6.0 RAMPING AND FLOW FLUCTUATION EVALUATIONS

6.1 DESCRIPTION AND PURPOSE

Hydroelectric facilities typically have the capability of increasing and decreasing flow levels downstream of the facilities. In general, the rate at which these changes occur is called the “ramp rate” or “ramping.” From a fisheries perspective, ramping down the river flow has the potential to strand fish in areas of the channel that are relatively low-gradient, or where pockets or side channels exist in the river channel. Stranding is defined as the separation of fish from flowing water as a result of declining river stage from rapid decreases in flow (“down-ramping”). Smaller juvenile fish (less than about 50 mm long) are most vulnerable to potential stranding because of weak swimming ability and typical habitat preference. River channel configuration, channel substrate type, time of day, water temperature, and flow level before down-ramping (antecedent flow) are also key factors that determine stranding incidence.

Artificial flow fluctuations from hydroelectric power operations can create a varial zone on the streambed where the biomass of algae and macroinvertebrates can be significantly reduced, especially if low-gradient riffle areas are dewatered frequently. Because macroinvertebrates are the primary food source for most riverine fish, extreme flow fluctuations can adversely affect fish growth in streams where the fish population is food-limited. Also, changes in flow that are too great or frequent can disrupt fish spawning success and dewater eggs incubating in the streambed gravels. Therefore, it is important to consider the season as well as the rate and magnitude of flow change when developing ramping regimes that minimize adverse impacts on fish.

The purpose of this study is to evaluate the potential for adverse fisheries impacts associated with current ramping regimes in each of the river reaches affected by the Klamath Hydroelectric Project. The impact that Project-induced flow fluctuations may have on water quality was assessed as part of separate water quality studies and analyses.

6.2 OBJECTIVES

The objectives addressed by this set of studies were as follows:

- Describe the extent of existing flow fluctuations in terms of rate of stage change (ramp rate) and frequency in the riverine reaches of the Klamath River as affected by Project operations.
- Describe the physical extent of streambed habitat affected by peaking operations in the J.C. Boyle peaking reach.
- Describe the potential for down-ramping to strand fish. Verify this with field observations in the J.C. Boyle peaking reach.
- Characterize the potential impacts of Project ramping on fish resources.

6.3 RELICENSING RELEVANCE AND USE IN DECISIONMAKING

PacifiCorp will evaluate potential ramp rate effects on the fisheries in all the riverine sections of the study area that are affected by Project operations. Study results will be used in conjunction with other information (e.g., fisheries assessments, whitewater rafting, water quality, sediment transport, macroinvertebrates, riparian vegetation, power production, and economics) to develop ramping alternatives that take into account the important tradeoffs among competing resource values.

6.4 METHODS AND GEOGRAPHIC SCOPE

6.4.1 Methods

The general approach to studying the down-ramping issue was to review and analyze existing information and conduct additional field studies as appropriate. In most cases where ramping is done only rarely and not for power production purposes, it was appropriate to determine an acceptable ramp rate without conducting field studies by applying conservative guidelines that are within equipment control limitations. However, in the J.C. Boyle peaking reach, which is affected by daily load factoring much of the year, field study was required to quantify the extent of the de-water (varial) zone and to determine the extent to which fish stranding may be occurring under current operations.

The assessment of the effects of down-ramping (flow fluctuations) on fish considered four primary factors associated with flow: (1) ramping rate, (2) timing, both seasonal and diurnal, (3) frequency, and (4) amplitude of the flow change, especially with regard to the minimum flow within the cycle. In addition to these flow variables, stream channel morphology plays a significant role in the susceptibility of fish and other aquatic organisms to the peaking flows and, thus, was described in the J.C. Boyle peaking reach.

6.4.1.1 Ramping Methods

The issue of down-ramping has been addressed in the Link River and below Iron Gate dam through BOs for ESA fish species in the river (USFWS, 1996; NMFS, 2002). Down-ramping rates that differ from those in the current FERC license have been established for these reaches. These rates are based on conservative criteria.

Below is a general list of activities associated with this analysis. This is followed by detailed descriptions of how these activities were performed.

All Reaches

- Review and describe pertinent literature and background information on down-ramping effects on fish and the specific factors causing effects.
- Identify aquatic species and life stages that are potentially vulnerable to rapid flow changes and their periods-of-occurrence.
- Determine the magnitude, frequency, and rate of river stage reductions at Project facilities.
- Determine equipment and operational constraints related to flow controls at Project facilities and any needs to modify these facilities in the future.

J.C. Boyle Peaking Reach

- Use stream cross sections and corresponding stage-discharge relationships from instream flow studies to quantify the varial zone and impact zone (for alternative scenarios) between various flow increments.
- Conduct field observations of actual down-ramp events to determine the lag time of flow change events and any attenuation in the rate-of-change of stage between the powerhouse and Copco reservoir.
- Conduct concurrent observations of fish stranding incidence and fish condition during actual down-ramp events.

6.4.1.2 General Literature Review

A general review of literature on the potential effects of the river flow fluctuations/peaking on fish was performed to provide background on the issue of ramping. Most available information was on salmonids, which are of primary concern in the Klamath River. Both anadromous salmonids and resident trout were emphasized in the review. Categories of effects included juvenile fish stranding, behavioral changes, and macroinvertebrate production. Factors associated with stranding included channel configuration, species and life stages, timing (seasonal and diurnal), and rate of river stage reduction. Behavioral factors included spawning disruption, emigration/movement, age/size structure changes, growth, and condition factor. Effects on macroinvertebrates were included to the extent that they were an important source of food for most fish in the Klamath River.

6.4.1.3 Identification of Sensitive Fish Species and Life Stages (All Reaches)

Native fish species including redband/rainbow trout, suckers, chubs, dace, lamprey, and sculpin were considered in all reaches above Iron Gate dam to the extent that information is available regarding ramping effects on these species. Each species' life stage timing, location of occurrence, and size in these reaches was used to determine the fishes' potential vulnerability to ramping operations. Information to assess vulnerability was obtained from existing reports and new data derived from the fisheries assessments task conducted in these river reaches in 2001 and 2002. Field studies conducted in the J.C. Boyle peaking reach for fry stranding (see below) occurred during periods when newly emerged fry and small YOY fish were present because these life stages are most susceptible to stranding.

The species of prime concern downstream of Iron Gate dam included Chinook and coho salmon and steelhead trout, especially their emergent fry stages. Previous studies have shown that after salmonid fry reach 40 to 50 mm in length, their stranding vulnerability drops significantly (Hunter, 1992; Olson, 1990; Woodin, 1984). Fry vulnerability is probably a result of their low swimming ability and preference for shallow shoreline and side channel habitats that are most susceptible to dewatering during down-ramping. Chinook salmon fry are known to begin emerging from the gravel as early as January below Iron Gate dam.

6.4.1.4 Description of Existing Down-Ramping

Hourly stream flow data as available since 1990 were analyzed to depict the rate (stage change per hour) and frequency of down-ramping in project reaches. This time period contained a good representation of wet, average, and dry years. Gauge sites included the Link River (below East Side powerhouse), Keno (below Keno dam), J.C. Boyle (below powerhouse), and Iron Gate dam.

The analysis consisted of computing the change in river stage from 1 hour to the next, ranking these stage changes, and then computing the percent of time within the period that a particular stage reduction rate is being equaled or exceeded. The results were graphed as exceedance curves so one can readily determine the rate of stage change and the percent of time that that rate or a higher rate occurs. Because down-ramping is the primary issue with flow fluctuations, only the stage reductions were shown on the graph. The exceedance percentages were computed and graphed for each month and for specific time periods associated with the most vulnerable stranding periods (e.g., Chinook fry from January through June) as well as for each month. The percent of times when stage is constant or increasing will not be shown, but can be determined from the graph by subtracting the exceedance percentage for stage reduction from 100 percent.

In addition to the Iron Gate gauge (located about 0.6 mile downstream of Iron Gate dam), stage-discharge relationships for several cross sections between Iron Gate dam and the Shasta River were examined to relate stage changes at the Iron Gate gauge, which is a narrow confined channel location, to wider downstream locations that have greater potential for fry stranding. These downstream stage-discharge relationships are available from the USGS instream flow study cross sections.

6.4.1.5 Quantification of Varial Zone (J.C. Boyle Peaking Reach)

To assess potential aquatic resource effects from flow fluctuations associated with peaking operations at J.C. Boyle, it is important to quantify the amount of streambed that is alternatively watered and dewatered within the peaking cycle. This area is referred to as the zone-of-influence, or varial zone. Aquatic productivity in terms of algae and macroinvertebrates is severely limited within this zone. Areas with beach slopes of less than 2 percent within the varial zone have high potential for stranding of salmonid fry under certain conditions (Bauersfeld, 1978; Woodin, 1984; Olson, 1990).

Quantification of the varial zone between different increments of flow was based on the stage-discharge relationships and cross sections surveyed as part of the instream flow study conducted in 2002 (see Study 1.12). A total of 71 cross sections was available for analysis in the peaking reach. Standard output of the hydraulic model used in the instream flow study includes wetted perimeter as a function of flow at each cross section. Wetted perimeter versus discharge data was made available for each individual cross section, grouped by mesohabitat type (riffle, run, pool, and glide), and combined for all cross sections.

The summarized wetted perimeter/discharge information was tabulated onto worksheets that provided a tool to allow one to readily quantify the varial zone between two different stream flows. The varial zone was depicted as average wetted perimeter change in feet and as percent change from the high flow to the low flow being compared. This quantification of the varial zone between flow increments was used to compare aquatic streambed effects among various alternative peaking regimes and with a non-peaking flow regime.

The data presented in the varial zone worksheet tables were based on 12 cross sections that were surveyed in the upper peaking reach (near Frain Ranch) by Beak Consultants for the instream flow study associated for the previously proposed Salt Caves Hydroelectric Project (City of Klamath Falls, 1986).

6.4.1.6 Stranding Observations During Down-Ramp Events (J.C. Boyle Peaking Reach)

Observations for potential fish stranding in the J.C. Boyle peaking reach were conducted at two locations in Oregon (Frain Ranch) and at three locations in California. These sites were selected for having high potential for fry stranding based on low beach gradient (less than 2 percent), depressions, and presence of both aquatic vegetation and submerged grasses at the high-flow end of the ramping event. These sites were selected following a review of maps, aerial photos, and a reconnaissance by shore (in Oregon segment) and by raft (in California segment) under low-flow conditions.

The two Oregon sites included the large cobble/gravel bar immediately upstream of the Caldera Rapid (RM 214.3) and a point bar and side channel (RM 214.7). The sites in California included a side channel/island complex at RM 204.9, an island at RM 205.3, and a side bar/alcove at RM 205.6. Descriptions of each site included: (1) surface area and maximum width at exposed bars in the exposed varial zone, (2) surveyed beach gradient, and (3) substrate characteristics (size, embeddedness, algae/vegetation). In addition, photographs were taken at each site at low flow showing exposed areas. Observations were made 1 day per month in early June, July, and August 2002. Ramping on these dates (and generally throughout this period) consisted of up-ramping in the morning (at the powerhouse) and down-ramping in late afternoon through a flow range from approximately 1,500 (one turbine unit) to 350 cfs. Ramping rates at the gauge just downstream of the powerhouse were about 0.7 feet/hour (compared to the 0.75 feet/hour FERC limit).

The study sites and adjacent areas were inspected for any stranded or trapped fish following completion of down-ramping. Observations were made by two biologists slowly walking back and forth in the dewatered zone from end to end and then back again. Special attention was given to areas containing previously submerged vegetation (aquatic and terrestrial) and any depressions. Occasionally, some organic material and larger rocks were moved to look for any stranded or trapped fry. Approximately 1 to 2 hours were spent making observations at each site. Observers estimated and recorded the species, size, and number of stranded or entrapped fish, if any. Any recovered suckers less than about 6 inches long were noted as “unidentified suckers species” because suckers this small cannot be field-identified by species. Other information recorded for each site included: flow range during down-ramp event, time (day or night) of down-ramp, and general observations of any live fish seen along the stream margins or in isolated pocket waters.

A temporary staff gauge or use of differential leveling of water surface elevations was used near both the Oregon sites and the California sites to monitor the timing (lag time from powerhouse) and stage change associated with the ramping event. These data were reviewed to determine the time it takes for the flow ramping to reach the study sites from the powerhouse, and to determine the degree of the stage-change attenuation, if any, between the USGS gauge below the powerhouse and the study sites.

6.4.1.7 Comparative Fish Community Review

Klamath River fish sampling was conducted in 2001 and 2002 in the Keno reach, J.C. Boyle bypass reach, and the J.C. Boyle peaking reach to characterize the respective fish communities. Fish were collected primarily by electrofishing and angling (for trout). Each of these three reaches differs in their hydrologic regime. The peaking reach has much more frequent and extensive flow fluctuations compared to the Keno reach (above J.C. Boyle reservoir) and the bypass reach. Water quality also differs among these three reaches. Summer water temperatures and turbidity are much lower in the bypass reach compared to the Keno and peaking reaches. Daily average water temperatures and the water clarity are similar in the Keno and peaking reaches, but the peaking reach has much greater diurnal fluctuations for these water quality parameters as a result of peaking operations.

Comparisons of the fisheries data for the Keno and peaking reaches may provide valuable insight to potential effects of peaking operations at J.C. Boyle. Parameters that were compared included:

Electrofishing catch-per-unit effort (all species)

- Trout length
- Trout length-at-age
- Trout condition factor

The electrofishing CPUE data were examined seasonally and by segments (upper and lower) within both reaches.

In addition to this general fisheries community information, results of PacifiCorp's radiotelemetry trout movement study in the J.C. Boyle bypass and peaking reaches conducted in winter through summer of 2003, provided valuable information on spawning locations and movement patterns as possibly associated with peaking operations.

6.4.2 Geographic Scope

The geographic scope of the ramping studies included all riverine reaches affected by flow fluctuations associated with Project operations. The type and extent of study effort necessarily varied by river reach. The only reach affected by powerhouse load factoring is the 17-mile-long, peaking reach downstream of the J.C. Boyle powerhouse to Copco reservoir. This is the longest free-flowing reach in the study area. Because it is the reach of greatest concern regarding ramping effects, it required the most study effort, including field work. The short (0.5-mile-long) Link River, the 5-mile-long reach downstream of Keno dam, the 4-mile-long J.C. Boyle bypass, 1-mile-long reach below Copco No. 2 dam, and the river downstream of Iron Gate dam have controlled flow reductions only when spill flows are being reduced, when the diversions are initially being turned on following plant shutdown, or when adjusting flow to a different instream flow requirement. Flows downstream of Keno dam also may vary, depending on inflow and outflow water quantities in Keno reservoir (i.e., irrigation water transfers). The focus of study efforts in these reaches was on defining the frequency and rate of river stage reductions and current equipment limitations, so that the need for and opportunities to reduce flow fluctuations (and the possible need for equipment modifications) could be explored.

6.5 RELATIONSHIP TO REGULATORY REQUIREMENTS AND PLANS

This investigation is intended to provide baseline information that, together with environmental data and results of other past and ongoing studies, can be used to assess effects of Project operations on fish resources and to help formulate recommendations for protection, mitigation, and enhancement measures consistent with agency and tribal management goals. The following contain references to objectives for fisheries in the study area:

- CDFG Upper Klamath Wild Trout Management Plan
- ODFW Klamath River Basin Fish Management Plan
- USFWS and NMFS Endangered Species Act requirements
- Klamath River Wild and Scenic River Plan
- Tribal natural resource goals and objectives and cultural values
- Klamath River Basin Task Force (KRBFTF) Long Range Plan

The results will be used to help determine whether and where current Project operations are allowing healthy fish populations to be maintained at levels consistent with management objectives, and, if not, what changes to Project operations or facilities might be needed to achieve these objectives.

6.6 TECHNICAL WORK GROUP COLLABORATION

PacifiCorp worked with stakeholders to establish a collaborative process for planning and conducting studies needed to support Project relicensing documentation. Beginning in early 2001 the stakeholders and PacifiCorp developed a Process Protocol to guide the collaborative effort. The structure is comprised of a Plenary group (all interested stakeholders) and a number of technical working groups. As part of this structure, an Aquatics Work Group (AWG) was established to address most of the fisheries studies, except those related to fish passage, which had its own working group. The AWG has met approximately monthly. Additional meetings (often via phone conference) of AWG participants have been held to address specific study topics. In late 2003, several of the monthly AWG meetings were combined with the Fish Passage Work Group meetings to address some of the study topics that cross over both work groups.

6.7 RESULTS AND DISCUSSION

6.7.1 Review of Literature of Effects of Flow Reductions (Down-Ramping) and Rapidly Varying Flows on Fish Below Hydroelectric Projects

Streamflows downstream of hydroelectric projects often are altered by facility operations. In some cases, the facilities include a diversion dam, which leaves a bypassed reach with stabilized, albeit reduced flows. Some projects operate as run-of-river below reservoirs and in these cases the flow regime mimics reservoir inflow, which may be a natural regime. Other projects using water stored in reservoirs tend to stabilize flows in the short term (days, weeks) and sometimes long term (seasonally).

The most dramatic flow changes occur downstream of hydroelectric peaking facilities. In a typical peaking operation, water is stored in reservoirs at night when electrical demand is relatively low and then is released through turbines during the day to satisfy increased electrical demand. These flow changes can be great in magnitude and rapid. The term "rapidly varying flow" generally pertains to hydroelectric peaking projects. The daily fluctuations in flow create what is referred to as a "varial zone" (i.e., the portion of the river bottom that is alternately flooded and dewatered).

In terms of fisheries/aquatic impacts, there is a major difference between a **non-peaking** project that **occasionally changes flow (ramps)** in response to natural hydrologic or minimum flow changes, and a **peaking** project that typically ramps rapidly, frequently, and through a wide flow range. For **non-peaking** plants discharging to a stream, ramping may only occur during a planned maintenance event, in response to hydrologic conditions (e.g., spill) or during an emergency outage event. For these types of facilities, conservative ramp rates are adopted (economic costs are not a large factor). **Peaking** projects that discharge to a stream, however, create impacts on fish resources, directly and indirectly, as a result of the rapidly varying flows and creation of a varial zone on the streambed. Therefore, in reviewing the effects of streamflow fluctuations for the Project, it is important to distinguish among those developments that are (1) peaking facilities affecting riverine habitat, (2) peaking facilities that discharge directly to a reservoir thereby not affecting riverine habitat, and (3) non-peaking facilities, which at times need to alter flows. The following list summarizes the operations of the Project developments.

- Link River—Non-peaking. Flow changes occur in response to seasonal changes in minimum flows in the Link River and downstream areas, and in response to changes in irrigation water input/output to Keno reservoir. Also, flow through the East Side powerhouse is reduced at night (then raised during the day) during the summer to minimize fish entrainment through the powerhouse as stipulated in the 2001 BO. Flow changes do occur when powerhouse or canal maintenance is required, although this is typically a single annual event.

- Keno dam—No hydroelectric facilities. Dam operated as ROR to stabilize water level of Keno reservoir. Rapid flow changes occasionally occur as a result of irrigation return flows and storm events.

- J.C. Boyle bypass—Flows are maintained constant when inflow to the J.C. Boyle reservoir is less than 3,000 cfs. Flow changes occur only during periods of high-flow spill or occasionally when the J.C. Boyle powerhouse is shut down, water is spilled at the dam, and then returned to service following a maintenance event.

- J.C. Boyle peaking reach—This 17-mile-long reach of river is highly affected by daily load-following operations during much of year.

- Copco No. 1—A peaking facility, but discharges directly to Copco No. 2 reservoir, resulting in no riverine impacts.

- Copco No. 2—A peaking facility operated synchronously with Copco No. 1. Discharges directly into Iron Gate reservoir, resulting in no riverine impacts.

- Copco No. 2 bypass—Typically maintains a stable, but low flow (5 to 10 cfs). If Copco No. 2 powerhouse is out of service, discharges from Copco No. 1 generally are not peaked, but this is not a FERC license requirement. Annual maintenance at this facility results in a flow reduction as spill is terminated post-maintenance.

- Iron Gate dam—A non-peaking facility. Iron Gate reservoir operates as a re-regulation reservoir to stabilize flows downstream of Iron Gate dam. Flow changes occur at the dam only as a result of hydrologic events (spill) or to change minimum instream flows as directed by the USBR, through the NMFS BO (NMFS, 2002).

The following discussion associated with flow fluctuations begins with fish stranding because this can be an issue for both peaking and non-peaking facilities discharging to a river. Effects on fish spawning, egg development, fish movement, and growth are reviewed next as they pertain primarily to peaking projects (in this case J.C. Boyle).

6.7.1.1 Stranding

Nearly all studies of fish stranding resulting from rapid flow reductions have been on salmon and trout (reviewed by Hunter, 1992). Not only are these species of important commercial and sport value, their fry stages appear to be more vulnerable to stranding from rapid flow reductions compared to other species typically found in these same streams.

When salmon and trout fry emerge from streambed gravel, they tend to seek the quiet, shallow waters near the shoreline. During this period the fry are susceptible to controlled flow changes such as those that may occur below hydroelectric projects or other flow regulation facilities. Rapid increases in flow are generally not a problem and do not cause fish stranding. However, if reduction of flow is too rapid, the young fry can become stranded along the shoreline. Once stranded, they either die from lack of water or, if caught in shallow depressions, become susceptible to bird predation and elevated temperatures. Although a rapid flow reduction may strand only a small portion of the population, repeated fluctuations, which typify hydroelectric peaking facilities, can cause significant cumulative mortalities.

Studies conducted on salmonid fry stranding have indicated a number of variables that can affect the probability of stranding during down-ramping events. These variables include fish species, fish size, streambed morphology, substrate type, prior flow conditions, time of day, water temperature/season, and rate of river stage reduction (down-ramp rate). These variables are discussed below.

<u>Fish Species</u>

Most fry stranding studies have concentrated on Chinook salmon fry because this species is known to be vulnerable to stranding. Coho salmon appear to be less susceptible to gravel bar stranding compared to Chinook salmon, but may be more prone to pothole entrapment because of their habitat association with large organic debris (Olson, 1990; Beck Associates, 1989). The incident of coho stranding has been rather low in most studies, but this may be influenced by the fact that most research has occurred on large and medium-sized rivers, whereas most coho salmon spawning and juvenile rearing occurs in small streams and tributaries (Hunter, 1992). Chum and pink salmon fry, in particular, did not seem to be as susceptible to stranding as Chinook fry in the Sultan River, presumably because of their preference for greater water velocity as well as their tendency to migrate rapidly downstream shortly after emergence (Olson, 1990). On the Skagit River, however, chum and pink salmon fry appeared to be more susceptible to stranding than Chinook fry (Beck Associates, 1989).

Results of steelhead fry stranding tests on the Skagit River were inconclusive in regard to their stranding compared to salmon (Woodin et al. 1984). However, Olson (1990) observed that steelhead fry in the Sultan River may have been just as vulnerable to gravel bar stranding as Chinook salmon fry, although the relative abundance of each species in the study area during testing was not determined. Also, Chinook fry in the Sultan River were constantly dispersing downstream out of the study area, in contrast to the steelhead trout fry, and this may have influenced the relative numbers of stranded fry observed during the field tests.

Several studies suggest that resident trout fry are less susceptible to stranding than salmon fry. A fry stranding study in an experimental stream channel testing down-ramping rates of 11.8 inches/hour and 23.6inches/hour found that coho salmon fry were as much as ten times more susceptible to stranding as were rainbow trout (Bradford et al. 1995). Studies in Norway on the Nidelva River, which experiences flow reductions from about 5,000 to 1,000 cfs in 20 minutes (35-inch stage change), documented the stranding of numerous Atlantic salmon and brown trout fry, but the number of salmon fry stranded was 3.8 times greater than the number of trout fry stranded (Hvidsten, 1985).

In the Beaverhead River in Montana, Nelson (1986) found no relationship between the number of potential stranding events (defined as more than 30 percent decline in flow per day) and the subsequent numbers of yearling brown trout evaluated during a 14-year period. Following a sudden flow decrease in the Snake River in Wyoming, Kroger (1973) examined several exposed riffle beds and observed some stranded *Cottus* species, but no rainbow trout.

Fish Size and Life History Stage

Studies conducted on the Columbia, Cowlitz, Skagit, and Sultan rivers in Washington all have indicated that Chinook salmon juveniles longer than 50 mm are much less prone to stranding than those less than 50 millimeters long (Bauersfeld, 1977, 1978;Woodin et al. 1984; Olson, 1990). For steelhead trout fry, Olson (1990) found that only fry less than 40 mm were prone to stranding in the Sultan River. This is similar to findings on the Skagit River in Washington. No information is available for resident trout, but presumably they are most susceptible to stranding during and shortly after the fry emergence period when they are 20 to 30 mm long.

Streambed Morphology / Channel Configuration

Streambed morphology has been recognized as an important factor in determining fish stranding potential, but one that is difficult to evaluate given the infinite types of streambed configurations. During the Cowlitz River studies, however, it was determined that most of the Chinook fry stranding occurred on gravel bars of less than 2 percent slope; Chinook stranding was rarely observed on slopes greater than 4 percent (Bauersfeld, 1978). Similarly, in the 2 years of study on the Sultan River, nearly all stranded salmon and steelhead trout fry were observed on bars with slopes less than 4 percent (Olson, 1990). In an experimental channel, Monk (1989) found significantly more Chinook fry stranded on 1.8 percent slopes than on 5.1 percent slopes.

Streambed morphology differs by river stage. In most streams, exposure of low gradient gravel bars tends to be greatest at lower flow levels. In several cases a “critical” flow level has been identified below which stranding potential increases dramatically (Bauersfeld, 1978; Woodin, 1984; Olson, 1990). The critical flow often is near the minimum flow established for the project operation (Hunter, 1992). Wetted perimeter-versus-discharge relationships can be useful in defining this critical flow. On the Sultan River, a critical flow was established at 300 cfs (required minimum flow is 200 cfs) below which down-ramping is to be done most conservatively (Olson, 1990). Also established for the Sultan River are intermediate flow ranges of 300 to 750 cfs and 750 to 1,500 cfs for which faster down-ramping is allowed at the higher flow range. Mean annual flow for the Sultan River is approximately 750 cfs and power plant capacity corresponds to a river flow of 1,500 cfs.

Side channels and associated potholes also can be problem areas where daily hydroelectric peaking flows alternately flood and dewater these areas (Woodin et al. 1984; Olson, 1990). Studies of fry stranding in these areas have been conducted on the Skagit River (Woodin, 1984; Beck Associates, 1989) and on the Sultan River (Olson, 1990). The primary conclusion of these studies was that the incident of stranding was not related to the ramping rate, but rather to the amplitude of flow change (and thus the number of potholes and side channels affected) and the frequency of flow changes through these locations. The exposure of potholes and side channels to dewatering within the flow fluctuation range is stream-reach specific. Lower gradient stream reaches, especially in alluvial streams, appear to be of most concern for pothole and side channel stranding.

Additional discussion of side channel stranding is provided below.

Substrate Type

The influence of substrate on stranding potential has not been evaluated independently in the field; however, stranding has been observed in all types of substrate ranging from sand to boulder. Most studies have concentrated on cobble and gravel because these substrates are typical of low-gradient sites where salmonid fry stranding is most likely to occur. Sandy areas often have shallow depressions prone to rapid percolation and, therefore, also may be of concern if fry are present. In addition, wetted organic debris (root wads, logs, leaf piles) is often a preferred cover habitat for juvenile salmon and trout and, consequently, can be an area of concern if occurring in the dewatered zone. In a laboratory study, Monk (1989) found that Chinook salmon and steelhead trout fry were more prone to become stranded on cobble substrate than on gravel. In the Sultan River, more Chinook salmon fry were stranded on cobble than on gravel, but steelhead trout fry were found in similar numbers on both cobble and gravel. However, more steelhead fry may have been undetected amongst the cobble.

Prior Flow Conditions

It has been suggested that stable flows for a week or more before a down-ramp event could increase the incidence of stranding compared to a situation where flows are ramped daily (Phinney, 1974). The hypothesis is that fry may develop fidelity to shoreline margins that support benthos production, thereby being more reluctant to move offshore during flow reduction. On the Sultan River, Olson (1990) tested this hypothesis for 2-week-prior and a 4-day-prior stable flow conditions. He found no difference in beach stranding among the 2-week, 4-day, and 1-day scenarios. For side channels, however, Olson found that 2 weeks of stable flow before a down-ramp event (but not 4 days) probably would increase the likelihood of fry remaining in certain side channels.

Time of Day/Season

The effect of time of day on the susceptibility of juvenile salmonids to stranding has been demonstrated strongly for salmon fry, but less clearly for trout fry except during the winter. Woodin et al. (1984) and Olson (1990) found much fewer salmon fry stranded during night down-ramping trials in March and April. These findings have resulted in more restrictive down-ramping rates (FERC license requirements) during daylight hours on the Skagit and Sultan rivers. On the Skagit River, which is affected by daily peaking operations from Seattle City Light’s hydroelectric projects, the new FERC license stipulates that down-ramping during the salmon fry emergence period be done only during the night, although a relatively rapid rate of about 10 inches/hour is permitted.

The diurnal susceptibility of juvenile trout to stranding is not well defined except for the winter period. Studies on the Sultan and Skagit rivers during the summer found little evidence of a difference between day and night stranding for steelhead trout fry. In a laboratory experiment, Monk (1989) also was unable to detect an effect of time of day for steelhead trout fry during the summer. However, during cold water winter conditions, Bradford et al. (1995) found that juvenile rainbow trout and coho salmon were much more prone to stranding at night. The tendency of trout in the winter to seek concealment cover in the substrate during the day was hypothesized as support for this finding.

Down-Ramp Rate

The rate of down-ramping, depicted as decline in river stage or flow per hour, has been the primary focus of stranding studies for salmonids. Logically, the faster the down-ramping rate, perhaps beyond some threshold level to which the fish have naturally adapted, the more likely fish are to be stranded. In terms of stranding susceptibility, however, the rate of stage change is not meaningful by itself without consideration of the beach gradient along the stream edge. Thus, it is the rate of water edge recedence that relates best with stranding susceptibility.

As a point of reference in reviewing down-ramping rates, it is useful to consider how rapidly stage changes occur in unregulated streams. The utility of doing so is founded on the principle that a particular fish species (e.g., Chinook salmon) evolved under natural flow regimes and thus has developed innate behaviors to successfully handle the type of flow changes that occur naturally. This behavioral adaptation should be common to the species throughout its range and, therefore, is not stream-specific. Thus, the behavioral response of a particular species of fish to a flow attribute, such as fluctuation, should be transferable from the unregulated, natural-flow stream to another regulated stream within the species' range. Hunter (1992) examined hourly flow data from several unregulated salmonid streams in western Washington to determine the frequency of stage decreases at various rates. He found that the streams were in a state of stage decline nearly 50 percent of the time. Stage decreases exceeding 2 inches/hour were not uncommon, but occurred only in the fall, winter, and spring when base flows were seasonally higher and responding to cessation of storm events. Hunter’s provisional recommendations for down-ramping during non-summer months, while based on various field study results, are generally consistent with the 2 inches/hour rate observed in unregulated streams.

When assessing the effects of various rates of down-ramping it is important to distinguish between “beach” stranding of fish and “entrapment” of fish (Hunter, 1992). Studies have shown that the rate of down-ramping is an important variable associated with the probability of “beach” stranding, but not necessarily the "entrapment" of fish in potholes and side channels (Beck Associates, 1989; Olson, 1990). Pothole entrapment occurs when the water level declines enough to isolate potholes containing fish. Similarly, side channel entrapment occurs when river flows decline to the point that flow stops entering the top end of the channel. Fish entrapment in such areas can occur naturally in unregulated streams following storm events or during the declining limb of the hydrograph. Even extremely slow rates of stage drop, either natural or controlled, cannot prevent this type of entrapment and stranding.

A prime example of side channel entrapment is a documented case in the Klamath River that occurred in 1998 at a site about 20 miles downstream of Iron Gate dam (Hardin-Davis, Inc., 2002). In late April 1998, an artificial spawning channel became isolated from the main river entrapping several hundred salmonid fry, mostly Chinook salmon, in three pools. The channel became isolated as main river flows declined from 4,363 to 1,987 cfs following a high flow event. The total drop in stage in the main river near the spawning channel site exceeded 3 feet. The flows during the event exceeded the turbine capacity at Iron Gate (1,750 cfs), and the rates of flow change were beyond what could be controlled by the hydroelectric Project. The average rate of flow decline during the 3-day period was 33 cfs per hour, which equates to a 0.4 inches/hour stage drop at the Iron Gate gauge. The maximum stage decline for a single hour during the 3-day event at the site was estimated to be 1.1 inches/hour (Hardin-Davis, Inc., 2002). These rates of stage decline, even during the maximum 1-hour flow drop, are less than those that often occur in unregulated streams after storm events (Hunter, 1992) and generally are within agency ramping rate guidelines. This fry entrapment event in 1998, although occurring in an artificially modified channel, comports with the findings on the Sultan and Skagit rivers that fish entrapment/stranding in side channels is independent of the rate of stage drop and is rather a function of the channel becoming disconnected from the main river as flows drop below a certain level.

The issue of pothole and side channel entrapment is primarily associated with hydroelectric peaking projects with wide swings in flow that can alternately flood and dewater these potential entrapment areas during the peaking cycle. This can be of concern especially in the spring when newly emerged fry are dispersing or when smolts are moving downstream and thus are more apt to enter these areas when watered.

One of the most comprehensive studies (1985-1987) testing multiple down-ramping rates on salmonids was conducted by Olson (1990) on the Sultan River in Washington below the Jackson Hydroelectric Project. This hydroelectric project is not a peaking project and, therefore, ramping rates, based on the study results, were conservatively established to minimize the potential for fry stranding. The study involved numerous tests of down-ramping at rates ranging from 1 to 8 inches/hour under various conditions of flow, time-of-day, and season. Ramping rate recommendations for the most encountered streamflow conditions ranged from 1 inches/hour (summer low flow, night) to 6 inches/hour (spring and winter, night). The summer rates were established to protect emergent steelhead trout fry; the spring rates for salmon fry.

The Washington State Department of Fisheries (Hunter, 1992) established provisional fall-back down-ramping criteria (subject to modification with site-specific study) that range from 2 inches/hour to a desired avoidance of down-ramping during daylight hours in the late winter and spring months. These criteria were based largely on the results of Olson (1990), although conservatively interpreted assuming the worst-case conditions unique to the Sultan River.

Hunter's (1992) recommended criterion of no ramping during the daylight hours in late winter and spring was based on the findings of many studies indicating that salmon fry are much more vulnerable to stranding during the day compared to night. On the Sultan River, however, site-specific studies led to the establishment of a 4 inches/hour daytime rate when river flows exceed mean annual flow, and 2 inches/hour daytime rate when flows are less than the mean annual flow (Olson, 1990). The nighttime rate initially was recommended to be 6 inches/hour, but later was changed to 4 inches/hour because there was no economic incentive to ramp down faster than 4 inches/hour.

Controlled-rate down-ramping studies of the stranding potential for **resident trout** are available only for experimental stream channels. In one study, YOY rainbow trout were subject to down-ramping rates of 2.4 inches/hour, 11.8 inches/hour, and 23.6 inches/hour in an artificial stream channel with a 2 percent gravel bar slope (Bradford et al. 1995). Trials were conducted in the winter at temperatures less than 4°C to simulate conditions of low metabolic activity. During the nighttime trials, when the trout were not seeking concealment within the substrate, no fish were stranded at the 2.4 inches/hour down-ramp rate, but a small proportion (less than 5 percent) became stranded at the higher rates. However, during the daytime trials, about 5 percent of the fish placed in the experimental channel were stranded at the 2.4 inches/hour down-ramp rate while 27 percent and 33 percent were stranded at rates of 11.8 inches/hour and 23.6 inches/hour, respectively. This study concluded that juvenile rainbow trout may be extremely vulnerable to stranding during rapid daytime flow reductions in the winter when water temperatures are low enough to initiate daytime concealment behavior.

In another study using a series of artificial stream channels, rainbow trout fry were exposed to five-fold fluctuations in flow at ramping rates of 6 inches/hour (Irvine, 1987). While the objectives of this study were to assess fry emigration, growth, and condition as affected by simulated hydroelectric peaking flows, no fry stranding was observed at the 6 inches/hour morning and evening down-ramp trials. This study, in contrast to the study of Bradford et al. (1995), was conducted when fish were active, growing, and not seeking daytime concealment in the substrate.

Summary for salmon stranding: The size of fish, the species, and the time of day are the most important variables associated with stranding potential and the establishment of safe down-ramping rates. Stranding of juvenile salmon in potholes and side channels is largely independent of the rate of stage decrease. Coho salmon fry appear to be less susceptible to beach stranding on gravel bars than Chinook, pink, and chum salmon. Salmon fry larger than 50 mm are rarely observed stranded and this fact has led to more restrictive down-ramp rates for the period during and shortly after fry emergence (typically January through May). The significantly greater susceptibility of salmon fry to stranding during daylight hours has led to more restrictive ramp rate recommendations for daytime compared to nighttime.

Summary for steelhead trout stranding: The size of the fry is of primary importance in determining susceptibility to stranding. Beach stranding of fry larger than 40 mm rarely occurs and, thus, the post-emergence period in early summer is of greatest concern. Unlike salmon, steelhead fry have not demonstrated a clear distinction between day and night stranding susceptibility. As with salmon, side channel and pothole entrapment/stranding of steelhead trout is not related to the rate of stage reduction.

Summary for resident trout stranding: Available literature suggests that down-ramping in daylight hours during the winter at rates greater than 2 inches/hour can cause significant stranding if small trout are present in the depth zone subject to dewatering. At night, however, winter rates of 6 inches/hour appear not to cause stranding. During the non-winter seasons when trout are more active, ramp rates of 6 inches/hour also have not been shown to cause stranding. However, controlled stranding studies have not been conducted on resident trout during the fry emergence period.

Spawning

The influence that flow fluctuations have on fish spawning behavior is primarily a function of the magnitude of flow change rather than the rate of change. Trout and salmon select a fairly limited range of depths and current velocities when spawning. Therefore, it is conceivable that wide-ranging changes in depth and velocity associated with large and frequent flow changes during the spawning period would interfere with the selection and completion of spawning sites, thus hindering the reproduction and recruitment of young. However, studies on flow fluctuations and salmonid spawning have had conflicting results.

The disruption of spawning by flow changes was observed below a power plant on the Campbell River in British Columbia where Chinook salmon repeatedly started and abandoned redds before completion, with the level of disruption related to the magnitude of flow change (Hamilton and Buell, 1976). This study concluded that there may have been substantial losses of viable eggs as a result of untimely release of eggs, failure to properly fertilize eggs, or failure to adequately cover the eggs with gravel. When active redd sites were repeatedly exposed to dewatering in the Columbia River (below Priest Rapids dam), Chinook salmon often abandoned spawning attempts at the site and moved elsewhere, often to less desirable locations (Bauersfeld, 1978). Approximately half of the redds constructed in the zone of fluctuation contained no eggs, indicating that the daily flow fluctuations caused fish to construct more than one redd.

In a more detailed follow-up study below Priest Rapids dam, Chapman et al. (1986) was not able to confirm most of the findings of Bauersfeld (1978). Chinook salmon forced off of redds by daily flow fluctuations returned to complete their redds at increased flows. Live embryos were observed in 84 percent of the redds in the zone of fluctuation; however, whether they contained the full complement of eggs was not determined. The observation that salmon will return to complete their redd when flows increase, after having been forced off by insufficient water, also was reported by Stober et al. (1982) for salmon in the Skagit River, Washington.

Specific responses of spawning resident trout to flow fluctuations have not been documented. However, Nelson (1986) was able to demonstrate a relationship between the numbers of yearling brown trout produced in the Beaverhead River, Montana, during a 14-year study and the total range of flows during the 2-month spawning period. The lowest production occurred on years when flows were intentionally reduced (followed by increases) to facilitate completion of the fish sampling efforts associated with the study. It was not determined whether the relationship was a result of spawning disruption, redd dewatering, or simply a habitat limitation within the flow cycle. Flows in the study reach were influenced by a large irrigation storage facility (Clark Canyon reservoir) and were not fluctuated frequently as would occur below a hydroelectric peaking facility.

6.7.1.2 Redd Dewatering

Many studies have been conducted on the effects of dewatering of salmon and trout redds. These studies have demonstrated that salmonid eggs can survive for weeks in dewatered gravel if they remain moist and are not subjected to freezing or high temperature (Stober et al. 1982; Reiser and White, 1983; Becker and Neitzel, 1985). In a study using artificial redds subjected to controlled water flows, Chinook salmon and steelhead trout eggs were dewatered for up to 5 weeks before being rewatered in hatchery incubators and monitored for final hatching success (Reiser and White, 1983). The hatching success of dewatered eggs for both species was slightly greater than for controls. The length of the dewater period and substrate quality did not influence egg hatching success.

Other studies have shown the resilience of salmonid eggs to periods of dewatering. Hobbs (1937) found that brown trout redds dewatered for about 5 weeks still contained 83 percent viable eggs. Similar findings of brown trout eggs within dewatered redds were reported by Hardy (1963). In laboratory studies, Becker et al. (1982) reported Chinook salmon eggs survivals of more than 80 percent after 12 days of incubation in dewatered conditions. The accepted hatchery practice of shipping eyed salmonid eggs in containers with no water further illustrates resistance to dewatering.

Reiser and White (1983) caution that there is a difference between eggs that are dewatered and those that are incubated in essentially stagnant water. The high survival of dewatered eggs appears to be related to good oxygen transport via the influx of air into the gravel interstitial spaces, then dissolving into the thing layer of water surrounding the egg. Standing water, however, can lose its oxygen to biotic decay.

Although salmonid eggs may withstand extended periods of dewatering, newly hatched alevins are less tolerant. Reiser and White (1983) estimated that Chinook salmon alevins could withstand less than 10 hours of dewatering. Becker et al. (1982) reported about 50 percent mortality of newly hatched alevins that had been dewatered for 4 hours. Alevins, unlike eggs, tend to be mobile in the subsurface inter-gravel flow. Therefore, they may be able to survive declining water levels by descending through inter-gravel spaces if these spaces are not obstructed by fines (Stober et al. 1982).

The fact that eggs can withstand extended periods of dewatering can be factored into the development of safe flow fluctuation regimes below dams, especially where salmon with long incubation periods are involved (Neitzel et al. 1985). However, in the case of rainbow trout, the relatively short egg incubation period overlaps with spawning activity on the front end and with hatching on the back end. Therefore, there may be little or no opportunity to allow periodic egg dewatering if there is concern of flow fluctuations affecting spawning success or dewatering of alevins.

6.7.1.3 Movement

The effects of flow fluctuations on the downstream movement of salmon and trout fry have been studied only in experimental stream channels. For Chinook salmon fry, McPhee and Brusven (1976) found that a 17-fold flow fluctuation caused 60 percent of the Chinook salmon fry to leave the experimental stream channel. When the flow fluctuations were reduced to threefold, the emigration rate was reduced to 14 percent. The flows used in the experimental channel, however, were small, ranging from 1.8 to 0.1 cfs, thus raising the question as to whether the emigration was the result of the fluctuation or a lack of sufficient rearing space at the lower flows.

In a similar experiment using larger (flows from 3 to 12 cfs) and replicate stream channels, Irvine (1986) found that the emigration of recently emerged Chinook salmon fry (average length 35 mm) was increased by fluctuating discharge, but only when flows were increasing and when average water velocities exceeded 1.0 feet per second (fps) at the peak discharge within the cycle. Although exposed to flow fluctuations for 6 weeks, the increased emigration occurred in the first two cycles and not during subsequent flow changes. All emigration occurred at night. Irvine (1986) also found that fluctuating flows most affected emigration rates from the experimental stream section when fry were tending to migrate anyway, based on observations in the control stream. The conclusion of the study was that flow fluctuations increased emigration rates for Chinook salmon fry, but only during the first 2 or 3 weeks following emergence when fry are tending to disperse naturally.

Results of trout fry movement associated with flow fluctuations have been mixed. Irvine (1987) found that up to fivefold flow changes occurring twice daily, 5 days a week, had no effect on downstream emigration of rainbow trout fry. However, Ottaway and Clarke (1981) found that more brown trout fry emigrated from stream channels after flows were increased than before. These two studies are not totally comparable because the Irvine (1987) study was specifically designed to test effects of fluctuations whereas the Ottaway and Clarke (1981) study tested only the influence of raising flows and hence water velocities to rates (1.0 to 1.7 fps) that likely exceeded the fry’s preference or tolerance. The rainbow trout fry used by Irvine were larger (average 60 mm) than those used by Ottaway and Clarke (1981) (25 mm) suggesting that size or age may be important in determining whether flow changes affect fry emigration. Ottaway and Clarke (1981) concluded that trout fry are probably most apt to move downstream in response to increases in water velocity just after the swim-up stage and, thereafter, become less influenced by flow changes as they grow.

Ottaway and Clarke (1981) also tested the response of Atlantic salmon fry to increased flow and found that they responded differently than trout. The downstream movement of Atlantic salmon fry decreased as flow and water velocities increased. The authors speculated that the movement response to lower velocities was a result of an innate behavior to avoid becoming trapped at the edges of rivers as water levels decline.

Similar to the results of Irvine (1987), Pert and Erman (1994) found that radio-tagged rainbow trout (154 to 261 mm) did not leave the proximity of the study area in the M.F. Stanislaus River, California, when exposed to daily moderate (threefold) artificial flow fluctuations from a hydroelectric project. Ramping time from base to peak flow level was 30 to 45 minutes. Base flows were never less than 60 cfs. In this study tagged fish exhibited two distinct patterns as discharge changed. Some fish were faithful to a small area, whereas others moved about the larger study area. Some individuals were located closer to the streambed at the highest flows, possibly to avoid high focal point velocities. This tendency of trout to lower their position in the water column in response to increased water velocity has been observed in other studies as well (Rincon and Lobon-Cervia, 1993). In the study by Pert and Erman (1994), the authors speculate that individual fish may exhibit one of two general foraging strategies under fluctuating flows. In one strategy the fish remains relatively stationary intercepting drifting food items in an energetically favorable site. In the other strategy, transient fish move about the stream feeding on epibenthic organisms. The authors suggest that the transient strategy may be more profitable under variable discharge regimes, and that peaking operations from hydroelectric projects may select for individuals that prefer or can adapt to this strategy.

Summary regarding movement: Studies conducted on trout and Chinook salmon have demonstrated that wide flow fluctuations can encourage greater rates of downstream movement, but typically only for a short period following fry emergence when they are tending to disperse naturally. After fish grow out if this stage, they become more territorial and are less apt to move downstream in response to flow changes. In cases where increased emigration of emergent fry has been shown, most movement takes place during increasing flows, particularly when water velocities where fry occur begin to exceed about 1 fps.

6.7.1.4 Growth and Condition

Numerous studies (reviewed in Cushman, 1985) have demonstrated that rapidly and widely varying stream flows tend to reduce species diversity, density, and biomass of benthic organisms. Streambed areas that are alternately flooded and dewatered can become nearly devoid of benthic production. Certain macroinvertebrate species are selectively affected by fluctuating flows. Several studies (Powell, 1958; Williams and Winget, 1979; Gislason, 1980) have found that certain species of mayflies, stoneflies, and caddisflies were adversely affected by rapidly varying flows while dipterans, primarily chironomids, tend to increase in dominance.

River dwelling salmonids, as well as most other riverine fish species, depend heavily on aquatic invertebrates for food. Therefore, it is reasonable to assume that reduced benthos densities caused by widely varying flows can reduce the growth and condition of fish in these waters. While such a connection has been demonstrated in some cases (Powell, 1958), other studies have documented increased fish growth. A cause-and-effect has been difficult to demonstrate in most streams because of the confounding influence of other factors, such as physical habitat availability and water quality, both of which can be naturally limiting, or additionally enhanced or limited by flow fluctuations.

In a controlled study specifically designed to assess effects of flow fluctuations on rainbow trout growth and condition during a 6-month rearing period, Irvine (1987) found that rainbow trout fry grew significantly more in a fluctuating flow regime (fivefold daily fluctuation) compared to a stable flow regime, but there was no significant difference in condition factor (length-weight relationship). It was observed that invertebrate drift densities sometimes increased during flow changes and perhaps the increased availability to trout of invertebrate prey was responsible for trouts weight gain (Irvine, 1987).

The tendency for invertebrate drift to increase under unnatural flow fluctuation has been demonstrated in several studies (McPhee and Brusven, 1976; others in Cushman, 1985). The increase in drift can be particularly pronounced when flow fluctuations first begin following a period of constant flow (Irvine, 1985). Drift rates then tend to decline after successive days of flow fluctuation, probably attributable to depletion of the benthos after the repeated fluctuations in discharge. Elevated drift also occurs in response to increases in flow that capture terrestrial insects from riverbanks (Mundie and Mounce, 1976). In some cases it has been suggested that flow changes may benefit downstream fish populations by increasing the numbers of drifting insects (Mundie and Mounce, 1976; Brooker, 1981). However, the frequency that fluctuations occur undoubtedly can influence the long-term effect on invertebrate drift and any associated response by the fish community.

One of the more comprehensive "before and after" studies of the effects of a flow regime change on a trout populations was conducted on the Colorado River below Glen Canyon dam (McKinney et al. 2001). In this study, changes in rainbow trout growth, condition factor, relative abundance, and size frequency were compared between a 4-year base period and a 6-year post-alteration period where the magnitude of daily flow variability was reduced nearly fourfold and the minimum flow increased by about 50 percent. The results indicated that the relative abundance of rainbow trout increased, presumably because of improved availability of shallow nearshore habitat for small trout. An increase in annual mean water temperature of nearly 1ºC also may have contributed to the increase. Coinciding with the increased abundance, however, was a decrease in condition factor for all sizes of trout combined and most significantly for size classes more than 152 mm. The most notable change in the trout population, aside from the general increase in abundance, was a shift in the size structure. While the proportion of smaller trout in the population increased, the proportion of "trophy-sized" trout more than 406 mm declined from 40 percent to less than 10 percent, presumably because of density-dependent growth effects associated with the greater total numbers of trout. The authors conclude by noting that managers may need to consider the trade-off between producing larger numbers of trout or larger sizes of trout.

Summary regarding growth: While reduced biomass and altered species composition of macroinvertebrates are typical responses to extreme flow fluctuations, the effect this has on fish growth in the affected stream is less clear and is undoubtedly site specific. Increased insect drift and its availability to fish may, in some cases, compensate for the reduced density of invertebrates on the stream bottom. In other cases, food availability may not be a growth limitation factor in the particular stream. Other factors, such as habitat availability, water temperature, competition, and population abundance, also influence fish growth. In cases where fish abundance can be increased with improvements to physical habitat, the higher densities of fish can correspond with declines in growth, size, and condition of fish in the population.

6.7.2 Existing Down-Ramping

6.7.2.1 Link River

Restrictions and Limitations

Link River dam is owned by the USBR. However, PacifiCorp operates the dam per a contract agreement with the USBR. Before 1992, PacifiCorp had considerable operational flexibility to use Upper Klamath Lake as a storage reservoir for flood control and to increase downstream power production. Since 1992, ESA requirements for Upper Klamath Lake elevations and downstream minimum flows have limited PacifiCorp's operational flexibility.

Flow releases at Link River dam are controlled by six primary spill gates that can pass up to 1,000 cfs, and an additional 25 stoplog spill gates that can pass up to 12,000 cfs when opened. Of the six primary gates, four can be operated remotely, and these are used to adjust flows in the Link River according to prescribed down-ramp rates.

Current ramp rates at Link River dam were put in place in 1987 through collaboration with ODFW. They are as follows:

- 50 cfs per 30 minutes at flows 300 to 500 cfs
- 100 cfs per 30 minutes at flows 500 to 1,500 cfs
- 20 cfs per 5 minutes at flows 0 to 300 cfs (min Q is 250 cfs late July to mid-October [USFWS, 2002] and 90 cfs the rest of the year)

These ramp rates were accepted in USFWS's 1996 BO for operation of the Klamath Hydroelectric Project. Using the USGS Link River gauge stage-discharge table, these ramp rates, defined in flow-per-time units, equate to stage changes of approximately 2 inches per hour.

In addition to these ramp rate restrictions, PacifiCorp is required per the 1996 BO to inspect the shoreline area of the Link River for any fish that might become stranded or trapped as flows are ramped down to less than 300 cfs. Experience has indicated that some small fish can become trapped in potholes at these lower flows and, therefore, efforts are made to locate and salvage any trapped fish by capturing and moving them to the main river channel. A side channel that becomes intermittent at about 100 cfs is the area most prone to entrapping small fish. Stranding or entrapment of fish has not been observed at flows greater than 300 cfs at the current ramping rates.

There is no ramp rate restriction for discharges at the East Side powerhouse (influencing about 800 feet of stream). Standard operating procedure is to drop flows 100 cfs per 15 minutes (400 cfs/hour). This equates to a stage drop of 4 to 5 inches per hour (at the USGS gauge). Numerous observations in this reach indicate that fish stranding does not occur at this down-ramp rate; however, some entrapment occasionally occurs at a single small location on the left bank as flows drop to less than 450 cfs. Because of this, PacifiCorp is required to have someone on site to monitor this location and salvage any trapped fish whenever flows are reduced to less than 450 cfs. This salvage procedure also is an outcome of the 1996 BO.

Although the East Side powerhouse is not operated for power peaking, a condition of the 2001 BO requires PacifiCorp to reduce diversion flows to 200 cfs (minimum operating level) at night to minimize the entrainment of fish, which otherwise occurs mostly at night (New Earth/Cell Tech and PacifiCorp, 1999). Flows then are increased during the day if sufficient water is available.

<u>Frequency and Rate of Current Down-Ramping</u>

A summary of hourly stage reductions as recorded at the Link River gauge for water years 1991 through 1999 is shown in Figure 6.7-1, which depicts the percent of time, within the indicated period and flow range (less than 1,500 cfs), that a particular rate of stage reduction was equaled or exceeded. For all 12 months combined, it can be seen that down-ramping (more than 0.01 foot/hour) occurred about 4 percent of the time. Down-ramping faster than 0.10 foot/hour occurred 1 percent of the time. Because down-ramping from Link River dam is limited to rates slower than about 0.20 foot/hour, the times when rates are faster than this (about 0.3 percent of the time) are mostly attributable to routine flow changes or uncontrolled forced outages at the East Side powerhouse, which has no ramp rate restrictions.

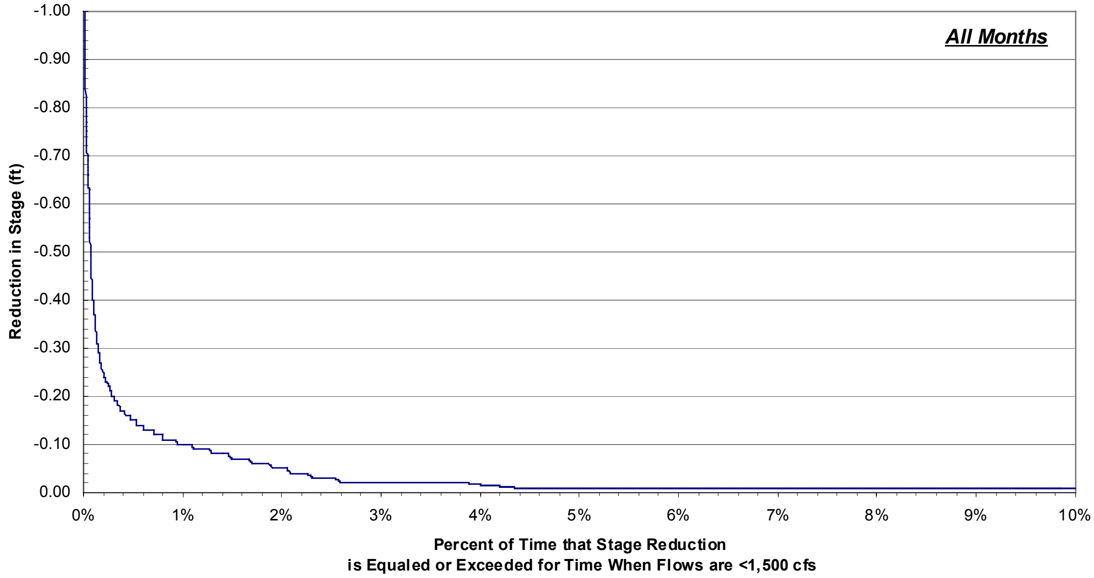

Figure 6.7-1. Link River: hourly reduction of stage for flows less than 1,500 cfs, water years 1991 through 1999.

For the April-September period, when small fish are most apt to be present, there is little difference in the down-ramping frequency by rate compared to all months combined (Figure 6.7-2).

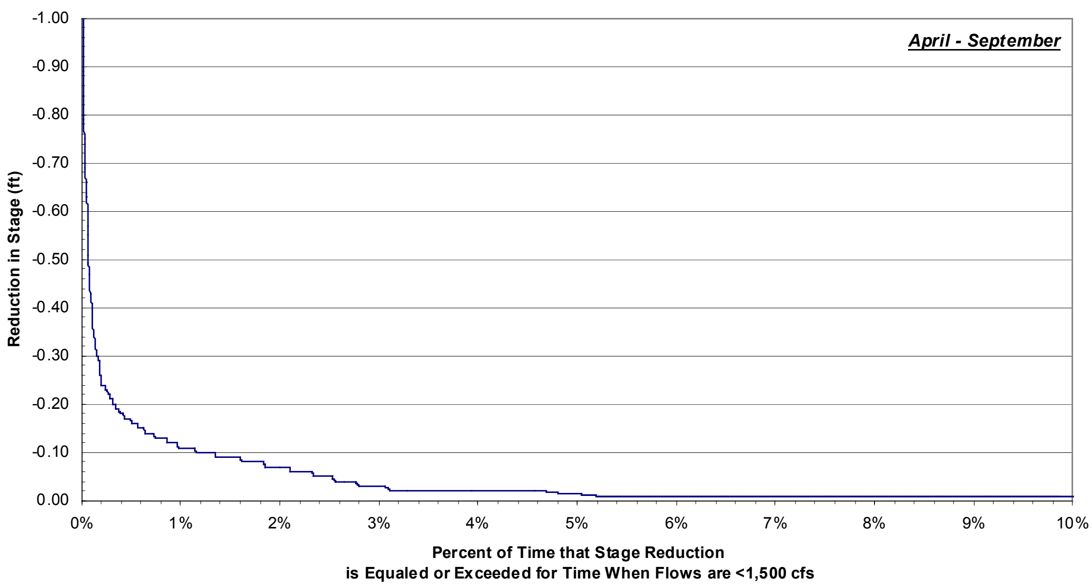

Figure 6.7-2. Link River: hourly reduction of stage for flows less than 1,500 cfs, April through September 1991 through 1999.

The Link River Dam also diverts water to the West Side powerhouse. This facility has a flow capacity of 250 cfs and must be block-loaded at full capacity only. The West Side plant operates secondarily to the East Side plant and to the minimum flow requirement at the dam. Therefore, it operates only when there is sufficient flow. The powerhouse currently is not operated during mid-July through mid-October to minimize entrainment losses of endangered suckers (USFWS, 2002). Water from the powerhouse discharges directly to Keno reservoir and, thus, there are no concerns about down-ramping effects on fish.

6.7.2.2 Keno Dam

Restrictions and Limitations

Keno dam is located approximately 21 miles downstream of Link River dam. There is no power generating capability at this facility. Numerous sources of inflow and outflow occur at Keno reservoir, which is also known as Lake Ewauna. A description of the rather complicated water movements into and out of Lake Ewauna is provided in a recent report titled "Explanation of Facilities and Operational Issues Associated with PacifiCorp's Klamath Hydroelectric Project" (PacifiCorp, 2002).

In as much as possible, Keno dam is operated to maintain a steady reservoir elevation (within approximately 0.1 foot), while continuing to pass enough water to maintain flow requirements downstream at Iron Gate dam. The steady reservoir elevation allows the USBR to manage its irrigation water through its various diversion channels. Also, the steady reservoir elevation is best suited for the numerous irrigation pumps that are located in Lake Ewauna and allows for gravity flow onto ODFW's Miller Island Wildlife Refuge.

Flows entering Keno reservoir can be highly variable as a result of natural runoff events, as well as irrigation return flows. The Klamath Straits drain and the Lost River diversion channel together can deliver up to 3,300 cfs of irrigation return water to Keno reservoir. These flows occasionally vary by more than 1,000 cfs in a 24-hour period (PacifiCorp, 2002). Often when these high return flows occur, flows entering from the Link River also are high and variable. PacifiCorp and the USBR coordinate their operations daily during these periods of high flow fluctuations to avoid excessive reservoir fluctuations.

Frequency and Rate of Current Down-Ramping

There is no FERC-required ramp rate below Keno dam. However, PacifiCorp's standard operating procedure is to manage flow changes in observation of a 500 cfs per hour ramp rate or 9 inches/hour (as measured at the USGS Keno Gauge No. 11509500) when not in a high-flow situation. When flows are less than 1,500 cfs (approximate mean annual flow), stage reductions (down-ramping) occur less than 3 percent of the time (Figure 6.7-3). Down-ramping at rates less than 0.1 foot/hour occurs about 1 percent of the time. The frequency of various down-ramp rates is similar for the April-September period (Figure 6.7-4) as it is for all months combined for times when the flow is less than 1,500 cfs.

The few times that hourly flow changes at Keno exceed 500 cfs/hour occur most often from January through April and when flows are greater than 1,500 cfs. When flows are greater than 1,500 cfs in the 5-mile Keno reach, the water's edge is generally above the toe-of-bank and, thus, stage changes result in less exposure of streambed compared to when the river is at lower flows.

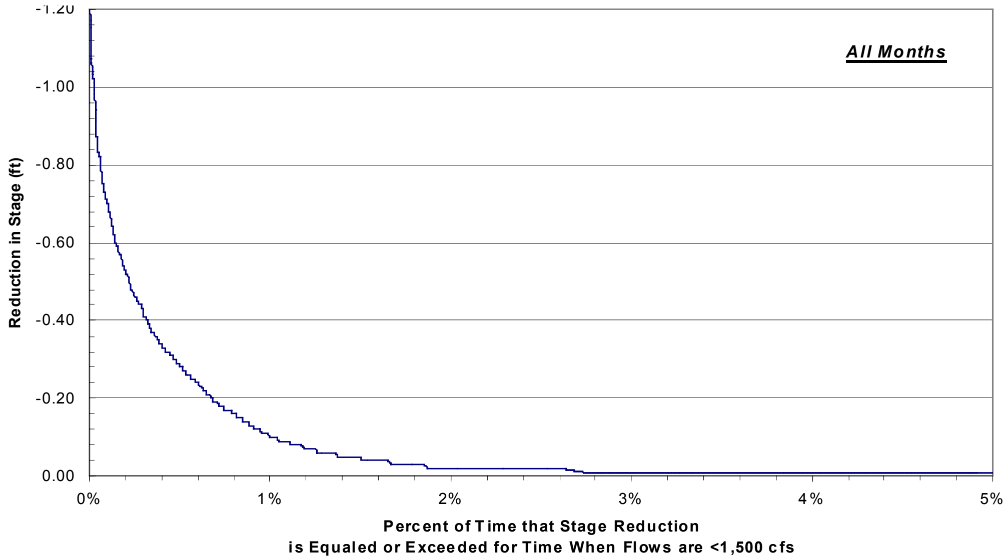

Figure 6.7-3. Klamath River at Keno: hourly reduction for flows less than 1,500 cfs, water years 1990 through 2001.

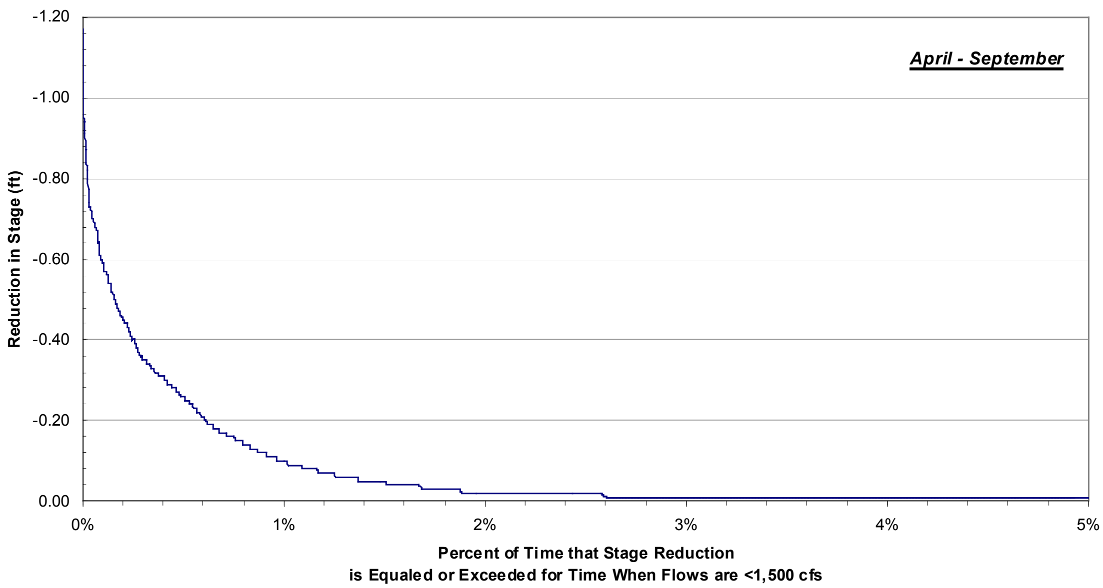

Figure 6.7-4. Klamath River at Keno: hourly reduction of state for flows less than 1,500 cfs, April through September 1990 through 2001.

6.7.2.3 J.C. Boyle Bypass

Restrictions and Limitations

The J.C. Boyle Development consists of a reservoir, dam, diversion canal, and powerhouse, which is located 4 miles downstream of the dam. The powerhouse has a rated hydraulic capacity of 2,850 cfs. Also, there is a minimum flow requirement of 100 cfs immediately downstream of the dam. Another 250 cfs of spring water enters the bypass, starting about 1 mile downstream of the dam. When inflow to J.C. Boyle reservoir exceeds 2,950 cfs and the reservoir is full, excess water is spilled into the 4-mile-long bypass reach.

The FERC license requires PacifiCorp to ramp up and ramp down flow changes in the J.C. Boyle bypass at a rate less than 9 inches/hour as measured at the USGS gauge (No. 11510700) located just downstream of the powerhouse. Standard operating procedure, however, is to change flows 135 cfs per 10 minutes (or 810 cfs/hour), which is equivalent to about 0.6 foot/hour at the USGS gauge.

The spillway at J.C. Boyle dam consists of three radial gates, each of which can pass approximately 10,000 cfs. Only one gate, however, is auto-remote controlled. Therefore, when river flows exceed approximately 13,000 cfs (assuming the powerhouse is operating), the control of ramping requires manual operation of gates. Flows this high occur rarely.

Frequency and Rate of Current Down-Ramping

Compliance to the 9 inches/hour down-ramp rate in the J.C. Boyle bypass is measured at the USGS gauge downstream of the powerhouse. During the times when spill is occurring at the dam, down-ramping occurs only about 10 percent of the time and at rates considerably less than the 9 inches/hour limit (Figure 6.7-5). Because spill occurs at the dam about 10 percent of the time during the year, down-ramping occurs only about 1 percent of the total time in a year on average.

6.7.2.4 J.C. Boyle Peaking Reach

Restrictions and Limitations

Typically, the J.C. Boyle powerhouse is operated as a power peaking facility, especially when river flows reaching the dam are less than the rated turbine hydraulic capacity of 2,850 cfs. Power generation, and hence flow through the powerhouse, is shaped to coincide with peak customer electricity demand during the daytime. During the summer, peak demand typically occurs in the late afternoon and early evenings. Given the FERC-required up-ramp rate limit of 9 inches per hour below the powerhouse, generation must begin well in advance of peak electric load requirements so that the unit(s) are at full capacity for the peak demand period. Also, during the summer PacifiCorp attempts to bring river flows up in late morning to facilitate white water rafting.

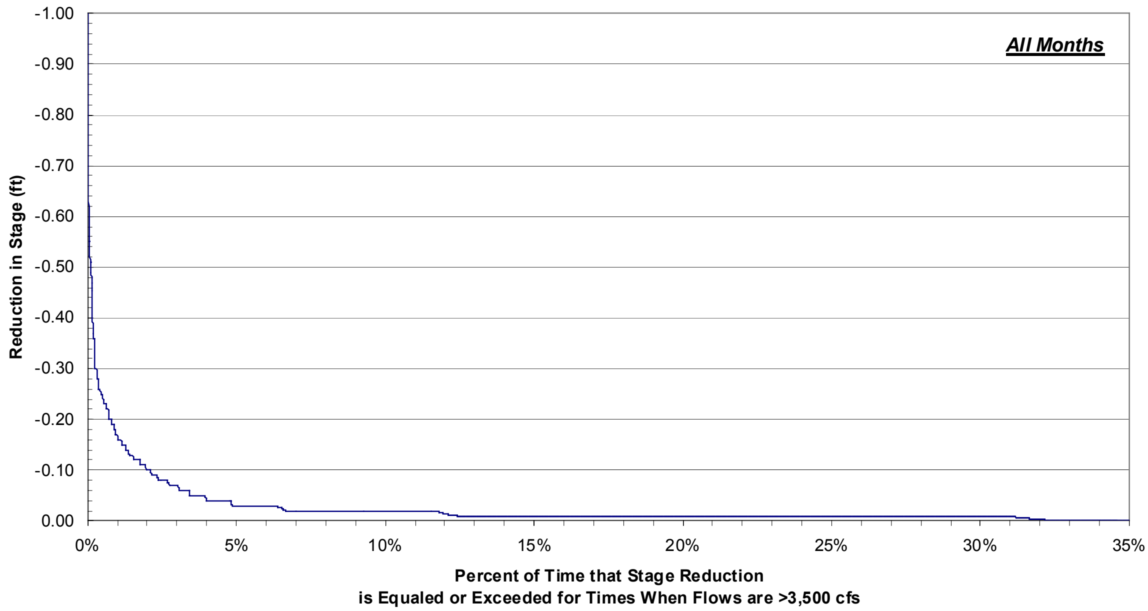

Figure 6.7-5. Klamath River at J.C. Boyle bypass: hourly reduction of stage for flow greater than 3,500 cfs, water years 1991 through 2001.

The J.C. Boyle peaking reach between the powerhouse and Copco reservoir is 17 miles long. When ramping is initiated at the powerhouse it generally takes about 5 to 6 hours for the flow change to arrive at Copco reservoir. Ramping can take place during any month of the year, but is most likely to occur in the dryer summer and autumn months.

Frequency and Rate of Current Down-Ramping

During times that spill is not occurring at the dam, discharges at the J.C. Boyle powerhouse are being down-ramped about 20 percent of the time (Figure 6.7-6). The rates of stage decline at the gauge location reflect the current practice of down-ramping (and up-ramping) at generally between 0.4 and 0.75 foot/hour. Ten percent of the time ramp rates exceed 0.3 foot/hour. Five percent exceed 0.6 foot/hour, and about 2 percent exceed 0.75 foot/hour (9 inches/hour). Ramping frequency and rates are similar in the April-September period as they are for all months combined (Figure 6.7-7).

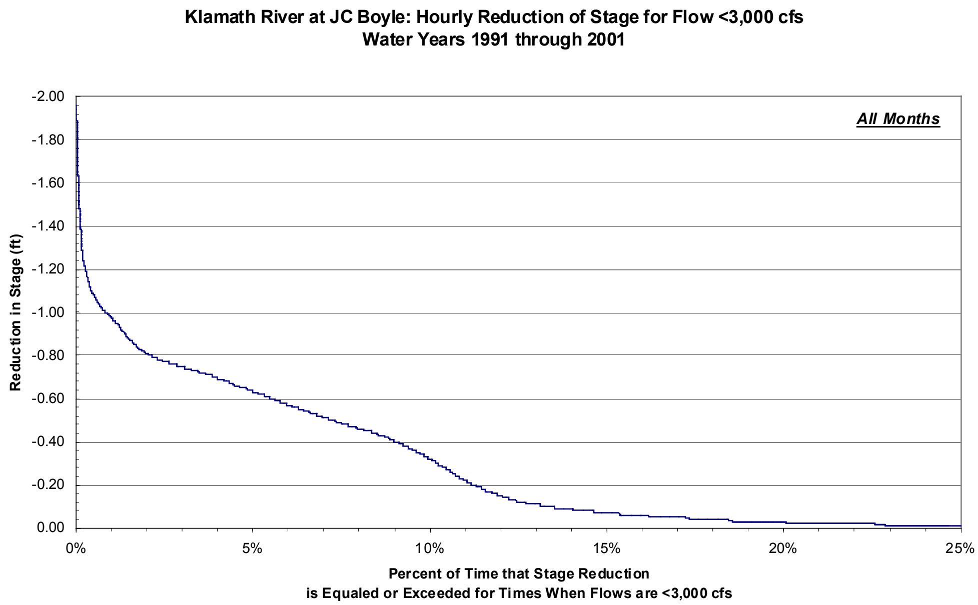

Figure 6.7-6. Klamath River at J.C. Boyle peaking: hourly reduction of stage for flow less than 3,000 cfs, water years 1991 through 2001.

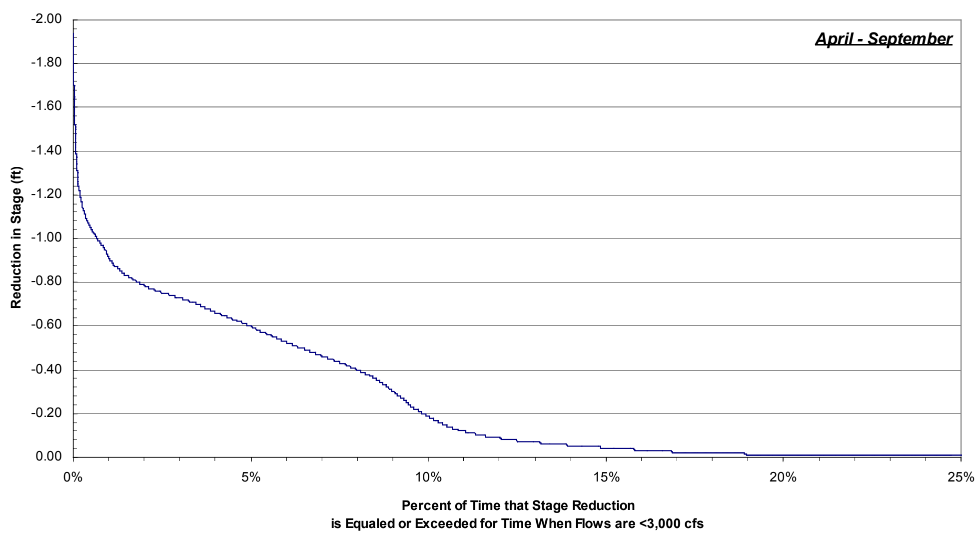

Figure 6.7-7. Klamath River at J.C. Boyle peaking: hourly reduction of stage for flow less than 3,000 cfs, April through September 1991 through 2001 (excluding 1996).

The J.C. Boyle powerhouse occasionally experiences unscheduled shutdowns during which time stage reductions at the USGS gauge may exceed 9 inches per hour for a short time while flows in the intake canal and possibly at the dam must be balanced. When the powerhouse shuts down, the canal headgate automatically closes to prevent additional flow into the canal. At the same time, a sensor (float) at the downstream end of the canal triggers the operation of the canal spill gates. If only one generating unit is in operation (1,500 cfs or less) and it shuts down, the canal may be able to capture the water without triggering the canal spill gates. If shutdown is lengthy spill gates at the dam may need to be opened.

The current equipment that monitors and adjusts flows at J.C. Boyle to control down-ramping has several sources of measurement and response error (variability) which sometimes makes it difficult to comply or appear to comply to ramp rates on an hourly basis (which is essentially a single per-hour snapshot). Controlling ramping requires synchronized monitoring at the USGS gauge, tailwater elevation at the powerhouse, and headwater elevation in J.C. Boyle reservoir at the canal headgate. Measurement variability at the three locations can collectively result in stage declines being recorded with some degree of error. In 2003, PacifiCorp replaced the canal headgate and updated the Project control software so as to provide better monitoring and control of flow changes at the J.C. Boyle Development.

Quantification of Varial Zone

To assess potential aquatic resource effects from flow fluctuations associated with peaking operations at the J.C. Boyle powerhouse, it is important to quantify the amount of streambed that is alternatively watered and dewatered in the peaking cycle. This area is referred to as the varial zone. Aquatic productivity in terms of algae and macroinvertebrates is limited in this zone. Also, low gradient areas in the varial zone have high potential for stranding of salmonid fry under certain conditions (Bauersfeld, 1978; Woodin, 1984; Olson, 1990).

Quantification of the varial zone between different increments of flow was based on the stage-discharge relationships and cross sections surveyed as part of the instream flow study. Data from 71 cross sections were available for analysis in the peaking reach. Standard output of the hydraulic model used in PHABSIM includes wetted perimeter as a function of flow at each cross section. These wetted perimeter versus discharge relationships were developed for individual habitat types (riffle, run, pool, and glide) and various habitat groupings, including all types combined (Figures 6.7-8 through 6.7-12).

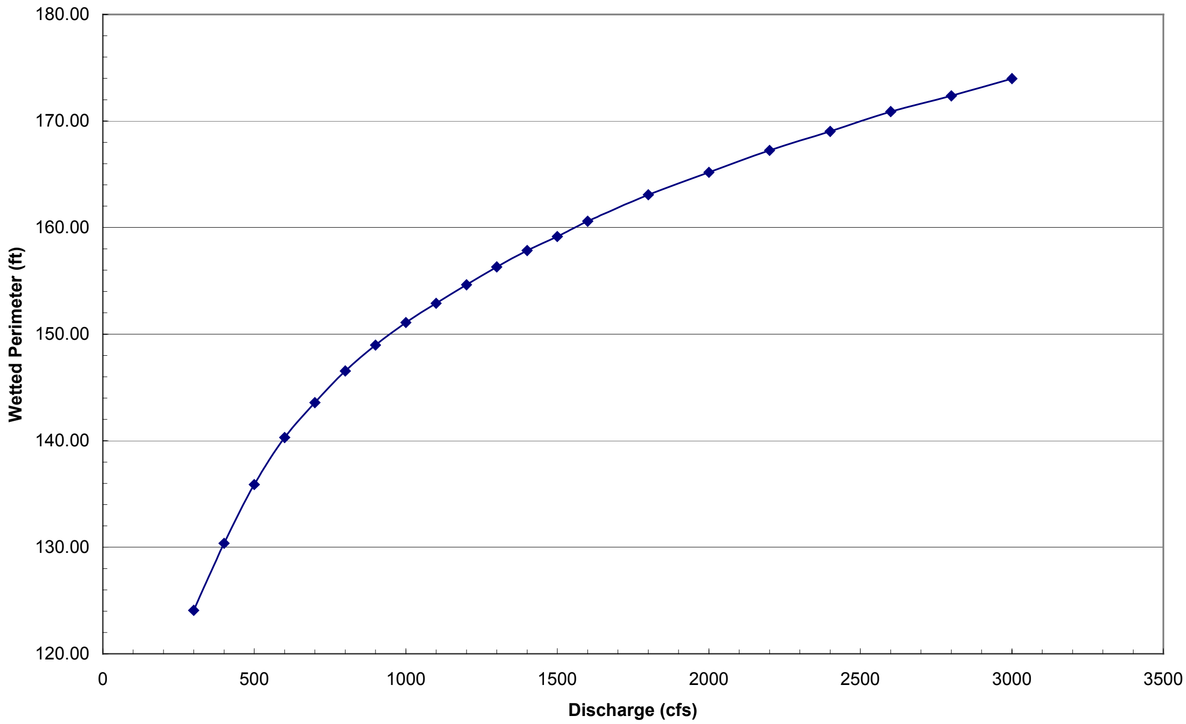

Figure 6.7-8. Wetted perimeter vs. discharge for all habitat in the J.C. Boyle peaking reach.

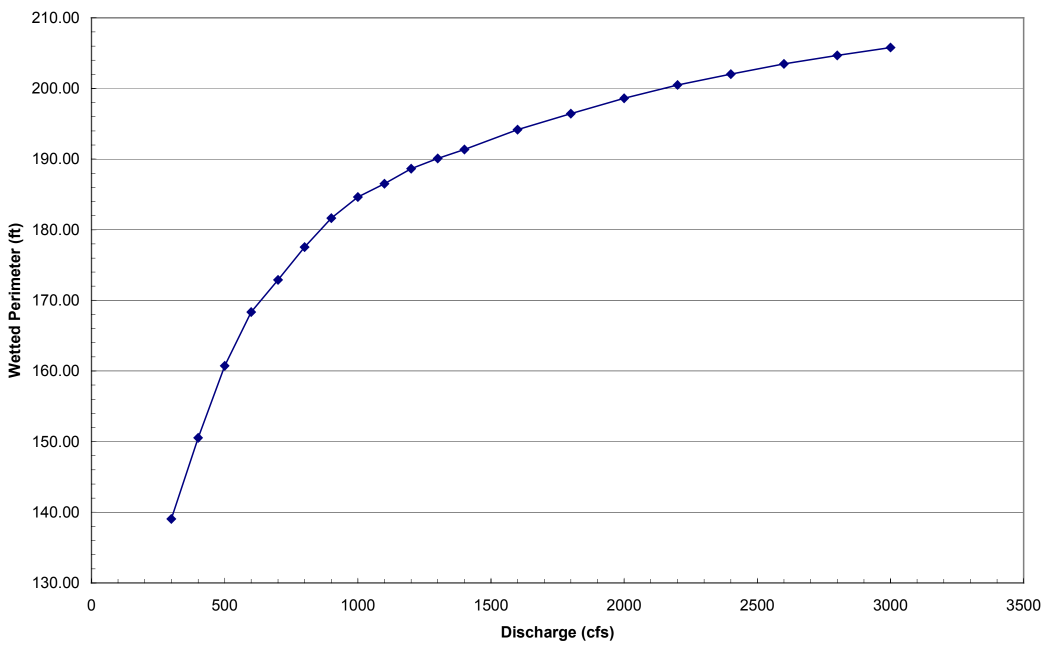

Figure 6.7-9. Wetted perimeter versus discharge for riffle habitat in the J.C. Boyle peaking reach.

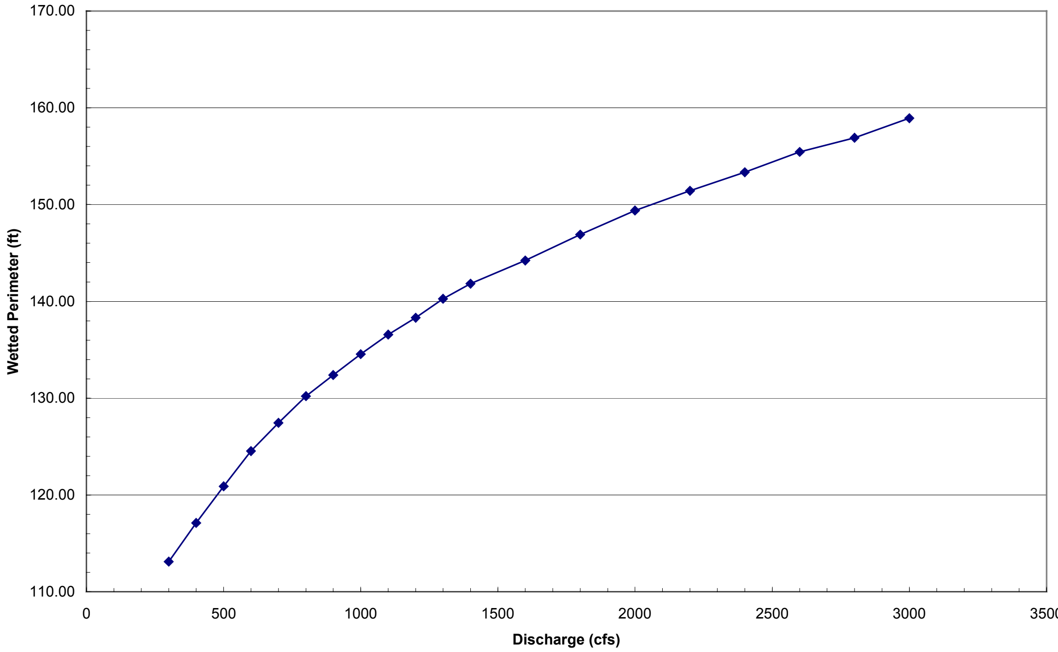

Figure 6.7-10. Wetted perimeter versus discharge for run habitat in the J.C. Boyle peaking reach.

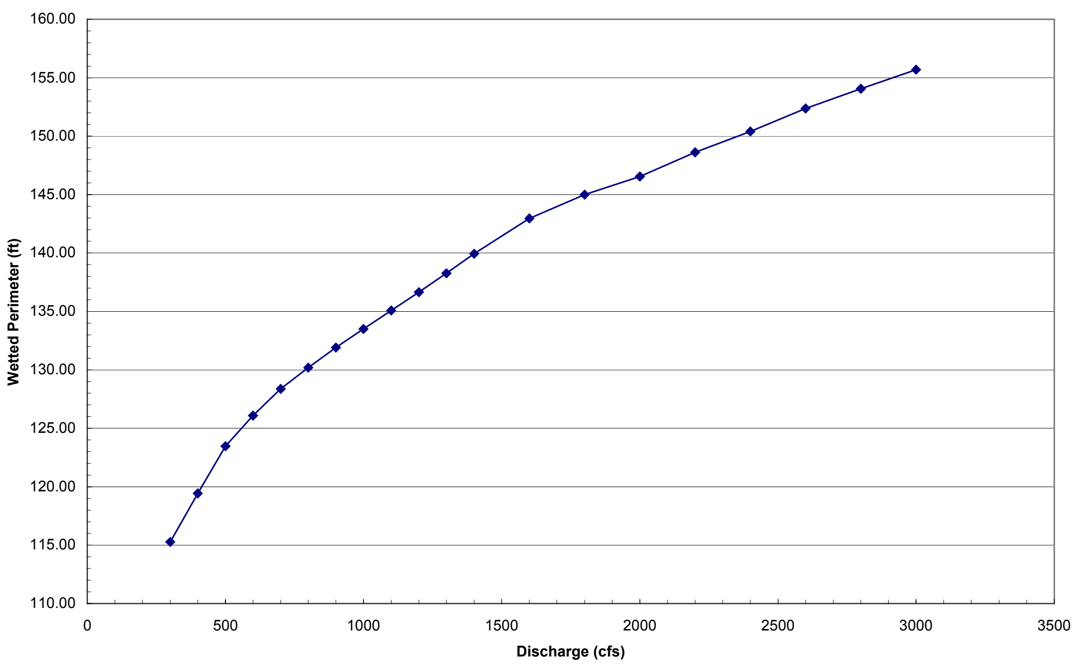

Figure 6.7-11. Wetted perimeter versus discharge for pool habitat in the J.C. Boyle peaking reach.

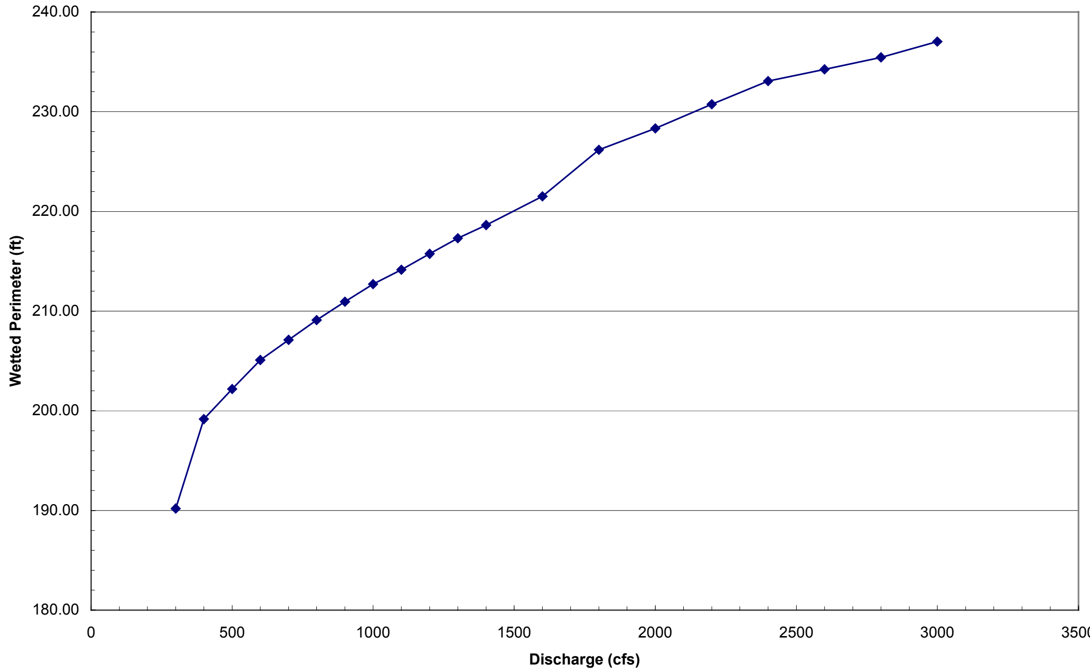

Figure 6.7-12. Wetted perimeter versus discharge for glide habitat in the J.C. Boyle peaking reach.

The summarized wetted perimeter/discharge information was tabulated onto worksheets to provide a tool to allow one to readily quantify the varial zone between two different stream flows. The varial zone is depicted as average wetted perimeter change in feet (Tables 6.7-1 and 6.7-2) and as percent change from the high flow to the low flow being compared (Tables 6.7-3 and 6.7-4). This quantification of the varial zone between flow increments was developed to compare aquatic streambed effects among various alternative peaking regimes and with a non-peaking flow regime.

The streambed in the varial zone, by definition, is not continuously wetted, and consequently, has little or no "effective" value for production of benthic organisms, such as algae and macroinvertebrates. Therefore, in terms of assessing impacts among peaking flow alternatives, it is the differences in the amount of continuously wetted streambed during several weeks time that best relates to benthic productivity potential. This is especially true in riffles, which tend to produce greater densities of benthic organisms than other mesohabitats. The "continuously wetted" streambed is best represented by the estimated wetted perimeter at the base flow within the peaking (or non-peaking) cycle. The following are examples of an impact assessment for the J.C. Boyle peaking reach using wetted perimeter information:

- Current peaking cycle (350-cfs base flow) compared to a summer run-of-river (ROR) alternative (assuming a constant 700-cfs flow)
- Reduced peaking cycle with a 500-cfs base flow compared to 700-cfs ROR

In the first example, applying the "all-habitat" wetted perimeter-flow curve (see Figure 6.7-8), the average wetted perimeter at the 350-cfs base flow is 127.2 feet. At the assumed ROR flow of 700 cfs, the wetted perimeter is 143.6 feet. Therefore, the current peaking cycle provides

16.3 feet (11.4 percent) less wetted perimeter compared to ROR. Applying only the riffle mesohabitat relationship between wetted perimeter and flow (see Figure 6.7-9), the current peaking cycle provides 28.1 feet (16.3 percent) less wetted perimeter compared to ROR.

In the second example, it is assumed that the minimum flow in the peaking cycle is increased from 350 to 500 cfs. For the all-habitat comparison, the difference in wetted perimeter between the 500-cfs base flow and the 700-cfs base flow for ROR is 7.7 feet (5.4 percent). The riffle-only wetter perimeter difference is 12.2 feet (7.0 percent). This second example demonstrates that only a moderate increase in minimum flow (in this case 150 cfs) in the peaking cycle would substantially reduce the amount of streambed that is rendered unproductive from peaking.

Table 6.7-1. J.C. Boyle peaking wetted perimeter vs. discharge for all habitat.

Table shows changes in wetted perimeter (feet) that would occur during downramping from starting flow to ending flow

Average Wetted Perimeter	Ending Flow	Starting Flow (cfs) → Flows (cfs)	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1600	1800	2000	2200	2400	2600	2800	3000
124.09		300		-6.28	-11.80	-16.20	-19.47	-22.46	-24.88	-27.01	-28.79	-30.54	-32.20	-33.74	-36.49	-39.00	-41.08	-43.15	-44.93	-46.78	-48.27	-49.88
130.37		400			-5.52	-9.92	-13.19	-16.18	-18.60	-20.73	-22.51	-24.26	-25.92	-27.46	-30.21	-32.71	-34.80	-36.87	-38.65	-40.50	-41.99	-43.60
135.90		500				-4.39	-7.67	-10.65	-13.08	-15.20	-16.98	-18.74	-20.40	-21.94	-24.69	-27.19	-29.28	-31.34	-33.13	-34.98	-36.46	-38.08
140.29		600					-3.27	-6.26	-8.68	-10.81	-12.59	-14.35	-16.01	-17.54	-20.29	-22.80	-24.88	-26.95	-28.74	-30.58	-32.07	-33.68
143.56		700						-2.99	-5.41	-7.54	-9.32	-11.07	-12.73	-14.27	-17.02	-19.53	-21.61	-23.68	-25.46	-27.31	-28.80	-30.41
146.55	↑	800							-2.42	-4.55	-6.33	-8.09	-9.75	-11.29	-14.03	-16.54	-18.62	-20.69	-22.48	-24.32	-25.81	-27.42
148.97		900								-2.13	-3.91	-5.66	-7.33	-8.86	-11.61	-14.12	-16.20	-18.27	-20.05	-21.90	-23.39	-25.00
151.10		1000									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
152.88		1100										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
154.64		1200											0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
156.30		1300												0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
157.83		1400													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
160.58		1600														0.00	0.00	0.00	0.00	0.00	0.00	0.00
163.09		1800															0.00	0.00	0.00	0.00	0.00	0.00
165.17		2000																0.00	0.00	0.00	0.00	0.00
167.24	Ending Flow	2200																	0.00	0.00	0.00	0.00
169.03		2400																		0.00	0.00	0.00
170.87		2600																			0.00	0.00
172.36		2800																				0.00
173.97		3000																				

Table 6.7-2. J.C. Boyle peaking wetted perimeter vs. discharge for riffle habitat.

Table shows changes in wetted perimeter (feet) that would occur during downramping from starting flow to ending flow

Average Wetted Perimeter	Ending Flow	Starting Flow (cfs) → Flows (cfs)	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1600	1800	2000	2200	2400	2600	2800	3000
139.03		300		-11.50	-21.69	-29.32	-33.86	-38.53	-42.59	-45.60	-47.48	-49.60	-51.06	-52.32	-55.13	-57.41	-59.58	-61.47	-63.01	-64.46	-65.64	-66.77
150.53		400			-10.19	-17.82	-22.37	-27.03	-31.09	-34.10	-35.98	-38.10	-39.56	-40.82	-43.64	-45.91	-48.08	-49.97	-51.51	-52.96	-54.14	-55.27
160.72		500				-7.63	-12.18	-16.84	-20.91	-23.92	-25.79	-27.91	-29.37	-30.64	-33.45	-35.72	-37.89	-39.79	-41.32	-42.77	-43.95	-45.08
168.35		600					-4.55	-9.21	-13.28	-16.29	-18.16	-20.28	-21.74	-23.01	-25.82	-28.09	-30.26	-32.16	-33.69	-35.14	-36.32	-37.45
172.90		700						-4.66	-8.73	-11.74	-13.62	-15.73	-17.19	-18.46	-21.27	-23.55	-25.72	-27.61	-29.14	-30.60	-31.77	-32.90
177.56		800							-4.07	-7.08	-8.95	-11.07	-12.53	-13.80	-16.61	-18.88	-21.05	-22.95	-24.48	-25.93	-27.11	-28.24
181.63		900								-3.01	-4.89	-7.00	-8.46	-9.73	-12.54	-14.82	-16.99	-18.88	-20.41	-21.87	-23.04	-24.17
184.64		1000									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
186.51		1100										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
188.63		1200											0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
190.09		1300												0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
191.36		1400													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
194.17		1600														0.00	0.00	0.00	0.00	0.00	0.00	0.00
196.44		1800															0.00	0.00	0.00	0.00	0.00	0.00
198.61		2000																0.00	0.00	0.00	0.00	0.00
200.51		2200																	0.00	0.00	0.00	0.00
202.04		2400																		0.00	0.00	0.00
203.49		2600																			0.00	0.00
204.67		2800																				0.00
205.80		3000																				

Table 6.7-3. J.C. Boyle peaking wetted perimeter vs. discharge for all habitat.

Table shows percent reduction in wetted perimeter that would occur during downramping from starting flow to ending flow

Wetted Perimeter	Ending Flow	Flows (cfs)	Starting Flow (cfs) → 300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1600	1800	2000	2200	2400	2600	2800	3000
124.09		300		4.82%	8.69%	11.55%	13.56%	15.32%	16.70%	17.87%	18.83%	19.75%	20.60%	21.38%	22.72%	23.91%	24.87%	25.80%	26.58%	27.38%	28.00%	28.67%
130.37		400			4.06%	7.07%	9.19%	11.04%	12.48%	13.72%	14.72%	15.69%	16.59%	17.40%	18.81%	20.06%	21.07%	22.04%	22.87%	23.70%	24.36%	25.06%
135.90		500				3.13%	5.34%	7.27%	8.78%	10.06%	11.11%	12.12%	13.05%	13.90%	15.37%	16.67%	17.72%	18.74%	19.60%	20.47%	21.16%	21.89%
140.29		600					2.28%	4.27%	5.83%	7.15%	8.24%	9.28%	10.24%	11.12%	12.64%	13.98%	15.06%	16.11%	17.00%	17.90%	18.61%	19.36%
143.56		700						2.04%	3.63%	4.99%	6.09%	7.16%	8.15%	9.04%	10.60%	11.97%	13.08%	14.16%	15.06%	15.98%	16.71%	17.48%
146.55		800							1.63%	3.01%	4.14%	5.23%	6.24%	7.15%	8.74%	10.14%	11.27%	12.37%	13.30%	14.24%	14.97%	15.76%
148.97		900								1.41%	2.56%	3.66%	4.69%	5.61%	7.23%	8.66%	9.81%	10.92%	11.86%	12.82%	13.57%	14.37%
151.10		1000									0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
152.88		1100										#DIV/0!	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
154.64		1200											0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
156.30		1300												0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
157.83		1400													0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
160.58		1600														0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
163.09		1800															0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
165.17		2000																0.00%	0.00%	0.00%	0.00%	0.00%
167.24		2200																	0.00%	0.00%	0.00%	0.00%
169.03		2400																		0.00%	0.00%	0.00%
170.87		2600																			0.00%	0.00%
172.36		2800																				0.00%
173.97		3000																				

Table 6.7-4. J.C. Boyle peaking wetted perimeter vs. discharge for riffle habitat.

Table shows percent reduction in wetted perimeter that would occur during downramping from starting flow to ending flow

Wetted Perimeter		Flows (cfs)	Starting Flow (cfs) →																			
	Ending Flow ↑		300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1600	1800	2000	2200	2400	2600	2800	3000
139.03		300		7.64%	13.49%	17.41%	19.59%	21.70%	23.45%	24.70%	25.46%	26.29%	26.86%	27.34%	28.40%	29.22%	30.00%	30.66%	31.18%	31.68%	32.07%	32.44%
150.53		400			6.34%	10.58%	12.94%	15.22%	17.12%	18.47%	19.29%	20.20%	20.81%	21.33%	22.47%	23.37%	24.21%	24.92%	25.49%	26.03%	26.45%	26.85%
160.72		500				4.53%	7.04%	9.48%	11.51%	12.95%	13.83%	14.80%	15.45%	16.01%	17.23%	18.18%	19.08%	19.84%	20.45%	21.02%	21.47%	21.90%
168.35		600					2.63%	5.19%	7.31%	8.82%	9.74%	10.75%	11.44%	12.02%	13.30%	14.30%	15.24%	16.04%	16.68%	17.27%	17.75%	18.20%
172.90		700						2.63%	4.81%	6.36%	7.30%	8.34%	9.04%	9.65%	10.95%	11.99%	12.95%	13.77%	14.42%	15.04%	15.52%	15.99%
177.56		800							2.24%	3.83%	4.80%	5.87%	6.59%	7.21%	8.55%	9.61%	10.60%	11.44%	12.12%	12.74%	13.25%	13.72%
181.63		900								1.63%	2.62%	3.71%	4.45%	5.08%	6.46%	7.54%	8.55%	9.42%	10.10%	10.75%	11.26%	11.75%
184.64		1000									1.01%	2.12%	2.87%	3.51%	4.91%	6.01%	7.04%	7.91%	8.61%	9.27%	9.79%	10.28%
186.51		1100										1.12%	1.88%	2.53%	3.94%	5.05%	6.09%	6.98%	7.68%	8.34%	8.87%	9.37%
188.63		1200											0.77%	1.42%	2.85%	3.98%	5.03%	5.92%	6.64%	7.30%	7.84%	8.34%
190.09		1300												0.66%	2.10%	3.23%	4.29%	5.19%	5.91%	6.59%	7.12%	7.63%
191.36		1400													1.45%	2.59%	3.65%	4.56%	5.29%	5.96%	6.51%	7.02%
194.17		1600														1.16%	2.24%	3.16%	3.90%	4.58%	5.13%	5.65%
196.44		1800															1.09%	2.03%	2.77%	3.46%	4.02%	4.55%
198.61		2000																0.94%	1.70%	2.40%	2.96%	3.49%
200.51		2200																	0.76%	1.47%	2.03%	2.57%
202.04		2400																		0.71%	1.29%	1.83%
203.49		2600																			0.58%	1.12%
204.67		2800																				0.55%
205.80		3000																				

6.7.2.5 Copco

Restrictions and Limitations

Copco No. 1 powerhouse has a maximum hydraulic generating capacity of 3,200 cfs. The powerhouse is a peaking facility, but it discharges directly to Copco No. 2 reservoir at the base of the dam. Therefore, there is no riverine habitat directly affected by the Copco No. 1 peaking operations.

Copco No. 2 is a peaking facility that operates synchronously with Copco No. 1. The powerhouse, located about 1.5 miles downstream of the Copco No. 2 diversion dam, discharges directly to Iron Gate reservoir.

There are no ramp rate requirements for the 1.5-mile-long bypass reach between Copco No. 2 dam and Copco No. 2 powerhouse. However, in the event of an unscheduled powerhouse shutdown at the Copco No. 2 powerhouse, Copco No. 1 powerhouse is shut down in response. If the outage at Copco No. 2 powerhouse will be lengthy, PacifiCorp may elect to operate Copco No. 1 powerhouse and spill water at Copco No. 2 dam. Although not regulated by the FERC, Copco No. 1 rarely operates in a peaking mode under such circumstances.

Nearly all spill gates at Copco No. 1 and Copco No. 2 dams are manually operated. Therefore, the ability to control ramping, if needed, in the Copco No. 2 bypass would be limited if flows passing the Project exceed the hydraulic capacity of the powerhouses (both 3,200 cfs).

Frequency and Rate of Current Down-Ramping

There is no gauge at the Copco locations, therefore, data on the frequency and rate of current down-ramping are not available.

6.7.2.6 Iron Gate Dam

Restrictions and Limitations

The Iron Gate Development consists of a reservoir, dam, and powerhouse. It is the most downstream hydroelectric facility of the Klamath Hydroelectric Project. The powerhouse is located at the base of the dam and there is no bypass reach.

The Iron Gate powerhouse consists of a single 18-MW unit with a hydraulic capacity of 1,735 cfs. In the event of a turbine shutdown, a synchronized bypass valve diverts water around the turbine to maintain flows downstream of the dam.

Iron Gate dam and powerhouse are operated for base load generation and to provide stable flows in the Klamath River downstream of the dam. The powerhouse is not used for load following. At flows less than about 1,735 cfs, the Iron Gate turbine can be regulated closely to control ramping rates. At flows more than 1,735 cfs, Iron Gate spills and has little or no control over downstream flows. The concrete spillway has no flow control gates. Therefore, control of spill at Iron Gate dam, to the extent that it can, moves upstream to the Copco facilities. Flow control becomes complicated in this flow range (1,735 to 3,200 cfs) because of the influence of turbine discharges, reservoir retention time, reservoir-induced flow attenuation, and tributary inflow between Copco and Iron Gate.

At flows exceeding 3,200 cfs, flows at Copco can be controlled only via 13 sets of spill gates, 11 of which are manually operated. The margin of error in operating these gates is large, and, if the reservoir is full, control of spill may not be possible.

The FERC ramp rate restriction at Iron Gate dam is 3 inches per hour (as measured at the USGS gauge 11516530 downstream of the dam) or 250 cfs per hour, whichever is less, "provided that the licensee shall not be responsible for conditions beyond its control."

Currently, ramp rates at Iron Gate dam are prescribed by the 2002 BO issued by the NMFS for the USBR to protect coho salmon. The rates are:

- 50 cfs per 2-hour period when not spilling (less than 1,750 cfs)
- 150 cfs per 4-hour period when spilling (more than 1,750 cfs)

The ramp rates stipulated in the BOs are five times more restrictive (slower) than the FERC ramp rate restrictions. The BO ramp rates equate to about 0.4-inch per hour at the USGS gauge. Rate of stage decreases at non-pool cross sections downstream of the Iron Gate gauge (based on 10 PHABSIM cross sections between Iron Gate dam and Interstate 5) average 2/3 the rate seen at the USGS gauge for the same cfs/hr change. Thus, the 0.4-inch/hour at the USGS gauge (current ramp rate) equates to about 0.25-inch/hour in wider areas of the river where stranding potential would be greatest. Rates become further attenuated downstream.

In addition, the BO specifies that flows cannot be reduced more than 150 cfs per 24 hours when not spilling, and no more than 300 cfs per 24 hours when spilling.

<u>Frequency and Rate of Current Down-Ramping</u>

Because Iron Gate is not a load following facility, ramping occurs on a limited number of occasions during the year. These occasions include (1) when spring runoff decreases to the extent that spill is no longer needed, (2) during annual maintenance when the turbine and bypass valve are shut down and downstream flow requirements are met via the spillway, (3) when changing USBR's instream flows below the dam. As shown in Figure 6.3-8, Iron Gate down-ramps (more than 0.01 foot/hour) less than 3 percent of the time during the year when flows are less than 3,200 cfs. When ramp rates were limited to 3 inches per hour, (pre-BO), ramping generally occurred at much lower rates (most less than 1-inch per hour). Since the BO rates were imposed, the frequency of down-ramping has not changed, but the rates have been significantly reduced to mostly less than 0.05 foot per hour (see Figure 6.7-13).

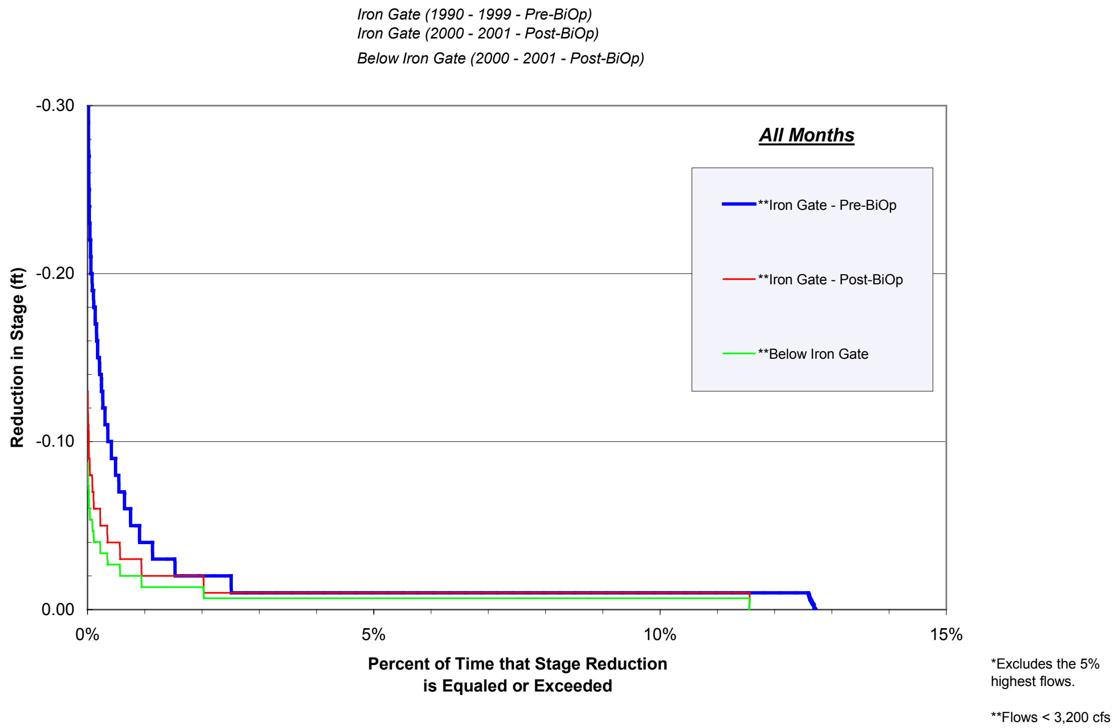

Figure 6.7-13. Hour by stage reduction.

Down-ramping frequency and rate also were depicted for the January through June period, which corresponds to the time when salmonid fry would be most abundant (Figure 6. 7-14). The ramping frequency and rates for this period are similar to those in the all-months period.

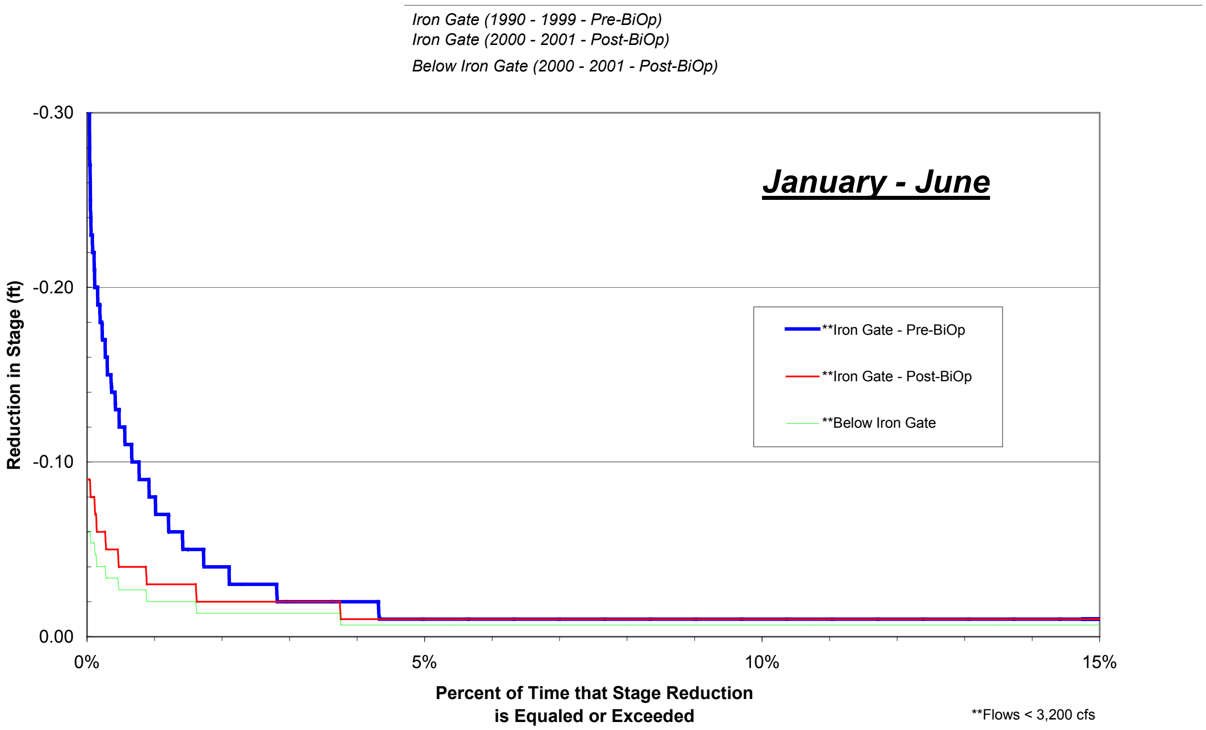

Figure 6.7-14. Hour by stage reduction, January–June.

Down-ramp compliance at Iron Gate is measured at the USGS gauge about 0.5 mile below the dam. The gauge is located in a relatively narrow section of river and is not representative of wider sections where fish stranding potential would be greatest. Therefore, the rate of stage decreases at the gauge were compared to non-pool cross sections downstream of the Iron Gate gauge (based on 10 IFIM cross sections between Iron Gate and Interstate 5). On average, stage changes for the same cfs per hour change at these wider cross sections were 2/3 the rate seen at the USGS gauge. Thus the 0.4-inch/hour at the USGS gauge (current ramp rate) equates to about 0.25-inch/hour in wider areas of the river. Rates naturally become further attenuated downstream as additional flow enters the river

6.7.3 Stranding Observations During Down-Ramp Events (J.C. Boyle Peaking Reach)

Observations made for fish stranding in the J.C. Boyle peaking reach were conducted at two locations in Oregon at Frain Ranch (Figure 6.7-15) and at three locations in California downstream of Shovel Creek (Figure 6.7-16). These sites were selected for having high potential for fry stranding based on (1) large exposure area, (2) low beach gradient (less than 2 percent), (3) depressions and potholes, (4) presence of both aquatic vegetation and submerged grasses at the high-flow end of the ramping event, (5) top of islands, and (6) association with side channels. These sites were selected following a review of maps, aerial photos, and a reconnaissance by shore (in Oregon segment) and by raft (in California segment) under low flow conditions.

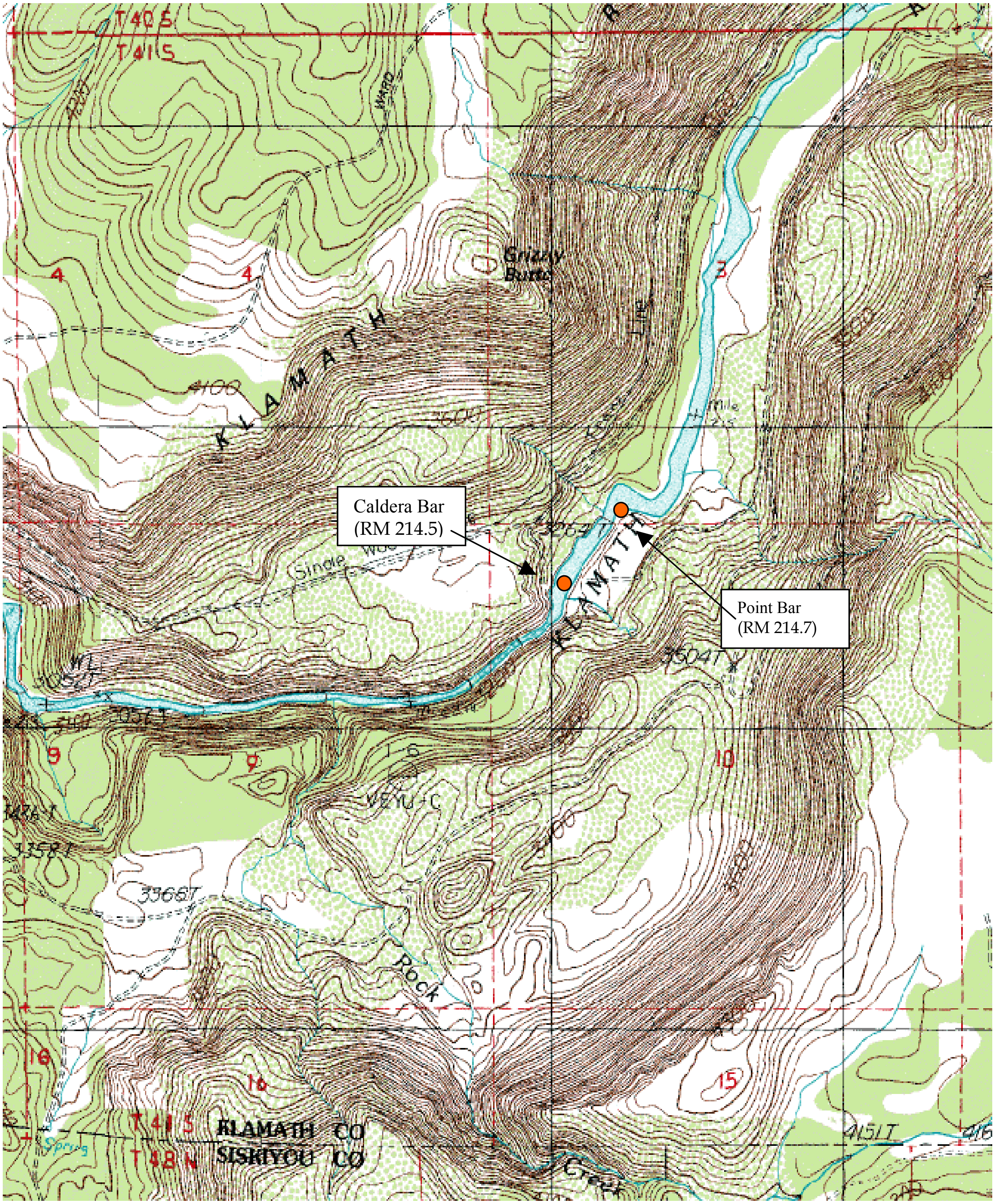

Figure 6.7-15. Stranding observation sites, Frain Ranch.

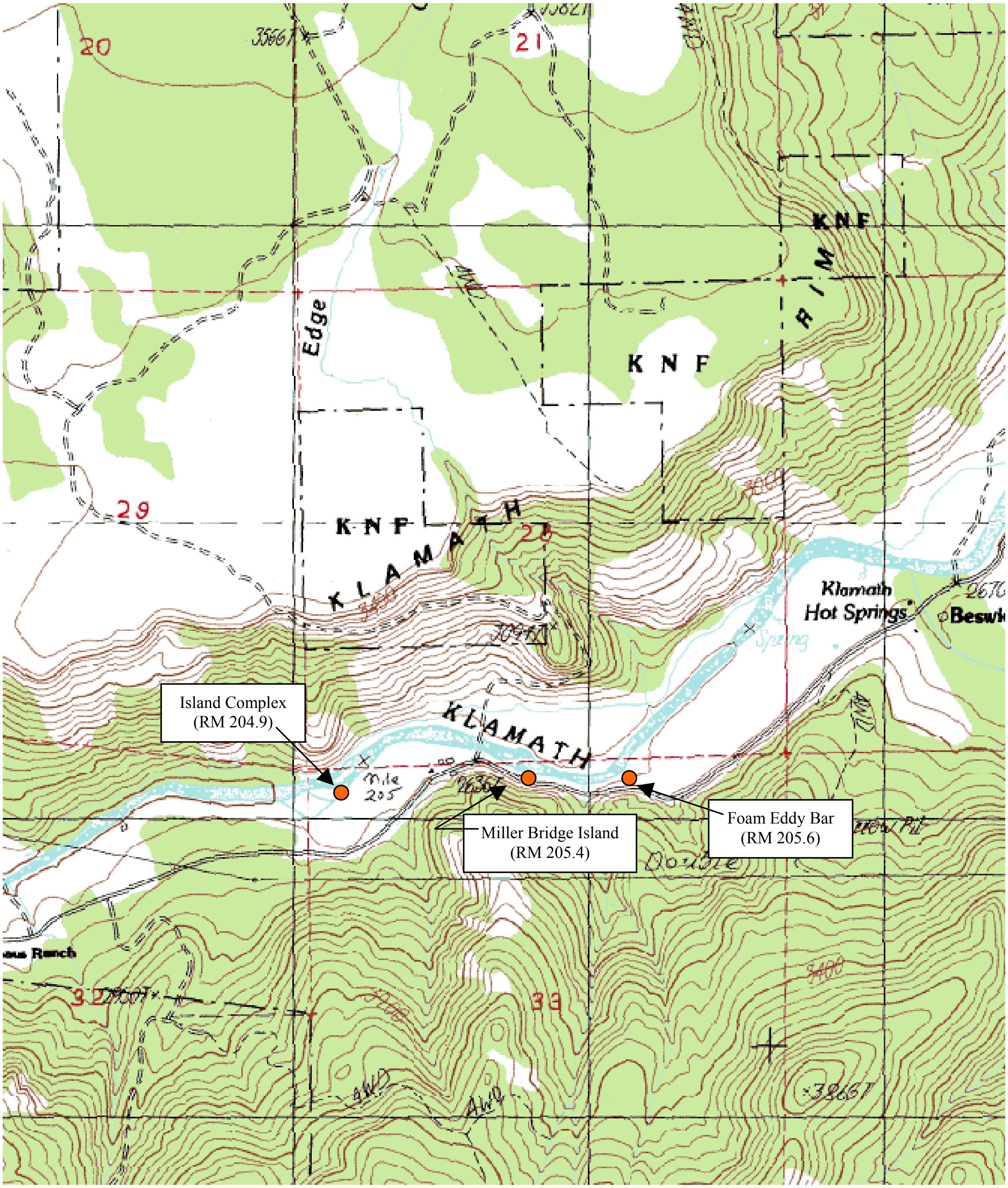

Figure 6.7-16. Stranding observation sites, downstream of Shovel Creek.

The two Oregon sites include the large cobble/gravel bar immediately upstream of Caldera Rapid (RM 214.3) and a point bar/side channel complex (RM 214.7). The sites in California include a side channel/island complex at RM 204.9, an island at RM 205.3, and a side bar/alcove at RM 205.6. Descriptions of each site are provided in Table 6.7-5 and include: (1) surface area, (2) maximum width of exposed bars in varial zone, (3) surveyed beach gradient, and (4) substrate characteristics (size, embeddedness, algae/vegetation). In total, the sites represent 75,500 square feet of area that becomes dewatered during down-ramping.

Observations were made on May 31, July 11, and August 8-9, 2002, and again on June 10-11, July 14, and August 19-20, 2003. These time periods were chosen to coincide with the period of greatest potential fry occurrence, especially trout fry. Ramping on these dates (and throughout these periods) generally consisted of up-ramping in the morning (at the powerhouse) and down-ramping in late afternoon or evening through a flow range from approximately 1,500 (one turbine unit) to 350 cfs. The test conducted June 10-11, 2003, occurred following a down-ramp from 2,800 to 350 cfs (both turbine units). Ramping rates recorded at the USGS gauge just downstream of the powerhouse averaged about 0.7 foot/hour.

The study sites and adjacent areas were inspected for any stranded or trapped fish following completion of down-ramping. Observations were made by two individuals slowly walking back and forth in the dewatered zone from end to end and then back again. Special attention was given to areas containing previously submerged vegetation (aquatic and terrestrial) and any depressions. Occasionally, some organic material and larger rocks were moved to look for any stranded or trapped fry. Approximately 1 to 2 hours were spent making observations at each site.

The results of the fish stranding/entrapment observations made in 2002 are shown in Table 6.7-6. During the three tests conducted in 2002 no fish of any species or size were observed stranded. However, eight to ten live trout fry were observed trapped in a pothole at the Foam Eddy bar (California) on July 11, 2002. The particular pothole was near shore and shaded, and was not at risk of drying up before the next flow cycle. Trout fry were observed swimming along the margins of all California sites in 2002, but not at the Oregon sites. Numerous small dace, often several hundred, were observed swimming along the margins at most sites, but none was seen stranded.

In the three tests conducted in 2003, six fish were observed stranded (Table 6.7-7): four sculpin, one speckled dace, and one unidentified sucker. Five of the six fish were observed at the Frain Ranch sites in Oregon. None of the fish was of a fry size for its species. The sculpins ranged from 75 to 85 mm; the dace was 110 mm; and the sucker was 135 mm.

Table 6.7-5. Peaking reach fish stranding observation sites.

Site Name	River Mile	Exposure Area (ft^2)*	Maximum Width of Exposed Bar (ft)*>	Beach Gradient (%)	Substrate	Notes
Island Complex	204.9 (CA)					
Side Channel		14,000	80	0.8 - 1.1	Non-embedded large cobble	Interstitial flow emerges half way down side channel at 350 cfs
Side Bar		4,800	40	1.8 - 2.0	Embedded medium cobble & algae	Includes long shallow depression near bank
Miller Bridge Island	205.4 (CA)	9,400	100 (includes grass)	1.9	Non-embedded large cobble & inundated grass	Includes side bar with considerable canary grass, top of island, side channel, and alcove
Foam Eddy Bar	205.6 (CA)	13,200	110	0.1 - 3.6	1/2 non-embedded & 1/2 embedded large cobble	Bar contains longitudinal depression near bank. Flow receedance angle varies
Caldera Bar	214.5 (OR)	22,800	130	1.2	1/2 embedded & 1/2 non-embedded mixed cobble	Considerable algae and interspersed grass on bar. Numerous depressions
Point Bar	214.7 (OR)		105			
Bar		4,400		1.1	Non-embedded large cobble	Flow receedance angle varies
Grass Island		3,100			Silt-grass	Several open areas on island
Side Channel		3,800			Embedded mixed cobble	Upper portion of side channel low gradient

*Exposure between toe-of-bank and water edge at 350 cfs.

Table 6.7-6. Peaking reach fish stranding and entrapment observations, 2002.

Site	May 31, 2002					July 11, 2002					August 8-9, 2002				
	ΔFlow	Day/ Nght	No. Strand.	No. Trap.	Notes	ΔFlow	Day/ Nght	No. Strand.	No. Trap.	Notes	ΔFlow	Day/ Nght	No. Strand.	No. Trap.	Notes
Island Complex	1,500 - 350	N	0	0		1,500 - 350	N	0	0	Numerous dace along margins	1,500 - 350	D → N	0	0	100s of 1 to 1.5-in dace along margins Several trout fry along margin
Miller Bridge	1,500 - 350	N	0	0		1,500 - 350	N	0	0	Several trout fry in side channel Numerous dace at S.C. mouth	1,500 - 350	D → N	0	0	Several trout fry in side channel
Foam Eddy	1,500 - 350	N	0	0		1,500 - 350	N	0	8-10 trout fry	Trapped fry in 10' x 3' pothole Several trout fry observed along river margin	1,500 - 350	D → N	0	0	
Caldera	1,500 - 350	N	0	0		1,500 - 350	D	0	0	100s of dace along river margin	1,500 - 350	D	0	0	
Point BAR	1,500 - 350	N	0	0		1,500 - 350	D	0	0	Numerous dace in river above S.C.	1,500 - 350	D	0	0	

Table 6.7-7. Peaking reach fish stranding and entrapment observations, 2003.

Site	**June 10-11, 2003**					**July 14, 2003**					**August 19-20, 2003**				
	ΔFlow	**Day/ Nght**	**No. Strand.**	**No. Trap.**	**Notes**	**ΔFlow**	**Day/ Nght**	**No. Strand.**	**No. Trap.**	**Notes**	**ΔFlow**	**Day/ Nght**	**No. Strand.**	**No. Trap.**	**Notes**
Island Complex	2,800 - 350	N	0	0	3 trout fry observed in river above side channel	1,500 - 350	N	0	0	100s of 1" dace along margins Sculpin darting among rooks	1,700 - 350	N	0	0	Dark. Flashlights used.
Miller Bridge	2,800 - 350	N	0	0	Numerous dace	1,500 - 350	N	0	0	No trout fry observed in s.c.	1,700 – 350	N	1 sculpin (80 mm)	0	Dark
Foam Eddy	2,800 - 350	N	0	0	1 trout fry observed in river margin	1,500 - 350	N	0	0	No trout fry observed along margin	1,700 - 350	N	0	0	Dark
Caldera	2,800 - 350	N	1 dace (110 mm)	0	Stranded dace ~50 ft from bank	1,500 - 350	D	0	0	100's of dace along margin before and as dropping 5 garter snakes on bar	1,700 - 350	N	1 sucker sp. (135 mm)	0	Dark
Point BAR	2,800 - 350	N	2 sculpin (75 mm each)	0	Both stranded sculpin near grass edge on sand/silt substrate	1,500 - 350	D	0	0	3 garter snakes on bar	1,700 - 350	N	1 sculpin (85 mm)	0	Dark. 2 garter snakes on bar

The susceptibility of fish to stranding is dependent on numerous variables that cannot be evaluated independently in actual in-river down-ramping tests. The numbers of small fish along the stream margins at the start of down-ramping certainly would influence the numbers of fish potentially stranded. Also, the ability to observe small fish that may have become stranded on cobble bars is limited. Therefore, results of the fish stranding observations are not quantitative in terms of estimating the numbers of fry that were stranded during down-ramping. However, the results give an indication as to whether fry stranding is potentially a significant source of mortality in the peaking reach of the Klamath River. This was the rationale for selecting observation sites that were considered “worst case” in terms of their physical characteristics associated with fry stranding potential.

Results of the stranding observation tests, while demonstrating some limited stranding of non-trout species, provided no indication that trout fry were being stranded by the current down-ramping in the peaking reach. The failure to observe any stranded trout fry could be influenced by low numbers of fry present at the study sites. Results of trout fry distribution studies conducted in the summer 2003 (see Section 3.5) found trout fry at sites just downstream of the J.C. Boyle powerhouse, but none near Frain Ranch where the two Oregon stranding observation sites were located. However, trout fry were observed during the fry distribution study downstream of the mouth of Shovel Creek (a known spawning tributary) where all of the California stranding test sites were located. Also, trout fry were observed at base flow along the margins of all three stranding test sites in California following the down-ramp tests. Thus, while trout fry generally may not be abundant in the peaking reach, the stranding observation sites in California corresponded to where most fry seem to be distributed in the reach.

Another factor that may have influenced the results of the fish stranding observations is the attenuation of the down-ramping rate, measured by stage change per hour, as the water travels downstream of the powerhouse. The down-ramp attenuation (and lag time) was evaluated at lower Frain Ranch (5.4 miles below the powerhouse) and at the mouth of Shovel Creek (13.4 miles below the powerhouse). At Frain Ranch, the powerhouse down-ramp rate of approximately 9 inches/hour became attenuated to about 5 inches/hour (Figure 6.7-17). This equates to a 44 percent reduction. At the Shovel Creek site, a powerhouse down-ramp rate of about 8 inches/hour was attenuated to about 3 inches/hour (Figure 6.7-18). This equates to a 62 percent reduction. At both sites, the rate of attenuation was accompanied by a corresponding increase in the duration of the down-ramp event. For example, the 3-hour-duration down-ramp event at the powerhouse lasted 6 hours at the mouth of Shovel Creek (see Figure 6.7-18).

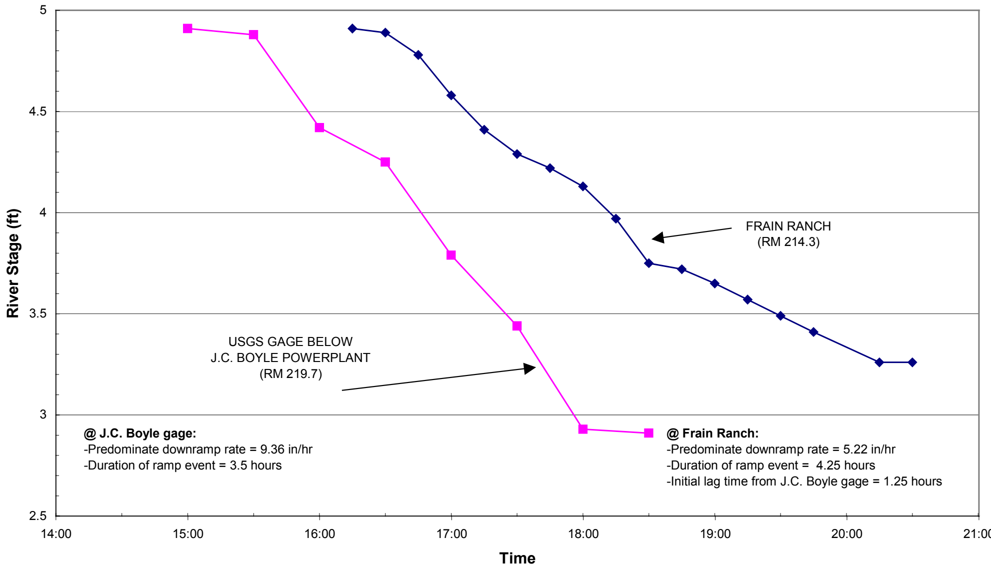

Figure 6.7-17. Klamath River stage reduction comparison between J.C. Boyle gauge and surveyed data at lower Frain Ranch—July 14, 2003. (Distance = 5.4 miles. Flow reduced from 1,800 cfs to 345 cfs.)

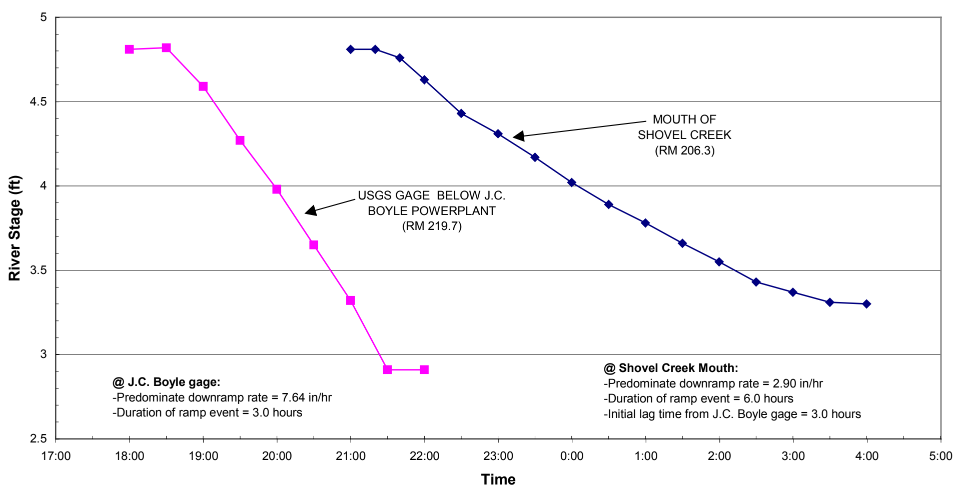

Figure 6.7-18. Klamath River stage reduction comparison between J.C. Boyle gauge and surveyed data at mouth of Shovel Creek—August 20, 2003. (Distance = 13.4 miles. Flow reduced from 1,710 cfs to 350 cfs.)

6.7.4 Fish Community Comparisons (Keno, J.C. Boyle Bypass, J.C. Boyle Peaking Reach)

Comparisons of the fisheries data for the Keno and peaking reaches were made in an effort to explore potential effects of peaking operations at J.C. Boyle. The peaking reach experiences much more frequent and extensive flow fluctuations compared to the Keno reach (above J.C. Boyle). Water quality also differs between these two reaches primarily because of peaking. While the daily average water temperatures and water clarity are similar in the Keno and peaking reaches, the peaking reach experiences much greater diurnal fluctuations for these water quality parameters. During the off-peak hours without power generation, the flow in the peaking reach consists mostly of spring water (from bypass reach) and thus is relatively cool and clear compared to the Keno reach. During the summer, these off-peak, low flows periods typically occur at night and in the morning daylight hours.

Rapidly varying flows as a result of peaking operations have the potential to affect fish resources both directly and indirectly. Potential direct impacts include stranding of small fish during down-ramping, disruption of spawning, and dewatering of incubating eggs. Potential indirect effects include changes in fish growth and condition as a result of changes in the composition and abundance of benthic macroinvertebrates, which provide the primary food source for fish in streams. If these effects are individually or cumulatively significant, one would expect to see differences in the overall fish communities and various metrics describing those communities between the non-peaking Keno reach and the peaking reach downstream of the J.C. Boyle powerhouse.

Information compared for the two reaches includes (1) relative catch rates of all species sampled with backpack electofishing, (2) trout size distribution from angling, (3) trout age differences, (4) trout condition factor, (5) trout length-at-age, (6) trout growth, (7) and trout stomach contents.

6.7.4.1 Relative Catch Rates—All Species

Electrofishing catch rates were used to compare fish communities in the Keno and peaking reaches. Based on the combined catches in all segments and seasons for each reach, relative catch rates indicate that fathead minnows and chubs (blue and tui) are more abundant in the Keno reach (Table 6.7-8). However, most of these species in the Keno reach were collected from a single location just downstream of Keno dam. The location consisted of quiet water pockets among large boulders interspersed with reed canary grass. It is likely that the calm water at this location was attractive to the large number of chubs and fathead minnows that move downstream out of Keno reservoir. These species prefer slack-water habitat, especially lakes and reservoirs. This location also contained many marbled sculpin.

Table 6.7-8. Keno and peaking reaches, fish catch per-hour by back-pack electrofishing for all seasons and segments combined.

Common Name	Keno Reach	Peaking Reach
Redband trout	46.2	19.1
Blue chub	85.0	4.4
Tui chub	64.0	5.2
Speckled dace	190.6	286.3
Sculpin (marbled)	226.2	106.0
Lamprey	0.4	0
Lost River sucker	0.4	0
Unknown sucker spp.	0	30.2
Bluegill	0.4	0
Pumpkinseed	0.4	0
Fathead minnow	107.4	0
Unknown species*	42.0	0

* Most likely fathead minnows and/or chubs.

To factor out the influence of this single location, catch rates in the lower half of the Keno reach were compared to those in the peaking reach. This comparison indicates that the difference in fish communities is not very apparent, especially for the native riverine species, speckled dace and marbled sculpin (Table 6.7-9). These two species were the most commonly observed in both reaches. Although much less abundant than in the upper Keno reach, the lower Keno reach still had a greater relative catch rate of fathead minnow and chubs compared to the peaking reach. These species are prolific in the upstream Upper Klamath Lake and Keno reservoir, located upstream of the Keno reach. Annual entrainment of these species at the East Side and West Side power canals was estimated to be more than 300,000 (New Earth/Cell Tech and PacifiCorp, 1999). It is unknown whether the greater relative abundance of fathead minnows and chubs in the Keno reach is the result of their recruitment from the upstream reservoir or whether flow fluctuations in the peaking reach create unfavorable conditions for them to reside there. However, the fact that few chubs and fathead minnows were observed in the non-peaking bypass reach below J.C. Boyle dam suggests that recruitment from upstream rather than flow fluctuations account for the difference. The peaking reach had a greater relative catch rate of suckers, which are native to the system, compared to the Keno reach.

Table 6.7-9. Keno reach segments and peaking reach, fish catch per-hour by back-pack electrofishing.

Common Name	Keno Reach		Peaking Reach
	Upper Segment	Lower Segment	
Redband trout	3.0	69.7	19.1
Blue chub	222.3	10.4	4.4
Tui chub	142.5	21.4	5.2
Speckled dace	165.7	204.1	286.3
Sculpin (Marbled)	469.8	93.8	106.0
Lamprey	0	0.5	0
Lost River sucker	1.0	0	0
Unknown sucker spp.	0	0	30.2
Bluegill	1.0	0	0
Pumpkinseed	0	0.5	0
Fathead minnow	231.4	40.1	0
Unknown species*	99.0	11.0	0

* Most likely fathead minnows and/or chubs.

The electrofishing catch rate of small redband trout in the Keno reach (69.7 fish/hour) was substantially greater than that in the peaking reach (19.1 fish/hour) (see Table 6.7-9). However, most of the trout in the Keno reach were observed in the lowest 0.5 mile just above J.C. Boyle reservoir. The upper Keno segment produced a trout catch rate of 3.0 fish/hour. Recruitment of juvenile trout into the Keno reach is believed to be from Spencer Creek, which is a tributary of J.C. Boyle reservoir (ODFW, 1991). Therefore, the relatively high catch rates in the lowermost Keno reach may be merely indicative of their source from Spencer Creek. Perhaps similarly related to recruitment source, most of the electrofished trout from the peaking reach were collected in the California segment downstream of Shovel Creek, which is known to be the primary spawning location for trout in the lower peaking reach (Beyer, 1984).

Peaking operations at the J.C. Boyle powerhouse occur primarily from late spring through early winter. Therefore, a comparison of catch rate trends through the seasons may indicate cumulative effects of peaking. For the two primary native riverine species, speckled dace and marbled sculpin, catch rates in the Keno reach declined steadily for both species through the May through October sampling season (Table 6.7-10). In the peaking reach, catch rates for these species increased substantially between spring and summer, followed by a moderate decline in the fall. These results do not suggest any cumulative effect associated with peaking for these two most common native species.

Table 6.7-10. Keno and peaking reaches seasonal fish catch per hour by backpack electrofishing.

Common Name	Keno Reach			Peaking Reach		
	Spring	**Summer**	**Fall**	**Spring[1]**	**Summer**	**Fall**
Redband trout	72.0	25.0	42.3	0	63.2	2.9
Blue chub	83.4	0	132.9	10.3	0	0
Tui chub	7.6	41.7	110.7	24.1	0	0
Speckled dace	306.9	211.4	108.3	68.8	497.7	261.4
Sculpin (marbled)	552.0	166.9	60.7	31.0	144.8	116.2
Lamprey	1.3	0	0	0	0	0
Lost River sucker	1.3	0	0	0	0	0
Unknown sucker spp.	0	0	0	0	0	59.5
Bluegill	1.3	0	0	0	0	0
Pumpkinseed	0	0	0.8	0	0	0
Fathead minnow	21.5	65.4	182.9	0	0	0
Unknown species[2]	0	162.7	0.8	0	0	0

1 California segment of peaking reach not sampled.
2 Most likely fathead minnows and/or chubs.

The typical daily peaking operation involving one turbine unit at the J.C. Boyle powerhouse produces a streambed varial zone of about 30 feet and a river stage drop of about 20 inches during a period of 3 to 6 hours (depending on location from powerhouse). It would seem likely that small fish species preferring to reside and feed in shallow nearshore areas would be adversely affected by these frequent flow fluctuations. This might be especially true for speckled dace, which prefer shallow areas close to the shoreline, and sculpin and suckers, which have strong fidelity to the bottom substrate. However, the electrofishing catch rate data do not indicate any major differences in fish communities between the non-peaking Keno reach and the J.C. Boyle peaking reach that cannot be attributed to other factors (chub and minnow recruitment from Keno reservoir, and trout fry recruitment from tributaries).

6.7.4.2 Trout Comparison

Size

The ODFW conducted angler surveys in of the Klamath River (to the Oregon-California border) from 1979 through 1982. This period followed a change in trout management that included a cessation of planting of hatchery-reared trout. Therefore, all fish were assumed to be naturally produced. Trout captured in the Keno reach were considerably larger than those captured in the peaking reach (Figure 6.7-19). More than half of the Keno reach trout exceeded 300 mm, whereas about 24 percent of the peaking reach trout were larger than 300 mm.

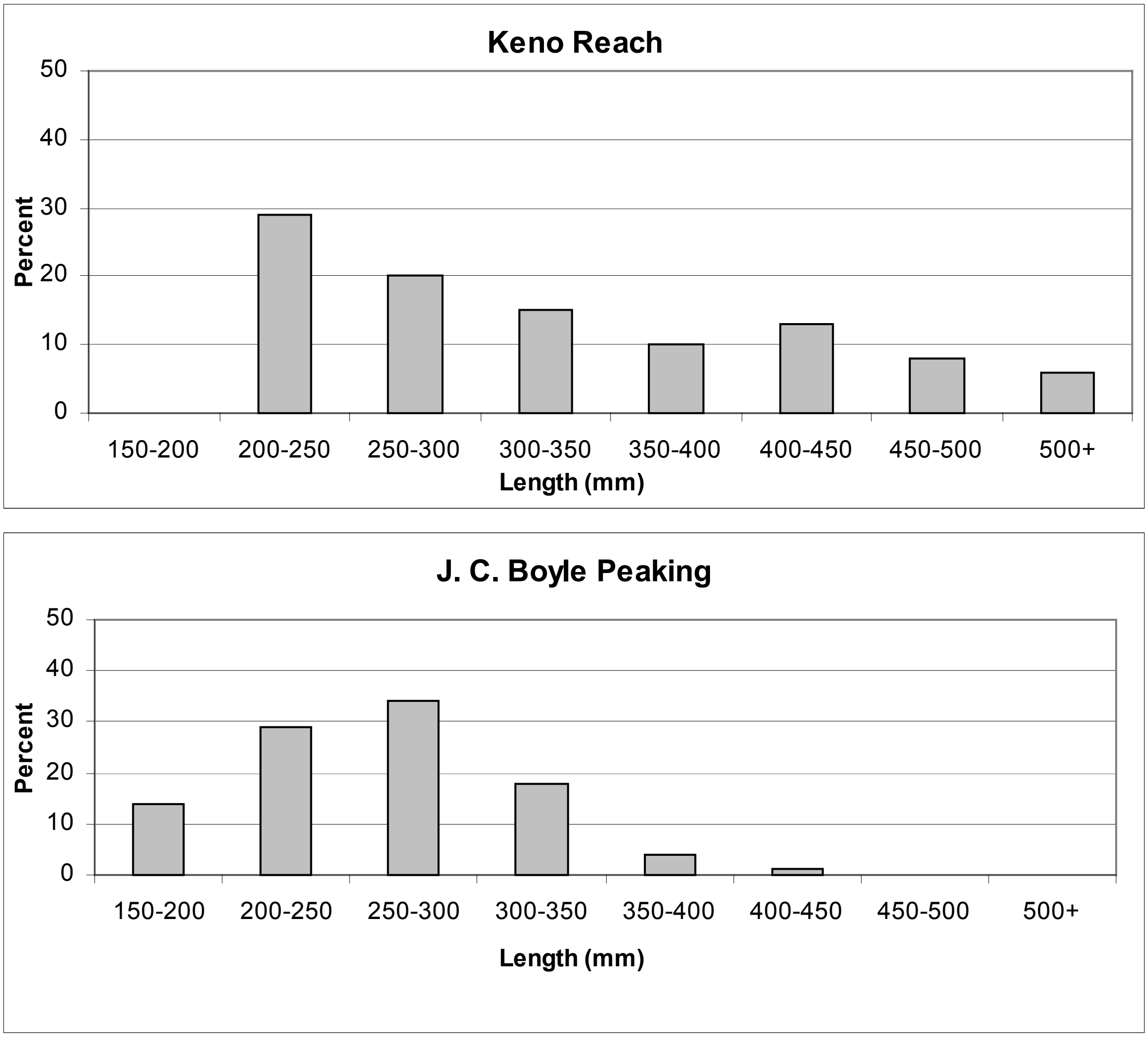

Figure 6.7-19. Redband trout length frequency from 1979–1982 ODFW angler surveys.

Results of sampling conducted by angling in 2002 indicate the same general differences in trout length in the two reaches as was seen in the 1979-1982 data (Figure 6.7-20). Average lengths were 271 and 251 mm for the Keno and J.C. Boyle peaking reaches, respectively. Trout in the Keno reach exhibited a much larger range in size primarily because there was a greater number of larger fish in the population. In the Keno reach, 28 percent of the trout were more than 300 mm compared to 16 percent in the peaking reach.

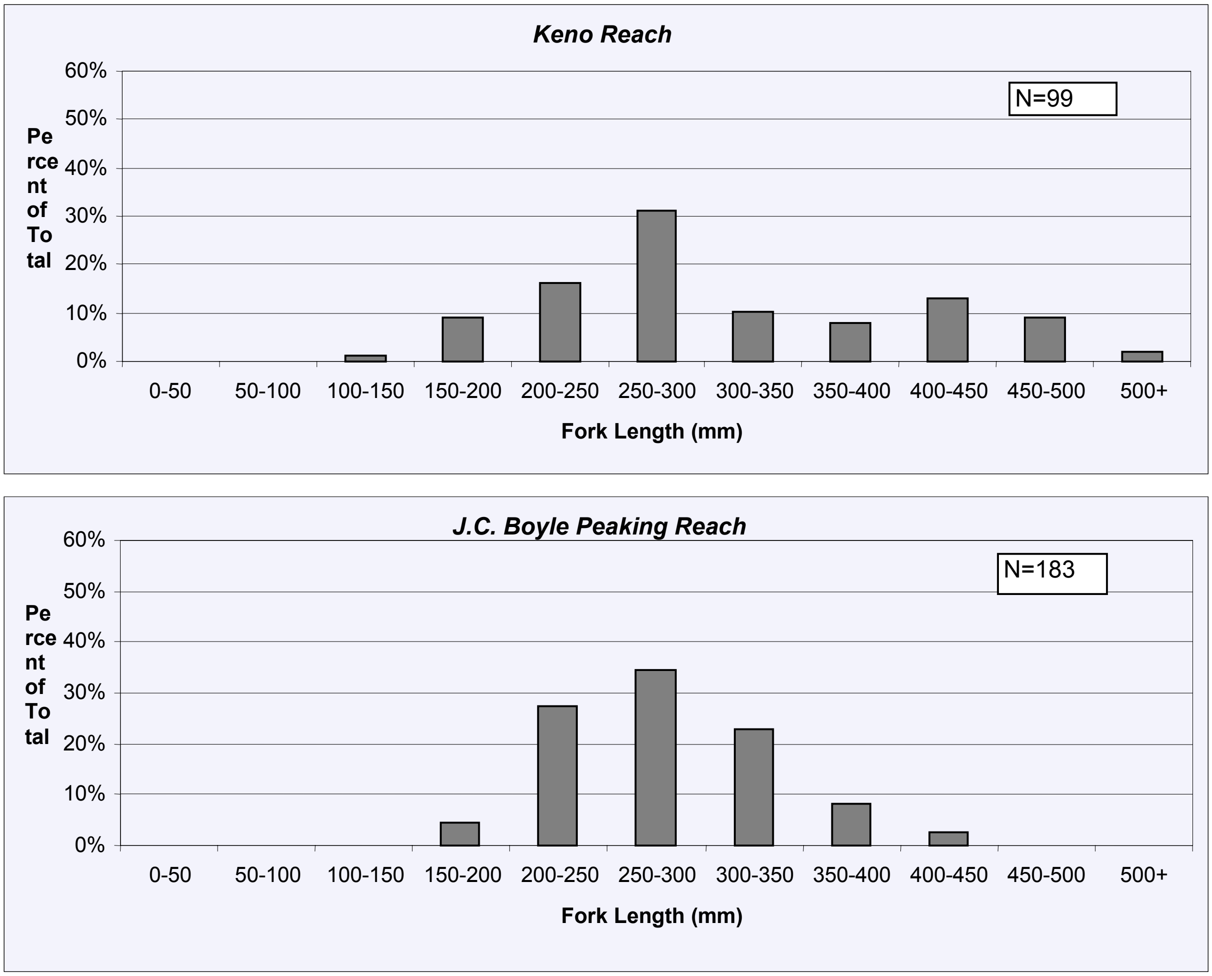

Figure 6.7-20. Length frequency of trout: all seasons (2002) angling.

Both the ODFW data and the 2002 sampling data for the Keno reach indicate a possible secondary peak in size at about 400 mm. This pattern suggests that some environmental condition associated with trout in the Keno reach may favor greater growth as the fish become larger. This pattern was not observed in the peaking reach. Another factor to consider is the fishing regulations. Unlike the J.C. Boyle bypass and peaking reaches, the Keno reach is closed to angling in the summer and the reduced fishing pressure may contribute to older, larger trout found in this reach.

Catch Rates

Angler surveys conducted by the ODFW between 1979 and 1984 show that catch rates (fish per hour) in the Keno reach were consistently lower than in the peaking reach (Table 6.7-11). Average catch rates for these 6 years were 0.23 and 0.78 fish per hour for the Keno and peaking reaches, respectively. While differences in population abundance (available fish) may have contributed to these catch rate differences, water clarity and stream flow conditions also affect fishability/catchability in these reaches. Water in the Keno reach is typically quite turbid, and flows are often higher than those in the peaking reach. In the peaking reach, most angling occurs during the off-peak generation hours when flows are low and water clarity is high, which is conducive to high catchability of trout.

Table 6.7-11. Redband trout catch per hour, ODFW angler survey data 1978–84.

	Reach	
Year	**Keno Reach**	**J.C. Boyle Peaking Reach**
1979	0.33	0.74
1980	0.27	0.71
1981	0.09	1.31
1982	0.13	0.56
1983	0.08	0.56
1984	0.49	0.77
Average	0.23	0.78

Sampling conducted in 2002 by angling indicated the same general differences in trout catch rates between the two reaches as previously seen in the ODFW sport angler data. Catch rates were lower in the Keno reach compared to the peaking reach (Table 6.7-12). Seasonal sampling indicated greatest catch rates in the fall for both reaches. Catch rates in the upper and lower segments of the Keno reach were similar, as were catch rates in the Oregon (upper) and California (lower) segments of the peaking reach.

Table 6.7-12. Redband trout catch per hour by angling, 2002.

Keno Reach						
	Total	**Spring**	**Summer**	**Fall**	**Upper**	**Lower**
Catch per hour	0.6	0.6	0.2	1.1	0.5	0.8
J.C. Boyle Peaking Reach						
	Total	**Spring**	**Summer**	**Fall**	**Oregon**	**California**
Catch per hour	1.2	0.9	1.1	2.7	1.1	1.3

Condition Factor

Condition factor (K) is the length-weight relationship used to express relative robustness of fish, and is assumed to be related to environmental conditions. Condition factors for rainbow trout greater than 1.0 are generally indicative of healthy fish (Carlander, 1969). Seasonal differences in condition factors often occur because of slow growth periods (e.g., winter) and spawning activity (e.g., post-spawn weight loss). Therefore, condition factors for trout captured in the Klamath River were computed by season and the total average represents the simple (unweighted) average of the three seasonal values.

Condition factors for trout in both reaches and seasons exceeded 1.0, indicating healthy fish (Table 6.7-13). Average condition factors for the Keno and peaking reaches were 1.18 and 1.20, respectively. No clear pattern of differences in condition factor was apparent by season.

Table 6.7-13. Condition factors (K) of redband trout caught in 2002.*

Season	Reach	
	Keno	**Peaking**
Spring	1.16	1.19
Summer	1.13	1.18
Fall	1.24	1.15
Average	**1.18**	**1.20**

* Only fish larger than 50 mm.

Age Structure

The length frequency data for trout indicate clear difference in size between the two river reaches. Specifically, the Keno reach contains a greater proportion of larger fish than the peaking reach. Differences in size can be attributable to differences in growth (see below) or age composition or a combination of both. To assess both of these factors, scales from 157 trout (approximately equal numbers per reach) were viewed under a microscope to determine age (and back calculated length-at-age). Because the scales were collected from trout captured primarily by angling, the younger (smaller) fish in the population were not represented in the sample. Also, age determination of older fish is difficult using scale reading, and the confidence in aging fish older than 5 years is poor. Therefore, trout age data are presented only for ages 1 through 5. While these data may not accurately represent the complete age structure of each population, they should reasonably represent the relative differences between the two river reaches for ages 1 through 5.

As shown in Figure 6.7-21, trout tend to be older in the Keno reach compared to those in the peaking reach. The percentage of trout 3 years and older was 52 percent in the Keno reach and 34 percent in the peaking reach. These results indicate that differences in trout age structure between the two reaches probably contribute to the observed differences in size composition.

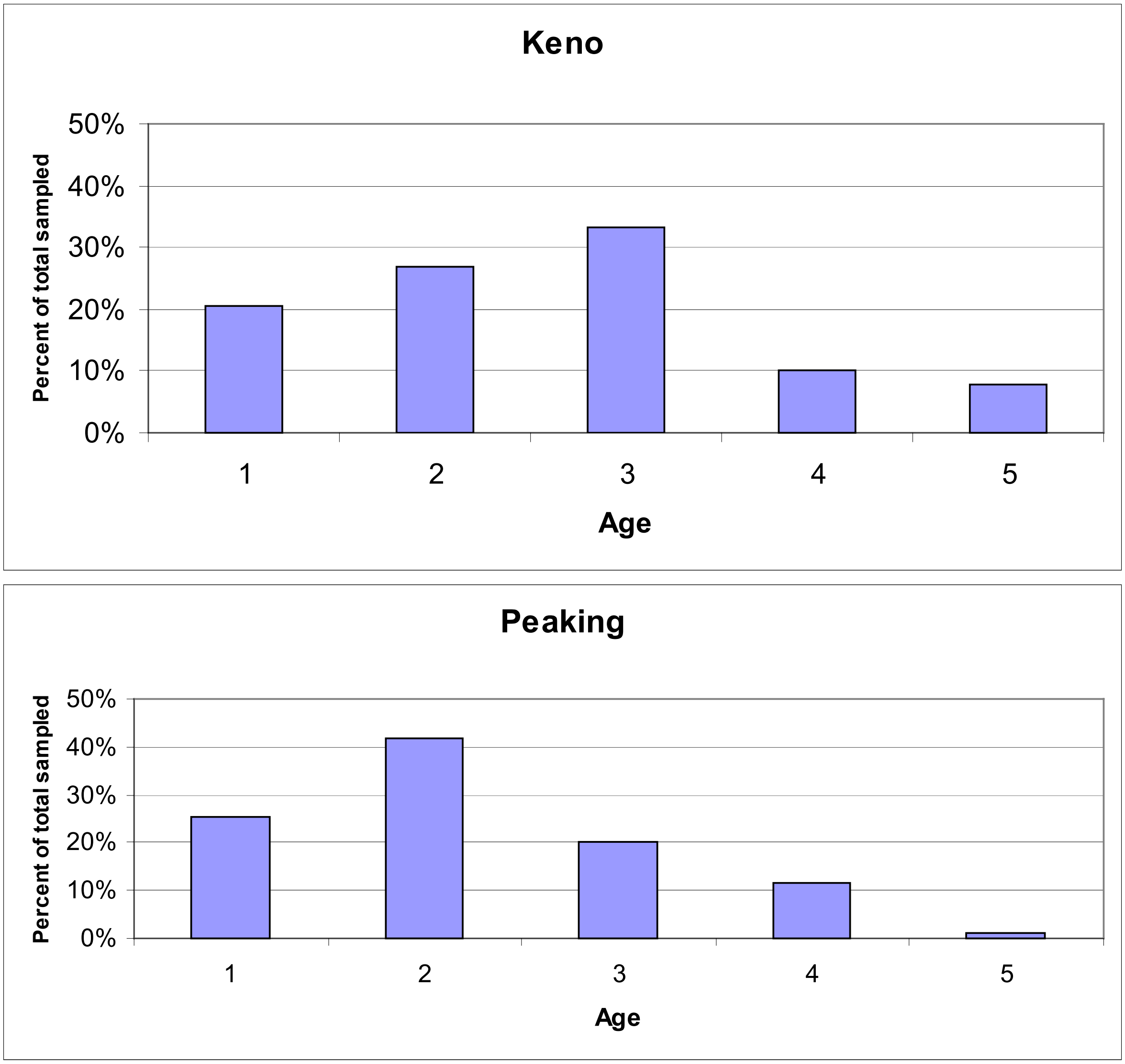

Figure 6.7-21. Age distribution of redband trout by reach.

The higher proportion of older fish in the Keno reach is consistent with the typical population response to a lower harvest rate (Anderson and Nehring, 1984). Logically a relatively lower harvest rate allows more of the fish to survive to an older age. Angler catch rates in the Keno reach are about one-third of those in the peaking reach based on ODFW angler surveys (see above).

Trout Length-at-Age and Growth

A total of 157 trout scales, with approximately equal numbers representing each of the two river reaches, was examined for determination of age and back-calculation of fish length to each annulus. A least-squares linear regression model was generated on the basis of the relationship between FL and scale radius. This model (formula) was used to estimate length at previous ages. Specific methods and initial results of the back-calculations are presented in a technical memorandum in Appendix 3-D.

The average back-calculated length-at-age (to last annulus) for trout from the Keno and peaking reaches is shown in Figure 6.7-22. Trout at age 1 and age 2 from the Keno reach were smaller on average than those of the same age from the peaking reach. At age 3, however, Keno reach trout were of similar size to those in the peaking reach, and by age 4, Keno reach trout were larger than peaking reach fish. A statistical evaluation of these length-at-age patterns was conducted using a generalized linear model that looked at length as a function of age, reach location, and the differences in the age function in different reaches. The linear function of length-at age was significantly different (p less than 0.001) between the two reaches (see Appendix 3-D).

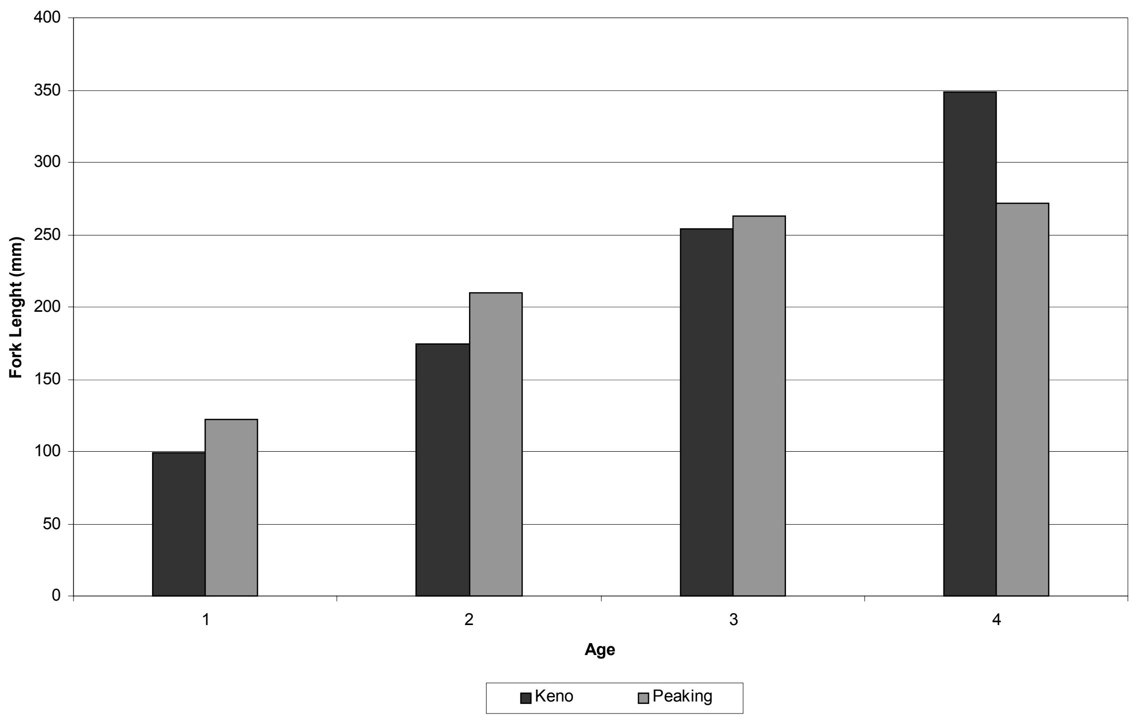

Figure 6.7-22. Average back-calculated length-at-age for redband trout.

Average annual growth rates of trout were determined by comparing the estimated length at last annulus to the previous-to-last annulus for each individual fish and then averaging the length differences. Results of the growth analysis (Figure 6.7-23) are consistent with the length-at-age analysis. Growth is greater in the peaking reach compared to the Keno reach for trout through age 2, but similar for the age increment between 2 and 3. After age 3, growth rates are greater for Keno reach fish compared to peaking reach fish.

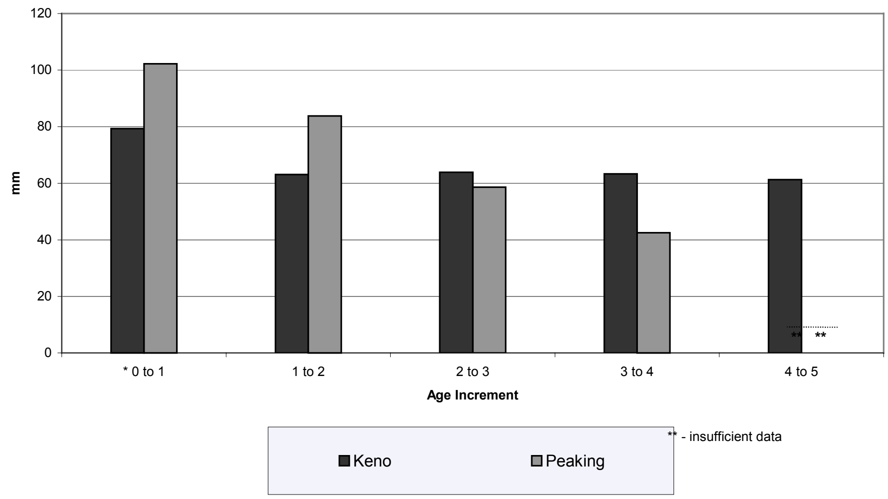

Figure 6.7-23. Average growth (mm/yr) of redband trout caught in Klamath River: Keno and peaking reaches.

Typically, growth rates of trout tend to decline with age (Carlander, 1969). This is the pattern observed for trout in the peaking reach. Keno reach trout, however, show an unusual pattern of relatively constant growth (length gain per year) between age 1 and 5. The relatively higher growth rates for Keno reach trout after age 3 could be indicative of a shift in diet to larger prey organisms, such as fish, or a shift in location to a more energetically favorable habitat, such as a lake. A limited stomach content analysis conducted in 2002 indicated that trout from the Keno reach as well as those from the peaking reach were eating predominately insects (Table 6.7-14). The analysis did not include a taxonomic or size determination of the ingested insects. Because the fish from which stomachs were obtained were captured in the river, the analysis would not have detected whether some of the fish had previously reared in J.C. Boyle or Keno reservoirs.

Table 6.7-14. Stomach contents of redband trout collected by angling, 2002.

Parameter	Keno Reach	J.C. Boyle Peaking Reach
N	23	31
Percent of fish stomachs containing:		
Fish	4 (1)[1]	3 (1)[2]
Invertebrates	96	100
Other	43	19
Percent of contents by weight		
Fish	3	2
Invertebrates	79	86
Other	18	13

[1] The Keno reach trout containing fish was 413 mm, caught in spring.

[2] The peaking reach trout containing fish was 236 mm, caught in summer.

A review of the growth rates for individual fish from age 2 to 3 indicate considerably more variability among fish in the Keno reach compared to the peaking reach (Figure 6.7-24). The relatively rapid growth (more than 100 mm/year) of some of the Keno reach fish may be indicative of their part-time residence in Keno or J.C. Boyle reservoirs. Although downstream movement of trout has not been studied at Keno dam, large trout are commonly observed in the power canals of the East Side and West Side Developments, indicating downstream movement out of Upper Klamath Lake. Because Keno reservoir often experiences episodes of poor water quality (high temperature and low dissolved oxygen) it is reasonable to assume that some trout also would emigrate from Keno reservoir during these periods. Regarding the possibility of trout rearing in J.C. Boyle reservoir, Keno reach trout are known to spawn almost exclusively in Spencer Creek, which is a tributary to J.C. Boyle reservoir (ODFW, 1991). Therefore, mature trout from the Keno reach must pass through the reservoir on their way to and from Spencer Creek. It is unknown if or how much time they spend rearing in the reservoir.

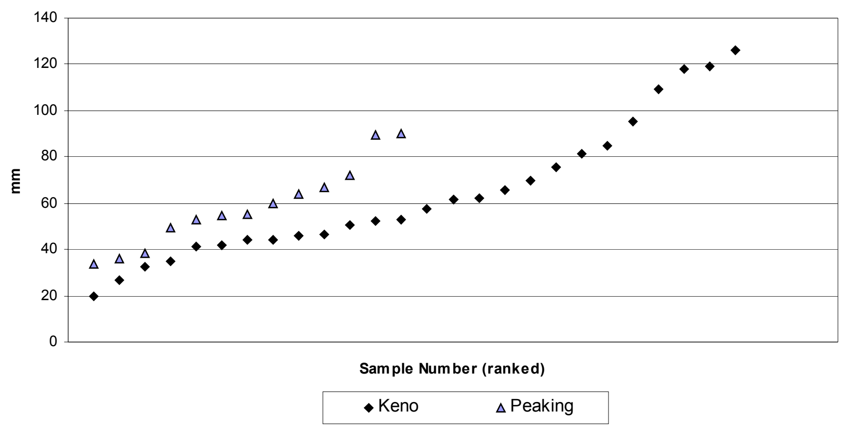

Figure 6.7-24. Growth (mm/yr), between years 2 and 3, of individual trout caught in the Keno and peaking reaches.