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Instream Flows and Coho Salmon Habitat in the Lower Klamath River

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Introduction

The Klamath River Basin, from its headwaters in south central Oregon to its estuary by Requa, California, covers an area of approximately 9,691 square miles. For practical purposes, the Klamath Basin can be described as consisting of an upper and a lower section separated by a river reach with a series of four hydroelectric dams (Figure 1). The Upper Klamath Basin, upstream from Keno Dam, includes the sub-basins of the Williamson, Wood, Sprague, and Lost rivers; the Upper Klamath Lake, Tule Lake, Clear Lake, and Gerber Reservoir. The Lower Klamath Basin, downstream from Iron Gate Dam, comprises the tributary sub-basins of the Shasta, Scott, Salmon, and Trinity rivers, in addition to the lower sections of the Klamath River. This report, which assesses the possible effects of 2001 IGD water releases on coho salmon availability, focuses primarily on the Lower Klamath Basin because the distribution of anadromous salmonids (those that spawn and rear in freshwater, but complete their growth and maturation at sea) in this basin is restricted to the lower section by hydroelectric dams.

A review of the geology and hydrology of the Klamath River Basin suggests that during dry periods and before dam constructions, the upper basin was the principal source of water for the Lower Klamath River in late summer and early fall (Hecht and Kamman 1996). The upper and lower parts of the basin have different geomorphologies. The Upper Klamath Basin is characterized by volcanic basalts with numerous fractures and cavities that give the area a high water storage capacity; whereas the Lower Klamath Basin is rich in alluvial fans and lake clay sediments and has only a minor component of thin volcanic basalts. Snowmelts recharge the groundwater reservoirs of the upper basin on an annual cycle. Historically, these aquifers, in combination with Upper Klamath Lake, Lower Klamath Lake, and a vast network of wetlands, may have maintained relatively high and constant flows in the Lower Klamath River during late summer and early fall months (Boyle 1976; Hecht and Kamman 1996).

Many studies indicate that salmonid resources in the Klamath Basin have been negatively affected by the cumulative impacts of more than a century of different human activities. The most severe and irreversible impacts, however, seem to be those associated with the development of irrigation and hydroelectric projects that have eliminated access to hundreds of miles of fish habitat and have changed the annual hydrograph (i.e., graphical representation of water discharge over time) as well as the summer temperature regime of the Lower Klamath River (KRBFTF 1991; Trihey and Associates 1996; USFWS 1997; INSE 1999).

The following species of anadromous fish are found in the Klamath Basin: coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*), steelhead trout (*O. mykiss*), coastal cutthroat trout (*O. clarkii*), green sturgeon (*Acipenser medirostris*), eulachon (*Thaleichthys pacificus*), and Pacific lamprey (*Lampetra tridentata*). Historically, chinook salmon (of both fall and spring types), coho salmon, and steelhead trout entered Klamath Lake. From Upper Klamath Lake, it is likely that spring chinook salmon and steelhead trout moved farther upstream into the uppermost tributaries of the basin (KRBFTF 1991; Deas and Orlob 1999).

Although all species of anadromous fish in the Klamath River are in serious decline, two salmonid species in particular—coho salmon and steelhead trout—have undergone status review by the National Marine Fisheries Service (NMFS) under the Endangered Species Act (ESA). As a result, coho salmon have been listed as threatened. The listing of this species, as well as that of the Lost River sucker and shortnose sucker in the upper part of the basin, has prompted the implementation of unprecedented water management actions by the Bureau of Reclamation (BOR) between April 1 and September 30, 2001. In the case of coho salmon, a formal ESA Section 7 consultation process was initiated on January 22, 2001, between the BOR and the NMFS. As a result, the NMFS issued a Biological Opinion (BO) that found "jeopardy and adverse modifications" of critical salmon habitat in the Lower Klamath River and provided a "Reasonable and Prudent Alternative" (RPA) that established an interim spring-fall IGD water-release schedule aimed at preventing further decline of the listed fish and adverse modifications to its habitat.

This chapter provides a general review of key aspects of coho salmon habitat, introduces the reader to different human impacts that affect salmonids and their habitat in the Klamath Basin, describes the status of salmonid stocks in the Pacific Northwest and in the Klamath Basin in particular, and explains the relationship between instream flows and fish habitat availability. Finally, the chapter reviews the most salient aspects of the RPA and elaborates on the potential effects of this year's water releases on coho salmon habitat in the Lower Klamath Basin.

Status of wild salmonids in the Pacific Northwest

The different species of salmonids comprise local populations, referred to as stocks, which are adapted to the specific environmental conditions of their watersheds of origin (Ricker 1972). In the particular case of anadromous populations, their tendency to spawn in their natal streams maintains a high level of reproductive isolation between them. This type of isolation allows for the development of watershed-specific adaptations (e.g., thermal tolerance and migration timing) at the population level and increases the genetic variability of the species (Thorpe et al. 1981). A high level of genetic variation among the populations of a species provides the basis for future evolution, and an "insurance" of adaptation to environmental change (White and Nekola 1992).

Many wild populations of anadromous salmonids (*Oncorhynchus* spp.) in western North America are currently at risk of becoming extinct, while others have declined from 50 percent to 85 percent of their average historic abundance (Nehlsen et al. 1991; Northcote and Burwash 1991; Slaney et al. 1996). A review by Weitkamp et al. (1995) of coho salmon status in California, Oregon, and Washington identified six different population groups (i.e., Evolutionary Significant Units—ESUs) and indicated that wild populations in all ESUs are significantly below historical levels. In southern Oregon, Nehlsen et al. (1991) considered all but one coho salmon population to be at "high risk of extinction." In northern California, coho salmon populations, including hatchery fish, could be at 6 percent of the abundance they had during the 1940s. They have been eliminated in many streams, and in some watersheds, adults are observed only one year in three (CDFG 1994). In other words, two of the three spawner lines have been lost.

It is obvious that the anadromous salmonid populations of the Klamath Basin are not the only ones in the Pacific Northwest that face a bleak future. Such widespread declines cannot be attributed to one single land development project, nor even to one natural factor. However, it is worth noting that although several hypotheses have been advanced to explain these declines (e.g., overfishing, freshwater habitat loss, interactions with hatchery fish, and ocean habitat changes), freshwater habitat loss has been associated with the decline of every one of the 214 salmonid stocks that Nehlsen et al. (1991) identified as either facing high to moderate risk of extinction or being of special concern. These researchers recognized different factors that had a negative impact on wild stocks, but concluded that freshwater habitat degradation and loss were among the leading causes of their decline. Even though there may be some stocks that are primarily affected by a single factor, in light of the available evidence it is reasonable to conclude that a combination of all the above-mentioned factors, with their relative importance varying from year to year, is behind the widespread decline in salmonid abundance.

The abundance and distribution pattern of animals is determined by the availability and spatial distribution of resources (Milinski and Parker 1991). The uneven distribution of resources, in both space and time, creates patches of better or poorer "habitat" among which individual organisms distribute themselves. Habitat can be defined simply as the "place" where an organism lives and the range of environmental conditions (both physical and biological) it requires to live, grow, and reproduce (Odum 1971). The spatial scale of an organism's habitat is not fixed; rather, it is determined by the range of action (home range) of that organism. Thus, the habitat of a large or relatively mobile organism (i.e., birds) is large and contains within its physical boundaries the smaller-scale habitats of smaller, or less mobile, organisms. This kind of organization implies a hierarchy of habitats that are nested in space. A river represents a particularly good system to further illustrate this point. The entire watershed makes up the environment of smaller-scale subsystems, such as stream sections, which in turn constitute the environment of habitat systems at even smaller scales, such as stream reaches. Each stream reach is made up of smaller components, pools, and riffles, and these habitats contain patches or microhabitats of different types (Frissell et al. 1986). Habitat components, at different spatial scales, are all interconnected by the flowing water and receive the cumulative effects of upstream human activities and natural landscape level processes. Such cumulative effects may reduce or eliminate fish habitat in large river channels, small stream reaches, marshes, and even estuaries (Henderson 1991; Turner and Meyer 1993; Williams 1993).

Habitat degradation and loss are side effects of different types of human activities. The initial changes to the aquatic components of a watershed begin with the early alterations that humans introduce to its terrestrial components. Mining and logging have historically preceded a number of other land-use activities in coastal watersheds of the Pacific Northwest. These "extraction operations" indirectly affected stream morphology and hydrology by modifying the soil and its vegetation cover. They also have directly altered stream channels and their substrates through practices such as moving heavy machinery and skidding logs across channels and building—and subsequently blasting—"splash dams" to float and transport the logs downstream. The expansion of agriculture into river valleys and the encroachment of grazing into riparian zones have altered the connectivity of stream channels with their floodplains. In California and Oregon, hydroelectric projects have been particularly common. Dams created impassible barriers to fish migration, and the regulation of flows altered the structure of channels and the hydrology of rivers. More recently, urban sprawl has begun to cover, in an irreversible manner, ever-larger portions of coastal watersheds (Gregory and Bisson 1997).

To understand how land-use activities such as agriculture, dam construction, mining, logging, or urban development may affect fish production, it is necessary to know the habitat requirements of the different species and to identify the general environmental changes brought about by human activities in each watershed. Because juveniles of different salmonid species have specific nursery habitat requirements and different lengths of freshwater residence, they are not equally susceptible to all development activities. As an example, in British Columbia, land uses have harmed some sockeye salmon (*O. nerka*) stocks at two different stages of their life cycle. During the egg incubation phase, they may be negatively affected by the silt deposition and gravel displacement that inadequate mining and timber harvest practices may cause; during the juvenile migration period, they may be prevented from entering lake nursery habitat by newly built dams (Nehlsen et al. 1991). Chum salmon (*O. keta*) have been largely affected by degraded water quality and siltation of spawning bed gravel in many watersheds (Nehlsen et al. 1991). In the case of coho salmon, their relatively long period of residence in freshwater makes this species particularly susceptible to habitat alterations caused by human activities (Hicks et al. 1991; Henderson 1991).

Coho salmon habitat requirements

Coho salmon are anadromous salmonids that typically exhibit a 3-year life cycle almost equally divided between the freshwater and the sea phase (Sandercock 1991). Although in some populations coho salmon fry inhabit lakes, where they are found in the littoral zone (i.e., near the shore) (Mason 1974), the majority prefer small coastal streams and relatively small tributaries of larger systems (such as the Shasta and Salmon rivers within the Klamath Basin). Shortly after emergence from the gravel, juvenile coho salmon establish feeding territories that they will defend from other salmonids. They tend to be more territorial in stream reaches with fast-flowing waters, whereas in slow-flowing areas it is common to find them forming loose aggregates and cruising for food (Mundie 1969).

Individuals that "take residence" normally occupy a small space with slow-moving waters, from which they make short excursions to feed or to chase intruders away. Subordinate fish, which are not able to establish a territory, tend to be less aggressive than dominant individuals and have a reduced growth rate due to their lack of access to good feeding areas (Chapman 1962). In general, the young of this species prefer zones with reduced water velocity, favor pools over other types of habitat, and use instream structures as protection from high water flows. In this manner they may minimize their energy expenditures to maintain position while feeding on drifting prey (Mundie 1969; Everest and Chapman 1972; Fausch 1993). Coho are visual predators and seldom feed from the bottom. They prefer to capture invertebrates that drift either suspended in the water column or on the surface (Nielsen 1992). In addition to providing prey items and shelter from water velocity, instream and riparian cover provides other benefits. Low-hanging overhead cover such as undercut banks and root wads may decrease the amount of light reaching the water surface, thereby making fish less visible to potential predators and minimizing stream temperature extremes (Murphy and Hall 1981). Instream cover also can provide refuge from predators and simultaneously increase visual isolation among competitors. Visual isolation may reduce aggressive interactions among competitors, and therefore could lead to an increase in the number of fish occupying a given area (Dolloff 1986; Fausch 1993).

As is the case for other salmonids, coho salmon prefer cool and well-oxygenated waters. The upper lethal temperature for juvenile coho is 25ºC (Sandercock 1991). Brett (1952) found that exposure to temperatures in excess of 25ºC or a quick rise in temperature from less than 20ºC to 25ºC resulted in a high mortality rate. Brett also observed that coho preferred a temperature range of 12ºC to 14ºC, which is close to the optimum temperature for maximum growth efficiency. In autumn, as water temperatures decline and flows increase, juvenile coho salmon redistribute either into deeper pools, smaller tributaries, or lateral channels where cover provided by fallen logs or root wads is abundant (Bustard and Narver 1975; Cederholm and Scarlett 1982; McMahon and Hartman 1989; Nickelson et al. 1992).

Fish habitat and instream flows

Nothing defines fish habitat better than water. The quality and the quantity of this indispensable fish "habitat component" determines whether fish can actually live in a particular aquatic habitat, what species of fish can use it, and how many individuals can occupy it. Salmonids can live only in water with chemical (i.e., oxygen concentration and pH) and physical (i.e., temperature) characteristics that are within their relatively narrow range of tolerance. Water quality requirements for salmon have been well established by a large number of physiological studies (Bjornn and Reiser 1991; Groot and Margolis 1991). However, water quantity requirements, particularly for stream-dwelling fish, have been more difficult to determine.

Some of the most common tests of the flow/fish relationship took the form of a series of analyses of correlations between fish abundance (e.g., density or number of fish per unit of area) and various physical and chemical characteristics of the stream flow regime (Binns and Eiserman 1979). Despite regional and watershed specific differences, several studies have identified consistently the same set of variables as very important in controlling fish abundance. These variables are water velocity, minimum water column depth, instream cover, substrate composition, water temperature, dissolved oxygen, alkalinity, and turbidity (Gosse and Helm 1981; Shirvell and Dungey 1983). The fact that almost all these variables are influenced by instream flows in a direct or indirect manner explains why water flows can have such a strong controlling effect on fish numbers.

Water velocity and water column depth affect upstream fish migration.The faster the velocity of water, the harder it is for fish to migrate upstream (although fish may take advantage of turbulent flows and eddies to be assisted in their upriver migration); and the deeper the water column, the more likely it is fish will save energy by traveling trough deep and relatively colder waters. For a series of techniques to estimate stream discharges that provide suitable depths and velocities for upstream passage of adult salmonids, see Thompson (1972). The amount of spawning habitat in a stream also is regulated by flows. D.H. Fry (cited in Bjornn and Reiser 1991, p. 89) explains that "as flow increases, more and more gravel is covered and becomes available for spawning. As flows continue to increase, velocities in some places become too high for spawning, thus canceling out the benefit of increases in usable spawning area near the edges of the stream. Eventually, as flows increase, the losses begin to outweigh the gains, and the actual spawning capacity of the stream starts to decrease. If spawning area is plotted against streamflow, the curve will usually show a rise to a relatively wide plateau followed by a gradual decline." Egg incubation is affected by the amount and velocity of the water circulating among the gravel particles and eggs. This, in turn, may increase or decrease with the depth and the quantity of the surface water (Wickett 1954).

Seeding rate (abundance of spawners) is the primary factor regulating the abundance of juvenile salmonids present in a stream. Because numbers of anadromous spawners are determined in part by their ocean survival, their numbers do not necessarily show a direct relationship with instream flows in their natal streams. That said, it is worth noting that Smoker (1955) found a correlation between the commercial catch of coho salmon and annual runoff, summer flow, and lowest monthly flow in 21 western Washington basins 2 years prior. Smoler's data were for the 1935–-54 period, but in the last decades of the 20th century, hatchery production of coho salmon smolts increased to the point that such comparisons are no longer possible in most systems. However, Mathews and Olson (1980) analyzed data from Washington for the 1952–77 period and found that summer instream flows still had an important influence on total coho salmon production in Puget Sound area streams.

Given a certain level of seeding, there are several environmental factors that control the abundance of fry. In turn, smolt production in streams and rivers also is affected by flows. Factors such as the amount of suitable habitat, quality of cover, and productivity of the stream set an upper limit (i.e., carrying capacity) on the abundance of juvenile fish, and the population is held at that level by density-dependent interactions (i.e., competition and some types of predation). Carrying capacity, and hence fish abundance, may vary yearly if controlling habitat components, such as instream flow, changes from year to year at critical periods such as late summer (Bjorn and Reiser 1991).

The amount of suitable habitat to be occupied by salmonids in streams is a function of instream flows, channel morphology, gradient, and in some cases instream or riparian cover availability. Suitable habitat for each salmonid life stage has water of sufficient depth and quality flowing at appropriate velocities. The addition of cover increases the complexity of the habitat and usually the carrying capacity of the stream reach. Diversion of water from streams and/or impoundments leads to altered instream flows and potential changes in the carrying capacity of streams for salmonids. The relationship between flow and carrying capacity varies with channel geometry and even valley form (e.g., it differs between a channel dominated by riffle habitat within a narrow canyon and a channel with many pools in a broad valley). In general, the relationship must start at the origin (no flow, no fish), increase (not necessarily in a uniform manner) with flow increases up to a point, and then level off or even decline if flows become excessive. The existence of this relationship has been empirically demonstrated (see Kraft 1972; Stalnaker 1979; White et al. 1981) and is not in dispute; what remains to be defined is the nature of the relationship (or the shape of the curve representing this relationship) between flow levels and fish abundance. Because the relationship is not a linear one and it varies with channel structure and the fish species under consideration, its theoretical formulation has been the goal of many models.

The complex dynamics of river systems, combined with the diverse repertoire of adaptive behaviors salmonids are able to display, limit the predictive capability of any model, and instream flow quantification methodologies are not an exception to this. Nevertheless, such methodologies constitute broadly applicable and useful tools to establish the minimum flows needed in a stream channel to ensure that a given proportion of habitat is available to fish during low-flow periods. However, since pre-determined instream flows are not compatible with the emerging emphasis on ecosystem-based management, these methodologies can be more effective at protecting aquatic resources if used within the context of watershed-scale adaptive management programs.

Instream flow quantification methodologies are classified into two general categories: standard setting, and incremental methodologies. Standard setting methodologies are techniques used to determine the minimum flow needed to protect certain habitat types of interest for the benefit of fish and other aquatic life. The application of these methods usually results in a minimum flow value for a specified stream reach, below which water may not be withdrawn for consumptive use. The minimum or "threshold" flow is almost always less than the historical level and, therefore, reduces the current amount of available habitat; yet these methods are used in many states. Standard-setting methods can be further divided into non-field (e.g., Tennant Method) and field (R2CROSS) types (Espegren 1998).

The Tennant Method is a non-field technique used for setting "target" percentages of mean annual discharge that are expected to "protect" specified amounts of aquatic habitat (Tennant 1976). This method was developed for fish-bearing stream sections and has become popular because it is a quick, cheap, easy, and objective approach that can be readily applied to both recorded flows and estimated mean annual discharges. The Tennant Method has been commonly used in the U.S. since 1976 (second only to the more popular Instream Flow Incremental Methodology or IFIM) and many regulatory agencies still consider it a useful, albeit coarse, tool that can be used to set instream flow appropriations over a large number of streams in a short period of time and at a relatively low cost. However, because it is a non-field method, many managers and scientists consider that it should not be used as the sole basis for developing instream flow recommendations (Castleberry et al. 1996). In fact, Tennant (1976) indicates that field verification of this method is necessary to establish what are appropriate "target" flow levels.

Incremental methodologies, such as the Instream Flow Incremental Methodology (IFIM), combine hydraulic data with biological information on selected aquatic organisms to assess habitat alteration relative to incremental changes in flow. They help evaluate a series of possible alternative development scenarios and their effect on aquatic species (Stalnaker 1993). These methods were developed from habitat versus flow functions that take into consideration life-stage-specific relations for target species (i.e., fish migration, spawning and nursery habitat availability versus flow). They are field-based techniques often used to evaluate the impacts of hydroelectric projects and to develop conditions for water licenses and permits on very controversial stream segments with high water-development potential. Incremental methodologies simulate the quantity and quality of potential habitat resulting from proposed water development, illustrated for a series of alternative flow regimes (Trihey and Stalnaker 1985). Their downside, from the perspective of the stream ecosystem, is that they do not define flow targets in terms of the natural variability of the hydrograph, paying little attention to the importance of dynamic flow changes in maintaining the river ecosystem structure and function. They focus only on the most "valued" species and the most vulnerable life stages of that species, which involves a subjective value judgment. This is a particularly important issue if we are to begin thinking of stream flow management as part of a larger program of ecosystem management.

Human activities in the Klamath Basin

The Klamath Basin has a long history of human activities that have altered its hydrology and, as a result, the availability and quality of fish habitat in the system. Commercial harvesting of timber in the Lower Klamath Basin started in the late 1800s, concurrent with the development of a commercial fishery in the river estuary and surrounding coastal waters (KRBFTF 1991). Mining, primarily for gold, was a very common activity, particularly in the middle reaches of the Klamath River. The cultivation of crops and the raising of cattle began in the 1850s. The hydrology of most of the Klamath Basin was altered drastically by the development of many water-diversion projects. Although mining was the first activity that diverted water from the river, irrigation diversions for agriculture has been, and still is, a very common practice, not only in the upper basin but also in some lower tributaries to the Klamath River like the Shasta, Scott, and Trinity rivers.

Mining

Gold mining had its own impact on the aquatic environment of the Klamath Basin. In the 1800s, it was carried out primarily by means of suction dredging and placer mining—two methods that disrupt stream substrates and negatively impact fish spawning beds, food production, and nursery habitats (Bjornn et al. 1977; Hassler et al. 1986). Other types of mining, such as tunnel mining for gold, copper, and chromite, have been intermittent in different parts of the basin during the past 100 years, and instream gravel mining has been a more sporadic activity (KRBFTF 1991).

Forestry

Gold mining used large amounts of timber, and this demand made possible the establishment of many lumber mills in the central part of the Klamath Basin (Wells 1881). Timber harvest increased with the arrival of the railroad in 1887 to Yreka (California), and experienced extraordinary growth after World War II. Because of this, log rafting, road construction, skid trail construction, earth removal, and other related practices increased to the point of presenting a threat to fish life in the Klamath River, and "corrective actions" were ordered by the California Legislature in 1957 (KBRFTF 1991).

Agricultur*e*

While forestry has been the predominant type of land use in the lower basin, agriculture and ranching have flourished in the fertile valleys and hillside grasslands of the Upper Klamath Basin as well as in the floodplains of tributaries such as the Shasta and Scott rivers. Land clearing to provide for much-sought-after farm and ranchland modified the vegetation of entire valleys, with native trees and perennial grasses being replaced by crops and junipers, brushes, and forbs (USSCS 1983; KRBFTF 1991).

As farmland became more valuable, flood control measures became increasingly common , and as a result riparian vegetation was removed from entire river reaches, stream channels were straightened, and dikes were built along stream banks. Flooding was not the only problem, however, and by the mid 1900s pressure to conserve soil and water resources prompted farmers and ranchers in various valleys to organize soil conservation districts (KRBFTF 1991).

Water diversions

The U.S. Bureau of Reclamation began the construction of the Upper Klamath Irrigation Project, near Klamath Falls, Oregon, in 1905. Marshes, Lower Klamath Lake, and most of Tule Lake were drained and a complex network of levees, dikes, pumping stations, and channels were developed to divert water from the Upper Klamath Lake and Klamath River to irrigate ~220,000 acres of agricultural land (i.e., the Project). The main water-diversion facilities that were built on the Klamath River immediately downstream from Upper Klamath Lake include the A Canal (1906–1907), the Lost River Diversion Dam (1912), the Link River Dam (1921), and Keno Dam (1967) (see Rykbost's chapter in this report for a detailed description of the water-diversion system in the Upper Klamath Basin). The network of irrigation channels was designed to re-route water from the lake through farmland and return the unused water volume back to the river. The Project's operation becomes more water-intensive during very dry years due to the requirements of agricultural crops. Hence, during dry years the quantity and quality of water returned to the Lower Klamath River becomes more dependent upon the Project's operations than in years when rainfall and snow pack are at normal or high levels. Project water requirements, in combination with the series of dams that were built in the Klamath River for the production of electricity, reduce summer flows, increase nutrient load, and alter water temperature in the river. This seems to affect the quantity and quality of fish habitat downstream from IGD during summer and early fall, especially during dry years (KRBFTF 1991; USGS 1995; Deas and Orlob 1999).

Hydroelectric projects

During the late 1800s, small, water-impounding dams supplied the water needed for mining and farming operations. However, these small projects did not represent a permanent barrier to fish migration because they were often washed out during floods. It was not until 1892 that the first large dam was built; it was part of the hydroelectric power plant project on the Shasta River. Since then, the California Oregon Power Company (COPCO) identified numerous potential dam sites in the Klamath River, but because the proposed projects were not always feasible based on hydroelectric power production alone, whenever possible the company tried to develop irrigation supply benefits as well (Boyle 1976; KRBFTF 1991).

The KRBFTF (1991) report shows that COPCO's Klamath River flow records started in May 1910, before the construction of any of the dams. These flows were measured on a daily basis at Ward's Bridge and reached a maximum level of 4,500 cfs and a minimum of 1,450 cfs. Over time, these records revealed a change in the river flow regime from a relatively uniform flow to one with lower flows in the summer and higher flows in early spring. Boyle (1976) and the USGS (1995) have attributed the relative uniformity in the river's flow to the moderating influence of the large and shallow Upper and Lower Klamath lakes in the headwaters of the basin. The Klamath Irrigation Project, located in the lower portion of the Upper Klamath Basin, has been considered the cause of the observed changes in the river's flow regime. These hydrological changes apparently became more accentuated as the Bureau of Reclamation's irrigation projects progressed (Boyle 1976) and COPCO moved ahead with its plans to build a series of hydroelectric dams (KRBFTF 1991).

The first large dam on the mainstem of the Klamath River was Copco 1, which was completed in 1917 in the Ward's Canyon area, northeast of the town of Yreka, California. Copco 1 created a reservoir with a holding capacity of 77,000 acre-feet of water. This hydroelectric project created the first impassable barrier to the migration of anadromous salmonids to the Upper Klamath Basin (Snyder 1931). In 1925, Copco 2 was completed immediately downstream from Copco 1 (Boyle 1976). Because no minimum flows were required for the operation of these dams, their water releases fluctuated from 200 cfs to 3,200 cfs in response to peak power demands and regulatory capacity. Such changes in flow made the water level in the river rise or drop several feet within a 20-minute period (Jones and Stokes 1976, KRBFTF 1991, Deas and Orlob 1999). These extreme and frequent changes in flow had very negative impacts on fish habitat and fish production in the Lower Klamath Basin (Snyder 1931; Jones and Stokes 1976). In 1947, the proposed "solution" to this problem was the construction of a re-regulating dam below Copco 2 that would eliminate the daily peaks of water discharge. It took 13 years for the construction of this dam to begin. Water users in the upper basin were concerned about the allocation of water and opposed COPCO's plans for more dams. It was not until the Federal Power Commission (FPC) approved COPCO's Big Bend hydropower project, and commanded the extension of its contract with the Bureau of Reclamation, that upper-basin water rights were dealt with in a manner that allowed plans for the construction of a flow-regulating dam to proceed (KBRFTF 1991). In 1958, the FPC granted approval for the construction of Big Bend dam and power plant (now known as J.C. Boyle) upstream of Copco 1, on the Oregon side of the interstate border. By then, COPCO had reached an agreement with the California Department of Fish and Game regarding flow-release regimes, and thus obtained the state water rights and the license from the FPC to build the recommended flow-stabilizing dam downstream from Copco 2 (Jones and Stokes 1976). The construction of IGD began in 1960 and it was completed by 1962. IGD is located 7 miles below Copco 2 and its reservoir has a capacity of 58,000 acre-feet of water. It now marks the limit to upstream fish migration in the Klamath River.

Main tributaries of the Lower Klamath River

In addition to the Lower Klamath River mainstem, salmonids are known to utilize spawning and nursery habitats in its many tributaries. The largest tributary systems, such as the Shasta, Scott, Salmon, and Trinity sub-basins, may influence the Lower Klamath River mainstem's water volume and quality and, therefore, its salmonid carrying capacity (KRBFTF 1991).

The confluence of the Shasta River with the Lower Klamath River is located approximately 14 miles downstream from IGD, at mile 176 of the river's mainstem. The Shasta River Sub-basin covers an area of approximately 340 square miles. It contains an estimated 50,000 acres of agricultural land under active irrigation, which in 1988, as an example, used 150,500 acre feet of water (KRBFTF 1991; Siskiyou County Farm Bureau 2001). Like the upper part of the Klamath Basin, the Shasta Valley receives very little rainfall (between 11 and 17 inches per year), and groundwater within this system is recharged via melting snow and stored in porous volcanic rocks. Stream flows and agricultural uses within the Shasta River sub-basin are dependent upon inputs from springs and subsurface flows.

In 1928, Dwinnell Dam was built on the upper Shasta River to hold irrigation water for the Montague Water Conservation District. Thus, Lake Shastina, with its maximum water-storage capacity of 41,300 acre-feet, was created. Dwinnell Dam not only prevents anadromous salmonids from using the upper reaches of this system but is reported to prevent the recruitment of new gravel and have negative effects on the quality of the water in the river below. Water in Lake Shastina heats up during the summer months and is enriched with nutrients derived from agricultural and urban-related activities. The release of this water into the Shasta River below the dam decreases its dissolved oxygen concentration and increases its temperature, thus further reducing the availability of good-quality salmonid habitat in this sub-basin during the summer months. (Dong et al. 1974; KRBFTF 1991).

The Scott River enters the Lower Klamath River at mile 143, or 47 miles downstream of IGD. The Scott River Resource Conservation District (RCD) is 1,176,160 acres in size, with 294,160 privately owned acres and 882,000 acres of public land (CARCD 2000). In this region, flat and fertile valleys have been used since the early 1900s for crop production, grazing, and urban development. Estimates of water use within the Scott River Valley in 1988 show that 96,400 acre-feet of water were delivered via 200 diversions along 240 miles of ditches and pipelines to 34,100 acres of crop and pasture lands. The amount of irrigated land in the valley was reported to have changed very little between 1958 and 1991 (Siskiyou County Farm Bureau 2001). Although large and permanent dams were never built on the Scott River, summer nursery habitat for salmonids has still been affected by human activities. As early as 1974, fish habitat-related problems were documented in many reaches of this river that were either totally dry or running in an intermittent manner during July, August, and part of September (CDFG 1974).

The Salmon River sub-basin, which drains into the Lower Klamath River near mile 68, is the only one of the major sub-basins within the Lower Klamath Basin that is not affected by water diversion projects. A large proportion of this catchment area is under National Wilderness designation and is covered by forests. Therefore, fire, road construction, and timber harvest have been the main types of disturbances that have affected the system during the past century (USFWS 1994). In 1977, fires burned 56,000 acres of forest in this sub-basin, and some 450 million board feet of wood were reported salvaged during the subsequent 5 years. Another 78,128 acres of forest were burnt in 1987 (KRBFTF 1991). Numerous landslides and high sediment loads have negatively affected spawning gravel and invertebrate production in the river. USFWS (1994) assessments of habitat attributes, however, indicate that the relatively low quality of the spawning habitat may have only minor negative implications for salmon production in this sub-basin. The main limiting factor is the elevated summer water temperature, which is high enough to reduce the survival of juvenile salmonids (USFWS 1994).

The Trinity River sub-basin is the largest and most complex of all sub-basins and joins the Lower Klamath River at mile 43. During the first half of past century, the Trinity River was characterized by a dynamic and meandering channel that moved back and forth across its relatively broad floodplain over time (USFWS 1999). This sub-basin sustained large chinook salmon, coho salmon, and steelhead runs until the construction of the Trinity and the Lewiston dams (a.k.a. Central Valley Project's Trinity River Division or TRD) in the early 1960s. This project not only prevented fish access to 109 miles of spawning and nursery habitat above Lewiston, California, but it diverted between 80 and 90 percent of the annual flow of the upper portion of this river into the Sacramento River Basin. This resulted in drastic changes in the flows of the Trinity River, which affected its channel morphology, its substrate composition, and the characteristics of both its flood plain and riparian areas. The original channel structure included an alternating sequence of gravel-rich riffles and deep pools that provided good salmonid habitat. In the absence of high flow events after dam construction and operation, the channel structure changed to a continuous and uniform "run" or glide type of habitat that became confined, over time, by riparian berms (KRBFTF 1991; USFWS 1999; USDI 2000). The changes in the Trinity River had a strong and negative effect on the sub-populations of salmonids that relied upon it. Despite hatchery supplementation, fish abundance in the Trinity River has been reduced between 53percent (steelhead) and 96percent (coho salmon) after the construction and operation of the TRD Project began (USFWS 1999; USDI 2000). After a lengthy review and decision-making process, the Department of Interior ordered the TRD Project to put into practice a "preferred alternative" that included the augmentation of variable annual instream flow releases from Lewiston Dam, a coarse sediment introduction plan, the construction and rehabilitation of 47 channels, and the implementation of adaptive management and watershed restoration programs (USDI 2000). It is estimated that trans-basin water exports from the Trinity into the Sacramento River will be curtailed by 52percent because of this decision (Ahern 2000).

In addition to the four sub-basins described above, smaller scale water diversion projects for land irrigation have been built in several minor direct tributaries of the Lower Klamath Basin. The affected creeks are: Grider Creek, Cottonwood Creek, Horse Creek, Bogus Creek, Little Bogus Creek, and Willow Creek (KRBFTF 1991).

Status of Klamath Basin coho salmon

According to the BO (NMFS 1991), the Southern Oregon/Northern California Coast coho salmon Evolutionary Significant Unit (SONCC ESU) "was listed as threatened under the ESA on May 6, 1997. This ESU includes coho salmon populations between Cape Blanco, Oregon, and Punta Gorda, California." The listing of these stocks was the response of NMFS to abrupt declines in their abundance, in particular during the past decade. The designation of "critical habitat" (i.e., waterways, substrate, and riparian zones below naturally impassable historical barriers) for the stocks within the above-mentioned ESU followed in May of 1999.

Historically, the Klamath River Basin was well known for its large chinook salmon runs. Its coho salmon populations were relatively large, but never as abundant as in some of the large basins north of Cape Blanco, such as the Columbia River or the Fraser River (Weitkamp et al. 1995). Over time, however, coho salmon stocks have been greatly reduced and now are formed largely by hatchery-produced fish. Small, wild runs of coho salmon still remain in the basin (CDFG 1994). Out of a total of 396 streams within this ESU that once had coho salmon runs, Brown et al. (1994) found recent survey information for 115 (30 percent) of them. Seventy-three (64 percent) of these streams still supported coho salmon, while 42 (36percent) did not. The streams identified as lacking coho salmon runs were all tributaries of the Klamath and Eel rivers (Brown et al. 1994; Weitkamp 1995).

Estimates from 1994 data for the SONCC ESU in the Klamath Basin assess the average spawning coho salmon population at 7,080 wild fish and 17,156 hatchery fish. Combined with Rogue River estimates, spawning adult coho salmon are estimated to be 10,000 wild fish and 20,000 hatchery fish (PFMC 1999).

Because fish sampling in the Klamath River has focused on economically important salmon runs (i.e., fall chinook salmon), data on wild coho spawners (i.e., escapement estimates) have not been collected on a regular basis. Unfortunately, fish-counting weirs are removed from the river after the fall chinook salmon migration is over and before flows reach high levels. The migration of adult coho salmon typically peaks during these periods of high water discharge; therefore, the spawning counts of this species based on the operation of fall chinook sampling devices capture only the earliest coho salmon that enter the system. High flows during the period that coho usually migrate upstream make the use of fish-counting weirs impractical and often dangerous. In a similar manner, juvenile trapping efforts in this basin also have focused on chinook salmon smolts and have provided relatively poor estimates of coho salmon smolt output.

Notwithstanding these technical difficulties, the California Department of Fish and Game has estimated that total coho salmon runs are less than 6percent of what they were in the 1940s (CDFG 1994); this estimate is within the range reported by other sources that already identified Klamath River coho salmon as of special concern a decade ago (Nehlsen at al. 1991).

Fish-counting weir data for the Shasta and Scott rivers show similar declines in the abundance of coho salmon spawners during the last 30 years. Shasta River fish counts, during years when trapping started and ended at equivalent times, show an average escapement (i.e., number of spawners that return to their natal stream) of 217 coho salmon in the 1970s and only 7 in the 1990s. Between 1991 and 2000, coho salmon counts ranged from 0 to 24 fish, with 1 or 0 fish counted during four of these years (CDFG unpublished data). Counting weirs in the Scott River indicated an equivalent trend with an annual average count of 25 coho salmon (range = 5 to 37) between 1982 and 1986, and an average of 4 fish (range = 0 to 24) between 1991 and 1999. Again, within the past decade, one single year accounted for most of the fish observed, whereas no coho salmon were counted during four of those years (CDFG unpublished data). These data emphasize the importance that one year's spawning success can have on the survival of these coho salmon stocks.

Smolt data also suggest that Klamath Basin coho salmon stocks are in trouble. Juvenile traps, operated on the river's mainstem, were used to estimate indices of smolt production. Based on counts from these traps between 1991 and 2000, the annual average number of wild coho salmon smolts was estimated at only 548 individuals (range = 137 to 1268 individuals) (USFWS 2000). For the same period, an average output of 2,975 wild coho salmon smolts (range = 565 to 5,084 individuals) was estimated for Willow Creek, within the Trinity River sub-basin (USFWS 2000). The incomplete trapping record provides limited information in terms of temporal trends, but it still is a useful indicator of the extremely small size of coho salmon populations in the Klamath Basin. Furthermore, the presence of young-of-the-year coho salmon in these smolt traps helps to shed some light on how the young fish are distributed within the system during their period of freshwater residence.

Although, coho salmon show a strong preference for small streams over mainstem river habitat, some fry may end up being displaced into mainstem and even estuarine habitat if fish densities are too high or stream habitat is somehow limited (Sandercock 1991). In the spring, shortly after emerging from the gravel, coho fry distribute themselves throughout their natal stream reach and establish feeding territories that are aggressively defended from any intruders. As late emerging fry try to establish their own feeding "posts," they find that most of the nearby good nursery habitat already has been claimed by the early emerging individuals, which had the opportunity to start feeding earlier and, consequently, grow bigger and become successful at defending their territories. The territorial behavior of the young coho salmon tends to force them to move in search of vacant nursery habitat (Chapman 1962). Although some fry move upstream, the vast majority move downstream. Thus, many individuals end up in the river's mainstem and even in the estuary where they are not likely to survive (Sandercock 1991).

A 1997 USFWS report and the 2001 mainstem trap data (CDFG unpublished data) show that young-of-the-year coho salmon are emigrating from the Shasta and Scott rivers, where they probably were spawned, into the mainstem of the Lower Klamath River between March and August. Considering the low numbers of coho salmon fry that have been reported for these sub-basins, it is unlikely that these fish were displaced downstream because of competitive interactions with other juveniles of their own species. Instead, the most likely explanation for their summer movement is that declining water quality and quantity in the lower-order tributaries force these young fish to seek refuge elsewhere. Thus, they end up in the river's mainstem earlier than in other river systems. This exploratory behavior and movement in search of adequate nursery habitat has been well documented, especially before the onset of winter (Sandercock 1991).

Lower Klamath River instream flows

All Klamath River Basin hydrological studies that we had access to (USGS 1995; Hecht and Kamman 1996; Trihey and Associates 1996; INSE 1999) conclude that human activities have altered flows in the Lower Klamath River. However, the nature of these changes and their precise magnitude is somewhat ambiguous and, consequently, their effects on salmonid habitat availability and fish abundance remains contentious, to say the least.

A USGS (1995) study characterized the baseline flow regime for the Klamath River Basin. Baseline flows in this case meant historical flow conditions that provide a basis for comparison of past flow conditions to contemporary and possible future alternative water management scenarios. This study did not identify any significant changes in annual water discharge at Keno Dam (on the Klamath River, upstream from hydroelectric dams) between 1914 and 1960 that could be attributed to human intervention in the flow regime. However, the analysis of monthly flows showed a discernible seasonal change in water discharge both below IGD and in the Scott River after 1960. Lower Klamath River flows below IGD have become higher in February and lower between June and September than in previous decades. Evaluations of seasonal trends in flow for the Scott River near Fort Jones also show a reduction in flow between July and August after 1960. Such changes in flow could be attributed to changes in crop patterns, irrigation techniques, and water demand due to changes in summer weather patterns, according to the USGS (1995). The analysis of daily flow fluctuations in the Lower Klamath River presented in this study confirmed that the operation of IGD created a steady flow and eliminated abrupt changes in water discharge of up to 2,000 cfs. The biggest single changed item in the USGS gage records was flow during dry years. This led the authors of the study to conclude that human water use during years of drought drastically reduces the already limited flows of the Lower Klamath River.

In 1996, Hecht and Kamman were commissioned by the Yurok Tribe to quantitatively estimate the historic flow patterns in the Klamath River for Trihey and Associates (1996) to subsequently develop recommendations regarding flow needs for salmon. Although agricultural diversions were in place in 1905 above Klamath Lake (i.e., on the Williamson and Sprague rivers), USGS gage data from 1905 though 1912 at Keno were used to estimate “natural flows” in the river. These data reflected a period of record during which water diversions were at a minimum, until the construction of the Lost River Diversion Dam in 1912 (Hecht and Kamman 1996). The years 1905 through 1912 were identified to be above average for precipitation and runoff in much of the Upper Klamath Basin. To counter this, stream flow and rainfall data were normalized to a period of average rainfall using annual precipitation indices. Hecht and Kamman (1996) divided the average flow/annual precipitation during the 1905–1912 period by the average flow/annual precipitation value over a long-term period (1905–1994). These indices suggested that conditions during the 1905–1012 period were wetter than normal in northern California at Yreka (index 1.21) than in southern Oregon al Klamath Falls (index 1.04). (Note that the higher the index above 1.0, the wetter the 1905–1912 period relative to average conditions over the longterm.). The authors explained that they chose the Klamath Falls (1905–1994) index because it is closer to the center of the Upper Basin and appears to be an accurate record. They found it preferable to the longer (1872–1994) but more distant record from Yreka, which included data of poor quality for 1911 and 1912. They did not use the index of 1.34, calculated using the BOR’s inflow records, because this index suggested conditions were wetter than indicated by either of the rainfall records. This index is likely to have been affected by the long-term decline in inflow to Upper Klamath Lake from the Sprague and Williamson river systems. This artificially reduced the long-term inflow average, which, as the denominator in the calculation of the index, leads to an inflated result (Hecht and Kamman 1996).

To estimate pre-project flows at IGD, Hecht and Kamman (1996) added historical flow accretions between Keno and IGD to the Keno flow record. These accretions were estimated in a separate study by CH2M Hill using USGS flow records, because no gage data existed for IGD until 1960. After adding the estimated accretions to the pre-Project flows at Keno, Hecht and Kamman (1996) concluded that the average annual flow in the Lower Klamath River at IGD was about 1.8 million acre-feet/year prior to the completion of the Irrigation Project. A second phase of Hecht’s and Kamman’s (1996) study comprised the analysis of changes in flow at a gauging station over time. Stations with long flow records were selected and similar pre and post-Project water-year types were identified. They chose and matched water-year types that had similar earlier short-term and long-term conditions, such as 1916/1985 and 1918/1987. For example, both 1916 and 1985 experienced above-normal runoff and precipitation, and were preceded by 4 years of high water availability. Thus, the 1916/1985 year pair represents historical vs. current flow conditions for relatively wet periods; while the 1918/1987 pair corresponds to flow conditions during relatively dry periods.

Based on their analyses, Hecht and Kamman (1996) concluded that flows in the Lower Klamath River have been reduced from historical levels by water-diversion projects in the Upper Klamath Basin and the Shasta, Scott, and Trinity sub-basins. They also indicated that the Project changed the seasonal distribution of flows, usually increasing water discharge very slightly during fall and early winter and markedly reducing spring and summer flows. This shift in flow regimes between pre-project times and the mean monthly 1961–96 flows is shown in Figure 2 (based on Hecht's and Kamman's data). A graph of annual average pre-project flows (hydrograph) indicates that higher flows were available in the river channel before all diversions and dams were built. According to Hecht and Kamman (1996), the Upper Klamath Basin in July–August of 1911–1913 (pre-Project wet period) contributed between 30 and 35percent of the river flow at its mouth; whereas during July–August of 1983–1985 (a comparably wet post-Project period) this flow contribution was reduced to 10 or 15percent of the flow at the river's mouth. Their study estimated that, during droughts, the post-Project flow contributions of the upper basin to the flow recorded at the mouth of the river becomes even lower, approximately 5percent%.

Hecht's and Kamman's (1996) "pre-project" flow estimate at IGD was subsequently used by Trihey and Associates (1996) to develop minimum instream flow recommendations. Trihey and Associates (1996) used the Tennant Method and applied it based on 60percent of the mean annual discharge estimated by Hecht and Kamman (1996). The recommended minimum instream flows are included in Table 1 along with those originally established by the Federal Energy Regulatory Commission (FERC) and those requested by the Yurok Tribe in response to the draft BO by the NMFS.

In 1999, a study was initiated by faculty from the Institute for Natural Systems Engineering (INSE) of Utah State University to quantify the minimum monthly flows for the Klamath River below IGD needed to maintain and restore the aquatic resources of the river, with special emphasis on salmonids. These researchers elaborated interim minimum instream flow recommendations using a battery of hydrology-based methods. Such recommendations were intended to be of temporary application (Phase I) until field-based methods, incorporating site-specific information, tributary flows, and water quality, are used to validate and refine the minimum recommended flows (i.e., Phase II of INSE report, draft manuscript completed but not made public yet). The minimum instream flow recommendations described by INSE (1999) were calculated on the premise that suitable salmonid habitat is directly related to flow regime and were focused on four basic flow components: fish habitat flows, channel maintenance flows, riparian flows, and valley maintenance flows. For purposes of determining interim minimum instream flows for the Klamath River, INSE (1999) used five different minimum instream flow setting methods (i.e., Hoppe, New England Flow Recommendations Policy, Northern Great Plains Resource Program, Tennant, and Washington Baseflow) and subsequently took the average monthly flow across the five estimated values to calculate the "best estimate". This study has been criticized by Miller (2001), who prepared a review for the BOR, for making the independent corroboration of its analyses and conclusions difficult by not providing supportive data, using "outdated" methods when "newer" more biologically based methods were available, modifying the methods used without clear justification, and not providing complete citations in the document and materials in the appendix.

Although the reports by USGS (1995), Hecht and Kamman (1996), and INSE (1999) differ in their characterization of the magnitude of changes that occurred in the river, their discrepancies are relatively minor and can be explained by differences in their initial objectives, analytical techniques, and underlying assumptions. However, they all describe a common scenario of water depletion in the river as well as annual and monthly flow changes that follow the patterns of water use in the upper basin and in the main sub-basins of the lower basin. The study by Hecht and Kamman (1996) estimates "pre-project" mean annual flows at IGD for a normal water year (i.e., neither too wet nor too dry) of about 2,575 cfs (equivalent to 1.8 million acre-feet of water). This is based on 1905–12 gage records, corrected for a normal year because that period was wetter than normal. The mean annual flow these studies calculated using 1961–96 gage records was 2,060 cfs (approximately 1.5 million acre-feet). This suggests a flow reduction of 515 cfs or 372,800 acre-feet, which roughly matches the estimated 245,000 to 350,000 acre-feet (depending on year type) used by the Klamath Project operations. This reduction in annual flow is controversial for some who prefer to use the historical rainfall records from Yreka to estimate pre-Project flows. These records suggest the 1905–1912 period was 20percent wetter than normal and justify the pre-Project average annual flow at IGD to be corrected accordingly to approximately 1.5 million acre-feet/year, which is not different from the post-Project estimates of Hecht and Kamman (1996). Such comparison, however, may not be appropriate since it is comparing flows that are normalized using two different precipitation gages—the Yreka gage for the pre-Project flows and the Klamath Falls one for the post-Project.

Both the USGS (1995) study and Hecht's and Kamman's (1996) report arrive, independent of each other, at the conclusion that water management practices have increased late winter and early spring flows, and reduced summer flows compared to estimated pre-Project flows (see Figure 2).

Dams and water diversions in the basin not only have changed the Lower Klamath River's seasonal pattern of flow but also have negatively affected the quality of the water. In recent years, temperatures on the mainstem of Lower Klamath River have exceeded 20ºC for periods of weeks between mid-July and late September. This trend has been particularly evident during dry years such as 1994 (Kier and Associates 1997). Although instream flows between July 1 and September 1, 2001, were higher than during previous dry years, due to regulation changes set forth by the BO (NMFS 2001), maximum daily temperatures below IGD ranged from 19.6ºC to 22.5ºC and minimum daily temperatures from 18.6ºC to 20.6ºC for the 90 days of record (USGS 2001).

The combined effects of high temperatures, high nutrient concentrations, and low dissolved oxygen levels during the summer months can create extremely stressful conditions for coho salmon and other salmonids in the Lower Klamath River. High nutrient concentrations (especially N and K) typically promote eutrophication. This condition and the associated increase in the abundance of algae and aquatic plants tend to lead to increased sedimentation and water temperatures, slower water velocities, and lower levels of dissolved oxygen at night. In June of 2000, temperatures and dissolved oxygen levels reached critical levels in the Klamath River and resulted in an estimated kill of >1,000 fish/mile for ~10 miles (CDF&G 2000).

Stream flows affect salmonid habitat in a variety of ways. Increased water flows provide a lower stream surface-to-volume ratio, which may buffer the diurnal fluctuations in stream temperatures and dissolved oxygen levels (INSE 1999). This practice also is recommended by Bartholow (1995) for selected times of the year such as June and October, because during the warmer July–September period it is important to maintain the beneficial effects that colder water from springs and some tributaries may provide to salmonids (at least during normal flow years). Larger stream volumes also accompany increased habitat availability on the margins of the channel (Bjornn and Reiser 1991). This habitat not only functions as shelter to juvenile coho salmon but also adds to the connectivity between riparian vegetation and the stream channel that is critical for maintaining food webs and energy flows through a functional riparian ecotone (Otting 1999, Dwire 2001).

Implications of 2001 Biological Opinion for coho salmon

Based on the consultation history presented in the 2001 BO (NMFS 2001), the NMFS received a request for formal consultation under section of the ESA on March 1999, when the BOR forwarded a draft Environmental Assessment of the Klamath Project Annual Operations Plan. On July 12, 1999, the NMFS issued a BO on the operation of the Klamath Project through March 2000. On April 4, 2000, NMFS informed the BOR that the 1999 BO and the associated incidental take statement had expired on March 31, 2000, and that their agency had to request ESA section 7 consultation again with regard to the operation of the Klamath Project. The BOR responded with a letter on April 26, 2000, stating that "[the BOR has] determined that the proposed flows [included in the letter]…are both sufficient and necessary to avoid possible 7 (d) foreclosures and to fulfill Reclamation's obligation to protect Tribal trust resources." On January 22, 2001, the BOR requested initiation of formal ESA section 7 consultations with regard to the ongoing operation of the Klamath Project. This letter included a Biological Assessment of the Project's operation on coho salmon from the SONCC ESU.

As part of this consultation, the NMFS reviewed the status of SONCC coho salmon, the environmental conditions in the area, the potential effects of the proposed ongoing operation of the Klamath Project, and its cumulative effects. Afterwards, it concluded that the proposed action was "likely to jeopardize the continued existence of SONCC coho salmon" and adversely alter critical coho salmon habitat. Subsequently and as part of the BO, the NMFS presented its "Reasonable and Prudent Alternative" (RPA) to the operations proposed by the BOR. The RPA was based on the premises that: a) the operation of the Klamath Project substantially affects flows, fish habitat, and water quality in the Lower Klamath River; and b) the Klamath Project is not the only human activity that has a negative effect on salmonid habitat and anadromous salmonid populations in the Klamath Basin. According to the NMFS (2001), the proposed RPA aimed to prevent further decline of the listed species that the NMFS concluded were likely to be jeopardized by the ongoing operation of the Klamath Project. The agency indicated that it was in the process of collecting additional information and conducting analyses about the relationship between IGD releases and fish habitat availability with the intent to develop a comprehensive BO addressing all water-year types to be provided to the BOR on or before June 7, 2001. In the meantime, the April 6, 2001 BO was a subset of the more comprehensive report being developed and was intended to specify only the minimum instream flows for the April–September period of 2001.

As described earlier in this section, there is ample evidence that water releases from IGD have a strong effect on the amount of salmonid spawning and, in the case of coho salmon, nursery habitat available in the Lower Klamath River mainstem. This point becomes particularly important during the spring–summer months when flows in tributaries to the Lower Klamath River are at their lowest level and, in the case of extremely dry years like 2001, contribute only a negligible amount of water to the mainstem of the river. Furthermore, because summer nursery habitat for salmonids in these "almost-dry" tributaries seems to become extremely scarce as flows go down, the mainstem of the river and some minor spring-fed brooks are likely to become the only refuge juvenile coho salmon (and steelhead) use to survive until fall.

During summer and in dry years, water releases at IGD contribute significantly to instream flows in the Klamath River. Because of the hydrology of the system, the climate of the region, and the number of tributaries present, the importance of IGD releases increases with river mile, according to a flow study conducted by the U.S. Geological Survey (1995). Therefore, the IGD to Shasta River reach is the one that relies the most upon IGD water releases. Based on USGS gage data, the BO estimates that, on average, between July and October, from 1962 to 1991, water releases at IGD contributed approximately 60 to 85percent of the river flows measured at Seiad Valley (Fig. 1), and 50 to 65percent of the river flows measured at Orleans (Fig. 1). These data also seem to indicate that the importance of IGD water releases increases during dry years; thus, late summer estimates have suggested that about 90percent of the river flow in the Seiad Valley was directly attributable to IGD water releases (NMFS 2001).

Considering both the above mentioned contributions of IGD releases to the Lower Klamath River flow and the preliminary field data provided by INSE (from its Phase II flow study, in preparation), the NMFS presented through its BO an RPA to replace the BOR's water-release plan for this critically dry year. The RPA states that under IGD releases of 1,700 cfs for April and May, coho salmon fry would have access to approximately 50percent of the maximum available habitat and chinook salmon fry would have access to close to 65percent of their nursery habitat. Through this process and aiming at maintaining between 40 and 65percent of the mainstem channel's salmonid habitat during different months, the RPA established the April–September minimum water releases at IGD. Such releases (both from the draft and final versions of the BO) are summarized in Table 2, along with FERC's minimum flows, the flows proposed by the BOR for dry and critically dry (like 2001) years. The table also includes the actual flows that were measured at IGD between April and September 2001 (obtained from the USGS Web site). Although the RPA flows recommended in the final version of the BO (NMFS 2001) stand out as relatively high when compared to those recommended by either FERC or BOR, they are much lower than the minimum instream flows recommended for the restoration and maintenance of aquatic resources by the

INSE's Phase I study (INSE 1999) (see Fig. 3). In fact, the RPA flows (NMFS 2001) are closer in magnitude to the minimum instream flows recommended by Trihey and Assoc. (1996) and by the Yurok Tribe (2001); however, the shape of the graphics (i.e., hydrographs) that these various flow regimes generate is somewhat different (Figure 3). The main difference between the instream flows recommended by FERC or BOR for a critically dry year, like 2001, and the ones requested by the BO (NMFS 2001), Trihey and Assoc. (1996), or the Yurok Tribe (2001), is during spring and early summer. Those who recommend higher flows argue that coho smolts (which have been rearing in the system for some 12 to 14 months and are ready to enter coastal waters) migrate to the ocean in the spring and are likely to benefit from relatively higher flows. The assumption behind the request for higher flows is that the higher the flow, the shorter the duration of the trip to the estuary and, therefore, the higher the survival coho smolts may enjoy. Although, there is no guarantee that the "additional" release of water will work as intended and make a difference in the final number of fish that survive their seabound migration, the assumption finds support in some studies on smolt migration and survival (see Sandercock 1991).

The BO's RPA clearly states the need to balance the needs for higher flows in the spring with the need for regulating flows in a manner that can ensure that after one of the driest winters in recent decades the limited water supply available would last until the fall. This balancing act may explain why the water release at IGD (1,700 cfs) requested in the RPA for the spring period, although higher than the one approved by FERC, is lower than the water releases asked for by Trihey and Assoc. (2,500 cfs) or the Yurok Tribe (2,100 cfs). In contrast, the instream flows requested for the first 2 weeks of June by the RPA show a slightly higher peak (2,100 cfs) than those petitioned for by other parties (except for the INSE) (Fig. 3). The rationale behind these "flushing" flows is that they could help the last coho salmon smolts move downstream and enter coastal waters before the water in the Lower Klamath River becomes too warm for salmon to survive. For the rest of the summer, July–September, the flows requested in the RPA remain constant at 1,000 cfs. Such flows are slightly more than the ones FERC established for July during critically dry years but they match the flow levels established by FERC and recommended by Trihey and Assoc. (1996) and the Yurok Tribe (2001) for the month of August. Contrary to what might be expected, the September flows requested in the RPA only match those that Trihey and Assoc. (1996) suggested but are lower than the flows established by FERC or asked for by the Yurok Tribe (2001). The slight increase in September's water discharge has been proposed to assist upstream migrating fall chinook salmon. This type of action is supported by a study on fall chinook passage in the Lower Klamath River by Vogel and Marine (1994), but only for late September and October. Based on the arguments presented in the RPA, the recommended instream flows for September seem to be another balancing act between what is needed for the maintenance of fish habitat in the short term and what can be released from IGD without risking insufficient water availability later on.

The Lower Klamath River has been listed as water-quality impaired by both Oregon and California under Section 303 (d) of the Federal Clean Water Act. Excessively high water temperatures, elevated nutrient concentrations, and the associated low dissolved oxygen levels have all been identified as important limiting factors for salmonids. The water release schedule requested in the RPA may help alleviate the effects of low in-steam flows on salmonid habitat, but it cannot solve water quality-related problems. This limitation, at least regarding water temperature, is due to the shallow characteristics of the Iron Gate Reservoir, which does not have a hypolimnion (i.e., lower and colder layer of water in a lake or reservoir) large enough to release relatively colder water into the river below. By increasing the volume of water present in the channel, it seems that the minimum instream flows requested in the RPA would help reduce the amplitude of the daily fluctuations in water temperature. This is likely to lessen the already high temperature-induced stress juvenile coho salmon may suffer in the Lower Klamath River. The effectiveness of this practice, however, is uncertain and deserves close examination.

There are important information gaps (e.g., coho salmon population structure, habitat distribution, juvenile migration patterns, water temperature regimes, water quality parameters, etc.) that need to be addressed in the Klamath River Basin before the effects of future water allocation decisions can be understood, anticipated, and minimized in an adequate and just manner. In the meantime, it is not surprising that agencies such as the NMFS, which are responsible for the management of common natural resources, may opt for a risk-averse approach when regulating instream flows during a critically dry year like 2001 in a river like the Klamath with listed coho salmon. Unfortunately, such a response is not satisfactory for many of the basin's stakeholders—either for those who contest that the recommended flows were not enough to avoid negative effects on the river's coho salmon stocks or for those who consider that instream flows do not affect fish habitat availability and fish abundance. Once additional information becomes available, it is hoped that the final decision on water allocation during years of scarcity will respond to the legitimate needs of Klamath River Basin's stakeholders through the development of an effective program of ecological and social restoration/protection that facilitates the coexistence of people and fish.

Figures And Tables

Fig. 1 will be a map of the Klamath River Basin.

Fig. 2. Mean Monthly Flows at Iron Gate Dam

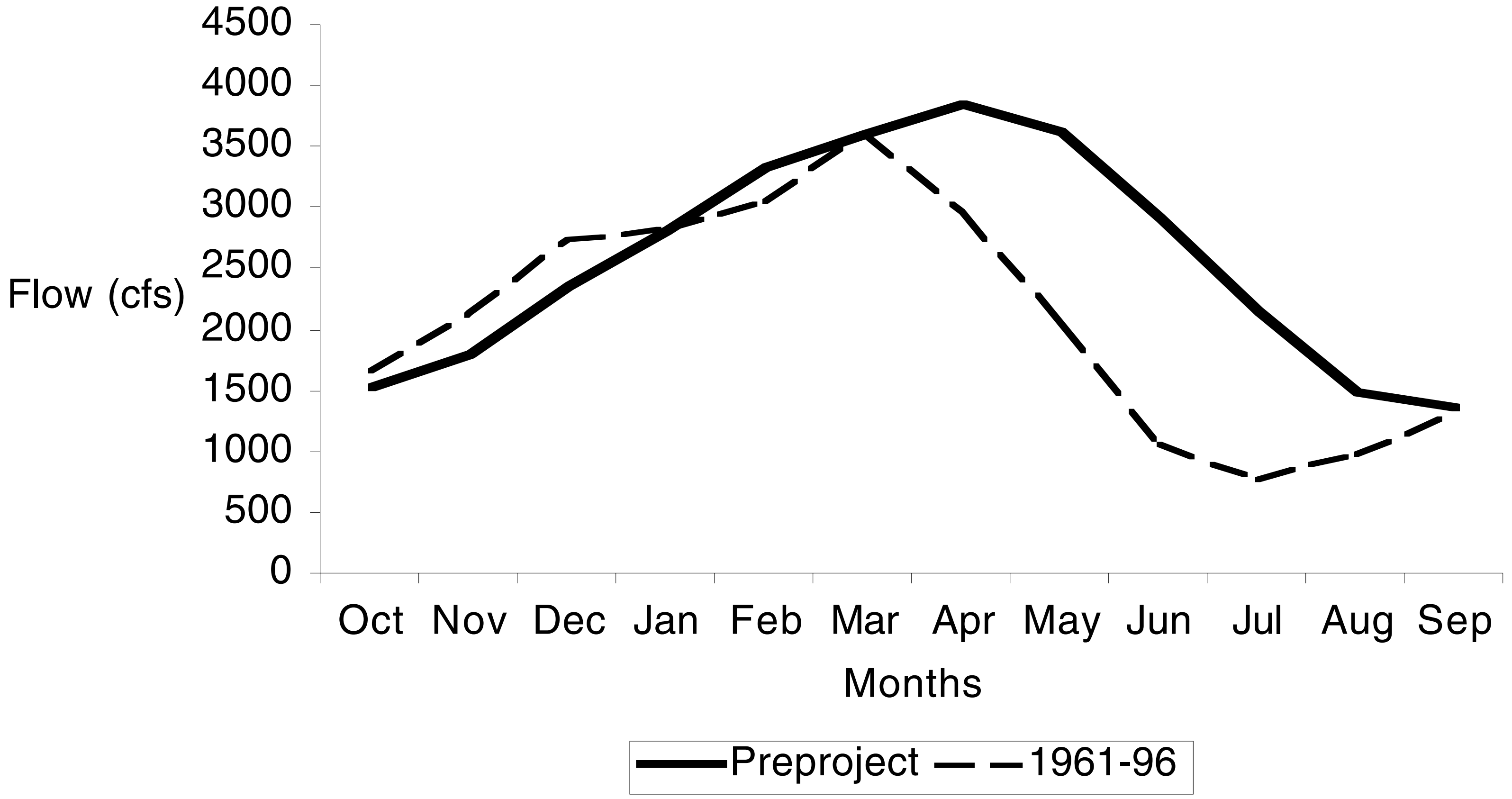

Fig. 3. Minimum Monthly Flows at Iron Gate Dam Proposed by Different Parties

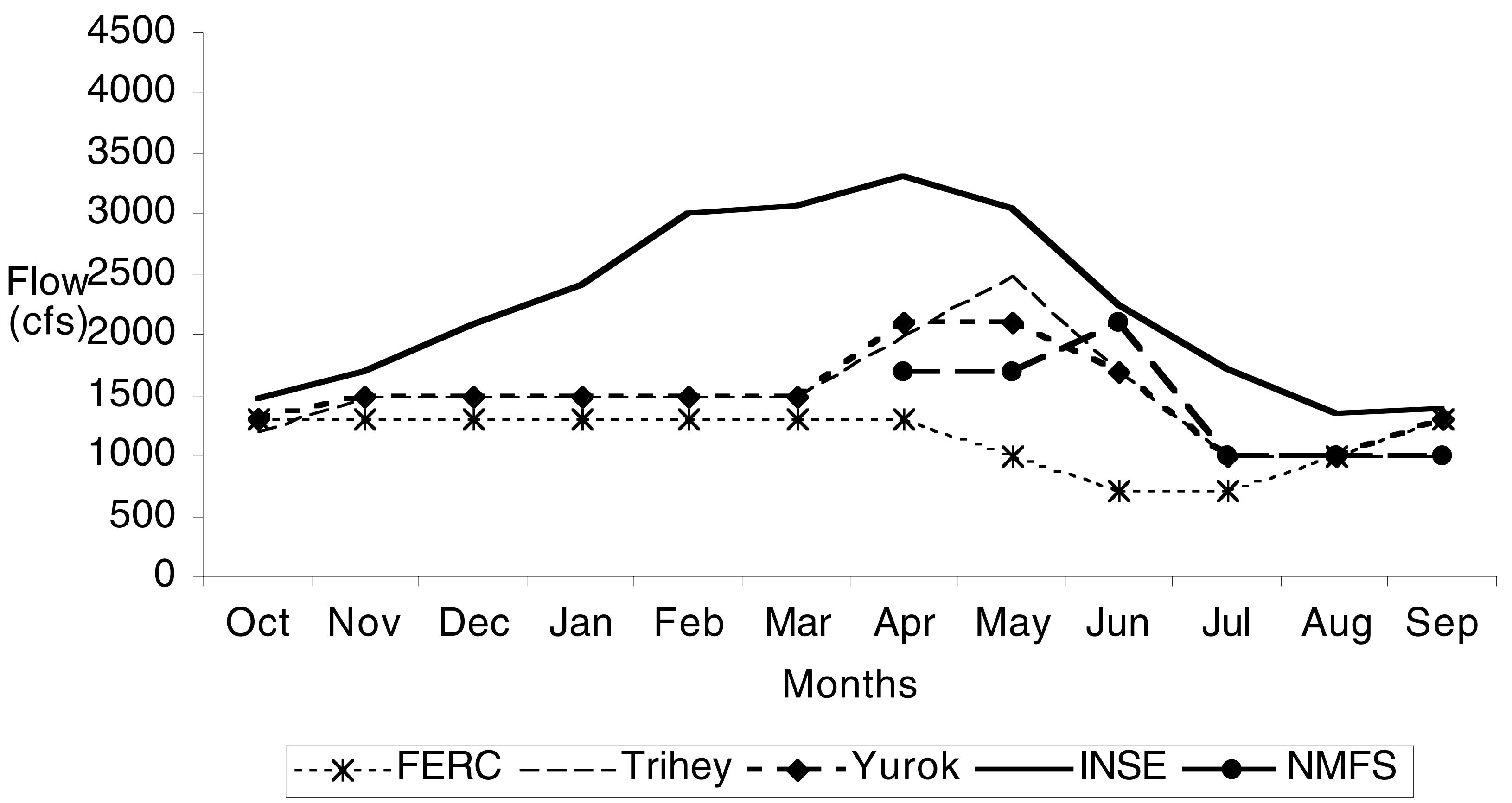

Table 1. Estimated pre-project mean monthly flows, mean monthly flows between 1961 and 1996, and recommended minimum monthly flows at Iron Gate Dam (data from INSE 1999).

Month	Mean Monthly Pre-project Flows (1905–12) (cfs)	Mean Monthly Flows (1961–96) (cfs)	FERC (cfs)	Trihey & Assoc. (Tennant) (cfs)	Yurok Tribe (cfs)	INSE (Mean Various Methods) (cfs)
October	1,536	1,664	1,300	1,200	1,300	1,476
November	1,809	2,142	1,300	1,500	1,500	1,688
December	2,358	2,744	1,300	1,500	1,500	2,082
January	2,827	2,825	1,300	1,500	1,500	2,421
February	3,331	3,047	1,300	1,500	1,500	3,008
March	3,604	3,601	1,300	1,500	1,500	3,073
April	3,857	2,970	1,300	2,000	2,100	3,307
May	3,627	2,046	1,000	2,500	2,100	3,056
June	2,930	1,050	710	1,700	1,700	2,249
July	2,147	758	710	1,000	1,000	1,714
August	1,503	970	1,000	1,000	1,000	1,346
September	1,370	1,303	1,300	1,000	1,300	1,395

Table 2. Recommended minimum monthly flows at Iron Gate Dam.

Date	**FERC Minimum Flows**	**BOR Proposed Dry Year average minimum flows**	**BOR proposed critically dry year minimum flows**	**NMFS *Draft* 2001 Biological Opinion Flows**	**NMFS *Final* 2001 Biological Opinion Flows**	**Actual Flows, 2001**
April 1–15	1,300	728	569	1,700	1,700	1,528
April 16–30	1,300	754	574	2,100	1,700	1,667
May 1–15	1,000	761	525	2,100	1,700	1,749
May 16–31	1,000	924	501	2,100	1,700	1,704
June 1–15	710	712	476	1,800	2,100	2,099
June 16–30	710	612	536	1,400	1,700	1,695
July 1–15	710	547	429	1,000	1,000	1,008
July 16–31	710	542	427	1,000	1,000	1,016
August	1,000	647	398	1,000	1,000	1,026
September	1,300	749	538	1,300	1,000	1,025

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