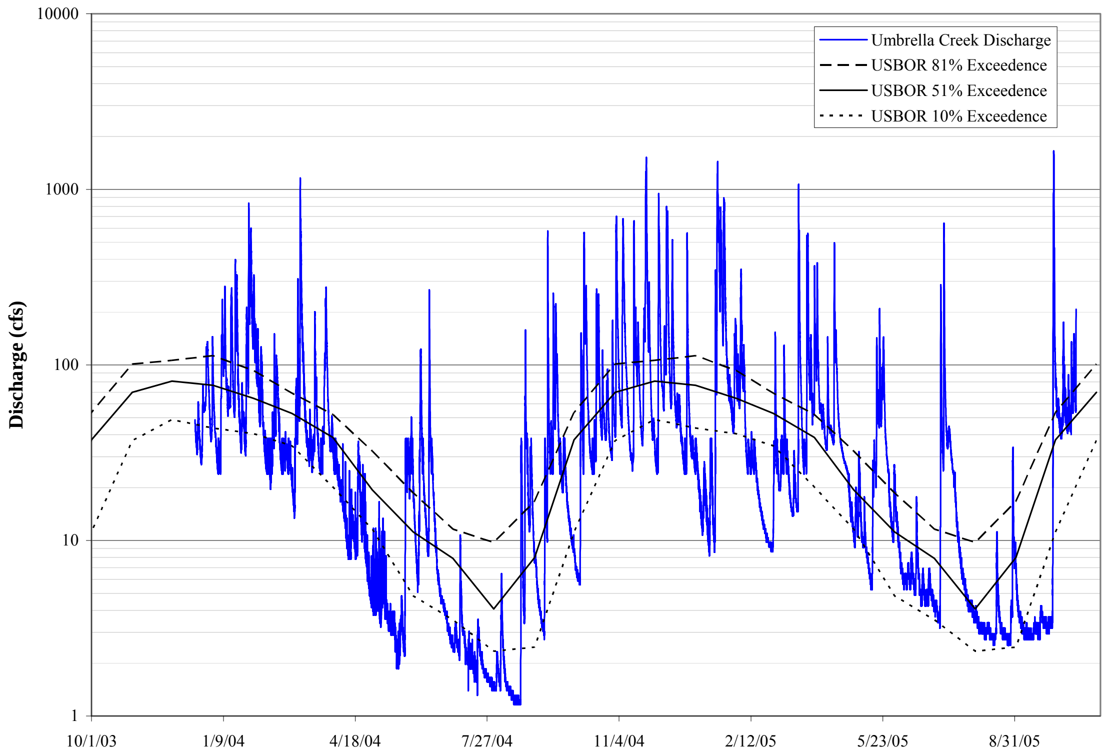

Figure 4.54. Provisional Umbrella Creek discharge data plotted with USBOR synthesized monthly average streamflow exceedence curves (source: MFM, unpublished data; Lieb and Perry 2004).

4.4.2 Big River

Big River is the largest tributary to Lake Ozette. Big River enters the lake along the west side of Swan Bay (Figure 3.16). The Big River watershed drains approximately 22.8 mi^2 (59.1 km^2) and includes several tributaries. The largest tributary is Trout Creek, with a drainage basin area of 5.1mi^2 (13.3 km^2), followed by Dunham (2.1mi^2/13.3 km^2), Solberg (1.4 mi^2/3.7 km^2), Boe (1.1mi^2/2.8 km^2), and Stony creeks (0.8 mi^2/2.1 km^2). The upper mainstem flows to the south-southeast across a relatively wide valley underlain by Pleistocene glacial drift deposits. The northeast side of the valley is bound by topographically steep, Eocene age volcanic flows and breccias (Crescent Formation). The southwest side of the valley is bound by slightly less steep Oligocene-Eocene age marine sedimentary rocks. As the river exits this unique valley it plunges over a set of barrier falls shortly before turning nearly 90 degrees and flowing to the west-southwest. Below the falls, the lower mainstem meanders across a wide (~0.5 mi) gently sloping valley composed of Holocene fluvial deposits and Pleistocene glacial till and drift deposits before entering Lake Ozette.

4.4.2.1 Big River Floodplain Conditions

Big River floodplain conditions and processes have been significantly modified over the last 100 years. Roads and pastures within the floodplain, and to a lesser extent residences, have changed flooding frequency, wood recruitment, channel migration rates, and much of the character of the floodplain. Herrera (2006) reports that 1 to 2 meters of channel incision have occurred during the last 50 years in the lower 11 km (6.8 mi) of Big River. They attribute this channel incision to changes in base level, wood removal, and forest clearing. For the purpose of this report, Big River floodplain impacts have been divided into four categories: changes in base level, road-related impacts, agricultural and residential impacts, and stream clearing and timber harvest impacts. Figure 4.55 depicts Big River channel and floodplain alterations from Swan Bay Road upstream to the 7402 Road Bridge.

4.4.2.1.1 Altered BaseLevel Related Floodplain Impacts

Herrera (2006) suggested that much of the observed channel incision in the lower reaches of Lake Ozette tributaries was likely a result of changes in lake level associated with logjam removal from the Ozette River. Herrera (2006) concluded that water surface elevations of Lake Ozette act as a base level control for lake tributaries and that the base level directly affects the channel profile of tributaries. They found that the lower reaches of all lake tributaries investigated were incised upstream of the point at which high lake levels could impose backwater conditions. They made no attempt to differentiate the length of Big River channel incision that was hypothesized to have been caused by changes in base level of Lake Ozette and those thought to be a response to Big River instream wood removal. Where channel incision was thought to have occurred as a result of changes in base level, floodplain connectivity was rated as poor by Herrera (2006).

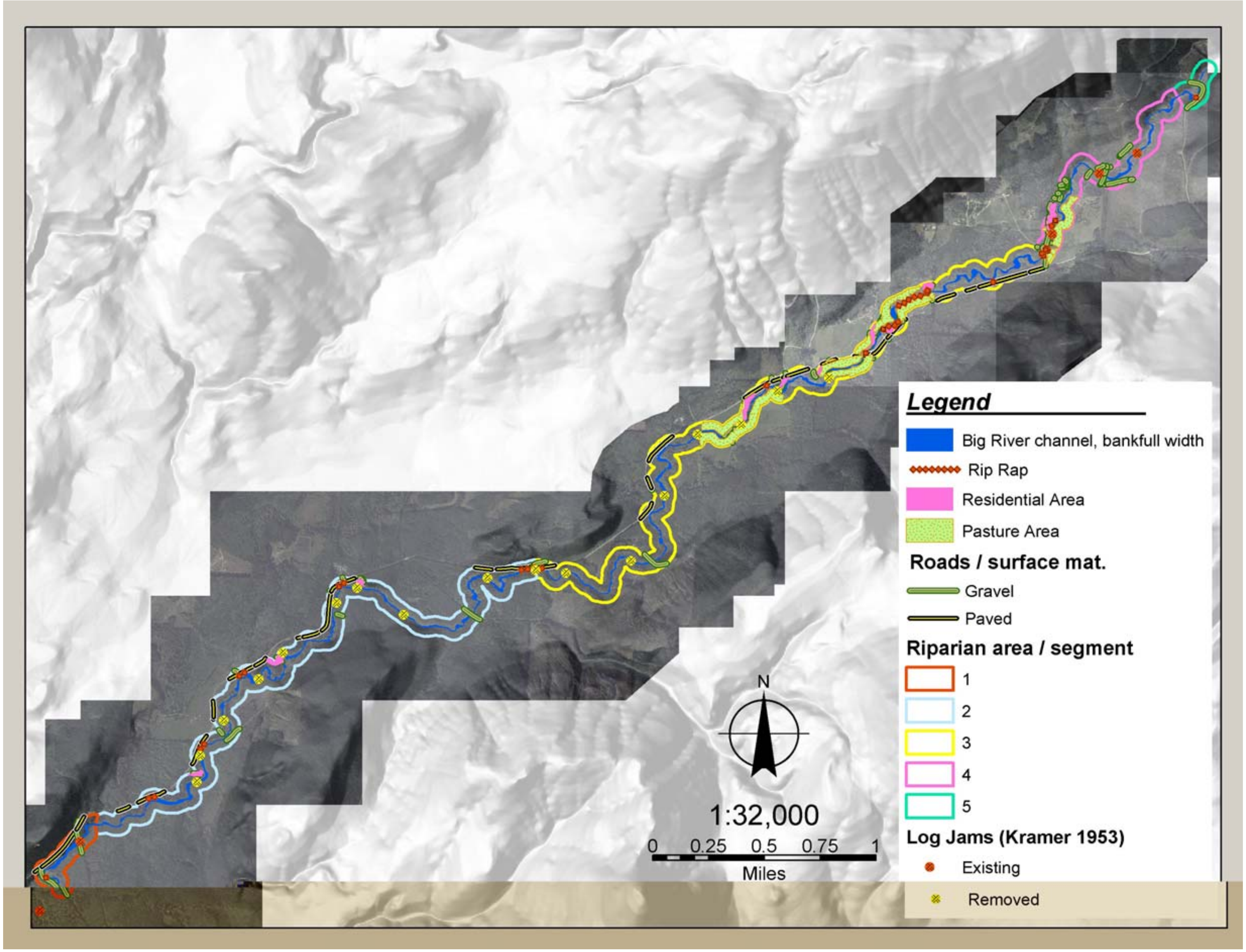

Figure 4.55. Riparian and floodplain alterations within 200 feet of the bankfull edge of Big River (source: channel-segments based on Haggerty and Ritchie 2004; alterations based on 2003 aerial photo review and miscellaneous observations).

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4.4.2.1.2 Road-Related Floodplain Impacts

The Hoko-Ozette Road roughly follows the original wagon trail to Lake Ozette from Clallam Bay. Lake Ozette was described as "*isolated*" by "*an almost impassible road*" in 1923-26 by Kemmerich (1945). The first "road" to Lake Ozette came in 1926 (Jacobs et al. 1996), but it was clearly still plagued with problems. Kramer (1953) noted that in December 1952 the Hoko-Ozette road was at times under water. Road construction, along with repeated "lifts" (which raise the level of the road to prevent flooding) and subsequent bank armoring along the mainstem of Big River, has restricted channel migration, LWD recruitment, and stream-floodplain interactions. Smith (2000) rated floodplain conditions along Big River as poor, based upon the quantity of riparian-adjacent roads.

The bankfull edge of Big River was delineated using georectified aerial photos of the Big River using ArcMap 9.0 (2003 color aerial photos). The zone within 200 feet of the river's bankfull edge was then examined for long-term alterations, such as roads, pastures, residential development, roads, and bank hardening. Road lengths within 200 feet of the river's bankfull edge were calculated for each road segment within each stream segment depicted in Figure 4.55. Total riparian road length based on 2003 aerial photos and 2005 WDNR GIS transportation layer is 6.1 miles. Interestingly, Smith (2000) found that there were 6.1 miles of riparian roads adjacent to the mainstem Big River, but the methods used to make this calculation are unclear. There are 8.8 miles of road per square mile of riparian area within 200 feet of the river's bankfull edge. The highest road densities within 200 feet of the bankfull edge were found in segment 1; where road density averaged 17.8 mi/mi^2 of riparian area (within 200 feet of river; Table 4.10).

Table 4.10. Road lengths within 200 feet of the bankfull edge of Big River and channel segment length.

Channel Segment	Segment Length (Mi.)	Road Length (Mi.)	Miles of Road/ Mile of River	Miles of Road/Sq Mi of Riparian Area
1	0.42	0.66	1.58	17.77
2	3.57	1.66	0.46	6.51
3	3.90	2.97	0.76	10.33
4	1.41	0.83	0.59	8.90

The Hoko-Ozette Road more or less parallels the river from Swan Bay Road (RM 1.55) to the confluence with Boe Creek (RM 9.43), a stream length of 7.9 miles (12.7 km). The Hoko-Ozette Road makes up more than 50% (3.06 miles) of the road length within 200 feet of Big River in segments 1 through 4. Channel segment 3 contains the greatest length of road, but is also the river's longest segment; nonetheless, riparian road density is high (10.3 mi/mi^2 of riparian area). Riprap or other bank hardening features can be found in the banks of Big River in at least 17 locations, preventing the river from migrating across its floodplain and in some cases preventing flood waters from accessing the floodplain. Nearly 4,100 feet of bank armoring structures have been identified along Big River. Several bridge crossings constrict the river and block flood flows from traveling on the floodplain (e.g. Swan Bay Road, 7402 Road).

4.4.2.1.3 Agricultural and Residential Floodplain Impacts

Agricultural development along the floodplain of Big River began in the late 19th century. Pioneer families worked for years to clear virgin forest into workable pasture. Kramer (1953) noted that erosion was evident along stream reaches in lower Big River that had been cleared for agricultural purposes. An inventory of riparian-adjacent pastures visible on color aerial photos (2003 flight) indicates that the majority of pasture land and residences occur within segments 2 through 4 (Trout Creek to just downstream of the Boe Family Bridge). Pasture and residential areas adjacent to the river within 200 feet of the bankfull edge were delineated and area and length by segments are reported in Table 4.11.

Table 4.11. Summary of Big River pasture and residential development within 200 feet of the bankfull edge.

Channel Segment ID	Segment Length (Miles)	Riparian Area Acres (within 200 ft of BF)	Pasture Area Acres	Residential Area Acres	Pasture and Residential Area as a Percentage of Total Riparian Area	Percent of River Length with Pastures or Residences within 200 Feet of BF Edge
1	0.42	23.8	na	na	0.0%	0.0%
2	3.57	162.7	1.5	1.5	1.8%	5.4%
3	3.90	184.0	20.2	3.9	13.1%	35.9%
4	1.41	59.3	6.6	2.2	14.8%	19.9%

Floodplain and riparian encroachment by pastures and residences was highest in segments 3 and 4, where 13 to 15% of the riparian area within 200 feet of Big River has been converted from forest to pasture or residential use. Approximately 20% of the length of the river between segment 1 and 4 has pastures or residences within 200 feet of the bankfull edge. Many but not all of the lowest quality habitat segments (based on pool quality and LWD abundance) in Big River were located adjacent to pastures and/or residences. Lack of shade and forested riparian habitat along these reaches can raise stream temperatures, reduce bank stability, increase sedimentation and bank erosion rates, and delay or prevent habitat from recovering to pre-disturbance conditions.

Figure 4.56 displays three aerial photos from 1994, 2000, and 2003 along a bend of Big River just upstream of the Hoko-Ozette Road. This section of Big River historically was affected by in-channel wood removal, riparian logging and clearing, channelization, and bank protection using old cars and rock. Big River responded to these changes by going through a series of channel evolution stages (Cederholm and Koski 1977; Simon and Hupp 1992; Simon 1995; Herrera 2006). First, the channel incised (degraded) due to confined banks and lack of bed roughness. Channelized reaches confined flood flows and accelerated velocities, aided by lack of LWD roughness. Channel incision was then followed by bank instability and the collapse of over-steepened banks. Bank failure was partially mitigated by bank armoring (cars and rock), but these measures were only effective locally where significant armor maintenance occurred (i.e., County road). Sediment that eroded from bank failure, channel incision, and other upland sources was transported downstream toward the bend in Figure 4.56, causing local channel aggradation. This aggradation, along with the lack of a functional riparian corridor and accelerated velocities from upstream channelized reaches, further accelerated bank erosion, which can be observed between 1994 and 2003. Over time, this section of Big River may again reach an equilibrium width, depth, roughness, and sediment transport capacity, but only after significant channel change (Simon and Hupp 1992; Simon 1995; Herrera 2006). Other sections of Big River both up and downstream of these photos show similar signs of channel evolution. However, these other reaches display earlier stages of channel evolution such as incision and bank collapse, which indicate the likelihood of significant future changes in channel stability.

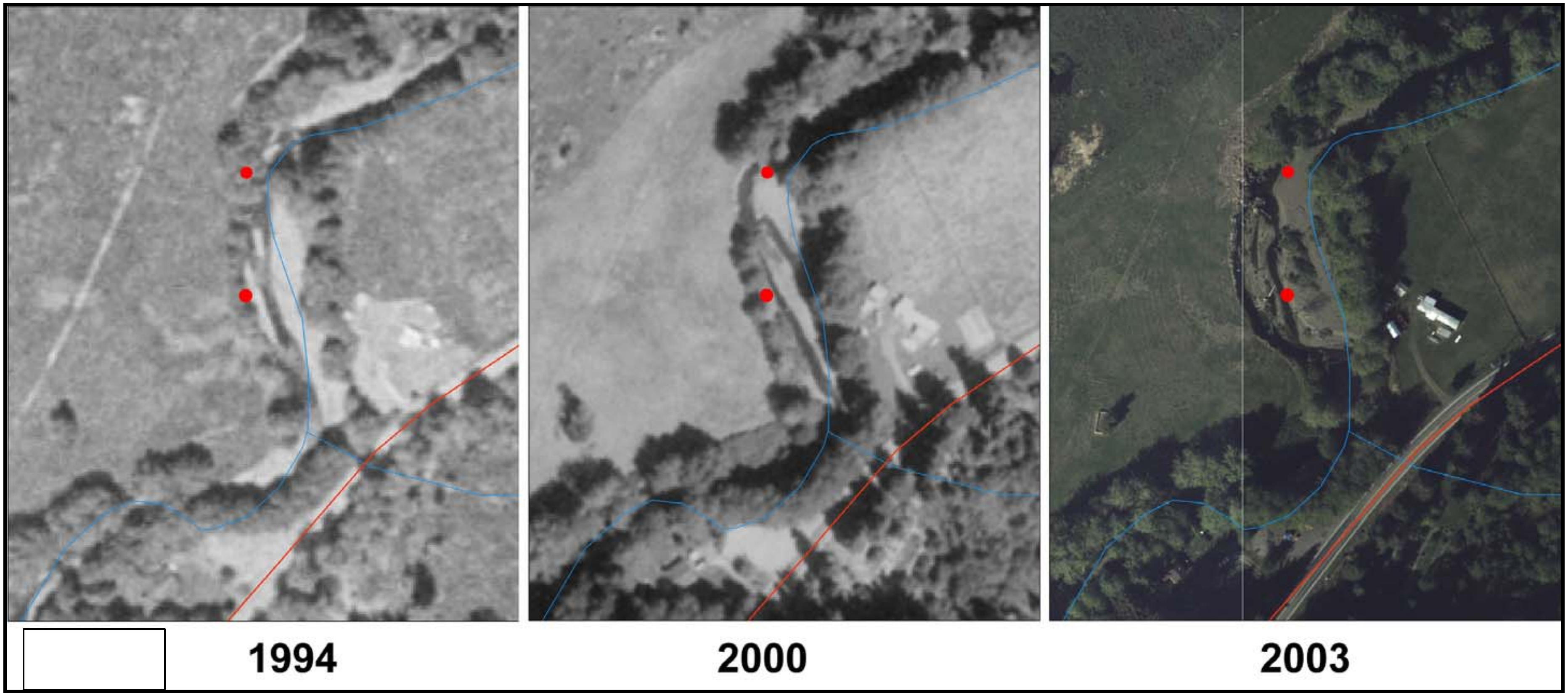

Figure 4.56. Nine-year photo history of Big River just upstream of the Hoko-Ozette Road bridge near confluence with Stony Creek. Photos illustrate progressive bank erosion and channel widening. (Note: Red dots are in the same position in each photo for reference.)

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4.4.2.1.4 Stream Clearing and Forestry Related Floodplain Impacts

Floodplain conditions and processes are believed to have been altered by LWD removal operations. Kramer (1953) describes clearing 3.5 miles of the river of logs and debris between approximately RM 2 and RM 6. The effects of LWD removal on river-floodplain interactions during this period are not well documented, but Smith (2000) cites channel incision as another floodplain problem in the watershed. Past clear-cut timber harvesting adjacent to Big River has resulted in degraded riparian conditions for most of the river's length. Wood removal, insufficient LWD recruitment, and channel incision have reduced floodplain connectivity in Big River throughout most of the stream length in segments 1 through 4.

4.4.2.2 Big River Riparian Conditions

Riparian conditions in Big River have been highly modified during the last 100 years. Along the mainstem of Big River nearly all (>95%) of the old growth riparian forest has been clear-cut once or converted to pasture land. Meyer and Brenkman (2001) reported that 84% of forest within the Big River watershed was 40 years old or less. Less than 1% of the forest within the watershed was classified as >80 years old (Meyer and Brenkman 2001). Smith (2000) rated the riparian conditions along Big River as poor to fair. However, the data used by Smith (2000) were limited to only a fraction of the river's length. Roads and/or pastures occupy miles of the river's historical riparian forests. Orthophotos taken in the summer of 2000 show that while the majority of riparian forests have been converted to stands dominated by red alder, some residual large conifer trees are still present scattered in small patches, as are some fairly continuous stream reaches dominated by stands of young- to medium-age conifers. Prior to timber harvest, riparian stands were composed of Sitka spruce, western hemlock, and western red cedar. Riparian stands in many of the primary tributaries to Big River are also degraded from pre-disturbance condition. Extensive stands of young to medium-aged red alders dominate the riparian forest along many of the tributaries.

Disturbed stream banks in many portions of Big River are infested with reed canary grass (*Phalaris arundinacea*) that has altered channel and floodplain interactions. Japanese knotweed (*Polygonum cuspidatum*) and Giant knotweed (*Polygonum sachalinense*) are rapidly colonizing portions of the lower mainstem (Figure 4.57. These non-native invasive plants are competing with native riparian plant colonization of stream banks and floodplains, which can alter floodplain and channel migration dynamics (e.g., floodplain roughness and sediment filtering efficiency; bank stability and erosion rates; and future LWD recruitment).

Figure 4.57. Photo depicting knotweed colonization along the mainstem Big River (source: photo from Clallam County Noxious Weed Control Board 2005).

4.4.2.3 Big River Pool and LWD Habitat Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 and are summarized in detail by Haggerty and Ritchie (2004). Field data were collected for almost 17,000 meters of channel within the mainstem of Big River and 16,000 meters in tributaries. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 33 habitat segments encompassing the 17,221 meters of channel in the mainstem (from the Swan Bay Road to the anadromous barrier). A total of 6,756 pieces of LWD were inventoried, of which 69%, 24%, and 7% were categorized as conifer, deciduous, and unknown respectively. Only slightly more than 1% of the pieces inventoried were classified as key pieces. Approximately 75% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.58 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in the Big River watershed.

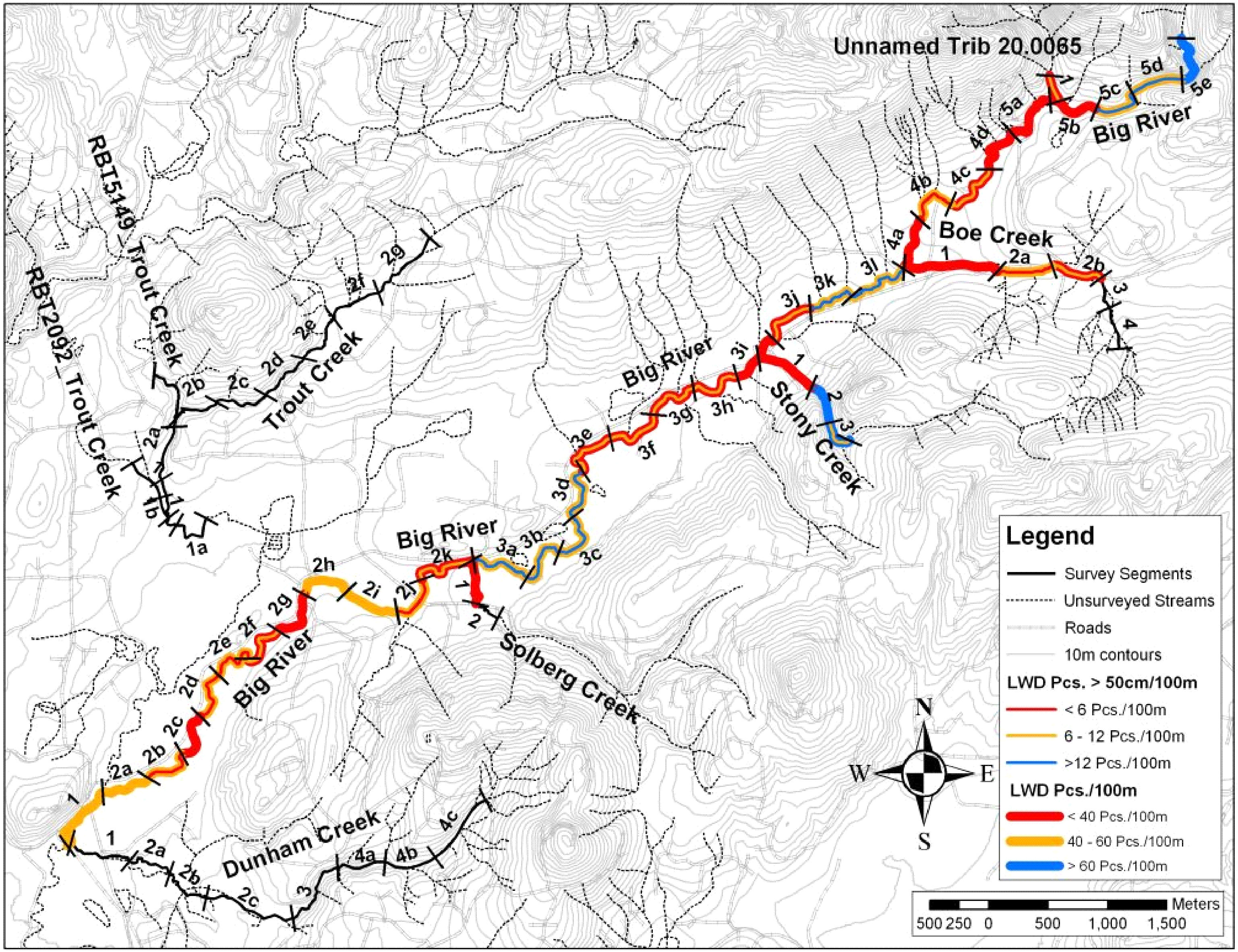

Figure 4.58. Big River watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

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Pool habitat conditions were evaluated for the same habitat segments mentioned above. A total of 399 pools were inventoried in the mainstem of Big River. The average maximum pool depth was 1.03 meters and average pool length was 29 meters. Typically the best pool habitats were associated with LWD (Haggerty and Ritchie 2004). Haggerty and Ritchie (2004) found that on average pools formed by the largest LWD were the deepest, longest, and most complex (Table 4.12). Pools formed by key-piece-sized LWD had an average maximum pool depth nearly 1.5 times greater than pools formed by LWD < 50cm diameter. Haggerty and Ritchie (2004) rated several pool habitat condition variables including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.59 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Big River watershed.

Table 4.12. Big River Pool Attributes Grouped by Primary Pool Forming Agent (source: Haggerty and Ritchie 2004).

Pool Forming Agent	Number of Pools	Avg Max Pool Depth	Avg Res. Pool Depth	Avg Pool Length	Avg No. of Pieces of LWD Forming Pools	0-5% Woody Cover in Pool	6-20% Woody Cover in Pool	>20% Woody Cover in Pool
Key LWD	37	1.31	1.08	41.7	5.1	36%	28%	36%
L+ LWD	94	1.11	0.93	32.0	3.8	57%	30%	13%
L/L- LWD	83	1.14	0.90	31.4	3.3	49%	38%	13%
Medium LWD	63	0.92	0.70	22.6	2.1	53%	31%	16%
Small LWD	2	0.81	0.58	15.45	2.0	50%	50%	0%
Free-formed	98	0.86	0.70	22.5	0.0	86%	13%	1%
Free-formed w/LWD	19	0.96	0.79	33.8	1.4	74%	16%	11%

Riparian forest alterations including bank armoring, channelization, agricultural development, riparian logging, and invasive non-native vegetation have decreased the near- and long-term LWD recruitment potential along almost the entire length of Big River. Stream reaches with the lowest LWD piece counts and poorest pool quality habitat were most often adjacent to the most significantly impacted riparian and floodplain areas. In-stream LWD removal and decreased recruitment are likely responsible for the degraded LWD conditions observed in Big River. The low gradient nature of Big River appears capable of developing free-formed pools independent of LWD. However, the habitat and LWD data summarized by Haggerty and Ritchie (2004) illustrate the importance of large and key-piece-sized LWD in forming high quality habitat features. Recent recruitment of small and medium size LWD appears incapable of producing the same habitat complexity as seen in those habitats formed by LWD > 50 cm diameter.

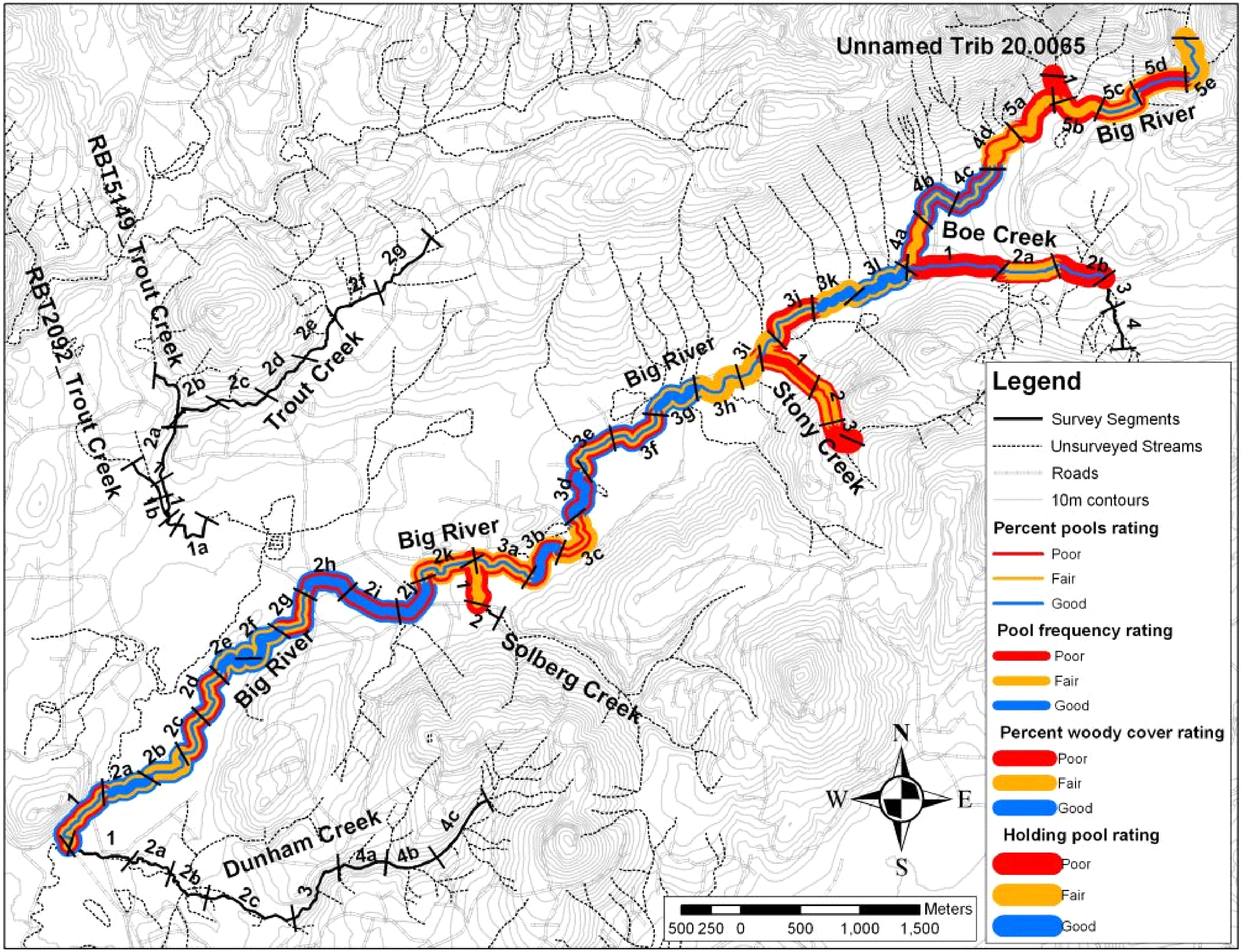

Figure 4.59. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Big River watershed (source: Haggerty and Ritchie 2004).

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4.4.2.4 Big River Streambed and Substrate Conditions

Limited data are available regarding Big River substrate conditions. Kramer (1953) described the Big River as having almost a continuous bed of gravel from the Hoko-Ozette Road Bridge to about a mile from the mouth. Bortleson and Dion (1979) reported that Big River contained approximately 351,000 ft^2 (32,600m^2) of spawnable habitat in the mainstem. McHenry et al. (1994) sampled substrate conditions in two Big River stream reaches, segment 2h (Figure 4.58) and segment 5b. McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in spawning gravels for the lower sample site of 15.7% (wet-sieve equivalent; dry-sieve method equal to 9.5%) and 17.3% (wet-sieve equivalent; dry-sieve method equal to 8.5%) in the upper site. Martin Environmental (1999) rated spawning conditions good in all segments surveyed (2.5 miles [4.1 km] of channel) in 1998, based upon the quantity of spawnable habitat in riffles and pool tail-outs. Smith (2000) rated fine sediment levels in spawning gravels "poor" in Big River.

The current (2006) estimated road density for the Big River watershed is 6.4 mi/mi^2 (4.0 km/km^2; Ritchie, unpublished data). High road densities in the Big River watershed likely contribute to the high levels of fine sediment observed in spawning gravel. Debris flows in the upper watershed are also a source of both coarse and fine sediment. Herrera (2006) described the upper reaches of Big River as appearing to be overwhelmed by coarse sediment inputs. They found that portions of river flowed exclusively through subsurface sediments in the channel at low flow (these areas correspond to segments 3i, 3j, and 4a in Figure 4.58).

4.4.2.5 Big River Water Quality

Water quality data have been collected intermittently in Big River since the mid-1970s to present. Early data collected by Bortleson and Dion (1979) are very limited for Big River. Until recently the most comprehensive water quality dataset was summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 21, 1993 through November 30, 1994. Table 4.13 contains a summary of water quality sampling data for Big River from Meyer and Brenkman (2001).

Table 4.13. Summary of water quality data collected in Big River from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	3.5	6.0	22.6	7.3	0.7
Maximum	16.8	7.1	70.0	11.6	185.0
Mean	10.0	6.7	49.0	9.7	23.7
Number Months Sampled	n=21	n=16	n=21	n=17	n=15

In recent years, additional water quality data have been collected near the confluences of Boe, Solberg, and Trout creeks in Big River. Makah Fisheries Management began collecting water quality data in Big River in January 2004. Data collection is ongoing and is typically collected monthly, but sampling frequency increases to approximately twice per month during spring and summer months Table 4.14 summarizes the results of water quality sampling by MFM in Big River. Water quality conditions measured by MFM are roughly within the same range of conditions measured by Meyer and Brenkman (2001). Some of the minor differences between datasets can be attributed to increased sample frequency during May, June, and July in the MFM dataset.

Table 4.14. Summary of water quality data collected from three sites in Big River from January 15, 2004 through October 7, 2005 (source: MFM, unpublished data).

		Stream Temperature (°C)	pH	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/l)	Turbidity (NTU)
Big River Below Trout Creek	**Minimum**	5	5.9	29.4	8.5	0
	Maximum	15.9	7.2	61.1	16	177
	Mean	10.2	6.7	50.3	11.3	12
	Number of Days Sampled	n=30	n=30	n=30	n=30	n=30
Big River Above Solberg Creek	**Minimum**	5.4	6.2	0	9.1	0
	Maximum	15.4	7.3	60	16.1	61.6
	Mean	10.3	6.8	49.3	11.6	3.5
	Number of Days Sampled	n=31	n=31	n=30	n=30	n=31
Big River Above Boe Creek	**Minimum**	5.3	6.6	0	8.5	1
	Maximum	16.5	7.3	59.3	20.4	13
	Mean	10.4	7	46.6	11.8	1.5
	Number of Days Sampled	n=31	n=31	n=30	n=30	n=31

Additional stream temperature monitoring was also conducted using a thermograph and data logger during the summer of 1993 (Meyer and Brenkman 2001). However, the thermograph became exposed, rendering summertime temperature data invalid for Big River (Meyer and Brenkman 2001). Klinge (1991) also investigated stream temperatures in Big River. During the summer of 1990, daily stream temperatures averaged > 16°C for 37 days between July 6 and August 17 (Klinge 1991). The peak temperature recorded was 18.3°C (Klinge 1991). Additional stream temperature data were also collected in Big River during the following years: 1997, 2002, 2003, and 2004. Figure 4.60 illustrates daily maximum and 7-day moving daily average maximum stream temperature for the lower Big River (RM 1.7- near Trout Creek) during the summers of 1997 and 2004. Stream temperatures exceeded 16°C on 25 and 52 days during monitoring in 1997 and 2004 respectively. Temperatures exceeding 18°C were recorded on 18 days in 2004 and none in 1997 (MFM unpublished stream temperature data).

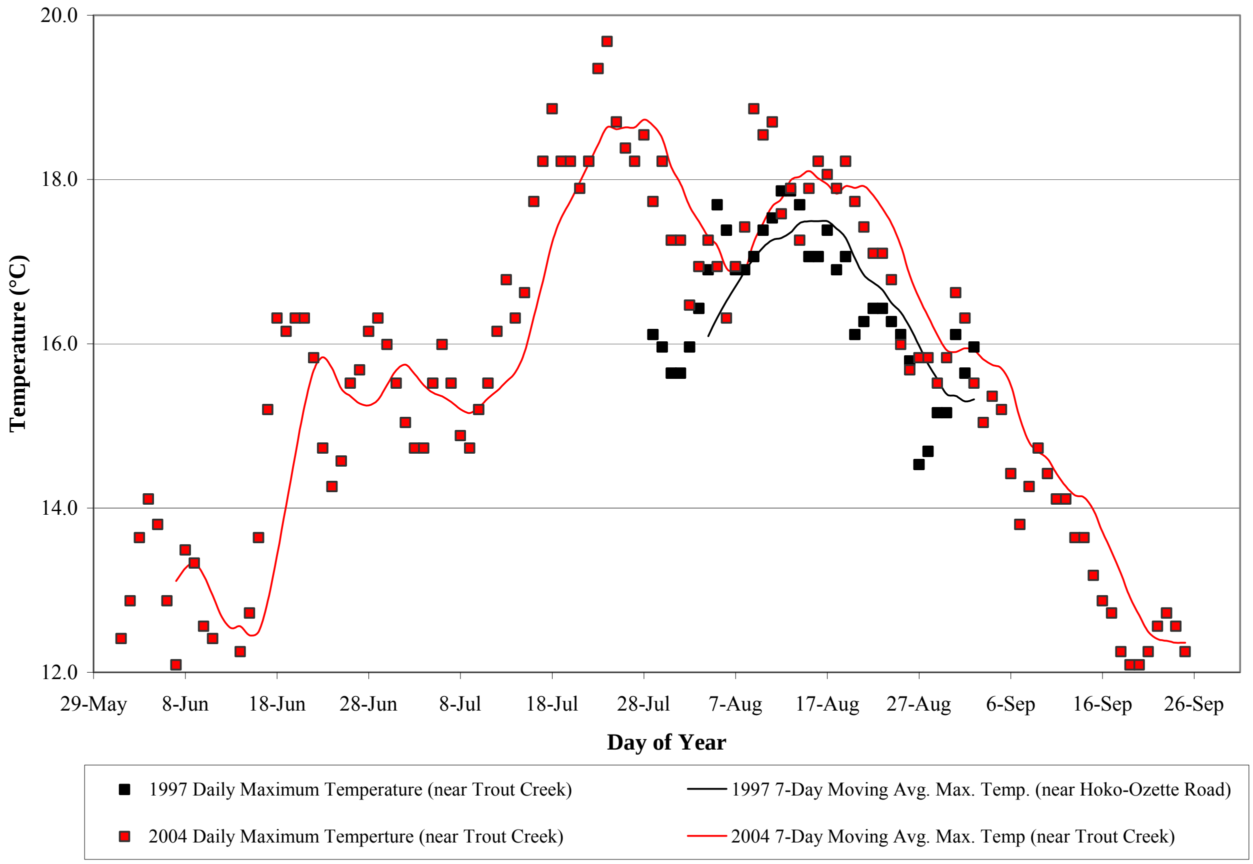

Figure 4.60. Big River daily maximum and 7-day moving average maximum stream temperature near Trout Creek during the summers of 1997 and 2004 (source: MFM, unpublished stream temperature data).

Temperature data were collected at sites near Solberg Creek and near Boe Creek during the summers of 2002 and 2003. However, the thermograph deployed near Boe Creek malfunctioned so there is no data available for upstream/downstream temperature comparisons in 2003. Figure 4.61 illustrates daily maximum and 7-day moving daily average maximum stream temperature for Big River at RM 4.8 and RM 8.1 during the summer of 2002. Stream temperatures exceeded 16°C on 9 days at RM 4.8 (near Solberg Creek) and 34 days at RM 8.1 (near Boe Creek). Temperatures exceeding 18°C were recorded on 2 days in 2002 and only at the site near Boe Creek (MFM unpublished stream temperature data). In 2003 stream temperatures at RM 4.8 exceeded 16°C on 22 days, but never exceeded 18°C (peak temp 17.9°C).

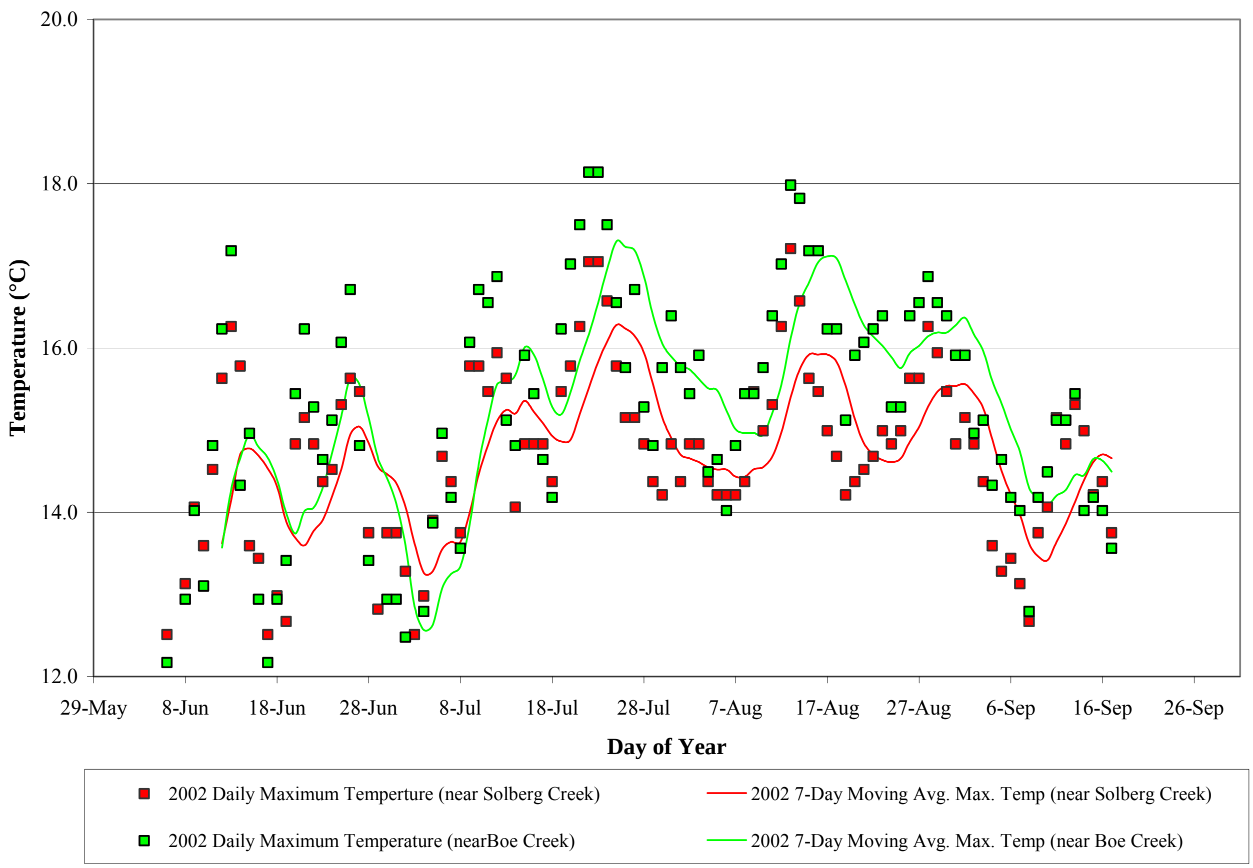

Figure 4.61. Big River daily maximum and 7-day moving average maximum stream temperature near Solberg and Trout creeks during the summer of 2002 (source: MFM, unpublished stream temperature data).

In addition to stream temperature data, the Makah Tribe has collected bacteria data (fecal coliform) in Big River from 2002 to present. Water was collected on a total of 16 days for the site near Solberg Creek, 11 days near the site near Trout Creek, and 9 days for the site near Boe Creek. All but one of the samples collected at Solberg Creek contained higher bacteria concentrations than samples collected near Boe Creek (Figure 4.62). The limited data suggests that there is a source of bacteria entering Big River between Boe and Solberg Creek. These data further suggest that Big River does not comply with Washington State Water Quality Standards within the reach between Boe Creek and Solberg Creek (greater than 10% of samples exceed 100 colonies per 100 ml). Sites upstream and downstream of Solberg Creek appear to comply with water quality standards, since the geometric mean of all samples is less than 50 and not more than 10% of samples exceed 50 colonies/100ml.

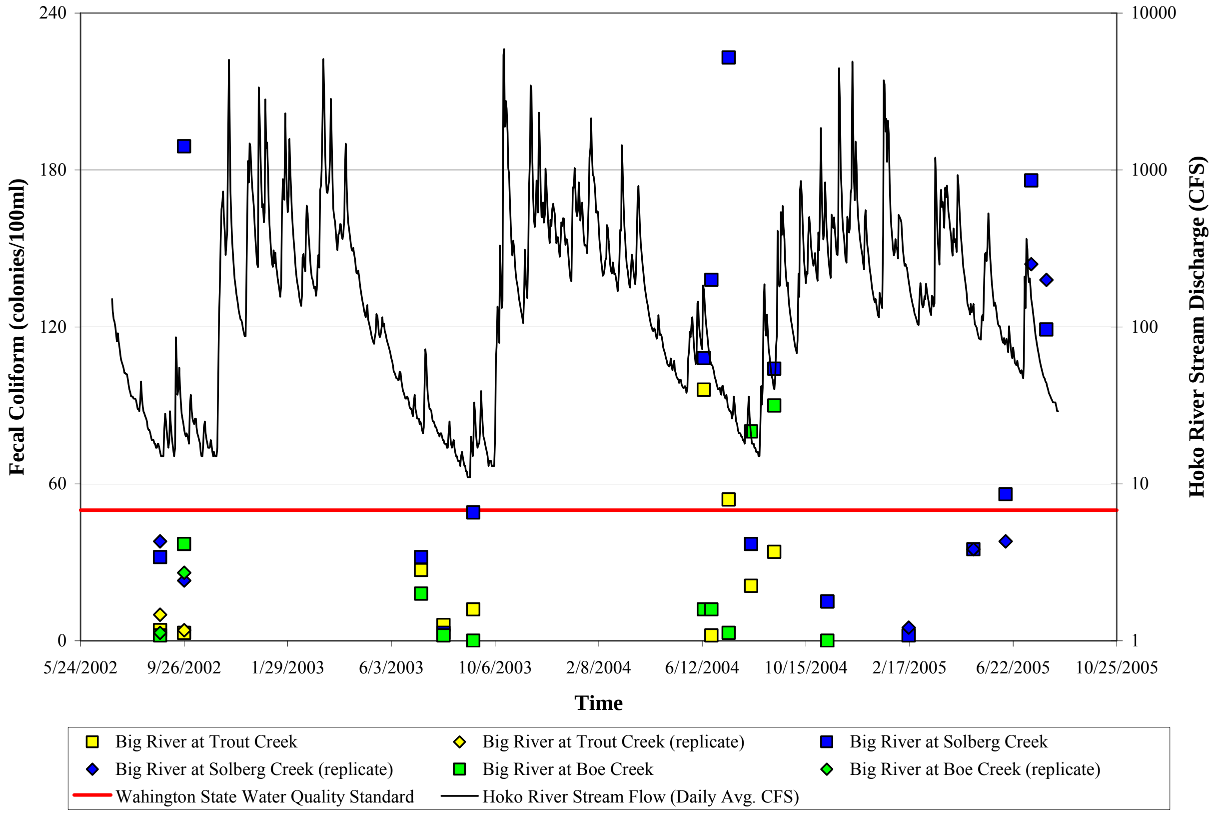

Figure 4.62. Fecal coliform concentrations from three sites along Big River from 2002 to 2005, contrasted with Hoko River streamflow data and Washington State Water Quality Standards (source: USGS streamflow data; MFM, unpublished water quality data).

Meyer and Brenkman (2001) expressed additional concern regarding pH, dissolved oxygen, and turbidity levels in Big River. Extremely high turbidities of 185 NTUs were recorded by Meyer and Brenkman (2001). They concluded that water quality conditions for fish were marginal in Big River. Smith (2000) rated the water quality "poor" for Big River based upon stream temperatures consistently exceeding the Washington State Water Quality Standards. Jacobs et al. (1996) suggested that turbidity levels exceeded the threshold at which feeding juvenile salmonids are negatively impacted but voiced no concern over the dissolved oxygen, pH, and conductivity levels recorded by Meyer and Brenkman (2001). Timber harvest and log haul during the wet season often contribute to the high turbidity levels observed during rainfall events.

Makah Fisheries Management installed a continuous submersible turbidity sensor on Big River on State Land on 2/8/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed down an open-bottom, vertically porous pipe attached to the bridge structure in well mixed water. The sensor is attached to floats within the pipe, allowing the sensor to adjust vertically with stage changes, assuring the sensor viewing area is off the channel bed during high flows. The sensor (Forest Technology Systems DTS-12 turbidimeter) measures in Nephelometric Turbidity Units (NTU), is factory calibrated annually in Formazin standards of known NTU, has a built-in wiping mechanism to self clean the sensor before every measurement, and measures 100 turbidity samples every 15 minutes and returns the median, mean, minimum, maximum, BES, and variance, in addition to water temperature. Field maintenance consists of periodic equipment checks that consist of cleaning the sensor with soap and water, removing any major debris from the sensor, wiper, boom, or pipe, and flushing the structural components.

Median turbidity values (15-minute) are plotted in Figure 4.63, along with discharge. Turbidity (and SSC) peaks in Big River usually last for less than a day, depending on the length of the flood pulse event. During small discharge events, turbidity rises sharply on the rising limb of the discharge hydrograph, but then falls more rapidly than discharge on the falling limb of the hydrograph. This is even more evident in Figure 4.64 for a summer storm in Big River, where the turbidity peak precedes the discharge peak and then recedes at a higher rate than discharge. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). Thus, for most common discharge events, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources.

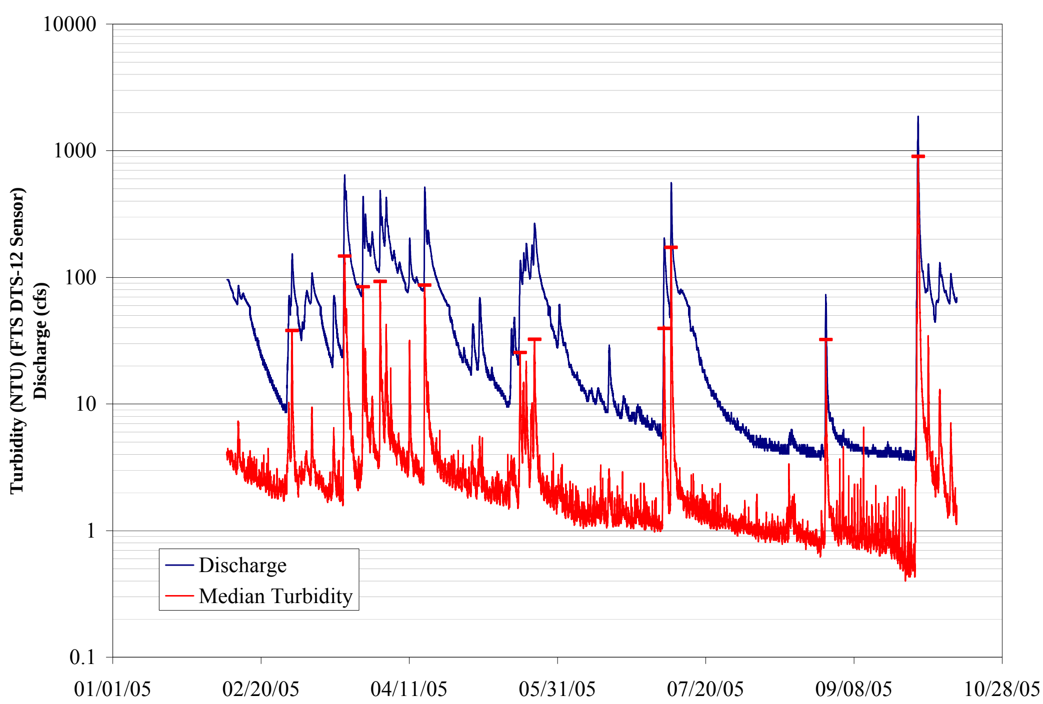

Figure 4.63. Preliminary results from continuous turbidity readings and provisional stream discharge data for Big River (source: MFM, unpublished data).

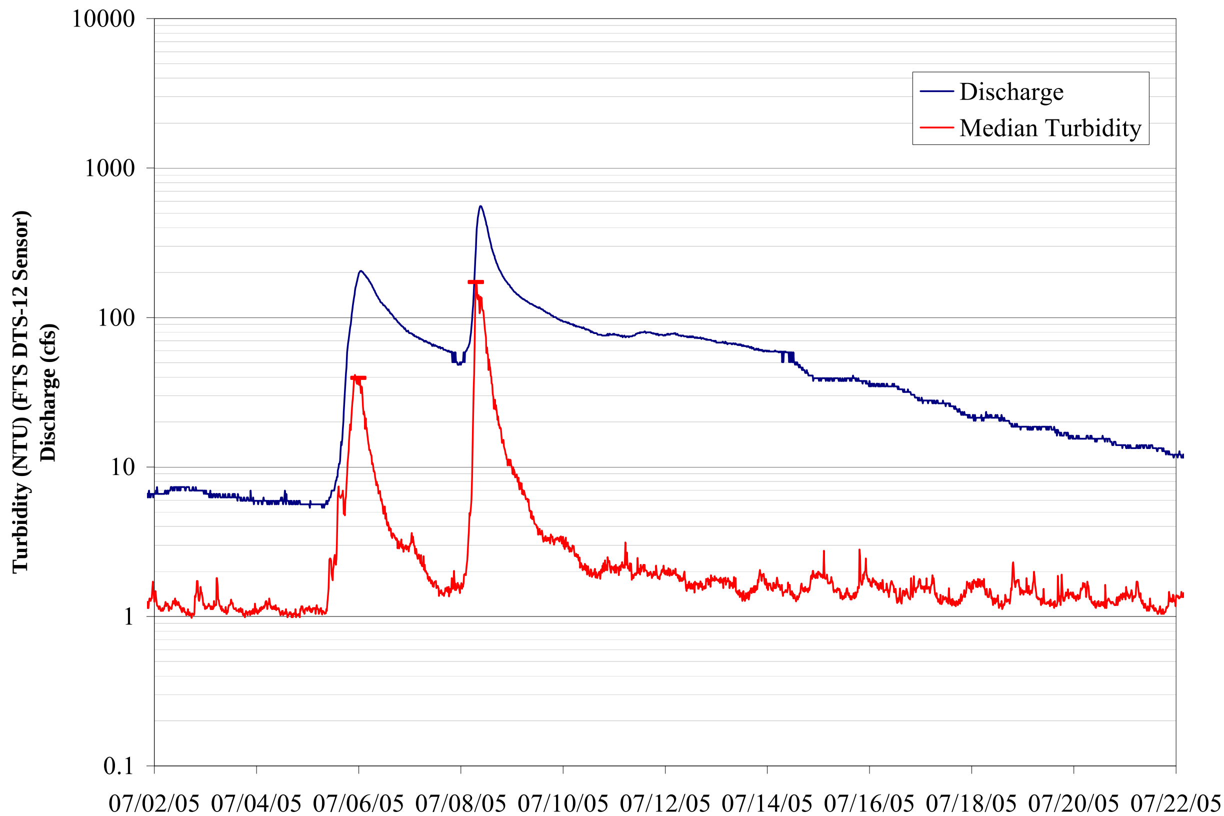

Figure 4.64. Big River turbidity and discharge data for July 2005 storm events (source: MFM, unpublished data).

However, the relationship between turbidity (and SSC) and discharge varies between storm events, as can the degree that hysteresis loops are present in the relationship. A single relationship (or curve) between turbidity (or SSC) and discharge during a single storm event indicates an unlimited sediment supply with transport dependent on available flow energy. Clockwise hysteresis loops in the turbidity (or SSC) and discharge relationship indicates a depletion of the sediment supply during an event, with wider loops indicating degree of depletion (Nistor and Church 2005). As observed in most of the tributary storm event data (to date) in the Ozette watershed, turbidity (and SSC) are dependent on the supply of fine sediment, as indicated by the dominance of clockwise hysteresis loops (Figure 4.65). However, during the few larger discharge events measured in Big River, Umbrella Creek and Coal Creek, the turbidity (or SSC) and discharge relationships display largely one single relationship, indicating that at relatively high discharges there is an unlimited supply of fine sediment within these stream reaches and a breakdown of supply limitation (Figure 4.65).

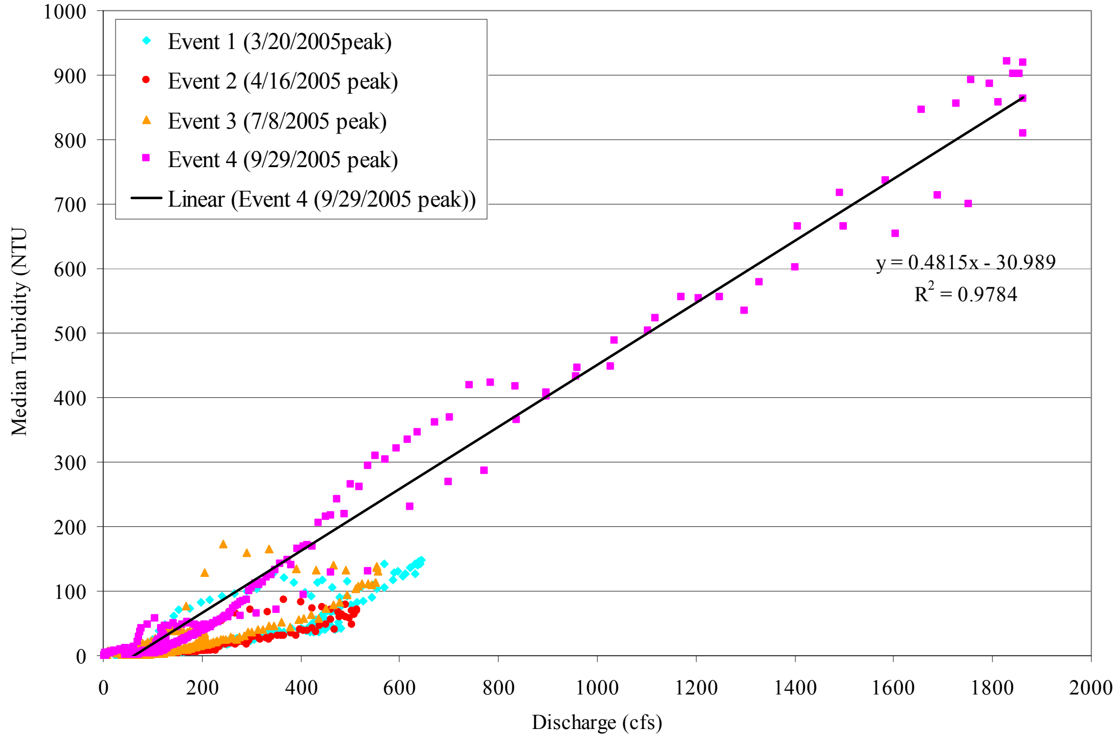

Figure 4.65. Relationship between discharge and median turbidity during four Big River storm events (source: MFM, unpublished data).

Few spatial water quality data are available for the Big River watershed, including turbidity. Three water quality sampling sites exist on Big River, oriented longitudinally along the mainstem. During a relative small discharge event on 2/4/05, turbidity measurements were taken approximately every hour at these three sites during the rising and falling limbs of the hydrograph (Figure 4.66). Measurements were made using a calibrated Hydro Lab water quality multi-probe. Peak turbidities were lowest near the upstream end of the Big River alluvial valley and increased in the downstream direction. This pattern of increasing turbidity in the downstream direction could be a result of increasing turbidity (or SSC) input between these sampling points from tributary sources (washload) or from re-suspension of the finer fraction of bed material deposited locally. While both sources are likely responsible for this longitudinal increase in turbidity, the lower end of Big River has evolved into a fine sediment aggrading reach dominated by silt and sand deposition from local and upstream sources, following initial gravel bed conditions in the 1950s (Kramer 1953) and channel incision for several decades after the 1950s (Herrera 2006).

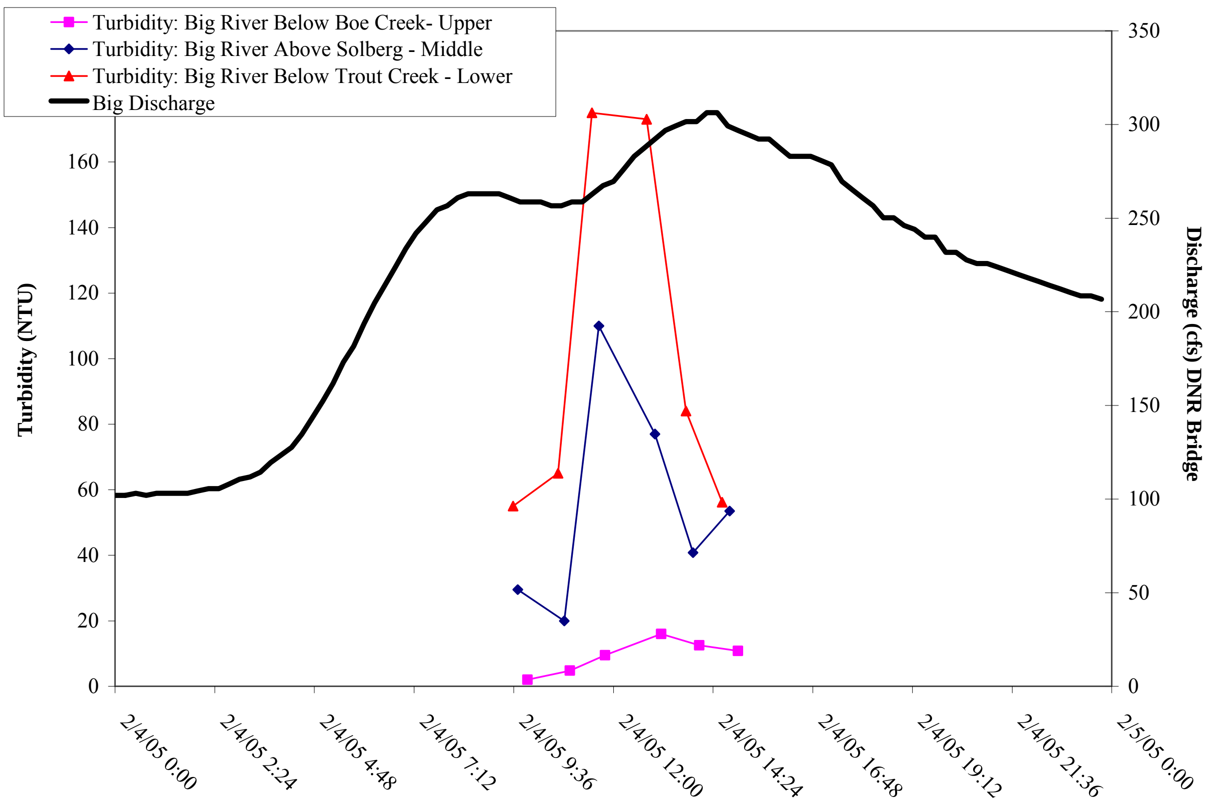

Figure 4.66. Longitudinal changes in turbidity in Big River during February 2005 precipitation event (source: MFM, unpublished data).

4.4.2.6 Big River Hydrology and Streamflow

Makah Fisheries Management installed a continuous stream gage on Umbrella Creek at the Hoko-Ozette Road County Bridge on 11/03/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s-cfs) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional).

Instantaneous discharge at Big River for water years 2004 and 2005 is plotted in Figure 4.54. In addition to these data, exceedence probabilities (% of time average flow exceeds a given discharge) are displayed that define the 90%, 49%, and 11% exceedence values. These values were calculated by the U.S. Bureau of Reclamation (USBOR) as part of water resource investigations for the Water Resource Inventory Area (WRIA) 20 Watershed Planning Process (Lieb and Perry 2004). Regression equations were developed using monthly total streamflow at Big River and monthly total streamflow at the nearby Hoko River gage (USGS 12043300). These synthesized data only represent monthly averaged flows (cubic feet per second) and exceedence of those average flows, but are very useful for defining both the general flow regime (hydrograph magnitude, duration, timing) and variability over time (1962 to 1999). Note that at any given point in time, the instantaneous discharge is much higher or lower than the average monthly flow.

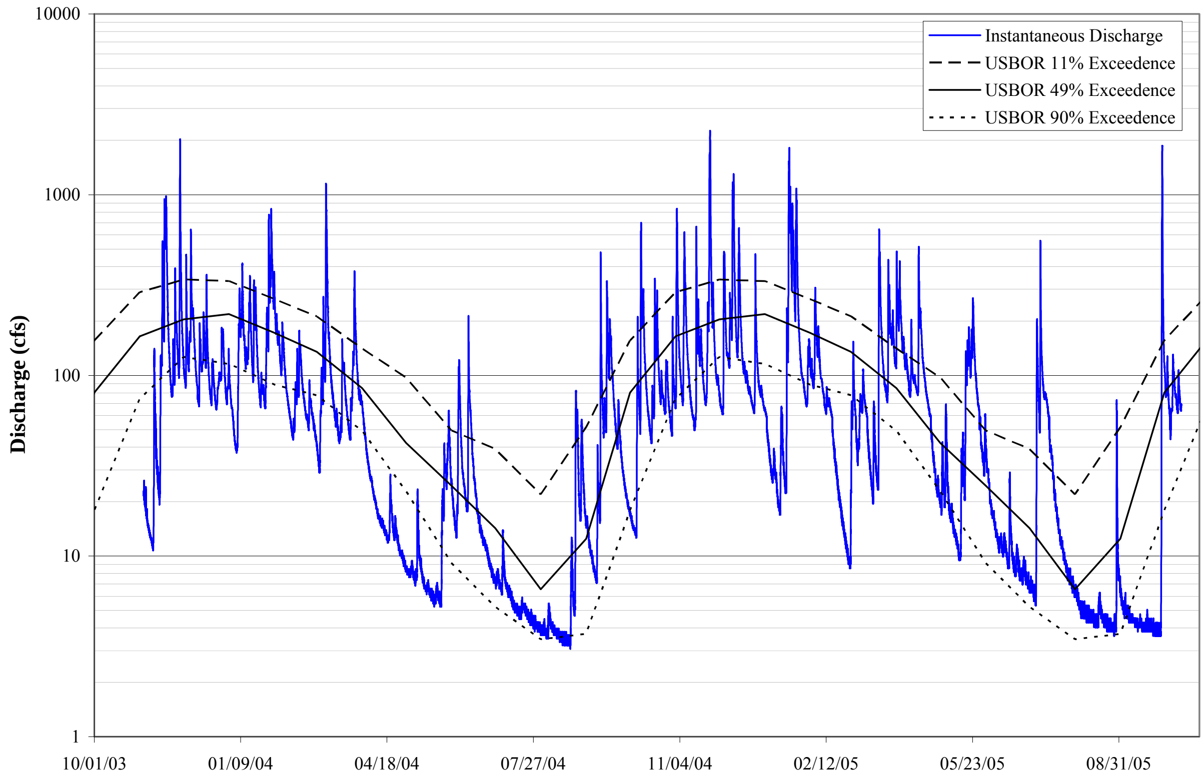

Figure 4.67. Provisional Big River discharge data plotted with USBOR synthesized monthly average streamflow exceedence curves (source: MFM unpublished data; Lieb and Perry 2004).

4.4.3 Crooked Creek

Crooked Creek is the second largest tributary to Lake Ozette (Table 1.1). Crooked Creek enters the lake along the northeast shoreline between Swan Bay and Boot Bay (Figure 3.16). Crooked Creek drains approximately 12.2 mi^2 (31.6 km^2) and includes two main tributaries. The two largest tributaries are the North and South Fork Crooked Creek, with drainage basin areas of 3.3 mi^2 (8.4 km^2) and 4.5 mi^2 (11.6 km^2) respectively. Crooked Creek flows from east to west, draining mostly low relief terrain underlain by Pleistocene age glacial drift and till deposits. From the confluence with the South Fork, the mainstem loses only about 20 meters in elevation over of a distance of more than 6 kilometers, resulting in a highly sinuous channel (i.e. Crooked Creek). Just upstream from the South Fork is the confluence between the mainstem and the North Fork. The mainstem upstream of the North Fork becomes quite small, with a basin area < 0.8 mi^2 (2.07 km^2).

4.4.3.1 Crooked Creek Floodplain Conditions

No formal assessment of Crooked Creek floodplain conditions has been conducted. A review of maps and aerial photos indicates that Crooked Creek lacks an extensive stream adjacent road network. There is no agricultural development within the watershed, as almost the entire watershed is managed for commercial timber production. Floodplain impacts are presumed to be moderate or low. Localized channel incision averaging 3.3 feet (1m) was documented by Herrera (2006) in the lower 2.5 mi (4 km) of Crooked Creek. Relic wood was functioning in portions of this section of Crooked Creek to maintain fair floodplain connectivity.

4.4.3.2 Crooked Creek Riparian Conditions

Riparian conditions in Crooked Creek vary greatly depending on location. Meyer and Brenkman (2001) report that 69% of the forest within the Crooked Creek watershed is 40 years old or less and 53% of the forest is less than 11 years old. Timber harvest operations started much later in Crooked Creek than in Umbrella Creek and Big River and substantially more old growth forest and riparian areas are unharvested. Nearly 17% of the watershed's forests were classified as > 80 years old (Meyer and Brenkman 2001). Unfortunately, the forest adjacent to almost the entire length of mainstem has been clear-cut. Smith (2000) rated the riparian conditions along the mainstem Crooked Creek as "fair" to "poor." A very small buffer was left along the south side of the middle mainstem when the area was clear-cut and this area was classified as "fair" by Smith (2000). The majority of mainstem riparian areas are now dominated by red alder. Riparian conditions are much better in the lower reaches of the South and North Forks. The South Fork flows through a stand of old growth forest before entering the mainstem. Most of the forest along the North Fork has been clear-cut, but stream side buffers were left along the lower half of the stream. The mainstem upstream of the North Fork flows mostly through a remnant forest below the anadromous barrier.

4.4.3.3 Crooked Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 and 2000 and are summarized in detail by Haggerty and Ritchie (2004). Field data were collected for almost 6,900 meters of channel within the mainstem Crooked Creek and 3,200 and 740 meters in the North and South forks respectively. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected within five habitat segments encompassing almost 3,000 meters of channel. Approximately 1,453 pieces of LWD were inventoried and 83%, 11%, and 5% were

characterized as conifer, deciduous, or unknown, respectively. Of the three largest tributaries to Lake Ozette, Crooked Creek had the lowest proportion of LWD categorized as deciduous. Key-piece-size LWD made up almost 4% of the LWD inventoried, but small and medium size LWD still made up 80% of all LWD inventoried.
Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.68 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in the Crooked Creek watershed

Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables, including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.69 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Umbrella Creek watershed. A total of 107 pools were inventoried in the mainstem of Crooked Creek. Within the 3,000 meters of channel surveyed, the bankfull width of the mainstem changed dramatically. Below the South Fork the mainstem has an average width of about 15 meters.

Upstream of the South Fork the mainstem width is reduced to about 10 meters and upstream of the North Fork BFW averages only 5 to 6 meters. Variable stream width makes it difficult to draw straightforward connections between LWD influences and pool attributes. Nonetheless, the highest quality pools were most often associated with the largest LWD. Pools formed by key pieces were 68% deeper and twice as long as pools formed by medium or small LWD and free-formed pools without LWD. Key piece LWD represented only 4% of the LWD but formed 30% of the total pool habitat by length. Slightly more than 82% of the pools formed by LWD were formed by LWD > 50cm diameter, even though these made up only 20% of the total LWD documented (Haggerty and Ritchie 2004). Smith (2000) rated LWD conditions as “poor” in parts of the South Fork but good in the mainstem, North Fork, and parts of the South Fork.

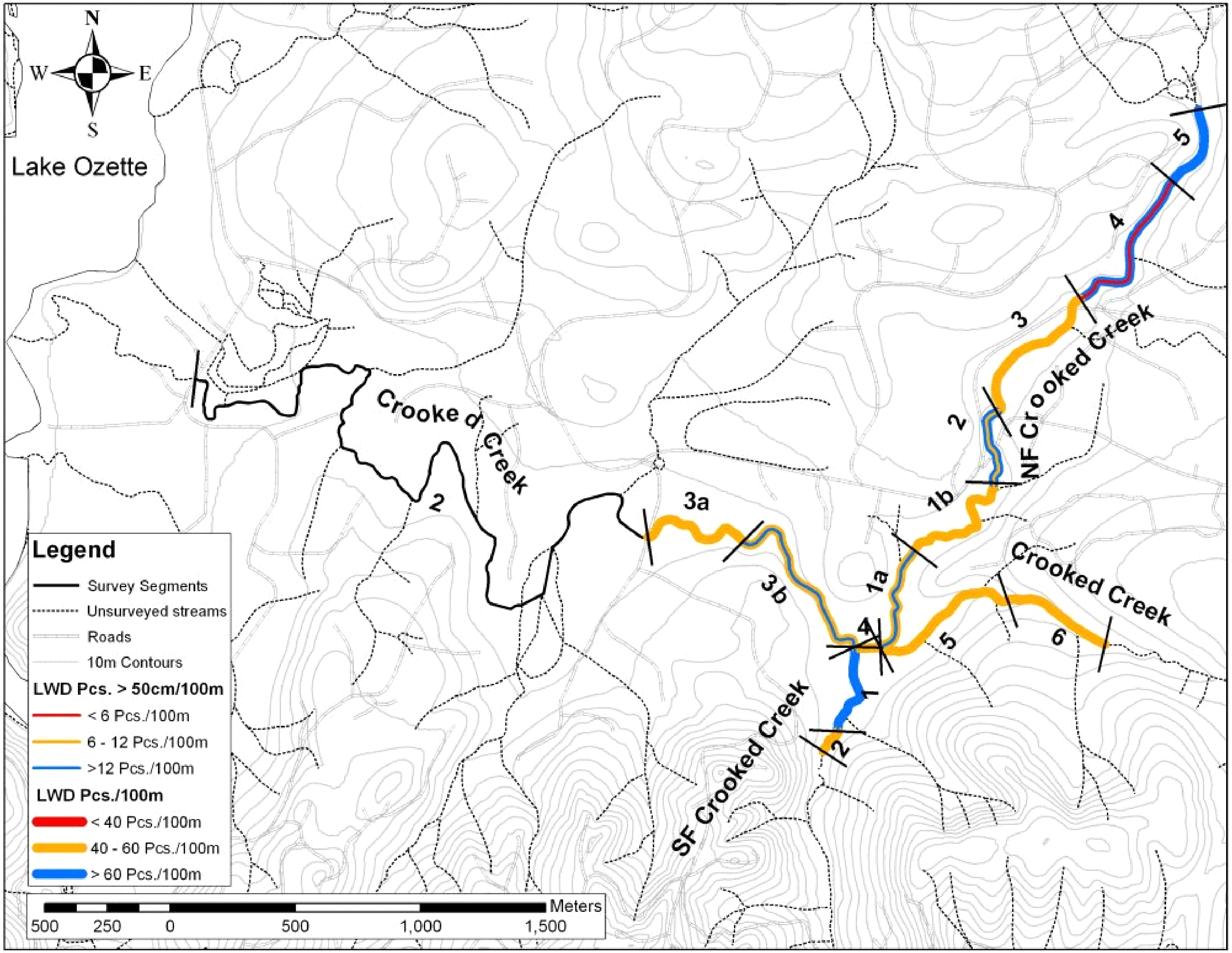

Figure 4.68. Crooked Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

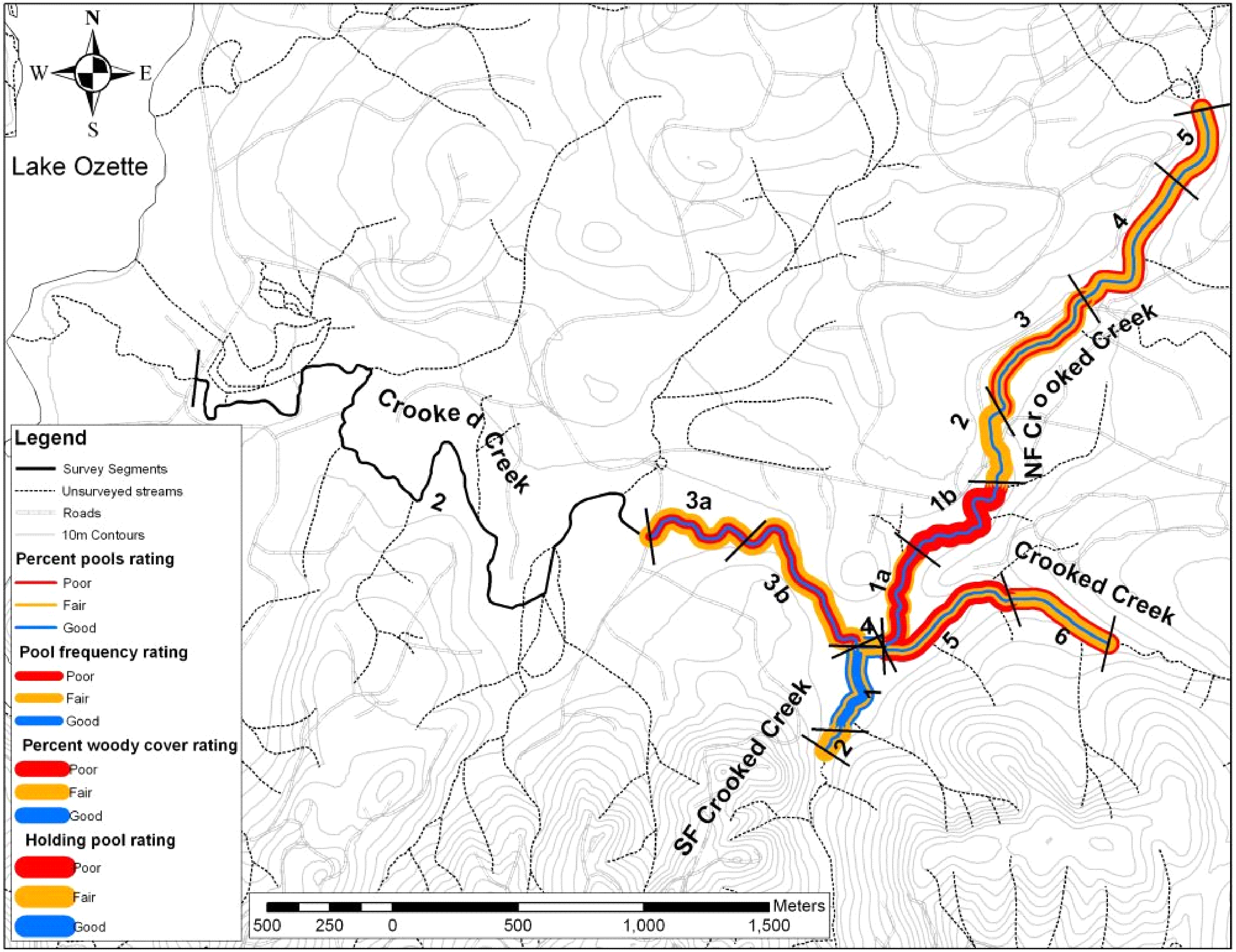

Figure 4.69. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Crooked Creek watershed (source: Haggerty and Ritchie 2004).

4.4.3.4 Crooked Creek Streambed and Substrate Conditions

Limited data are available regarding Crooked Creek substrate conditions. McHenry et al. (1994) sampled substrate conditions at one site in the mainstem (segment 3b; Figure 4.69), as well as at one site in both the South (segment 1; Figure 4.69) and North (segment 1b; Figure 4.69) forks. McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in spawning gravels for the mainstem site of 14.0% (wet-sieve equivalent; dry-sieve method equal to 7.3%). McHenry et al. (1994) reported fine sediment levels in the North and South forks were 23.9% (wet-sieve equivalent; dry-sieve method equal to 13.0%) and 16.7% (wet-sieve equivalent; dry-sieve method equal to 9.3%), respectively. Martin Environmental (1999) rated spawning conditions good in the mainstem segment surveyed (1.1 mi/1.8 km of channel) in 1998, based upon the quantity of spawnable habitat in riffles and pool tail-outs. Smith (2000) rated fine sediment levels in spawning gravels "poor" in the North and South forks and fair in the mainstem. The current (2006) estimated road density for the Crooked Creek watershed is 5.7 mi/mi^2 (3.5 km/km^2; Ritchie, unpublished data). The high road densities in the Crooked Creek watershed likely contributed to the moderate to high levels of fine sediment observed in spawning gravels. Additional substrate characterization for Crooked Creek can be found in Haggerty and Ritchie (2004).

4.4.3.5 Crooked Creek Water Quality

Water quality data for Crooked Creek are even more limited than for Umbrella Creek and Big River. Bortleson and Dion (1979) collected a very limited quantity of water quality data in Crooked Creek, which included temperature point samples, discharge, and specific conductivity. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 20, 1993 through November 30, 1994. Table 4.15 contains a summary of water quality sampling data for Crooked Creek from Meyer and Brenkman (2001).

Table 4.15. Summary of water quality data collected in Crooked Creek from July 20, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	pH	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/l)	Turbidity (NTU)
Minimum	2.6	5.7	17.9	7.5	0.0
Maximum	16.1	7.2	53.2	12.0	41.0
Mean	10.2	6.5	38.2	10.0	8.4
Number Months Sampled	n=20	n=15	n=20	n=16	n=15

Additional stream temperature monitoring was also conducted using a thermograph and data logger during the summer of 1993 and 1994 (MFM unpublished data; Meyer and

Brenkman 2001). A review of available temperature data for lower Crooked Creek indicates that data were collected during four summers from 1990 through 1997. Temperature data were collected on a total of 335 days between June 1 and September 30 (1990-1997). Maximum annual temperatures were recorded between July 9 (1990) and August 5 (1997; Table 4.16). The 7-day moving average maximum daily temperatures observed from 1990 through 1997 are depicted in Figure 4.70. Figure 4.71 depicts the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C.

Table 4.16. Summary of maximum daily stream temperature observations from lower Crooked Creek during temperature monitoring from 1990 through 1997 (source: MFM, unpublished data; Klinge 1991; Meyer and Brenkman 2001).

Year	Number of Days Sampled (6/1 to 9/30)	Date of Peak Temperature	Peak Temp (C)	Date of Peak 7-Day Moving Average Daily Maximum Temp.	Peak 7-Day Mov. Avg. Daily Max. Temp. (C)
1990	122	7/9	18.3	8/8	17.8
1993	72	8/4	20.7	8/7	19.2
1994	107	7/20	20.3	8/15	19.3
1997	34	8/5	18.1	8/10	17.5

Figure 4.70. Lower Crooked Creek 7-day moving average daily maximum stream temperature 1990-1997 (source: MFM, unpublished stream temperature data; Klinge 1991; Meyer and Brenkman 2001).

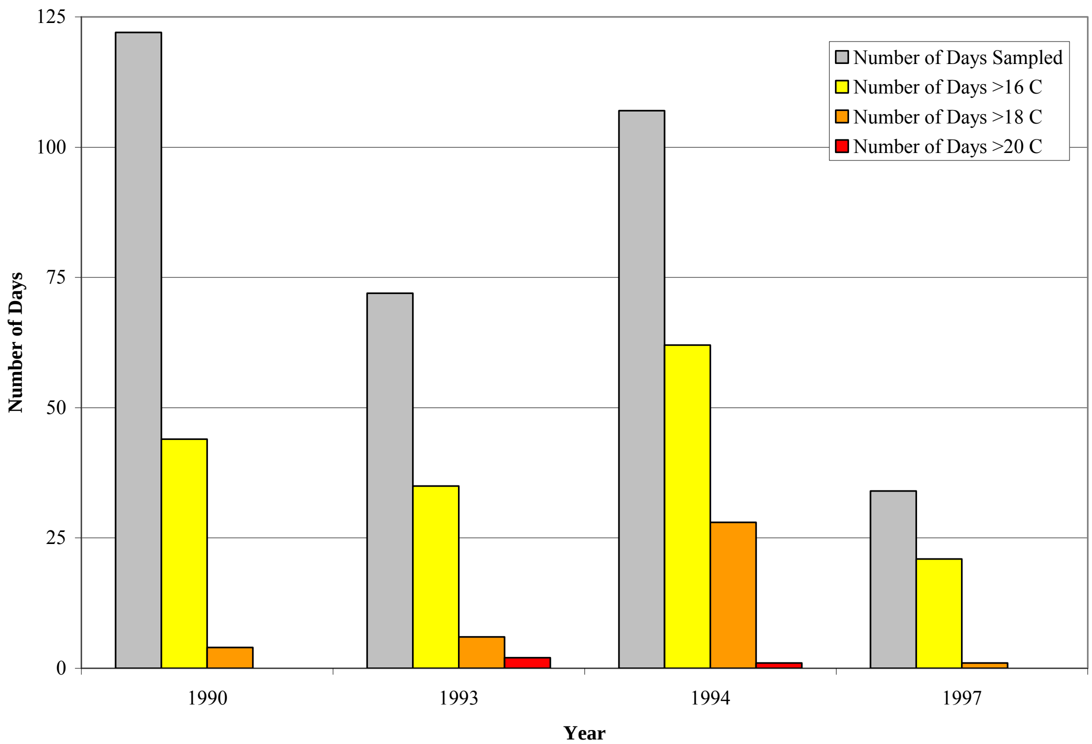

Figure 4.71. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20 °C in Lower Crooked Creek from 1990 through 1997 (source: MFM, unpublished stream temperature data; Klinge 1991; Meyer and Brenkman 2001).

Maximum daily stream temperature exceeded 16°C on 162 days (48% of the days sampled) between June 1 and September 30 (1993-1997). During the warmest period of summer, July 15 through August 15 data were collected on 106 days. Stream temperatures exceeded 16°C on 89 days (84% of the days sampled). Stream temperature exceeded 18°C on 46 days (28% of the days sampled). Stream temperatures exceeding 20°C were recorded on 3 days (<1% of the days sampled). Over 78% of the days where maximum stream temperature was greater 18°C were between July 15 and August 15 (this period represented 32% of the time period for which data were collected). Only 9 (<22%) stream temperatures greater 18°C were recorded outside of the July 15 to August 15 period (68% of the data were collected outside of this time period).

Crooked Creek pH levels were documented by Meyer and Brenkman (2001) to exhibit the greatest variation in the tributaries sampled, ranging from 5.7 to 7.2. Turbidity levels were nearly an order of magnitude less during the November 30, 1994 storm event than those observed in Big River and Umbrella Creek. Meyer and Brenkman (2001) concluded that water quality conditions were marginal in Crooked Creek. Specific water quality concerns raised by Meyer and Brenkman (2001) were related to dissolved oxygen levels below 8.0 mg/l and pH levels below 6.0. Smith (2000) rated the water quality "poor" for Crooked Creek based upon stream temperatures consistently exceeding the

Washington State Water Quality Standards. Jacobs et al. (1996) voiced no concern over the dissolved oxygen or pH levels in Crooked Creek.

Makah Fisheries Management installed a continuous submersible turbidity sensor on Crooked Creek on 9/25/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed from a bank-mounted boom that reaches out over the channel and places the sensor toward the center of the channel in well-mixed water (methods used are similar to those in Big River and Umbrella Creek. For additional details see Sections 4.4.1.5 and 4.4.2.5).

Median turbidity values (15-minute) are plotted in Figure 4.72, along with discharge. Turbidity (and SSC) peaks in Crooked Creek usually last for less than a day, depending on the length of the flood pulse event. Turbidity rises sharply on the rising limb of the discharge hydrograph and falls more rapidly than discharge on the recession limb. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). Thus in Crooked Creek, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources.

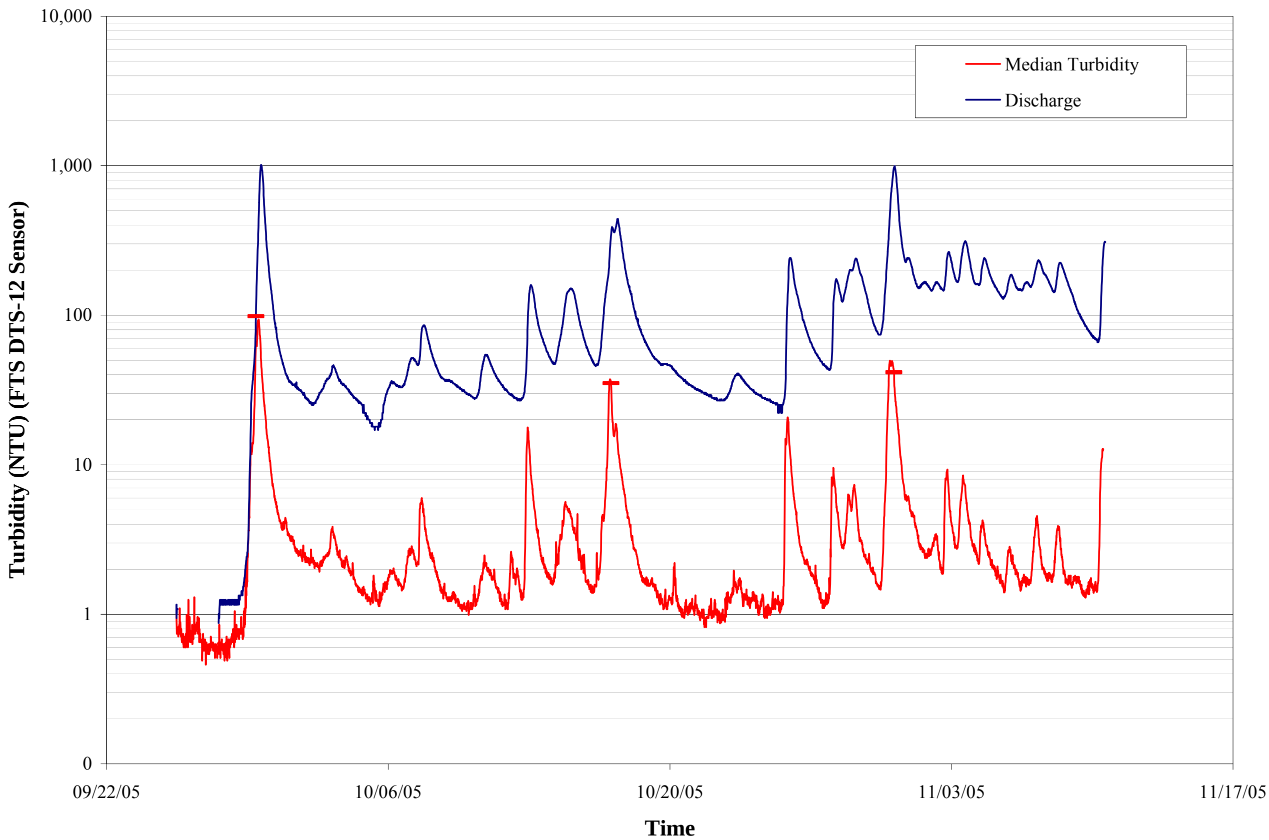

Figure 4.72. Preliminary results from continuous turbidity readings and provisional stream discharge data for Crooked River (source: MFM, unpublished data).

4.4.3.6 Crooked Creek Hydrology and Streamflow

Makah Fisheries Management installed a continuous stream gage on Crooked Creek at the 5830 Road Bridge on 12/19/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional). Instantaneous discharge at Crooked Creek for water years 2004 and 2005 are plotted in Figure 4.73.

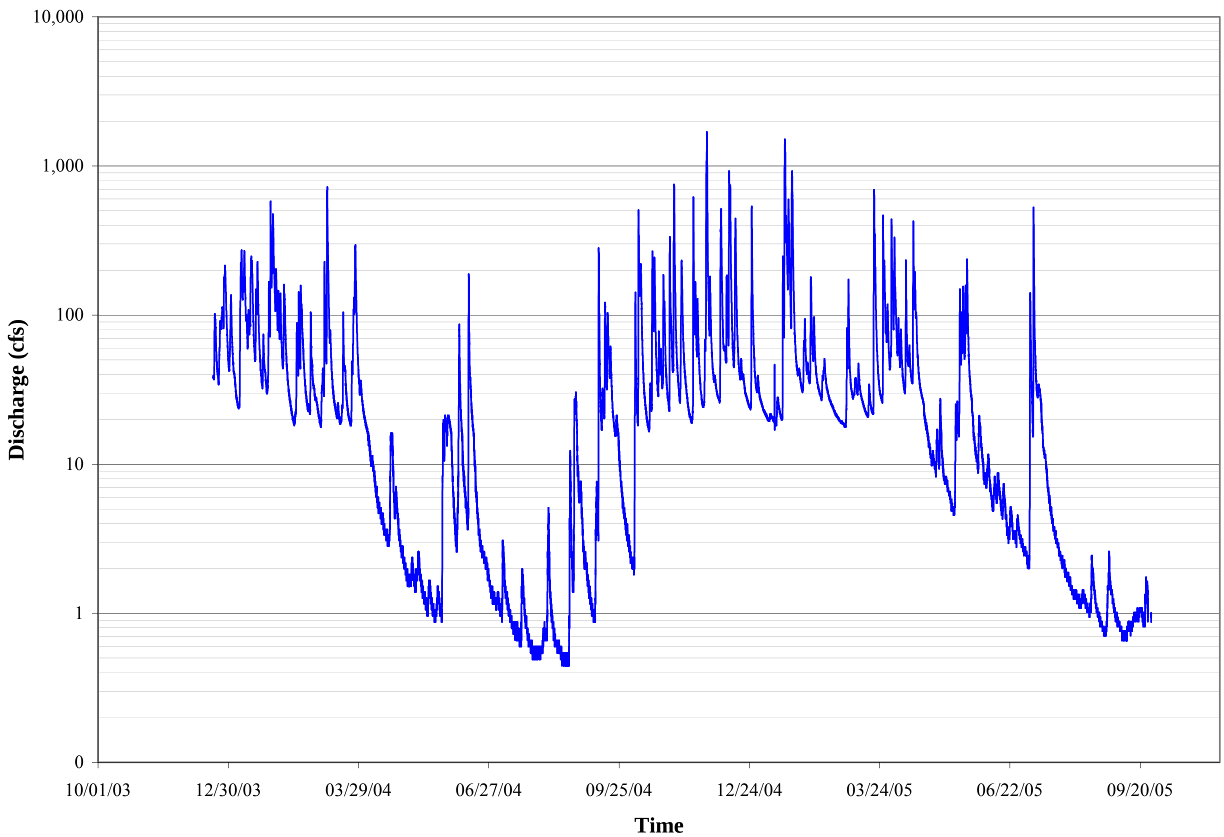

Figure 4.73. Provisional Crooked Creek discharge data (source: MFM, unpublished data).

4.4.4 Coal Creek

Coal Creek is a right-bank tributary to the Ozette River that enters just downstream from the lake's outlet (Figure 3.16). Coal Creek is the fourth largest tributary in the Ozette watershed and the largest tributary to the Ozette River. The Coal Creek watershed drains approximately 4.57 mi^2 (11.84 km^2) and consists of the mainstem of Coal Creek, two main unnamed tributaries (20.0050 and LBT 22,772), and several smaller tributaries. The mainstem is a predominantly south flowing stream. The western and southern portions of the watershed are underlain with Pleistocene age glacial till and drift deposits with very low relief (maximum elevations of about 200-300 feet above sea level). The headwaters of Coal Creek are located in the northeastern portion of the watershed and are underlain by Oligocene-Eocene aged marine sedimentary rock units. Approximately 95% of the watershed is privately owned (Herrera 2006); the remaining land is owned by WDNR. Nearly 100% of the watershed is managed for industrial forestry and has been clear-cut at least once.

4.4.4.1 Coal Creek Floodplain Conditions

No comprehensive, field-based assessment of Coal Creek floodplain conditions has been conducted, but it seems clear that floodplain connectivity is problematic in the lower reaches of Coal Creek. Smith (2000) does not provide an overall rating for floodplain conditions in Coal Creek, but cites J. Freudenthal as stating that channel incision is a problem in Coal Creek. Herrera (2006) reported that the lower 1.25 miles (2.0 km) of Coal Creek has undergone approximately 3.3 feet (1m) of channel incision over the last 50 years. Herrera (2006) found significant evidence of floodplain disconnection in lower Coal Creek, as well as the presence of an inset floodplain, which they suggested was an indicator that the channel may be re-stabilizing. Herrera (2006) also found a number of distributary channels near the confluence with the Ozette River and suggested that historically, when a more dynamic deltaic floodplain existed, prior to channel incision, these channels would have transported high flows toward Lake Ozette. Herrera (2006) concluded that much of the channel incision in Coal Creek is likely a response to wood removal from the Ozette River.

4.4.4.2 Coal Creek Riparian Conditions

Riparian areas in Coal Creek are highly altered from their historical conditions. Nearly 100% of the old growth riparian forest has been clear-cut along the mainstem and tributaries. Forest age structure is similar to that seen in other Ozette sub-basins where nearly all the timber stands are less than 50 years old. Orthophotos taken in the summer of 2000 reveal that most of the riparian areas are dominated by young stands of red alder. Very few if any residual large conifer trees are present in the watershed. Lower Coal Creek flows through a patch of large second growth forest and contains a mix of both conifer and hardwoods. The upper mainstem consists of riparian forests dominated by conifer. Prior to timber harvest, riparian forests were primarily composed of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). Residual in-channel LWD in some areas provides evidence of the massive trees that once grew along Coal Creek. Riparian conditions in the two primary tributaries to Coal Creek are also highly degraded from the pre-disturbance condition. Mixed stands of young to medium age forests dominate the riparian composition of the main tributaries to Coal Creek and some of its larger tributaries.

4.4.4.3 Coal Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 and 2000 in Coal Creek and are summarized in detail by Haggerty and Ritchie (2004). Habitat data were collected in over 4.8 miles (7.8 km) of channel within the mainstem of Coal Creek and 1.5 miles (2.4 km) in the two largest tributaries. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 14 habitat segments encompassing the 4.8 miles of channel in the mainstem. A total of 5,488 pieces of LWD were inventoried, of which 73%, 26%, and 1% were categorized as conifer, deciduous, and unknown respectively. Only 1% of the pieces inventoried were classified as key pieces. Approximately 89% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.74 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in Coal Creek watershed. Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables, including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.75 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Coal Creek watershed. A total of 348 pools were documented in the mainstem of Coal Creek. The highest quality pools were most often associated with the largest LWD pieces. Key-piece-size LWD made up only 1% of the total LWD abundance and had a frequency of only 0.07 pieces/CW, but formed 15% of the total pool habitat (by length). Large (Key, L+, and L/L-) LWD made up 11% of the total LWD abundance, had a frequency of about 0.63 pieces/CW, and formed 51% of the total pool habitat.

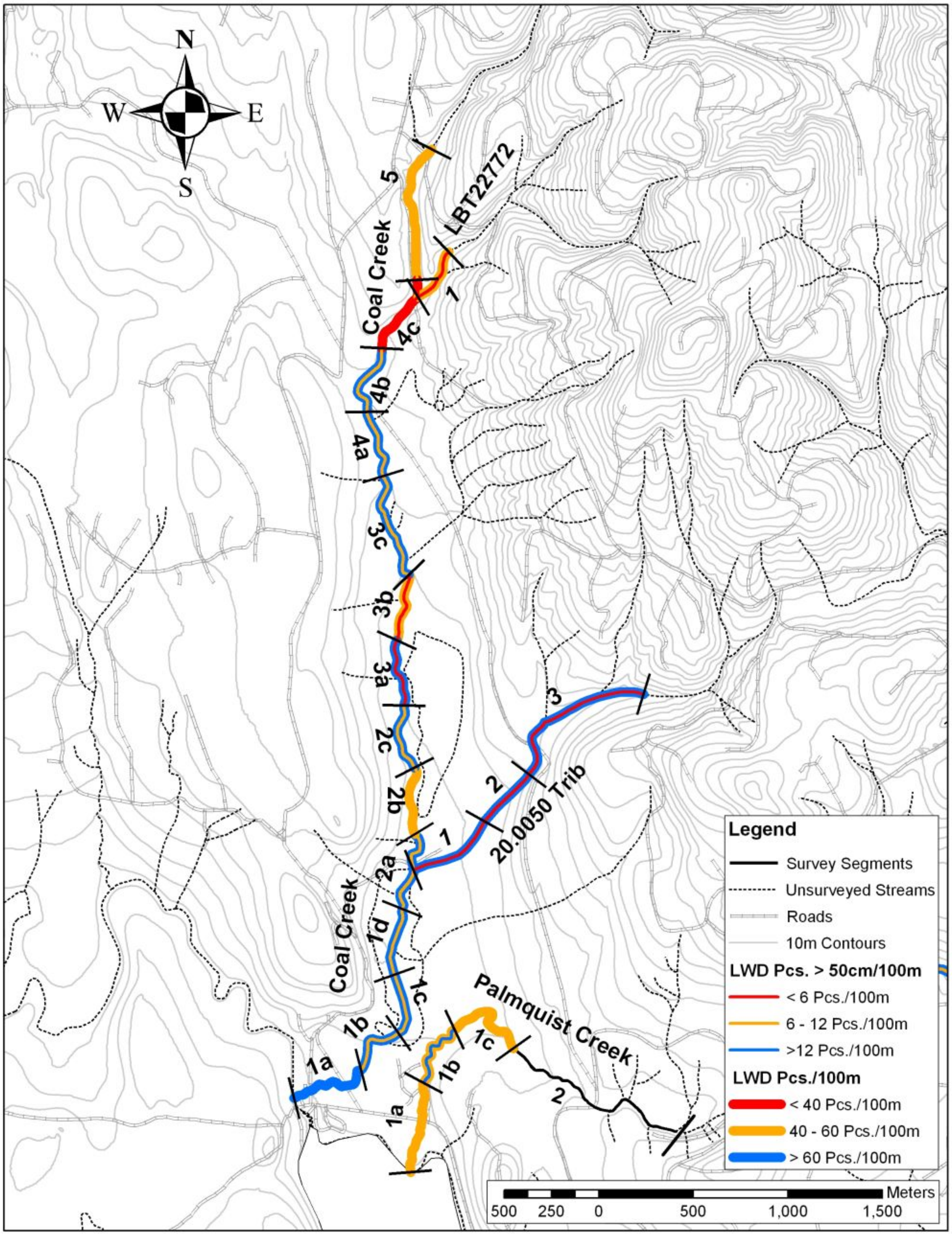

Figure 4.74. Coal Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

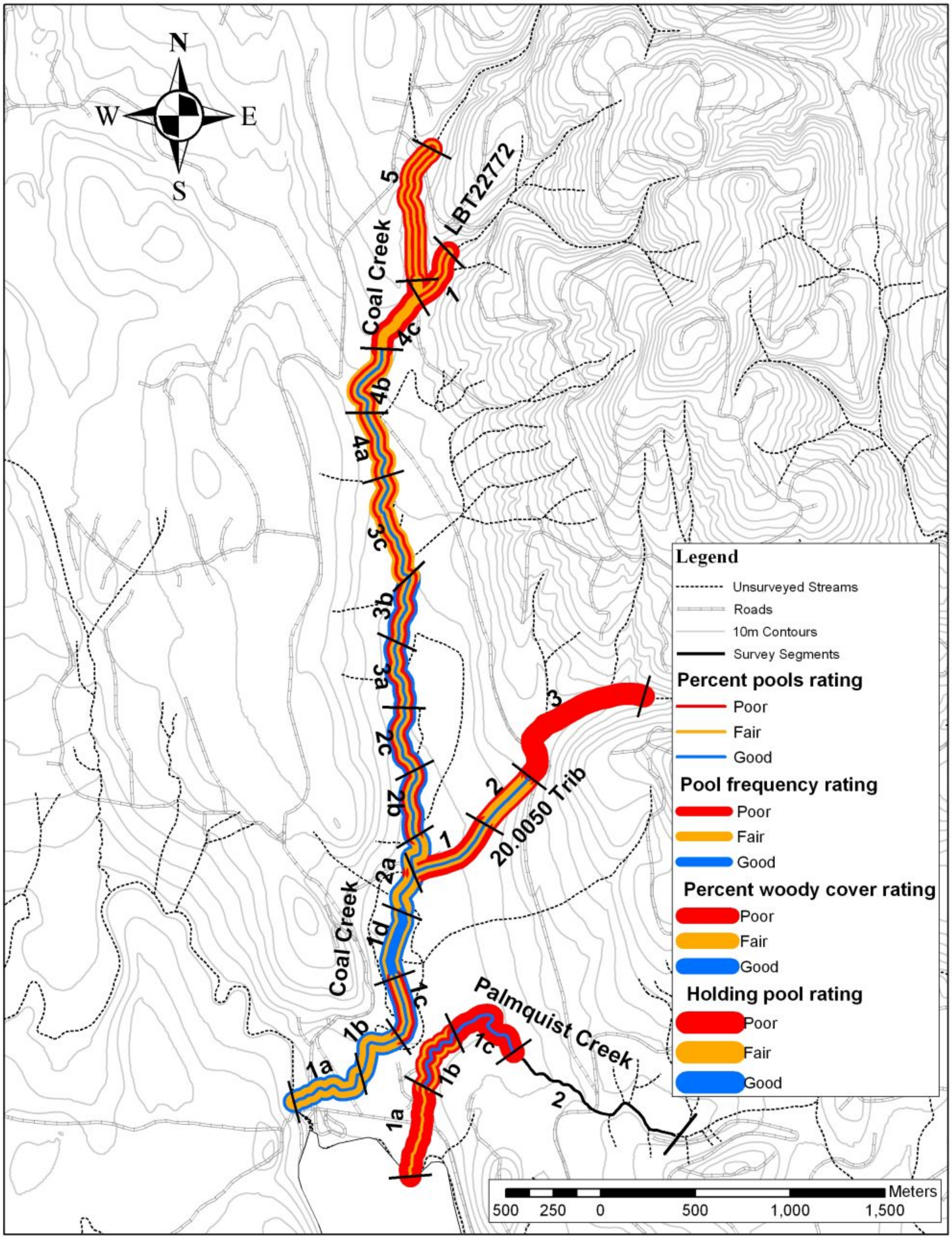

Figure 4.75. Coal Creek pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Coal Creek watershed (source: Haggerty and Ritchie 2004).

Riparian forest removal has dramatically decreased the quantity and quality of trees available for recruitment into Coal Creek. Habitat and LWD data collected in Coal Creek illustrate the importance of large and key-piece-sized LWD in forming high quality habitat features. Recent recruitment of small and medium size LWD appears incapable of producing the same habitat quality and complexity as seen in those habitats formed by LWD > 50 cm diameter. As described above, the LWD conditions in most habitat segments ranked poor for key piece frequency and nearly 79% ranked fair or poor for large piece frequency. The loss of large and key-piece-sized LWD has reduced pool quality throughout most of Coal Creek by reducing the number of high quality habitats. Figure 4.76 illustrates the role of the largest LWD in forming deep pools with sufficient cover.

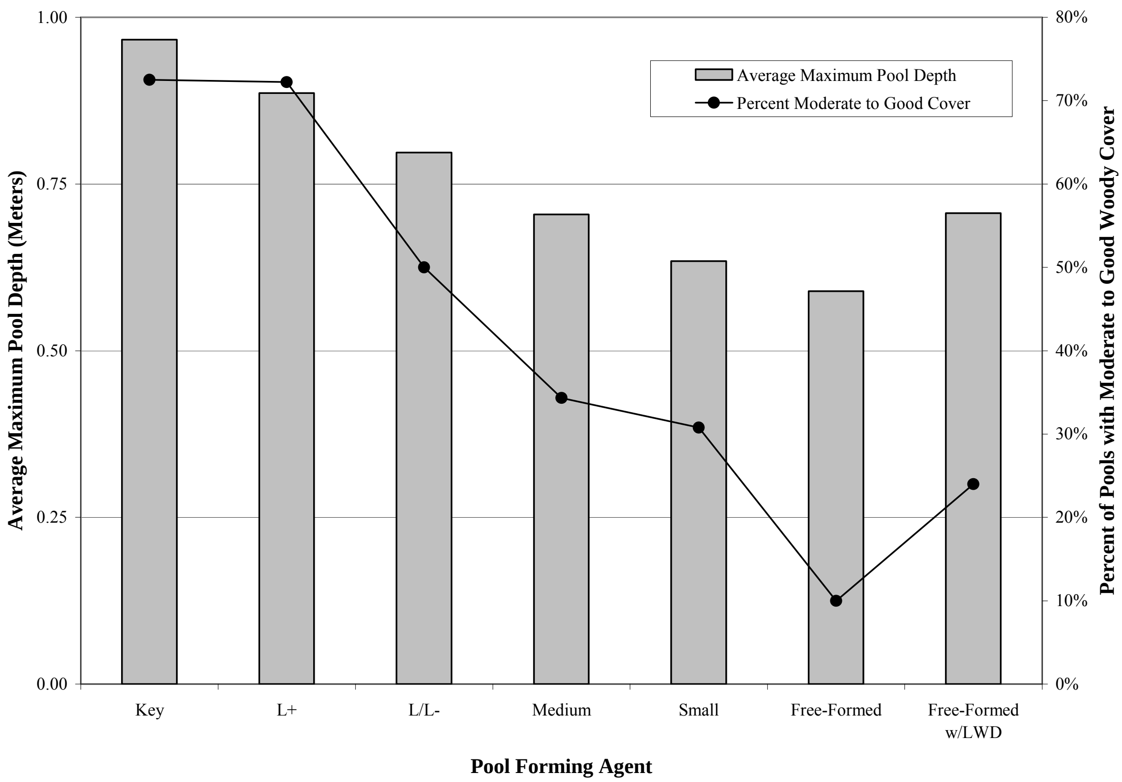

Figure 4.76. Relationship between primary pool forming agent and pool depth and percent pool cover for Coal Creek (source: Haggerty and Ritchie 2004). Note: L+ = LWD>50cm diameter and > 5m length; L/L- = LWD> 50cm diameter < 5m length; medium = LWD 50-20cm diameter; small = LWD 10-20cm diameter; moderate woody cover = 6-20% cover; and good woody cover = >20% woody cover.

4.4.4.4 Coal Creek Streambed and Substrate Conditions

Spawning gravel quality samples have not been collected in Coal Creek. General substrate classifications by habitat segment based on field observations are included in Haggerty and Ritchie (2004). Substrate conditions in segment 1 are described as chiefly composed of mud, silt, and sand in the lower 600 feet of Coal Creek. Gravel patches were noted in several locations upstream in segment 1, but in general the substrate was dominated by sand. Haggerty and Ritchie (2004) describe the substrate conditions in segment 2 as containing high levels of fine-grained materials; gravel bars and spawning gravel are present in many locations but many gravel areas were covered in silt and sand. No substrate observations were included for segment 3. Segment 4 was described as dominated by gravel but grading to cobble near the segment 4/5 break. Segment 5 is composed primarily of cobble, gravel, and boulders. While fine sediment in spawning gravel data are not available for Coal Creek, it is likely that fine sediment levels are similar to those observed in other low gradient Ozette tributaries. The current (2006) estimated road density for the Coal Creek watershed is 6.1 mi/mi^2 (3.8 km/km^2; Ritchie, unpublished data). Herrera (2006) found that sediment input and transport have increased significantly during the last 50 years; they attribute increased sediment loads in Coal Creek to road construction, clear-cutting, and channel incision.

4.4.4.5 Coal Creek Water Quality

Water quality data for Coal Creek are even more limited than for Umbrella Creek and Big River. Bortleson and Dion (1979) collected a very limited quantity of water quality data in Coal Creek, which included temperature point samples, discharge, and specific conductivity. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from December 16, 1993 through November 30, 1994 at the Seafield Mainline Bridge near Ozette River. Table 4.15 summarizes water quality sampling data for Coal Creek from Meyer and Brenkman (2001).

Table 4.17. Summary of water quality data collected in Crooked Creek from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	5.7	5.7	27.3	5.7	1.5
Maximum	14.8	6.8	76.2	11.4	48.3
Mean	9.8	6.4	54.9	9.5	12.5
Number Months Sampled	n=14	n=14	n=14	n=14	n=10

In recent years additional water quality data have been collected in Coal Creek near the Ozette River at the Seafield Mainline Bridge. Makah Fisheries Management began collecting water quality data in Coal Creek in January 2004. Data collection is ongoing and typically occurs monthly, but sampling frequency increases to approximately twice per month during spring and summer months. Table 4.18 summarizes the results of water quality sampling by MFM in Coal Creek. Water quality conditions measured by MFM are roughly within the same range of conditions measured by Meyer and Brenkman (2001). Some of the minor differences between datasets can be attributed to increased sample frequency during May, June, and July in the MFM dataset.

Table 4.18. Summary of water quality data collected in Coal Creek from January 15, 2004 through October 7, 2005 (source: MFM, unpublished water quality data).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	5.2	5.8	30.7	8.1	0.0
Maximum	15.0	7.0	70.4	15.1	57.0
Mean	10.1	6.5	55.5	11.0	4.0
Number Sample Points	n=31	n=31	n=29	n=31	n=31

Stream temperature monitoring has also been conducted using thermographs and data loggers. Green Crow, Quileute Natural Resources (QNR), and MFM have collected data at various sites along Coal Creek since 1997. A review of available temperature data for Coal Creek found that data were collected during seven summers from 1997 through 2005. Stream temperature data were collected at several sites throughout the mainstem of Coal Creek from 1997 through 1999. Figure 4.77 depicts maximum daily stream temperature by river mile for six sites in Coal Creek during the summer of 1997. These data show that the maximum stream temperature decreased from RM 4 to RM 3 and then increased from RM 3 to RM 1.43. It is suspected that cooler tributary waters entering between RM 1.43 and 1.25 are responsible for the observed cooling in this reach. Nevertheless, the highest stream temperatures were observed at the lowest monitoring station.

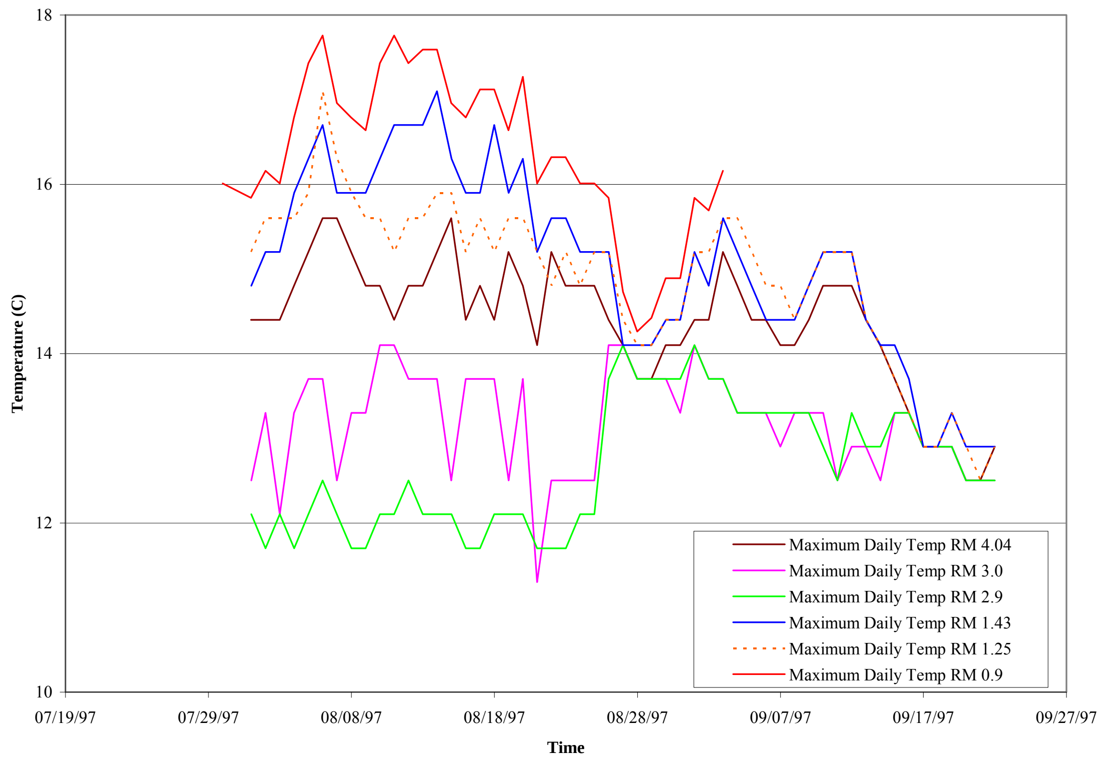

Figure 4.77. Coal Creek maximum daily stream temperature at six sites during the summer of 1997 (source: MFM and Green Crow, unpublished data).

Stream temperature data were collected at six sites during the summer of 1999 and are depicted in Figure 4.78. These data show quite a different trend than data collected in 1997. Maximum daily stream temperatures were the lowest farthest upstream, and highest at the lowest point measured downstream. Some of the differences between 1997 and 1999 can partially be explained by the lower maximum daily temperatures observed in 1999. Another explanation could be that stations monitored in 1999 did not include sites directly downstream from major tributaries.

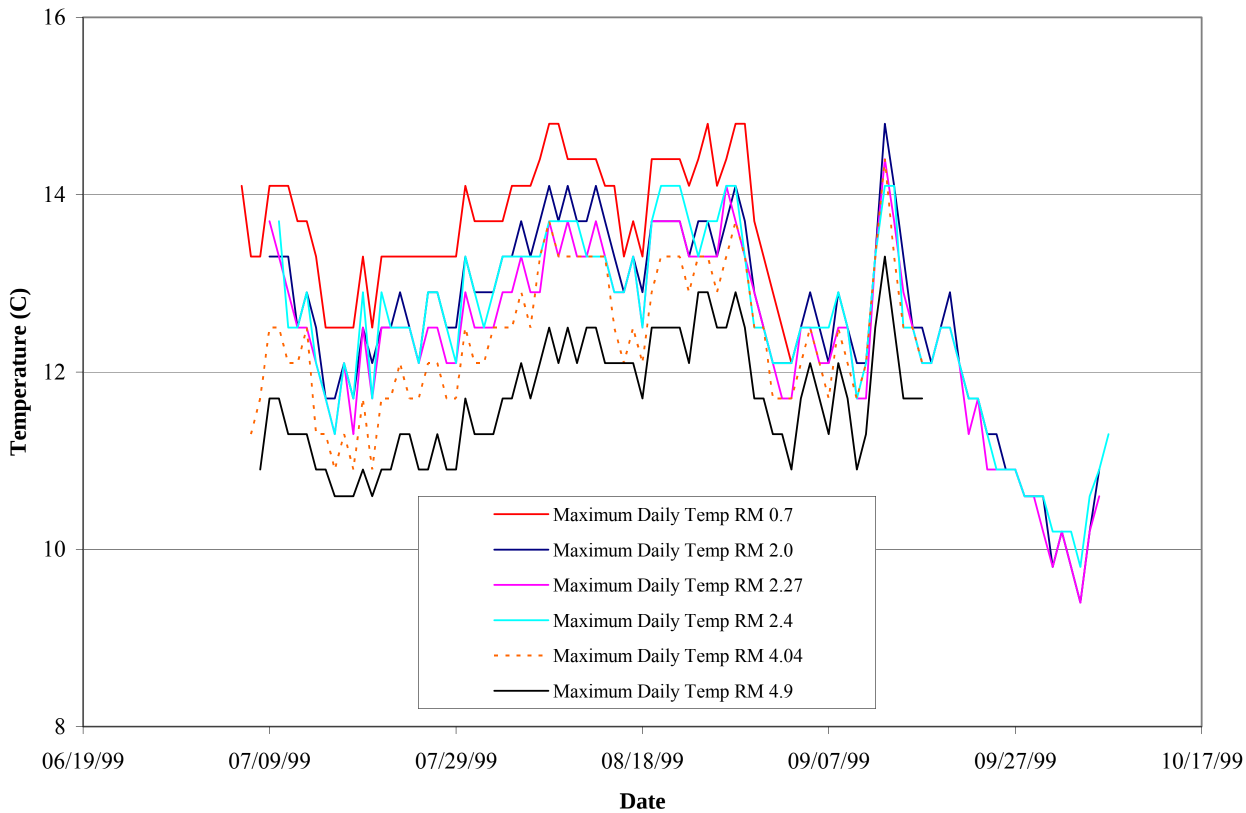

Figure 4.78. Coal Creek maximum daily stream temperature at six sites during the summer of 1999 (source: QNR and Green Crow, unpublished data).

In order to compare stream temperature data across multiple years, Coal Creek data were evaluated from RM 0.5 to RM 0.9. This reach was selected due to the fact that the most number of years of data are available and stream temperatures are highest in this reach. Temperature data were collected on a total of 640 days between June 1and September 30 (1997-2005). Maximum annual temperatures were recorded between June 6 (2003) and August 27 (1998; Table 4.19). The 7-day moving average maximum daily temperatures observed from 1997 through 2005 are depicted in Figure 4.79. Figure 4.80 depicts the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C.

Table 4.19. Summary of maximum daily stream temperature observations from lower Umbrella Creek during temperature monitoring from 1997 through 2005 (sources: MFM QNR, and Green Crow, unpublished data).

Year	Number of Days Sampled (June 1 to September 30)	Date(s) of Peak Temperature	Peak Temperature (C)	Date of Peak 7-Day Moving Average Daily Maximum Temp.	Peak 7-Day Moving Average Daily Maximum Temperature (C)
1997	35	8/5	17.8	8/15	17.4
1998	90	8/27	17.1	8/31	15.5
1999	60	8/8	14.8	8/13	14.5
2002	104	7/23	16.7	7/25	16.1
2003	120	6/6	16.7	7/24	15.7
2004	114	7/24	18.1	7/24	17.4
2005	117	8/1	15.9	8/2	15.4

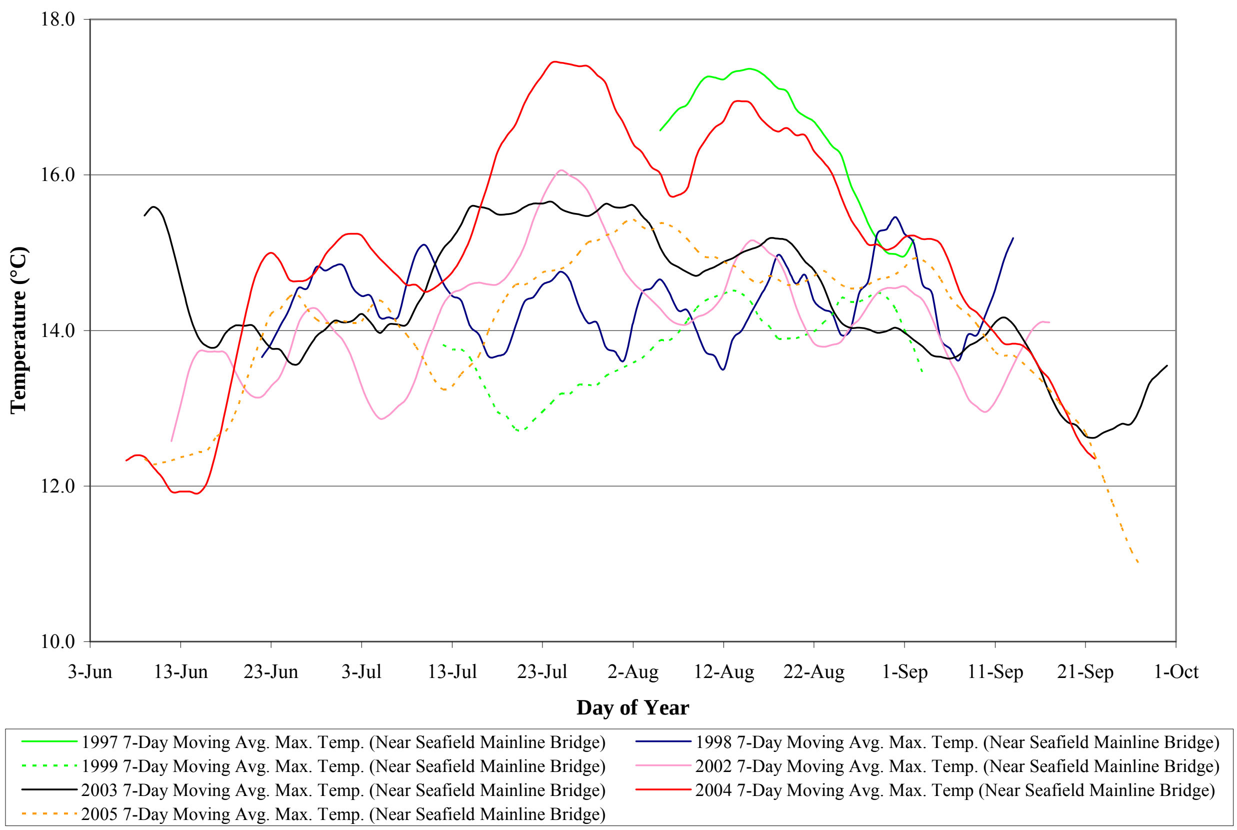

Figure 4.79. Coal Creek 7-day moving average maximum stream temperature near Seafield Mainline Bridge (MFM, Green Crow, and QNR, unpublished stream temperature data).

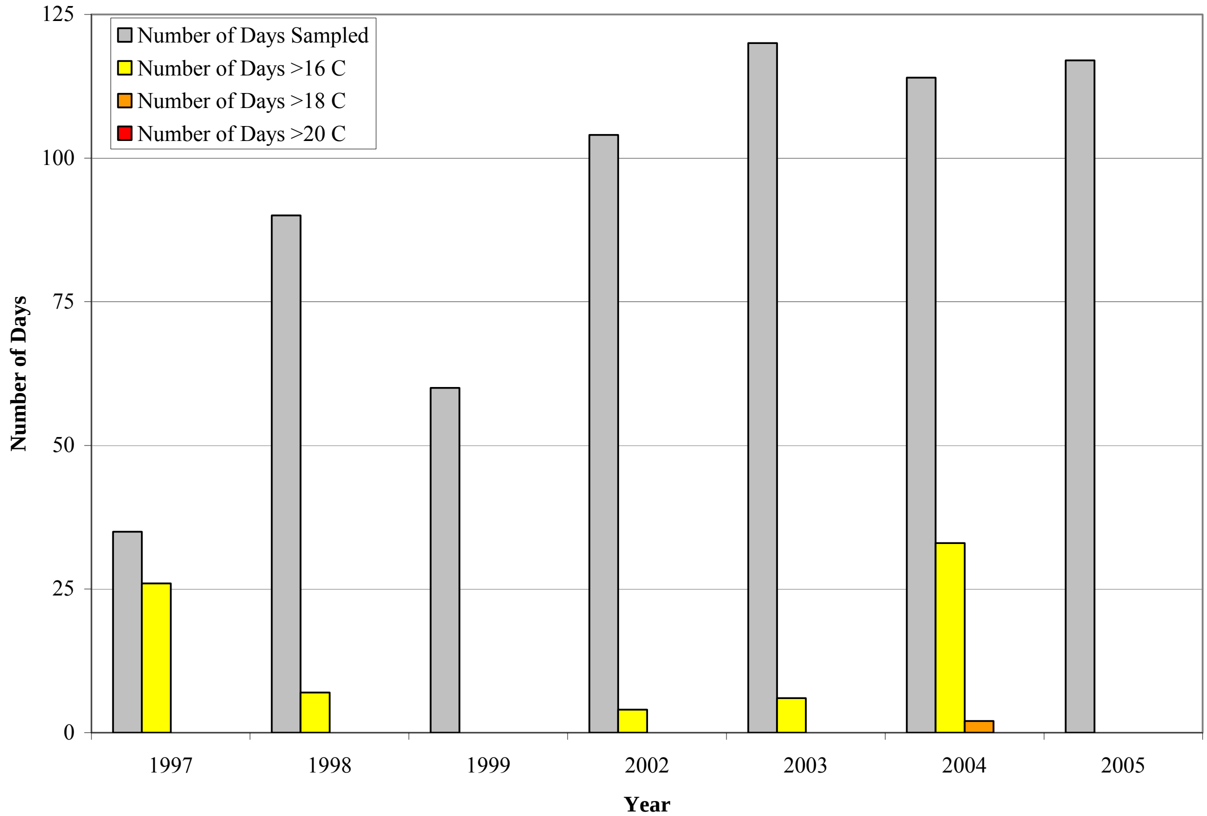

Figure 4.80. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20°C in Lower Coal Creek from 1997 through 2005 (MFM, Green Crow, and QNR, unpublished stream temperature data).

Maximum daily stream temperatures exceeded 16°C on 76 days (12% of the days sampled) between June 1 and September 30 (1997-2005). During the warmest period of summer, July 15 through August 15, data were collected on 209 days. Stream temperatures exceeded 16°C on 48 days (23% of the days sampled). Stream temperatures exceeded 18°C on 2 days (1% of the days sampled). Stream temperatures in Coal Creek are much cooler than those observed in the Ozette River, Big River, Umbrella Creek, and Crooked Creek. Most of the riparian areas that were clear-cut in the 1950s and 1960s have grown back in dense stands of second growth and appear capable of maintaining enough shade to prevent excessive temperatures.

4.4.4.5.1 Turbidity and Suspended Sediment Concentration

Makah Fisheries Management installed a continuous submersible turbidity sensor on Coal Creek on National Park Service land on 10/15/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed from a bank-mounted boom that reaches out over the channel and places the sensor toward the center of the channel in well-mixed water (methods used are similar those in Big River and Umbrella Creek. For additional details see Sections 4.4.1.5 and 4.4.2.5). In addition, at Coal Creek an automated pump sampler is controlled by the same data logger as the turbidity sensor. Pump samples of SSC are collected at different turbidity thresholds or levels. These samples are collected throughout the range of turbidity and are used to correlate turbidity to suspended sediment concentration. Pump samples are processed in whole through filtration at a laboratory and used to calculate SSC.

Median turbidity values (15-minute) are plotted in Figure 4.81, along with discharge and points in time when turbidity threshold pump samples were taken. The relationships between median turbidity and suspended sediment concentration are shown in Figure 4.82. Calculated suspended sediment concentration and discharge data are depicted in Figure 4.83 for the period October 2005 to January 2006.

As shown in these figures, turbidity and SSC peaks in Coal Creek usually last for less than a day, depending on the length of the flood pulse event. The relationship between median turbidity and suspended sediment concentration is excellent (Figure 4.82), resulting in reliable estimates of SSC (Figure 4.83). This type of relationship is being developed for other Ozette tributaries. For the short period of record at Coal Creek, data indicate that turbidity and SSC values are generally correlated to discharge on both the rising and falling limbs of the hydrograph, with little hysteresis. For example, the relationship between median turbidity, SSC, and discharge at Coal Creek are shown in Figure 4.84 for a single storm event on 11/10/05, displaying this single relationship. A single relationship (or curve) between turbidity (or SSC) and discharge indicates an unlimited suspended sediment supply with transport dependent on available flow energy (Hicks and Gomez 2003; Nistor and Church 2005)

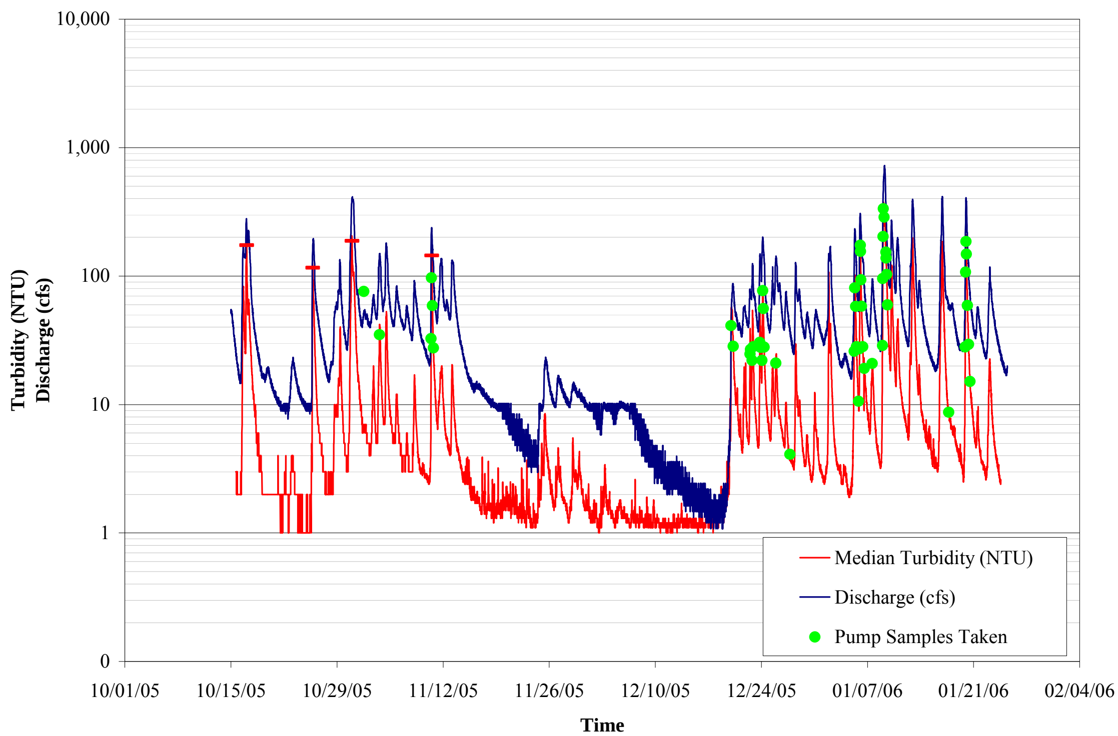

Figure 4.81. Provisional continuous turbidity and stream discharge data for Coal Creek (source: MFM, unpublished data).

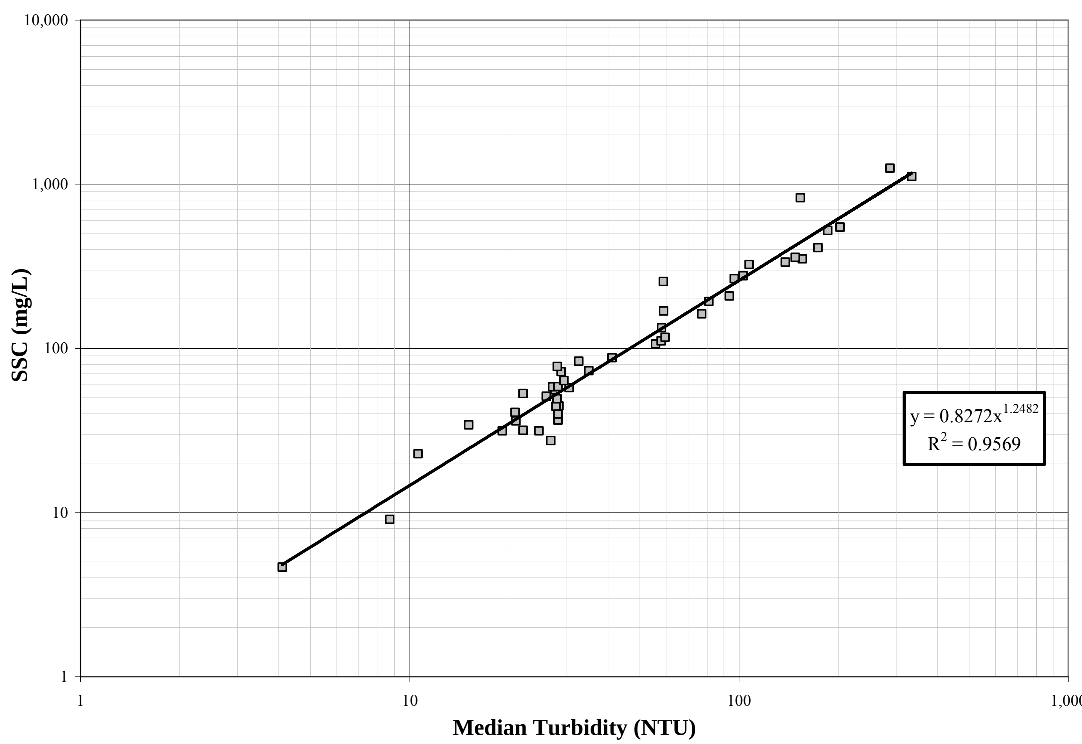

Figure 4.82. Relationships between median turbidity and SSC at Coal Creek (source: MFM, unpublished data).

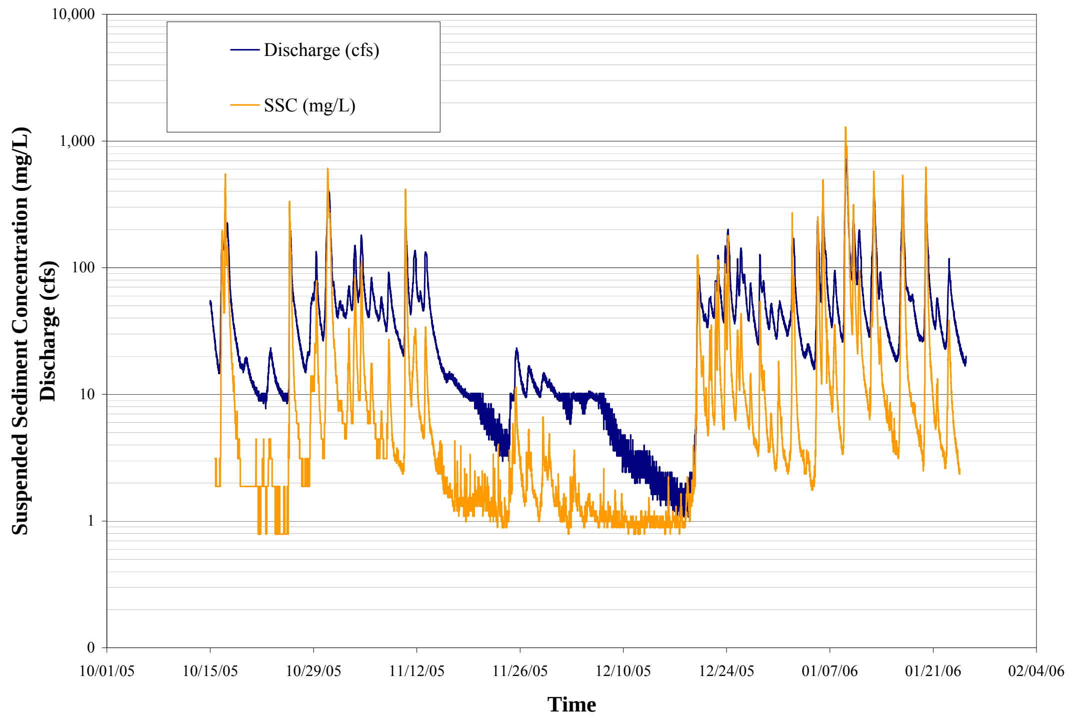

Figure 4.83. Provisional SSC and stream discharge data for Coal Creek (source: MFM, unpublished data).

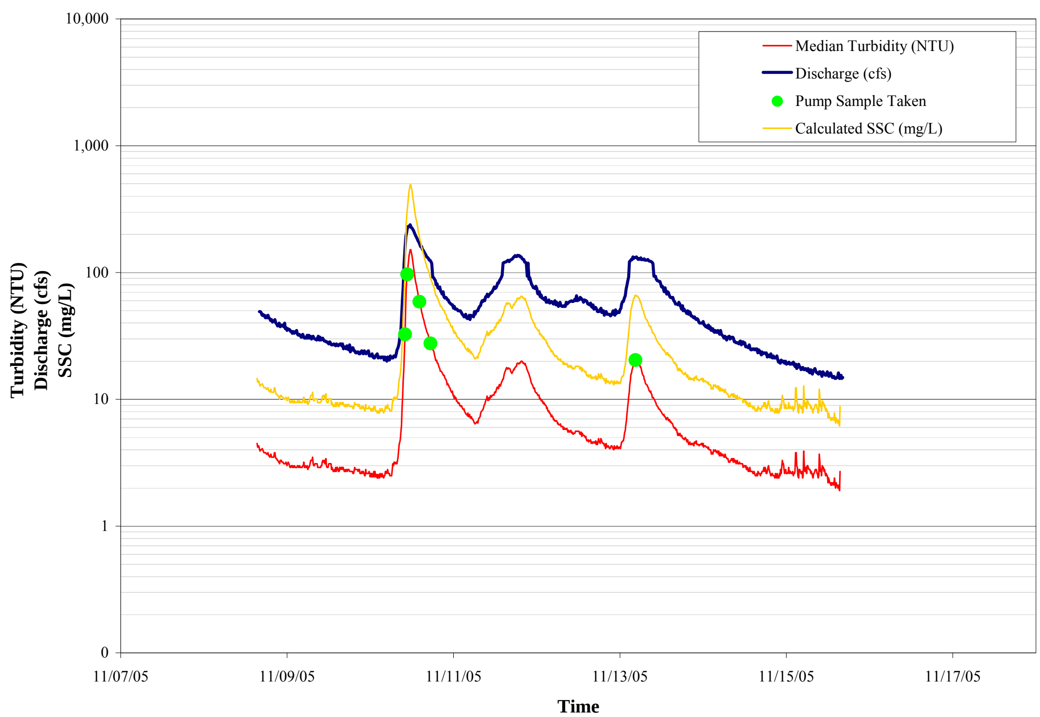

Figure 4.84. Turbidity, discharge, and calculated SSC during a Coal Creek storm event (source: MFM, unpublished data).

4.4.4.6 Coal Creek Hydrology and Streamflow

Makah Fisheries Management installed a continuous stream gage on Coal Creek above Ozette River on 12/18/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional). Instantaneous discharge at Coal Creek for water years 2004 and 2005 are plotted in Figure 4.85.

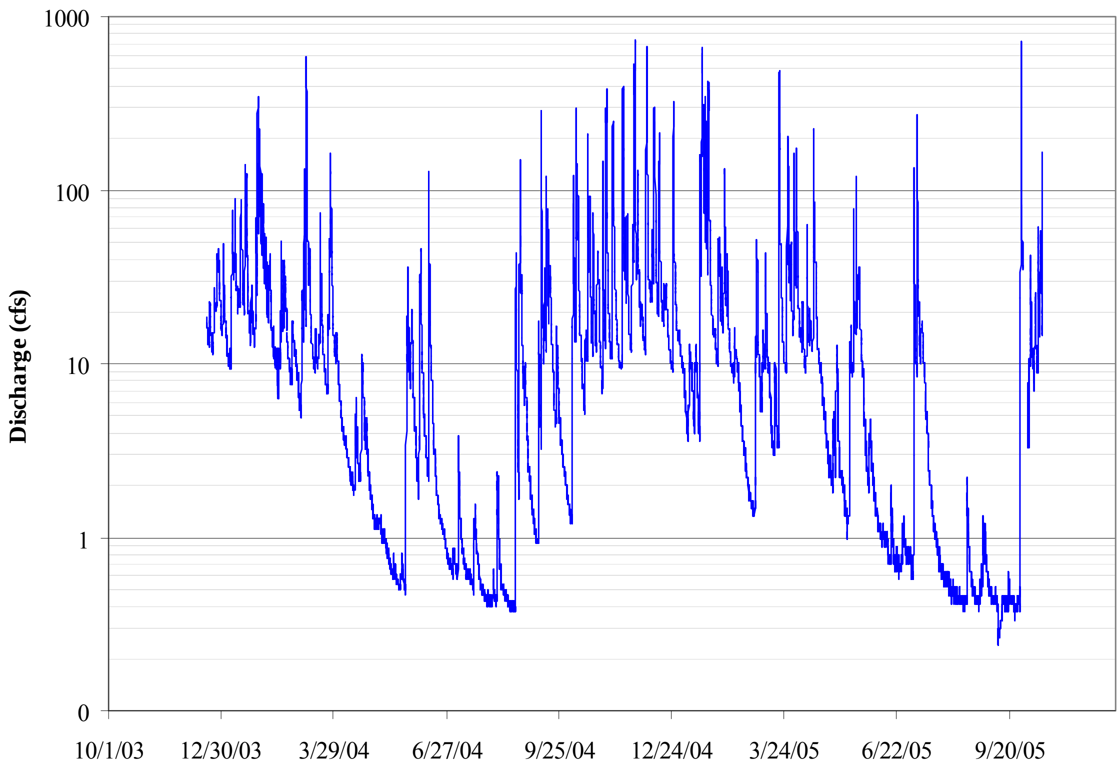

Figure 4.85. Provisional Coal Creek discharge data (source: MFM, unpublished hydrologic data).

4.4.5 Siwash Creek

Siwash Creek drains 2.87mi^2 (7.43km^2) of land and is the fifth largest tributary to Lake Ozette (Table 1.1; Figure 3.16). Siwash Creek enters the lake along the south end of the eastern shoreline of the lake, at a small point just south of Olsen's Beach. The lower 2 miles of Siwash Creek flow to the west, in a valley confined by small hills underlain by Pleistocene age glacial till deposits. Side tributaries draining from the south originate in moderately steep, low hills underlain by Eocene-Miocene aged marine sedimentary rock units. The stream winds around a resistant bedrock knob in a narrow ravine between river mile 2 and 3. Upstream of the ravine, the channel flows through a wide unconfined valley underlain by Pleistocene age glacial till and outwash deposits. Siwash Creek is currently not used by sockeye salmon, but it supports the largest run of kokanee spawners in the Lake Ozette watershed. Detailed information for Siwash Creek is included in this report mainly because of its robust population of kokanee. Documenting and understanding habitat elements that are capable of sustaining a healthy population of kokanee may provide critical insight into factors affecting tributary spawning sockeye salmon in the watershed. In addition, Siwash Creek enters Lake Ozette within a quarter mile of Olsen's Beach and is a potential source of fine sediment to the Olsen's Beach.

4.4.5.1 Siwash Creek Floodplain Conditions

No comprehensive field-based assessment of Siwash Creek floodplain conditions has been conducted. Smith (2000) does not provide an overall rating for floodplain conditions in Siwash Creek. Herrera (2006) reported that the lower 0.25 mile (0.5 km) of Siwash Creek has undergone approximately 3.3 feet (1m) of channel incision over the last 50 years. Herrera (2006) described floodplain connectivity as "fair" for Siwash Creek upstream of the incision near the lake. Lower Siwash Creek averages 7.2 to 8.5 meters BFW (Haggerty and Ritchie 2004) and the associated floodplain is small. Martin Environmental (1999) measured flood prone width in the lower 1.5 miles of Siwash Creek; minimum and maximum widths were 69 ft (21 m) and 357 ft (109 m), respectively.

4.4.5.2 Siwash Creek Riparian Conditions

Riparian conditions in Siwash Creek are highly altered from their historical conditions. The vast majority of the old growth riparian forest has been clear-cut along the mainstem and tributaries. Forest age structure is similar to that seen in other Ozette sub-basins where most of the forest stands are less than 50 years old. Smith (2000) reports that 83% of the forest within the Siwash Creek watershed is less than 20 years old. Orthophotos taken in the summer of 2000 reveal that large portions of the riparian area are dominated by young stands of red alder. Unlike in many Ozette tributaries, there are still a few stands of residual large conifer trees within the watershed. Some riparian forests were retained in the lower mile of Siwash Creek during logging operations. Prior to timber harvest, riparian forests were primarily composed of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). Residual in-channel LWD and intact riparian areas in the lower watershed provide evidence of the massive trees that once grew along Siwash Creek.

4.4.5.3 Siwash Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 2000 in Siwash Creek and are summarized in detail by Haggerty and Ritchie (2004). Channel data were collected in over 2.8 miles (4.6 km) of channel within the mainstem of Siwash Creek. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 5 habitat segments encompassing 1.9 miles of channel (only channel data were collected in segment 5; see Figure 4.86). A total of 1,757 pieces of LWD were inventoried, of which 69%, 25%, and 6% were categorized as conifer, deciduous, and unknown, respectively. Just over 4% of the pieces inventoried were classified as key pieces. Approximately 74% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.86 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in Siwash Creek.

Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables, including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.87 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in Siwash Creek.

A total of 80 pools were inventoried in the mainstem. The average maximum pool depth was 1.02 meters (residual pool depth=0.88m) and the average pool length was 30.8 meters. Many pools were complex and contained multiple scour pockets, thereby increasing pool length (and percent habitat area) and decreasing pool frequency. The quality of pool habitat appears to be directly related to LWD conditions. The best pool conditions were typically associated with the largest LWD. Nearly 57% of key-piece-sized LWD formed pools, while only 5% of small LWD were classified as pool forming. No pools were formed by small LWD independent of larger LWD. Large LWD (diameter > 50 cm) made up 26% of the total LWD piece count but formed 83% of all pools, the highest observed percentage in any stream system surveyed in the Ozette watershed. Approximately 93% of pool habitat was formed by LWD; only 5% of the total pool habitat was formed independent of LWD (2% of the pool habitat was classified as free-formed w/LWD).

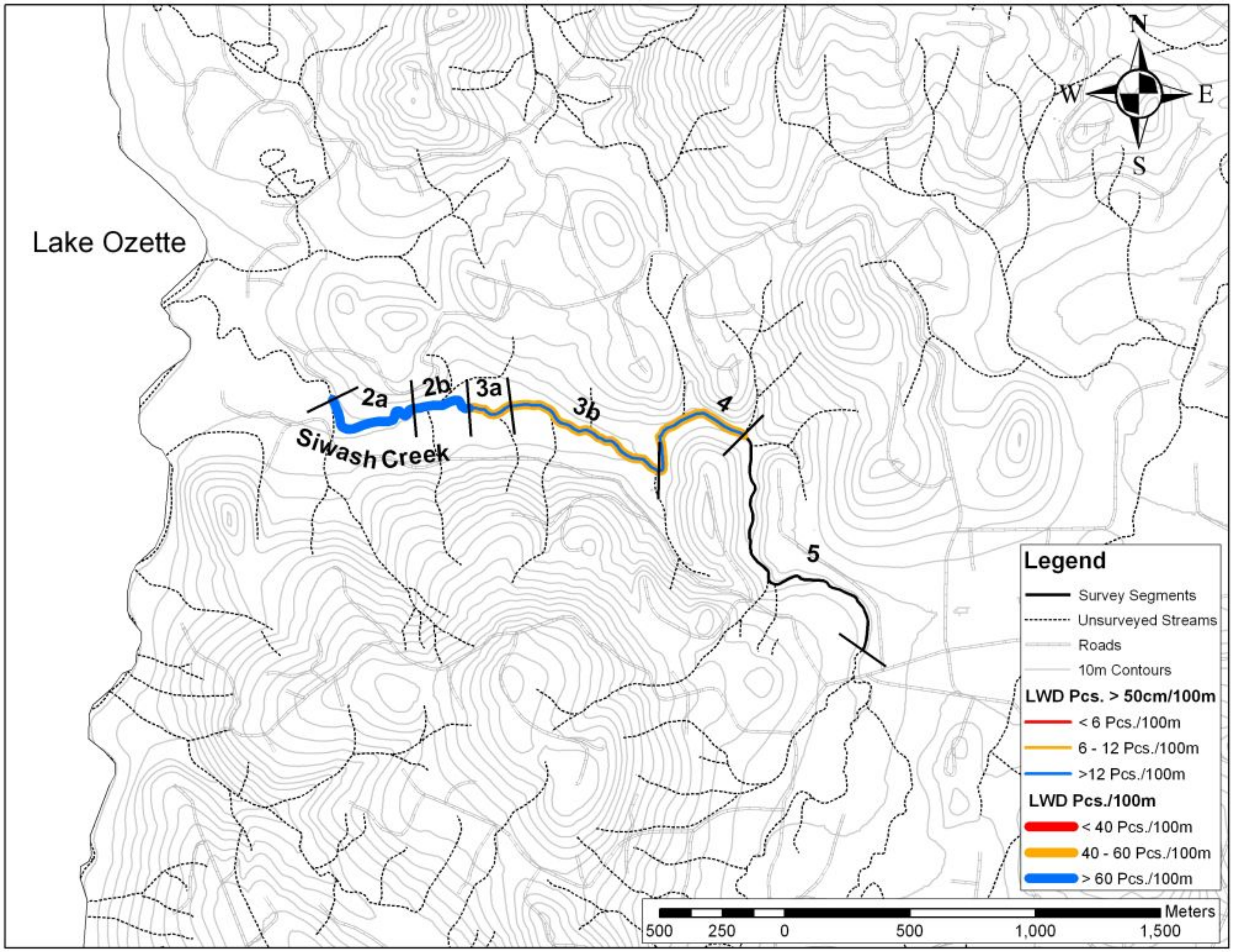

Figure 4.86. Siwash Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

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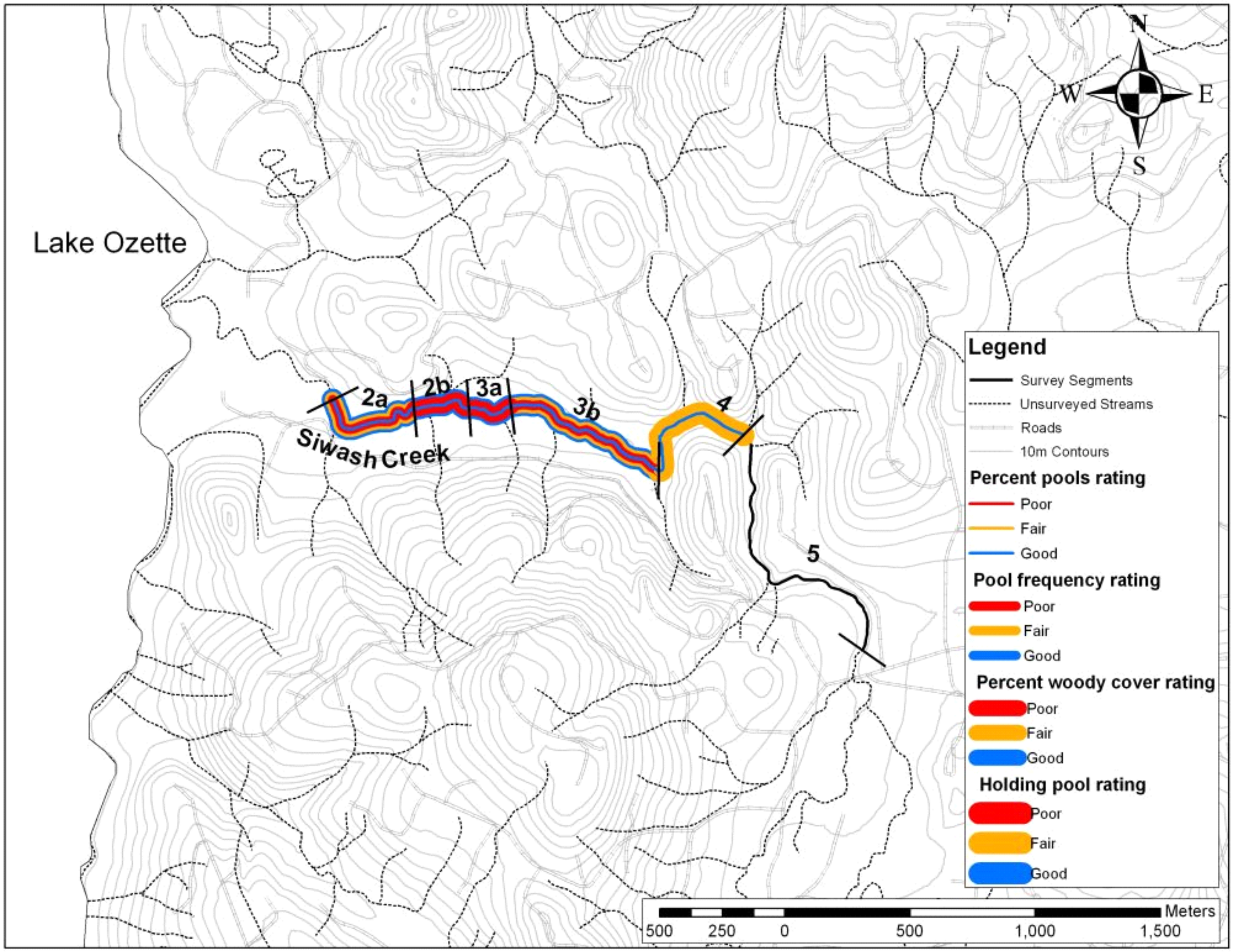

Figure 4.87. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in Siwash Creek (source: Haggerty and Ritchie 2004).

4.4.5.4 Siwash Creek Streambed and Substrate Conditions

Recent data regarding Siwash Creek substrate conditions are limited to general substrate classifications based on field surveys conducted by MFM (*in* Haggerty and Ritchie 2004) and Martin Environmental (1999). Dominant substrate conditions in segment 1 (see Figure 4.86) of Siwash Creek were classified as 100% gravel by Martin Environmental (1999). Haggerty and Ritchie (2004) found that segments 2 through 4 were dominated by gravel substrate. Segment 5 is dominated by cobble and boulders with a minor gravel component. McHenry et al. (1994) sampled substrate conditions in the lower half of segment 2a (in Figure 4.86). A total of ten samples were collected from representative pool tailouts and/or glides where suitable spawning habitat was present. McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in Siwash Creek averaged 24.0% (wet-sieve equivalent; actual dry-sieve method equal to 13.9%). Smith (2000) rated Siwash Creek "poor" for fine sediment levels in spawning gravel. The current (2006) estimated road density for the Siwash Creek watershed is 5.7 mi/mi^2 (3.5 km/km^2; Ritchie, unpublished data).

4.4.5.5 Siwash Creek Water Quality

Water quality data have been collected in Siwash Creek intermittently from the mid-1970s to present. Early data collected by Bortleson and Dion (1979) are quite limited for Siwash Creek. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 22, 1993 through October 18, 1994. Table 4.20 contains a summary of water quality sampling data for Siwash Creek from Meyer and Brenkman (2001). Additional stream temperature monitoring was also conducted using a thermograph and data logger during the summer of 1994 (Figure 4.88). .

Table 4.20. Summary of water quality data collected in Siwash Creek from July 22, 1993 through October 18, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	3.7	6.2	25.1	9.4	0.0
Maximum	15.1	7.3	73.0	11.4	22.0
Mean	10.3	6.8	52.6	10.2	5.6
Number of Samples	n=18	n=13	n=17	n=14	n=13

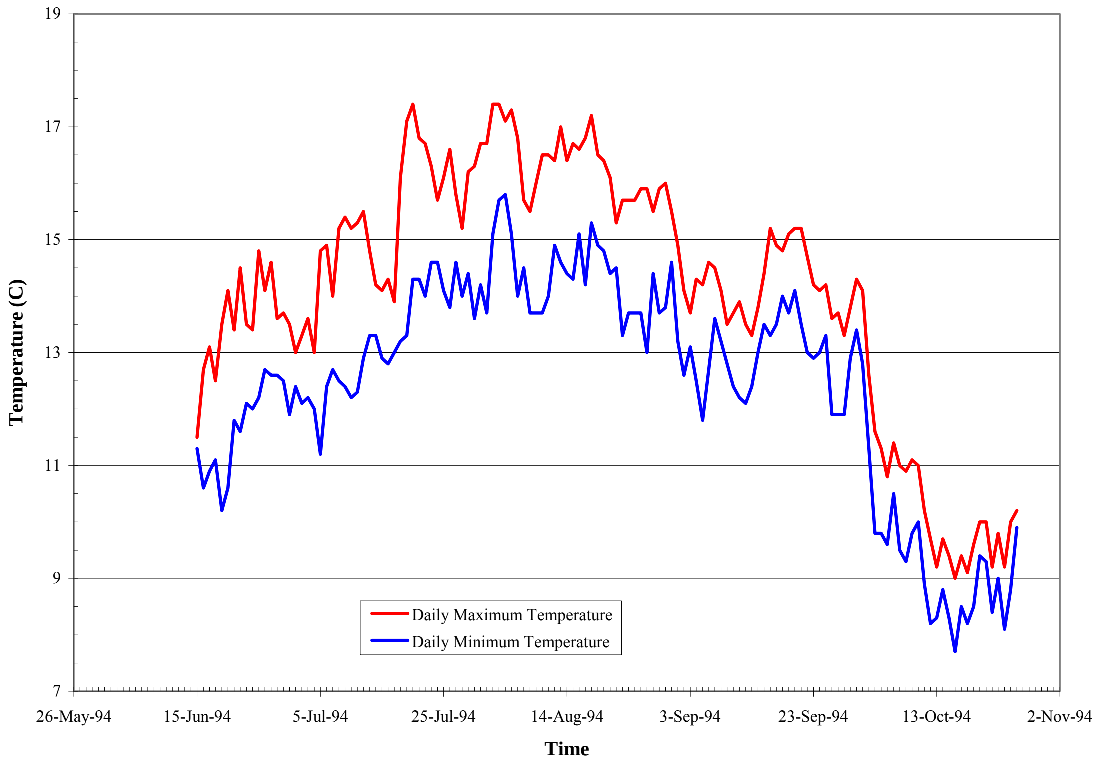

Figure 4.88. Siwash Creek daily maximum and minimum stream temperature data near ONP boundary (source: Meyer and Brenkman 2001).

Makah Fisheries Management installed a continuous submersible turbidity sensor on Siwash Creek on State Land on 04/21/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed from a bank-mounted boom that reaches out over the channel and places the sensor toward the center of the channel in well-mixed water. (Methods used are similar to those in Big River and Umbrella Creek. For additional details see Sections 4.4.1.5 and 4.4.2.5.)

Median turbidity values (15-minute) from Siwash Creek are plotted in Figure 4.89, along with discharge from Crooked Creek. Turbidity (and SSC) peaks in Siwash Creek usually last for less than a day, depending on the length of the flood pulse event. Turbidity rises sharply on the rising limb of the discharge hydrograph and falls more rapidly than discharge on the recession limb. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). Thus in Siwash Creek, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources.

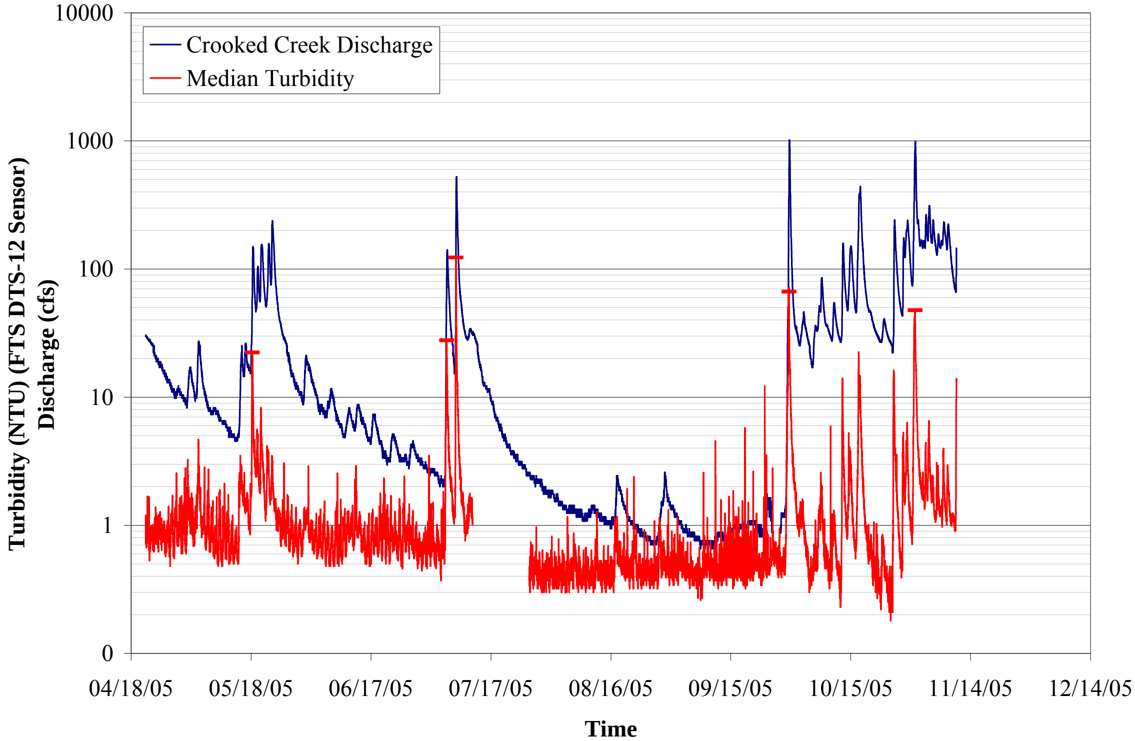

Figure 4.89. Provisional Siwash Creek continuous turbidity data contrasted with Crooked Creek stream discharge data (source: MFM, unpublished data).

4.4.5.6 Siwash Creek Hydrology and Streamflow

No continuous streamflow data are available for Siwash Creek. Meyer and Brenkman (2001) collected instantaneous discharge measurements in several Ozette watershed streams in 1993 and 1994. Figure 4.90 depicts instantaneous stream discharge measurements for Umbrella, Crooked, Siwash, and South creeks from 1993 to 1994. Streamflow in South and Siwash creeks are very similar to one another, whereas streamflows in Umbrella and Crooked Creek are generally higher than those measured in Siwash Creek.

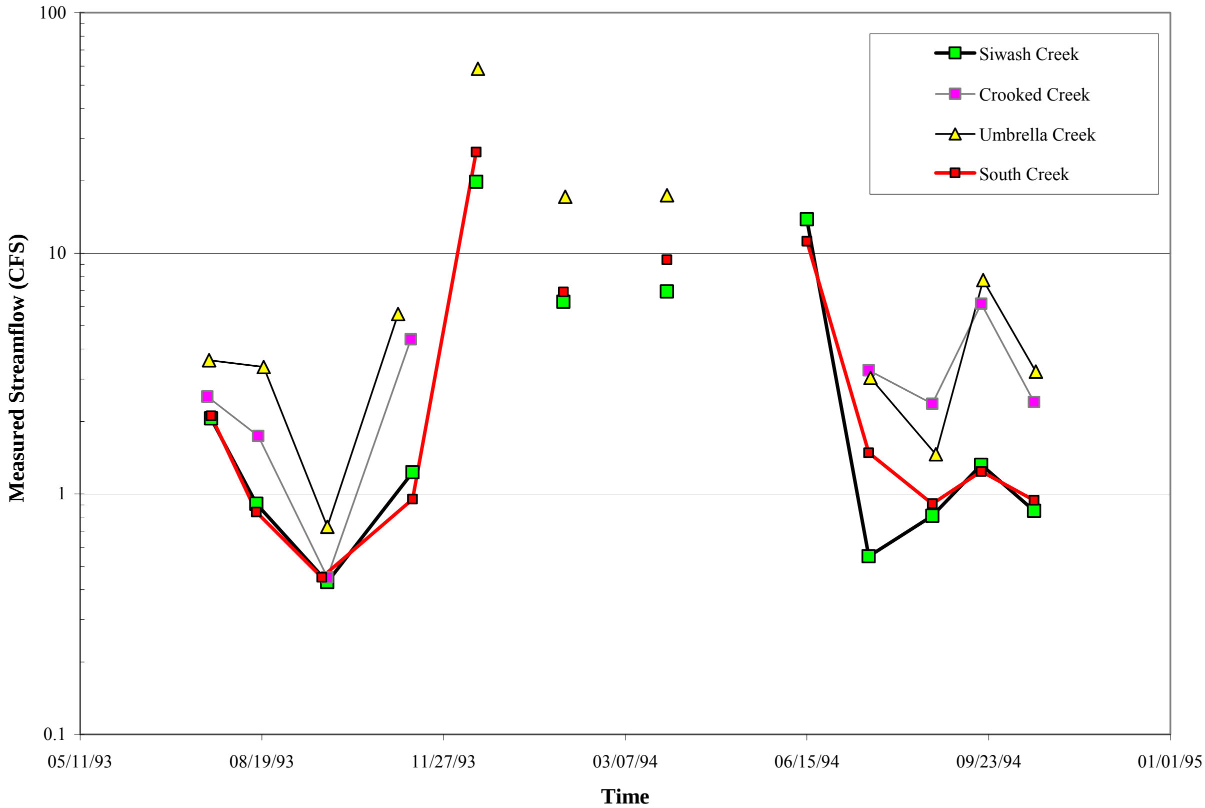

Figure 4.90. Instantaneous discharge measurements for Siwash, Crooked, Umbrella, and South Creeks (source: Meyer and Brenkman 2001)

5 LIMITING FACTORS AFFECTING LAKE OZETTE SOCKEYE

Many of the limiting factors described in this chapter were first identified during preliminary work by the Lake Ozette Sockeye Steering Committee in 1999 and 2000. The concepts presented here are a continuation of these initial efforts and are based upon direction given by committee stakeholders in the summer of 2004. The limiting factors affecting the productivity and survival of Lake Ozette sockeye have been previously investigated and documented in detail in several reports and studies (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; Gustafson et al. 1997). Chapter 5 updates previous work and incorporates recent research in an effort to provide a complete description of the best available information regarding limiting factors affecting Ozette sockeye salmon productivity and abundance.

5.1 METHODS AND FRAMEWORK

Limiting factors affecting Lake Ozette sockeye are identified by geographic area in Sections 5.2 through 5.6. Geographic areas assessed for limiting factors are the following:

- Estuary and Nearshore Environment (Section 5.2)
- Ozette River (Section 5.3)
- Lake Ozette (Section 5.4)
- Lake Ozette Tributaries (Section 5.5)
- Off-Shore Marine Environment (Section 5.6)

All limiting factors that may affect Lake Ozette sockeye are assessed and included within Sections 5.2 through 5.6.2. Several limiting factors that are unlikely to significantly decrease Lake Ozette sockeye productivity and/or viability are also included for completeness, and to illustrate the exhaustive nature of the review of potential or perceived limiting factors. In the following subsections, limiting factors are presented by geographic area and then further described by the sockeye life history stage affected within each geographic area. The degree to which a potential limiting factor is likely to limit sockeye productivity is also discussed by life stage, within each geographic area. Processes and/or actions influencing several of the limiting factors are discussed following the introduction of each limiting factor.

A qualitative rating for each of the limiting factors affecting sockeye salmon survival and productivity by sub-population and life stage is included in Chapter 6.

5.2 ESTUARY AND NEARSHORE ENVIRONMENT

Lake Ozette sockeye occupy the small Ozette River estuary and the nearshore environment of the Pacific Coast during their smolt emigration period, as well as during their adult migration into the Ozette River (see Sections 3.1.1, 3.1.9, 3.1.10). These two life history phases in these environments are the focus of this section. Tidal prism and estuarine habitat conditions (see Section 4.1), predation, direct harvest, and nearshore ocean productivity (see Section 4.1) are all factors that currently or in the past have limited sockeye salmon survival and productivity.

5.2.1 Tidal Prism and Physical Estuarine Habitat Conditions

Changes in the tidal prism and estuarine habitat conditions appear to have occurred during the last 50 years. The cause of these apparent changes is poorly understood, as are the potential effects on Lake Ozette sockeye.

5.2.2 Predation

Predation on sockeye salmon in the Ozette River estuary and nearshore environment is not well documented. No data exist regarding smolt predation in the estuary or nearshore environment. It is suspected that juvenile sockeye are preyed upon during their migration through the estuary and nearshore, but the degree to which this occurs remains unknown. During the summer of 2000, a joint study was conducted by NOAA-National Marine Mammal Laboratory (NMML) and MFM investigating pinniped interactions with Lake Ozette sockeye. Adult sockeye entering the Ozette River were captured in the estuary using a trap. Sockeye were handled, examined for scarring, tagged, and then released. It was found that 32.9% (27/82) of the sockeye captured in the estuary had scars associated with predation events. Scars were classified as “new” or “old” based upon the freshness of the wound. Just over 77% of the scarred fish had scars that were classified as “old” and 52% had scars classified as “new.” Several of the sockeye captured had scars from multiple predation events resulting in scars classified as both “old” and “new.” Figure 5.1 depicts a sockeye that has predator associated scarring classified as both “old” and “new.”

Gearin et al. (2002) were unable to determine the location where the scarring events took place but speculated that the likely areas were (1) the estuary downstream of the trap, (2) just off-shore of the mouth where sockeye stage prior to entering the river, or (3) off-shore in the open ocean. Sockeye trapping conducted during the summer of 2000 provided further evidence of harbor seal (*Phoca vitulina*) and river otter (*Lutra canadensis*) predation in the Ozette River (Gearin et al. 2002). Gearin et al. (2002)) concluded that the predator scarring rate (32.9%) for fish in the lower river was exceptionally high. The amount of predation mortality was not quantified in observations conducted in the lower Ozette River during the 1998, 1999, and 2000 sockeye returns. In addition to direct predation mortalities, unsuccessful predation events resulting in open wounds and lesions in the lower river and nearshore environment likely decrease the fitness of adult sockeye and make them more susceptible to disease during the protracted lake holding period.

Figure 5.1. Sockeye captured in the Ozette River estuary with “old” arch marks and “new” bite marks (source: MFM photo archives).

5.2.2.1 Predators

5.2.2.1.1 Sea lions (Zalophus californianus; Eumetopias jubatus)

Pinniped-sockeye interactions observed in the Ozette watershed from 1998 through 2000 did not include observations of sea lions within the Ozette River or lake (Gearin et al. 2000). Gearin et al. (2000) found that 25% of the identifiable scars on sockeye captured in the lower river were from wounds inflicted by sea lions. Based on an examination of the inter-canine distances measured on scarred sockeye it was determined that 15% of the scars were associated with California sea lions (*Zalophus californianus*) or sub-adult Steller sea lions (*Eumetopias jubatus*) and that 10% of the scars were from adult Steller sea lions. Since sea lions have not been observed within the river, it is thought that nearly all sea lion predation occurs in the nearshore or open ocean. Steller sea lion and California sea lion population counts from May through August within 18.5 km of the Ozette River mouth ranged from 404 to 1,016, and 0 to 541 individuals, respectively (Gearin et al. 1999). Sea lion scat samples were collected in 1998 from within 11.5 miles (18.5 km) of the Ozette River, and salmonid remains were found in 9.6% (18/187) of the scats with identifiable prey items (Gearin et al 1999). Gearin et al. (1999) were unable to determine the salmonid species found in the sea lion scat samples examined.

5.2.2.1.2 Harbor Seals (Phoca vitulina)

A large population of harbor seals use the area near the mouth of the Ozette River. Harbor seal abundance within 5 km of the Ozette River mouth from May 5 to June 30, 1998 ranged from 950 to 1,393 (Gearin et al. 1999). Gearin et al. (2000) found that 60% of the identifiable scars on sockeye captured in the lower river were from wounds inflicted by harbor seals. Gearin et al. (1999) collected and examined 347 harbor seal scats from haul-outs within 3.4 miles (5.5 km) of the mouth of the Ozette River. (Only 330 scats contained identifiable prey.) Salmonids were found in only 1.5% of the samples collected and were identified as coho and Chinook; no sockeye remains were detected in any of the harbor seal scat samples examined. However, none of the harbor seal scat samples were collected from the Ozette River.

Harbor seal activity at the mouth of the Ozette River was systematically monitored during the spring and summer of 1998 (Gearin et al. 1999). During the period from June 3 to June 30, 1998, 1.3 individual seals per hour were observed in the river and off of the river's mouth; this period corresponds to the peak sockeye migration period for 1998. From July 1 through July 22, 1998, only 0.31 individual seals per hour were observed in the river and off of the river's mouth. Seal observations per hour were more than 4 times higher during the peak sockeye migration period (average daily entry estimated at 43 sockeye – see Haggerty 2005d) than the period just after peak migration when sockeye entry into Lake Ozette averaged just over 7 sockeye/day.

During pinniped monitoring in 1998, no direct predation events on sockeye were observed in the river or off of the river's mouth (Gearin et al. 1999). Additional monitoring in the lower river was conducted for 22 days in 1999. No predation on sockeye by harbor seals was observed in 1999 (Gearin et al. 2002). However, seals were frequently observed foraging in the lower river during monitoring from 1998 to 2000 (Gearin et al. 1999; Gearin et al. 2002). On June 9, 2000, harbor seals were observed killing 2 sockeye salmon. Gearin et al. (2002) were unable to quantify the number of sockeye salmon killed by harbor seals in the lower Ozette River. They concluded that part of the difficulty in deriving predation estimates is that visual observations are often limited to daylight hours and much of the predation appears to occur during darkness.

5.2.2.1.3 River Otters (Lutra canadensis)

River otters are quite common in the Ozette River; but no river otter population estimates exist. Gearin et al. (1999) describe the Ozette River as ideal river otter habitat. River otters are distributed throughout the entire length of the river. Predation monitoring during the sockeye run from 1998 through 2000 was conducted in the lower river. No direct observations of river otters killing sockeye salmon were made in the lower river and nearshore environment during the 3-year monitoring period (Gearin et al. 1999; Gearin et al. 2002).

5.2.2.1.4 Other Predators

The entire suite of predators that prey upon juvenile and adult sockeye salmon in the Ozette estuary and nearshore environment is unknown. It is likely that in addition to pinnipeds, several species of birds and fish also prey on Lake Ozette sockeye. On June 22, 2000, a bald eagle (*Haliaeetus leucocephalus*) was observed carrying and eating a large salmonid, most likely an adult sockeye, at the mouth of the Ozette River.

5.2.2.2 Factors Affecting Predation

5.2.2.2.1 Increases in Pinniped Abundance

The California sea lion population across its range (from Mexico to British Columbia) has increased dramatically during the last 60 years (NMFS 1997). Commercial harvest of California sea lions from the 1800s to 1940s had reduced their numbers, but the population gradually began to increase with the end of commercial hunting in the 1940s (NMFS 1997). Since the passage of the Marine Mammal Protection Act (MMPA) in 1972, the population has steadily increased at a rate of 5% per year (NMFS 1997). Harbor seal populations have also experienced significant increases since the passage of the MMPA (NMFS 1997). Within Washington State, the harbor seal population decreased during the 1940s and 1950s in part as a result of the state-financed bounty program[16] (Carretta et al. 2005). Overall, from 1983 to 1996 the Washington coastal harbor seal population increased annually at a rate of 4%, but it declined at a rate of 1.6% from 1991 to 1996, suggesting that the population exceeded equilibrium (Carretta et al. 2005). In contrast, Steller sea lion populations have declined significantly throughout most of their range during the last 40 years (NMFS 1997). Steller sea lion populations worldwide have declined by more than two-thirds since 1980 (Trites and Larkin 1996). The only region where Steller sea lion populations are thriving is from Oregon to Southeast Alaska.

Localized population trend data for pinnipeds near the mouth of the Ozette River are not available, but it is assumed that the current number of pinnipeds interacting with Lake Ozette sockeye in the estuary and nearshore environment has increased significantly in the last 50 years, in accord with the regional population trends for these animals. It is further assumed that the increased abundance of pinnipeds in coastal Washington waters has increased the number of Lake Ozette sockeye killed by pinnipeds. NMFS (1997) concluded that pinniped predation on salmon populations can act as an additional factor in salmonid population declines and can affect recovery of depressed salmonid populations in some situations. In Oregon State the Independent Multidisciplinary

[16] Over 17,000 harbor seals were killed by bounty hunters between 1943 and 1960 (Newby 1973 *in* Carretta et al. 2005).

Science Team ([IMST] 1998) concluded that a robust predator population could suppress recovery of depleted wild stocks of salmonids.

5.2.2.2.2 Abandonment of Ozette Village

Ozette Village was one of the five Makah villages. The pre-European-contact human population size of the village is unknown. The village was located near Cape Alava, about 2 miles southwest of the Ozette River, and much of the subsistence needs of the people living there were obtained from the ocean. Ozette villagers were avid sealers and the village provided an excellent location for fur seal hunting. Fur seals were hunted off of Umatilla Reef, where the seals were only 3 miles from shore. Female fur seals were the main pinniped harvested by Ozette villagers. In addition to the village, seasonal fishing stations were also located along the Ozette River near the mouth, Lake Ozette's outlet, and the south end of the lake near the spawning beaches. In early times a weir and trap were used to capture migrating sockeye in the lower river, while spears, dip-nets, and drift nets made of nettles were used to capture sockeye in the upper river and lake. It is assumed that during this period, competitors such as harbor seals and river otters were likely hunted in the lake and river by tribal fishermen and hunters.

In 1893, the Ozette Reservation was established by Congress to protect the rights of 64 villagers living there (Wray 1997). The population decreased in 1896 when natives were forced to move to Neah Bay so that their children could attend school. By 1914 there were only 17 natives remaining at Ozette and by 1932 there were only two (Wray 1997). The abandonment of the village and traditional fishing and hunting places and techniques was a slow process. By the late 1970s, all traditional hunting and sockeye fisheries in and along the lake and river ended. The end of traditional native fishing and hunting in the lake and river during the last 100 years has likely increased the number of sockeye predators.

5.2.2.2.3 Decreased Sockeye Abundance

As with other prey-predator interactions across global ecosystems, healthy populations of prey species (e.g., salmon) often overwhelm predators (e.g., pinnipeds) by migrating in mass past interaction points, reducing the total number and percentage of predator-prey interactions. Decreases in the number of adult sockeye returning and juveniles migrating from Lake Ozette in the past are thought to have increased the percentage of juveniles and adults preyed upon. In recent years the overall Lake Ozette sockeye population has increased, and it is likely that the predation rate has remained stable or decreased in the estuary and nearshore environment. However, there are no quantifiable data to calculate predation rates, let alone predation rates through time. There is at least one example from coastal Oregon where it was determined that larger proportions of the salmon run were preyed upon by harbor seals during years of lower salmon abundance than during years of higher salmon abundance (Brown and Mate 1983 *in* IMST 1998)

5.2.3 Directed Lake Ozette Sockeye Harvest

Currently no directed sockeye harvest occurs in the nearshore marine environment or the Ozette River estuary. Historically, the in-river sockeye fishery occurred near the mouth and at the lake's outlet; areas along the entire length of the river were also fished, but apparently not to the same degree as the two locations noted above. A trap was used to capture sockeye in the lower river, but it has not been used in the last 80 plus years. In interviews with Makah fishermen in 1941, Swindell (1941) asked about the use of this trap and none of the fishermen present could remember the last time it was fished. After trapping was abandoned, set nets were the primary fishing method used (Brennan 1941; WDF 1955). The Makah Tribe's commercial sockeye fishery ceased in 1977 and all ceremonial and subsistence fishing ended in 1982, in an effort to protect and increase the abundance of spawning sockeye (Jacobs et al. 1996). No directed sockeye harvest has taken place since the cessation of the tribal ceremonial and subsistence fishery. Past sockeye over-exploitation in fisheries has been described as a factor for the decline of Ozette sockeye by several investigators (Dlugokenski et al. 1981; Jacobs et al. 1996; Gustafson et al. 1997; MFM 2000). The small size of the Ozette River during the sockeye run makes sockeye especially susceptible to net fisheries. Sockeye harvest data from 1948 through 1977 depict a decreasing trend in catch through time; note there are no harvest data prior to 1948 (Figure 5.2). For additional fisheries impacts see Sections 5.3.5, 5.6.1.1, 6.2.1.6, 6.2.2.2, 6.2.12.6, and 6.2.13.1.

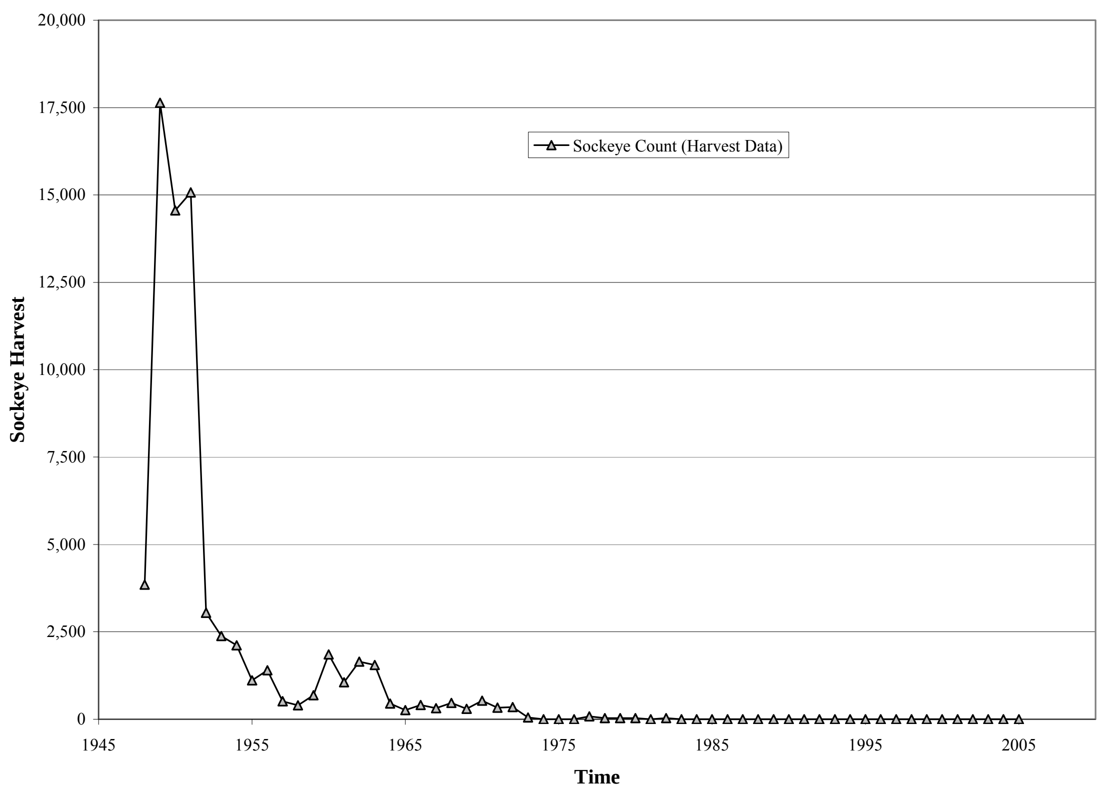

Figure 5.2. Makah tribal harvest of Lake Ozette sockeye (source: WDF 1955; Jacobs et al. 1996).

5.2.4 Nearshore Environment

The remote and relatively pristine nature of the shoreline in the vicinity of the Ozette River is reflected in the diversity and abundance of marine life in the area. Physical changes to the nearshore environment have not been documented, but changes in nearshore productivity are thought to vary significantly by season (see below). Changes in juvenile predator abundance and food availability are likely to affect early marine survival. Most marine mortality occurs shortly after marine entry (Peterman 1982).

The long freshwater lake holding behavior of Lake Ozette sockeye necessitates sufficient energy supplies for survival during the several months they spend without feeding. Food availability and growth are important factors in successful reproduction (Tyler et al. 2001), and maturing adult sockeye salmon during their last 5-6 months at sea will consume as much food as in all previous months at sea combined, doubling their body weight (Brett 1983 *In* Tyler et al. 2001). In the Strait of Juan de Fuca, Beacham (1986) found that the dominant prey (by volume) of sockeye >21.5 inches FL were euphausiids, amphipods, crab larvae, and mysids. The occurrence of empty stomach contents was 30%. The effect of changes in the early marine juvenile rearing conditions and late-stage marine life history of Ozette sockeye is unknown. Available marine survival estimates for Lake Ozette sockeye indicate relatively high marine survival.

Variability in the climatic and oceanic systems can alter the productivity of the nearshore ecosystem, and thus nutrients available to sockeye. For example in 2005, warm sea surface temperatures (SSTs) were observed by NOAA off the coast of central Oregon and extending to British Columbia. This phenomenon was reflected in satellite images, showing warm water off the mouth of the Columbia River extending up toward Vancouver Island, largely due to breakdown of the wind-driven currents that drive upwelling of cold, nutrient-rich water. During these warm SST's, observers did not find the typical dense aggregations of pelagic fishes that occupy the mid portions of the water column along the shelf break; rather, the fish were dispersed along the shelf break and upper slope areas. After mid July, 2005, observers documented a return of deeper waters upwelling to the surface as a result of strong winds from the north. Phytoplankton, which form the base of marine food webs, are dependent on these nutrient-laden waters for their growth and proliferation. Sockeye salmon growth in coastal waters can be expected to vary over years to decades as ocean productivity wanes and waxes.

5.3 OZETTE RIVER

Lake Ozette sockeye use the Ozette River as a migratory corridor during the smolt emigration and adult migration life history phases (see Sections 3.1.1 and 3.1.9). Sockeye spawning in the Ozette River has never been documented, but there remains the possibility that some sockeye spawning could occur in portions of the Ozette River. The smolt emigration and adult migration life history phases in the Ozette River are the focus of the limiting factors discussion presented in this section. Logjam and LWD removal (see Section 1.5.5 and 4.3.3), streamflow (see Section 4.3.6), water quality (see Section

4.3.5), predation (Sections 2.2.8), disease, and directed sockeye harvest are all factors that currently limit or in the past have limited sockeye salmon survival and productivity in the Ozette River.

5.3.1 Instream LWD Conditions

A full description of the LWD conditions in the Ozette River is provided in Section 4.3.3. In general, LWD size, frequency, and functionality are considered degraded from pre-disturbance levels. The majority of LWD reductions in the Ozette River are attributable to repeated LWD removal operations conducted over the last 100 years (e.g. Kramer 1953). Wood removal from the river appears to have been discontinued sometime in the mid-1980s, and LWD concentrations appear to be increasing. An intact riparian corridor along the Ozette River ensures a supply of future LWD.

5.3.1.1 Effects on In-River Habitat Conditions

The influence and importance of LWD on channel dynamics and stability, as well as fish habitat quality, is one of the most studied aspects of forest and stream interactions (Maser and Sedell 1994; Gregory et al. 2003; Montgomery and Piegay 2003). The ability of LWD to enhance fish habitat is well documented (Grette 1985; Bisson et al. 1987; Cederholm et al. 1997). Large woody debris has been shown to affect pool formation (Bilby and Ward 1989; Bilby and Ward 1991; Beechie and Sibley 1997), size, depth and quality (Haggerty and Ritchie 2004), and sediment accumulation and bar formation (Lisle 1986; Bilby and Ward 1989), as well as to sort and accumulate fine sediment and organic debris (Bilby and Ward 1989). All of these factors are thought to significantly influence the physical quality of fish habitat. Large woody debris can also act to provide cover and create channel complexity, which is critically important to some salmonid species such as coho (Nickelson et al. 1992).

Ozette River is a low gradient river with low and peak flows mediated by storage in the large lake it drains. Similar to other forested rivers in the world and the Pacific Northwest (see review above), wood plays an important part of the river's function, stability, and habitat complexity. At all Ozette River discharges of almost four orders of magnitude (4 cfs to 2200 cfs), wood interacts with the channel and flow. Due to the relatively large wood in and around Ozette River and its low gradient, wood plays an important role in roughening the channel and creating a backwater effect connecting the channel and its modest-sized floodplain. During high flows, large wood jams are responsible for maintaining most of the deep scour pools that exist along the river, except for several that are forced by rock-hardened river bends.

In addition, most suitable gravel spawning sites along the river have been created and maintained by the sediment trapping, scouring, and sorting mechanisms of large wood jams. While Ozette River is relatively starved of new, recent, coarse sediment, existing

LWD functions in trapping and sorting sediment that does enter the system (e.g., from Coal Creek) and aid in mobilizing fine sediment downstream or onto the floodplain.

The loss of large (>50 cm diameter) LWD in the Ozette River through removal has undoubtedly resulted in reduced habitat complexity throughout much if not all of the Ozette River (Section 4.3.3). Riparian forest removal adjacent to the upper 0.4 miles of the Ozette River has reduced LWD inputs, delaying the recovery and habitat potential of the upper river. Lake Ozette sockeye have not been observed spawning or rearing in the Ozette River, and therefore the direct effects on sockeye in the Ozette River are likely limited. As described earlier, the average duration of in-river adult migration is 65.2 hrs (Section 3.1.1). Smolt residence time in the river is thought to be similar to that of adults but no studies have been conducted to determine the quantity of time spent in the river by smolts.

Other species such as chum and Chinook salmon historically spawned in the Ozette River (Phinney and Bucknell 1975). The effects of wood removal on spawning habitat in the Ozette River are unknown, but chum and Chinook salmon populations experienced a precipitous decline in the years directly following the 1952 WDF wood removal project in the Ozette River. The decline in Chinook and chum salmon abundance likely can only be partially attributed to wood removal, and the effects of LWD removal on degradation of spawning conditions remains unclear. The decline also follows “high” sockeye, chum, and Chinook harvests in the previous 3 to 5 years. McHenry et al. (1996) describe the decline in local Chinook harvest during this period as interesting, and note that the decline coincides with the expansion of the British Columbia troll fishery.

5.3.1.2 Hydrologic and Hydraulic Effects

An initial investigation into the hydraulic influence of logjams on the water surface elevations of the Ozette River and Lake Ozette is summarized in PWA (2002). In 2004 and 2005, further model refinement and a detailed examination of the hydraulic and hydrologic effects of logjams in the upper Ozette River was conducted by Herrera Consulting (see Herrera 2005). Herrera (2005) developed a continuous hydraulic model of the Ozette River using an unsteady version of HEC-RAS. “Unsteady” refers to the model’s acceptance of short time-step (one-hour) hydrograph input, to model differential flow conditions over time. The purpose of the model was to analyze the hydraulic effects of current, past, and variable wood loading scenarios on water surface profiles of the lake and river. Herrera (2005) modeled a reach extending 3,200 feet (975 m) downstream from the lake’s outlet. This reach covered the upper portion of the river where wood was locally removed circa 1890 to 1950. The model reach covered only a portion of the Ozette River where WDF removed log jams in 1952. The upper 3000 feet of the river was presumably already free of large wood in 1952, because WDF did not remove any log jams there. Input parameters of the model included: channel geometry data (cross-sections and profile); floodplain conditions and constraints; continuous flow hydrographs; and channel and wood loading conditions. Channel and wood loading data were collected from the upper 1 mile of the Ozette River and are depicted in Figure 5.3.

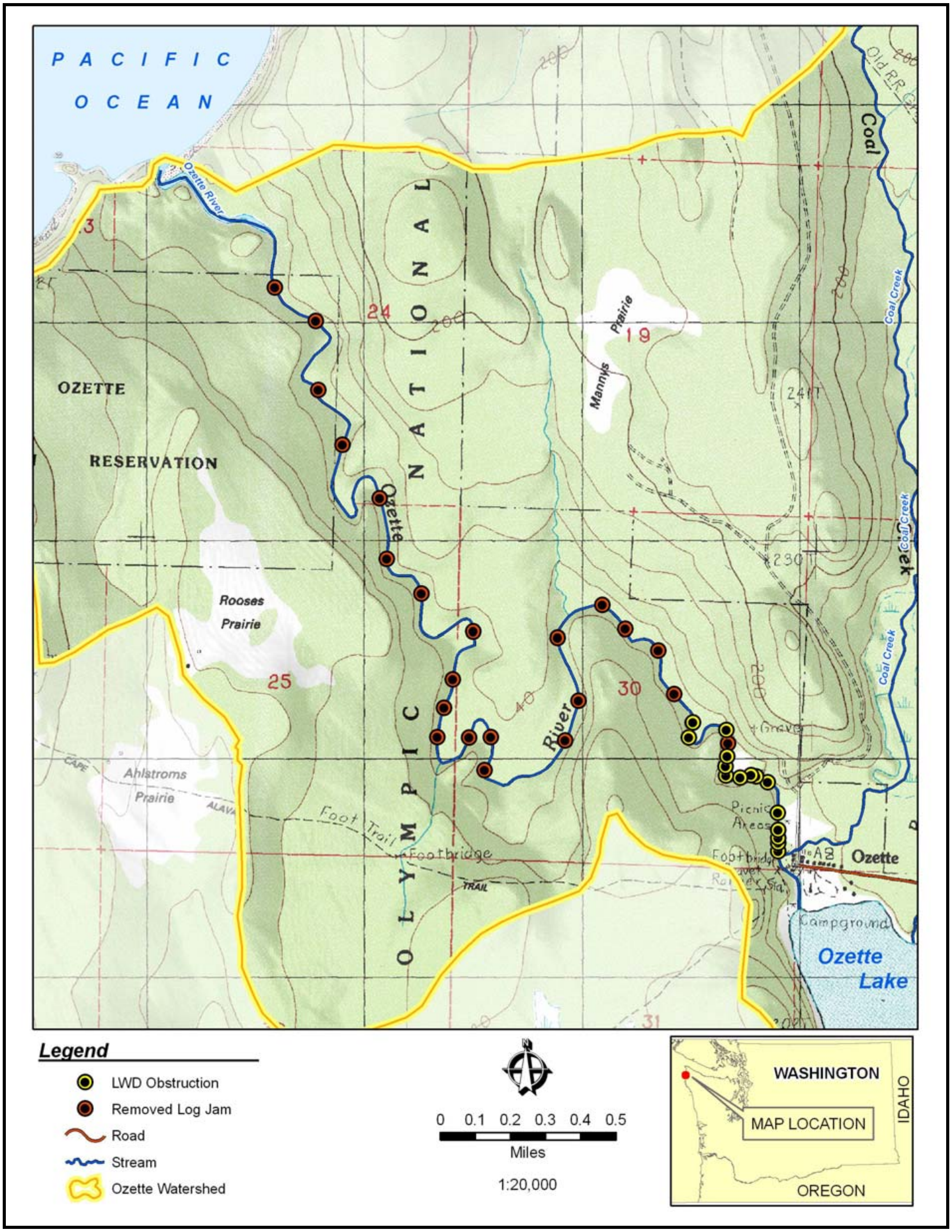

Figure 5.3. Location of large woody debris obstructions in July 2004 in the Ozette River and WDF logjam removal locations from summer 1952 (source: Kramer 1953; Herrera 2005).

Herrera (2005) modeled logjams using the obstruction feature of HEC-RAS to analyze hydraulic effects of logjams. The modeled period extended from December 1, 2003 through January 30, 2005. The model was calibrated using existing continuous discharge data from Ozette River and Coal Creek, wood loading conditions at existing log jams, and observed water surface elevations at surveyed cross-sections along the modeled reach. During the calibration, existing reach scale and local (LWD jam) channel roughness values were calculated from the HEC-RAS model. These roughness values were then used as a baseline for developing different wood loading scenarios (see below).

Upon model calibration to existing channel conditions and measured hydrographs from the Ozette River and Coal Creek stream gages, numerous wood loading scenarios were modeled. Jam spacing of 200, 500, and 1,000 feet and percent channel blockages of 0, 20, 40, 60, and 80 percent were used to represent a wide range of wood loading scenarios. One wood loading scenario included the current conditions of three “major jams” with a 20% increase in channel blockage. For each scenario, roughness values were altered locally along the study reach, as calculated from the continuum of various-sized jams in the initial calibration, supplemented by jam roughness and head loss values at other jams in western Washington.

Modeling results indicate that logjams in the upper 3,000 feet of the Ozette River exert a significant influence on both river and lake levels. The first three scenarios modeled by Herrera were (1) no logjams, (2) the current wood loading condition, and (3) the current wood loading condition but with increased jam size represented by an increase of 20% blockage at each jam (Figure 5.4). Results from wood loading scenarios of 200-foot jam spacing at 0, 20 40, 60 percent blockage are shown in Figure 5.5. Results from wood loading scenarios of 500-foot jam spacing at 0, 20 40, 60, 80 percent blockage are shown in Figure 5.6. Results from wood loading scenarios of 1,000-foot jam spacing at 0, 20 40, 60, 80 percent blockage are shown in Figure 5.7.

Note that for Figure 5.4 through Figure 5.7, the short-term (~one hour) discharge blips in the modeled hydrographs are a result of a model glitch that should be ignored. Future model runs will be able to correct these short-term errors, which are a result of poor floodplain definition in several upper cross-sections of the model (Herrera 2005). The short-term duration of these blips or spikes had a negligible effect on calculations of lake level elevation duration or averages.

While it is not possible to know exactly what the historical wood loading conditions were, especially in the upper 3000 ft of the river where wood was removed between circa 1890 to 1952, it is possible to estimate a range of likely wood loading scenarios. Kramer (1953) describes the removal of 26 large jams concentrated between RM 2 and RM 4 (mapped between RM 1 and 4.7 by Kramer [1953]), which, if evenly spaced, would result in a 400-foot to 750-foot average spacing. Undoubtedly, additional smaller jams (not channel spanning) existed that were not removed, pushing the spacing closer to ~500 feet. Herrera (2005) speculated that historical conditions were within the 200-foot spacing-60% blockage and the 500-foot-80% blockage range, based upon data, maps, and photos in Kramer (1953) and current wood conditions (Figure 5.5 and Figure 5.6). They assumed that wood load conditions in the upper Ozette River were similar to those documented by Kramer (1953) for the middle river because of similar historical riparian conditions, with additional wood in the upper river derived from floating wood from the lake blown into the head of the river by dominant winds from the south.

Herrera (2005) concluded from the modeling results that LWD jams have a significant influence on magnitude and duration of river and lake levels, but that timing appears to be essentially unaffected by variations in wood loading. Modeling results indicate that increases in lake level attributable to logjams are greatest during periods of high lake stage, moderate during median stages, and less during periods of low lake stage.

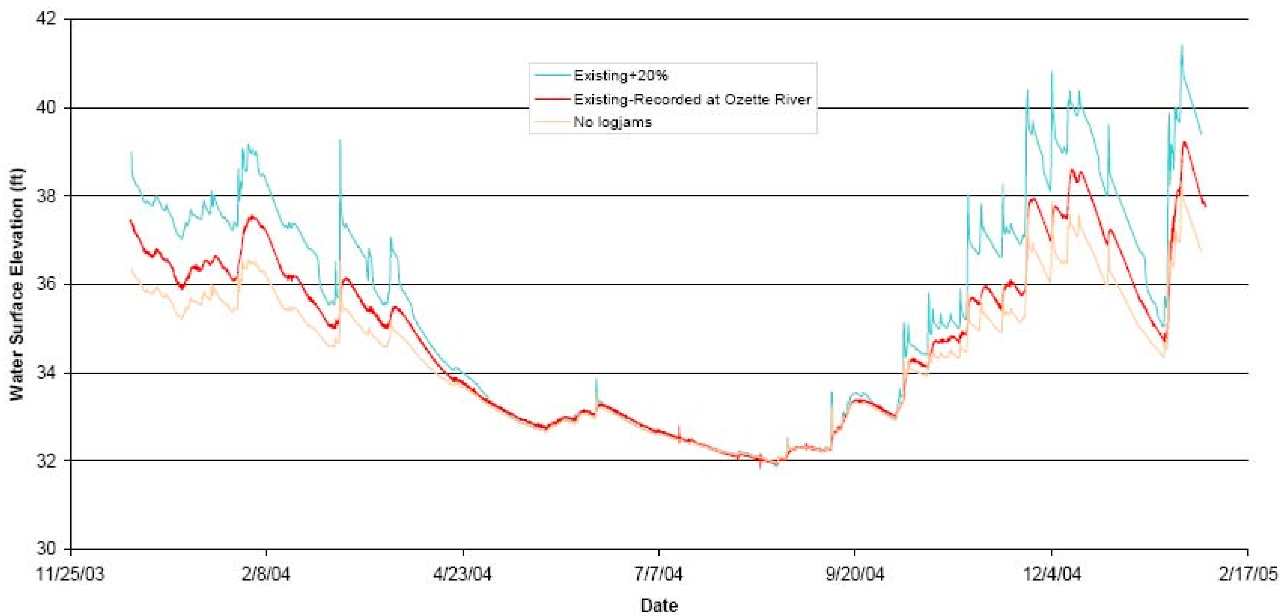

Figure 5.4. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, existing conditions plus 20% increase in jam blockage, and no logjams (source: Herrera 2005).

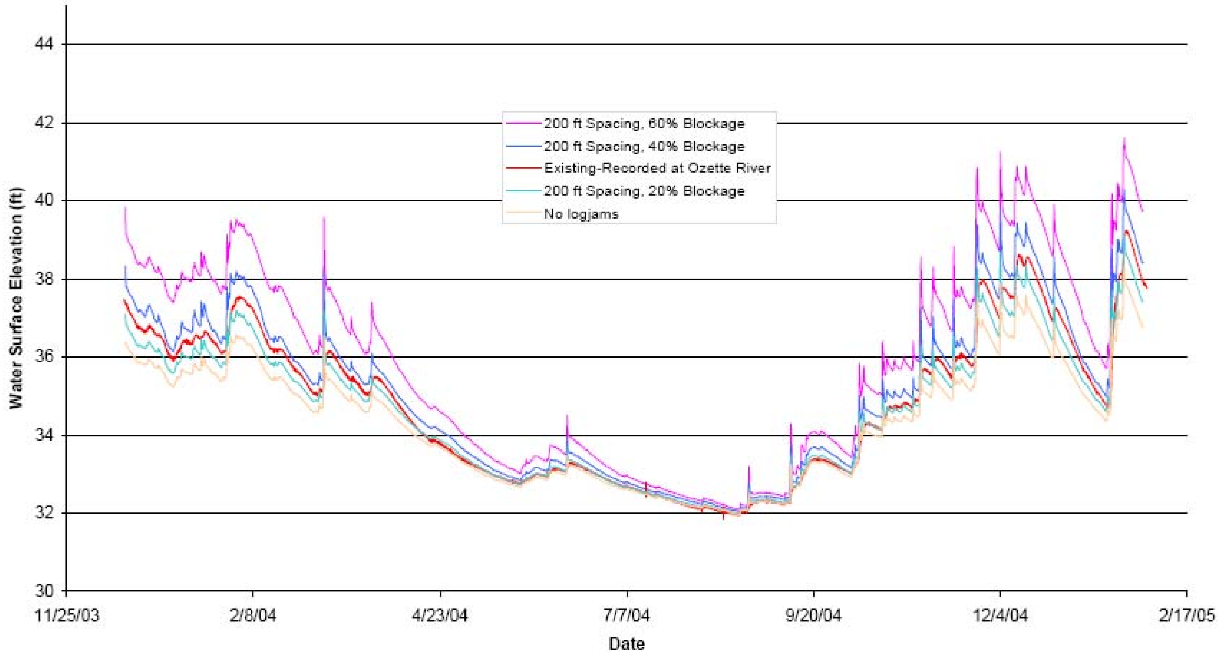

Figure 5.5. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, no jams, and 200-foot spacing at 20, 40, and 60 percent blockage (source: Herrera 2005).

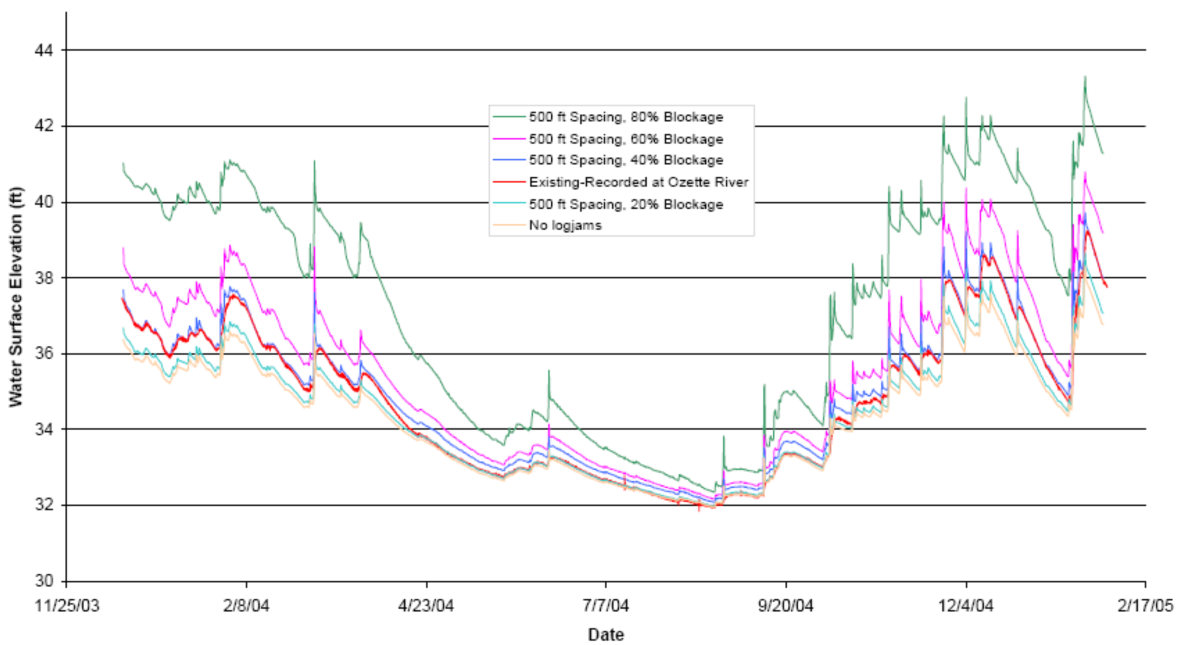

Figure 5.6. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, no jams, and 500-foot spacing at 20, 40, 60, and 80 percent blockage (source: Herrera 2005).

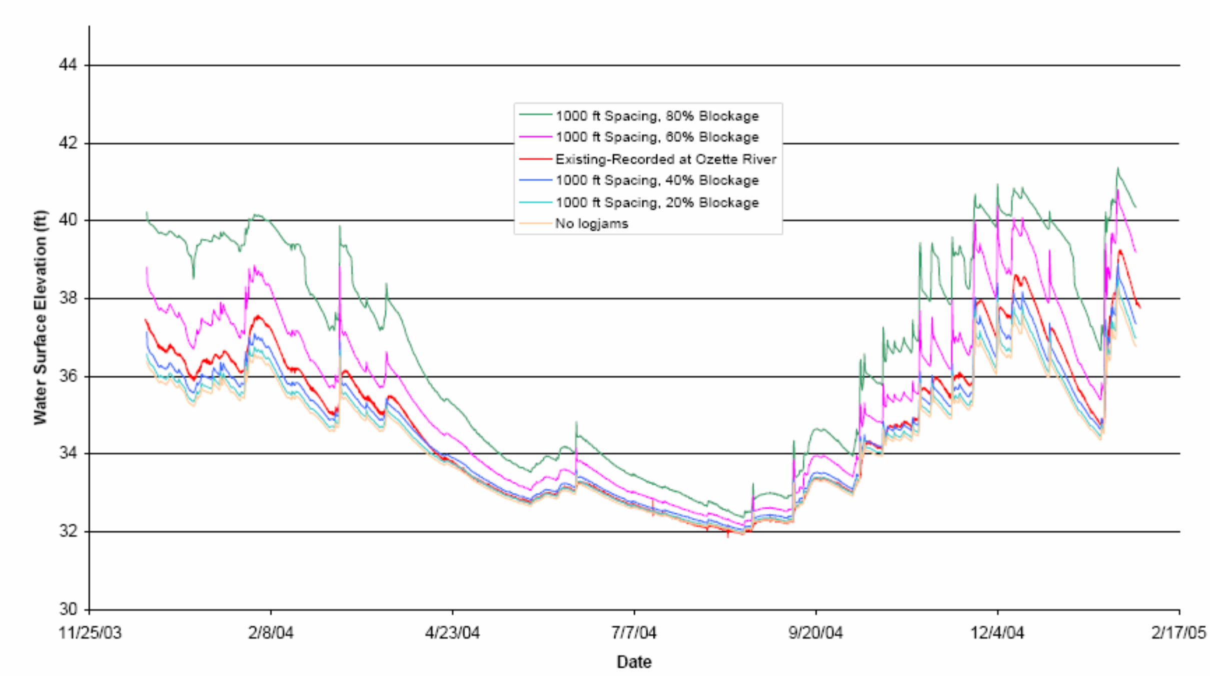

Figure 5.7. Comparison of modeled water surface elevations at the lake's outlet for existing conditions, no jams, and 1,000-foot spacing at 20, 40, 60, and 80 percent blockage (source: Herrera 2005).

The percent blockage of jams was modeled after the existing shape and configurations of existing jams, with added number of jams and percent blockage, which tended to concentrate wood at the middle and high portions of the cross-section. Some large wood currently in or over the channel has been delivered by relatively recent windthrow or other disturbance (after the wood removal circa 1890 to 1980), resulting in wood that spans the channel instead of accumulating low in the channel. Historical photos in Kramer (1953) indicate that wood had accumulated low in the cross-section (potentially water saturated), rather than spanning from bank to bank. Historical, modeled, or real placement of LWD lower in the cross-section elevation would likely have larger influences on low and medium lake and river stages (Robin Kirschbaum, personal communication 2005; PWA 2002). Initial results from earlier studies that modeled wood lower in the cross-sections (PWA 2002) found that wood in the outlet had higher influences on medium lake and river stages, which would have a greater effect on summer lake levels, stream discharge, and vegetation colonization.

A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions. The unsteady HECRAS hydraulic model of the Ozette River would only need minor modifications for future use (Herrera 2005), but would need to be coupled with a distributed watershed model (e.g., DHSVM or similar) to simulate historical, current, and future lake inflow hydrology as a result of changes in land use, vegetation cover, drainage density, roads, and soil water storage.

Available modeled water surface elevation estimates indicate that jam removal has decreased spring and early summer lake levels and, as result, decreased streamflow during the spring and summer low flow period and decreased lake levels during lake beach spawning, incubation, and emergence periods. Furthermore, it appears that other factors such as the sediment accumulation at the mouth of Coal Creek have also decreased low flows at a given lake stage (see Sections 4.3.6.1 and 5.3.2.1; also see Figure 4.37, Figure 4.38, Figure 4.39, Figure 5.8, Figure 5.9, and Figure 5.10)

The direct effects on sockeye in the Ozette River from wood removal and its influence on lake and river stage are unclear. The effects of low flows on adult and juvenile sockeye salmon in the Ozette River are discussed in Section 5.3.2.2. NOTE: This particular limiting factor operates between geographical boundaries and is thought to primarily affect the conditions along the shoreline of Lake Ozette and therefore to affect sockeye salmon spawning and egg incubation at the spawning beaches (see Section 5.4.1 and 5.4.2 for further discussion).

5.3.2 Ozette River Hydrology

5.3.2.1 Peak Flows

The temporal spatial distribution of juvenile and adult sockeye in the Ozette River precludes them from exposure to peak flow events in the river. Any potential increases in peak flows in the Ozette River are thought to have a negligible effect on sockeye salmon.

5.3.2.2 Low Flows

Section 5.3.1.2 above discusses the potential effects of wood removal on both high and low lake levels and streamflows in Ozette River. Additional empirical data collected over the last 30 years suggest that additional factors have reduced Ozette River streamflow. As presented in Section 4.3.6, a significant change in the stage-discharge relationship occurred in the Ozette River between 1979 and 2002, indicating that discharges in Ozette River are lower for a given stage in 2002 than in 1979. For example, Ozette River stage (and lake level) was higher throughout the entire summer of 2002 than the summer of 1979, but discharge was generally only a fraction of that observed in 1979. Between June 1 and September 2, 2002, river stage ranged from 0.69 to 0.08 feet higher than during the same period in 1979, averaging 0.31 feet (Figure 5.8). However, streamflow during this period for 2002 ranged from 11% to 109% of that observed during the same period in 1979, averaging only 57% of 1979 streamflow. WY 2002 precipitation totals were higher than WY 1979 totals in every month from October to July (except February), as was stage (Figure 5.9). March through August precipitation totals were 32% higher in WY 2002 than WY 1979. Starting in early May 2002, in spite of higher rainfall and lake stage, Ozette River measured streamflows were less than flows in measured WY 1979 (Figure 5.10). Both measured rainfall and stage data indicate that streamflows would be significantly higher in 2002 than in 1979 in the absence of hydrologic changes.

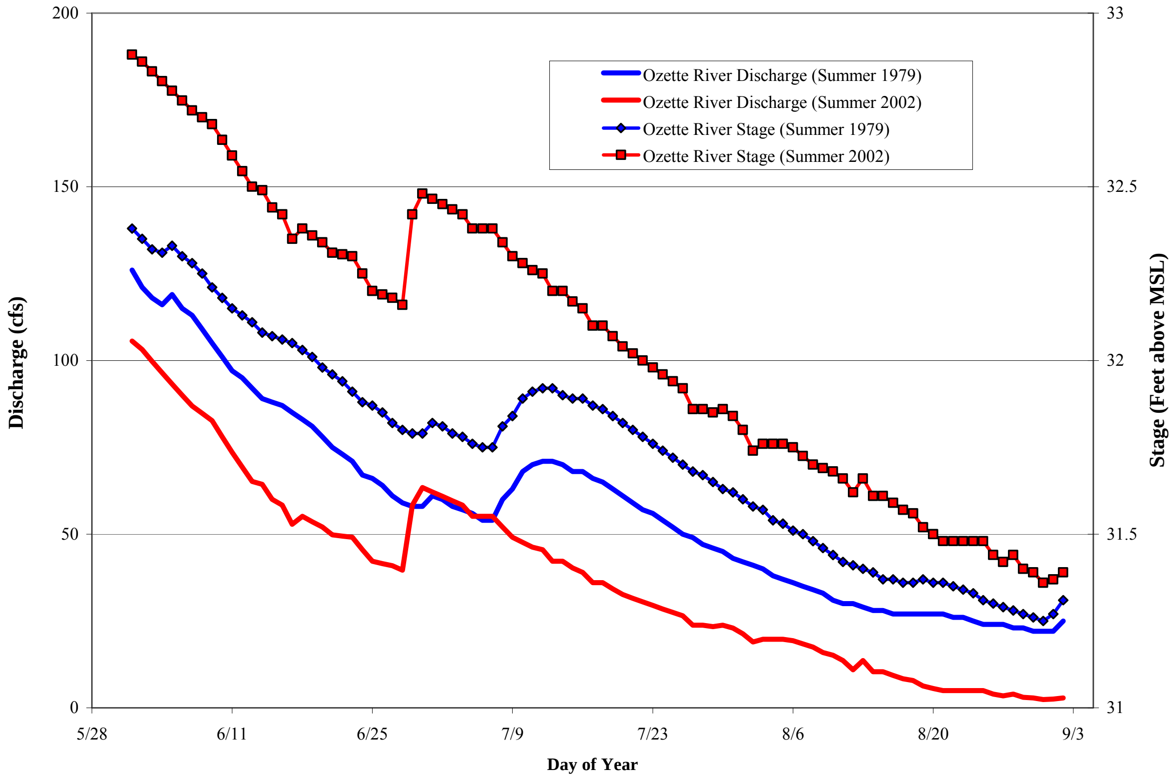

Figure 5.8. Comparison of Ozette River 1979 and 2002 summer low flow discharge estimates and stage data (source: USGS and MFM).

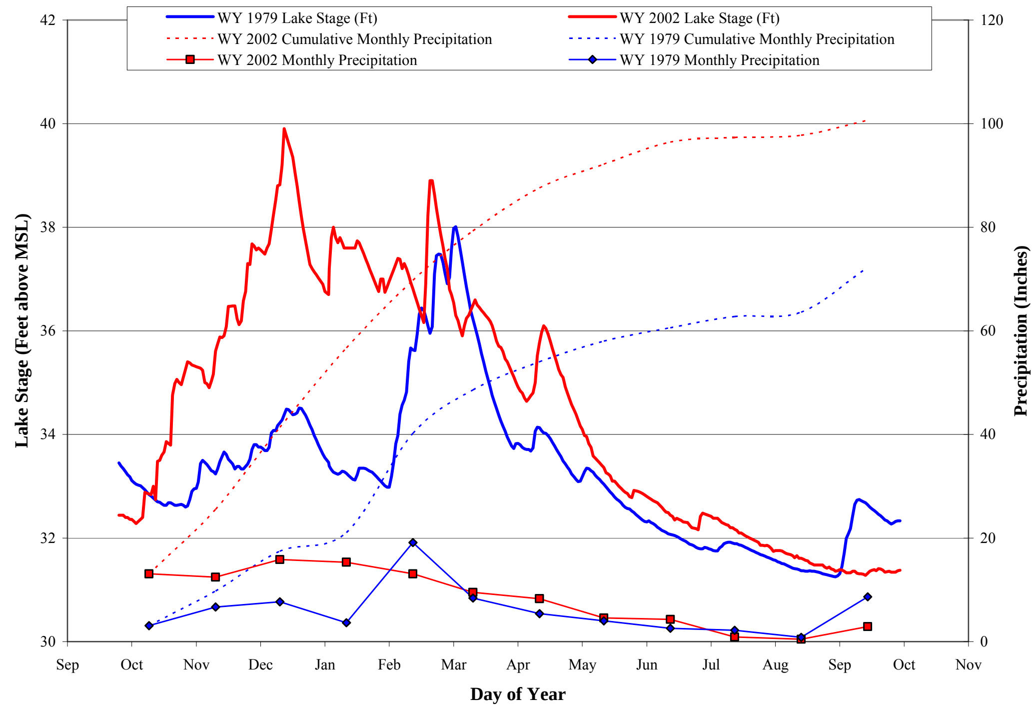

Figure 5.9. Comparison of Lake Ozette WY 1979 and WY 2002 lake stage and monthly and cumulative water year precipitation at Quillayute Airport (source: USGS and MFM, published and unpublished streamflow data; NOAA-NCDC 2005).

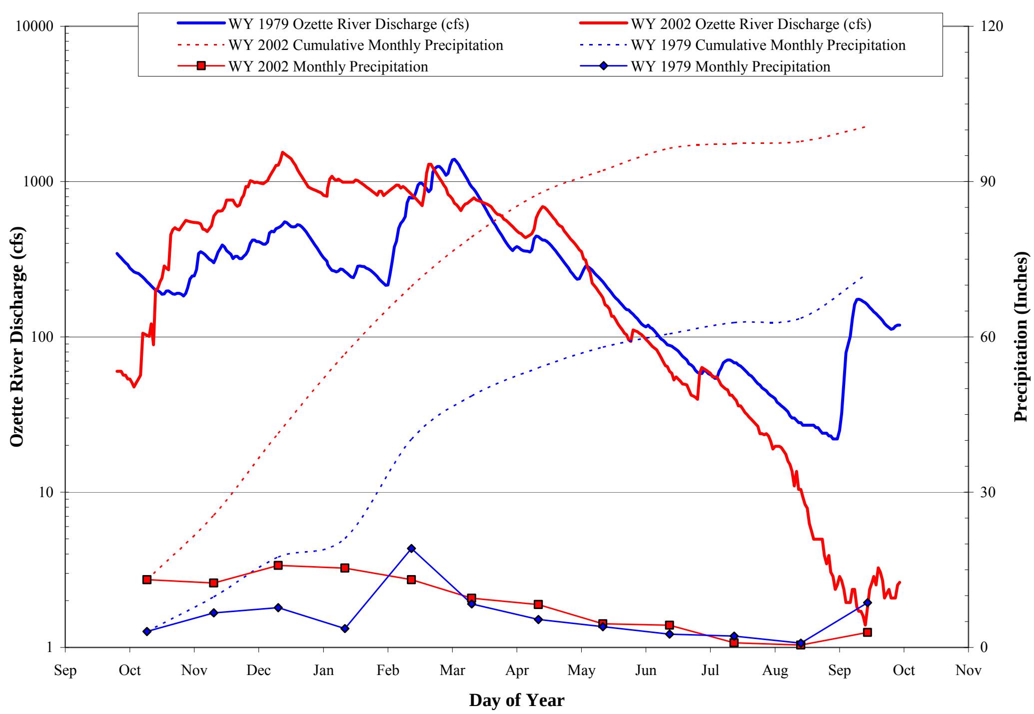

Figure 5.10. Comparison of Ozette River WY 1979 and WY 2002 streamflow discharge and monthly and cumulative water year precipitation at Quillayute Airport (source: USGS and MFM, published and unpublished streamflow data; NOAA-NCDC 2005).

5.3.2.2.1 Factors Affecting Low Flows

Available discharge data for the Ozette River at the lake outlet indicate a clear trend of decreasing baseflow (summer discharge) over time from the 1970s to 2000s (see Figure 4.44). The decrease is likely caused by multiple factors acting cumulatively over time. Identified factors include: climate, stage-discharge relationship, hyporheic flow, shoreline evapotranspiration, and tributary baseflow inputs. The following sections (Sections 5.3.2.2.1.1, 5.3.2.2.1.2, 5.3.2.2.1.3, 5.3.2.2.1.4, and 5.3.2.2.1.5) identify these factors and describe the mechanisms by which they may affect summer low flows in the Ozette River.

5.3.2.2.1.1 Climate

Available data do not indicate that climatic controls on precipitation or lake level have changed dramatically over time to influence Ozette River discharge. Rather, internal mechanisms are at play. The 2002 and 2003 dry-season summer rainfall and lake stage do not appear to be rare or uncommon events. Dry season summer rainfall and lake stage were also comparably low during the summers of 1967, 1982, 1985, 1992, 1996, and 1998 for rainfall (Figure 1.4) and lake stage 1985 and 1998 (Figure 4.13). As an example comparison, WY 2002 precipitation totals were higher than WY 1979 totals in every month from October to July (except February), as was lake stage (Figure 5.9). March through August precipitation totals were 32% higher in WY 2002 than WY 1979. Ozette River stage (and lake level) was higher throughout the entire summer of 2002 than 1979, but 2002 river discharge was generally only a fraction of that observed in 1979 (Figure 5.8).

5.3.2.2.1.2 Stage-Discharge Relationship

A significant change in the stage-discharge relationship occurred in the Ozette River between 1979 and 2002 (Section 4.3.6; Figure 4.37), indicating that discharges in Ozette River are lower for a given stage in 2002 compared to 1979. The shift in the rating curve has not been uniform and has been a result of different processes working at different stages or sections of the rating curve. The primary mechanism for changing the lower end of the stage-discharge relationship has been sediment deposition in the Ozette River from Coal Creek. Repeat channel cross-sections at the Ozette River Bridge from the 1970s and 2000s (Figure 4.38 and Figure 4.39) indicate that the channel thalweg has aggraded by 1 foot. This has affected the low-flow local-control on the release of water from the lake during summer months.

In addition, reach scale sedimentation from Coal Creek has aggraded the channel beyond the bridge cross-section to well downstream of Coal Creek, as indicated by field evidence of sand and fine gravel aggradation within the upper mile of Ozette River. This reach scale sedimentation, coupled with recent LWD recruitment has altered the medium and high rating curves during hydraulic conditions of reach scale channel control.

For reduced summer river discharges, it is hypothesized that reduced discharge at a given stage is primarily a function of reduced access to stored lake water below an elevation of 30 to 31 feet (NGVD 1929). As the lake draws down in the summer and baseflow inputs to the lake diminish in significance, Ozette River discharge becomes largely dependent on water stored in the lake from the previous rain events and the wet season.

5.3.2.2.1.3 Hyporheic Flow

As described above sedimentation at the mouth of Coal Creek has raised the hydraulic control of the lake outlet by 1-foot over the last twenty-five years. However due to the porosity of the sediment (silt, sand and fine gravel), hyporheic flow occurs through the sediment wedge. A fraction of the water that once flowed above the Ozette River bed may now flow within substrate interstices. Undoubtedly, hyporheic flow was always a component of discharge but the percentage of hyporheic flow to total flow may have changed due to sedimentation.

Extreme low discharge data presented in Section 4.3.6.2 indicate approximately a 30% increase in surface flow below the Coal Creek confluence. Recent discharge measurements both above and below Coal Creek indicate less contribution of hyporheic flow to surface flow (MFM 2007 unpublished data).

5.3.2.2.1.4 Shoreline Vegetation and Evapotranspiration

Between 1953 and 2003 there was a 56% reduction in unvegetated shoreline around Lake Ozette (Section 4.2.1). This reduction was due to shrub and herb vegetation colonizing unvegetated shoreline areas. This vegetation has increased summer evapotranspiration rates around the perimeter of Lake Ozette, potentially influencing lake levels and thus river discharge.

5.3.2.2.1.5 Tributary Baseflow Inputs

Few empirical discharge data exist for Ozette tributaries (Figure 4.33). However a detailed literature review of potential land-use impacts on stream discharge (Sections 5.5.1.2.1 and 5.5.1.2.2) indicate that the degree of forest plantation development and road network construction in the Ozette watershed could have altered the flow regimes of Ozette tributaries. More specifically, it is hypothesized that summer base flows to Lake Ozette have declined due to loss of fog drip, increased summer transpiration efficiency of water by young plantation trees, reduction in soil water retention due to road cuts and ditches, and less floodplain water storage (and release) due to channel simplification and incision. These hypothesized reductions in summer water inputs to Lake Ozette could translate to reduced Ozette River discharge.

5.3.2.2.2 Biological Effects

Reduced streamflow has the potential to affect water quality, predation rates and efficiency, and migration, reducing the fitness of migrating Ozette sockeye. The overall decrease in baseflow (summer discharge) during the sockeye migration periods remains unknown and the relative contribution of the factors identified in Section 5.3.2.2.1 is poorly understood, as are the biological effects. The most substantial reductions in streamflow occur from mid- to late-summer (when streamflows are naturally lower). Adult sockeye migrate through the Ozette River from early-spring through late-summer while most emigrating sockeye smolts transit the river during spring. The overall degree to which low flow changes affect emigrating sockeye smolts is unknown. Quantification of streamflow reduction during smolt emigration, and potential impacts remain a data gap. However, sufficient data exist to indicate that low summer flows likely impact adult sockeye migration.

Figure 5.11 depicts the 2003 adult sockeye return (plotted as daily percentage of the total return) contrasted with the observed 2003 Ozette River discharge and the theoretical historical discharge that would have existed prior to the shift in the stage-discharge relationship (i.e., 2003 stage data and the 1979 USGS rating curve). In RY 2003, approximately 8% of the sockeye entered the lake when streamflow exceeded 400 cfs and over 62% entered when streamflow was greater than 100 cfs. Approximately 10% of the RY 2003 sockeye entered the lake when flows were less than 35 cfs. The lowest flow in which sockeye were observed migrating was 11 cfs. A comparison of observed summer 2003 river stage and discharge data where streamflow was less than 100 cfs during the sockeye run, to the observed 2003 stage and discharge calculated using the old 1979 USGS rating curve and observed 2003 stage, indicates that streamflow averaged only 34% of what it would have been before the stage-discharge shift occurred.

Reduced streamflow at a given stage is thought to be primarily a function of reduced access to stored lake water below an elevation of 30 to 31 feet above MSL (Figure 4.38 and Figure 4.39). The overall degree to which baseflows have declined during the sockeye migration period remains somewhat unclear, because the complex interplay between the stage-discharge shift and other factors affecting Ozette River hydrology (see Section 5.3.2.2.1). The stage-discharge shift was not detected until 2002. However, available data indicate that the shift occurred slowly over time (Figure 4.37) with the most substantial changes occurring most recently. Reduced low flows during the sockeye migration period could affect water quality, predation rates and efficiency, and migration timing, reducing the fitness of migrating Ozette sockeye. However, the overall effect on Lake Ozette sockeye is unknown.

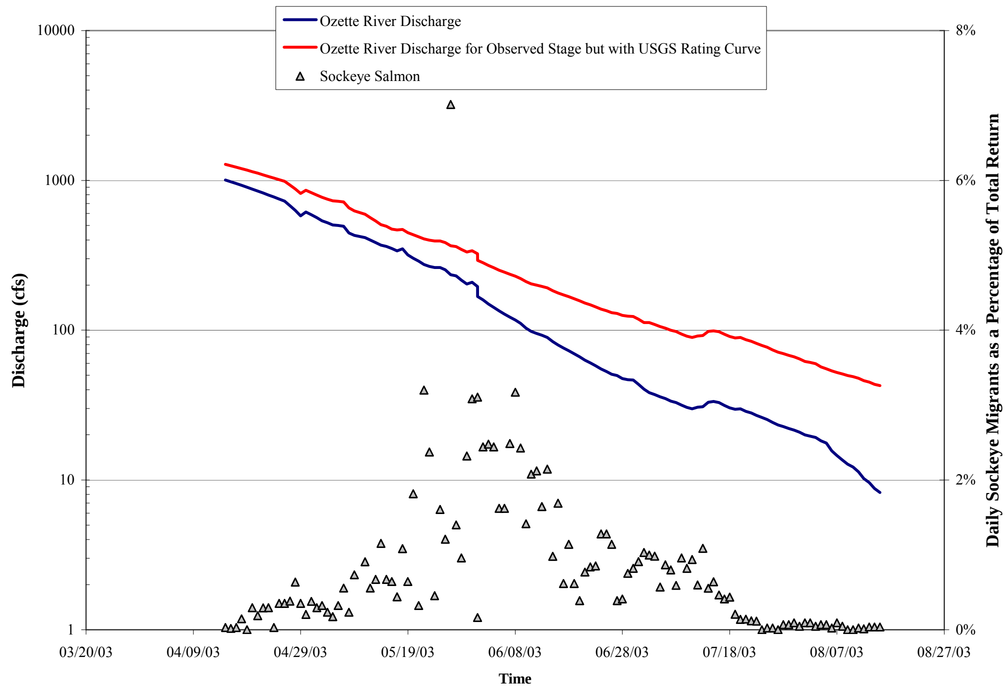

Figure 5.11. 2003 sockeye return (plotted as daily percentage of the total return) in relation to the observed 2003 Ozette River discharge vs. the theoretical historical discharge based on 1979 USGS rating curve (source: USGS and MFM, published and unpublished streamflow data; Haggerty 2005a).

5.3.3 Water Quality

Stream temperature and turbidity (suspended sediment) are the two primary water quality attributes identified that have the potential to limit sockeye salmon productivity and survival in the Ozette River. Water quality conditions in the Ozette River are described in detail in Section 4.3.5. The most significant potential effects of water quality on Lake Ozette sockeye salmon are mortality or decreased fitness resulting from temperature stress (e.g. increased susceptibility to disease or parasites), and mortality or decreased fitness from gill trauma caused by high concentrations of fine sediment during storm events. Fine sediment also affects pool characteristics in the Ozette River.

5.3.3.1 Stream Temperature

5.3.3.1.1 Effect of High Water Temperature on Sockeye Salmon

This subsection contains a brief review of the known lethal and sub-lethal effects of elevated stream temperature on southern North American sockeye stocks. Results from studies examining lethal effects of high water temperature vary by sockeye stock and life stage. Brett (1952) determined that 25.6°C was the upper lethal temperature threshold for juvenile sockeye salmon and that no sockeye salmon held at temperatures of 25°C for longer than one week could survive (method used: incipient lethal temperature). In thermal tests with adult Fraser River sockeye Servizi and Jensen (1977) concluded that thermal shock caused mortalities at temperature greater than 24°C, and a combination of thermal stress and *Flexibacter columnaris* (Chondrococcus columnaris) caused mortalities observed at 24°C, while mortalities observed at temperatures between 22 and 24°C were attributed to *F. columnaris*. Servizi and Jensen (1977) concluded that no mortality occurred after holding adult sockeye for 15 days at 21°C. Farrell and Hinch (2004) point out that the results of Servizi and Jensen (1977) may not be applicable to the "wild" situation because fish were pre-treated with oral antibiotics and dipped in fungicide.

Studies of Fraser River adult sockeye conducted in 2003 and 2004 found varying rates of mortality in holding experiments (Farrell and Hinch 2004). Adult late-run Fraser River sockeye held at 19.6°C experienced 50% mortality after 9 days, and sockeye held at 15.9°C experienced 50% mortality after 29 days. Adult Harrison River sockeye held at 18.0°C experienced 50% mortality after 16 days. DFO (2005) concluded that these results likely represent the worst-case scenario, because sockeye were handled several times and held in aquaria in order to conduct the studies. Kemmerich (1945) attempted to hold (in Umbrella Creek) adult Lake Ozette sockeye captured at the lake outlet. The water temperature in Umbrella Creek was 18°C, and these sockeye experienced a 72% mortality after 7 days. Other attempts to hold sockeye for prolonged periods in Lake Ozette and the Ozette River have resulted in fungal growth on sockeye, as well as high mortality rates (MFM unpublished data; Kemmerich 1945)).

Fraser River sockeye researchers have also found a correlation between accumulated temperature units (ATU) or degree-days and pre-spawning mortality. When sockeye are exposed to 450 to 500 ATUs, they are more likely to die prior to reaching the spawning grounds (DFO 2005). Since 1995, several stocks of Fraser River sockeye salmon have experienced extremely high rates (occasionally exceeding 90%) of in-river en route and pre-spawning mortality (Cooke et al. 2004). High in-river Fraser River sockeye mortality rates documented after 1995 prompted intensive monitoring of in-river environmental conditions, as well as sockeye run timing, migration rates, and physiological studies (DFO 2005). In 2004, nearly 72% of the in-river sockeye run (including early Stuart, early summer, summer, and late-run stocks) could not be accounted for on the spawning grounds (DFO 2005). Fraser River researchers used two simple models to estimate total mortality of all stock groups based on temperature alone and estimated mortality at 45% to 88% for the 2004 sockeye run (45% Late, 72% Early Stuart, 88% Early Summer and Summer; DFO 2005).

High water temperatures have been shown to result in delayed sockeye migration. In the Okanagan River, sockeye migrations cease when water temperatures exceed 21°C and resume when temperatures fall below 21°C (Hyatt et al. 2003). Fraser river sockeye researchers have found more general relationships between elevated water temperatures and sub-lethal effects to sockeye. DFO (2005) concluded that high water temperature in the Fraser River led to direct mortality, and sub-lethal effects included fungal and bacterial growth, delayed migration, increased physiological stress, decreased energy reserves to reach spawning grounds and spawn successfully, and increased mortality following non-lethal fisheries encounters. Specific data on water temperatures, sockeye exposure times, and resulting sub-lethal effects are generally lacking in the sockeye literature. In the Fraser River system, late-run sockeye entering the system earlier than normal are exposed to warmer than normal water temperatures. This has been found to result in a higher accumulation of temperature degree days, promoting a rapid proliferation of *Parvicapsula* and other infections (DFO 2005).

5.3.3.1.2 High Temperature Impacts on Lake Ozette Sockeye Salmon

The impact of high water temperatures in the Ozette River on Ozette sockeye is not fully understood. In order to evaluate temperature regimes experienced by migrating sockeye in the Ozette River, average daily mean and maximum stream temperature was examined relative to run timing. Composite average mean and maximum daily stream temperature were calculated from years where data existed (mean temp n=4; max temp n=6; analysis excluded data collected in 1999, when temperature data was collected only in the upper section of the estuary). Figure 5.12 depicts the composite average mean and maximum daily stream temperature in the Ozette River compared to a composite average of the daily cumulative proportion of adult and juvenile migrants entering and exiting lake Ozette (for adult sockeye this includes return years 1998 through 2003; data from 2002 and 2004 were used to generate the smolt cumulative run curve).

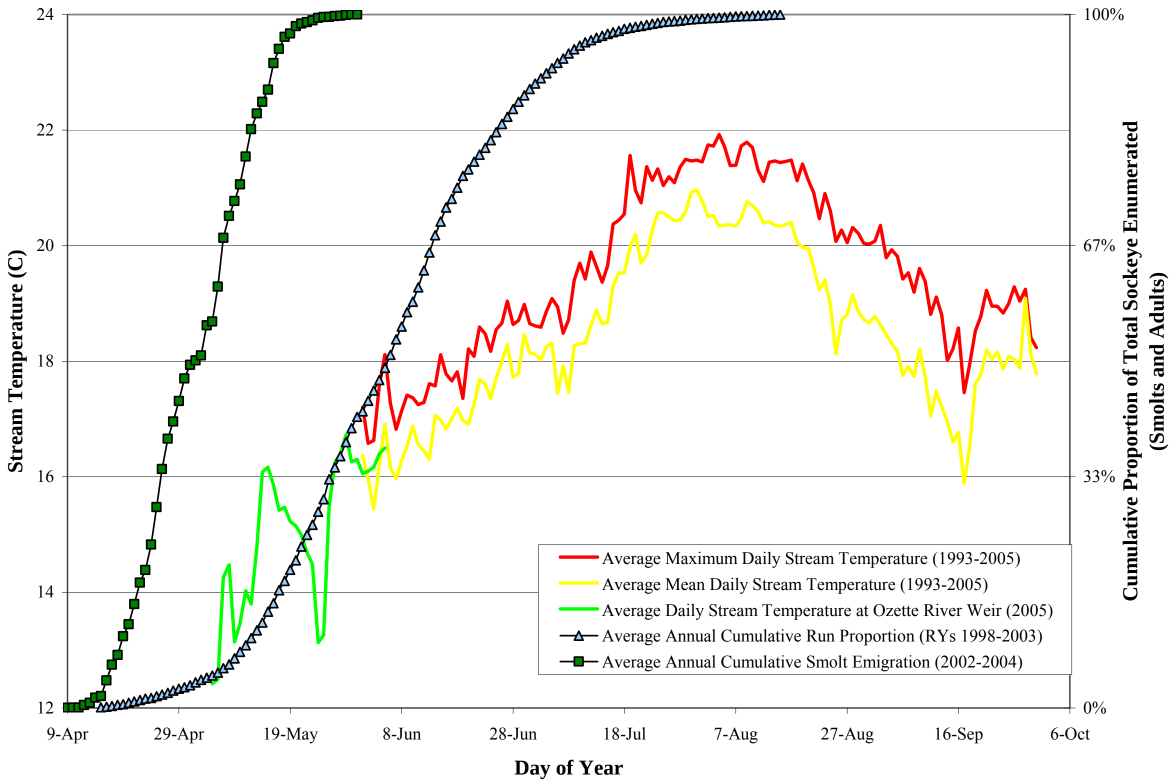

Figure 5.12. Comparison of Ozette River daily average mean and maximum stream temperature observed from 1993 through 2005, Ozette sockeye smolt emigration timing (2002-2004), and adult run timing (RY 1998-2003). Data sources: Peterschmidt and Hinton 2005 (smolt data); Haggerty 2004a, 2005a, 2005b, 2005c, and 2005d (adult data); Meyer and Brenkman 2001 and MFM, unpublished data (water temperature).

Temperature data during the peak smolt emigration period is generally lacking for the Ozette River. However, temperature data collected in May 2005 and data collected in June 1994 and 2002-2005 indicate that mean temperatures are likely less than 16 °C during most years. Based on smolt trapping data collected from 1979 through 2004, only a small fraction (<<5%) of the average annual smolt emigrants exit the lake after May. Maximum observed temperatures from June 1 to June 15 range from 16.6 to 20.0 °C. Brett (1952) determined that preferred temperature for juvenile sockeye was between 12 and 14°C; physiological optimum is 15°C (Brett 1971 *in* Pauley et al. 1989). Currently stream temperatures during the smolt emigration do not appear to pose any risk to the survival of the vast majority of emigrating smolt. However, future temperature sampling in the Ozette River should begin in April so that long-term trends in timing and temperature can be evaluated in the future.

Maximum stream temperatures approaching 24°C have been recorded during the adult sockeye migration period (MFM unpublished stream temperature data). Data included in Figure 5.12 indicate that 52.3%, 10.8%, 1.5% and 0.0% of the average annual run enter the lake when average mean daily stream temperature in the Ozette River exceeds 16°C, 18°C, 20°C, and 22°C respectively. These data also indicate that 57.2%, 26.2%, 2.5%, and 0.0% of the average annual run enter the lake when average maximum daily stream temperature exceeds 16°C, 18°C, 20°C, and 22°C.

However, the relationship between average daily mean and maximum temperatures and average run timing does not represent the temperatures experienced by individual returns. Therefore, all paired temperature and run timing data were compared by run year. These data were only available for RYs 2002-2004. Figure 5.13, Figure 5.14, and Figure 5.15 depict Ozette River stream temperature and sockeye run timing for return years 2002, 2003, and 2004. Interestingly, the percent of sockeye migrating up the Ozette River when daily mean stream temperature exceeded 18 °C ranged from 16.3% (RY 2003) to 55.9% (RY 2004), averaging 31.2% (~3 times greater than the values predicted from Figure 5.12). The percent of sockeye migration that occurred when daily maximum stream temperature exceeded 20 °C ranged from 5.6% (RY 2003) to 28.2% (RY 2004), averaging 14.1% (~6 times greater than the values predicted from Figure 5.12).

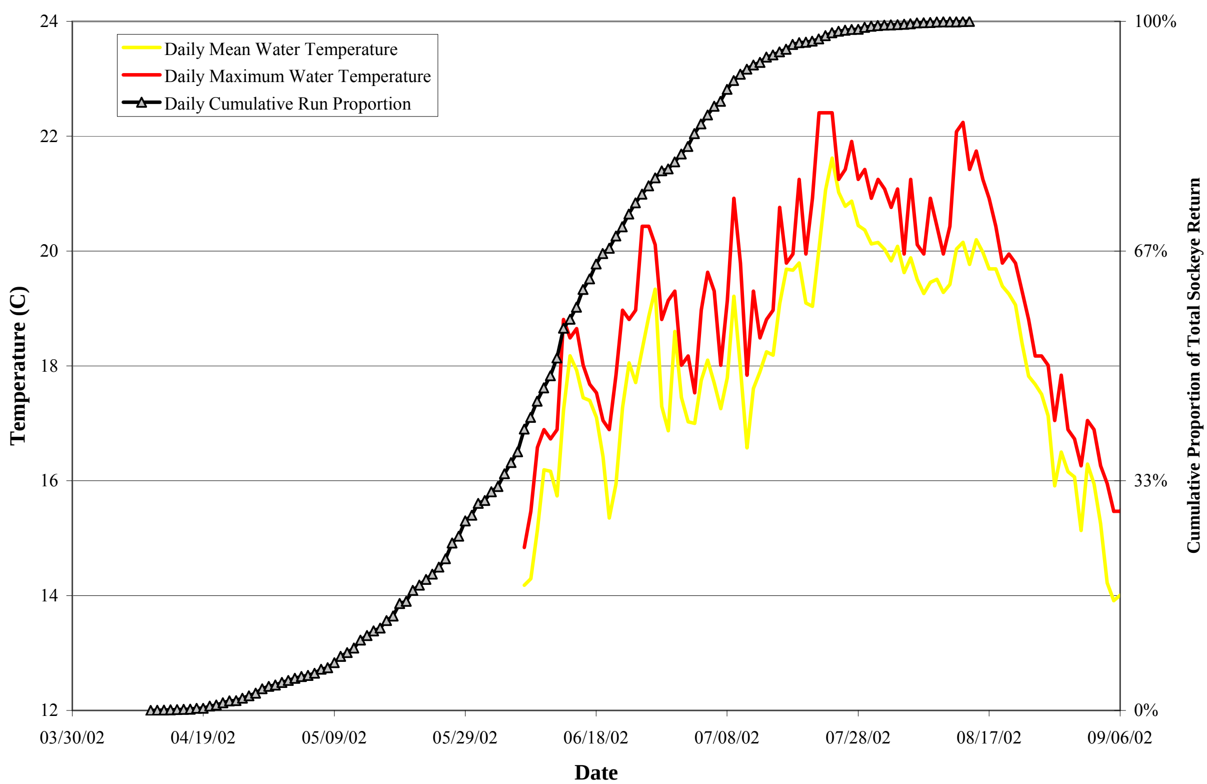

Figure 5.13. Ozette River maximum and average daily stream temperature in 2002 contrasted with RY 2002 cumulative sockeye run-timing curve (source: Haggerty 2004a [adult data]; MFM, unpublished data [water temperature]).

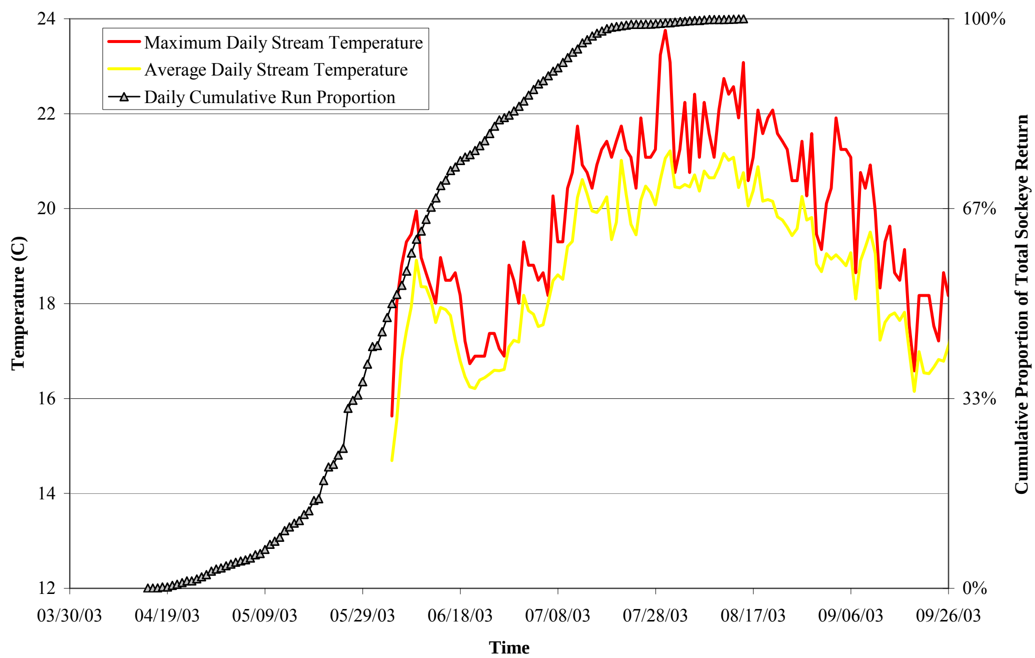

Figure 5.14. Ozette River maximum and average daily stream temperature in 2003 contrasted with RY 2003 cumulative sockeye run-timing curve (source: Haggerty 2004a [adult data]; MFM, unpublished data [water temperature]).

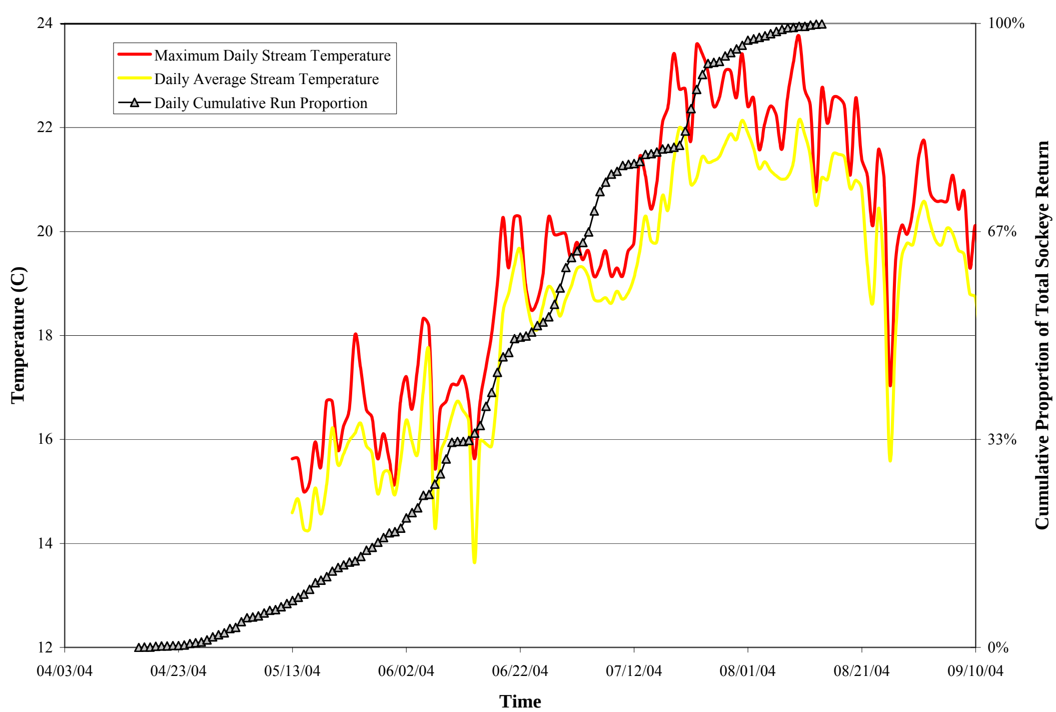

Figure 5.15. Ozette River maximum and average daily stream temperature in 2004 contrasted with the preliminary RY 2004 cumulative sockeye run-timing curve (source: Haggerty 2004a [adult data]; MFM, unpublished data [water temperature]).

The effects of high (>18°C) stream temperatures on sockeye salmon depend upon several factors, including temperature, exposure time, specific stock temperature tolerances, and more. Ozette River water temperatures are primarily a result of Lake Ozette surface temperatures, which are controlled by spring and summer air temperatures and heating days. Therefore, river (lake) temperature varies by annual climatic conditions (see Section 1.3.2). Stream temperature data collected during summer 2005 showed little temperature moderation in the first two miles downstream from the lake (Figure 4.32), suggesting that temperatures observed near the lake's outlet are an excellent indicator of downstream temperatures and overall temperatures experienced by migrating sockeye salmon. Late summer low flow temperatures may follow a different downstream pattern. In order to determine the proportion of the annual run exposed to different temperature ranges, the number of sockeye observed transiting the weir were categorized as being exposed throughout the river to temperatures recorded just downstream from the confluence with Coal Creek. Figure 5.16 depicts the proportion of adult Lake Ozette sockeye exposed to different temperature ranges in the Ozette River.

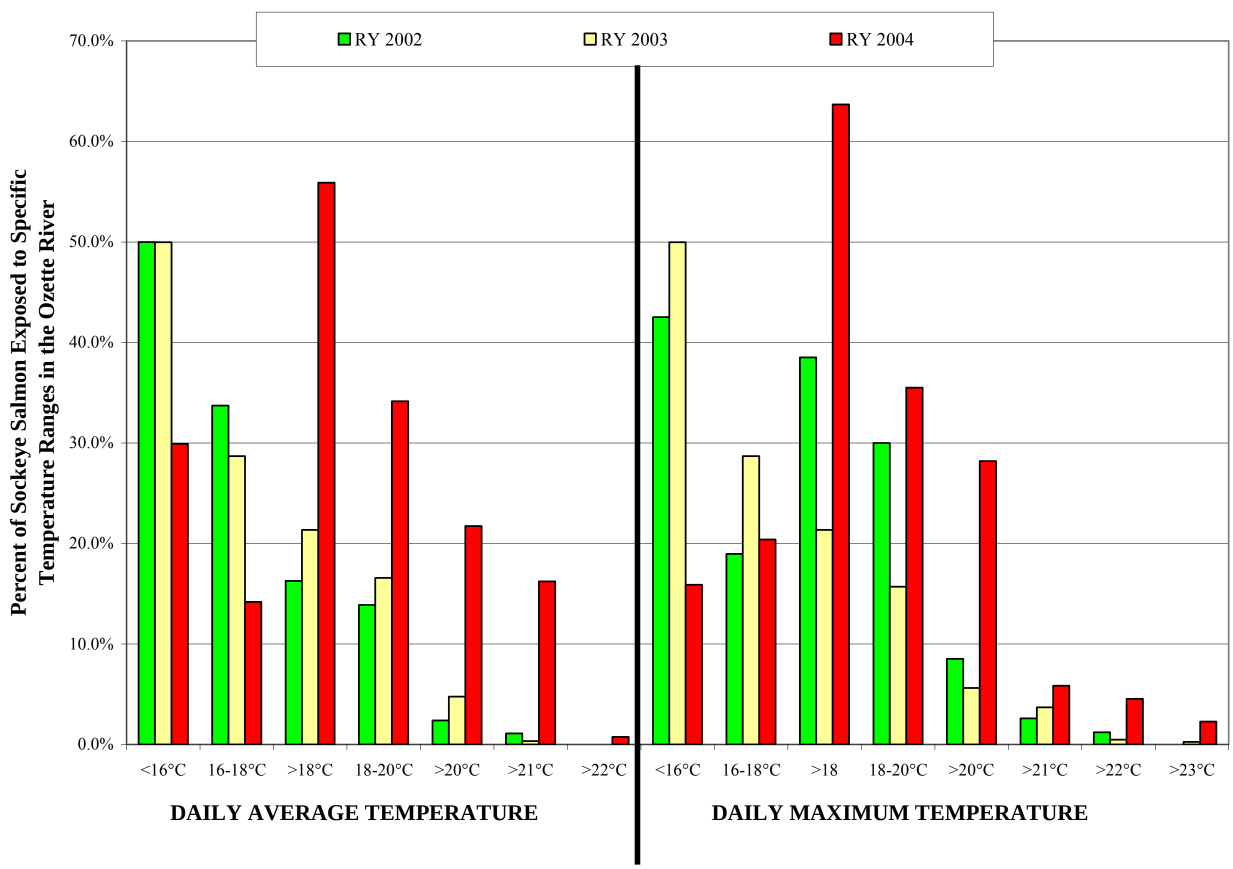

Figure 5.16. Estimated percentage of annual sockeye returns (RY 2002-2004) to Lake Ozette exposed to various temperature range categories (source: Haggerty 2004a, 2005a, and MFM unpublished data).

Gearin et al. (2002) reported that the mean transit time for adult sockeye from the estuary to lake entry in RY 2000 was 65.2 hours (Figure 3.4; range=17-154hrs). Sockeye may encounter excessive temperatures in the Ozette River, but their exposure time appears to be short. The effects of 2- to 4-day exposure to temperatures between 18-24 °C is not well documented in the scientific literature. However, it is important to note that some individuals linger in the river longer; approximately 8% of sockeye reported by Gearin et al. (2002) spent 6 to 7 days between the estuary and the lake. However, no studies specifically designed to evaluate Lake Ozette sockeye temperature tolerances have been completed. Therefore, we suggest a range of different impacts that could occur based on studies conducted with Fraser River sockeye (summarized in DFO 2005). Table 5.1 depicts the estimated proportion of Lake Ozette sockeye exposed to different temperature ranges during upstream migration and the potential biological effects for RYs 2002, 2003, and 2004.

Table 5.1. Proportion of Lake Ozette sockeye runs exposed to different temperature ranges during upstream migration and the potential biological effects (source: Haggerty 2004a, 2005a, and MFM unpublished data).

Average Daily Temperature Exposure	Percent of Sockeye Run Exposed to Specified Temperature Range			Potential Effects
	RY 2002	RY 2003	RY 2004	
<18°C	83.7%	78.7%	44.1%	No Direct Effect
18-19°C	6.6%	8.0%	5.0%	Decreased swimming performance, increased energy use
19-20°C	7.3%	8.6%	29.2%	Increased physiological stress, slow or delayed migration
20-21°C	1.3%	4.4%	4.8%	Increased risk of pre-spawning mortality and disease
>21°C	1.1%	0.3%	16.2%	Chronic exposure can lead to severe stress, direct en-route mortality, and delayed pre-spawning mortality

Jacobs et al. (1996) speculated that adult sockeye returning to Lake Ozette during periods when maximum daily stream temperatures exceed 18°C may be delayed because of high water temperatures. Some sockeye may be delayed in their return to the lake, but sockeye weir data indicate that Ozette sockeye migration continues even as water temperatures approach 24°C. In the Okanagan River, sockeye migrations generally cease when water temperatures exceed 21°C and resume when temperatures fall below 21°C (Hyatt et al. 2003). However, the Okanagan-Columbia river system is complex and provides more thermal refugia for sockeye.

In the case of Ozette River, once sockeye have begun their journey upstream, a behavioral response to high temperatures that delays migration will result in increased exposure to elevated temperatures. Sockeye that haven't entered the river could hold in the ocean or estuary until more favorable river conditions occur, but there is no evidence that migration ceases during high temperatures. The counting weir may delay migrants from entering the lake and increase their exposure time to elevated stream temperatures. Weir operations since 1998 have been conducted with the weir left open 24-hrs/day for free passage into the lake in order to minimize impacts of high water temperatures and predation caused by the weir.

High water temperatures in the Ozette River during adult migration are not known to result in significant direct en-route mortality. However, high temperatures probably make sockeye more susceptible to disease and infection. Elevated temperatures can promote fungal and bacterial infections, as well as secondary wound infection, making sockeye more susceptible to pre-spawning mortality. Monitoring of run timing and Ozette River stream temperature should continue in the future. An investigation of thermal refugia habitat in the Ozette River should be conducted to determine whether deep pools or springs exist that could provide holding habitat for migrants to reduce thermal stress.

5.3.3.2 Suspended Sediment and Turbidity

Elevated turbidity and suspended sediment concentration (SSC) have numerous negative impacts on fish and other stream biota, including behavioral effects, physiological effects, and habitat effects. Behavioral effects of turbidity and SSC on fish include changes in foraging, predation, avoidance, territoriality, homing, and migration (Waters 1995; Bash et al. 2001). Physiological effects include gill trauma and damage, reduced respiration, changes in blood physiology due to stress, disruption of osmoregulation during salmonid smolt migration, and reduced oxygen transfer to incubating eggs in gravel affected by sedimentation (Waters 1995; Bash et al. 2001). Habitat impacts include: changes in the abundance and diversity of prey (e.g., invertebrates and mircofauna); altered primary production (i.e., photosynthesis) (Waters 1995; Bash et al. 2001; Suttle et al. 2004); changes in temperature regimes (Waters 1995); increased channel sedimentation (Everest et al. 1987); increased gravel and cobble embeddedness (Bash et al. 2001); reduced gravel permeability, intergravel water flow and oxygen transfer (i.e., hyporheic flow); reduced gravel porosity and emergence success (McNeil and Ahnell 1964; Everest et al. 1987; McHenry et al. 1994; Reiser 1998); reduced pool habitat volume and habitat complexity (Lisle and Hilton 1999); and increased bedload mobility and scour depths (Lisle et al. 2000).

Sources of turbidity and SSC in the Ozette River are limited to inputs from Coal Creek and a few small tributaries that enter downstream of Coal Creek. Long-term turbidity and SSC data are not available for the Ozette River (see Section 4.3.5). For Coal Creek near the confluence with Ozette River, continuous turbidity and SSC data are available only for October 2005 to January 2006 (see Section 4.4.4.5).

The potential effects of elevated suspended sediment and turbidity levels on sockeye salmon in Ozette River were evaluated based on the estimated frequency of storm events during time periods when sockeye salmon are known to inhabit the river. Sockeye salmon use the Ozette River seasonally. Smolt emigration occurs primarily in April and May, with some limited emigration during March and June. Adult sockeye migration occurs from April through August, with very limited entry in September (MFM 1999 unpublished weir data; Kemmerich 1945). High suspended sediment loads entering the Ozette River during the adult sockeye migration are not extremely frequent, since precipitation levels decrease leading into early summer. However, during high intensity rainfall events in spring and summer, and when antecedent streamflow conditions and lake levels are low, high levels of suspended sediment do enter the Ozette River from Coal Creek during the sockeye migration period. Time lapse underwater video data and trap data collected 1999-2003 were used to determine the number of days when poor visibility or no visibility occurred. Note that these visibility events only include periods when streamflow direction of the Ozette River is reversed (see Figure 4.41) into Lake Ozette (the weir, trap, and video camera are positioned upstream of Coal Creek). Six such events occurred from 1999 to 2003, resulting in video image visibility classified as "non-viewable" (see Haggerty 2004a; 2005b; 2005c; 2005d) and approximately 12 events occurred when visibility was classified as "very poor." All events classified as non-viewable conditions (6) occurred either when daily precipitation was greater than 1 inch (25 mm) or when two-day precipitation was greater than 2 inches (50 mm). The frequency of such events at Ozette River near the confluence of Coal Creek (i.e., at the counting weir) during sockeye migration is shown in Figure 5.17 below.

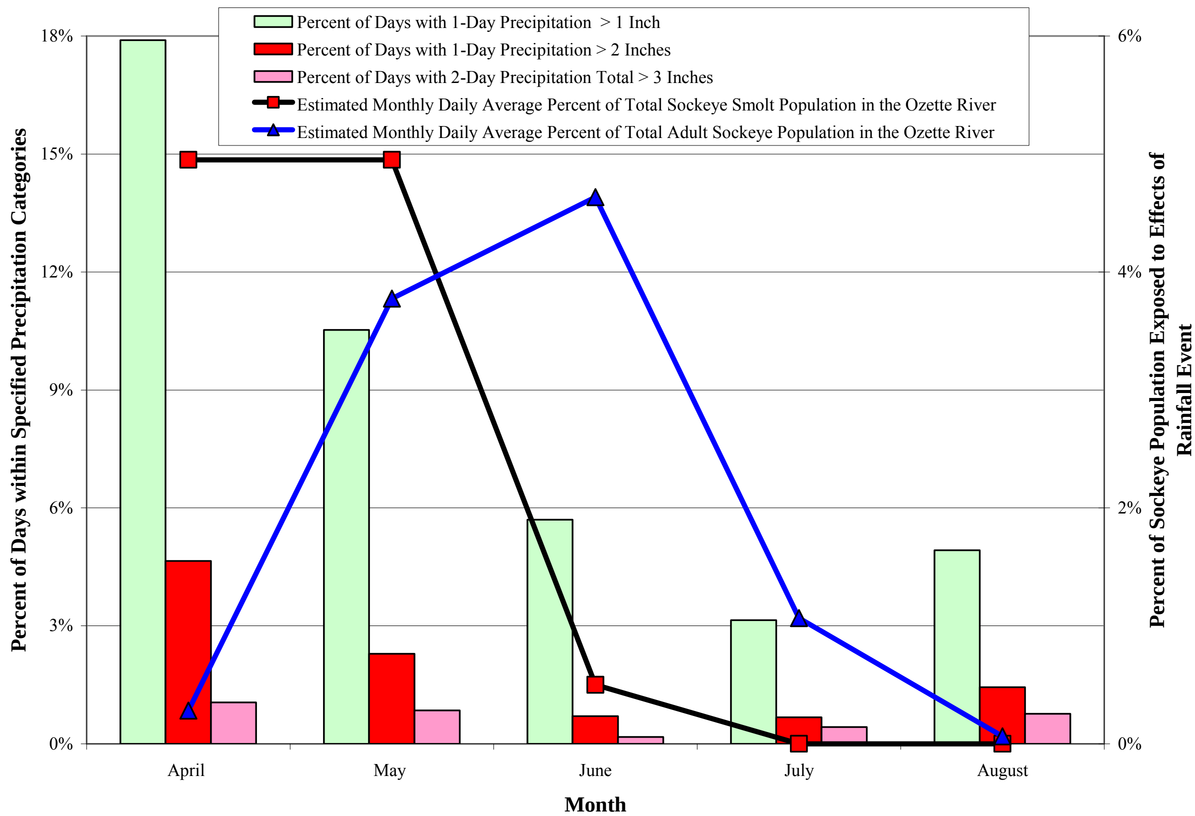

Figure 5.17. Spring and summer monthly summary of the percentage of days when 2-day and daily precipitation totals exceed specified ranges (Quillayute Airport Data 1967-2004) and the estimated monthly daily average percent of total adult and smolt sockeye population contained in the Ozette River (adult sockeye percent based on monthly daily mean proportion of sockeye run transiting the counting weir in RYs 1998-2003 [from Haggerty 2005d] and a mean 3-day residence time in the Ozette River; sockeye smolt percentage based on 2002-2004 smolt emigration data and a 3-day residence time in the Ozette River).

Preliminary sediment data collected in Coal Creek (Section 4.4.4.5.1) indicate that turbidity and SSC are correlated to both stream discharge and precipitation (rainfall). Using the available continuous sediment data from Coal Creek, relationships were developed between peak SSC and peak discharge for 19 different storm events (Figure 5.18). In addition, for these same 19 storm events, peak SSC was compared to the total 24-hour rainfall preceding the storm event (Figure 5.19). To determine average sediment concentrations for each of these 19 storm events, the average SSC was calculated from continuous data (See Section 4.4.4.5.1) from the initial rise in SSC during an event to the point that SSC values returned to base levels (i.e., the average SSC value from trough to trough of the sediment hydrograph). These average storm event SSC values were then compared to the total 24-hour rainfall preceding the storm event (Figure 5.20).

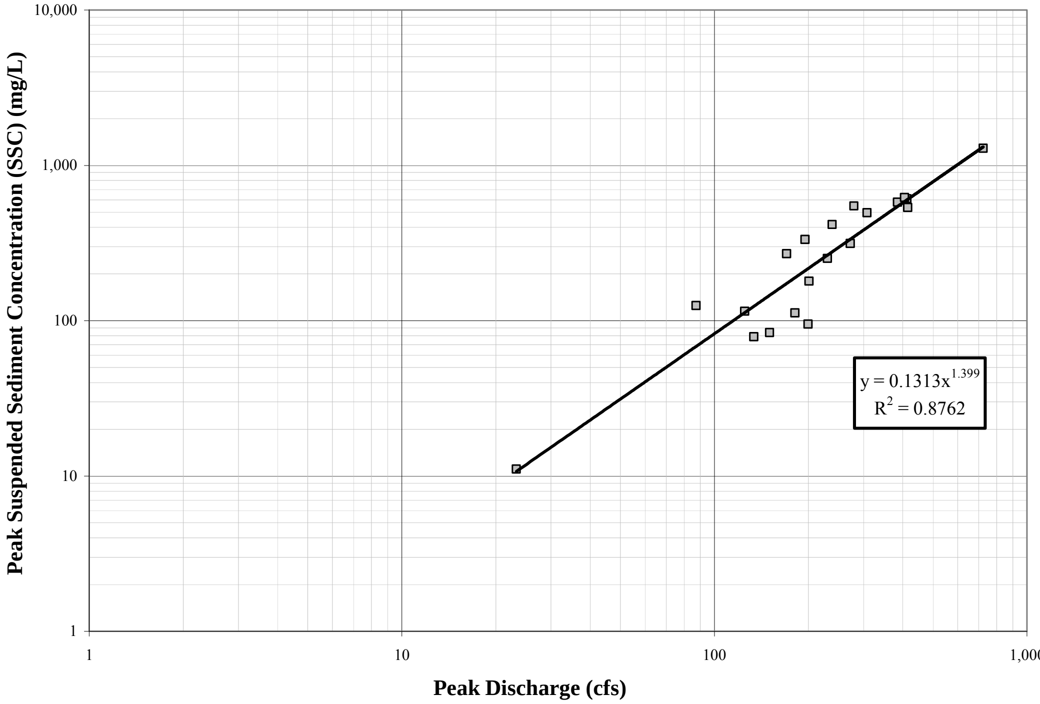

Figure 5.18. Correlation between peak discharge and peak SSC in Coal Creek near Ozette River (source: MFM, unpublished data).

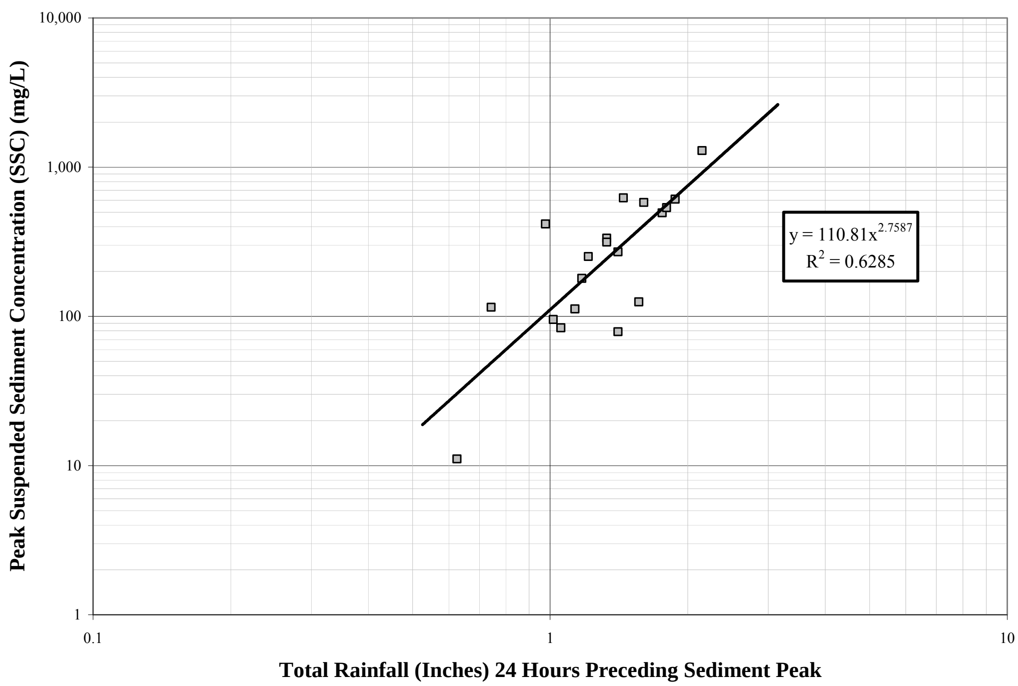

Figure 5.19. Relationship between total 24-hour rainfall and peak SSC in Coal Creek (source: MFM, unpublished data).

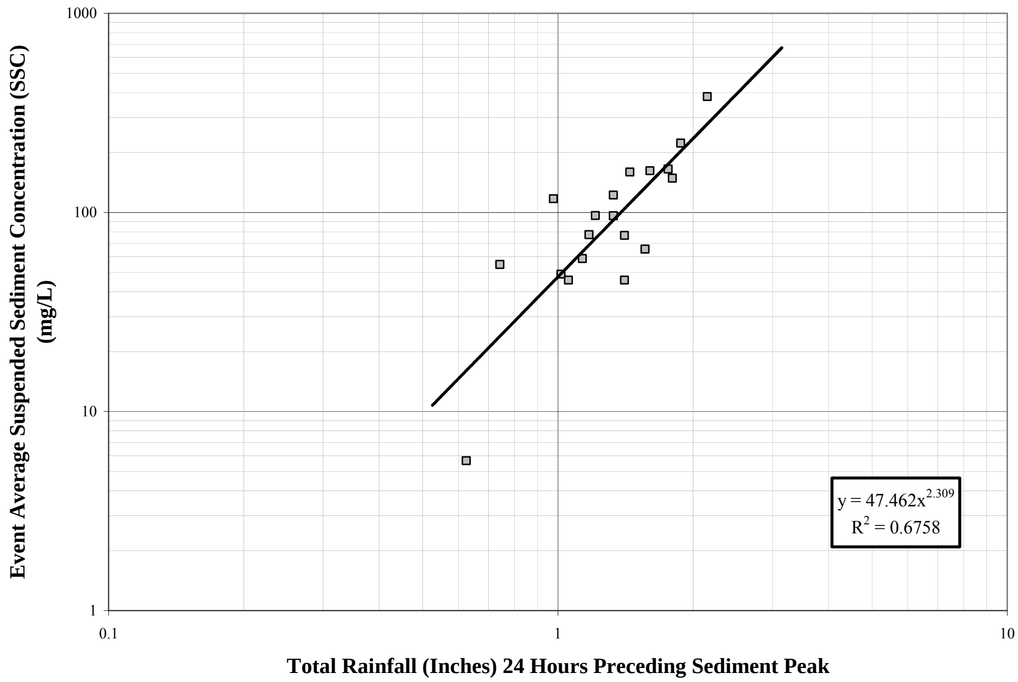

Figure 5.20. Relationship between total 24-hour rainfall and the event average SSC in Coal Creek (source: MFM, unpublished data).

These observational data indicate that for Coal Creek near the confluence of Ozette River, suspended sediment concentrations reach moderate peak values (100 mg/L) and average values (50 mg/L) after the 24-hour rainfall exceeds one inch. For rainfall events greater than 2 inches in 24 hours, peak SSC values exceed 600 mg/L, while average values exceed 200 mg/L. For the short period of sediment record at Coal Creek, major rainfall events have not exceeded 3 inches in 24 hours. However, available data (Figure 5.19 and Figure 5.20) predict that a 3-inch, 24-hour storm would produce peak SSC values exceeding 2000 mg/L, with average values around 500 mg/L. This is consistent with the projected trend of the turbidity-SSC rating curve for Coal Creek (See Section 4.4.4.5.1; Figure 4.82). From the 19 different sampled storm events, the average duration of the event was 14.3 hours, with peak concentrations lasting for 1 to 2 hours.

The data above can be used in conjunction with available empirical models of the physiological and behavioral impacts of SSC and duration on adult and juvenile salmonids. Newcombe and Jensen (1996) developed several empirically based models on the impacts of SSC on salmonids based on 80 published research studies. They developed a scale of “severity of ill effects” on the physiology and behavior of salmonids, ranging from 0 to 14, with 0 = no effect; 7 = moderate physiological effect, habitat degradation and impaired homing; and 14 = 80 to 100% mortality.

Based on data tables in Newcombe and Jensen (1996), severity indexes were calculated for various rainfall, average SSC, peak SSC, and duration values for storm events in Coal Creek. Two different tables were used from Newcombe and Jensen (1996). The first table was based on empirical data but only partially completed the matrix, requiring estimation from the closest neighbor value. The second theoretical matrix used a mathematical model to fill in missing data gaps in the empirical model. Both values are shown in Table 5.2 below.

Table 5.2. Suspended sediment concentration (SSC) severity index values for different rainfall and SSC events in Coal Creek. Average and peak SSC based on MFM, unpublished water quality data. Severity indices based on Newcombe and Jensen (1996).

24-Hour Rainfall	Average SSC	Peak SSC	Duration	Severity Index (Empirical)	Severity Index (Theoretical)
1 inch		100 mg/L	1 hour	4	5
1 inch	50 mg/L		14 hours	5	6
2 inch		600 mg/L	1 hour	4	6
2 inch	200 mg/L		14 hours	6	6
3 inch		2000 mg/L	1 hour	6	7
3 inch	500 mg/L		14 hours	8	7

During the month of April, when average Ozette River streamflow is still around 400 cfs, SS inputs from Coal Creek would normally be diluted by flow contributions from the Ozette River. Dilution of 50% of the SSC would have a negligible influence on the predicted effects on sockeye salmon at the concentration levels estimated to occur following the 2-inch storm event. More severe potential effects during the month of April would likely have a lower severity index due to the effects of dilution.

From May to August when lake level is typically low, no or very limited dilution from the Ozette River would be expected, because high intensity rainfall events usually reverse the flow of the Ozette River (during low lake level periods) and Ozette River flow is made up almost entirely of Coal Creek discharge. Severity indexes estimated from data tables in Newcombe and Jensen (1996) indicate that for moderately common storm events (10% to 3% probability of occurrence on any given day from May to August) in Coal Creek near Ozette, moderate behavioral and physiological stress could occur for both juvenile and adult sockeye.

Effects could include moderate physiological stress (6); moderate habitat degradation and impaired homing (7); and major indications of physiological stress and poor condition (8). However, the proportion of the population exposed to any given event is low (<6%). During the month of May, no more than 7.5% of the smolt and 6% of the adult populations are expected to encounter SSC predicted to result in moderate physiological stress. The proportion of the adult population expected to encounter SSC that results in moderate physiological stress is lower for June (~4.8%), July (1%), and August (<<1%). Cumulatively, approximately 12% of the population on average would be exposed to SSC expected to result in moderate physiological stress.

The effects of SSC on salmonids presented in Newcombe and Jensen (1996) should be used with caution, as most of the empirical data used for the synthesis was conducted in a controlled environment (laboratory flumes and tanks). Different studies used different combinations of sediment particle size caliber to create desired sediment concentrations and in some studies sediments may have been cleaned and washed of heavy metals or other material naturally found in streams. The particle size distribution making up the concentrated sediment suspended in water is extremely important in terms of effects on live salmonids and habitat in real streams (Newcombe and Jensen 1996). Larger suspended particles and more angular particles typically have greater impacts on physiology, while smaller particles have a greater impact on behavior (e.g., site distance and feeding). In addition, laboratory studies do not address synergistic effects of SSC (e.g., effects on predation, disease, temperature stress).

During relatively small events in Coal Creek, suspended sediment samples typically consist of silt and clay. As discharge magnitude and turbulence increases, a larger percent of the suspended sediment load consists of fine sand particles, as indicated by dozens of water samples filtered for SSC. In lower Coal Creek, abundant fine sand is readily observable in bar deposits, in overbank deposition on the floodplain, and in bar deposits at the confluence with Ozette River (see Sections 4.3.4 and 4.3.6.1). Examination of these sand particles from SSC samples under a microscope shows them to be quite angular and un-rounded. Future angularity measurements are needed from additional suspended sediment samples from all Ozette tributaries.

The size and angularity of suspended sediment particles coming from Coal Creek may partially explain field observations of increased significant physiological and behavioral stress on Ozette sockeye adults during migration. On June 11, 2000 approximately 2.3 inches of rainfall occurred in 24 hours (3.3 inches in 48 hours) while sockeye mark and recapture studies were being conducted in the Ozette River. Coal Creek was carrying high levels of suspended sediment into the Ozette River; the water was extremely turbid. Following the storm event in Coal Creek and the Ozette River, sockeye were noted as being "covered in silt" and an unspecified number were observed bleeding from the gills. Note that observers could not differentiate between silt and fine sand. While data from Newcombe and Jensen (1996) suggest this event would have a severity index of approximately 7, field observations indicate that the severity index was greater than 8. Gill abrasion is also influenced by water temperature (Newcombe and Jensen 1996), with increased abrasion during higher temperatures, which are observed during the later half of the adult sockeye migration into Lake Ozette.

In addition to biological effects, sedimentation can affect sockeye habitat in the Ozette River. Section 4.3.6 (Ozette River Hydrology) outlines the hydraulic and hydrologic influences of sediment deposition in Ozette River from Coal Creek sources. The bar controlling lake outflow and Ozette River discharge was once described as a "cobble riffle" (USGS, unpublished discharge measurement notes 1976-1979), while today the riffle contains very few cobble particles and is dominated by sand and small gravel. Fine sediment deposition has aggraded the bar upstream of Coal Creek by approximately 1 foot (Figure 4.38 and Figure 4.39; also see Section 4.3.6), which has altered both lake level fluctuations and Ozette River discharge (Section 5.3.2.2). Altered discharge output into Ozette River has reduced the quantity of water during critical adult sockeye migration periods, especially during the later half of the run (Section 5.3.2.2). In addition, aggradation of the hydraulic control of Lake Ozette has altered the fluctuations of lake levels, with slightly increased lake levels in the summer period. However, the exact impact of this more recent change on sockeye beach spawning habitat is unknown, especially in comparison to larger alterations to the lake's hydraulics and level variability (Kramer 1953; Herrera 2005).

5.3.4 Predation

Aquatic mammal and piscivorous fish predation on juvenile and adult sockeye in the Ozette River is well documented in the upper river, near the lake's outlet. Juvenile sockeye are preyed upon by a host of predators in the Ozette during their emigration in spring. Known predators in the Ozette River include river otters, seals, northern pikeminnow, and cutthroat trout. Additional potential predators include birds (e.g. bald eagles, osprey [*Pandion haliaetus]*, and mergansers[*Mergus spp.*]) and terrestrial mammals. No studies have been conducted exclusively focusing upon potential impacts of predators at the lake's outlet or in the Ozette River during the smolt emigration period.

During the summer of 2000, adults entering the Ozette River were captured in the estuary using a trap. Sockeye were handled, examined for scarring, tagged, and then released. It was found that 32.9% (27/82) of the sockeye captured in the estuary had scars associated with predation events. Fish were then recaptured going into Lake Ozette and reexamined to determine the rate of in-river scarring. Gearin et al. (2002) determined that the incidence of scarring increased from the lower river trapping site in the estuary by 10.7%. However, their sample size was small, as only 82 sockeye were trapped and released. Potentially more important than the findings showing increased in-river scarring, is the fact that only 50% (41) of the sockeye captured in the lower river could be accounted for entering the lake. Only 30 tagged sockeye were recaptured at the upper trap. Three tagged fish that were not recaptured at the Ozette counting weir were later recaptured on the beaches (eight fish were assumed to have lost their tags based on tag loss estimates). These data suggest that some fish may have delayed their upstream migration into the lake until after the trap was removed. The trap was removed 10 days after the last fish trapped in the lower river were tagged and released. Gearin et al. (2002) concluded that the 50% of sockeye missing from the upper river were either removed by predators in the river, died from other sources of mortality, escaped without being detected through the weir, or passed into the lake after the weir and trap were removed.

As described in Section 3.1.1, the mean transit time for tagged sockeye from the estuary to the upper counting weir was 65.2 hours for the 28 sockeye tagged and recaptured in 2000 (range 17-154 hrs). Based on these transit times, sockeye are vulnerable to predation in the river for nearly three days on average. Gearin et al. (2002) concluded that the proportion (43.6%) of sockeye with predator related scarring entering the lake was "*a cause for concern.*" A comparison of this rate to other scarring rates summarized for Pacific Northwest salmon stocks in NMFS (1997) indicates that it is among one of the highest rates observed in all other California, Oregon, and Washington predation studies. However, the total sample size of the 2000 Ozette River study was small. Time-lapse video data collected between 1998 and 2004 also included notes on sockeye scarring. From 1999 to 2003, sockeye scarring rates ranged from 5.5% to 10.6% (n=8,470;Table 5.3).

Table 5.3. Time-lapse video sockeye scarring rates for return years 1999 through 2003 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d).

Return Year	Time-Lapse Video Sockeye Scarring Rate	Number of Sockeye Viewed for Scarring
1999	10.6%	138
2000	7.7%	2,506
2001	5.7%	1,351
2002	7.0%	2,724
2003	5.5%	1,751

These data are limited to observations that come from imagery of one side of the sockeye transiting the viewing chamber. The top, bottom, and right hand side of the sockeye are seldom captured on video. During RY 2000, sockeye scarring was detected using time-lapse video, which revealed that 7.7% (192/2506) of sockeye had scars likely inflicted from pinnipeds (Haggerty 2005c). Sockeye were viewed for scars during RY 2000 when they were temporarily held in a 4-by-8-ft trap to examine for tags. These fish were not handled, but were visually examined in the river; not all scarring was detectable using this method. A total of 237 of 822 (28.8%) sockeye had visible scars and/or wounds. Scarring rates were 3.7 times higher for fish visually examined while held in the small trap as compared to those viewed using time-lapse video. Scarring rates were 5.7 times higher for fish that were examined by actually handling the fish than those detected using the time-lapse video data. Given this fact, the actual sockeye scarring rates are likely 3 to 6 times higher than those reported using time-lapse video data; actual scarring rates could easily average 30-60%. In addition to direct predation mortalities, unsuccessful predation events resulting in open wounds and lesions likely decrease the fitness of adult sockeye and make them more susceptible to disease during the protracted 3- to 9-month lake holding period. Fraser River researchers have found that sockeye salmon blood clotting capabilities decline at temperature exposures of 18-21°C and that some sockeye may die by bleeding to death from small cuts and lesions (Hinch 2005).

5.3.4.1 Predators

5.3.4.1.1 Harbor Seals (Phoca vitulina)

Harbor seals are frequently observed in the lower river but are less common in the upper river (Gearin et al. 1999; Gearin et al. 2002). The number of seals using the upper Ozette

River and Lake Ozette is unknown. Gearin et al. (2002) concluded that the number of harbor seals that frequent the Ozette River appears to be low (2-4 animals), but that even this low number could potentially impact Lake Ozette sockeye. No harbor seal population census data exist, but detailed observations of seals have been recorded and summarized during predation observation field work (see Gearin et al. 1999; Gearin et al. 2000; Gearin et al 2002) and sockeye enumeration and trapping activities from 1998 through 2004 (see Haggerty 2004a; Haggerty 2005a-d). No direct predation events on sockeye smolt by harbor seals have been documented in the Ozette River.

During return year 1998, a total of 7 seal observations were made at the weir. Five observations were made by visual observers and 2 were detected on time-lapse video footage (Haggerty 2005d). In 1998, detailed notes were not included with the seal observation data, so it is unknown how many of the observations were actually predation events, but at least one event included a sockeye mortality (Gearin et al. 2002). In 1999, both time-lapse video and visual observers were used to enumerate sockeye transiting the weir (Haggerty 2005d). Time-lapse video observers detected a total of 7 seals transiting the weir between May 5 and June 3, 1999 (Haggerty 2005d). During this same time period visual observers stationed at the weir made 24 seal observations, including three documented predation events[17] resulting in the deaths of two sockeye salmon (MFM unpublished weir data). Visual observers detected three times as many seals as the time-lapse video. Many of the visual observations were of seals "working" the front of the weir versus transiting the weir (MFM unpublished weir data). All seal observation events during 1999 occurred at dark or near twilight hours (Haggerty 2005d and MFM unpublished weir data).

During RY 2000, both underwater time-lapse VCR and visual observer data were collected at the Ozette weir. However, in 2000, the two data types are not paired observations. Observer data were collected during trapping operations on the opposite side of the river from the time-lapse video system. Seals were observed a total of 40 times in 2000 (Haggerty 2005c). Only two of the observations were classified as predation events, and neither appeared to result in the direct morality of the sockeye. Seal activities near the weir and trap occurred almost exclusively at night or twilight (>90% of observations; Haggerty 2005c). Table 5.4 includes all seal observations made at the Ozette River counting weir for return years 1999 through 2004. Seals appear to behave differently around the weir than otters and likely have a lower chance of being captured on video preying on sockeye than otters. Almost all of the time-lapse video observations of seals are transits through the weir. Visual observers stationed at the weir observed seals working the face of weir and in these cases there would be no chance for the camera to detect this behavior. Almost all seal activities were observed between dusk and dawn when lake level was greater than 32.5 ft at the ONP staff gage. Figure 5.21 depicts the RY 2002 seal observations at the weir, peak sockeye migration time period, and lake level. These data indicate that seal abundance in the upper river is controlled primarily by streamflow conditions and not sockeye abundance. It is presumed that at

[17] Sockeye counting weir mammal predation events were defined as events when sockeye salmon were clearly observed being chased, clawed, bitten, or carried off by predators.

flow levels corresponding with lake levels below 32.5 feet, migration conditions in the Ozette River preclude seals from entering the upper river.

Table 5.4. Summary of harbor seal activity at the Ozette River counting weir for RY 1999 through 2004 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d; MFM unpublished data).

Return Year	Total number of seal observations from time-lapse VCR data	Total number of seal observations made by visual observers	Total number of predation events observed	Total number of sockeye observed killed by seals
1999	7	24	3	2
2000	34	6	2	0
2001	8	0	0	0
2002	40	na	0	0
2003	0	na	0	0
2004	7	na	0	0

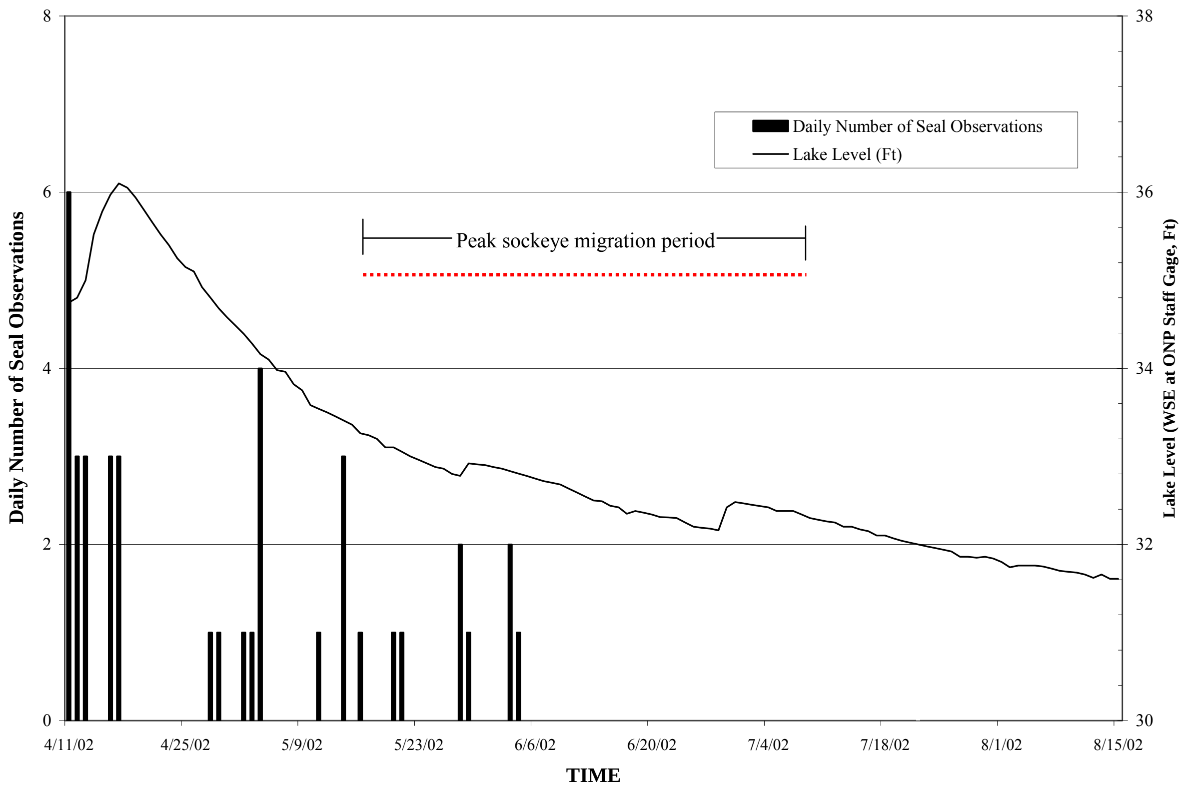

Figure 5.21. Comparison between 2002 daily number of seals detected by time-lapse VCR, lake level, and peak sockeye migration period (modified from Haggerty 2004a).

5.3.4.1.2 River Otters (Lutra canadensis)

As described above in Section 5.2.2.1.3, river otters are abundant in the Ozette River; the river provides ideal otter habitat. The number of river otters using the Ozette River is unknown. River otters can be observed during all hours but primarily hunt during twilight and darkness. River otters have been observed preying upon both juvenile and adult sockeye at the counting weir and during smolt trapping operations. Prior to RY 2004, over 99% (105/106) of observed otter-adult sockeye predation events occurred at night or during twilight hours (from Haggerty 2004a, 2005a, 2005b, 2005c, 2005d). During RY 2004, more than 22% of the otter-adult sockeye predation events occurred during daylight hours (6/27; MFM unpublished weir data). The fact that otter predation mostly occurs at night makes it extremely difficult to accurately quantify the number of sockeye preyed by otters in the Ozette River (Gearin et al. 2002). Gearin et al. (1999) collected and examined 40 river otter scats along the Ozette River during June 1998. The majority of these samples were collected from within 200 meters of the adult counting weir. Prey content analysis from these scat samples revealed that crayfish were present in higher frequencies than any other prey type. Figure 5.22 depicts the frequency of common prey types from river otter scat samples. Additional prey items detected in river otter scats include snails, clams, lamprey, insects, isopods, smelt, amphibians, and spiders. The only salmonid prey items that could positively be identified by species were Chinook and coho salmon; no sockeye remains could be positively identified.

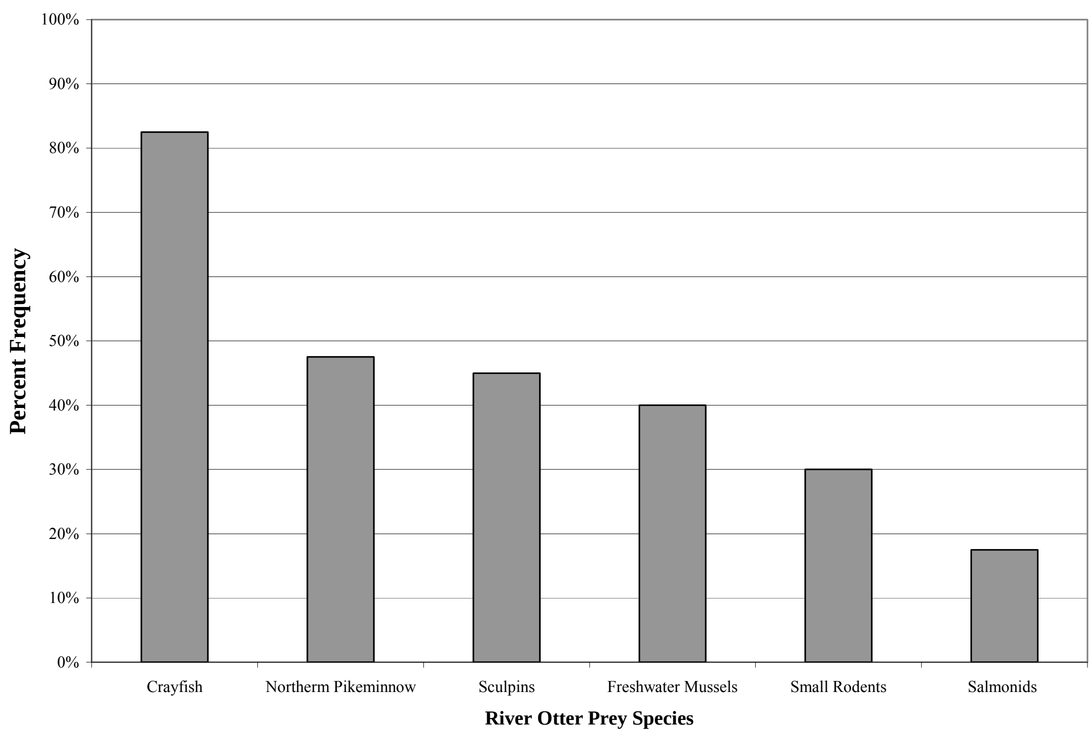

Figure 5.22. Frequency of most common prey identified from river otter scats collected in the Ozette River during June 1998 (n=40; modified from Gearin et al. 1999)

Gearin et al. (2002) concluded after 3 years of pinniped monitoring in the Ozette River that they were unable to quantify or give a reasonable estimate of the number of sockeye preyed by river otters. River otter observations made during adult sockeye enumeration work have been collected since 1998 and show what appears to be a steady increase in the number of observed otter-related sockeye mortalities (Figure 5.23). River otters have been observed killing more sockeye in the Ozette River than any other species of predator.

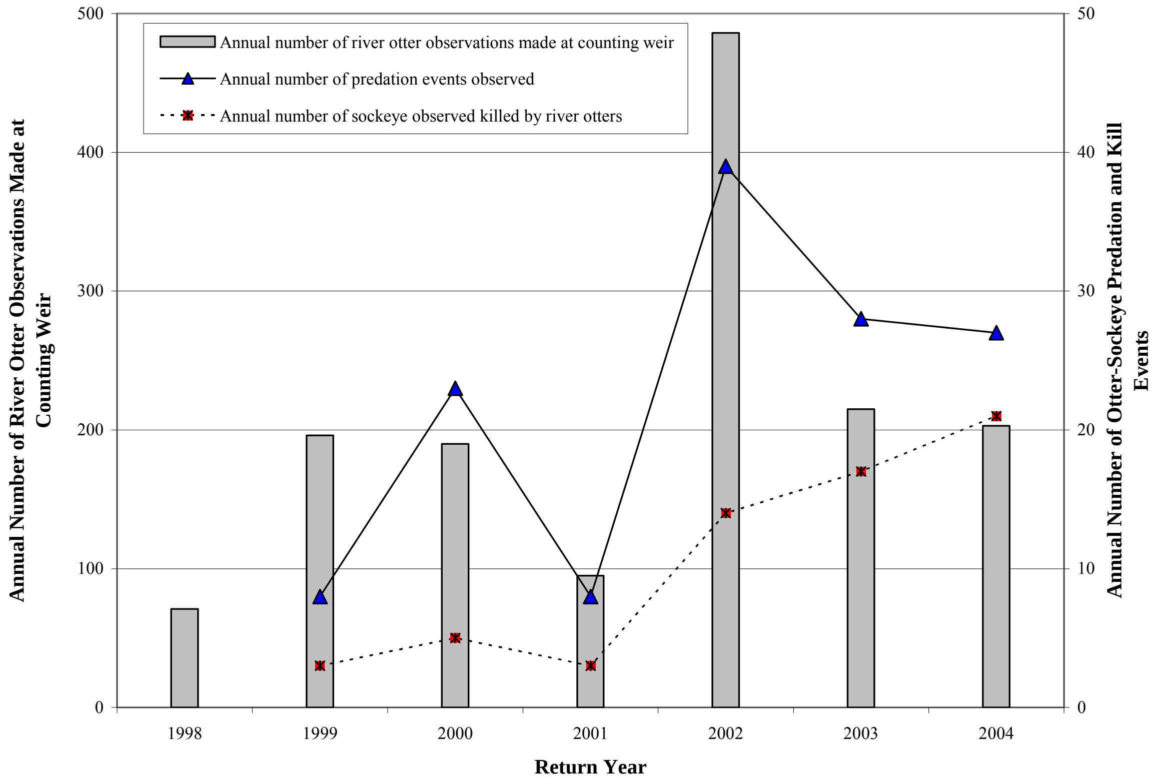

Figure 5.23. Annual number of otters, sockeye-otter predation events, and number of otter-sockeye kill events observed at the Ozette counting weir from 1998 through 2004 (source: Haggerty 2004a, 2005a, 2005b, 2005c, 2005d; MFM unpublished data).

5.3.4.1.3 Northern Pikeminnow (Ptychocheilus oregonensis)

A description of the Lake Ozette northern pikeminnow population is included in Section 2.2.8. Northern pikeminnow are known to prey upon juvenile sockeye in the Ozette River. Documentation of predation within the river is limited to observations from adult trapping, tagging, and weir enumeration work, as well as sockeye smolt trapping. Time-lapse video data collected at the Ozette counting weir from 1999 through 2004 indicates that northern pikeminnow are present in the upper river during the entire sockeye smolt emigration period. Smolt trapping data collected from 2001 to 2004 also clearly demonstrate that these two fish species occur together throughout the emigration period. Cumulative daily northern pikeminnow and sockeye and coho smolt counts for 2004 are shown in Figure 5.24. Approximately 61% of all sockeye smolt captures occurred during an 11-day period from May 3 to May 14, 2004. Similarly, 54% and 46% of the northern pikeminnow and coho smolt captures were during this same time period.

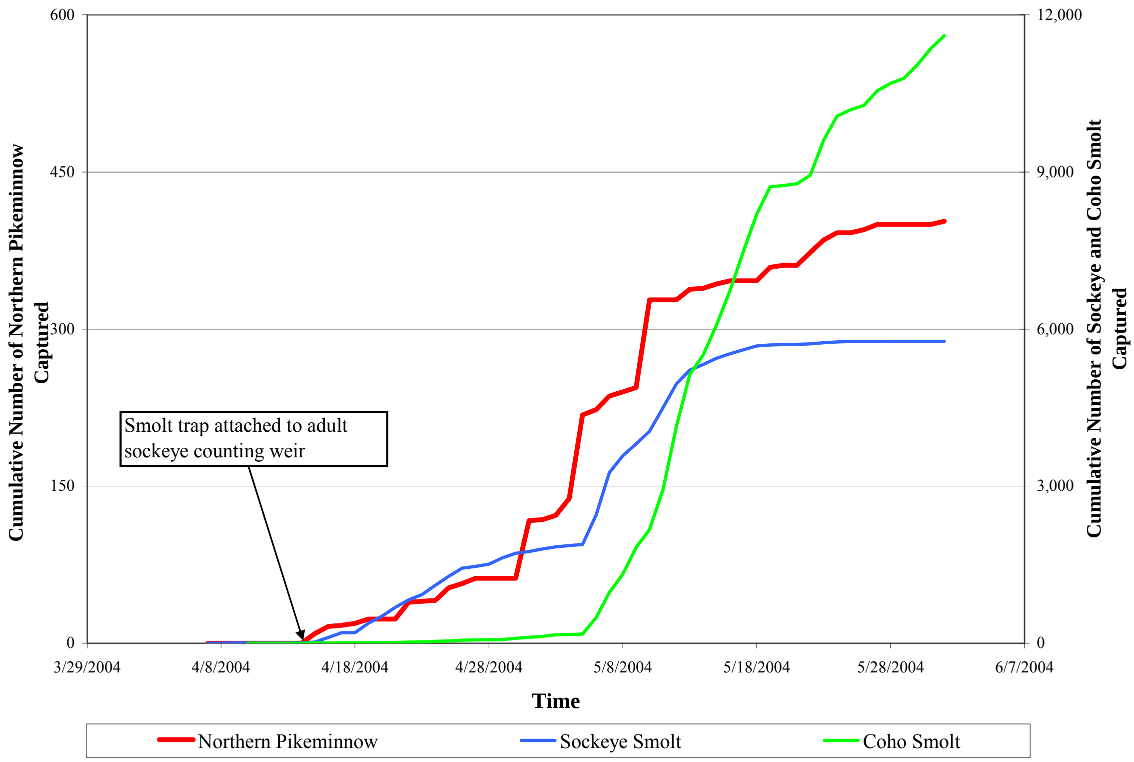

Figure 5.24. Cumulative northern pikeminnow and sockeye and coho smolt captures in the Ozette River, Spring 2004 (source: MFM, unpublished data).

Northern pikeminnow captured in the smolt trap are typically sampled for stomach contents. Sockeye smolt mortalities during trapping in 2002, 2003, and 2004 were 131, 12, and 57 sockeye smolts respectively (Crewson 2003; Peterschmidt 2005). Almost all sockeye smolt mortalities resulted from predation by northern pikeminnow (Crewson 2003; Peterschmidt 2005). Northern pikeminnow captures during this same time period were 394, 31, and 403. The smolt trap was not deployed until after the peak of the sockeye smolt emigration in 2003, when only 31 northern pikeminnow were captured. The total number of northern pikeminnows utilizing the Ozette River during the sockeye smolt emigration period is unknown. Smolt trap counts of northern pikeminnow are only a fraction of the total population. No estimates of the number of sockeye smolts consumed by northern pikeminnow in the Ozette River are available. Large numbers of northern pikeminnow can be seen throughout the upper Ozette River during spring, but their frequency and distribution downstream is unknown. These large schools of northern pikeminnow can be seen during daylight areas swimming from bank to bank in what appears to be a foraging behavior upstream of the adult counting weir.

5.3.4.1.4 Cutthroat Trout (Oncorhynchus clarki)

A description of the Lake Ozette cutthroat population is included in Section 2.1.6. Cutthroat trout are known to prey upon juvenile sockeye in the Ozette River. Smolt trap and adult sockeye weir data indicate that cutthroat trout likely occur in only limited numbers in the Ozette River during the smolt emigration period. Stomach contents of adult cutthroat trout captured during smolt trapping operations have not been examined. Predation work conducted by Beauchamp et al. (1993) and Dlugokenski et al. (1981) did not include cutthroat captured in the Ozette River. Beauchamp et al. (1993) found that within the lake, per capita consumption of salmonids by cutthroat trout was 25 times greater than that for northern pikeminnows.

5.3.4.1.5 Introduced Fish Species

Currently there are six known non-native fish species in the Ozette watershed: tui chub, American shad, yellow perch, largemouth bass, yellow bullhead, and brown bullhead. Within the Ozette River, largemouth bass are the only non-native predator of sockeye smolt. Largemouth bass are infrequently observed in the Ozette River and they are thought to occur in low numbers. A few largemouth bass have been captured during trapping activities during the sockeye smolt emigration period.

5.3.4.1.6 Terrestrial Mammals

Black bears (*Ursus americanus)*, cougars (*Puma concolor*), bobcats (*Lynx rufus*), raccoons (*Procyon lotor*), and other terrestrial mammals may also prey upon juvenile and adult sockeye in the Ozette River. However, conditions in the Ozette River during adult and juvenile migration periods are far from optimal for terrestrial mammals. No direct observations could be found of terrestrial mammal predation on juvenile and adult sockeye salmon in the Ozette River.

5.3.4.1.7 Avian Predators

Avian predators are assumed to prey upon sockeye smolt in the Ozette River, although we were unable to find any documentation of this. Osprey, bald eagles, hooded mergansers (*Mergus cucullatus*), common mergansers (*Mergus merganser americanus*), belted kingfishers (*Ceryle alycon*), and great blue herons (*Ardea herodias*) are all predators found in the Ozette River. Hooded mergansers are commonly observed fishing near the lake outlet during the smolt emigration period. Bald eagles have been observed taking adult sockeye-sized salmonids in the lower river and adult sockeye in the lake. Bald eagles or other large birds likely prey upon adult sockeye within the Ozette River. However, the overall number of adult sockeye killed by birds is thought to be low.

5.3.4.2 Factors Affecting Predation

5.3.4.2.1 LWD Removal

Logjam removal and habitat conditions in the Ozette River are discussed in detail in Sections 1.5.5 and 4.3. The removal of LWD from the Ozette River is thought to have significantly affected habitat conditions within the river. Currently, large stretches of the river are devoid of functional LWD. Pool frequency and refuge cover is low or nonexistent in wood-starved reaches. Haggerty and Ritchie (2004) examined 1,963 pools within the Ozette watershed and found that high quality pool habitats were most often associated with LWD obstructions and that the larger the LWD forming the obstruction, the larger and more complex were the pools and pool habitats associated with them. During multiple snorkel surveys of the entire Ozette River, the majority of pools were found to be formed by wood. Pools formed by key-piece-sized wood were generally 1 to 3 meters deeper than the channel upstream or downstream, where LWD was lacking. Habitat simplification in the Ozette River is believed to increase both juvenile and adult sockeye salmon's susceptibility to predation. Logjam removal may also have affected the streamflow conditions in which large predators such as seals can navigate into the river. Frequent, large logjams may have hindered seal migration up the river during lower flows. Currently seals are not observed using the upper river when the lake level drops below 32.5 ft; it is assumed that upstream passage is limited during levels lower than 32.5ft.

5.3.4.2.2 Increases in Aquatic Mammal Abundance

Regional factors affecting increases in pinniped abundance are described in Section 5.2.2.2.1. Additional factors such as the change in jurisdiction (from State to NPS) of the Ozette River and Lake Ozette are thought to have also increased the number of river otters within the watershed. No river otter census data are available, so no population trends have been documented. Also note that harbor seal use of the upper Ozette River and Lake Ozette was not documented until the late 1980s. Use of the upper river appears to have increased during the last 15 or 20 years.

5.3.4.2.3 Abandonment of Ozette Village

See Section 5.2.2.2.2

5.3.4.2.4 Changes in the Streamflow Regime of the Ozette River

There are two main factors that appear to have affected streamflow in the Ozette River: 1) wood removal from the Ozette River, which has been shown to lower lake stage, and 2) a shift in the stage-discharge relationship, which appears to be attributable to recent (during the last 20 years) sediment deposition and accumulation near the confluence with Coal Creek. Lower stage and/or discharge have been shown to affect daily sockeye entry timing into the lake. During periods of lower discharge, sockeye enter the lake primarily during twilight or darkness, but the majority enter during daylight hours when lake stage is above 33.5 feet (Figure 3.5). In order to fully understand the impact of wood removal on spring and early summer lake stage in comparison to potentially altered lake inflow discharge, a more dynamic hydrologic model is needed to account for all water budget attributes in the watershed. Nonetheless, lower stage and/or flow results in a higher percentage of sockeye transiting the upper river during time periods of known increased predator activity. In addition, it is thought that sockeye are more easily preyed upon by river otters during periods of lower flow.

5.3.4.2.5 Decreased Sockeye Abundance

See Section 5.2.2.2.3.

5.3.4.2.6 Changes in Lake and Fisheries Management

Changes in lake and fisheries management have the potential to increase the abundance of certain predators. For example, implementation of fishing regulations requiring release of coastal cutthroat trout may increase the abundance of cutthroat trout in the lake. Increased numbers of cutthroat trout in the lake would likely result in increased mortality on juvenile sockeye, as cutthroat trout are the primary predators of juvenile sockeye rearing in Lake Ozette (Beauchamp et al. 1995). While it is not possible to estimate the total impacts on mortality to juvenile sockeye and reductions in adult run-size, conservative estimates indicate regulation changes could result in a 10-22% reduction in the annual abundance of returning adult sockeye salmon

In 1953, the NPS acquired the strip of land between the west shore of the lake and the ocean. In 1976, it acquired the lake and a narrow strip of land around its perimeter (Meyer and Brenkman 2001). Jurisdiction of Lake Ozette was transferred from the State to the National Park Service. The transfer of jurisdiction resulted in regulations prohibiting trapping and hunting in and adjacent to the lake and river. This has likely resulted in an increased number of river otters within the watershed.

5.3.4.2.7 Ozette Sockeye Weir and Smolt Trapping Operations

Over the course of the last 80 years, weirs, weighted nets, traps, and fyke nets have all been used to enumerate adult and juvenile sockeye in the Ozette River. During almost all of the last 27 years, some form of a channel-spanning weir has been placed across the Ozette River during the peak of the adult sockeye migration. During the late 1970s and early 1980s, a weighted net and counting board were used to enumerate migrating adults. More recently a rigid weir has been used. Each year since 2001, an adult counting weir and rotary screw trap have been installed and operated just downstream of the ONP footbridge on the Ozette River (Figure 5.25). The width of the river at the weir location is approximately 100 ft (30m). Depth typically averages 3 to 6 feet at the time of installation. The weir is composed of several hundred metal tubes supported by large aluminum brackets that are held in place by a series of wooden tripods. During some years, half-inch *Vexar* is placed along the upstream face of the weir to increase smolt trap efficiency.

Figure 5.25. Photo looking from the right to the left bank of the Ozette River, showing the counting weir, adult trap, and rotary screw trap.

Sockeye smolts can pass between the narrow openings between weir pickets, but numerous hours of observation indicate that some smolts are reluctant to pass between these openings. Schools of smolts, all facing upstream, will swim from side to side upstream of the weir until they either swim into the smolt trap, pass downstream through the adult sockeye opening, or turn downstream and swim between the pickets. Sockeye smolts can be vulnerable to predation when they encounter the weir and are unable or unwilling to find a route downstream. Schools of northern pikeminnow can be observed upstream of the weir attempting to eat emigrating sockeye and/or other species of juvenile salmonids.

When sockeye smolt are captured in the screw trap they are temporarily held in a live box. While in the live box, smolt are vulnerable to predation by northern pikeminnow and cutthroat trout also captured in the live box. Measures have been taken in the design of the live box to minimize predation impacts by including a predator exclusion zone within the live box. Observed sockeye smolt mortalities during trapping in 2002, 2003, and 2004 were 131, 12, and 57 sockeye smolts respectively (Crewson 2003; Peterschmidt 2005). Almost all sockeye smolt trap mortalities documented resulted from predation by northern pikeminnow (Crewson 2003; Peterschmidt 2005). During trapping from 2002 through 2004, it is estimated that only 5 to 18% of the total sockeye smolts emigrating downstream during the trapping season were captured and held in the live box.

Adult sockeye migrating into the lake are especially susceptible to predators as they transit the weir. The weir acts as a bottleneck to migrating sockeye; harbor seals and river otters appear to use the weir as an aid in hunting. Seals and otters have frequently been observed working the face of the weir, swimming back and forth across the river in search for sockeye. One interesting note is that 92% of all successful otter-sockeye predation events in return years 2000-2004 were observed when lake levels were between 33.2 and 32.0 feet, even though 48% of sockeye migrated outside of this lake level range. Also, more than 95% of all successful predation events observed have been during nighttime or twilight. The proportion of the sockeye run migrating during daylight hours has been shown to decrease as lake level and streamflow decline (see Section 3.1.1). It appears that the degree to which the weir and trapping operations increase adult sockeye salmon susceptibility to predation increases as lake level declines.

5.3.5 Directed Sockeye Harvest

Currently there is no directed sockeye harvest occurring in the Ozette River. For more information regarding directed sockeye harvest, see Section 5.2.3. In the Ozette watershed no fisheries are conducted during the sockeye run in which sockeye are harvested or captured as bycatch. A review of punch card returns and projected harvest estimates (1964-2004) indicates that very little if any sockeye harvest occurred prior to restrictions limiting harvest. Only eight salmon of undefined species are estimated to have been harvested within the migration timing of sockeye between 1964 and 2004.

5.3.6 Disease

No systematic monitoring of sockeye health in the river occurs. Observations of infections and fungus growth are occasionally included in weir observation notes, but no systematic inventory data are collected. During trapping in RY 2000, 899 sockeye were visually examined for external tags and physical condition. Less than 1% of the sockeye transiting the weir had visible fungal growth. However, at least some individual sockeye have been observed with severe external infections, and these likely die before reaching the spawning grounds (see Section 5.4.6).

5.4 LAKE OZETTE

Lake Ozette sockeye use the lake during several life history phases: adult holding (3.1.2); adult sockeye beach spawning and egg incubation (3.1.4); sockeye fry emergence and dispersal (3.1.6); and juvenile freshwater rearing (3.1.8). These life history phases in the lake are the focus of the limiting factors discussion presented in Section 5.4. Degraded and altered shoreline sediment conditions (4.2.1), hydrology and lake level (4.2.5), water quality (4.2.3), food availability (4.2.4), predation, competition, disease, hatchery impacts, and directed sockeye harvest are all factors that have been evaluated to determine the degree to which each factor currently or in the past has limited sockeye salmon survival and productivity in Lake Ozette.

5.4.1 Watershed Hydrology and Lake Level

The hydrology of the Ozette watershed and Lake Ozette is complex and controlled by several variables, which can be affected by natural and human-caused factors. As described in Section 5.3.1.2, logjams in the upper one mile of the Ozette River can exert a major hydraulic influence on lake stage. Wood removal beginning with the onset of homesteading (1890s) and continuing until the mid-1980s is thought to have significantly affected lake levels. Herrera (2006) linked channel incision in the lower reaches of lake tributaries to base level lowering of Lake Ozette. Herrera (2005) was unable to determine the precise amount that low, median, or peak lake levels have declined or changed from pre-settlement conditions. Instead they define a range of wood loading scenarios and predict resultant lake stages for a predefined period of existing lake stage and discharge data. Lake stage data from October 15, 2004 through January 30, 2005 were used to model of effect of different wood loading scenarios on lake stage during the beach spawning period (Figure 5.26).

This simulation suggests that mean water surface elevations during the modeled spawning period can vary by up to 4.1 feet, depending on wood loading conditions within the Ozette River. Current wood loading conditions relative to a completely jam-free river result in a mean lake level increase of 0.8 feet during the modeled spawning time period. The wood loading condition of the upper Ozette River before the onset of wood removal operations is unknown. Herrera (2005) suggests that historical conditions were within the 200-foot spacing, 60% blockage and 500 foot, 80% blockage range, based on maps, photos, and descriptions in Kramer (1953). Results predict that mean lake level during the modeled spawning period with current wood loading conditions is 1.5 to 3.3 feet lower than under historical wood loading conditions (Figure 5.26). These predictions correspond well with channel incision observations of approximately 3 feet (1 meter) observed in Ozette tributaries by Herrera (2006).

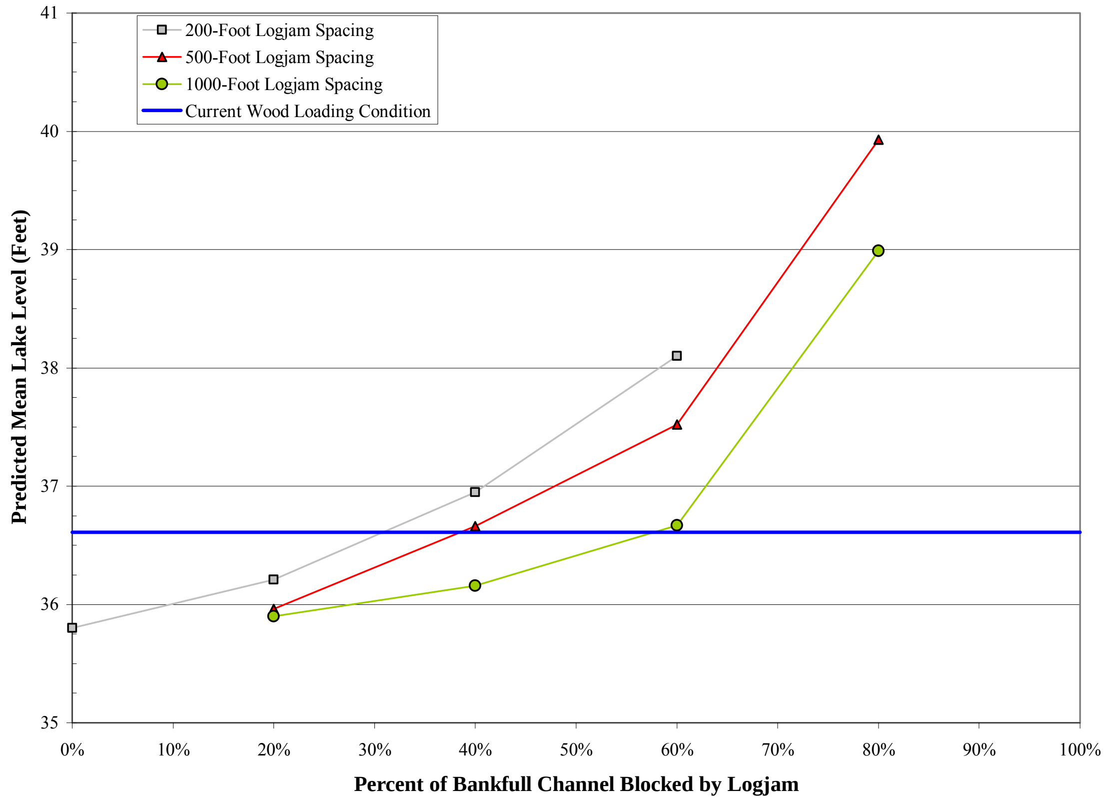

Figure 5.26. Comparison of observed mean lake level for October 15, 2004 through January 30, 2005 and different wood loading scenarios in the Ozette River and their corresponding predicted mean lake levels (modified from Herrera 2005). Note that this predicted mean lake level was for the modeled spawning period (October 15, 2004 to January 30, 2005), and does not correspond to the long-term measured mean lake level of 34 feet (Section 4.3.5).

Collectively, the findings of Herrera (2005, 2006) strongly suggest that mean lake level during the beach sockeye spawning period has been lowered by 1.5 to 3.3 feet. Lower mean lake levels would directly result in decreased beach spawning area (see Section 5.4.2.2.2). Potentially even more importantly, long-term lake level changes associated with Ozette River logjam removal could affect the quality of beach spawning gravels utilized by spawning sockeye. Herrera (2005, 2006) suggest that lowered lake levels could have a significant influence on the ability of vegetation to colonize the shorelines in spring and summer months. They conclude that changes in winter lake levels associated with high wood loading in the Ozette River could help to reduce or eliminate plant colonization and persistence along the portions of the shoreline once thought to be used by spawning sockeye salmon.

It still remains unclear how long-term lake level changes associated with LWD removal or land use effects on hydrology (Section 5.5.1) may affect seasonal lake level changes. It is hypothesized that wood removal at the outlet (lower sustained lake levels) and increased inflow discharge (temporarily elevated lake levels) have together increased the variability of lake level changes during the spawning and incubation season.

5.4.1.1 Seasonal Lake Level Changes

Seasonal lake level changes are known to directly result in sockeye redd dewatering. This occurs when sockeye spawn in November, December, and January at elevations along the beaches that become exposed by lowering lake levels before incubation and emergence. Redd desiccation has been observed or noted as occurring during several of the years when spawning ground surveys have been conducted (Dlugokenski et al. 1981; MFM unpublished spawning ground surveys). Only one year of spawning ground survey data exists for which any quantification of redd desiccation can be calculated. Redds were mapped during the RY 2000 spawning season and a total of 7 redds (~3% of redd surface area) at Olsen's Beach were deposited above the lake stage at which emergence was projected to occur. Redd elevation data were not collected at Allen's Beach during these surveys.

The relationship between redd dewatering and embryo survival for lake spawning sockeye is unclear. Since many sockeye spawning on Ozette beaches appear to select sites with upwelling associated with springs and seeps, some dewatered sockeye eggs may survive to hatching. If subsurface pathways through interstitial spaces to open water of the lake exist, survival to emergence may be possible in dewatered redds. However, high fine sediment levels observed in most beach spawning locations suggest that dewatered egg survival may be low. Peak spawn-timing, depth of spawning, and lake level at emergence are all important factors that influence the degree to which redd desiccation will occur. Years with early high lake levels (November and December) that coincide with peak spawn timing followed by lower than average late-winter and early-spring months likely result in more significant redd desiccation events (e.g. WY 1990; 1992; 1998). It is unclear what effect the long-term role of LWD removal or land use effects on hydrology has on timing or rate of seasonal lake level changes.

5.4.2 Spawning Gravel Quality and Quantity

The quantity and quality of beach spawning gravels in Lake Ozette are known to have declined significantly from their historical conditions to present. Reduced spawning gravel quantity and quality appear to be <u>key</u> limiting factors affecting the success of beach spawning sockeye in Lake Ozette. The degree to which habitat quantity has been reduced has not been quantified for the entire lake shoreline. The degree that habitat quality has been reduced has also not been quantified, due to the complexities required to quantify changes in habitat quality. Habitat quality reduction varies by site; for example, the entire Umbrella Beach spawning area has been covered by several acres of fine sediment deposition and no longer provides suitable habitat. Herrera (2006) collected bulk sediment samples at five sites along the mouth and delta and more than 50% of the substrate was composed of fine sediment less than 0.85 mm diameter.

Other potential spawning areas have been reduced by vegetation colonization, varying from small-scale increases in vegetation, to entire beach segments colonized by shrubs and grasses (adjacent to areas currently used by spawning sockeye). In general, high levels of fine sediment (<0.85 mm), vegetation encroachment and colonization of spawning gravels, reduced numbers of suitable spawning habitats, and changes in lake levels during spawning and incubation are thought to be the primary factors that have reduced spawning gravel quality and quantity. Detailed information regarding current beach spawning habitat conditions is included in Section 3.1.4 and 4.2.1.

5.4.2.1 Spawning Gravel Quality

During incubation, salmonid eggs require sufficient water flow to supply egg pockets with oxygen and carry away waste products (Bjornn and Reiser 1991). Water circulation through salmon redds is a function of redd porosity, permeability, and hydraulic gradient (Bjornn and Reiser 1991). Fine sediment that settles into redds during the egg incubation period can impede water circulation and fry movement, which can result in decreased egg-to-emergence survival (Bjornn and Reiser1991). Studies throughout the Pacific Northwest have found that increased levels of fine sediment (<0.85mm) in spawning gravels decreases egg to emergence survival (Cederholm et al. 1981; Bjornn and Reiser 1991; McHenry et al. 1994). Measured levels of fine sediment collected during fall of 1999 and 2000 on Olsen's and Allen's beaches averaged 25% fines less than 0.85mm (n=56; gravimetric processing method). Fine sediment levels in spawning gravels are highly variable on both beaches.

Egg basket studies conducted during the winter of 2000 and 2001 on Olsen's Beach indicate that egg to emergence survival is low (Crewson 2002). In 2001, eyed sockeye eggs were incubated in Olsen's Beach cleaned and uncleaned gravel inside egg baskets buried at 15 sites along the beach for 21 days. No statistically significant differences in survival were measured between cleaned and uncleaned gravel. Egg survival in uncleaned gravel baskets averaged 14.3% (0.23 stdv; n=15). Egg survival in cleaned gravel baskets averaged 10.6% (0.095 stdv; n=5). Median egg survival measured in 2001 on Olsen's Beach was 2% for uncleaned gravel and 8% for cleaned gravel (median =7% for all samples). Cleaned (n=5) and uncleaned (n=2) samples were positioned at two sites. Egg survival in the uncleaned gravel was 0% and 10.6% in the cleaned gravel.

Hatchery incubated eggs in cleaned and uncleaned gravel had survivals of 99.8% and 61.2% respectively (Crewson 2002). Eggs were also incubated in Jordan egg incubators above the lake bottom adjacent to Olsen's Beach in 2001 and survival was very high (99.4%). High egg survival in Olsen's Beach cleaned gravels incubated in the hatchery and high egg survival in artificial incubators incubated above the gravel on the beach, coupled with low survival of eggs in cleaned and uncleaned gravels incubated in the beach substrate, strongly suggest that incubation conditions in beach substrate are very poor and the source of the mortality observed during the study. Intermediate survival (62%) of eyed eggs incubated in uncleaned Olsen's Beach gravel in the hatchery suggest that fine sediment plays a significant role in egg mortality. These data also strongly suggest that other factors also contribute to reduced survival (e.g. vegetation, upwelling, inter-gravel flow). Green egg to fry survival rates based on egg basket studies suggest that survival rates range from 45-0%, averaging less than 1% (based on a spawning distribution pattern similar to basket placement, constant mortality rate throughout the incubation period, zero egg retention in spawners, 100% fertilization, no predation, and no redd superimposition). Dlugokenski et al. (1981) used a hydraulic sampler to obtain eyed eggs from a portion of a single redd on Olsen's Beach to examine early egg survival conditions. They found that survival to eyed stage was 47% for the single redd sampled and concluded that this was within a comparable range of natural production in other sockeye systems. Several factors that have the potential to affect incubation conditions in spawning gravels have been identified and include: high levels of fine sediment and increased sediment production in tributaries and delivery to lake spawning sites, vegetation colonization of gravels, decreased sockeye population size, upwelling (inter-gravel flow), and lake level alterations.

5.4.2.1.1 Factors Affecting Spawning Gravel Quality

5.4.2.1.1.1 Sediment Production and Delivery from Tributaries

Delivery of fine sediment to the lake from tributaries has increased during the last 50 to 100 years (Herrera 2006). Current sediment production rates are estimated to be more than three times greater than pre-disturbance production rates (Herrera 2006). Herrera (2006) attributes the recent (last 50 years) increased sediment production mainly to forest practices (primarily roads and clear-cutting) and channel incision associated with LWD removal from the Ozette River. While it appears that increased sediment production in lake tributaries has resulted primarily from land-use activities, it is not fully understood to what degree these increases have affected the <u>remaining</u> utilized beach spawning habitats. Historically utilized beaches, such as Umbrella Beach, have a clear link between sediment source and delivery. Dlugokenski et al (1981) documented the creation of a sand bar off of the mouth of Umbrella Creek, and the siltation of sockeye spawning grounds at Umbrella Beach. McHenry et al. 1996 stated, "*Mass sedimentation from logging on private land has eliminated spawning habitat in Umbrella Bay [Beach]*." Herrera (2006) describes 5.7 acres of fine and coarse sediment aggradation between 1964 and 2003 at Umbrella Beach.

The following four figures (Figure 5.27 through Figure 5.30) are products of an ongoing GIS analysis of aerial photos from 1953-2006, due to be published in a research report to ONP in 2007 (Ritchie, unpublished data). Figure 5.27 illustrates the relationship between percent of old growth forest clear-cut and delta growth through time in the Umbrella Creek watershed. A highly significant relationship (r^2=0.87; $p<0.001$) between percent old growth clear-cut and total delta growth was found (Figure 5.28). A highly significant relationship (r^2=0.95; $p<0.001$) between percent old growth clear-cut and proximal delta growth was also found (Figure 5.28). Figure 5.29 illustrates the relationship between road density and delta growth through time in the Umbrella Creed watershed. A highly significant relationship (r^2=0.88; p<0.001) between road density and total delta growth was found (Figure 5.30). A highly significant relationship (r^2=0.96; p<0.001) between road density and proximal delta growth was also found (Figure 5.30).

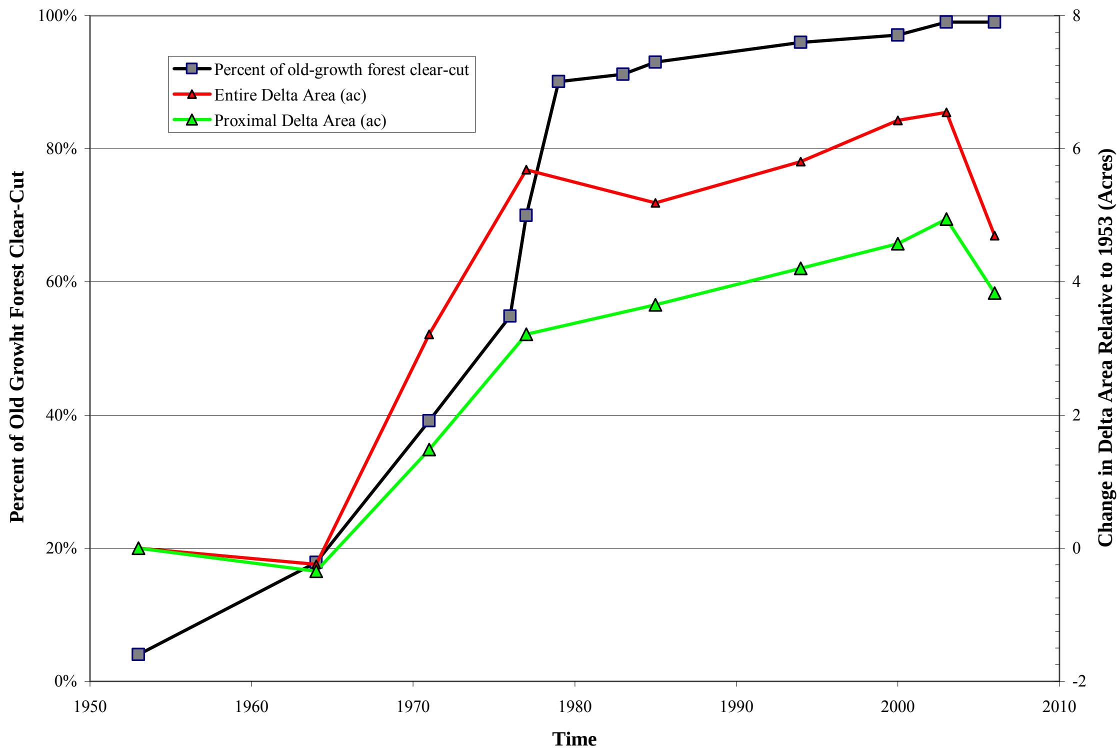

Figure 5.27. Percent of old growth forest clear-cut contrasted with total delta and proximal delta area change through time.

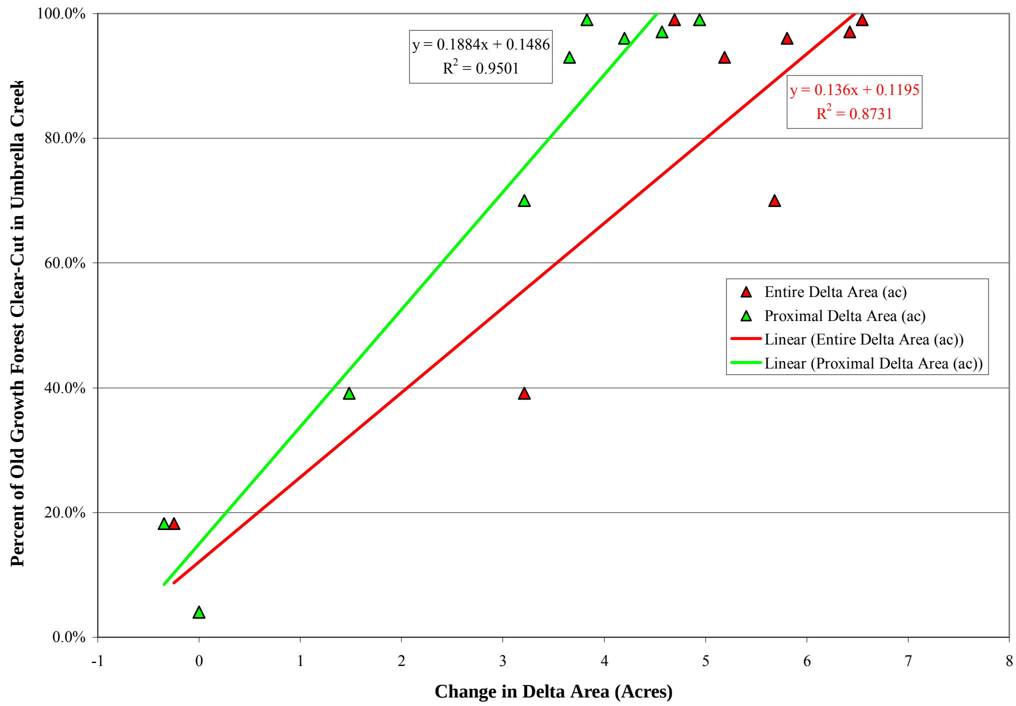

Figure 5.28. Relationship between percent old growth forest clear-cut and total and proximal delta growth for the Umbrella Creek sub-basin.

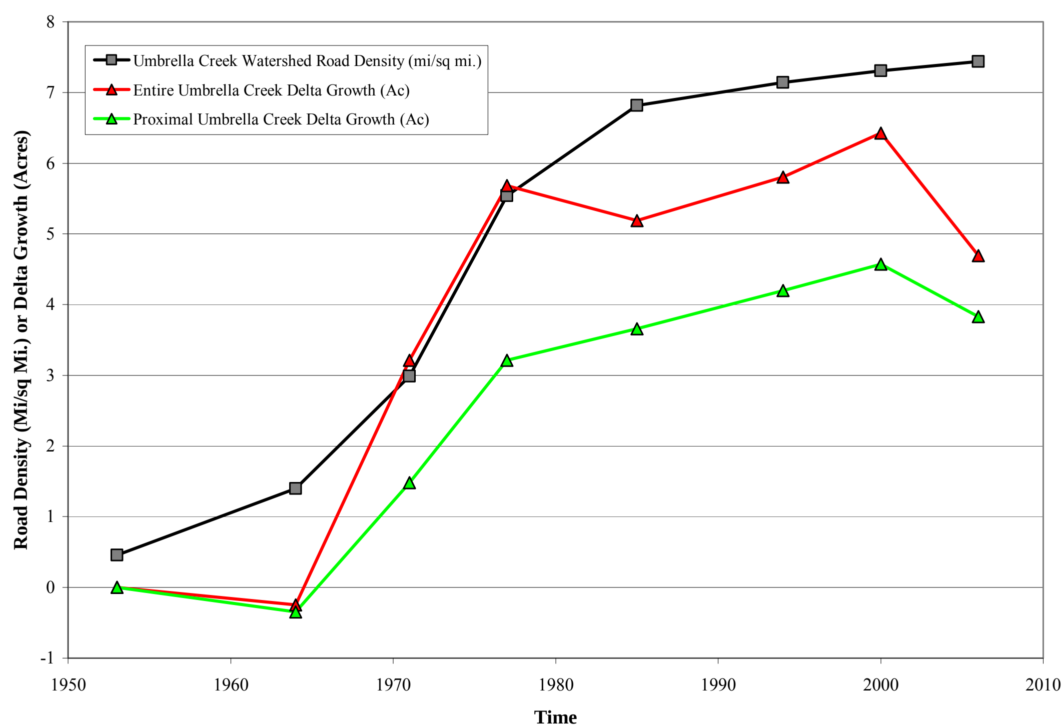

Figure 5.29. Umbrella Creek road density contrasted with entire and proximal delta growth through time.

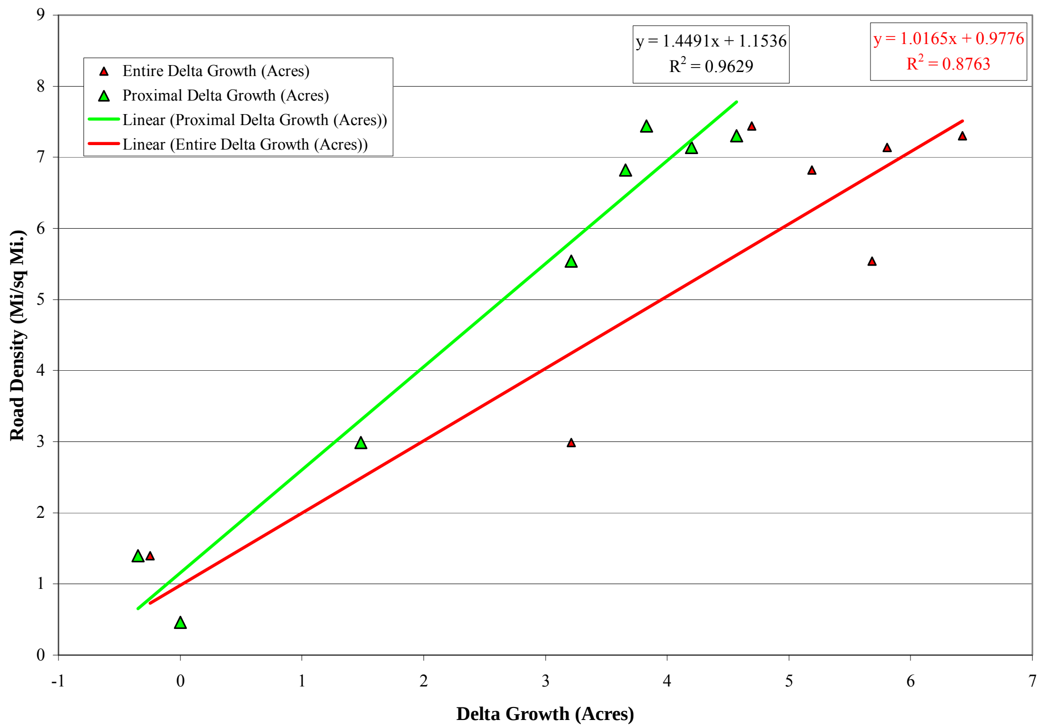

Figure 5.30. Relationship between road density and total and proximal delta growth for the Umbrella Creek watershed.

Sediment delivery from streams and slopes, combined with lateral lake shore transport, are the primary mechanism for fine sediment delivery to sockeye spawning habitat. Therefore sediment delivery would be expected to be highest close to sediment sources. This is interesting since the remaining beach spawning sites appear to be as far away from the main sediment sources (Umbrella Creek, Big River, and Crooked Creek) as possible and pre-existing habitat closer to these sources is no longer used for spawning (e.g. Umbrella Beach). It is highly unlikely that significant quantities of fine sediment from Umbrella Creek, Big River, and Crooked Creek are transported to Allen's or Olsen's beaches. The dominant transport direction is northward along the eastern shoreline of the lake, and both Allen's and Olsen's beaches are far south from these tributaries. However, fine sediment delivery to the lake also occurs from smaller lake tributaries near the remaining spawning beaches. No shoreline sediment routing models have been developed for Ozette, but general wind patterns are depicted in Figure 1.9 and generalized relative longshore transport vectors are shown in Figure 5.31.

Olsen's beach spawning areas are much closer to larger tributary sediment sources (i.e., Siwash, Elk, 20.0073) than Allen's Beach (i.e., Allen's Slough). The mouth of Elk Creek is within 280 feet (85 m) of the Olsen's Beach spawning area and the prevailing wind and sediment transport direction is toward the spawning area. Siwash Creek is within 1,250 feet (381 m) of Olsen's Beach and sediment transport and dominant wind direction is toward the spawning area. Unnamed tributary 20.0073 is within 900 feet (274 m) of Olsen's Beach and sediment transport and dominant wind direction is away from the spawning area. South Creek is located within 2.4 miles (3.8 km) of south Olsen's Beach. Sediment transport direction is generally north-northeast, but complex beach geography with north-west trending shorelines likely limit sediment transport to the northeast.

Streams near Allen's Beach include: Allen's Slough, West Shore Tributary 5, and West Shore Tributary 6. A few very small streams also enter the lake along Allen's Beach. Allen's Slough is approximately 2,700 feet (823 m) from the southern end of Allen's Beach. Allen's Slough is low energy; sediment transport and dominant wind direction are toward the east and north-east edge of Allen's Bay, away from the spawning area at Allen's Beach. Shoreline geometry suggests that only suspended sediment could be transported to Allen's Beach from Allen's Slough. West Shore Tributary 6 enters the lake along the north shore of Cemetery Point (see Figure 3.7). Shoreline substrate conditions are gravel and cobble near the confluence. West Shore Tributary 5 enters the lake 300 feet north of Allen's Beach. Fine sediment is the dominant substrate at the confluence and along the shoreline to the north. Sediment transport and dominant wind direction is away from the spawning area.

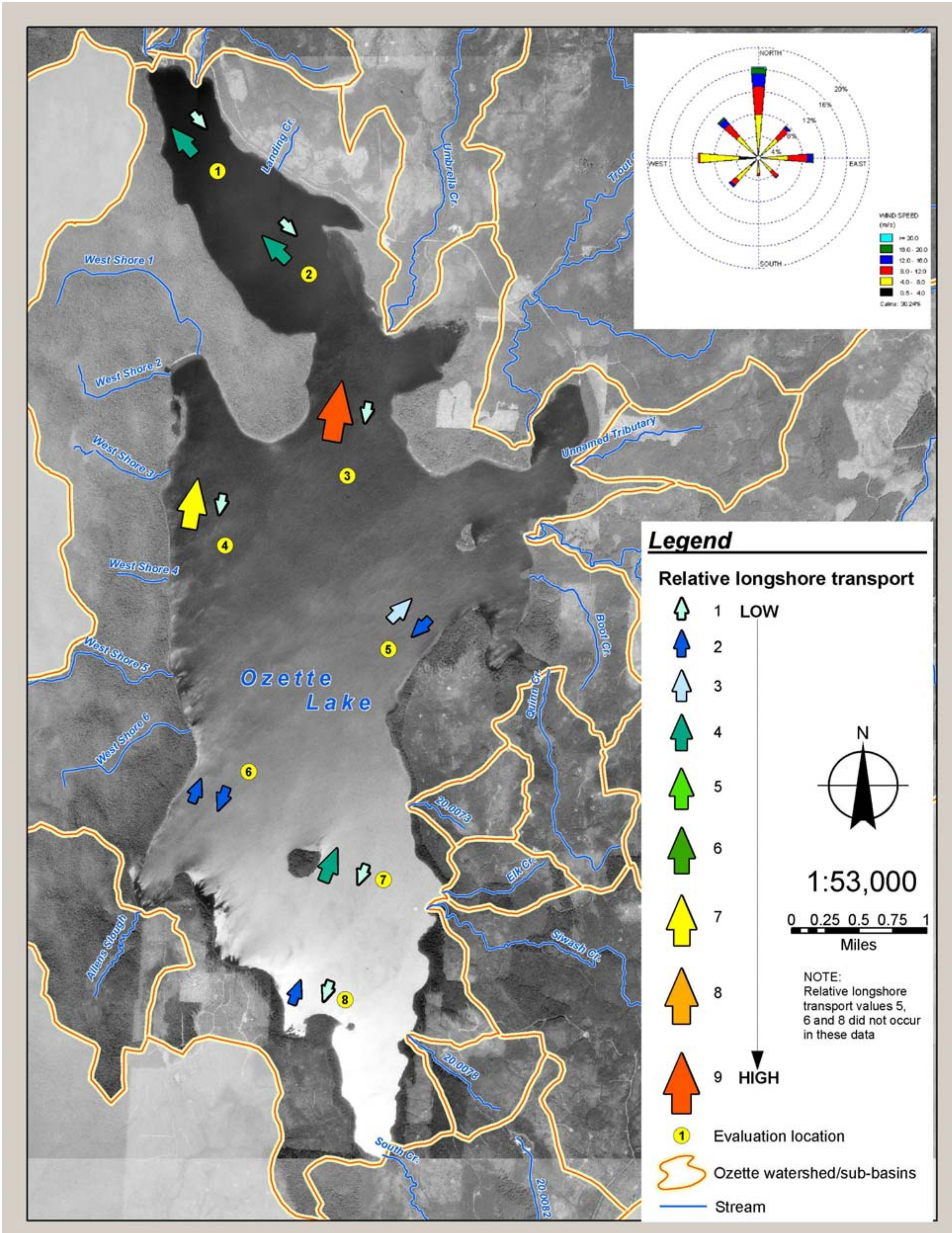

Figure 5.31. Magnitude and direction of dominant relative longshore transport for eight sites on Lake Ozette (modified from Herrera 2006)

Additionally, a small unnamed stream enters the lake just north of the base of the small spit. Sediment substrate in the vicinity of the confluence is composed entirely of fine sediment. Fine sediment along this segment of the beach truncates spawning habitat located to the south. The spit defining the boundary between Allen's Bay and the lake suggests that dominant long-shore drift direction at south Allen's Beach is southwest, toward Allen's Bay. A detailed investigation of shoreline sediment routing is recommended to determine sediment routing along the shorelines of the lake.

Fine sediment core sample data indicate that Olsen's Beach has slightly higher levels of fine sediment (n= 46, average 26.1%, range 7.0 to 72.7%) than Allen's Beach (n= 13, average 22.6%, range 4.6 to 44.3%). However, the sample size at Allen's Beach is relatively small and may not fully represent the diversity of substrate conditions at all the dispersed (and deep) spawning sites at Allen's. The core, concentrated, and dispersed spawning areas at Olsen's Beach appear to be well-represented by the 46 sample sites.

5.4.2.1.1.2 Small Spawning Population Size

The small beach spawning aggregations that have persisted during the last 30 years may have been reduced to levels incapable of sufficiently cleaning spawning gravels and maintaining vegetation-free spawning gravels. During the act of spawning, salmonids winnow fine sediment from spawning substrate (Kondolf et al. 1993). Lack of sufficient numbers of spawners could result in degraded habitat conditions, as well as increased levels of fine sediment within spawning gravels. In stream systems, fine sediment excavated from the substrate during spawning is transported downstream and out of the egg pocket. For mass spawning fish (e.g., chum [or sockeye]), gravel cleaning and coarsening at least temporarily (Peterson and Quinn 1996; Kondolf et al. 1993; Peterson and Foote 2000) reduces the fine sediment levels in the bed and redd (Kondolf and Wolman 1993; Kondolf et al. 1993; Moore 2006), increasing egg to fry survival. The reduction of mass spawning fish populations such as sockeye, resulting from other limiting factors (e.g. overfishing), has been hypothesized to create a negative feedback loop due to reduced gravel bed maintenance of fine sediment levels in lake or streams, or scour depths in streams (Montgomery et al. 1996).

No documented research on the effect of mass spawning sockeye on beach substrates was located during an exhaustive literature review. However, one point worthy of note is that many of the gravel samples collected where low levels (<10%) of fine sediment were recorded appeared to be in sites that were spawned in during the previous winter. The role of sockeye spawning on gravel quality maintenance is poorly understood but may be of particular importance on Ozette beaches and should not be overlooked as a limiting habitat factor. Moore (2006) determined that when habitat modification by salmon promotes their own success, there will be feedback between generations. Understanding whether recovery of a small population will be inhibited by lack of habitat maintenance is critical.

5.4.2.1.1.3 Colonization of Native and Non-Native Vegetation

Colonization of native and non-native vegetation along the lake shoreline may influence sediment particle size distribution along the spawning beaches. Ritchie (2005) and Herrera (2005, 2006) both found increases in shoreline vegetation during the last 50 years. Herrera (2005) determined that vegetation has substantially encroached along the lake shoreline as a result of the lowering of both winter and summer lake levels following large scale wood removal operations in the Ozette River. Vegetation colonization of the spawning gravels can decrease wave energy in and around the spawning gravels, which can result in increased fine sediment deposition. A positive feedback loop can develop between vegetation colonization and sediment deposition: increased sediment improves vegetation colonization, and increased vegetation further increases sediment deposition. The dense root networks of vegetation submerged in the winter act as excellent filters for trapping fine sediment and building up a soil layer over previous gravel bed surfaces. Furthermore, vegetation colonization that blocks or limits wave energy and wave-driven currents can negatively affect sockeye spawning in lake shore areas where sockeye are dependent on wave-driven currents for egg oxygenation.

5.4.2.2 Reduced Spawning Area

Suitable spawning habitat area in Lake Ozette has declined during the last 50 to 100 years. The historical spawning distribution of beach spawning Lake Ozette sockeye is not fully understood. Dlugokenski et al. (1981) observed sockeye spawning to the north of Umbrella Creek during surveys in the late 1970s, but no sockeye have been observed spawning there since (despite exhaustive surveys). Currently available spawning habitat along the beaches appears able to produce only a small fraction of the population abundance that is thought to have once occupied the lake. One reasonable explanation to limits affecting the beach spawning component of the population is loss of spawning area at extant spawning beaches, as well as the complete loss of some spawning aggregations (e.g. Umbrella Beach). Kemmerich (1939) describes Ozette sockeye spawning as occurring "*especially at the mouths of several creeks.*" Ozette sockeye are no longer observed spawning at creek mouths. The number of beach spawning aggregations that have been entirely eliminated remains unknown. The dominant spawning behavior of Lake Ozette sockeye described by Kemmerich (1939) is no longer observed. It is unknown whether sufficient habitat exists to initiate recovery of the beach spawning population without first rehabilitating additional spawning habitat. It seems unlikely that beach spawning population abundance can recover to pre-decline levels without increasing the number of beach spawning aggregations, as well as the quantity of suitable spawning habitat. Increased sediment production from tributaries, small spawning population size, and colonization of native and non-native vegetation have all acted as factors to decrease the area of suitable spawning gravel. Predicted changes in lake level following wood removal could also significantly affect suitable spawning habitat area. The cumulative effects of increased sediment production, changes in lake level, and vegetation colonization have reduced the suitable spawning habitat (above 31.5 ft MSL) area by more than 70% at Olsen's and Allen's beaches.

5.4.2.2.1 Increased Sediment Production in Tributaries

Increased sediment production in the Umbrella Creek watershed appears to be the primary factor responsible for the loss of the Umbrella Beach spawning aggregation (see Sections 5.4.2.1.1 and 5.4.2.1.1.1). While no direct measurements of past sediment production are available, indirect estimates of past and current sediment production strongly suggest that large-scale changes in sediment production (> 3 times pre-disturbance sediment production rates), storage, and transport have occurred during the last 50 years in Lake Ozette tributaries (Herrera 2006). Herrera (2006) estimates that delta growth between 1964 and 2003 was approximately 5.7 acres (23,000 m^2). Much of the delta growth described by Herrera (2006) was just north of the mouth of Umbrella Creek. This is the same area where spawning sockeye salmon were observed by Dlugokenski et al. (1981). Much of the new (post-1964) delta is now vegetated in shrubs, as is much of the older (pre-1964) delta, which contained little vegetation along the lake margins in 1964 (see Figure 4.7). Additional sediment input and delivery to the lake from other tributaries also may have resulted in spawning habitat losses. However, there are no confirmed sites other than Umbrella Beach where this is thought to have occurred.

5.4.2.2.2 Changes in Lake Level

Changes in Ozette Lake level associated with logjam removal in the Ozette River could have two main impacts on spawning habitat availability: 1) lower water surface levels in the lake (especially during the growing season) could influence the ability for vegetation to colonize spawning gravels, and 2) lower lake levels result in less spawning gravel habitat inundated during the spawning and incubation period. Herrera (2005, 2006) suggests that lowered lake levels could have a significant influence on the ability of vegetation to colonize the shorelines in spring and summer months. They concluded that associated winter lake levels with high wood loading in the Ozette River, coupled with wet season wind events, could help reduce or eliminate plant colonization and persistence along the portions of the shoreline once thought to be utilized by spawning sockeye salmon (see Section 5.4.2.2.3).

Collectively, the findings of Herrera (2005, 2006) strongly suggest that mean lake level during the beach sockeye spawning period has been lowered by 1.5 to 3.3 feet from historical levels. Lowered mean lake levels during the spawning and incubation periods directly result in decreased beach spawning area. Herrera (2005, 2006) was unable to fully quantify the percent of habitat lost due to lowered lake levels. Herrera (2005) estimated that a 3.3 ft (1 m) increase in mean lake level would result in 33 to 39 lineal feet of inundated beaches at Olsen's and Allen's beaches, respectively. These estimates were based on elevation data derived from LiDAR data and did not include WSE during the critical egg incubation period. In order to better understand and estimate losses to beach spawning habitat, the lowest water surface elevations during the spawning and incubation period (for existing conditions as well as under different wood loading scenarios) and beach geometry were plotted together for the core spawning area at Olsen's Beach (Figure 5.32). Projected incubation period was determined based on RY 2003 spawn timing and incubation duration based on average incubation temperatures. The lowest lake level during projected incubation period was based on continuous lake level measurements.

Core spawning area habitat losses were estimated based on wood loading conditions in the Ozette River of 200 ft jam spacing at 60% blockage and 500 ft spacing at 80% blockage. It was estimated that 700 sq ft (~11%) and 2,100 sq ft (~33%), respectively, of "new" spawning habitat would be usable under these wood loading conditions. It is important to note that beach geometry plays a critical role in estimating potential spawning habitat loss. Transects north and south of the core spawning area are plotted in Figure 5.33. Estimated losses for the south beach under presumed historical wood loading conditions ranged from 3 to 6 horizontal feet and 6 and 12 horizontal feet for the transect to the north. These estimates are significantly less than those presented in Herrera (2005). The beach geometry within areas surveyed at Allen's Beach are much more uniform than areas surveyed at Olsen's. Figure 5.34 depicts a typical beach profile at Allen's Beach contrasted with lowest stage observed during egg incubation and modeled lake stage for two wood loading scenarios in the Ozette River. Estimated spawning area loss for the 200 ft spacing, 60% blockage wood loading scenario is approximately 6 horizontal feet, and the estimated spawning area loss for the 500 ft spacing, 80% blockage is approximately 26 horizontal feet.

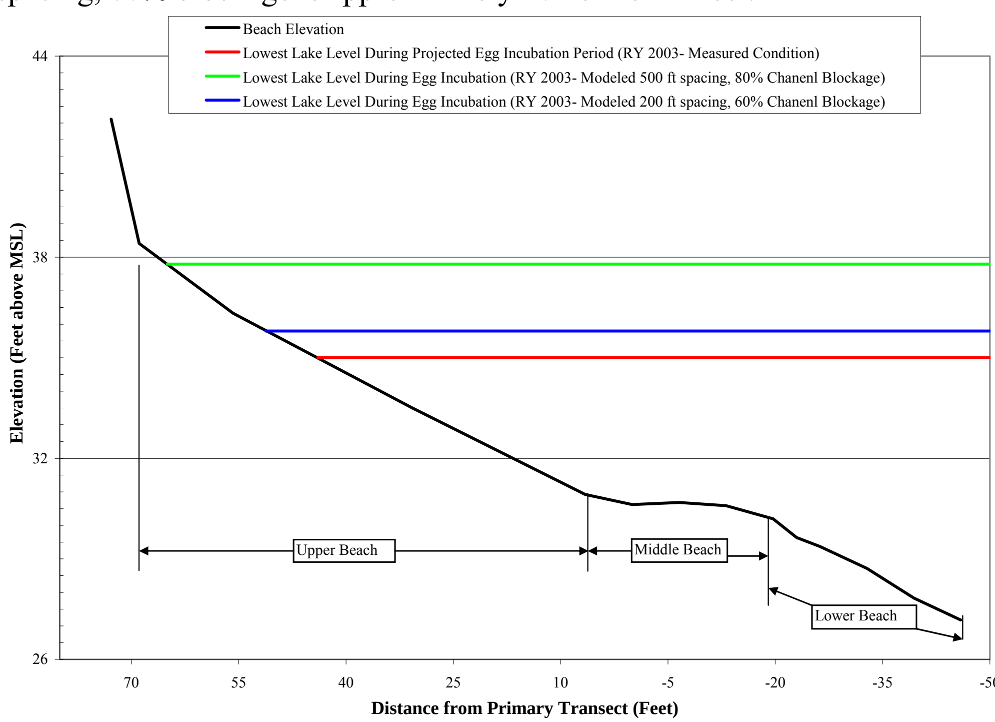

Figure 5.32. Comparison of lowest observed stage during projected incubation period at Olsen's Beach (RY 2003) core spawning area and modeled lowest water surface elevations during incubation for two Ozette River wood loading scenarios (based on Herrera 2005 model outputs).

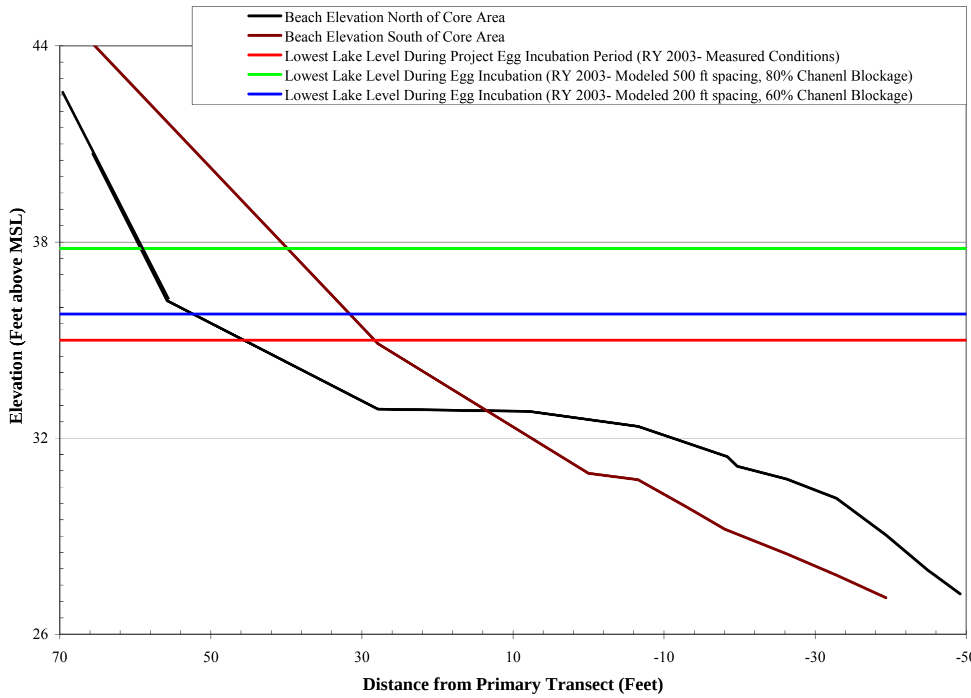

Figure 5.33. Comparison of lowest stage observed during projected egg incubation period at Olsen's Beach (RY 2003) spawning areas and modeled lowest WSEs during incubation for two Ozette River wood loading scenarios.

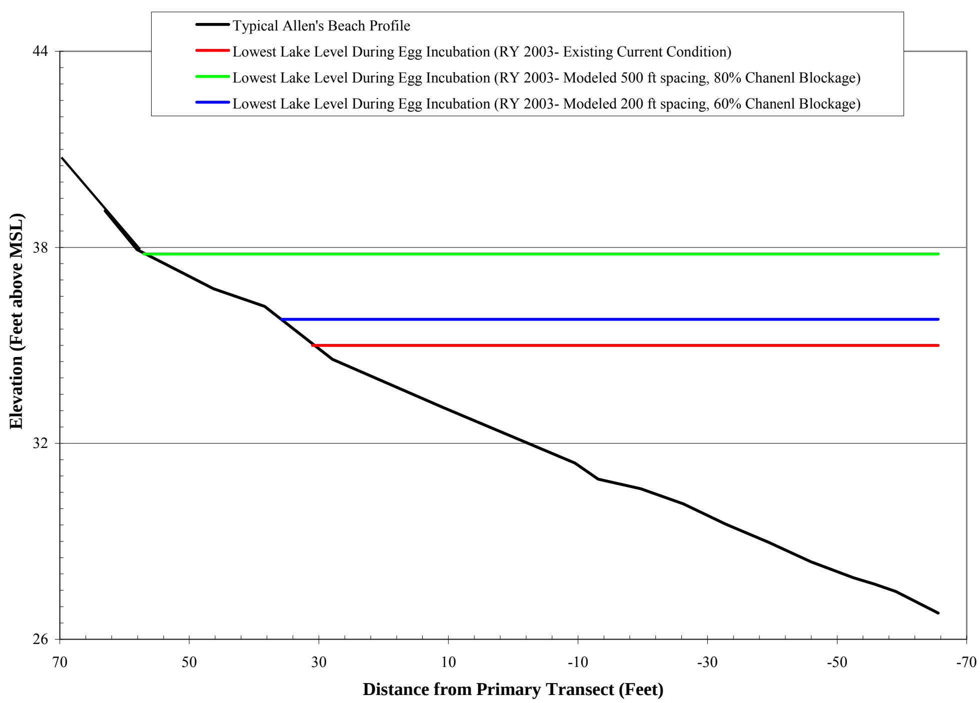

Figure 5.34. Comparison of lowest stage observed during projected egg incubation period at Allen's Beach (RY 2003) spawning areas and modeled lowest WSEs during incubation for two Ozette River wood loading scenarios.

5.4.2.2.3 Colonization of Native and Non-Native Vegetation

Colonization of native and non-native plants in spawning gravel directly reduces the quantity of spawning habitat available for sockeye. Ritchie (2005), Herrera (2005, 2006), and Ritchie (2006) all found significant increases in shoreline vegetation during the last 50 years. Ritchie (2005) compared 45.6 km of shoreline from 1953 to 2003 (using geo-rectified aerial photos), and determined that 40.4% of the shoreline showed an increase in shoreline vegetation between 1953 and 2003. There was no change along 59.3% of the shoreline, and only about 0.3% of the shoreline showed a decrease in vegetation (see Section 4.2.1). Ritchie (2006) conducted a high resolution analysis of vegetation colonization of the shoreline from 1953-2003 (see Section 4.2.1). Ritchie identified 1,034,887 ft^2 (96,144 m^2) of unvegetated shoreline around the lake in 1953, and only 451,561 ft^2 (41,951 m^2) of unvegetated shoreline in 2003, a decrease of 56%. Ritchie found that unvegetated area at Allen's Beach dropped by 67%, from 125,645 ft^2 (11,673 m^2) in 1953, to 41,716 ft^2 (3,876 m^2) in 2003 (Figure 4.8). The length of shoreline analyzed was 8,670 ft (2,643 m). Unvegetated area at Olsen's Beach declined from 27,322 ft^2 (2,538 m^2) in 1953, to 9,343 ft^2 (868 m^2) in 2003, a decrease of 66% over 2,804 ft (855 m) of shoreline (Figure 4.9).

5.4.2.3 Other Factors Affecting Egg to Emergence Survival

Additional interrelated factors are believed to reduce egg to emergence survival along the spawning beaches. Redd superimposition on the spawning beaches is thought to significantly reduce the survival of earlier deposited eggs on the spawning beaches. The degree to which this is occurring is difficult to measure, but sockeye spawning on Olsen's Beach seem to be especially prone to multiple spawning events in the same location during the same season. As described in Section 3.1.4, during RY 2000, sockeye were observed spawning in the same location over an 89-day period, and over 90% of the redd surface area measured had been spawned-in multiple times during the spawning season. These observations provide additional evidence that suitable/preferred spawning area is limited. Since Ozette sockeye appear to prefer areas with springs and seeps for spawning, it is thought that alterations in the location, degree, and depth of upwelling could negatively affect beach spawning, although no such alterations have been documented. Also see Section 5.4.5 for more factors affecting egg to emergence survival.

5.4.3 Water Quality

Water quality data for Lake Ozette are presented in detail in Section 4.2.3. In general, water quality in Lake Ozette is thought to be negligible as a limiting factor for sockeye salmon at all life history stages in the lake with the exception of adult spawning. Turbidity (specifically suspended sediment) during spawning may affect sockeye salmon spawning on the beaches of Lake Ozette. However, the degree to which suspended sediment and turbidity affect spawners remains unclear. In historical spawning sites at the mouths of creeks (e.g. Umbrella Beach) suspended sediment concentrations are much higher (see Section 4.4.1.5; Figure 5.43) and the potential effects on sockeye more severe than at Olsen's and Allen's beaches, which are partially removed from the largest tributary inputs.

Meyer and Brenkman (2001) measured a large turbidity plume at the north end of the lake in March 1994. Turbidity in the middle of Swan Bay was 35 NTUs (higher than turbidity measured in Big River). High intensity storms that generate large floods and high SSC levels can generate long duration turbidity/SSC events in the lake. This increases the duration that sockeye salmon are exposed to high turbidity levels. For example, the December 15, 1999 flood resulted in high turbidity levels throughout the entire lake; visibility in the lake approached zero. Visibility remained poor (1-3 feet) for several weeks following the flood. Such high turbidity levels of long duration in the lake are likely to be caused by abundant clay or very fine silt, rather than sand input from the tributaries, which is more likely to be transported by wind-driven currents along the shoreline. In a review of the literature, Cook-Tabor (1994) cites several studies that reported negative effects on salmonids at turbidity levels of 15-30 NTU and gill tissue damage when exposed to turbidity levels of 25 NTU over 5-7 days. High turbidity and resulting poor visibility could affect mate selection efficiency and decrease efficiency in locating suitable spawning habitat, as well as decrease predator avoidance capability.

5.4.4 Food Availability/Competition

Sockeye prey composition and availability, as well as competition for prey in Lake Ozette, have been investigated in part or whole by Bortleson and Dion (1979), Dlugokenski et al. (1981), Blum (1988), Beauchamp and LaRiviere (1993), and Meyer and Brenkman (2001). Past surveys in Lake Ozette indicate that juvenile *O. nerka* occur at higher frequencies in the pelagic zone than all other fish species combined (Beauchamp and LaRiviere 1993). Approximately 94% of the fish >100mm (FL) caught in vertical gill nets in April 1991 were sockeye salmon pre-smolts or kokanee (Beauchamp et al 1995). In the summer months only 54% of the gill net catch was composed of kokanee salmon, but age 0 sockeye/kokanee salmon were not susceptible to gill net capture (Beauchamp et al. 1995). *Daphnia pulicaria* dominate the diet of juvenile *O. nerka* salmon throughout the year (Beauchamp et al. 1995). Benthic invertebrates, adult insects, and copepods comprised 7-46% of the adult kokanee salmon diets from late-summer through early-spring (Beauchamp et al. 1995).

Beauchamp et al (1995) estimated that juvenile sockeye and all year classes of kokanee consumed less than 1% of the monthly standing stock of *Daphnia pulicaria* > 1.0 mm in size, suggesting that food availability for rearing fish was not limiting *O. nerka* productivity. All researchers (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; Beauchamp and LaRiviere 1993), independent of methodologies, have concluded that Lake Ozette sockeye productivity and survival are not limited by food availability or competition.

5.4.5 Predation

Predation on sockeye salmon occurs during all life history phases within the lake. Sockeye salmon are preyed upon by a host of predators in the lake, including harbor seals, river otters, northern pikeminnow, cutthroat trout, sculpin, other native and non-native fishes, and various species of birds. Several studies have been conducted within the lake attempting to determine predation levels on sockeye salmon at various life history stages (Dlugokenski et al. 1981; Beauchamp and LaRiviere 1993; Gearin et al. 1999; Gearin et al. 2002). None of these studies was able to determine the number or proportion of sockeye salmon preyed upon at any life history stage. Additional observations and studies have also documented predation on sockeye salmon at different life history stages. Brief descriptions of sockeye predation by life history stage in Lake Ozette are included below.

A complete description of adult sockeye holding in Lake Ozette can be found in Section 3.1.2. During the period that adult sockeye hold in the lake, they are primarily susceptible to predation by river otters and harbor seals. Combined acoustic and radio tag studies were conducted with RY 2000 and RY 2001 adult sockeye salmon. Hughes et al. (2002) determined that the vast majority of RY 2000 tagged sockeye appeared to have died before spawning, near Rocky Point and off of the mouth of Umbrella Creek. Hughes et al. (2002) also found a similar pattern with RY 2001 tagged fish; they appeared to have died near Rocky Point, Preachers Point, Boot Bay, and off of Umbrella Creek. Hughes et al. (2002) speculated that predation may have played a role in the pre-spawning mortality of sockeye. Since most tags in fish that were assumed to have died prior to spawning could not be retrieved (because of depth), researchers were unable to confirm the cause of death. One RY 2000 CART tagged sockeye was recovered from Allen's Beach and it was determined to have been killed by a harbor seal (Hughes et al. 2002; Figure 5.35). Otter scat were collected during the summer of 2001 through 2003 to determine whether river otters were actively preying upon adult sockeye holding in the lake. These samples have not been fully processed, so results from this work are not yet available.

A complete description of sockeye spawning on Lake Ozette beaches can be found in Section 3.1.4. Beach spawning sockeye are preyed upon during spawning by river otters, harbor seals, and bald eagles (Gearin et al. 2002). Gearin et al. (2002) suggested that the majority of predation occurs at nighttime, based upon the very limited predation activity they observed during daylight hours while monitoring predation activities along the primary spawning beaches. Gearin et al. (2002) were unable to quantify the amount of predation occurring at the primary beach spawning sites because most predation occurs during darkness. They concluded that the primary spawning beaches were possibly the areas of most concern within the watershed with respect to adult sockeye predation, because sockeye on the spawning grounds are most valuable (with respect to reproduction) and vulnerable.

Sockeye are more vulnerable to predation along the beaches because they are in shallow water and often preoccupied by the act of spawning or redd defense. During RY 2000, an extensive effort was made to recover carcasses for a sockeye genetics study (see Crewson et al. 2001 and Hawkins 2004). During carcass recovery work it was noted that 47% (36 of 77) of sockeye carcasses recovered from Allen's Beach consisted only of heads (Hughes et al. 2002). Many of these appeared to be from fish in relatively good condition (see Figure 5.35) that may have been killed before or during spawning (Hughes et al. 2002).

Gearin et al. (2002) examined 27 of these carcasses and concluded that 52%, 33%, and 15% were from pre-spawners, spawners, and spawned-out sockeye respectively. Carcass recovery on Olsen's Beach the same year found that less than 10% of the carcasses recovered consisted of only heads (n>100; MFM, unpublished field notes). Gearin et al. (2002) examined 43 sockeye carcasses recovered from the beaches in RY 2000 and RY 2001 and judged that 84% were eaten by river otters and 14% by harbor seals. Predator delineation was based on inner-canine distance measurements from recovered sockeye. There is the possibility that sockeye preyed upon by seals were later scavenged by otters, which could affect the proportions reported by Gearin et al. (2002).

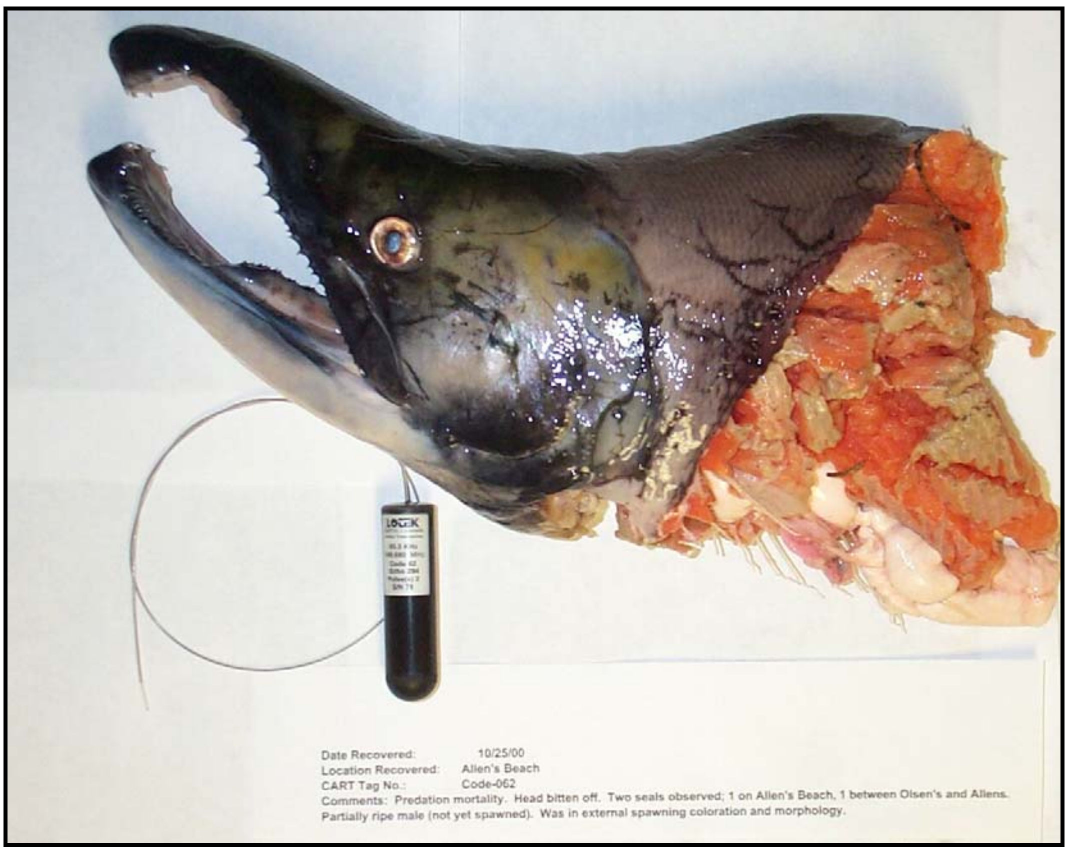

Figure 5.35. Pre-spawning predation mortality recovered from Allen's Beach October 25, 2000 (CART Tag No. 062; source: MFM photo archives).

Sockeye eggs incubating in redds constructed on the beaches are susceptible to predation by sculpin, cutthroat trout, and, potentially, river otters. No attempt to measure sockeye egg predation on the beaches has been conducted. However, sculpin and cutthroat trout have been directly observed preying on sockeye eggs. Foote and Brown (1998) determined that 16 to 32% of sockeye eggs deposited on spawning beaches studied on Lake Iliamna were preyed upon by sculpins. In addition to sculpin and cutthroat trout, sockeye eggs may also be preyed upon by aquatic insects. During egg basket studies conducted during the winter of 2000/01 at Olsen's Beach, leeches appeared to prey upon nearly all of the eggs within one of the egg baskets placed in beach substrate. Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in the nearshore environment of the beaches. Emergent sockeye fry are believed to quickly disperse from the beaches and enter the pelagic zone of the lake (Jacobs et al. 1996). No work has been conducted to estimate emergent sockeye fry predation along the beaches. Potential predators at this life history stage include sculpin (sp), northern pikeminnow, cutthroat trout, juvenile steelhead trout, juvenile coho salmon, yellow perch, and largemouth bass. Predator interactions at this early life history stage remain a data gap and it is possible that significant levels of predation occur in the vicinity of the spawning beaches.

A complete description of rearing by juvenile sockeye originating from Lake Ozette beaches can be found in Section 3.1.8. Both tributary and beach spawning populations of sockeye are vulnerable to predation within the limnetic zone of the lake. Within the limnetic zone, sockeye and kokanee are the predominant species present (Beauchamp and LaRiviere 1993). While the lake harbors a wide array of fish species, there is little spatial and temporal overlap between most species of potential predators (Beauchamp and LaRiviere 1993). The primary piscivores within the limnetic zone are northern pikeminnow and cutthroat trout (Beauchamp and LaRiviere 1993). Predation research within the lake has been unable to calculate the proportion of juvenile sockeye preyed on by limnetic piscivores. However, Beauchamp and LaRiviere were able to determine that 72% of the annual diet (by volume) of large (>300mm FL), limnetic northern pikeminnow consisted of age-0 and age-1 *O. nerka*. They also found that 40% of the diet of large (>300mm FL), limnetic cutthroat trout consisted of age-0 and age-1 *O. nerka* during spring and summer months.

5.4.5.1 Predators

5.4.5.1.1 Harbor Seals (Phoca vitulina)

Harbor seals are most commonly observed in the lake during fall and winter months, but seals will also enter during spring or early summer while following migrating sockeye up river. No harbor seal population census data exist for the lake, but detailed observations of seals have been recorded and summarized during predation observation field work (see Gearin et al. 1999; Gearin et al. 2000; Gearin et al 2002), sockeye spawning ground surveys, and CART tag tracking activities from 1998 through 2001. Harbor seals are believed to prey primarily on adult salmonids while in the lake. No direct predation events on juvenile sockeye in the lake have been documented.

Seal observation data for the lake is difficult to summarize for multiple years because of varying effort between years and differences in observers present and observation methods employed. The most comprehensive seal observation dataset was collected during fall and winter 2000. Gearin et al. (2002) spent a total of over 188 hours conducting pinniped predation observations at four key locations along the lake between November 2, 2000 and January 11, 2000 (Table 5.5). A total of 71.75 hours of observation spanning 19 days was conducted at Allen's Beach. During this time period, a total of five seals were observed along Allen's Beach; three of these seals appeared to be transiting the area; one was observed foraging along the shore; one was observed chasing a sockeye salmon (Gearin et al. 2002).

Table 5.5. Pinniped predation observer effort during return year 2000 sockeye spawning season at four key locations along Lake Ozette (Gearin et al. 2002).

Date	Allen's Beach (hrs)	Olsen's Beach (hrs)	Umbrella Creek (hrs)	Big River (hrs)	Total
11/2/00	3.75	2	1.75	0	7.5
11/3/00	3.75	2.25	1.75	0	7.75
11/7/00	0.5	1.25	0	0	1.75
11/8/00	5.75	3.25	1.5	1.75	12.25
11/9/00	3.0	3.0	4.5	1.0	11.5
11/14/00	4.75	5.25	3.7	0	13.7
11/15/00	7.5	2.95	3.0	0.5	13.95
11/28/00	4.5	0	4.0	0.75	9.25
11/29/00	0	4.5	4.5	1.0	10.0
11/30/00	1.5	3.0	4.5	0	9.0
12/11/00	3.0	4.5	1.5	0	9.0
12/12/00	1.5	4.5	3.0	0	9.0
12/18/00	3.0	3.25	3.0	0	9.25
12/19/00	4.5	3.0	1.5	0	9.0
12/27/00	4.5	1.5	3.0	0	9.0
12/28/00	4.5	3.0	1.5	0	9.0
1/3/01	5.0	3.0	1.5	0	9.5
1/4/01	4.5	3.0	1.5	0	9.0
1/9/01	3.0	4.75	1.5	0	9.25
1/10/01	3.25	2.0	4.25	0	9.5
Total	**71.75**	**59.95**	**51.45**	**5.0**	**188.15**

A total of almost 60 hours of observation spanning 19 days was conducted at Olsen's Beach. During this time period, seals were observed on only two days. Seals were observed foraging along the shoreline, chasing fish, and in one case eating a large salmonid that appeared to be a sockeye (Gearin et al. 2002). Surveys were conducted at the mouth of Umbrella Creek for a total of 51.45 hours on 19 days. Seals were observed on three of these days. In one case, a seal was observed chasing a large salmonid. A total of 5 hours of observation was conducted at the mouth of Big River during 5 days. No seals were seen at the mouth of Big River (Gearin et al. 2002).

In addition to work conducted by Gearin et al. (2002), additional observations of seals within the lake and on the spawning beaches were also made by MFM staff during spawning ground surveys and CART tracking during the 2000 spawning season. Between October 25, 2000 and February 13, 2001, a total of 17 days were spent on the lake. Seals were observed in the lake or along the spawning beaches on 8 of the 17 days. The first observation occurred on October 25, 2000 at Allen's Beach and the last observation occurred on January 31, 2001 between Olsen's Beach and Preachers Point. Observations from 2000/01 indicate that seals are present along the spawning beaches and lake throughout the sockeye spawning period. Examination of carcasses recovered from Allen's Beach indicated that most of the predation mortality was caused by river otters (Gearin et al. 2002). However, there is the potential that otters scavenged the remains left by seals, implicating the wrong animal. Sockeye during spawning are extremely vulnerable to predation by seals and the limited number of beach spawners in the lake could be drastically affected by only a handful of seals.

5.4.5.1.2 River Otters (Lutra canadensis)

River otters are common year-round inhabitants of Lake Ozette. As described earlier, there are no river otter population estimates for the Ozette watershed. River otter predation on sockeye salmon in the lake is poorly understood. As described above, river otters are known to prey upon adult sockeye salmon on the spawning grounds, but predation at other life history stages has not been documented. CART tagging studies conducted during RYs 2000 and 2001 indicate that there is potentially significant pre-spawning mortality occurring within the lake (Hughes et al. 2002). Holding mortalities resulting from predation may be associated with river otters. Gearin et al. (2002) recommend that further investigations of pre-spawning lake holding mortalities be conducted since the source of mortalities could not be determined in 2000 and 2001. Hughes et al. (2002) found that nearly 50% of the tagged sockeye could not be accounted for on the spawning grounds in 2001.

Predation of adult sockeye on the spawning grounds by river otters is cause for concern (Gearin et al. 2002). Preliminary field evidence collected from Allen's Beach during the RY 2000 spawning season indicates that nearly 34% of the sockeye were killed by river otters prior to the completion of spawning (total pre-spawning predation mortality was estimated to be 40% on Allen's Beach; 6% of these mortalities were attributed to harbor seals). It is possible that many of the mortalities linked with river otters are actually associated with harbor seals and that river otters are scavenging the remains left by seals. However, due to the fact that nearly all successful predation occurs at night along the spawning beaches, it was not possible to determine precisely which predators are responsible for the mortalities occurring.

5.4.5.1.3 Northern Pikeminnow (Ptychocheilus oregonensis)

A description of the Lake Ozette northern pikeminnow population is included in Section 2.2.8. As described above, northern pikeminnow are known to prey upon juvenile sockeye in the limnetic zone. However, only a small percentage (2-8%) of the northern pikeminnow population uses the limnetic zone throughout the year (Beauchamp et al. 1995). Beauchamp et al. (1995) determined that for every 1,000 large northern pikeminnows, 5,600 age-0 and age-1 *O. nerka* were consumed. Per capita consumption of juvenile *O. nerka* was 25 times less for northern pikeminnows than for cutthroat trout. However, 1,000 large (>300 mm FL) northern pikeminnow exclusively feeding on *O. nerka* in the limnetic zone could consume 620,000 fry annually (Beauchamp et al. 1995). Beauchamp et al. (1995) describe this as a worst case scenario, but they also found that all northern pikeminnow >450 mm FL within the limnetic zone exclusively fed on juvenile *O. nerka*. Beauchamp et al. (1995) concluded that predation could undermine recovery efforts if piscivore populations are sufficiently large, and that piscivore abundance must be determined in order to assess the total predation from piscivorous fish. Additional northern pikeminnow predation may be occurring within the lake near the outlet of the Ozette River, but no studies have been conducted to specifically target this area. Sockeye fry emigrating from Big River and Umbrella Creek have a brief increased susceptibility to predation from northern pikeminnow as they move through the nearshore environment during their migration to the lake’s limnetic zone

5.4.5.1.4 Cutthroat Trout (Oncorhynchus clarki)

A description of the Lake Ozette cutthroat population is included in Section 2.1.6. Cutthroat trout are known to prey upon juvenile sockeye in Lake Ozette. Earlier work conducted by Dlugokenski et al (1981) found that sockeye composed no more than 4% of cutthroat trout’s annual diet (sampling was mostly nearshore). As described above, Beauchamp et al. (1995) determined that 40% of the diet of large (>300mm FL), limnetic cutthroat trout consisted of age-0 and age-1 *O. nerka* during spring and summer months. Beauchamp et al. (1995) used a bioenergetics model to compute the annual consumption of age-0 *O.* nerka and determined that for each 1,000 cutthroat trout greater than 300 mm FL a total of 138,900 *O. nerka* fry were consumed. Beauchamp et al. (1995) estimated that the population of large (>300mm FL) cutthroat trout was between 5,000 to 10,000 fish at the time of their study and determined that this number of cutthroat trout would consume between 700,000 and 1,400,000 age-0 *O. nerka*. However, the estimated population of age-0 sockeye/kokanee at the time of their study was 1.5 to 3 times less than the estimated consumption; so caution should be used when considering these consumption estimates.

Cutthroat trout in Lake Ozette appear to be a significant predator of juvenile *O. nerka*. Much of the large discrepancy in diets described by Beauchamp and LaRiviere (1993) and Dlugokenski et al. (1981) are mostly likely a result of the different methods used to sample the lake. This degree of difference suggests that a much better understanding of the spatial and temporal distribution of large cutthroat trout in the nearshore and limnetic zones needs to be developed in order to more accurately understand and estimate predation rates. The high number of coho salmon using the lake for rearing and migration and their absence in the diet of cutthroat trout described by Beauchamp and LaRiviere (1993) is worth noting since the methods presented do not describe how salmonid species were differentiated. Dlugokenski et al. (1981) found juvenile coho in the stomachs of cutthroat trout almost half as often as sockeye were found. No sockeye eggs were documented in any of the cutthroat trout examined in either of these studies.

5.4.5.1.5 Sculpin (Cottus spp.)

Within Lake Ozette, sculpin predation is thought to be primarily on sockeye eggs during spawning and incubation. No estimate of the number of sculpin on the spawning beaches is available. The number or proportion of eggs preyed upon by sculpin on the spawning beaches is also lacking. Dlugokenski et al. (1981) examined the stomach contents of 74 sculpin and found eggs in 20. Sockeye eggs were only identified in 4 of the sculpins examined. It is unclear how many of the sculpins sampled were captured from the primary sockeye spawning grounds. In addition to egg predation on the beaches, sculpin also likely prey upon emergent fry, but this has not been documented in Ozette. No sockeye fry were found in any of the sculpin examined by Dlugokenski et al. (1981).

5.4.5.1.6 Other Native Fish Species

Other native fish species likely to prey on juvenile sockeye in Lake Ozette include juvenile coho salmon and steelhead trout. The lack of juvenile steelhead in vertical gillnet sampling conducted over a number of years suggests that steelhead rearing is limited to the tributaries. However, in 1999 over 8,200 age-0 steelhead were captured in what appeared to be a migration to the lake (from Umbrella Creek). Juvenile steelhead/rainbow trout primarily feed on aquatic insects, amphipods, aquatic worms, and fish eggs; they only occasional feed on small fish. Given the lack of spatial overlap in habitat used by juvenile sockeye and steelhead, it is assumed that steelhead predation on juvenile sockeye is very limited.

Juvenile coho salmon were also absent in vertical gillnet sampling reported in Beauchamp et al. (1995) and Dlugokenski et al. (1981). The lack of juvenile coho in vertical gillnet sampling could be a function of mesh and fish size. As described in Section 2.1.2.2.5 large numbers of age-0 coho have been observed migrating into the lake. Age-0 coho have also been captured and observed along the shoreline of the lake. Studies conducted in British Columbia and Alaska have shown that lake rearing juvenile coho can be significant predators of sockeye fry (Sandercock 1991; Ruggerone and Rogers 1992).

5.4.5.1.7 Non-Native Fish Species

Six non-native fish species have been documented in Lake Ozette: tui chub, American shad, yellow perch, largemouth bass, yellow bullhead, and brown bullhead (see Section 2.3). Tui chub, American shad, yellow bullhead, and brown bullhead were not considered to be likely predators of juvenile sockeye salmon. As described in Section 2.3.3, yellow perch were not found to consume juvenile sockeye in Lake Ozette. Only largemouth bass are considered likely predators of juvenile sockeye. Gillnet sampling conducted by Dlugokenski et al. (1981) and Beauchamp and LaRiviere (1993) yielded a total catch of only six largemouth bass. The only identifiable fish remains in the stomach contents were yellow perch. Beauchamp and LaRiviere (1993) concluded that largemouth bass and juvenile sockeye were spatially segregated during the growing season but a combination of conditions in spring could draw the bass nearshore earlier while fry and smolt pass through the littoral zone, making juvenile sockeye susceptible to predation by largemouth bass.

5.4.5.1.8 Avian Predators

No attempt to quantify avian predation rates for sockeye salmon in the lake has been conducted. Bald eagles have been observed to successfully prey upon adult sockeye on the spawning beaches. Other large raptors may also be capable of taking adult sockeye. However, bird predation on adult sockeye on the spawning beaches is thought to be rare. Predation by birds on juvenile sockeye has not been documented in the lake but likely occurs. Gearin et al. (2002) reported that osprey (*Pandion haliaetus)* were observed numerous times successfully preying upon kokanee in the vicinity of Allen's Beach. It is unclear whether these fish were kokanee or juvenile sockeye based upon the information provided in Gearin et al. (2002).

5.4.5.1.9 Terrestrial Mammals

Terrestrial mammals have not been documented preying on beach spawning sockeye in Lake Ozette. However, black bear tracks and scat were found by Gearin et al. (2002) along Allen's Beach during the RY 2000 spawning period.

5.4.5.2 Factors Affecting Predation

5.4.5.2.1 LWD Removal in Ozette River

Logjam removal in the Ozette River may have increased the efficiency and ability of harbor seals to migrate into the lake and therefore increased the number and frequency of seals using the lake during spring, fall, and winter.

5.4.5.2.2 Increases in Pinniped Population

See Sections 5.2.2.2.1 and 5.3.4.2.2 for complete discussions on regional pinniped population increases. In addition to regional increases in harbor seal abundance during the last 50 years, the utilization of Lake Ozette by harbor seals appears to be a recently developed strategy. Seals were not observed in the lake until the late 1980s (Larry Sears, personal communication, 2005; Adamire 2000). Seal predation in the lake is not thought to be a factor for the decline in Ozette sockeye abundance, but it is a factor that contributes to the population's inability to recover.

5.4.5.2.3 Abandonment of Ozette Village

See Section 5.2.2.2.2

5.4.5.2.4 Decreased Sockeye Abundance

See Section 5.2.2.2.3.

5.4.5.2.5 Changes in Lake and Fisheries Management

See Section 5.3.4.2.6

5.4.5.2.6 Introduced Species

Sockeye predation by introduced species appears to be very limited in Lake Ozette. There is very little spatial overlap between introduced piscivorous species and juvenile sockeye.

5.4.6 Disease

Lake Ozette sockeye are known to be susceptible to Infectious Hematopoietic Necrosis (IHN) virus, a fish pathogen common in most Pacific Northwest and Alaska *O. nerka* populations (Wood 1980). While this rhabdovirus has been responsible for high mortalities in juvenile sockeye from other Pacific Northwest and Alaska populations, it has not been implicated in adult salmonid pre-spawning mortalities. Disease is believed to have a low impact on adult sockeye holding in Lake Ozette. There is no direct evidence of significant disease mortality of free swimming adult sockeye in the lake. However, little is known about this life stage of Ozette sockeye, and it should be noted that in some years only a fraction of the adult fish enumerated at the weir are accounted for during lake and tributary spawning ground surveys. Radio telemetry studies conducted in 2001 were unable to detect movement after September in nearly half of the sockeye tagged, suggesting significant pre-spawning mortality. Disease has the potential to magnify the effects of predation and elevated water temperature because injured and stressed fish are more susceptible to disease. In addition, during some years when adult sockeye were trapped and their condition was recorded at the weir, a substantial number exhibited significant predator lacerations, which make holding sockeye prone to secondary infections by opportunistic infectious fish pathogens that are endemic to the watershed.

5.4.7 Tributary Hatchery Program

Hatchery practices implemented through the HGMP include measures to minimize potential disease and genetic impacts on beach spawning aggregations (see Section 3.2.3). The Umbrella Creek Hatchery "stock" poses limited genetic risk by breeding with beach spawning sockeye, since Umbrella Creek sockeye are essentially the same genetically as Olsen's Beach sockeye (NMFS 2003). Imprinting juvenile sockeye using on-station rearing in release watersheds reduces the risk of hatchery-origin sockeye straying onto beaches. Mark and recapture data collected at Olsen's and Allen's beaches indicates that few, if any, Umbrella Creek hatchery releases return to spawn on Lake Ozette beaches. For example, approximately 25% of the BY 1995 Umbrella Creek fed fry released were adipose fin clipped and in 1999, 121 adult sockeye salmon were sampled on Olsen's Beach and none were adipose fin clipped. This suggests that there was no or at least very little straying from tributary releases onto spawning beaches (MFM 2000). Carcass sampling from 2000 through 2002 at the primary sockeye spawning beaches was determined to be ineffective at monitoring the origin of sockeye based on fin clips since the condition of many carcasses precluded accurate determination of adipose fin clip status. Spawning adults returning from hatchery releases after 1999 were mass marked using thermal otolith marks, but the results from these returns are not yet available. In addition, hatchery operational protocols limiting the duration of the hatchery program limit the likelihood for Ryman-Laikre effects, should some straying to beaches occur.

5.5 LAKE OZETTE TRIBUTARIES

Lake Ozette sockeye utilize tributaries during three life history phases described in Section 3.1: adult sockeye entering, migrating, and holding (3.1.3); adult sockeye spawning and egg incubation (3.1.5); and sockeye fry emergence and dispersal (3.1.7). These life history phases in Lake Ozette tributaries are the focus of the limiting factors discussion presented in this section. Stream hydrology (4.4.1.6, 4.4.2.6, and 4.4.3.6), water quality (4.4.1.5, 4.4.2.5, and 4.4.3.5), floodplain conditions (4.4.1.1, 4.4.2.1, and 4.4.3.1), channel habitat conditions (4.4.1.3, 4.4.2.3, and 4.4.3.3), spawning gravel quality and quantity (4.4.1.4, 4.4.2.4, and 4.4.3.4), channel stability, predation, competition, and hatchery broodstock removal are all factors that have been evaluated to determine the degree to which each factor currently or in the past has limited sockeye salmon survival and productivity in Lake Ozette.

5.5.1 Watershed Hydrology

The hydrology of the Ozette Watershed has been poorly studied over the contemporary settlement period of the Ozette region. However, various lake level, climate, and hydrology data have been collected at various places in the watershed and coastal region, for different reasons, and these can be massed together to highlight the major physical patterns of the lake's hydrology. These data are presented in detail in Sections 4.2.5, 4.3.6, 4.4.1.6, 4.4.2.6, 4.4.3.6, 4.4.4.6, and 4.4.5.6. Within tributaries to Lake Ozette, the exact extent to which land use and channel modifications have affected and/or altered watershed hydrology cannot be determined with the limited data that have been collected. A summary of Lake Ozette tributary hydrology is included in Section 5.5.1.1 and a literature review of potential land use effects on stream hydrology is included in Section 5.5.1.2, with potential implications for Ozette hydrology summarized in Section 5.5.1.2.2.

5.5.1.1 Summary of Lake Ozette Tributary Hydrology

Due to the short record at the four stream gages on tributaries to Lake Ozette, only summary statistics for water year (WY) 2005 can be calculated. These data are displayed in Table 5.6. Data for Ozette River and Hoko River for WY 2005 and averages for the period of record are included as reference. The annual coefficient of variation (CV) is a measure of overall flow variability and was calculated using daily average discharge, with CV equaling the standard deviation of daily discharge divided by the annual mean daily discharge. For Ozette tributaries, these values (1.61 to 2.16) represent highly variable streamflow conditions. These CV values are similar to other perennial rain-dominated streams in the coastal Pacific Northwest, but with higher variability than other Western Washington streams with a considerable component of snow (Poff 1996). CV typically increases with a decreasing watershed area. Coefficient of variation values for Ozette River are similar to those defined by Poff (1996) as "super stable groundwater" streams with extremely stable daily flow regimes, largely due to the storage and stabilizing effect of Lake Ozette on the flow regime of Ozette River.

Table 5.6. Summary of streamflow statistics for Water Year 2005 (source: USGS and MFM unpublished streamflow data).

Stream Gage	Mean Discharge	Maximum Discharge	Max Date	Minimum Discharge	Min Date	Standard Deviation	Coefficient of Variation
Ozette River	453	1,377	1/23/2005	25.1	9/26/2005	327	0.72
Big River	92	2,258	11/24/2004	3.61	9/26/2005	162	1.61
Umbrella Creek	64	1,654	9/29/2005	2.53	8/27/2005	133	1.87
Crooked Creek	52	1,690	11/24/2004	0.66	9/10/2005	113	1.92
Coal Creek	23	731	11/24/2004	0.24	9/10/2005	58	2.16
Hoko River (WY '05)	324	8,570	11/24/2004	15.99	9/24/2005	536	1.65
Hoko River (Average)	402	8,678	na	21	na	589	1.47

For a comparison of peak flow values estimated during WY 2005, flood frequency and magnitude values were calculated using USGS Regional Regression Equations developed to estimate peak discharges for naturally flowing, unregulated streams in Washington State (Table 5.7; Sumioka et al. 1998). USGS Regional Regression Equations for the west side of the Olympic Peninsula were used to estimate peak flows for recurrence intervals from 2 to 100 years for the Ozette tributaries (Region 1 in Sumioka et al. 1998). Annual precipitation estimates were drawn from PRISM data (Table 5.7) and watershed area values were calculated for the basin area upstream of each stream gage location. Using these estimates, 2005 peak flow values in these Ozette tributaries had a return interval of between approximately 25 and 10 years, or 4% to 10% probability of occurring any one year.

Table 5.7. Estimated frequency and magnitude of peak stream discharges in Ozette tributaries.

Return Interval (Years)	Frequency	Big River	Umbrella Creek	Crooked Creek	Coal Creek
2	0.5	1,375	1,072	914	415
10	0.1	2,157	1,680	1,434	652
25	0.04	2,535	1,974	1,686	766
50	0.02	2,861	2,228	1,903	865
100	0.01	3,209	2,499	2,133	969

As stated in Section 4.2.5, Lake Ozette (7,554 acres) has an enormous impact on water storage and release up to the seasonal time step, creating a unique hydrologic signature for both Lake Ozette water levels and Ozette River discharge. Figure 5.36 displays a partial inflow-outflow hydrograph for Lake Ozette for WY 2004 and 2005. Instantaneous

(15-minute) discharge for Ozette River and Coal Creek were summed to estimate surface water outflow from the lake outlet region. Instantaneous (15-minute) discharge for Umbrella, Big River, and Crooked Creek were summed to get a partial picture of instantaneous inflow hydrology. Obviously, these data do not represent the total surface water inflow to the lake (50% of the watershed area) nor do they account for groundwater flow in or out of Lake Ozette, or evaporation from the lake itself. However, they do highlight the storage capacity of the lake, and time and magnitude delay of discharge in Ozette River.

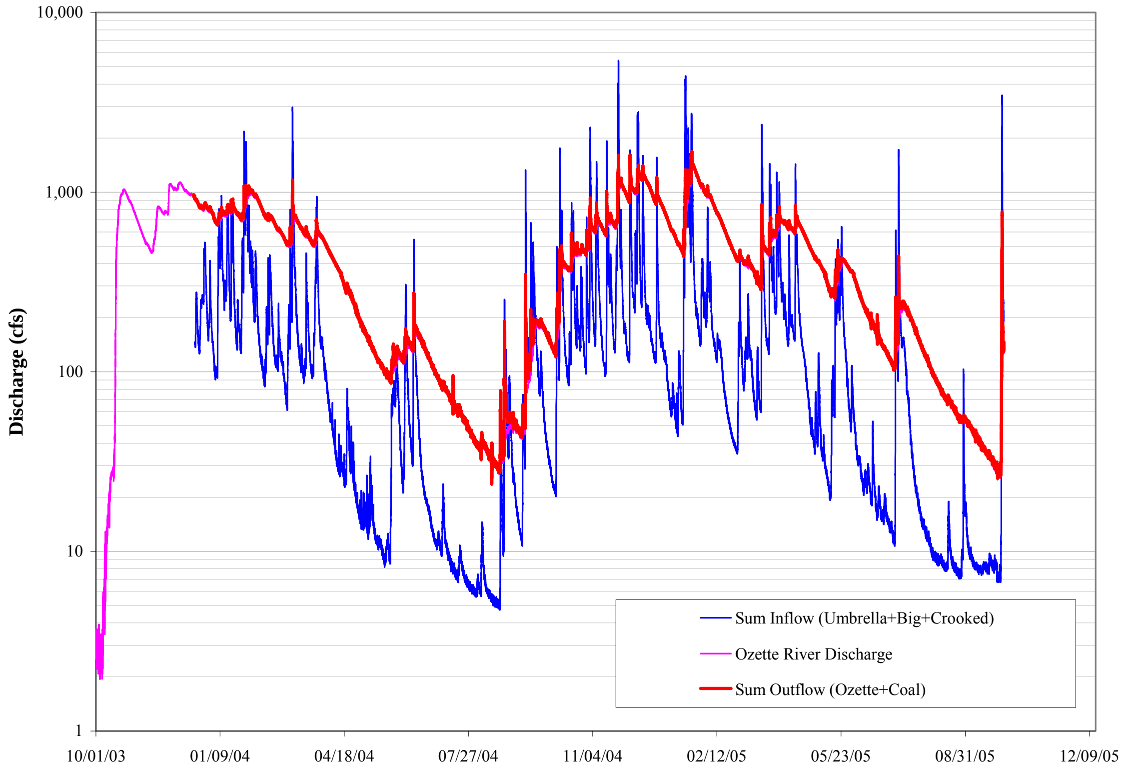

Figure 5.36. Summed partial inflow and outflow hydrographs for Lake Ozette.

5.5.1.2 Land Use Effects on Stream Hydrology

5.5.1.2.1 Literature Review

Land use can affect the hydrologic cycle by reducing infiltration capacity, changing the amount and effectiveness of vegetation cover (e.g. precipitation, interception and transpiration), changing the way water is routed to stream channels (shallow subsurface flow vs. overland flow), changing the timing and volume of runoff, and changing channel bed roughness and thus water velocity in channels and in overland flows. Alterations to these hydrologic controls can result in changes to base and peak flows. Such changes may be expected to result from a variety of land-use alterations, such as urbanization, grazing, agriculture, forest removal, road construction, and others. Increases in the magnitude and frequency of flow and flood pulse events can translate into alterations in channel morphology and pattern, and thus habitat for aquatic species. Changes in low base flow levels can alter critical dry season habitat for many aquatic species. Hundreds of studies worldwide have been conducted that relate altered water yields and flow regimes to changing land use, and generalizations can be drawn to the extent that land use in Ozette has altered hydrologic processes, but without quantification.

Obvious flow regime alterations occur following urbanization (e.g., Hollis 1975; Booth 1990; Booth and Jackson 1997) and conversion to agriculture (Wilk et al. 2001; Grip et al. 2005; Scott el al. 2005; Brown et al. 2005). Hydrologic impacts in forested regions have also been well studied, with over 166 controlled paired catchment studies worldwide (Andreassian 2004; Grip et al. 2005; Brown et al. 2005). In summary:

1. *Annual* water yield unequivocally increases for some time following a significant (10 to 25%) reduction of forest vegetation cover in a watershed (Bosch and Hewlett 1982; Bruijnzeel 1990; Stednick 1996; Sahin and Hall 1996; Bruijnzeel 1996; Robinson et al. 2003; Andreassian 2004; Jones and Post 2004; Brown et al. 2005).
2. Increases in water yield are largely a result of reduced precipitation interception and reduced transpiration (Bosch and Hewlett 1982; Brown et al. 2005).
3. The increase in water yield and flow is proportional to the percentage of the basin harvested or cleared (Bosch and Hewlett 1982; Stednick 1996; Grip et al. 2005; Brown et al. 2005).
4. Water yield changes are greater in high rainfall regions (Bosch and Hewlett 1982; Brown et al. 2005).
5. Changes in annual water yield or seasonal discharge following watershed disturbance are not necessarily static over time.
6. If the watershed is allowed to permanently revegetate to the native vegetation type with few road or other land use impact legacies, water yields will likely return to normal after a decade or decades (Stednick 1996; Jones and Grant 1996; Thomas and Megahan 1998; Jones and Post 2004; Hölscher et al. 2005; Brown et al. 2005).
7. However, if native forests are not allowed to recover through continued intensive or rotational land use activities, or if lasting legacies remain from significant permanent alterations (e.g., high road stream connectivity or permanent change to agriculture), then water yields will remain in a varying altered state (Thomas and Megahan 1998; Jones 2000; Grip et al. 2005; Brown et al. 2005).
8. Permanent changes to vegetation such as afforestation or permanent deforestation (agriculture or urbanization) have greater long-term water yield effects than disturbance and regrowth land use, but significant changes can occur nonetheless.

In watersheds where both forest harvest and significant road construction have occurred, few paired catchment studies (e.g., Jones, 2000) have been able to differentiate the hydrologic effects of roads over known impacts of forest removal. However, it is clear that the removal of the forested canopy and/or the associated presence of a road network alter hydrologic process quite differently, and can alter water production either synergistically or additively (Bowling and Lettenmaier 2001). Coe (2004) published a detailed review of the hydrologic (and sediment) impacts of forest roads with the following results:

1) Roads can dramatically alter runoff processes at the site scale through the production of hortonian overland flow (HOF) (Reid and Dunne 1984; Luce and Cundy 1994; Ziegler and Giambelluca 1997; Ziegler et al. 2000), the interception of subsurface storm flow (Megahan 1972; Wemple and Jones 2003), and stream piracy by ditches (Wemple et al. 2001).
2) Roads can intercept subsurface storm flow (LaMarche and Lettenmaier 2001; Bowling and Lettenmaier 2001; Wemple and Jones 2003) and more rapidly route water to the stream network (Wemple et al. 1996; Wemple and Jones 2003), augmenting the rising limb of stream runoff hydrographs (Wemple and Jones 2003) and reducing base flows (Bruijnzeel 1988).
3) Roads can lead to an extension of the channel network through gullying, or alteration of the channel network through stream piracy (Montgomery 1994; Wemple et al. 1996; Veldhuisen and Russell 1999; Croke and Mockler 2001).
4) Roads and road stream crossings can increase the landslide and gully frequency and thus delivery of coarse and fine sediment to the stream network (Sidle et al. 1985; Montgomery 1994; Veldhuisen and Russell 1999; Sidle and Wu 2001; Brardinoni et al. 2002).
5) Delivery of water and sediment to streams from road overland flow and ditch transport is highly variable in space, time and management intensity (Luce and Black 2001; Luce 2002), but largely dependent on cross drain spacing and road/stream connectivity at stream crossings or road induced gullies (Montgomery 1994; Wemple et al. 1996; Veldhuisen and Russell 1999; Croke and Mockler 2001; Wemple and Jones 2003; Croke et al. 2005).

In small watersheds in the Pacific Northwest with both forest harvest and road networks, *common* peak flow events (<1 to 2-year recurrence interval [RI] up to the 10-year RI) increase following forest harvest and road building in small catchments (Harr et al. 1975; Jones and Grant 1996; Thomas and Megahan 1998; Beschta et al. 2000; Jones 2000; Bowling et al. 2000; Jones and Grant 2001; Lewis et al. 2001; Jones and Post 2004). Changes in the magnitude of peak flows have been documented for events up to the 7- to 10-year RI (Lewis et al. 2001; Bowling and Lettenmaier 2001, respectively). However, the relative effect of forest harvest and roads on peak flows typically decreases as flow return interval increases beyond the 10-year RI (see below). Common peak flows (0.5- to 2-year RI [or greater]) have a major influence on channel form (Leopold 1964), as well as dominant and/or effective sediment transport (Wolman and Miller 1960; Knighton 1998; Lewis et al. 2001). Changes in the magnitude of these flows could induce profound changes to aquatic species' habitat quality and quantity. For example, if the frequency of common peak floods doubled, the geomorphic work performed on the channel would roughly double, destabilizing the channel.

Paired catchment data sets do not exist to support the hypothesis that low frequency *extreme* flow events (i.e., the 50- or 100-year recurrence interval) increase in magnitude following forest harvest or road building, and thus it is still a source of significant debate (Jones and Grant 1996; Thomas and Megahan 1998; Bowling et al. 2000). As time passes, longer term data sets in more controlled environments should shed light on these unknowns.

The cumulative effects of hydrologic alterations within large watersheds (i.e., the scale of the Ozette watershed or bigger) are relatively unknown and undocumented due to lack of long-term, controlled, paired-watershed studies at a large scale. However, numerous detailed physically based models (e.g., Distributed Hydrologic Vegetation Simulation Model [DHVSM]) have been developed to explain and control for physical processes at a large spatial scale and have proven useful in predicting changes in peak flows due to vegetation removal or forest roads. Several modeling studies (LaMarche and Lettenmaier 2001; Bowling and Lettenmaier 2001; Wigmosta and Perkins 2001; see Coe 2004) suggest that:

1) The largest changes are observed with the mean annual flood.
2) The effect of forest harvest and roads on peak flows decreases as flow return interval increases.
3) Road runoff effects are largely a result of the road interception subsurface storm flow.
4) Roads can concentrate or shorten the time to peak flow due to increased water routing efficiency.
5) Roads coupled with forest removal have an additive rather than synergistic effect.

As previously mentioned, *annual* water yield increases after forest vegetation removal, due to decreased (winter) precipitation interception and reduced (summer) transpiration. With time, forest regrowth, and no disturbance legacies (e.g., roads), these changes diminish toward background at the annual time scale.

Seasonal changes in water yield also change with time (Jones and Post 2004). With forest regrowth, winter peak flow changes are greatest during the first decade after removal. Similarly in winter rainfall-dominant regions, summer *base* flows increase for several years following forest vegetation removal, at small absolute levels but large proportional levels (Bosch and Hewlett 1982; Keppeler and Ziemer 1990; Hicks et al 1991a; Hicks et al 1991b; Jones and Post 2004; Brown et al. 2005). However, eventual regrowth of young vigorous trees results in significant increases in summer evapotranspiration when soil moisture and rainfall are at their lowest. Young regrowth trees transpire at much higher rates than to mature or old-growth forests (Andreassian 2004; Jones and Post 2004; Brown et al. 2005). Over extended periods following harvest and regrowth, summer streamflows can decline significantly below pre-harvest levels (Keppeler and Ziemer 1990; Hicks et al. 1991a; Jones and Post 2004), reducing quality of summer rearing habitat for salmonids (Hicks et al. 1991b). For long-term paired catchment studies, it has been found that relatively short rotations of young vigorous conifer stands (both native and non-native) significantly reduce summer dry season water yields and base flows at a high level proportional to undisturbed flows (Jones and Post 2004; Brown et al. 2005). In addition, for coastal watersheds where fog drip is a significant component of the summer water balance, forest canopy removal can reduce fog moisture capture and thus reduce summer water yield and base flows (Ingwersen 1985). However, local vegetation, climate, and topographic conditions will dictate the magnitude and timing of changes in seasonal water yield and base flow, with potentially offset timing impacts of different mechanisms (e.g., initial fog drip reduction followed by transpiration increase).

Generalized channel responses to changes in flow and sediment discharge are depicted in Table 5.8. Long- and short-term channel responses to flow and sediment discharge affect the quality and productivity of sockeye habitats. Relatively small changes in streamflow or sediment discharge can work cumulatively or additively with other channel and floodplain alterations, such as large woody debris removal, to decrease the inherent productivity of salmonid habitats (e.g., increased flow and decreased bed roughness results in increased bed mobility). Hydrological influences on salmonid behavior and productivity can be pronounced. General discussions of sockeye preferences and responses to flow conditions by life stage are discussed in Section 5.5.1.3.

Table 5.8. Generalized adjustment in stream geometry, pattern, and stability based on changes in flow and sediment discharge (Kellerhals and Church 1989; Knighton 1998; Downs and Gregory 2004), changes in base level (Downs and Gregory 2004), and changes in large woody debris.

	Dependent or Adjustable Factors							
	Channel Geometry			Channel Pattern		Bed and Bank Stability		
Changes in Independent Factors	**Width[1]**	**Depth**	**Slope**	**Sinuosity**	**Meander Wavelength**	**Degradation (Incision)**	**Aggradation**	**Bank Erosion**
Water discharge increases alone (e.g., deforestation)	↑	↑	↑	↓	↑	↑	↓	↑
Water discharge decreases alone (e.g., afforestation)	↓	↓	↓	↑	↓	↓	↑	↓
Sediment discharge increases alone (e.g., road building on unstable slopes)	↑	↓	↑	↓	↑	↓	↑	↑
Sediment discharge decreases alone (e.g., road & harvest BMPs)	↓	↑	↓	↑	↓	↑	↓	↓
Water and sediment discharge both increase (e.g., deforestation and road building)	↑	↕	↕	↓	↑	↕	↕	↑
Water and sediment discharge both decrease (e.g., downstream of a reservoir)	↓	↕	↕	↑	↓	↕	↕	↕
Water increases and sediment decreases (e.g., climate change toward a more humid pattern)	↕	↑	↓	↑	↕	↑	↓	↑
Water decreases and sediment increases (e.g., water supply diversion plus road building and harvest)	↕	↓	↑	↓	↕	↓	↑	↕
Base Level Increase (e.g., Higher Mean Lake Levels)	↕	↕	↓	↑	↓	↓	↑	↑
Base Level Decrease (e.g., Lower Mean Lake Levels)	↕	↕	↑	↓	↑	↑	↓	↑
Decreased large wood debris (e.g., riparian harvest)	↕	↕	↑	↓	↑	↑	↓	↕
Increased large wood debris (e.g., rehabilitation)	↕	↕	↓	↑	↓	↓	↑	↕

[1] Non-cohesive bank material (↑ = Increase; ↓ = Decrease; ↕ Either an increase or decrease)

5.5.1.2.2 Implications for Ozette Watershed Hydrology

Lack of long-term hydrologic data sets in the Ozette watershed preclude precise *quantification* of any potential changes to hydrology and flow regimes from land use and channel modifications. Speculation on the exact magnitude of changes would be unfounded. However, from the literature review above and knowledge of the processes known to affect flow regimes, *qualitative* changes can be described.

The Lake Ozette watershed has a temperate rainforest climate dominated by evergreen conifers with precipitation exceeding 100 inches (2500 mm) per year. The major watersheds draining into Lake Ozette have experienced one to two significant cycles of conifer vegetation clearing and regrowth over the last 100 years. At any given time, typically at least one third (>33%) of the watershed vegetation is in a hydrologically immature state (< 30 years old; Table 5.9). Vegetative hydrologic (im)maturity is defined as the capacity for a forest canopy to significantly intercept precipitation in the form of either rain or snow. Scientifically, this term does not apply only to rain-on-snow precipitation zones (see literature above). In the Lake Ozette watershed, current harvest rotations (~40 years) are pushing vegetation cover toward consistent immaturity (~75%). A moderately dense network of unpaved roads has been constructed over the last 60 years, with road densities greater than 6 mi/mi^2 on non-federal forested lands (Table 5.9).

Table 5.9. Sub-basin summary of road density, watershed disturbance, and hydrologic immaturity. (source: Ritchie, unpublished data; MFM, unpublished data)

Sub-Basin	**Basin Area** (mi^2)	**Road Density** ($mi./mi^2$ [year])	**Watershed Disturbance** (% of basin logged at least once by 2003)	**Hydrologic Immaturity** (% of basin vegetation less than 25 years old [circa 1979-2004])
Coal Creek	4.6	6.07 (2006)	98%	34.1%
Umbrella Creek	10.6	7.44 (2006)	99%	57.3%
Big River (All)	22.8	4.60 (1994) 6.43 (2006)	98%	34.1%
Big River (Upper)	8.43	6.50 (2006)	98%	45.4%
Crooked Creek	12.2	5.20 (1994)	90%	58.5%

NOAA's Matrix of Pathways and Indicators (NMFS 1996), provides qualitative ratings for watershed conditions such as road density and hydrologic condition. Watersheds with road densities less than 2 mi/mi^2 are considered *properly functioning*, while watersheds with road densities greater than 3 mi/mi^2 are considered *not properly functioning.* Road densities greater than 3 mi/mi^2 are considered *not properly functioning* because of significant (e.g., 20-25%) increases in drainage network density due to roads. NMFS (1996) does not provide thresholds for percent vegetative cover in hydrologic immaturity. However, the U.S. Forest Service (USDA 1993) combines road density and hydrologic immaturity to develop a watershed risk rating (Figure 5.37). This rating uses a threshold of 30% hydrologic immaturity to indicate potential watershed impairment. These indicators and thresholds are generic and "actual" impacts depend on watershed-specific conditions. However, these indicators do suggest the relative level of risk to resources from land use activities.

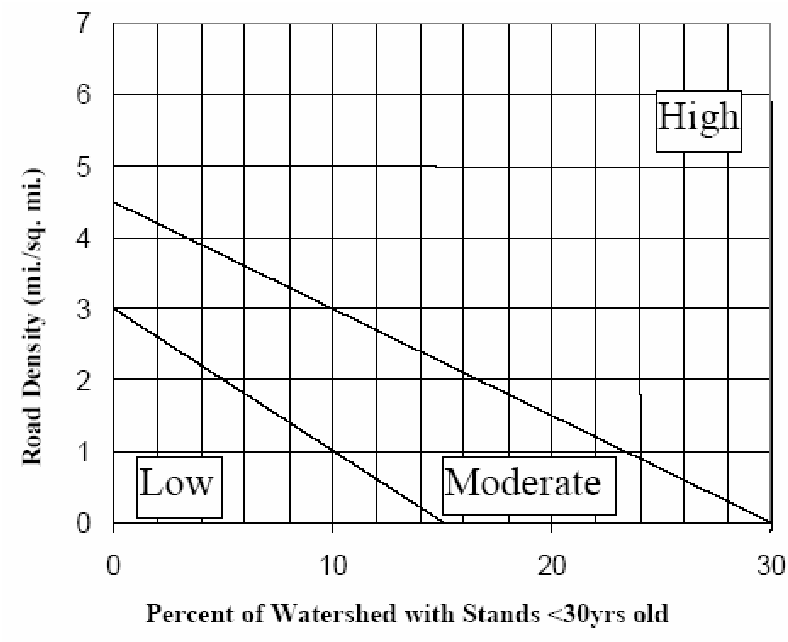

Figure 5.37. Watershed risk rating (source: USDA 1993).

If the above indicators are used as qualitative baseline for watershed hydrologic functionality, then every major sockeye sub-basin in Ozette would be rated as *not properly functioning* and at a high risk of resource impact (Table 5.9). If more conservative thresholds were used, such as 5 mi/mi^2 of road and > 50% hydrologic immaturity, then several Ozette sub-basins would still be rated as *not properly functional, at risk, or very likely impaired* (i.e., Umbrella Creek and Crooked Creek). These ratings will change when shorter harvest rotations alter the percentage of basin area in hydrologic immaturity.

From the literature cited above and local observation on the ground of altered vegetative patterns and drainage networks, a conservative assumption would be that land use has very likely impaired Ozette tributary hydrology, but the exact magnitude of change is unknown. From hundreds of controlled studies around the world and in the Pacific Northwest, every watershed that has experienced land use changes as significant as Ozette (>33% vegetative immaturity plus > 4 mi/mi^2 of road building) has experienced some changes in water yield and flow regime. In fact, out of all worldwide controlled studies, conifer forests in high precipitation zones such as Ozette experience the largest absolute and relative changes to flow regimes from timber harvest and regrowth (Bosch and Hewlett 1982; Brown et al. 2005

Since forest integrity and land use have been permanently changed in the Ozette watershed from old-growth conditions, water yield and flow regimes would not be expected to be able to fully recover to their original state. In Pacific Coast conifer watersheds similar to Ozette, common peak flow events (<1 to 2-year recurrence interval up to the 10-year RI) increase following forest harvest and road building. However, the relative change and thus significance of this potential increase is unknown in Ozette (e.g., 5%, or 50% increase in the magnitude of a 2-year event). Large peak flood events (i.e., the 50- or 100-year recurrence interval) would not be expected to be influenced by land use change in Ozette.

Initially upon conversion from old-growth conifer to commercial plantation conifer in the Ozette watershed, base flow (summer) water yields would be expected to increase for several years. Exceptions might occur for streams located within the coastal fog belt, where canopy removal could reduce summer base flow contributions from fog drip (e.g., Coal and Umbrella Creek). However, over the long term with permanent conversion to plantation conifer, base flow (summer) water yields would be expected to decline below pre-harvest conditions due to the vigorous dry season (summer) growth of young plantation conifer trees (<40 years old) and reduced winter water storage from timber harvest and roads. However, again the relative change and thus potential significance of long-term decreased base flows is unknown in Ozette (e.g., 5% or 50% decrease in summer 7-day low flow). For additional factors potentially affecting base flow, see Section 5.5.1.4.

Obviously, quantitative hydrology remains a data gap in Ozette. Due to the ubiquitous nature of land use change in Ozette, no controlled basins are currently available locally to test the scientific principles outlined above. However, future research could take advantage of modern watershed hydrology modeling to help quantify a range of likely scenarios of how land use has affected water yields and flow regimes in Ozette. For example, a distributed watershed model (Distributed Hydrology Soil Vegetation Model [DHSVM] or similar) could be developed to simulate historical, current, and future lake inflow hydrology as a result of changes in land use, vegetation cover, drainage density, roads, and soil water storage. This model could be coupled with the unsteady HECRAS hydraulic model of the Ozette River (Herrera 2005) to develop a fully encompassing watershed hydraulic and hydrological model of Ozette that incorporates lake inflow, outflow, and evaporation (i.e., a water budget). From a development like this, the range of potential impacts on sockeye salmon survival in both tributaries and the lake could be more deeply understood.

5.5.1.3 Tributary Streamflow and Sockeye Survival

Beyond the physical influences streamflows have on stream channels (see Sections 5.5.1.2 and 5.5.4.3), high flows (natural or anthropogenically modified) can also significantly alter the behavior of salmonids and their ability to access certain habitats. One of the principal controls of available spawning habitat in gravel bedded rivers is streamflow. Streamflow regulates the quantity of gravel area covered by water and the velocity and depth of spawning gravel. Each salmonid species has a range of preferred spawning conditions, which include substrate size, water velocity, and depth (Bjornn and Reiser 1991).

Bortleson and Dion (1979) evaluated Ozette tributary spawning habitat availability based on preferred velocities of 1 to 2.5 ft/sec and depth greater than 0.5 ft to determine the range of preferred flows. Bortleson and Dion (1981) report the preferred stream discharge in Big River and Umbrella Creek as 154±74 and 85±41 cfs respectively. Figure 5.38 depicts Umbrella Creek average daily streamflow (cfs) and the preferred streamflow conditions during spawning based on analysis conducted by Bortleson and Dion (1979). Prolonged dry periods in early fall resulting in low streamflows can delay the migration of adult sockeye into Ozette tributaries. Low flows in 2002 resulted in the delay of sockeye entering Umbrella Creek; the first sockeye did not migrate upstream of RM 0.8 until November 13, 2002. Delayed migration may make adult sockeye more prone to predation in lower Umbrella Creek or in holding areas off the confluence in the lake, as well as affect fitness and overall spawning success.

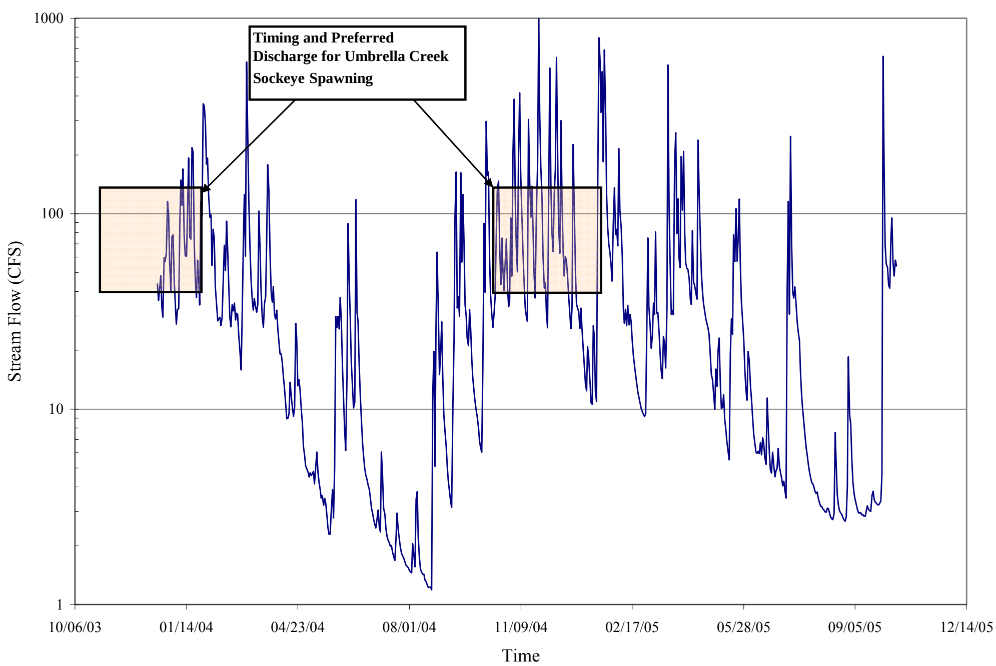

Figure 5.38. Umbrella Creek average daily stream discharge and sockeye spawn timing and preferred flow conditions (modified from Bortleson and Dion 1979)

Extended periods of high streamflow (caused by high storm frequency and intensity) can shift the distribution of spawning from "normal" positions in the channel to the margins where velocity and depth more closely match the preferred conditions (e.g., Ames and Beecher 2001). When this occurs and is followed by normal or low flows, eggs in redds constructed along the channel margins or in less optimal positions in the channel may experience increased mortality during incubation due to redd dewatering, or fine sediment intrusion. Extended dry periods yielding low flows following more or less "normal" flow conditions can produce the same effect with respect to redd dewatering. Conversely, below average flows during spawning that force fish to spawn low in the channel (thalweg), followed by large flood events, can increase the susceptibility to redd scour (Ames and Beecher 2001; Lapointe et al. 2000; see Section 5.5.4.3). Thus, for sockeye spawning in compound channels under variable discharge regimes, there is a trade off between spawning low in the cross-section and risking scour mortality versus spawning high along channel margins and risking redd desiccation or sedimentation related mortality. Figure 5.39 illustrates dewatered redds in Big River during week 9 of the 2005/2006 spawning season, after a period of minimal rainfall and low streamflow. Figure 5.40 shows the Big River discharge hydrograph for the 16-week sockeye spawning season during 2005/2006. Figure 5.41 displays the same discharge data, but as discharge exceedence curves for grouped two-week periods covering the same spawning season. Sockeye salmon spawned throughout the period shown, but peak spawning occurred in November (weeks 5 to 10) during moderate discharges. Following this peak spawning period, discharge dropped precipitously due to an abnormally long period without significant rainfall (weeks 11 and 12). Weeks 11 and 12 had median (50 percentile) discharges an order of magnitude less than during earlier or later periods.

Dozens of redds created during weeks 5 to 10 became completely dewatered to depth and exposed to low ambient-air relative humidity for a two-week period (weeks 11 and 12), especially in compound channel cross-sections with a distinct thalweg and lateral bar deposits. Furthermore, redds created high along channel margins also experienced significant fine sediment deposition following January flood events (weeks 15 and 16) with turbidity values over 500 NTU and suspended sediment concentrations over 1000 mg/L. Conversely, fish that spawned very low in the channel during weeks 11 and 12 were at the greatest risk of bed disturbance during early January (weeks 15 and 16). Fish that spawned in middle elevation points in the cross-section (weeks 8, 9, 10) and survived dewatering due to hyporheic flow maintenance, were in the best location to avoid subsequent high discharge disturbances. This example illustrates the tradeoffs between spawning low in a cross-section and avoiding dewatering, compared to spawning higher in the cross-section and avoiding bedload transport and scour. In summary, high streamflow variability during the sockeye spawning and incubation period can result in reduced probabilities of successful egg to fry survival. In relatively flashy rain-dominated watersheds on the Olympic Peninsula, flow variability is a survival factor that salmonids have naturally had to contend with. However, human land use practices (e.g., forestry and agriculture) can alter flow regimes and increase the variability of flows during the incubation period (see Section 5.5.1.2), by reducing water retention and base flows and increasing common (<2-year RI) peak flows.

Figure 5.39. Example of dewatered and partially dewatered sockeye salmon redds in Big River during week 9 (source: MFM photo archives).

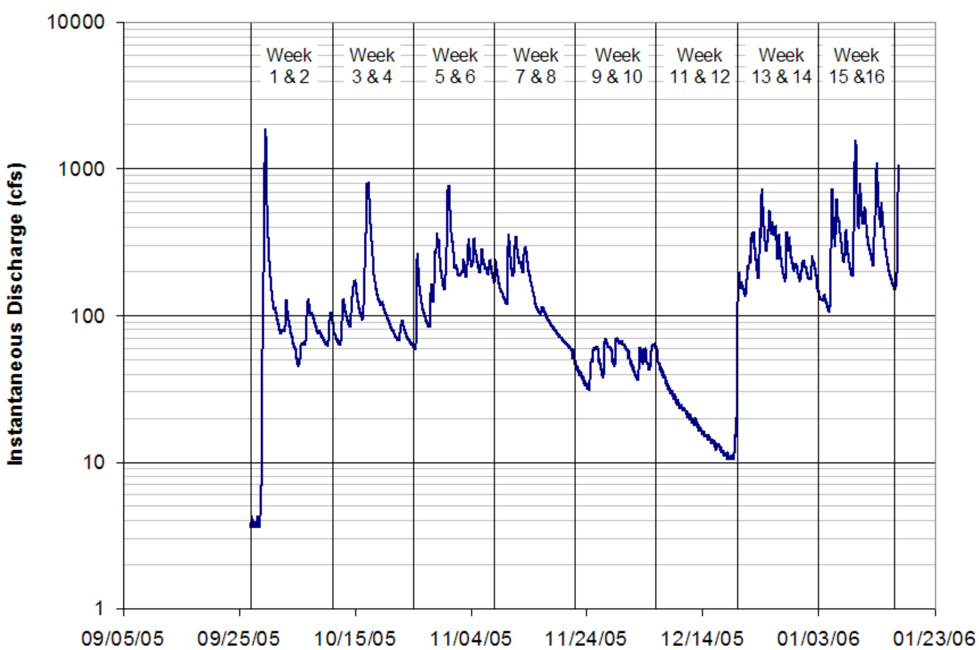

Figure 5.40. Big River hydrograph during water year 2006 sockeye spawning period (source: MFM provisional streamflow data).

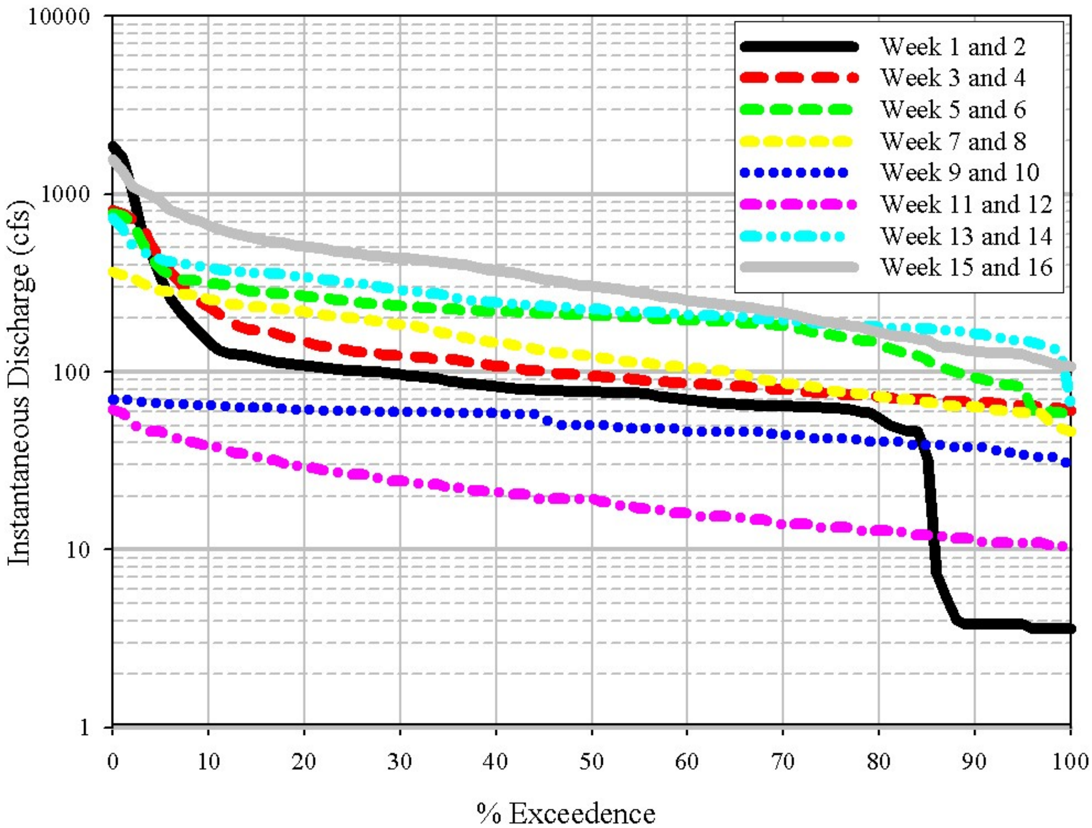

Figure 5.41. Big River flow duration curves over the 16-week spawning period for sockeye salmon, water year 2006. Weeks 1 and 2 (27-Sep to 10-Oct); Weeks 3 and 4 (11 Oct to 24 Oct); Weeks 5 and 6 (25 Oct to 7 Nov), Weeks 7 and 8 (8 Nov to 21 Nov); Weeks 9 and 10 (22 Nov to 5 Dec); Weeks 11 and 12 (6 Dec to 19 Dec); Weeks 13 and 14 (20 Dec to 2 Jan); Weeks 15 and 16 (3 Jan to 16 Jan). Source data based on MFM provisional streamflow data.

High or higher than average flows during spring may be beneficial to the offspring of tributary spawners. It is assumed that higher flows and increased stream velocities increase the rate of emigration into the lake, decreasing exposure to predation. Tabor et al. (1998) suggested that predation rates were low in most sites studied in the Cedar River during the 1997 fry emigration to Lake Washington because of high streamflow. They found that at mid-channel sites, where velocities were moderate or high, little predation of sockeye salmon was observed. They found the highest levels of predation in side-channels and outlet channels to off-channel habitats where velocities were lowest. However, no local data exist in the Ozette watershed to quantitatively define the exact magnitude of hydrologic changes or variability due to land use. Thus any increased impact to sockeye survival is an unknown and remains a data gap.

5.5.1.4 Potential Effects of LWD Removal and Channel Alterations on Streamflow

Channel-floodplain connectivity along Big River and other tributaries (Umbrella, Crooked, etc) has been altered as a result of wood roughness removal (Kramer 1953), channelization caused by roads, and channel incision (Herrera 2006). Beyond the habitat impacts of these geomorphic changes, significant hydrological impacts have likely occurred. Floodplains are significant storage zones of water from multiple sources, including overbank river and tributary water, groundwater, hillslope runoff, and direct precipitation (Mertes 1997; 2000). Floodplain water storage, both on the surface and in subsurface pore spaces, can significantly reduce peak discharges (Whiting and Pomeranets 1997; Mertes 2000) and can significantly increase baseflow recharge during dry periods (Kondolf et al. 1987; Whiting and Pomeranets 1997; Whiting 2002; Fleckenstein et al. 2004). Altering the inundation frequency and magnitude of floodplains (e.g., through channelization or roughness reductions) can alter the effectiveness of floodplains at storing water both on the surface and subsurface (Mertes 2000). Channel incision can lower the ambient water table and more effectively drain floodplains and associated wetlands, as can significant groundwater pumping (Kondolf et al. 1987; Fleckenstein et al. 2004).

Golder (2005) investigated the potential storage capacity of the Big River floodplain along 5 miles of Big River. Assuming a floodplain area of 2.5 square miles (5 miles long by ½ mile wide), a subsurface aquifer porosity of 20%, and a workable unsaturated zone thickness of 5 feet, over 69 million cubic feet of water could be stored in the current unsaturated zone of Big River. If this storage volume was full at the beginning of summer and released over a 90-day period (say June 15 to Sept 15) at a constant rate, base flows would be theoretically augmented by 9 cubic feet per second (cfs). In reality, this augmentation rate would change over time, with larger (than 9 cfs) inputs earlier in the 90-day period and smaller inputs (less than 9 cfs) during the end of the period (Golder 2005). While these estimates provide a maximum benefit of floodplain storage, they do indicate the importance of these areas for streamflow maintenance.

5.5.2 Water Quality

A complete review of water quality data for Ozette sockeye tributaries is included in Sections 4.4.1.5, 4.4.2.5, and 4.4.3.5. Meyer and Brenkman (2001) point out that DO, pH, and stream temperature failed to meet state water quality standards in some of the Ozette tributaries during their sampling period and voiced additional concern over high turbidity levels in Umbrella Creek and Big River. Jacobs et al. (1996) concluded that no obvious problems for sockeye salmon appear evident based on pH, DO, and conductivity. Jacobs et al. (1996) suggests that water temperatures in Ozette tributaries do not directly jeopardize sockeye salmon survival because the periods of high stream temperature and sockeye presence do not coincide. A comparison of recent (1990-2005) temperature data from Umbrella Creek, Big River and Crooked Creek indicate there is very little over lap between natural-origin sockeye and stream temperatures greater than 16°C (Figure 5.42).

The only water quality attributes measured during the period that sockeye utilize tributaries that may act directly to limit sockeye salmon survival and productivity are pH and turbidity. Meyer and Brenkman (2001) suggested that the low pH levels observed in Coal Creek and Crooked Creek are below values at which salmonid egg development and hatching success can be affected. In laboratory trials, Ikuta et al. (1999) found that at pH 5.8 kokanee homing behavior was completely inhibited and at pH 6.0 spawning behavior was inhibited. Recent water quality data sampling work conducted by MFM showed very similar results to those found by Meyer and Brenkman for temperature, pH, turbidity, and DO. No specific investigation of pH levels and salmonid productivity have been conducted in Ozette tributaries. Most of the low pH levels recorded by Meyer and Brenkman (2001) were during high flow events in Coal and Crooked Creeks. MFM pH data collected during the sockeye spawning period in Umbrella Creek and Big River averaged 6.5 and 6.6 respectively.

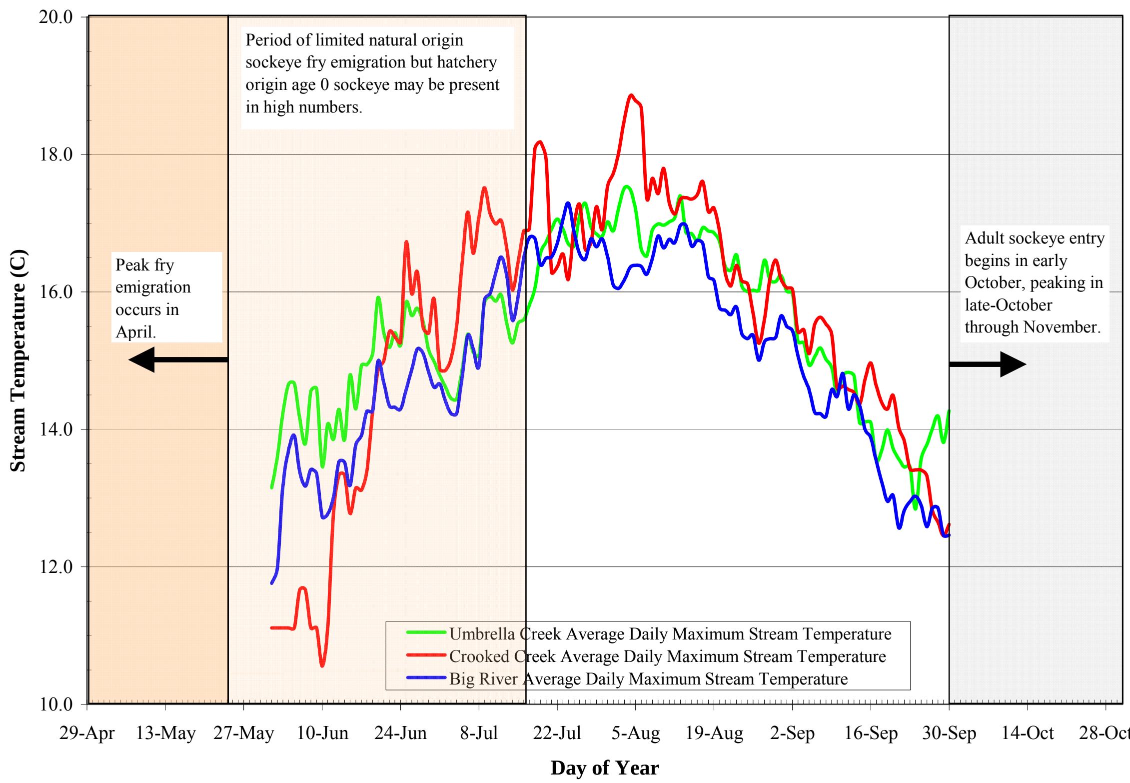

Figure 5.42. Period of sockeye salmon fry and adult utilization in Lake Ozette tributaries contrasted with annual average daily maximum stream temperature in lower Umbrella Creek (n=9), Big River (RM 1.7-4.8; n=4), and lower Crooked Creek (n=4).

High levels of turbidity in Umbrella Creek and Big River have been documented and/or described by Meyer and Brenkman (2001), Jacobs et al. (1996), Smith (2000), and MFM (2000). While turbidity data are quite limited for Ozette tributaries, it was still possible to compare turbidity levels in multiple stream systems for several storm events. Figure 5.43 depicts recorded peak turbidity (NTUs) for Big River and Coal, Umbrella, Crooked, and Siwash Creeks during 21 small to medium scale storm events. Coal Creek, Big River, and Umbrella Creek all show higher turbidity levels during all storm events where data exist, similar to results found by Meyer and Brenkman (2001). In the Ozette watershed, tributary turbidity and SSC are well correlated, indicating that turbidity is a decent surrogate for SSC (Figure 4.82; see also Section 4.4.4.5.1).

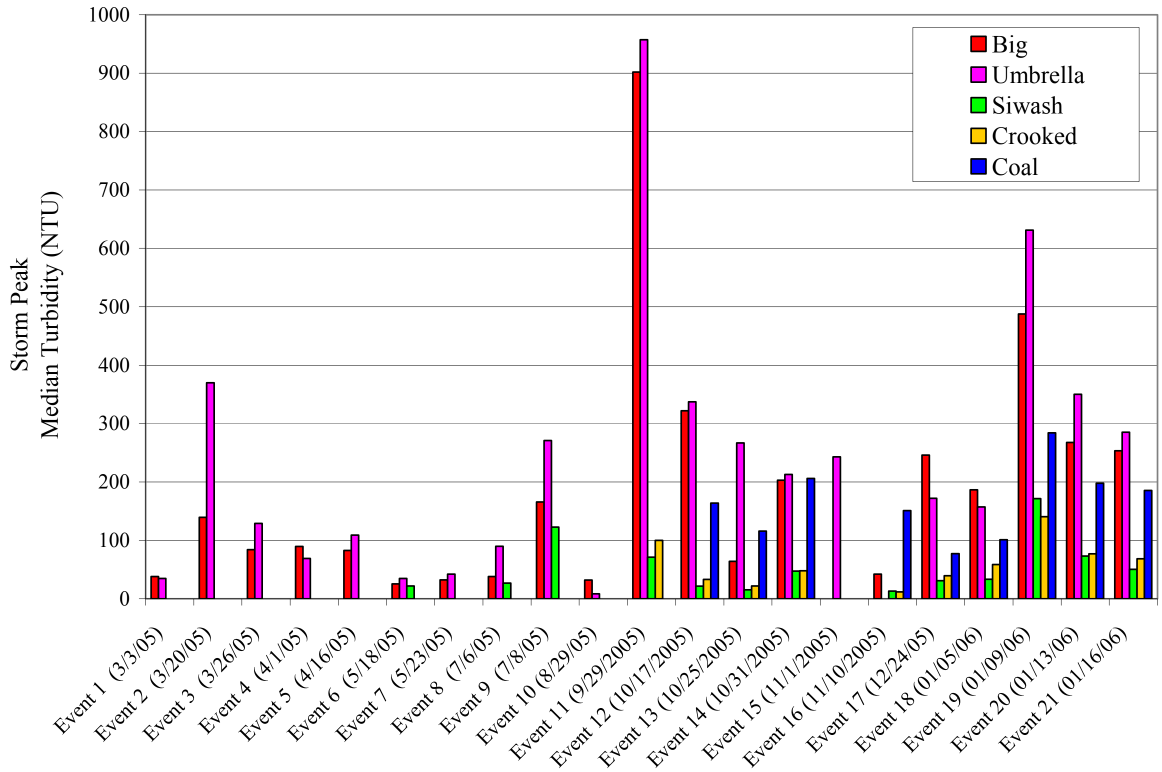

Figure 5.43. Peak turbidity (NTUs) for Big River and Coal, Umbrella, Crooked, and Siwash Creeks during 21 small to large scale storm events (source: MFM, unpublished turbidity data).

Elevated turbidity levels can directly affect fish survival through altered behavioral changes, such as reduced visual sight distance, prey feeding, and predator avoidance. However, the suspended particulate material in the water, for which turbidity is a surrogate, is the main direct and indirect factor impacting fish and biota. Thus, both SSC and turbidity have been studied in detail in relation to fish survival, habitat integrity, and stream health.

Elevated turbidity and SSC have numerous negative impacts on fish and other stream biota, including behavioral effects, physiological effects, and habitat effects. Behavior effects of turbidity and SSC on fish include changes in foraging, predation, avoidance, territoriality, homing and migration (Waters 1995; Bash et al. 2001). Physiological effects include gill trauma and damage, reduced respiration, changes in blood physiology due to stress, disruption of osmoregulation during salmonid smolt migration, and reduced oxygen transfer to incubating eggs in gravel affected by sedimentation (Waters 1995; Bash et al. 2001). Habitat impacts include changes in the abundance and diversity of prey (e.g., invertebrates and mircofauna); altered primary production (i.e., photosynthesis: Waters 1995; Bash et al. 2001; Suttle et al. 2004); changes in temperature regimes (Waters 1995); increased channel sedimentation (Everest et al. 1987); increased gravel and cobble embeddedness (Bash et al. 2001); reduced gravel permeability, intergravel water flow and oxygen transfer (i.e., hyporheic flow); reduced gravel porosity and emergence success (McNeil and Ahnell 1964; Everest et al. 1987; McHenry et al. 1994; Reiser 1998); reduced pool habitat volume and habitat complexity (Lisle and Hilton 1999); and increased bedload mobility and scour depths (Lisle et al. 2000).

Using detailed SSC data in correlation with continuous turbidity data from Coal Creek, the potential effects of suspended sediment on adult and juvenile sockeye salmon physiology and behavior were assessed in comparison to empirical severity models in the literature (Newcombe and Jensen 1996). These data are presented in Section 5.3.3.2. Due to the significantly higher turbidity values in tributaries, such as Big River and Umbrella Creek (Figure 5.43), it is likely that turbidity and SSC have greater impact on sockeye physiology and behavior (adults and juveniles) in other tributaries than estimated for Coal Creek near the confluence of Ozette River. Furthermore, the frequency of turbidity events is significantly higher during the period that sockeye inhabit Ozette tributaries versus the Ozette River. Figure 5.44 depicts the total number of hours that turbidity exceeded any given NTU value. Future turbidity and suspended sediment data collection in Umbrella Creek and Big River will be needed to fully evaluate the potential effects of turbidity and SSC in tributaries.

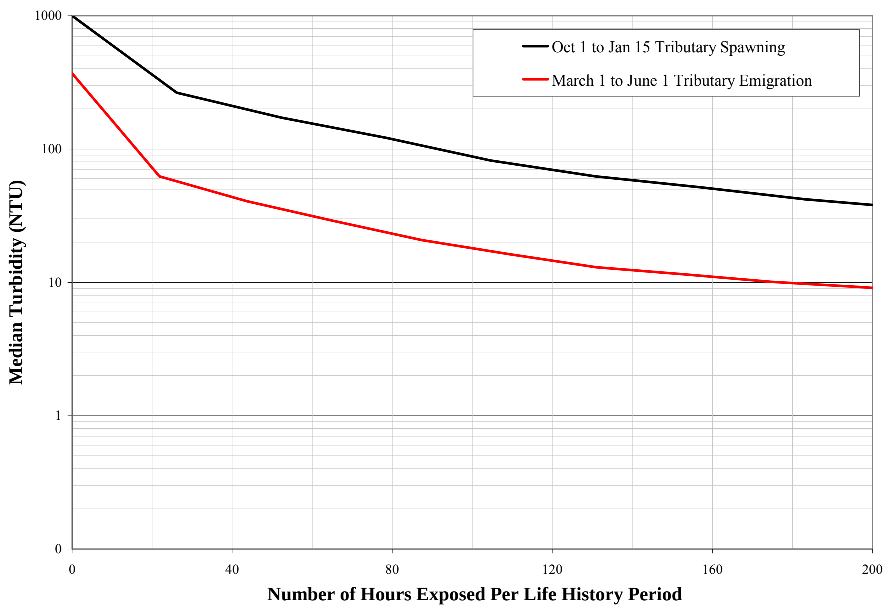

Figure 5.44. Duration of time (hours) that turbidity exceeded a given NTU during the spawning or emigration period (Umbrella Creek, WY 2006; source: MFM, unpublished data).

5.5.3 Floodplain Conditions

Descriptions of floodplain conditions in Big River, Umbrella Creek, and Crooked Creek are included in Sections 4.4.2.1, 4.4.1.1, and 4.4.3.1. Although no formal floodplain assessment has been conducted in the watershed, general observations of floodplain conditions seem to indicate better conditions exist in Umbrella and Crooked Creeks than in Big River. Herrera (2006) notes that widespread channel degradation was observed during their field surveys and that all tributaries showed some degree of channel incision, decreased channel-floodplain connectivity, high sediment loading, limited LWD loading, and diminished future LWD recruitment potential. Herrera (2006) determined that the majority of sediment production and greatest channel incision and channel instability were in Big River.

It is difficult to directly link floodplain conditions to limitations on sockeye salmon productivity. However, channel-floodplain connectivity plays an important role in sediment transport and storage dynamics, as well as in regulating hydraulic and hydrologic processes. Floodplains are significant storage zones of water from multiple sources, including overbank river and tributary water, groundwater, hillslope runoff, and direct precipitation (Mertes 1997; 2000). As channels incise and become disconnected from their floodplains, several responses can be expected, including lowering of water table, decreased bank stability, increased sediment transport, increased stream energy, increased water depths at flood stage, and general channel instability. Cumulatively, altered floodplain processes coupled with other changes in watershed processes, such as increased sediment and water production and delivery to the channel network, can result in increased fine sediment levels, decreased bed stability, and increased sediment delivery to the lake. Herrera (2006) suggest that channel incision and floodplain disconnection indicate that fine sediment transport of instream sediment has increased relative to historical levels and has the potential to degrade lakeshore habitats.

Other floodplain alterations such as stream adjacent roads, bank armoring, and wood removal can have localized direct effects on habitat suitability and stability. Herrera (2006) suggests that LWD loading appears to influence the magnitude of channel incision and channel-floodplain connectivity in Ozette tributaries. Herrera (2006) found that most areas with poor channel-floodplain connectivity were most often associated with poor wood loading conditions and that where good wood loading conditions were present, fair to good channel-floodplain connectivity still existed. Maintenance or reestablishment of channel-floodplain connectivity in Ozette tributaries is critical to recovery of pre-disturbance channel processes and habitat regulating mechanisms. Some areas where channels have become disconnected from their floodplains may recover naturally over time, as forests grow, LWD is recruited to the channel network, and channels evolve toward a more stable width, depth and slope configuration (Herrera 2006). However, many areas either have no adjacent riparian forests due to conversion to pasture, residences, and/or roads, or have poor wood recruitment potential. Section 4.4.2.1 and Figure 4.55 illustrate the type and location of floodplain alterations in Big River. Without some form of intervention, channel and habitat conditions adjacent to these impacted floodplains are expected to continue to degrade and result in lower quality sockeye salmon habitat in the future.

5.5.4 Channel Habitat Conditions

5.5.4.1 Instream LWD and Pool Habitat Conditions

A comprehensive inventory of habitat conditions in tributaries to Lake Ozette and the Ozette River can be found in Haggerty and Ritchie (2004). Instream LWD conditions are described in detail for Umbrella Creek (Section 4.4.1.3), Big River (Section 4.4.2.3), Crooked Creek (Section 4.4.3.3), Coal Creek (Section 4.4.4.3), and Siwash Creek (Section 4.4.5.3). Haggerty and Ritchie (2004) evaluated LWD data at the segment level for the Ozette tributaries based upon LWD frequency (pieces/100m and pieces/BFW), key and large (>50cm diameter) piece frequency, and the percent of pieces of LWD classified as large (Figure 5.45). They found pieces per 100 m rated good in only 25% of the habitat segments surveyed and that 44% and 32% of the segments rated fair and poor, respectively. Key pieces/BFW rated good in only 1% of the segments and fair in 19%; just over 80% of the segments rated poor (Haggerty and Ritchie 2004). LWD > 50cm diameter/100 m rated good in 23% of the segments and fair in 39%; the remaining 38% of segments rated poor. Haggerty and Ritchie (2004) point out an interesting relationship in the Big River mainstem where high frequency, large diameter pieces of LWD occur in three discrete forested reaches between agricultural land, where LWD abundance is much lower. The highest LWD piece count/100 m was found in Coal Creek and lowest was found in Big River.

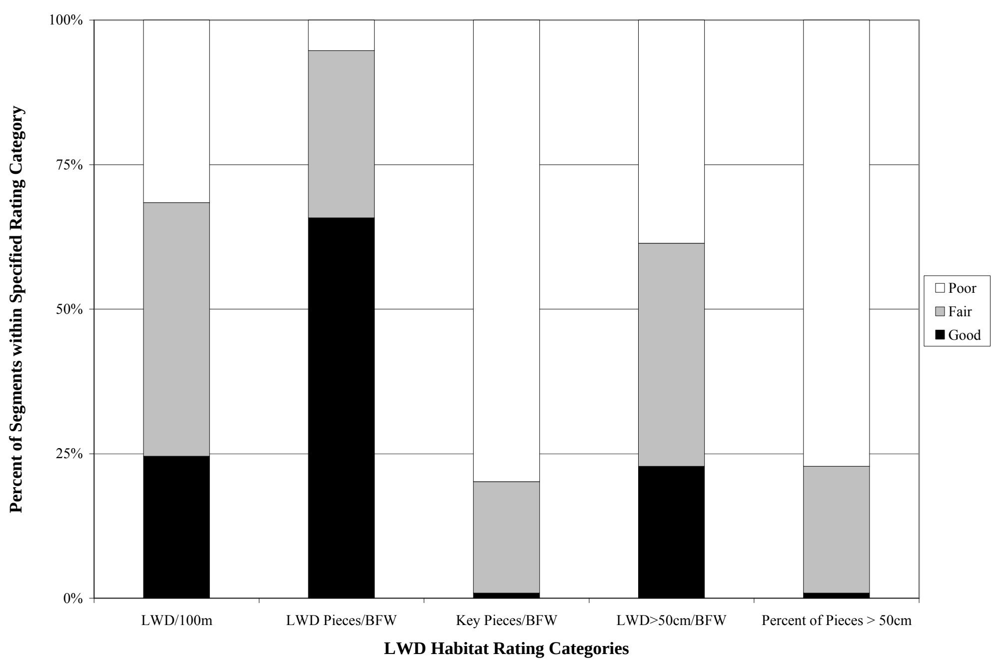

Figure 5.45. Ozette watershed tributary segment level LWD habitat ratings (source data from Haggerty and Ritchie 2004).

5.5.4.1.1 LWD and Instream Habitat Complexity

The influence and importance of LWD on channel dynamics and stability, as well as fish habitat quality, is one of the most studied aspects of forest and stream interaction (Maser and Sedell 1994; Gregory et al. 2003; Montgomery and Piegay 2003). The ability of LWD to enhance fish habitat is well documented (Grette 1985; Bisson et al. 1987; Cederholm et al. 1997). Large woody debris has been shown to affect pool formation (Bilby and Ward 1989; Bilby and Ward 1991; Beechie and Sibley 1997), pool size, depth and habitat quality (Haggerty and Ritchie 2004), bed stability (Bilby 1984; Smith et al. 1993), sediment accumulation and bar formation (Lisle 1986; Bilby and Ward 1989), sediment size (texture) (Buffington and Montgomery 1999b), as well as to sort and accumulate fine sediment and organic debris (Bilby and Ward 1989). All of these factors are thought to significantly influence the physical quality and complexity of fish habitat. Large woody debris can also act to provide cover and create channel complexity, which is critically important to some salmonid species such as coho (Nickelson et al. 1992).

Large woody debris can have profound hydraulic and hydrological effects on channels and floodplains (see Sections 5.5.1.4 and 5.5.4.1.2). Logjams and LWD can also act to store and stabilize sediment within the channel (see Section 5.5.4.2.2 and 5.5.4.1.3). The ability of LWD to form pools and instream habitat complexity is also important. The role of LWD in stabilizing channels, storing spawning gravels, and maintaining floodplain connectivity is thought to be critical to successful sockeye spawning in Big River. Also important to sockeye salmon are the high quality pool habitats formed and maintained by LWD. Haggerty and Ritchie (2004) summarized pool attributes from 1,963 pools surveyed in Ozette tributaries and found that average maximum pool depth was strongly correlated with pool forming LWD size class, as was the percent by length of pools classified as having moderate to good woody cover (Figure 5.46). Pools formed by LWD >50cm diameter and greater than 16 feet in length were found to be 53% deeper than pools formed by LWD <50 cm in diameter and free- or bed-formed pools. Key and large+ piece-formed pools are 53% deeper than medium, small, and free-formed pools. The relationship between piece size and pool depth and cover illustrates the important influence of large LWD (> 50cm diameter) on pool quality.

Haggerty and Ritchie (2004) found that the quantity of pool habitat is also strongly influenced by LWD piece size (Figure 5.47). For example, even though key-sized LWD comprised only 593 of 30,289 inventoried pieces of LWD (2%), it formed 17% of the inventoried pool habitat by length and LWD pieces > 50 cm in diameter formed 76% of the LWD-formed pool habitat, even though these combined size classes represent only 18% (5,520 pieces) of the inventoried LWD. Small and medium-sized LWD make up 82% of the inventoried LWD (24,769 pieces), but form only 24% of the LWD-formed pool habitat. The importance of pool habitat for sockeye salmon is thought to primarily be limited to pre-spawning holding. The frequency of holding pools was evaluated throughout the tributary spawning range of Ozette sockeye and does not appear to be a significant limiting factor. The frequency of holding pools in general is thought to have declined, but sufficient numbers of holding pools exist in stream areas utilized by holding sockeye.

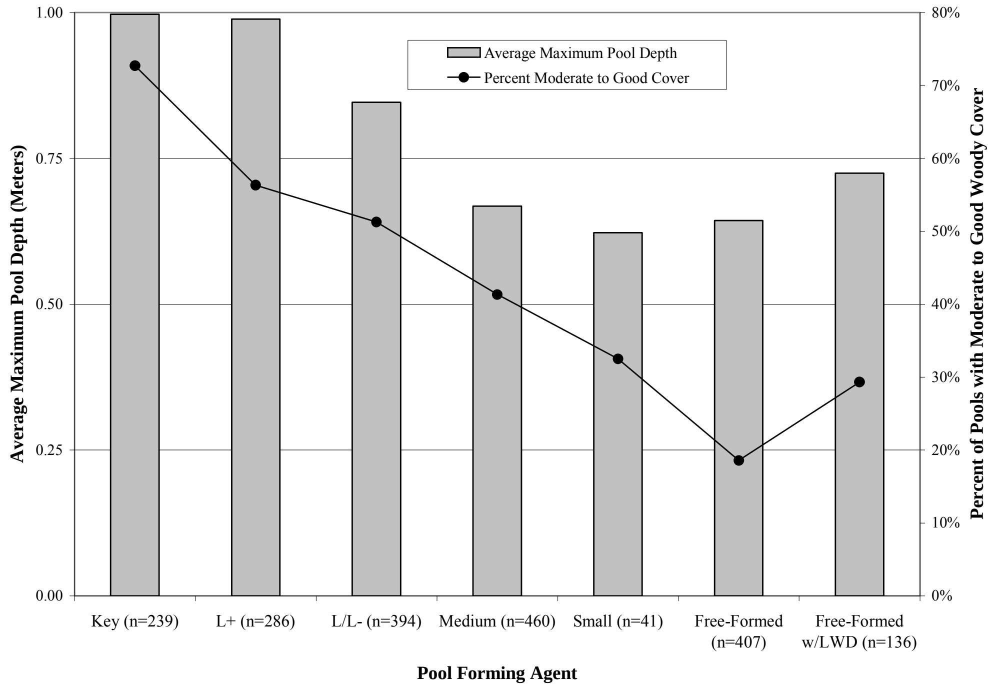

Figure 5.46. Relationship between primary pool forming agent and pool depth and cover for Ozette tributaries (source: Haggerty and Ritchie 2004).

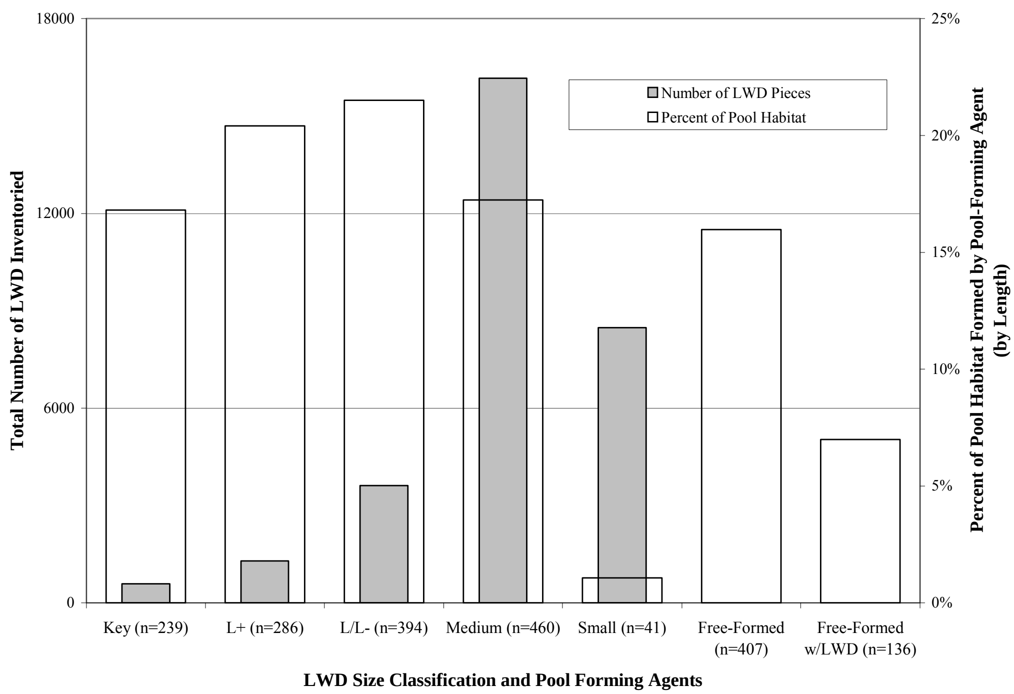

Figure 5.47. LWD piece count and percent pool habitat formed by pool forming agent for Ozette tributaries (source: Haggerty and Ritchie 2004).

5.5.4.1.2 Hydrological and Hydraulic Effects

Large woody debris (LWD) is an important frictional and roughness component in stream channels and floodplains. The roughness and turbulence created by in-channel wood is an extremely important energy dissipater in streams, aiding in channel stability (Bilby 1984; Smith et al. 1993). Large woody debris has been shown to be a major roughness element in rivers in the Pacific Northwest and around the world (Shields and Gippel 1995; Gippel 1995; Gippel et al. 1996; Dudley et al. 1998; Buffington and Montgomery 1999a; Hygelund and Manga 2003), greatly contributing to channel stability and habitat complexity. The height (stage) of water of a given discharge flowing through a channel reach is directly related to the roughness of the channel (Linsley et al. 1982; Sturm 2001), with increased wood load leading to increased stream stages. Large woody debris roughness is a major contributor in maintaining floodplain connectivity during both common and extreme flood events. Loss of wood debris and subsequent channel incision are major factors influencing the maintenance of floodplain connectivity in channels degraded by land use activities (Simon and Hupp 1992; Simon 1995; Wallerstein and Thorne 2003).

The effects of reductions in LWD in Ozette tributaries appear to have altered floodplain connectivity (Herrera 2006) and reduced floodwater storage and peak flow attenuation (Section 5.5.3). In addition, the reduction of LWD in Ozette tributaries is hypothesized to have altered in-channel hydraulic patterns around bars, bends and other roughness elements, reduced channel stability, and influenced the susceptibility of sockeye redds to scour (Section 5.5.4.3).

5.5.4.1.3 Effects on Sediment Storage and Stability

Large woody debris has been shown to be a major instream factor that influences sediment storage in forested streams in the Pacific Northwest (e.g., Nakamura and Swanson 1993). Buffington and Montgomery (1999a; 1999b) emphasize the dynamic feedback processes between water and sediment supply, sediment size, hydrologic roughness (LWD), and the provision of adequate spawning substrate (size and distribution) for salmonids. A loss of hydrologic roughness in the form of LWD was predicted to result in reach scale bed-surface coarsening and a loss of potential spawning habitat (Buffington and Montgomery 1999a), while increased sediment supply typically results in bed-surface fining in response reaches and a reduction in both spawning habitat quality and quantity (Buffington and Montgomery 1999b). In wood-rich stream reaches with increased sediment supply, wood roughness may accelerate the trapping and deposition of the finer components of bedload and result in textural fining, but will also provide increased roughness and turbulence that could keep the finer particles of the increased sediment supply in suspension. If the wood roughness also helps maintain floodplain connectivity, suspended sediment aided by wood roughness could more easily be transported out of the channel and deposited and stored on the floodplain.

5.5.4.2 Spawning Gravel Quality and Quantity

Reduced spawning gravel quality and the accumulation of fine sediment in spawning gravels during egg incubation is thought to be a limiting factor affecting the success of spawning sockeye in the watershed (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; McHenry et al. 1994; Gustafson et al. 1997; MFM 2000; Meyer and Brenkman 2001; NMFS 2003). Detailed information regarding current tributary spawning habitat conditions is included in Section 4.4.1.4, 4.4.2.4, and 4.4.3.4.

During incubation, salmonid eggs require sufficient water flow to supply egg pockets with oxygen and carry away waste products (Bjornn and Reiser 1991). Water circulation through salmon redds is a function of redd porosity, permeability, and hydraulic gradient (Bjornn and Reiser 1991). Fine sediment that settles into redds during the egg incubation period can impede water circulation and fry movement, which can result in decreased egg-to-emergence survival (Bjornn and Reiser1991). Studies throughout the Pacific Northwest have found that increased levels of fine sediment (<0.85mm) in spawning gravels decreases egg to emergence survival (Cederholm et al. 1981; Bjornn and Reiser 1991; McHenry et al. 1994). McHenry et al. (1994) found that Lake Ozette tributaries were among those with the highest proportion of fine sediment (18.7%-volumeteric equivalent) of streams sampled on the north Olympic Peninsula. Within the Ozette watershed, all sites sampled by McHenry et al. (1994) were in disturbed sub-watersheds. No control sites could be established to define un-impacted conditions draining identical geology.

However, results indicated poor gravel quality compared to either regional reference conditions or other nearby watersheds draining similar geology (McHenry et al. 1994). McHenry et al. (1994) found that coho and steelhead egg to alevin survival decreased drastically when fine sediment (<0.85mm) exceeded 13% (volumetric method) in Olympic Peninsula streams. Numerous other researchers have also found that survival to emergence relates negatively to the percentage of fines in gravel (McNeil and Ahnell 1964; Koski 1966; Cederholm et al. 1981; Cederholm et al. 1982; Tappel and Bjornn 1983; Tagert 1984; Chapman 1988).

5.5.4.2.1 Fine Sediment in Spawning Gravels

Fine sediment production has increased in the Lake Ozette watershed following European-American settlement. Changes in land use have altered disturbance regimes and replaced native vegetation age and species composition. These are considered primary factors for increased sediment production and delivery to streams (Pimentel and Kounang 1998; Opperman et al 2005). Insufficient data exist to exactly quantify the increase in the Lake Ozette watershed, although this topic is a focus of ongoing research. Current sediment production rates are estimated to be more than three times greater than pre-disturbance production rates (Herrera 2006). Herrera (2006) attributes the recent (last 50 years) increased sediment production mainly to forest practices (primarily roads and clear-cutting) and channel incision associated with LWD removal from the Ozette River.

Numerous examples of poorly designed, constructed, and maintained roads, as well as poorly designed and implemented timber harvest operations have been identified in the past (MFM 2000; Dlugokenski et al. 1981). Extensive clear-cut logging and road building have occurred within the sub-basins utilized by sockeye salmon (Umbrella Creek, Big River, and Crooked Creek; see Table 5.9).

Sediment production and delivery, and general habitat degradation in Lake Ozette tributaries from commercial forest operations have long been implicated as major limiting factors affecting salmonid survival (USFWS 1965; Phinney and Bucknell 1975; Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; WDF et al. 1994; Jacobs et al. 1996; Lestelle 1996; McHenry et al. 1996; MFM 2000; Smith 2000). Dlugokenski et al. (1981) described logging road surfacing quality as poor and noted that road surfacing literally crumbled under the weight of a loaded logging truck. They noted that during their surveys, trees were felled across Umbrella Creek and yarded through the channel; they also noted one location in the mainstem where heavy equipment had been operating in the channel. Habitat impacts inventoried and described by Dlugokenski et al. (1981) were related to forest practices conducted without regard to fish, fish habitat, or water quality. Numerous other studies from the Pacific Northwest have linked clearcut logging and associated road construction and use to increased sediment production (e.g. Brown and Krygier 1971; Megahan and Kidd 1972; Burns 1972; Farrington and Savina 1977; Beschta 1978; Cederholm et al. 1981; Cederholm et al 1982; Reid and Dunne 1984; Sidle et al. 1985; Montgomery 1994; Madej 1996; Wemple et al. 1996; Veldhuisen and Russell 1999; Lewis et al. 2001; Sidle and Wu 2001; Luce and Black 2001; Wemple et al. 2001; Brardinoni et al. 2002; Constantine et al. 2005).

No pre-disturbance fine sediment data are available for Ozette tributaries. Thus it may not be possible to exactly quantify the effects of increased sediment production on spawning gravel quality (percent fines) with 100% certainty. Dlugokenski et al. (1981) sampled fine sediment at six (6) locations (samples per location unknown) in Umbrella Creek in 1979 and found that fine sediment (<0.6 mm) averaged 17.8% (see Section 4.4.1.4). McHenry et al. (1994) sampled fine sediment in spawning gravels at three (3) locations (total n=30) in Umbrella Creek and found that fine sediment levels (<0.85 mm) averaged 16.1%. All samples from both studies were taken from the same general segment of Umbrella Creek (i.e., below the East Branch and upstream of the county bridge). The McHenry et al. (1994) data were scaled[18] to estimate wet sieve equivalent (volumetric) fine sediment less than 0.6 mm for comparing to Dlugokenski et al. (1981) data. Scaling the McHenry et al. (1994) data yielded an estimate of 12.4% fine sediment (<0.6 mm).

These data indicate that levels of fine sediment in Umbrella Creek spawning gravels contained up to 44% more fines in 1979 than in 1991. During the 10-year period prior to the 1979 gravel sampling, approximately 37% of the Umbrella Creek watershed was clearcut (MFM unpublished GIS Data). Only 7% of the watershed was clearcut during the 12 years prior to the 1991 sampling (MFM unpublished GIS Data). Fine sediment levels, depositional history at the Umbrella delta, observations by Dlugokenski et al.

[18] Scaling assumed an even distribution of sediment volume in size classes between 0.106 and 0.85 mm.

(1981) and Phinney and Bucknell (1975) of spawning gravel siltation, and logging history suggest that substantial sediment inputs occurred following a period of intensive clearcutting and road building (before 1979), resulting in very high levels of fine sediment in spawning gravels, as well as large quantities of sediment being transported downstream to Umbrella Beach spawning sites. During the period of less intensive land use in Umbrella Creek from 1979 to 1991, fine sediment levels appear to have declined from very high levels to moderately high levels.

The above examples provide evidence that past land use practices have affected the quality of spawning gravel in Ozette tributaries. High densities of roads that are hydrologically connected to the dense stream network by ditch systems, extensive clearcut logging, mass wasting, channel and bed destabilization, wood removal, decreased bank stability, windthrow, and channel incision have all increased sediment production and delivery to the stream network within the primary sockeye tributaries. Dozens of observations have been made during the last decade of sediment inputs violating State water quality standards and forest practice regulations within the primary sockeye spawning tributaries. However, changes in the proportion of fine sediment in spawning gravels in the Ozette watershed have not been quantified.

Cederholm et al. (1982) found that when logging road densities exceeded 2.9 mi/mi^2 the percentage of fine sediment in spawning gravel consistently exceeded the highest levels observed in natural undisturbed basins. Cederholm et al. (1982) also found a clear relationship between road density and percent fines in spawning gravels, which showed that on average, as road density increased, so did fine sediment levels in spawning gravels. Road density alone is not necessarily a good predictor of fine sediment levels in spawning gravels. Several factors (road type, road surfacing, road use, connectivity to stream network) influence sediment production and delivery from forest roads to streams (e.g., Luce and Black 2001). Connectivity to the stream network is related to the density of both the road and stream networks (Gucinski et al 2001). Production and delivery of sediment will not always result in measurable changes in spawning gravel composition. Rittmueller (1986) found a highly significant positive correlation between sediment yield from road surfaces and fine sediment levels in spawning gravels (e.g. a Coal Creek tributary [Dickey watershed] had the highest level of fines and the highest sediment yield from roads, and this particular road system is part the Ozette watershed).

Duncan and Ward (1985) found that for a select set of southwest Washington streams, fine sediment levels in spawning gravel were more closely correlated with soil and watershed lithology than road density, although both geology and road delivery points were positively correlated to fine sediment levels in spawning gravel. This study included only road attribute correlation tests and did not include forest attribute data or time since disturbance. In addition, while fine sediment levels were significantly different for different lithologies, the differences were relatively small compared to the range of variability of fine sediment in Pacific Northwest spawning gravels (i.e., basalt=10.02% and sandstone=11.58%). Within the Ozette watershed, McHenry et al. (1994) found no statistically significant correlation between numerous land use variables (road length, road density, forest age class, etc…) and fine sediment levels in spawning gravels. However, all Ozette tributaries contained high road densities and >80% of the tributary watershed area had been clearcut, potentially obscuring correlations between land use and fine sediment levels.

McHenry et al. (1994) suggests that marine sedimentary rock types (such as those in Ozette) are extremely friable and erode rapidly to yield sand and silt particles and could *partially* explain high levels of fine sediment found in spawning gravels. However, in undisturbed drainage basins, with similar geology, fine sediment levels rarely exceed 10% (McHenry et al. 1996). In the Dickey watershed, Coal and Skunk creeks had pre-logging fine sediment levels of 11.8% and 8.0% respectively (Samuelson et al. 1982 *In* McHenry et al. 1996). Following logging, McHenry et al. (1996) report that fine sediment levels increased to 24.7% and 18.1% in Coal and Skunk creeks respectively.

Rittmueller (1986) studied fine sediment levels in spawning gravels from streams draining the west slope of the Olympic Peninsula (from the Dickey watershed, south to the Clearwater watershed). Rittmueller found significant ($p<0.05$) positive correlations between fine sediment levels, percent watershed clearcut (Figure 5.48), and road density. Rittmueller (1986) studied streams draining watersheds with a full suite of land use histories. Watershed area clearcut varied from 0 to 80%, and road density ranged from 0 to 4.3 mi/mi^2. Watershed lithologies were the same or similar in Rittmueller's study as those found in the Ozette watershed.

Ozette sediment and percent watershed area clearcut data[19] were plotted with the Rittmueller data in Figure 5.48 for comparative purposes. Ozette data plot within the range predicted by the Rittmueller regression model. The Rittmueller data were separated into two groups, greater than 50% watershed area clearcut and less than 50% watershed area clearcut, to determine what if any differences would occur if watersheds with the most extensive clearcut history were removed from the regression analysis. Interestingly, for watersheds with >50% basin area clearcut, the same significant positive correlation could not be detected. When the McHenry data were pooled with the Rittmueller high impact watersheds (>50% clearcut), no significant relationship could be detected. However, when the McHenry data were pooled with all of Rittmueller's data, a significant ($p<0.05$) positive correlation was found. Figure 5.48 and the above discussion suggest that there may be a threshold at which road density is no longer a strong predictor of fine sediment levels.

[19] Note: Percent watershed area clearcut is an indicator of watershed disturbance and not a measure of sediment input or impact to spawning gravel. The actual quantity of sediment produced and routed into spawning gravels above "natural" background level can come from various sources and activities (roads and road use, management related mass wasting [from roads and clearcuts], clear-cutting, wet-weather log hauling, wood removal, channel and bed destabilization, decreased bank stability, management related windthrow, etc…).

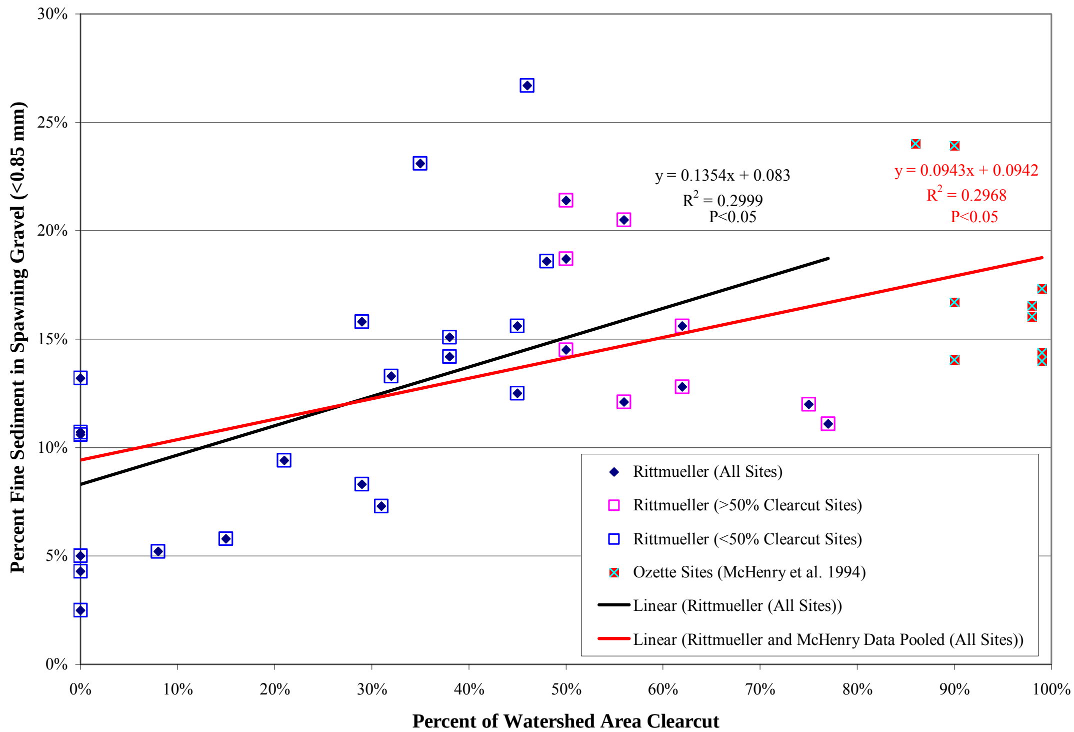

Figure 5.48. Relationship between fine sediment (<0.85 mm) in spawning gravels and percent of watershed area clearcut for Olympic Peninsula streams (source: Rittmueller 1986; McHenry et al. 1994).

Rittmueller (1986) also found a significant ($p<0.05$) positive correlation between road density and fine sediment levels in spawning gravel (Figure 5.49). Ozette fine sediment and road density data were plotted with the Rittmueller data in Figure 5.49 for comparative purposes. Ozette data plot within the range predicted by the Rittmueller road density regression model. The Rittmueller data were then separated into two road density groups, greater than 3 mi/mi^2 and less than 3 mi/mi^2, to determine what if any differences would occur if watersheds with the highest road densities were removed from the regression analysis. Interestingly, for watersheds with road densities >3 mi/mi^2 the same significant positive correlation could not be detected. When the McHenry data were pooled with the Rittmueller high road density watersheds (>3 mi/mi^2), no significant relationship could be detected. However, when the McHenry data are pooled with all of Rittmueller's data a significant ($p<0.05$) positive correlation was found. Figure 5.49 and the above discussion suggests that there may be a threshold at which road density is no longer a strong predictor of fine sediment levels.

Cederholm et al. (1982) fine sediment and road density data from the Clearwater watershed were examined to see what relationship, if any, existed between fine sediment levels and streams with high road densities. As seen with the Rittmueller data, Cederholm's high road density watersheds were found to have a poor correlation with fine sediment levels in spawning gravels. Finally all Ozette, Rittmueller, and Cederholm high road density (range 3.05 to 6.15 mi/mi^2) and fine sediment data were pooled; only a very weak correlation (r^2=0.01) could be detected (Figure 5.50).

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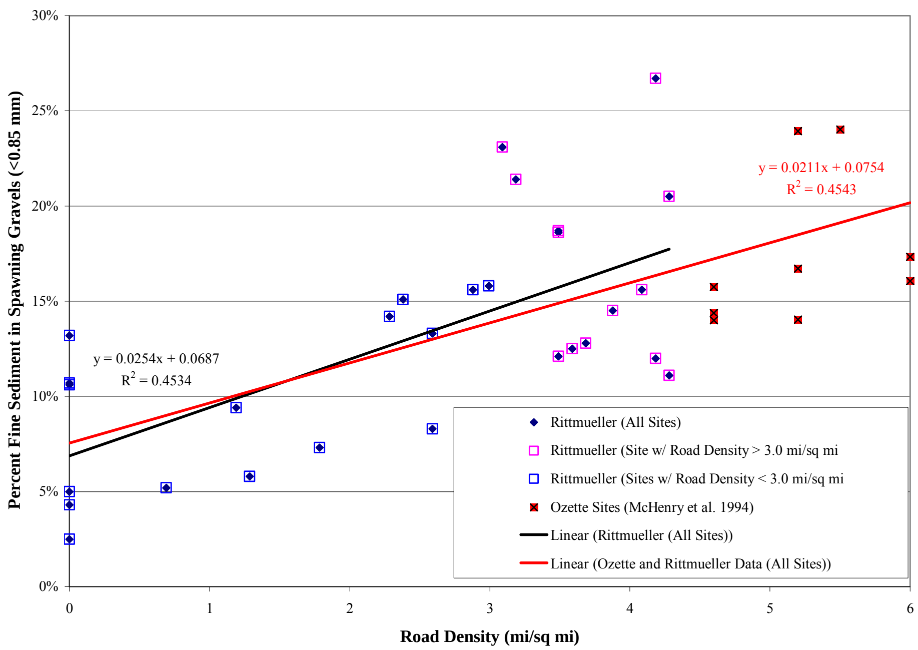

Figure 5.49. Relationship between fine sediment (<0.85 mm) in spawning gravels and road density for Olympic Peninsula streams (source: Rittmueller 1986; McHenry et al. 1994).

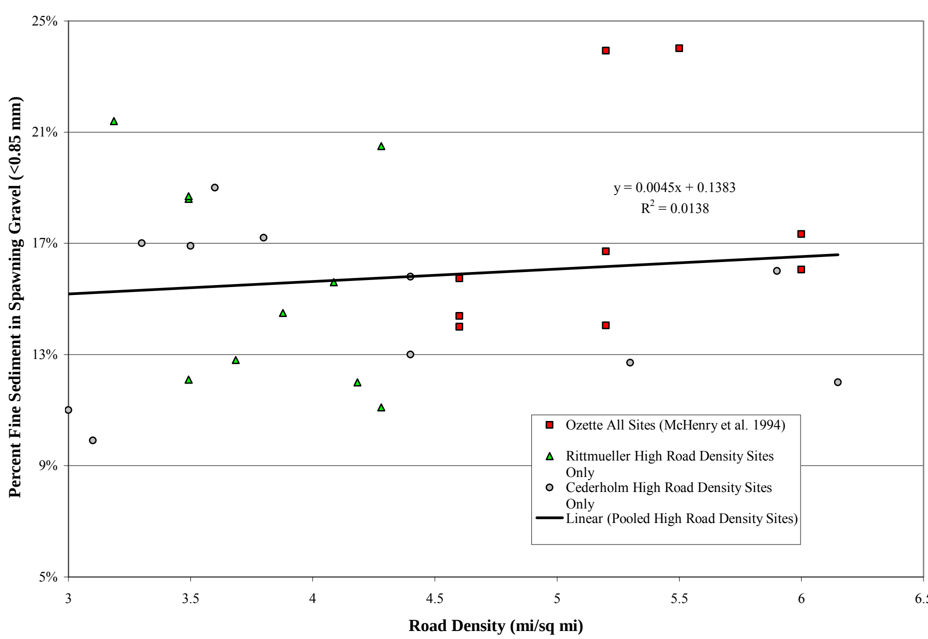

Figure 5.50. Relationship between fine sediment (<0.85 mm) in spawning gravels and road density for Olympic Peninsula and Ozette high road density watersheds (source: Cederholm et al. 1982; Rittmueller 1986; McHenry et al. 1994)

The analysis above strongly suggests that there is a threshold (~50% clearcut and road density > 3.0 mi/mi^2) at which road density and percent watershed clearcut no longer explain the variability between sites within highly disturbed landscapes. When comparing only the most heavily impacted watersheds no significant relationships between fine sediment levels in spawning gravels and road density or percent of watershed area clearcut could be found in any study conducted on the Olympic Peninsula (e.g. Cederholm et al. 1980; Rittmueller 1986). This reasonably explains why McHenry et al. (1994) were unable to find statistically significant correlations between land use variables and fine sediment levels. Key studies, such as Cederholm et al. (1982), could never have found significant relationships between road density and fines in gravel without watersheds that contained little or no roads. A clear linkage between roads and logging and their effects on spawning gravel require at least some un-impacted streams. Because fine sediment levels are moderate to high in all Ozette tributaries and there are no statistically significant relationships between land use variables and fine sediment levels, it has been suggested that fine sediment levels are naturally high and unaffected by land use. While it may never be possible to exactly determine the amount that fine sediment levels have increased in Ozette tributaries due to land use with 100% certainty, it would be illogical to dismiss the preponderance of evidence that indicate that sediment production and delivery to the stream network has dramatically increased and this increased sediment production has degraded spawning gravel conditions. Many factors may ultimately regulate fine sediment levels in spawning gravels, but clearcut logging and logging roads are thought to be the primary source of increased fine sediment levels in Ozette tributaries.

5.5.4.2.2 Decreased Number of Suitable Spawning Habitats

Past estimates of available spawning habitat area in the mainstem of Big River and Umbrella Creeks range from 46,000 (Dlugokenski et al. 1981) to 60,000 (Blum 1988) sockeye. Currently, tributary run sizes average less than 5,000 spawners total, and therefore Lake Ozette tributary spawning sockeye do not appear to be limited by available spawning habitat. However, the quantity of suitable spawning habitat area in Ozette tributaries is thought to have been reduced due to the effects of gravel mining, wood removal, reduced wood abundance, channelization, bank armoring, increased fine sediment inputs and abundance, and colonization of bar deposits by non-native vegetation. No attempts to quantify available spawning habitat have been conducted in recent years but a complete inventory of LWD and pool habitat conditions revealed that several reaches that had low LWD levels also had correspondingly coarser sediment than preferred for spawning salmonids.

Significant correlations between the surface area of sediment accumulations and LWD volume have been shown for streams draining old-growth forests in western Washington (Bilby and Ward 1989). Beechie and Sibley (1997) studied streams draining second-growth forests and found no correlation between percent gravel (percent of habitat with dominant gravel substrate, 16-64 mm) and LWD/m, LWD volume/m, or LWD volume/m^2. They speculated that debris volumes within their survey sites may have been too low to see a correlation between percent gravel and LWD debris volumes. In old-growth Alaskan streams, Martin (2001) found that gravel dominance within habitat units increased with both increased LWD frequency and volume. Bilby and Ward (1991) found that streams draining old-growth forests had larger areas of LWD-associated sediment accumulations than those found in streams draining second-growth forests.

Kramer (1953) described the Big River as having almost a continuous bed of gravel from the Hoko-Ozette Road Bridge to about a mile from the mouth. Substrate conditions in this stream reach were described as mostly sand and pebbles with occasional gravel patches by Haggerty and Ritchie (2004), a result of sedimentation from upstream. The quantity of lost suitable spawning habitat due to sedimentation, gravel mining, vegetation encroachment, bank armoring, and channel incision has not been thoroughly investigated.

5.5.4.3 Channel Stability (Scour)

Gravel scour in Ozette tributaries has been described as a limiting factor affecting salmonid survival (MFM 2000; Meyer and Brenkman 2001). While numerous observations have been made of highly mobile stream beds in tributary spawning areas, no direct monitoring of scour depth has been conducted in Lake Ozette tributaries. Relative to other life history stages, the gravel incubation and alevin rearing periods are critical to population levels, as a majority of individuals perish during them (Quinn 2005). Channel stability and scour are important factors influencing embryo survival incubating in gravel. Channel stability is influenced by many factors, including streamflow, sediment inputs, sediment transport imbalances, bed and bank material, size and density of LWD, and channel-floodplain connectivity. The survival of incubating salmonid embryos in gravel-bed rivers is sensitive to changes in bedload scour depth associated with floods, in addition to fine sediment levels (Seegrist and Gard 1972; Erman et al. 1988; Tripp and Poulin 1986; Montgomery et al. 1996; DeVries 2000; Schuett-Hames et al. 2000; Haschenburger 1999; Lapointe et al. 2000; McNeil and Ahnell 1964; Everest et al. 1987; Reiser and Bradley 1993; McHenry et al. 1994).

In Washington State, several studies of juvenile salmonid emigration or returning adult abundance have been related to flood magnitude during the previous incubation period, often with strong correlations (e.g., Seiler et al. 2001; Ames and Beecher 2001; Green et al. 2005). For example, Seiler et al. (2001) estimated that for common floods (0.5- to 2-year RI) during the Chinook incubation period, egg to migrant fry survival was approximately 15%. Egg to migrant fry survival dropped below 10% during larger floods (> 10-year RI), and survival was extremely low (<5%) during floods greater than the 50-year RI. Bedload scour is hypothesized to be the leading cause of mortality for reduced survival, but other factors such as fine sediment intrusion associated with streambed scour or reduced holding or feeding opportunities following emergence could also be confounding factors.

Bedload scour data from Washington State indicate that only modest changes in the magnitude of common peak flow events (0.5- to 2-year RI) from land use or climate change could significantly alter the frequency and depth of bedload scour and influence the survival of incubating salmonid embryos in gravel bed rivers (Montgomery et al. 1996; Shellberg 2002). Beamer and Pess (1999) and Pess et al. (2000) documented a significant increase in peak flow magnitude for the North Fork Stillaguamish River between 1928 to 1995, which was largely attributed to observed land use trends (increased road density and hydrologic immaturity over the period of record), and only partially attributed to climate variability (36% of variation). Using egg to fry survival and recruitment ratio data from the Skagit and Stillaguamish Rivers, Beamer and Pess (1999) estimated that a 25% increase in the 2-year RI flood has reduced egg to fry survival from 10% to 5%, with extremely low recruitment during floods greater than the 10-year RI under altered hydrologic conditions. In addition, variable streamflow (natural or anthropogenically enhanced) during the spawning and incubation period can result in reduced probabilities of successful egg-to-fry survival, by forcing salmon to spawn either high on the channel margins (increased desiccation and sediment entombment probability) or low in the channel thalweg (increased scour probability) (Ames and Beecher 2001; Lapointe et al. 2000; see Section 5.5.1.3).

For Ozette tributary sockeye, it is hypothesized that the combined influence of increased common peak flood magnitude, increased sedimentation of spawning reaches, reduced wood loads, and/or channelization and floodplain disconnection have synergistically destabilized relative bed stability and reduced sockeye egg to fry survival. In urban and agricultural areas, channel stability has been shown to decrease with increasing watershed disturbance and development (Booth 1990; Booth and Jackson 1997). In watersheds subject to forest harvest and road building, relative bed stability has been shown to decrease with increasing watershed and riparian disturbance, with greater changes in bed stability in basins underlain by weak sedimentary rock or with high road densities (Tripp and Poulin 1986; Faustini and Kaufmann. 2003), similar to the Ozette watershed. Channel stability is reduced as waves of bedload sediment move through the channel network from hillslope landslide failures associated with roads and other land use (Madej 1996; 1999) and local sediment transport imbalances can significantly affect the magnitude of scour and fill (Lisle et al. 2000). Salmonids spawning reach and site selection is often correlated with abundant LWD and cover (e.g., Merz 2001). Bed stability has been shown to decease following wood removal (Bilby 1984; Smith et al. 1993). Redd scour to the depth of salmonid egg pockets has been shown to be reduced in reaches or sites with abundant large stable LWD (Shellberg 2002), and increased in reaches with smaller mobile LWD (Schuett-Hames et al. 2000). Channelization can severely destabilize the vertical and horizontal stability of gravel and sand bedded channels (Cederholm and Koski 1977; Simon and Hupp 1992; Simon 1995).

For mass spawning fish (e.g., chum [or sockeye]), Montgomery et al. (1996) hypothesize from theoretical calculations that gravel coarsening from the act of mass redd construction could significantly reduce the mobility of the gravel bed and thus reduce scour depth. In addition, gravel cleaning and coarsening by mass spawning fish at least *temporarily* (i.e., several weeks) (Kondolf et al. 1993; Peterson and Quinn 1996) reduces the fine sediment levels in the bed and redd (Kondolf and Wolman 1993; Kondolf et al. 1993), increasing egg to fry survival. The reduction of mass spawning fish populations such as sockeye from other limiting factors could be further impacted by the negative feedback of reduced gravel bed maintenance of fine sediment levels or scour depths (Montgomery et al. 1996).

Since data are lacking in Ozette regarding 1) scour depths at sockeye redds, 2) the effects of flood peak magnitude on scour depths, 3) and the other factors mention above that affect scour, no quantitative conclusions can be made regarding the impact on sockeye egg to fry survival. The above-mentioned hypotheses and physical processes need to be tested in Ozette tributaries in order to understand the relative importance of each separate or cumulative effect on scour and sockeye egg to fry survival. Thus, scour and bed stability remains a critical data gap.

While direct gravel scour data are lacking, indirect evidence from the December 15, 1999[20] flood is available. Peak sockeye counts in Umbrella Creek for RY 1999 were recorded on November 29 (MFM unpublished spawning ground survey data). Peak spawning is thought to have occurred around this date. It was estimated that 1,477 sockeye spawned in Umbrella Creek in 1999 (see Section 3.5.2). Adult returns in 2003 were estimated to be 1,740; no BY 1999 hatchery sockeye were released into Umbrella Creek. It has been estimated that 1.2 sockeye returned to spawn in Umbrella Creek in 2003 for each sockeye that spawned in 1999. However, this example does not indicate that scour is not a problem in Ozette tributaries. Incubation flows following the December 15, 1999 flood event were ideal for incubating sockeye and it is unclear what proportion of the RY 2003 sockeye run were progeny of fish spawning after December 15, 1999 or before. These observations suggest that sockeye survival in Umbrella Creek, in a year with at least one extreme peak flow event, was high enough for sockeye to replace themselves. Scour data are considered an important data gap for Ozette tributaries and it is important to understand how scour may affect sockeye salmon's ability to utilize tributaries such as Umbrella Creek and Big River into the future.

5.5.5 Predation

Predation on juvenile and adult sockeye in Ozette tributaries is poorly documented. Known predators in the tributaries include: sculpin, juvenile coho, cutthroat trout, river otters, harbor seals, black bears, bob cat, cougar, and bald eagles (Gearin et al. 2002; MFM unpublished trap data). Other potential predators include northern pikeminnow, juvenile rainbow trout/steelhead, various bird species (osprey, merganser, belted-kingfisher), and other terrestrial mammals. No studies have been conducted exclusively focusing upon potential impacts of predators in Lake Ozette tributaries. Brief descriptions of sockeye predation by life history stage in Lake Ozette are included below.

A complete description of adult sockeye entering, migrating, and holding in Lake Ozette tributaries can be found in Section 3.1.3. During the period that adult sockeye enter,

[20] The December 15, 1999 flood event is thought to have a recurrence interval of about 50 years. Flow data are not available for Ozette tributaries during this event, but Hoko River discharge was estimated to be ~20,000cfs, and the resulting Lake Ozette lake level was the highest ever recorded.

migrate, and hold in lake tributaries they are primarily susceptible to predation by river otters, harbor seals, and terrestrial mammals. Gearin et al. (2002) observed a harbor seal chasing sockeye staging off of the mouth of Umbrella Creek during predator surveys in 2000. No direct seal predation events were observed by Gearin et al. (2002). Hughes et al. (2002) concluded that there is very little evidence of pre-spawning predation mortality in Umbrella Creek based on tagging, tracking, genetic sampling, and spawning ground surveys. In 2000, seven adult sockeye tagged with CART tags were tracked in Umbrella Creek and all were observed to have successfully spawned. A cougar was observed trying to take spawning sockeye in Umbrella during the winter of 2000 (MFM unpublished spawning ground survey data).

During spawning and egg incubation, sockeye eggs are susceptible to predation by sculpin, cutthroat trout, and, potentially, river otters. No attempt to measure sockeye egg predation in the tributaries has been conducted nor has it been suggested that significant levels of egg predation are occurring. Within other sockeye populations, many observations of egg feeding by predatory fishes and birds on eggs have been made, but most observers have concluded that the bulk of eggs eaten are dislodged by late-arriving spawners and would have had a low chance for survival (Foerster 1968; Burgner 1991). In a general review of sockeye salmon life histories, Burgner (1991) concluded that less is known about predation on eggs and alevins in the redds than at other life stages, but physical and chemical factors such as redd desiccation, freezing, lowered DO resulting from siltation, reduced flow, and dislodgement (scour or superimposition) are probably more important as mortality factors.

Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in tributaries. Burgner (1991) reviewed several studies conducted to determine fry predation rates for riverine spawned sockeye fry emigrating to nursery lakes and found widely ranging values: 63%-84% (Scully Creek, Lake Lakelse, 4 yrs), 66% (Six Mile Creek, Babine Lake, 1 yr), 13%-91% (Karymaiskiy Spring, Kamchatka Peninsula, 8 yrs), and 25%-69% (Cedar River, Lake Washington). Burnger (1991) concludes that while these sockeye fry predation rates may not represent the potential range of predation, they do indicate that predation losses can be extensive. No studies have been conducted to estimate emergent sockeye fry predation in the Ozette tributaries. However, fyke net trapping during and after hatchery sockeye fingerling releases was conducted in 1999 (BY 1998) and 2002 (BY 2001). In 1999, only 33% of the sockeye fingerlings released at RM 4.7 were recaptured in a fyke net stationed at RM 0.8; this suggests a 26%-60% (trapping efficiency ranged from 44.8% to 82.4%) instream mortality (from MFM 2000). Potential predators at this life history stage include sculpin (sp), cutthroat trout, juvenile steelhead trout, and juvenile coho salmon. Predator interactions at this early life history stage remain a data gap and it is possible that significant levels of predation occur in Umbrella Creek and Big River.

5.5.5.1 Predators

5.5.5.1.1 Harbor Seals (Phoca vitulina)

The small size of Lake Ozette tributaries appears to limit harbor seal distribution to the lower reaches of the tributaries. Gearin et al. (2002) observed a harbor seal move upstream from the mouth of Umbrella Creek, but they were unable to determine how far it went. Most harbor seal predation is likely limited to sockeye staging near the mouth of tributaries and in the lower reaches of tributaries.

5.5.5.1.2 River Otters (Lutra canadensis)

No specific data exists regarding the number of otters or the number of adult sockeye preyed upon by river otters in Lake Ozette tributaries. As described above, there is no evidence of significant levels of predation occurring on adult sockeye in Lake Ozette tributaries.

5.5.5.1.3 Native Fish Species

Native species known or believed to prey upon emigrating sockeye fry in the tributaries include: sculpins (sp), juvenile steelhead/rainbow trout, cutthroat trout, and juvenile coho salmon. During fry trapping studies in Umbrella Creek, sculpin appeared to selectively feed on swim-up sockeye fry inside the live box independent of fry density. Coho fry outnumbered sockeye 10.4 to 1 but were consumed at a ratio of 1.2 to 1; sockeye were nine times more likely to be consumed by sculpins than coho within the live box (MFM, unpublished trapping data). MFM (2000) postulated that higher predation rates on sockeye fry over coho fry may have been due to the sockeye's behavior of remaining motionless in the substrate within the trap where sculpin were also present.

During trapping studies in Umbrella Creek, salmonid stomachs were not sampled, but sockeye fry were thought to be consumed by juvenile steelhead, cutthroat trout, and coho pre-smolt and fry. Coho fry as small as 1.5 inches (35-40mm) were observed preying upon sockeye fry in the trap live box. In the Cedar River, sockeye fry migrating to Lake Washington constituted 2 to 52% wet biomass of steelhead smolt diets and averaged 13% of their diet from February through mid-May (Beauchamp 1995). Bioenergetics simulations indicated that under the "normal" scenario 15% of the emergent fry production was consumed by steelhead smolts.

5.5.5.1.4 Introduced Fish Species

Introduced fish species have not been observed in Lake Ozette tributaries, but species such as largemouth bass may prey upon emigrating sockeye fry in the lower reaches of Big River, Umbrella Creek, and Crooked Creek.

5.5.5.2 Factors Affecting Predation

5.5.5.2.1 Large Woody Debris and Stream Habitat Conditions

The relationship between LWD and predator avoidance with respect to sockeye salmon is poorly documented in the general sockeye literature. Habitat and LWD data collected in Ozette tributaries clearly shows a linkage between pool habitat quality and complexity and large wood. Haggerty and Ritchie (2004) found that on average the deepest pools with the most cover complexity were most often associated with the pools formed by key-piece-sized LWD. It is assumed that the deepest pools with the greatest cover and complexity likely provide the best predation refuge habitat for pre-spawning adult sockeye. Holding pool frequency and overall pool habitat quality was evaluated for Umbrella Creek, Big River, and Crooked Creek by Haggerty and Ritchie (2004) and their results are included in Figure 4.49, Figure 4.59, and Figure 4.69. The relationship between LWD and sockeye fry predator avoidance is even less clear than with respect to holding adult sockeye. Sockeye fry appear to move mostly during twilight hours or during nighttime. They appear to move downstream mostly along the margins of the channel and have not been observed holding in pools during daylight hours. It is thought that tributary sockeye fry burrow into the stream substrate during daylight hours and therefore the importance of LWD for cover and predator avoidance is less than for other salmonid species (such as coho salmon). Substrate conditions such as embeddedness may play a more important role for sockeye fry in predator avoidance than LWD in Lake Ozette tributaries.

5.5.5.2.2 Increases in Regional Pinniped Population

See Sections 5.2.2.2.1 and 5.3.4.2.2.

5.5.5.2.3 Abandonment of Ozette Village

See Section 5.2.2.2.2

5.5.6 Competition

Within Lake Ozette tributaries, competition is limited primarily to spawning, since emergent sockeye fry quickly migrate to the lake upon emergence from the gravel. Both intraspecific and interspecific competition are apparent in tributaries to the lake, as sockeye competing with one another for spawning habitat, sockeye competing and/or spawning with kokanee for spawning habitat, and sockeye competing with coho salmon for spawning habitat. The degree and type of competition thought to occur in tributaries varies by stream system. Within Umbrella Creek, spawning competition for suitable spawning sites and mates is more intense than in Big River and Crooked Creek. In recent years, large numbers (1,000 to 4,000) of spawning sockeye use habitat in a fairly discrete section of Umbrella Creek; most spawning takes place in a 2.2-mile-long section of the stream. Competition within this reach can be intense and redd superimposition plays a significant role in determining the number of fertilized eggs that ultimately make it into the spawning gravels to incubate.

During the peak spawning period, downstream of mass-spawning areas in Umbrella Creek, hundreds of sockeye eggs can be seen along the bottom of the stream or being transported downstream. The degree of redd superimposition likely varies depending upon the number of spawners returning to Umbrella Creek, as well as how they distribute themselves during the spawning period. Some spawning competition with coho salmon must also occur since both species spawn during at the same time and in the same habitat (although must coho spawning appears to occur in the upper mainstem and tributaries to Umbrella Creek). If the coho population size continues to increase there is expected to be increased competition between coho and sockeye salmon for suitable spawning habitat. Competition and interaction with kokanee is thought to be minimal in Umbrella Creek since few kokanee spawn in this stream system. However, sockeye spawning with kokanee-size *O. nerka* in Umbrella Creek has been observed and documented on several occasions (Figure 5.51).

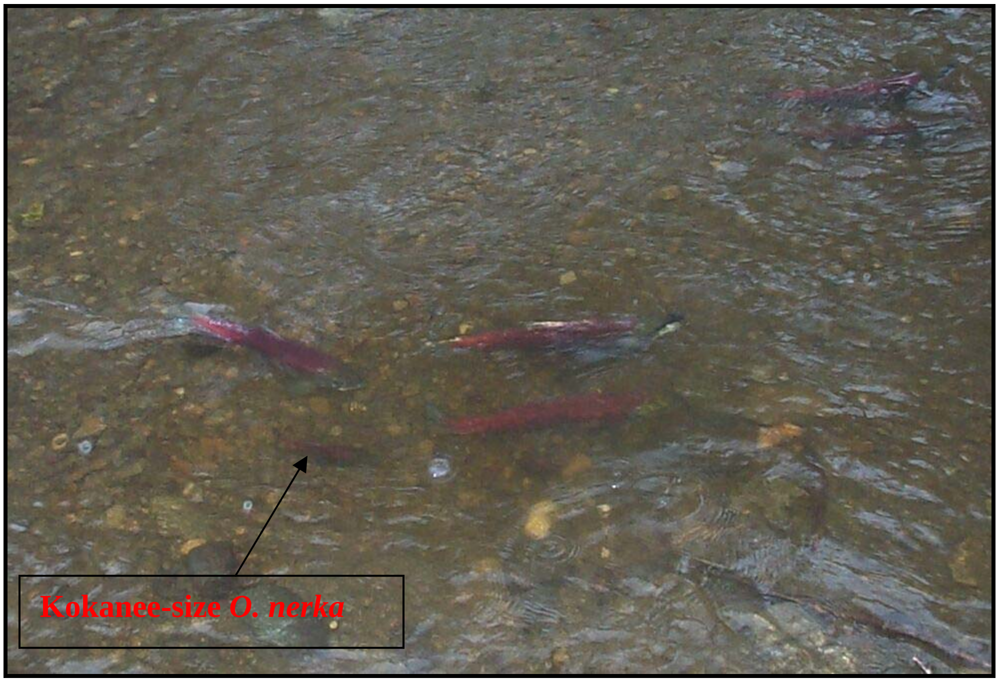

Figure 5.51. Example of kokanee-size *O. nerka* spawning with adult sockeye (source: MFM photo archives).

Within Big River the current size of the spawning run is small relative to Umbrella Creek and intraspecific competition of spawning sites is thought to be much lower than in Umbrella Creek. However, if the Big River spawning aggregation grows considerably, then intraspecific competition for suitable habitat should increase. Some Big River sockeye spawning occurs during the same time and within the same habitat as coho spawning, and therefore some competition for suitable habitat between these species must occur. Much of the Big River coho spawning occurs in the upper mainstem and in tributaries such as Boe, Solberg, and Trout Creeks, which may act to minimize interspecific competition with sockeye salmon. Kokanee spawning in the mainstem of Big River is very rare. A review of nearly 200 spawning ground surveys (1970-2005) conducted in the mainstem of Big River during the kokanee spawning season yielded only one observation of kokanee, and these fish were not observed spawning.

The exact number of sockeye spawning in Crooked Creek is unknown, but is thought to be relatively low based upon spawning ground survey data collected from 1999 through 2004. Kokanee abundance is far greater than sockeye abundance; peak kokanee counts per mile averaged 100-500 during years with complete surveys (see Figure 2.1). Competition and interaction with kokanee in Crooked Creek is expected to be fairly common. Kokanee spawn timing is slightly earlier than observed sockeye spawn timing and may act to minimize interaction and gene flow between these populations. Spawning ground data from Crooked Creek suggest that both coho salmon and kokanee out number sockeye, but coho spawning densities are not thought to exceed the habitat carrying capacity in this stream system. Hatchery releases into Crooked Creek no longer occur because of concerns over sockeye-kokanee interactions and the fact that the two groups represent discrete populations of *O. nerka.*

5.5.7 Hatchery Broodstock Collection

Hatchery broodstock collection from Umbrella Creek was first conducted in 2000 (MFM 2000). In the first year, broodstock were collected using dip and gill nets in the mainstem of Umbrella Creek. Starting in RY 2001, all sockeye broodstock were collected at the Umbrella Creek weir (RM 0.8). Broodstock collection protocols are intended to minimize negative impacts to naturally spawning Umbrella Creek sockeye (MFM 2000). Broodstock are selected randomly and representatively from the total return to Umbrella Creek and include both natural-origin and hatchery-origin sockeye (MFM 2000). Broodstock collection protocols limit the number of sockeye retained at the weir in order to protect against population diversity losses in both naturally and hatchery spawned sockeye. Broodstock collection is limited to 40 pairs when Umbrella Creek run size is less than 533, and all progeny are to be released into Umbrella Creek. When the run- size is greater than 533, up to an additional 60 pairs may be collected in Umbrella Creek for use in Big River; total broodstock collection cannot exceed 15% of the run size (MFM 2000). Since 2000, broodstock collection has ranged from 11.4% to 4.8% of the total run size, averaging 7.5% (MFM, Unpublished broodstock collection data).

5.5.8 Disease

Tributary spawning ground surveys during the last 10 years have provided no evidence of pre-spawning disease-induced mortality in the tributaries. If disease-related pre-spawning mortality of tributary spawning sockeye occurs at significant levels, then it must occur in the lake and therefore go undetected in the tributaries.

5.6 OFF-SHORE MARINE ENVIRONMENT

5.6.1 General Marine Survival

As described in Section 3.5, limited marine survival data indicate that *total* marine survival rates appear good, averaging 15-27% (brood years 1988, 1990, and 2000; see Section 3.5). While these data are limited (3 years; questionable accuracy), they do suggest, at least for the brood years estimated, that marine survival has had limited influence on the recent low abundance of Lake Ozette beach spawning aggregations. Also note that the 15.5% survival for BY 2000 is survival from smolt to spawner and includes pre-spawning holding mortality in the lake. Koenings et al. (1993) summarized average marine survival rates for sockeye salmon based on geographic location and smolt size. Large sockeye smolts (>115mm) in the southern range (latitude <55°N) averaged 17.1% marine survival (this estimate was primarily derived from Lake Washington sockeye survival estimates). This provides further evidence that marine survival estimates for Ozette sockeye are within the range expected for the stock.

In recent years, fisheries biologists have speculated that temporarily poor ocean conditions contributed to the decline of Ozette sockeye (Jacobs et al. 1996; MFM 2000). The major decline for Ozette sockeye can broadly be described as occurring from 1948-1978. This time period roughly corresponds to a period of low productivity for Bristol Bay sockeye stocks (Peterman et al. 1998). The abundance of Fraser River sockeye in the 1960s was low, and increased to high levels in the 1980s. Increases were attributed to climatic regime shift starting in the winter of 1976-77 (Beamish et al. 1997). However, Peterman et al. (1998) suggests that decadal-scale environmental changes that occurred in the mid-1970s mainly improved productivity for northern sockeye stocks (particularly Bristol Bay stocks), while effects on southern stocks were on average much smaller and more variable among stocks. In addition, in a recent review, Pyper et al. (2005) found "*no evidence that broad, ocean-basin-scale environmental processes simultaneously influenced survival rates of pink, chum, and sockeye salmon across the regions of the northeast Pacific…*".

While marine survival is a critical component in determining the ultimate abundance of Lake Ozette sockeye, broad-scale, regional studies of decadal-scale productivity suggest that changes in marine survival played a limited role in the decline of Ozette sockeye.

5.6.1.1 Interception and Harvest

No marine harvest data for Lake Ozette sockeye exist. In order to understand how marine harvest might affect Lake Ozette sockeye, information from nearby sockeye stocks were used to estimate Lake Ozette sockeye marine spatial and temporal distributions. Marine area migration timing for Lake Ozette sockeye salmon was estimated for Southeast Alaska (SEAK) and West Coast Vancouver Island (WCVI) marine areas. Migration timing estimates were back-calculated from 1998-2003 mean daily lake entry timing data developed by Haggerty (2005d). A coastal area migration rate of 32 miles per day was estimated for migrating Fraser River sockeye salmon (Jim Cave, Pacific Salmon Commission, pers. comm. with Tim Tynan NMFS, January 5, 2006; Quinn 1988). Combining migration rates with nautical distance, estimates were applied to lake entry timing data to approximate Ozette sockeye abundance and timing in northern marine approach areas (Figure 5.52). A near-coastal migration rate similar to that observed for early migrating sockeye salmon (e.g. Early Stuart Stock) was assumed, as was a northern land-fall along the southeast Alaskan coast (Figure 5.53). Lake Ozette sockeye are assumed to enter freshwater without delay after arriving at the river mouth, similar to Early Stuart sockeye (i.e. lake entry and arrival at the river mouth assumed to be equal).

Recent periods were identified when the major West Coast marine area sockeye-directed fisheries occurred in Southeast Alaskan marine waters (District 104 purse seine fisheries; Figure 5.54) and in Canadian West Coast Vancouver Island areas (Areas 121-127 troll fisheries; Figure 5.55). These data and periods were derived from Pacific Salmon Commission Northern Boundary Committee and Fraser Panel annual reports.

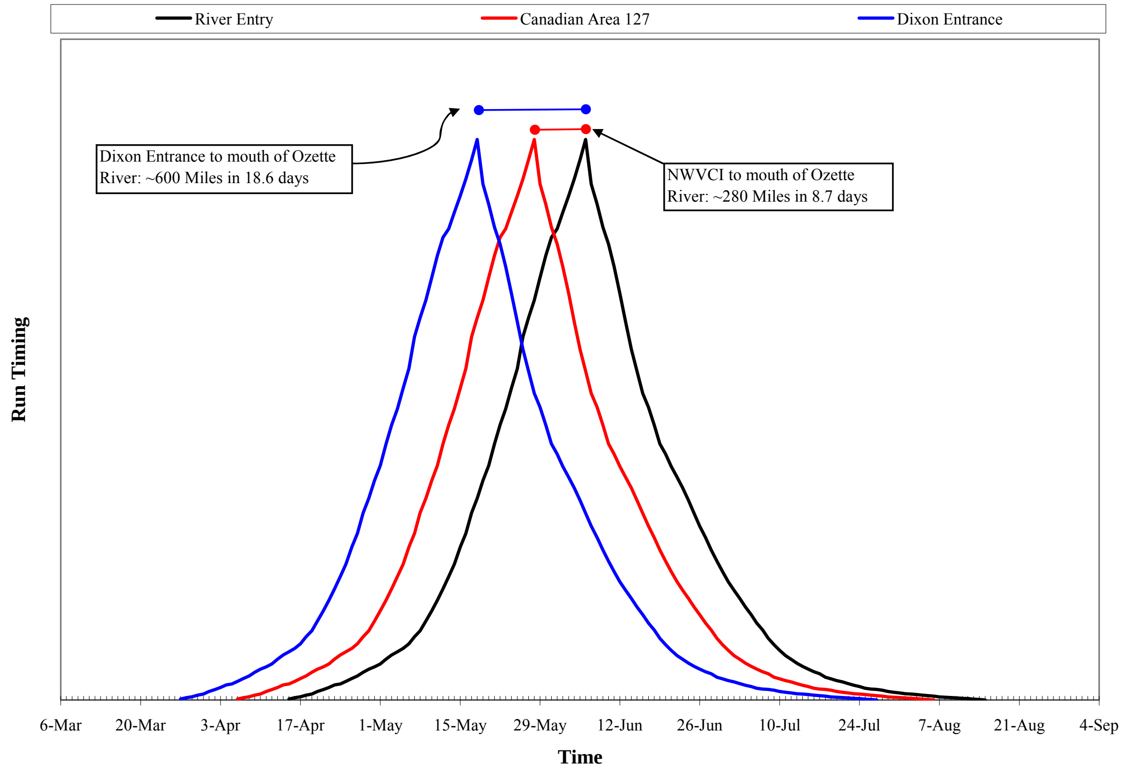

Figure 5.52. SEAK (Dixon Entrance) and North WCVI (Canadian Area 127) marine area timing estimates back-calculated from 1998-2003 average run timing, assuming rate of 32 miles per day and applied to distances from Ozette River.

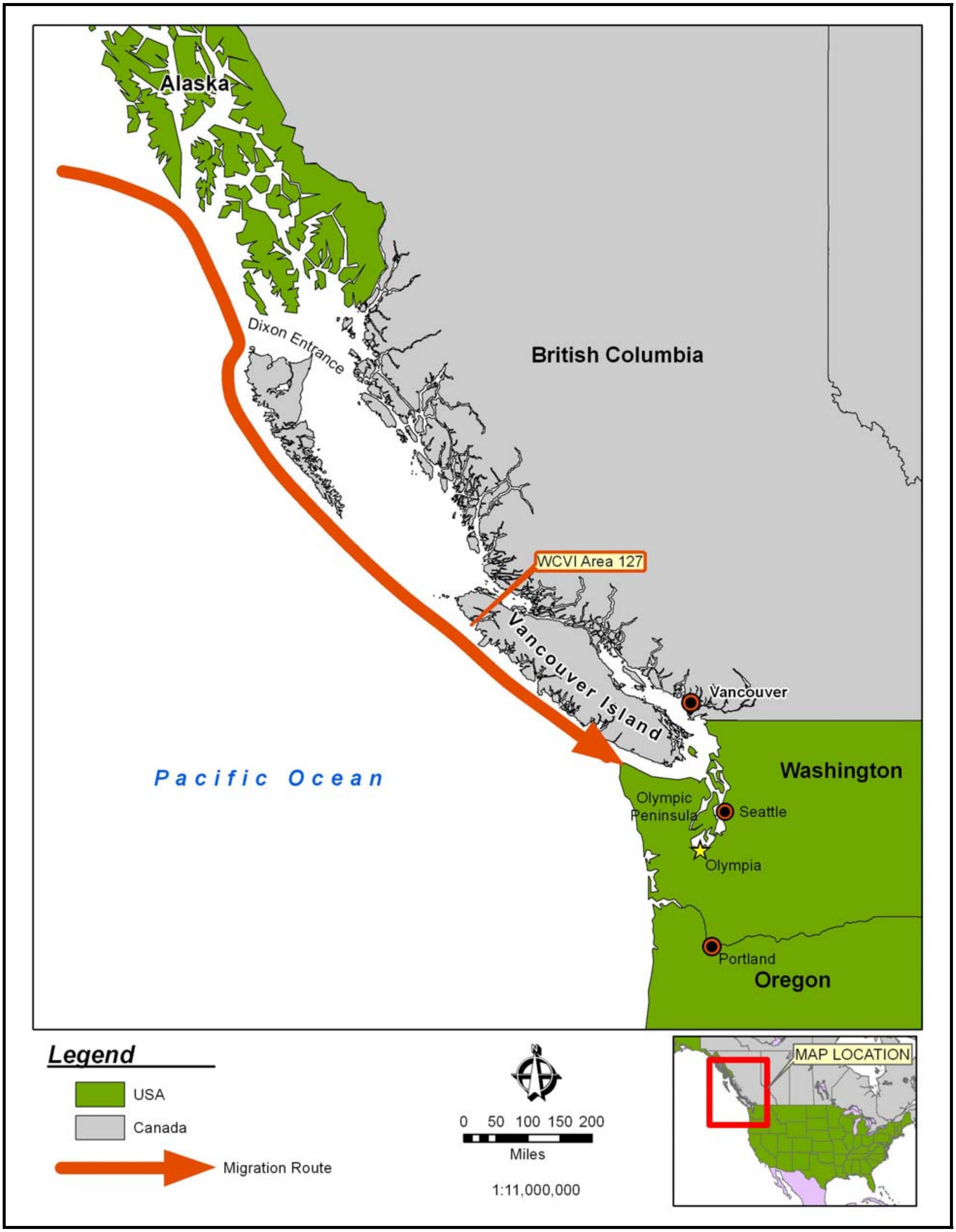

Figure 5.53. Assumed Lake Ozette sockeye ocean migration route.

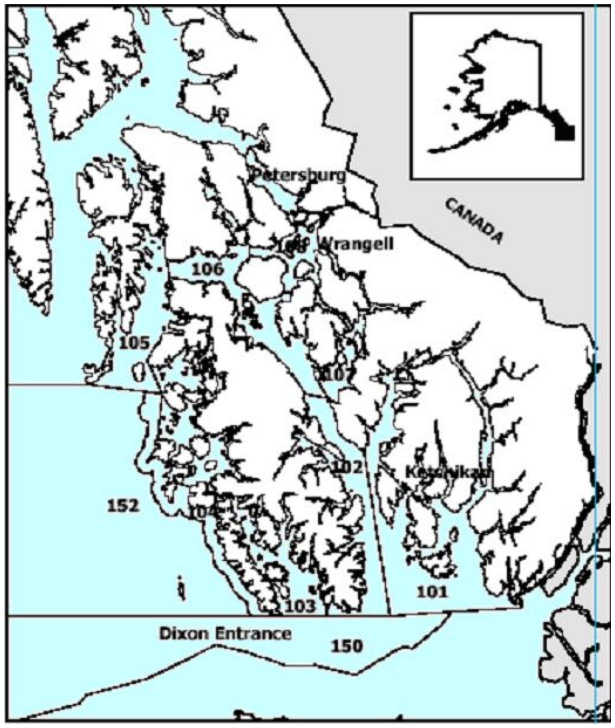

Figure 5.54. Alaska Department of Fish and Game southern Southeastern Alaska regulatory districts.

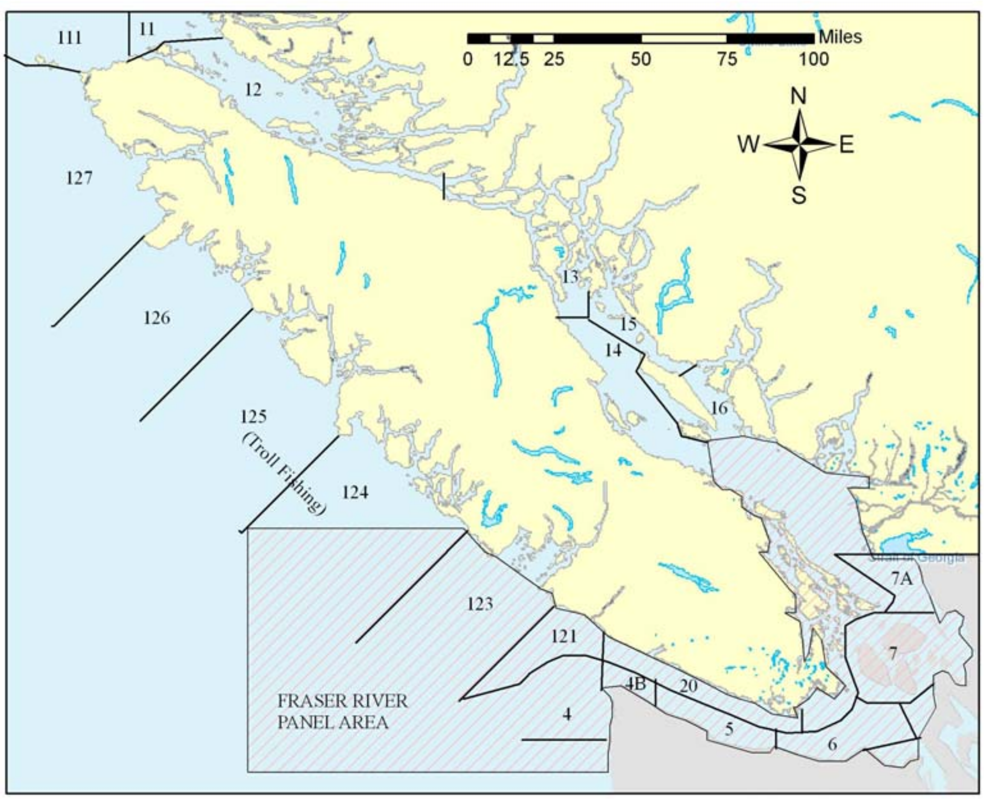

Figure 5.55. British Columbia and Washington State fishery management areas, including Fraser River Panel Area (boundaries and units are approximated).

Charts were assembled to compare Ozette sockeye migration timing with the timing of fisheries in recent years to determine whether the fisheries could be intercepting Ozette sockeye (Figure 5.56 and Figure 5.57). Purse seine fisheries in Alaska District 104 (Figure 5.54), directed at Southeast Alaska-origin pink salmon (and Skeena/Nass sockeye stocks), intercept inbound Fraser River sockeye in some years at significant levels. However, fisheries in District 104 have not commenced until early July in recent years, with peak sockeye catches occurring in early August. The fishery appears to occur too late in the season to pose a substantial threat of interception to Ozette sockeye (Figure 5.56).

Sockeye-directed troll fisheries occurring in West Coast Vancouver Island (WCVI) Areas 121-127 (Figure 5.55) harvested significant numbers of Fraser River sockeye salmon in the 1980s and early 1990s. However, this fishery has been virtually closed since 1996 for domestic allocation purposes. The estimated timing of Ozette sockeye salmon migration in the WCVI troll fishing areas would indicate that less than 10% could be subject to harvest in troll fisheries (Figure 5.57). The PSC Area 20 (Figure 5.55) gillnet test fishery commencing on or about June 21 each year may also intercept Ozette sockeye. Area 20 is approximately one day’s travel from the mouth of the Ozette River. Approximately 25% of run could be subject to harvest in the Area 20 test fishery (Figure 5.57).

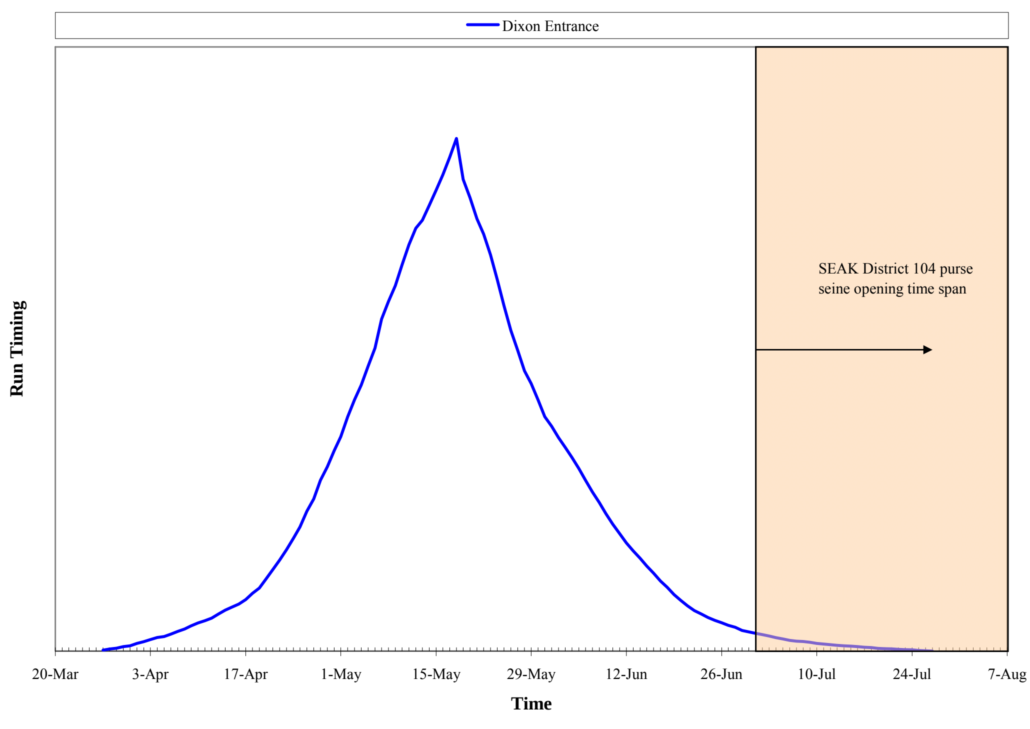

Figure 5.56. Estimated Lake Ozette sockeye Dixon Entrance migration timing compared with recent SEAK D104 purse seine opening time span.

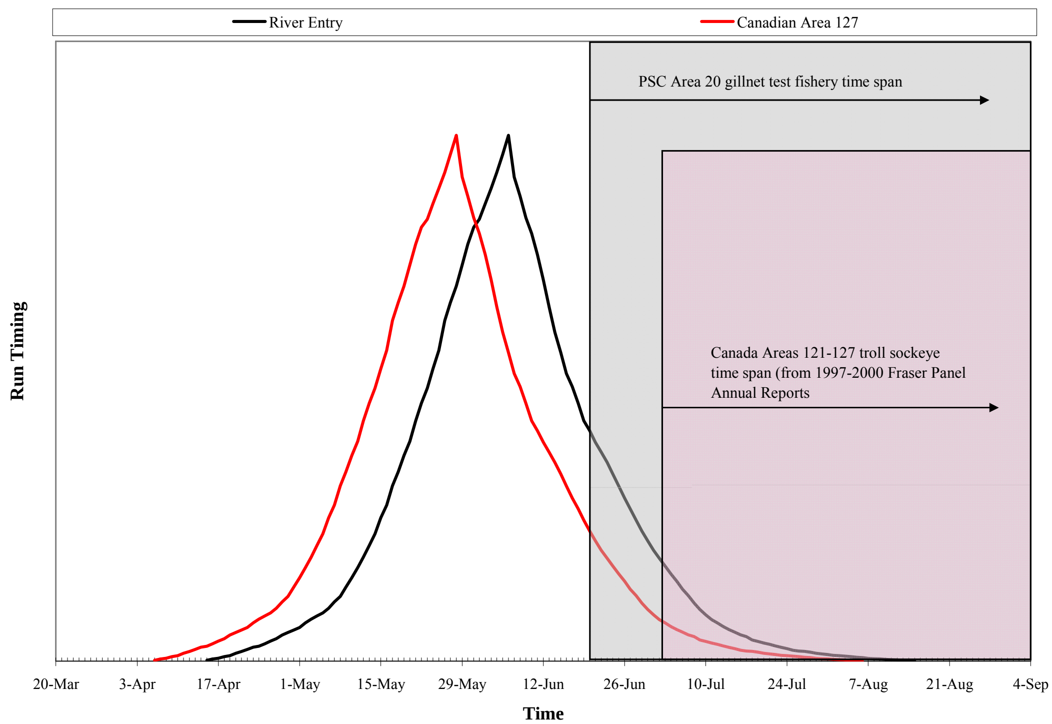

Figure 5.57. Estimated Lake Ozette sockeye WCVI migration timing compared with Canadian Areas 121-127 sockeye troll fisheries opening time span (1985-1995) and PSC Area 20 gillnet test fishery.

The Pacific Fishery Management Council ([PFMC] 2004) states that Council Area (southern U.S. coastal sport, commercial, and tribal fisheries) have no measurable impact on sockeye salmon. An additional review of recent (1995-2004) sport catch in coastal Washington fishing areas and Marine Areas 5 and 6 indicate that average sockeye catch is negligible. Partial time series sport catch data for these same areas from 1979 to 1994 further indicate that sport catch of sockeye salmon is negligible. Bycatch of sockeye in coastal whiting and bottom trawl fisheries also appears to be negligible, as few if any sockeye have been observed as bycatch.

5.6.2 Regional Sockeye Population Trends

In order to more fully understand potential mechanisms affecting Lake Ozette sockeye abundance at a scale larger than the Ozette watershed, time-series abundance data were compared to Lake Quinault sockeye abundance data to determine if similar trends in abundance are apparent between the two populations. Lake Quinault is located approximately 52 miles southwest of Lake Ozette, and is the closest sockeye population with long-term time series data on sockeye abundance. Lake Quinault sockeye exhibit several similar life-history strategies as Lake Ozette sockeye. Early run timing, protracted run timing, and long adult lake holding period before spawning (Gustafson et al. 1997) are key similarities between the two populations. Several dissimilarities between the populations also exist; for example Quinault sockeye are predominantly large river and tributary spawners (WDF et al. 1994). Recent abundance of Lake Quinault sockeye has been significantly reduced from historical abundance, similar to Ozette sockeye.

Lake Quinault sockeye run sizes averaged 234,212 from 1910 to 1956 (QIN, unpublished run size data). The last sockeye run greater than 200,000 adults occurred in 1956. From 1957 to 1975, the run size averaged 75,262 sockeye per year, representing an average run size reduction of 68%. From 1976-2004, the run size averaged 47,636 sockeye per year, representing an average run size reduction from the 1910-1956 period of 80%. The largest run size between 1910 and 2004 occurred in 1941 and was estimated to be 1,071,740 adult sockeye. The smallest adult return during this same time period occurred in 1999, when only 6,724 sockeye returned to Lake Quinault. The smallest return ever recorded was 0.6% of the highest return.

Run-size estimates for Lake Ozette sockeye are not available until the late 1970s. Harvest data are available from 1948 to present. Peak recorded harvest occurred in 1949, with 17,638 sockeye caught. Assuming 60% harvest rate results in an estimated run size of 29,396 sockeye in 1949. The smallest Lake Ozette sockeye run size estimate is for return year 1991, when 407 sockeye were estimated to enter the lake (assumes late run timing, estimate assuming mean 1998-03 run timing equals 1,520). The difference between the largest and smallest run size is approximately 1.3% using the estimates above. Recently the run size has averaged 3,600 sockeye (12% of highest abundance estimated from 1948 to present).

The abundance of both Quinault and Ozette sockeye have been significantly reduced from their historical numbers. Lake Quinault sockeye run sizes from 1996-2003 averaged 17% of the pre-1957 average run size. Ozette sockeye run sizes from 1996-2003 averaged 12% of the estimated peak abundance, which occurred in 1949. While the exact population reductions in both Lake Quinault and Lake Ozette sockeye will never be known, the estimates presented above are within the range of what could be reasonably expected. Interestingly, the estimated declines in Quinault and Ozette sockeye are within a very similar range. From 1957 to present neither of the populations has been able to produce a single return that approximates the size of returns observed prior to 1957.

6 ANALYSIS OF LIMITING FACTORS BY LIFE STAGE

Chapter 6 of the report summarizes and rates limiting factors presented in Chapter 5. Limiting factors are rated for degree of impact and synthesized in this chapter. This chapter includes an analysis of limiting factors by life stage and presents a series of limiting factors hypotheses and sub-hypotheses. These hypotheses are intended to serve as the scientific foundation for identifying recovery actions in the Lake Ozette sockeye recovery plan. The hypotheses cover all the limiting factors identified in this investigation; they are not restricted to key limiting factors. Each hypothesis presented in Sections 6.2.1 through 6.2.13 is supported by information presented in Chapters 1 through 5.

6.1 METHODS AND APPROACH

Each limiting factor hypothesis was evaluated based on the following definition of a limiting factor: physical, biological, or chemical conditions (e.g., inadequate spawning habitat, insufficient prey resources, or suspended sediment concentration) experienced by sockeye at the spawning aggregation scale, resulting in reductions in viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity). Limiting factors that affect sockeye at this scale affect subpopulations and threaten the viability of the ESU. Key limiting factors are those with the greatest impacts on a population's ability to reach its desired status.

The Lake Ozette Steering Committee's technical workgroup evaluated and rated each of the limiting factors hypotheses based upon the degree of impact on the population or sub-population during each life stage. The degree of impact of each limiting factor was categorized as one of the following: unknown, negligible, low, moderate, or high. Figure 6.1 and Figure 6.2 depict the degree of impact assigned to each of the primary limiting factors by life stage. Table 6.1, Table 6.2, and Table 6.3 include all limiting factors ratings by life stage for each sub-population, as well as both sub-populations combined (during lake residency/adult holding).

Section 6.2 includes a narrative description of the degree of impact and certainty of impact based on the workgroup's limiting factors ratings. These ratings are qualitative and are based on the workgroup's knowledge of Lake Ozette sockeye. In addition, a narrative describing the rationale for determining a specific degree of impact and certainty of impact is included. It is important to note that many data gaps exist within the Ozette watershed and our understanding of limiting factors is based upon a limited number of studies and/or data limited to certain life history stages. Continued monitoring and additional studies are needed to fill data gaps in the future (see Chapter 7).

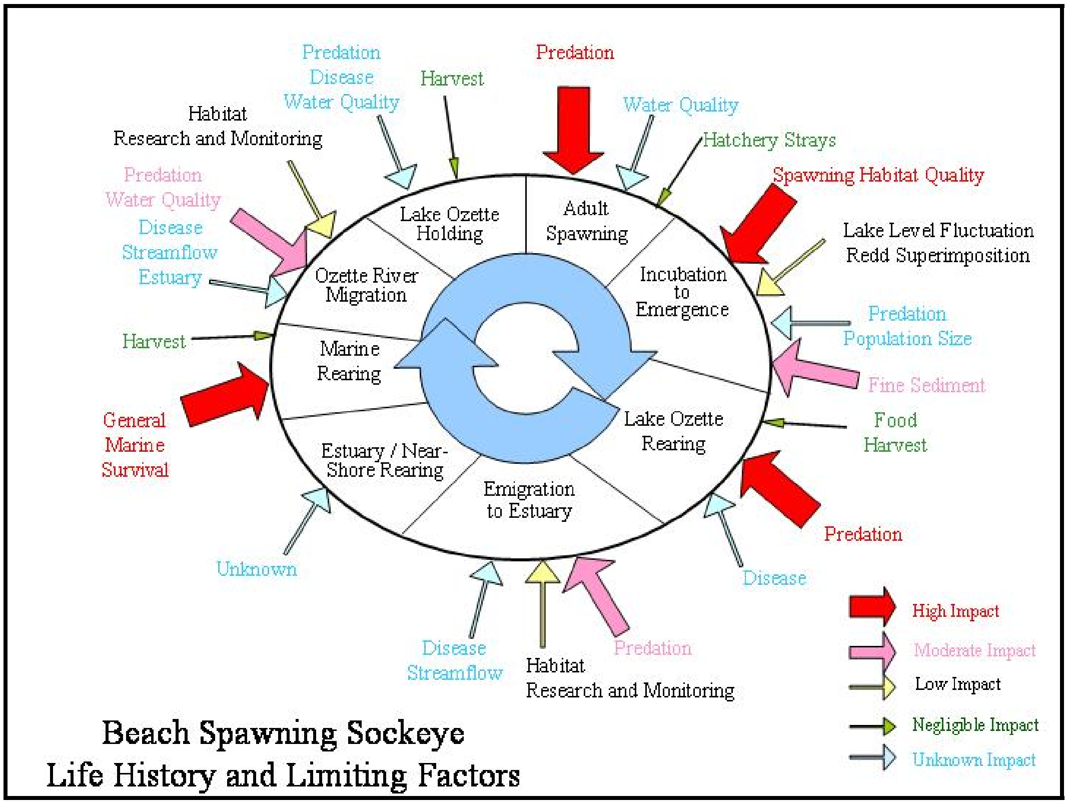

Figure 6.1. Beach spawning sockeye life history and rated limiting factors.

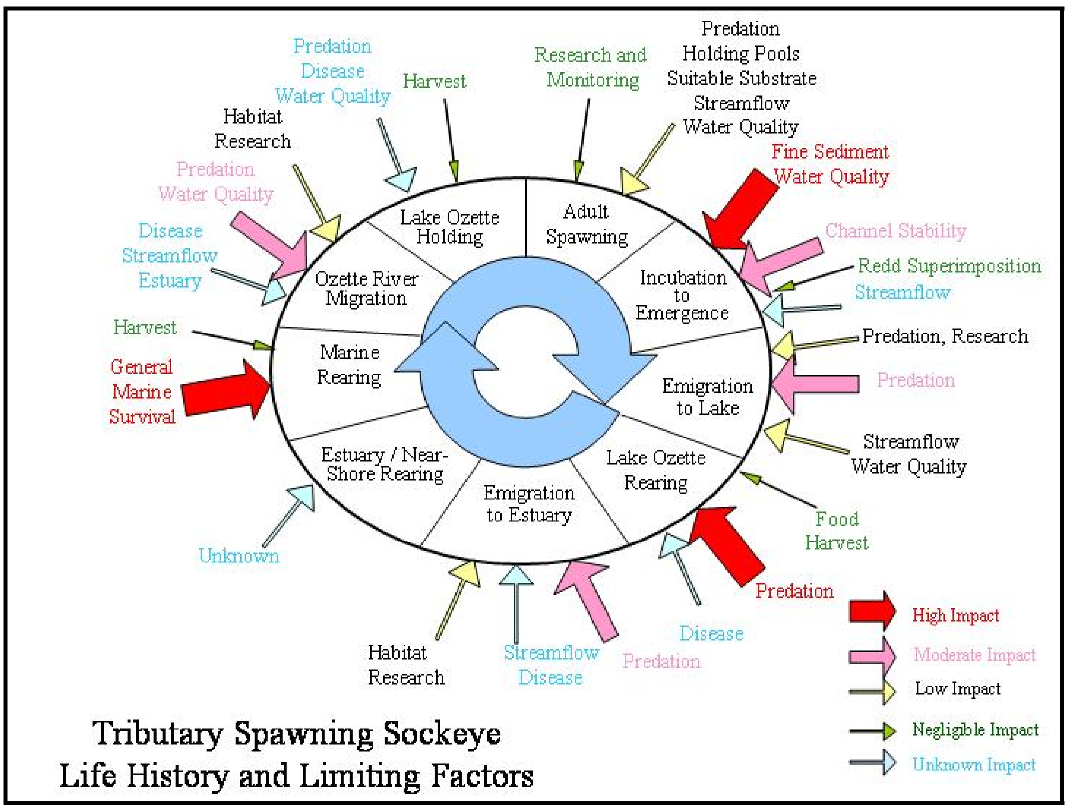

Figure 6.2. Tributary spawning sockeye life history and rated limiting factors.

Table 6.1. Limiting factors rating by life stage for both beach and tributary spawners during lake residency and adult holding.

SUB-POPULATION	LIMITING FACTOR	*LIFE HISTORY STAGE*				
		ADULT SOCKEYE ENTERING THE SYSTEM	ADULT SOCKEYE HOLDING IN LAKE	JUVENILE PELAGIC REARING	JUVENILE EMIGRATION	MARINE ENVIRONMENT
BOTH BEACH AND TRIBUTARY SPAWNERS	Predation	**Moderate** Hypothesis 1 Section 6.2.1.1	**Unknown** Hypothesis 7 Section 6.2.2	**High** Hypothesis 41 Section 6.2.11.1	**Moderate** Hypothesis 45 Section 6.2.12.1	**NA**
	Ozette River stream habitat	**Low** Hypothesis 2 Section 6.2.1.2	**NA**	**NA**	**Low** Hypothesis 46 Section6.2.12.2	**NA**
	Water quality (suspended sediment and temperature)	**Moderate** Hypothesis 3 Section 6.2.1.3	**Unknown** Hypothesis 7 Section 6.2.2	**NA**	**Low** Hypothesis 47 Section 6.2.12.3	**NA**
	Ozette River streamflow	**Unknown** Hypothesis 4 Section 6.2.1.4	**NA**	**NA**	**Unknown** Hypothesis 48 Section 6.2.12.4	**NA**
	Tidal prism/estuary alterations	**Unknown** No Hypothesis Section 6.2.1.5	**NA**	**NA**	**Unknown** No Hypothesis Section 6.2.12.5	**NA**
	Directed harvest	**None** Hypothesis 5 Section 6.2.1.6	**None** Hypothesis 8 Section 6.2.2.2	**None** Hypothesis 42 Section 6.2.11.2	**None** Hypothesis 49 Section 6.2.12.6	**None** Hypothesis 51 Section 6.2.13.1
	Non-directed harvest	**NA**	**Negligible** Hypothesis 9 Section 6.2.2.2	**Negligible** Hypothesis 43 Section 6.2.11.2	**NA**	**Negligible** Hypothesis 52 Section 6.2.13.1
	Disease	**Unknown** No Hypothesis Section 6.2.1.7	**Unknown** Hypothesis 7 Section 6.2.2	**Unknown** No Hypothesis Section 6.2.11.3	**Unknown** No Hypothesis Section 6.2.12.7	**NA**
	Feeding/food availability	**NA**	**NA**	**Negligible** Hypothesis 44 Section 6.2.11.4	**NA**	**NA**
	Research and monitoring	**Low** Hypothesis 6 Section 6.2.1.8	**NA**	**NA**	**Low** Hypothesis 50 Section 6.2.12.8	**NA**
	Marine Survival	**NA**	**NA**	**NA**	**NA**	**High** Hypothesis 53 Section 6.2.13.2

Table 6.2. Limiting factors rating by life stage for beach spawners.

SUB-POPULATION	LIMITING FACTORS	*LIFE HISTORY STAGE*			
		ADULT SOCKEYE STAGING ON BEACHES	ADULT SOCKEYE SPAWNING	EGG INCUBATION	FRY EMERGENCE AND MIGRATION TO PELAGIC ZONE
BEACH SPAWNERS	Predation	**Low** Hypothesis 11 Section 6.2.3.1	**High** Hypothesis 11 Section 6.2.4.1	**Unknown** No Hypothesis Section 6.2.5.2	**Unknown** Hypothesis 18 Section 6.2.6.2
	Suitable spawning substrate (size, position, intra-gravel flow cond.)	**NA**	**NA**	**High** Hypothesis 13 Section 6.2.5.1	**NA**
	Fines in gravel (quality and quantity)	**NA**	**NA**		**Moderate** Hypothesis 17 Section 6.2.6.1
	Changes in shoreline vegetation (quality and quantity)	**NA**	**NA**		**NA**
	Seasonal lake level changes	**NA**	**NA**	**Low to Moderate** Hypothesis 14 Section 6.2.5.3	**Low to Moderate** Hypothesis 14 Section 6.2.6.3 and 6.2.5.3
	Water quality	**Unknown** No Hypothesis Section 6.2.3.2	**Unknown** No Hypothesis Section 6.2.4.2	**NA**	**NA**
	Small population size (habitat maintenance)	**NA**	**NA**	**Unknown** Hypothesis 16 Section 6.2.5.5	**NA**
	Competition (redd superimposition)	**NA**	**NA**	**Low to Moderate** Hypothesis 15 Section 6.2.5.4	**NA**
	Genetic impacts from tributary hatchery strays	**NA**	**Negligible** Hypothesis 12 Section 6.2.4.3	**NA**	**NA**

Table 6.3. Limiting factors rating by life stage for tributary spawners.

SUB-POPULATION	LIMITING FACTORS	*LIFE HISTORY STAGE* ADULT SOCKEYE ENTERING TRIBUTARIES	ADULT SOCKEYE SPAWNING	EGG INCUBATION	FRY EMERGENCE AND MIGRATION TO PELAGIC ZONE
TRIBUTARY SPAWNERS	Predation	**Low** Hypothesis 19 Section 6.2.7.1	**Low** Hypothesis 24 Section 6.2.8.1	**Low** Hypothesis 36 Section 6.2.9.6	**Moderate** Hypothesis 38 Section 6.2.10.1
	Holding pools	**Low** Hypothesis 20 Section 6.2.7.2	**Low** Hypothesis 25 Section 6.2.8.2	**NA**	**NA**
	Suitable spawning substrate	**NA**	**Low** Hypothesis 26 Section 6.2.8.3	**NA**	**NA**
	Fines in gravel	**NA**	**NA**	**High** Hypothesis31 Section 6.2.9.1	**NA**
	Streamflow	**Low** Hypothesis 21 Section 6.2.7.3	**Low** Hypothesis 27 Section 6.2.8.4	**Unknown** Hypothesis 33 Section 6.2.9.3	**Low** Hypothesis 39 Section 6.2.10.2
	Channel stability and floodplain alterations (scour)	**NA**	**NA**	**Moderate** Hypothesis 32 Section 6.2.9.2	**NA**
	Interactions w/kokanee	**NA**	**Negligible to Low** Hypothesis 28 Section 6.2.8.5	**NA**	**NA**
	Water quality	**Low** Hypothesis 22 Section 6.2.7.4	**Low** Hypothesis 29 Section 6.2.8.6	**High** Hypothesis 34 Section 6.2.9.4	**Low** Hypothesis 40 Section 6.2.10.3
	Redd superimposition	**NA**	**NA**	**Neg. to Moderate** Hypothesis 35 Section 6.2.9.5	**NA**
	Research and monitoring	**Negligible** Hypothesis 23 Section 6.2.7.5	**Negligible** Hypothesis 30 Section 6.2.8.7	**Low** Hypothesis 37 Section 6.2.12.8	**NA**

6.2 LIMITING FACTORS HYPOTHESES BY LIFE STAGE

As described above, this section of the report presents a series of limiting factors hypotheses by life stage. Each hypothesis includes a narrative description of the degree of impact and certainty of impact in the workgroup's limiting factors rating. In addition, a narrative describing the rationale for determining a specific degree of impact and certainty of impact is included for each limiting factor hypothesis. Sub-hypotheses were developed for some complex limiting factors, which include linkage between each limiting factor and the processes and/or threats that may influence the limiting factor. Most sub-hypotheses include a link to the subsection of the report where detailed supporting evidence can be found. Not all sub-hypotheses include detailed narrative descriptions in other subsections of the report; some were included because members of the rating workgroup considered them important. The following limiting factors hypotheses are intended to serve as the scientific foundation for designing recovery actions for the Lake Ozette Sockeye Recovery Plan.

6.2.1 Adult Sockeye Salmon Entering System

The primary limiting factors affecting sockeye salmon entering the Ozette River and migrating to Lake Ozette include aquatic mammal predation (Section 6.2.1.1), Ozette River habitat conditions (Section 6.2.1.2), water quality (Section 6.2.1.3), and research and monitoring (Section 6.2.1.8). Additional limiting factors include reduced low flows (Section 6.2.1.4), changes in tidal prism and physical estuarine habitat conditions (Section 6.2.1.5), and disease (Section 6.2.1.7). The population impact of these additional limiting factors is unknown. No impact on sockeye salmon results from permitted in-river sport or tribal fisheries (Section 6.2.1.6).

6.2.1.1 Aquatic Mammal Predation

Hypothesis 1: Sockeye predation by aquatic mammals, primarily harbor seals and river otters in the Ozette River, estuary, and nearshore environment, reduces the number of effective spawners and therefore reduces the size of the sockeye population.

LEVEL OF IMPACT: Moderate
CERTAINTY OF IMPACT: Moderate

RATIONALE: Sockeye entering Lake Ozette have a high incidence of predator induced scarring and open wounds (~30-50%). A mark and recapture study conducted in 2000 (Gearin et al. 2002) indicates that 10% of the sockeye recaptured entering the lake were wounded by seals and otters in the Ozette River, while up to an additional 50% of the fish marked downstream were not successfully recaptured entering the lake, suggesting that a significant but unquantifiable level of aquatic mammal predation occurs in the river, estuary, and nearshore environment. The level of impact on the population is thought to increase as the run size decreases, so the actual level of impact was rated as moderate for periods of low abundance and low during periods of moderate to high abundance. Tributary sockeye can buffer the effects of predation on the beach spawning population by increasing the number of sockeye entering freshwater and potentially "swamping" predators (see Sections 5.2.2 and 5.3.4).

Hypothesis 1A: Increases in the abundance of aquatic mammal predators within and adjacent to the Ozette watershed have increased the number of sockeye salmon killed by aquatic mammal predators (Sections 5.2.2.2.1, 5.2.2.2.2, 5.3.4.2.2, and 5.3.4.2.6).

Hypothesis 1B: Abandonment of the Ozette Village and fishing stations on the Ozette River have led to an increased number of aquatic mammals preying upon sockeye salmon within the estuary and river (Section 5.2.2.2.2).

Hypothesis 1C: The depressed nature of the Lake Ozette sockeye population influences the effect of aquatic mammal predation on the sockeye population. Low abundance of sockeye increases the rate of predation (Section 5.2.2.2.3).

Hypothesis 1D: Changes in the streamflow regime of the Ozette River affect migration conditions encountered by sockeye salmon, reduce predator avoidance capabilities and enhance predation efficiencies (Section 5.3.4.2.4).

Hypothesis 1E: Large woody debris removal has reduced the quantity and quality of pool habitat in the Ozette River. Resultant reduced pool depth, volume, and cover decreased predator avoidance capabilities and refuge areas for sockeye, increasing predator efficiency (Section 5.3.4.2.1).

Hypothesis 1F: Operation of the adult sockeye counting weir and smolt trap act as a bottleneck for migrating adult sockeye, increasing their susceptibility to predation (Section 5.3.4.2.7).

Hypothesis 1G: Large woody debris removal has enhanced the migration conditions for aquatic mammals in the Ozette River, allowing for unimpeded passage upstream; this influences harbor seals' ability to prey upon sockeye in the river (as well as providing unobstructed access to the lake during most flow conditions -; Section 5.3.4.2.1).

6.2.1.2 Ozette River Habitat Conditions

Hypothesis 2: Large woody debris removal has reduced the quantity and quality of pool habitat in the Ozette River. Resultant reduced pool depth, volume, and cover decreased predator avoidance capabilities and refuge areas for sockeye, increasing predator efficiency and reducing refuge habitat.

LEVEL OF IMPACT: Low

CERTAINTY OF IMPACT: Moderate

RATIONALE: The loss of large (>50 cm diameter) LWD in the Ozette River through removal operations has undoubtedly resulted in reduced habitat complexity throughout much if not all of the Ozette River. Riparian forest removal adjacent to the upper 0.4 miles of the Ozette River have reduced LWD inputs, delaying the recovery and habitat potential of the upper river. Adult sockeye spend a limited amount of time in the Ozette River, reducing their exposure to degraded habitat conditions. Habitat simplification mainly affects adult sockeye by reducing refuge habitat, making sockeye more susceptible to predation (Section 5.3.4.2.1).

6.2.1.3 Water Quality

Hypothesis 3: High stream temperatures and low frequency, high intensity turbidity events reduce the fitness of sockeye salmon entering Lake Ozette, and result in increased egg retention and pre-spawning mortality; in some cases, high stream temperatures exceeding 20°C result in direct en route mortality.

LEVEL OF IMPACT: Moderate
CERTAINTY OF IMPACT: Moderate

RATIONALE: High stream temperatures and low frequency, high intensity turbidity events occur during the sockeye migration period. Temperatures approaching 24°C have been recorded during the adult migration period. Sockeye covered in silt and bleeding from the gills have been observed following high turbidity and suspended sediment concentrations (hereafter, "SSC") events. Cumulatively, approximately 12% of the population on average would be exposed to high SSC events based upon the frequency and duration of these events during the migration period. These events would result in moderate physiological stress (Newcombe and Jansen 1996) based on the expected sockeye exposure times, which are a function of average measured migration times (Gearin et al. 2002). The level of impact of this limiting factor hypothesis was rated as moderate primarily based upon temperature impacts. Collectively, poor water quality conditions, especially during the later part of the run, are cause for concern (see Sections 4.3.5, 5.3.3, 5.3.3.1, 5.3.3.1.1, 5.3.3.1.2, and 5.3.3.2).

Hypothesis 3A: High stream temperatures in the Ozette River are a natural condition (see Sections 5.3.3.1, 5.3.3.1.1, and 5.3.3.1.2). However, increased summer air temperatures resulting from climate change have increased average water temperatures during the sockeye migration period by 1 to 2°C (based on average air temperature increases observed during the last 90 years for the months of June, July, and August in Forks WA). Continued and predicted climate change will likely continue to increase the temperature of the Ozette River, negatively affecting adult migrants.

Hypothesis 3B: The high road density (6.1 mi/mi^2), extensive clear cutting (98% of watershed clear-cut at least once), and channel incision (e.g., from LWD removal in the Ozette River) in the Coal Creek watershed have resulted in degraded water quality conditions (turbidity and SSC) in Coal Creek (Sections 4.4.4.4, 4.4.4.5, and 4.4.4.5.1) and the Ozette River to the detriment of migrating adults' health and survival (Sections 4.3.4, 4.3.5, 5.3.3, and 5.3.3.2).

Hypothesis 3C: Removal of LWD has resulted in decreased depth, complexity and availability of pools that serve as refuge areas from temperature (and low flows), resulting in higher stress potential during migration (Sections 4.3.3, 5.3.3.1, 5.3.3.1.1, and 5.3.3.1.2.

Hypothesis 3D: Warmer water temperatures, earlier in the season, have shifted marine area migration and freshwater entry timing earlier during the last 30 years.

6.2.1.4 Streamflow

Hypothesis 4: Sedimentation in the Ozette River from Coal Creek has reduced the quantity of water available as streamflow from the lake at a given stage. Changes in this stage discharge relationship, changes in hyporheic and surface flow conditions, increased lake evapotranspiration, and reductions in tributary baseflow inputs have reduced summer low flows. Reduced streamflows affect water quality, predation rates and efficiency, and migration, reducing the fitness of migrating adult sockeye.

LEVEL OF IMPACT: Unknown
CERTAINTY OF IMPACT: NA

RATIONALE: Available discharge data for the Ozette River at the lake outlet indicate a clear trend of decreasing baseflow (summer discharge) over time from the 1970s to 2000s (See Figure 4.33, Figure 4.42, Figure 4.44). The decrease is likely caused by multiple factors acting cumulatively over time.

Available data do not indicate that climatic controls on precipitation or lake level have changed dramatically over time to influence Ozette River discharge. Rather, internal mechanisms are at play (see Section 5.3.2.2.1.1). A significant change in the stage-discharge relationship occurred in the Ozette River between 1979 and 2002 (Section 4.3.6; Figure 4.37), indicating that discharges in Ozette River are lower for a given stage in 2002 compared to 1979 (Section 5.3.2.2.1.2). The percentage of hyporheic flow to total flow may have changed due to sedimentation near the confluence of the Ozette River and Coal Creek (Section 5.3.2.2.1.3). Shoreline vegetation colonization of the perimeter of Lake Ozette has increased evapotranspiration, potentially influencing lake levels and thus river discharge (Section 5.3.2.2.1.4). Summer base flows to Lake Ozette may have declined due the effects of land use on fog drip, summer transpiration efficiency of dominant vegetation, soil water retention, and floodplain water storage (Section 5.3.2.2.1.5). These hypothesized reductions in summer water inputs to Lake Ozette could translate to reduced Ozette River discharge.

Reduced streamflow has the potential to affect water quality, predation rates and efficiency, and migration, reducing the fitness of migrating adult sockeye. For example in RY 2003 just under 38% of the sockeye entered when lake levels were less than 100 cfs. Approximately 10% of the RY 2003 sockeye entered the lake when flows were less than 35 cfs and the lowest flow in which sockeye were observed migrating was 11 cfs. The overall decrease in baseflow (summer discharge) during the sockeye migration period remains unknown and the relative contribution of the aforementioned factors is poorly understood, as are the biological effects.

6.2.1.5 Tidal Prism and Physical Estuarine Habitat Conditions

Changes in the tidal prism and estuarine habitat conditions appear to have occurred during the last 50 years (see Section 4.1). The cause of these apparent changes is poorly understood, as are the potential effects on Lake Ozette sockeye.

6.2.1.6 Fisheries Impacts

Hypothesis 5: There are no open fisheries within the Ozette River during the adult sockeye migration period and therefore there are no impacts on sockeye salmon from in-river fisheries.

LEVEL OF IMPACT: None
CERTAINTY OF IMPACT: High

RATIONALE: The river is closed to all sport fishing until August 1st. When the river is open, selective fishery rules apply and all sockeye must immediately be released. There are no non-directed fishery impacts during the adult migration due to permitted fisheries. No tribal salmon fisheries are conducted within the watershed (see Section 5.2.3). Some poaching may occur but poaching has not been documented by the NPS.

6.2.1.7 Disease

No systematic monitoring of sockeye health in the river occurs. Observations of infections and fungus growth are occasionally included in weir observation notes but no systematic inventory data are collected. Trapping work conducted in during RY 2000 visually examined 899 sockeye for external tags and physical condition. Less than 1% of the sockeye transiting the weir had visible fungal growth. However, at least some individual sockeye have been observed with severe external infections and likely die prior to reaching the spawning grounds (see Section 5.4.6).

6.2.1.8 Research and Monitoring

Hypothesis 6: Operation of the adult sockeye counting weir and smolt trap result in limited, if any, direct impacts on sockeye resulting from encounters with counting equipment. However, the weir acts as a bottleneck for migrating adult sockeye, increasing their susceptibility to predation, and delays upstream migration, increasing exposure time to poor water quality conditions.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: High

RATIONALE: No direct mortalities at the weir resulting from encounters with weir and smolt trapping equipment have been documented. However, adult sockeye migrating into the lake are especially susceptible to predators as they transit the weir. The weir acts as a bottleneck to migrating sockeye; harbor seals and river otters appear to use the weir as an aid in hunting. Seals and otters have frequently been observed working the face of the weir, swimming back and forth across the river in search for sockeye. It appears that the degree to which the weir and trapping operations increase adult sockeye salmon susceptibility to predation increases as lake level declines (see Section 5.3.4.2.7). The counting weir may also delay migrants from entering the lake and increase their exposure time to elevated stream temperatures and/or high SSC. Weir operations since 1998 have been conducted with the weir left open 24 hrs/day to allow free passage into the lake in order to minimize impacts of high water quality and predation caused by the weir (5.3.3.1.2).

6.2.2 Adult Sockeye Holding in Lake Ozette

The primary limiting factors affecting sockeye salmon holding in Lake Ozette include predation, disease, and water quality (Section 6.2.2.1). Negligible impacts were attributed to sport fisheries occurring within the lake (Section 6.2.2.2).

6.2.2.1 Predation, Disease, and Water Quality

Hypothesis 7: The number of sockeye surviving to spawn is reduced by predators, disease, and other factors during the extended holding period in Lake Ozette prior to spawning.

LEVEL OF IMPACT: Unknown
CERTAINTY OF IMPACT: NA

RATIONALE: The disposition of adult sockeye entering the lake and holding for several months prior to spawning is unknown. Assessment of population status and mortality rates during the holding period is complicated by the relatively large size of the lake, the small size of the population, sockeye holding behavior, and limnological conditions that limit direct observations of sockeye mortalities and the number of sockeye surviving to spawn in the lake. Limiting factors affecting sockeye holding in Lake Ozette include: (1) predation by aquatic mammals (see Sections 5.4.5, 5.4.5.1.1, and 5.4.5.1.2): (2) disease (see Section 5.4.6): and (3) delayed pre-spawning mortality related to decreased fitness (e.g. from elevated temperature; see Sections 4.2.3, 4.3.5, 4.3.6, 5.3.2.2, 5.3.3.1, 5.3.3.1.1, 5.3.3.1.2, and 5.3.3.2) or a combination of these factors. The degree to which any of these factors limit sockeye survival is unknown and remains a data gap.

6.2.2.2 Fisheries Impacts

Hypothesis 8: Very low numbers (if any) of sockeye are caught in ONP's Lake Ozette catch and release fishery.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: Moderate

RATIONALE: The lake is open to catch and release salmon fishing and therefore there are potential impacts on sockeye attributable to directed salmon fisheries occurring in the lake. However, it is unlikely that individuals actually target sockeye in the lake. There are no data regarding fishing pressure (e.g. angler days) or targeted sockeye encounters within the lake. The above conclusions are based on experience and knowledge of the Lake Ozette sport fisheries by members of the limiting factors rating workgroup.

Hypothesis 9: Incidental hooking and catching of sockeye salmon occurs at an extremely low levels (if any) within the lake during sport fisheries targeting trout, bass, or other non-salmon species. Incidental hooking or catching of sockeye salmon has a negligible effect on the sockeye population.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: Moderate

RATIONALE: Lake Ozette is large and currently only a few thousand adult sockeye are present within the lake at any given time, reducing the likelihood of incidental hooking in sport fisheries targeting other species. Sockeye salmon are typically poor biters in freshwater, a behavior that further reduces the probability of incidental hooking. Additionally, Lake Ozette has low fishing pressure, which also reduces the potential impact of incidental hooking and/or catching within the lake. There are no data regarding fishing pressure (e.g. angler days) or non-targeted sockeye encounters within the lake; these conclusions are based on the experience and knowledge of members of the limiting factors rating workgroup about the Lake Ozette sport fisheries.

6.2.3 Adult Sockeye Staging at Spawning Beaches

The primary limiting factors affecting sockeye salmon staging along the spawning beaches are predation (Section 6.2.3.1) and water quality (Section 6.2.3.2).

6.2.3.1 Predation

Hypothesis 10: Predation of adult sockeye salmon primarily by harbor seals and river otters during the pre-spawning staging period reduces the number of effective spawners and therefore reduces the size of the sockeye population.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Low

RATIONALE: Indirect observational data suggests that sockeye salmon are much less vulnerable to predation during the pre-spawning staging period because the fish hold offshore, in deeper water, and at lower densities, making them less susceptible to predation. Most pre-spawning mortality from predation is thought to occur on the spawning grounds rather than in the off-shore staging environment. However, no direct estimates of predation-related mortality have been made during the sockeye staging period. High impacts on sockeye are attributed to predation on the spawning grounds (see Sections 5.4.5, 5.4.5.1.1, 5.4.5.1.2, and 6.2.4.1).

6.2.3.2 Water Quality

The effects of water quality on sockeye salmon during the staging period are unknown and remain a data gap. However, limited water quality data collected in the offshore environment suggest that conditions are favorable for sockeye and that water quality is not likely a significant limiting factor during this life history stage. Sockeye are exposed to less optimal water quality conditions closer to the shoreline and near tributary outfalls (see Sections 5.4.3 and 6.2.4.2). For a complete review of water quality conditions see Sections 4.2.3, 4.4.1.5, 4.4.2.5, 4.4.3.5, 4.4.4.5, 4.4.5.5, 5.3.3, 5.3.3.1, 5.3.3.1.1, 5.3.3.1.2, and 5.3.3.2

6.2.4 Adult Sockeye Spawning on Lake Beaches

Predation (Section 6.2.4.1) is the primary limiting factor affecting sockeye salmon spawning on the beaches. Other limiting factors identified are water quality (Section 6.2.4.2) and genetic impacts from tributary hatchery strays (6.2.4.3).

6.2.4.1 Predation

Hypothesis 11: Predation of adult sockeye salmon primarily by harbor seals and river otters reduces the number of effective spawners and therefore reduces the size of the sockeye population.

LEVEL OF IMPACT: High
CERTAINTY OF IMPACT: Moderate

RATIONALE: Data collected during the spawning season in 2000 suggest that 40% or more of the sockeye at Allen's Beach were killed by harbor seals and river otters prior to completion of spawning. Data from Olsen's Beach during the same year indicates that approximately 10% of the spawners were killed by seals and otters. Both predatory mammal species have been observed foraging at known beach spawning areas during the sockeye spawning period. Continued monitoring is needed to fully document the degree of predation occurring, but the limited data collected to date indicate the potential for substantial predation on the spawning grounds (see Sections 5.4.5, 5.4.5.1.1, and 5.4.5.1.2).

Hypothesis 11A: Increases in the abundance of aquatic mammal predators within the Ozette watershed have led to an increase in the number of sockeye salmon killed by aquatic mammal predators (Sections 5.2.2.2.1, 5.2.2.2.2, 5.3.4.2.2, and 5.3.4.2.6).

Hypothesis 11B: Abandonment of the Ozette Village and fishing stations on the lake has led to an increase in the number of aquatic mammals preying upon sockeye salmon in the lake and on the spawning beaches (Section 5.2.2.2.2).

Hypothesis 11C: Protections afforded by the Federal Marine Mammal Protection Act and by anti-hunting/trapping rules implemented by ONP have contributed to the increasing number of aquatic mammal predators on spawning beaches, resulting in increased sockeye pre-spawning mortality due to predation (Sections 5.2.2.2.1 and 5.3.4.2.6).

Hypothesis 11D: The depressed nature of the Lake Ozette sockeye population enhances the effect of aquatic mammal predation on the sockeye population; low abundance of sockeye increases the realized rate of predation (Section 5.2.2.2.3).

Hypothesis 11E: Predation on sockeye congregating on the spawning beaches is a newly developed strategy for harbor seals. No seals were observed in the lake until the mid- to late1980s, and, with this new behavior, it can be assumed that predation impacts on beach spawning sockeye have increased relative to historical levels (Section 5.4.5.2.2).

6.2.4.2 Water Quality

High turbidity and SSC levels in tributaries to the lake can result in high turbidity levels along the lake shoreline. The frequency of high turbidity events and the direct effect on spawning sockeye are unknown but may include moderate physiological stress, habitat avoidance, and spawning habitat degradation. Turbidity and SSC data are lacking on the extant spawning beaches and are considered an important data gap. In general, existing beach spawning habitats, especially Allen's Beach, are less susceptible to stream-derived turbidity and SSC (due to proximity to major sediment sources from eastern tributaries). However, at historical spawning sites, such as Umbrella Beach, turbidity impacts are expected to be similar to those in Umbrella Creek (see Section 6.2.8.6).

6.2.4.3 Tributary Hatchery Program Impacts

Hypothesis 12: Straying of tributary hatchery program sockeye adults to beach spawning areas adversely affects the genetic diversity and fitness of the beach spawning population.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: High

RATIONALE: Hatchery practices implemented through the HGMP include measures to minimize potential disease and genetic impacts on beach spawning aggregations (see Sections 3.2.3 and 5.4.7). Imprinting juvenile sockeye using on-station rearing in release watersheds reduces the risk of hatchery-origin sockeye straying onto beaches. Mark and recapture data collected at Olsen's and Allen's beaches indicates that few if any Umbrella Creek hatchery releases return to spawn on Lake Ozette beaches. Approximately 25% of the BY 1995 Umbrella Creek fed fry released were adipose fin clipped and in 1999, 121 adult sockeye salmon were sampled on Olsen's Beach and none were adipose fin clipped. This suggests that straying from tributary releases onto spawning beaches was nonexistent or at least very low (MFM 2000). Spawning adults returning from hatchery releases after 1999 were mass marked using thermal otolith marks (100% marking), as well as fin clips (45% of all fry and fingerlings since BY 1999 have been fin clipped) allowing for monitoring of hatchery-origin fish throughout the watershed. The results from otolith sampling are not yet available. Also, note that sockeye straying onto Olsen's Beach are likely to have a limited genetic impact if successful spawning occurs, since Olsen's and Umbrella Creek sockeye share common genetics (Hawkins 2004).

6.2.5 Sockeye Egg Incubation on Beaches

The primary limiting factors affecting sockeye salmon egg incubation on the beaches include reduced spawning habitat quality and quantity (Section 6.2.5.1), predation (Section 6.2.5.2), and seasonal lake level changes (Section 6.2.5.3). The small population size on the spawning beaches during the last 30-40 years has had an unknown degree of impact on the quality and quantity of spawning habitat (see Section 6.2.5.5).

Competition (Section 6.2.5.4) for reduced spawning area has also been identified as a limiting factor affecting the recovery of Ozette sockeye.

6.2.5.1 Reduced Spawning Habitat Quality and Quantity

Hypothesis 13: Reduced quality and quantity of beach spawning habitat in Lake Ozette has decreased egg to emergence survival, resulting in reduced fry production from the beach spawning aggregations.

LEVEL OF IMPACT: High
CERTAINTY OF IMPACT: High

RATIONALE: The quality and quantity of beach spawning habitat varies by spawning beach and site within each of the extant spawning beaches (see Section 4.2.1). The results of egg incubation studies on Olsen's Beach strongly suggest that egg survival is extremely poor (<<10%) within most of the primary spawning area. Not all egg mortality in tests could be explained by fine sediment concentrations alone. Several environmental variables are likely at work collectively reducing egg survival. Sockeye salmon egg-to-fry survival on Lake Ozette beaches is limited by lack of adequate oxygen exchange from incubation water to the eggs, caused independently by two primary factors and their synergistic interactions: 1) reduced intergravel flows and 2) high levels of fine sediment (i.e. < 0.85mm). Fine sediment levels and intergravel flows are partially controlled by lake level, wave energy, tributary sediment inputs, vegetation, seasonal groundwater levels, and other mechanisms. The synergistic effects of multiple variables (inputs/processes/actions) that interact to limit egg to emergence survival make it extremely difficult to link each specific process or input to a specific level of impact. Cumulatively, incubation conditions (lake level, fine sediment, vegetation, intra-gravel flow, etc…) on the spawning beaches are poor and the impact was therefore rated as high (see Section 5.4.2.1).

Fine sediment levels exceed 25% (dry method; wet sieve equivalent ~37%) on the remaining spawning beaches. Fine sediment levels exceed 50% at Umbrella Beach (from Herrera 2006). Increased sediment production in tributaries and delivery to spawning beaches have decreased the quantity of spawning habitat available (see Sections 5.4.2.2 and 5.4.2.2.1). The total quantity of spawning habitat eliminated because of increased fine sediment deposition altering substrate size and character is unknown, but at least one entire spawning beach has been lost (Umbrella Beach). Quantification of lost spawning habitat due to lake level alterations from wood removal in the Ozette River is presented in detail in Section 5.4.2.2.2. Vegetation colonization along the shoreline of the lake between 1953 and 2003 resulted in a 56% net decrease in the quantity of unvegetated shoreline (Section 5.4.2.2.3).

The Olsen's Beach spawning population has been reduced to very few individuals in the recent past (see Figure 3.25) and has rebounded back to several hundred spawners in following years, suggesting that a limited amount of highly productive spawning habitat may still exist at Olsen's Beach.

Hypothesis 13A: Large woody debris removal from the Ozette River has reduced average lake levels during the spawning and incubation period, resulting in decreased spawning habitat availability, especially along the upper margins of shallow beach areas (Section 5.4.2.2.2).

Hypothesis 13B: Wood removal from Ozette River, coupled with alteration of watershed hydrology by land use, has changed the variability of lake levels, which has reduced the time that spawning habitat is available or that redds are covered in water (Sections 4.2.5, 5.4.1, 5.4.1.1, and 5.5.1.2.2).

Hypothesis 13C: Alterations in lake level variability from lake-outlet wood removal and tributary-inflow hydrologic change, coupled with tributary wood removal and channel incision, have altered hyporheic and groundwater hydraulics and hydrology. Altered hydrology shifted emergent (upwelling) hyporheic or groundwater rates and locations (lateral and vertical) along the shoreline of the lake and tributary deltas, thereby reducing egg-to-fry survival on historically used spawning beaches. (Note: this sub-hypothesis has not been thoroughly investigated and there are no supporting data.)

Hypothesis 13D: Extensive road construction has altered groundwater hydrology, shifting emergent (upwelling) groundwater rates and locations (lateral and vertical) along the shoreline of the lake, thereby reducing egg-to-fry survival on historically used spawning beaches (Note: this hypothesis has not been thoroughly investigated and there are no supporting data.)

Hypothesis 13E: Large woody debris removal from Ozette River has reduced average lake levels during the growing season and enhanced the ability of vegetation to colonize beach spawning habitat and trap fine sediment (Sections 5.4.2.1.1.3 and 5.4.2.2.3; see also Herrera 2005).

Hypothesis 13F: Vegetation encroachment along the shoreline of Lake Ozette during the last 30-100 years has significantly decreased the quality and quantity of beach spawning habitat available (Sections 4.2.1, and 5.4.2.1.1.3).

Hypothesis 13G: Large woody debris removal from Ozette River has reduced average lake levels, resulting in channel incision in tributaries and a subsequent release of stored sediment into the lake and beach spawning habitats, contributing to the elimination of at least one of the historical spawning sub-populations (Umbrella Beach) (Section 5.4.2.1.1.1; see also Herrera 2005, 2006).

Hypothesis 13H: Increased sediment production in tributaries from land use activities (e.g. road building, clearcut logging, etc) and delivery to lake beaches has decreased the quantity and quality of beach spawning habitat that is available for successful egg incubation, contributing to the elimination of at least one of the historical spawning sub-populations (Umbrella Beach; Section 5.4.2.1.1.1).

Hypothesis 13I: Small beach spawning population sizes during the last 30-40 years have been incapable of maintaining suitable spawning habitat and mitigating the increased levels of fine sediment and vegetation along beach spawning habitats (Section 5.4.2.1.1.2).

Hypothesis 13J: Reduced spawning habitat quality and quantity have increased competition for suitable habitat at low to moderate spawning escapement levels, resulting in increased redd superimposition and decreased egg-to-fry survival (see Section 6.2.5.4).

6.2.5.2 Egg Predation

Egg predation occurs at unknown levels on the spawning beaches. Known predators of sockeye eggs at Lake Ozette include sculpins (see Sections 2.2.2 and 5.4.5.1.5) and aquatic insects (see Section 5.4.5). Currently there is no evidence that suggests that egg predation has increased relative to historical baseline levels. However, at low spawning escapement levels egg predation could play an important role in limiting population growth as a result of the potential depensatory effects of predation.

6.2.5.3 Seasonal Lake Level Changes

Hypothesis 14: Seasonal lake level changes result in redd dewatering limiting survival to emergence.

LEVEL OF IMPACT: Low to Moderate
CERTAINTY OF IMPACT: High

RATIONALE: The level of impact varies depending upon redd elevations relative to water surface elevation at emergence. Detailed redd mapping on Olsen's Beach during the winter of 2000/01 indicated that approximately 3% of the total redd surface area (7 total redds) was completely dewatered at the time of emergence. Spawning surveys conducted between 1999 and 2004 do not indicate that high levels of redd dewatering are occurring in Lake Ozette (see Section 5.4.1.1). However, high lake levels early in the spawning season followed by drought conditions would likely result in moderate levels of redd dewatering when winter lake levels reach levels below 33 ft (MSL- NGVD 1929).

6.2.5.4 Competition (Redd superimposition)

Hypothesis 15: Reduced spawning habitat quality and quantity have increased the competition for suitable habitat at low to moderate spawning escapement levels, resulting in increased redd superimposition and decreased egg-to-fry survival.

LEVEL OF IMPACT: Low to Moderate
CERTAINTY OF IMPACT: Moderate

RATIONALE: The impact was rated as moderate for the Olsen's Beach core spawning area and low for all other sites. Redd superimposition on the spawning beaches is thought to significantly reduce the survival of earlier deposited eggs on the spawning beaches. The degree to which this is occurring is difficult to measure but sockeye spawning on Olsen's Beach seem to be especially prone to multiple spawning events in the same location during the same season. As described in Section 3.1.4, during RY 2000, sockeye were observed spawning in the same location over an 89-day period and more than 90% of the redd surface area measured had been spawned-in multiple times during the spawning season. These observations provide additional evidence that suitable/preferred spawning area is limited. Since Ozette sockeye appear to prefer areas with springs and seeps for spawning, it is thought that alterations in the location, degree, and depth of upwelling could negatively affect beach spawning; although no such alterations have been documented (see Section 5.4.2.3).

6.2.5.5 Small Population Size

Hypothesis 16: Small beach spawning population sizes during the last 30-40 years have been incapable of maintaining suitable spawning habitat and mitigating fine sediment inputs and vegetation colonization along some of the beach spawning habitats.

LEVEL OF IMPACT: Unknown
CERTAINTY OF IMPACT: NA

RATIONALE: The small beach spawning aggregations that have persisted during the last 30 years may have been reduced to levels incapable of sufficiently cleaning spawning gravels and maintaining vegetation-free spawning gravels. During the act of spawning, salmonids winnow fine sediment from spawning substrate (Kondolf et al. 1993). Lack of sufficient numbers of spawners could result in degraded habitat conditions, as well as increased levels of fine sediment within spawning gravels. The reduction of mass spawning fish populations such as sockeye, as a result of other limiting factors (e.g. overfishing) has been hypothesized to create a negative feedback loop due to reduced gravel bed maintenance of fine sediment levels in lake or streams, or scour depths in streams (Montgomery et al. 1996; see Section 5.4.2.1.1.2).

6.2.6 Lake Beach Fry Emergence and Dispersal

The primary limiting factors affecting sockeye salmon egg incubation on the beaches include fine sediment (Section 6.2.6.1), predation (Section 6.2.6.2), and seasonal lake levels changes (Section6.2.6.3).

6.2.6.1 Fine Sediment

Hypothesis 17: Fine sediment deposition in sockeye redds reduces the ability of surviving fry to emerge from gravel.

LEVEL OF IMPACT: Moderate
CERTAINTY OF IMPACT: Moderate

RATIONALE: Fine sediment levels exceed 25% (dry method; wet sieve equivalent ~37%) on the remaining spawning beaches . Fine sediment levels exceed 50% at Umbrella Beach (from Herrera 2005). Egg incubation studies conducted in 2000 and 2001 found that fine sediment deposition on redds occurred during egg incubation. Fine sediment deposition during incubation can form an impenetrable layer of fine sediment, impeding emergence. Poor survival from eyed egg to pre-emergence indicates that the majority of mortality occurs prior to emergence. Therefore the level of impact was defined as moderate (see Sections 5.4.2.1, 5.4.2.1.1, and 5.4.2.1.1.1).

6.2.6.2 Predation

Hypothesis 18: Predation of sockeye fry during emergence reduces the number of fry rearing in the pelagic zone of the lake.

LEVEL OF IMPACT: Unknown
CERTAINTY OF IMPACT: NA

RATIONALE: The level of impact of predation at emergence in unknown. A number of species of aquatic predators exist throughout the littoral zone. Directly upon emergence, sockeye fry are vulnerable to non-native piscivorous species such as largemouth bass and yellow perch. Small numbers of beach spawners and poor egg-to-fry survival can make juvenile sockeye vulnerable to the depensatory effects of predation at reduced abundance. Predator interactions at this early life history stage remain a data gap, but it is possible that significant levels of predation occur in the vicinity of the spawning beaches.

6.2.6.3 Seasonal Lake Level Changes

Seasonal lake level effects during emergence are the same as those examined for egg incubation above, see Section 6.2.5.3.

6.2.7 Adult Sockeye Entering, Migrating, and Holding in Tributaries

Several factors were evaluated for their impacts on adult sockeye entering, migrating, and holding in Lake Ozette tributaries, including predation (Section 6.2.7.1), holding pool quantity and quality (Section 6.2.7.2), streamflow (Section 6.2.7.3), water quality (Section 6.2.7.4), and research and monitoring (Section 6.2.7.5).

6.2.7.1 Predation

Hypothesis 19: Adult sockeye predation in tributaries occurs at low levels and is not likely a significant limiting factor.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate/High

RATIONALE: Hughes et al. (2002) concluded that there is very little evidence of pre-spawning predation mortality in Umbrella Creek based on tagging, tracking, genetic sampling, and spawning ground surveys. In 2000, seven adult sockeye tagged with CART tags were tracked in Umbrella Creek and all were observed to have successfully spawned (see Sections 5.5.5, 5.5.5.1, 5.5.5.1.1, 5.5.5.1.2, and 5.5.5.2).

6.2.7.2 Holding Pool Quantity and Quality

Hypothesis 20: Current holding pool frequency and volume has a limited effect on adult sockeye salmon survival during the migration and holding period.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: High

RATIONALE: Holding pool frequency downstream of the primary spawning areas in Umbrella Creek and Big River is good or fair in most channel segments (Figure 4.49 and Figure 4.59); however, some segments in Big River have reduced pool volume due to lack of wood and pool filling by sediment aggradation. Other pool attributes (e.g. percent woody cover) have reduced quality in many of the channel segments within Umbrella Creek and Big River (see Sections 4.4.1.3, 4.4.2.3, and 5.5.4.1). Female sockeye, while preparing to spawn, will frequently be attacked by adjacent territorial females; therefore, females preparing to spawn will often hold in pools before moving onto the spawning grounds (Quinn 2005). As tributary sockeye population sizes increase, the quantity and quality of pool habitat will become more important.

6.2.7.3 Streamflow

Hypothesis 21: Prolonged periods of low streamflow during the fall delays adult migration into tributaries, thus increasing sockeye exposure to predation events near the mouths of streams and reducing their fitness, increasing egg retention and pre-spawning mortalities.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Low

RATIONALE: Delayed migration of sockeye into tributaries during October and November has been observed during extreme low base flow conditions and a delay in the onset of the wet season (i.e., the first few rains). The population impact of delayed migration due to streamflow is thought to be low. Unlike sockeye spawning in shallow water at beaches, sockeye congregating near tributary mouths are more flexible in their holding depths and locations, enabling fish to minimize predator interactions. Climatic variability in precipitation timing is a natural phenomenon that sockeye salmon have adjusted to. Land use changes in hydrological processes would not be expected to change the timing of migration flows, which are dependent on climatic precipitation inputs. However, land use could affect low base flow magnitudes to a currently unknown degree, which, under natural conditions with higher sustained base flows, may have allowed sockeye to migrate into tributaries earlier in the spawning season. Climate change in the future could alter the timing of the onset of the wet season (i.e., the first few rains).

6.2.7.4 Water Quality

Hypothesis 22: Elevated turbidity and SSC levels increase stress and reduce sockeye fitness, resulting in increased egg retention rates and pre-spawning mortalities.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: High turbidity levels, which are an indicator of SSC, have been recorded in Ozette spawning tributaries, especially Umbrella Creek and Big River (peak values >500 NTU). Peak streamflow and turbidity events are common during the sockeye migration and spawning period. For the duration of the 2005 sockeye migration and spawning period, 85 hours had turbidity values greater than 100 NTU (Figure 5.44; Section 5.5.2). Elevated turbidity and SSC can have negative behavioral and physiological effects on adult sockeye, including negative effects on predator avoidance, territory selection, mate selection, homing and migration, gill function and integrity, respiration, and blood physiology. The high road densities in spawning tributaries (>4.0 mi/mi^2), extensive clear cutting (~98% of Umbrella Creek and Big River watershed clear-cut at least once), increased channel instability, mass wasting events, and other land use activities (e.g. agriculture) all contribute to elevated turbidity and SSC levels in tributaries. Dozens of observations of sediment inputs violating State water quality standards have been made during the last decade within the primary sockeye spawning tributaries, but no attempt to quantify the magnitude that turbidity and SSC have increased due to land use activities has been made (see Sections 4.4.1.5, 4.4.2.5, 4.4.3.5, 4.4.4.5.1, and 5.5.2). Note: the impact of SSC levels on other species may be significantly different than the impact on adult sockeye.

6.2.7.5 Research and Monitoring

Hypothesis 23: Weir trapping operations in Umbrella Creek increase susceptibility to predation and/or result in direct mortality during trapping.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: High

RATIONALE: Detailed records are kept regarding any direct mortality of sockeye during trapping in Umbrella Creek. Few instances have been recorded when sockeye have been directly impacted. Nonetheless, low numbers of sockeye salmon have been injured and in some cases killed by weir and trapping operations by becoming wedged between weir and trap pickets. Frequent monitoring of the weir and trap operation ensures that fish stress and mortality levels are adequately minimized. Predation at or near the Umbrella Creek weir has not been observed.

6.2.8 Adult Sockeye Spawning in Tributaries

The primary limiting factors affecting sockeye salmon spawning in tributaries include predation (Section 6.2.8.1), holding pool quantity and quality (Section 6.2.8.2), reduced quantity suitable spawning substrate (Section 6.2.8.3), streamflow (Section 6.2.8.4), kokanee-sockeye interactions (Section 6.2.8.5), water quality (Section 6.2.8.6), and research and monitoring (Section 6.2.8.7).

6.2.8.1 Predation

Hypothesis 24: Adult sockeye predation in tributaries occurs at low levels and is not likely a significant limiting factor.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: Hughes et al. (2002) concluded that there is very little evidence of predation mortality on spawning sockeye in Umbrella Creek based on tagging, tracking, genetic sampling, and spawning ground surveys. In 2000, seven adult sockeye tagged with CART tags were tracked in Umbrella Creek, and all were observed to have successfully spawned (see Sections 5.5.5, 5.5.5.1, 5.5.5.1.1, 5.5.5.1.2, and 5.5.5.2).

6.2.8.2 Holding Pool Quantity and Quality

Hypothesis 25: Current holding pool frequency and volume does not significantly affect adult sockeye salmon spawning.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: Moderate

RATIONALE: Holding pool frequency within the primary spawning areas in Umbrella Creek and Big River ranges from poor to good depending upon the channel habitat segment (Figure 4.49 and Figure 4.59). Pool habitat quality (frequency, complexity, depth, size) can be characterized as intermediate within the primary spawning areas of Umbrella Creek and Big River (Sections 4.4.1.3, 4.4.2.3, and 5.5.4.1). Once sockeye salmon begin the spawning process, they become territorially focused on protecting their respective redds, and utilization of pool habitat becomes much less important (than during the holding period - Section 6.2.7.2). Reduced pool quality within the primary tributary spawning grounds is therefore thought to have a negligible impact on sockeye salmon spawning success.

6.2.8.3 Quantity of Suitable Spawning Habitat

Hypothesis 26: Riparian forest removal, yarding and equipment operation in and across streams, stream cleaning and wood removal, as well as increased sediment production and delivery to streams has decreased the quantity of suitable spawning habitat (i.e., gravel) available to tributary spawning sockeye.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: High

RATIONALE: Gravel storage behind large woody debris has been systematically reduced throughout sockeye spawning tributaries (Section 5.5.4.2.2). This has been coupled with increased fine sediment delivery to mainstem spawning reaches, together altering the distribution and availability of suitable spawning gravel. Some mainstem sections (e.g., lower Big River) have been entirely transformed from gravel bed to sand bed (see Kramer's [1953] substrate description). However, at the watershed scale, gravel quantity is still high, but with reduced quality (Section 5.5.4.2) and stability (Section 5.5.4.3). Currently the effect of reduced gravel quantity on tributary spawning sockeye is low, but as the population increases, the effects of lost habitat will result in increased redd superimposition and reduced freshwater productivity.

6.2.8.4 Streamflow

Hypothesis 27: Streamflow variability can shift the distribution of spawning from "normal" positions in the channel, to the channel margins (e.g. during extended periods of high flow) or low in the thalweg (e.g. during periods of extended low flow) resulting in egg deposition in less optimal sites, where eggs are more susceptible to dewatering or scouring.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: Extended periods of high streamflow (caused by high storm frequency and intensity) can shift the distribution of spawning from "normal" positions in the channel to the margins, where velocity and depth more closely match the preferred conditions (e.g., Ames and Beecher 2001). When this occurs and is followed by normal or low flows, eggs in redds constructed along the channel margins or in less optimal positions in the channel may experience increased mortality during incubation due to redd dewatering or fine sediment intrusion. Extended dry periods yielding low flows following more or less "normal" flow conditions can produce the same effect with respect to redd dewatering. Conversely, below average flows during spawning that force fish to spawn low in the channel (thalweg), followed by large flood events, can increase susceptibility to redd scour (Ames and Beecher 2001; Lapointe et al. 2000; see Section 5.5.4.3). Thus, for sockeye spawning in compound channels under variable discharge regimes, there is a tradeoff between spawning low in the cross-section and risking scour mortality versus spawning high along channel margins and risking redd desiccation or sedimentation-related mortality (see Section 5.5.1.3)

6.2.8.5 Kokanee-Sockeye Interactions

Hypothesis 28: Kokanee spawning with sockeye salmon in tributaries occurs at extremely low levels and the genetic impacts on the sockeye population are minimal.

LEVEL OF IMPACT: Negligible to Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: Kokanee-sockeye interactions are thought to be minimal in Umbrella Creek since few kokanee spawn in this stream system. However, sockeye spawning with kokanee-size *O. nerka* in Umbrella Creek has been observed and documented on several occasions. Kokanee spawning in the mainstem of Big River is very rare. A review of nearly 200 spawning ground surveys (1970-2005) conducted in the mainstem of Big River during the kokanee spawning season yielded only one observation of kokanee, and these fish were not observed spawning. The impact of kokanee-sockeye interactions in Umbrella Creek and Big River was rated as negligible. Within Crooked Creek, kokanee abundance is far greater than sockeye abundance and peak kokanee counts per mile averaged 100-500 during years with complete surveys. Competition and interaction between kokanee and any sockeye present in Crooked Creek is expected to be fairly common. Kokanee spawn timing is slightly earlier than observed sockeye spawn timing, which may act to minimize interaction and gene flow between these populations. Hatchery releases designed to introduce sockeye into Crooked Creek no longer occur due to concerns over sockeye-kokanee interactions and the fact that the two groups represent discrete populations of *O. nerka*.

6.2.8.6 Water Quality

Hypothesis 29: Elevated turbidity and SSC levels during adult tributary spawning reduces the spawning fitness of sockeye salmon, increases egg retention rates and pre-spawning mortality, and affects the behavioral process of mate selection.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: High turbidity levels, which are an indicator of SSC, have been recorded in Ozette spawning tributaries, especially Umbrella Creek and Big River (peak values >500 NTU). Peak streamflow and turbidity events are common during the sockeye migration and spawning period. For the 2005 sockeye migration and spawning period, 85 hours monitored had turbidity values greater than 100 NTU (Figure 5.44; Section 5.5.2). Elevated turbidity and SSC can have negative behavioral and physiological effects on adult sockeye, including negative effects on predator avoidance, territory selection, mate selection, homing and migration, gill function and integrity, respiration, and blood physiology. The high road densities in spawning tributaries (>4.0 mi/mi^2), extensive clear cutting (~98% of Umbrella Creek and Big River watershed clear-cut at least once), increased channel instability, mass wasting events, and other land use activities all contribute to elevated turbidity and SSC levels in tributaries. Dozens of observations of sediment inputs violating State water quality standards have been made during the last decade within the primary sockeye spawning tributaries, but no attempt to quantify the magnitude that turbidity and SSC have increased due to land use activities has been made (see Sections 4.4.1.5, 4.4.2.5, 4.4.3.5, 4.4.4.5.1, and 5.5.2). Note: the impact of SSC levels on others species may be significantly different than the impact on adult sockeye.

6.2.8.7 Research and Monitoring

Hypothesis 30: Spawning ground surveys result in the disturbance of spawning sockeye but do not result in direct adult sockeye mortality. Stress caused by human encounters on the spawning grounds results in negligible increases in egg retention and therefore does not affect overall egg-to-fry survival.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: Moderate

RATIONALE: Spawning ground surveys are conducted approximately every 7 to 10 days within the primary sockeye spawning reaches. Surveyors are trained to avoid or minimize the disturbance of spawning sockeye. Years of spawning ground surveys in Umbrella indicate that spawning sockeye salmon pay little attention to surveyors and therefore little if any impact occurs. For impacts on incubating eggs, see Section 6.2.9.7

6.2.9 Sockeye Egg Incubation in Tributaries

Identified limiting factors affecting sockeye salmon egg incubation in tributaries include high levels of fine sediment (Section 6.2.9.1); channel stability and floodplain alterations (Section 6.2.9.2); streamflow (Section 6.2.9.3); water quality (Section 6.2.9.4); competition (Section 6.2.9.5); predation (Section 6.2.9.6); and research and monitoring (Section 6.2.9.7).

6.2.9.1 Fine Sediment

Hypothesis 31: High levels of fine sediment (<0.85mm) in spawning gravels reduce intra-gravel flow, reduce oxygenation of redds, and increase fry entombment, resulting in decreased egg-to-fry survival.

LEVEL OF IMPACT: High
CERTAINTY OF IMPACT: Moderate

RATIONALE: High levels of fine sediment have been documented from core sample data from spawning gravels in Ozette tributaries (see Sections 4.4.1.4, 4.4.2.4, and 4.4.3.4). During incubation, salmonid eggs require sufficient water flow to supply egg pockets with oxygen and carry away waste products (Bjornn and Reiser 1991). Water circulation through salmon redds is a function of redd porosity, permeability, and hydraulic gradient (Bjornn and Reiser 1991). Fine sediment that settles into redds during the egg incubation period can impede water circulation and fry movement, which can result in decreased egg-to-emergence survival (Bjornn and Reiser1991). Studies throughout the Pacific Northwest have found that increased levels of fine sediment (<0.85mm) in spawning gravels decreases egg to emergence survival (Cederholm et al. 1981; Bjornn and Reiser 1991; McHenry et al. 1994). McHenry et al. (1994) found that coho and steelhead egg to alevin survival decreased drastically when fine sediment (<0.85mm) exceeded 13% (volumetric method) in Olympic Peninsula streams. Numerous other researchers have also found that survival to emergence relates negatively to the percentage of fines in gravel (McNeil and Ahnell 1964; Koski 1966; Cederholm et al. 1981; Cederholm et al. 1982; Tappel and Bjornn 1983; Tagert 1984; Chapman 1988).

The high density of poorly constructed, surfaced, and maintained roads along with extensive, frequent timber clear-cutting in most sub-basins from the 1950s to present have resulted in increased sediment production and delivery to tributaries. Additionally, mass wasting, channel and bed destabilization, wood removal, decreased bank stability, and channel incision have increased sediment production and delivery to the stream network within the primary sockeye spawning tributaries. The exact degree that each input specifically increases or alters fined sediment levels in spawning gravel remains unknown (Section 5.5.4.2.1). Duplicating sediment sampling conducted by McHenry et al. 1994 could help answer important questions regarding current and past fine sediment levels, as well as aid in predicting actions and timeframes required for gravel quality to reach desired conditions for adequate fry production.

Hypothesis 31A: Increased sediment production and delivery to sockeye tributaries from land use activities (e.g. road building and clearcut logging) has increased the quantity of fine sediment in spawning gravels (Section 5.5.4.2.1).

6.2.9.2 Channel Stability and Floodplain Alterations

Hypothesis 32: Decreased channel stability and floodplain alterations have reduced egg-to-fry emergence survival in sockeye tributaries.

LEVEL OF IMPACT: Moderate
CERTAINTY OF IMPACT: Low

RATIONALE: There is no uncertainty that the bed and banks of sockeye spawning tributaries have been destabilized by land use and management practices over the last 100 years. What remains uncertain is the degree to which instability has lowered egg-to-fry survival during gravel bed incubation. Sediment transport and scour depth data have not been systematically collected along with fine sediment data at representative sockeye spawning locations. These data gaps need to be filled to assess the impact of wood removal, base level changes, incision, channelization, watershed sediment delivery, movement of sediment pulses, and streamflow magnitude on egg-to-fry survival. For a complete discussion on channel stability see Section 5.5.4.3.

Hypothesis 32A: Reduced large wood debris delivery from riparian logging and direct large woody debris removal has decreased the stability of the tributary channel beds and banks, increased coarse sediment transport and scour, and increased fine sediment delivery from eroding banks (Section 5.5.4.3).

Hypothesis 32B: Large woody debris removal from Ozette River has reduced the average lake levels resulting in channel incision in tributaries, and thus decreased channel stability.

Hypothesis 32C: Channelization of floodplain tributaries (i.e., Big River) from paved roads, unpaved roads and railroad grades, bank armoring (e.g., rip-rap and cars), channel relocation, and bridge crossings has decreased channel complexity, reduced large wood delivery, reduced floodplain connectivity, concentrated flood energy in the channel, and thus decreased channel stability (Sections 5.5.4.3 and 5.5.3).

Hypothesis 32D: Increased water runoff from road networks and vegetation clearing has increased the magnitude of common peak flood events, increased the frequency and magnitude of sediment transport events, and thus decreased channel stability (see Section 5.5.1.2.2).

Hypothesis 32E: Increased production of coarse and fine sediment from upland sources such as landslides and roads, and in channel sources such as eroding banks, has delivered large volumes of sediment to the mainstem channel networks, which has promoted stream bed instability as this material migrates downstream (5.5.4.2.1).

6.2.9.3 Streamflow

Hypothesis 33: Streamflow variability and human-caused hydrologic changes have decreased egg-to-fry survival.

LEVEL OF IMPACT: Unknown
CERTAINTY OF IMPACT: NA

RATIONALE: Lack of long-term hydrologic data sets in the Ozette Watershed preclude precise quantification of any potential changes to hydrology and flow regimes from land use and channel modifications. The high road densities in sockeye tributaries (>4.0 mi/mi^2), extensive clear cutting (>95% of sockeye watersheds clear-cut at least once), and lack of floodplain connectivity (e.g., channelization and wood removal) cumulatively lead to the hypothesis that hydrologic change has occurred in Ozette tributaries, but with an unknown magnitude (Section 5.5.1.2.2). This is consistent with the voluminous literature that water yield changes begin following a significant (10 to 25%) reduction of forest vegetation cover, with the highest impacts in conifer forests in high precipitation zones. The quantification of this potential limiting factor remains a data gap.

Hypothesis 33A: Increased water runoff from road networks and vegetation clearing has increased the magnitude of common peak flood events, increased the frequency and magnitude of sediment transport events, and thus decreased channel stability (Section 5.5.1.2.2).

Hypothesis 33B: Reduced watershed storage of water due to hydrologically connected road networks, reduced vegetation interception, and lack of floodplain connectivity (e.g., channelization and wood removal) has decreased base flow levels and increased the susceptibility of redds to becoming dewatered during incubation (Section 5.5.1.2.2).

6.2.9.4 Water Quality

Hypothesis 34: High levels of turbidity and SSC result in fine sediment deposition in sockeye redds, decreasing egg survival.

LEVEL OF IMPACT: High
CERTAINTY OF IMPACT: Moderate

RATIONALE: High turbidity and SSC have been recorded in Ozette spawning tributaries, especially Umbrella Creek and Big River (peak values >500 NTU). Peak streamflow and turbidity events are common during the sockeye incubation period. The high road densities in spawning tributaries (>4.0 mi/mi^2), extensive clear cutting (~98% of Umbrella Creek and Big River watershed clear-cut at least once), increased channel instability, mass wasting events, and other land use activities such as agriculture all contribute to elevated turbidity and SSC levels in tributaries. Dozens of observations of sediment inputs violating State water quality standards have been made during the last decade within the primary sockeye spawning tributaries, but no attempt to quantify the magnitude that turbidity and SSC have increased due to land use activities has been made (see Sections 4.4.1.5, 4.4.2.5, 4.4.3.5, 4.4.4.5.1, and 5.5.2). Degraded water quality conditions contribute to fine sediment levels in spawning gravels (Section 6.2.9.1), which reduces intra-gravel flow, reduces oxygenation of redds and eggs, and increases fry entombment.

6.2.9.5 Competition (Redd superimposition)

Hypothesis 35: Sockeye salmon spawn in high densities and competition for optimal spawning sites is intense, resulting in redd superimposition and reduced egg-to-fry survival.

LEVEL OF IMPACT: Negligible to Moderate
CERTAINTY OF IMPACT: High

RATIONALE: Within Umbrella Creek, spawning competition for suitable spawning sites and mates is more intense than in Big River and Crooked Creek (see Section 5.5.6). In recent years, large numbers (1,000 to 4,000) of spawning sockeye have utilized habitat in a fairly discrete section of Umbrella Creek (most spawning has been observed in a 2.2-mile-long stream reach). Competition for spawning habitat within this reach can be intense, and redd superimposition plays a significant role in determining the number of fertilized eggs that ultimately make it into the spawning gravels to incubate. During the peak spawning period, downstream of mass-spawning areas in Umbrella Creek, hundreds of sockeye eggs can be seen along the bottom of the stream or being transported downstream. The degree of redd superimposition likely varies depending upon the number of spawners returning to Umbrella Creek, as well as how they distribute themselves during the spawning period. Redd superimposition at levels occurring in Umbrella Creek likely reduces the overall egg-to-fry survival rate, but net production is not thought to be reduced. That is to say, if fewer sockeye spawned in Umbrella Creek, the net fry production would be reduced, not increased. However, if sockeye were distributed evenly throughout all suitable habitats, egg-to-fry survival would increase, as would net fry production. Redd superimposition has a negligible impact in overall egg-to-fry survival in Big River and Crooked Creek.

6.2.9.6 Predation

Hypothesis 36: Predation on sockeye eggs in tributaries occurs at low levels and is not likely a significant limiting factor.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Low

RATIONALE: Egg predation in tributaries has not been thoroughly investigated, but potential impacts are thought to be low (see Section 5.5.5). Egg pumping tests conducted in 1998 and 1999 did not indicate that significant egg predation was occurring in Umbrella Creek. Tributary egg predation largely remains a data gap.

6.2.9.7 Research and Monitoring

Hypothesis 37: Spawning ground surveys result in low levels of direct sockeye mortality caused by sockeye redd disturbance.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: High

RATIONALE: Spawning ground surveys are conducted approximately every 7 to 10 days within the primary sockeye spawning reaches. Surveyors are trained to identify and record all types of spawning activity, even under difficult or cryptic situations. Surveyors are also trained to avoid walking in areas suitable for spawning and to walk along channel margins and dry bars. Observed redds are flagged on the nearest branch or tree for future reference. Over time, redds can become masked in appearance because of algae growth, water depth, or bedload transport. It remains possible that surveyors could still walk or step on redds and crush eggs. However, years of experience and the precautions mentioned above keep impacts low.

6.2.10 Tributary Fry Emergence and Dispersal

Identified limiting factors affecting sockeye salmon during the fry emergence and dispersal phase in Lake Ozette tributaries include predation (Section 6.2.10.1), streamflow (Section 6.2.10.2), and water quality (Section 6.2.10.3).

6.2.10.1 Predation

Hypothesis 38: Predation of sockeye fry during emergence, emigration, and dispersal reduces the number of fry rearing in the pelagic zone of the lake.

LEVEL OF IMPACT: Moderate
CERTAINTY OF IMPACT: Low

RATIONALE: Estimates of post-release survival for 1998 brood year Umbrella Creek Hatchery released fingerlings moving downstream from RM 4.8 to RM 0.8 ranged from 74% to 40% (see Section 5.5.5). Burgner (1991) reviewed several studies conducted to determine fry predation rates for riverine spawned sockeye fry emigrating to nursery lakes and found widely ranging values: 63%-84% (Scully Creek, Lake Lakelse, 4 yrs), 66% (Six Mile Creek, Babine Lake, 1 yr), 13%-91% (Karymaiskiy Spring, Kamchatka Peninsula, 8 yrs), and 25%-69% (Cedar River, Lake Washington). Large numbers of predators (cottids, cutthroat, coho yearlings) were captured incidentally in fyke net trapping of natural-origin fry in Umbrella Creek during spring 1999. Predators consumed sockeye fry relative to coho fry at a ratio of 8.3 to 1, based on the relative abundance of each species, suggesting that sockeye fry were the preferred prey species during the months of April and May even though coho fry abundance was much greater (see also Section 3.1.7).

Hypothesis 38A: Small population size and reduced egg-to-fry survival reduce the overall number of fry and increase the relative impact of predators on the prey population.

6.2.10.2 Streamflow

Hypothesis 39: Low streamflows at emergence and emigration hinders migration to the lake, increasing transit time, exposure time in the fluvial environment, and susceptibility to predation. Streamflows can be further reduced by land use activities and changes in water retention capability.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Low

RATIONALE: Sockeye salmon emerge from the spawning gravel in Ozette tributaries from March to May (see Section 3.1.7). This is generally a period of decreasing discharge because of reduced precipitation inputs following the mid-winter maximum monthly precipitation (see Section 5.5.1.1). Climatic variability in precipitation timing and the stochastic nature of weather events are phenomena that sockeye salmon have generally adjusted to under natural conditions and population levels. However, unusually low streamflow and precipitation during tributary emigration can affect the rate of sockeye emigration (e.g., spring 2004) and likely their mortality (Section 5.5.1.3).). Tabor et al. (1998) suggested that predation rates were low in most sites studied in the Cedar River during the 1997 fry emigration to Lake Washington because of high streamflow. They found that at mid-channel sites, where velocities were moderate or high, little predation of sockeye salmon was observed. Seasonal droughts and reduced streamflow could be exacerbated by land use changes. These changes may affect the magnitude, but not timing, of base flows. Land use (including channel modifications) could affect low base flow magnitudes to an unknown degree, which under natural conditions with higher sustained base flows, may have allowed sockeye to emigrate into Lake Ozette during a shorter time period. Climate change into the future could alter the timing and magnitude of flows needed to transport sockeye fry down into Lake Ozette.

6.2.10.3 Water Quality

Hypothesis 40: Increased sediment production and delivery from tributary watersheds has increased turbidity and SSC levels during sockeye fry emigration, which has reduced sockeye fry fitness, increased gill abrasion, and altered oxygen uptake.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: High turbidity levels, which are an indicator of SSC, have been recorded in Ozette tributaries, especially Umbrella Creek and Big River (peak values >500 NTU). Peak streamflow and turbidity events are common during the sockeye fry emigration period. For the 2005 sockeye emigration period, 15 hours monitored for water quality had turbidity values greater than 100 NTU (Figure 5.44; Section 5.5.2). However, at least for 2005, the spawning period was shown to have greater turbidity levels than the fry emigration period. Generally, there is less average monthly precipitation during emigration, and thus flood events carrying high sediment loads are less frequent than during adult spawning. However, high turbidity and sediment levels still occur during emigration. Elevated turbidity and SSC can have negative behavioral and physiological effects on juvenile sockeye, including negative effects on predator avoidance, swimming and emigration efficiency, gill function and integrity, respiration, and blood physiology. The high road densities in spawning tributaries (>4.0 mi/mi^2), extensive clear cutting (~98% of Umbrella Creek and Big River watershed clear-cut at least once), increased channel instability, mass wasting events, and other land use activities all contribute to elevated turbidity and SSC levels in tributaries. Dozens of observations of sediment inputs violating State water quality standards have been made during the last decade within the primary sockeye spawning tributaries, but no attempt to quantify the magnitude to which turbidity and SSC have increased due to land use activities has been made (see Sections 4.4.1.5, 4.4.2.5, 4.4.3.5, 4.4.4.5.1, and 5.5.2).

6.2.11 Juvenile Freshwater Rearing

Identified limiting factors affecting sockeye salmon during the juvenile freshwater rearing phase in Lake Ozette are predation (Section 6.2.10.1), fisheries impacts (Section 6.2.11.2), disease (Section 6.2.11.3), and food availability/competition (Section 6.2.11.4).

6.2.11.1 Predation

Hypothesis 41: Changes in predator-prey abundances in the lake environment have increased the rate at which juvenile sockeye are consumed by predators (e.g. cutthroat trout, northern pikeminnows) and resulted in decreased fresh water survival, as well as an overall decrease in the number of sockeye returning to spawn.

LEVEL OF IMPACT: High
CERTAINTY OF IMPACT: Moderate

RATIONALE: A predation study conducted by Beauchamp et al. (1995) suggests that cutthroat trout consume most of the fry produced within the watershed (see Section 5.4.5). Other factors such as harvest and habitat degradation may have reduced the sockeye population to levels where predators consumed the majority of juveniles. However, it is thought that increased sockeye fry recruitment to the lake from tributary production has decreased the rate of predation since Beauchamp conducted studies of Ozette *O. nerka* predation. Age-0 *O. nerka* population dynamics have likely changed dramatically since the early 1990s, commensurate with the advent of substantial fry production by the tributary hatchery program. Future studies should specifically monitor piscivorous fish predation of juvenile sockeye in the lake. Quinn (2005) found that average survival from fry-to-smolt for sockeye in other lake systems averages roughly 25% and that predation is presumably responsible for most of the mortality in the sockeye lakes studied.

Hypothesis 41A: Changes in fisheries management requiring the release of cutthroat trout (effective in 2002) in Lake Ozette will increase the abundance of large cutthroat trout, resulting in increased sockeye predation and a net reduction in freshwater survival and subsequent recruitment to the lake unless the age-0 *O. nerka* population size increases (Section 5.3.4.2.6).

Hypothesis 41B: Introduction of non-native species (e.g. yellow perch, bass) has increased predation rates on sockeye salmon, but because there is little spatial/temporal overlap between non-native species and sockeye salmon the overall impact is low (Section 5.3.4.1.5).

Hypothesis 41C: Increased sockeye abundance in Lake Ozette, mainly from increased production in tributaries acts as a buffer for beach spawned juveniles, decreasing the impact of predation on the sub-population.

6.2.11.2 Fisheries Impacts

Hypothesis 42: There are no directed sockeye/kokanee fisheries in Lake Ozette and therefore there are no direct sockeye harvest impacts occurring within the lake.

LEVEL OF IMPACT: None
CERTAINTY OF IMPACT: High

RATIONALE: The lake is closed to salmon fishing and therefore there are no impacts on sockeye attributable to directed sockeye fisheries occurring in the lake. Incidental hooking and non-directed impacts are discussed in Hypothesis 43 below.

Hypothesis 43: Incidental hooking and catching of juvenile sockeye salmon occurs in low numbers within the lake during sport fisheries targeting trout, bass, or other non-salmon species. Incidental hooking or catching of juvenile sockeye salmon has a negligible effect on the sockeye population.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: Moderate

RATIONALE: The smolt emigration period begins before the sport fishery opening on the lake. The majority of the sockeye smolts are in the lake during the first few weeks when the lake is open to fishing. Lake Ozette has low fishing pressure, which reduces the potential impact of incidental sockeye encounters. ONP fishing regulations require the immediate release of all salmonids. Age 0 sockeye are unlikely to be susceptible to fishing due to their small size during the period when the lake is open to sport fishing. There are no data regarding fishing pressure (e.g. angler days) or non-targeted sockeye encounters within the lake; these conclusions are based on the experience and knowledge of members of the limiting factors rating workgroup about the Lake Ozette sport fisheries.

6.2.11.3 Disease

No systematic monitoring of juvenile sockeye health in the lake occurs. The degree to which disease may affect the population is unknown (see Section 5.4.6).

6.2.11.4 Food Availability/Competition

Hypothesis 44: Food availability and competition for food resources has a negligible effect on juvenile sockeye productivity in Lake Ozette.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: Moderate

RATIONALE: Beauchamp et al (1995) estimated that juvenile sockeye and all year classes of kokanee consumed less than 1% of the monthly standing stock of *Daphnia pulicaria* > 1.0 mm in size, suggesting that food availability for rearing fish was not limiting *O. nerka* productivity. All researchers (Bortleson and Dion 1979; Dlugokenski et al. 1981; Blum 1988; Beauchamp and LaRiviere 1993), independent of methodologies, have concluded that Lake Ozette sockeye productivity and survival are not limited by food availability or competition for food resources (see Section 5.4.4).

6.2.12 Seaward Migration

Identified limiting factors affecting sockeye salmon during the juvenile freshwater rearing phase in Lake Ozette include predation (Section 6.2.12.1), Ozette River habitat conditions (Section 6.2.12.2), water quality (Section 6.2.12.3), streamflow (Section 6.2.12.4), estuarine habitat conditions(Section 6.2.12.5), fisheries impacts (Section 6.2.12.6), disease (Section 6.2.12.7), and research and monitoring (Section 6.2.12.8).

6.2.12.1 Predation

Hypothesis 45: Predation in the Ozette River during smolt emigration reduces the number of juvenile sockeye entering the ocean, therefore reducing freshwater survival.

LEVEL OF IMPACT: Moderate
CERTAINTY OF IMPACT: Moderate

RATIONALE: Smolt trapping and adult sockeye weir enumeration data indicate that large numbers of predators congregate in the Ozette River during the smolt emigration period. Stomach analysis of northern pikeminnow indicates that they actively feed on sockeye and coho smolts (see Section 5.3.4.1.3). The impact on the population was rated as moderate at low sockeye abundance and low at moderate and high smolt abundances.

Hypothesis 45A: Weir and trapping structures used for research and monitoring in the Ozette River delay and spatially confine seaward migrating smolts, providing increased predator opportunity and efficiency (see Section 6.2.12.8).

Hypothesis 45B: Low streamflows in the Ozette River lengthen migratory time, increasing the duration of sockeye smolt exposure to aquatic predators (Section 6.2.12.4).

Hypothesis 45C: Low levels of LWD and reduced pool complexity increases vulnerability to predation and reduces the abundance and quality of refuge areas (Section 6.2.12.2).

6.2.12.2 Ozette River Habitat Conditions

Hypothesis 46: Low levels of LWD and reduced pool complexity increase the vulnerability of sockeye smolts to predation and reduces the quantity and quality of refuge habitats.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: The loss of large (>50 cm diameter) LWD in the Ozette River through removal operations has undoubtedly resulted in reduced habitat complexity throughout much if not all of the Ozette River. Riparian forest removal adjacent to the upper 0.4 miles of the Ozette River has reduced LWD inputs, delaying the recovery and habitat potential of the upper river. Lake Ozette sockeye have not been observed spawning or rearing in the Ozette River and therefore the direct effect on sockeye in the Ozette River are likely limited (Section 5.3.1.1). Habitat simplification mainly affects sockeye smolts by reducing refuge habitat, making sockeye more susceptible to predation.

6.2.12.3 Water Quality

Hypothesis 47: High stream temperatures and low frequency, high intensity turbidity events reduce the fitness of juvenile sockeye salmon emigrating to the Pacific Ocean, and results in decreased survival in the river and during the early marine life history phase.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: Moderate

RATIONALE: High stream temperatures and low frequency, high intensity turbidity events occur during the sockeye smolt emigration period. However, the majority of the sockeye smolt population emigrates before stream temperatures reach >16°C. Only a small fraction of sockeye smolts encounter temperatures exceeding 18°C. Low frequency, high intensity turbidity events resulting in moderate physiological stress occur during the smolt emigration period. During the month of April, when average Ozette River streamflow is still around 400 cfs, SS inputs from Coal Creek would normally be diluted by flow contributions from the Ozette River. However, dilution of 50% of the SSC would have a negligible effect on the predicted effects on sockeye salmon at the concentration levels estimated to occur following a 2-inch precipitation event (Section

5.3.3.2). Predicted higher suspended sediment concentrations in Coal Creek during the month of April would likely have a lower severity index (in the Ozette River) due to the effect of dilution caused by higher streamflows in the Ozette River.

From May to August when lake level is typically low, no or very limited dilution from the Ozette River would be expected, because high intensity rainfall events usually reverse the flow of the Ozette River (during low lake level periods) and Ozette River flow is made up almost entirely of Coal Creek discharge. Severity indexes estimated from data tables in Newcombe and Jensen (1996) indicate that for moderately common storm events (10% to 3% probability of occurrence on any given day from May-August) in Coal Creek, moderate behavioral and physiological stress could occur for juvenile sockeye (see Section 5.3.3.2 and Table 5.2). Effects could include moderate physiological stress (6); moderate habitat degradation and impaired homing (7); and major indications of physiological stress and poor condition (8). During the month of May, no more than 7.5% of the smolt populations are expected to encounter SSC predicted to result in moderate physiological stress.

6.2.12.4 Streamflow

Hypothesis 48: Sedimentation in the Ozette River from Coal Creek has reduced the quantity of water available as streamflow from the lake at a given stage. Changes in this stage discharge relationship, changes in hyporheic and surface flow conditions, increased lake evapotranspiration, and reductions in tributary baseflow inputs have reduced summer low flows. Reduced streamflows affect water quality, predation rates and efficiency, and migration, reducing the fitness of emigrating sockeye smolts.

LEVEL OF IMPACT: Unknown
CERTAINTY OF IMPACT: NA

RATIONALE: The overall degree to which flow has been reduced during the sockeye smolt emigration period remains unquantified. Details on Ozette River hydrology can be found in Sections 4.3.6, and 5.3.2. The most substantial reductions in streamflow occur from mid- to late-summer (when streamflows are naturally lower) and when sockeye smolts are not present. Quantification of streamflow reduction during smolt emigration, and potential impacts remain a data gap.

6.2.12.5 Tidal Prism and Physical Estuarine Habitat Conditions

Changes in the tidal prism and estuarine habitat conditions appear to have occurred during the last 50 years (see Section 4.1). The cause of these apparent changes is poorly understood, as are the potential effects on Lake Ozette sockeye. Changes in the estuarine habitat conditions have an unknown impact on sockeye smolt survival. This potential limiting factor remains a data gap.

6.2.12.6 Fisheries Impacts

Hypothesis 49: There are no open fisheries within the Ozette River during the juvenile sockeye emigration period and therefore there are no impacts on sockeye salmon from permitted in-river fisheries.

LEVEL OF IMPACT: None
CERTAINTY OF IMPACT: High

RATIONALE: The river is closed to all sport fishing until August 1. When the river is open, selective fishery rules apply and all sockeye must be released immediately. Sockeye smolt emigration is complete by mid-June and therefore there are no impacts from fisheries.

6.2.12.7 Disease

No systematic monitoring of juvenile sockeye health occurs in the Ozette River. The degree which disease may affect the population is unknown (see Section 5.3.6).

6.2.12.8 Research and Monitoring

Hypothesis 50: Research and monitoring activities directed at migrating sockeye smolt (traps, weirs) result in almost no direct mortality. Low levels of indirect mortality associated with predation at the trapping site occur.

LEVEL OF IMPACT: Low
CERTAINTY OF IMPACT: High

RATIONALE: Smolt trapping data indicates that very few direct mortalities result from smolt trapping (<1% of all smolts encountered). The indirect effects of smolt trapping are discussed in the predation hypothesis above (see Section 6.2.12.1).

6.2.13 Marine Ocean Phase

6.2.13.1 Fishery Interception

Hypothesis 51: No directed Lake Ozette sockeye fisheries occur in the marine environment and therefore there are no impacts.

LEVEL OF IMPACT: None
CERTAINTY OF IMPACT: High

RATIONALE: No directed Lake Ozette sockeye fisheries occur in the marine environment and therefore there are no impacts.

Hypothesis 52: Non-directed fishery interceptions (from sport, commercial, and tribal salmon and ground fish fisheries) of Ozette sockeye occur at extremely low levels and the impact of past and current west coast fisheries is negligible.

LEVEL OF IMPACT: Negligible
CERTAINTY OF IMPACT: High

RATIONALE: PFMC (2004) states that Council Area (southern U.S. coastal sport, commercial, and tribal) fisheries have no measurable impact on sockeye salmon. An additional review of recent (1995-2004) sport catch in coastal Washington fishing areas and Washington Marine Areas 5 and 6 indicate that average sockeye catch is insignificant relative to the number of sockeye present. Partial time series sport catch data for these same areas from 1979 to 1994 further indicate that sport catch of sockeye salmon are negligible. Bycatch of sockeye in coastal whiting and bottom trawl fisheries also appears to be negligible, as few if any sockeye have been observed as bycatch. The early-return timing of Ozette sockeye substantially limits their occurrence in marine migratory areas when and where commercial and sport fisheries directed at other sockeye populations (e.g., Southeast Alaska, Northern British Columbia, and Fraser River stocks) occur (see Section 5.6.1.1).

6.2.13.2 General Marine Survival

Hypothesis 53: Survival in the marine environment is driven by large-scale climatic processes and variability in marine survival rates for sockeye salmon is significant. Ultimately, the number of adult sockeye returning to the Ozette River is largely defined by marine survival, which is driven by processes that are not controllable.

LEVEL OF IMPACT: High
CERTAINTY OF IMPACT: High

RATIONALE: Average mortality of large southern (< 55°N longitude) sockeye smolts in the marine environment averages 83% (Koenings et al. 1993). Mortality in the marine environment is likely the largest single mortality factor affecting Ozette sockeye. However, it is important to recognize that: 1) very high mortality rates in the marine environment are natural, and 2) there are no known direct actions that can be taken in the marine environment to improve survival for Ozette sockeye (see Section 5.6.1).

Hypothesis 53A: While marine survival is a critical component in determining the ultimate abundance of Lake Ozette sockeye, broad-scale, regional studies of decadal-scale productivity indicate that changes in marine survival played a limited role in the decline of Ozette sockeye.

7 RESEARCH, MONITORING, AND EVALUATION NEEDS

During the preparation of this report several physical and biological data gaps were identified regarding sockeye salmon population limiting factors. Some limiting factor data gaps are relatively small because of the extensive physical or biological data currently available. Other data gaps are relatively large, such as where limiting factors were rated as having an unknown degree of impact on the sockeye population. Developing a comprehensive and/or quantitative understanding of all limiting factors will likely remain unattainable because of limited resources and the highly dynamic nature of sockeye salmon and their environment. However, ongoing and expanded monitoring of population integrity and key physical and biological processes will promote a deeper understanding of the most influential limiting factors already outlined in this report.

The following research, monitoring, and evaluation needs are a combination of ongoing efforts that need to recur annually and specific studies or monitoring efforts needed to fill data gaps. Research, monitoring, and evaluation needs are presented by life history stage and include key questions that could be answered by future research. Appendix F contains the working draft research and monitoring priorities developed as part of the draft LFA in 2001. Where applicable, concepts from Appendix F are included below in Sections 7.1 through 7.13

7.1 ADULT SOCKEYE ENTERING SYSTEM

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for the adult sockeye river entry and lake migration life history phase:

- Adult Sockeye Run Size and Run Timing
- Ozette River Stage and Discharge
- Predation (nearshore, estuary, and in-river)
- Ozette River Water Quality
- Ozette River Habitat Conditions
- Ozette River Estuary Conditions and Alterations

Key questions to be addressed through research and monitoring are included in Sections 7.1.1 through 7.1.6.

7.1.1 Adult Sockeye Run Size and Run Timing

It is recommend that adult sockeye run size and timing data continue to be collected. Attempts are needed to improve population estimates and investigate use of fish-friendlier methods of enumeration (e.g., side viewing sonar). Determining accurate run size and abundance trends of the population is critical to attaining recovery of Lake Ozette sockeye. Tracking population fluctuations over time will help determine the success of restoration activities, as well as the success of the overall Lake Ozette Sockeye Recovery Plan. Abundance data are a critical component for developing productivity estimates by life stage. These data will also help answer questions regarding changes in run timing and degree of inter-annual run timing variation.

7.1.2 Ozette River Streamflow

Ozette River discharge during adult migration has been reduced on average. Additional detailed hydraulic and hydrological modeling is required to determine the exact magnitude to which flows have been altered by various factors in combination (river hydraulics such as roughness and sedimentation, climate, hyporheic flow, lake evapotranspiration, and reductions in tributary baseflow inputs). The effect of changes to streamflow on migrating sockeye remains unknown (see Hypothesis 4 in Section 6.2.1.4) and should be a focus of future research and monitoring.

Better quantification of the nature of hyporheic flow through the outlet of Lake Ozette could be fairly easily conducted using standard techniques (Bencala et al. 1983; Harvey et al. 1996; Harvey and Wagner 2000; Packman and Bencala 2000). Additional measurements and modeling data are needed for quantification of shoreline vegetation effects on lake evapotranspiration. Future research should take advantage of modern watershed hydrology modeling to help quantify a range of likely scenarios of how land use has affected water yields and flow regimes in Ozette. For example, a distributed watershed model (Distributed Hydrology Soil Vegetation Model [DHSVM] or similar) could be developed to simulate historic, current, and future lake inflow hydrology as a result of changes in land use, vegetation cover, drainage density, roads, and soil water storage. This model could be coupled with unsteady HECRAS hydraulic model of the Ozette River (Herrera 2005) to develop a fully encompassing watershed hydraulic and hydrologic model of Ozette that incorporates lake inflow, outflow, and evaporation (i.e., a water budget).

7.1.3 Predation

Continued monitoring of in-river predation is an important component for understanding the degree that predation affects the sockeye population at different abundance levels.

7.1.4 Ozette River Water Quality

It is recommend that water quality data (temperature, turbidity, SSC) continue to be collected.

Have stream temperatures increased during the last 50 years? How much? How do high stream temperatures limit Ozette sockeye? Variations in timing of spawning migrations may be in response to river flow and water temperature. During some years, such as 2003, stream temperatures approach lethal levels. During years of high water temperature during the sockeye run, snorkel surveys or other additional surveys of the river should take place in order to determine how much in-river mortality is occurring.

How much have turbidity and SSC levels increased in Ozette River and Coal Creek during the last 50 years? How do high turbidity and SSC values limit Ozette sockeye? How does sediment deposition over time at the mouth of Coal Creek affect lake levels? Are these sedimentation effects permanent or temporary? How competent is the Ozette River at flushing sediment derived from Coal Creek downstream? How does sediment derived from Coal Creek affect spawning and incubation habitat for Chinook and chum salmon in Ozette River? How does sedimentation in Ozette River affect the unique biota of the river (e.g., net spinning caddis flies, freshwater sponge, endemic mussels, etc.) and thus the ecosystem that sockeye migrate through?

7.1.5 Ozette River Habitat Conditions

Do large logjams that form deep pools in the Ozette river provide important refuge habitat for adult sockeye salmon? Do deep pools provide thermal refuge habitat for adult sockeye? How does habitat complexity and/or simplification affect predation of adult sockeye?

7.1.6 Estuary Conditions

Are there unique tidal prism influences that enhance or are detrimental to the sockeye life cycle? Quantify the changes in estuary volumes and habitat availability over time in response to altered spit morphology at the ocean mouth. Analyze sequential historical photos, in conjunction with field surveys. How has nutrient and salinity exchange changed in the estuary and how has this affected sockeye rearing and migration habitat?

7.2 ADULT SOCKEYE HOLDING IN LAKE OZETTE

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for the adult sockeye lake holding life history phase:

- Predation

- Disease
- Other Lake Holding Mortality Sources

Levels and sources of mortality of adult sockeye holding in the Lake Ozette are relatively unknown. Predation and disease have been only partially investigated. Note that the degree of impact was categorized as unknown for Hypothesis 7 (the number of sockeye surviving to spawn is reduced by predators, disease, and other factors during the extended holding period in Lake Ozette prior to spawning).

What impacts do these factors have on adult sockeye in the lake environment? What is the cumulative effect of stress during migration (e.g., ocean conditions, streamflow timing, temperature, predation wounds) on the development of disease during the lake holding period? How do lake holding conditions affect the development or suppression of disease? How will changes in lake holding habitat into the future (e.g., temperature) affect disease?

Continued monitoring of lake predation (i.e., seal and river otter predation) is an important component for understanding the degree that predation affects the sockeye population at different abundance levels. As a small beginning step, river otter scat samples collected during the summers of 2002 and 2003 need to be examined.

7.3 ADULT SOCKEYE STAGING AT SPAWNING BEACHES

No monitoring or research needs have been identified for this life history stage.

7.4 ADULT SOCKEYE SPAWNING ON LAKE BEACHES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for the adult sockeye beach spawning life history phase:

- Beach Spawner Distribution and Abundance
- Predation
- Quantify Suitable Habitat/Identify Non-Utilized Suitable Habitat
- Monitor Interaction With Kokanee
- Lake Ozette Water Quality

Key questions to be addressed through research and monitoring are included in Sections 7.4.1 through 7.4.5.

7.4.1 Beach Spawner Distribution and Abundance

Improved enumeration techniques are needed for quantifying annual adult spawning escapement at all beach spawning locations (e.g., intensive dive surveys, mark and recapture, sonar or acoustic estimates). There is a general lack of information relative to the number of successful spawners on the beaches.

Key questions include: How many sockeye spawn each year on each beach? Are other beach spawning areas also used? If so, to what extent? Are secondary areas such as north Olsen's Beach and Cemetery Point used each year and to what degree?

7.4.2 Spawning Habitat Quantification

The total amount of suitable beach spawning habitat has not been quantified. The current distribution of suitable spawning habitat needs to be quantified and mapped. These data will be critical if establishment of new spawning areas is attempted in Ozette (see also Section 7.5.1).

What makes habitat suitable for spawning? Traditionally we have used substrate and depth as indicators of suitable beach spawning habitat. We need to include quantification of additional factors for suitable habitat such as groundwater and hyporheic upwelling presence/absence, pore velocity, wind-driven current velocities, beach slope, vegetation presence/condition, aspect, wind fetch, substrate pore space (e.g., cobble/boulder voids), etc. Habitats need to be differentiated by those suitable for spawning due to upwelling, versus habitat that may be suitable for spawning due to wind or wave or seiche driven currents.

7.4.3 Predation

It is recommended that annual monitoring of harbor seal and river otter predation take place at known spawning areas of Lake Ozette. The one year in which predation monitoring occurred indicated that significant (10-40%) pre-spawning predation occurred. Key questions include: What percent of beach spawners are consumed prior to spawning? Which predators consume more sockeye salmon? Do river otters forage on sockeye carcasses left by harbor seals?

7.4.4 Kokanee-Sockeye Spawning Interaction

Continue to monitor kokanee-sockeye spawning interaction. Attempt to quantify the number of kokanee spawning on sockeye beaches. This can be done during sockeye spawning ground surveys combined with genetic sampling. Key questions include: How many kokanee or kokanee size *O. nerka* spawn annually with sockeye salmon on the beaches? What effect does this level of hybridization have on the population? Are there increasing numbers of kokanee spawning with sockeye on the beaches?

7.4.5 Water Quality

The frequency of high turbidity events and the direct effect on spawning sockeye are unknown but may include moderate physiological stress, habitat avoidance, and spawning habitat degradation. Turbidity and SSC data are lacking on the extant spawning beaches and these are considered an important data gap. In general, existing beach spawning habitats, especially Allen's Beach, are presumed less susceptible to stream-derived turbidity and SSC (because they are not close to major sediment sources from eastern tributaries).

Key questions include: Is there evidence of anthropogenic impacts on water quality in the lake? If so, to what extent have any changes affected beach spawning sockeye and how do these impacts vary by location? What are the patterns and concentrations of turbidity/SSC across the lake and along different beach habitats during various storm events? What beaches/locations are more susceptible to habitat degradation due to fine sediment deposition? Do spawning habitat and water quality differ between deltaic beach spawning locations and more remote shoreline spawning locations? Is water quality changing over time?

7.5 SOCKEYE EGG INCUBATION ON SPAWNING BEACHES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye egg incubation on spawning beaches:

- Spawning Habitat Quality and Quantity
- Egg Predation
- Seasonal Lake Level Changes

Key questions to be addressed through research and monitoring are included in Sections 7.5.1 through 7.5.3.

7.5.1 Spawning Habitat Quality and Quantity

Spawning habitat quality and quantity has been reduced across many beaches around Lake Ozette. Several factors have been implicated for the reduction in the quality and quantity of spawning habitat, including vegetation encroachment, increased fine sediment production and delivery to the lake, changes in lake level, and watershed hydrology. Research focusing on egg-to-fry survival and beach spawning habitat characteristics could greatly improve our understanding of current habitat conditions and aid in the development of recovery strategies for beach spawning habitat. A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions.

Additional studies of egg-to-fry survival are needed in various beach spawning habitat conditions (substrate size distribution, substrate pore space (e.g., gravel/cobble/boulder voids), water depth, upwelling hydraulic gradient, pore velocity, beach slope, wind-driven current velocities, vegetation presence/condition, aspect, wind fetch, etc. These studies should differentiate egg-to-fry survival between habitats that may be suitable for spawning due to upwelling, versus habitat that may be suitable for spawning due to wind or wave or seiche driven currents, plus all other factors.

An initial draft proposal has already been developed to research these various egg-to-fry survival factors by testing the success of egg planting and reintroduction efforts in different types of existing and rehabilitated beach habitats (Schneidler 2006). Consult this document before initiating any research ideas, so that existing ideas can be built upon and expanded to fit exact research needs.

7.5.2 Egg Predation

Egg predation remains a data gap for Ozette spawning beaches. Key questions include: How much egg predation occurs? What species are egg predators? What effect does egg predation have on the different spawning aggregations?

7.5.3 Seasonal Lake Level Changes

Seasonal changes in lake level have been shown to dewater sockeye redds, potentially resulting in egg mortality. The proportion of redds dewatered due to seasonal changes in lake level varies by year dependent upon several factors. Continued mapping of redd locations and elevations (e.g., redd water depths or heights above water at specific lake stages) is needed across the beach spawning distribution to better quantify redd dewatering or lake level changes on incubation survival or redd conditions (e.g., temperature, water exchange through redd). Currently there is only one year of the data needed to quantify the proportion of spawning area dewatered.

A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions, and thus changes in the impacts of redd dewatering.

7.6 LAKE BEACH FRY EMERGENCE AND DISPERSAL

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye fry emergence and dispersal on spawning beaches:

- Early Life History
- Fry Predation
- Seasonal Lake Level Changes

Key questions to be addressed through research and monitoring are included in Sections 7.6.1 through 7.6.3.

7.6.1 Sockeye Fry Life History

The temporal and spatial distribution of sockeye fry remains unknown. It is generally assumed that Ozette sockeye fry quickly migrate to the pelagic zone upon emergence. Studies are needed to determine nearshore habitat utilization after emergence and aid in understanding predator prey relationships, as well as food type and availability during the fry stage.

7.6.2 Fry Predation

Fry predation remains a data gap for Ozette spawning beaches. Key questions include: How much fry predation occurs? What species of fish (or birds or mammals) are sockeye fry predators? What effect does fry predation have on the different spawning aggregations and beach spawners collectively? Is fry predation at the mouths of tributaries and deltaic spawning locations different from predation of fry off remote extant beaches?

7.6.3 Seasonal Lake Level Changes

Seasonal changes in lake level have been shown to dewater sockeye redds, potentially resulting in egg mortality. If upwelling conditions prevent redd dewatering and thus prevent egg and fry desiccation, emerging fry may still lack access to the lake rearing environment (e.g., fry emerging from a redd on a spring above lake level may be unable to swim down the beach into the lake). Redd dewatering needs to be investigated at meso- and micro-scales to determine the exact mortality factors (e.g., desiccation versus disconnection). The proportion of redds dewatered due to seasonal changes in lake level varies by year dependent upon several factors. Continued monitoring of lake stage and collection of redd elevation data is recommended. Currently there is only one year of the data needed to quantify the proportion of spawning area dewatered. A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions, and thus changes in the impacts of redd dewatering.

7.7 ADULT SOCKEYE ENTERING, MIGRATING, AND HOLDING IN TRIBUTARIES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye entering, migrating, and holding in Lake Ozette tributaries:

- Population Abundance and Distribution
- Streamflow
- Water Quality
- Predation

Key questions to be addressed through research and monitoring are included in Sections 7.7.1 through 7.7.4.

7.7.1 Population Abundance and Distribution

Currently Umbrella Creek sockeye are enumerated at river mile 0.8 using a weir and trap. It is recommended that weir operations be continued in Umbrella Creek. Methods need to be developed and implemented in all sockeye spawning tributaries (e.g., Big River and Crooked Creek) so that accurate population estimates can be made annually. Abundance data is a critical component of recovery monitoring. Experimentation is needed to improve population estimates and investigate utilization of fish-friendlier methods of enumeration (e.g., side viewing sonar).

Determining accurate run size and abundance trends of the population is critical to attaining recovery of Lake Ozette sockeye. Tracking population fluctuations over time will help determine the success of restoration activities, as well as the success of the overall Lake Ozette Sockeye Recovery Plan. Abundance data are a critical component for developing productivity estimates by life stage.

7.7.2 Streamflow

The hydrology of the Ozette Watershed has been poorly studied over the contemporary settlement period of the Ozette region. It is recommended that streamflow data collection continue over the long term in all major tributaries to Lake Ozette and the Ozette River.

Data collection at the following tributary sites should continue in the following order of priority:

1. Coal Creek
2. Umbrella Creek
3. Big River
4. Crooked Creek
5. Siwash Creek

Long-term streamflow data would allow for a comprehensive understanding of the impacts that low streamflow has on adult sockeye migration in tributaries.

A fully encompassing watershed hydraulic and hydrological model that incorporates lake tributary inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in tributary and lake level dynamics between historical, current, and future watershed conditions. This model could be calibrated to long-term tributary streamflow data. Thus, the range of potential impacts on sockeye salmon survival both in tributaries and the lake could be more thoroughly understood.

7.7.3 Water Quality

Collection of summer and fall temperature data in all Ozette tributaries needs to continue and be slightly expanded to ensure adequate records and coverage for each major tributary. These data would allow for a better understanding of the impacts of high fall stream temperatures on initial adult sockeye migration into tributaries.

Collection of continuous turbidity and SSC measurements in all Ozette sockeye tributaries needs to continue over the long term, with the goals of understanding the magnitude and duration impacts of high sediment loads on adult sockeye migration into tributaries and detecting long-term (decadal) trends in turbidity and suspended sediment concentration.

7.7.4 Predation

During the period that adult sockeye enter, migrate, and hold in lake tributaries they are primarily susceptible to predation by river otters, harbor seals, and terrestrial mammals. While not likely a major or key limiting factor, tributary predation on adults remains a data gap. Little information exists on the rates of predation, species involved, or relative impacts to the overall population of tributary spawners.

7.8 ADULT SOCKEYE SPAWNING IN TRIBUTARIES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye spawning in tributaries:

- Streamflow and Adult Spawning Locations
- Spawning Habitat Quality
- Spawning Habitat Quantity
- Water Quality During Spawning
- Competition with Other Species

Key questions to be addressed through research and monitoring are included in Sections 7.8.1 through 7.8.5.

7.8.1 Streamflow

See Section 7.7.2.on streamflow for additional description of streamflow monitoring needs in Ozette tributaries.

Long-term streamflow data would allow for a better understanding of the impacts streamflow has on adult sockeye spawning timing and locations in tributaries. Tradeoffs exist between spawning low in a cross-section and avoiding dewatering, compared to spawning higher in the cross-section and avoiding bedload transport and scour. High streamflow variability during the sockeye spawning and incubation period can result in reduced probabilities of successful egg-to-fry survival. Quantification of natural and human induced streamflow impacts on egg-to-fry survival in Ozette tributaries remains a major data gap.

7.8.2 Spawning Habitat Quality

The quality of spawning habitat in Ozette tributaries has been reduced due to fine sediment deposition, LWD removal, and channel destabilization, with resultant changes on hyporheic flow paths and scour depths. The extent that these changes have altered adult sockeye spawning site selection or spawning success is unknown and needs to be quantified.

7.8.3 Spawning Habitat Quantity

In many Ozette tributaries, the quantity of suitable spawning habitat area has been reduced due to the effects of LWD removal, reduced LWD recruitment, increased fine sediment inputs and abundance, channelization and bank armoring, gravel mining, and colonization of bar deposits by non-native vegetation. In some reaches of Big River and Umbrella Creek, spawning gravel beds have been completely converted to sand bed or cobble bed, respectively. No attempts have been made to quantify loss of available spawning habitat over time, which remains a data gap.

7.8.4 Water Quality

Collection of continuous turbidity and SSC measurements in all Ozette sockeye tributaries needs to continue over the long term, with the goals of understanding the magnitude and duration of impacts of high sediment loads on adult sockeye spawning in tributaries and detecting long-term (decadal) trends in turbidity and suspended sediment concentration.

7.8.5 Competition

Both intraspecific and interspecific competition exists in Ozette tributaries: sockeye competing with one another for spawning habitat, sockeye competing and/or spawning with kokanee for spawning habitat, and sockeye competing with coho salmon for spawning habitat. The degree and type of competition thought to occur in tributaries varies by stream system, species population abundance, and habitat quality and availability. Within certain reaches with modest numbers of sockeye (Umbrella Creek), competition can be intense and redd superimposition can play a significant role in egg-to-fry survival. Spawning competition with coho salmon also occurs since these species spawn at the same time/habitat, but coho populations will need to increase for this to become a significant factor. Competition and interaction with kokanee is thought to be minimal in Umbrella Creek since few kokanee spawn in this stream system, but is more common in other streams (e.g. Crooked Creek), where sockeye numbers are low but kokanee numbers are moderate. Future monitoring and data collection are needed to quantify this intraspecific and interspecific competition.

7.9 SOCKEYE EGG INCUBATION IN TRIBUTARIES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye egg incubation on spawning beaches:

- Spawning Habitat Quality
- Spawning Habitat Quantity
- Egg Predation

Key questions to be addressed through research and monitoring are included in Sections 7.9.1 through 7.9.3.

7.9.1 SPAWNING HABITAT QUALITY

Under post-disturbance conditions, Lake Ozette tributaries have some of the highest levels of fine sediment (18.7% volumetric) in spawning gravels sampled on the north Olympic Peninsula. Salmonid egg-to-alevin survival decreases drastically when fine sediment (<0.85mm) exceeds 13% (volumetric). While no pre-disturbance fine sediment data are available for Ozette tributaries, in nearby undisturbed drainage basins with similar geology, fine sediment levels rarely exceed 10%. Future data collection of fine sediment levels in spawning gravel in Ozette tributaries is needed to track fine sediment impacts over time and document watershed efforts to reduce sedimentation and restore watershed processes sockeye depend on. In addition, other data on sockeye spawning habitat quality are lacking, such as hyporheic flow conditions within redds and the influence of increased fine sediment levels on egg-to-fry survival.

In Ozette tributaries, it is hypothesized that the combined influence of increased sedimentation of spawning reaches, reduced wood loads, increased common peak flood magnitude, and/or channelization and floodplain disconnection have synergistically destabilized relative bed stability and reduced sockeye egg-to-fry survival. However, since data are lacking in Ozette regarding: 1) scour depths at sockeye redds, 2) the effects of flood peak magnitude on scour depths, 3) the effects of fine sediment on scour, 4) the effect of sediment transport imbalances on scour, and 5) the effect of overall wood load and channel stability on scour, no quantitative conclusions can be made regarding the impact on sockeye egg-to-fry survival. The above-mentioned hypotheses and physical processes need to be tested in Ozette tributaries in order to understand the relative importance of each separate or cumulative effect on scour and sockeye egg-to-fry survival. Thus, scour and bed stability remains a critical data gap.

7.9.2 Spawning Habitat Quantity

In many Ozette tributaries, the quantity of suitable spawning habitat area has been reduced as a result of the effects of LWD removal, reduced LWD recruitment, increased fine sediment inputs and abundance, channelization and bank armoring, gravel mining, and colonization of bar deposits by non-native vegetation. In some reaches of Big River and Umbrella Creek, spawning gravel beds have been completely converted to sand bed or cobble bed, respectively. No attempts have been made to quantify loss of available spawning habitat over time, which remains a data gap.

7.9.3 Egg Predation

No attempt to measure sockeye egg predation in the tributaries has been conducted nor has it been suggested that significant levels of egg predation are occurring. Within other sockeye populations, predatory fishes and birds have been observed feeding on eggs, but most observers have concluded that the bulk of eggs eaten are dislodged by late-arriving spawners and would have had a low chance for survival. In a general review of sockeye salmon life histories, Burgner (1991) concludes that less is known about predation on eggs and alevins in the redds than at other life stages, but physical and chemical factors such as redd desiccation, freezing, lowered DO resulting from siltation, reduced flow, and dislodgment (scour or superimposition) are probably more important as mortality factors. However, egg predation remains a data gap in Ozette tributaries.

7.10 TRIBUTARY FRY EMERGENCE AND DISPERSAL

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye egg incubation on spawning beaches:

- Streamflow
- Predation
- Water Quality
- Fry Abundance

Key questions to be addressed through research and monitoring are included in Sections 7.10.1 through 7.10.4.

7.10.1 Streamflow

It is assumed that higher flows and increased stream velocities increase the rate of emigration into the lake, decreasing exposure to predation. It is hypothesized that predation rates are lower on emigrating juveniles during high streamflow. But these key questions and data gaps still need to be answered. How do high streamflows influence fry emigration survival? How does natural streamflow variability and/or changes in streamflow variability affect juvenile sockeye emigration survival?

7.10.2 Predation

Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in tributaries. No studies have been conducted to estimate emergent sockeye fry predation in the tributaries. Potential predators at this life history stage include sculpin (sp), cutthroat trout, juvenile steelhead trout, and juvenile coho salmon. Predator interactions at this early life history stage remain a data gap and it is possible that significant levels of predation occur in Umbrella Creek and Big River.

7.10.3 Water Quality

Collection of continuous turbidity and SSC measurements in all Ozette sockeye tributaries needs to continue over the long term, with the goals of understanding the magnitude and duration of impacts of high sediment loads on sockeye fry emigration from tributaries and detecting long-term (decadal) trends in turbidity and suspended sediment concentration.

7.10.4 Fry Abundance

Fry abundance data within Ozette tributaries is very sparse. No sockeye fry emergence data have been collected from sockeye redds to quantify the incubation success and population of initial fry recruits. In addition, fry survival and abundance data within the tributary environment are lacking. Enumerating fry with fyke nets occurred during one year, but results were marginal and impacts on fry survival were questionable. Future efforts need to focus not only on egg-to-fry survival and emergence success, but also on the survival and population abundance of fry between initial tributary emergence and lake rearing. However, enumeration techniques need to be developed that can both accurately estimate fry abundance and also ensure low levels of mortality from enumeration efforts. New technologies may be available to aid in this challenging enumeration issue.

7.11 JUVENILE FRESHWATER REARING

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for juvenile sockeye freshwater rearing in Lake Ozette:

- Fry-to-Smolt Survival Rates and Predation
- Zooplankton Abundance and Lake Productivity

Key questions to be addressed through research and monitoring are included in Sections 7.11.1 and 7.11.2.

7.11.1 Fry-to-Smolt Survival Rates and Predation

Lake Ozette juvenile sockeye productivity and survival are currently not limited by food availability or competition. Consumption demand by kokanee and juvenile sockeye is satisfied by less than 1% of the instantaneous production of the preferred large Daphnia (*Daphnia sp*.) throughout the growing season. In addition, Ozette sockeye smolts are the third largest (by length and weight) yearling sockeye smolts documented in the recorded literature.

The exact degree that predation in Lake Ozette limits smolt production still remains partially unquantified. Juvenile sockeye and smolts are preyed upon by a host of predators in Lake Ozette, including northern pikeminnow, cutthroat trout, sculpin, other native and non-native fishes, and birds. In the limnetic (open water) zone of Lake Ozette, cutthroat trout have been documented to be the major predator of juvenile *O. nerka*, whereas northern pikeminnow have a reduced predation influence because of limited limnetic feeding. However, northern pikeminnow, sculpin, cutthroat trout, juvenile steelhead trout, juvenile coho salmon, yellow perch, and largemouth bass may be significant predators of juvenile sockeye along lake margins and near tributary confluences.

Monitoring is needed to better define the rates of sockeye survival from emergent fry-to-smolts within Lake Ozette. Key questions that need to be answered into the future include: What are the major and minor sources of mortality of juvenile sockeye fry in Lake Ozette? What species are the primary predators of juvenile sockeye along lake margins, in the limnetic zone, and in and near the Ozette River? With future population recovery, will sockeye fry be capable of swamping predation in the lake? Will increased numbers of sockeye fry increase fry-to-smolt survival rates by swamping predators?

7.11.2 Zooplankton Abundance and Lake Productivity

Lake productivity and zooplankton production have been the focus of much research attention in the past in Lake Ozette. While current lake productivity is high and current zooplankton biomass consumption is low, these conditions may not remain constant into the future as sockeye populations recover. Under increased pressure from recovering sockeye fry and smolt levels (or other species), the standing crop of zooplankton may begin to wane to a point that lake productivity and zooplankton abundance become significant limiting factors on the entire sockeye population. Therefore, as sockeye recovery progresses into the future, additional monitoring of lake productivity and zooplankton abundance is essential to understand how the lake ecosystem responds to and supports increasing sockeye (and salmonid) abundance.

7.12 SEAWARD MIGRATION

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for juvenile sockeye smolts during seaward migration:

- Streamflow
- Habitat
- Predation
- Water Quality
- Estuary Alterations

Key questions to be addressed through research and monitoring are included in Sections 7.12.1 through 7.12.5.

7.12.1 Streamflow

Ozette River discharge during juvenile emigration has been reduced on average. Additional detailed hydraulic and hydrological modeling is required to determine the exact magnitude that flows have been altered by various factors in combination (river hydraulics such as roughness and sedimentation, climate, hyporheic flow, lake evapotranspiration, and reductions in tributary baseflow inputs). The effect of changes to streamflow on emigrating sockeye remains unknown (see Hypothesis 48 in Section 6.2.12.4) and should be a focus of future research and monitoring.

7.12.2 Habitat

Do large logjams that form deep pools in the Ozette river provide important refuge habitat for juvenile sockeye salmon during emigration? Do deep pools provide thermal refuge habitat for juvenile sockeye? How do habitat complexity and/or simplification affect predation on juvenile sockeye?

7.12.3 Predation

Juvenile sockeye smolts are preyed upon by a host of predators in the Ozette River, including river otters, seals, northern pikeminnow, cutthroat trout, birds, and terrestrial mammals. Continued and expanded monitoring of in-river predation on juvenile sockeye is an important component for understanding the degree that predation affects the sockeye population at different abundance levels.

7.12.4 Water Quality

It is recommended that water quality data (temperature, turbidity, SSC) continue to be collected. Have stream temperatures increased during the last 50 years? How much? How do high stream temperatures limit Ozette sockeye juvenile emigration? Are variations in timing of juvenile emigrations a response to river flow and water temperature?

How much have turbidity and SSC increased in Ozette River and Coal Creek during the last 50 years? How do high turbidity and SSC values affect Ozette sockeye juvenile physiology, behavior, and habitat? How does sediment derived from Coal Creek affect rearing habitat further downstream in Ozette River (i.e., pool depth, refugia availability, and predator visual site distance)? How does sedimentation in Ozette River affect the unique biota of the river (e.g., net spinning caddis flies, freshwater sponge, endemic mussels, etc.) and thus the ecosystem that juvenile sockeye migrate through and feed in?

7.12.5 Estuary Alterations

Little is known about the behavior of juvenile Ozette sockeye emigration down the Ozette River. However, at least some populations of sockeye are known to rear in the estuarine environment for extended periods in systems with sizable estuaries. Many populations of sockeye use the nearshore for at least 2-6 weeks following emigration from their natal stream (Burgner 1991). The Ozette system does not include a sizeable estuary, but the nearshore region surrounding the mouth of the Ozette River is an extensive, complex, and productive shallow sub-tidal environment.

To what extent do Ozette juvenile sockeye use the Ozette River estuary for rearing during emigration? Are there unique tidal prism influences that enhance or are detrimental to juvenile sockeye? Quantify the changes in estuary volumes and habitat availability over time in response to altered spit morphology at the ocean mouth. Analyze sequential historical photos, in conjunction with field surveys. How has nutrient and salinity exchange changed in the estuary and how has this affected sockeye rearing and emigration habitat?

7.13 MARINE OCEAN PHASE

Limited marine survival data indicate that *total* marine survival rates are good, averaging 15 to 27%. Marine survival for large sockeye smolts (>115mm) in the southern range (latitude <55°N) averages 17.1%. However, additional data are needed to better define the inter-annual variability in marine survival, as well as to document population trends and mortality factors through time.

It is unknown to what degree Ozette sockeye use the nearshore environment prior to their migration to northern inshore or offshore marine rearing environments. Marine geographic and habitat usage for Ozette sockeye during the entire marine life history phase remains a major data gap.

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APPENDIX A- Summary of Sockeye Weir Count Methods Used (1977-2003).

Appendix A- Summary of Sockeye Weir Count Methods Used (1977-2003)						
YEAR	**Method**	**Start Date**	**End Date**	**Potential errors**	**Dataset Available**	**Source**
1977	N = n + harvest. Weir was made of net weighted to bottom by lead line and chain. Counts from dusk to dawn with 24-hour counts only made bi-weekly from platform over illuminated counting board. Assumed there were no daytime migrants, weir presumably left open during day but unknown (Rob Snyder notes that it was mostly left open).	~5/14/1977	~8/10/1977	Missed early portion of the run, daytime migrants, weir not fish tight, potential no collected for multiple days within survey period	NO	Dlugokenski et al. (1981)
1978	N = n + harvest. Weir was made of net weighted to bottom by lead line and chain. Counts from dusk to dawn with no documented 24-hour counts. Assumed there were no daytime migrants, weir presumably left open during day but unknown (Rob Snyder notes that it was mostly left open).	~5/24/1978	~8/8/1978	Missed the majority of May counts, daytime migrants not monitored, weir may have not been fish tight, 60 fish were counted transiting the weir on May 16 and 17 prior to full scale monitoring	Partial dataset available	Dlugokenski et al. (1981)
1979	N = n + harvest. Weir was made of net weighted to bottom by lead line and chain. Counts from dusk to dawn with no documented 24-hour counts. Assumed there were no daytime migrants, weir presumably left open during day but unknown (Rob Snyder notes that it was mostly left open).	~5/20/1979	~8/8/1979	Missed a large portion of the May counts at least several fish per night were passing the weir prior to installation, daytime migrants not monitored, weir may have not been fish tight.	NO	Dlugokenski et al. (1981)

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YEAR	**Method**	**Start Date**	**End Date**	**Potential errors**	**Dataset Available**	**Source**
1980	Partial count N=n+havest, where n= n/p where p = proportion of fish transiting the weir between June 5 and June 24. Weir was made of net weighted to bottom by lead line and chain. Counts from dusk to dawn with no documented 24-hour counts. Assumed there were no daytime migrants, weir presumably left open during day but unknown (Rob Snyder notes that it was mostly left open).	?	?	Model is fairly inaccurate since it has the errors associated with the total counts described above. The potential errors in methods in 1977-1979 are also applicable to the daily counts in 1980	NO	Dlugokenski et al. (1981)
1981	Partial count N=n+havest, where n= n/p where p = proportion of fish transiting the weir between June 5 and June 24. Weir was made of net weighted to bottom by lead line and chain. Counts from dusk to dawn with no documented 24-hour counts. Assumed there were no daytime migrants, weir presumably left open during day but unknown (Rob Snyder notes that it was mostly left open). At least two days within the monitoring period were unmonitored.	6/8/1981	7/8/1981	Model is fairly inaccurate since it has the errors associated with the total counts described above. The potential errors in methods in 1977-1979 are also applicable to the daily counts in 1980	Yes- based upon plotted data taken off of graph	MFM 1981C
1982	Partial count N=n+havest. Weir was made of pickets with attached live trap. Counts are probably much better than in the years prior to 1982. Assumed that counts represent close to all fish transiting the weir (24 hour monitoring).	Deployed 5/21/1982; 24-hr counts 6/9/1982	8/17/1982	No expansion was done for missing data in April, May, or the first part of June- sporadic data for a few weeks prior to June 9.	Yes	MFM 1982B; Yellow Field Notebook Data
1983	No counts conducted due to lack of funding.	na	na	na	na	MFM 1983A
1984	Partial count N=n/p+havest. Where p was derived from the Dlugokenski model and dataset. Weir was made of pickets with attached live trap. Counts are probably much better than in the years prior to 1982. Assumed that counts represent close to all fish transiting the weir (24 hour monitoring).	6/19/1984	8/7/1984	Missed over half of June and all of May and April-	Yes	MFM 1984A
1985	No counts conducted.	na	na	na	na	LaRiviere 1991

Appendix A- Summary of Sockeye Weir Count Methods Used (1977-2003)

YEAR	Method	Start Date	End Date	Potential errors	Dataset Available	Source
1986	Counts conducted but no records could be found.	?	?	No records for RY 1986	NO	na
1987	No counts conducted.	na	na	na	na	LaRiviere 1991
1988	Partial count N=n/p. Where p was derived from the Dlugokenski model but data used for expansion were from the 1982 and 1984 weir datasets. The same full spanning picket weir was used in 1988 but no trap was attached. Fish were counted as the passed over an illuminated 3ft long, white, counting board by observers stationed on a small observation platform. The weir was installed just upstream of the ONP footbridge. Fish were counted from 2000 hr to 0600 hr. The weir was closed during non-observer time periods 0600 hr to 2000 hr. In conjunction with these observations a hydroaccoustic method was also employed but failed to yield adequate data.	6/27/1988	6/29/1988	Only three days of weir data collected, errors in expansion are likely huge	Yes	LaRiviere 1991
1989	Partial count N=n/p. Where p was derived from the Dlugokenski model but data used for expansion were from the 1982 and 1984 weir datasets. The same full spanning picket weir was used in 1989. A trap was attached for one night of monitoring. Fish were counted as the passed over an illuminated 3ft long, white, counting board by observers stationed on a small observation platform. The weir was installed just upstream of the ONP footbridge. Fish were counted from 2000 hr to 0600 hr. The weir was closed during non-observer time periods (0600 hr to 2000 hr).	6/19/1989	6/30/1989	Only 10-11 days worth of data were collected. Expansion relies on years with incomplete weir datasets.	Yes	LaRiviere 1991

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YEAR	**Method**	**Start Date**	**End Date**	**Potential errors**	**Dataset Available**	**Source**
1990	Partial count N=n/p. Where p was derived from the Dlugokenski model but data used for expansion were from the 1982 and 1984 weir datasets. The same full spanning picket weir was used in 1990. A trap was attached for trapping and approximately 17% of the sockeye counted past the weir were caught in the trap. In general, fish were counted as the passed over an illuminated 3ft long, white, counting board by observers stationed on a small observation platform. The weir was installed just upstream of the ONP footbridge. Fish were counted from 2000 hr to 0600 hr. The weir was closed during non-observer time periods (0600 hr to 2000 hr).	6/7/1990	8/11/1990	Weir fish 4-5 days per/week and left closed for up to 48 hrs at a time. This likely decreased the rate at which sockeye were detected. Expansion based upon partial dataset expansions.	Yes	LaRiviere 1991
1991	Partial count N=n/p. Where p was derived from the Dlugokenski model but data used for expansion were from the 1982 and 1984 weir datasets. The same full spanning picket weir was used in 1991. A trap was attached for trapping, but most fish were enumerated as they passed over an illuminated, white counting board. Observers were stationed on the ONP footbridge and were ably to open and close attached trap with ropes and pulleys. Fish tight by 5-23-1991 (although report mentions that smaller fish could squeeze through the pickets). On 5/23, 24, &27, fish were passed from 0430 to 0700 and from 2200 - 0000. From 5-29 - 6/17, 6/24 - 7/3, 7/10 - 7/12 fish were passed once daily from 0500-0700. From 5-29 - 6/17, 6/24 - 7/3, 7/10 - 7/12 fish were passed once daily from 0500-0700 every other day in early morning. Weir monitoring was de-emphasized from 7/3 - 7/12, fish were counted every other morning and the weir was left open.	5/23/1991	7/12/1991	Model only uses data from 6-19-1991 through the 30th. No data available to compare run-shape with other years. Several potential errors associated with the RY 1991 run-size estimate. Only 10 or 11 day's worth of data used in expansion.	No	Drange and LaRiviere 1991

Appendix A- Summary of Sockeye Weir Count Methods Used (1977-2003)

YEAR	Method	Start Date	End Date	Potential errors	Dataset Available	Source
1992	Partial count N=n/p. Where p was derived from the Dlugokenski model but data used for expansion were from the 1982 and 1984 weir datasets. The same full spanning picket weir was used in 1992. No trap was used to capture fish in 1992. Observers were presumably stationed on the ONP footbridge and able to count sockeye passing over a counting board (field report lacked sufficient method details). Fish were breeching weir between 5-29-1992 and 6-14-1992. Weir was left closed but sockeye were noted as burrowing under the weir pickets.	5/29/1992	7/9/1992	Closing weir at night likely decreased weir detection accuracy by fish by-passing the weir. Expansion uses less than half of the actual fish counted. The same issues of using partial datasets to expanded for partial datasets also applies to the original 1992 run-size estimate. 10-11 days of data used to generate total run-size.	Yes	MFM, 1992 Report of Activities
1993	Counts conducted but no records could be found.	?	?	No records for RY 1993	NO	na
1994	Counts conducted but no reports could be found	6/6/1994	7/15/1994	Same as 1989-1995	Yes	MFM Data Files
1995	Counts conducted but no records could be found.	?	?	No records for RY 1995	NO	na
1996	Partial count N=n/p. Where p was derived from the Dlugokenski model. The Ozette River counting weir was installed at the same location as used in RY 1989-1995. Weir setup and installation was similar to that used during RY 1989-1995. The weir was closed during the daytime (typically from 0500 to 23:00) and at other non-observer time periods. Data from the weir is available for 12 complete "days" between June 18th and June 29th. The data are currently only available in the form of daily counts. No daytime data are present within the dataset.	6/18/1996	6/29/1996	Fish were burrowing between pickets when weir was closed Dave Easton saw at least 10 sockeye bypass the weir during daylight hours.	Yes	MFM Data Files; Haggerty 2004F

Appendix A- Summary of Sockeye Weir Count Methods Used (1977-2003)

YEAR	Method	Start Date	End Date	Potential errors	Dataset Available	Source
1997	Partial count N=n/p. Where p was derived from the Dlugokenski model. The Ozette River counting weir was installed at the same location as used in RY 1989-1996. Weir setup and installation was similar to that used during RY 1998. However, only visual observers monitored the weir during RY 1997. The weir was closed during the daytime (typically from 06:00 to 22:00) and at other non-observer time periods. Data from the weir is available for 18 complete "days" between June 10th and June 30th. The data are currently only available in the form of daily counts. No daytime data are present within the dataset.	6/9/1997	7/1/1997	Potential errors are outlined in Haggerty 2004F; main issues are related to the proportion of sockeye transiting the weir which are detected by the methods employed.	Yes	MFM Data Files; Haggerty 2004F
1998	N=(R*V) +C (as described in MFM 2000). Where R represented the ratio of sockeye transits observed by visual observers vs. the number detected by camera method, used to expand for observer detection rate. The Ozette River counting weir was installed on May 5, 1998, in the upper river at the Olympic National Park foot bridge (located near the lake outlet; this is same location as used in RY 1999-2004. Weir setup and installation was similar to that used in past years. Both visual observers and a time-lapse VCR system were used to enumerate sockeye transiting the weir. Makah Fisheries Management (2000) stated that the weir was monitored from May 5, 1998 through August 6, 1998. However, field notes and data files indicate that data were collected at the weir from May 7th through August 6, 1998. Visual observers were stationed at the weir starting May 7th and ending July 2, 1998. The video system was operated from June 16th through August 6, 1998.	5/7/1998	7/2/1998	Potential errors are outlined in Haggerty 2004F; main issues are related to the proportion of sockeye transiting the weir which are detected by the methods employed.	Yes	MFM Data Files; Haggerty 2004F

Appendix A- Summary of Sockeye Weir Count Methods Used (1977-2003)						
YEAR	**Method**	**Start Date**	**End Date**	**Potential errors**	**Dataset Available**	**Source**
1999	N=(R*V) +C (as described in MFM 2000). Where R represented the ratio of sockeye transits observed by visual observers vs. the number detected by camera method, used to expand for observer detection rate. The Ozette River counting weir was installed on April 30, 1999 in the upper river at the Olympic National Park foot bridge. Weir setup and installation was similar to that used during RY 1998. Both visual observers and a time-lapse VCR system were used to enumerate sockeye transiting the weir. The video system operated for a total of 153 days from May 1, 1999 to September 30, 1999. In addition to the video system observers were stationed at the weir opening between 2200 and 0700 beginning April 30, 1999 and ending August 6, 1999.	5/1/1999	9/30/1999	Potential errors are outlined in Haggerty 2004F; main issues are related to the proportion of sockeye transiting the weir which are detected by the methods employed.	Yes	MFM Data Files; Haggerty 2004F
2000	See Haggerty 2005D for detailed methods used for calculating N. The Ozette River counting weir was installed on April 19, 200 in the upper river at the Olympic National Park foot bridge. Weir setup and installation was similar to that used during RY 1998 and 1999. Both a time-lapse VCR system and a trap were used to enumerate sockeye transiting the weir. The video system and trap were operated from April 19, 2000 through August 12, 2000.	4/19/2000	8/12/2000	Potential errors are outlined in Haggerty 2005D; main issues are related to the proportion of sockeye transiting the weir which were detected by the video system, some missing time expansion.	Yes	MFM Data Files; Haggerty 2005D

Appendix A- Summary of Sockeye Weir Count Methods Used (1977-2003)						
YEAR	**Method**	**Start Date**	**End Date**	**Potential errors**	**Dataset Available**	**Source**
2001	See Haggerty 2005C for detailed methods used for calculating N. The Ozette River counting weir was installed on April 30, 2001 in the upper river at the Olympic National Park foot bridge. Weir setup and installation was similar to that used during 2000 but included an attached smolt screw trap and an adult trap located along the right bank. *Vexar* screen in trap limited viewing conditions for part of the return. Lighting issues also played a role in limiting image quality at times. Both a time-lapse VCR system and a trap were used to enumerate sockeye transiting the weir.	4/30/2001	8/18/2001	Potential errors are outlined in Haggerty 2005C; main issues are related to the proportion of sockeye transiting the weir which were detected by the video system, some missing time expansion.	Yes	MFM Data Files; Haggerty 2005C
2002	See Haggerty 2005A for detailed methods used for calculating N. The Ozette River counting weir was installed on April 11, 2002 in the upper river at the Olympic National Park foot bridge. Weir setup and installation was similar to that used during 2001 but didn't include an adult trap Both a time-lapse VCR system and a computer hard drive and software system were used to enumerate sockeye transiting the weir.	4/11/2002	8/14/2002	Potential errors are outlined in Haggerty 2005A; main issues are related to the proportion of sockeye transiting the weir which were detected by the video system vs. hard drive system, missing time expansion.	Yes	MFM Data Files; Haggerty 2005A
2003	See Haggerty 2005B for detailed methods used for calculating N. The Ozette River counting weir was installed on May 12, 2003 in the upper river at the Olympic National Park foot bridge. Weir setup and installation was similar to that used during 2002. Both a time-lapse VCR system and a computer hard drive and software system were used to enumerate sockeye transiting the weir.	5/12/2003	8/12/2003	Potential errors are outlined in Haggerty 2005C; main issues are related to the proportion of sockeye transiting the weir which were detected by the video system, some missing time expansion.	Yes	MFM Data Files; Haggerty 2005B

APPENDIX B-Summary of Sockeye Run-Size Estimates for RY (1977-1995)

YEAR	High Detection (90%)			Moderate Detection (70%)			Low Detection (50%)			Median	n=
	Average DRP	1998 DRP LATE	2000 DRP EARLY	Average DRP	1998 DRP LATE	2000 DRP EARLY	Average DRP	1998 DRP LATE	2000 DRP EARLY		
1977	2,141	1,517	3,730	2,752	1,950	4,795	3,853	2,730	6,713	2,752	666
1978	1,584	1,355	2,398	2,037	1,742	3,083	2,851	2,439	4,317	2,398	844
1979	1,038	736	1,809	1,335	946	2,326	1,869	1,324	3,256	1,335	323
1980	820	581	1,428	1,054	747	1,836	1,475	1,045	2,570	1,054	255
1981	668	468	1,554	858	602	1,998	1,202	843	2,797	858	239
1982	4,131	3,409	6,375	na	na	na	na	na	na	4,131	2122
1983	na	na	na	na	na	na	na	na	na	na	na
1984	2,474	2,325	5,639	na	na	na	na	na	na	2,474	518
1985	na	na	na	na	na	na	na	na	na	na	na
1986	na	na	na	na	na	na	na	na	na	na	na
1987	na	na	na	na	na	na	na	na	na	na	na
1988	7,599	4,661	25,554	9,770	5,992	32,855	13,678	8,389	45,997	9,770	218
1989	1,304	812	4,257	1,677	1,043	5,473	2,347	1,461	7,663	1,677	143
1990	560	407	1,141	719	523	1,467	1,007	732	2,053	732	174
1991	1,520	991	5,044	1,955	1,274	6,486	2,736	1,783	9,080	1,955	182
1992	2,870	2,315	4,222	3,690	2,976	5,429	5,166	4,167	7,600	4,167	1182
1993	na	na	na	na	na	na	na	na	na	na	na
1994	728	565	1,371	936	727	1,762	1,311	1,018	2,467	1,018	213
1995	na	na	na	na	na	na	na	na	na	na	na

DRP= Daily Run Proportion.

APPENDIX C- Summary Table of Annual Lake Ozette Sockeye Beach Spawning Ground Surveys.

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.

Return Year	Lake Survey or Capture Site	Date	Observation or Capture Comments	Information Source	BROOD YEAR	Peak Count or No. of Collections
1973	Ozette beaches	1/10/1974	The only area sockeye spawning was observed in was along Olsen's Beach. Five dead and one live sockeye observed	J. Meyer written communication in Bortleson and Dion 1979	A	6
1976	West Shore	11/9/1976	Spawning ground survey from Elk Creek north to Preachers Point- No sockeye observed.	Bortleson and Dion 1979	D	0
1976	Ericson's Bay	11/9/1976	Spawning ground survey of Ericson's Bay- No sockeye observed	Bortleson and Dion 1979	D	0
1976	Olsen's Beach	2/8/1977	Spawning ground survey of Olsen's Beach- 6-10 live and 1 dead sockeye observed along with 6 redds in 1-2ft of water.	Bortleson and Dion 1979	D	11
1976	Allen's Beach	2/8/1977	Allen's spawning ground survey- 1 live sockeye	Bortleson and Dion 1979	D	1
1978	Olsen's Beach	11/22/1978-1/22/1979	5 spawning ground surveys conducted; peak count (12/20/78) 60 live and 4 dead sockeye.	Dlugokenski et al. 1981	B	64
1978	Allen's Beach	12/6/1978-2/23/1979	5 spawning ground surveys conducted; peak count (1/14/79) 150 live.	Dlugokenski et al. 1981	B	150
1978	Umbrella Beach	1/20/1978-3/1/1979	3 spawning ground surveys conducted; peak count 30 live sockeye	Dlugokenski et al. 1981	B	30
1978	Near Quinn Creek	Jan. 1979	Several ripe sockeye captured in gill net near the mouth of Quinn Cr. (Boot Bay Area).	Dlugokenski et al. 1981	B	5
1983	Olsen's Beach	12/13/1983-12/14/1983	Broodstock capture, egg take totaled 27,000-15000 eggs. At 3,000 eggs/female and 1:1 sex ratio capture provides an estimate of 18-10 sockeye.	MFM 1984B	C	18

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.						
Return Year	**Lake Survey or Capture Site**	**Date**	**Observation or Capture Comments**	**Information Source**	**BROOD YEAR**	**Peak Count or No. of Collections**
1985	Olsen's Beach	Dec. 1985	Broodstock capture of 40 adult sockeye.	MFM 1986	A	40
1986	Olsen's Beach	Dec. 1986	Broodstock capture of 43 adult sockeye.	MFM unpublished broodstock collection data	B	43
1987	Olsen's Beach	11/16/1987-2/26/1988	11 spawning ground surveys conducted, first sockeye observed on 11/27. Peak count was 50 sockeye on 1/21/1988. Lat sockeye observed 2/26/1988	MFM unpublished spawning ground survey data	C	50
1987	Allen's Beach	12/11/1987-2/26/1988	8 spawning ground surveys conducted, 50 sockeye observed 12/11/1987; peak count 57 sockeye on 1/21/1988. No sockeye observed on 2/26/1988.	MFM unpublished spawning ground survey data	C	57
1987	Umbrella Beach	11/16/1987-11/27/1987	2 spawning ground surveys conducted, no sockeye observed.	MFM unpublished spawning ground survey data	C	0
1987	Allen's and Olsen's beaches	12/8/1987-12/23/1987	Broodstock capture of 123 adult sockeye from both beaches.	MFM unpublished broodstock collection data	C	123
1988	Olsen's Beach	11/15/1988-3/23/1989	10 spawning ground surveys conducted, first and peak sockeye counts occurred on 12/2. 7 sockeye were observed on 2/23/1989.	MFM unpublished spawning ground survey data	D	80
1988	Allen's Beach	11/15/1988-3/23/1989	10 spawning ground surveys conducted, 31 sockeye were observed on 11/15, peak sockeye counts (100 fish) occurred on 12/9. 11 sockeye were observed on 1/27/1989.	MFM unpublished spawning ground survey data	D	100
1988	Umbrella Beach	12/2/1988-3/23/1989	5 spawning ground surveys conducted, no sockeye observed.	MFM unpublished spawning ground survey data	D	0

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.

Return Year	Lake Survey or Capture Site	Date	Observation or Capture Comments	Information Source	BROOD YEAR	Peak Count or No. of Collections
1988	Allen's and Olsen's beaches	12/2/1988-12-15/1988	Broodstock capture of 193 adult sockeye from both beaches.	MFM unpublished broodstock collection data	D	193
1989	Olsen's Beach	11/26/1989-2/23/1990	12 spawning ground surveys conducted, despite intense efforts sockeye were observed on only 2 occasions, peak count 2 sockeye.	MFM unpublished spawning ground survey data	A	2
1989	Allen's Beach	11/26/1989-2/23/1990	12 spawning ground surveys conducted, despite intense efforts very few sockeye were observed, first sockeye observed on 11/30 (n=3), 1-2 sockeye captured or observed on each survey through 1/30/1990.	MFM unpublished spawning ground survey data	A	3
1989	Allen's and Olsen's beaches	12/11/1989-12-21-1989	Catch was poor only at total of 6 sockeye and 1 kokanee captured in four days of fishing at both beaches.	MFM unpublished broodstock collection data	A	6
1990	Olsen's Beach	11/5/1990-12/12/1990	Fished and viewed sockeye for 8 days, one dead fish seen on 11/6, 20 sockeye captured on 11/8, last fish caught and released on 12/12.	MFM unpublished broodstock collection data	B	21
1990	Allen's Beach	11/8/1990-12/12/1990	One dead sockeye observed on 11/8, 11 fish caught on 12/6, none captured on 12/12.	MFM unpublished broodstock collection data	B	12
1991	Allen's and Olsen's beaches	?	No specific breakdown by beach, a total of 175 sockeye were collected for broodstock.	MFM unpublished broodstock collection data	C	175
1992	Allen's and Olsen's beaches	?	No specific breakdown by beach, a total of 109 sockeye were collected for broodstock.	MFM unpublished broodstock collection data	D	109
1993	Allen's and Olsen's beaches	?	No specific breakdown by beach, a total of 32 sockeye were collected for broodstock.	MFM unpublished broodstock collection data	A	32

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.

Return Year	Lake Survey or Capture Site	Date	Observation or Capture Comments	Information Source	BROOD YEAR	Peak Count or No. of Collections
1994	Baby Island, Allen's, and Olsen's beaches	12/16/1994	A total of seven sockeye redds were observed at Olsen's Beach, Baby Island, and Allen's Beach.	Meyer and Brenkman 2001	B	na
1994	Allen's and Olsen's beaches	?	No specific breakdown by beach, a total of 54 sockeye were collected for broodstock.	MFM unpublished broodstock collection data	B	54
1995	Allen's and Olsen's beaches	Nov. 1995	No specific breakdown by beach, a total of 94 sockeye were collected for broodstock. 33 genetic tissue samples were collected at Allen's.	MFM unpublished broodstock collection data	C	127
1996	Allen's and Olsen's beaches	11/24/1996-12/23/1996	No specific breakdown by beach, a total of 200 sockeye were collected for broodstock. 100 genetic tissue samples were collected at Olsen's Beach 11/24/96-12/23/96. 101 genetic samples collected at Allen's.	MFM unpublished broodstock collection data; Hawkins 2004	D	200
1997	Olsen's Beach	?	A total of 263 sockeye were collected for broodstock.	MFM unpublished broodstock collection data	A	263
1998	Olsen's Beach	?	A total of 88 sockeye were collected for broodstock. Additional fish were captured for genetic tissue sampling. A total of 136 sockeye were sampled.	MFM 2000	B	136
1998	Allen's Beach	?	27 sockeye were captured for tissue sampling.	Hawkins 2004	B	27
1999	Olsen's Beach	11/2/1999-3/1/2000	12 spawning ground surveys conducted, first sockeye observed 11/2/1999, peak dive counts were 12 sockeye, poor visibility after 12/13. A total of 10 redds were identified during the spawning season.	MFM unpublished spawning ground survey data	C	12

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.

Return Year	Lake Survey or Capture Site	Date	Observation or Capture Comments	Information Source	BROOD YEAR	Peak Count or No. of Collections
1999	Olsen's Beach	11/11/1999-12/23/1999	A total of 29 sockeye were collected for broodstock. An additional 76 sockeye were captured and tissues were sampled. A total of 105 fish were handled.	MFM 2000; Crewson et al. 2001	C	105
1999	Allen's Beach	11/2/1999-3/1/2000	12 spawning ground surveys conducted, first sockeye and redd observed 11/2/1999, peak dive counts were only 4 sockeye, survey conducted along lead line transect- not an entire overview of the beach as in other years.	MFM unpublished spawning ground survey data	C	4
1999	Miscellaneous Shoreline Surveys	11/10/1999-2/23/2000	Surveys of areas north and south of Allen's transect, Baby Island, Boot Bay, Cemetery Point, Umbrella Beach, and east Ericson's Bay. Sockeye activity only observed at South Allen's.	MFM unpublished spawning ground survey data	C	na
2000	Olsen's Beach	11/8/2000-1/4/2001	Genetic tissue sampling; 59 samples taken from carcasses, 41 samples from sockeye captured with gill net.	Crewson et al. 2001.	D	100
2000	Olsen's Beach	11/15/2000-2/13/2001	11 spawning ground surveys conducted, on 11-15 there were 20 or more sockeye spawning (8 redds) and a group of 60-80 fish holding offshore in 20-25ft of water, peak dive counts occurred on 11-15. 30-50 sockeye observed each week until 1/22, last fish observed 1/31	MFM unpublished spawning ground survey data	D	100

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.

Return Year	Lake Survey or Capture Site	Date	Observation or Capture Comments	Information Source	BROOD YEAR	Peak Count or No. of Collections
2000	Allen's Beach	11/15/2000-2/13/2001	11 spawning ground surveys conducted, along main transect on 11-15 there were12 or more sockeye spawning (3 redds), dozens holding offshore, more fish located south of lead line, 25 fish on one redd on 12/4, peak activity on 1/4/2001. No fish observed after 1/11/2001. Peak activity south of lead line was on 11/21/00 when approximately 30 redds and 100 sockeye were observed. In total on 11-21-00 approximately 48 redds and 150+ sockeye were present. Kokanee present at several locations.	MFM unpublished spawning ground survey data	D	150
2000	Miscellaneous Shoreline Surveys	11/15/2000-2/6/2000	Surveys of areas north and south of Allen's transect, Pt north of Olsen's, Boot Bay, Cemetery Point, Umbrella Beach, and east Ericson's Bay. Activity only reported at Cemetery Point and point north of Olsen's. Peak counts of 20 sockeye at Cemetery point on 11-21, last fish observed 1/4. Sockeye active north of Olsen's from 12/4 to 1/11/01- peak count of 8 live sockeye and 5 redds.	MFM unpublished spawning ground survey data	D	28
2001	Olsen's Beach	11-1/2001-unknown	11 redds and at least 23 sockeye observed on 11-1-01. 30 sockeye and several active redds observed on 11-14-01. A total of 107 carcasses were sampled plus 5 live fish on 1-4-02.	MFM unpublished spawning ground survey data	A	111
2001	Allen's Beach	11-1/2001-unknown	Only partial dataset was recovered for this year. 18 carcasses collected, half collected on 1/4/02 when at least 3 live fish were also seen. Peak count from the two existing surveys was 51 sockeye on 11/14/01.	MFM unpublished spawning ground survey data	A	51

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.						
Return Year	**Lake Survey or Capture Site**	**Date**	**Observation or Capture Comments**	**Information Source**	**BROOD YEAR**	**Peak Count or No. of Collections**
2002	Olsen's Beach	10/22/02-12/5/02	Only 4 spawning ground surveys were made. Peak counts on last survey (12/5), 61 live fish at point north of Olsen's Beach and 97 live fish at Olsen's Beach.	MFM unpublished spawning ground survey data	B	158
2002	Allen's Beach	10/22/02-12/5/02	Only 4 spawning ground surveys were made. Peak counts on last survey (12/5), 190 live fish along Allen's Beach observed by visual survey. Highest visual counts ever made!!!	MFM unpublished spawning ground survey data	B	190
2003	Olsen's Beach	9/24/2003-2/4/2004	8 spawning ground surveys conducted, 153 sockeye observed 12/17/2003, no fish observed before peak survey, last fish observed on 1/15/04.	MFM unpublished spawning ground survey data	C	153
2003	Allen's beach	9/24/2003-2/4/2004	7 spawning ground surveys conducted, 170 (125L, 45D) sockeye observed 12/11/2003, 20 live sockeye observed on 11/5. Peak live count on 12/17/03 (134L), about 50 of these fish were on point to the north.	MFM unpublished spawning ground survey data	C	213
2003	Cemetery Point, Baby Island, and Umbrella Beach	11/5/2003	No activity observed.	MFM unpublished spawning ground survey data	C	0
2004	Olsen's Beach	10/20/2004-1/5/2005	6 spawning ground surveys were made. First fish observed on beach on 10/20 but no spawning until 11/17. Peak live count on 12/1 last fish observed on 1/5/05 but no surveys after this date. No dive surveys, 2 snorkel surveys after peak boat count.	MFM unpublished spawning ground survey data	D	73
2004	Allen's beach	10/20/2004-1/5/2005	6 spawning ground surveys were made. First fish observed on beach on 11/4 but no spawning until 12/23. Peak live count on 11/17, last fish observed on 1/5/05 but no surveys after this date. No dive surveys, 2 snorkel surveys after peak boat count.	MFM unpublished spawning ground survey data	D	44

Appendix C- Summary table of annual Lake Ozette sockeye beach spawning ground surveys.						
Return Year	**Lake Survey or Capture Site**	**Date**	**Observation or Capture Comments**	**Information Source**	**BROOD YEAR**	**Peak Count or No. of Collections**
2004	Cemetery Point, Baby Island, and Umbrella Beach	11/4/2004-1/5/2005	3 surveys at Umbrella Beach, no fish or redds observed. Cemetery Point surveys are included in the main Allen's Beach surveys.	MFM unpublished spawning ground survey data	D	0

APPENDIX D-Summary Table of Lake Ozette Tributary Channel Attributes.

Appendix D- Summary of Lake Ozette tributary channel attributes (by habitat segment)

Stream Name	Habitat Segment	Habitat Segment ID	Upstream End (Meter)	Segment Length	Gradient	Channel Confine-ment	BFW	Number of BFWs
Coal Creek	1a	PS-1	500	500	<1%	C-M	12	41.6
Coal Creek	1b	PS-2	1,000	500	<1%	M-C	10.3	48.5
Coal Creek	1c	PS-3	1,500	500	<1%	M-C	10.2	48.8
Coal Creek	1d	PS-4	2,042	542	<1%	M-C	11	49.3
Coal Creek	2a	PS-5	2,700	658	<1%	C-M	7.8	83.9
Coal Creek	2b	PS-6	3,200	500	<1%	M	8.5	58.5
Coal Creek	2c	PS-7	3,700	500	<1%	M	8.7	57.2
Coal Creek	3a	PS-8	4,200	500	<1%	U	8	62.4
Coal Creek	3b	PS-9	4,700	500	<1%	U	8.6	58
Coal Creek	3c	PS-10	5,500	800	<1%	U	8	99.8
Coal Creek	4a	PS-11	6,000	500	1-2%	U	7.2	69.7
Coal Creek	4b	PS-12	6,500	500	1-2%	U	8.2	61.2
Coal Creek	4c	PS-13	7,000	500	1-2%	U	6.9	72.5
Coal Creek	5	PS-14	7,803	804	2-4%	C	5.5	145.8
20.0050	1	PS-15	700	700	<1%	U	6.3	111.3
20.0050	2	PS-16	1,200	500	1-2%	U	6.3	78.9
20.0050	3	PS-17	2,134	934	2-4%	M	5.7	163.6
LBT 22,772	1	PS-18	305	305	2-4%	C-M	5.5	55.3
Palmquist Creek	1a	PS-19	500	500	<1%	U	4.6	108.5
Palmquist Creek	1b	PS-20	1,000	500	1-2%	U	4.8	103.2
Palmquist Creek	1c	PS-21	1,625	625	1-2%	U	6	104.3
Palmquist Creek	2	na	2,900	1,275	1-2%	M	5.8	221.4
Umbrella Creek	1a	PS-22	500	500	<1%	U	15.9	31.4
Umbrella Creek	1b	PS-23	1,300	800	<1%	U	18.4	43.4
Umbrella Creek	2a	PS-24	1,800	500	<1%	U	14.7	34.1
Umbrella Creek	2b	PS-25	2,300	500	<1%	U	18.6	26.9
Umbrella Creek	2c	PS-26	2,800	500	<1%	U	16.7	29.9
Umbrella Creek	2d	PS-27	3,300	500	<1%	U	15.8	31.7
Umbrella Creek	2e	PS-28	3,800	500	<1%	U	17.1	29.3
Umbrella Creek	2f	PS-29	4,300	500	<1%	U-M	16.4	30.4
Umbrella Creek	2g	PS-30	4,800	500	<1%	U	16.5	30.4
Umbrella Creek	2h	PS-31	5,300	500	<1%	U	17.1	29.3
Umbrella Creek	2i	PS-32	6,000	700	<1%	U-M	13.6	51.5
Umbrella Creek	3a	PS-33	6,500	500	1-2%	M	12.7	39.4
Umbrella Creek	3b	PS-34	7,000	500	1-2%	M-C	12.8	39.2
Umbrella Creek	3c	PS-35	7,500	500	1-2%	M-C	11.4	43.7
Umbrella Creek	4a	PS-36	8,000	500	1-2%	U-M	13.5	37.2
Umbrella Creek	4b	PS-37	8,500	500	1-2%	U-M	15.7	31.9
Umbrella Creek	5a	PS-38	9,000	500	1-2%	C	13	38.5

Appendix D- Summary of Lake Ozette tributary channel attributes (by habitat segment)

Stream Name	Habitat Segment	Habitat Segment ID	Upstream End (Meter)	Segment Length	Gradient	Channel Confine-ment	BFW	Number of BFWs
Umbrella Creek	5b	PS-39	9,500	500	1-2%	C	10.1	49.5
Umbrella Creek	5c	PS-40	10,200	700	1-2%	C	9.5	73.4
Umbrella Creek	6	PS-41	10,972	772	1-2%	M-C	6.7	116
W.B. Umb. Creek	1a	PS-42	500	500	1-2%	C	9.8	51.2
W.B. Umb. Creek	1b	PS-43	1,000	500	1-2%	C-M	8.4	59.5
W.B. Umb. Creek	1c	PS-44	1,800	800	1-2%	C-M	8.5	93.6
W.B. Umb. Creek	2a	PS-45	2,300	500	2-4%	C	7.8	64.3
W.B. Umb. Creek	2b	PS-46	2,800	500	2-4%	C	6.8	73.1
W.B. Umb. Creek	2c	PS-47	3,400	600	2-4%	C-M	6.8	88.3
W.B. Umb. Creek	3	PS-48	4,054	654	2-4%	C	4	165.4
E.B. Umb. Creek	1a	PS-49	500	500	0-2%	M-C	7.8	64.4
E.B. Umb. Creek	1b	PS-50	1,000	500	0-2%	M-C	7.3	68.9
E.B. Umb. Creek	1c	PS-51	1,600	600	0-2%	M	8.2	73.4
E.B. Umb. Creek	2	PS-52	2,469	869	1-2%	U-M	5.8	150
LBT 5,210	1	PS-53	396	396	1-2%	M	5.1	76.9
LBT 8,100	1	PS-54	213	213	1-2%	M	5.8	36.4
RBT 9,400	na	na	366	366	1-2%	M	3.7	98.3
RBT 15,663	1	PS-55	409	409	2-4%	C	4.3	101.4
Hatchery Creek	na	na	457	457	1-3%	M-C	5.5	83.5
Elk Creek	1	na	400	400	<1%	U	4.6	86.4
Elk Creek	2	na	1200	800	1-2%	M	5.7	139.2
Elk Creek	3	na	1818	618	1-3%	C	4.9	101.7
Big River	1	PS-56	671	671	<1%	U	16.3	41.1
Big River	2a	PS-57	1,200	529	<1%	U	17	31.1
Big River	2b	PS-58	1,700	500	<1%	U	17.3	28.8
Big River	2c	PS-59	2,200	500	<1%	U	16.5	30.3
Big River	2d	PS-60	2,700	500	<1%	U	15.8	31.7
Big River	2e	PS-61	3,200	500	<1%	U	17.8	28.1
Big River	2f	PS-62	3,700	500	<1%	U	20.8	24
Big River	2g	PS-63	4,200	500	<1%	U	18.1	27.6
Big River	2h	PS-64	4,700	500	<1%	U	19.2	26
Big River	2i	PS-65	5,200	500	<1%	U	20.6	24.3
Big River	2j	PS-66	5,700	500	<1%	U	22.1	22.7
Big River	2k	PS-67	6,444	744	<1%	U	20.9	35.5
Big River	3a	PS-68	7,000	556	0.1-2%	U	20.7	26.9
Big River	3b	PS-69	7,500	500	0.1-2%	U	20.6	24.3
Big River	3c	PS-70	8,000	500	0.1-2%	U	20	24.9
Big River	3d	PS-71	8,500	500	0.1-2%	U	25	20
Big River	3e	PS-72	9,000	500	0.1-2%	U	20	25
Big River	3f	PS-73	9,500	500	0.1-2%	U	18.5	27
Big River	3g	PS-74	10,000	500	0.1-2%	U	23.7	21.1
Big River	3h	PS-75	10,500	500	0.1-2%	U	32.4	15.4
Big River	3i	PS-76	11,000	500	0.1-2%	U	23	21.7
Big River	3j	PS-77	11,500	500	0.1-2%	U	20.5	24.4

Appendix D- Summary of Lake Ozette tributary channel attributes (by habitat segment)

Stream Name	Habitat Segment	Habitat Segment ID	Upstream End (Meter)	Segment Length	Gradient	Channel Confine-ment	BFW	Number of BFWs
Big River	3k	PS-78	12,000	500	0.1-2%	U	27.4	18.3
Big River	3l	PS-79	12,680	680	0.1-2%	U	25.4	26.7
Big River	4a	PS-80	13,200	520	0.1-2%	U	19.5	26.6
Big River	4b	PS-81	13,700	500	0.1-2%	U	26.2	19.1
Big River	4c	PS-82	14,200	500	0.1-2%	U	26.1	19.2
Big River	4d	PS-83	14,700	500	0.1-2%	M	23.8	21
Big River	5a	PS-84	15,200	500	1-3%	C	18.8	26.5
Big River	5b	PS-85	15,700	500	1-3%	C	17.9	28
Big River	5c	PS-86	16,200	500	1-3%	C	16.8	29.8
Big River	5d	PS-87	16,700	500	1-3%	C	13.3	37.5
Big River	5e	PS-88	17,221	521	1-3%	C	20.4	25.5
Dunham Creek	1	na	700	700	0-1%	U	10.1	69.2
Dunham Creek	2	na	2,600	1,900	0.1-2%	U	12.1	157
Dunham Creek	3	na	3,300	700	2-3%	M	11.5	61.1
Dunham Creek	4	na	5,061	1,760	2-4%	C	7.7	228.6
Trout Creek	1a	na	500	500	1-2%	U	7.9	63.2
Trout Creek	1b	na	1,000	500	1-2%	U	9	55.3
Trout Creek	2a	na	1,500	500	1-3%	M-C	8.9	56.4
Trout Creek	2b	na	2,000	500	1-3%	M-C	7.9	63.1
Trout Creek	2c	na	2,500	500	1-3%	C	7.5	66.7
Trout Creek	2d	na	3,000	500	1-3%	C-M	8.4	59.2
Trout Creek	2e	na	3,500	500	1-3%	M	8	62.8
Trout Creek	2f	na	4,000	500	1-3%	C-M	6.2	81.1
Trout Creek	2g	na	4,695	695	1-3%	C-M	5.7	121
Solberg Creek	1	PS 89	462	462	1.20%	U	9	51.5
Solberg Creek	2	na	701	239	1-3%	M	9.1	26.2
Stony Creek	1	PS-90	600	600	1-3%	C	5.1	118.2
Stony Creek	2	PS-91	1000	400	3-5%	C	5.9	68.2
Stony Creek	3	PS-92	1323	323	2-4%	C	6.3	51.2
Boe Creek	1	PS-93	945	945	1-3%	U	6.1	155.9
Boe Creek	2a	PS-94	1,500	555	1-3%	M	5.3	104.7
Boe Creek	2b	PS-95	2,056	556	1-3%	M	4.6	120.7
Boe Creek	3	na	2,400	344	2-3%	U	3.7	92.3
Boe Creek	4	na	2,896	496	3-6%	C	2.8	176.1
Crooked Creek	1	na	na	~1,200	<1%	U	na	na
Crooked Creek	2	na	3993	3993	<1%	U	15.2	263
Crooked Creek	3a	PS-97	4,500	507	<1%	U	15.2	33.4
Crooked Creek	3b	PS-98	5,309	809	<1%	U	14.7	55
Crooked Creek	4	PS-99	5,642	333	<1%	U	10.1	33
Crooked Creek	5	PS-100	6,400	758	1-2%	U-M	5.4	141.5
Crooked Creek	6	PS-101	6,940	540	1-3%	C	5.5	98.7
SF Crooked Creek	1	PS-102	600	600	1-2%	U	16.4	36.5
SF Crooked Creek	2	PS-103	765	165	1-2%	C	14.5	11.4
N.F. Crooked	1a	PS-104	500	500	<1%	U	10.1	49.3

Appendix D- Summary of Lake Ozette tributary channel attributes (by habitat segment)

Stream Name	Habitat Segment	Habitat Segment ID	Upstream End (Meter)	Segment Length	Gradient	Channel Confine-ment	BFW	Number of BFWs
N.F. Crooked	1b	PS-105	1,100	600	<1%	U	9.1	66.3
N.F. Crooked	2	PS-106	1,500	400	1-2%	M	9.4	42.5
N.F. Crooked	3	PS-107	2,300	800	1-2%	C	8	100
N.F. Crooked	4	PS-108	2,900	600	2-3%	M	6.3	95.2
N.F. Crooked	5	PS-109	3,206	306	2-4%	C	6.2	49.2
Siwash Creek	2a	PS-110	500	500	<1%	U	7.3	68.6
Siwash Creek	2b	PS-111	1,000	500	<1%	U	7.2	69.1
Siwash Creek	3a	PS-112	1,500	500	1-2%	U	8	62.7
Siwash Creek	3b	PS-113	2,400	900	1-2%	U	8.5	106.1
Siwash Creek	4	PS-114	3,071	671	1-3%	M	8.5	78.5
Siwash Creek	5	na	4,595	1,524	2-4%	C	7.4	205.9

APPENDIX E-Summary of Lake Ozette tributary LWD and Habitat Ratings.

APPENDIX E- LWD and Pool Habitat Ratings

Stream	Habitat Segment	Pool Segment ID	LWD Pieces per 100 M	LWD Pieces per BFW	Key Pieces per BFW	Large Pieces per BFW	Percent of Pieces Large (>50cm)	Pool Frequency	Percent Pool	Percent woody cover	Holding Pools
Coal Creek	1a	PS-1	Good	Good	Poor	Good	Poor	Fair	Good	Fair	Good
Coal Creek	1b	PS-2	Good	Good	Poor	Fair	Poor	Fair	Good	Fair	Good
Coal Creek	1c	PS-3	Good	Good	Poor	Poor	Poor	Fair	Good	Poor	Good
Coal Creek	1d	PS-4	Good	Good	Fair	Fair	Poor	Good	Good	Fair	Good
Coal Creek	2a	PS-5	Good	Good	Poor	Fair	Poor	Fair	Good	Fair	Good
Coal Creek	2b	PS-6	Fair	Good	Poor	Fair	Poor	Fair	Good	Poor	Good
Coal Creek	2c	PS-7	Good	Good	Poor	Fair	Poor	Fair	Good	Poor	Good
Coal Creek	3a	PS-8	Good	Good	Poor	Poor	Poor	Fair	Good	Poor	Good
Coal Creek	3b	PS-9	Fair	Good	Poor	Poor	Poor	Fair	Good	Poor	Good
Coal Creek	3c	PS-10	Good	Good	Poor	Poor	Poor	Fair	Good	Poor	Fair
Coal Creek	4a	PS-11	Good	Good	Poor	Fair	Poor	Fair	Good	Poor	Fair
Coal Creek	4b	PS-12	Good	Good	Poor	Fair	Poor	Fair	Good	Poor	Fair
Coal Creek	4c	PS-13	Poor	Fair	Poor	Poor	Poor	Fair	Fair	Poor	Poor
Coal Creek	5	PS-14	Fair	Fair	Poor	Poor	Poor	Poor	Fair	Fair	Poor
20.0050 Trib	1	PS-15	Good	Fair	Poor	Poor	Poor	Fair	Good	Poor	Poor
20.0050 Trib	2	PS-16	Good	Good	Poor	Poor	Poor	Fair	Good	Fair	Poor
20.0050 Trib	3	PS-17	Good	Fair	Poor	Poor	Poor	Poor	Poor	Poor	Poor
LBT22772coal	1	PS-18	Fair	Fair	Poor	Poor	Poor	Fair	Poor	Poor	Poor
Palmquist Creek	1a	PS-19	Fair	Fair	Poor	Fair	Poor	Poor	Fair	Poor	Poor
Palmquist Creek	1b	PS-20	Fair	Fair	Poor	Fair	Poor	Poor	Good	Fair	Poor
Palmquist Creek	1c	PS-21	Fair	Fair	Poor	Fair	Poor	Poor	Good	Poor	Poor
Umbrella Creek	1a	PS-22	Good	Good	Poor	Good	Poor	Fair	Good	Good	Good
Umbrella Creek	1b	PS-23	Good	Good	Poor	Good	Poor	Fair	Good	Good	Good

APPENDIX E- LWD and Pool Habitat Ratings

Stream	Habitat Segment	Pool Segment ID	LWD Pieces per 100 M	LWD Pieces per BFW	Key Pieces per BFW	Large Pieces per BFW	Percent of Pieces Large (>50cm)	Pool Frequency	Percent Pool	Percent woody cover	Holding Pools
Umbrella Creek	2a	PS-24	Fair	Good	Poor	Good	Fair	Fair	Good	Fair	Good
Umbrella Creek	2b	PS-25	Fair	Good	Fair	Good	Fair	Good	Good	Fair	Good
Umbrella Creek	2c	PS-26	Fair	Good	Fair	Good	Fair	Good	Good	Fair	Good
Umbrella Creek	2d	PS-27	Fair	Good	Poor	Fair	Poor	Fair	Good	Fair	Good
Umbrella Creek	2e	PS-28	Good	Good	Fair	Good	Poor	Fair	Good	Poor	Good
Umbrella Creek	2f	PS-29	Poor	Good	Poor	Fair	Poor	Fair	Good	Poor	Good
Umbrella Creek	2g	PS-30	Fair	Good	Poor	Fair	Poor	Fair	Good	Poor	Good
Umbrella Creek	2h	PS-31	Fair	Good	Poor	Fair	Poor	Fair	Good	Poor	Good
Umbrella Creek	2i	PS-32	Poor	Good	Poor	Poor	Poor	Poor	Fair	Poor	Poor
Umbrella Creek	3a	PS-33	Poor	Fair	Poor	Poor	Poor	Poor	Fair	Poor	Good
Umbrella Creek	3b	PS-34	Fair	Good	Poor	Poor	Poor	Fair	Good	Fair	Poor
Umbrella Creek	3c	PS-35	Poor	Good	Poor	Poor	Poor	Poor	Poor	Fair	Poor
Umbrella Creek	4a	PS-36	Poor	Good	Poor	Poor	Poor	Fair	Poor	Poor	Fair
Umbrella Creek	4b	PS-37	Fair	Good	Poor	Poor	Poor	Fair	Fair	Fair	Good
Umbrella Creek	5a	PS-38	Poor	Fair	Poor	Poor	Poor	Fair	Poor	Fair	Fair
Umbrella Creek	5b	PS-39	Poor	Fair	Poor	Poor	Poor	Poor	Poor	Poor	Fair
Umbrella Creek	5c	PS-40	Poor	Fair	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Umbrella Creek	6	PS-41	Poor	Poor	Poor	Poor	Poor	Fair	Poor	Poor	Poor
W.B. Umbrella Creek	1a	PS-42	Poor	Fair	Poor	Fair	Poor	Poor	Poor	Poor	Poor
W.B. Umbrella Creek	1b	PS-43	Fair	Good	Poor	Fair	Poor	Poor	Poor	Poor	Poor
W.B. Umbrella Creek	1c	PS-44	Good	Good	Poor	Fair	Poor	Fair	Fair	Poor	Poor
W.B. Umbrella Creek	2a	PS-45	Fair	Fair	Poor	Poor	Poor	Poor	Poor	Poor	Poor
W.B. Umbrella Creek	2b	PS-46	Good	Good	Poor	Fair	Poor	Poor	Poor	Poor	Poor
W.B. Umbrella Creek	2c	PS-47	Fair	Good	Fair	Fair	Poor	Fair	Good	Poor	Poor
W.B. Umbrella Creek	3	PS-48	Fair	Fair	Fair	Fair	Poor	Poor	Poor	Fair	Poor
E.B. Umbrella Creek	1a	PS-49	Poor	Poor	Poor	Poor	Poor	Fair	Poor	Poor	Poor

APPENDIX E- LWD and Pool Habitat Ratings

Stream	Habitat Segment	Pool Segment ID	LWD Pieces per 100 M	LWD Pieces per BFW	Key Pieces per BFW	Large Pieces per BFW	Percent of Pieces Large (>50cm)	Pool Frequency	Percent Pool	Percent woody cover	Holding Pools
E.B. Umbrella Creek	1b	PS-50	Poor	Fair	Poor	Poor	Poor	Poor	Fair	Fair	Poor
E.B. Umbrella Creek	1c	PS-51	Poor	Poor	Poor	Poor	Poor	Fair	Fair	Poor	Poor
E.B. Umbrella Creek	2	PS-52	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
LBT5210_EB Umbr	1	PS-53	Fair	Fair	Poor	Poor	Poor	Poor	Poor	Poor	Poor
LBT8100_EB Umbr	1	PS-54	Poor	Fair	Poor	Poor	Poor	Good	Fair	Poor	Poor
RBT15663_Umbr Creek	1	PS-55	Good	Fair	Poor	Fair	Poor	Poor	Poor	Poor	Poor
Big River	1	PS-56	Fair	Good	Fair	Fair	Poor	Fair	Good	Poor	Good
Big River	2a	PS-57	Fair	Good	Fair	Fair	Poor	Good	Good	Fair	Good
Big River	2b	PS-58	Fair	Good	Poor	Poor	Poor	Fair	Good	Fair	Good
Big River	2c	PS-59	Poor	Good	Poor	Poor	Poor	Fair	Good	Poor	Good
Big River	2d	PS-60	Fair	Good	Poor	Poor	Poor	Fair	Good	Poor	Good
Big River	2e	PS-61	Fair	Good	Poor	Poor	Poor	Good	Good	Fair	Good
Big River	2f	PS-62	Poor	Good	Fair	Fair	Poor	Good	Good	Fair	Good
Big River	2g	PS-63	Poor	Good	Poor	Poor	Poor	Fair	Good	Poor	Good
Big River	2h	PS-64	Fair	Good	Poor	Fair	Poor	Good	Good	Poor	Good
Big River	2i	PS-65	Fair	Good	Poor	Fair	Poor	Good	Good	Poor	Good
Big River	2j	PS-66	Fair	Good	Poor	Poor	Poor	Good	Good	Poor	Good
Big River	2k	PS-67	Poor	Good	Poor	Fair	Poor	Fair	Good	Poor	Fair
Big River	3a	PS-68	Fair	Good	Poor	Good	Fair	Fair	Good	Poor	Fair
Big River	3b	PS-69	Fair	Good	Fair	Good	Fair	Good	Good	Poor	Fair
Big River	3c	PS-70	Fair	Good	Fair	Good	Fair	Poor	Fair	Fair	Fair
Big River	3d	PS-71	Fair	Good	Fair	Good	Fair	Good	Good	Poor	Good
Big River	3e	PS-72	Poor	Good	Poor	Good	Fair	Fair	Good	Poor	Good
Big River	3f	PS-73	Poor	Fair	Poor	Fair	Good	Fair	Good	Poor	Good
Big River	3g	PS-74	Poor	Good	Poor	Good	Fair	Good	Good	Fair	Good

APPENDIX E- LWD and Pool Habitat Ratings

Stream	Habitat Segment	Pool Segment ID	LWD Pieces per 100 M	LWD Pieces per BFW	Key Pieces per BFW	Large Pieces per BFW	Percent of Pieces Large (>50cm)	Pool Frequency	Percent Pool	Percent woody cover	Holding Pools
Big River	3h	PS-75	Poor	Good	Poor	Good	Fair	Fair	Good	Fair	Fair
Big River	3i	PS-76	Poor	Fair	Poor	Fair	Fair	Fair	Good	Fair	Fair
Big River	3j	PS-77	Poor	Fair	Poor	Fair	Fair	Fair	Good	Poor	Poor
Big River	3k	PS-78	Fair	Good	Poor	Good	Fair	Good	Good	Fair	Fair
Big River	3l	PS-79	Fair	Good	Poor	Good	Fair	Good	Good	Fair	Good
Big River	4a	PS-80	Poor	Fair	Poor	Poor	Poor	Fair	Fair	Poor	Good
Big River	4b	PS-81	Fair	Good	Poor	Fair	Poor	Good	Fair	Poor	Good
Big River	4c	PS-82	Poor	Good	Poor	Fair	Poor	Good	Fair	Poor	Good
Big River	4d	PS-83	Poor	Good	Poor	Fair	Poor	Fair	Fair	Poor	Fair
Big River	5a	PS-84	Poor	Fair	Poor	Poor	Fair	Fair	Fair	Poor	Poor
Big River	5b	PS-85	Poor	Fair	Poor	Poor	Fair	Fair	Fair	Poor	Poor
Big River	5c	PS-86	Fair	Good	Poor	Good	Fair	Fair	Good	Poor	Fair
Big River	5d	PS-87	Fair	Good	Poor	Good	Fair	Poor	Good	Poor	Fair
Big River	5e	PS-88	Good	Good	Good	Good	Fair	Fair	Good	Fair	Fair
Solberg Creek	1	PS-89	Poor	Fair	Poor	Poor	Poor	Fair	Fair	Poor	Poor
Stony Creek	1	PS-90	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Poor
Stony Creek	2	PS-91	Good	Good	Poor	Good	Fair	Fair	Poor	Fair	Poor
Stony Creek	3	PS-92	Good	Good	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Boe Creek	1	PS-93	Poor	Poor	Poor	Poor	Poor	Poor	Good	Poor	Poor
Boe Creek	2a	PS-94	Fair	Fair	Poor	Poor	Poor	Fair	Good	Fair	Poor
Boe Creek	2b	PS-95	Poor	Poor	Poor	Poor	Poor	Poor	Good	Poor	Poor
Unnamed Trib 20.0065	1	PS-96	Poor	Fair	Poor	Fair	Poor	Poor	Poor	Poor	Poor
Crooked Creek	3a	PS-97	Fair	Good	Poor	Fair	Poor	Poor	Good	Fair	Fair
Crooked Creek	3b	PS-98	Fair	Good	Poor	Fair	Fair	Poor	Good	Fair	Fair
Crooked Creek	4	PS-99	Fair	Good	Poor	Poor	Poor	Fair	Good	Fair	Good
Crooked Creek	5	PS-100	Fair	Fair	Fair	Fair	Poor	Fair	Good	Poor	Poor

APPENDIX E- LWD and Pool Habitat Ratings

Stream	Habitat Segment	Pool Segment ID	LWD Pieces per 100 M	LWD Pieces per BFW	Key Pieces per BFW	Large Pieces per BFW	Percent of Pieces Large (>50cm)	Pool Frequency	Percent Pool	Percent woody cover	Holding Pools
Crooked Creek	6	PS-101	Fair	Fair	Fair	Fair	Fair	Fair	Good	Fair	Poor
SF Crooked Creek	1	PS-102	Good	Good	Fair	Good	Poor	Good	Good	Fair	Good
SF Crooked Creek	2	PS-103	Fair	Good	Poor	Fair	Poor	Fair	Good	Fair	Fair
NF Crooked Creek	1a	PS-104	Fair	Good	Poor	Fair	Poor	Poor	Good	Poor	Fair
NF Crooked Creek	1b	PS-105	Fair	Fair	Poor	Fair	Poor	Poor	Good	Poor	Poor
NF Crooked Creek	2	PS-106	Good	Good	Fair	Good	Poor	Fair	Good	Fair	Fair
NF Crooked Creek	3	PS-107	Fair	Good	Fair	Fair	Poor	Fair	Good	Poor	Fair
NF Crooked Creek	4	PS-108	Good	Fair	Poor	Poor	Poor	Fair	Good	Fair	Poor
NF Crooked Creek	5	PS-109	Good	Good	Fair	Fair	Poor	Fair	Good	Fair	Poor
Siwash Creek	2a	PS-110	Good	Good	Fair	Good	Poor	Poor	Good	Fair	Good
Siwash Creek	2b	PS-111	Good	Good	Fair	Fair	Poor	Poor	Good	Poor	Good
Siwash Creek	3a	PS-112	Fair	Good	Poor	Good	Fair	Poor	Good	Poor	Good
Siwash Creek	3b	PS-113	Fair	Good	Fair	Good	Fair	Poor	Good	Fair	Good
Siwash Creek	4	PS-114	Fair	Fair	Fair	Good	Fair	Fair	Good	Fair	Fair

APPENDIX F-List of Ranked Research and Monitoring Priorities (by Life Stage).

Edit from the Lake Ozette Sockeye Habitat Technical Work Group 2001 Draft LFA

A-ADULT SOCKEYE ENTERING SYSTEM

Adult Sockeye Entering the Ozette River

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Population size, run-timing	Ongoing
2	Streamflow	
3	Predation	1998-2000+
4	Water quality	Ongoing
5	In-river habitat conditions	
6	Estuary alterations	

PRIORITY JUSTIFICATION

1. Run Size: Determining the current run-size and abundance trend of the sockeye population is critical to attaining recovery of Lake Ozette sockeye. Tracking population fluctuations over time will be a gauge to determine the success of restoration activities, as well as the success of the overall Lake Ozette Sockeye Recovery Plan . Also, has run timing in Ozette changed? How much inter-annual run-timing variation occurs?
2. Streamflow: Streamflows during that adult migration have been reduced. Detailed modeling is required to determine the exact magnitude that flows have been altered. What effect changes to streamflow have on migrating sockeye remains unknown (see Hypothesis 4 in Section 6.2.1.4).
3. Predation: Continued monitoring of in-river predation is an important component to understanding the degree that predation affects the sockeye population at different abundance levels.
4. Water quality: Have stream temperatures increased during the last 50 years, how much? How do high stream temperatures limit Ozette sockeye? Variations in timing of spawning migrations may be in response to river flow and water temperature (flow and temperature as intensity factors of migration). Water temperature during mid-summer is generally greater than the preferred range for sockeye. Turbidity has also been shown to affect Lake Ozette sockeye during the adult migration. Continue to monitor water temperature and turbidity.
5. Habitat conditions: Due large logjams which form deep pools in the Ozette river provide important refugee habitat for sockeye salmon? Do deep pools provide thermal refugee habitat. How does habitat affect predation?
6. Estuary Alterations: Are there unique tidal prism influences that enhance or are detrimental to the sockeye life cycle (analyze sequential historical photos).

B-ADULT SOCKEYE HOLDING IN LAKE

Adult Sockeye in Lake Ozette

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Population, distribution, holding, habitat characteristics	Ongoing
2	Predation and disease	Ongoing

PRIORITY JUSTIFICATION
1. Population: Determining the current sockeye population abundance, distribution, and where they hold within the lake will be important to understand behavior, habitat use, survival, and achieve recovery. Tracking the population movement and habitat use over time will be a gauge to design restoration activities (Makah and NPS research).
2. Predation and disease: What impacts do these factors have on adult sockeye in the lake environment? Examine scat collected during the 2002 and 2003 summers.

C-ADULT SOCKEYE SPAWNING ON BEACHES

1. Number and distribution
2. Predation (NOAA and MFM research)
3. Suitable substrate quantity and quality (location of spawning beaches, potential spawning beaches)
4. Water quality
5. Habitat (suitability of vegetation and sediment)
6. Sex ratio; fecundity, age
7. Morphology
8. Possible interactions between sockeye and kokanee (stray rates, genetic analyses)
9. Natural sub-populations (stray rates, genetic analyses)

Adult Sockeye Spawning in Lake Ozette

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Number, distribution, sex ratio of total population and sub-populations	Ongoing
2	Suitable substrate, habitat characterization	Ongoing
3	Predation	Ongoing
4	Water quality	1997

PRIORITY JUSTIFICATION:
1. Abundance and distribution: There is a lack of information on the abundance and distribution of spawners along the Lake Ozette shoreline (Makah and NPS research).
2. Suitable substrate: An analysis of the substrate will aid in determining areas of suitable spawning habitat (Makah and NPS research).

3. Predation: Little is known about predation of adult sockeye in Lake Ozette. Adults spend a 5+ month period in lake during spawning season. This is a substantial amount of time when little is known about mortality. Heavy seal activity was observed on both spawning beaches in 1999 and seal predation of spawners has been observed in the past.
3. Water quality: Is there evidence of anthropogenic impacts to water quality in the lake? If so, to what extent have any changes influenced adult holding? Is water quality changing over time (NPS data)?
   -Data are not available for shoreline habitats (water temperature and intra-gravel dissolved oxygen.
   -There are elevated turbidity levels during storm events.

D-SOCKEYE ENTERING TRIBUTARIES

1. Predation
2. Population and distribution within and among streams
3. Water quality
4. Competition and interaction with kokanee
5. Flow rates
6. Habitat Characteristics

Sockeye Entering Tributaries

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Population and distribution	On going
2	Water quality	On going
3	Habitat characteristics	On going

PRIORITY JUSTIFICATION

1. Population and distribution: Distribution and relative abundance of tributary spawners (NOR’s and hatchery returns) continues to be monitored (MFM).
2. Water quality: Are there water quality issues unique to the spawning tributaries that would make them ultimately more or less viable to survival of the fry (variety of thermograph sites; turbidity)?
3. Habitat characteristics: Are there unique tributary features of the areas being utilized. Could land-use over time have altered this habitat in a manner that would have impacted sockeye use?

E-SOCKEYE SPAWNING IN TRIBUTARIES

1. Redd count
2. Population
3. Distribution (both redds and fish)
4. Predation
5. Quality, quantity, and suitability of spawning substrate (scouring, fine sediment levels)

6. Water quality
7. Flow
8. Chemical influence
9. Habitat quality and quantity
10. Morphology (sex ratio, size, truss measurements, genetic variation)
11. Interaction between sockeye and kokanee

Sockeye Spawning in Tributaries

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Redd count, population, distribution, morphology, interrelationship with sockeye and kokanee	Ongoing
2	Substrate suitability quality and quantity, habitat quality and quantity	On going
3	Water quality, flow, chemical influence	Ongoing
4	Predation	?

PRIORITY JUSTIFICATION

1. Redd count, etc.: Distribution and relative abundance of tributary spawners (NOR's and hatchery returns) continues to be monitored (MFM). Continue to measure spawner replacement rates of NOR and hatchery returns. Are tributary spawners uniquely different from beach spawners? Continue to enumerate sympatric spawning among kokanee and sockeye, if observed.
2. Substrate suitability, etc.: What type and how much spawning substrate is available to the sockeye in the tributaries. Continue to characterize tributary habitat (MFM).
3. Water quality, etc.: Are there unique water chemistry profiles that encourage/discourage tributary use? What type of hydrology suits spawning sockeye? (various thermograph sites). Predation: Determine impact of predation on sockeye tributary spawners. What are the circumstances and the overall impacts to the population?

F-SOCKEYE EGG INCUBATION IN LAKE

1. Egg predation (during and after spawning)
2. Gravel quality and quantity (suitable substrate)
3. Habitat suitability (upwelling/springs)
4. Fertilization mortality rates
5. Change in lake water levels (8 feet per year)
6. Water quality (temperature, dissolved oxygen)
7. Changes in sedimentation, turbidity
8. Incubation duration
9. Outside chemical influence

Sockeye Egg Incubation on Beaches

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Suitable substrate, habitat, changes in sedimentation, turbidity	ongoing
2	Egg to hatching survival	2000+
3	Egg predation	2000+
4	Lake levels	1997

PRIORITY JUSTIFICATION

1. Suitable substrate, etc: (What spawning beaches are utilized, what type of habitat is utilized, what is substrate composition? Determine habitat characteristics, substrate used during the incubation period. All viewed as critical for reproductive success.
2. Egg to hatching survival: Critical data gaps exist on early life history survival. What is egg to hatching survival? Are there fertility issues?
3. Egg predation: To what extent is predation impacting early life history (i.e. natural predation such as sculpin, peamouth, cutthroat trout, coho, or introduced predators such as perch and largemouth bass, mergansers and other piscivorous birds?
4. Lake levels: Influence of fluctuating lake levels or evidence of anthropogenic impact related to lake level. -The lake level may vary as much as 8 feet annually. This may impact the beach spawning areas.

G-SOCKEYE EGG INCUBATION IN TRIBUTARIES

1. Egg predation (during and after spawning)
2. Gravel quality and quantity
3. Habitat suitability (upwelling/springs)
4. Fertilization mortality rates
5. Change in lake water levels (8 feet per year)
6. Water quality (temperature, dissolved oxygen)
7. Changes in sedimentation, turbidity
8. Incubation duration
9. Outside chemical influence
10. Tributary scour, fine sedimentation

Tributary Egg Incubation in Tributaries

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Egg to emergent survival, predation, sedimentation, scour, fertilization mortality	Ongoing
2	Gravel quality and quantity, habitat suitability	Ongoing
3	Water quality, incubation duration	Ongoing

PRIORITY JUSTIFICATION

1. Egg to emergence survival: What percent of the eggs survive to the emigrant fry stage? What types of habitat issues impact this survival?
2. Gravel quality, etc.: What is the preferred spawning substrate for optimal egg survival. Are these incubation areas also utilized by other species that would result in a detrimental effect to sockeye? How much and where is this habitat available? Is it being utilized?
3. Water quality, etc: Are there water chemistry and hydrology factors occurring in the tributaries that could impact hatching success? Are there variables that impact egg incubation?

H-SOCKEYE FRY EMERGENCE AND MIGRATION IN LAKE

1. Predator biomass and predation rate estimates
2. Mortality
3. Food Availability
4. Migration

Sockeye Fry Emergence and Migration in Lake

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Predation	2000+
2	Food availability	2000+
3	Migration	2000+

PRIORITY JUSTIFICATION

1. Predation: Cursory evidence suggests that sockeye fry are preyed upon by coho and sculpin. To what extent is unknown (biomass studies required). Other possible predators of sockeye fry include yellow perch and cutthroat trout.
2. Food availability: Is proper size and type of zooplankton available for swim up sockeye fry in Lake Ozette during their emergence period?
3. Temporal and spatial distribution of fry remains unknown.

I-SOCKEYE FRY EMERGENCE AND OUT-MIGRATION IN TRIBUTARIES

1. Predation
2. Mortality
3. Food Availability
4. Migration

Tributary Fry Emergence and Emigration

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Migration	Ongoing
2	Predation	Ongoing
3	Food availability	2000+
4	Mortality	Ongoing

PRIORITY JUSTIFICATION

1. Migration: Where are fry migrating to and how long and under what circumstances are they migrating?
2. Predation: What unique circumstances are the fry encountering on their travels to the lake? What percentage of this population is successful on this migration?
3. Food availability: What are sockeye fry consuming and where? What is the preferred diet and to what extent is it available in the system? What other fish, etc., are also seeking out this food source?
4. Mortality: How successful is sockeye productivity through emergence? What percentage of the eggs hatch? Is this comparable with same species in other stream environments or different species in the same environment?

J-SOCKEYE PELAGIC REARING

1. Predation
2. Food availability

Pelagic Rearing

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Predation	
2	Food availability	

PRIORITY JUSTIFICATION

1. Predation: What predators impact the juvenile sockeye population in Lake Ozette? What percentage of the juvenile population survives this predation? Are the predators introduced or naturally occurring in this system?
2. Food availability: What are the juveniles consuming in the lake environment? How available is this food? What is the competition for this food? Does it vary with seasonal changes?

K-JUVENILE SOCKEYE EMIGRATION

1. Population
2. Predation
3. Water quality

Juvenile Emigration

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Population	2000+
2	Predation	2000+
3	Water quality	Ongoing

PRIORITY JUSTIFICATION

1. Population: What proportion of NOR and hatchery lake- and tributary-origin smolts survive to emigration?
2. Predation: What predator circumstances do the juveniles encounter during emigration? What type of impact does this have on the population?
3. Water quality: Are there unique water chemistry and hydrologic circumstances that impact emigration? Water quantity in the river also needs to be measured during emigration.

L-MARINE ENVIRONMENT

1. Population trends (regional and large scale). What is the ocean survival rate of smolt emigrants?
2. Productivity of marine environment
3. Harvest

Marine Environment

Ranked Priority	Life Stage Factor	Planned or/ Conducted
1	Population trends	2000+
2	Productivity of marine environment	2000+
3	Harvest	2000+

PRIORITY JUSTIFICATION

1. Population trends: What is the smolt to adult survival rate? How has marine survival varied over time? Can environmental- or human- induced changes over time be correlated with population abundance variations?
2. Productivity of marine environment: How successful are the sockeye in the marine phase of their life cycle? What are they eating and how available is it? Do they share this food source with other species?
3. Harvest: Historically, what volume of sockeye was harvested? What percentage of these fish were Lake Ozette sockeye? How many sockeye have been caught as a non-target species? What influence did this have on the population? -Marine interception of Lake Ozette sockeye appears to be low based on their early run timing in relation to the opening of fisheries off of Vancouver Island.