Evaluation of Interim Instream Flow Needs in the Klamath River

Phase II

Final Report

Prepared for:

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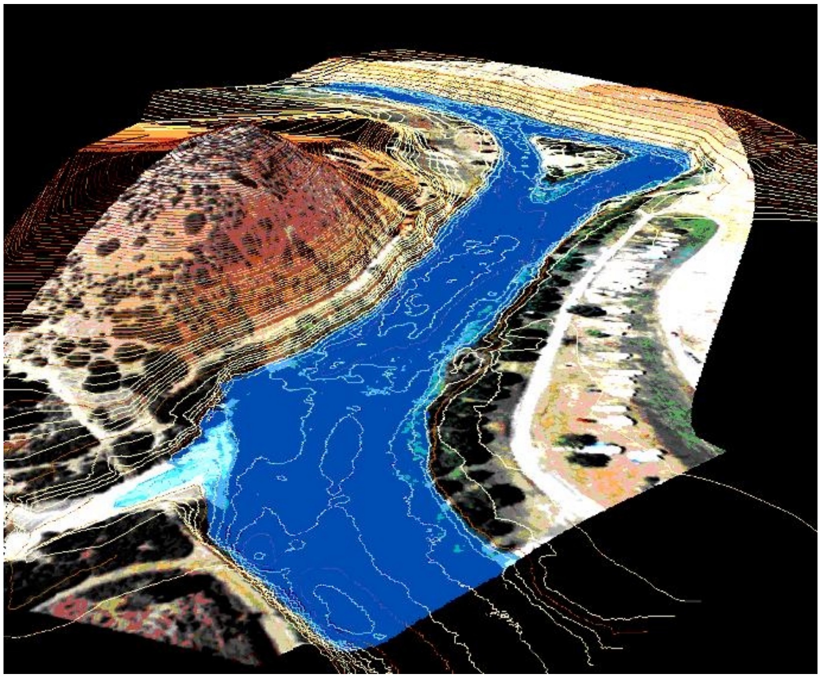

Prepared by:

Dr. Thomas B. Hardy
Mr. R. Craig Addley
Institute for Natural Systems Engineering
Utah Water Research Laboratory
Utah State University
Logan, Utah 84322-4110

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Executive Summary

Previous instream flow recommendations developed as part of Phase I (Hardy, 1999) recommended interim instream flows in the main stem Klamath River based on analyses of hydrology data. At that time, site-specific data suitable for analysis and evaluation using habitat based modeling were not available. This report details the analytical approach and modeling results from site-specific studies conducted within the main stem Klamath River below Iron Gate Dam downstream to the estuary. Study results are utilized to make revised interim instream flow recommendations necessary to protect the aquatic resources within the main stem Klamath River between Iron Gate and the estuary. This report also makes specific recommendations for future research needs as part of the on-going strategic instream flow studies being undertaken by the U.S. Fish and Wildlife Service and collaborating private, local, state, federal, and tribal entities.

This report was developed for the Department of the Interior (DOI) who provided access to a technical review team composed of representatives of the U.S. Fish and Wildlife Service, Bureau of Reclamation, Bureau of Indian Affairs, U.S. Geological Survey, and the National Marine Fisheries Service. The technical

review team also included participation by the Yurok, Hoopa Valley, and Karuk Tribes given the Departments trust responsibilities and the California Department of Fish and Game as the state level resource management agency. The technical review team provided invaluable assistance in the review of methods and results used in the analysis, provided comments on draft sections of the report, and provided data and supporting material for use in completion of the Phase II report. In addition, several agencies and private individuals provided written comments on the Preliminary Draft Report, which have been addressed in this report where appropriate.

This report is organized to follow the general process used to implement the technical studies. It first provides important background information on the historical and current conditions of the anadromous species, highlights factors that have contributed to their decline, provides an overview of the Phase I study process and its principal findings. The report then continues with a description of the Phase II technical study process. Key sections address methods and findings for each technical component such as study design, study site selection, field methods, analytical approaches, summary results, and recommended instream flows.

The Phase II study relied on state-of-the-art field data collection methodologies and modeling of physical habitat for target species and life stages of anadromous fish. The field methods were directed toward achieving a three-dimensional representation of each study site that incorporated between 0.6 to over one mile of river depending on the specific study site. At each study site, a spatially explicit substrate and vegetation map was developed and then integrated with the three-dimensional channel topography in GIS. Fieldwork also involved collection of hydraulic calibration data and fish observation data. The later information was used in the development of habitat suitability criteria, conceptual habitat model development and implementation, and habitat model validation efforts.

Hydrology in the main stem Klamath River below Iron Gate Dam was estimated differently for different purposes in Phase II. For example, we used simulated unimpaired inflows (i.e., no depletions) to Upper Klamath Lake routed to Iron Gate Dam with no Klamath Project imposed water demands. This simulated scenario represents the best available estimates of the unimpaired flows below Iron Gate Dam for the purposes of this study. The remaining flow scenarios included the use of Upper Klamath Lake net inflows, historical Klamath Project water demands, and the USFWS Biological Opinion (2000) target Upper Klamath Lake water elevations. These scenarios represent different potential operational flow scenarios as points of reference to the instream flow recommendations developed as part of Phase II. Differences between these simulated flow scenarios required the use of different models and/or modeling assumptions. The assumptions and modeling tools are described in the appropriate technical sections of the report. The estimated hydrology at each study site was used in both the physical habitat modeling and temperature simulations using the USGS Systems Impact Assessment Model (SIAM) or its components.

Physical habitat modeling at each study site relied on two-dimensional hydraulic simulations that were coupled to three-dimensional habitat models. The analytical form of the habitat models varied for spawning, fry, and ‘juveniles’ (i.e., pre-smolts). These modeling results were compared to available 1-dimensional cross section based hydraulic and habitat modeling at study sites that overlapped between existing USFWS/USGS and Phase II studies.

Habitat suitability criteria for target species and life stages of anadromous fish were developed from site-specific data for chinook spawning, chinook fry, and steelhead 1^+. These curves were validated both by field observations using the habitat modeling results as well as by comparison to results from an individual based bioenergetics model for drift feeding salmonids developed at USU. A separate procedure was developed to obtain habitat suitability curves for chinook juvenile (i.e., pre-smolts), steelhead fry, and coho fry based on available literature data. This approach used a systematic process to construct an ‘envelope’ habitat suitability curve that encompassed the available literature curves. The overall process included a validation component that compared the habitat versus discharge relationships between envelope curves to the site-specific curves for chinook spawning, chinook fry, and steelhead 1^+. The results validated the use of the envelope curves for use as interim criteria pending further research and development of site-specific curves for these species and life stages within the Klamath River.

Habitat modeling involved the integration of substrate and cover mapping with the three-dimensional topography and hydraulic properties at each study site with the habitat suitability curves. Habitat modeling was undertaken for chinook spawning, fry, and juveniles, coho fry and juveniles, and steelhead fry and steelhead 1^+. Different habitat models were developed for spawning, fry, and juveniles. The study generated a salmonid fry habitat model that incorporated a distance to escape cover that also required sufficient depth within the escape cover in order for it to be utilized at a given flow rate. This model also incorporated quantitative differences in the type of escape cover.

The habitat modeling results for each species and life stage were validated against the spatial distribution of each species and life stage surveyed at study sites at different flow rates. These results generally demonstrated that the integrated habitat modeling was validated for the study in terms of spawning and fry life stages. Our assessment of the pre-smolt or juvenile life stage results is that they are consistent for the existing habitat model assumptions. However, we discuss what we perceive to be inherent biases in these results (juveniles) based on the existing habitat model structure and make specific recommendations of what additional work would likely improve the results for this particular life stage.

Temperature simulations based on the unimpaired flow regime below Iron Gate Dam were conducted with HEC5Q as part of the SIAM applications. These results supported the findings in Phase I that flows lower than ~ 1000 cfs during the late summer would likely increase the environmental risk to anadromous species due to almost continual exposure to chronic temperature thresholds. We believe that these simulation results show that there is very little flexibility for reservoir operations at Iron Gate Dam to mitigate deleterious flow dependent temperature effects. This finding has previously been reported by the USGS (Bartholow 1995) and Deas (1999).

The integration of the habitat modeling with the unimpaired hydrology was used to develop habitat reference values for target species and life stages at each study reach on a monthly basis for flow exceedence ranges between 10 and 90 percent. The reference habitat value was computed as the percent of maximum habitat associated with the unimpaired flow values for each species and life stage on a monthly basis. This reference habitat value was used as one ‘target’ condition to guide the selection of monthly flow recommendations at a given exceedence flow level.

The flow recommendation process also employed a prioritization of species and life stages to be considered within the year and/or within a specific month. The prioritization of life stages was taken from the life history sequence of anadromous species (i.e., spawning, fry, and then juveniles). The initial priority order for species was defined as chinook, then coho, and finally steelhead. It is stressed that this initial prioritization was used to conceptually simplify the flow recommendation process only, and that all species and life stages were examined as part of the overall analysis. The process then relied on an iterative procedure to select target flows for each month at a given exceedence level. This procedure attempted to pick a target flow that would simultaneously preserve the underlying characteristics of the seasonal unimpaired hydrograph at that exceedence flow, the underlying relationship of the unimpaired hydrograph between all exceedence flow levels, while striving to maximize habitat for the priority species and life stages relative to the unimpaired habitat reference conditions. The corresponding monthly flow rates at each exceedence level were then used to compute the percent of maximum habitat for all other species and life stages in a given month. These values were then compared to their respective unimpaired habitat values to ensure that adequate protection of habitat for non–priority species and life stages remained reasonable.

The flow recommendations developed in the Iron Gate to Shasta River Reach were ‘propagated’ downstream to each successive reach by addition of the reach gains as presently defined by the USGS in their MODSIM module of SIAM. It is recognized that these reach gains reflect existing depletions in tributary systems (e.g., Shasta and Scott Rivers) but are the only estimates presently available for use in the simulation models for the system. The flow recommendations for each river reach were then used to compute the percent of maximum habitat on a monthly basis for each species and life stage. The recommended flow based calculation of percent of maximum habitat for each species and life stage was then compared against the associated unimpaired flow based habitat values.

Although flow recommendations were developed for the 10 to 90 percent exceedence range (i.e., nine water year types), five water year types were identified representing Critically Dry, Dry, Average, Wet, and Extremely Wet inflow conditions for Upper Klamath Lake. These water year classifications parallel those developed for the Trinity River and were used as operational definitions in the Phase I report. Furthermore, the USBR KPSIM model was modified to use this five-water year type format for simulating operations under different instream flow requirements below Iron Gate Dam. The 90, 70, 50, 30, and 10 percent exceedence flow levels were assigned to each of these water year types, respectively (i.e., critically dry to extremely wet). This assignment was used to demonstrate several key points regarding the use of recommendations at this level of resolution (i.e., five water year types) and how the existing operational models for the Klamath Project simulate flow scenarios.

These five water year type dependent recommendations were utilized in the U.S. Bureau of Reclamation’s Klamath Project Simulation Module (KPSIM) to simulate project operations over the 1961 to 1997 period of record. This analysis confirmed that the project could be operated to achieve these recommendations in all but 19 of the 468 simulated months in this period of record. These results also highlighted that an alternative water year ‘classification’ strategy for specifying instream flows should be considered in lieu of a five water year type scheme. We provide a specific recommendation of how this could be approached based on the instream flow recommendations developed in Phase II.

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Introduction

The determination of necessary instream flow requirements in the main stem Klamath River has received heightened attention since the passage of the 1986 Klamath River Basin Restoration Act, the development of annual and longer-term operations plans for the Bureau of Reclamation's Klamath Project, and the listing or proposed listings of Klamath River Basin anadromous fish. For the past 38 years, instream flows within the Klamath River below Iron Gate Dam have been substantially determined by the minimum flow regime specified at Iron Gate Dam under PacifiCorp's license from the Federal Energy Regulatory Commission. Although PacifiCorp is obligated to meet FERC minimum flows, they have generally operated the facility according to the Bureau of Reclamation Annual Operating Plans since 1996.

Interim flow recommendations for the Department of Interior were developed for the main stem Klamath River in Phase I (Hardy, 1999) using the best available scientific methods and data at that time. Those recommendations were made to address instream flows required to support the ecological needs of aquatic resources, particularly anadromous fish species, in the Klamath River below Iron Gate Dam. The Phase I report provided a review of available historical information on the physical, chemical and biological conditions within the Klamath River, and included information on the principal tributary systems in the Klamath Basin: Shasta, Scott, Salmon and Trinity Rivers. It included a synoptic overview of the life history requirements, spatial and temporal distributions, and potential limiting factors that may influence anadromous fish and other flow related aquatic resources.

Phase I provided a discussion of the hydrology based methods and analyses utilized for recommending interim instream flows. It emphasized the need for an ecologically based flow regime in order to protect the physical, chemical and biological processes necessary to aid in the restoration and maintenance of the aquatic resources in the main stem Klamath River. The recommended instream flows in Phase I were made on an interim basis pending the completion of more intensive, site-specific instream flow analyses that are the subject of this report (Phase II).

The purpose of the Phase II study is to provide revised recommendations for seasonal instream flows within the main stem Klamath River below Iron Gate Dam based on different water year types. These flow recommendations are necessary to aid restoration efforts and the maintenance of the aquatic resources within the main stem Klamath River in light of the Department of the Interior's trust responsibility to protect tribal rights and resources as well as other statutory responsibilities, such as the Endangered Species Act.

Revised recommendations are made in light of site-specific hydraulic, habitat, water quality and temperature analyses and the life history requirements of the anadromous species and other related flow dependent aquatic resources (e.g., aquatic macroinvertebrates). The Phase II recommended instream flows within the main stem Klamath River below Iron Gate Dam represent progress in the longer-term effort to restore anadromous fisheries within the Klamath Basin. Figure 1 provides an overview of the Klamath River Basin and shows the subbasin delineations used below in the description of factors affecting anadromous species. The Phase II technical assessments were confined to the main stem Klamath River between Iron Gate Dam and the estuary.

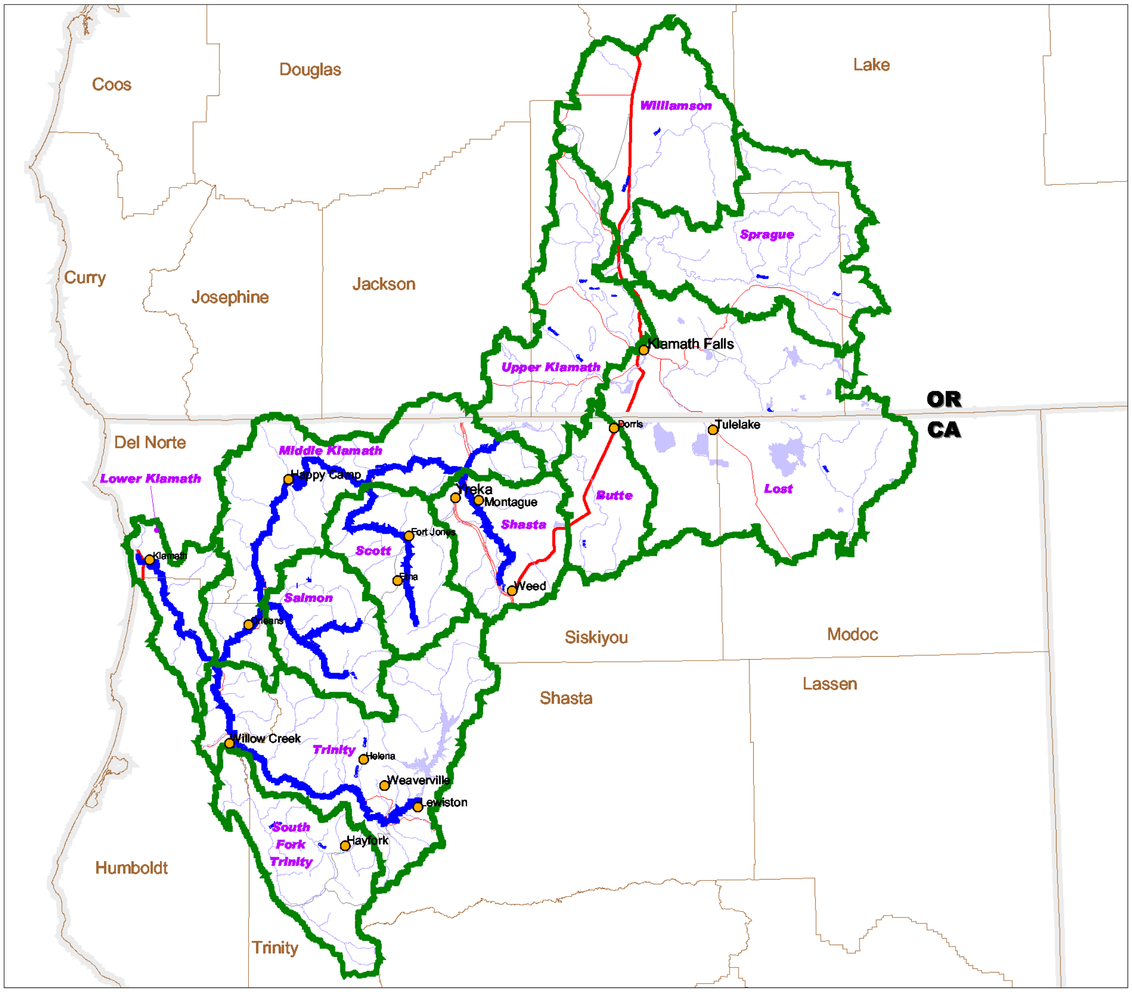


Figure 1. Klamath River Basin with major subbasin delineations.

Background

In this section of the report, key background information developed during the Phase I efforts are summarized. This information is intended to set the historical and existing context of the fisheries resources in the Klamath River Basin as a whole while providing specific information on the main stem Klamath River below Iron Gate Dam. Both historical and existing distribution maps for fisheries resources within the Klamath River Basin developed by the USFWS were a major source of information (CH2MHILL 1985). These maps were provided as Appendix A in the Phase I report. Additional information was used as noted in the citations below.

Overview of Fisheries Resources

The historical (pre-development) distribution of anadromous species within the Klamath River Basin extended above Upper Klamath Lake into the Sprague and Williamson River systems and Spencer Creek (Coots 1962, Fortune et al., 1966). Historical distributions in the Lower Klamath Basin (i.e., below Klamath Lake) included the Klamath main stem, Shasta, Scott, Salmon, and Trinity Rivers including many of the smaller tributary streams within the Lower Klamath River Basin.

The anadromous species that utilized the Upper Klamath River Basin included chinook salmon and probably included steelhead and coho (e.g., Coots 1954). The anadromous species in the Lower Klamath Basin include spring/summer, fall and winter run steelhead, spring and summer/fall run chinook, and coho. Other salmon reported from the Klamath include the chum and pink (Snyder 1930). The Klamath Basin Ecosystem Restoration report (Garret 1997) lists chum salmon as being extirpated from the Klamath Basin but infrequent captures of both chum and pink salmon still occur.

Other important fisheries resources include white and green sturgeon, pacific lamprey, coastal cutthroat trout, and eulachon (candlefish) (KRBFTF 1991). However, lack of historical quantitative collection data (i.e., pre-1900's) makes the determination of the historical distribution of these species difficult beyond that of the main stem and tributaries in the Lower Klamath River.

Historical Distribution

<u>Steelhead</u>

Historically, the Klamath supported large populations of spring/fall/winter run steelhead populations (Snyder 1930, CDFG 1959). Steelhead were distributed throughout the main stem and principal tributaries within the Lower Klamath Basin such as the Shasta, Scott, Salmon, and Trinity River basins, and many of the smaller tributary streams. Steelhead were also likely distributed in upstream tributaries of Upper Klamath Lake in the Upper Klamath Basin. Snyder (1930) and Fortune et al. (1966) indicate that steelhead were likely present in the Upper Basin in the Sprague and Williamson Rivers but that the historical data is inconclusive. Presently, steelhead are known to utilize the main stem Klamath River in cold water refugia at tributary confluences (Belchik, pers. com). The fall/winter run steelhead utilized the Salmon, Scott, Trinity, and South and North Fork Trinity Rivers. In addition, Elk, Clear, Indian, Independence and Blue Creeks are known to contain fall steelhead. Historically however, steelhead would utilize any tributary with access for spawning and juveniles would migrate upstream in tributaries even where spawning habitat did not exist. Summer run steelhead are known to utilize the Salmon, New, Scott and South and North Fork Trinity Rivers, Wooly, Redcap, Elk, Bluff, Dillon, Indian, Clear, Canyon, Camp, Blue, Grider and Ukonom Creeks (see citations in KRBFTF 1991).

Coho Salmon

The historical distribution of coho salmon in the Klamath River Basin is reported to have included 113 tributary streams in the Klamath-Trinity River drainage (Brown and Moyle 1991). Their historical utilization of the Upper Klamath Basin is not known from conclusive records (Fortune et al., 1966). Historical data document the collection of coho as far upstream as the Klamathon Racks (Snyder 1930) and they are now known to inhabit the Shasta, Scott, Salmon and Trinity River Basins. It is assumed that all tributaries with sufficient access and habitat supported coho.

Chinook Salmon

The historical distribution of chinook salmon in the Klamath River Basin is known to have extended above Klamath Lake into the Sprague and Williamson Rivers (Fortune et al. 1966). They were also distributed throughout the Lower Klamath Basin in the principal tributaries (i.e., Trinity, Scott, Shasta, and Salmon Rivers) and several of the smaller stream systems such as Fall, Jenny, and Bogus Creeks (Coots 1962). Historically, spring chinook runs were considered to be more abundant prior to the turn of the century (Moyle 1976, Moyle et al., 1989) when compared to the dominance of summer/fall runs since that time (Snyder 1930). Spring chinook were historically collected in the vicinity of the current Iron Gate Dam (Iron Gate Hatchery records). During the pre-1900s some of the spring run chinook were destined for the Salmon River, other lower main stem tributaries and likely tributaries upstream of Klamath Lake (Snyder 1930, Fortune et al. 1966). The apparent shift to a summer/fall run population occurred by the end of the first decade following 1900 (see citations in Snyder 1930, Moffett and Smith 1950).

Green (and White) Sturgeon

No quantitative data on the historical upstream distribution of green or white sturgeon are known but they have been observed in the main stem Klamath River as far upstream as Iron Gate Dam. It is not known whether Klamath Lake would have posed an upstream migration barrier. Sturgeon are still found in Klamath Lake but are thought to be extremely rare (Belchik, pers. com.). Green sturgeon have also been observed in the Trinity and South Fork Trinity Rivers, and in the Salmon River (see citations in KRBFTF 1991).

Coastal Cutthroat Trout

Coastal cutthroat trout are known to be distributed throughout the lower Klamath River tributaries but the population status and distributions are poorly known. Collections from the estuary, lower tributaries, and Hunter Creek are documented (see citations in KRBFTF 1991).

Eulachon (Candlefish)

Eulachon are thought to be extremely rare or extirpated in the Klamath River (Belchik, pers. com.). Historical data suggests that they utilized the lower 5 to 7 miles of the Klamath River during March and April for spawning. Eggs incubate for approximately two to three weeks and the larvae then migrate back to the ocean (Moyle 1976 as cited in KRBFTF 1991).

Pacific Lamprey

The distribution of lamprey in the Klamath River is poorly known. Lamprey have been observed on salmon at the Klamathon Racks and they have been collected from Cottonwood Creek near Hornbrook (Coots 1962). This may represent a non-anadromous form in the Klamath Basin. Lamprey have also been observed in the Trinity River and dwarfed landlocked forms have also been reported from the Klamath River above Iron Gate Dam and in Upper Klamath Lake. Lamprey are also suspected of utilizing the Scott, Shasta, and Salmon Rivers (see citations in KRBFTF 1991).

Current Distribution

At the present, habitat of anadromous salmonids is limited in the Klamath River Basin to the main stem and tributaries downstream of Iron Gate Dam. Upstream distribution in several of the tributaries (e.g., Trinity) has also been limited due to construction of dams and diversions. Access to the Upper Klamath Basin by anadromous species was effectively stopped with the completion of Copco Dam No. 1 in 1917 although reduced access to tributaries in the Upper Klamath Basin likely occurred starting as early as the 1912-14 period with construction of the Lost River diversion canal and completion of Chiloquin Dam. Access to the upper reaches of the Trinity River and its tributaries were blocked in 1961 with completion of Lewiston Dam. The final reduction in upstream main stem habitat access occurred in 1962 with the completion of Iron Gate Dam. The following synopsis on the existing distribution of key species was primarily adopted from CH2MHILL (1985) and USBR (1997) and references contained in the annotated bibliography of Appendix C in the Phase I report.

Overall Population Trends in Anadromous Species

The following section provides a brief synopsis of the population trends for steelhead, coho, and chinook salmon within the Klamath Basin. Unless otherwise noted, this material is taken from the coho and steelhead status review documents of the National Marine Fisheries Service and the Biological Assessment on the Klamath Project 1997 Operations Plan.

Steelhead

Run sizes prior to the 1900s are difficult to ascertain, but were likely to have exceeded up to several million fish. This is based on the descriptions of the salmon runs near the turn of the century provided in Snyder (1933). The best quantitative historical run sizes in the Klamath and Trinity river systems were estimated at 400,000 fish in 1960 (USFWS 1960, cited in Leidy and Leidy 1984), 250,000 in 1967 (Coots 1967), 241,000 in 1972 (Coots 1972) and 135,000 in 1977 (Boydston 1977). Busby et al. (1994) reported that the hatchery influenced summer/fall-run in the Klamath Basin (including the Trinity River stocks) during the 1980's numbered approximately 10,000 while the winter-run component of the run was estimated to be approximately 20,000. Monitoring of adult steelhead returns to the Iron Gate Hatchery have shown wide variations since monitoring began in 1963. However, estimates during the 1991 through 1995 period have been extremely low and averaged only 166 fish per year compared to an average of 1935 fish per year for 1963 through 1990 period (Hiser 1994). In 1996 only 11 steelhead returned to Iron Gate Hatchery. NMFS considers that based on available information, Klamath Mountain Province steelhead populations are not self-sustaining and if present trends continue, there is a significant probability of endangerment (NMFS 1998). However, steelhead were not listed under the ESA.

Coho

At present, coho populations are substantially lower than historical population levels evident at the turn of the century and are listed as threatened under the ESA. NMFS estimated that at least 33 populations are at moderate to high risk of extinction at this time. Coho populations within the Southern Oregon/Northern California Coast Evolutionarily Significant Unit (ESU), which includes the Klamath River Basin, are severely depressed and that within the California portion of the ESU, approximately 36 percent of coho streams no longer have spawning runs (NMFS 1997). Annual spawning escapement to the Klamath River system in 1983 was estimated to range from 15,400 to 20,000 (USFWS 1983, cited in Leidy and Leidy 1984). These estimates, which include hatchery stocks, could be less than 6 percent of their abundance in the 1940's and populations have experienced at least a 70 percent decline in numbers since the 1960's (CDFG 1994 as cited by Weitkamp et al. 1995). Monitoring of coho returns at the Iron Gate Hatchery have ranged from 0 fish in 1964 to 2,893 fish in 1987 and are highly variable. Based on limited monitoring data from the Shasta River, coho returns have been variable since 1934 and show a great decrease in returns for the past 7 years.

Chinook

The total annual catch and escapement of Klamath River chinook salmon in the period between 1915 and 1928 was estimated at between 300,000 and 400,000 (Rankel 1982). Coots (1973) estimated that 148,500 chinook entered the Klamath River system in 1972. Between 1978 and 1995 the average annual fall chinook escapement, including hatchery-produced fish was 58,820 with a low of 18,133 (CDFG 1995). Overall, fall chinook numbers have declined drastically within the Klamath Basin during this century. As noted previously, spring chinook runs appear to be in remnant numbers within the Klamath River Basin and have been completely extirpated from some of their historically most productive streams, such as the Shasta River (Wales 1951).

Factors Attributed to the Decline of Anadromous Species

Basin Wide Overview

The decline of anadromous species within the Klamath River Basin can be attributed to a variety of factors which include both flow and non-flow factors. These include over harvest, affects of land-use practices such as logging, mining, stream habitat alterations, and agriculture. Other important factors have included climatic change, flood events, droughts, El Nino, fires, changes in water quality and temperature, introduced species, reduced genetic integrity from hatchery production, predation, disease, and poaching.

Significant effects are also attributed to water allocation practices such construction of dams that blocked substantial areas from upstream migration and have included flow alterations in the timing, magnitude, duration and frequency of flows in many stream segments on a seasonal basis. The following synopsis is taken primarily from CH2MHILL (1985), USBR (1997), KBRBFTF (1991) and references contained in the annotated bibliography contained in Appendix C in the Phase I report.

Based on a review of the literature examined during the Phase I study, it is reasonable to assume that the Klamath River Basin was primarily in a natural state prior to about 1800. However, by the mid 1800s a variety of factors were already contributing to the decline of the anadromous stocks. During this period both accelerated timber harvest, placer/gravel/suction mining, and commercial exploitation of salmon stocks were underway.

Over exploitation of the commercial fisheries (ocean and in river), placer mining, and local dam construction were attributed to declining salmon stocks as early as the 1920s. Snyder (1930) considered the decline of the spring run chinook to have occurred prior to the closure of the river at Copco in 1917 and attributed this decline primarily to over exploitation of the salmon stocks and activities associated with placer, gravel, and suction mining in the Basin. The concern of over exploitation and declines in the anadromous stocks of the Klamath River Basin led to the closure of commercial fishing in 1933. Prior to the 1990's, excessive ocean harvest rates seriously reduced salmon stock abundance in the Klamath River System.

Passage of the Pacific Fisheries Management Council's Salmon Plan in 1978, followed by the formation of the Klamath River Salmon Management Group in 1985 and the Klamath River and the Klamath Fisheries Management Council in 1987 has led to improved management of Klamath Basin fisheries resources. During the 1980's, ocean harvest rates on age-4 Klamath fall chinook averaged 53 percent (PFMC 1991), however since 1991 the average age-4 ocean harvest is less than 12.5 percent (PFMC 1998). This reduction in ocean harvest is partially due to the recognition of river tribal fishing rights, as well as to regulations for conservation of Klamath Basin fall chinook. Age-4 river harvest rates have also substantially declined since 1990, dropping from an average of 65 percent from 1986-1989 to an average of 32 percent following 1989.

Timber harvest activities within the Klamath River Basin have also contributed to the long-term decline in the salmon stocks beginning from the turn-of-the-century. This included deterioration of habitat from increased sediment loading and general deterioration of large-scale watershed areas. The extensive placer/gravel/suction mining within the Basin resulted in serious habitat modifications beginning in the early 1900s and directly impacted salmon runs during this period. The extensive habitat modifications to both the main stem and tributary systems are still evident today (e.g., the Scott River).

Although upstream migration of the anadromous stocks were effectively blocked with the construction of Copco Dam in 1917, water allocation practices to meet agricultural demands in the upper Klamath Basin continued to affect downstream anadromous species due to alteration in the shape and magnitude of the hydrograph below Iron Gate Dam.

Diversion of water to meet agricultural demands in both the Scott and the Shasta River systems has been implicated as causing significant reductions in habitat availability and quality for spawning and rearing chinook. Depletions of stream flow in the Scott River and almost every tributary within this subbasin are associated with severe limitations for coho and steelhead juvenile rearing habitat availability and stranding of juvenile fall chinook, coho, and steelhead during the irrigation season in average and below average water years. Diversion of water for agricultural purposes and the associated return flows are responsible for higher than normal water temperatures and degraded water quality in both the Shasta and Scott River systems.

Spring run chinook and spring run steelhead are considered to be extinct or at remnant population levels in the Scott and Shasta rivers largely as a result of poor summer flow conditions. Iron Gate Dam has also blocked access to several cool water springs and tributaries (Jenny and Fall Creeks) below Copco Dam that were utilized by spring chinook. These creeks and the main stem Klamath River supported chinook prior to construction of Iron Gate Dam (Kent Bulfinch, pers. com. cited by Belchik, pers. com.).

Although historical data does not exist to determine the temperature and water quality regime of the main stem Klamath River below Klamath Lake, existing flows below the Scott River during the late summer period have been associated with lethal combinations of high temperature and low dissolved oxygen, as evidenced by fish kills. Bartholow (1995) evaluated available water temperature data in the Klamath Basin and generally concluded that during low flow summer periods the natural conditions in the Klamath main stem are likely marginal for anadromous species due to elevated temperature. However, existence and use of thermal refugia is well documented.

It is evident from a review of the available data that the completion of Copco Dam in 1917 and completion of Trinity Dam in 1962 significantly reduced the Basin wide distribution of anadromous species. However, the construction of localized dams associated with placer, gravel, and suction mining, timber harvest, and fisheries practices impacted anadromous species prior to these major dams. For example, a splash dam constructed on the main stem Klamath River at Klamathon in 1889 effectively blocked upstream migration of anadromous species to the upper Klamath Basin until 1902.

Effective blockage of several tributary streams by dams for mining also occurred in the 1930s, many of which were not removed until the 1950s. This included Hopkins, Camp, Indian, Beaver, Dutch and Cottonwood Creeks on the main stem Klamath, and several tributaries in both the Salmon and Scott River basins. Dwinell Dam was completed in 1928 on the upper Shasta River, which effectively blocked upstream migration. No minimum instream flow was required at this facility.

The existence of Trinity/Lewiston Dams, and Iron Gate Dam, and Dwinell Dam are also attributed to negative changes to the quality and quantity of available spawning gravels suitable for use by anadromous species below these facilities. Prior to the construction of Iron Gate Dam, hydropower releases (i.e., rapid flow ramping) were also associated with deleterious conditions for spawning and young of the year anadromous species in the main stem Klamath River. Iron Gate operations have flow ramping rate criteria under Article 40 of PacificCorp FERC License that states that a ramping rate not to exceed 3 inches per hour or 250 cfs/hour whichever produces the least amount of fluctuation as measured at the Iron Gate gage. PacificCorp voluntarily targets ramp rates at Iron Gate gage to approximate two inches per hour (Frank Shrier, pers. com.).

Large-scale changes in the channel form below Trinity Dam are also known to have resulted in loss of productive salmon rearing habitat. Restoration of the channel is being recommended in the Trinity River Flow Evaluation Report (USFWS et al., 1998). Recommendations from this study include both modifications in the minimum instream flow requirements as well as the release of flood flows for rehabilitation of the riparian community and stream channel.

Additional factors that impacted the anadromous species in the Klamath Basin have included high pre-spawning mortalities in the 1950 through 1953 period and adverse effects due to extreme flooding in 1955, 1964, and 1974 and drought during 1976-77. The pre-spawning mortality was associated with hatchery produced fall chinook returning to the Fall Creek Hatchery where over escapement to the Hatchery resulted in fish being forced back into the Klamath River where a lack of natural spawning gravel caused redd superimposition. In addition, higher mortalities associated with angling are also suspected (see Appendix C in Phase I report).

The extensive and extreme magnitude of fires in 1987 is also considered to have been deleterious to anadromous species due to the increased run off from the disturbed watersheds within the Klamath Basin. Cumulative impacts to many of the tributary watersheds in conjunction with alteration of the hydrograph below Iron Gate Dam have contributed to the formation and persistence of large delta fans at tributary confluences. These fans during periods of low flow may inhibit or have completely blocked access to these tributaries by anadromous species.

Finally, concern has been raised over increased predation of anadromous species by the resurgence of the sea lion populations at the mouth of the Klamath River and predation by brown trout below Lewiston Dam on the Trinity River. Although these other cumulative factors have contributed to limiting conditions for many of the aquatic resources, reduction in habitat access due to existing dams and continuing alterations of the flows (with associated deteriorated water quality) remain important limiting factors. In particular, this includes the main stem Klamath River.

The Upper Klamath Basin

The construction of Copco Dam was started in 1910 and likely impacted upstream migration of anadromous species at that time. The Dam was completed in 1917 and effectively eliminated over 100 miles of potential anadromous fish habitat in the upper Klamath Basin. The continuing effect on the Lower Klamath Basin is primarily due to changes in the hydrology and potentially water quality. Releases below Iron Gate Dam have been associated with water temperatures above acute salmonid exposure criteria (i.e., 20 C) and dissolved oxygen below chronic exposure levels (i.e., 7 mg/l) during the late summer. Most water quality problems within the main stem Klamath River associated with fish kills have been reported below the Scott River. Although as noted previously, naturally high water temperatures likely existed prior to main stem dam construction. This was due to the large surface areas associated with Upper and Lower Klamath Lakes. Ssome mitigating cool water inflows from springs and tributaries likely offset these temperatures to some extent and provided cool or cold water refugia to salmonids. Water allocation practices to meet agricultural demands now result in higher winter flows and lower summer flows compared to the natural hydrograph. Poor water quality arising from Upper Klamath Lake is a combination of natural high concentrations of nutrients in tributaries of Klamath Lake and nutrient enrichment due to land-use practices in the upper Basin. It may be difficult to ameliorate water quality in the Lower Klamath Basin given the water quality characteristics in the Upper Klamath Basin. Increased flows are anticipated to improve water quality to some degree, but changes in water management and land use practices may also be required to fully address water quality issues in the lower basin.

The Shasta Subbasin

Water quality in the Shasta River has been impacted by the creation of Lake Shastina in 1928. This reservoir receives high nutrient loading due to upstream land-use practices. Problems associated with adverse water temperatures for anadromous species have been recognized in the Shasta River for over 20 years, which are attributable to the numerous water diversions on the Shasta River and its tributaries and agricultural practices within the Basin. The Shasta River has been highly impacted from grazing practices. The lack of large woody debris in the stream and loss of recruitment potential has decreased the complexity of the river channel for many years. The loss of significant riparian areas from over grazing has also contributed to elevated adverse water temperatures. Several tributaries are also poorly connected to the main stem Shasta (e.g., Little Shasta Creek) and very low dissolved oxygen levels occur in some reaches during critical low flow summer periods (Deas, pers. com.).

Historical anadromous fish using the Shasta River basin include fall chinook, coho, fall steelhead and Pacific lamprey. Historical data indicate a decline in chinook spawning runs within the Shasta Basin since the 1930s. Available data for both coho and steelhead spawning runs are not entirely reliable to ascertain long-term population trends, although steelhead is considered to have experienced declines.

It is estimated that the Shasta River presently maintains approximately 35 miles of fall chinook habitat and 38 miles of coho habitat and are similar to values reported in 1955 but remain below pre-development levels. However, actual utilization of this remaining habitat is contingent upon suitable flow conditions that may not be met during average and dry years due to water diversion. Fall steelhead habitat is estimated at approximately 55 miles and is somewhat reduced compared to estimates derived in 1955.

Lake Shastina has likely blocked suitable habitat upstream that was historically utilized by steelhead in the headwaters of the Shasta River. The lack of gravel recruitment below Lake Shastina may also negatively affect river morphology and fish habitat. Accessibility to the currently available steelhead habitat is contingent upon suitable flow conditions and lack of migration barriers at agricultural diversions (see Appendix A in Phase I report).

Overall, anadromous fish production in the Shasta River basin is thought to be limited by low flows and high summer water temperatures, stream diversions and degraded spawning gravels. Cumulative depletions of water for agricultural use during the May through October period of average and dry years may restrict access by fall chinook to the lower 10 to 15 miles of the river. Low flow conditions during these types of water years also reduce suitable rearing habitat for both coho and steelhead juveniles.

In this area however, water quality in the Big Springs area remains tolerable for rearing juveniles through the summer months. These conditions are exacerbated due to increased water temperatures that can exceed upper limits for the anadromous species. These conditions have resulted in a known fish kills for juvenile steelhead. Additional impacts within the Basin are associated with grazing practices that can result in increases in sedimentation that adversely affects steelhead spawning and rearing habitats. No quantitative data on the distribution or abundance of Pacific lamprey is currently known.

The Scott Subbasin

Principal factors affecting the distribution and quality of habitat within the Scott River basin are associated with the numerous agricultural diversions along the main stem of the River and its tributaries as well as the loss of beavers, grazing and levies which have contributed to degradation of habitat and alterations in the Scott River channel. Existing diversions within the main stem Scott River and its tributaries exceed 650 cfs. The cumulative effects of these diversions are severely depleted instream flows in many sections. Additional flow reductions, including dry channels, have been associated with groundwater pumping for irrigated land use, which affect both tributary streams as well as the lower main stem Scott River.

Current anadromous use of the Scott River includes fall chinook salmon, coho salmon, fall steelhead, and Pacific lamprey. Fall chinook salmon are known to utilize the main stem Scott River and several of its major tributaries. It is believed that both coho and steelhead are more widely distributed but no quantitative information exists to estimate runs sizes. Trend data on chinook salmon would appear to indicate a general decline in the Scott River basin since the 1960s at least. In the absence of more quantitative data it is assumed that the trends in coho and steelhead within the Scott subbasin are reflected in the overall trends for the remainder of the Klamath Basin at-large.

However, during the past decade, steelhead numbers (fall, winter and spring/summer-run) have declined dramatically on the Klamath River side of the Klamath Basin relative to numbers found on the Trinity River side. Many of the index streams in this area of the Basin have their headwaters in wilderness areas, suggesting the limiting environmental bottleneck is in the main stem Klamath River (CDFG, pers. com.). It is estimated that approximately 59 total river miles of habitat within the Scott River, East Fork Scott River and lower Mill Creek currently exist for fall chinook. The estimated historical miles of available coho salmon habitat in the Scott River basin was 126 miles. Available data suggests that existing habitat now constitutes approximately 88 miles. The estimated extent of steelhead habitat is approximately 142 miles within this Basin (see Appendix A in Phase I report).

The anadromous fish production within the Scott River basin is impacted by reduced flows, degraded spawning habitat, high summer water temperatures, and several un-screened diversions. Cumulative water withdrawals in conjunction with groundwater pumping during the agricultural season of May to October currently limits upstream migration for fall chinook at approximately River mile 42. In average to dry years these low flows severely limit both coho and steelhead juvenile rearing habitat suitability and availability during the May to October period. These low flows in conjunction with agricultural return flows are also associated with high water temperatures in the main stem Scott River and many of its tributaries. Land-use practices have been noted to cause increase sedimentation problems over most of the main stem Scott River.

The Salmon Subbasin

The Salmon River represents one of the most pristine watersheds still existing within the entire Klamath River basin. Although a high percentage of the Salmon River is under a wilderness designation, other areas have significant road networks and have undergone significant timber harvest. In addition to the timber harvest practices, grazing and the 1987 fire have had negative affects on the Salmon River watershed and Salmon River channel. The Salmon River supports spring and fall chinook salmon, coho salmon, spring and fall steelhead, Pacific lamprey and green sturgeon. Fall chinook populations within the Salmon River have shown declines that are associated with factors external to the Salmon River.

Insufficient data presently exists to make inferences on the status of coho populations within the Salmon River, but they are believed to reflect overall trends within the Lower Klamath River Basin. The current status of steelhead populations are also not known, but again, summer steelhead numbers have stayed depressed in the Salmon River drainage and numerous other tributaries such as Clear Creek, Bluff Creek and Dillon Creek (CDFG, pers. com.). No quantitative information on the distribution and status of Pacific lamprey is known. No quantitative information on the status of green sturgeon populations is known although they are considered to inhabit the lower six miles of the Salmon River.

Current estimates of fall chinook habitat within the Salmon River are approximately 81 miles, which is approximately nine miles less than the highest historical estimates. Historical estimates of coho habitat within the Salmon River and its tributaries are approximately 105 miles. Existing estimates are approximately 85 miles. Historical estimates for steelhead within the Salmon River do not exist but they are assumed to be similar to that of coho and therefore are approximately 109 miles (see Appendix A in Phase I report).

No significant impediments to anadromous fish production within the Salmon River basin currently exist. However, areas of unstable spawning gravels have been identified in reaches of both the North Fork and South Fork Salmon Rivers. Finally, elevated water temperatures that exceed upper growth requirements for salmonid juveniles have occasionally been reported. These events are attributed to natural climatic factors.

The Mid-Klamath Subbasin

The Klamath Task Force defines the Mid-Klamath Subbasin as the main stem Klamath River from Iron Gate Dam to Weitchpec. This section of the main stem Klamath River can be impacted by water quality from upstream releases at Iron Gate during low flow periods. Elevated water temperatures during the late summer period have been observed. In the past decade this reach of the main stem Klamath River has been impacted by reductions in water quality as a consequence of timber management and mining activities. These are primarily associated with increased turbidity. Water releases at Iron Gate Dam due to Klamath Project operations impact main stem river flows in this reach of river. Water allocation practices within both the Shasta and Scott River basins also contribute to flow alterations in this reach of river. Changes in the flow regime are generally reflected in increased winter flows and reduced summer flows when compared to historical conditions as noted by USGS (1995) and Balance Hydrologics, Inc (1996).

The main stem Klamath River and many of its tributaries are utilized by spring and fall chinook salmon, coho, and spring and fall steelhead. Pacific lamprey and green sturgeon are also known to utilize this reach of river. The main stem Klamath should not be considered only a migration corridor. In 1995, over 6,000 fall chinook spawned in the main stem (USFWS pers. com.). The production from these spawners must rear in the main stem until smoltification occurs. In addition to the main stem recruitment, tributary pre-smolt outmigrants must rear in the main stem until smoltification. These fish rely on the main stem Klamath River for up to 2 years. Lamprey and sturgeon rely on rearing in the Klamath River for up to 5 or 6 years and 1 to 3 years, respectively. In addition, spawning in the main stem by chinook is known to occur from below Iron Gate downstream to Orleans. Overall trends in anadromous fish for this subbasin generally reflect the long-term declines for the Klamath River basin as noted previously. The remaining chinook populations are primarily composed of fall run. The specific status of coho within this reach of the main stem Klamath River and tributaries is also difficult to ascertain due to lack of site-specific quantitative data. In general it is assumed that populations follow the general trend for the Lower Klamath River basin. This also applies to steelhead. No quantitative data are available on the status or distribution of Pacific Lamprey but they are believed to be distributed similar to that of steelhead. No quantitative data for green sturgeon populations are available for this reach of river.

Estimated available habitat for spring and fall chinook is approximately 168 miles within this subbasin. The estimated available habitat for steelhead within this section of the mid Klamath Basin is approximately 250 miles of spawning and rearing habitat. Coho are estimated to have access to approximately 190 miles (see Appendix A in Phase I report).

Principal factors affecting anadromous fish production within this section of the Klamath Basin include high water temperatures and poor water quality (e.g., pH and dissolved oxygen), suspected loss of spawning gravels, flow reductions for some tributary systems, flow depletions within the Upper Klamath River Basin and altered characteristics in the timing and magnitude of main stem flows. In addition, Highway 96 and parallel roads to the main stem and tributaries have impacted fish habitats and access. Alterations in the channel due to upstream dams have been associated with armoring of the stream bed and lack of gravel recruitment from blocked upstream sources. Land-use practices in several of the tributaries have resulted in sedimentation that has adversely impacted fall chinook, steelhead, and coho production in Dry, Ten Mile, Elk, Indian, and Thompson Creeks. Several tributaries are also impacted by agricultural diversions either from un-screened diversions or flow reductions during the agricultural season. Land use practices such as logging, homesteading, road building, grazing, etc, have impacted many tributaries within this Subbasin and those mentioned previously are just examples.

The Trinity Subbasin

In the following section for the Trinity Subbasin, the discussion of the factors that have affected anadromous species are broken down into the three distinct areas. These three areas are the Upper, Middle, and Lower Trinity Subbasins.

This convention was retained to be consistent with previous work and is the terminology utilized in the Phase I report.

Upper Trinity Subbasin

With the completion of Trinity Dam and Lewiston Dam, access to the entire upper Trinity subbasin was effectively blocked for all anadromous species in 1962.

This included spring and fall chinook salmon, coho, steelhead, and Pacific lamprey that were known to utilize this subbasin for spawning and rearing habitat (see Appendix A in Phase I report). Estimated losses for chinook spawning habitat is 59 miles and 109 miles for steelhead habitat. It is unknown how much coho habitat was lost but it would likely be similar to chinook.

Prior to 1981, flows in the Trinity River below Lewiston were reduced by approximately 80 percent. In addition to a substantial reduction in the base flow regime, operations eliminated almost all flood events. This resulted in substantial channel alterations in the main stem of the Trinity River that are associated with deleterious conditions for anadromous species and major changes in the channel form. Pending the completion of the Trinity River Flow Evaluation Report and the associated EIS/EIR flows currently in the main stem Trinity River remain significantly reduced.

The Mid-Trinity Subbasin

Flow releases below Lewiston Reservoir had historically resulted in colder water temperatures during the summer and warmer temperatures during the winter when compared to natural conditions, and these conditions have adversely impacted anadromous species. Alterations in the flow regime to address these issues are currently underway. During the period of 1963 and 1981 flows in the main stem Trinity below Lewiston Dam were reduced by approximately 80 percent and peak flows were essentially eliminated. This resulted in a substantial narrowing of the river channel and fossilization of point bars by riparian vegetation. This was associated with reduced quantity and quality of anadromous rearing habitat. Subsequently, improved minimum instream flows as well as initiation of higher flow events have been undertaken in an attempt to rehabilitate the river channel and associated riparian community.

Utilization of the mid-Trinity subbasin by anadromous species includes fall and spring chinook, coho, spring and fall steelhead, green sturgeon, and Pacific lamprey. Overall populations of chinook are considered to have declined within this basin. Although escapement estimates for coho vary, there has not been a discernible decline noted for this basin since closure of Lewiston Dam. The estimates of the escapement from this section of the Klamath Basin clearly indicate a substantial decline for steelhead. No quantitative data exists to estimate population status or trends for either the Pacific lamprey or green sturgeon.

Available habitat for both coho and chinook salmon are estimated at about 140 miles. Total estimated habitat for steelhead is approximately 225 miles. Green sturgeon are considered to have limited access to approximately nine miles of the main stem Trinity River downstream of Burnt Ranch (see Appendix A in Phase I report).

Although the most significant reduction in both quantity and quality of available habitat for anadromous species occurred with the construction of the Lewiston and Trinity dams, other factors such as poor land-use practices have also contributed. Additionally, significantly degraded habitat is attributed to the 1964 flood. Problems continue within this subbasin due to erosion, bank instability, and sediment input which had adverse impacts on available anadromous fish habitat.

The primary factors that are considered to limit anadromous fish production in the Trinity River subbasin include reduced flows from agricultural diversions, migration barriers, sedimentation, and riparian encroachment on the main stem Trinity River channel. Formation of tributary deltas is also occurred due to the lack of higher flow releases from the upstream dams that can inhibit or preclude access to tributaries by anadromous species during low flow periods. Formation of these deltas are also associated with increased sediment loads due to poor land-use practices in several of the tributaries. As noted previously, the lack of high flow events since closure of Lewiston Dam has resulted in significant encroachment by riparian vegetation that has led to alteration in the physical characteristics of the river channel. This general narrowing and deepening has resulted in significant losses to important early life stage rearing habitats for many of the anadromous species. Both the increased minimum flows and prescribed high flow events from Lewiston Dam are anticipated to improve these conditions. Although not a major factor, some agricultural diversions in the basin may unnecessarily reduce access to spawning and rearing areas for anadromous species. Finally, hydraulic and dredge mining activities have impacted the Trinity and its tributaries for many years.

The South Fork Trinity Subbasin

Although no major water development has occurred within the South Fork Trinity River subbasin, sedimentation from the naturally erodible soils has increased due to poor land-use practices in the past, primarily by timber management activities. The 1964 flood resulted in a significant deterioration of anadromous spawning habitats in this tributary, which is still undergoing rehabilitation through natural processes today. Fires, timber harvest, road construction and historic mining practices with the added large flood events have all played a role in the loss of anadromous salmonid production within this Subbasin.

Historical distributions of anadromous species within the South Fork Trinity subbasin include fall, winter, and spring run steelhead, spring and fall chinook salmon, coho, green sturgeon, and Pacific lamprey. Overall, trends for the anadromous species are generally considered to be in decline reflective of the entire Lower Klamath Basin. No quantitative data presently exists to determine the population status for Pacific lamprey and green sturgeon.

Existing estimates of available anadromous species habitat are considered to be nearer historical conditions than in previous decades after the 1800's and are attributable to habitat improvement efforts over the past 20 years. The estimated steelhead distribution indicates they have access to approximately 190 miles of river habitat, which include both spawning in rearing areas. Estimated coho habitat is approximately 115 miles in this basin. The current distribution of chinook within the basin indicates that existing available habitat is near historical levels and is approximately 115 miles. Although no quantitative data exists to estimate the distribution of Pacific lamprey they are currently believed to have access to similar areas as that of steelhead (see Appendix A in Phase I report).

The primary factors that affect anadromous fish production include sedimentation, reduced water quality, areas of reduced flows from agricultural diversions, hydroelectric developments, and upstream migration barriers at agricultural diversions. Adverse impacts due to sedimentation have been a historical problem throughout the subbasin due to the natural characteristics of the underlying geology. These problems, however, have increased due to some historical land-use practices primarily associated with timber harvesting. Although natural in origin, the 1964 flood resulted in serious sediment induced problems such as disruption of spawning riffles, filling of rearing and holding habitats (i.e., pools), and in many locations stream channels were significantly widened and became shallower. In some instances, the loss of the riparian community in conjunction with the widening of the stream channel has been attributed as the mechanism causing elevated water temperatures that may limit the amount of anadromous species habitat in this system. Agricultural diversions primarily during the irrigation season are known to result in reduced flows in several of the tributaries that may impact rearing habitat for anadromous species in the Hayfork Creek watershed.

The Lower Trinity Subbasin

Major factors that impact the salmonid production capacity in the lower Trinity River are due to upstream water allocation practices at Lewiston and Trinity dams. As noted previously, these diversions have resulted in a 70 to 90 percent reduction in base flows with operation of the Trinity River Division. This reach of the Trinity River has also experienced elevated water temperatures during the summer that has been attributed to reduced summer flows from upstream diversions in conjunction with lost riparian vegetation shading. Slightly increased releases subsequent to 1981 from Lewiston Dam have had no appreciable effect on the thermal regime or anadromous species habitat within this segment of the river however, the minimum prescribed flow, pending the completion of the Trinity Flow Study and implementation of recommended measures still represents the third lowest flow of record. Historical water pollution problems have also been associated with fish kills within this section of the river but are not known to occur today.

This segment of the Trinity River contains important habitat for spawning fall chinook, spring chinook, winter and fall steelhead, coho, green sturgeon, and Pacific lamprey. Many of the tributary streams in this segment of the river are also important rearing habitats for these anadromous species. Coho are known to require one year of freshwater growth. Coho that exit tributaries within or outside of this subbasin that are pre-smolts, must rear in the main stem Klamath River until smoltification has completed. The overall population trends for chinook salmon follow those described for other segments of the Trinity River. Historical utilization of the Trinity by coho salmon is not well understood and it is felt that a few coho currently utilize this segment of the river for spawning and rearing. Reliable quantitative data for population trends for steelhead, spring chinook, green sturgeon and Pacific lamprey are not available for this area of the river. It is generally believed, however, that steelhead numbers are below historical conditions in this basin (see Appendix A in Phase I report).

The historical data on the distribution of chinook only indicate utilization of the main stem, and the degree to which tributary systems were utilized is unknown. No historical distribution data exists to estimate habitat use for coho, steelhead, green sturgeon, or Pacific lamprey. It should be noted that considerable restoration efforts for habitat improvement in the post 1964 flood event have occurred within this and upstream segments of the Trinity basin as a whole.

The primary factors that are considered to limit anadromous fish production in the lower Trinity subbasin include loss of juvenile rearing habitat as a consequence of high summer water temperatures within the main stem, reduction in suitable spawning gravels from sedimentation from several tributaries, reduction in steelhead rearing habitat due to water diversion practices, and migration barriers due to agricultural diversions. Many of the sedimentation problems, however, can be attributed to natural processes. Adverse logging practices in the tributaries to the Trinity River have also been associated with degradation of anadromous fish habitat.

The Lower Klamath Subbasin

The Lower Klamath Subbasin is defined by the Klamath Task Force starting at Weitchpec to the mouth. Flows and water quality in this section of the main stem Klamath River can be dominated by tributary inflows and releases from Iron Gate Dam during low flow periods. Outside of the high spring runoff period, flow patterns are affected by the cumulative water allocation practices in the respective tributaries and operation of the Klamath Project, especially during below normal water years.

Anadromous species that use the main stem Klamath River include spring and fall chinook salmon, spring, fall and winter steelhead, coho, Pacific lamprey and green sturgeon. This section of the main stem represents an important migration corridor for these anadromous species. However, CDFG has presented information that suggests that there is a delay in movement of fish through the lower Klamath (Wallace, CDFG, pers. com.). This information indicates the importance of adequate flows for rearing life stages of fall chinook and other species. Pre-smolt coho and steelhead originating from upstream and adjacent tributaries must also reside in the lower Klamath main stem until smoltification has completed. Furthermore, this section of the main stem represents the principal spawning area for green sturgeon. Although definitive data does not exist to quantitatively assess the status of the anadromous stocks, the available data indicate that fall chinook populations are severely below historical levels. Current populations of coho may be reflective of levels indicative of the 1960s, but are considered below historical numbers. As has been indicated previously, steelhead are considered to have declined from historical levels.

Estimated habitat use within this section of the Klamath Basin indicates that approximately 100 miles of spawning and incubation habitat are utilized by chinook. The estimated available coho habitat is approximately 130 miles, while estimated steelhead habitat is approximately 150 miles. Green sturgeon are considered to utilize approximately 66 miles of the lower main stem Klamath River. Distribution information for Pacific lamprey is not available but is considered approximately the same as that noted for steelhead. Generally, the current distributions of available habitat for these anadromous species are considered to represent historical conditions (see Appendix A in Phase I report). Although available habitat is near historical levels in terms of miles, alterations in the flow pattern and water quality effectively reduce the amount of effective habitat during seasonal periods.

The primary factors which are considered to potentially limit anadromous fish production in this segment of the main stem Klamath River are associated with historical degradation of habitat due to land-use practices such as timber management as well as by the cumulative effects of upstream flow depletions and alterations in the seasonal hydrograh. These impacts are associated with degradation of spawning gravel from sedimentation and historically from the creation of migration barriers. At present, migration barriers in this section of the main stem and tributaries are not considered problematic. This section of the main stem Klamath River is also known to experience elevated summer water temperatures. These temperatures can often exceed optimal limits for rearing of juvenile spring chinook, coho, and steelhead.

Life History Traits

The following section provides a brief synoptic description of key life history traits for each of the species. For a more complete treatment of life history traits the reader is referred to Leidy and Leidy (1984), USBR (1997), CH2MHILL (1985) and KRBFTF (1991).

Steelhead

The Klamath Basin supports three runs of steelhead generically referred to as spring/ summer, fall and winter runs. Typically mature spring/summer steelhead enter the Klamath River between mid-April to late May. These fish migrate upstream to most of the principal tributaries including many of the larger creeks where they hold until spawning between January/April of the next year. Weir counts on the New River that is approximately 84 miles from the delta showed adult summer steelhead show downstream migration in mid-March, peaked in mid-April and diminished by the end of May (USFWS pers. com.). Fall run steelhead will typically enter the River as early as July, but primarily during October and November where they hold for several months before moving to spawning areas in smaller tributaries. Winter run steelhead typically move into the River between December through February and may continue through May while migrating to their spawning areas. Approximately 16 to 22 percent of spawning steelhead are repeat spawners (USFWS pers. com.) One of the more unique characteristics of the Klamath River Basin is the presence of half pounders. These steelhead are immature (non-spawning) males and females, which are found in the summer and fall run steelhead migrations. Half pounders that enter the Klamath River generally return to the ocean the following winter or spring. After egg deposition, eggs typically incubate from 4 to 7 weeks with the fry typically emerging during March through June. The length of time for egg incubation is a function of water temperature. The juveniles may remain in fresh water for one to three years before emigration. Emigration of natural steelhead smolts from the Klamath Basin typically occurs between March to late July. Field collections suggest that most emigrating steelhead arrive in the estuary during April and May. Although steelhead utilizes the Klamath River as a migratory corridor to access spawning tributaries, some spawning does occur in the main stem. Its importance to resident life stages throughout the year cannot be understated. For example, a large percentage of wild Klamath River steelhead show two years of freshwater growth and a half-pounder life stage exists. Tributary out-migration data show that a large percentage of steelhead entering the Klamath are fry and yearlings that must rear in the main stem for an additional year or two. Half-pounders rear in the Klamath and tributaries from August-April. Steelhead prefer water temperatures which range between 7.2 and 14.4 C. Optimal growth temperatures range between 10.0 and 12.8 C. Upper lethal limits on temperature have been reported as 23.9 C.

Coho Salmon

Coho typically migrate into the Klamath River during mid-September through mid-January. Upstream migrations are typically associated with pulse flows due to fall rain events. Although coho primarily spawn in tributary streams from November through Jan. they have been observed spawning in side channels, at tributary confluences, and suitable shoreline habitats in the main stem. Egg incubation lasts approximately seven weeks and typically occurs during

November through March. Alevins remain in the gravel approximately two to three weeks and then emerge as free-swimming fry during February to mid-May with the peak in April and May. Coho will typically rear in freshwater for one year before emigrating to the ocean. This usually occurs in the spring following the first winter. Out migration can begin as early as February and continue through mid-June, with peak numbers arriving in the estuary during April and May. Optimal temperature ranges for coho are 3.3 to 20.5 C, although preferred rearing temperatures are 12.0 to 14.0 C. Upper lethal temperatures have been reported as 25.6 C.

Chinook Salmon

Spring chinook salmon typically enter the Klamath River as early as February through the month of July. Peek immigration has been reported as occurring from March to mid-June. Migrating adults tend to hold in deeper pools of the tributaries where they remain throughout the summer before spawning in the fall. Spawning may occur from September through mid-November. Spring chinook spawning in the Salmon River occurs from mid-September through mid-October. Spring chinook are generally believed to migrate farther upstream than the fall runs.

Once the eggs are deposited, incubation generally occurs from 40 to 60 days. Alevins and fry remain in the gravel for approximately two to four weeks and begin to emerge during December. However, USFS emergence traps on the Salmon River show emergence extending into late May. Optimal incubation temperatures range between 4.4 and 13.3 C. Spring chinook will typically hold in freshwater for approximately one year with emigration generally occurring through March to July although USFS Salmon River outmigration traps show that spring chinook smolts emigrate during fall and spring months. Typical rearing habitats for juvenile spring chinook are runs and pools. Optimal temperature for juvenile spring chinook ranges between 13.9 C and 19.4 C. Upper threshold temperature for juveniles has been reported as 25 C.

Fall chinook are typically separated into two runs, fall and late fall runs. The fall run enters the Klamath river from mid-July through mid-October while the late fall run occurs from November through December with some as late as February. Fall chinook spawning occurs throughout the lower reaches of tributaries with less than one-third of the total fall chinook run utilizing the main stem Klamath River for spawning. Although approximately 50 percent of the main stem Klamath spawning occurs in the upper 13 miles, significant spawning occurs as far downstream as Happy Camp at river mile 110. Spawning, in limited numbers, has been observed downstream as far as Orleans. Egg incubation generally requires 50 to 60 days at water temperatures that range between 5 C and 14.4 C. Some have reported emergence of the fry from the gravel during the November to February period. However, Klamath River main stem spawning and temperature data collected by the USFWS in 1993 and 1994 was used to predict emergence timing for the 1994 and 1995 water years using daily temperature units. Emergence from the 1993 run began in early February and peaked in early March 1994 compared to water year 1995 when emergence began in early March and peaked in early April (USFWS pers. com.). Emergence timing in the tributaries is believed to be earlier than the main stem. Due to different life history strategies, outmigration of natural chinook is year round. Type I chinook outmigrate in the spring and early summer months. Type II outmigrate in the fall and Type III hold over through the winter and migrate in early spring (Sullivan 1989). The majority of Klamath River chinook outmigrate using the Type I strategy. Mid-Klamath River tributaries such as Elk Creek have a Type II strategy. A wet and cold spring can cause a shift of the peak outmigration up to one month later than a dry warm water year. Young of year chinook outmigrating through the Big Bar trap subside in early August. Shasta River chinook outmigrate from late January through early May. The secondary pulse should not be confused with the fall, Iron Gate Hatchery release.

Green Sturgeon

Both white and green sturgeon have been found in the Klamath River, however the green sturgeon is the most abundant of the two. The white sturgeon are known to periodically migrate up the Klamath River (see citations in CH2MHILL 1985). Green sturgeon typically enter the Klamath River in late February and may continue to do so through late July. Although sturgeon have been observed as far upstream as Iron Gate Dam they typically do not migrate above Ishi Pishi Falls on the main stem Klamath. As noted previously migrating sturgeon also utilize the Trinity, South Fork Trinity, and lower Salmon River. Spawning typically occurs during March to July with peak spawning occurring during April, May to mid-June. Emigration of post spawning adults generally occurs throughout the summer and fall with peaks in August and September. Out migration of sturgeon juveniles may occur when they are less than one year old or as long as two years old. Out migration begins in the upper reaches of the basin as early as July while peaking in September in downstream areas.

Coastal Cutthroat Trout

It is believed that coastal cutthroat trout enter the Klamath River during the November through March period and spawn during the spring. Juveniles may rear for up to one or two years in either streams or the estuary before migrating to the ocean.

Eulachon (Candlefish)

Eulachon typically enter the Lower Klamath River during the March and April period and spawn immediately. Eggs typically incubate for two to three weeks after which the larvae out migrate.

Pacific Lamprey

Very little information is known about the Pacific lamprey within the Klamath River Basin. The Yurok Tribal Fisheries Program has documented lamprey entering the Klamath River from October through April with the peak often occurring in December or January. Lamprey are thought to spawn during April to July. Egg incubation typically occurs over a two to three-week period with the ammocoetes remaining in the substrate for up to five or six years before out migrating. Emigration is thought to typically occur during the late summer months. However, observed immigrations in March appear to be associated with high flows (Walt Lara Sr. pers. com. cited by Belchik pers. com.). Lamprey have been observed spawning in Dillon Creek in June and eyed juveniles as free swimming and attached to steelhead in cool water refugia from Bluff Creek to Bogus Creek (Belchik, unpublished data).

The Ecological Basis of Flow Regimes for Aquatic Resources

In order to place the work of Phase I and Phase II in context, the ecological basis for the establishment of instream flows to protect, enhance, and ultimately provide suitable conditions for the recovery of the anadromous species must be understood. The following section of the report highlights the importance of flow in the overall framework of physical, chemical, and biological processes that operate in river ecosystems. It also provides a brief overview of the historical and current direction of instream flow assessment research and applications.

River ecosystems create a temporally and spatially variable physical, chemical, and biological template within which fish and other aquatic resources can exist if they possess the proper suite of physiological, behavioral, and life history traits (Poff and Ward, 1990; Orth, 1987). This environmental template in conjunction with species-specific life history traits is often characterized as a multi-dimensional niche of environmental conditions (e.g., envelopes of depth, velocity, substrate, temperature) and resources (e.g., food, space) that describes the environmental conditions necessary for species survival. Suitable environmental conditions and resources must be available in terms of their quantity, quality and timing in order to sustain a viable long-term population (Statzner1988; May and MacArthur 1972; Pianka 1974; Colwell and Futuyma 1971).

Because a variety of factors and resources are required to meet the life history requirements of species, the short and long term success of individuals and ultimately populations can be limited by a single factor or by a combination of factors. In river systems, the suitability of environmental conditions for aquatic resources are directly related to the characteristics of the flow regime. Therefore, quantification of flow requirements that will provide for the long-term protection of the aquatic resources must be undertaken from an ecological basis in light of the flow dependent environmental factors that may limit these aquatic resources.

In essence, an ecologically based flow regime must incorporate the spatial and temporal flow conditions necessary to ensure long-term protection of the aquatic resources. The flow regime must maintain the linkage between the physical, chemical, and biological components of river ecosystems, which result in the formation and persistence of fish and macroinvertebrate habitat.

Quantification methodologies currently recognize that suitable flow regimes can be broken down into four basic flow components (Petts et al., 1995; Hill et al., 1991). These four flow components are fish habitat base flows, channel maintenance flows, riparian flows, and valley maintenance flows. Although the specific methods by which each of these flow components are quantified vary, all components are essential to maintain the ecological health of the stream system (Hill et al., 1991).

Phase I and Phase II focus on the fish habitat base flow component. Quantification of the remaining flow components was not quantitatively addressed given the existing state of the physical system, which presently allows propagation of these higher flow events within the main stem Klamath River. Specifically, with the exception of sustained drought periods, uncontrolled releases from the Upper Klamath Basin below Iron Gate Dam continue with sufficient frequency and magnitude, such that these flows are likely to protect the physical processes within the main stem Klamath River necessary for channel and riparian maintenance flows.

Research directed at the evaluation of instream flow requirements has resulted in the development and application of a large number of methodologies over the past several decades. This focused research on instream flow assessment methods continues at an elevated rate today. Excellent reviews of many of the techniques developed and applied within the United States and elsewhere can be found in Hardy (1998a), Reiser et al. (1989), CDM (1986), EPRI (1986), and Gore (1989). Some of the existing research within the “discipline” of instream flow assessments is focused on modification or extension of existing methodologies, while other efforts are being directed at development and application of new tools. This is driven to some extent by the current ecosystem management objectives of resource agencies and a growing consensus among both researchers and practitioners that the disciplinary basis upon which the fundamental science and analytical procedures are developed, validated and applied in instream flow assessments will continue to benefit from a broader ecological perspective (Hardy1998a; Orth 1995; Stanford 1994).

Current research has focused on the development and application of tools and assessment frameworks aimed at a quantitative characterization of the factors controlling fisheries resources rather than continued application of tools for evaluation of a single target species from the limited perspective of physical habitat. This broadly includes research on trophic level dynamics, process oriented delineation of flow induced changes in the physical and biological components of the aquatic environment (e.g., the Trinity River Flow Evaluation Report), and in the development of broader based ecological frameworks for the evaluation of impact assessments or restoration efforts in aquatic ecosystems (e.g. Johnson and Law 1995; Johnson et al. 1995; Hearne et al. 1994; Capra et al. 1995; Leclerc et al. 1995; Addley 1993; Nehring and Anderson 1993; Muhar et al. 1995).

Other pertinent research within the broader arena of instream flows has focused on the delineation of key life history characteristics in terms of ontogenetic shifts in habitat use under natural and induced flow variability (Heland et al. 1995; Bardonnet and Gaudin 1990; Bardonnet et al. 1993; Crisp and Hurley 1991), the relationship between flow and macroinvertebrate community dynamics (Lancaster and Hildrew 1993; Gore 1989; Jowett et al. 1991; Weisberg et al. 1990; Statzner et al. 1991), and the importance of trophic level dependencies between macroinvertebrates and fish (Filbert and Hawkins 1995; Bevelhimer 1996; Weisberg and Burton 1993; Easton and Orth 1992; Roell and Orth 1994).

Efforts employing mechanistic individual based bioenergetics, physical habitat based population models, and multi-variate statistical approaches have also produced encouraging results (Guensch et al. 2001; Addley 1993; Jager et al. 1993; Bovee et al. 1994; Hill and Grossman 1993; Jowett 1992). This has included results based on linking community level distribution and abundance with spatially explicit delineations of the habitat mosaic at the meso-scale (Aadland 1993; Dibble and Killgore 1994; Bain 1995; Jowett 1992). A broader view of the river corridor as an integrated ecosystem has also provided excellent research on methods and frameworks for delineating the process driven linkages between flow, sediment transport, channel structure, and the riparian community (Goodwin and Hardy 1999; Hill et al. 1991; Nillson et al. 1991; Rabeni and Jacobson 1993; Stromberg et al. 1991; Stromberg 1993).

Many of these techniques will be applicable to the Klamath Basin for evaluating instream flow needs and restoration activities within an adaptive management framework as part of long-term on-going management efforts. Most of these methods were beyond the specific scope of the Phase I study due to data limitations. However, the Phase II initiated many of these components and provide key data and results for use in longer-term efforts.

Phase I Process and Interim Instream Flow Recommendations

Phase I General Process

The process used for the development of the Phase I interim instream flow recommendations involved not only the technical work conducted at USU, but input and technical review from a Technical Team. This Technical Team was made up from representatives from state, federal, and tribal personnel who have extensive knowledge of the anadromous species in the Klamath River. The Technical Team was formed at the request of USU to allow access to this knowledge base and to provide a mechanism for USU to obtain input and technical review through each step of the work. The Technical Team was utilized during the process for information exchange, technical discussions on methodologies and study results, and ultimately the technical review of the Phase I report. Once the Draft Phase I report had been produced, the Technical Team as well as the public provided written comments to USU. All relevant comments were addressed to the degree that they had substantiated technical merit and appropriate changes were incorporated into the final Phase I report.

Phase I Technical Approach

A variety of analysis methods, covering a range of analytical techniques, were initially considered for use in the evaluation of minimum flow needs as part of Phase I. However, lack of requisite data precluded application of any field based methods such as the Physical Habitat Simulation System. Based on this review of methods, an assessment of data availability, and discussions with the Technical Team, Phase I utilized a suite of hydrology based methods for the instream flow assessments. The potential applicability of each method was evaluated based on underlying assumptions, type of system(s) in which the method was developed or applied, target species, previous applications, specific data requirements, and potential for adoption to the Klamath River.

Based on this review, five hydrology based methods were selected for estimation of the interim instream flow recommendations as part of Phase I. These methods are briefly described below. In order to apply these methods, hydrology for the main stem Klamath River below Iron Gate Dam needed to be estimated for ‘historical’ conditions. In this context, historical conditions refer to conditions prior to the Klamath Project and to the extent possible, prior to substantial water development in the Upper Klamath River Basin. Estimation of the hydrology used in Phase I is discussed in the next section.

Phase I Hydrology Analyses

Most of the existing stream gage records are highly impacted by upstream water use and therefore determination of historical conditions is difficult. The following summary is primarily taken from USGS (1995) that completed a characterization of hydrology data in the Klamath River Basin based on periods of record for existing gages. The analysis conducted by USGS indicated that at annual flow-volume level, gage data do not strongly reflect changes in water allocation strategies in the main stem Klamath River near Keno, the Shasta River, the Scott River, or the Salmon River. However, flow alterations (e.g., depletions and seasonal shifts in the magnitude) are evident at the monthly level. The annual flow regime downstream of Lewiston in the Trinity River clearly reflects the large trans-Basin diversions that began in 1961 with the construction and operation of the Central Valley Project Trinity River Division. This change in hydrology becomes less detectable downstream during high flow periods due to unimpaired runoff at downstream locations in the Trinity River and is not readily apparent in main stem of the Klamath during the spring runoff period in normal and above normal water years.

One of the more unique characteristics of the historical flow regime of the main stem Klamath River was the rather ‘smooth’ annual hydrograph, which is attributed to the hydraulic buffering of the large storage capacity in Tule, Upper and Lower Klamath Lakes prior to development in the upper basin (Balance Hydrologics, Inc. 1996). Within year variability of flows on a seasonal and daily basis within the main stem Klamath River below Copco Dam are well documented. In addition, seasonal shifts in the annual hydrograph are readily apparent due to water allocation practices in the Upper Klamath Basin as reflected in the gage data below Iron Gate Dam, which are also well documented. These include flow depletions of ~250,000+ acre-feet and seasonal shifts in the pattern of the annual hydrograph.

The following discussion on changes to within year hydrology is confined to the Lower Klamath Basin and is presented here for convenience. The analysis by USGS concluded:

> “ The Klamath River at Keno, Shasta River near Yreka and the Scott River near Ft. Jones are influenced by irrigated agricultural water use. Two of these locations show a discernible change in relative runoff compared to the Salmon River beginning about the1960's. ... we conclude this phenomenon is not due to changes in the Salmon River drainage, but due to changes in the upper Klamath and Scott basins. These changes could be due to changes in crop patterns, irrigation techniques, water demand due to a persistent change in summer weather patterns or other causes. We believe this phenomenon is related to man’s activities.”

Although a variety of flow analyses have been conducted within the Klamath Basin, two principal works were reviewed extensively during Phase I: USGS (1995) and Balance Hydrologics, Inc. (1996). In both of these efforts, analyses were conducted to characterize both existing and historical hydrology within the Lower Klamath River Basin on an annual, monthly and daily basis. Although these two reports differ somewhat in their conclusions on the degree or magnitude of changes, these differences are attributed to the purposes of the analyses, analytical techniques employed, and underlying assumptions used in the analyses.

One of the findings of the USGS work is that, on a total annual flow volume basis, flows from the Upper Klamath Basin have not changed 'substantially' over time compared to the total annual flow volume within the Klamath River (i.e., pre versus post Klamath Project flows in the main stem Klamath River). However, USGS and Balance Hydrologics (1996) both note that annual depletions from the Upper Klamath Basin (i.e., above Iron Gate) are evident and that both monthly and daily flows show the effects of water use in the Upper Klamath Basin. This includes increased flows in the Klamath River from the Lost River diversions during the winter and spring runoff periods. However, the effects of these diversions were not quantified as part of the Phase I analyses.

What the two analyses found in common is that the estimated average annual outflow from the Upper Klamath Basin at Keno was approximately 1.5 million ac-ft (2,156 cfs). The equivalent 'pre-project' estimated average annual flow at Iron Gate for a normal water year, which accounts for accretions in flow below Keno, was approximately 1.8 million acre-feet (2,575 cfs). This value was derived by adjusting the computed mean annual flow from the 1905 to 1912 period of record at the Keno gage to account for the above normal precipitation pattern during this gaged period (see Balance Hydrologics, Inc., 1996).

In comparison, the long-term average annual flow measured at Iron Gate for the 1961 to 1996 period of record is 2060 cfs. The difference between the historical and existing mean annual flow is approximately 515 cfs, which corresponds to roughly 372,800 ac-feet. This compares to reported consumptive uses for water for the Klamath Project (i.e., depletions to the main stem Klamath River below Iron Gate) that have been estimated at between 245,000 and 350,000+ acre-feet depending on water year type. These estimates however, <u>do not</u> account for consumptive uses above Klamath Lake (Larry Dugan, pers. com.). Typical Klamath Project operations may result in as much as 500,000 acre-feet of water deliveries for agricultural and related demands during dry water years. In addition, water management practices in the Upper Klamath Basin above Iron Gate Dam result in seasonal flows that are now higher in the late winter and early spring and lower during the summer period compared to expected historical flow patterns. There is also a strong indication that flows are more variable now (see Balance Hydrologics, Inc., 1996). This is attributed to the use of water for agricultural purposes, power generation, and perhaps the effect of lost seasonal flow buffering with the loss of storage in Lower Klamath and other Upper Klamath Basin wetlands.

The estimated pre-project flows in the main stem Klamath River at Keno and Iron Gate were selected as the best representative values in the application of the various hydrology based methods for Phase I. The choice of these locations and the estimated pre-project flows is justified since these values integrate basically all the flows leaving Oregon, and represent the best estimate of hydrologic conditions which the anadromous stocks would have evolved under.

Several flow statistics were required for the evaluation of instream flows using the hydrology based instream flow assessment methods in Phase I. These are the average annual flow, mean and median monthly flows, and various monthly flow duration (exceedance) statistics.

Iron Gate Mean Annual, Average and Median Monthly Flows

The mean annual and average monthly flows below Keno and Iron Gate Dam for a normal water year were taken from Balance Hydrologics, Inc. (1996). These estimated flows are provided in Table 1. As noted, the Iron Gate values were obtained from the 1905-1912 gage readings at the Keno gage adjusted to normal water year flows. These adjusted values include estimated normal year monthly accretions between the Keno and Iron Gate gages.

The U.S. Bureau of Reclamation (USBR) concurred that, for the purposes of Phase I, these mean annual and adjusted monthly flows were the best estimates of pre-project flows in the main stem Klamath River below Iron Gate Dam (Larry Dugan, pers. com.).

The median monthly flows at Iron Gate were derived from the Keno daily discharge data for the 1905-1912 period of record by computing the monthly flow duration (exceedance) statistics (see Appendix B in Phase I report). These values were then adjusted by 1.04 following the work of Balance Hydrologics, Inc (1996) to approximate an average water year. The monthly average water year accretions listed in Table 1 were then added to obtain the estimated median monthly (i.e. 50 percent exceedance) flows for Iron Gate as shown in Table 2.

Table 1. Estimated pre-project mean annual and average monthly flows in cfs at Keno and Iron Gate Dam. (Note: MAF = Mean Annual Flow)

	Keno 1905-1912 Mean (cfs)	Keno Adjusted Index (1.04) Normal Year	Percent of MAF	Monthly Normal Year Accretions (cfs)	Iron Gate Normal Mean (cfs)	Percent of MAF
Oct	1236	1188	0.57	348	1536	0.60
Nov	1518	1460	0.70	349	1809	0.70
Dec	1915	1841	0.89	517	2358	0.92
Jan	2295	2207	1.06	620	2827	1.10
Feb	2670	2567	1.24	764	3331	1.29
Mar	3027	2911	1.40	693	3604	1.40
Apr	3326	3198	1.54	659	3857	1.50
May	3182	3060	1.48	567	3627	1.41
Jun	2630	2529	1.22	401	2930	1.14
Jul	1809	1739	0.84	408	2147	0.83
Aug	1202	1156	0.56	347	1503	0.58
Sep	1060	1019	0.49	351	1370	0.53
Mean (cfs)	2156	2073			2575	

Table 2. Estimated pre-project median monthly flows in cfs at Keno and Iron Gate Dam.

	Keno 1905-1912 Median (cfs)	Keno Adjusted Index (1.04) Normal Year	Monthly Normal Year Accretions (cfs)	Iron Gate Normal Year Median (cfs)
Oct	1240	1192	348	1540
Nov	1495	1438	349	1787
Dec	1830	1760	517	2277
Jan	2250	2163	620	2783
Feb	2640	2538	764	3302
Mar	2690	2587	693	3280
Apr	3100	2981	659	3640
May	3060	2942	567	3509
Jun	2480	2385	401	2786
Jul	1760	1692	408	2100
Aug	1160	1115	347	1462
Sep	1050	1010	351	1361
Mean (cfs)	2063	1984		2486

Iron Gate Monthly Flow Exceedence Value Estimates

Pre-project median monthly flows (i.e., 50 percent exceedence) as well as 40, 60, 70, 80 and 90 percent exceedence values were estimated at Iron Gate for use in several of the instream flow analyses. The daily flow records at Iron Gate Dam are sufficiently impacted by water allocation practices that their direct use for computing monthly exceedence values was deemed inappropriate. The required flows for specific monthly exceedence values were derived by computing the monthly flow-exceedence values using the daily flow records for the 1905-1912 period of record at Keno (see Appendix B in Phase I). Since this period of record corresponds to an above normal precipitation pattern, the flows were adjusted at each of these exceedence values by 1.04 to derive a ‘normal year’ estimate for each of the flow-exceedence values at Keno. The corresponding flow for each exceedence value at Iron Gate was then obtained by adding normal year accretions below Keno for the 40, 50, and 60 percent exceedence values. Although Balance Hydrologics, Inc. (1996) infer that accretions for wet, normal, dry and critically dry water years were previously computed by CH2MHill for the USBR (see Page 15 in Balance Hydrologics, Inc., 1996), only normal and wet year accretions were reported. The USBR provided estimated accretions for dry years (1977, 1981, 1987, 1992, 1994), which were averaged for each month and then added to the flows associated with the 70, 80, and 90 percent exceedence values to obtain these estimates at Iron Gate. These values are provided in Table 3. It is recognized that this particular approach to estimating the required flow values associated with particular exceedence ranges for use in the hydrology based instream flow approaches discussed below likely over estimates to some degree the flows at high exceedence ranges and to some degree under estimates the flows at low exceedence ranges. However, since most of the hydrology based methods are oriented toward estimation of minimum flows rather than optimal flows, this bias was not considered problematic for the intent of Phase I.

A more detailed examination of flows based on mass balance simulations using results from the USGS and other models was undertaken as part of Phase II.

Table 3. Estimated Iron Gate pre-project flows (cfs) for associated monthly exceedence values used in various hydrology methods and where derived from an analysis of the daily flow records at Keno for the 1905-1912 period of record.

Exceedence	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
40	2889	3351	3674	3784	3692	2988	2379	1626	1524	1540	1801	2344
50	2783	3302	3280	3640	3509	2786	2100	1462	1361	1540	1787	2277
60	2591	3033	3231	3572	3192	2670	1879	1366	1332	1463	1743	2209
70	2269	2567	2659	2935	2791	2389	1691	1273	1196	1320	1640	1877
80	2125	2423	2620	2935	2714	2245	1585	1182	1162	1272	1582	1839
90	2096	2375	2466	2771	2560	2034	1460	1128	1068	1186	1476	1820

Review of Hydrology Based Methods Used in Phase I

The hydrology methods discussed below were applied in deriving flow estimates within the main stem Klamath River. Each method is described briefly and the manner in which the method was applied or adopted is discussed. Methods were modified or adapted based on the physical or biological setting of the Klamath River and input from the Technical Team. It must be stressed that the approach taken in the Phase I report (and the philosophy of the review team) was that if a method was broadly applicable from a biological perspective and where basic assumptions could be reasonably met, it was applied. This approach avoided a priori or post priori justification of a single method and strived to treat each method as providing independently derived estimates of the instream flow requirements based on valid but unique underlying assumptions. The monthly instream flow estimates derived from each technique were then ‘aggregated’ based on a simple average of each monthly estimated instream flow to derive the final flow recommendations on a monthly basis. The following section provides a brief synopsis of each method used in Phase I

Hoppe Method

This method was developed from studies on the Frying Pan River, Colorado and estimates flow requirements from percentiles on an annual flow duration curve for salmonid species. A flow that is equaled or exceeded 17 percent of the time is set for a 48-hour period to maintain flushing flows. However, Phase I did not consider this component of the flow regime. The flow that is equaled or exceeded 40 percent of the time is recommended for protection of spawning flows and the flow that is equaled or exceeded 80 percent of the time is recommended to maintain flows for food production and aquatic cover. In essence, this approach strives to protect the higher flow component associated with the spring high flow spawning period and to provide survival habitat in terms of food production and physical habitat during the low flow periods.

The biological rationale for this approach was adapted for the Klamath River by using the monthly 40 percent exceedence flows to protect spawning and incubation for the September through February period, the monthly 60 percent exceedence flows during March through May period to protect incubating eggs, and the monthly 80 percent exceedence flows for the June through August period for food production and protection of rearing habitats for fish. The actual monthly exceedence values were utilized in order to preserve the characteristics of the pre-project flow patterns within a normal water year.

New England Flow Recommendation Policy

This method is based on the assumption that aquatic resources have evolved to survive the most severe or adverse environmental conditions in the most stressful month of the year and encompasses both salmonid and invertebrate species. Utilizing hydrology records, the aquatic base flow is set as the median August flow, unless superceded by spawning requirements which are equivalent to the historical (pre-project) median flow throughout the spawning period. Where inadequate flow records exist or where flows have been altered from water projects, recommendations are derived from the average median August flows computed from representative streams in the region in terms of cubic feet per square mile (cfsm). In this instance, the ‘default’ flows are 0.5 cfsm for all times of the year unless superceded by spawning and incubation flows which are defined as 1.0 cfsm in the fall/winter or 4.0 cfsm in the spring for the entire applicable spawning and incubation periods.

This method was adopted for application in the Klamath by computing the flow associated with the 50 percent exceedance value for the spawning period from September to February using the daily flow records at Keno gage for the 1905 to1912 period of record. The computed flow (1630 cfs) was then adjusted by 1.04 (see Balance Hydrologics Inc., 1996) and the monthly accretions for each of these months were added to the flow estimate. A similar approach was taken for the incubation/emergence period during February through May using the Keno gage daily flow records for the 1905 to 1912 period of record. The computed 50 percent exceedance flow of 2870 cfs was then adjusted by 1.04 and the normal year accretions for each month were added to this value. Finally, the daily gage data for August at Keno using the daily flow records from the 1905-1912 period of record was computed and then adjusted by 1.04. The monthly normal water year accretions were then added to each month. The highest flow computed for each month was set as the instream flow requirement.

<u>Northern Great Plains Resource Program Method</u>

This method was developed from the assumption that established aquatic resource populations (independent of species composition) are a result of normal or average flows as opposed to ‘abnormal’ flows (e.g., extreme low or high flow components of the flow regime). The approach is based on the computation of mean monthly flows from the existing period of record and in the situation where the mean monthly flows are normally distributed, the ‘t’ statistic is used the establish the bounds for normal flows. That is, extreme values are discarded. Where mean monthly flows are not normally distributed, then professional judgment is utilized to censor the data records.

The daily flow records for each retained month (i.e., flows retained after data censoring) are then used to construct monthly flow duration curves and the flow that is equaled or exceeded 90 percent of the time is specified as the required flow to protect the aquatic ecosystem in that month. Further adjustments are made to recommended flows during the spring runoff period using a flow that is ‘near the mean annual flow of record’ during the high flow months. During low flow months, additional reductions in the flow may be made where ‘sharing’ of water with beneficial out-of-stream uses may be warranted. These two flow adjustments are based on professional judgment and negotiations. Adjustments for low flow months was deemed inappropriate given the status of the anadromous stocks in the Klamath River Basin and as noted previously, the high flow component is not considered under Phase I.

Since the existing historical flow records at the Keno gage have such a short period of record, all the data were utilized to derive monthly flow durations. The corresponding 90 percent exceedence values were then obtained from the monthly flow duration analyses. In this instance, the estimated dry year accretions were added to each monthly value after adjusting by 1.04 to eliminate the above normal year bias.

Tennant Method

This basic methodology attempts to protect the health of aquatic habitat based on an observed correlation between habitat conditions and flow regime as a percentage of the mean annual flow. The technique was developed from a variety of streams that were dominated by salmonid species but has been broadly applied to a wide range of systems including non-salmonid systems.

Tennant is broadly accepted in the literature as a reconnaissance-level technique. It was previously employed by Trihey (1996) to estimate instream flow requirements for tribal trust species in the Klamath River. These estimated flows subsequently served as a basis by which the ‘Modified Yurok’ flow regime proposal was developed for consideration in Klamath Project operations. The modified Yurok proposal was developed through a facilitated workshop of Klamath Basin fisheries biologists and represents a DELPHI based recommendation.

At its most fundamental level, the Tennant Method relies on the available long term gage data to derive an exceedence based flow level. As such, it inherently incorporates the range of water year variability by nature of the flow-exceedence basis of the computations. What remains difficult however, is the selection of an ‘appropriate’ percent of the mean annual flow to utilize and how then this flow volume should be partitioned between various months based on the life history needs of the target species and life stages. There is no widely accepted ‘method’ or ‘rule-of-thumb’ that can be relied on to select the flow category for use in defining a flow recommendation. Comparative studies between Tennant and more site-specific studies would suggest that flow criteria between the 30 percent and 60 percent ranges of the mean annual flow (MAF) are common (Wesche 1973, Wood and Whelan 1962, Joy et al. 1981, Orth and Maughan 1981, Prewitt and Carlson 1979, Nelson 1980). It is recognized that in many of these applications the targeted species and river systems are very different from the Klamath, but remain roughly consistent across species and systems. Nelson (1980) suggests that the Tennant Method may in some instances; overestimate instream flow requirements compared to site-specific analyses in larger river basins. However, this is not known to be generally true across a variety of systems. Fundamentally, the use of Tennant for estimating minimum instream flows remains widely applied and accepted.

Given the objectives of the Phase I analyses and a desire to maintain a conservative view toward protection of the aquatic resources within the Klamath River, an 80 percent of MAF basis was selected for use in the application of Tennant. This represents the mid-point of the Optimal Range for protection of resources. This percent of the mean annual flow was partitioned between all months within the year based on the percent distribution of pre-project mean monthly flows. In this instance, the application of the Tennant Method was 'modified' to allow the hydrograph to mimic natural flows patterns as is commonly undertaken with this technique for adjustment of seasonal flow patterns (e.g., Ott and Tarbox 1977, Bayha 1978, Estes 1985, Fernet 1987, Trihey 1996).

Washington Base Flow Method

This methodology estimates the required instream flow levels based on a ranking of the stream in terms of wildlife, fisheries, scenic and esthetic, water quality, navigational, and other environmental values. The technique is applicable to salmonid systems. The average rating is then used in a nomographic solution to obtain a flow-duration percentile. This flow-duration percentile is then used to estimate the flow recommendation using the flow duration curve for the river. In the absence of site-specific rankings in each of these categories, the highest stream ranking (i.e., 24) was chosen and the solution for Western Washington during the low flow period was selected for use with this technique. This choice is considered to be justified given the high value fisheries, ESA considerations, high recreational values of the main stem Klamath River below Iron Gate Dam including both sport fishing and recreational boating, and the importance of this river for overall environmental concerns to tribal trust resources.

The resulting flow-duration statistic associated with this approach is the 60 percent exceedence. This basic technique was modified for this report to utilize the 60 percent exceedence value on a monthly basis in order to preserve the natural pattern of seasonal flows. The monthly 60 percent flow exceedence values based on the daily discharges at Keno for the 1905-1912 period of record were used and the normal year monthly accretions were added to each month. The preservation of the seasonal pattern of natural flows is considered important in light of the flow dependant cues of anadromous species to flow timing in the main stem in conjunction with tributary flows.

Phase I Recommended Interim Flows

Iron Gate Dam to the Shasta River

Since each of the various hydrology based techniques were considered to provide a independent estimate of required flows based on differing but valid biological assumption, the individual monthly values for each method were averaged across all techniques to derive the 'best estimate' of the recommended interim monthly instream flows. The resulting monthly instream flow recommendations for Iron Gate to the Shasta River reach are provided in Table 4. These values are compared to pre-project, historical (Klamath Project Operations) and previous monthly instream flows in Table 5.

What is apparent from a comparison of the Phase I recommended flows below Iron Gate is that during the September through March period these flows would have been met under historical (i.e., existing) operations of the Klamath Project, while actual flows were below the recommend flows during the remaining months of the year. The current lack of sufficient storage (e.g., increased retention from restored wetlands and marshes, or increased capacity of existing facilities) in the Upper Klamath Basin precludes the ability to hold water during the early spring period when higher than pre-project flows are now typical. This lack of adequate storage may prevent the release of water necessary for the attainment of the Phase I recommended flows due to high demands during the late spring and summer period to meet water demands within the Upper Klamath Basin (i.e., above Iron Gate).

Table 4. Summary of pre-project normal water year mean and median flows at Iron Gate Dam, instream flow estimates (cfs) by method and recommended monthly Minimum Instream Flows (MIF) below Iron Gate Dam.

	Iron Gate Mean Flows	Iron Gate Median Flows	Hoppe	NEABF	NGP	Tennant	Washington	MIF
Oct	1536	1540	1540	1915	1186	1229	1508	1476
Nov	1809	1787	1801	1916	1476	1447	1799	1688
Dec	2358	2277	2344	2084	1820	1886	2277	2082
Jan	2827	2783	2889	2187	2096	2262	2670	2421
Feb	3331	3302	3351	3524	2375	2665	3124	3008
Mar	3604	3280	3231	3453	2466	2883	3333	3073
Apr	3857	3640	3572	3419	2771	3086	3689	3307
May	3627	3509	3192	3327	2560	2902	3297	3056
Jun	2930	2786	2245	1863	2034	2344	2761	2249
Jul	2147	2100	1585	1870	1460	1718	1938	1714
Aug	1503	1462	1182	1809	1128	1202	1407	1346
Sep	1370	1361	1524	1918	1068	1096	1371	1395

Table 5. Comparison of pre-project mean flows in a normal year, recommended monthly instream flows and previous instream flow recommendations and historical Iron Gate releases (1961-1996) period of record (all flows are in cfs).

	Pre-project Mean	MIF	Iron Gate 1961-96	FERC	Trihey	Yurok
Oct	1536	1476	1664	1300	1200	1300
Nov	1809	1688	2142	1300	1500	1500
Dec	2358	2082	2744	1300	1500	1500
Jan	2827	2421	2825	1300	1500	1500
Feb	3331	3008	3047	1300	1500	1500
Mar	3604	3073	3601	1300	1500	1500
Apr	3857	3307	2970	1300	2000	2000
May	3627	3056	2046	1000	2500	2500
Jun	2930	2249	1050	710	1700	1700
Jul	2147	1714	758	710	1000	1300
Aug	1503	1346	970	1000	1000	1300
Sep	1370	1395	1303	1300	1000	1300

The Phase I recommended flows below Iron Gate Dam are also typically higher than previous recommendations (see Table 5). The major difference in the Phase I recommended flow regime and that of the modified Yurok and Trihey proposed flow regimes is that Phase I flows attempt to track the shape of the natural pattern in the ‘pre-project’ hydrograph. This is considered important in terms of linking the magnitude and timing of the flow releases below Iron Gate to better match the pre-project relationship in the timing of higher flows with tributaries. This pattern of flow is anticipated to provide a better ecological flow regime that contains not only the physical but ecological linkages between the main stem and tributary systems.

The Phase I recommended flows are substantially higher than the existing FERC flow requirements. The FERC flow regime is at or below critically dry exceedence flows (i.e. ≥ 80 percent exceedence). This is potentially problematic during the summer and early fall period when low flows can contribute to high maximum daily water temperatures below Iron Gate Dam. The FERC recommended flow regime also departs substantially from the natural flow regime of the Klamath River throughout the whole year. During the construction of Iron Gate Dam, concerns were raised by resident fisheries scientists over the appropriate magnitude of minimum flows. This is evident from a review of the historical correspondence record that shows that the final FERC flow regime was a negotiated settlement and not derived from strong biological evaluations of the flow needs of the fishery in the main stem Klamath River below Iron Gate Dam (see Phase I, Appendix C).

Shasta River to Scott River

The 1933 to 1996 gage data for the Shasta River near Yreka was used to compute the long term mean annual flow (173 cfs) and subsequently to estimate the mean monthly flows as shown in Table 6. These flow values are underestimated due to diversions and depletions associated with agricultural practices within the basin.

Table 6. Estimated mean monthly flows (cfs) in the Shasta River near Yreka (1933-1996) period of record.

October	151.3
November	194.6
December	276.6
January	324.2
February	337.2
March	309.1
April	201.5
May	131.5
June	96.9
July	43.2
August	38.1
September	74.6

One goal of the Phase I recommendations was to maintain the linkage between both flow timing and magnitude for the main stem Klamath River and its tributaries in order to maximize the opportunity for emigration and immigration of anadromous salmonids and protection of the physical, chemical, and biological processes.

Therefore, the instream flow recommendations derived for the Iron Gate to Shasta River reach were adjusted by adding the average monthly ‘accretions’ corresponding to the mean monthly flows in Table 6 to estimate the instream flows for the Shasta to Scott River reach. Pending more specific work within the tributaries as well as the main stem of the Klamath River during Phase II, this approach was considered conservative in terms of maintaining flow linkages both within the two reaches of the main stem Klamath River as well as between the main stem and the Shasta River. The resulting instream flows are presented in Table 7.

Table 7. Recommended monthly instream flows for the Shasta to Scott River reach (all values are in cfs).

	Iron Gate MIF	Shasta Mean Monthly Flows	Estimated MIF
Oct	1476	151	1627
Nov	1688	195	1883
Dec	2082	277	2359
Jan	2421	324	2745
Feb	3008	337	3345
Mar	3073	309	3382
Apr	3307	201	3508
May	3056	131	3187
Jun	2249	97	2346
Jul	1714	43	1757
Aug	1346	38	1384
Sep	1395	75	1470

Monthly Transition Flows

Existing ramping rates for Iron Gate Dam are presently being evaluated by PacifiCorp and BOR. Studies were targeted for the fall of 1999 as directed in the 1999 Biological Opinion for Klamath Project Operations. However, because of the possibility of stranding of young-of-the-year salmonids in April, May and June, Phase I recommendations suggested limiting ramping rates to no more than 50 cfs per hour. It is anticipated that suitable ramping rates below Iron Gate Dam will be established as part of the FERC relicensing for Iron Gate Dam.

Phase I Evaluation of Water Temperatures

The hydrology based techniques employed for Phase I implicitly assume that other factors such as water quality or temperature are not limiting. This of course is not true for the main stem Klamath River below Iron Gate Dam where deleterious water temperatures and low dissolved oxygen have been associated with fish kills during the late summer low flow period. Bartholow (1995) reviewed the available data on temperature effects on anadromous species in the Klamath River and found that the main stem Klamath experiences elevated temperatures deleterious to salmonids from May through October. Bartholow considered acute thermal effects for salmonids, especially egg and larval life stages were to be expected to occur at mean daily water temperatures of 20 C or for consecutive exposures at a weekly mean temperature at 15 C. He concluded that water temperatures in the Klamath are presently marginal at best for anadromous salmonids for much of the summer and early fall period.

The USGS presently utilizes the EPA Quality Criteria for Water within their Systems Impact Assessment Model (SIAM) for the Klamath River (USGS 2001), which considers acute thermal conditions for coho and chinook salmon as 22 C and chronic exposures to occur at 16 C. Empirical observations of fish mortalities below Iron Gate during the summer period dictates that the flow dependant nature of the thermal regime on a seasonal basis needs to be factored into the flow recommendations.

As a preliminary screening of the relationship between flow and temperature below Iron Gate, Dr. Mike Deas (U.C. Davis) provided simulations of daily water temperatures for mid-August from Iron Gate Dam (RM 190.1) to the USGS Gage near Seiad Valley (RM 128.9). Simulations were completed for steady state releases from Iron Gate for at least 7 days prior to August 14 to ensure no transient effects remained in the simulation of the system. Because tributary flow contributions change daily and water temperature changes hourly, a dynamic component exists in results for August 14 simulated mean, maximum, and minimum temperature data, but it is minor. Simulated flow releases were modeled between 200 and 3000 cfs.

At low flow rates, water temperature results are compromised due to physical representation of river geometry where modeled flows are excessively shallow due to fixed trapezoidal cross sections. Maximum daily temperatures are probably too high and minimums too low for flows <500 cfs. Mean temperatures however, are probably representative. The effect of tributary contributions on maximum and minimum temperatures may also not be representative. Lower river results are probably more realistic due to increased tributary and accretion contributions (Deas, personnel communication).

Based on these caveats, only the simulated data from 500 to 1500 cfs were used in a qualitative manner in the Phase I. Although these simulations are only a first approximation, the results shown in Figures 2 and 3 for mean and maximum daily temperatures respectively, demonstrate a clear relationship between flow release volume and thermal response in the main stem Klamath River that occur at least downstream to the Scott River, where ambient conditions then dominate.

It is evident that increasing flow rates result in a reduction in the both the mean and maximum daily temperatures in the longitudinal profile of temperatures below Iron Gate Dam. This is attributed to the known relationship between higher flow volumes and damping of the range in maximum daily temperatures due to higher thermal mass with increasing flow rates. Previous work by PacifiCorp (1995) and Bartholow (1995) indicate that Iron Gate Dam may not have sufficient storage (or a deep water release point) sufficient to mitigate thermal effects with cool/cold water releases downstream of Iron Gate Dam for any substantial length of time.

Release of the available cool water pool from Iron Gate Dam may place required cool water needs of the Iron Gate Dam Hatchery at risk. However, flow reductions in dry or critically dry years during late summer and early fall clearly have the potential to exacerbate thermal effects down stream of Iron Gate Dam.

Additional temperature modeling was conducted by the USGS for the Phase I recommended monthly instream flows below Iron Gate Dam based on 1996 observed meteorological conditions using HEC5Q within SIAM. Only summary results were provided in the form of daily temperature plots below Iron Gate and Seiad. The results indicate that a 0.0 C to 0.6 C increase in mean daily temperatures would likely occur with Phase I instream flow releases. Although the overall average difference compared to the 1996 baseline averaged less than 0.4 C for the July through September period, this magnitude is likely within the noise of model input parameters given the gross estimations of wind speed, relatively humidity, air temperature, shading, and other model parameters. The temperature differential at Seiad was less than the ranges found immediately below Iron Gate Dam.

The results from these temperature simulations clearly reinforce the concerns of the effects of low flow releases during the summer period below Iron Gate Dam. The data also suggest that the recommended flow regimes will provide an incremental improvement to the thermal regime below Iron Gate Dam in terms of both the mean and maximum daily temperatures. It should be noted that prior to the construction of Iron Gate Dam as well as under natural conditions, a substantial volume of the flows in the vicinity of Iron Gate Dam were dominated by cold water inflows from springs and tributaries and would have contributed to the maintenance of cool water refugia within this reach of river. Historical fisheries data clearly show that prior to building Iron Gate Dam that this section of the Klamath River (i.e., above present Iron Gate Dam) supported anadromous species, which targeted use of these cold-water inflows (Robert Franklin and Kent Bulfinch, pers. com.). Although existing conditions within the Klamath River in terms of Iron Gate Dam, upstream reservoirs, and Klamath Lake likely result in higher than would be expected temperature releases from Iron Gate Dam compared to natural conditions, this is not justification to consider lower flow releases as adequate to meet the anadromous species needs at this time. The temperature results supported the Phase I flow recommendations within the main stem Klamath River below Iron Gate Dam compared to existing flow regimes.

These results, in conjunction with the flow recommendation analysis would suggest that instream flow recommendations should not be adjusted for water year types represented by dry and critically dry water years pending more refined analyses based on site specific methodologies being conducted under Phase II. The Phase I report also acknowledged that alterations and refinements in the interim instream flow recommendations would be made based on application of additional assessment techniques being undertaken as part of Phase II.

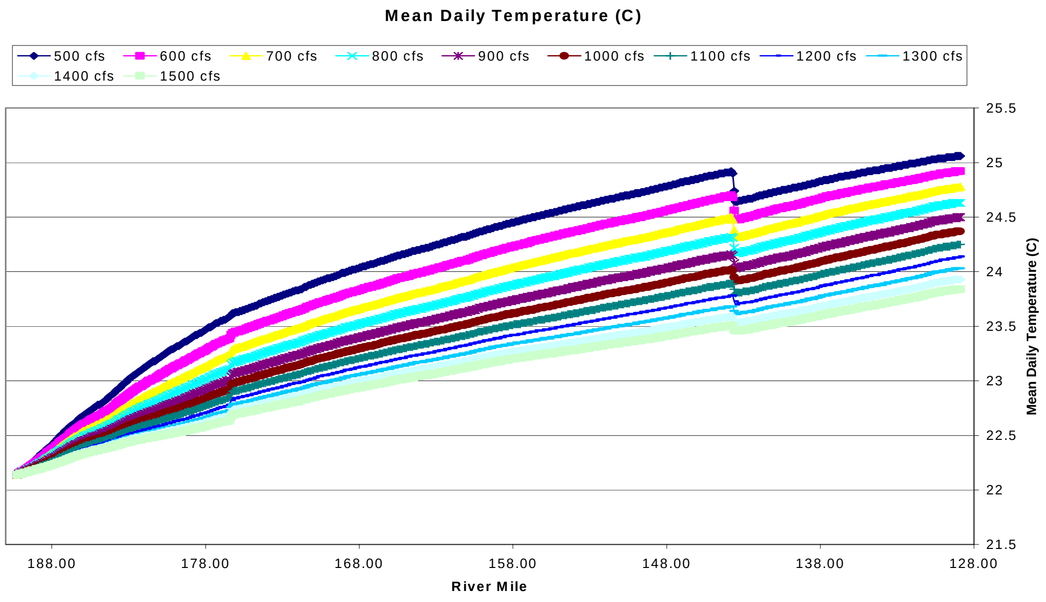


Figure 2. Longitudinal profiles of simulated mean water temperatures below Iron Gate Dam typical of mid-August meteorological conditions.

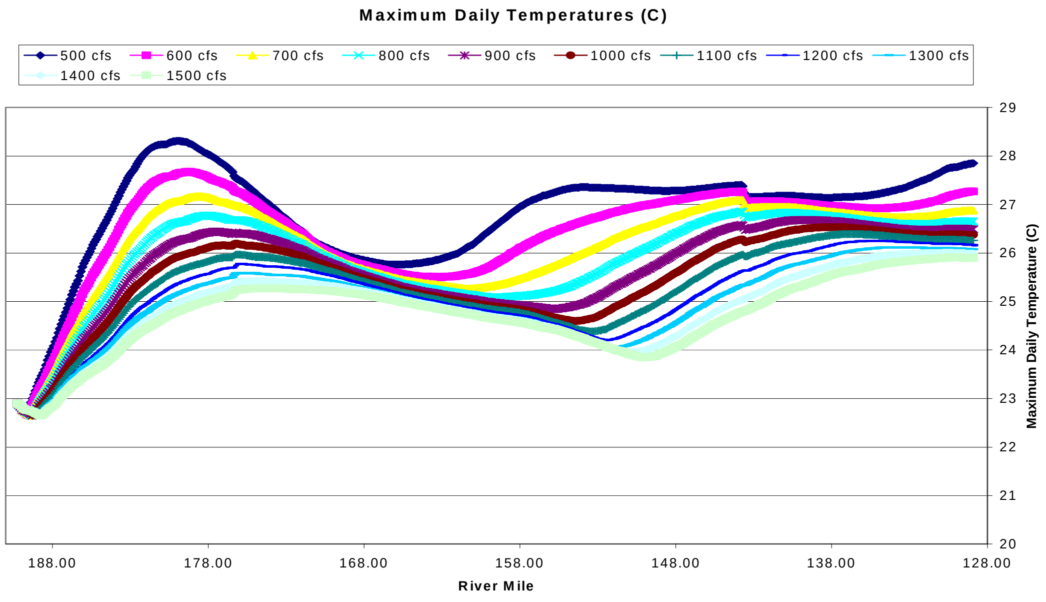


Figure 3. Longitudinal profiles of simulated mean water temperatures below Iron Gate Dam typical of mid-August meteorological conditions.

Phase II

During the work on Phase I, Phase II site-specific field studies were initiated to develop the requisite data for application of state-of-the-art instream flow assessment methods. Collaborative modeling efforts were also undertaken by USGS and the USBR for water quantity and water quality modeling for the Klamath River. The USFWS, CDFG, and Tribal resources also provided collaborative work on fish distributions, habitat suitability curve data collection and analyses, and miscellaneous supporting fieldwork as described below. This section of the report provides a description of all the technical components undertaken by USU and collaborative efforts relied upon in the Phase II technical evaluations.

Phase II General Process

The work conducted during Phase II followed continued the collaborative process of Phase I and involved close coordination between USU and the Technical Team. The Technical Team was utilized during the study for information exchange, technical discussions on methodologies, and review of study results. The team provided input and technical review for:

- Study design
- Study reach selection
- Study site selection
- Field methods
- Hydrology modeling
- Hydraulic modeling calibration and simulations
- Water quality modeling
- Species and life stage periodicities
- Species and life stage habitat suitability criteria development and validation
- Habitat modeling development and validation
- Integration of study results

In addition to technical review and input, most members of the Technical Team also provided technical assistance and collaborative efforts for field data collection and analyses. This included for example, habitat mapping, collection of fish observation data, and analysis of habitat use data for development of habitat suitability criteria. Collaborative efforts are noted where appropriate throughout the remainder of the report.

Study Design

The study design for the Phase II work was developed by USU after extensive discussions with the state, federal, and tribal representatives during the Phase I process. This included input and discussions with the Technical Working Group of the Klamath Task Force. As noted previously, these discussions focused on specific technical approaches for the selection of study sites, data collection strategies, collaborative efforts with existing studies (i.e., USGS/USFWS SIAM efforts), analytical techniques, and proposed modeling approaches.

Phase II Integrated Assessment Framework

The primary objective for Phase II was to develop instream flow recommendations using best available science based on application of state-of-the-art field data collection and modeling techniques. This effort is focused on the use of physical habitat modeling as a central element. The approach taken in Phase II focused on improved water quantity, temperature and water quality modeling within the main stem Klamath River made available by collaborative efforts of state, federal and tribal resource agencies. The application and integration of the study components relied on a multidisciplinary assessment framework that parallels the Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service. This framework is illustrated in Figure 4.

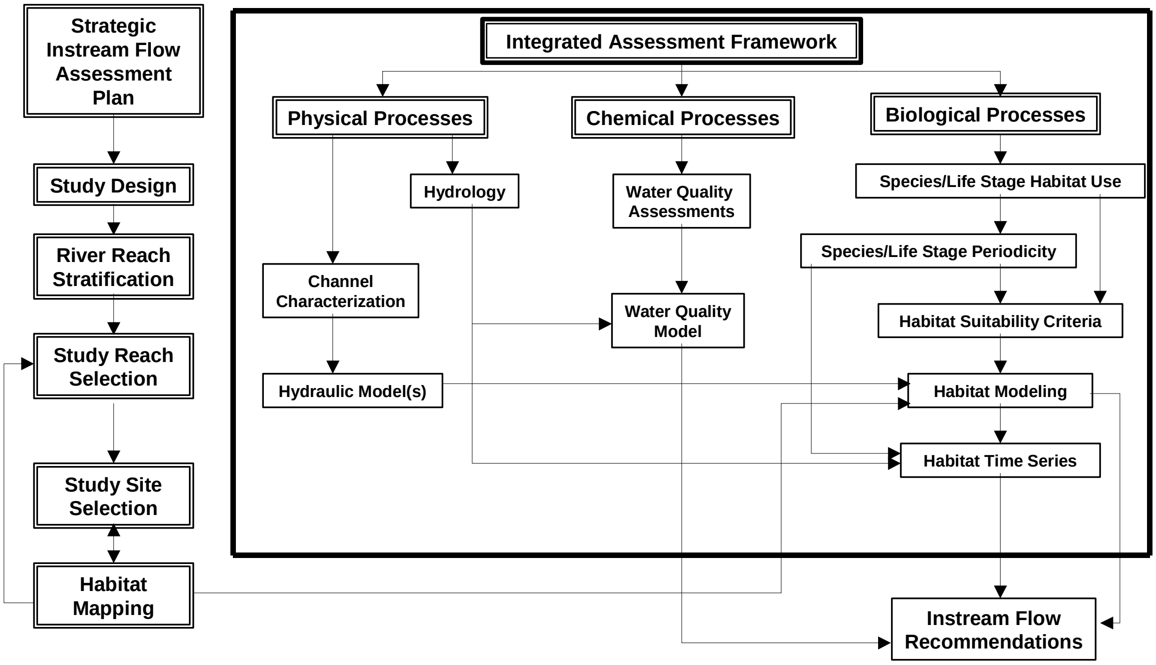


Figure 4.	Multidisciplinary assessment framework utilized for Phase II.

Figure 4 also illustrates the integrated nature of the physical, chemical, and biological processes and specific technical assessment components required to address instream flows in the main stem Klamath River. The initiation of the Strategic Instream Flow Assessment Plan component of this framework predates Phase I and Phase II. This component started with the identified need to assess the instream flow requirements in the main stem Klamath River as part of the objectives of the Klamath Restoration Act as well as on-going recovery actions by state, federal, tribal, local, and private groups. In addition, the USBR in collaboration with the USGS, BIA, USFWS, NMFS, Tribes, and the Technical Work Group from the Klamath River Basin Fisheries Task Force also facilitated the development of a long-term instream flow study plan for the Klamath River Basin to extend the work being conducted in Phase II.

The following sections of the report detail the specific approaches and results associated with each component of the assessment framework used in Phase II.

Delineation of the Spatial Domain

The Phase II study primarily focused on the main stem Klamath River below Iron Gate Dam for most components of the assessment framework. However, the hydrology and water quality (including temperature) components involved modeling inflows to Upper Klamath Lake and routing this water to Iron Gate Dam. The flows and initial conditions for water quality were then modeled below Iron Gate Dam. The Phase II assessments do not include work within the principal tributary systems (i.e., Shasta, Scott, Salmon, and Trinity Rivers). These systems are targeted for assessments as part of the long-term strategic flow study mentioned previously.

River Reach Stratification

The Technical Team was utilized to stratify the main stem Klamath River into ‘homogeneous’ study reaches. This stratification was primarily based on the junctions of major tributary systems within the main stem Klamath River. The purpose of this stratification was to delineate sections of river that function in a similar manner in terms of flow volumes and overall channel characteristics. The discussions also considered additional factors such as species and life stage distributions, access, locations of on-going fieldwork for other research (e.g., USGS/USFWS, Tribal fisheries programs), culturally sensitive areas for the tribes, existing modeling capabilities for water quantity and quality, and pragmatic constraints dictated by time and budget constraints on field work for study site delineations.

The Technical Team conducted a site reconnaissance of the main stem from Iron Gate Dam to estuary as part of this stratification process. Based on the technical discussions and site reconnaissance, five river reaches were delineated:

1. Iron Gate Dam to the Shasta River
2. Shasta River to the Scott River
3. Scott River to the Salmon River
4. Salmon River to the Trinity River
5. Trinity River to the Estuary

These reach delineations are shown by different colors within the main stem Klamath River in Figure 5. Table 8 provides the starting, ending, and total length of river miles associated with each of these segments.

Table 8. Starting, ending, and total length of river miles for each river reach segment identified for Phase II studies.

Segments	**Iron Gate Dam to Shasta River**	**Shasta River to Scott River**	**Scott River to Salmon River**	**Salmon River to Trinity River**	**Trinity River to Estuary**
Starting Mile	**0.00**	**13.45**	**46.94**	**125.23**	**148.10**
Ending Mile	**13.45**	**46.94**	**125.23**	**148.10**	**194.07**
Segment Length (miles)	**13.45**	**33.49**	**78.29**	**22.87**	**45.97**

Overview of Study Site Selection

The selection of study sites for Phase II were determined through a collaborative effort with the Technical Team and ongoing studies being conducted by the USGS and USFWS. The USGS/USFWS were in the process of collecting 1-dimensional cross section data within the first two river reaches as part of the development work for the Systems Impact Assessment Model (SIAM) and intended application of their salmon production model component (SALMOD).

Phase II study site locations were chosen to be broadly representative of channel characteristics within each delineated river reach and in some cases to overlap with existing USGS/USFWS study sites. These overlapping study sites were selected to permit comparison between USGS/USFWS study results with those generated in Phase II due to very different field data collection and modeling strategies between the two studies. Study site selection specific to the USGS/USFWS and Phase II work are described in more detail below.

The process for selection of study sites involved the use of ground-based habitat mapping. This mapping effort characterized the available mesohabitats (i.e., fish habitat) within each river reach segment. Based on the mapping results, specific study site locations were selected based on the respective USGS/USFWS and Phase II study objectives.

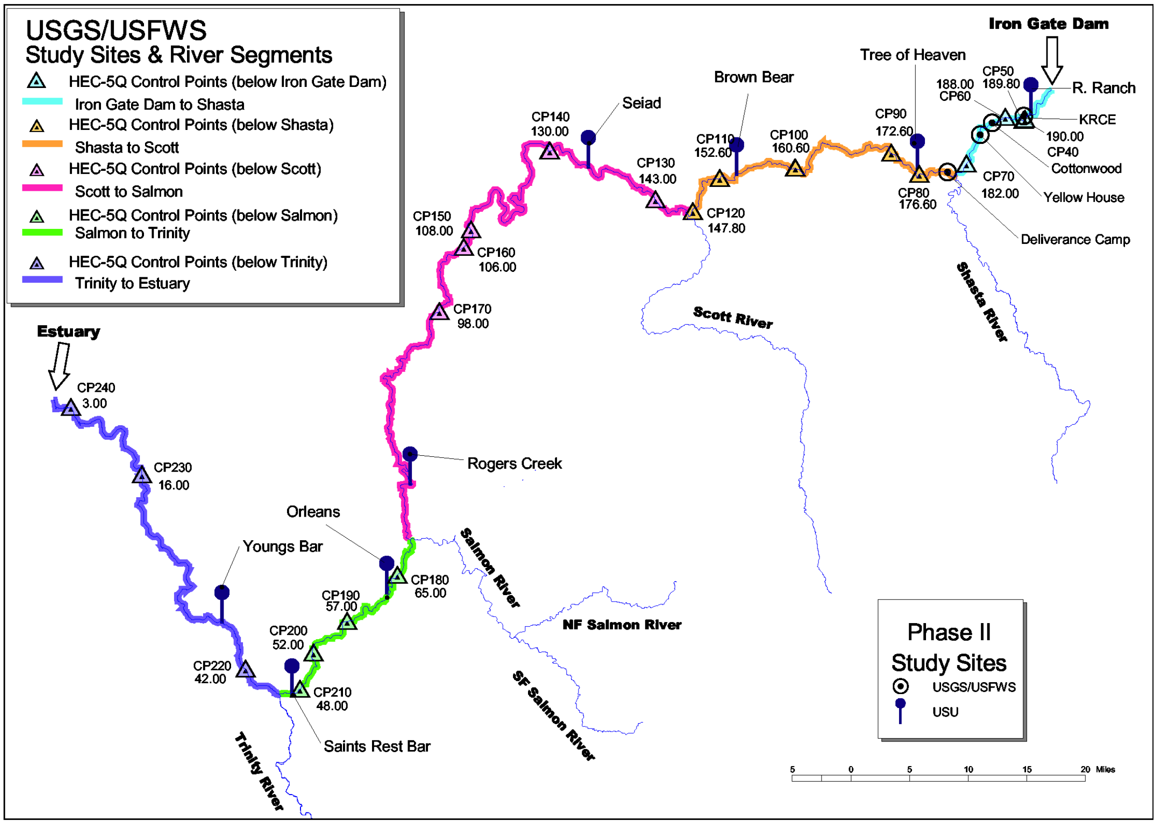


Figure 5. River reach delineations, USGS/USFWS (1-D) and USU (intensive) study site locations, river mile, and SIAM control point (CP) locations within the main stem Klamath River.

Habitat Mapping

The USFWS, USGS, and Yurok Tribes undertook field based mapping of mesohabitat types from Iron Gate Dam to the estuary. The mesohabitat classification scheme employed was developed by the USGS/USFWS study team in collaboration with other state, federal, and tribal resource agencies and adopted for use in Phase II for consistency.

Starting at Iron Gate Dam, each mesohabitat unit encountered was enumerated, assigned to a specific mesohabitat classification, GPS coordinates delineated for the start of the feature, and maximum depth recorded with an acoustic bottom sounder. An Advantage Laser Atlanta laser range finder was used to determine lengths and widths of mesohabitat units.

Mesohabitat classifications were broken into Low Slope (LS), Moderate Slope (MS), High Slope (HS) (same as Steep Slope (SS)), and Pools (P). In addition main channel, side channels, and split channel classifications were made. According to the USGS/USFWS a split channel was defined as a “permanent”, vegetated (trees) island that is not inundated even at a “high flow” (~ 10,000 cfs).

A side channel has a temporary, un-vegetated or seasonally vegetated island (e.g., a gravel or sand bar) that is inundated by low or moderate flows (~ 3,000 – 6,000), typically annually. Whenever a split or side channel condition was encountered, mesohabitat mapping was conducted for the main channel and each side/split channel separately.

Table 9 provides a summary of the mesohabitat mapping results for each delineated river reach. The habitat mapping results were also utilized to extrapolate the relationships between flow and available habitat within specific study sites to the reach level as described later in the report in the habitat modeling section. Note: The Trinity River to estuary reach has been omitted (see USU Two-dimensional Hydraulic Modeling section below).

Selection of USGS/USFWS Study Sites

Specific study sites for the USGS/USFWS based field efforts were selected to meet their study objectives for development of SALMOD as part of SIAM for the Lower Klamath Basin. The selection of these study sites were based on USGS/USFWS study objectives using the general framework for the application of the Physical Habitat Simulation (PHABSIM) of the Instream Flow Incremental Methodology (IFIM) as described in Bovee (1995). Based on these objectives and the habitat mapping results, seven study sites composed of thirteen hydraulic modeling sites were identified within the main stem Klamath River between Iron Gate Dam and upstream of the Scott River (see Figure 5, 1D-Sites). These study sites were selected to represent available habitats within the upper two river reaches corresponding to Iron Gate downstream to the confluence with the Shasta River and from the Shasta River downstream to the confluence with the Scott River. Four separate sampling sites were selected to represent the river reach above the confluence of the Shasta River. Three separate study sites were selected to represent the river reach below the confluence of the Shasta River. These study sites, listed in a downstream direction are (see Figure 5):

1. Rranch - Iron Gate to the Shasta River
2. KRCE - Iron Gate to the Shasta River
3. Cottonwood - Iron Gate to the Shasta River
4. Yellow House - Iron Gate to the Shasta River
5. Deliverance - Shasta River to the Scott River
6. Trees of Heaven - Shasta River to the Scott River, and
7. Brown Bear - Shasta River to the Scott River

Table 9. Proportion of available mesohabitat types within each river reach. Note: Mesohabitat types are defined as: LS = Low Slope, MS = Moderate Slope, SS = Steep Slope, P = Pool, POW = Pocket Water.

Iron Gate to Shasta:			**Shasta to Scott:**		
Main Channel			**Main Channel**		
Mesohabitat Type	**Total Length (feet)**	**Percent Total**	**Mesohabitat Type**	**Total Length (feet)**	**Percent Total**
LS	19860	35.03	LS	45668	25.42
MS	11868	20.93	MS	35241	19.62
SS	1914	3.38	SS	13262	7.38
P	23053	40.66	P	83738	46.61
RUN	N/A	N/A	RUN	1742	0.97
Total	56695	100	Total	179651	100
Side Channels			**Side Channels**		
Mesohabitat Type	**Total Length (feet)**	**Percent Total**	**Mesohabitat Type**	**Total Length (feet)**	**Percent Total**
LS	940	22.18	LS	3776	28.37
MS	1043	24.60	MS	3154	23.70
SS	N/A	N/A	SS	601	4.52
P	1927	45.46	P	5778	43.41
RUN	329	7.76	RUN	N/A	N/A
Unknown	N/A	N/A	Unknown	N/A	N/A
Total	4239	100	Total	13309	100
Split Channels			**Split Channels**		
Mesohabitat Type	**Total Length (feet)**	**Percent Total**	**Mesohabitat Type**	**Total Length (feet)**	**Percent Total**
LS	2308	58.59	LS	1437	20.97
MS	1157	29.37	MS	1790	26.12
SS	N/A	N/A	SS	1215	17.73
P	474	12.03	P	2410	35.17
Total	3939	100	Total	6852	100

Table 9. (Continued)

Scott to Salmon:			**Salmon to Trinity:**		
Main Channel			**Main Channel**		
Mesohabitat Type	**Total Length (feet)**	**Percent Total**	**Mesohabitat Type**	**Total Length (feet)**	**Percent Total**
LS	54383	13.13	LS	13230	10.64
MS	67572	16.32	MS	14712	11.84
SS	32437	7.83	SS	8505	6.84
P	249385	60.21	P	87238	70.18
RUN	10389	2.51	RUN	613	0.49
Total	414166	100	Total	124298	100
Side Channels			**Side Channels**		
Mesohabitat Type	**Total Length (feet)**	**Percent Total**	**Mesohabitat Type**	**Total Length (feet)**	**Percent Total**
LS	6915	29.31	LS	2120	31.56
MS	3333	14.13	MS	1418	21.11
SS	2496	10.58	SS	494	7.35
P	8363	35.45	P	2686	39.98
RUN	403	1.71	RUN	N/A	N/A
Unknown	2081	8.82			
			Total	6718	100
Total	23591	100			
Split Channels			**Split Channels**		
Mesohabitat Type	**Total Length (feet)**	**Percent Total**	**Mesohabitat Type**	**Total Length (feet)**	**Percent Total**
LS	3790	50.55	LS	N/A	N/A
MS	2449	32.66	MS	N/A	N/A
SS	660	8.80	SS	N/A	N/A
P	599	7.99	P	N/A	N/A
Total	7498	100	Total	N/A	N/A

Within each of these general river stretches, the location of specific study and hydraulic modeling sites were chosen based on representing key morphological attributes of the river such as main channel, side channel, and split channels, known locations of chinook spawning and rearing habitats, and hydrologic considerations such as inflows from major tributaries. The mesohabitat mapping results were used in conjunction with field observations and professional judgment to select specific mesohabitats where detailed hydraulic and habitat characterizations would be collected at each study site as described below.

Selection of USU Study Sites

Selection of USU study sites based on Phase II study objectives followed the general framework for the application of the PHABSIM component of the Instream Flow Incremental Methodology (IFIM). The Technical Team participated in a field-based review of the Klamath River from Iron Gate to the estuary in light of general channel morphology, changes in flow associated with tributary inflows, and known habitat use by anadromous species. Based on this review, USU in collaboration with the Technical Team selected eight locations within the main stem Klamath River for intensive field based analyses. Each of these study sites was selected to be generally characteristic of the specific river reaches where they were located and in some cases to also allow comparison of modeling results based on the USGS study sites and modeling approaches. The location of the eight Phase II study sites within each of the five river reaches are indicated in Figure 5 (labeled as USU) and denoted by the following locations:

1. RRanch
2. Trees of Heaven
3. Brown Bear
4. Seiad
5. Rogers Creek
6. Orleans
7. Saints Rest Bar
8. Youngs Bar

Physical Processes

This section of the report highlights the methodologies for fieldwork and associated modeling efforts used to characterize the key physical processes within the main stem Klamath River. These efforts were specifically targeted to acquire and analyze data necessary to support the habitat modeling undertaken as part of the Biological Processes of the Phase II study.

Channel Characterization

The approaches taken to characterize the channel are directly linked to the intended modeling approach and objectives of the study. Therefore, the approaches differ markedly between the USGS/USFWS study and the fieldwork undertaken as part of the Phase II assessments by USU. Each approach is detailed below.

USGS/USFWS Field Methodologies for Channel Characterization

The USGS/USFWS study relies on the application of the hydraulic and habitat modeling as implemented in the Physical Habitat Simulation System (PHABSIM) (Hardy 2000). As such, their field methodologies were specifically designed to target the characterization of the channel properties for use in this modeling system. PHABSIM relies on cross sections to define the channel topography and then employs 1-dimensional hydraulic modeling to characterize the hydraulic properties over desired ranges of discharges. At each of the USGS/USFWS hydraulic modeling study sites, cross section profiles within specific mesohabitat types (with the exception of high gradient riffles) were used to characterize the channel topography, water surface elevations at three discharges, and the velocity profiles at several calibration flows. Figures 6 and 7 conceptually illustrate the field-based characterization of the river at a study site using a cross section approach.

Complete velocity profiles were generally obtained only at low and intermediate flow rates. Discharge measurements and mid-channel velocities were taken at the high calibration flow at one or more cross sections at each study site using an acoustic doppler current profiler. Which cross sections were measured was dictated by the ability to collect “good data” that was restricted by the severity of surface turbulence and safety considerations for the field crew (Jim Henriksen, personal communication). In addition, at each vertical along each cross section, the substrate, cover type, and distance to cover were delineated. At two study sites, RRanch and Trees of Heaven, an additional velocity and water surface elevation data set were collected for validation testing of the hydraulic modeling. Hydraulic modeling utilizing these data is described later in more detail. Table 10 lists the discharge and water surface elevation calibration sets collected at each of the USGS/USFWS hydraulic modeling study sites.

Table 10. Discharge and water surface elevation calibration sets collected at each of the USGS/USFWS hydraulic modeling study sites.

	RRanch LB	**RRanch Main**	**RRanch RB**	**KRCE Main**	**KRCE Side**	**Cotton1**	**Cotton2**
Low	324	1010	714	1119	35	1037	1037
Medium	1373	3366	1941	3310	301	3175	3142
High	4606	7926	3190	7780		7618	7337
Low	**Yellow**	**Deliverance**	**Trees1**	**Trees2**	**Brown Bear**		
Medium	1098	1412	1485	1485	1545		
High	3078	3114	3451	3220	3654		
	8548	8473	9621	9621	8870		

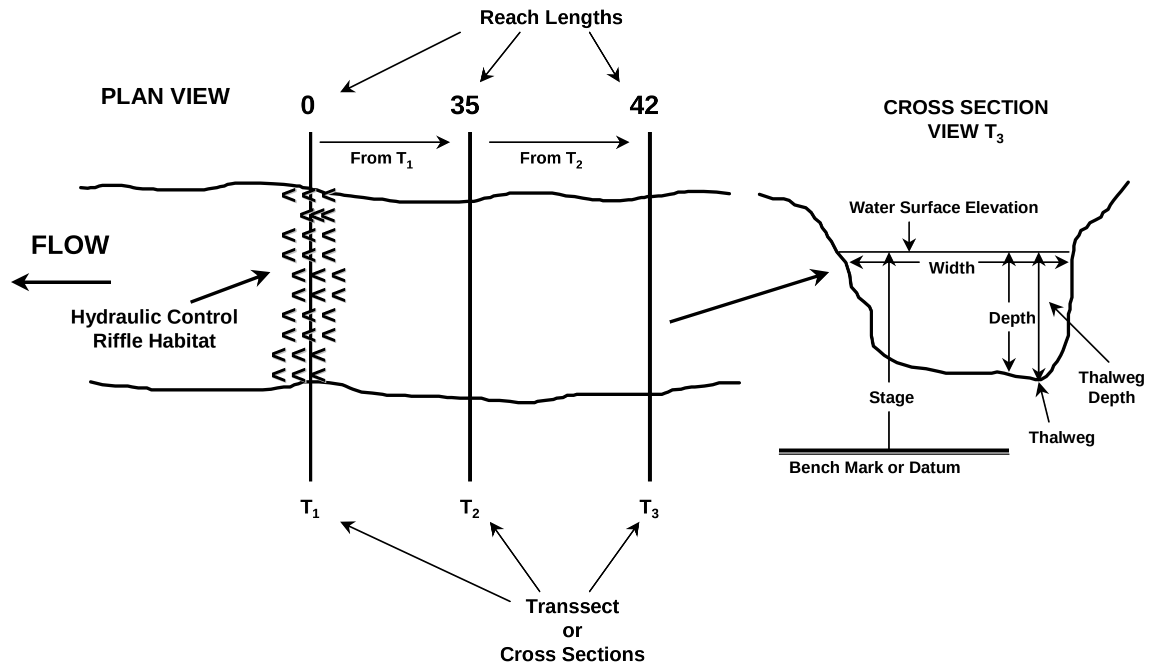


Figure 6. Idealized representation of channel characteristics in plan view based on cross sections.

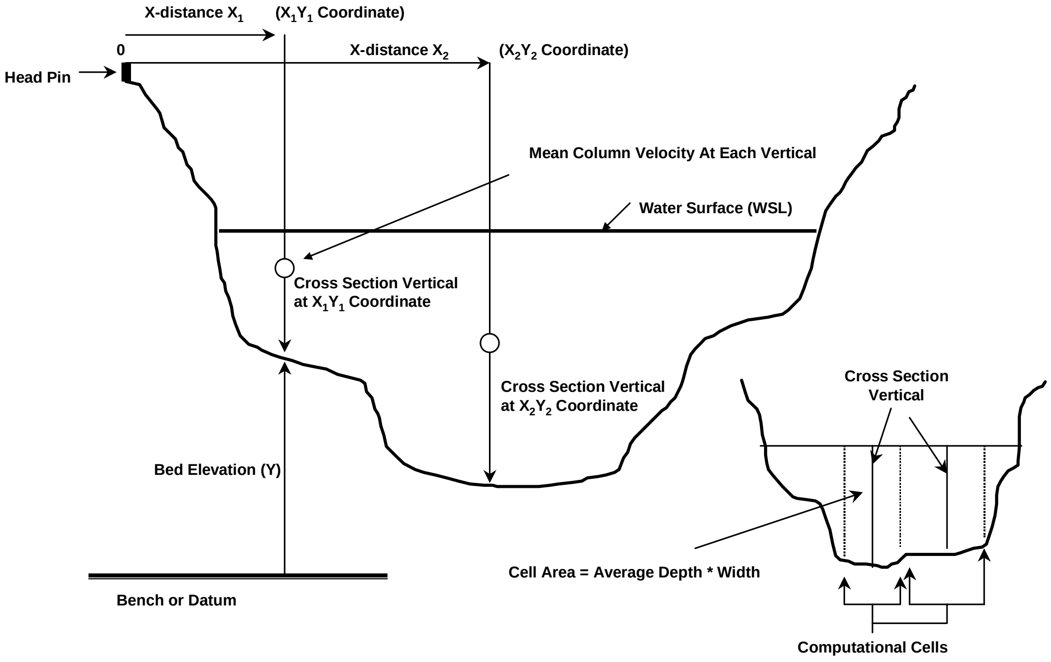


Figure 7. Idealized representation of channel characteristics in transverse view based on cross sections.

USU Field Methodologies for Channel Characterization

The field methodologies used by USU for Phase II to characterize the channel at each study site differs fundamentally from the approach described above for the USGS/USFWS study. In the approach taken by USU, the objective was to delineate the channel characteristics (i.e., channel topography, substrate, and vegetation) in a spatially explicit manner over the entire study site. This approach to field data acquisition targets data suitable for 3-dimensional representation of the study site and application of 2-dimensional hydraulic modeling. The use of this type of hydraulic modeling requires that the spatial domain (i.e., study reach) be characterized in terms of its 3-dimensional topography. This 'view' of a study site is illustrated in Figure 8.

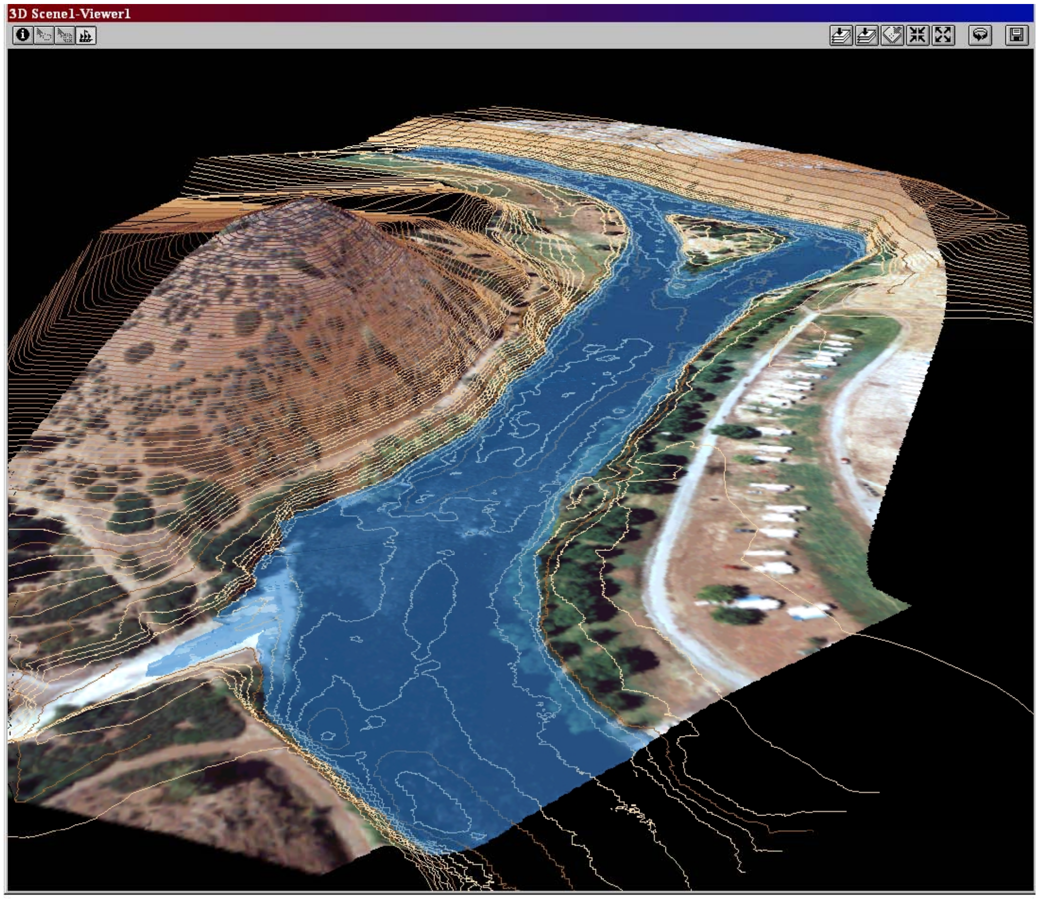


Figure 8. Three-dimensional representation of a study site based on field data collection methodologies employed by USU for Phase II.

The approach to the field data collection and subsequent analysis methods to achieve this type of characterization was accomplished through the application of low elevation high-resolution aerial photogrammetry and acoustic based mapping of the channel topography. The aerial photogrammetry is utilized to acquire channel topographies that are above water, while the acoustic based mapping is utilized to acquire below water topography. These two data sets are then integrated to obtain a single 3-dimensional representation of the channel. Each of the data acquisition and analysis steps are described below.

Establishment of a Control Network for Aerial Photogrammetry

A Global Position System (GPS) control network was established, using three to four control points that were placed along each of the eight study reaches. Points were placed in a non-linear alignment so that triangulations between points could be carried out to rectify coordinate positions. Control points were established using permanent survey markers that were located using survey grade GPS equipment or with standard survey techniques from known horizontal and vertical control points located near the study reach. When using GPS, data were collected on each control point for times varying from twenty minutes to ten hours depending on satellite configuration and previously established control points that were located in the study area. These data permit the rectification of all subsequent data collected at the site to a standard map projection in the Geographic Information System (GIS).

Aerial Photogrammetry Image Acquisition and Digital Terrain Modeling

Acquisition of low elevation high-resolution imagery was targeted to coincide with the lowest practical flow rates within the channel to maximize the exposure of channel topographies at each study site. Dates of collection, flight elevation, and flow rates at each of the eight study sites are shown in Table 11. An example of the low elevation high-resolution imagery for the RRanch study site is provided in Figure 9. Out-of-water digital terrain models (DTMs) were then generated at each intensive study site using Soft Copy Photogrammetry. This is explained in the next section.

Figure 9. Example of the low elevation high-resolution imagery for the RRanch study site employed by USU for Phase II characterizations of the river channel.

Table 11. Dates of image collection, flight elevations, and flow rates measured at the eight USU study sites.

Sites	Date of Image Collection	Image Frame	Flight Elevations	Flow Rate (cfs)
RRanch	8/24/1999	1-02	1059.809	1140
		1-03	1064.617	
		1-04	1065.222	
		1-05	1058.915	
		Average:	**1062.141**	
Seiad	8/24/1999	4-04	822.387	1470
		4-05	826.831	
		4-06	829.635	
		4-07	828.622	
		4-08	826.980	
		4-11	822.099	
		4-12	825.476	
		4-13	828.856	
		4-14	831.083	
		4-15	828.180	
		4-16	821.511	
		Average:	**826.515**	
Orleans	8/24/1999	6-03	521.449	2130
		6-04	519.932	
		6-05	515.774	
		6-06	512.974	
		6-07	510.109	
		6-08	503.838	
		6-09	507.045	
		6-10	509.099	
		6-11	511.487	
		Average:	**512.412**	
Brown Bear	8/24/1999	3-06	915.235	1226
		3-07	921.588	
		3-08	927.421	
		3-09	930.248	
		3-10	932.148	
		Average:	**925.328**	

Sites	Date of Image Collection	Image Frame	Flight Elevations	Flow Rate (cfs)
Youngs Bar	8/24/1999	9-05	481.776	3038
		9-07	456.712	
		9-08	464.556	
		9-09	467.831	
		9-10	470.365	
		9-11	471.526	
		Average:	**468.794**	
Trees of Heaven	8/24/1999	2-01	1014.172	1224
		2-02	1018.882	
		2-03	1025.264	
		2-04	1032.156	
		2-05	1041.428	
		2-06	1048.051	
		Average:	**1029.992**	
Rogers Creek	8/24/1999	5-01	568.423	1832
		5-02	570.465	
		5-03	574.068	
		5-04	575.765	
		5-05	579.970	
		5-06	585.394	
		5-09	563.358	
		5-10	571.051	
		5-11	578.813	
		Average:	**574.145**	
Saints Rest Bar	8/24/1999	7-02	472.690	2130
		7-03	479.986	
		7-04	492.593	
		7-05	499.833	
		7-06	505.818	
		Average:	**490.184**	

Photogrametric derived DTMs generally have coordinate accuracies of approximately 1/10,000th of the flying elevation. Flying elevations for each study site are shown in Table 10. Accuracy of the DTMs at each site therefore, was generally in the range of 0.03-0.09 meters (0.1-0.3 feet). In some instances, where topographies were obscured by riparian vegetation, they were delineated (i.e., horizontal and vertical measurements) using standard survey techniques with a total station. Topographic sampling in these cases was approached using a systematic irregular sampling strategy that focused on delineating changes in the plan form topography.

Aerial Photogrammetry Data Reduction

Aerial photography ground control targets were placed on the ground at each intensive study site and surveyed with GPS using the survey control network. All survey data were submitted to standard QA/QC checks at each site. This included for example, satellite configuration errors, checks on ellipsoid height errors, PDOP (point dilution of precision), L1/L2 fix statistics, etc. The aerial targets were used as horizontal and vertical control in the photogrammetry block adjustment process.

Aerial photographs were scanned at 12 *u*m using a high quality photogrammetric scanner. The interior orientation of each image was set in the photogrammetry software using the USGS camera calibration report parameters for the aerial camera. The ground control points in combination with between image tie-points were used within the photogrammetry software to perform a least-squares block bundle adjustment of all images. Statistics from this process were reviewed for accuracy with an allowable maximum Root Mean Square Error of 1.0 or less.

Following this step, stereo pairs for use in digital terrain modeling were generated. The three-dimensional topography (DTM's of above water topography) was then generated from the stereo pairs using standard softcopy photogrammetry techniques. All topography work was reviewed by a second research technician as a QA/QC check. Following generation of the complete above water DTM's, digital orthophotographs were produced for each study site. The orthophotographs were then used for the development of a GIS base map for each study site. This GIS (orthophotograph) base map was used primarily to overlay data from biological observation, substrate/cover mapping, hydrodynamic modeling (including computational meshes), topography contours, and fish habitat modeling as described below. The orthophotographs for each of the eight study sites are provided in Figures 10 through 17.

Figure 10. Orthophotograph of the USU RRanch study site.

Figure 11. Orthophotograph of the USU Trees of Heaven study site.

Figure 12. Orthophotograph of the USU Brown Bear study site.

Figure 13. Orthophotograph of the USU Seiad study site.

Figure 14. Orthophotograph of the USU Rogers Creek study site.

Figure 15. Orthophotograph of the USU Orleans study site.

Figure 16. Orthophotograph of the USU Saints Rest Bar study site.

Figure 17. Orthophotograph of the USU Youngs Bar study site.

Hydro-acoustic Mapping of Underwater Topography and Data Reduction

The hydroacoustic based mapping of the subsurface channel topography (i.e., under water topography) was undertaken with a boat mounted real time kinematic differentially corrected survey grade GPS system integrated with a scientific grade acoustic bottom profiling system. An acoustic doppler current profiling system (ADP) for measurement of the 3-dimensional velocity vectors throughout the water column was also integrated into the instrument package. The integrated boat mounted instrument package is shown in Figure 18.

The hydroacoustic mapping was conducted at a discharge that was greater than the discharge at which the aerial photogrammetry was collected to ensure an overlap between the DTMs generated from these data sets and to minimize the potential for missing topographies where the acoustic mapping was limited by water depths at the stream margins. Figure 19 illustrates a typical GPS track of the USU integrated boat mounted hydro-acoustic mapping instrument package while collecting bottom topographies at a river site. This figure also illustrates out of water terrain points derived from soft copy photogrammetry.

Table 12 lists the dates, flow rates, and number of sample points collected when acoustic mapping was conducted at each USU study site. Hydro-acoustic data reduction involved conversion of electronic data from field systems in the laboratory, data censoring, and QA/QC of the raw field data. Data censoring and QA/QC procedures were used to remove any data points where either bottom lock was lost on the hydro-acoustic profiling gear or GPS location data were degraded outside acceptable limits. In addition, the data were screened visually in the 3-dimensional photogrammerty software for outliers where shallow water interference caused errors in the hydro-acoustic data.

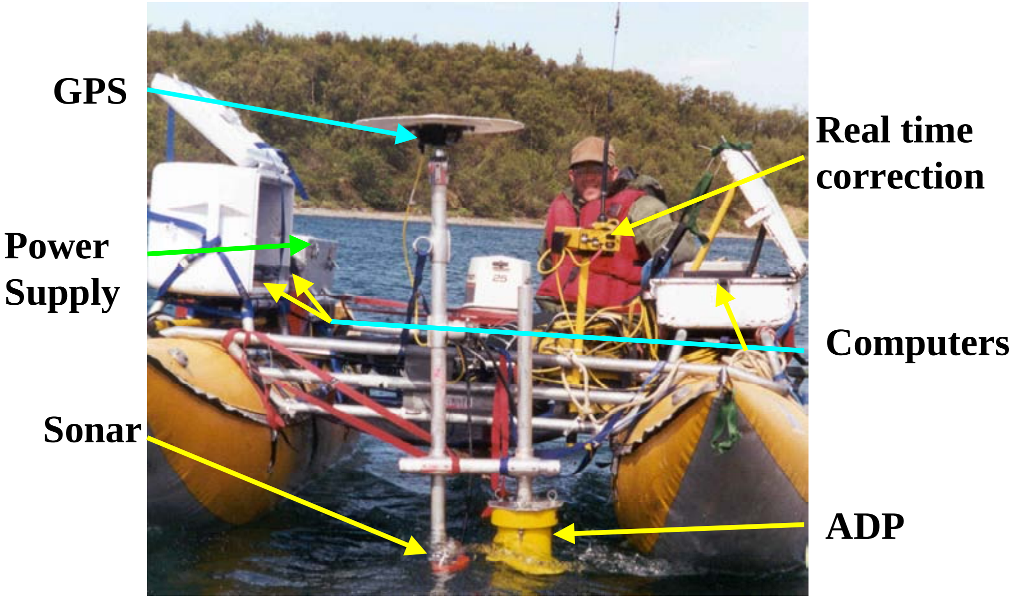


Figure 18. USU integrated boat mounted hydro-acoustic mapping instrument package.

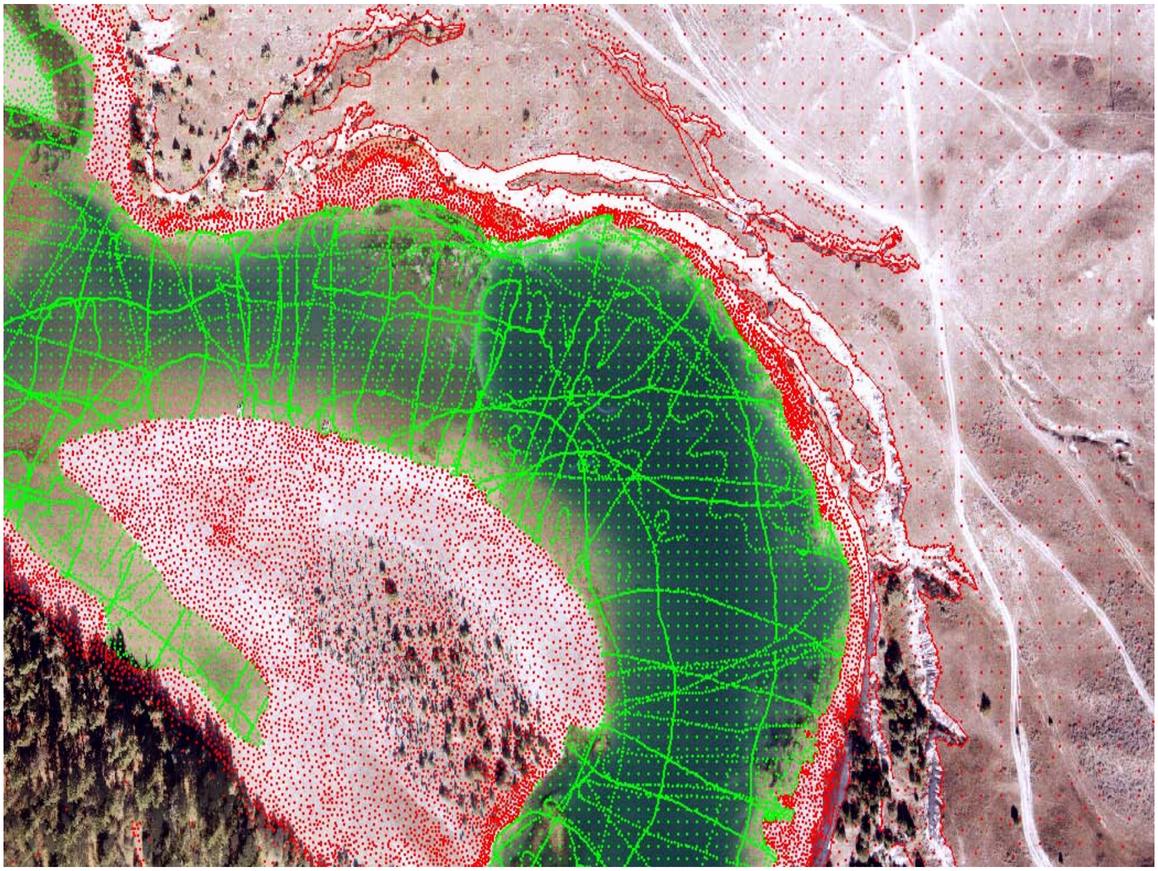


Figure 19. Typical GPS track (green lines) of the USU integrated boat mounted hydro-acoustic mapping instrument package while collecting bottom topographies at a river site. Red points identify photogrammetry derived terrain points.

Table 12. Dates, flow rates, and number of data points collected during acoustic mapping at each intensive study site.

Study Site	Collection Dates	Flow Rate(s) CFS	Number of Sonar Points
Rranch	3/29-3/30/99	5550,5530	18540
Trees of Heaven	3/25-3/27/99	6496	36400
Brown Bear	3/23-3/24/99	7563	22021
Seiad	3/16-3/20; 3/22/99	10300,9490,9220,10900,12600,1160	47407
Rogers Creek	8/26-8/27/99	1832	6970*
Orleans	4/1-4/3/99	16700,16900	23439
Saints Rest Bar	4/6/1999	16600,16500	9893
Youngs Bar	4/7-4/8/99	22580,22500	14677

* Data collected using ADP. All other data collected using single beam sonar.

Integration of Photogrammetry and Hydro-acoustic Data

The integration of the DTM data derived from the softcopy photogrammetry and the DTM data derived from the hydro-acoustic data were integrated with conventional survey data to generate a single spatially explicit terrain model for each intensive study site. This terrain model was then used to develop 3-dimensional computational meshes for input into the 2-D hydrodynamics (i.e., hydraulic) model for each study site. The development of the computational meshes and hydrodynamic modeling is discussed below.

Water Surface Elevation and Water Velocity Mapping

The longitudinal profile of the water surface elevation within each study site was measured at a minimum of three calibration discharges. The survey data was tied directly to the upstream and downstream control cross sections at each intensive site. These water surface profiles were accompanied by an estimate of the discharge at the site. The discharge and water surface elevation data sets were used for 2-dimensional hydrodynamics model calibration as described below. Velocity measurements using a three-dimensional acoustic doppler current profiler (ADCP) were undertaken throughout the study sites at the discharge associated with the delineation of the channel topographies. Table 12 indicates the dates of hydraulic calibration data set collections and associated flow rates at each USU study site.

Table 13. Dates of collection and flow rates for each calibration data set at USU study sites (WSE = Water Surface Elevation, cms = cubic meters per second).

Site	Date	High WSE (m)	High Q (cms)	Med WSE (m)	Med Q (cms)	Low WSE (m)	Low Q (cms)
Rranch	3/29/1999	624.99	157.164				
Rranch	6/3/1999			624.24	53.800		
Rranch	8/24/1999					623.99	32.280
Trees of Heaven	3/27/1999	566.41	183.953				
Trees of Heaven	6/2/1999			565.29	57.599		
Trees of Heaven	8/24/1999					564.94	34.661
Brown Bear	3/23/1999	471.23	214.168				
Brown Bear	6/9/1999			470.15	57.542		
Brown Bear	8/25/1999					469.76	34.718
Seiad	3/16/1999	384.17	291.674				
Seiad	6/10/1999			383.58	128.563		
Seiad	8/26/1999					383.12	41.627
Rogers Creek	4/14/2000	146.18	298.025				
Rogers Creek	6/29/1999			145.38	131.465		
Rogers Creek	8/26/1999					144.66	51.878
Orleans	4/1/1999	87.49	472.909				
Orleans	6/14/1999			87.21	365.301		
Orleans	9/1/1999					86.09	60.034
Saints Rest Bar	4/6/1999	464.41	32.487				
Saints Rest Bar	7/6/1999			146.97	31.203		
Saints Rest Bar	8/8/2000					63.18	30.212
Youngs Bar	4/7/1999	639.42	7.983				
Youngs Bar	7/1/1999			275.53	6.583		
Youngs Bar	9/2/1999					88.95	5.674

Substrate and Vegetation Mapping

Substrate and vegetation distributions were mapped at each study site by delineating filed interpreted polygons on color aerial photograph prints and then digitizing these polygon data in the laboratory. Substrate and vegetation codes were standardized for the study and are provided in Table 14. Where substrate could not be delineated directly, snorkeling, and underwater video were utilized. This work was undertaken through a collaborative effort by the Yurok Tribal fisheries resource personnel assisting with the Phase II work. The digitized polygon data were then overlaid onto the orthophotographs in the GIS in order to assign variable roughness values spatially within a study site at each computational mesh node location for use in the hydraulic modeling. As will be discussed below, the integration of the substrate and vegetation mapping with the hydraulic solutions at each computational mesh node were also used in the habitat modeling for fish. Figures 20 through 27 show the substrate and vegetation polygon distributions delineated for each intensive study site and overlaid on the study site orthophotographs.

Table 14. Standardized codes used for field delineations of polygons associated with substrate and vegetation at study reaches.

Code	Substrate or Vegetation Type	Code	Substrate or Vegetation Type
1	Filamentous algae	18	Clay
2	Non emergent rooted aquatic	19	Sand and/or silt (<0.1")
3	Emergent rooted aquatic	20	Coarse Sand (0.1-0.2")
4	Grass	21	Small Gravel (0.2-1")
5	Sedges	22	Medium Gravel (1-2")
6	Cockle burs	23	Large Gravel (2-3")
7	Grape vines	24	Very Large gravel (3-4")
8	Willows	25	Small Cobble (4-6")
9	Berry vines	26	Medium Cobble (6-9")
10	Trees <4"	27	Large Cobble (9-12")
11	Trees >4"	28	Small Boulder (12-24")
12	Rootwad	29	Medium Boulder (24-48")
13	Aggregates of small veg dom <4"	30	Large Boulder (>48")
14	Aggregates of large veg dom>4"	31	Bedrock-smooth
15	Duff, leaf litter, organic debris	32	Bedrock-rough
16	Small Woody Debris (SWD) <4"x12"		
17	Large Woody Debris (LWD)>4"x12"		

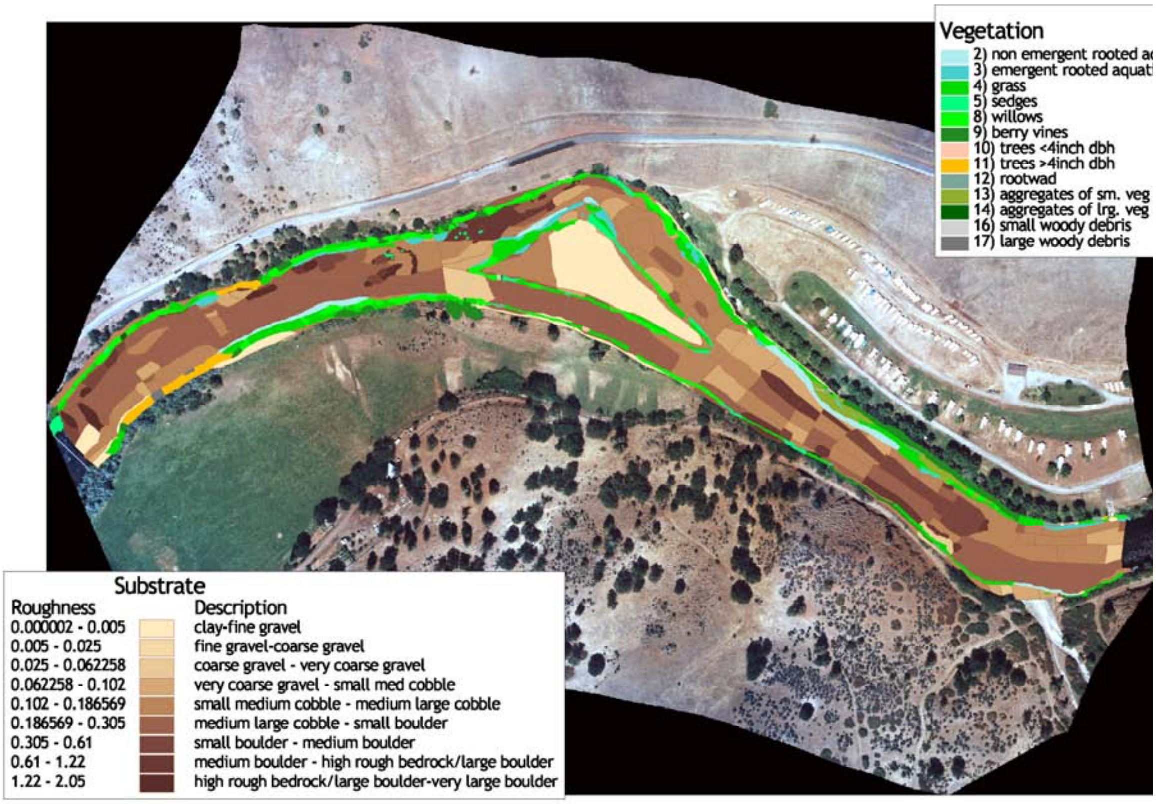


Figure 20. Spatial distribution of delineated substrate and vegetation at the USU RRanch study site.

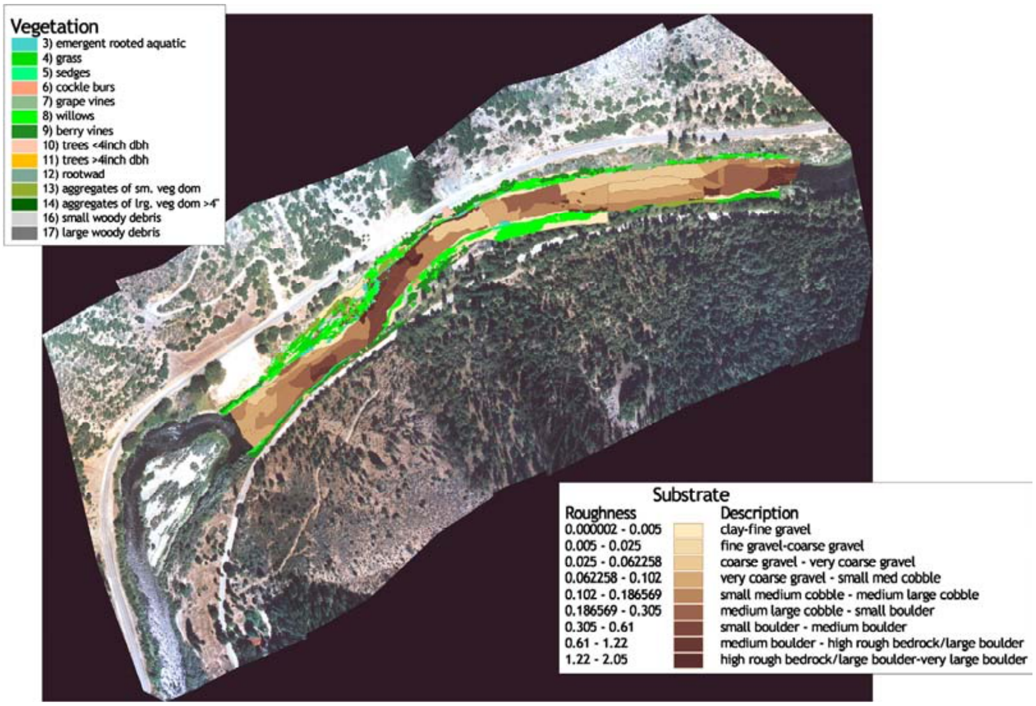


Figure 21. Spatial distribution of delineated substrate and vegetation at the USU Brown Bear study site.

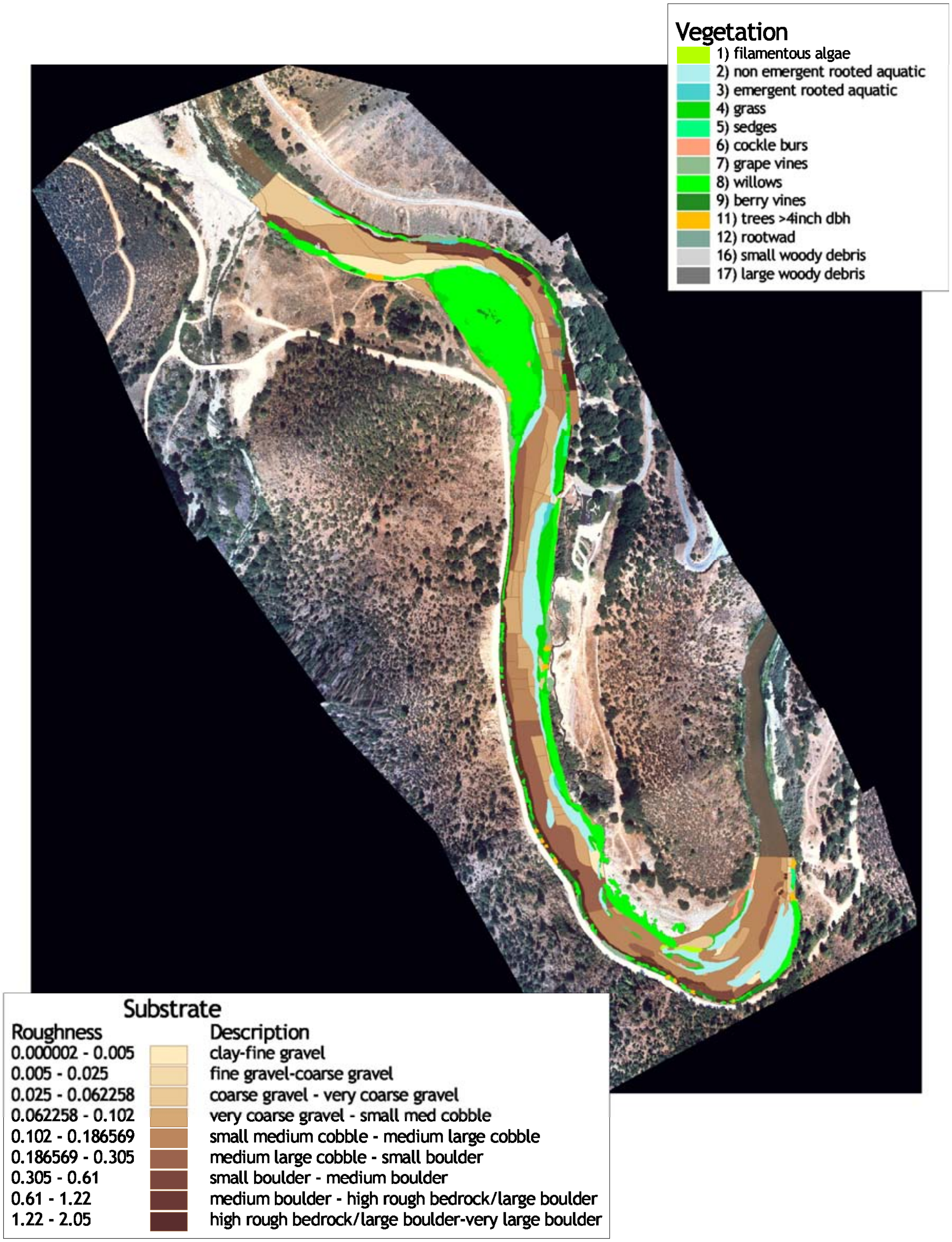


Figure 22. Spatial distribution of delineated substrate and vegetation at the USU Trees of Heaven study site.

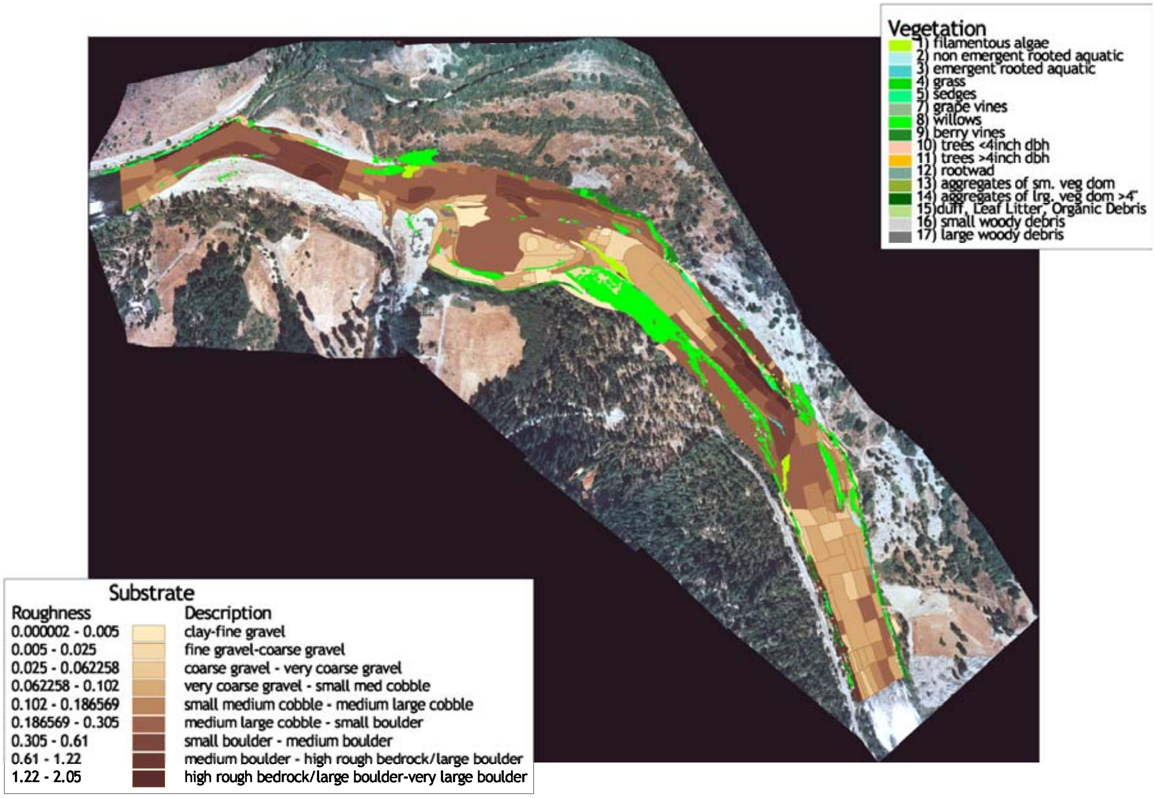


Figure 23. Spatial distribution of delineated substrate and vegetation at the USU Seiad study site.

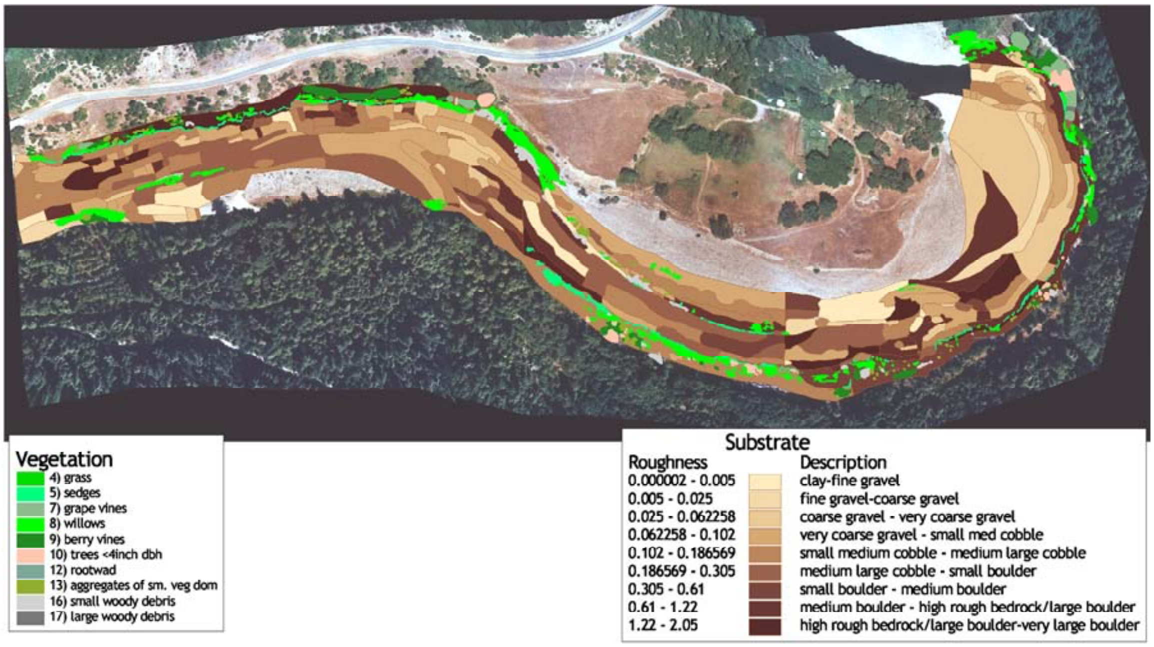


Figure 24. Spatial distribution of delineated substrate and vegetation at the USU Rogers Creek study site.

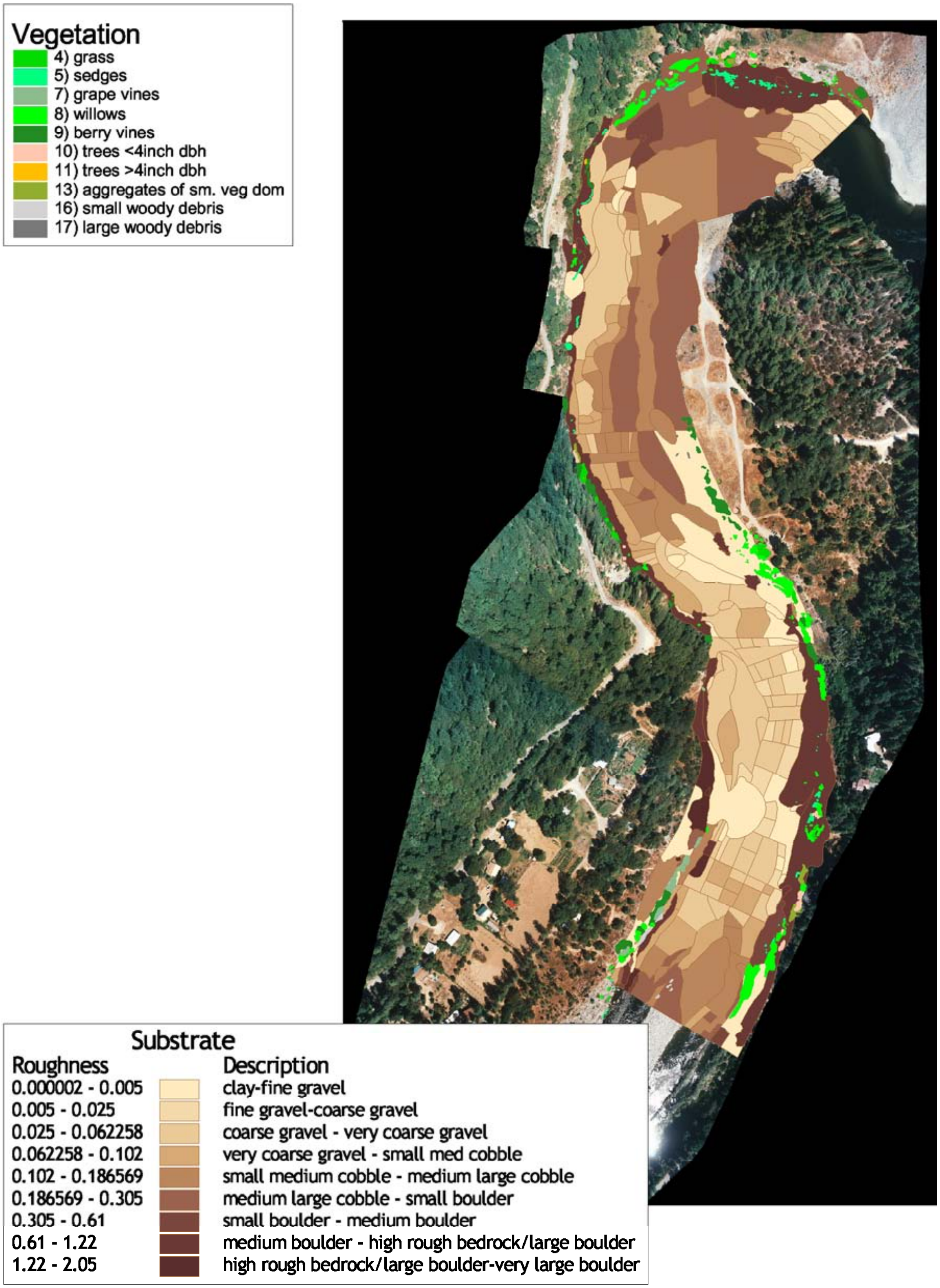


Figure 25. Spatial distribution of delineated substrate and vegetation at the USU Orleans study site.

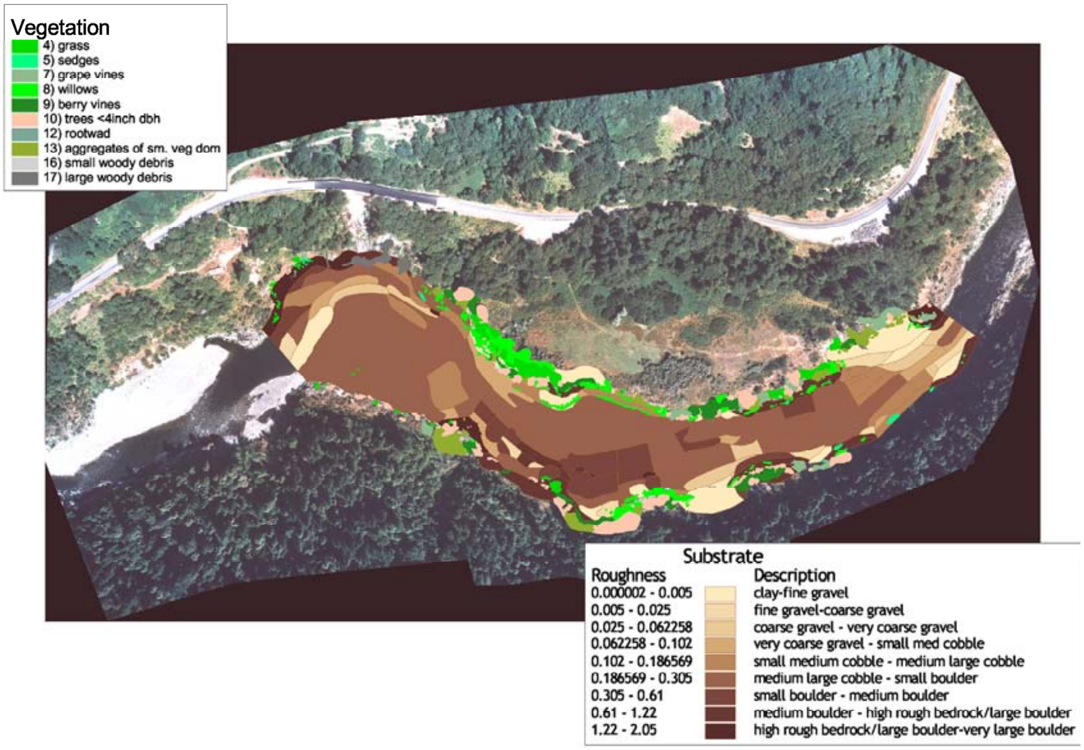


Figure 26. Spatial distribution of delineated substrate and vegetation at the USU Saints Rest Bar study site.

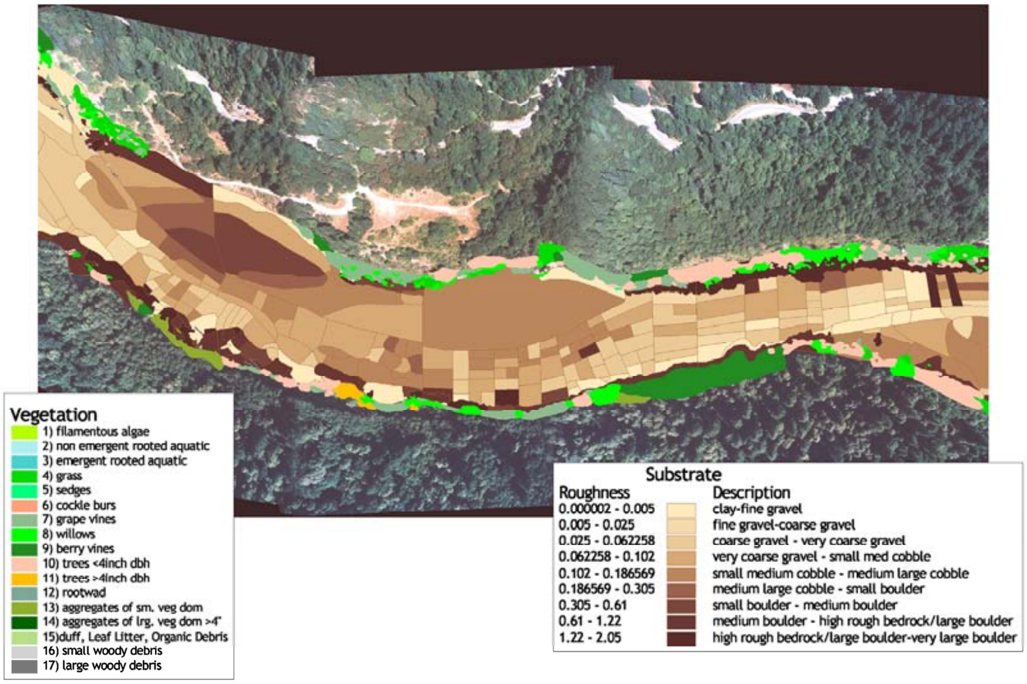


Figure 27. Spatial distribution of delineated substrate and vegetation at the USU Youngs study site.

Hydraulic Modeling

The approach to hydraulic modeling at each study site was undertaken specific to the requirements of each type of data set (i.e., 1-dimensional versus 2-dimensional data). The USGS/USFWS cross section data was analyzed using 1-dimensional hydraulics within PHABSIM, while hydraulic modeling at the USU study sites was analyzed using a two-dimensional hydraulic model. The specific modeling approaches for each type of data sets are described in detail within the following section of the report.

USGS/USFWS 1-dimensional Hydraulic Modeling

USU collaborated with personnel from the USGS for all the hydraulic modeling associated with their data at each of their study sites. USU was initially supplied with electronic copies of the reduced field data, which included:

a) Cross section geometry,
b) Computed and best estimates of the discharge for each calibration flow,
c) Measured velocities for each velocity calibration set,
d) Substrate and cover associated with each vertical at each cross section,
e) Distance to cover coding for each vertical at each cross section, and
f) Weightings for each cross section to extrapolate results to the reach level.

Water Surface Modeling

The determination of the relationship between the water surface (stage) and the discharge is the first step in hydraulic calibration and simulation phases of PHABSIM. The stage is used in the simulations to derive depth distributions for each cross section by subtraction of bed elevations across the channel from the stage; and to identify the location of the free surface to establish boundaries (i.e. wetted cell locations) for some of the equations that describe velocity distributions. If stage and bed elevation are known, depth may be determined at any location on the cross section.

Several approaches may be used in the prediction of stage-discharge relationships. In PHABSIM this includes: (1) linear regression techniques based on multiple measurements from the field (Stag-Q or IFG4); (2) use of Manning's equation (MANSQ); and (3) calculation of water surface profiles using standard step backwater computations (WSP). These three approaches represent the three main hydraulic modeling options within PHABSIM.

Water surface modeling at each study site followed recognized guidelines for calibration and simulation of water surface elevations for the application of

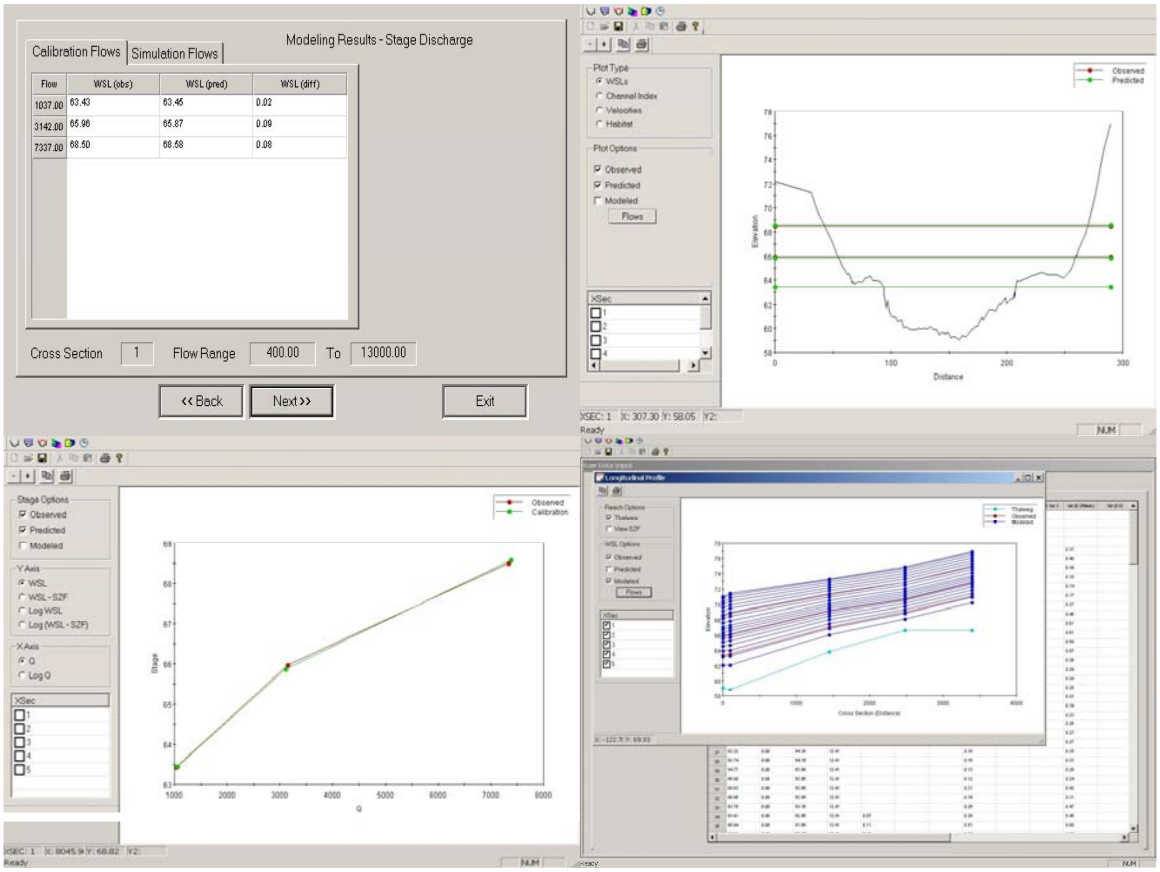
PHABSIM as outlined in Hardy (2000). In general, the calibration and simulation of water surface elevations for specific cross sections employed one or more of the following three models:

Stage-Q	The Stage-Q model uses a stage-discharge relationship (rating curve) to calculate water surface elevations at each cross section. In the stage-discharge relationship and simulations, each cross section is independent of all others in the data set. The basic computational procedure is conducted by performing a log-linear regression between observed stage and discharge pairs at each cross section. The resulting regression equation is then utilized to simulate water surface elevations at all flows of interest.
MANSQ	The MANSQ program utilizes Manning's equation to calculate water surface elevations on a cross-section by cross-section basis and therefore treats each cross section as independent. Model calibration is accomplished by a trial and error procedure to select a β coefficient, which minimizes the error between observed and simulated water surface elevations at all measured discharge and water surface elevation pairs.
WSP	The Water Surface Profile (WSP) program uses a standard step backwater method to determine water surface elevations at each cross section. The WSP program requires that all cross sections being analyzed in a given model run be dependent. That is, each cross section hydraulic characteristics in terms of bed geometry and water surface elevations are measured from a common datum. The model is initially calibrated to a measured longitudinal profile of the water surface elevations by adjusting Manning's roughness at each cross section and then to subsequent measured longitudinal water surface profiles at other discharges by adjustment of the roughness modifiers used within the model. This approach also requires all hydraulic controls within the modeled reach to be represented by cross sections.

The specific equations for each of these models and their application to water surface modeling in PHABSIM can be found in Hardy (2000).

Specific model selection (i.e., Stage-Q, MANSQ, or WSP) for specific cross sections over specific flow ranges was based on model performance comparisons between observed and simulated water surface elevations at the calibration flows. It also included reviews of the simulated model results over the full range of simulated discharges.

USU conducted the preliminary model calibrations for water surface elevations at all USGS study sites and provided these results to the USGS for review and revision. USGS then provided USU revised modeling results for all study sites, including updated and corrected calibration data. USU then conducted a final QA/QC evaluation of the hydraulic simulations. This involved a comparison of simulated and observed water surface elevations at each calibration flow and for all simulated discharges to ensure that model outputs were rational (i.e., water flowed down hill between successive cross sections within the hydraulic modeling study site). This QA/QC step is illustrated in Figure 28. This figure shows a series of ‘screen grabs’ from the PHABSIM modeling software used for the evaluation of water surface modeling. This software was developed at USU (Hardy 2000) and used for all PHABSIM modeling in Phase II.



Modeling Results - Stage Discharge

Flow	WSL (obs)	WSL (pred)	WSL (diff)
1037.00	63.43	63.45	0.02
3142.00	65.96	65.87	0.09
7337.00	68.50	68.58	0.08

Cross Section: 1
Flow Range: 400.00 To 13000.00

Figure 28. Example of observed versus predicted water surface elevation results used in the QA/QC modeling checks conducted by USU.

Calibration and simulation results at each study site for each cross section were also reviewed by the Technical Team and they concurred with USGS and USU that the hydraulic model calibration and simulations for water surface elevations met acceptable standards of practice for the application of PHABSIM (see, Hardy 2000).

Velocity Modeling

The second major step of hydraulic modeling within PHABSIM involves the determination of velocity profiles at each cross section within the river. PHABSIM models velocities at one cross section at a time and as such, treats the cross sections independently regardless of the model employed to generate the water surface elevations. Within PHABSIM, the IFG4 model is utilized for all velocity predictions, which are subsequently used in the habitat modeling components of the system.

Velocity modeling at each study site followed recognized guidelines for calibration and simulation of PHABSIM data sets as outlined in Hardy (2000). The IFG4 model was used for all velocity calibration and simulations. However, the specific IFG4 computational options (i.e., velocity calibration sets, use of cell specific Manning's n, etc.) for individual cross sections over specific flow ranges was based on model predictions compared to calibration data. It also included reviews of the simulated model results over the range of simulated discharges.

The specific equations and different approaches for velocity modeling and their application to simulation of velocity profiles in PHABSIM can be found in Hardy (2000).

USU conducted the preliminary model calibrations for velocities at all USGS study sites and provided these results to the USGS for review and revision. USGS and USU then worked collaboratively to revise and finalize the modeling approach for velocities at each cross section for all study sites, including updated and corrected calibration data.

USU then conducted a final QA/QC evaluation of these hydraulic modeling results. This QA/QC involved a comparison of simulated and observed velocities at each calibration flow and a review of the simulated velocity distributions at each vertical for all cross sections at all calibration flows. Finally, this process also examined the relationship of the velocities in each cell of each cross section for all simulated ranges of discharges to ensure that model outputs were rational (i.e., velocity magnitudes in edge cells were within realistic magnitudes for computed cell depths).

Examples of the QA/QC procedures for velocity modeling are illustrated in Figure 29. This figure shows comparisons between observed and predicted velocities at each of the three calibration flows (low, medium, and high clockwise from top right) and the simulation results over a range of discharges (lower right).

Calibration and simulation results at each study site for each cross section were reviewed by the Technical Team and they concurred with USGS and USU that the hydraulic model calibration and simulations for velocities met acceptable standards of practice for the application of PHABSIM (Hardy 2000).

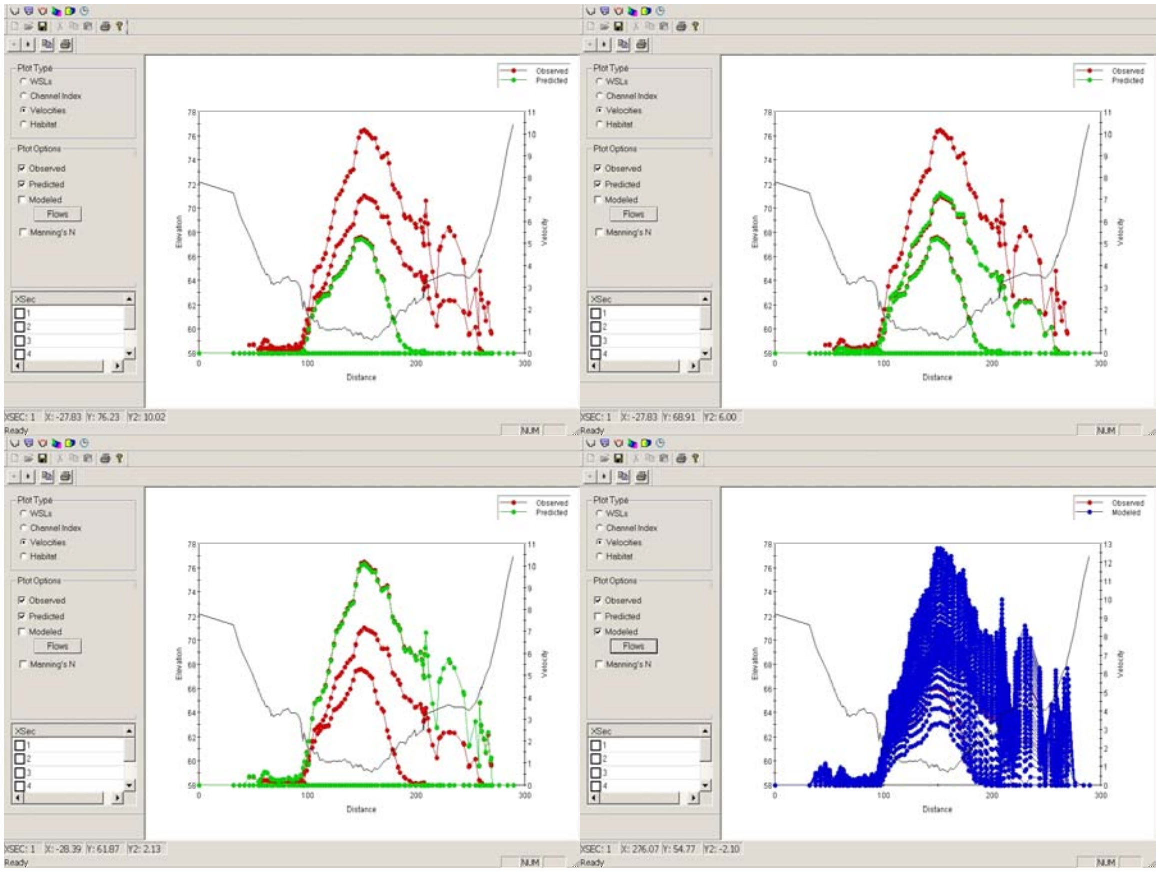


Figure 29. Example of observed versus predicted velocities results used in the QA/QC modeling checks conducted by USU.

USU Two-dimensional Hydrodynamic Modeling

Although a number of flow models were initially evaluated, the hydrodynamic model used by USU was a two-dimensional flow model. This model relies on a 2-dimensional, quasi-3-dimensional model formulation and was developed and used extensively for research on rivers by Jonathan Nelson of the USGS (Nelson 1996, Thompson et al. 1998, Nelson et al. 1995, McLean et al. 1999, Topping et al. 2000). The model relies on 3-dimensional riverbed topography, flow rate, and stage (i.e., water surface elevations) boundary conditions to calculate flow, velocities, water surface elevations and boundary shear stresses in the channel. It has been used in channels with or without islands in both high and low Froude number flows (i.e., sub-critical and super-critical flow conditions). The model solves the two-dimensional vertically averaged flow equations on an orthogonal curvilinear grid. It uses a spatially variable, scalar kinematic eddy viscosity turbulence closure that emphasizes vertical diffusion of momentum. The program was written to accommodate spatially variable channel roughness and was further modified at USU to enhance the wetting-drying algorithm and initial condition capabilities. These modifications were made to enhance computational efficiency during the iterative process of model calibration and improve overall simulation results. The technical description of this model and underlying equations can be found in citations noted above.

Development of Computational Meshes

The DTM generated from the spatial delineation of the study reach described above was used to create a curvilinear orthogonal mesh. The meshes were generated at each of the study sites using a smooth (gradually varying radius) stream centerline overlaid on the DTM. Meshes were refined (i.e., number of mesh elements (nodes) and spacing between nodes) of each mesh as much as practical given the size of the intensive study sites and limitations associated with computational time requirements. These meshes were used both for the hydrodynamics modeling and for the habitat modeling as described below. For this study, the computational meshes at all sites contained nodes every 1.6 meters (5.25 feet) across the river and 1.7 meters (5.58 feet) in the longitudinal direction (i.e., up and down the river). An example of the computational mesh for the RRanch study site is illustrated in Figure 30.

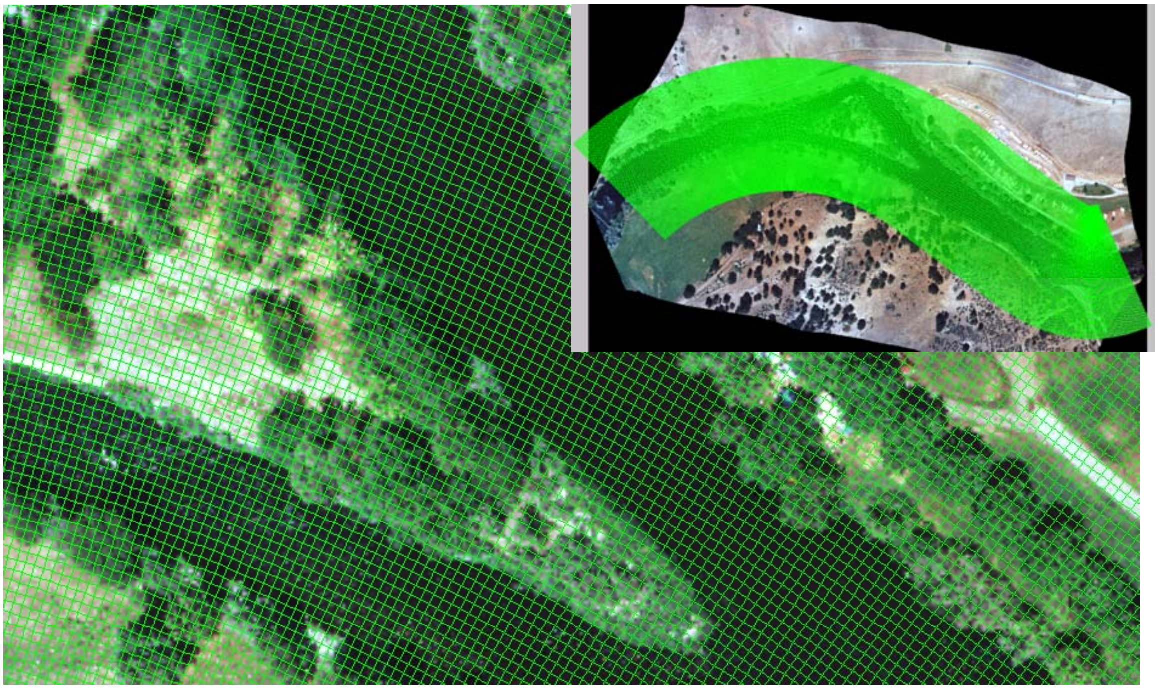


Figure 30. Example of the computational mesh at RRanch used in the hydrodynamic modeling of water surface elevations and velocities at USU study sites.

Water Surface Modeling

At each intensive study site, three sets of measured water surfaces and calibration discharges were surveyed (see Table 13) for use in calibration of the hydrodynamic model. The two-dimensional hydraulic model at each site was calibrated to measured water surfaces by adjusting roughness for each computational node. This calibration was facilitated from the overlays of the delineated substrate and vegetation polygons onto the computational meshes at each site as described previously (see Figures 20 through 27). For each substrate or vegetation type, we associated an estimated hydraulic roughness height based on the size of the particle size (or largest particle size when mixed substrates were delineated) or vegetation type in each substrate/vegetation category. In the case of substrates, the hydraulic roughness was based on a drag coefficient calculated from the roughness length (particle size) of each substrate category. In the case of vegetation, roughness was assigned according the morphometry and density of the vegetation delineated within a polygon (i.e. grass versus willows). Roughness values were assigned from published values in the literature for vegetation (Chow 1959, Arcement and Schneider 1989). The roughness associated with vegetation and substrate classes are provided in Table 14. An example of these assignments spatially within the USU RRanch study site is illustrated in Figure 31.

Table 14. Hydraulic roughness assigned to classes of vegetation used in the 2-dimensionalhydrodynamic modeling at USU study sites.

Vegetation Codes	**Roughness Sparse (s) and Dense (d)**	**Hydrodynamic Roughness Code**	**Approximate Mannings n**
Filamentous Algae	low (d&s)	500/500	High= 0.15
Non Emergent Rooted Aquatic	low (d&s)	500/500	Med High=0.10
Emergent Rooted Aquatic	high (d), med high (s)	900/800	Med=0.06
Grass	med (d), low (s)	700/500	Low=0.035
Sedges	med (d), low (s)	700/500	
Cockle Burs	med (d), low (s)	700/500	
Grape Vines	high (d), med (s)	900/700	
Willows	high (d), med (s)	900/700	
Berry Vines	high (d), med (s)	900/700	
Trees <4" dbh	med high (d), med (s)	800/700	
Trees >4" dbh	med high (d), med (s)	800/700	
Rootwad	high (d), med (s)	900	
Aggregates of Small Veg Dom (<4")	high (d), med (s)	900/700	
Aggregates of Small Veg Dom (>4")	high (d), med (s)	900/700	
Duff, Leaf Litter, Organic Debris	Typically use substrate		
Small Woody Debris (SWD) <4"x12"	high (d), med (s)	700	
Large Woody Debris (LWD) >4"x12"	high (d), med (s)	900	

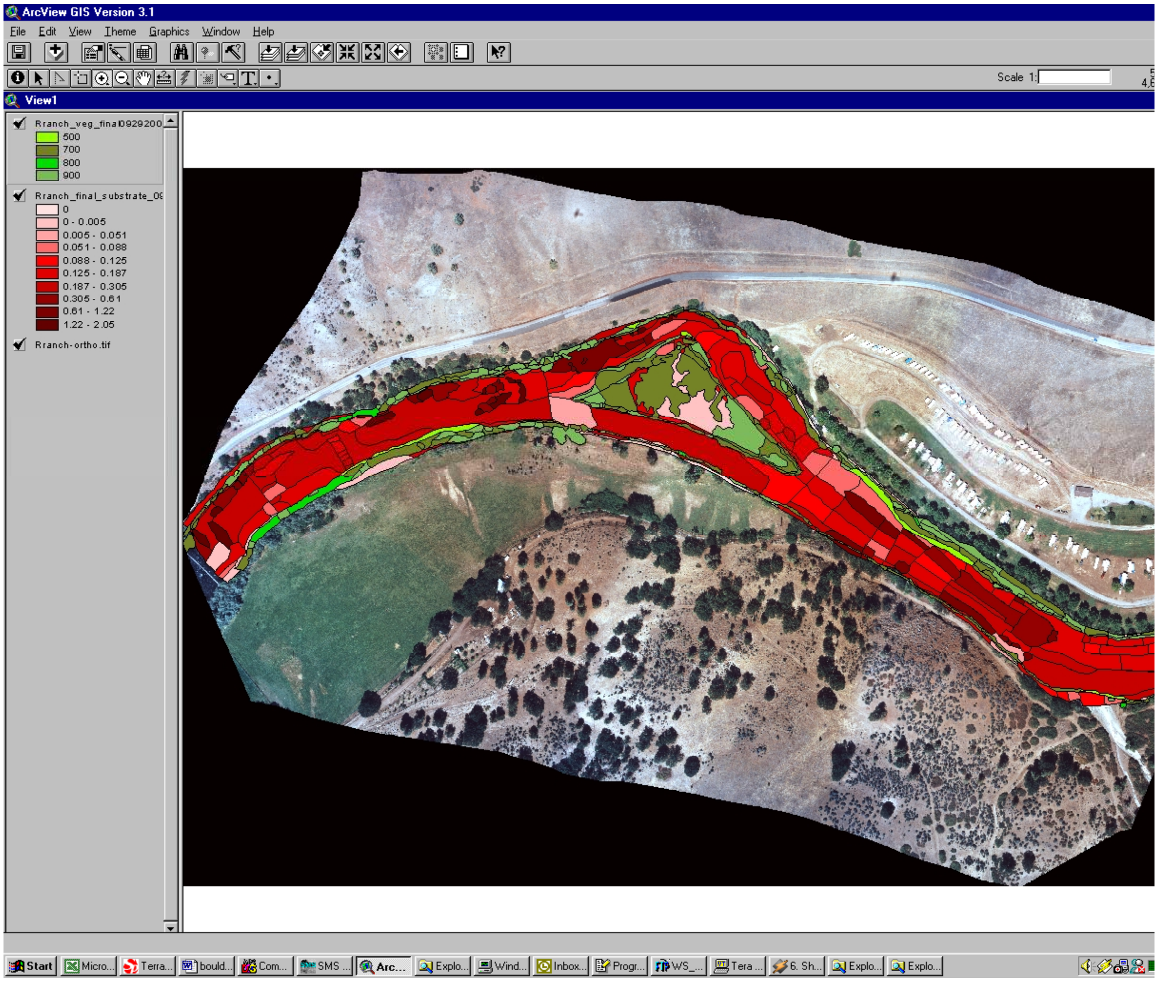


Figure 31. Example of spatially explicit assignment of variable roughness for different substrate and vegetation codes within the USU RRanch study site (vegetation roughness is in green and substrate roughness is in red).

This process assigned differential roughness spatially across all computational nodes as an initial starting point in the model calibration process. During the calibration phase of the hydrodynamics modeling, the roughness height assigned to specific nodes for substrate was increased or decreased by a constant percentage globally until the modeled water surface matched the measured water surface at that calibration flow. This was first undertaken at the high calibration flow. The calibrated roughness was then used in subsequent simulations to verify model performance at the medium and low calibration flows.

When a channel roughness height adjustment was obtained throughout the study site that generated accurate water surface elevation predictions at all calibration flows, the hydrodynamics model was assumed to be calibrated. All subsequent hydraulic simulations for various flows used in the habitat modeling were modeled with these same calibrated channel roughness heights. Water surface modeling results were generally within 1 to 5 centimeters over the entire spatial domain of each study site. This is illustrated for the results at the USU RRanch study site in Figure 32. This figure shows the difference between measured and modeled water surface elevations at a flow rate of 157 cubic meters per second (~ 5,544 cfs).

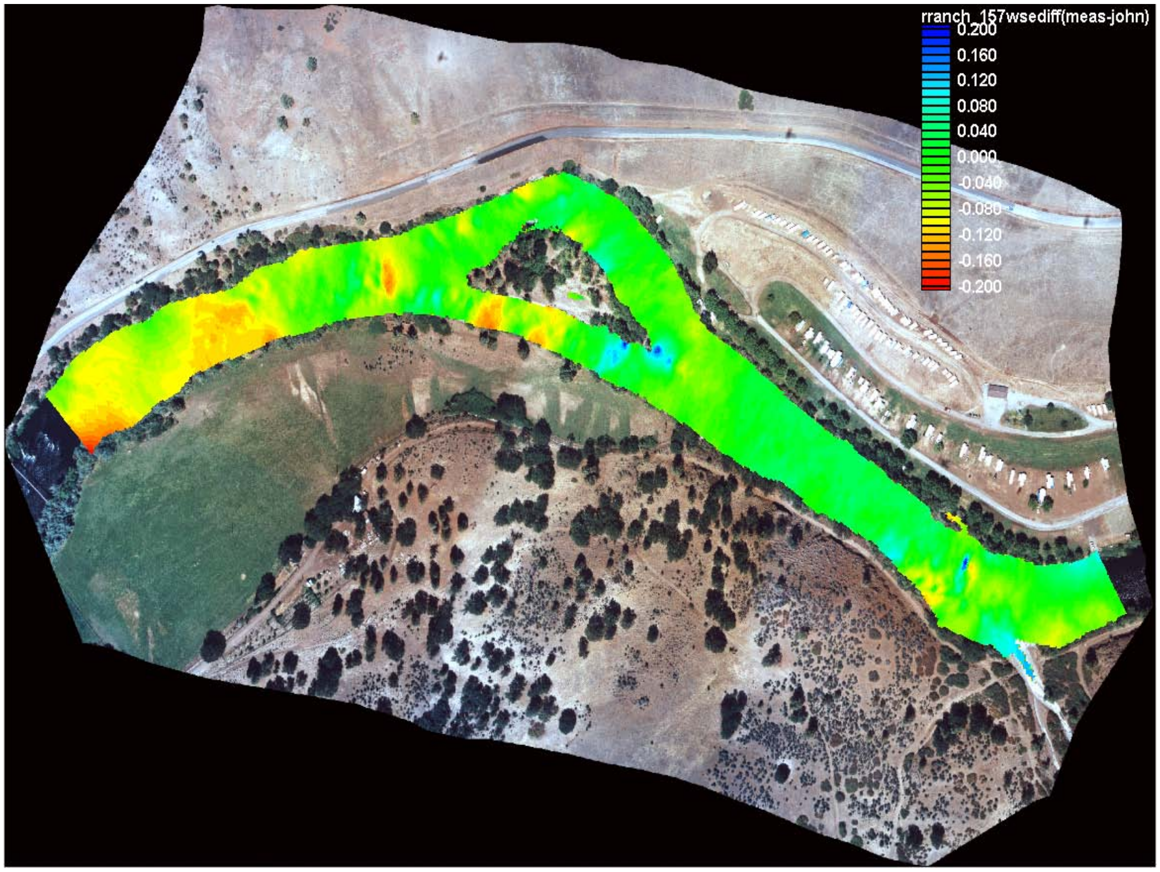


Figure 32. Difference between measured and modeled water surface elevations at the USU RRanch study site at a flow rate of 157 cubic meters per second (~5,544 cfs).

However, in some instances, especially where high turbulence was encountered within the study reach, predicted versus simulated water surface elevations could show apparent differences that were higher. This larger apparent difference for these sections is attributed to both the solutions from the hydraulic model as well as ‘errors’ associated with interpolation of the longitudinal water surface elevations over the study site used in making these comparisons. The interpolation of the water surface elevation assumes a linear relationship both longitudinally as well as transversely across the channel based on the locations of measured data. This is not always an accurate representation of the actual differences in the spatial distribution water surface elevations longitudinally and transversely observed in the field or generated from the modeling results. The hydraulic model predicts variable longitudinal and transverse water surface elevations within a study reach based on the flow and channel topographies as represented by the computational mesh. However, our evaluations of the modeling results are considered acceptable and on the order of resolution obtained from modeling results using the 1-dimensional models described previously.

Velocity Modeling

Vertically averaged mean column velocities are generated during the solution of the two-dimensional hydrodynamics equations at each of the mesh nodes. No “calibration” of the velocity modeling is required. Accuracy of modeled velocities is primarily dependent on the accuracy of the channel topography, the accuracy of the channel roughness inputs, accuracy of the water surface elevations, and the hydrodynamics model itself (appropriateness of equations used in the model and the turbulence sub-model used for the analytical solutions). The accuracy of the modeled velocities was assessed by comparing the modeled velocity patterns (direction and magnitude) to measured/observed velocity patterns collected during topography delineations. Measured velocities included three dimensional point velocity measurements from the Acoustic Doppler Profiler at each intensive study site and standard mean column velocity measurements collected as part of the USGS 1-dimensional hydraulics modeling at two overlap study sites (RRanch and Trees of Heaven). Figure 33 shows typical results of the velocity simulations obtained from the hydrodynamic model at a study site. In Figure 33, the flow rate was simulated to just allow water to begin overflowing the exposed gravel bar (see orthophotograph in upper right). The underlying colors are coded to depth with darker blue being deeper. At this flow rate, water is also flowing down the small side channel at the lower bottom of the image.

Based on a review of these comparisons we consider that the velocity modeling results to represent the spatial distribution of velocity magnitude and directions of the flow fields at each study site. For example, the overall pattern of the spatial distribution of velocity fields (e.g., eddies) was excellent when simulated and observed patterns of flow were examined.

However, the QA/QC evaluations conducted by USU at the Youngs Bar study site indicated that modeling solutions were unacceptable in terms of both water surface elevations and corresponding velocity simulations at the calibration flows. Our technical assessment indicated that the upstream boundary of the study site (see Figure 17) was being impacted by the large gravel bar that extended above the study site boundary. At different flow rates, water partitions between the main channel and along the lower inside corner of the channel (see lower right area in Figure 17). Insufficient channel topography existed to extend the study site upstream and adequate stage-discharge relationships to allow an accurate partitioning of the flows into the top of the modeled reach. Based on these results, the Youngs Bar study site was dropped from the assessments.

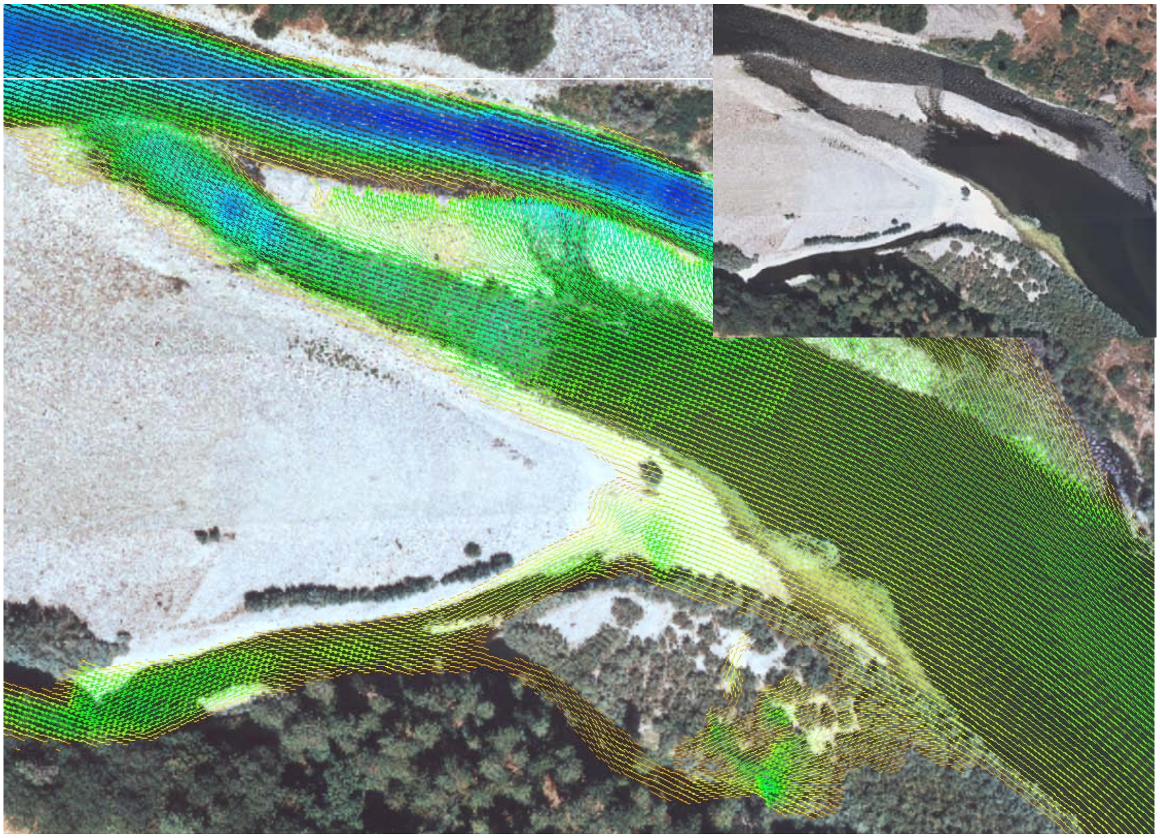


Figure 33. Example of the predicted velocity magnitude and their directions at the USU Seiad study site.

Ranges of Simulated Flows

For the USGS/USFWS based 1-dimensional hydraulic modeling the USU 2-dimensional based hydraulic modeling, the ranges of simulated flows for the models were based on the quality of the simulations and range of target flows desired for the assessments. For both the 1-dimensional and 2-dimensional hydraulic modeling, flow ranges between 400 and 8,000 cfs at stations in the river reach immediately below Iron Gate Dam are within what would be considered valid ranges for application of these modeling tools based on the measured calibration discharges and hydraulic modeling calibration and simulation results (Hardy 2000). For study sites in successive river reaches below Iron Gate Dam, the calibration data reflects increased flows associated with tributary accretions and therefore the range of simulated discharges increase proportionally. For example, at the Saints Rest Bar study site, the lower range of simulated flows is approximately 2200 cfs and the upper ranges is approximately 19,500 cfs. In all cases, the valid ranges of simulated flows generally encompass the expected monthly flow ranges for the main stem Klamath River germane to the assessment of instream flow recommendations. In some cases however, especially at very low exceedence ranges (i.e., high flows), flow rates were higher than the simulated ranges for the hydraulics. This is addressed where appropriate in the development of the instream flow recommendations.

Hydrology

Phase I relied on data from the Keno and Iron Gate gages to estimate unimpaired and historical (i.e., Klamath Project operations) flows for use in the hydrology based instream flow assessment methods. In Phase II, the underlying hydrology used in the assessment process was derived from model simulations. Simulated hydrology for Phase II was primarily focused from below Iron Gate Dam to the estuary. However, in all simulations, water routing from Upper Klamath Lake to Iron Gate Dam was required. As described below, this was accomplished using KPSIM and/or MODSIM a component of SIAM. The Phase II assessments considered four different flow scenarios (described below) and were defined as follows:

1. Unimpaired no project flows (No_Project)
2. USGS simulated historical Klamath Project Operations (USGS_Historical)
3. Klamath Project operations based on the existing FERC flow schedule and Upper Klamath Lake water elevations set at the USFWS 2000 Biological Opinion levels (FERC_ESA) (see Tables 15 and 16.).
4. Klamath Project operations based on the Phase I recommended flow schedule and Upper Klamath Lake water elevations set at the USFWS 2000 Biological Opinion levels (FP1_ESA) (see Tables 15 and 16.).

Table 15. Upper Klamath Lake elevation minimums used for the FERC_ESA and FP1_ESA simulations in the KPSIM modeling. (Blank values are linearly interpolated by KPSIM). Data supplied by USBR.

	PASTE USER INPUT VALUES IN THIS BLOCK				
	Wet	**Above Avg**	**Average**	**Below Avg**	**Dry**
Date	**1**	**2**	**3**	**4**	**5**
Sep-30	4139.0	4139.0	4139.0	4139.0	4139.0
Oct-31					
Nov-30					
Dec-31	4140.0	4140.0	4140.0	4140.0	4140.0
Jan-31					
Feb-15	4141.5	4141.5	4141.5	4141.5	4141.5
Feb-28					
Mar-15					
Mar-31					
Apr-15	4142.6	4142.6	4142.6	4142.6	4142.6
Apr-30					
May-15					
May-31	4142.6	4142.6	4142.6	4142.6	4142.6
Jun-15					
Jun-30					
Jul-15	4141.6	4141.6	4141.6	4141.6	4141.6
Jul-31	4139.0	4139.0	4139.0	4139.0	4139.0
Aug-31					
Sep-30	4139.0	4139.0	4139.0	4139.0	4139.0
	ESA	**ESA**	**ESA**	**ESA**	**ESA**

Table 16. Average daily flows (cfs) for FERC_ESA and FP1_ESA specified as model inputs for the main stem Klamath River at Iron Gate Dam for each of these simulations. These flow schedules were used in all water year types for these respective simulations.

Date	**Timestep**	**Flow (cfs)**	**Flow (cfs)**
Oct	1	1476	1300
Nov	2	1688	1300
Dec	3	2082	1300
Jan	4	2421	1300
Feb	5	3008	1300
Mar 1-15	6	3073	1300
Mar 16-31	7	3073	1300
Apr 1-15	8	3307	1300
Apr 16-30	9	3307	1300
May 1-15	10	3056	1000
May 16-31	11	3056	1000
Jun 1-15	12	2249	710
Jun 16-30	13	2249	710
Jul 1-15	14	1714	710
Jul 16-31	15	1714	710
Aug	16	1346	1000
Sep	17	1395	1300
		MIF Final Phase 1	**FERC**

Simulations were made in KPSIM for the 1961-2000 time period. The Year 2000 simulation results from KPSIM were eliminated from the output that was linked to MODSIM since that model only allows simulations through 1999.

For each of these scenarios, the simulated 1974 to 1997 water years were used in all analyses. Although MODSIM allows the analysis of flow scenarios for the 1961-1999 period of record, simulations in MODSIM were confined to the 1974 to 1997 water year period. This period or record corresponds to the only available data on consumptive use estimates for inflows into Upper Klamath Lake necessary to generate the unimpaired flow for the main stem Klamath River at Iron Gate Dam. This allowed a standardized period of record to be used for all comparisons between flow scenarios.

It is recognized that the simulation of flows in the main stem Klamath River below Iron Gate Dam has inherent uncertainties. This is based on the lack of quantitative data on pre-project conditions, limited estimations of flow depletions above Upper Klamath Lake, estimated reach gains, historical changes in water practice such as the Link River Dam, diversions to Tule Lake, historic Lower Klamath Lake flooding variability in annual and seasonal operating practices, estimated demand requirements, etc.

However, we believe that there is sufficient motivation to using a standardized assessment tool (i.e., KPSIM/SIAM) that incorporates Klamath Project operations since these tools will ultimately be used in evaluating the Phase II flow recommendations by management agencies as part of Klamath Project Operations planning, biological opinions, Iron Gate FERC relicensing, and the forthcoming Klamath Project EIS. Use of these tools will also facilitate a consistent evaluation of the recommended flows in light of Upper Klamath Lake water elevations and related ESA issues that must ultimately be considered (although not an element of this study). A second major factor in utilizing these tools is the ability to generate water temperature estimates below Iron Gate as part of the instream flow assessments as discussed later in the report.

In this section of the report, the specific methods employed in the application of these models for specific scenarios are documented.

The simulation results were obtained from application of three sources:

1. Bureau of Reclamation provided simulated unimpaired flows from Upper Klamath Lake for the 1974 to 1997 water year period,
2. Simulation results based on application of the Bureau of Reclamation’s KPSIM model, and
3. Simulation results based on application of the USGS MODSIM component of SIAM.

The System Impact Assessment Model (SIAM) developed by USGS (2001) is a modeling interface used to simulate water quality and flow in the Klamath River under different flow alternatives. Three stand-alone models have been integrated into SIAM to achieve this purpose. The models are: MODSIM (flows), HEC5Q (water quality), and SALMOD (fisheries). Our objective was to simulate Klamath River water temperatures and flows. Hence, the SALMOD portion was not used. The reader should consult USGS (2001) for technical documentation on SIAM.

Within the MODSIM (and HEC5Q) components of SIAM several preset flow scenarios and associated computational networks are available. Computational networks are composed of predefined river segment and node definitions that correspond to input or output locations for flows. These computational networks govern how the mass balance calculations are implemented for a specific ‘structure’ of the river system.

The ‘Network 2’ computational network was developed by USGS to model the Klamath River without any of the existing dams or alterations to the system. This network was created early in the SIAM development process but is no longer supported by the USGS. Network 2 was constructed to allow simulated output from Upper Klamath Lake to the Seiad Valley gage for water years 1961-97. MODSIM flow simulations in Network 2 use a monthly time step for this period of record. As will be noted below, this limitation of MODSIM to simulate unimpaired conditions below Seiad required additional analyses by USU to estimate the no project flows for study reaches in the lower river.

USGS also developed a ‘Network 3’ computational network that includes all dams and alterations to the system and simulates output from Upper Klamath Lake to the estuary. This computational network was used for the simulation of scenarios involving Klamath Project operations.

In our application of MODSIM (SIAM), we found initially that the Upper Klamath Lake elevations and storage capacities showed a dramatic difference between SIAM generated output and the corresponding information obtained from the (USBR), Klamath office (Jan. 2001). The MODSIM component does not model the reach from Upper Klamath Lake to Iron Gate Dam for multiple water year types in the same manner as the USBR project simulation model (KPSIM).

These initial problems were attributed to the fact that the USBR had provided an elevation-storage table that was “active” storage, and the USGS developed SIAM using a total elevation-storage relationship (see Figure 34). A revised version of SIAM was provided by the USGS that partially addressed the elevation issue (SIAM 2.6, Feb. 1, 2001). Improvement in these simulations was made by modification of the KPSIM input files by adjusting elevations to reflect total storage values. This correction is explained later in the discussion of KPSIM (i.e., KPOPSIM, Klamath Project Simulation Model).

The final simulations were conducted with SIAM (version 2.72) for all the assessments.

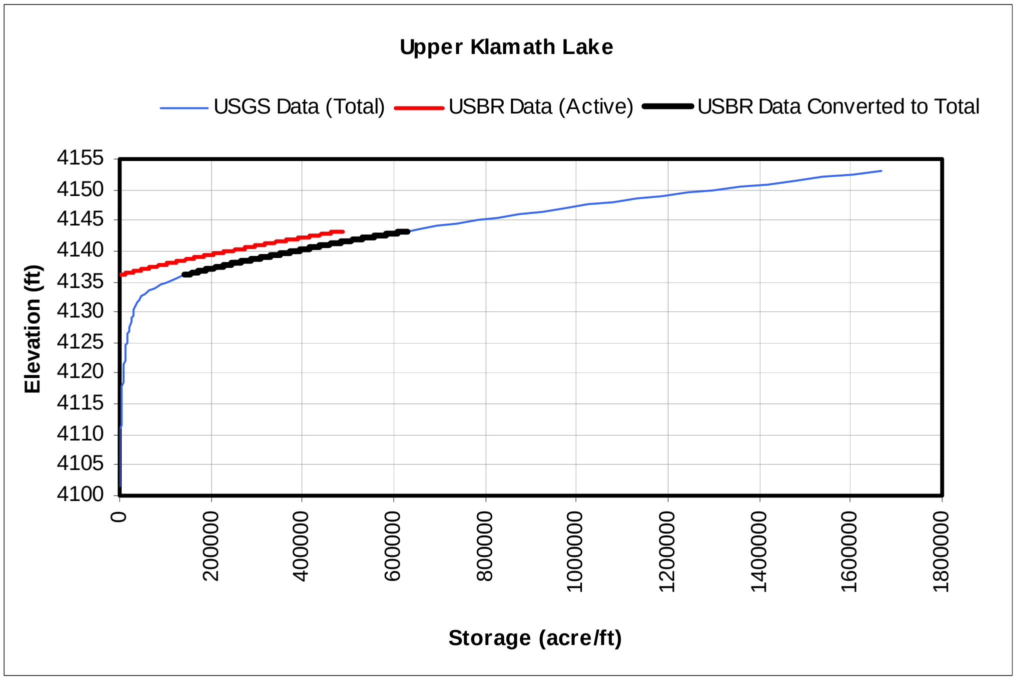


Figure 34. Comparison of Upper Klamath Lake storage versus elevation relationships between USGS and USBR data.

MODSIM and KPSIM Linkages

In our application of MODSIM we determined that it has limited capability to simulate the river system above Iron Gate Dam to realistically reflect actual Klamath Project operations. This is due to the inability of MODSIM to accurately model the Klamath Irrigation Project, especially under varying water supply and water demand scenarios over the 1961-1999 time period. This limitation is attributed to the objectives of the USGS in their development of SIAM and not necessarily a function of the analytical capabilities of the algorithms. Therefore, USU chose to use the USBR operations model for the Klamath Project (KPSIM) as a tool to 'front load' flows for use in SIAM (i.e., use KPSIM to generate flow inputs for SIAM data files). This front-loading of SIAM provided the most accurate flows from Link River Dam to Iron Gate that reflects actual project operations. Below Iron Gate Dam, MODSIM generated output was relied upon in the assessments for Phase II.

KPSIM generated flows for use in modeling different flow scenarios in MODSIM. It was used for the following MODSIM nodes:

1. Upper Klamath Lake storage with the elevation-storage modified to total storage to be consistent with SIAM.
2. Deliveries to the 'A' Canal,
3. Lost River Diversion Channel
4. North Canal

5. Ady Canal
6. Klamath Straits Drain outflows
7. Flows at Iron Gate

The KPSIM generated output flow data at these nodes were used as input for the MODSIM model. PCMSS (the MODSIM stand alone program) was used to update the appropriate network file. This process provided the most accurate water balance results for MODSIM simulations of Klamath Project operations. MODSIM was then used to compute the flows at all downstream locations.

KPSIM Modifications

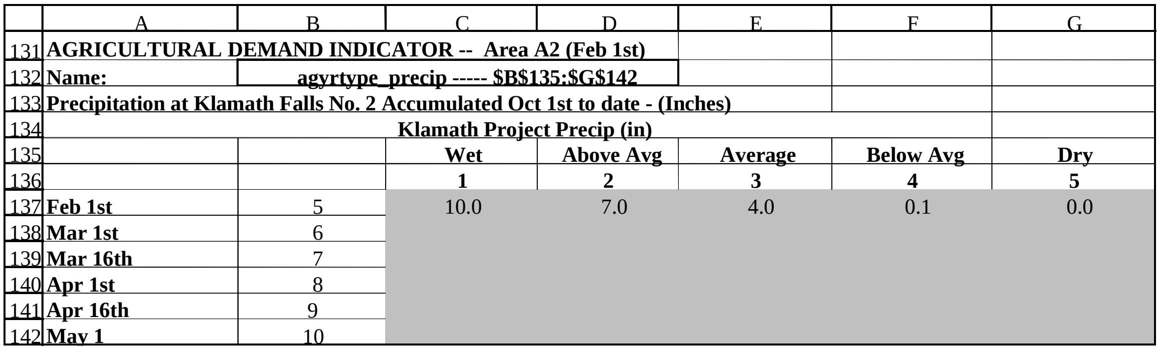
The USBR provided USU with a five water year type version of KPSIM (test version with placeholders) that included updated hydrology through 2000. USU made several changes and enhancements to this model as detailed below.

1. Change of Agriculture and Refuge Wet Year Type Demands

The five water year type version of KPSIM included the capability to simulate five agriculture demand year types as well as hydrologic year types. This version of KPSIM originally set the demands and associated demand indicators, which would result in more years having critically dry agriculture and refuge demands as compared to the USBR original four-year type model. This situation arose due to two modifications. First, the original (four year type) agricultural demand indicator values were used and an additional ‘fifth’ indicator was added (as a place holder for further options) for the wettest year type. Second, the demand values for the new below average and dry (two driest year types) retained the previous four-year type critically dry demand values. The foregoing requires an in depth understanding and working knowledge of KPSIM.

In order to meet USU analysis objectives, it was determined that it would be best to keep the agriculture and refuge demands the same as the four-year type version currently used by USBR. However, instead of having a placeholder for the wettest year demand indicator the original indicators were used for the three wettest year types and the below average year type was given a nominal low value (.1) and the dry demand indicator of 0 was retained from the original critically dry year type (Table 17).

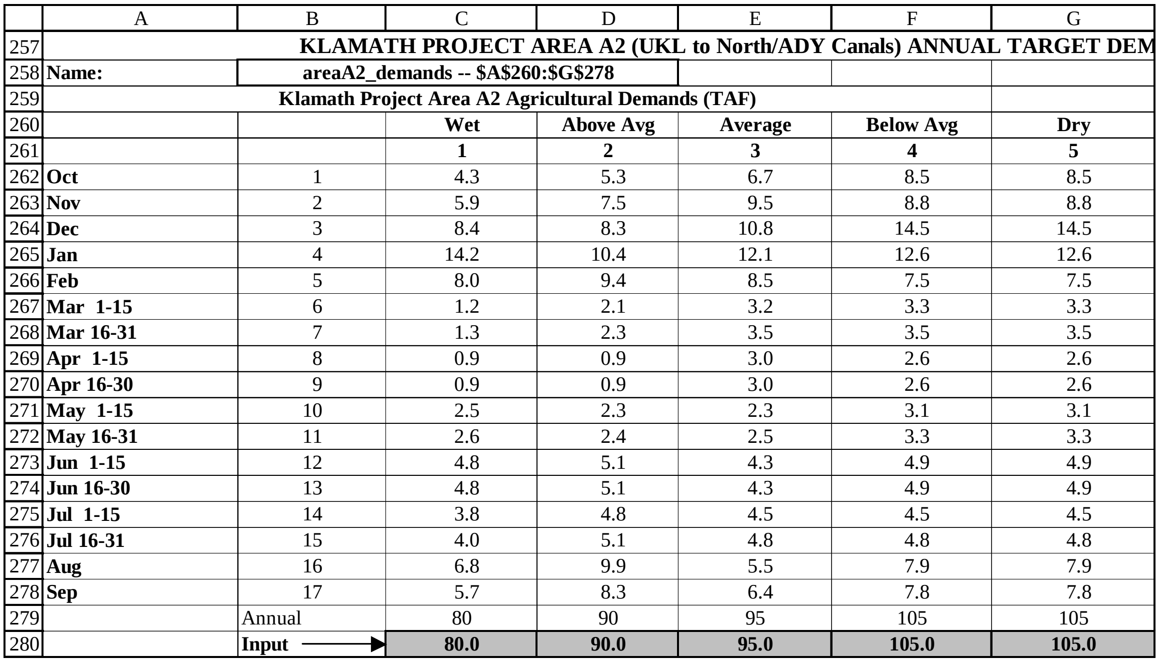
Table 17. Agricultural demand indicators for five water year types.



	A	B	C	D	E	F	G
131	**AGRICULTURAL DEMAND INDICATOR -- Area A2 (Feb 1st)**						
132	**Name:**	**agyrtype_precip ----- $B$135:$G$142**					
133	**Precipitation at Klamath Falls No. 2 Accumulated Oct 1st to date - (Inches)**						
134	**Klamath Project Precip (in)**						
135			**Wet**	**Above Avg**	**Average**	**Below Avg**	**Dry**
136			**1**	**2**	**3**	**4**	**5**
137	**Feb 1st**	5	10.0	7.0	4.0	0.1	0.0
138	**Mar 1st**	6					
139	**Mar 16th**	7					
140	**Apr 1st**	8					
141	**Apr 16th**	9					
142	**May 1**	10					

This allowed KPSIM to select the new dry or below average year types (originally critically dry demands) with identical demand inputs (see Table 18). With the current selection criteria (i.e., precipitation) this effectively maintains the demand year type distributions and classifications used in the four-water year type version of KPSIM.

Table 18. Input modifications to the KPSIM model demands.



	A	B	C	D	E	F	G
257	**KLAMATH PROJECT AREA A2 (UKL to North/ADY Canals) ANNUAL TARGET DEM**						
258	**Name:**	**areaA2_demands -- $A$260:$G$278**					
259	**Klamath Project Area A2 Agricultural Demands (TAF)**						
260			**Wet**	**Above Avg**	**Average**	**Below Avg**	**Dry**
261			**1**	**2**	**3**	**4**	**5**
262	**Oct**	1	4.3	5.3	6.7	8.5	8.5
263	**Nov**	2	5.9	7.5	9.5	8.8	8.8
264	**Dec**	3	8.4	8.3	10.8	14.5	14.5
265	**Jan**	4	14.2	10.4	12.1	12.6	12.6
266	**Feb**	5	8.0	9.4	8.5	7.5	7.5
267	**Mar 1-15**	6	1.2	2.1	3.2	3.3	3.3
268	**Mar 16-31**	7	1.3	2.3	3.5	3.5	3.5
269	**Apr 1-15**	8	0.9	0.9	3.0	2.6	2.6
270	**Apr 16-30**	9	0.9	0.9	3.0	2.6	2.6
271	**May 1-15**	10	2.5	2.3	2.3	3.1	3.1
272	**May 16-31**	11	2.6	2.4	2.5	3.3	3.3
273	**Jun 1-15**	12	4.8	5.1	4.3	4.9	4.9
274	**Jun 16-30**	13	4.8	5.1	4.3	4.9	4.9
275	**Jul 1-15**	14	3.8	4.8	4.5	4.5	4.5
276	**Jul 16-31**	15	4.0	5.1	4.8	4.8	4.8
277	**Aug**	16	6.8	9.9	5.5	7.9	7.9
278	**Sep**	17	5.7	8.3	6.4	7.8	7.8
279		Annual	80	90	95	105	105
280		**Input** →	**80.0**	**90.0**	**95.0**	**105.0**	**105.0**

2. KPSIM Priority Switching Between Upper Klamath Lake and Klamath River

The following section documents additional modifications made to the KPSIM model necessary to meet our modeling objectives.

a. On the criteria sheet several cells were added. Cell I12 is a switch when set to 0 or “off” would keep the original KPSIM priority system between Upper Klamath Lake and the Klamath River. When set to 1 or “on” it would make the Klamath River below Iron Gate Dam the first priority for water demands, Upper Klamath Lake elevations second, agricultural demands third, and refuge demands fourth. Cell I3 is a user input absolute minimum for the Upper Klamath Lake elevation and will override the USFWS Biological Opinion minimum lake elevations. Cell I14 is the corresponding minimum storage (from the look-up table in the spreadsheet).

b. In the module worksheet, column headings (S and T) were changed from the minimum Upper Klamath Lake elevation/storage values to a biological minimum Upper Klamath Lake elevation/storage value.

c. Added a fish delivery factor test within existing column AN switch for the revised Upper Klamath Lake and river priority switch. If the switch is off then the program will use the original logic, if the switch is on then the program will use the same equation but uses seasonal available fish flows (i.e., supplies) (column AM not column AL) based on the absolute minimum lake elevation.
d. Created a fish monthly available supply (column AQ) based on absolute minimum lake elevation, and is only active when the switch is on.

e. Added a logical test for release of fish flows (column AR) to allow the use of the original equations and fish supply logic if the switch is off, and also modified the “on” condition to calculate flows based on the fish flow available supply (column AQ).

All simulations with KPSIM were set up so that the river has the first priority for water deliveries (versus other demands). The reader should consult USBR technical documentation for further information on KPSIM. This can be made through the Klamath Falls Office or at the website address via the World Wide Web: www.mp.usbr.gov/kbao/models/index.html.

Year Type Classifications

The hydrologic year type indicators used to trigger the river flow requirements in KPSIM were set to Upper Klamath Lake net inflow for the April to September period. The Natural Resources Conservation Service (NRCS) makes stream flow forecasts for the net inflow into Upper Klamath Lake. The forecasts start in January and are updated monthly through June.

The historic Upper Klamath Lake net inflow data (i.e., 1961-1999) were used in defining five water year types used in our analysis based on a classification of exceedance flow volumes using the 12, 40, 60 and 88 percent exceedance probabilities. This breakdown into water year types follows the same procedure as Phase I and as implemented in the Trinity River Flow Evaluation Report. A comparison between USBR original four-water year type classification and the USU derived five-water year type classification are shown in Table 19.

<u>Simulated Unimpaired Flows below Iron Gate Dam (No_Project)</u>

Estimates of the unimpaired outflows from Upper Klamath Lake were provided by the Bureau of Reclamation. USU obtained consumptive use estimates above Upper Klamath Lake from Mr. Jonathan L. La Marche of the State of Oregon Department of Water Resources. These consumptive use estimates were developed as part of the technical work being conducted in support of the Alternative Dispute Resolution process for the Klamath Basin Adjudication in Oregon.

These consumptive use estimates were provided to the USBR and Phillip Williams and Associates (PWA). PWA then conducted a number of flow simulations for Upper Klamath Lake with the updated version of an existing MIKE 11 model for Upper Klamath Lake. The use of the MIKE 11 model, for these simulations rather than a simple mass balance approach, was undertaken to better reflect the actual dynamics of water flow through Upper Klamath Lake.

Table 19. Comparison of USBR four water year classification and USU five water year classification based on Upper Klamath Lake net inflows.

	USBR Original								**"New" Year Types**	
		Actual								**Actual**
	Water Year	**Historic Inflow (A-S)**	**Ranking**	**Calculated Exceedance**		**Estimated Exceedances**			**Water Year**	**Historic Inflow (A-S)**
	1983	876.5	1	2.50		12% flow	785.1981		**1983**	876.5
	1971	838.8	2	5.00		40%flow	568.5		**1971**	838.8
	1984	800.1	3	7.50		60% flow	458.3	Extremely Wet	**1984**	800.1
	1999	791.9	4	10.00		88% flow	286.7228		**1999**	791.9
	1974	783.5	5	12.50					**1974**	783.5
	1975	743.2	6	15.00					**1975**	743.2
	1982	737.7	7	17.50					**1982**	737.7
Above Average	**1998**	716.6	8	20.00					**1998**	716.6
	1993	677.9	9	22.50					**1993**	677.9
	1969	674.5	10	25.00				Wet	**1969**	674.5
	1967	620.8	11	27.50					**1967**	620.8
	1972	607.3	12	30.00					**1972**	607.3
	1963	589.4	13	32.50					**1963**	589.4
	1989	582.7	14	35.00					**1989**	582.7
	1996	568.9	16	40.00					**1996**	568.9
	1985	568.5	15	37.50					**1985**	568.5
	1965	558.3	17	42.50					**1965**	558.3
	1978	539.6	18	45.00					**1978**	539.6
	1995	523.8	19	47.50					**1995**	523.8
	1986	521.6	20	50.00				Normal	**1986**	521.6
	1997	517.2	21	52.50					**1997**	517.2
	1976	499.7	22	55.00					**1976**	499.7
	1964	496.7	23	57.50					**1964**	496.7
	1962	458.3	24	60.00					**1962**	458.3
	1966	444.7	25	62.50					**1966**	444.7
	1961	426.2	26	65.00					**1961**	426.2
Below Average	**1980**	372.7	27	67.50					**1980**	372.7
	1970	368.5	28	70.00					**1970**	368.5
	1987	366.1	29	72.50					**1987**	366.1
	1973	350.7	30	75.00				Dry	**1973**	350.7
	1979	331.4	31	77.50					**1979**	331.4
	1990	318.5	32	80.00					**1990**	318.5
	1977	300.8	33	82.50					**1977**	300.8
	1988	298.7	34	85.00					**1988**	298.7
Dry	**1968**	291.2	35	87.50					**1968**	291.2
	1981	268.7	36	90.00					**1981**	268.7
	1991	255.1	37	92.50				Critically Dry	**1991**	255.1
Critical	**1994**	179.1	38	95.00					**1994**	179.1
	1992	154.6	39	97.50					**1992**	154.6

The topographic geometry of the natural reef control structure used in the MIKE 11 models was developed from the actual cross-sectional profile constructed from a 2-foot contour map of the lake bathymetry developed in 1920. The reef hydraulics were modeled using a simple broad-crested weir with an invert elevation of 4137.6 feet and bottom and top widths of roughly 60- and 600-ft respectively (PWA 2001).

The unimpaired inflow hydrograph used in the simulations was obtained by adding the consumptive use estimates for the Klamath Basin developed by Oregon Department of Water Resources, to the existing USBR net inflow records. The daily consumptive use estimates and corresponding unimpaired outflow estimates are provided in Figures 35 and 36.

Simulations were conducted for the October 1973 to September 1997 period based on the natural reef elevation of the lake outlet. The October 1973 to September 1997 period corresponds to the extent of the consumptive use data records obtained from the Oregon Department of Water Resources.

USU was provided with the simulated estimates of unimpaired flow conditions just below Upper Klamath Lake. These simulated unimpaired flows are considered the best available data at present for flow conditions before agricultural development impacted flows in the Upper Klamath Basin. The specific technical approach undertaken for the Upper Klamath Lake component of the modeling is documented in PWA (2001).

These simulated outflows from Upper Klamath Lake were then used as inputs to the MODSIM model in order to estimate the unimpaired flows below Iron Gate Dam.

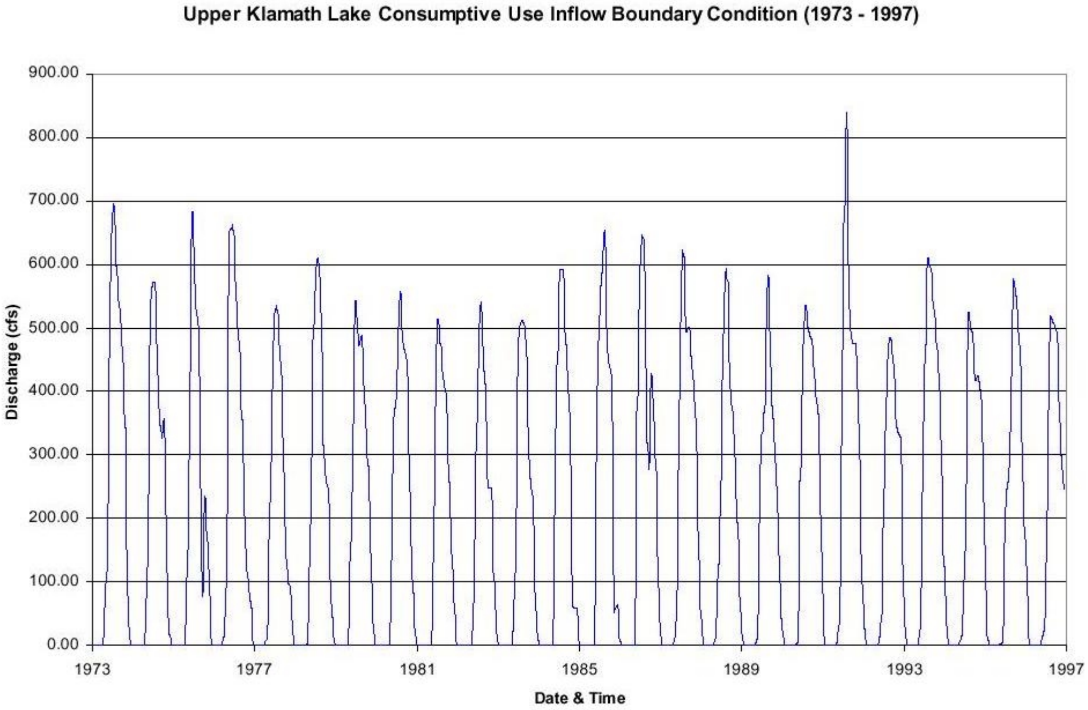


Figure 35. The October 1973 to September 1997 estimated daily consumptive use above Upper Klamath Lake (from PWA 2001).

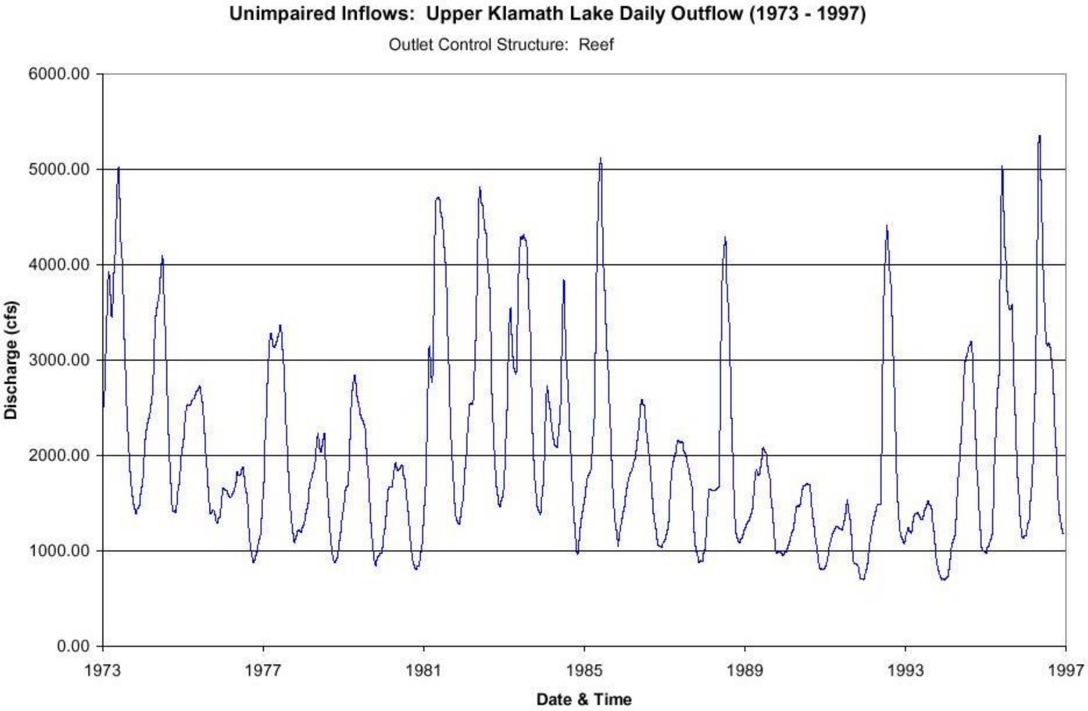


Figure 36. Estimated unimpaired outflows from Upper Klamath Lake. NOTE: only the October 1973 to September 1997 period of record contain estimated daily consumptive use adjustments (from PWA 2001).

This simulation of flows for the unimpaired conditions below Seiad was not possible with MODSIM due to the limitations in the structure of the Network 2 file in SIAM as noted above. Therefore, results for each control point below Seiad were computed by manually adding the reach gains computed from the Network 3 file for use in the Phase II assessments. The simulated unimpaired flows using MODSIM was accomplished in the following manner.

The USGS Network 2 (i.e., No_Project) file was used as a template and the node (accretion) values were updated using data provided by USBR. The updated accretions were used to modify the Network 2 file for the 1961 to 1997 period (37 years of data). Since nodes below Iron Gate in the Network 2 data file only contained values through 1997, the updated USBR data for 1998 and 1999 was excluded for the unimpaired simulations. This approach was required, since USGS no longer supports or updates their Network 2 computational node file. Network 2 has reservoir nodes eliminated to simulate a no project condition and stops at the Seiad gage. USU was limited to this simulation capability in SIAM for the unimpaired conditions. MODSIM inputs or constraints that were project related such as agriculture demands were set to zero.

Historical Klamath Project Operations (USGS_Historical)

The default SIAM simulation of historical Klamath Project operations based on the Network 3 structure for the system and used by USGS to calibrate their MODSIM model was used for this scenario. This simulation provided estimates of the flow regime between Iron Gate Dam and estuary based on existing system structure and operating rules. USU did not make any adjustments to this simulation. USU utilized the closest computational node to our study site locations in all the assessments as described below.

Simulated Klamath Project Operations with FERC Flows (FERC_ESA)

USU simulated Klamath Project operations based on the existing FERC minimum flow schedule below Iron Gate Dam using the Network 3 structure for the system. This scenario differs from the USGS historical operations simulation in that the KPSIM and MODSIM linkages (described above) were set such that flows below Iron Gate Dam met FERC minimum flows as the first priority. This scenario was implemented in order to assess the implications of the FERC flow schedule relative to unimpaired, historical, and Phase I recommendations.

Simulated Klamath Project Operations with Phase I Recommendations (FP1_ESA)

This scenario simulated Klamath Project operations based on the Phase I recommended monthly regime using the Network 3 structure for the system. The KPSIM and MODSIM linkages described above were utilized to set these flow targets below Iron Gate Dam as the first priority.

Relationship between MODSIM Computational Nodes and USU Study Sites

The results of the flow simulations in MODSIM were selected from the closest MODSIM computational node to the actual spatial location of USU study sites. Table 19 shows the relationship between MODSIM computational nodes and the associated USU study sites. In all cases, we felt that the simulated flow provided the best estimates at the study sites and that any bias (i.e., under estimation or overestimation of any reach gains between the MODSIM nodes and the USU study sites were relatively small. This was supported by field observations of the location of USU study sites in relation to the MODSIM control node locations.

Table 19. Relationship between MODSIM control points and USU study site locations.

USU Study Site	Corresponding SIAM CP/Node	Down or Upstream From USU Site
R. Ranch	**cp 40**	**up**
Tree of Heaven	**cp 80**	**exact**
Brown Bear	**cp110**	**down**
Seiad	**cp130**	**up**
Rogers Creek	**cp170**	**up**
Orleans	**cp190**	**down**
Saint's Rest Bar	**cp210**	**up**
Young's Bar	**cp220**	**up**

Comparison of Modeled Scenario Hydrology

The simulated flow results for each modeled scenario at each USU study site (see Table 19) were used to compute the long-term average monthly flows and associated monthly flow exceedance values. These results are presented in graphical form for the monthly average flows and in tabular form for the exceedances. Note that Saints Rests Bar data has been omitted.

<u>Mean Monthly Flows</u>

Iron Gate Dam

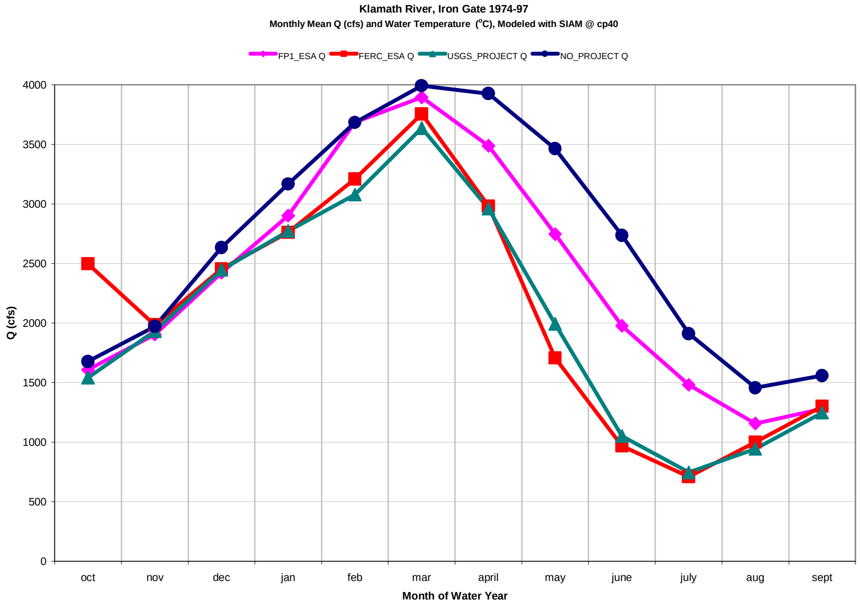


Figure 37. Mean monthly flows at Iron Gate associated with each simulated flow scenario. Flow in October (FERC) is from lake evacuations.

Trees of Heaven

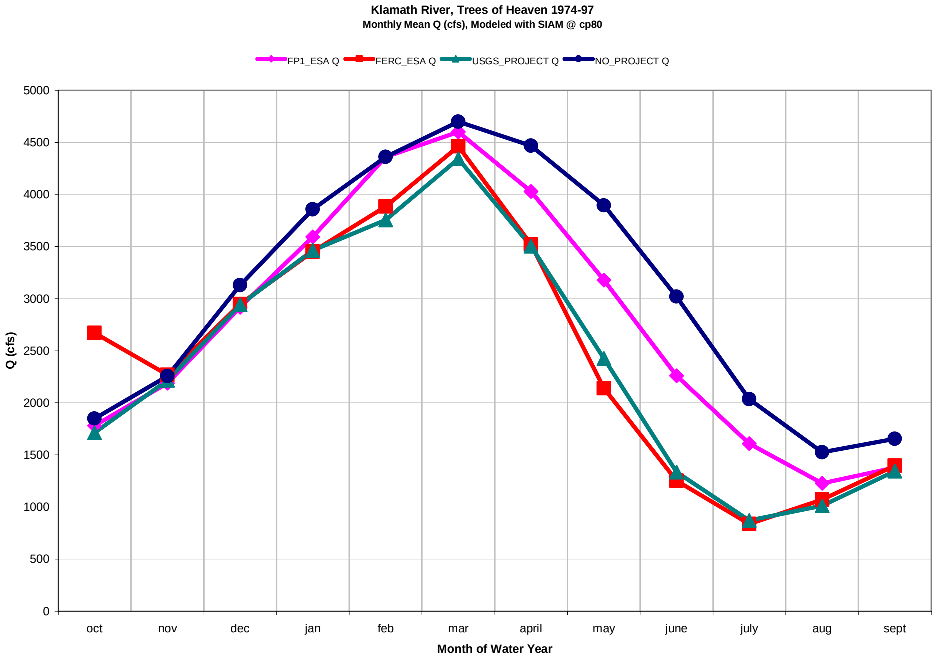


Figure 38. Mean monthly flows at Trees of Heaven associated with each simulated flow scenario.

Brown Bear

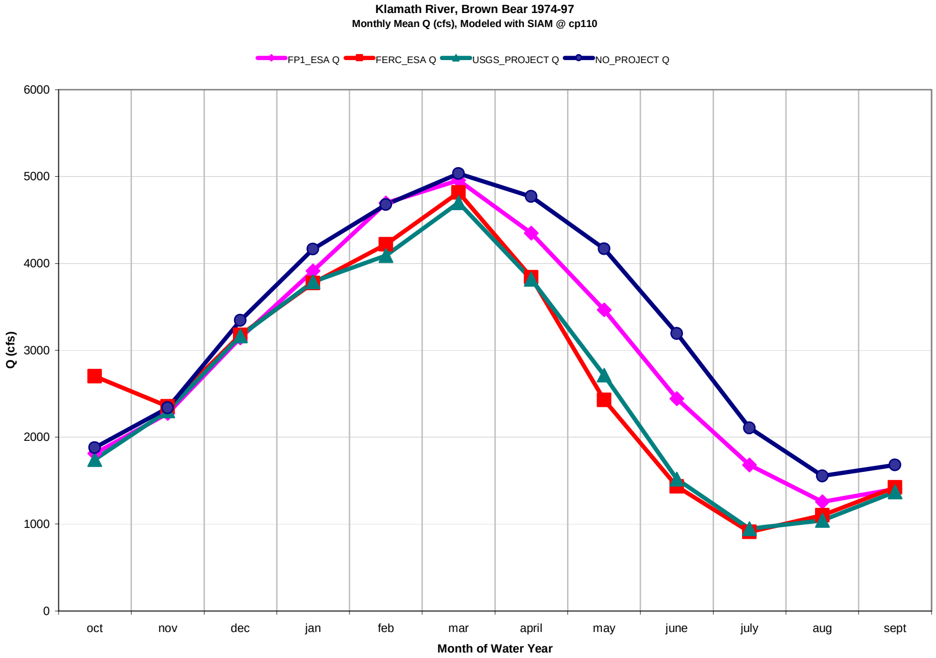


Figure 39. Mean monthly flows at Brown Bear associated with each simulated flow scenario.

Seiad

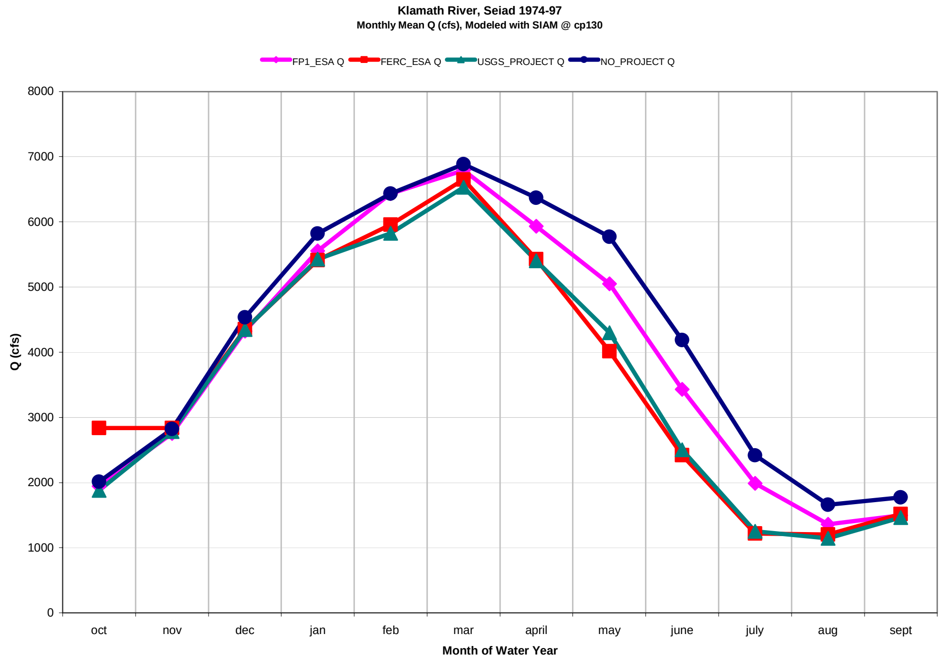


Figure 40. Mean monthly flows at Seiad associated with each simulated flow scenario.

Rogers Creek

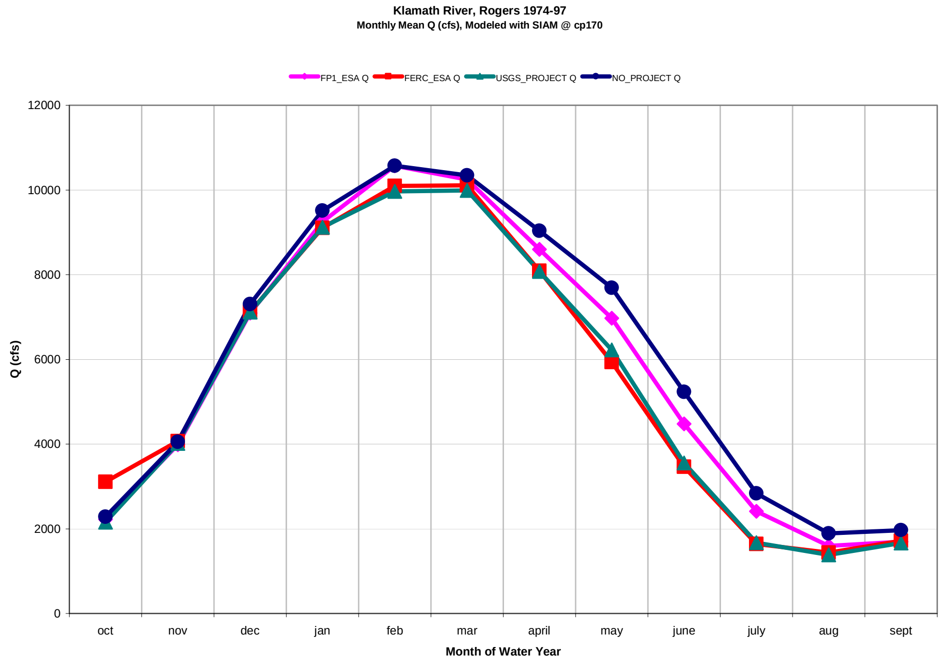


Figure 41. Mean monthly flows at Rogers Creek associated with each simulated flow scenario.

Orleans

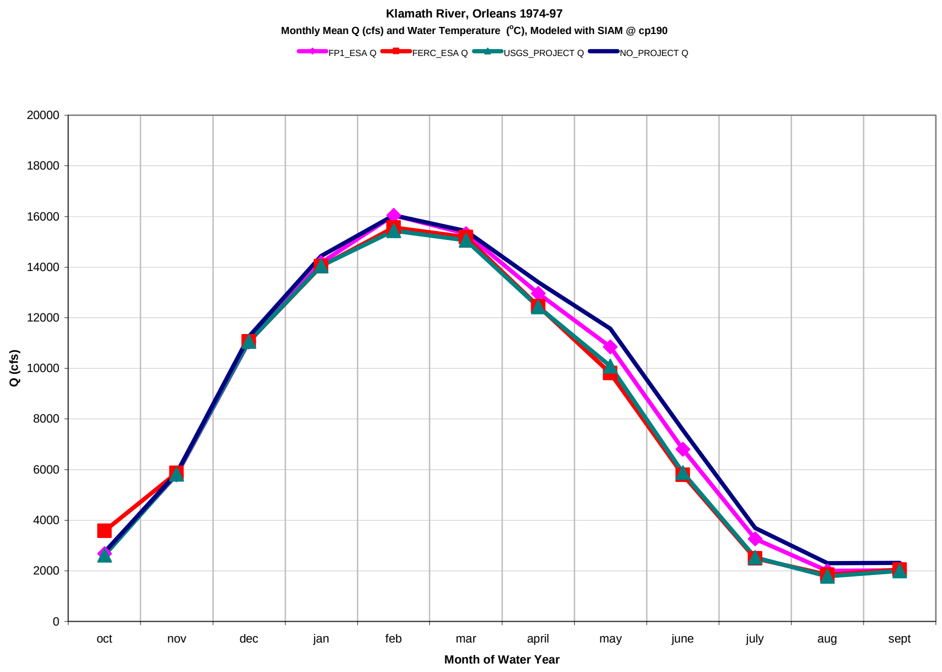


Figure 42. Mean monthly flows at Orleans associated with each simulated flow scenario.

Saints Rest Bar

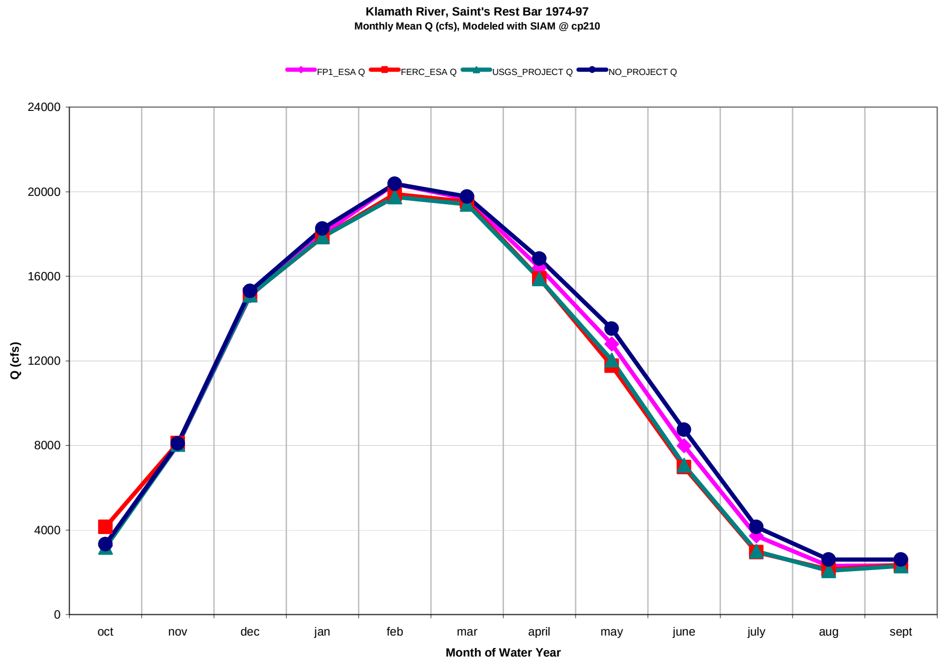


Figure 43. Mean monthly flows at Saint Rests Bar associated with each simulated flow scenario.

Monthly Flow Durations

Iron Gate Dam

Table 20. Monthly flow exceedance values (cfs) for each simulated scenario at Iron Gate Dam.

Klamath River, Iron Gate

Percent Exceedence Q (cfs), Period of Record 1974-97

Modeled with SIAM, cp40 (location in SIAM corresponding to Iron Gate)

Alternative	%	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
NO_PROJECT	10.0	2169.5	2664.2	4521.6	5281.8	6438.6	6301.8	6430.4	5258.6	4163.4	2828.7	2131.0	2076.0
	20.0	1991.0	2283.6	3541.1	3791.5	5416.0	5462.8	5390.9	4613.1	3689.9	2527.7	1935.5	1843.0
	30.0	1884.8	2081.4	2909.6	3666.2	4245.4	5044.7	4869.4	4312.6	3473.4	2128.5	1639.4	1813.0
	40.0	1699.5	2020.2	2459.8	2990.3	3724.2	4394.4	4540.9	3784.7	2870.0	1985.8	1490.3	1754.0
	50.0	1589.0	1897.0	2281.9	2738.2	3071.8	3913.5	3840.9	3568.0	2689.0	1854.2	1424.5	1502.5
	60.0	1491.9	1716.8	2099.8	2541.3	2914.3	3388.9	3078.0	2848.1	2216.0	1739.0	1299.7	1377.0
	70.0	1450.5	1613.2	1903.2	2299.4	2559.1	2837.9	2637.0	2360.8	2033.0	1461.8	1158.4	1295.5
	80.0	1393.9	1584.4	1761.9	2037.1	2248.9	2390.3	2342.0	2218.1	1797.0	1324.8	1141.0	1174.0
	90.0	1163.4	1433.6	1643.4	1870.6	1921.6	1908.9	1908.0	1961.6	1532.5	1147.7	1004.0	1021.0
USGS_PROJECT	10.0	2618.2	3761.9	4027.5	5264.4	6561.4	7208.4	5664.9	3833.9	2190.0	963.5	1056.5	1628.5
	20.0	1836.8	2991.2	3853.7	3886.9	5127.9	5697.9	5195.9	3256.0	1321.0	797.0	1035.0	1426.0
	30.0	1686.8	2073.2	3398.7	3265.4	3888.9	5144.4	4373.4	2580.0	1084.0	743.0	1028.0	1347.0
	40.0	1377.2	1526.8	2429.6	3076.0	3364.9	4215.9	3380.9	2134.0	888.0	731.0	1023.0	1340.0
	50.0	1342.0	1402.0	1825.0	2086.0	2441.0	3108.0	2661.0	1650.5	819.0	718.5	1017.5	1325.5
	60.0	1338.2	1341.4	1588.2	1815.0	1809.0	2615.0	1729.0	1370.0	746.0	713.0	1005.0	1306.0
	70.0	1322.0	1331.2	1478.2	1632.0	1598.0	2308.0	1499.5	1031.0	734.0	707.0	985.5	1095.5
	80.0	1015.8	1282.4	1374.6	1334.0	1107.0	1820.0	1167.0	1007.0	726.0	676.0	925.0	1008.0
	90.0	888.0	915.2	927.0	1071.0	741.0	688.0	749.5	801.5	677.5	539.0	622.0	823.0
FERC_ESA	10.0	4965.7	3341.1	5662.5	5094.4	7548.9	6550.9	5437.9	3429.4	1756.5	710.0	1000.0	1300.0
	20.0	3910.7	2637.0	3330.0	3956.9	4637.9	6079.9	5074.9	2660.0	1463.0	710.0	1000.0	1300.0
	30.0	3406.3	2355.2	2825.2	2905.0	3664.4	5165.4	4272.4	2218.0	857.5	710.0	1000.0	1300.0
	40.0	2604.2	2024.8	2152.8	2601.0	3137.0	4419.9	3452.9	1472.0	710.0	710.0	1000.0	1300.0
	50.0	1988.0	1632.0	1777.0	2109.5	2341.5	3097.0	2520.5	1136.0	710.0	710.0	1000.0	1300.0
	60.0	1300.0	1321.0	1569.0	2035.0	2103.0	2841.0	1675.0	1000.0	710.0	710.0	1000.0	1300.0
	70.0	1300.0	1300.0	1362.6	1538.5	1657.0	2511.0	1307.0	1000.0	710.0	710.0	1000.0	1300.0
	80.0	1300.0	1300.0	1300.0	1300.0	1300.0	1700.0	1300.0	1000.0	710.0	710.0	1000.0	1300.0
	90.0	1300.0	1300.0	1300.0	1300.0	1300.0	1300.0	1300.0	1000.0	710.0	710.0	1000.0	1300.0
FP1_ESA	10.0	3358.5	3341.1	4418.9	5007.9	7548.9	6391.9	5437.9	3429.4	2249.0	1714.0	1346.0	1395.0
	20.0	1476.0	2059.2	2917.2	2893.0	4637.9	5417.9	5074.9	3056.0	2249.0	1714.0	1346.0	1395.0
	30.0	1476.0	1880.4	2283.6	2690.0	3601.9	4328.4	3867.9	3056.0	2249.0	1714.0	1346.0	1395.0
	40.0	1476.0	1688.0	2082.0	2491.0	3008.0	3589.9	3465.9	3056.0	2249.0	1714.0	1346.0	1395.0
	50.0	1476.0	1688.0	2082.0	2421.0	3008.0	3073.0	3307.0	3056.0	2249.0	1714.0	1346.0	1395.0
	60.0	1476.0	1688.0	2082.0	2421.0	3008.0	3073.0	3307.0	3056.0	2249.0	1714.0	1346.0	1395.0
	70.0	1372.4	1572.0	2082.0	2421.0	3008.0	3073.0	2903.5	2672.0	1962.0	1497.5	1184.0	1339.0
	80.0	1115.4	1469.4	1789.8	2176.0	2265.0	3073.0	2265.0	2052.0	1475.0	1120.0	917.0	1019.0
	90.0	926.4	1083.0	1291.6	1640.0	1900.0	2815.0	1543.5	1436.0	1048.5	758.0	511.5	866.0

Trees of Heaven

Table 21. Monthly flow exceedance values (cfs) for each simulated scenario at Trees of Heaven.

Klamath River, Trees of Heaven

Percent Exceedence Q (cfs), Period of Record 1974-97

Modeled with SIAM, cp80 (location in SIAM corresponding to Trees of Heaven)

Alternative	%	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
NO_PROJECT	10.0	2397.3	3235.4	6052.0	7137.5	7891.5	7275.9	7461.9	6145.5	4663.4	3023.7	2246.1	2217.0
	20.0	2193.7	2523.4	4157.5	4951.8	6988.8	6762.5	6006.9	5202.5	4247.9	2867.4	2097.1	2067.0
	30.0	2095.9	2388.8	3371.9	4412.3	4981.0	6037.2	5617.9	4798.5	3726.9	2349.2	1706.1	1928.5
	40.0	1884.0	2322.4	2790.0	3420.9	4435.6	5378.6	5084.9	4114.7	3062.0	2082.6	1545.5	1888.0
	50.0	1760.3	2222.0	2646.8	3221.6	3646.6	4604.9	4462.9	3933.3	2931.5	1950.5	1522.7	1592.0
	60.0	1642.5	1908.0	2416.5	2893.5	3288.2	3806.0	3557.9	3262.2	2507.0	1815.5	1386.8	1456.0
	70.0	1606.3	1826.2	2144.1	2610.5	2867.7	3234.6	2894.5	2596.0	2218.0	1526.1	1199.5	1376.0
	80.0	1555.2	1776.8	2006.3	2472.6	2631.4	2698.1	2591.0	2411.6	1942.0	1382.9	1195.2	1223.0
	90.0	1272.6	1617.8	1855.0	2128.1	2182.0	2112.1	2055.5	2137.3	1615.5	1192.7	1019.0	1057.0
USGS_PROJECT	10.0	2846.2	4206.9	5276.7	7112.9	8170.4	8181.9	6696.4	4613.4	2643.5	1190.0	1197.0	1757.5
	20.0	2031.2	3223.4	4666.9	4813.9	6426.9	6548.9	5874.9	3854.9	1811.0	1013.0	1131.0	1551.0
	30.0	1883.6	2302.0	4043.7	4177.4	4624.9	6133.4	5111.9	3119.0	1423.5	902.0	1121.5	1515.0
	40.0	1563.4	1887.2	2704.4	3464.9	4075.9	5301.9	4171.9	2526.0	1220.0	872.0	1113.0	1444.0
	50.0	1515.0	1713.0	2105.0	2416.0	2843.5	3758.4	3085.4	2077.5	1040.5	822.5	1089.5	1422.5
	60.0	1504.0	1603.0	1875.8	2171.0	2303.0	3042.0	2131.0	1700.0	1024.0	786.0	1062.0	1396.0
	70.0	1479.4	1548.4	1817.0	1890.0	1968.5	2746.0	1752.5	1238.0	875.0	776.0	1017.0	1168.0
	80.0	1129.0	1504.6	1625.4	1663.0	1550.0	2128.0	1383.0	1174.0	830.0	743.0	975.0	1064.0
	90.0	1016.4	1093.8	1144.8	1427.0	1001.0	891.5	896.5	1026.5	784.5	595.5	645.5	864.0
FERC_ESA	10.0	5193.3	3785.7	6991.5	7115.4	9157.4	7407.4	6469.4	4220.9	2275.5	1003.5	1141.5	1469.0
	20.0	4115.5	2839.4	4135.3	4883.9	5518.9	6901.9	5754.9	3230.0	1624.0	922.0	1107.0	1434.0
	30.0	3587.9	2625.4	3277.8	3626.9	4399.9	6522.9	5010.9	2826.0	1372.0	859.5	1094.0	1417.5
	40.0	2781.6	2218.6	2525.6	2976.0	3847.9	5505.9	4100.9	1864.0	999.0	827.0	1070.0	1407.0
	50.0	2178.0	1889.0	2142.0	2485.5	2739.5	3647.4	2945.0	1574.5	935.0	799.5	1065.0	1398.0
	60.0	1489.8	1674.6	1889.6	2383.0	2479.0	3290.0	2155.0	1330.0	901.0	787.0	1056.0	1383.0
	70.0	1458.6	1613.8	1579.6	1898.5	2047.0	2935.5	1577.5	1253.5	865.0	782.0	1050.0	1364.0
	80.0	1416.4	1504.2	1546.2	1735.0	1578.0	2008.0	1516.0	1188.0	829.0	768.0	1032.0	1345.0
	90.0	1408.2	1483.8	1508.2	1527.0	1559.0	1531.5	1456.5	1164.0	795.5	748.0	1016.0	1339.5
FP1_ESA	10.0	3586.1	3785.7	5866.3	6900.9	9157.4	7233.9	6469.4	4242.4	2859.0	2007.5	1487.5	1564.0
	20.0	1690.4	2295.2	3442.6	3651.9	5518.9	6713.9	5754.9	3760.9	2715.0	1926.0	1453.0	1529.0
	30.0	1665.4	2159.2	2797.2	3485.9	4284.9	5248.4	4719.9	3596.4	2566.0	1863.5	1440.0	1512.5
	40.0	1658.2	2006.4	2520.2	2976.0	3791.9	4334.9	4113.9	3456.9	2508.0	1831.0	1416.0	1502.0
	50.0	1647.0	1911.0	2362.0	2797.5	3472.9	3688.9	3777.4	3389.9	2443.5	1801.0	1411.0	1493.0
	60.0	1634.0	1899.0	2334.2	2774.0	3348.9	3498.9	3620.9	3365.9	2410.0	1788.0	1402.0	1476.0
	70.0	1545.4	1892.8	2299.6	2708.0	3276.5	3477.9	3161.0	3046.0	2126.5	1562.0	1225.5	1387.5
	80.0	1270.2	1712.4	1994.2	2413.0	2768.0	3334.0	2515.0	2233.0	1569.0	1184.0	932.0	1068.0
	90.0	1035.2	1264.0	1499.8	1982.5	2275.5	3076.5	1716.5	1654.5	1159.0	803.0	535.5	907.0

Brown Bear

Table 22. Monthly flow exceedance values (cfs) for each simulated scenario at Brown Bear.

Klamath River, Brown Bear

Percent Exceedence Q (cfs), Period of Record 1974-97

Modeled with SIAM, cp110 (location in SIAM corresponding to Brown Bear)

Alternative	%	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
NO_PROJECT	10.0	2435.4	3479.1	6944.8	8065.1	8750.3	7822.6	8033.4	6718.5	4997.9	3142.7	2299.8	2259.0
	20.0	2233.0	2633.8	4560.7	5448.3	7551.3	7302.5	6373.9	5666.0	4604.9	3050.3	2143.5	2105.0
	30.0	2134.1	2453.8	3595.1	4751.5	5301.9	6501.2	6106.9	5099.9	3850.9	2452.3	1729.4	1950.0
	40.0	1915.4	2400.4	2911.2	3613.5	4721.7	5918.6	5465.9	4346.0	3174.0	2132.9	1576.5	1916.0
	50.0	1797.1	2282.0	2779.4	3413.6	3848.5	4942.2	4746.9	4155.9	3062.5	1999.4	1554.7	1613.0
	60.0	1672.3	1928.4	2533.5	3008.7	3418.9	3980.2	3814.9	3538.0	2660.0	1881.3	1433.2	1457.0
	70.0	1624.8	1857.2	2185.4	2709.2	2976.4	3416.0	3029.5	2747.9	2300.5	1561.9	1221.3	1395.5
	80.0	1582.8	1815.6	2076.2	2589.7	2800.7	2805.5	2708.0	2515.2	2033.0	1420.6	1204.8	1236.0
	90.0	1281.1	1650.4	1914.8	2183.2	2259.1	2187.6	2140.5	2224.8	1657.5	1213.1	1022.9	1062.0
USGS_PROJECT	10.0	2886.0	4379.9	6173.9	8099.9	9074.4	8652.4	7297.9	5131.9	2948.0	1320.5	1266.5	1792.0
	20.0	2075.0	3271.2	5099.3	5220.9	6862.9	7025.9	6263.9	4381.9	1999.0	1141.0	1180.0	1591.0
	30.0	1921.8	2366.0	4214.9	4533.9	4961.9	6739.9	5538.4	3544.4	1655.0	965.0	1158.5	1560.5
	40.0	1595.6	2000.8	2814.0	3590.9	4376.9	5870.9	4509.9	2773.0	1463.0	943.0	1154.0	1481.0
	50.0	1569.0	1847.0	2151.0	2521.5	3021.0	4105.4	3340.9	2415.5	1185.5	888.0	1117.0	1442.0
	60.0	1524.8	1624.4	2042.8	2303.0	2532.0	3234.0	2306.0	1945.0	1130.0	833.0	1093.0	1411.0
	70.0	1511.2	1597.2	1878.4	2122.0	2163.0	2929.5	1911.5	1379.0	984.0	816.5	1030.0	1176.5
	80.0	1148.0	1563.8	1702.0	1768.0	1590.0	2242.0	1505.0	1304.0	905.0	763.0	1002.0	1087.0
	90.0	1030.4	1128.4	1208.0	1558.5	1082.5	971.0	986.0	1114.0	838.5	624.0	651.5	875.5
FERC_ESA	10.0	5233.7	3958.7	7685.1	8223.4	10061.9	7879.9	7070.9	4761.9	2699.0	1176.0	1198.0	1525.5
	20.0	4156.1	2857.8	4558.9	5290.9	5954.9	7543.9	6142.9	3610.9	1889.0	1050.0	1157.0	1465.0
	30.0	3614.3	2689.2	3472.3	3983.4	4737.4	7081.4	5463.9	3218.0	1626.0	930.0	1133.0	1450.0
	40.0	2810.4	2394.4	2682.4	3118.0	4241.9	6074.9	4465.9	2111.0	1162.0	900.0	1103.0	1435.0
	50.0	2222.0	1918.0	2253.0	2642.5	2919.5	3925.9	3200.4	1827.0	1073.0	849.5	1092.0	1424.0
	60.0	1537.6	1800.2	1999.2	2474.0	2708.0	3507.9	2432.0	1574.0	1019.0	836.0	1080.0	1402.0
	70.0	1488.4	1719.6	1633.2	2133.5	2186.0	3126.5	1714.0	1414.0	974.0	826.5	1070.0	1383.5
	80.0	1433.8	1535.8	1607.8	1899.0	1668.0	2122.0	1638.0	1304.0	899.0	798.0	1042.0	1360.0
	90.0	1418.2	1518.2	1568.6	1594.5	1642.0	1623.0	1564.5	1242.5	846.0	768.5	1020.5	1345.5
FP1_ESA	10.0	3626.5	3958.7	6750.7	7900.4	10061.9	7862.4	7070.9	4845.4	3299.9	2180.0	1544.0	1620.5
	20.0	1734.4	2546.4	3684.9	4115.9	5954.9	7185.9	6142.9	4181.9	3004.0	2054.0	1503.0	1560.0
	30.0	1708.6	2232.6	3172.6	3909.4	4624.4	5814.4	5234.4	3968.4	2776.0	1934.0	1479.0	1545.0
	40.0	1686.0	2099.4	2653.6	3118.0	4148.9	4903.9	4445.9	3710.9	2659.0	1904.0	1449.0	1530.0
	50.0	1669.0	1950.0	2529.0	2953.5	3680.9	4035.9	4070.4	3622.9	2561.5	1852.5	1438.0	1519.0
	60.0	1657.4	1935.8	2422.0	2895.0	3486.9	3702.9	3795.9	3557.9	2483.0	1839.0	1426.0	1495.0
	70.0	1601.8	1928.2	2345.0	2806.0	3359.9	3664.9	3303.5	3250.9	2232.0	1599.5	1240.5	1404.0
	80.0	1298.0	1759.4	2039.6	2655.0	3258.0	3456.9	2637.0	2329.0	1624.0	1224.0	938.0	1081.0
	90.0	1044.6	1297.0	1560.6	2112.5	2394.0	3173.0	1839.0	1772.5	1230.5	824.0	542.5	919.0

Seiad

Table 23. Monthly flow exceedance values (cfs) for each simulated scenario at Seiad.

Klamath River, Seiad

Percent Exceedence Q (cfs), Period of Record 1974-97

Modeled with SIAM, cp130 (location in SIAM corresponding to Seiad)

Alternative	%	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
NO_PROJECT	10.0	2698.6	5070.9	10751.8	13368.2	13669.6	11193.2	10750.9	9904.3	7558.4	3818.1	2518.5	2469.5
	20.0	2431.9	3538.3	6826.0	7889.9	9543.1	9928.9	8614.9	8231.5	5887.9	3429.6	2295.5	2323.0
	30.0	2273.6	3032.8	5026.5	6703.9	7542.2	9424.3	8519.9	7512.0	5213.4	2853.9	1859.5	2078.5
	40.0	2110.1	2785.6	3931.8	4749.6	7014.5	8430.9	7396.9	5675.7	4017.9	2331.3	1729.4	1995.0
	50.0	1944.2	2527.0	3201.3	4031.0	4767.2	6554.9	6302.4	5387.3	3798.9	2179.8	1651.9	1677.0
	60.0	1764.8	2082.2	2885.4	3740.2	4565.2	4936.4	4768.9	4986.7	3215.0	2087.4	1543.5	1512.0
	70.0	1711.2	2006.2	2406.2	3375.9	3711.3	4439.4	3867.4	3643.0	2775.5	1693.1	1287.1	1453.5
	80.0	1635.9	1973.6	2319.1	3238.1	3308.6	3568.9	3438.9	3182.9	2477.0	1560.0	1237.7	1274.0
	90.0	1326.6	1790.6	2138.5	2398.5	2591.3	2638.1	2785.5	2735.3	1879.5	1296.3	1037.9	1092.0
USGS_PROJECT	10.0	3147.4	5500.1	11069.6	13352.9	13948.3	11726.3	9985.4	8118.9	5296.4	2222.5	1469.0	1928.0
	20.0	2266.2	3933.5	7485.1	7300.9	8832.9	10165.9	8003.9	6888.9	3744.9	1701.0	1365.0	1807.0
	30.0	2068.8	3174.2	5140.5	6469.4	6876.9	9414.9	7604.9	6031.9	2955.5	1365.0	1289.0	1679.5
	40.0	1791.2	2559.6	3647.7	4305.9	5950.9	8831.9	6789.9	4343.9	2124.0	1185.0	1250.0	1602.0
	50.0	1703.0	2434.0	3042.0	3671.4	4310.4	5658.9	4784.4	3740.9	1890.5	1041.5	1204.0	1526.0
	60.0	1639.0	1942.2	2609.2	3107.0	3522.9	4349.9	3251.0	3071.0	1817.0	1017.0	1183.0	1454.0
	70.0	1577.4	1755.8	2134.2	2686.0	2871.5	3779.9	2700.5	2242.5	1458.0	945.5	1073.5	1214.5
	80.0	1217.2	1665.2	1993.0	2410.0	2467.0	2999.0	2159.0	1939.0	1210.0	838.0	1041.0	1125.0
	90.0	1087.6	1243.0	1463.6	1929.0	1493.0	1448.0	1464.0	1553.0	1053.5	706.0	672.0	908.0
FERC_ESA	10.0	5495.5	5078.3	11429.6	13657.9	14740.8	11201.8	9758.4	7917.9	5100.4	1893.0	1394.0	1730.0
	20.0	4327.3	3951.1	6803.1	7369.9	7924.9	10423.9	8092.9	6351.9	3464.9	1680.0	1337.0	1594.0
	30.0	3741.3	2954.2	4419.1	5918.4	7192.4	9526.9	7588.9	5635.9	2747.9	1290.5	1263.0	1554.0
	40.0	2946.0	2740.0	3458.6	4698.9	6290.9	8792.9	6840.9	3770.9	2123.0	1164.0	1203.0	1542.0
	50.0	2367.0	2441.0	2901.0	3575.9	4002.4	5473.4	4643.9	3011.0	1782.0	1030.0	1188.0	1502.5
	60.0	1657.2	2170.6	2263.8	3054.0	3668.9	4581.9	3375.9	2876.0	1615.0	1005.0	1142.0	1468.0
	70.0	1570.4	1908.0	1986.8	2866.0	2951.5	4140.9	2622.0	2300.5	1454.5	959.5	1127.0	1433.0
	80.0	1502.4	1669.4	1840.0	2490.0	2239.0	2879.0	2411.0	1965.0	1188.0	915.0	1074.0	1395.0
	90.0	1467.0	1630.2	1751.6	1846.0	2031.0	2167.0	2087.0	1800.5	1052.5	837.5	1038.0	1369.0
FP1_ESA	10.0	3863.1	5123.5	11408.6	12747.4	14740.8	11201.8	9758.4	8001.4	5850.4	2897.0	1740.0	1825.0
	20.0	1924.6	3424.2	5865.9	6967.9	7924.9	9594.9	8092.9	6798.9	4913.9	2684.0	1682.0	1689.0
	30.0	1865.4	2818.4	4419.1	5918.4	6507.4	8598.4	7588.9	6219.4	3822.9	2294.5	1609.0	1649.0
	40.0	1834.6	2474.4	3585.3	4520.9	6290.9	7545.9	6356.9	5127.9	3512.9	2168.0	1549.0	1637.0
	50.0	1806.0	2355.0	3115.0	3786.4	4856.4	5589.4	5591.9	5019.4	3219.5	2034.0	1534.0	1597.5
	60.0	1772.4	2097.0	2717.6	3464.9	4496.9	4823.9	5040.9	4733.9	2930.0	2009.0	1480.0	1563.0
	70.0	1713.0	2090.4	2548.0	3390.9	3928.4	4523.9	4133.9	4083.9	2700.0	1729.0	1287.0	1457.0
	80.0	1373.6	1995.6	2283.8	2806.0	3435.9	4157.9	3343.9	2914.0	1866.0	1296.0	957.0	1119.0
	90.0	1075.0	1406.6	1836.4	2778.0	3060.0	3591.4	2483.5	2313.0	1517.0	907.0	566.0	949.0

Rogers Creek Bar

Table 24. Monthly flow exceedance values (cfs) for each simulated scenario at Rogers Creek.

Klamath River, Rogers Creek

Percent Exceedence Q (cfs), Period of Record 1974-97

Modeled with SIAM, cp170 (location in SIAM corresponding to Rogers Creek)

Alternative	%	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
NO_PROJECT	10.0	3174.6	8914.3	19220.6	22047.8	22946.4	17020.7	15911.8	13344.3	9838.3	4397.0	2825.1	2714.3
	20.0	3066.4	5623.0	12080.9	12940.5	13692.3	15094.9	12893.6	11607.7	7245.1	3989.1	2594.5	2525.5
	30.0	2545.6	5024.4	7381.3	11203.5	11995.1	14444.9	11428.9	9904.6	6450.8	3385.3	2218.6	2354.1
	40.0	2352.6	3526.9	6207.9	9856.6	10155.7	12022.0	10247.4	7567.3	5010.1	2831.3	2073.3	2154.9
	50.0	2160.3	2669.4	4283.2	5857.1	7627.2	9747.6	8726.3	7055.8	4524.7	2573.2	1789.1	1891.7
	60.0	2057.9	2393.5	3913.2	5561.0	6832.7	7094.1	6570.8	6503.1	4144.5	2465.3	1682.6	1726.4
	70.0	1902.2	2311.5	3520.1	5085.9	5813.5	6352.0	5249.7	4682.5	3471.2	2052.9	1508.4	1665.0
	80.0	1708.6	2248.2	2827.1	4650.6	4687.4	5229.6	4772.8	3777.5	2874.9	1968.8	1431.4	1423.7
	90.0	1469.2	2156.4	2736.3	3229.7	3913.4	4042.0	3730.6	3444.8	2213.8	1494.1	1165.0	1209.1
USGS_PROJECT	10.0	3556.5	9273.9	19206.1	22030.2	23775.2	17480.3	15144.8	11769.9	7777.4	2766.0	1765.5	2167.0
	20.0	2930.2	5971.5	12521.8	12871.8	12633.8	15306.8	11932.8	10221.9	5305.9	2264.0	1721.0	1943.0
	30.0	2328.4	4472.5	7893.9	11192.4	11398.8	14839.3	10780.4	8957.4	4198.4	1893.0	1633.5	1889.0
	40.0	2094.6	3826.1	5319.3	9255.9	9760.9	12421.8	10154.9	6129.9	3184.0	1682.0	1525.0	1847.0
	50.0	1980.0	2977.0	4871.9	5839.4	6979.9	8851.4	7080.4	5434.4	2824.5	1445.5	1468.5	1750.5
	60.0	1864.8	2238.2	3409.3	4792.9	5552.9	6910.9	5084.9	4701.9	2673.0	1325.0	1347.0	1645.0
	70.0	1749.4	2023.2	2834.0	4410.4	4955.9	5537.9	4082.4	3292.0	1995.5	1257.5	1271.5	1465.5
	80.0	1375.0	1899.4	2596.0	3888.9	3921.9	4130.9	3978.9	2547.0	1576.0	1148.0	1117.0	1283.0
	90.0	1219.0	1722.0	2395.0	2519.0	2732.5	2852.0	2483.5	2262.0	1393.0	938.0	866.0	1032.0
FERC_ESA	10.0	5904.7	8975.1	19896.5	22335.7	24264.7	17137.3	14918.3	11502.9	7580.4	2474.0	1714.5	2043.5
	20.0	4728.1	5840.7	12131.6	12808.8	13429.8	15742.8	12120.8	9602.9	5025.9	2243.0	1691.0	1823.0
	30.0	3910.9	4549.5	6759.3	10854.9	11344.8	14644.3	10687.9	8130.4	3909.9	1791.5	1596.0	1812.0
	40.0	3184.2	3850.1	5733.9	9631.9	9430.9	12722.8	10016.9	5556.9	3137.0	1661.0	1502.0	1765.0
	50.0	2570.0	3002.0	4196.9	5413.9	6974.4	8838.9	6939.9	4708.4	2678.5	1438.0	1435.5	1695.0
	60.0	1933.6	2456.4	3255.5	5049.9	5728.9	6916.9	5095.9	4556.9	2440.0	1362.0	1342.0	1623.0
	70.0	1733.6	2200.0	3042.8	4392.9	5041.4	6011.9	4259.4	3339.9	1998.5	1314.0	1290.5	1546.0
	80.0	1642.8	2116.2	2472.8	4015.9	4296.9	4500.9	3851.9	2619.0	1551.0	1106.0	1207.0	1523.0
	90.0	1561.8	1950.2	2140.4	2694.5	3292.0	3570.9	2914.5	2396.5	1391.5	1053.5	1165.5	1460.0
FP1_ESA	10.0	4218.9	9043.1	19896.5	21425.2	24264.7	16955.8	14918.3	11829.8	8163.9	3477.9	2060.0	2138.5
	20.0	2588.6	5929.7	10902.9	12085.8	12524.8	14781.8	12120.8	10137.9	6474.9	3247.0	2037.0	1918.0
	30.0	2190.0	4470.9	6759.3	10541.9	11344.8	13699.3	10696.4	8589.4	4957.9	2795.5	1942.0	1907.0
	40.0	2089.4	3534.4	5827.9	9626.9	9430.9	12566.8	9206.9	7174.9	4553.9	2665.0	1848.0	1860.0
	50.0	2018.0	2571.0	4196.9	5551.9	7865.4	8937.4	8204.9	6628.4	4040.9	2428.0	1782.0	1789.0
	60.0	1949.0	2376.6	3747.3	5342.9	6613.9	7384.9	6937.9	6293.9	3922.9	2306.0	1688.0	1718.0
	70.0	1787.0	2330.2	3081.8	4904.9	5920.9	6340.4	5515.9	5163.4	3343.4	2029.5	1473.5	1565.0
	80.0	1587.8	2154.6	2932.0	4638.9	4959.9	5702.9	4638.9	3685.9	2404.0	1561.0	1032.0	1276.0
	90.0	1232.8	1900.8	2656.4	3321.4	4529.9	4631.4	3503.4	3022.0	1823.5	1100.5	757.0	1066.5

Orleans

Table 25. Monthly flow exceedance values (cfs) for each simulated scenario at Orleans.

Klamath River, Orleans

Percent Exceedence Q (cfs), Period of Record 1974-97

Modeled with SIAM, cp190 (location in SIAM corresponding to Orleans)

Alternative	%	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
NO_PROJECT	10.0	4076.5	14569.1	31485.8	34459.8	34963.0	26537.5	23238.9	20800.5	15147.0	5862.6	3373.4	3228.0
	20.0	3975.5	8561.1	19554.1	19747.1	22862.6	22939.2	19451.5	18165.0	11273.5	5140.5	3156.3	2908.7
	30.0	3034.9	7939.0	10559.6	17341.1	17594.4	21607.0	17751.3	15931.4	8986.6	4495.8	2778.4	2756.8
	40.0	2771.1	4740.3	9650.7	15348.9	14982.0	17915.2	15132.9	11185.0	7328.0	3590.9	2647.4	2422.7
	50.0	2647.2	3209.4	6218.8	8981.3	11790.8	13983.5	12348.3	10031.5	6406.8	3199.1	2109.1	2206.4
	60.0	2482.3	2962.0	5467.2	8403.4	9981.1	10986.9	9991.8	9623.9	6026.4	3057.9	1982.7	2084.5
	70.0	2234.3	2839.5	4803.1	7407.6	8350.7	9236.3	8238.5	6961.7	4776.9	2611.3	1806.6	1838.4
	80.0	1885.1	2728.5	3676.9	6580.4	7397.9	7878.0	7219.1	5575.4	3591.6	2400.9	1725.6	1652.0
	90.0	1662.0	2546.9	3259.3	4358.5	5565.0	6046.9	5374.3	4906.4	2959.6	1868.5	1377.3	1402.8
USGS_PROJECT	10.0	4292.1	14927.0	31468.8	34188.5	35788.5	26601.6	22470.2	19228.3	13084.8	4128.4	2352.5	2694.5
	20.0	3767.5	9033.1	19992.9	19639.7	20870.7	22940.7	18270.8	16127.8	9333.9	3595.9	2306.0	2333.0
	30.0	2726.6	7208.9	11044.8	17399.3	17077.8	21908.7	17076.3	14835.8	6962.9	2939.5	2172.5	2284.5
	40.0	2519.8	4971.5	8853.5	14635.8	14585.8	18313.8	14873.8	10051.9	5500.9	2583.0	2006.0	2160.0
	50.0	2451.0	3766.9	6256.9	8611.4	11085.4	13424.3	10992.3	8521.4	4508.9	2174.0	1847.5	2095.0
	60.0	2185.6	2750.8	5036.5	7893.9	8687.9	10861.8	8504.9	7905.9	4367.9	1917.0	1635.0	1944.0
	70.0	2053.4	2551.2	4413.7	6844.9	7636.9	8386.4	7072.4	5626.4	3300.9	1801.5	1577.0	1736.0
	80.0	1604.4	2418.4	3502.9	5732.9	6254.9	6782.9	6423.9	4330.9	2537.0	1525.0	1285.0	1507.0
	90.0	1452.6	2271.0	2895.2	3634.9	4383.9	4855.9	4126.9	3736.4	2101.5	1240.5	1062.0	1247.5
FERC_ESA	10.0	6609.3	14628.2	32158.5	34494.0	36278.5	26574.6	22243.2	18941.3	12888.3	4084.9	2317.5	2664.5
	20.0	5565.5	8789.7	19603.3	19406.7	22597.7	23893.7	18438.8	15789.8	9053.9	3323.0	2254.0	2233.0
	30.0	4250.5	7438.5	9908.7	17007.3	16569.3	21429.7	17094.8	14156.3	6670.9	2791.0	2135.0	2176.5
	40.0	3729.3	5139.9	9247.9	14424.8	14256.8	18614.8	14752.8	9584.9	5445.9	2562.0	1983.0	2118.0
	50.0	3351.9	3346.9	5538.9	8426.4	11136.8	13546.8	10870.3	7826.9	4535.9	2166.5	1818.5	2026.0
	60.0	2430.6	3104.2	5111.9	7892.9	9016.9	10867.8	8410.9	7553.9	3988.9	1923.0	1630.0	1957.0
	70.0	2079.8	2798.4	4404.3	6827.9	7669.9	8807.4	7304.9	5637.4	3290.9	1860.0	1598.5	1779.5
	80.0	1881.0	2576.0	3287.8	5823.9	7006.9	7152.9	6288.9	4388.9	2512.0	1519.0	1437.0	1694.0
	90.0	1770.8	2416.6	2793.8	3822.9	4943.4	5574.9	4557.9	3856.9	2101.0	1392.0	1338.5	1619.0
FP1_ESA	10.0	4916.7	14696.2	32158.5	34118.5	36278.5	25989.6	22243.2	19268.8	13471.8	5088.9	2663.5	2759.5
	20.0	3664.1	8867.3	18374.6	19071.7	21692.7	22864.7	18438.8	16185.8	10501.9	4326.9	2600.0	2328.0
	30.0	2795.2	7354.1	9920.1	16619.3	16543.8	20347.2	17094.8	14574.8	7612.9	3794.4	2481.0	2271.5
	40.0	2483.6	4747.5	9424.3	14424.8	14256.8	18614.8	14091.8	10634.9	6984.9	3565.9	2329.0	2213.0
	50.0	2347.0	2953.0	5646.9	8609.4	12028.3	13645.3	12230.8	9866.9	5870.4	3082.0	2164.5	2120.0
	60.0	2273.6	2846.0	5330.1	7899.9	9743.9	11335.8	10357.9	9289.9	5481.9	2912.0	1974.0	1998.0
	70.0	2188.4	2771.4	4512.3	7271.9	8583.4	9355.9	8116.4	7497.4	4648.9	2489.5	1704.5	1734.0
	80.0	1711.6	2631.2	3821.3	6773.9	7577.9	7658.9	7140.9	5482.9	3604.9	2027.0	1227.0	1523.0
	90.0	1460.4	2545.2	3225.6	4417.9	6227.4	6359.9	5021.4	4495.9	2501.5	1411.0	963.5	1260.5

Saints Rest Bar

Table 26. Monthly flow exceedance values (cfs) for each simulated scenario at Saints Rest Bar.

Klamath River, Saints Rest Bar

Percent Exceedence Q (cfs), Period of Record 1974-97

Modeled with SIAM, cp40 (location in SIAM corresponding to Saints Rest Bar)

Alternative	%	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
NO_PROJECT	10.0	5108.2	20726.1	42762.3	42811.9	43202.5	32482.7	30103.6	24672.3	17448.3	6227.3	3565.4	3794.9
	20.0	4792.8	12912.9	29239.5	26269.5	28910.6	29340.3	25597.7	20516.8	12304.9	5720.1	3396.1	3216.0
	30.0	3734.3	10512.4	14838.4	21260.7	21804.7	27255.8	20833.7	17955.7	10720.9	5131.1	3111.0	3029.0
	40.0	3325.0	6791.3	12690.0	18301.0	20362.3	24041.5	18216.8	13649.8	8357.9	4230.5	2747.9	2740.0
	50.0	2940.8	4360.9	8722.8	13250.1	15770.6	17544.4	15957.3	11769.9	7508.3	3553.4	2437.6	2486.5
	60.0	2873.7	3751.9	7686.7	11249.4	12929.5	14819.1	11300.8	10554.9	6971.8	3400.8	2259.6	2355.0
	70.0	2664.9	3304.8	6007.3	9820.5	11381.3	12591.7	10898.8	8316.4	5532.9	3115.9	2138.7	2148.5
	80.0	2393.2	3162.6	4876.7	8556.1	10270.1	10509.2	9491.9	6992.4	4199.0	2774.8	1913.6	1816.0
	90.0	1933.7	3000.2	3812.9	5824.2	7635.7	7677.0	6493.8	5878.8	3381.0	2079.8	1501.9	1613.0
USGS_PROJECT	10.0	7166.9	32293.1	68093.7	66724.1	68813.1	51983.3	46829.4	31619.5	21510.7	6805.9	4037.4	4397.9
	20.0	5797.3	18914.2	42992.4	46069.4	42444.4	50310.3	33889.6	26697.6	14594.8	6102.9	3414.9	3567.9
	30.0	4642.9	14217.8	23322.1	33423.1	33708.5	43167.9	30609.6	24252.7	12349.3	5122.4	3327.9	3442.9
	40.0	4184.3	9481.5	17456.0	26272.6	29898.6	35064.5	24862.7	16784.8	10131.9	4807.9	3231.0	3277.0
	50.0	3616.9	5373.9	13105.8	20606.3	24206.2	27590.6	20917.7	14528.3	7844.4	3871.4	3023.5	3141.0
	60.0	3511.9	4895.1	10594.8	16000.8	19216.7	22916.7	15821.8	11531.8	7097.9	3478.9	2752.0	2830.0
	70.0	3290.0	4747.7	8445.3	14338.8	16495.8	18653.3	14236.3	10001.4	6089.9	3160.0	2628.0	2671.0
	80.0	2910.0	3838.5	6144.5	11958.8	14909.8	13809.8	12734.8	8659.9	5097.9	2878.0	2189.0	2377.0
	90.0	2277.6	3622.7	4866.5	6978.9	10233.9	10641.4	8197.9	7446.4	4143.9	2287.0	1672.0	1925.0
FERC_ESA	10.0	7464.3	20787.3	43440.4	43102.0	44088.9	33144.0	29110.6	22582.7	15191.3	4404.4	2751.5	3198.4
	20.0	6340.7	12180.8	29291.8	25271.7	28649.6	29627.6	24388.7	18779.8	10085.9	3967.9	2399.0	2663.0
	30.0	4821.3	10874.8	14140.0	20898.2	20769.7	26778.1	20021.7	16182.8	8833.9	3343.9	2344.0	2397.0
	40.0	4389.7	7191.1	12274.8	18250.8	19638.7	24743.7	17986.8	11278.8	6862.9	3219.0	2304.0	2331.0
	50.0	3833.9	4288.9	8167.9	12764.8	15118.8	16644.8	14914.8	9672.4	5527.4	2596.5	2162.5	2287.0
	60.0	3281.2	3587.3	7167.3	10744.9	11980.8	14700.8	10743.9	8442.9	4894.9	2397.0	2009.0	2238.0
	70.0	2665.6	3453.9	5681.7	9314.4	10571.9	11794.4	9521.4	7086.9	4148.4	2190.0	1836.0	2133.5
	80.0	2266.2	3095.0	4541.5	7971.9	9712.9	10309.9	8572.9	5775.9	3267.0	1956.0	1729.0	1853.0
	90.0	1964.4	2925.8	3540.3	5288.9	7015.4	7162.4	5677.9	5080.9	2559.0	1636.0	1486.0	1801.0
FP1_ESA	10.0	5722.9	20855.3	43440.4	42191.5	44088.9	32011.0	29110.6	22909.7	15774.8	5408.4	3097.5	3293.4
	20.0	4595.9	12450.4	28063.0	25378.7	27744.6	28561.6	24388.7	19330.7	11534.8	4971.9	2745.0	2758.0
	30.0	3398.9	10287.7	14201.0	20898.2	20769.7	26192.7	20068.7	16641.8	9775.9	4347.9	2690.5	2492.0
	40.0	3135.0	6798.7	12466.6	18073.8	19638.7	24743.7	17177.8	12322.8	7907.9	4222.9	2650.0	2426.0
	50.0	2837.0	3972.9	8344.9	12947.8	16010.3	16859.3	15558.8	11528.3	6953.9	3511.9	2495.5	2381.5
	60.0	2784.0	3728.5	7391.5	11129.8	12737.8	15169.8	11667.8	10498.9	6213.9	3194.0	2251.0	2277.0
	70.0	2387.2	3252.0	5878.9	9745.4	11584.8	12592.8	10866.3	8809.4	5405.4	2992.0	2048.5	2151.5
	80.0	2168.8	3079.8	5030.5	9092.9	10330.9	10193.9	9658.9	6900.9	4321.9	2424.0	1646.0	1745.0
	90.0	1700.0	2877.4	4051.5	5883.9	8298.9	7932.9	6141.4	5313.4	2943.0	1613.0	1036.0	1391.0

<u>Phase I versus Phase II Estimated Flow Comparisons</u>

A comparison of the estimated unimpaired flow exceedences generated from the gage data in Phase I (see Table 3) and the results of the simulated unimpaired flows show somewhat lower monthly values for the Phase II study results. These differences are attributed to revised flow accretions below Upper Klamath Lake proved by the USBR, uncertainty in the depletions for Upper Klamath Lake, and basic analytical differences (i.e., assumptions) between the simulated hydrology and the gage adjustment approach used in Phase I. We consider the current Phase II simulated flows to represent the best available estimates at this time.

Biological Processes

Macroinvertebrate Sampling and Processing

As part of the Phase II investigations, USU conducted simulations using a mechanistic individual based bioenergetics model of drift feeding salmonids. One of the required inputs for the model is an estimation of aquatic macroinvertebrate drift densities. To that end, the available drift at each study site was quantified.

Replicate samples below a riffle at each study site were collected and preserved for processing back at USU. Samples were processed using the standardized processing protocol developed by the Utah State University Macroinvertebrate Laboratory (Vinson and Hawkins 1996). Samples were only processed to obtain an estimate of total drift density broken down into five size classes for use in the bioenergetics modeling as described later in the report. Original and processed samples were preserved and archived at USU for potential future research needs. Table 27 shows the dates, number of replicate samples, and average total density of macroinvertebrates by size classes for each study site.

Table 27. Dates, number of replicate samples, and average total density of macroinvertebrates by size classes for each study site.

			Average Number of Invertebrates per Cubic Meter						
Date	**Site**	**Num. Of Samples**	**0-2mm**	**2-4mm**	**4-6mm**	**6-8mm**	**8-10mm**	**10mm**	**Total**
3/30/1999	R-Ranch	9	0.0000	23.6832	13.8430	4.4493	1.7675	0.0000	43.7428
8/2/1999	R-Ranch	3	99.8407	53.1837	4.4629	3.1067	2.5138	6.6930	169.7987
8/31/1999	R-Ranch	5	30.0666	183.7620	92.6930	3.8122	2.2555	2.7100	315.2960
3/26/1999	Tree of Heaven	9	2.2607	8.7121	15.4433	3.1416	5.6175	4.5754	39.7507
9/8/1999	Tree of Heaven	3	101.2060	194.1133	145.6040	17.1299	10.2323	41.7580	510.0433
9/9/1999	Tree of Heaven	12	79.5008	104.1994	75.0246	5.6308	3.9112	18.1978	286.4650
9/8/1999	Brown Bear	7	1.6898	8.0963	14.6277	5.6278	2.3112	45.3496	77.7020
3/24/1999	Brown Bear	9	0.0000	5.6115	7.9126	0.8880	0.3997	0.5763	15.3881
3/20/1999	Seiad	9	1.5909	7.3110	13.0362	6.0245	3.8161	3.9129	35.6913
8/3/1999	Seiad	9	62.6749	95.0092	13.6985	0.2501	1.5229	3.6410	176.7980
11/10/1999	Seiad	5	7.5038	11.3881	3.4341	1.0045	1.3102	10.6903	35.3310
8/24/1999	Rodgers Cr.	9	29.1212	28.5764	8.0316	0.0000	1.2585	14.0468	81.0343
4/2/1999	Orleans	8	0.0000	0.9224	0.3633	0.9145	1.8423	0.4612	4.5036
4/8/1999	Weitchpec	9	0.0000	2.5917	7.3496	2.2720	0.8549	1.3480	14.4161
8/23/1999	Weitchpec	9	17.7186	67.1503	8.5710	1.5666	0.2873	2.8830	98.1776
4/8/1999	Youngs Bar	9	0.0000	4.3814	1.2158	0.5395	2.0109	0.5395	8.6871
8/11/1999	Youngs Bar	6	32.9266	29.7342	11.4083	5.3099	6.2253	0.0000	85.6047

Fish Habitat Utilization

Fish habitat utilization data were collected to meet two critical study objectives. The first objective was to provide data suitable for development and testing of habitat suitability criteria (HSC) and the second objective was to provide data sets for validation of the habitat modeling results.

Fisheries collection data at intensive study sites involved a number of sampling protocols depending on the life stage and specific objective(s). Redd survey data were obtained from either the USFWS or Tribal collaborators. Data for other life stages were provided by CDFG, USFWS, and Tribal sources. The number of samples taken and number of sampling efforts over time varied between study sites.

Life stages of fry and juveniles were sampled through a combination of gear types including direct observations, seining, and electrofishing. Each sampling location (or redd count) was located either using GPS or standard surveying equipment. When standard surveying was undertaken, the survey was tied to the control network at the study site. Available collection data were registered to the orthophotographs in GIS for Habitat Modeling and HSC validation as discussed later in the report.

Data collected specifically for use in the development of HSC also included collection of physical attributes such as depth, velocity, substrate, cover, and distance to cover. This work was undertaken as part of ongoing study efforts by the USGS/USFWS, HSC development work contracted by the CDFG, with assistance from Tribal Fisheries Program personnel, specifically targeted collection of fish location data to validate the habitat modeling results at USU study sites.

Fish observation data for each study site are reported below in the section on habitat modeling validation.

Selection of Target Species and Life Stages for Phase II Evaluations

Due to the limitations of availability of site-specific or literature based HSC for all native species and life stages within the main stem Klamath River only specific species and life stages were included for quantitative analyses in Phase II. The specific species and life stages included in the Phase II analyses are listed in Table 28.

Table 28. Species and life stages used in quantitative assessments of instream flow requirements for the main stem Klamath River.

Species	**Life Stages**
Steelhead	Fry and 1+
Chinook	Spawning, Fry, and Juvenile
Coho	Fry and Juvenile

This list of species and life stages were derived from extensive discussions with the Technical Team. The selection of these species and life stages were made after reviewing simulation results using both site-specific and literature based HSC developed for the study. In addition, although some species and life stages were considered for inclusion based on available HSC in the literature (e.g., sturgeon), these curves were not considered appropriate for application to the Klamath River and therefore were not included in the analyses.

Given quantification of these species and life stages, and consideration of other species and life stage life history needs, and professional judgment it is assumed that flow protection for non-modeled species and life stages (e.g., sturgeon and non-salmonid species) will be met. This assumption has frequently been employed under similar circumstances in applied instream flow assessments where specific species and life stages are used to represent ‘indicator species’ or ‘guilds’ for multi-species aquatic communities (see Hardy 2000).

Species and Life Stage Periodicities

Hardy (1999) provided an interim species and life stage periodicity for the anadromous species within the main stem Klamath River. The Technical Team reviewed existing fisheries collection data from the Klamath River and additional literature on known or suspected species distributions and life stage periodicities. This review included consideration of potential longitudinal and seasonal variation within the main stem Klamath River between Iron Gate Dam and the estuary. The revised species periodicity by reach segment was derived from this compiled information and input from the Technical Team. It is recognized that potential refinement of this information will continue as part of the long-term instream flow study being conducted by the USFWS and other collaborators. The species and life stage periodicity used in the assessment of instream flows is provided in Table 29.

Habitat Suitability Criteria

The physical habitat modeling component of the Phase II assessments require that relationships between hydraulic properties and biological responses of target species and life stages be quantified. The common approach to defining these relationships is the development of Habitat Suitability Criteria (HSC). HSC represent how suitable a particular gradient of depth, velocity, substrate, cover, etc is to a target species and life stage. HSC typically represent the suitability of a particular factor (i.e., depth) on a scale between 0.0 and 1.0. A suitability value of 0.0 represents a condition (i.e., depth) that is wholly not suitable, while a 1.0 indicates a condition that is ‘ideally’ suitable.

Table 29. Species and life stage periodicities for the main stem Klamath River between Iron Gate Dam and the estuary (hatching indicates occasional usage for that month).

Iron Gate to Shasta	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Chinook Fry				■	■	■	■	■	▨			
Chinook Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Chinook Spawning/Inc.	■	■	■	■	■	■	▨					
Coho Fry					▨	■	■	■	■			
Coho Juv	■	■	■	■	■	■	■	■	■	■	■	■
Steelhead Fry							■	■	■	■	▨	▨
Steelhead Spring Juv						■	■	■				
Steelhead Summer Juv									■	■	■	■
Steelhead Generic Juv	■	■	■	■	■							

Shasta to Scott	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Chinook Fry				■	■	■	■	■	■			
Chinook Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Chinook Spawning/Inc.	■	■	■	■	■	■	▨					
Coho Fry					▨	■	■	■	■			
Coho Juv	■	■	■	■	■	■	■	■	■	■	■	■
Steelhead Fry							■	■	■	■	▨	▨
Steelhead Spring Juv						■	■	■				
Steelhead Summer Juv									■	■	■	■
Steelhead Generic Juv	■	■	■	■	■							

Scott to Salmon	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Chinook Fry					■	■	■	■	■			
Chinook Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Chinook Spawning/Inc.	■	■	■	■	■	■	▨					
Coho Fry					▨	■	■	■				
Coho Juv	■	■	■	■	■	■	■	■	■	■	■	■
Steelhead Fry							■	■	■	■	▨	▨
Steelhead Spring Juv						■	■	■				
Steelhead Summer Juv									■	■	■	■
Steelhead Generic Juv	■	■	■	■	■							

Salmon to Trinity	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Chinook Fry					■	■	■	■	■			
Chinook Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Chinook Spawning/Inc.	■	■	■	■	■	■	▨					
Coho Fry					▨	■	■	■	▨			
Coho Juv	■	■	■	■	■	■	■	■	■	■	■	■
Steelhead Fry							■	■	■	■	■	▨
Steelhead Spring Juv						■	■	■				
Steelhead Summer Juv									■	■	■	■
Steelhead Generic Juv	■	■	■	■	■							

In general, it is commonly considered most appropriate to develop site-specific HSC data from the river in which the instream flow assessment is undertaken. However, many factors such as under seeding, presence of predators, presence of introduced species, modified habitat, etc., can make development of HSC from the target stream system both infeasible and/or undesirable. Furthermore, poor field conditions (e.g., low water visibility) can also make collection of HSC data infeasible in many river systems on a seasonal basis. When site specific HSC cannot be developed then the next step undertaken is typically to assess the applicability of HSC from another river. This typically requires observational data for target species and life stages in the stream under study in order to attempt a validation or transferability test of the HSC. Existing methods for testing applicability (transferability) of HSC (e.g., Thomas and Bovee 1993) are not generally accepted and are known to produce inconsistent results (Dunbar and Ibbotson 2001). Finally, in the absence of transferable HSC, literature based curves in conjunction with professional judgment by species experts are often utilized to select HSC. This is perhaps the most commonly applied technique for HSC 'development' for instream flow assessments in the U.S. and internationally.

Hardy (2000) provides an extensive discussion of the different types of HSC, different methods for their development, and practical implications of their use in physical habitat modeling. The next section of the report is intended to lay an objective foundation from an ecological perspective for the assessment of the techniques used to develop site-specific HSC, adopt literature based HSC, and ultimately the application of HSC in the Phase II.

The Ecological Basis of Habitat Suitability Criteria (i.e. Niche Theory)

In order to understand the distribution and abundance of a species it is necessary to know several things:

- The life history requirements of the species,
- The resources that it requires (e.g., food, space),
- The effects of environmental conditions (e.g., velocity, temperature),
- The rates of birth, death, and migration, and the
- Interactions with their own and other species (competition and predation).

One of the fundamental concepts that has helped ecologists understand the distribution and abundance of species is the ecological niche (Hutchinson 1957; Schoener 1988). The ecological niche is the set of environmental conditions (e.g., temperature, depth, velocity) and resources (things that are consumed such as food) that are required by a species to exist and persist in a given location. There are many environmental conditions and resources that make up a niche. Typically, each condition and resource is thought of as a dimension of the niche. Along an individual dimension of a niche (e.g., temperature) there is a range of values of the condition or resource that is suitable for the species. There is also a range that is beyond the ability of the organism to exist. The many individual dimensions of the niche interact to create a multidimensional "niche volume" of conditions and resources that provide a suitable environment for a species (e.g., temperature, velocity, depth, food). This environment of suitable conditions and resources has been defined as the fundamental niche of a species.

The fundamental niche of a species must exist in a location both temporally and spatially for a species to occupy that location. Whether or not a species actually occupies a location, however, also depends on whether or not the species has access to the location and whether or not it is precluded from occupying the location by other species because of competition or predation. The portion of a species fundamental niche that a species actually occupies is called its realized niche. The realized niche varies depending on the number, types, and effectiveness of competitors and predators. The realized niche also depends on availability and variability of conditions and resources in the environment.

For riverine fishes, some of the most important niche dimensions are water temperature, hydraulics (interaction of depth and velocity), substrate, cover, and food. Multiple species can coexist in a river by utilizing a combination of niche dimensions differently. If two species utilize the same or nearly the same combination of resources and environmental conditions (niche) at the same time and in the same locations, the potential exists for the more competitive of the two species to exclude the other from the system or from much of its fundamental niche. Likewise, predators can exclude species from occupying much of their fundamental niche through intimidation or predation (Powers 1985; Schlosser 1987; and others).

Species and life stage specific HSC as used in instream flow determinations are an attempt to measure the important niche dimensions of a particular species and life stage (Gore and Nestler 1988). These criteria are then used to identify how the amount of space corresponding to the measured niche changes with river discharge. The assumption then, is that there is a positive relationship between the amount of space that exhibits suitable niche conditions and the potential numbers of the species and life stage in the river (Orth and Maughan 1982; Jowett 1992; Nehring and Anderson 1993; others).

In principle, increasing the range, availability, and abundance (diversity) of the important niche dimensions utilized by riverine fishes can increase the number of potential niches that can coexist in a river and can increase the diversity of fish species and life stages in the river. Several investigators have shown that species and life stage diversity in rivers is directly related to the diversity of important niche dimensions (e.g., Gorman and Karr 1978, Schlosser 1987).

Diversity of environmental conditions and resources results in biotic diversity (Allan 1995), but only if the spatial and temporal diversity is within a range of conditions that the species are pre-adapted to (only if diversity equates to a diversity of suitable niche conditions). For example, highly variable environmental conditions result in a diverse environment, but low species diversity (Horwitz 1978; Bain et al. 1988) because species are not adapted to the rapidly changing conditions. Several investigators have quantified the range of conditions and resources that various riverine fishes inhabit (Lobb and Orth

1991; Aadland 1993; Bain et al. 1988; Bowen et al. 1998), particularly with respect to depth and velocity. They have identified species and life stage guilds that utilize the niche dimensions of depth and velocity in a similar manner. Guilds typically use a set of environmental conditions or resources similarly, but typically differ in the temporal or spatial use of these resources or differ along other niche dimensions (i.e., food utilization) to coexist.

Because stream flow is one of the key factors that controls the temporal and spatial availability of stream hydraulics (interaction of depth and velocity), substrate, cover, food, and to a lesser extent temperature (e.g., Statzner and Higler 1986), stream flow within a given river system controls the abundance and diversity of niche dimensions and the diversity of species that can exist. One method of quantifying the effects of stream flow on riverine biota is to quantify the diversity of habitat types (types inhabited by typical riverine fish guilds) versus flow (e.g., Aadland 1993; Bowen et al. 1998). The diversity of the habitats types, particularly key bottleneck habitats that may affect recruitment of fishes at various times of the year (e.g, spawning or nursery habitat) can be used to identify stream flows that maintain habitats for a diversity of species and life stages (Bain et al. 1988; Scheidegger and Bain 1995; Nehring and Anderson 1993).

A particularly useful complement to this method is to individually quantify habitat for important or key species and life stages. Analysis of individual species and life stages has been used for a long time in instream flow assessments. Unfortunately, many of these past assessments looked only at a few individual species and/or life stages. It is important, however, to analyze individual species and life stages in the context of the entire community and ecology of the river (e.g., Orth 1987).

Given perfect knowledge of a species and life stage's realized niche (seasonally and with respect to discharge) in a river system, it would be possible to quantify how the amount of its realized niche changes with flow. This could be used to generate a flow regime that minimizes habitat bottlenecks for target species and life stages. If this analysis was done in concert with a community wide assessment (see above), the flow regime could be generated that did not create undue bottlenecks for other species and life stages in the system. Perfect knowledge of a species and life stage niche is at a practical level unobtainable however, and as a result, approximations of the realized niche must suffice (i.e., HSC).

HSC generated from fish observations in a river system are typically used to quantify the realized niche in terms of depth, velocity, substrate, and cover (although most investigators do not recognize them as such). However, generation of HSC is fraught with many difficulties. Some of the most serious of these are logistics constraints that affect the size, timing, and quality of the data sample, habitat availability biases that exist at the time of sampling and predation/competition biases that exist at the time of sampling.

HSC development is also complicated due to fish habitat use changes with fish size, season, temperature, activity, habitat availability, presence and abundance of competitors and predators, discharge, and changes between years (Orth 1987; Schrivell 1986; Heggenes 1990; Schrivell 1994; Smith and Li 1983; Bozek and Rahel 1992; Everest and Chapman 1972; Moore and Gregory 1988; Modde and Hardy 1992). These factors underscore the importance of validating the HSC, especially in terms of the habitat modeling results. This is specifically addressed below when reporting on the results of the habitat modeling.

Site Specific HSC

Site-specific HSC were developed for the main stem Klamath River for chinook spawning, chinook fry, and for steelhead 1^+ life stages for spring, summer, and seasonally combined data sets. These HSC are considered interim in light of the continued instream flow assessment work being undertaken as part of the long-term strategic flow study headed up by the USFWS. It is anticipated that these HSC will continued to be refined as additional information becomes available over time. HSC development was undertaken by a collaborative effort of the Technical Team that relied on HSC research funded by the CDFG. The Team reviewed analytical methods used for data reduction, curve fitting techniques, observational data, life history information, and work conducted in other systems. This assessment also included the professional judgment of several Technical Team members with extensive field experience in the Klamath River. The final site-specific interim HSC were provided to USU for use in all the habitat simulations.

Substrate and Vegetation Coding for HSC

Substrate and vegetation coding differed slightly between the 1999 and 2000 field assessments. Differences in the coding arose from participation of different study personnel. These differences were rectified into a common twenty-two category classification as shown in Table 30.

This classification scheme was employed for both the HSC but also used in the coding of ‘channel index’ values in both the 1-dimensional and 2-dimensional hydraulic simulation models as explained below. The classification scheme in Table 30 was also used in the habitat modeling portions of the study as described in that section.

Chinook Spawning

Chinook spawning HSC for depth, velocity and substrate were derived from field data collections within the main stem Klamath River below Iron Gate Dam downstream to the confluence with the Scott River during 1998 and 1999. Tim Hardin and Associates collected these data at approximately 1,200 (mid- to late-October) and 1,800 cfs (early November) as part of California Department of Fish and Game's on-going contributions to the instream flow assessments within the Klamath River. The study team sampled the entire river from below Iron Gate Dam to the Scott River during each sample period. The HSC curves were developed from 290 observations taken from identified redd locations. The final interim HSC values for velocity, depth, and substrate are proved in Figures 44 to 46.

Table 30. Substrate and vegetation coding scheme used for all HSC.

	Year 2000 substrate and vegetation codes			Year 2000 substrate and vegetation codes	
Final Code	Code	Description	Final Code	Code	Description
1	1	Filamentous algae	8	17	Large woody debris (LWD)>4"x12"
2	2	Non emergent rooted aquatic	12	18	Clay
3	3	Emergent rooted aquatic	12	19	S and and/or silt (<0.1")
4	4	Grass	12	20	Coarse sand (0.1-0.2")
4	5	Sedges	13	21	Small gravel (0.2-1")
4	6	Cockle burs	14	22	Medium gravel (1-2")
6	7	Grape vines	15	23	Large gravel (2-3")
6	8	Willows	16	24	Very large gravel (3-4")
6	9	Berry vines	16	25	Small cobble (4-6")
5	10	Trees <4"	17	26	Medium cobble (6-9")
5	11	Trees >4"	18	27	Large cobble (9-12")
10	12	Root wad	19	28	Small boulder (12-24")
11	13	Aggregates of small vegetation dominate <4"	20	29	Medium boulder (24-48")
11	14	Aggregates of large vegetation dominate >4"	21	30	Large boulder (>48")
7	15	Duff, leaf litter, organic debris	22	31	Bedrock-smooth
9	16	Small woody debris (SWD) <4"x12"	22	32	Bedrock-rough

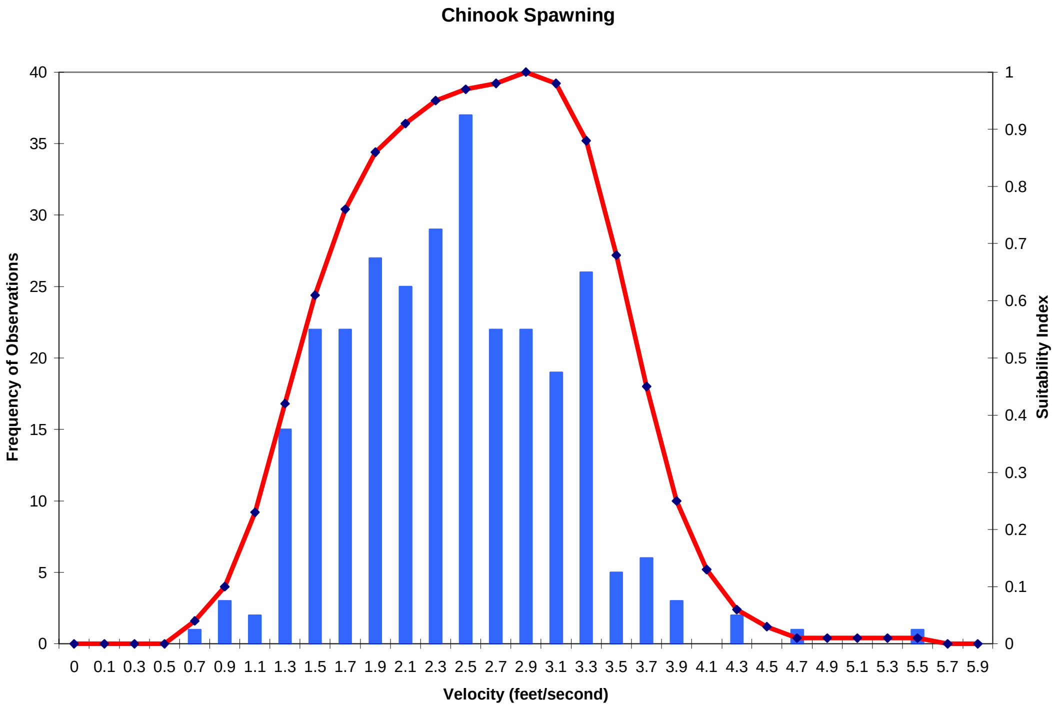


Figure 44. Frequency distribution (bars) and final interim HSC values (red line) for chinook spawning for velocity from the Klamath River.

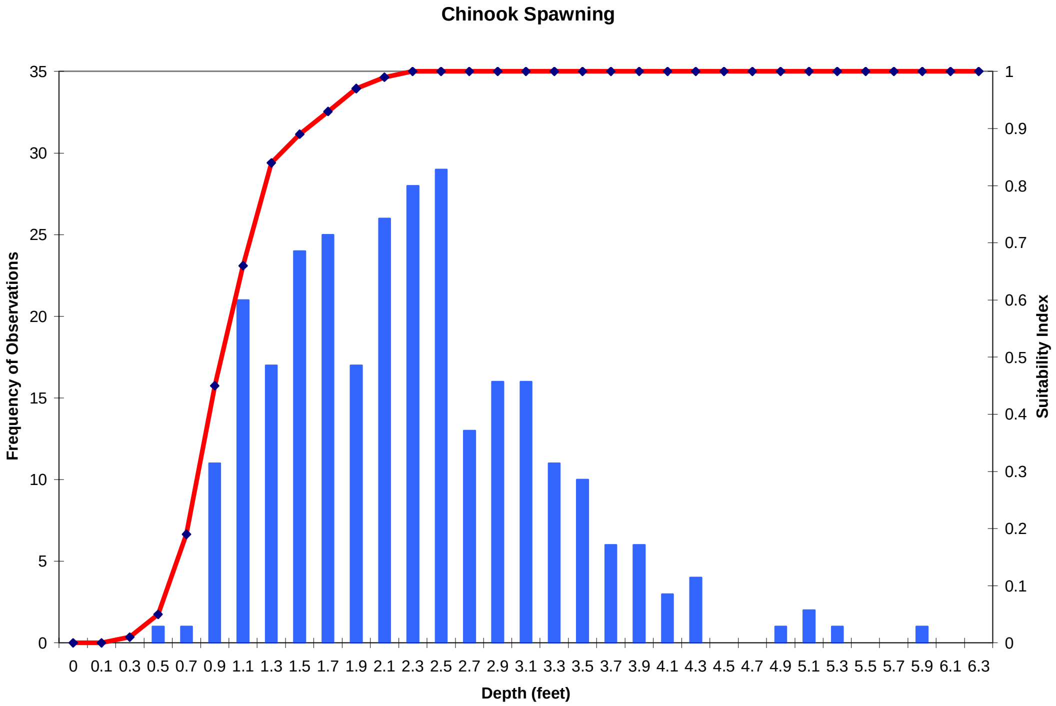


Figure 45. Frequency distribution (bars) and final interim HSC values (red line) for chinook spawning for depth from the Klamath River.

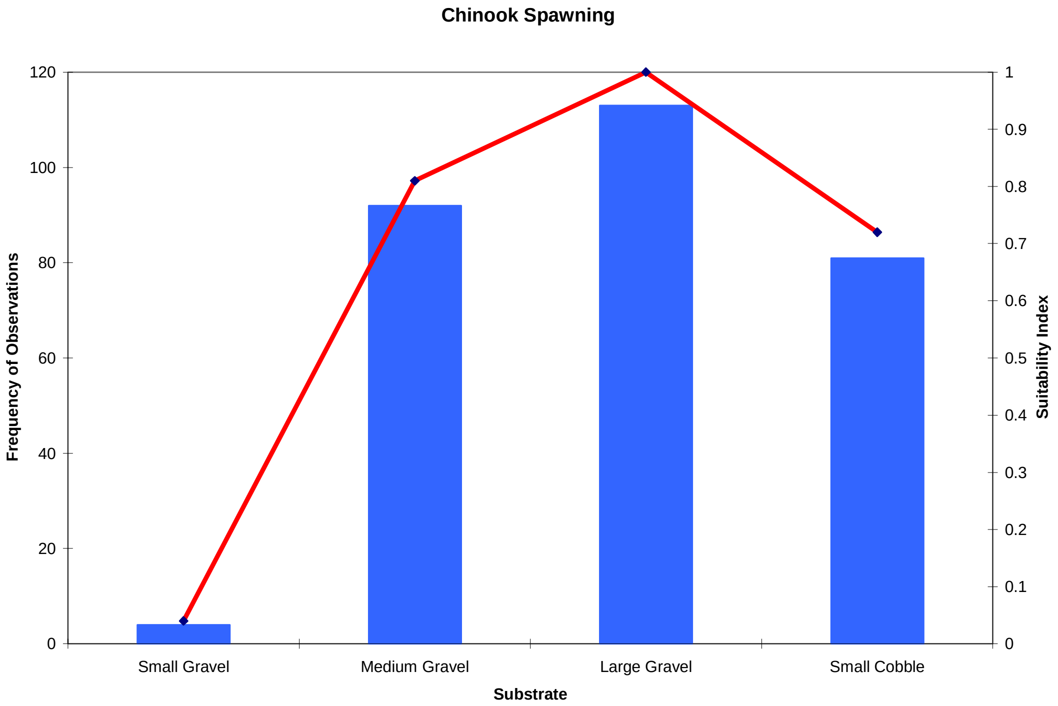


Figure 46. Frequency distribution (bars) and final interim HSC values (red line) for chinook spawning for substrate from the Klamath River.

Chinook Fry

Chinook fry data were collected from the main stem Klamath River below Iron Gate Dam downstream to Seiad during both 1998 and 1999. A total of 2498 observations were made for depth, 2252 for velocity, and 2300 for substrate and cover. HSC were developed for depth, velocity, cover type (i.e., no cover, object cover, instream cover, and combined cover), distance to cover, and relative value of cover type (i.e., substrate versus vegetation). No cover was defined, as conditions were the stream contained no form of escape cover. Object cover was defined as any feature adjacent to the water that proved ‘object’ cover from predators. Instream cover was defined as any feature within the stream (e.g., root snags, large cobble substrates, etc) that produced physical or hydraulic properties that could be used as cover. Combined cover was associated with any physical or hydraulic feature containing both object and instream cover elements.

The frequency distributions of the observed data and final HSC values for velocity, depth, and cover are provided in Figures 47 to 49.

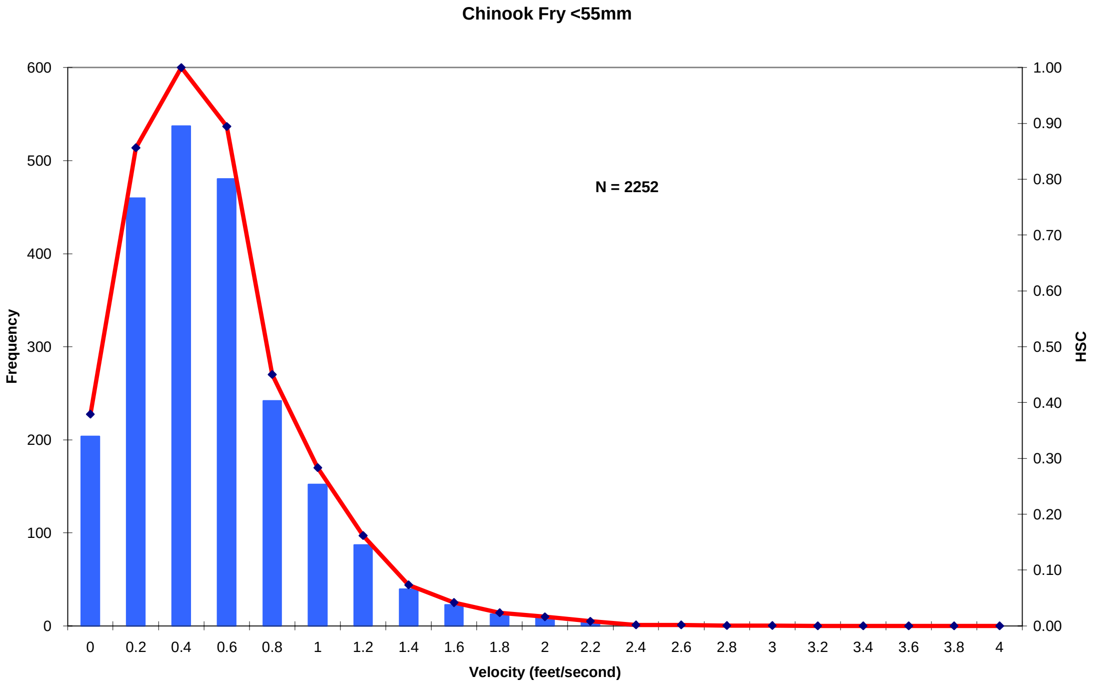


Figure 47. Frequency distribution (bars) and final interim HSC values (red line) for chinook fry for velocity from the Klamath River.

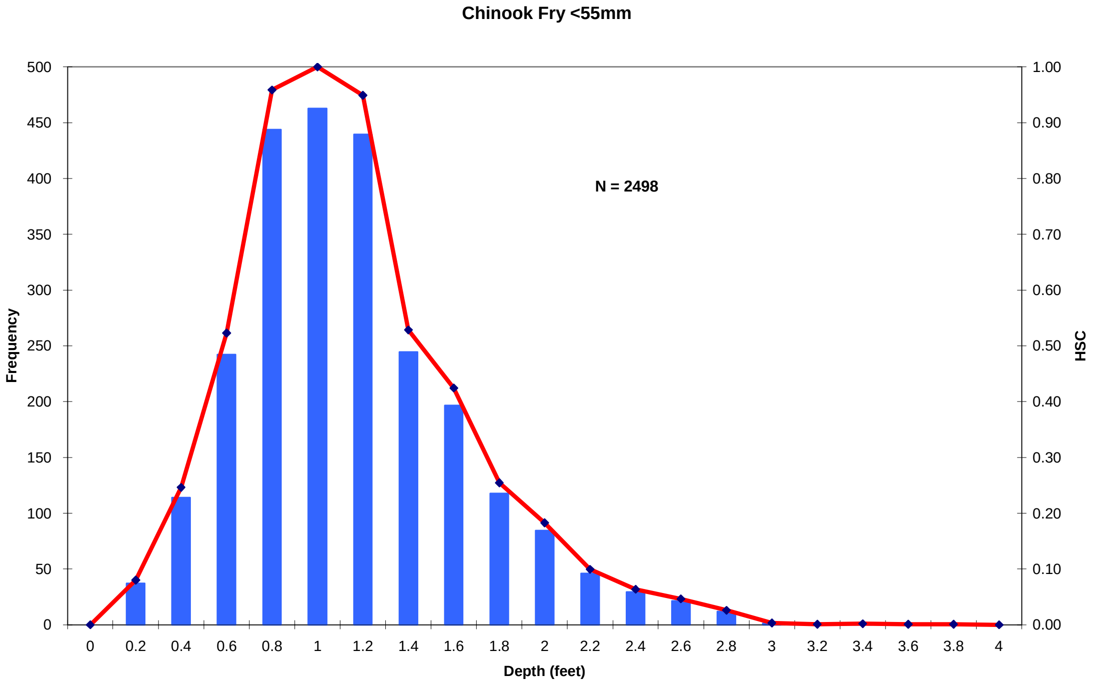


Figure 48. Frequency distribution (bars) and final interim HSC values (red line) for chinook fry for depth from the Klamath River.

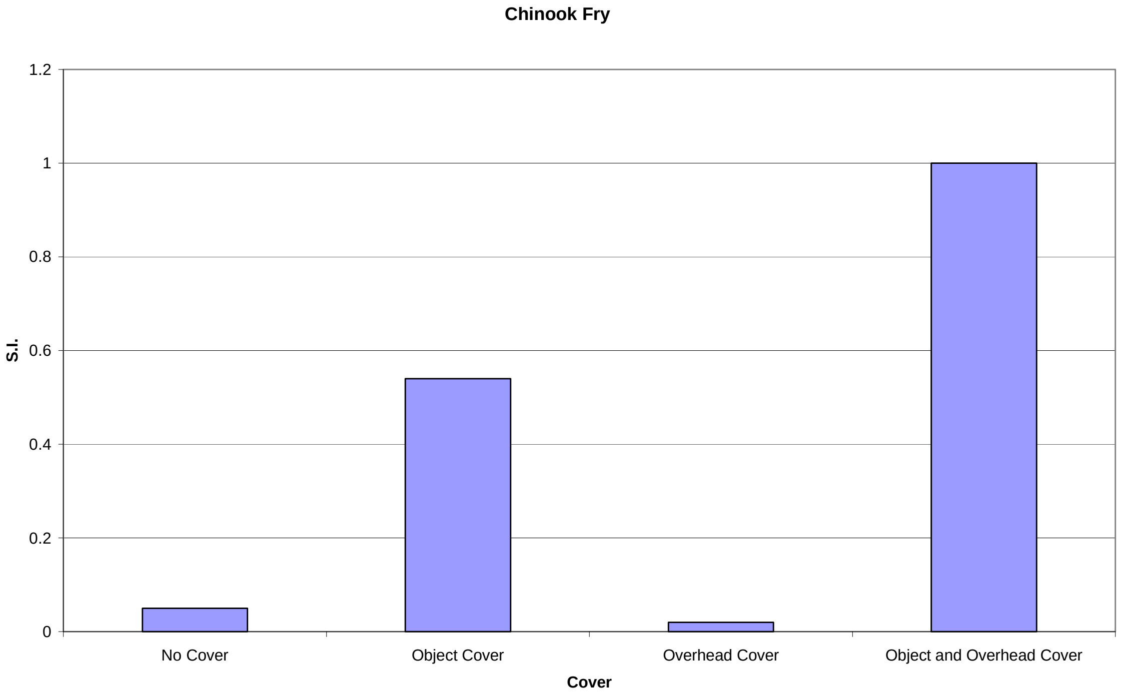


Figure 49. Frequency distribution (bars) and final interim HSC values (bars) for chinook fry for cover types from the Klamath River.

The analysis also included an empirical based field assessment that confirmed habitat use along the stream margins in association with cover versus use of the main river channel. This was accomplished through a combination of sampling techniques including direct under water observations, video, and electrofishing using longitudinal transects both along the stream margin and within the main river channel.

HSC development also included an assessment of dependency of chinook fry habitat use dependent on the distance to escape cover. Figure 48 shows the relationship between chinook fry and distance to escape cover derived from the field observations.

Note that for the distance to cover component of the habitat analysis, a single threshold of ≤ 2.0 feet was used for all habitat simulations as described later. As can be seen in Figure 50, this threshold distance incorporates 90 percent of all fish observational data.

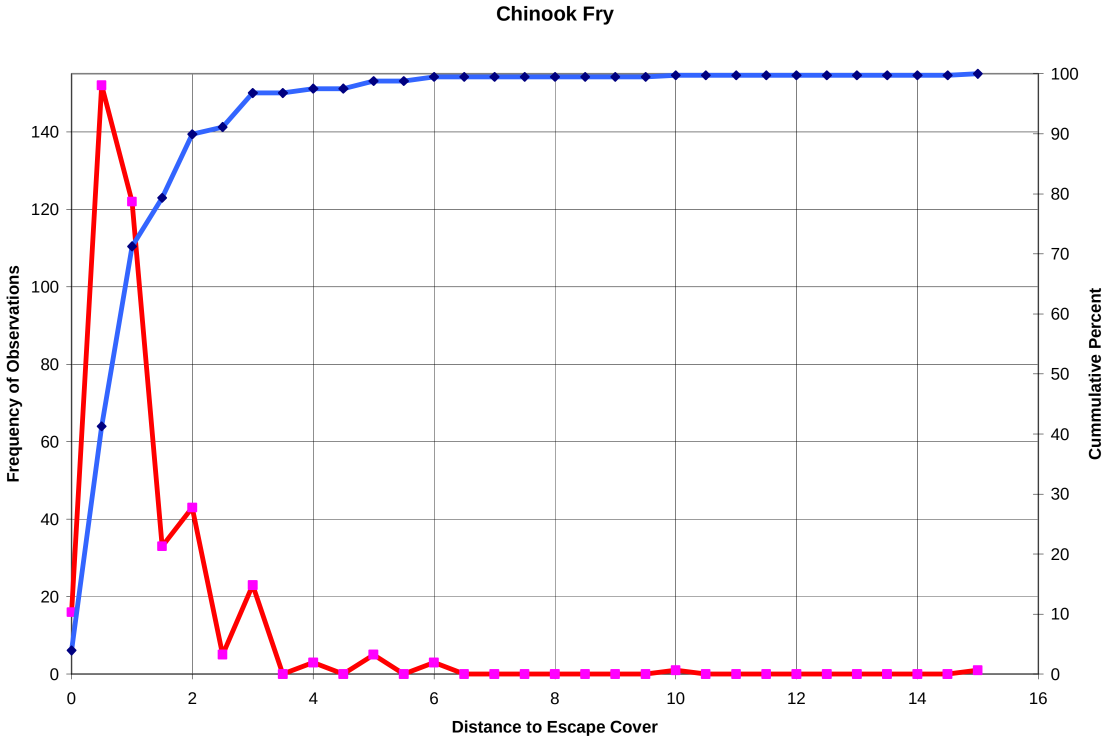


Figure 50. Relationship between frequency of observations (red) and the cumulative percent of observations (blue) and distance to escape cover for chinook fry.

In addition, analyses were conducted on the relationship between in-water escape cover as a function of cover type (i.e., vegetation versus substrate). Based on the observation data, the relative importance of vegetation escape cover was set at 1.0 while substrate escape cover was set at 0.17. This reflects the relatively small proportion of chinook fry found in association with substrate specific cover compared to the overwhelming number of observations associated with vegetation cover types. Table 31 provides the interim HSC in-water escape cover chinook fry.

Table 31. Interim in-water escape cover HSC for chinook fry.

In-Water Escape Cover Component	Interim HSC
Vegetation	1.00
Substrate	0.17

It should be noted that the field data collection for chinook fry were obtained at a relatively high flow rates during the first two field seasons. This had the potential to bias these HSC toward higher flow rate conditions. Chinook fry observations obtained during spring 2001 field sampling by USFWS field personnel at substantially lower flow rates, indicate very little bias if any in these HSC.

Chinook fry depth and velocity utilization and their association with inundated streamside vegetation appears to be consistent with the existing chinook fry HSC developed for the study (Tom Shaw, personnel communication).

Steelhead 1^+

Summertime steelhead 1^+ observations taken between Iron Gate Dam and Young's Bar during July to October 1999 were used to develop site-specific HSC for depth, velocity, substrate/cover, and distance to escape cover. The bulk of these data were collected from the RRanch and Seiad USU study sites. A total of 192 observations were made for depth, 193 for velocity, and 197 for substrate.

Springtime steelhead 1+ observations were made during March to May in 1999 and 2000 in the reach of river between Iron Gate Dam and Seiad Valley. A total of 158 observations were made for depth, 158 for velocity, and 151 for substrate. The HSC were developed specifically for spring, summer, and the seasonally combined data sets. The spring and summer partitioning of the data was undertaken to reflect changes in habitat utilization associated with both growth and responses to different environmental factors (e.g., temperature regimes). The seasonally combined data were utilized for assessing non-spring and summer conditions. The frequency distributions and final HSC values are provided in Figures 51 to 62.

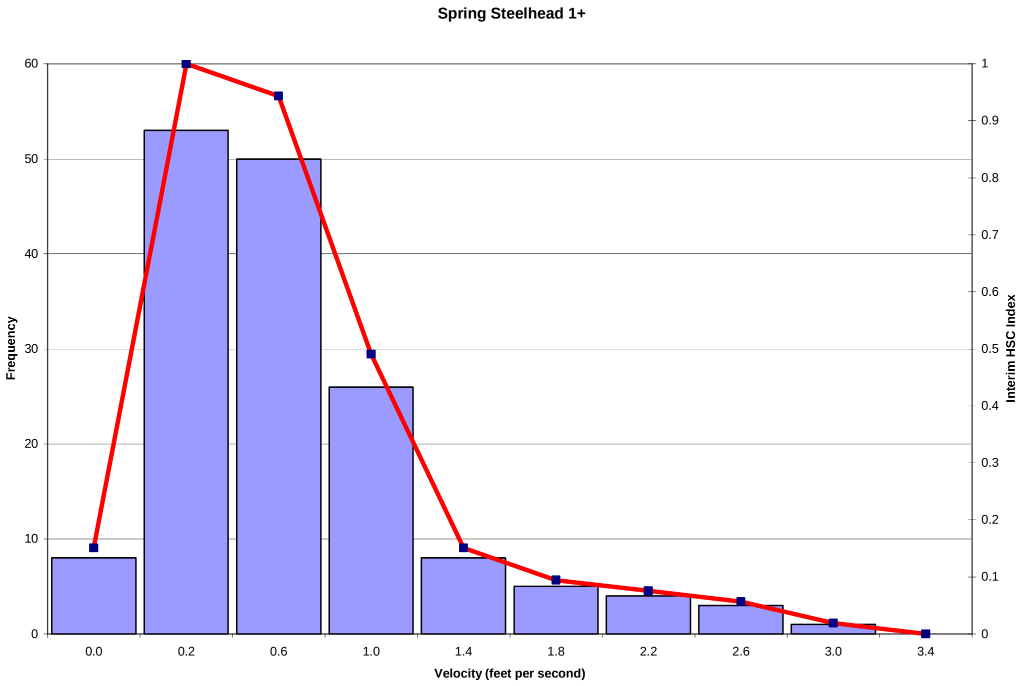


Figure 51. Frequency distribution (bars) and final interim HSC values (red line) for spring time steelhead 1^+ velocity from the Klamath River.

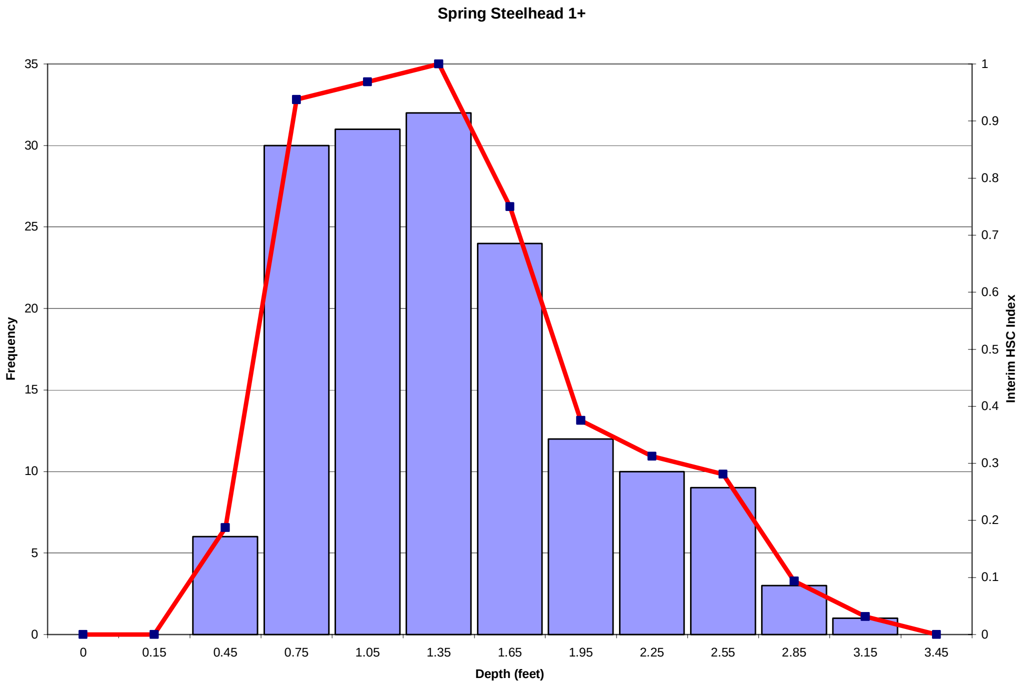


Figure 52. Frequency distribution (bars) and final interim HSC values (red line) for springtime steelhead 1^+ depth from the Klamath River.

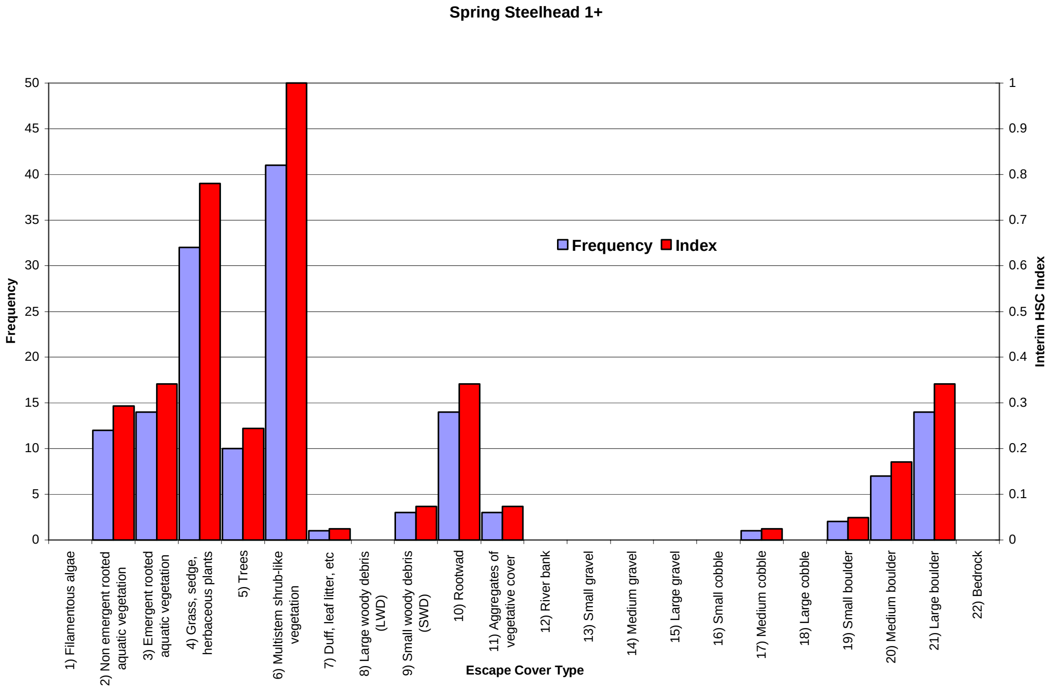


Figure 53. Frequency distribution (blue) and final interim HSC values (red) for springtime steelhead 1^+ escape cover from the Klamath River.

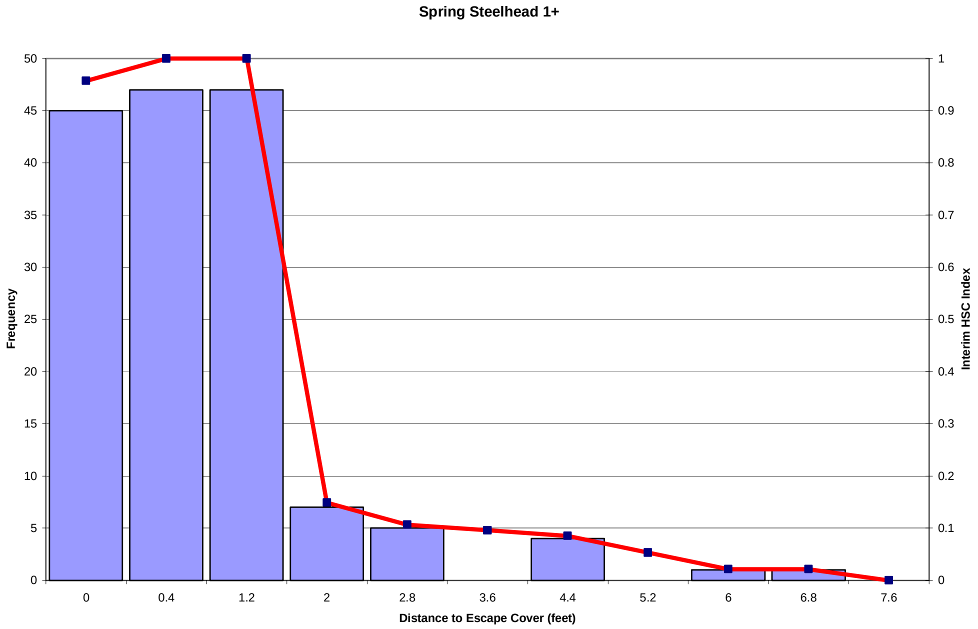


Figure 54. Frequency distribution (bars) and final interim HSC values (red line) for springtime steelhead 1^+ distance to escape cover from the Klamath River.

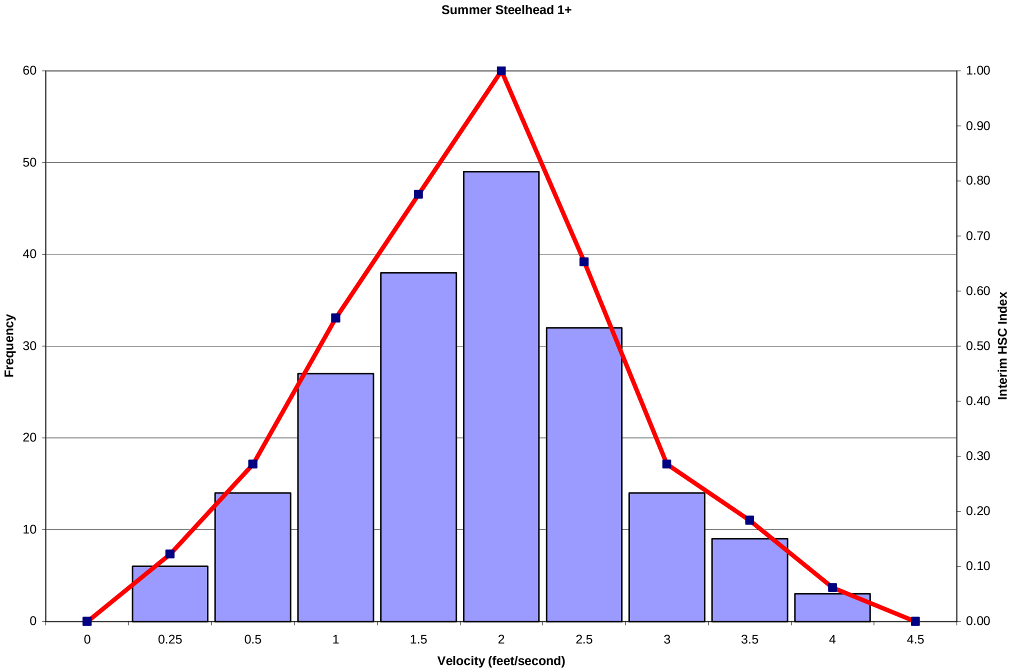


Figure 55. Frequency distribution (bars) and final interim HSC values (red line) for summertime steelhead 1^+ velocity from the Klamath River.

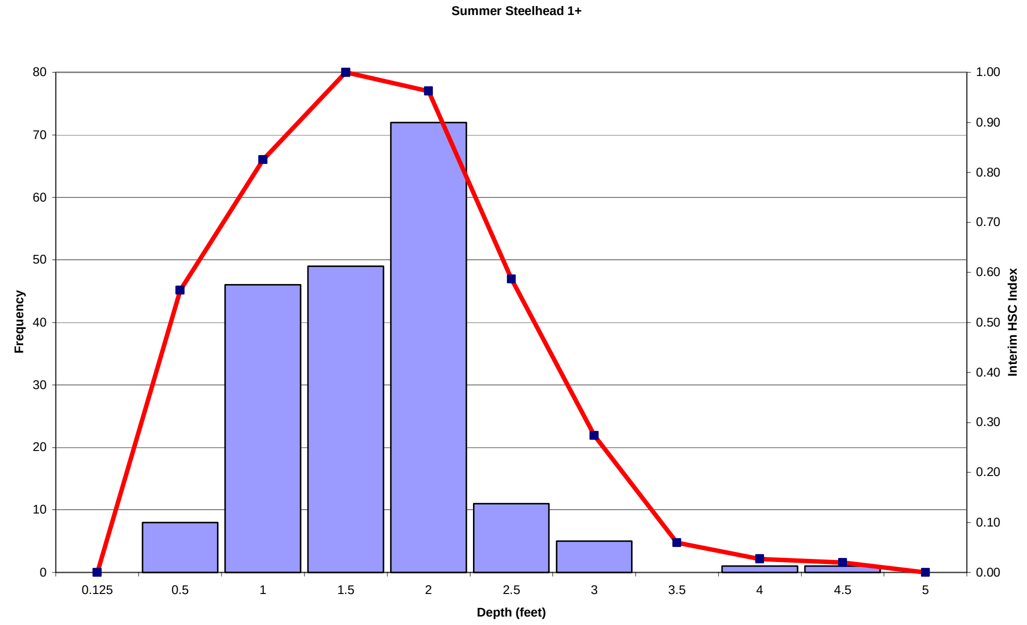


Figure 56. Frequency distribution (bars) and final interim HSC values (red line) for summertime steelhead 1^+ depth from the Klamath River.

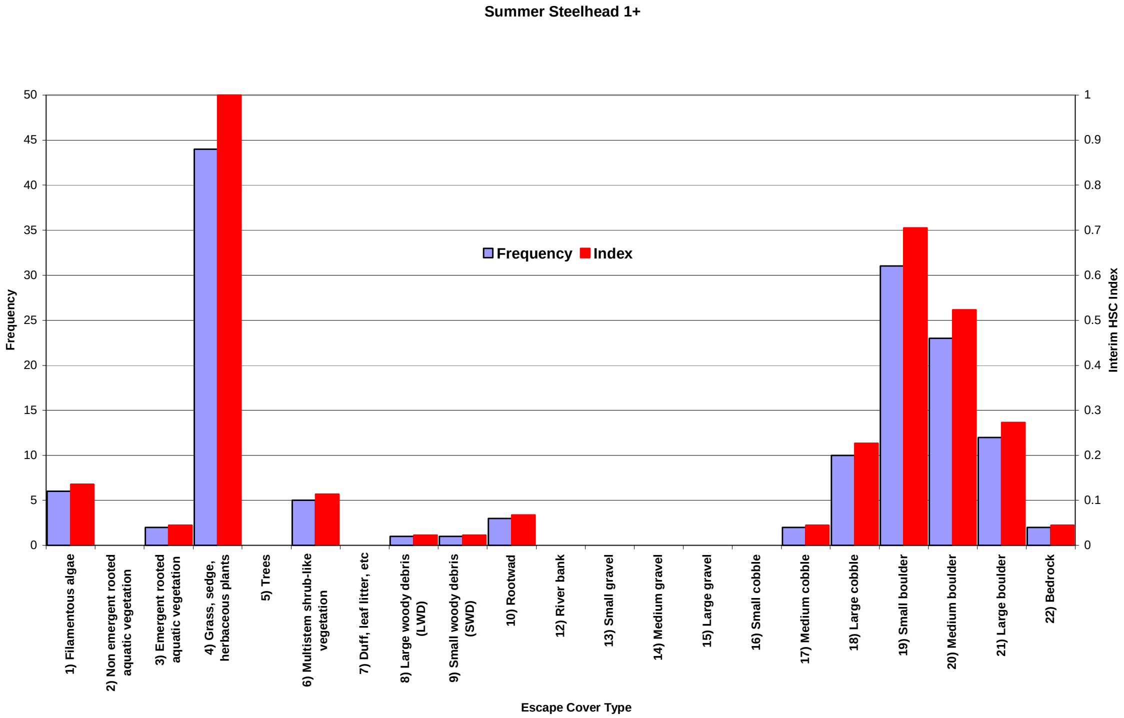


Figure 57. Frequency distribution (blue) and final interim HSC values (red) for summertime steelhead 1^+ cover from the Klamath River.

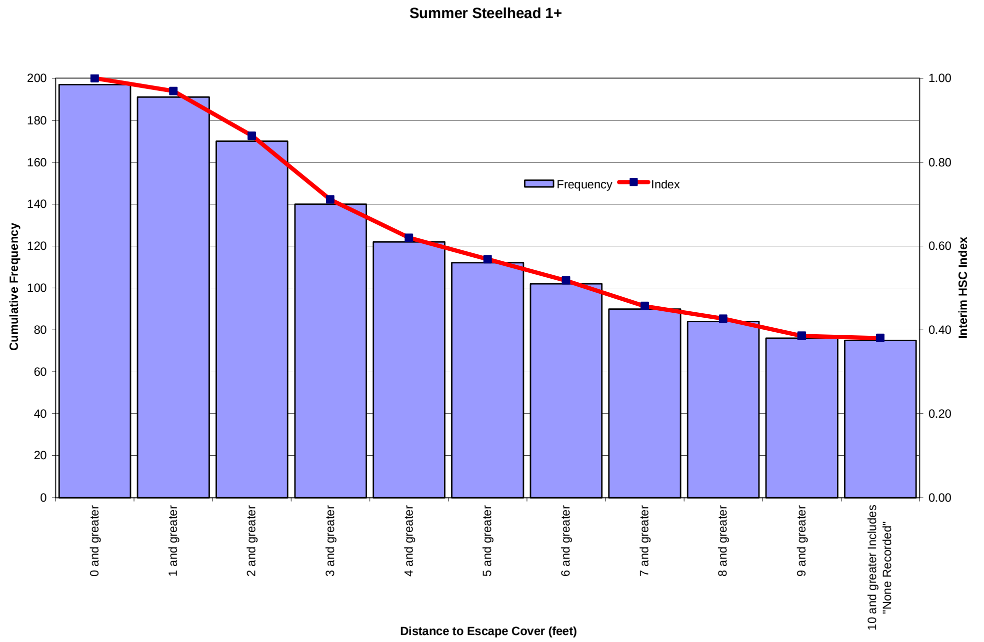


Figure 58. Frequency distribution (bars) and final interim HSC values (red line) for summertime steelhead 1$^+$ distance to escape cover from the Klamath River.

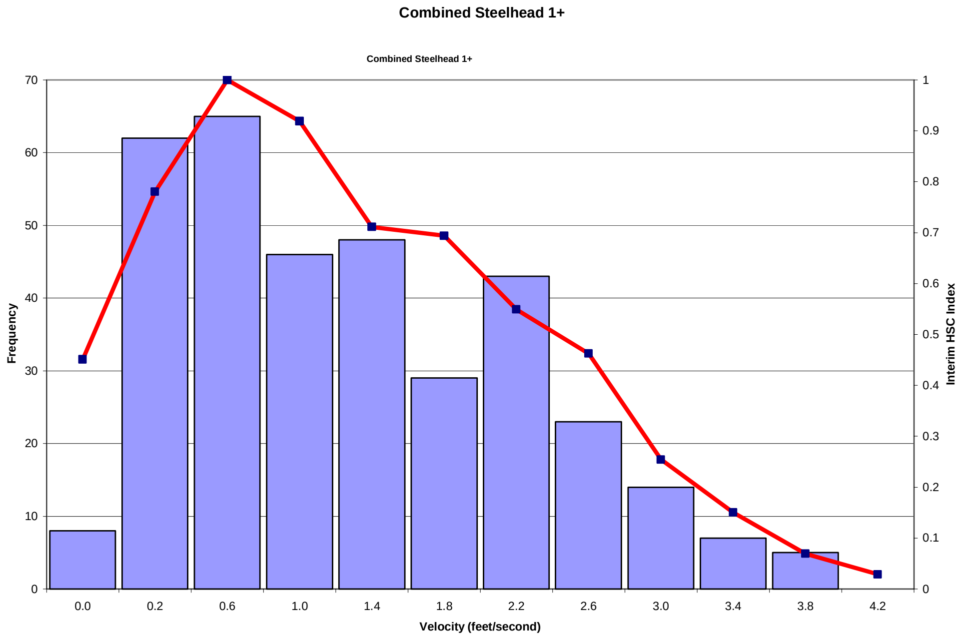


Figure 59. Frequency distribution (bars) and final interim HSC values (red line) for seasonal combined steelhead 1$^+$ velocity from the Klamath River.

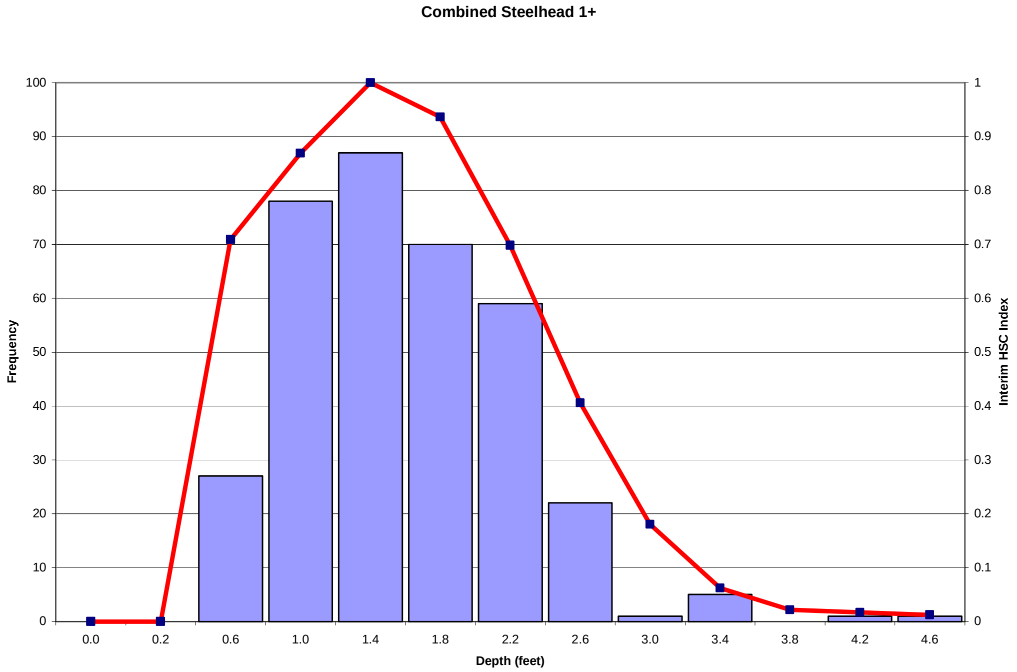


Figure 60. Frequency distribution (bars) and final interim HSC values (red line) for combined steelhead 1^+ depth from the Klamath River.

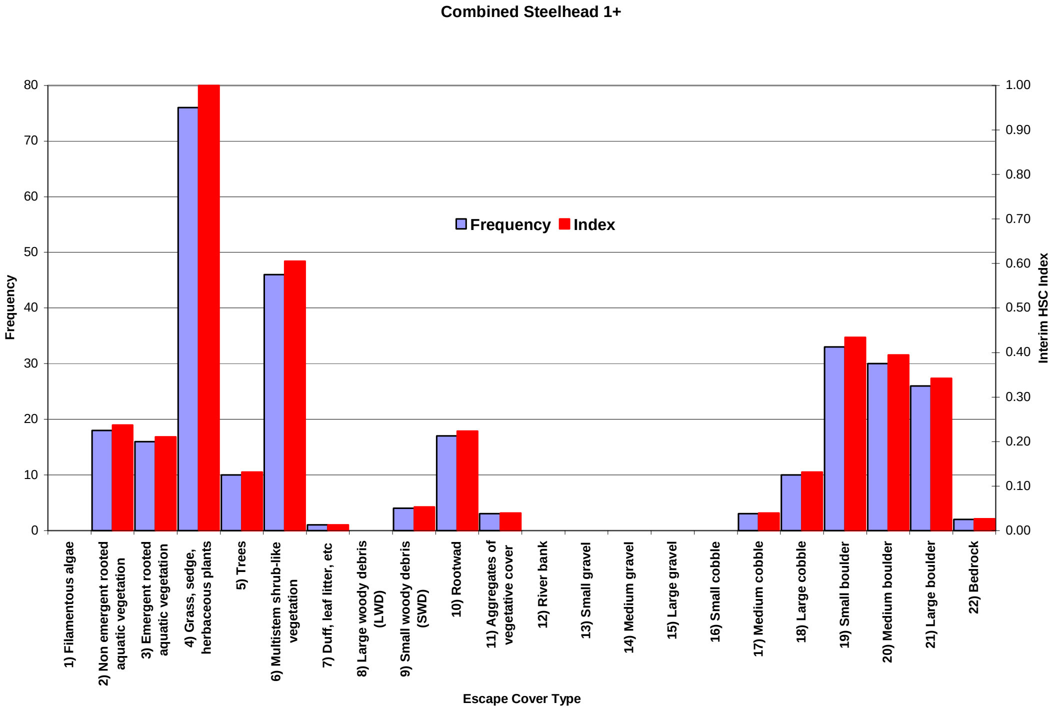


Figure 61. Frequency distribution (blue) and final interim HSC values (red) for combined steelhead 1^+ cover from the Klamath River.

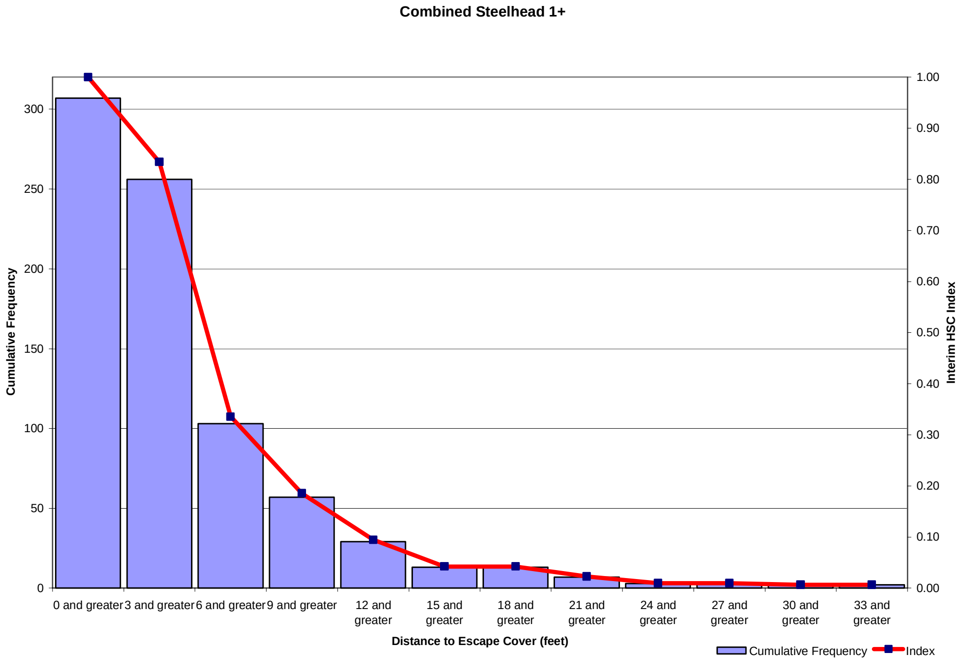


Figure 62. Frequency distribution (bars) and final interim HSC values (red line) for combined steelhead 1^+ distance to escape cover from the Klamath River.

Literature Based Habitat Suitability Criteria

Some investigators that have dealt with the inherent problems of HSC outlined in the discussion above have suggested that ‘enveloped HSC’ are a viable alternative solution when site-specific HSC are not available or concerns of bias may invalidate their application. In this context, enveloped HSC are derived by ‘drawing’ a composite HSC that envelops all the observation data or family of HSC derived from several sources. For example, Bozek and Rahel (1992) found differences in the suitability and preference (suitability criterial corrected for habitat biases) criteria of young cutthroat trout between years and between rivers. They found that composite models (combining data from rivers and years) provided a practical solution for representing the niche dimensions of depth and velocity. Jowett (1991) found that using enveloped suitability criteria from four rivers performed almost as well as stream specific criteria, and very much better than functions developed at one river and applied to another. Based on these results, he advocated the use of generalized envelope criteria.

Several authors, conversely, have advocated the use of only site-specific suitability criteria for describing the realized niche of a particular species and life stages (e.g., Moyle and Baltz 1985; Schirvell 1986; Gore and Nestler 1988). This is a reasonable approach where HSC development can be done properly, but the problems discussed previously are still inherent for site-specific data. In particular, when flows change or fish competitors/predators change the realized niche of a species or life stage, this change may not be encompassed in the potentially “narrowly” defined site specific data (also time, fish density, habitat availability, and flow specific data). In fact, narrowly defined site-specific curves frequently perform poorly when applied in locales other than where they were developed (e.g., Bozek and Rahel 1992; Jowett 1991).

At the present time, properly defined envelop curves appear to be one of the most practical approaches for describing the realized niche dimensions of species/life stages where high quality (properly developed) site specific data are not available (see Dunbar and Ibbotson 2001).

In order to consider other key target species and life stages in the Phase II assessments for which site-specific curves were not available, an envelope HSC development procedure was developed using literature-based HSC. HSC published for the following species and life stages were evaluated in light of data collection methods, number of samples, and where possible, type of river system for which the curves were derived.

- Steelhead – Fry
- Chinook – Juvenile
- Coho – Fry
- Coho – Juvenile

A systematic procedure was then developed for constructing generalized envelope HSC. This procedure was tested against the species and life stage site-specific HSC developed in the previous section.

Envelope HSC Development Procedure

Generalized envelope based HSC were determined from literature based curves using the following set of assumptions and methods:

1) Regardless of the system size represented by the literature HSC, the depth and velocity HSC are indicative of measured variations in the realized niche for a specific life stage of fish. However, irrational artifacts in the literature HSC (i.e., where zero (0) depths indicated some amount of suitability) were ignored in developing the curves.

2) HSC for a particular ‘life stage’ represent a range of fish sizes (e.g., fry = ~30mm through 55mm for chinook) and differences in the functional relationships for HSC can in part be attributed to differences in size classes of fish used in the HSC development.

3) Fish (especially fry and juvenile) are known to exhibit shifts in both depth and velocity utilization as they grow over the size ranges

specified for a particular life stage HSC. This is related to Number 2 above.

4) The utilization of envelope curves has been shown in the literature to be a valid approach to development and application of HSC in the absence of site-specific HSC. In general, 'envelope' HSC perform nearly as well as a site-specific HSC and generally better than a single site-specific curve that is transferred to a different system as noted above.

5) Available HSC for a given life stage were evaluated in terms of their functional relationships, known life history traits for depth and velocity use, and the fish size ranges intended for application of the HSC within the Klamath River.

HSC that had been published in the literature that were predominantly from the western United States were assembled and the relationships between velocity and depth plotted. For each HSC, the type of curve (i.e., utilization, preference, professional judgment, etc., was noted and the location where the HSC were developed (if known) for each target species and life stage. Appendix A contains the bibliographic references for these literature based HSC.

Utilizing these assumptions and professional judgment, literature-based curves were used to generate envelope HSC for the species and life stages noted above. The envelope curves were constructed to represent robust characteristics of the realized niche for each parameter (i.e., depth and velocity). The following section of the report highlights data sources and rationale associated with the HSC for each species and life stage.

Steelhead – Fry

The source, type, and location of steelhead fry velocity and depth literature HSC considered in the development of the envelope HSC are shown in Table 32.

Table 32. Source, curve type, and location of steelhead fry HSC used for the development of the velocity and depth envelope HSC.

Source	**Curves**	**Location**
Hosey & Associates (1986)	**Suitability, Cat I**	**Washington**
Hampton (1988a)	**Utilization, Cat II**	**California**
Beak Consultants (1985)	**Utilization, Cat II**	**Oregon**
USFWS (1987)	**Probability-of-use, Cat II; Winter Run**	**US**
Sanford (1984)	**Preference, Cat III**	**Washington/Oregon**
USFWS (1998)		**Trinity River**

Each of these HSC sets for velocity and depth are shown in Figures 63 and 64. The envelope HSC is also contained in each of these figures.

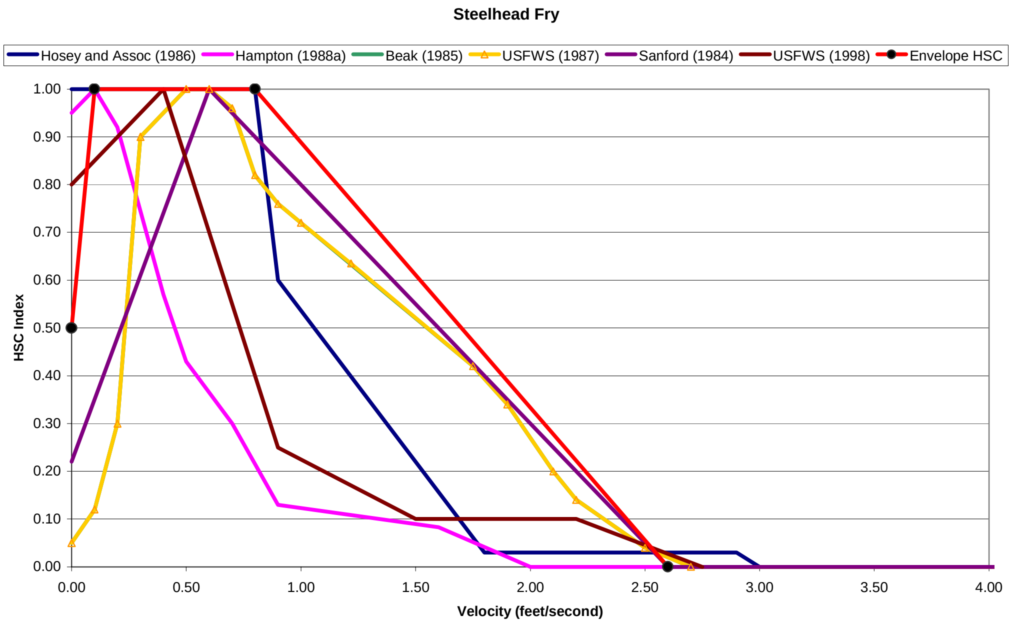


Figure 63. Literature based HSC and final envelope HSC for steelhead fry velocity.

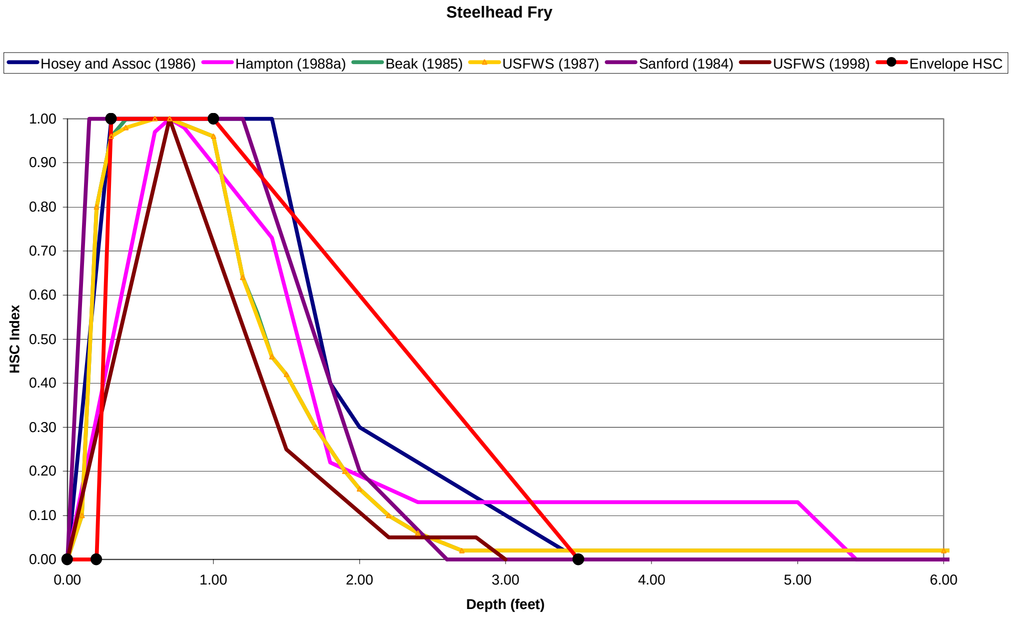


Figure 64. Literature based HSC and final envelope HSC for steelhead fry depth.

Coho – Fry

The source, type, and location of coho fry velocity literature HSC considered in the development of the envelope HSC are shown in Table 33. In this instance, some sources did not provide depth HSC.

Table 33. Source, curve type, and location of coho fry HSC used for the development of the velocity envelope HSC.

Source	Curves	Location
Hampton (1988a)	Utilization; Cat II	California
Bovee (1978)	Probability-of-use; Cat II	US Western
AEIDC (1981)	Cat II	Alaska
Sheppard & Johnson (1985a)	Cat II; June	New York
Sheppard & Johnson (1985b)	Cat II; October	New York
Hampton (1988b)	Preference; Cat III	California
Sanford (1984)	Cat III	Washington/Oregon
USFWS (1998)		Trinity River

Each of these HSC sets for velocity is shown in Figure 65. The envelope HSC is also contained in the figure.

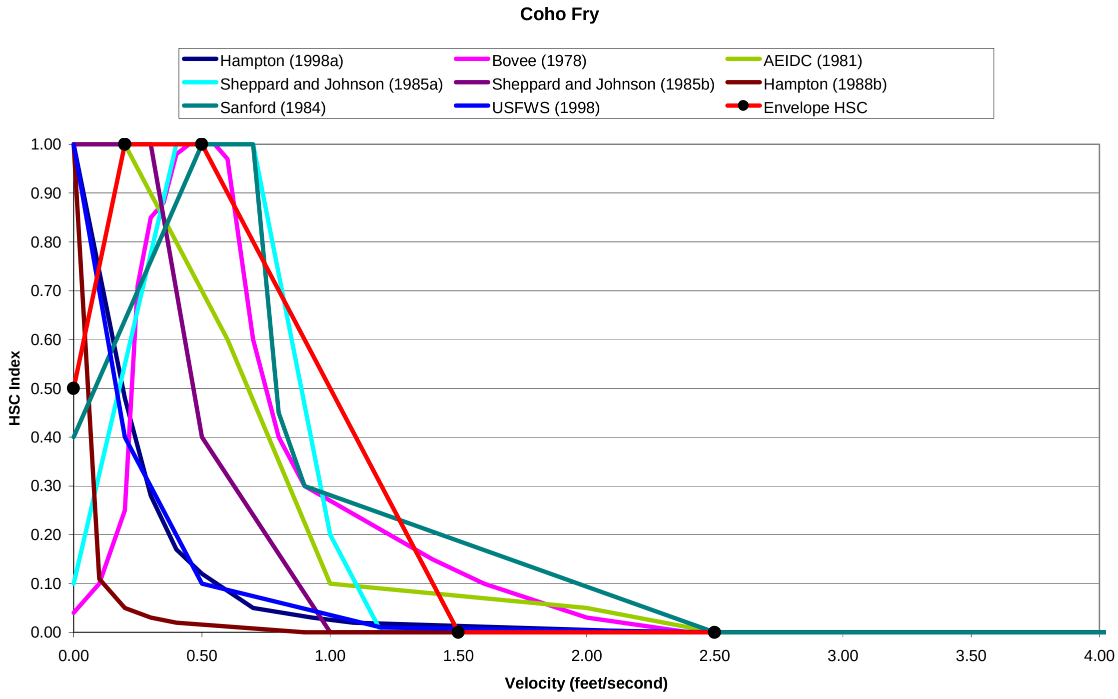


Figure 65. Literature based HSC and final envelope HSC for coho fry velocity.

The source, type, and location of coho fry depth literature HSC considered in the development of the envelope HSC are shown in Table 34. In this instance, some sources did not provide both velocity and depth HSC. Either was used if provided.

Table 34. Source, curve type, and location of coho fry HSC used for the development of the depth envelope HSC.

Source	**Curves**	**Location**
Hampton (1988)	**Utilization; Cat II**	**California**
Bovee (1978)	**Probability-of-use; Cat II**	**US Western**
AEIDC (1981)	**Cat II**	**Alaska**
Bustard & Narver (1975)	**Utilization; Cat II; Temperature = 7 C; Winter**	**B.C.**
Sheppard & Johnson (1985a)	**Cat II; June**	**New York**
Sheppard & Johnson (1985b	**Cat II; October**	**New York**
Hampton (1988)	**Preference; Cat III**	**California**
Sanford (1984)	**Cat III**	**Washington/Oregon**
USFWS (1998)		**Trinity River**

Each of these HSC sets for depth is shown in Figure 66. The envelope HSC is also contained in the figure.

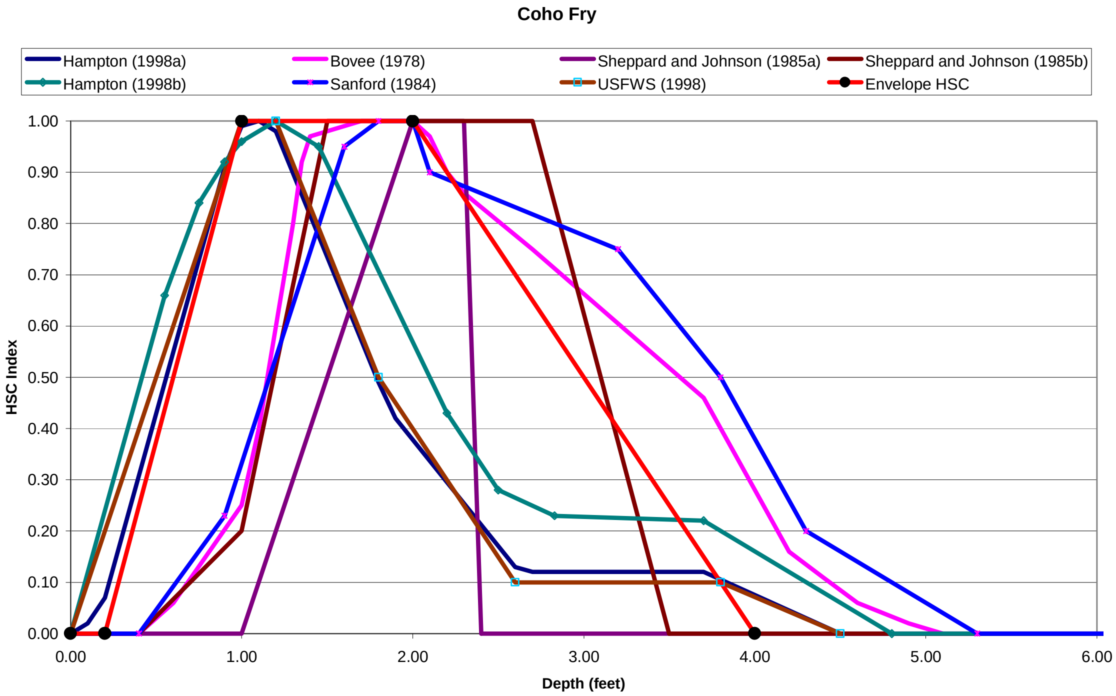


Figure 66. Literature based HSC and final envelope HSC for coho fry depth.

Coho – Juvenile

The source, type, and location of coho juvenile velocity literature HSC considered in the development of the envelope HSC are shown in Table 35. In this instance, some sources did not provide either velocity or depth HSC.

Table 35. Source, curve type, and location of coho juvenile HSC used for the development of the velocity envelope HSC.

Source	Curves	Location
AEIDC (1981)	Cat II	Alaska
Hampton (1988a)	Utilization; Cat II	California
Hampton (1988b)	Preference; Cat III	California
Suchanek et al. (1984a)	Utilization; Cat II	Susitna R., Alaska
Suchanek et al. (1984b)	Utilization; Cat II	Lower Susitna R., Alaska
USFWS (1998)		Trinity River

Each of these HSC sets for velocity is shown in Figure 67. The envelope HSC is also contained in the figure.

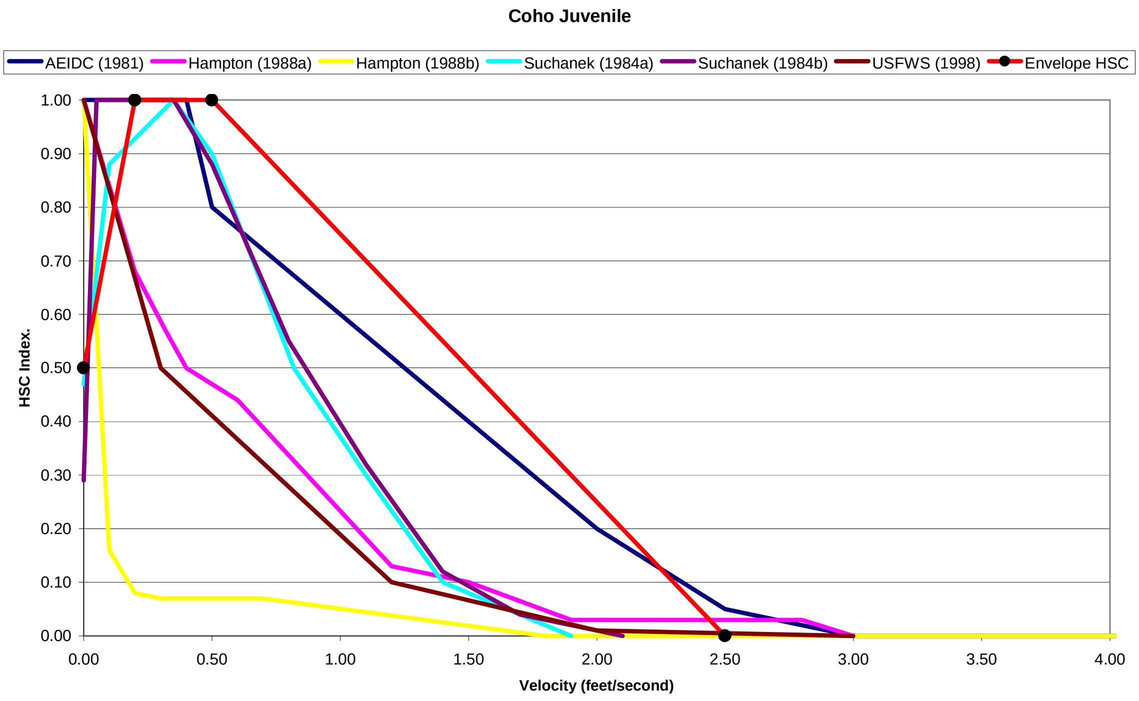


Figure 67. Literature based HSC and final envelope HSC for coho juvenile velocity.

The source, type, and location of coho juvenile depth literature HSC considered in the development of the envelope HSC are shown in Table 36. In this instance, some sources did not provide either velocity or depth HSC.

Table 36. Source, curve type, and location of coho juvenile HSC used for the development of the depth envelope HSC.

Source	Curves	Location
AEIDC (1981)	Cat II	Alaska
Hampton (1988a)	Utilization; Cat II	California
Bustard & Narver (1975)	Utilization; Cat II; Temperature = 7 C; Winter	B.C.
Hampton (1988b)	Preference; Cat III	California
Suchanek et al. (1984a)	Utilization; Cat II	Susitna R., Alaska
USFWS (1998)		Trinity River

Each of these HSC sets for depth is shown in Figure 68. The envelope HSC is also contained in the figure.

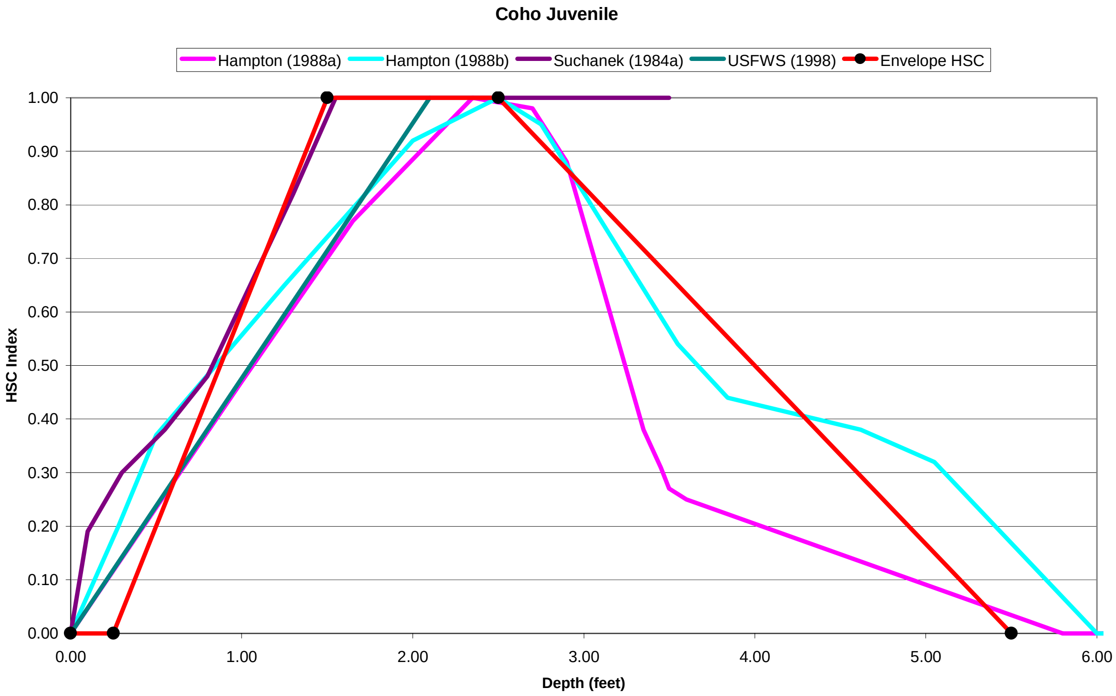


Figure 68. Literature based HSC and final envelope HSC for coho juvenile depth.

Chinook – Juvenile

The source, type, and location of chinook juvenile velocity literature HSC considered in the development of the envelope HSC are shown in Table 37.

Table 37. Source, curve type, and location of chinook juvenile HSC used for the development of the velocity envelope HSC.

Source	Curves	Location
Hampton (1988a)	Utilization, Cat II	California
Raleigh et al. (1986a)	Suitability, Cat I	US
Raleigh et al. (1986b)	Suitability, Cat I	US
Estes & Kuntz (1986)	Suitability (Utilization), Cat II	Alaska
Raleigh et al. (1986c)	Utilization, Cat II; Clear Water	Alaska
Raleigh et al. (1986d)	Utilization, Cat II; Turbid Water	Alaska
Raleigh et al. (1986) (Burger et al.)	Utilization, Cat II	Alaska
Raleigh et al. (1986) (Burger et al.)	Utilization, Cat II; Nose Velocity	Alaska
Bovee (1978)	Probability-of-use; Cat II	Idaho/Oregon
Reiser (1986); Reiser et al. (1989)	Suitability; Cat II	Idaho
Beak Consultants (1985)	Suitability Utilization, Cat II	Oregon
USFS (1989)	GAWS (suitability); Cat II	US Western
Hampton (1988b)	Preference, Cat III	California
Wampler (1985)	Preference, Cat III	Washington
Suchanek et al. (1984a)	Utilization; Cat II; High Turbidity	Susitna R., Alaska
Suchanek et al. (1984b)	Utilization; Cat II; Low Turbidity	Susitna R., Alaska
Suchanek et al. (1984c)	Utilization; Cat II; Clear Water	Susitna R., Alaska
Suchanek et al. (1984d)	Utilization; Cat II; (Depth curve for turbid water)	Susitna R., Alaska
USFWS (1998)		Trinity River

Each of these HSC sets for velocity is shown in Figure 69. The envelope HSC is also contained in the figure.

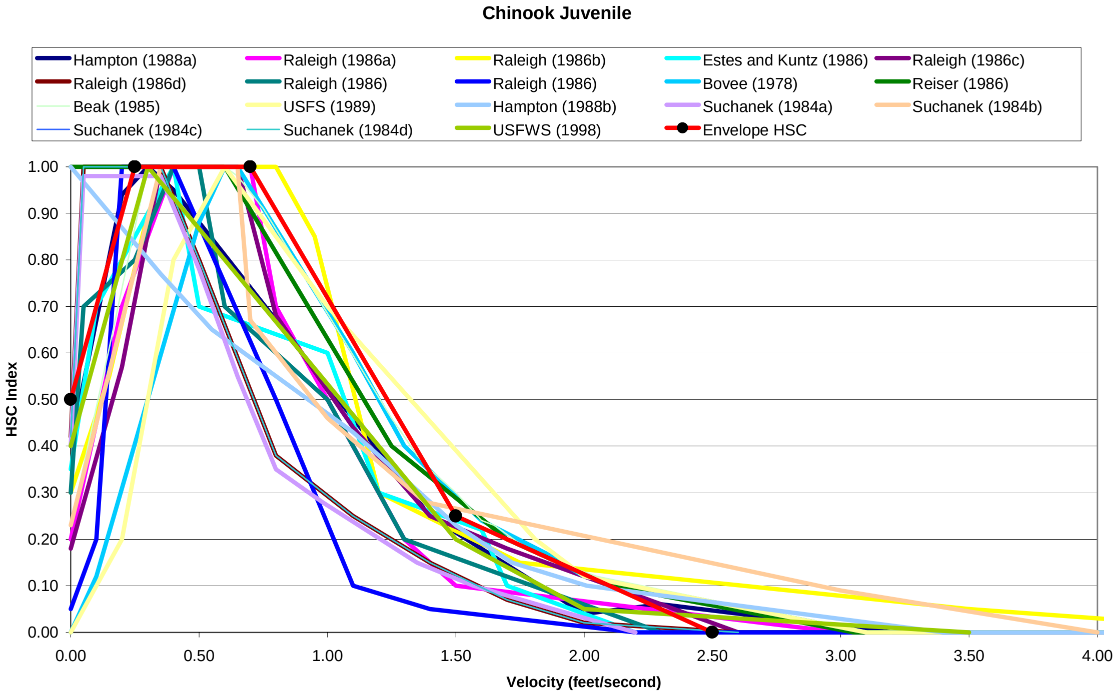


Figure 69. Literature based HSC and final envelope HSC for chinook juvenile velocity.

The source, type, and location of chinook juvenile depth literature HSC considered in the development of the envelope HSC are shown in Table 38.

Table 38. Source, curve type, and location of chinook juvenile HSC used for the development of the depth envelope HSC.

Source	**Curves**	**Location**
Hampton (1988a)	**Utilization, Cat II**	**California**
Raleigh et al. (1986a)	**Suitability, Cat I**	**US**
Raleigh et al. (1986b)	**Suitability, Cat I**	**US**
Estes & Kuntz (1986)	**Suitability (Utilization), Cat II**	**Alaska**
Raleigh et al. (1986c)	**Utilization, Cat II; Clear Water**	**Alaska**
Raleigh et al. (1986d)	**Utilization, Cat II; Turbid Water**	**Alaska**
Bovee (1978)	**Probability-of-use; Cat II**	**Idaho/Oregon**
Reiser (1986); Reiser et al. (1989)	**Suitability; Cat II**	**Idaho**
Beak Consultants (1985)	**Suitability Utilization, Cat II**	**Oregon**
USFS (1989)	**GAWS (suitability); Cat II**	**US Western**
Hampton (1988b)	**Preference, Cat III**	**California**
Wampler (1985)	**Preference, Cat III**	**Washington**
Suchanek et al. (1984b)	**Utilization; Cat II; Low Turbidity**	**Susitna R., Alaska**
Suchanek et al. (1984c)	**Utilization; Cat II; Clear Water**	**Susitna R., Alaska**
Suchanek et al. (1984d)	**Utilization; Cat II; (Depth curve for turbid water)**	**Susitna R., Alaska**
USFWS (1998)		**Trinity River**

Each of these HSC sets for depth is shown in Figure 70. The envelope HSC is also contained in the figure.

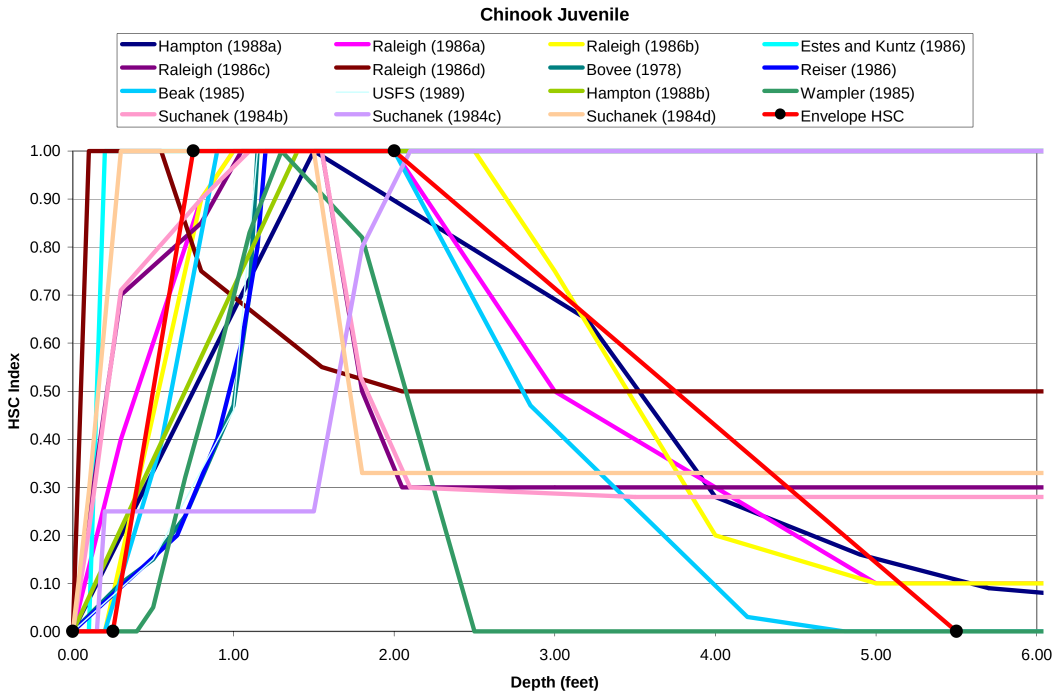


Figure 70. Literature based HSC and final envelope HSC for chinook juvenile depth.

In order to conduct a validation test of the envelope HSC development process, envelope HSC were also developed for the species and life stages in the Klamath River for which site-specific HSC were available. These included chinook spawning, chinook fry, and steelhead 1$^+$. For each of these species and life stages, the same methodology used to generate the envelope HSC described above was employed. The results for each species and life stage are provided below. In the following section of the report, the actual validation test is discussed.

Chinook – Fry

The source, type, and location of chinook fry velocity and depth literature HSC considered in the development of the envelope HSC are shown in Table 39.

Each of these HSC sets for velocity is shown in Figure 71 and depth is shown in Figure 72. The envelope HSC and Klamath site-specific HSC are also contained in these figures.

Table 39. Source, curve type, and location of chinook fry HSC used for the development of the velocity and envelope HSC.

Source	Curves	Location
Hampton (1988)	Utilization, Cat II	California
Raleigh et al. (1986)	Suitability, Cat I	California
Raleigh et al. (1986)	Suitability, Cat I	US
Raleigh et al. (1986) (Burger et al.)	Utilization, Cat II	Alaska
Beak Consultants (1985)	Suitability (Utilization), Cat II	Oregon
Raleigh et al. (1986)	Utilization, Cat II	Washington
Hampton (1988)	Preference, Cat III	California
USFWS (1998)		Trinity River
Campbell & Eddy (1988)	Utilization, Cat II	Washington
Rubin & Bjornn (1989) DRAFT	Suitability (Utilization); Pooled; Cat II	Idaho
Rubin & Bjornn (1989) DRAFT	Suitability (Utilization); Cape Horn Creek; Cat II	Idaho
Everest & Chapman (1972)	Utilization; 1966 data; Crooked Fork Creek	Idaho
Everest & Chapman (1972)	Utilization; 1966 data; Johnson Creek (Low Grad)	Idaho
Everest & Chapman (1972)	Utilization; 1966 data; Johnson Creek (High Grad)	Idaho

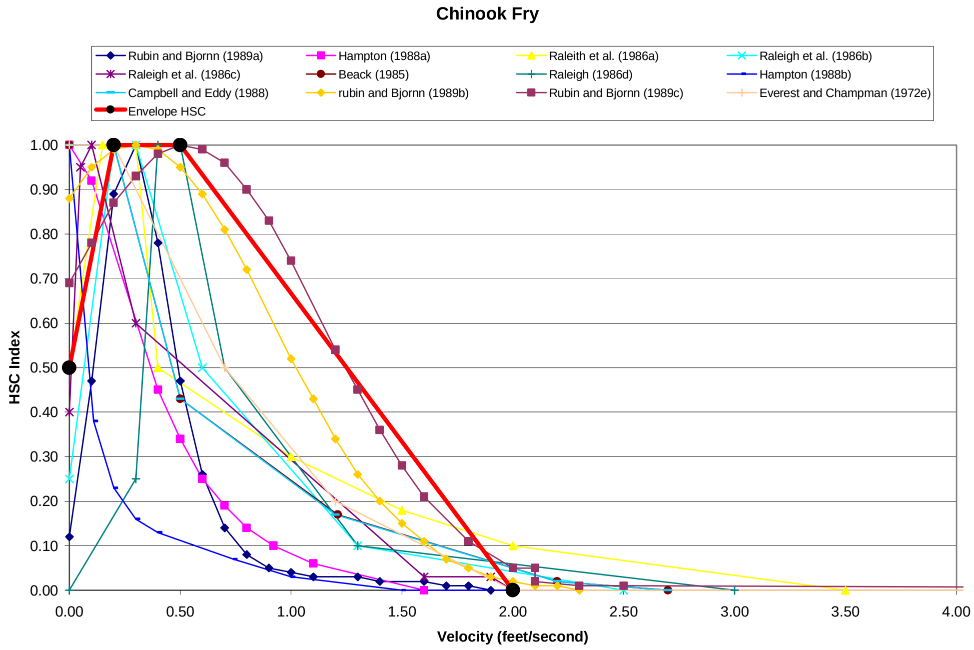


Figure 71. Literature based HSC, final envelope HSC (bold red), and Klamath site-specific HSC (bold black) for chinook fry velocity.

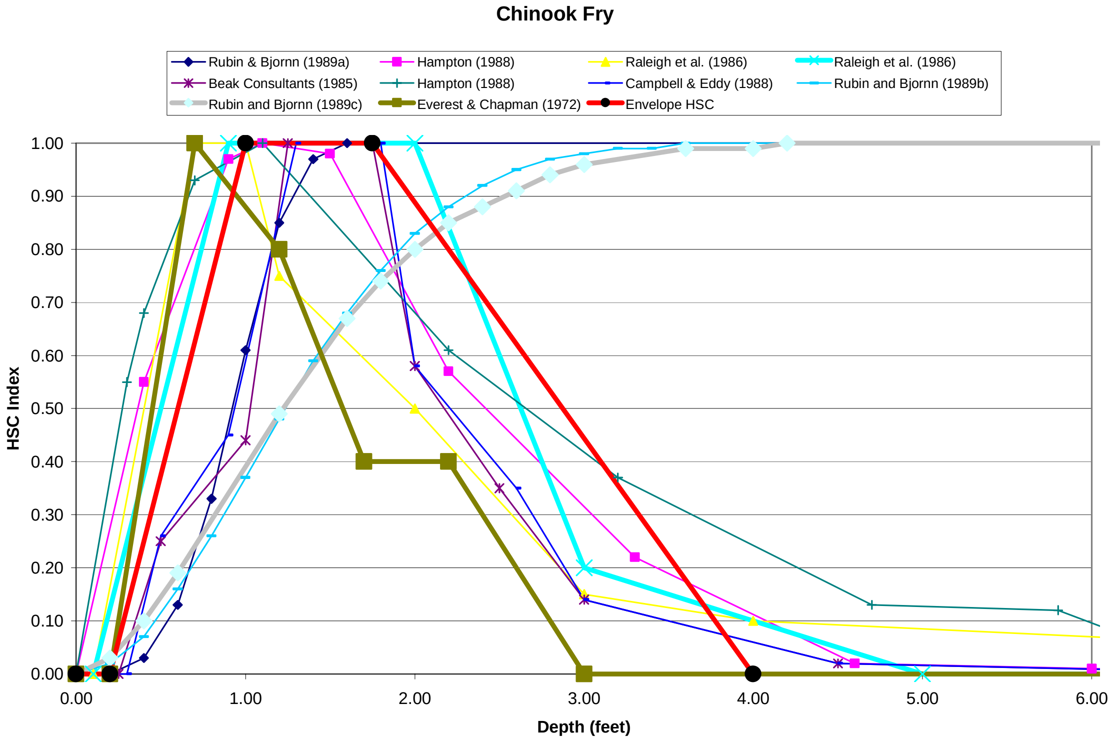


Figure 72. Literature based HSC, final envelope HSC (bold red), and Klamath site-specific HSC (bold black) for chinook fry depth.

Chinook – Spawning

The source, type, and location of chinook spawning velocity and depth literature HSC considered in the development of the envelope HSC are shown in Table 40.

Each of these HSC sets for velocity is shown in Figure 73 and depth in Figure 74. The envelope HSC and Klamath site-specific HSC are also contained in these figures.

Table 40. Source, curve type, and location of chinook spawning HSC used for the development of the velocity and depth envelope HSC.

Source	Curves	Location
Bovee (1978)	Probability-of-use; Cat II	Idaho/Oregon
Sams & Pearson (1963)	Suitability (Utilization), Cat II	Oregon
Bovee (1978)	Probability-of-use; Cat II	Oregon
Sams & Pearson (1963)	Suitability (Utilization), Cat II	Oregon
Raleigh et al. (1986)	Suitability; Cat I	US
Hampton (1988)	Utilization, Cat II	California
Reiser (1986); Reiser et al. (1989)	Suitability; Cat II	Idaho
Raleigh et al. (1986)	Utilization, Cat II	Washington
Raleigh et al. (1986)	Suitability (V=Cat II; D=Cat I)	Alaska
Raleigh et al. (1986)	Utilization; Cat II; Fall Run	California
Beak Consultants (1985)	Suitability (Utilization), Cat II	Oregon
Raleigh et al. (1986)	Utilization, Cat II (Spring Run)	Washington
USFS (1989)	GAWS (suitability); Cat II	US Western
Hampton (1988)	Preference, Cat III	California
Vogel (1982)	Preference, Cat III	California
Wa. Dept. Fish. Wild. (1987)	Preference, Cat III; Rivers	Washington
Wa. Dept. Fish. Wild. (1987)	Preference, Cat III; Large Rivers	Washington
Wa. Dept. Fish. Wild. (1987)	Preference, Cat III; Streams	Washington
Estes (1979)	Utilization, Cat II	Alaska
From Estes (1984)	Utilization, Cat II	Willow Creek, Alaska
Vincent Lang et al. (1984)	Utilization, Cat II	Lower Susitna R., Alaska
USFWS (1998)		Trinity River

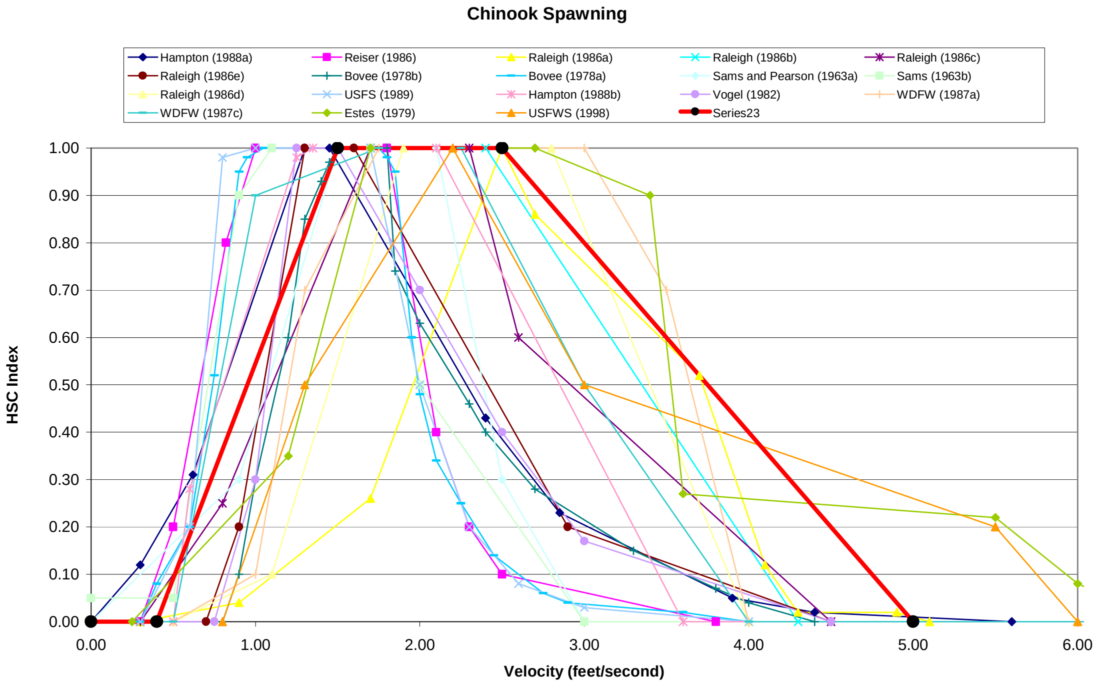


Figure 73. Literature based HSC, final envelope HSC (bold red), and Klamath site-specific HSC (bold black) for chinook spawning velocity.

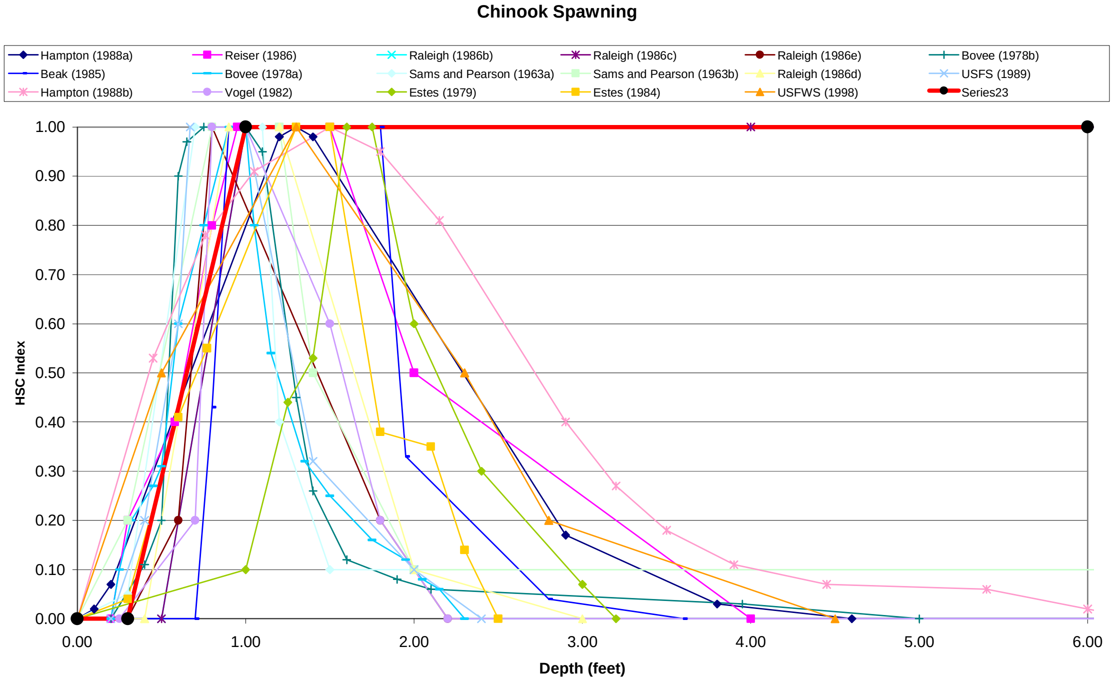


Figure 74. Literature based HSC, final envelope HSC, and Klamath site-specific HSC for chinook spawning depth.

Steelhead – 1^{+}

The source, type, and location of steelhead 1+ velocity and depth literature HSC considered in the development of the envelope HSC are shown in Table 41.

Table 41. Source, curve type, and location of chinook spawning HSC used for the development of the velocity and depth envelope HSC.

Source	Curves	Location
Hampton (1988)	Utilization, Cat II	California
Hosey & Associates (1986)	Suitability, Cat I; Summer	Washington
Hosey & Associates (1986)	Suitability, Cat I; Winter	Washington
Reiser (1986); Reiser et al. (1989)	Suitability; Cat II	Idaho
Beak Consultants (1985)	Utilization, Cat II	Oregon
USFWS (1987)	Probability-of-use, Cat II; Winter Run	US
USFS (1989)	GAWS (Suitability); Cat II	US (Western)
Hampton (1988)	Preference, Cat III	California
Wa. Dept. Fish. Wild. (1987)	Preference, Cat III	Washington
Sanford (1984)	Preference, Cat III	Washington/Oregon
USFWS (1998)		Trinity River
Everest & Chapman (1972)	Util., Cat. II; Crooked Fork Creek, Summer	Idaho
Everest & Chapman (1972)	Util., Cat. II; Johnson Creek, Low Grad., Summer	Idaho
Everest & Chapman (1972)	Util., Cat. II; High Grad., Summer	Idaho
Bovee (1978)	Probability-of-use (Depth may tail off); Cat II	Idaho/Washington
USFWS (1998)		Trinity River

Each of these HSC sets for velocity is shown in Figure 75 and depth is shown in Figure 76. The envelope HSC is also contained in the figure.

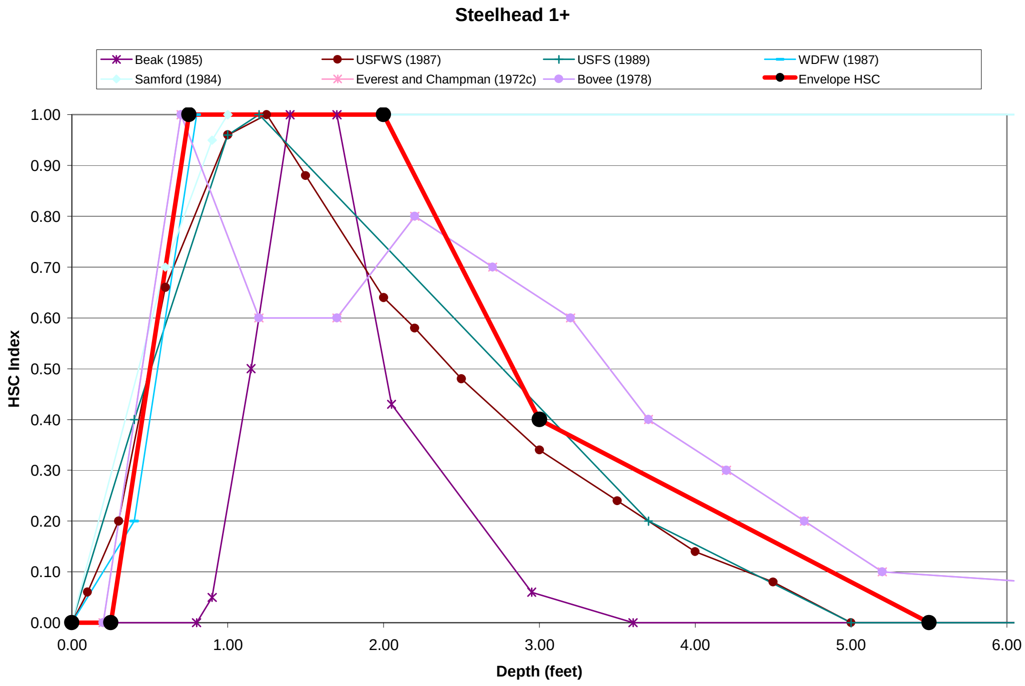


Figure 75. Literature based HSC, final envelope HSC, and Klamath site-specific HSC for steelhead 1$^+$ velocity.

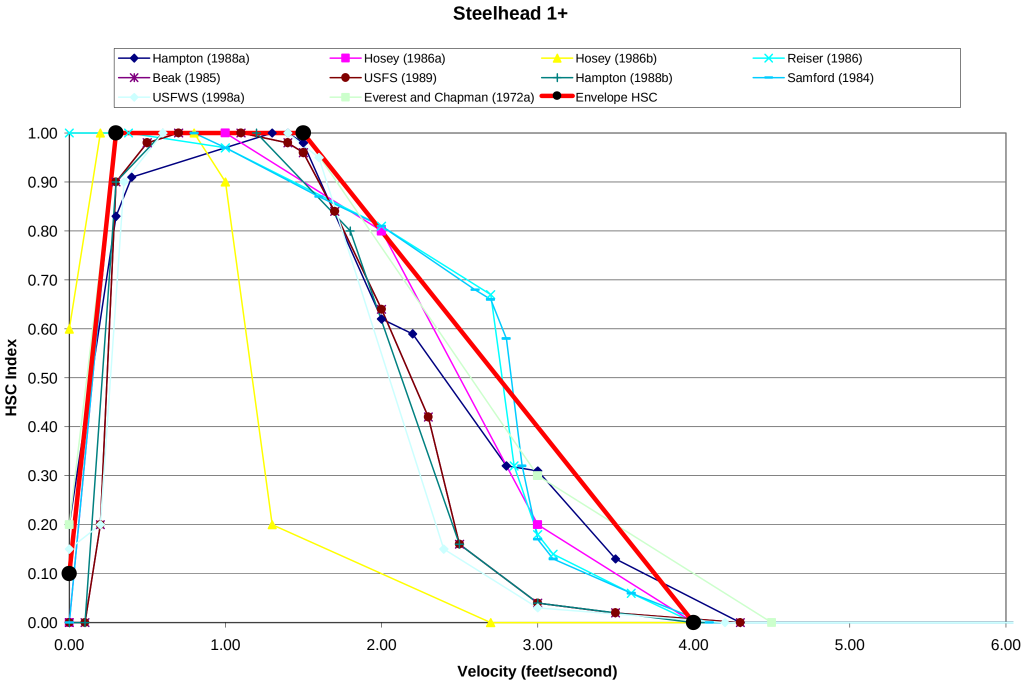


Figure 76. Literature based HSC, final envelope HSC, and Klamath site-specific HSC for steelhead 1$^+$ depth.

Site-Specific versus Envelope HSC Validation Test

As a validation of the overall concept, assumptions, and specific approach to development and application of the envelope HSC, we utilized the envelope curves developed in the previous section for chinook spawning, chinook fry, and steelhead 1^{+} to model the relationship between available habitat and discharge at several study sites. The habitat modeling also included the application of the site-specific HSC developed for the project (see above). Several different study sites were selected to represent different channel characteristics and proportions of habitat availability. Figures 77 to 84 show these comparisons.

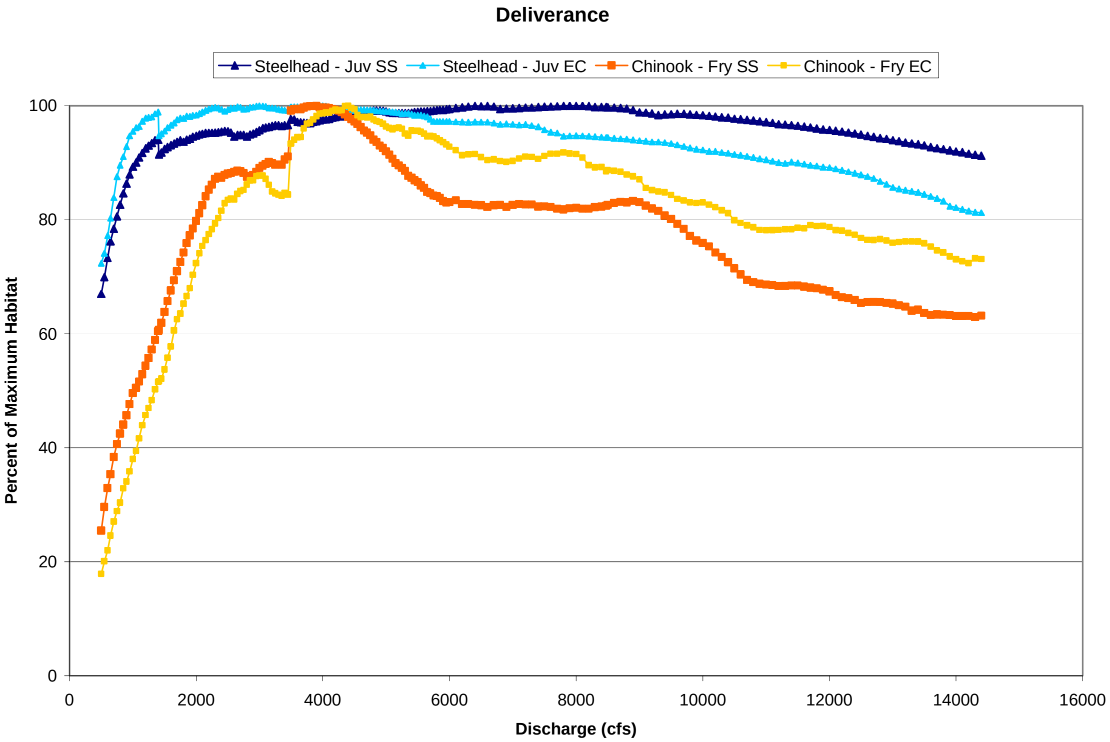


Figure 77. Comparison between generalized and site-specific habitat relationships, chinook fry, and steelhead juvenile life stages at the Deliverance study site using cross section data.

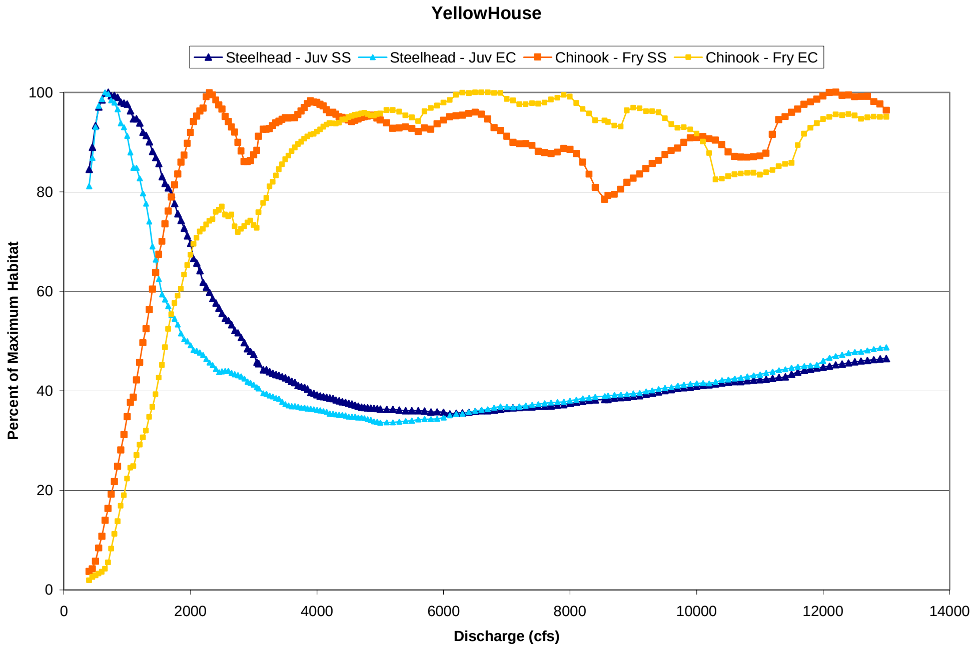


Figure 78. Comparison between generalized and site-specific habitat relationships chinook fry, and steelhead juvenile life stages at the Yellow House study site using cross section data.

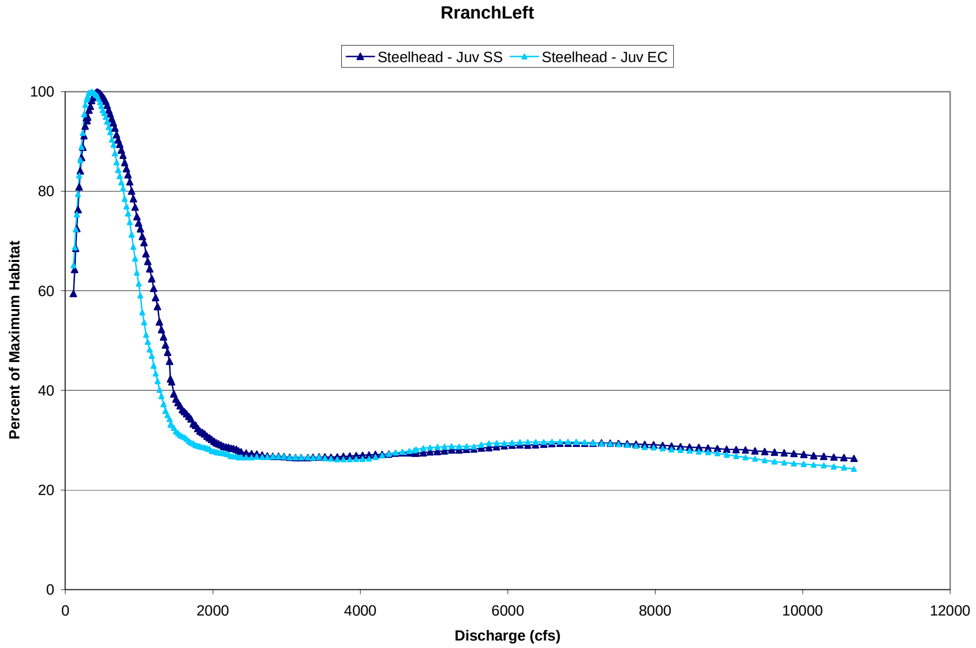


Figure 79. Comparison between generalized and site-specific habitat relationships for steelhead juvenile life stage at the RRanch Left channel study site using cross section data.

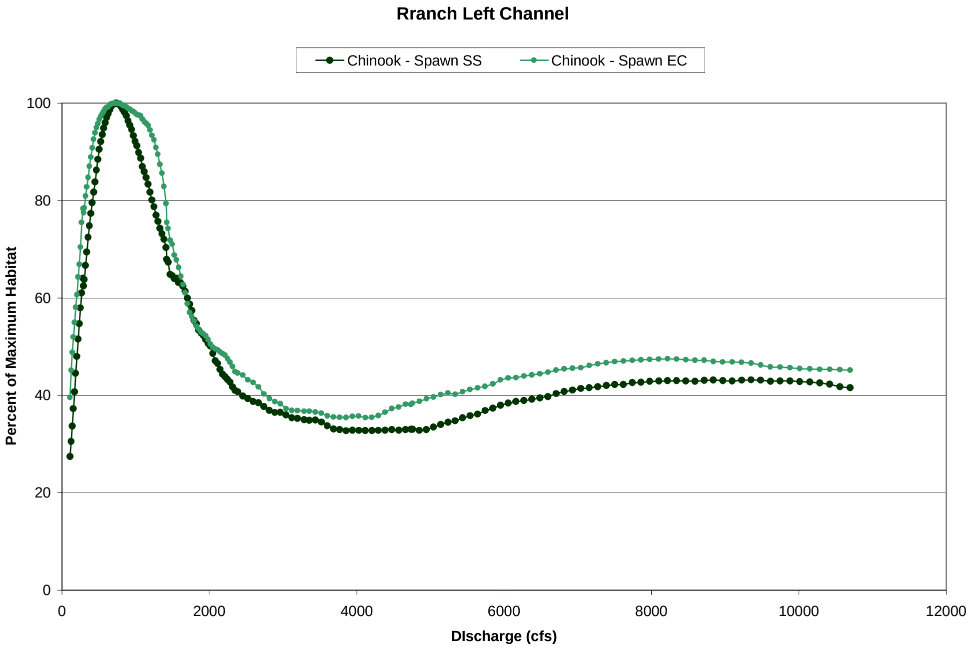


Figure 80. Comparison between generalized and site-specific habitat relationships for chinook spawning life stage at the RRanch Left channel study site using cross section data.

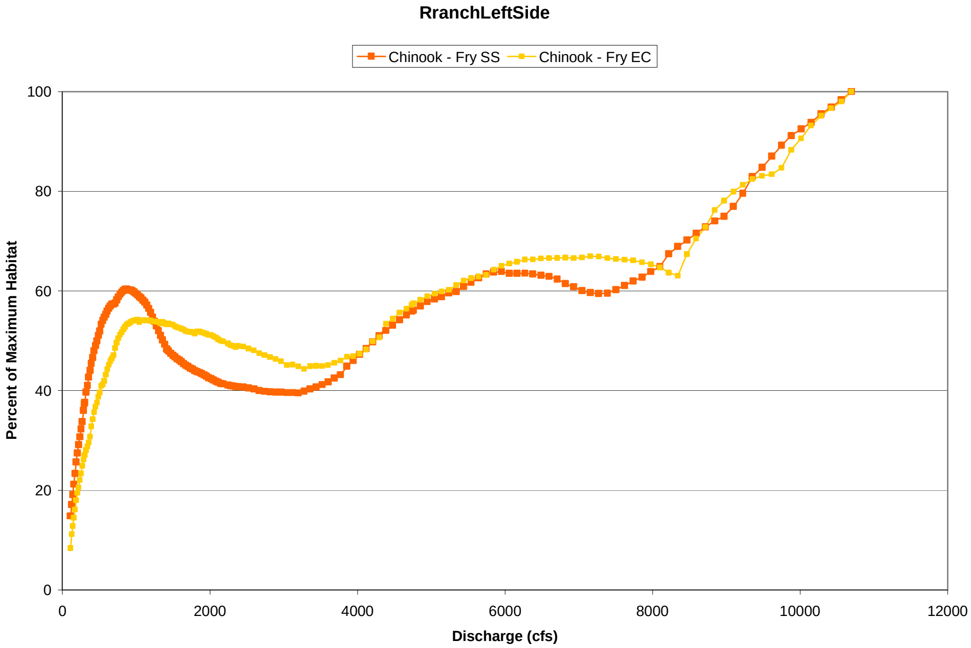


Figure 81. Comparison between generalized and site-specific habitat relationships for chinook fry life stage at the RRanch Left channel study site using cross section data.

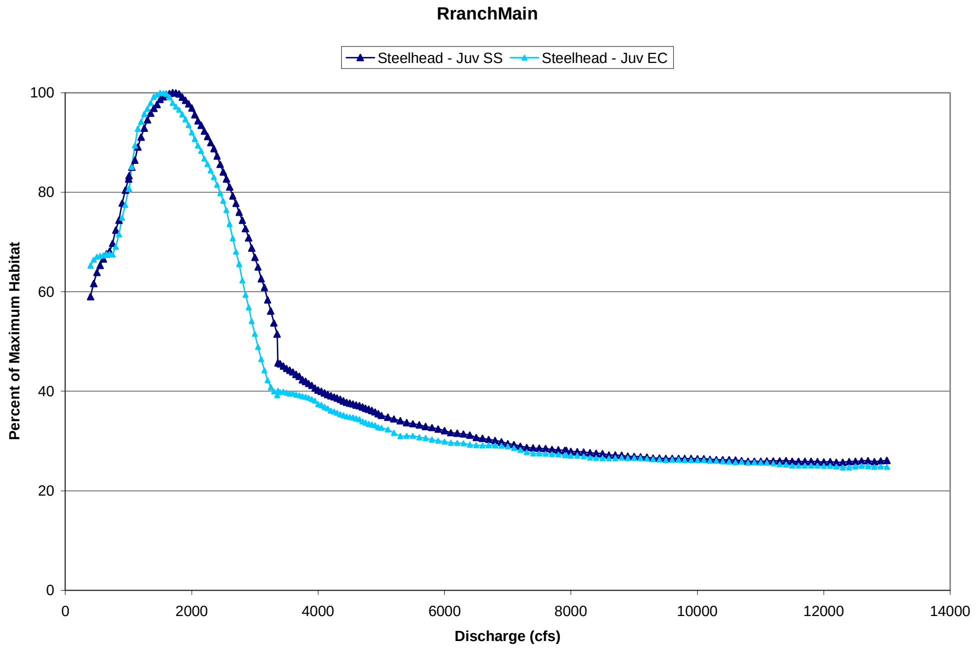


Figure 82. Comparison between generalized and site-specific habitat relationships for steelhead 1+ life stage at the Rranch main channel study site using cross section data.

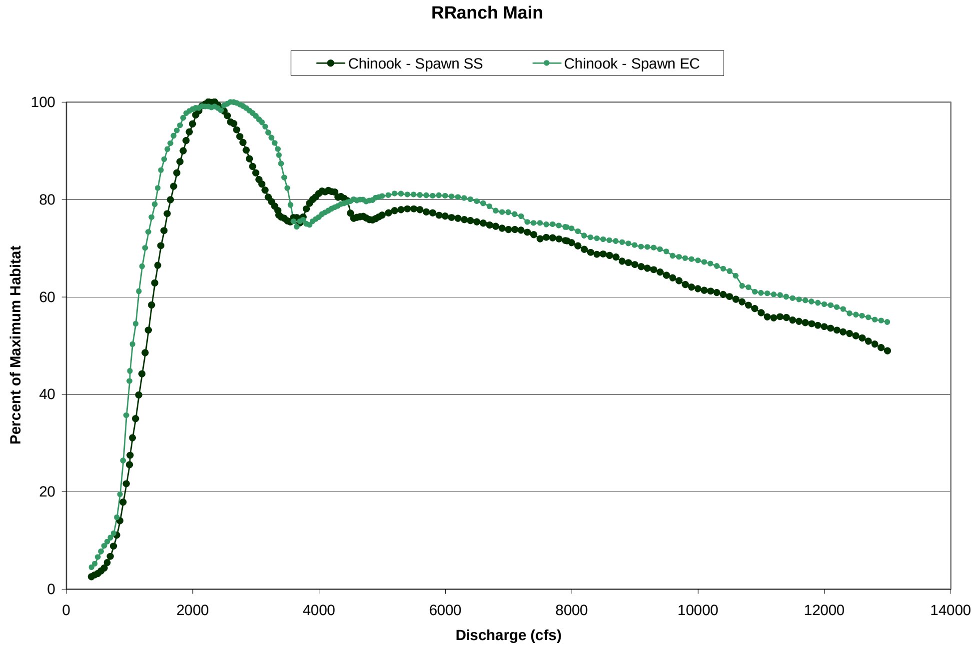


Figure 83. Comparison between generalized and site-specific habitat relationships for chinook spawning life stage at the RRanch main channel study site using cross section data.

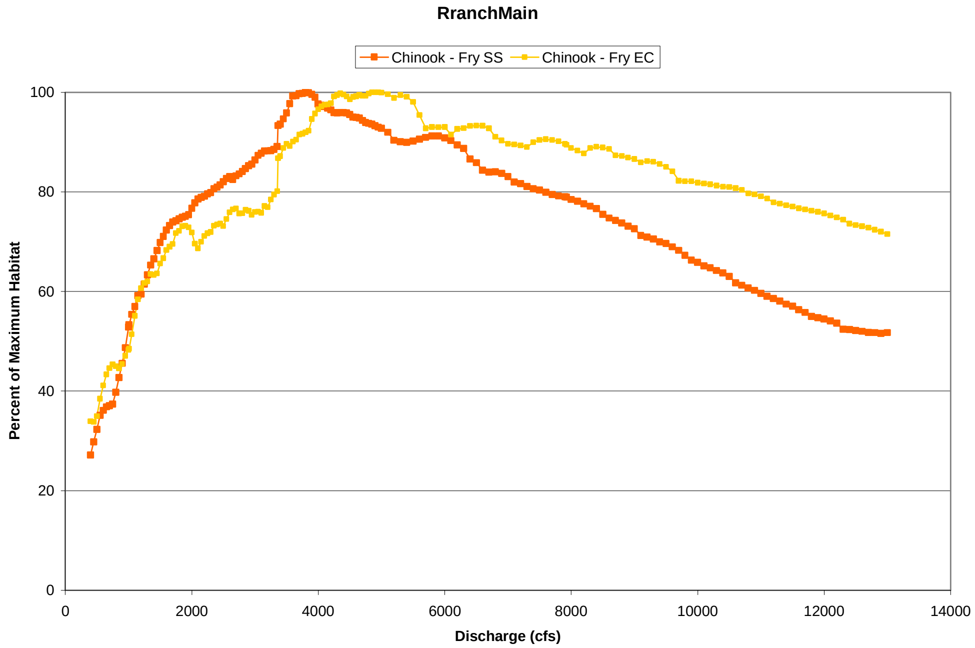


Figure 84. Comparison between generalized and site-specific habitat relationships for chinook fry life stage at the RRanch main channel study site using cross section data.

These results clearly show that the envelope HSC generate habitat results that are very similar to the site-specific HSC at all study sites. The results for chinook fry at RRanch main channel had perhaps the largest difference obtained in all the comparisons. The differences between all of the comparative relationships, even the worst ones, are generally not sufficient to impact instream flow management decisions given the similarity in the functional relationship of habitat versus discharge. This degree of variability in modeling results is also within the range of variability to be expected from application of physical habitat modeling approaches applied to the same reach in successive years or in the same reach by two different investigators (Hardy 1998b). Based on the strength of these comparative results, we consider that the development and application of envelope HSC to be a valid approach for the Klamath River in the absence of site-specific HSC. These results are consistent with other study results comparing site-specific to generalized HSC discussed and cited above.

Physical Habitat Modeling

In habitat modeling, an appropriate hydraulic model is applied to determine characteristics of the stream in terms of depth and velocity as a function of discharge. This information is integrated with habitat suitability curves to produce a measure of available habitat as a function of discharge.

The general assumption underlying habitat modeling is that aquatic species will react to changes in the hydraulic environment. This assumption is rooted in ecological principals and has been demonstrated to be valid in applied research (Stalnaker et al. 1995; Nehring and Anderson 1993; Bovee et al. 1994; Jager et al. 1993; Jowett 1992; Railsback et al. 1993; Studley et al. 1995). These changes in hydraulic properties are simulated for each computational cell within each cross section throughout the study reach. The stream reach simulation takes the form of a multi-dimensional matrix of the calculated surface areas of a stream having different combinations of hydraulic parameters (i.e., depth, velocity, and channel index), as illustrated in Figure 85. This figure shows the generalized representation of a segment of river for a series of transects that define a grid of habitat cells with their associated attributes of depth, velocity and channel index (i.e., substrate and cover). These cells represent the basic computational elements used by the habitat programs to derive relevant indices of available habitat. Depth and velocity attributes for each computational cell vary with simulated changes in discharge, and can result in changes in the amount and quality of available habitat.

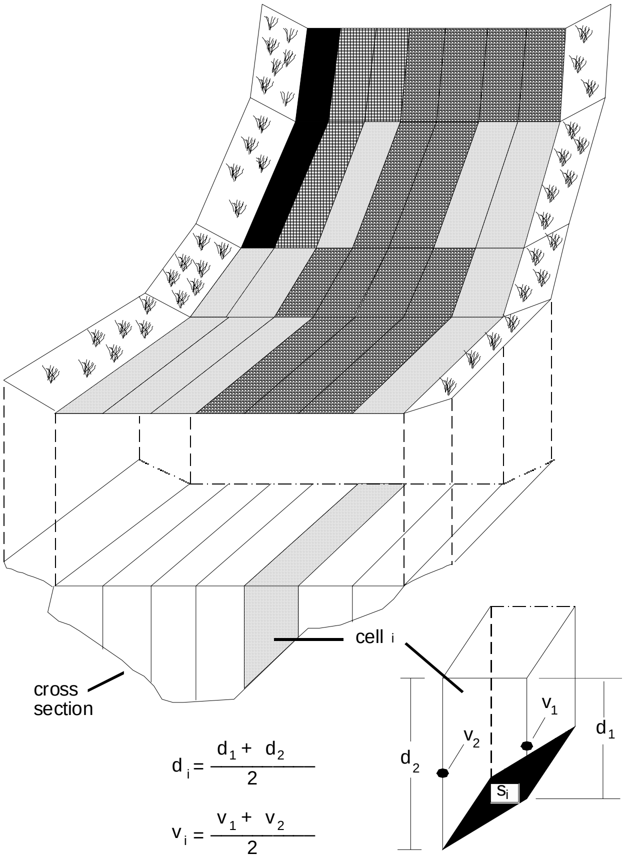


Figure 85. Conceptual representation of a stream reach by computational cells with attributes of depth, velocity, and channel index used in habitat modeling.

HSC are used to describe the adequacy of various combinations of depth, velocity and channel index conditions in each habitat computational cell to produce an estimate of the quantity and or quality of habitat in terms of surface area. This measure in its most generic sense is referred to as weighted usable area (WUA) and is expressed in terms of units of square feet per 1000 linear feet of stream. WUA is computed within the reach at a specific discharge by the following equation:

$$WUA = \frac{\sum_{i=1}^{n} A_i C_i}{\text{Reach Length (1000's feet)}}$$

Where:

A_i = Surface area of cell i,

C_i = Combined suitability of cell $_i$ (i.e., composite of depth, velocity and channel index individual suitabilities).

The combined or composite suitability of the cell is derived from the aggregation of the individual suitabilities for depth, velocity, and channel index based on the simulated depth, velocity and channel index attributes within a habitat computational cell. The individual suitabilities for depth, velocity and channel index are obtained from the corresponding species and life stage HSC. This is illustrated in Figure 86.

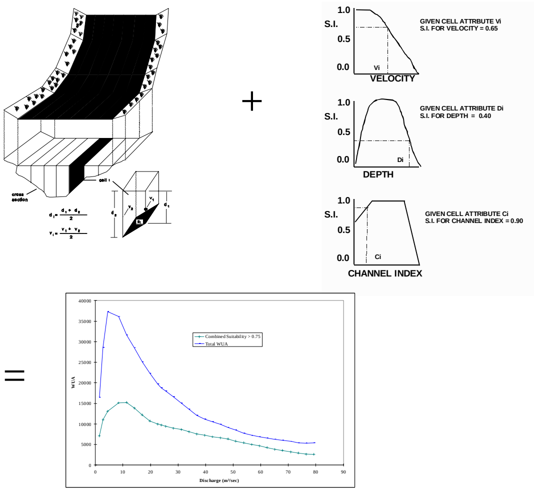


Figure 86. Calculation of component suitability index values for depth, velocity and channel index which generates the WUA versus discharge function for a species and life stage

Composite suitabilities can be computed by a number of methods. The most common are the multiplicative, geometric mean, or limiting value approaches. However, as will be discussed below, alternative methods can be used to meet specific modeling objectives. Although there are some differences between the implementation details used for either one- or two-dimensional habitat modeling, the approaches are conceptually the same. The specific habitat modeling approaches used in these studies are detailed in the following sections.

One-dimensional Cross Section Based Habitat Modeling

This section of the report outlines the specific technical approach and study results for habitat modeling using the USGS/USFWS 1-dimensional cross section data. The first analytical requirement once the hydraulic model calibration and simulation results were obtained (see above) is the appropriate weight to be associated with the results for each cross section. This weighting of individual cross sections is used to estimate the habitat at the reach level based on the habitat mapping results and is described in the next section.

USGS/USFWS Study Site Weightings for Reach Level Habitat Results

Table 42 indicates site locations and the number of cross sections collected by mesohabitat type within the two reach level segments represented by these data. These weightings were used as the basis to obtain both study site specific and reach level habitat results using USGS/USFWS cross section based data for the first two river reaches (i.e., Iron Gate to Shasta River, and Shasta River to Scott River).

Weightings were determined based on the longitudinal distance for each habitat type as a percent of the total reach length. The data in Table 42 were produced by USGS/USFWS from their habitat mapping results and provided to USU.

The USGS/USFWS one-dimensional hydraulic simulation results were used in conjunction with the HSC to predict available habitat as a function of discharge at each of the USGS/USFWS hydraulic modeling study sites. Results for specific hydraulic study sites were aggregated to the reach level based on the weighting in Table 42.

Table 42. Weighting of cross sections for each study site based on summary habitat mapping results.

Segment 1. Iron Gate to Shasta River

MHT	Low Slope (LS)		MHT	Moderate Slope (MS)		MHT	Pool		
Channel Type	Main		Channel Type	Main		Channel Type	Main		Total
Study Site	Transect	Percent	Study Site	Transect	Percent	Study Site	Transect	Percent	Precent
RRanch	6	4.0	RRanch	8	4.0	RRanch	9	4.4	
RRanch	7	4.0	KRCE	2	4.0	KRCE	5	4.4	
KRCE	3	4.0	Cotton	4	4.0	KRCE	6	4.4	
KRCE	4	4.0	Yellow	4	4.0	Cotton	2	4.4	
Cotton	5	4.0	Yellow	5	4.0	Cotton	3	4.4	
Cotton	6	4.0				Yellow	1	4.4	
Cotton	7	4.0				Yellow	2	4.4	
Yellow	6	4.0				Yellow	3	4.4	
Yellow	7	4.0							
Total	9	36.0	Total	5	20.0	Total	8	35.0	91.0

Note: Cotton Transect 7 and Yellow Transect 0 are hydraulic controls - no weighting value.

MHT	Low Slope (LS)		MHT	Moderate Slope (MS)		MHT	Pool		
Channel Type	Split/Mayor Q		Channel Type	Split/Mayor Q		Channel Type	Split/Mayor Q		
Study Site	Transect	Percent	Study Site	Transect	Percent	Study Site	Transect	Percent	
RRanch	2B	1.5	RRanch	5B	1.0	None			2.5

MHT	Low Slope (LS)			MHT	Moderate Slope (MS)		MHT	Pool		
Channel Type	Split/Minor Q			Channel Type	Split/Minor Q		Channel Type	Split/Minor Q		
Study Site	Transect	Percent		Study Site	Transect	Percent	Study Site	Transect	Percent	
RRanch	1	0.4		None			RRanch	2A	1.0	
RRanch	3	0.4								
RRanch	4	0.4								
RRanch	5A	0.4								
Total	4	1.5	3.0	Total	0	0.0	Total	1	1.0	2.5

MHT	Low Slope (LS)		MHT	Moderate Slope (MS)		MHT	Pool		
Channel Type	Side/Minor Q		Channel Type	Side/Minor Q		Channel Type	Side/Minor Q		
Study Site	Transect	Percent	Study Site	Transect	Percent	Study Site	Transect	Percent	
KRCE	3A	0.5	KRCE	1A	1.0	KRCE	2A	2.0	
KRCE	4A	0.5							
Total	2	1.0	Total	1	1.0	Total	1	2.0	4.0
							Grand Total		100.0

Segment 2. Shasta River to Scott River

MHT	Low Slope (LS)		MHT	Moderate Slope (MS)		MHT	Pool		
Channel Type	Main		Channel Type	Main		Channel Type	Main		Total
Study Site	Transect	Percent	Study Site	Transect	Percent	Study Site	Transect	Percent	Precent
Deliverance	1	9.3	Deliverance	2	4.2	Deliverance	5	8.5	
Trees of Heaven	3	9.3	Deliverance	3	4.2	Deliverance	6	8.5	
Brown Bear	4	9.3	Trees of Heaven	1	4.2	Trees of Heaven	5	8.5	
		9.3	Trees of Heaven	2	4.2	Trees of Heaven	6	8.5	
		9.3	Brown Bear	5	4.2	Brown Bear	2	8.5	
		9.3			4.2	Brown Bear	3	8.5	
Total	3	28.0	Total	5	21.0	Total	6	51.0	100.0
							Grand Total		100.0

Fry Life Stages - Escape Cover Dependent Modeling

Field observations and the analysis of data described in the section on HSC development clearly showed a strong association by fry life stages for both specific types of cover and distance to cover. USU conducted a number of initial habitat modeling runs using different HSC criteria and different approaches to illustrate the various methods that could be used to derive the composite suitability factor. The Technical Team reviewed simulation results involving these potential approaches. Based on the technical evaluation of the various simulation results, the Technical Team (and USU) determined that the best approach for representing the observed behavior of fry in the Klamath River was to calculate available habitat using an escape cover based channel index coding scheme in combination with a modification to computational algorithm of the standard habitat model within PHABSIM (i.e., HABTAE).

The channel index coding scheme used the following format:

X.YZ

Where:

X = A numerical value between 1 and 22 representing the vegetation and substrate coding scheme adopted for the study.
Y = A numerical value between 1 and 4 representing the cover type coding scheme adopted for the study.
Z = A numerical value that was 1 if the cell was within 2.0 feet of cover or 0 otherwise.

Escape cover modeling was implemented by designating cover codes at each vertical for each cross section based on field mapping. During field data collection, the distance to cover and type of cover was noted for each cell. Distance to cover was coded as '1.0' as long as a vertical (or cell) along a particular cross section was within two feet of escape cover. Otherwise, the cover component was set to '0.0'. Therefore, for any vertical (or cell) that was more than two feet from suitable escape cover, no habitat value would be assigned regardless of the relative suitability for depth or velocity. This restriction on distance to escape cover was empirically determined from field data collections on fry life stages within the main stem Klamath River as noted previously in the section on HSC development. These cover codes for all cross sections were provided to USU and subsequently used in the habitat analyses for these life stages.

If a cell was more than two feet from escape cover, the composite suitability of the cell was set to 0.0 (i.e., no habitat). If a cell was found to be within two feet of escape cover, then the composite habitat suitability value (CSI) for each cell was computed using the geometric mean of the individual suitabilities associated with velocity, depth, and type of escape cover. This value was then modified by whether the escape cover was substrate (0.17) or vegetation (1.0) (i.e., a cover type modifier). The composite suitability for a given habitat computational cell if it was within two feet of appropriate cover was determined by the following equation:

$$\text{CSI} = (\text{Depth}_{\text{SI}} * \text{Velocity}_{\text{SI}} * \text{Cover}_{\text{SI}})^{1/3} * \text{Cover Type Modifier}$$

In order to implement this equation, USU modified the existing version of the HABTAE model within PHABSIM to allow a fourth variable (i.e., cover type modifier) to be read from the HSC input file and utilized in the computation of composite suitability for a cell. The HSC for substrate allowed incorporation of the two-foot escape cover directly into the coding scheme and therefore did not require any additional information. Program modifications required both an increase in the array sizes for HSC input data to accommodate the combined substrate and distance to escape cover channel index coding scheme as well as a modification to the analytical subroutine in HABTAE that computes the composite suitability to accommodate the fourth variable in the manner described above. Prior to application of the modified algorithm, QA/QC of model output was checked against test data sets analyzed in spreadsheets.

Once these modifications had been implemented and simulation results available for additional review, the Technical Team met with USU at the Trees of Heaven study site. The flow rate at the study site for that day was used to simulate the distribution of the composite suitability at each cross section. The Technical Team then located each cross section within the study site and reviewed the predicted spatial locations for suitable cells at each cross section as a field validation of the modeling approach. This field based review showed overall excellent agreement between predicted and observed locations of suitable habitat at that flow rate.

Steelhead 1^+ Habitat Modeling

Based on comparisons between observed and predicted habitat utilization using a variety of computational approaches with combinations of depth, velocity, substrate, cover, and distance to cover, the best results for steelhead 1+ were obtained using only the geometric mean of the depth and velocity HSC. The composite habitat suitability for all simulations for a cell was derived from the geometric mean of the individual suitability’s associated with velocity and depth as follows:

$$CSI = = (Depth_{SI} * Velocity_{SI})^{1/2}$$

The opportunity for assessing steelhead 1^+ habitat simulations in the field was not possible. The Technical Team did an “office” examination of the simulation outputs.

Salmon Spawning Habitat Modeling

Chinook spawning was computed based on suitable values for depth, velocity, and substrate size with no escape cover or other distance constraints. The composite suitability for a given cell was computed as the geometric mean of the individual suitability’s associated with velocity, depth, and type of channel index (i.e., substrate) as follows:

$$CSI = = (Depth_{SI} * Velocity_{SI} * Substrate_{SI})^{1/3}$$

Habitat Modeling Implementation

Habitat modeling was undertaken using a modified version of the HABTAE program in PHABSIM developed at USU. The modification of the HABTAE program involved the use of a fourth HSC category in HSC input file structure and modification of the algorithm that computes the composite suitability values. This allowed implementation of the desired modeling approach for fry not available in the original version. Chinook spawning and all juvenile life stages were analyzed using the substrate coding for the channel index, while all fry life stages relied upon substrate, distance to cover, and cover type coding as described previously.

Evaluation of Study Site Specific Habitat Modeling Results

The Technical Team undertook an extensive review of the simulation results on a cross section-by-cross section basis for chinook fry, steelhead 1+, and chinook spawning. This review included an evaluation of the simulation results compared against field observations in terms of location and quality of depth, velocity, substrate, cover, distance to cover, and combined suitabilities. This included location of redds within study sites at or adjacent to cross section locations. Overall, the modeling results were found to match the observed distribution of habitat use for these species within the Klamath River based on the data and extensive experience of the field biologists involved on the Technical Team. This provided a field validation of the results.

River Reach Level Habitat Modeling Results

The reach level habitat versus discharge relationships for each species and life stage as well as the corresponding relationships normalized in terms of each species and life stage percent of maximum habitat are provided in Figures 87 and 90. As was noted previously, these habitat results integrate the availability of different mesohabitat types according to the proportion that they occur through each of the river reaches. The two river reach segments represented by the one-dimensional habitat modeling (PHABSIM) are Iron Gate to the Shasta River and Shasta River to the Scott River.

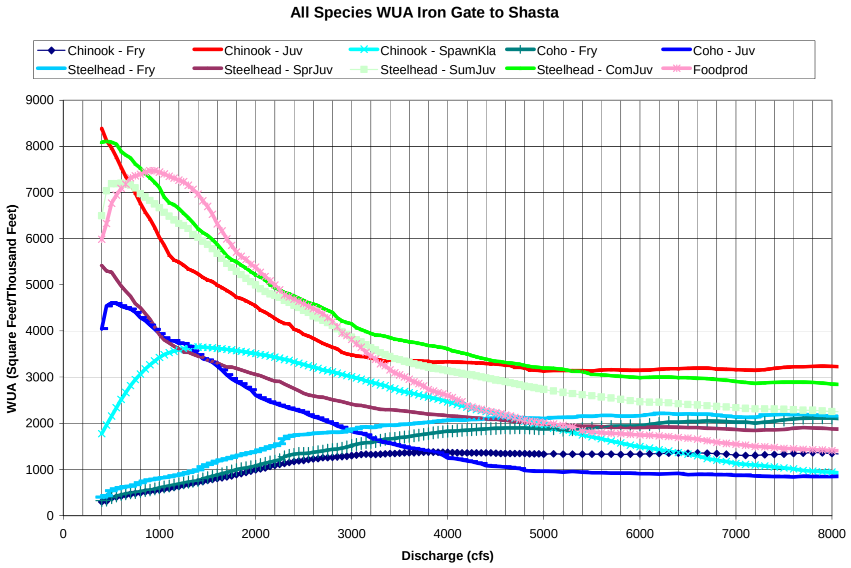


Figure 87. Relationship between available habitat and discharge for each species and life stage in the Iron Gate to Shasta River reach.

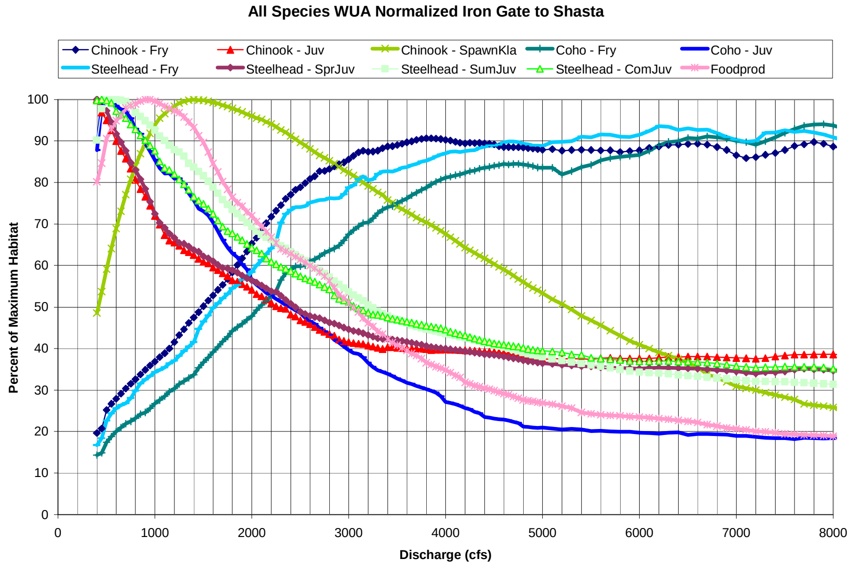


Figure 88. Relationship between percent of maximum habitat and discharge for each species and life stage for the Iron Gate to Shasta River reach.

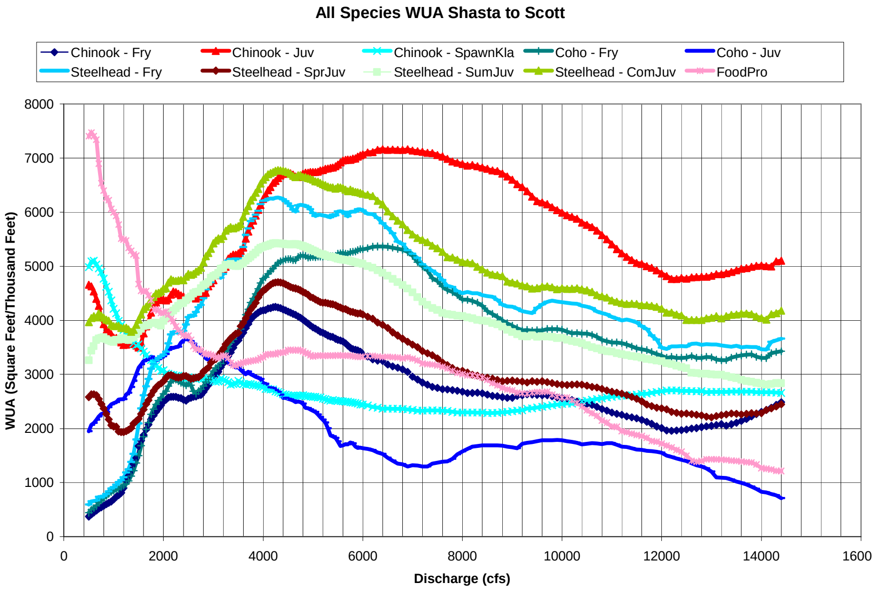


Figure 89. Relationship between available habitat and discharge for each species and life stage in the Shasta River to Scott River reach (one-dimensional modeling).

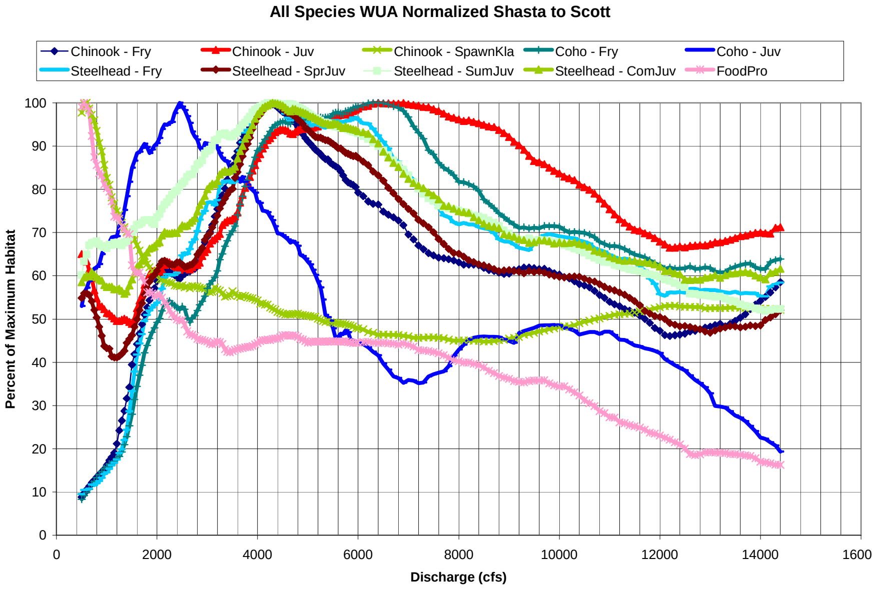


Figure 90. Relationship between percent of maximum habitat and discharge for each species and life stage for the Shasta River to Scott River reach (one-dimensional modeling).

Two-dimensional Based Habitat Modeling

The two-dimensional based habitat modeling paralleled the application of the PHABSIM modeling described above. However, due to the spatial nature of the intensive study site data a more refined habitat analysis was possible compared to the cross section based approach. This is described in this section of the report.

USU Study Site Weightings for Reach Level Habitat Results

The USGS/USFWS field based habitat mapping results were overlaid on the orthrophoto of each study site. GIS was then used to assign each node in the computational mesh the appropriate mesohabitat classification. An example of this at the RRanch study site is illustrated in Figure 91. USGS/USFWS 1-dimensional cross section locations have also been overlaid for reference.

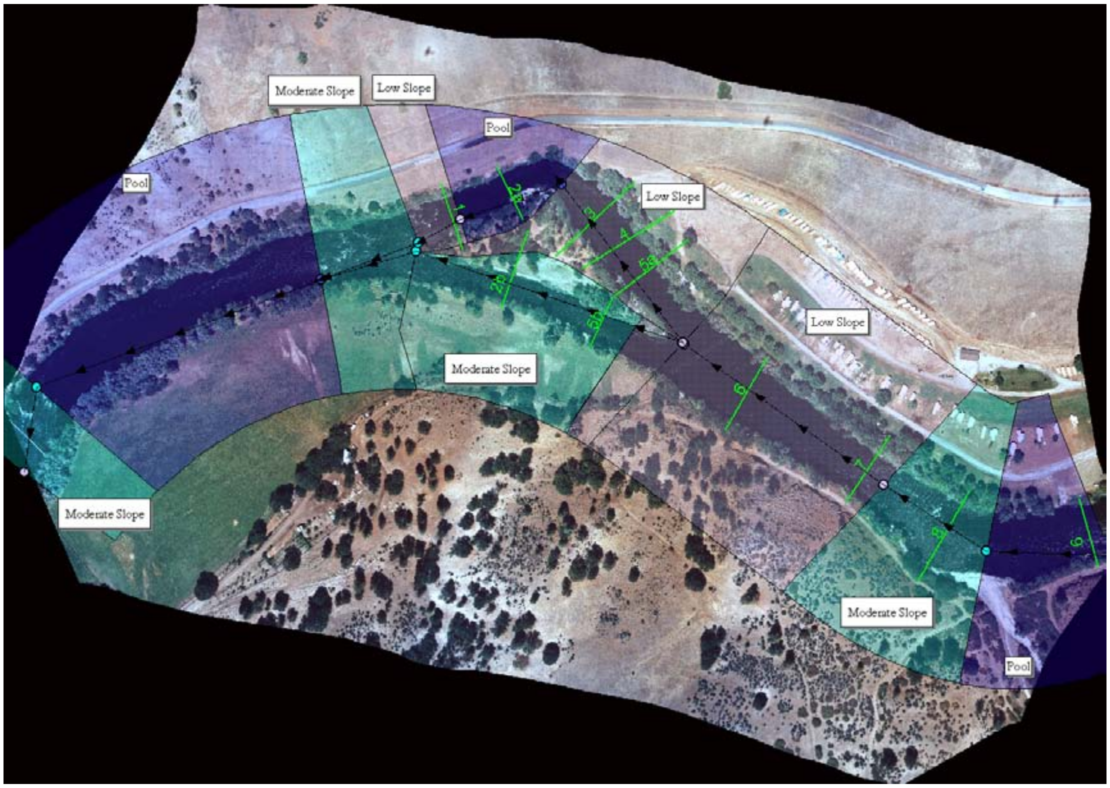


Figure 91. Example of the overlay of field based habitat mapping results on the RRanch study site used as a basis to assign habitat type attributes to each computational node element.

The mesohabitat mapping results were used to compute the total surface area for each habitat type associated with each of the five river reaches. The surface area of each mesohabitat type that was computed at the reach level was used to assign appropriate weighting factors to each computational node element. Table

43 provides the starting and ending river miles for each of the five river segments and the proportion of available mesohabitats within each segment.

Table 43. Starting and ending river miles for each river segment and proportion of available mesohabitat types within each segment.

Segments	Iron Gate Dam to Shasta River	Shasta River to Scott River	Scott River to Salmon River	Salmon River to Trinity River	Trinity River to Estuary
Starting Mile	0.00	13.45	46.94	125.23	148.10
Ending Mile	13.45	46.94	125.23	148.10	194.07
Segment Length (mi.)	13.45	33.49	78.29	22.87	45.97
Mesohabitat					
Main Channel	**Percent**	**Percent**	**Percent**	**Percent**	**Percent**
LS	35.03	25.42	13.13	10.64	22.34
MS	20.93	19.62	16.32	11.84	12.63
SS	3.38	7.38	7.83	6.84	1.33
P	40.66	46.61	60.21	70.18	61.24
RUN	0.00	0.97	2.51	0.49	0.96
POW	0.00	0.00	0.00	0.00	1.50
UNKNOWN	0.00	0.00	0.00	0.00	0.00
Totals	100.00	100.00	100.00	100.00	100.00
Mesohabitat					
Side Channel	**Percent**	**Percent**	**Percent**	**Percent**	**Percent**
LS	22.18	28.37	29.31	31.56	37.96
MS	24.60	23.70	14.13	21.11	16.55
SS	0.00	4.52	10.58	7.35	0.00
P	45.46	43.41	35.45	39.98	45.49
RUN	7.76	0.00	1.71	0.00	0.00
UNKNOWN	0.00	0.00	8.82	0.00	0.00
Totals	100.00	100.00	100.00	100.00	100.00
Mesohabitat					
Split Channel	**Percent**	**Percent**	**Percent**	**Percent**	**Percent**
LS	58.59	20.97	50.55	0.00	39.09
MS	29.37	26.12	32.66	0.00	37.34
SS	0.00	17.73	8.80	0.00	0.00
P	12.03	35.17	7.99	0.00	23.56
RUN	0.00	0.00	0.00	0.00	0.00
UNKNOWN	0.00	0.00	0.00	0.00	0.00
Totals	100.00	100.00	100.00	0.00	100.00

Assigning both the habitat type and proportional weight to each computational node element allowed the total habitat versus discharge relationships at the reach level to be computed directly from the habitat modeling results. Study site-specific habitat versus discharge relationships were also computed by assigning the node specific weighting factors a value of 1.0. This essentially computes habitat for the study site without proportioning the habitat availability to the reach level. In both instances, the weighting factor multiplies the area associated with each computational node to scale the results to the appropriate reach level or site-specific level.

Fry Escape Cover Modeling

The spatially explicit substrate and vegetation mapping for each of the study site was overlaid on the computational mesh and utilized to assign substrate and vegetation codes to every node in a manner similar to that described above for assigning mesohabitat attributes. This was accomplished using GIS. Based on the codes for either substrate or vegetation classes that were considered suitable for fry escape cover (i.e. HSC values were not 0.0), the distance to the nearest escape cover and the type of cover was computed for every computational node. A radial search algorithm was adopted for this purpose and computed within the GIS. In addition, the bed elevation associated with the location of the cover node was also recorded. This permitted the habitat modeling algorithm for fry to compute the depth of the cover element at the specified flow rate. These data were then exported for integration with the hydraulic solution properties (depth and velocity) data in the habitat modeling system developed by USU.

At a given flow rate, for each node, the integrated data sets included the x and y location, area for the node, bed elevation, simulated depth and mean column velocity, substrate and vegetation code of the node, habitat type, node weighting factor, distance to nearest escape cover, type of escape cover, and the elevation of the cell containing the escape cover. Other data such as temperature and drift size densities associated with the bioenergetics modeling are described in that section of report.

An algorithm to compute available habitat using these data and the HSC described previously was developed at USU specifically for this project. The algorithm uses the HSC for fry (or other) life stages to evaluate whether an existing node is within the user specified distance threshold for escape cover (e.g., two feet) and then determines whether the actual node containing the escape cover at that flow rate meets a specified minimum depth threshold (i.e., set at 0.4 feet for fry in this study). This depth criteria threshold was implemented to ensure that a cover element contained sufficient depth to allow access by fry to the escape cover at that simulated flow rate.

If both of these criteria are met, then the combined suitability of the node is computed from the geometric mean of the node depth, velocity, and cover type individual suitabilities. The combined suitability of the node is then adjusted by the cover type modifier derived form whether the cover element contained vegetation (i.e., suitability of 1.0) or substrate (i.e., suitability of 0.17). Otherwise, the habitat value of the node is set to zero.

This is computationally similar to the habitat modeling approach described for fry using the 1-dimensional PHABSIM approach. It differs however in that the distance to cover is computed from a radial search in all directions and incorporates an explicit depth threshold for the cover 'cell' (or node).

Steelhead 1$^+$ Habitat Modeling

Steelhead 1$^+$ modeling followed the same computational steps as described for this life stage using the 1-dimensional PHABSIM based modeling. Calculations were made on a node-by-node basis and the habitat modeling algorithm developed by USU incorporated this 'standard' modeling approach as the default option. A variety of alternative modeling options that incorporated distance to cover, and different combinations of depth, velocity, substrate, etc were also explored before using the specific approach described above for this study. This approach was selected based on comparisons between the simulated quantity and quality of available habitat and fish observation data at study sites.

Salmon Spawning Habitat Modeling

Chinook spawning habitat was computed on a node-by-node basis from the HSC values for depth, velocity, and substrate size with no escape cover or other distance constraints. This is equivalent to the approach taken with the 1-dimensional PHABSIM data sets. The composite suitability for a given node was computed as the geometric mean of the individual velocity, depth and channel index (substrate) suitability's as described previously.

HSC and Habitat Modeling Field Validation

Habitat simulations for each species and life stage were initially conducted at each study site without any reach level weightings (i.e., node weight values = 1.0). These site-specific habitat simulations were utilized at each intensive study site to empirically validate the HSC and in particular, to validate the habitat modeling results. For any species and life stages evaluated in the habitat modeling for which actual fish observations were available, a comparison between fish location and habitat modeling results was undertaken. This comparison represents an empirically based validation of the habitat modeling results.

Field data collections undertaken by state, federal, and tribal biologists in support of the Phase II work were provided to USU. These data delineated the spatial location of specific species and life stages and the flow rate at which the data were observed. Several flow rates were typically sampled at each study location. The number of fish observations also varied by date, location, species, and life stage. All available fish observation data were utilized for the comparisons. These data were used to overlay the fish locations on the orthophoto's at each study site and were represented as color circles on the images.

The simulated combined suitability at all nodes associated with a particular flow rate was used to generate contours of suitable habitat between 0.00001 and 1.0 to overlay the spatial distribution of predicted habitat at each study site. Setting the lower threshold at 0.00001 eliminated completely non-suitable conditions from the contour overlays of habitat. In the following figures, nodes with combined suitability less than this lower threshold are therefore 'transparent' and the underlying image of the river is visible.

It should be noted when examining these results that the computational mesh for each study site does not encompass the extreme upstream or downstream sections of the visible river in each orthophotograph. Some fish observations shown at the extreme upstream and downstream sections in the images are in fact outside the 'model spatial domain' and modeling results should not be interpreted as providing no habitat values in these areas. These circumstances are noted where appropriate in the figure legends.

Care should also be taken when comparing predicted habitat quality and fish observations. In several instances, observed flow rates associated with fish collections are not identical to the flow rates associated with the habitat simulations used in comparisons. This is noted where appropriate in the figure legends. It should be also be understood that the flow depicted in the imagery (flow when aerial photos were flown) is not always near the flow magnitude used in the modeling comparisons. Therefore, modeled stream boundaries (i.e., edge of water) and fish locations may be higher or lower than the water depicted in the images. This is readily apparent in some instances where fish appear to be located on 'dry ground'. It is also important to realize that fish observations occurred only within small sections of the study sites. Therefore, suitable habitat that contains no fish observations typically occur because no sampling occurred in these areas. Finally, it should be noted that fish observation data shown in the comparisons also contain observation data not utilized in the development of site-specific HSC and therefore actually represent both verification as well as validation data.

Chinook Spawning

Figures 92 through 99 show predicted habitat suitability (i.e., combined suitability at each node) versus the spatial location of chinook spawning redds at different flow rates for various study sites where observation data was available. It is clear from an examination of these results that there is generally excellent agreement between predicted and observed spatial distribution of redds at different flow rates and locations within the main stem Klamath River. Note in Figures 91 and 92 that a few redd locations were found in a 'patch' of stream (upper right center) that the model indicates is not suitable (i.e., no color). This area has substrate delineations that are too coarse for chinook spawning in the model although the depths and velocity were suitable. Field biologists indicate that this area has 'small patches' of suitable gravel behind large substrate elements that are utilized for spawning (USFWS, personnel communication). These small patch sizes were not incorporated into the substrate polygon mapping at the study sites described previously.

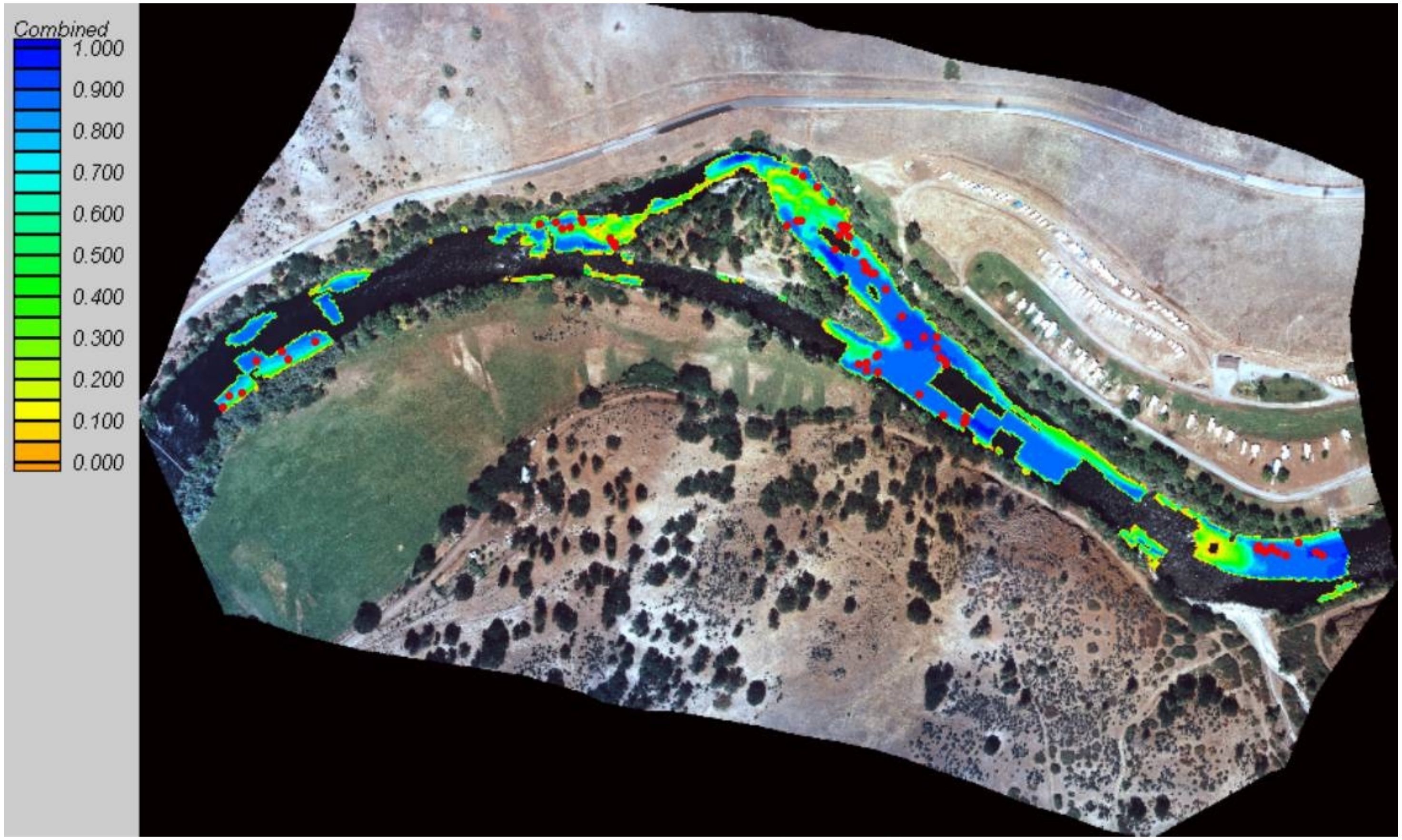


Figure 92. Suitability of predicted habitat versus observed spawning locations for chinook within the Rranch study site at approximately 1300 cfs.

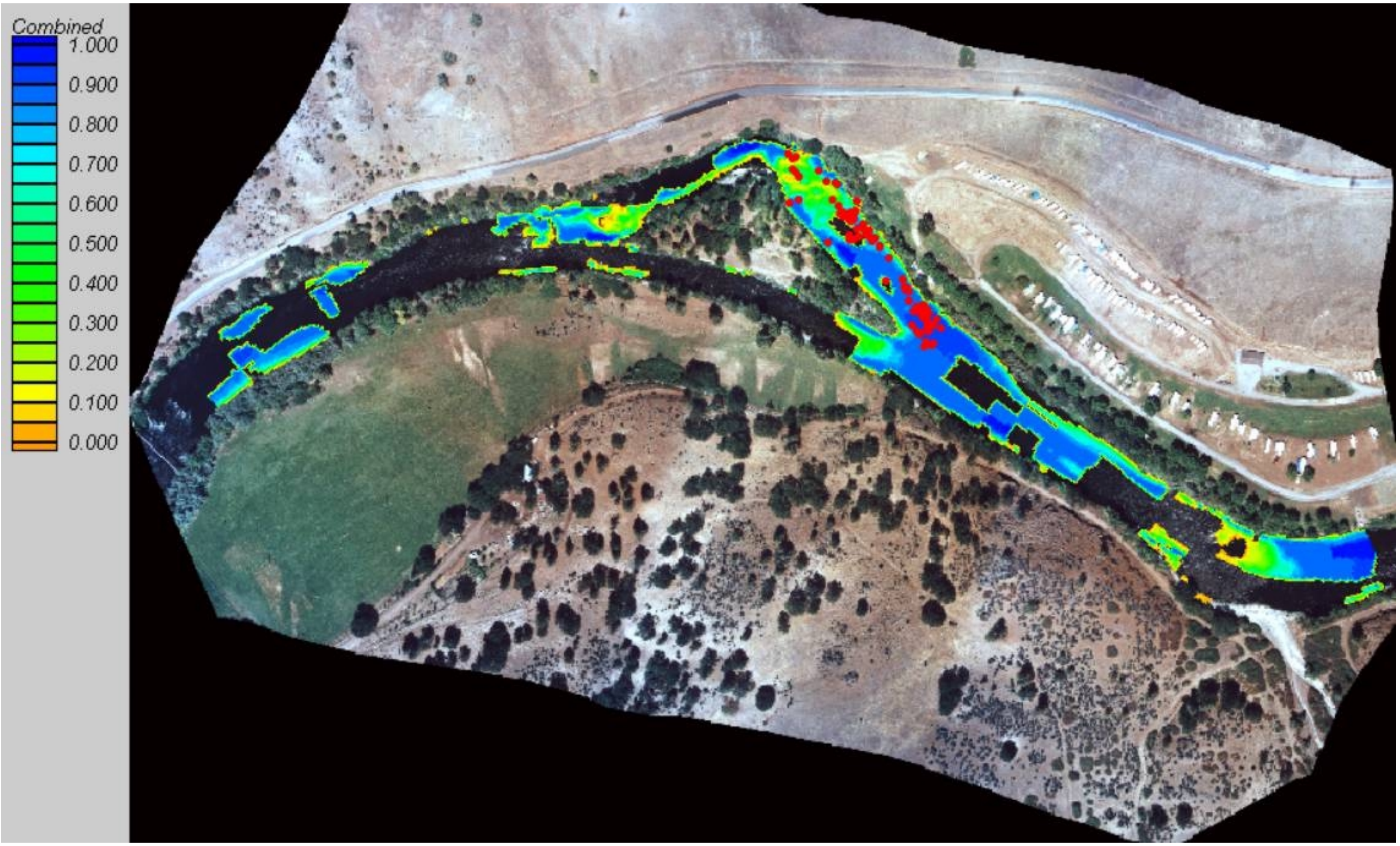


Figure 93. Suitability of predicted habitat versus observed spawning locations for chinook within the Rranch study site at approximately 1377 cfs.

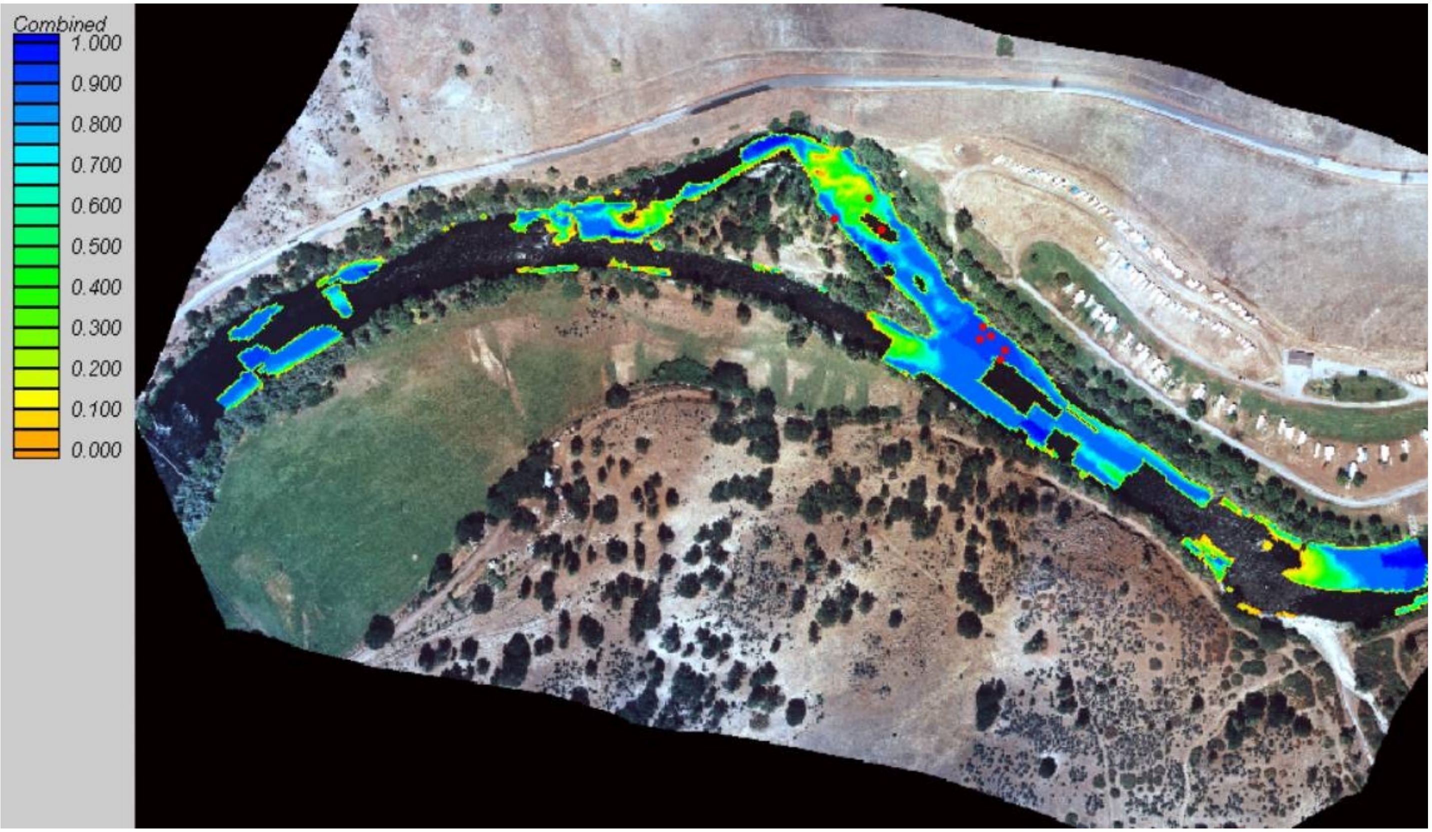


Figure 94. Suitability of predicted habitat versus observed spawning locations for chinook within the Rranch study site at approximately 1765 cfs.

In the previous three images, the highly suitable habitat to the lower right of the island is know to contain spawning redds (USFWS, unpublished field observations) although these redd locations were not surveyed in the collections.

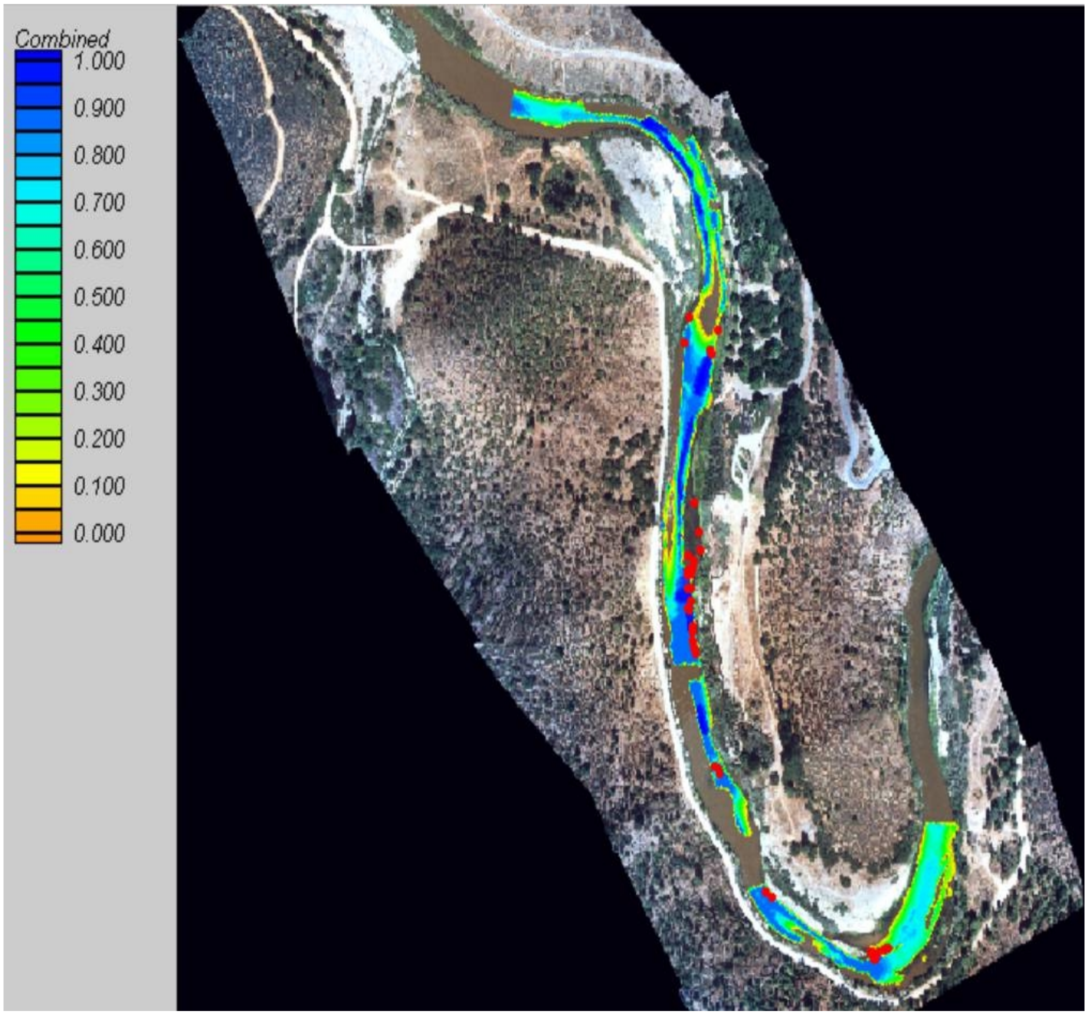


Figure 95. Suitability of predicted habitat versus observed spawning locations for chinook within the Trees of Heaven study site. Fish collections were made at approximately 1300 cfs and habitat simulations are shown for 1123 cfs. This accounts for the apparent lack of predicted habitat at redd locations at the center right channel location.

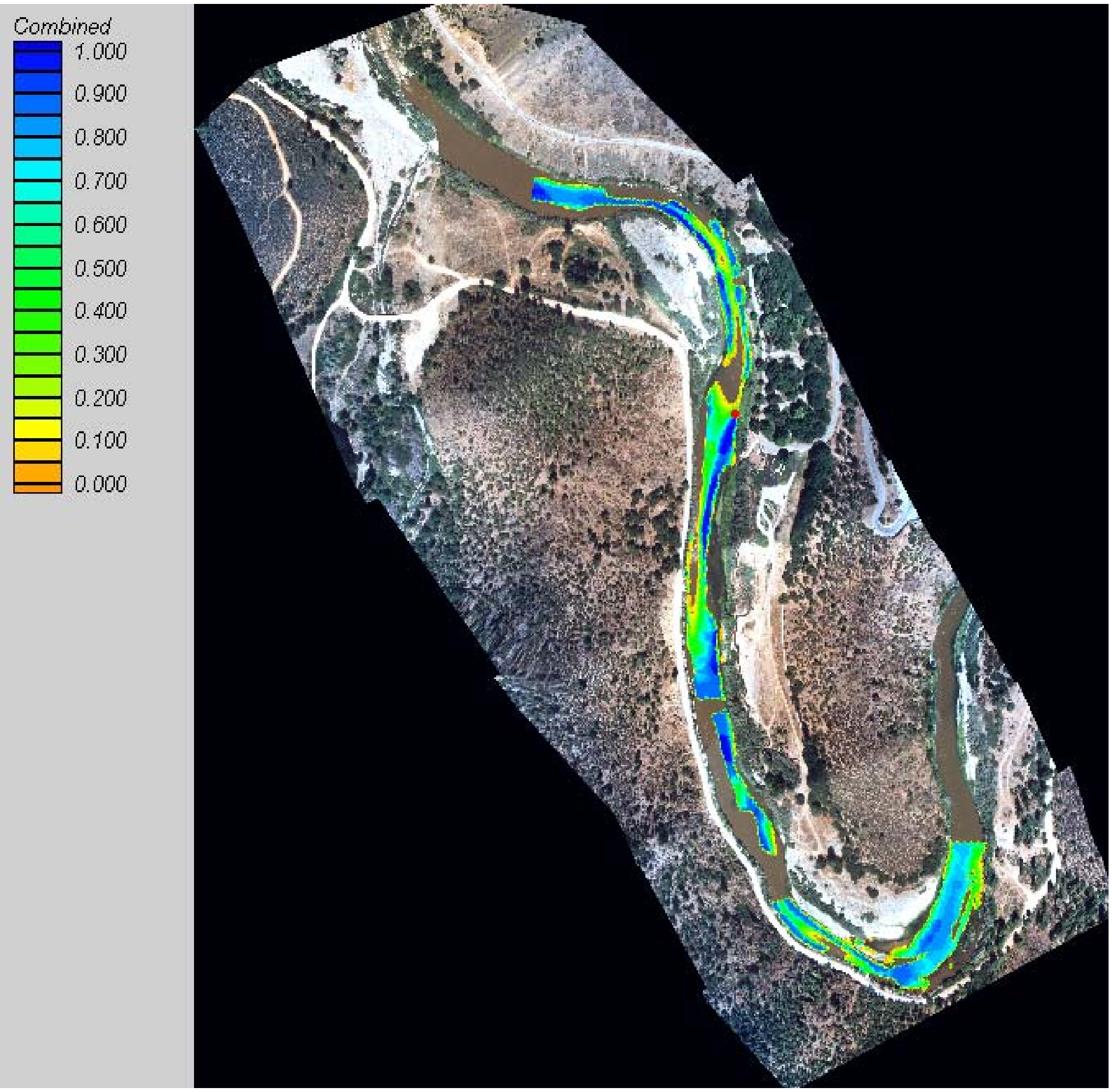


Figure 96. Suitability of predicted habitat versus observed spawning locations for chinook within the Trees of Heaven study site. Fish collections were made at approximately 1520 cfs.

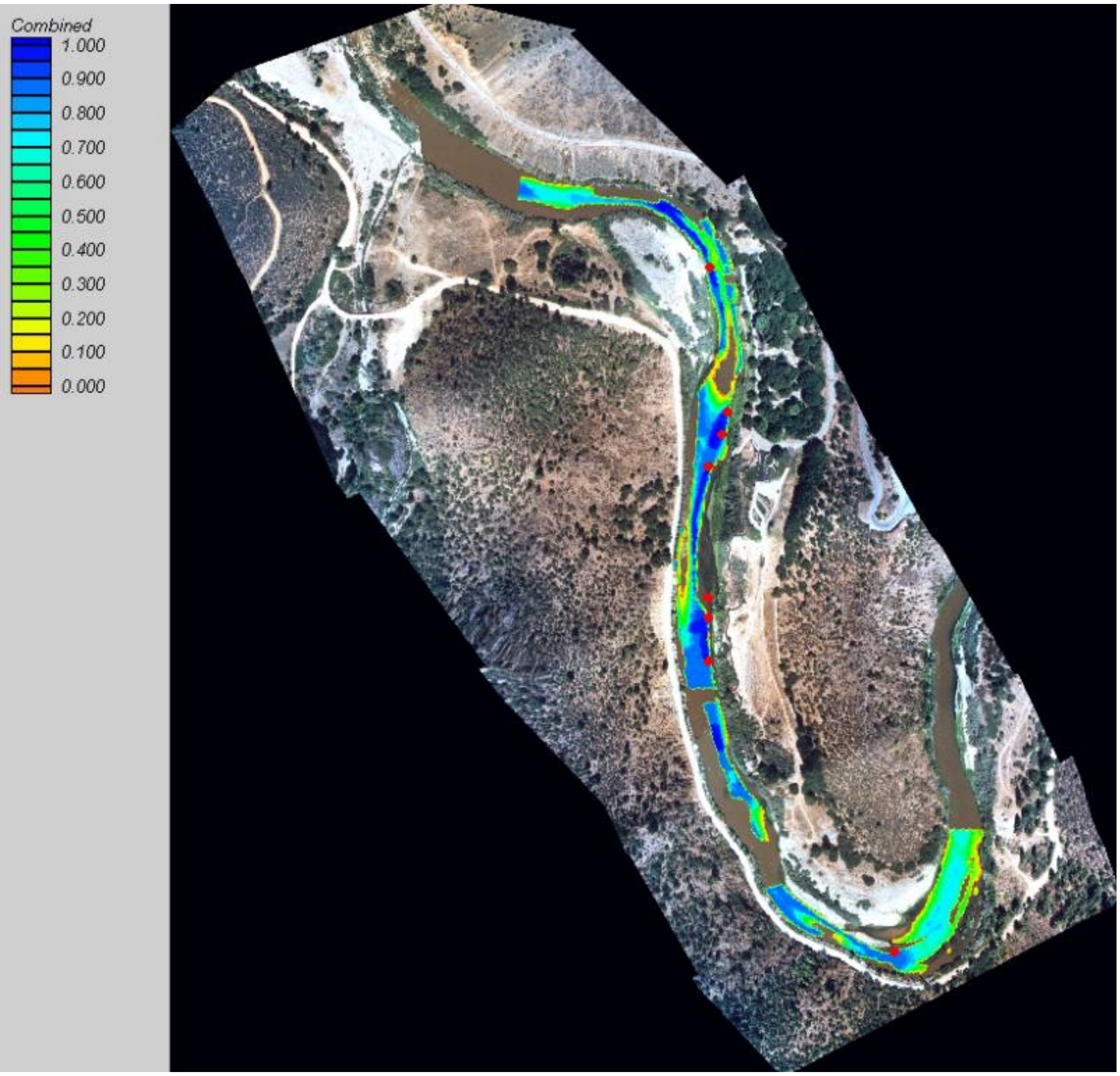


Figure 97. Suitability of predicted habitat versus observed spawning locations for chinook within the Trees of Heaven study site. Fish collections were made at approximately at 1765 cfs. The simulated habitat is at 1629 cfs.

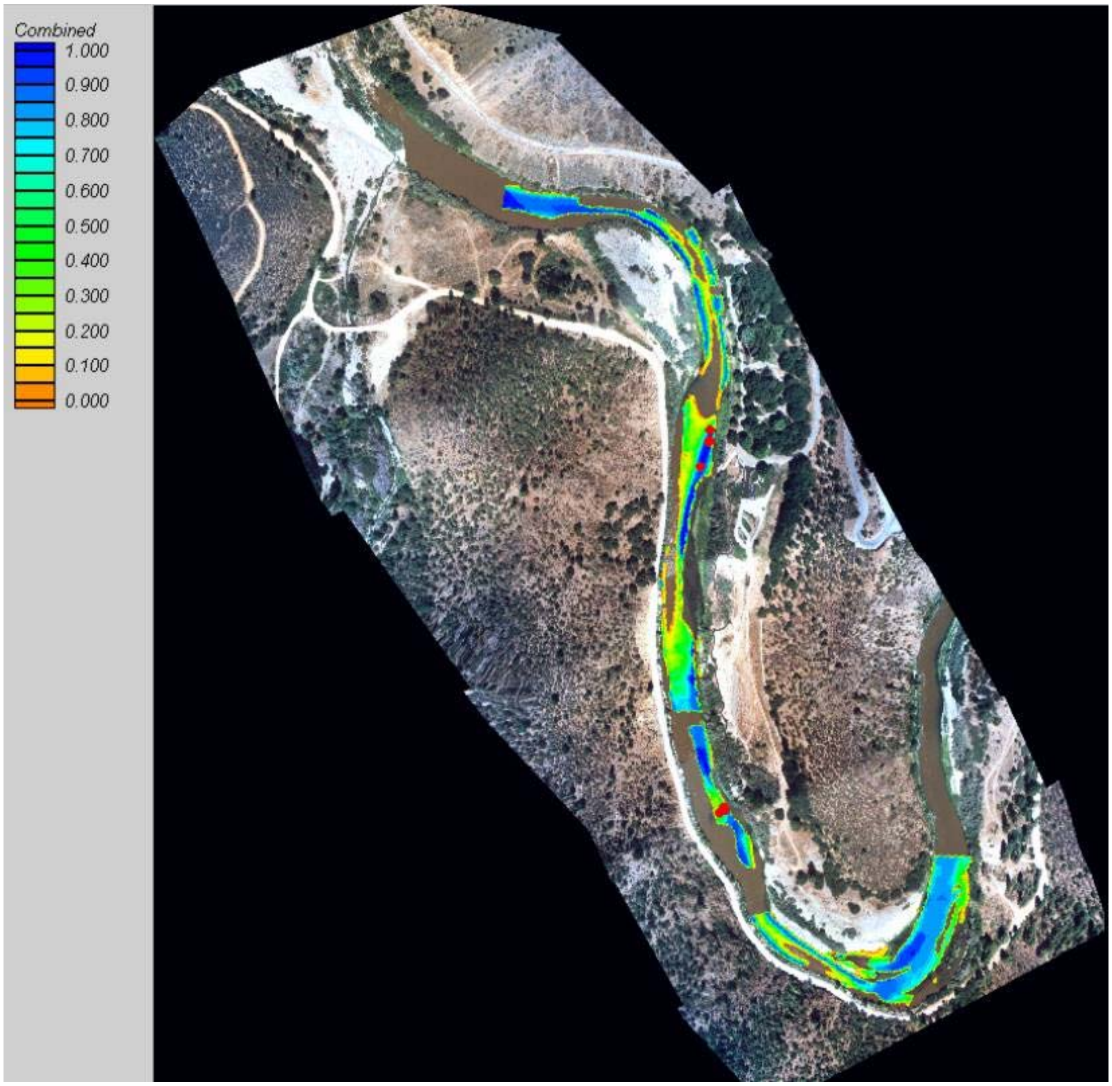


Figure 98. Suitability of predicted habitat versus observed spawning locations for chinook within the Trees of Heaven study site. Fish collections were made at approximately 2048 cfs.

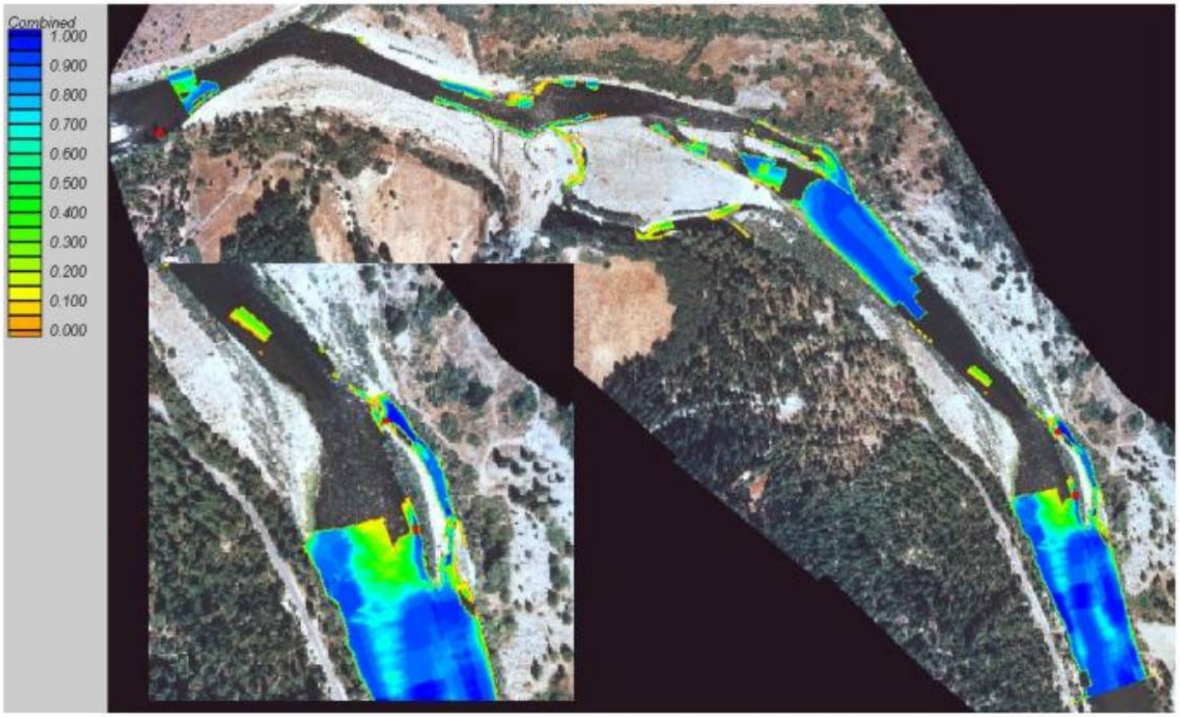


Figure 99. Suitability of predicted habitat versus observed spawning locations for chinook within the Seiad study site. Fish collections were made at approximately 2700 cfs

The simulation results shown above demonstrate that the habitat modeling works extremely well over a wide range of observed discharges and across a variety of study sites with very different habitat availability features. Based on these results we place a high degree of confidence in these modeling results.

Chinook Fry

Figures 100 through 106 show predicted habitat suitability (i.e., combined suitability at each node) versus the spatial location of chinook fry collected at different flow rates for various study sites where observation data was available.

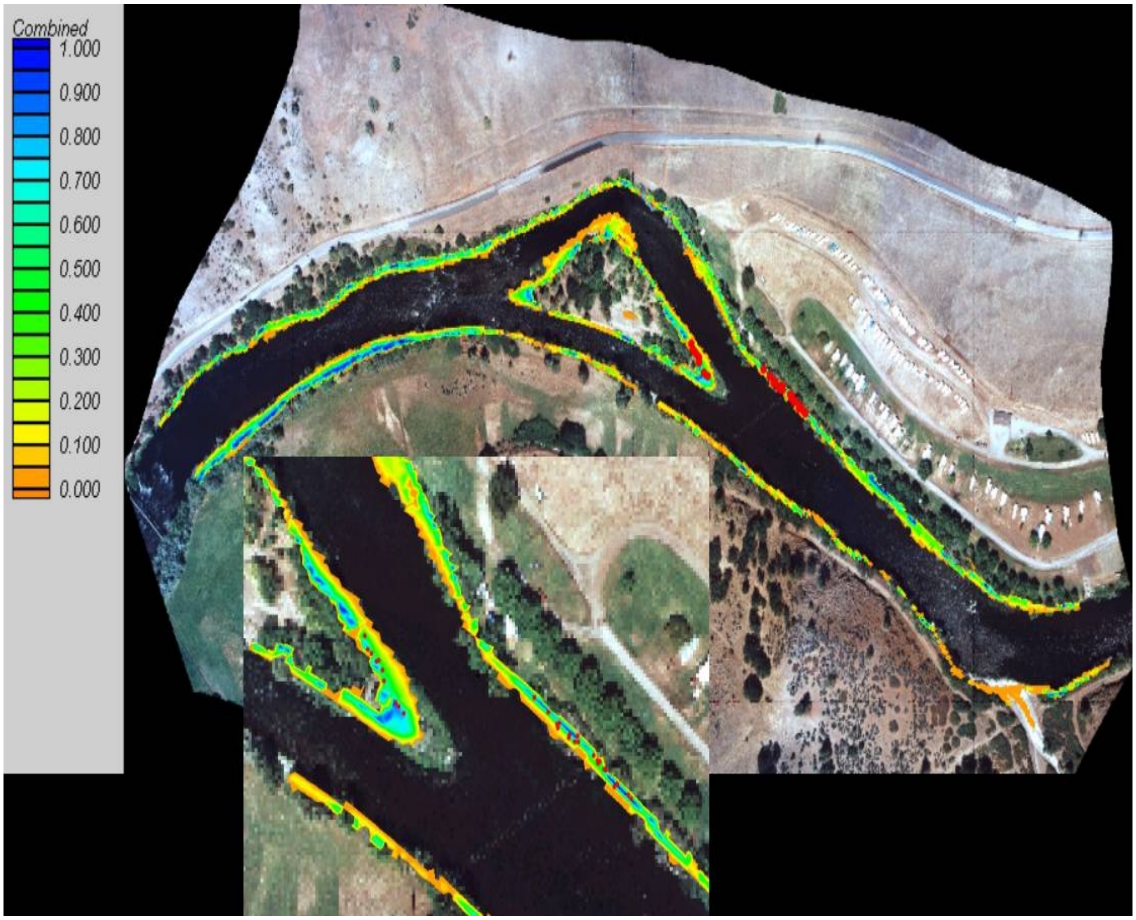


Figure 100. Suitability of predicted habitat versus observed fry locations for chinook within the Rranch study site. Fish collections were made at approximately 5230 cfs.

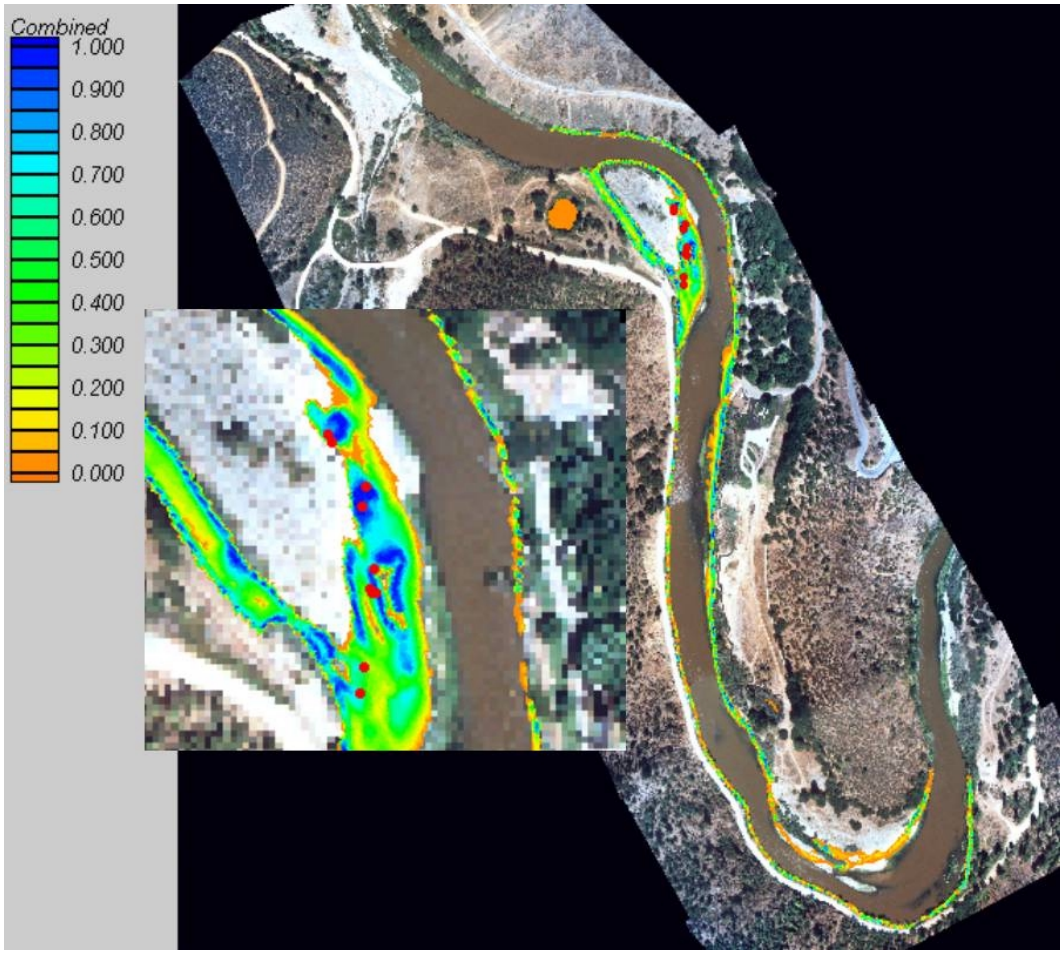


Figure 101. Suitability of predicted habitat versus observed fry locations for chinook within the Trees of Heaven study site. Fish collections were made at approximately 5190 cfs.

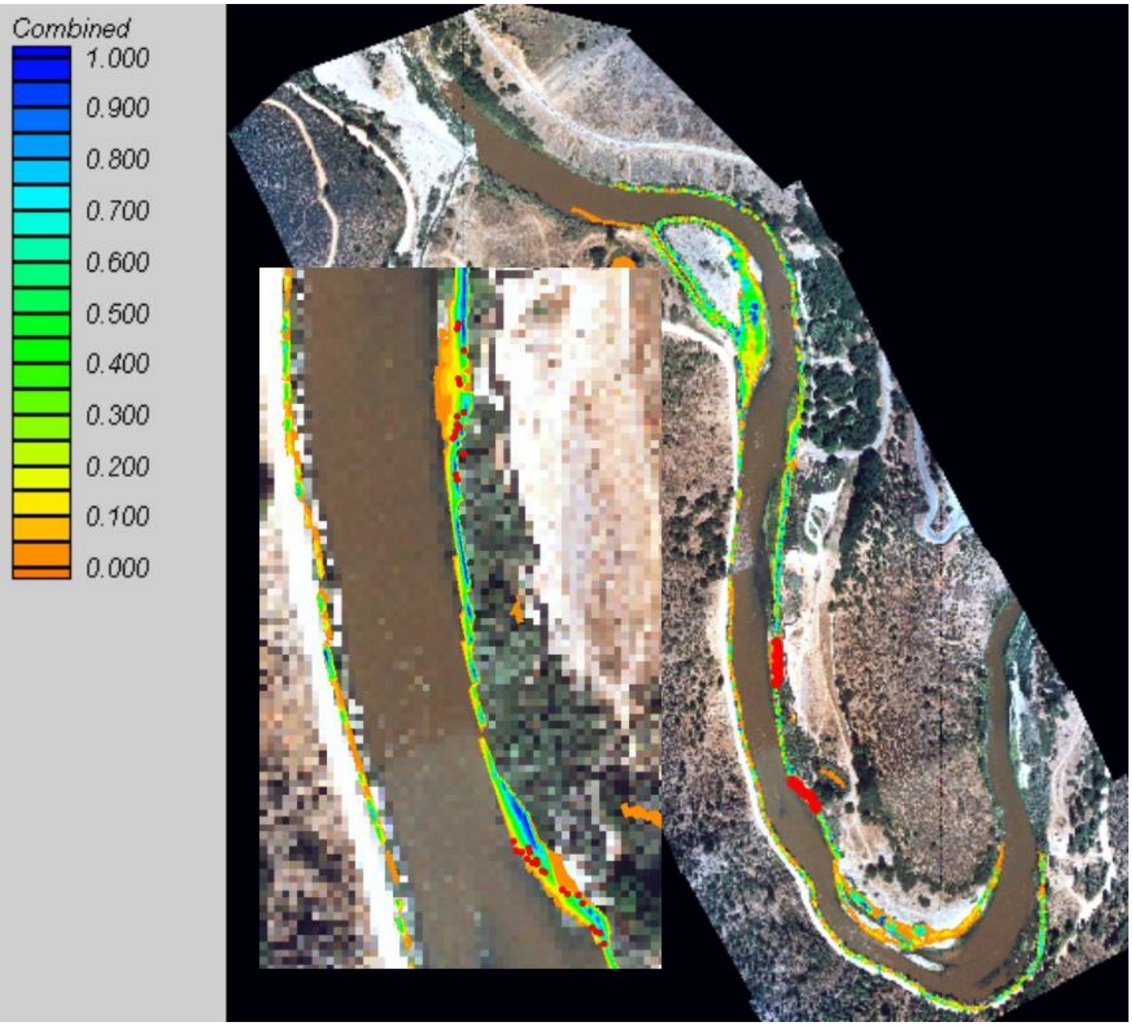


Figure 102. Suitability of predicted habitat versus observed fry locations for chinook within the Trees of Heaven study site. Fish collections were made at approximately 6000 cfs.

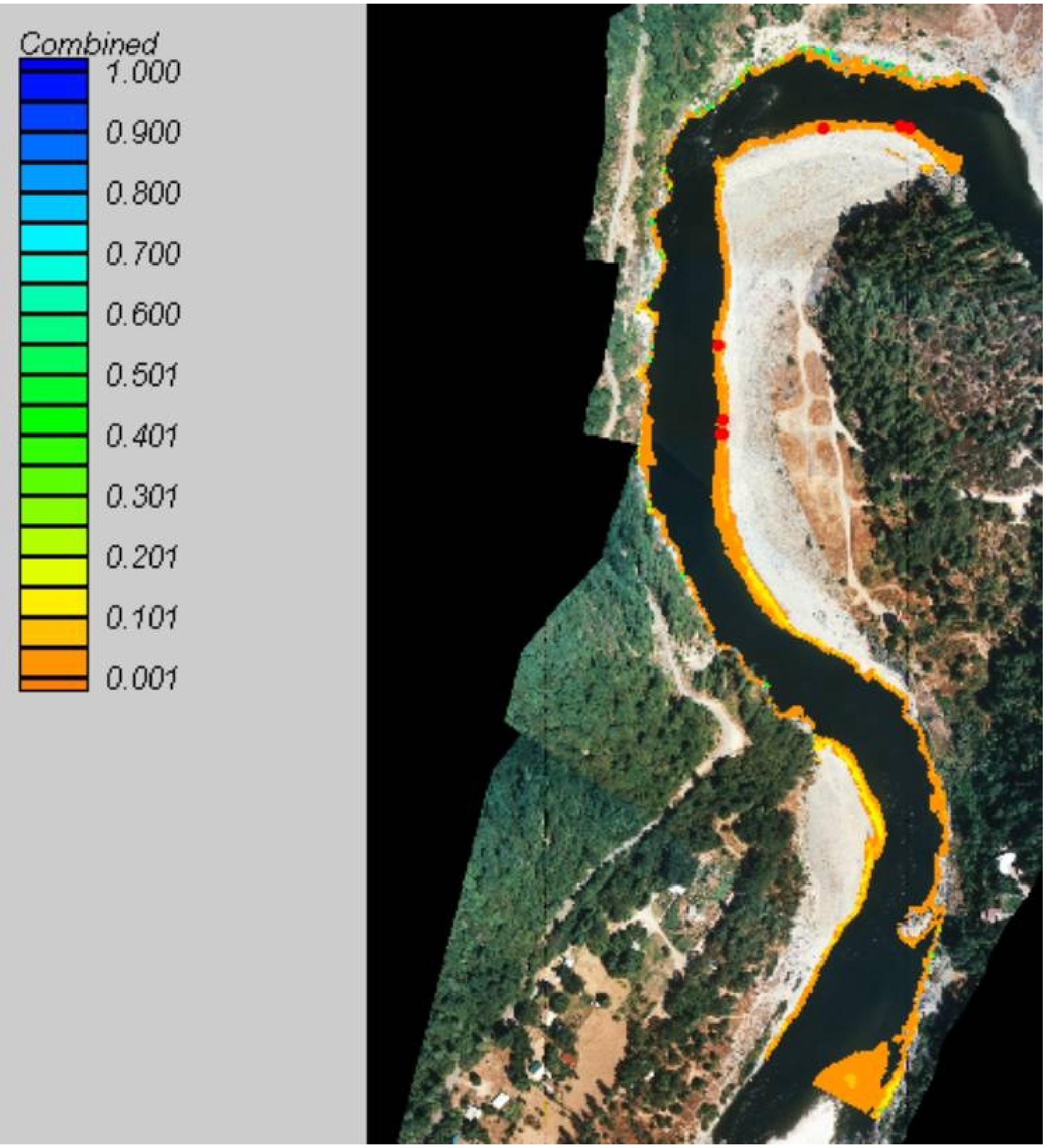


Figure 103. Suitability of predicted habitat versus observed fry locations for chinook within the Orleans study site. Fish collections were made at approximately 3350 cfs. Flows are simulated at approximately 3200 cfs.

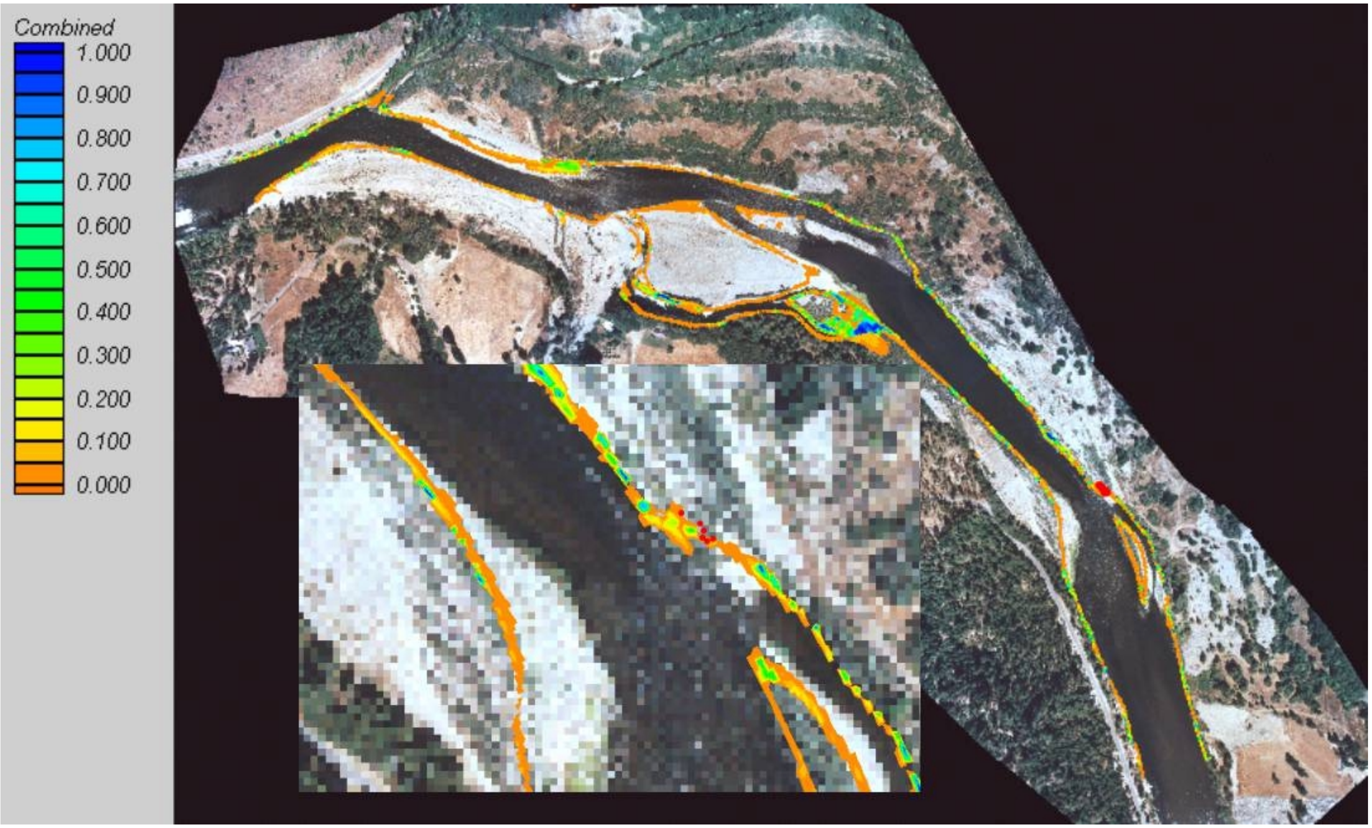


Figure 104. Suitability of predicted habitat versus observed fry locations for chinook within the Seiad study site. Fish collections were made at approximately 8475 cfs.

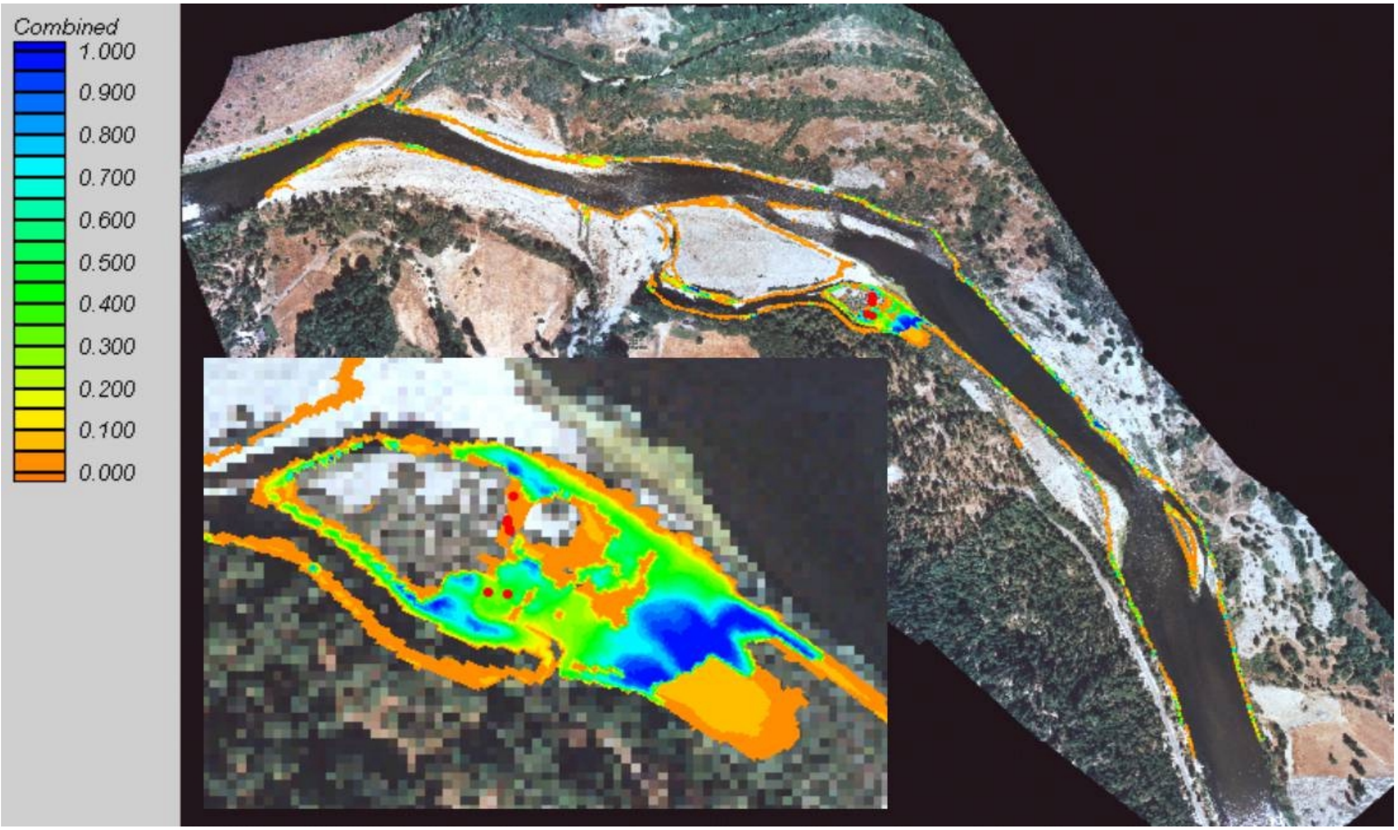


Figure 105. Suitability of predicted habitat versus observed fry locations for chinook within the Seiad study site. Fish collections were made at approximately 9960 cfs. Simulated flows are approximately 9320 cfs.

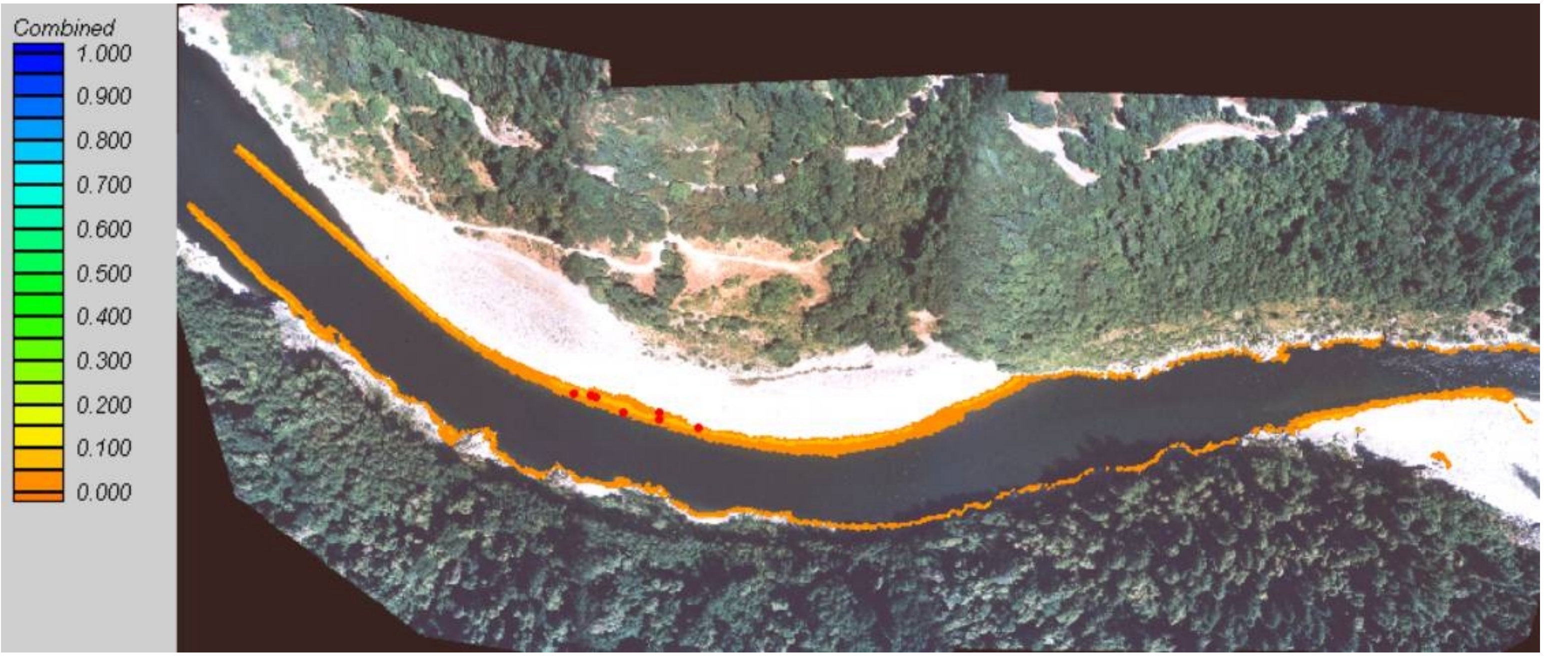


Figure 106. Suitability of predicted habitat versus observed fry locations for chinook within the Young's Bar study site. Fish collections were made at approximately 6850 cfs. Simulated flows are approximately 5340 cfs.

The simulation results shown above for chinook fry demonstrate that the habitat modeling works extremely well over a wide range of observed discharges and across a variety of study sites with very different habitat availability features. In particular, the incorporation of escape cover dependencies in the habitat simulations show a pattern of habitat in terms of spatial distribution and relative suitability that closely matches observed behavior and distribution in the river.

It should be pointed out, that fish habitat utilization is not expected to always occur in the highest combined suitability habitats for a variety of reasons as discussed at the beginning of the HSC Section of the report (e.g., predation, temperature, food availability, presence of predators, etc). However, it is expected that fish distributions should be spatially distributed in a ‘presence or absence’ manner associated with useable (i.e., combined suitability > 0.0) versus non-usable (i.e., combined suitability = 0.0) habitats. Based on these results we place a high degree of confidence in these modeling results.

Steelhead Fry

Figure 107 shows predicted habitat suitability (i.e., combined suitability at each node) versus the spatial location of steelhead fry collected at a single flow rate of approximately 1300 cfs at the RRanch study. These simulation results were generated using the generalized HSC as discussed above and therefore represent an important test for applicability of these HSC to the Klamath River. This comparison in essence represents an empirical based ‘transferability test’ that incorporates not only the form of the HSC but also the computational aspects of the habitat modeling equations chosen (i.e., how combined suitability is computed). Unfortunately, steelhead fry observations at other flow rates and study site locations were not available for a more extensive comparison of the modeling results.

It is clear from an examination of these results that there is generally good agreement between predicted and observed habitat utilization at this flow rate and fish locations match up well with the overall spatial mosaic of predicted habitat availability. It should be noted that the steelhead fry located at the lower far left in the image (i.e., downstream section of the river) lie outside the computational boundaries of the habitat model for this reach and should not be interpreted as being located in predicted non-suitable habitat.

Figure 107. Suitability of predicted habitat versus observed fry locations for chinook within the Rranch study site. Fish collections were made at approximately 1300 cfs. Fish at far left are outside the computational mesh

Coho Fry

No Coho fry observational data were available for a comparison of modeling results to be made within the main stem Klamath River. However, based on the simulation results for chinook fry and coho fry, and known life history strategies, we believe that the simulation results to be competent to use in the instream flow evaluations. Habitat simulation results for coho closely parallel the results shown for chinook fry in terms of the spatial distribution and magnitudes of suitable habitat.

Chinook Juvenile

Figures 108 and 109 show predicted habitat suitability (i.e., combined suitability at each node) versus the spatial location of chinook juveniles collected at two different flow rates at two study sites where observation data was available. These simulation results were generated using the generalized HSC as discussed above and therefore represent an important test for applicability of these HSC to the Klamath River.

It is clear from an examination of these results that there is good agreement between predicted and observed habitat utilization. Chinook juvenile locations generally match up well with the overall spatial mosaic of predicted habitat availability at these sites. More extensive observational data at a wider range of flows and at more study site locations would benefit these comparisons. However, for the available data, the modeling results support the efficacy of the generalized HSC for chinook juveniles in their application to the Klamath River.

Coho Juvenile

Figures 110 and 111 show predicted habitat suitability (i.e., combined suitability at each node) versus the spatial location of coho juveniles collected at two different flow rates at the Rranch study site where observation data was available. These simulation results were generated using the generalized HSC as discussed above and therefore represent an important test for applicability of these HSC to the Klamath River.

It is clear from an examination of these results that there is generally good agreement between predicted and observed habitat utilization. Coho juvenile locations match up well with the overall spatial mosaic of predicted habitat availability at these sites. As was noted for chinook juveniles, more extensive observational data at a wider range of flows and at more study site locations would benefit these comparisons. However, for the available data, the modeling results generally support the efficacy of the generalized HSC for coho juveniles in their application to the Klamath River.

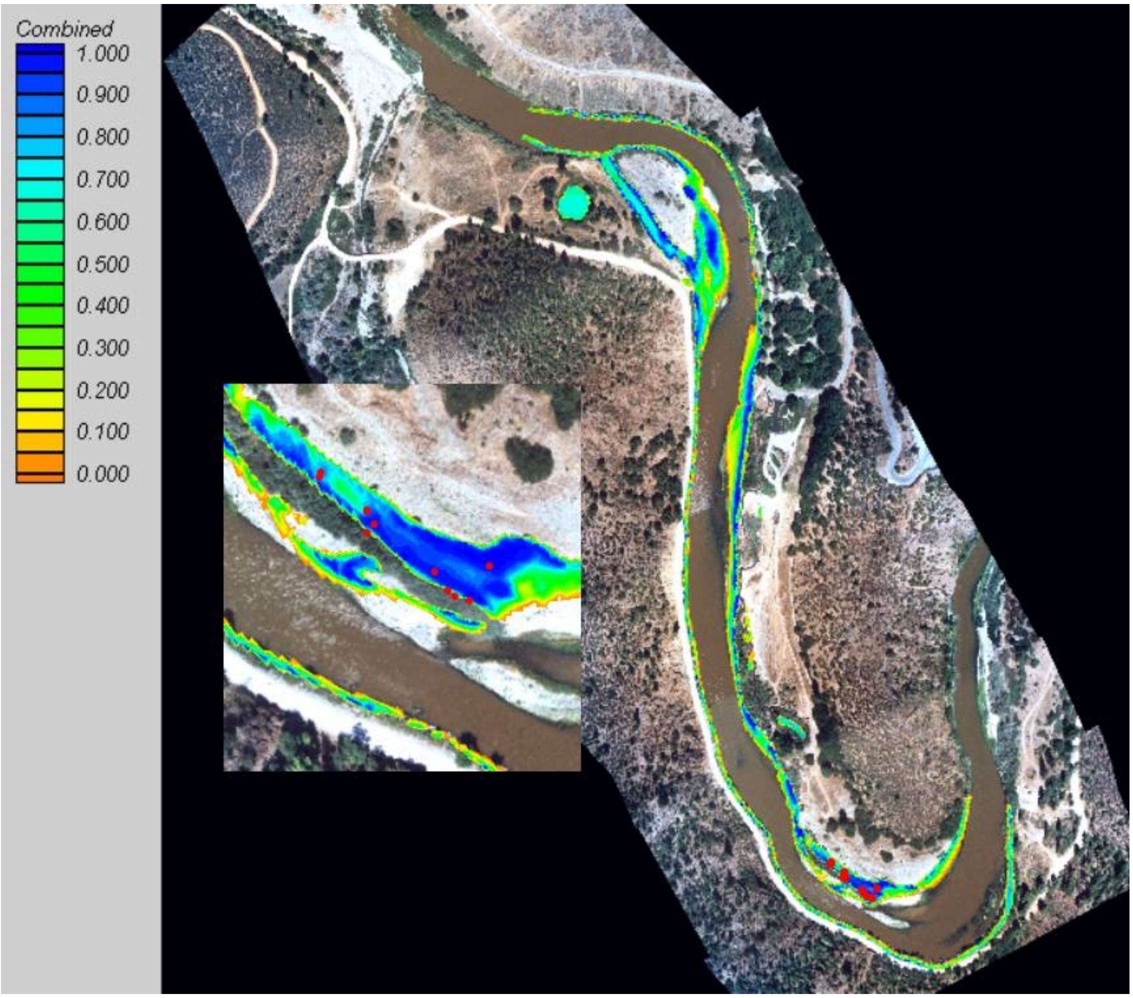


Figure 108. Suitability of predicted habitat versus observed juvenile locations for chinook within the Trees of Heaven study site. Fish collections were made at approximately 6000 cfs. Simulated flows are approximately 6500 cfs. Simulation of a flow rate closer to the fish observations would shift the distribution of high quality habitat toward the center of the stream and improve the already good agreement between observed fish and predicted habitat quality and location.

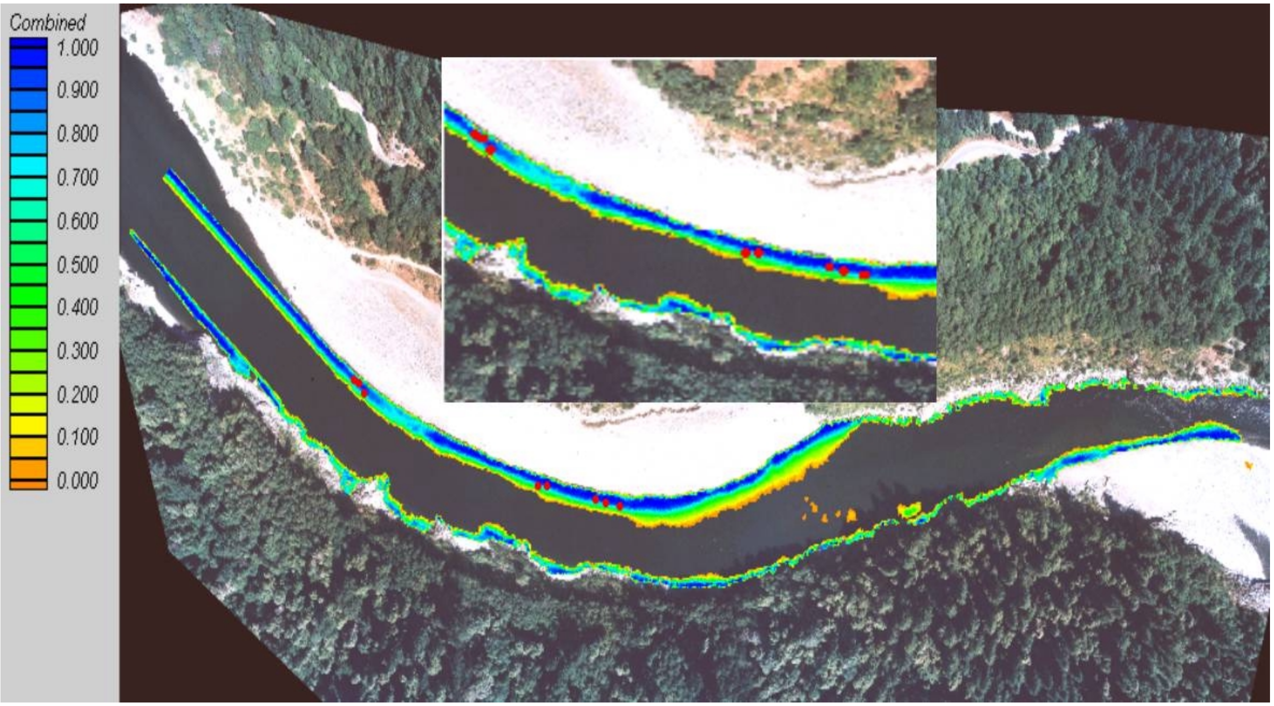


Figure 109. Suitability of predicted habitat versus observed juvenile locations for chinook within the Young's Bar study site. Fish collections were made at approximately 2825 cfs. Simulated flows are approximately 3140 cfs. Simulation of a flow rate closer to the fish observations would shift the distribution of high quality habitat toward the center of the stream and improve the already good agreement between observed fish and predicted habitat quality and location.

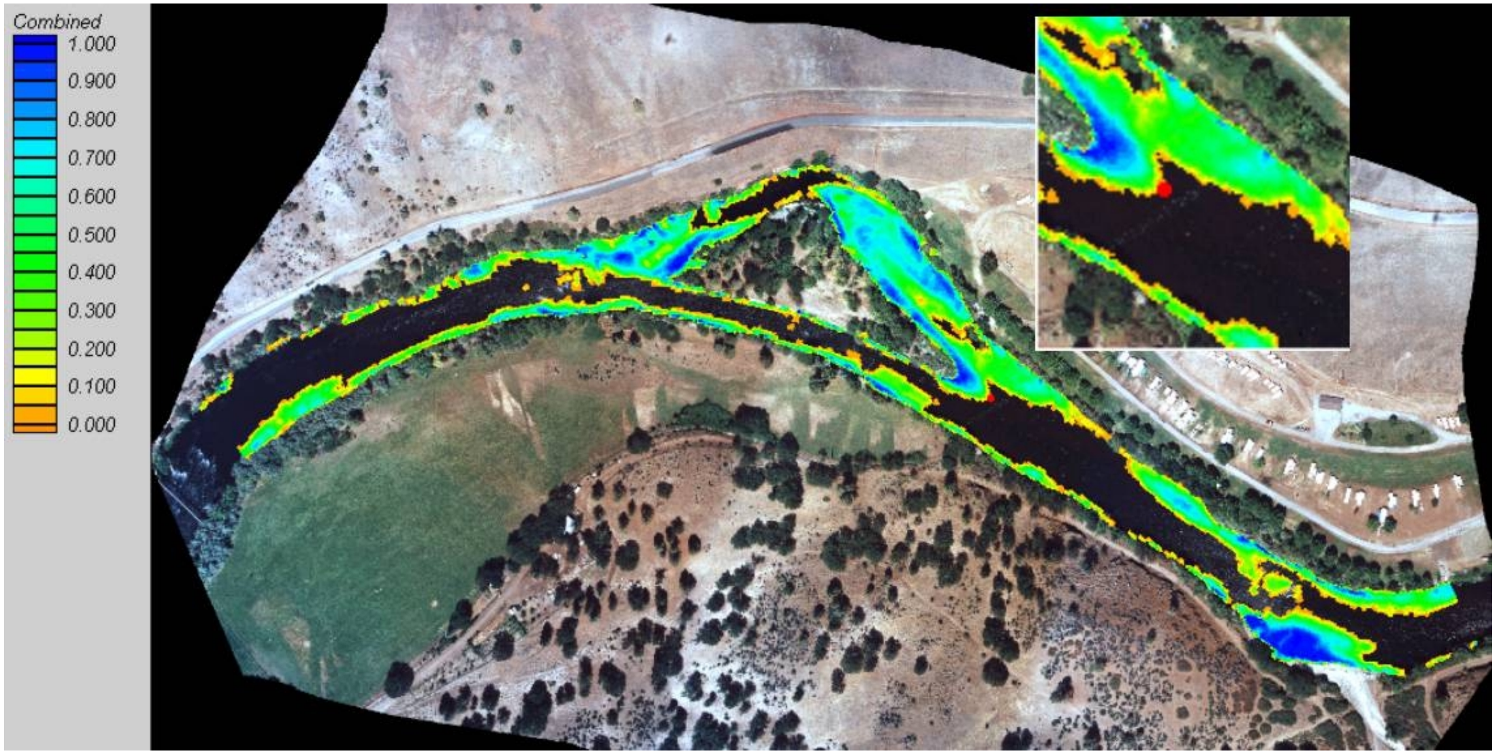


Figure 110. Suitability of predicted habitat versus observed juvenile locations for coho within the Rranch study site. Fish collections were made at approximately 1300 cfs.

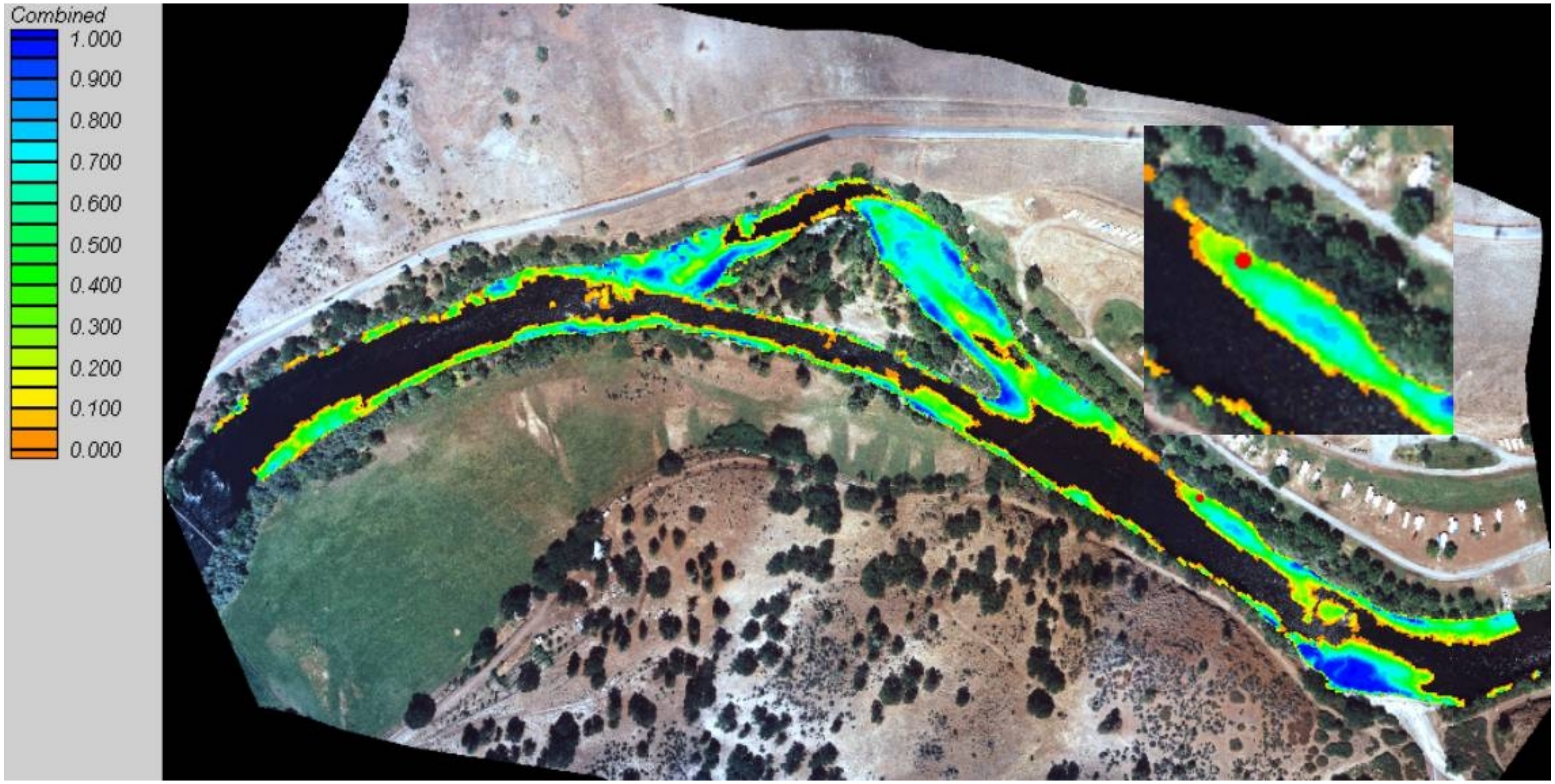


Figure 111. Suitability of predicted habitat versus observed juvenile locations for coho within the Rranch study site. Fish collections were made at approximately 1340 cfs.

Steelhead Juvenile

Figures 112 through 117 show key features of the hydraulic simulation limitations and associated predicted habitat suitability (i.e., combined suitability at each node) versus the spatial location of steelhead juveniles. Although these limitations are not considered to invalidate the habitat modeling, they are noted to highlight where future work may improve on the existing efforts. Furthermore, the type of limitation noted in the following example is confined to instances and spatial locations where boulder fields dominate the channel topography and therefore are somewhat limited in their potential bias of the modeling.

As will be shown, we believe the simulation results are generally of moderate quality for steelhead juveniles across sites and at different flow rates. However, we believe future modeling efforts can improve on these simulations if higher resolution computational meshes are utilized that can incorporate more ‘micro-topography’ associated with large roughness elements (i.e., boulders) within the stream channel. For example, Figure 112 shows the observed location of steelhead juveniles at the RRanch study site at a flow rate of approximately 1340 cfs.

Figure 112. Steelhead juveniles at the Rranch study site at a flow rate of approximately 1340 cfs.

As can be seen in Figure 112, these fish are clearly utilizing the velocity wake produced by a series of large boulders just upstream (i.e., the white water turbulence in the imagery). The corresponding simulation of combined habitat suitability at this location is shown in Figure 113 and Figure 114 contains the associated predicted velocity vectors at this same flow rate.

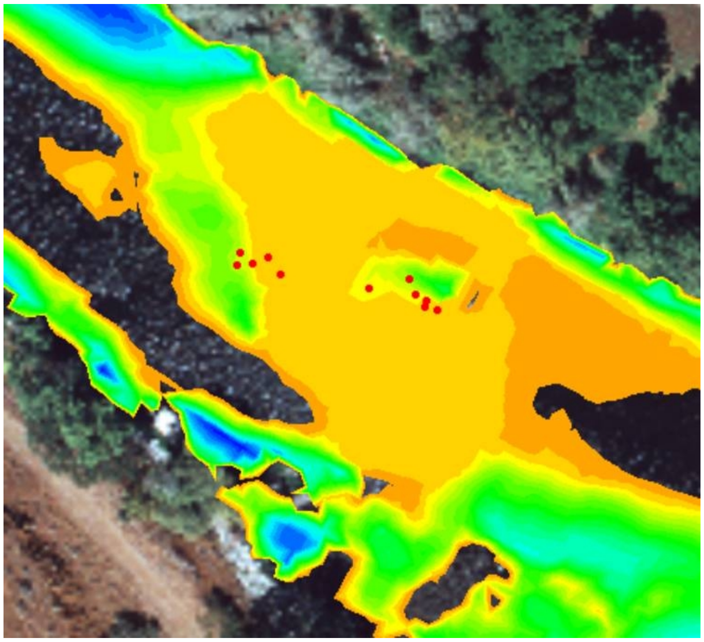


Figure 113. Suitability of predicted habitat versus observed juvenile locations for steelhead within the RRanch study site. Fish collections were made at approximately 1340 cfs.

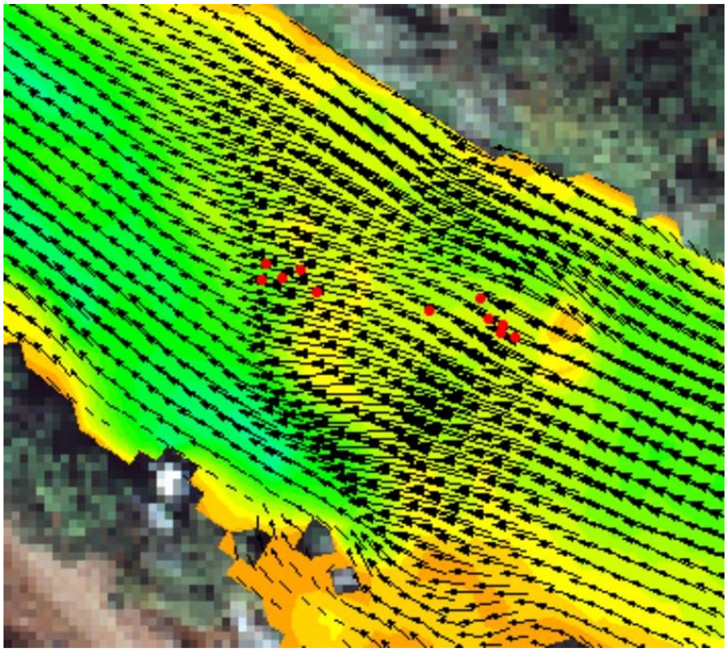


Figure 114. Simulated velocity vectors at RRanch at a flow of 1340 cfs.

Although the hydraulic modeling generally captures the gross affect of these boulders in the velocity simulations due to high roughness assigned to this region of the computational mesh from the substrate mapping, predicted velocity distributions are higher than what the fish are likely observing at this location in the stream and therefore the combined suitability is predicted too low. The fish observed at the locations downstream of the island in Figure 115 were subjected to focal point velocities that were much less than the mean column velocity. It was extremely difficult to snorkel here because water near the surface was very fast, but there were large boulder/bedrock features that created velocity breaks underneath the fast surface layer (Charlie Chamberlain, personal communication). The level of spatial resolution necessary to capture this type of boulder induced velocity wake would require a much finer resolution in the computational mesh in conjunction with much more detailed field based mapping of these types of roughness elements throughout the stream reach. Rather than a technical limitation, it is more a function of time, cost, and resources. This same 'micro-scale' affect of boulder fields that is below the spatial resolution of the computational mesh was also observed at the downstream section of the island at this same section as illustrated in Figures 115 through 117.

Figure 115. Steelhead juveniles at the RRanch study site at a flow rate of approximately 1340 cfs.

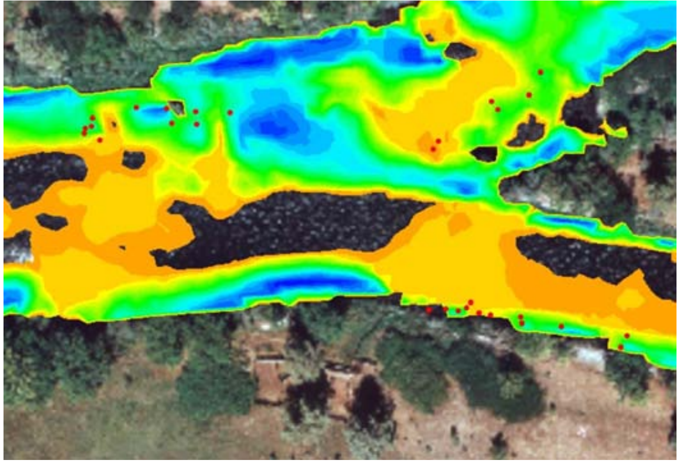


Figure 116. Suitability of predicted habitat versus observed juvenile locations for steelhead within the RRanch study site. Fish collections were made at approximately 1340 cfs.

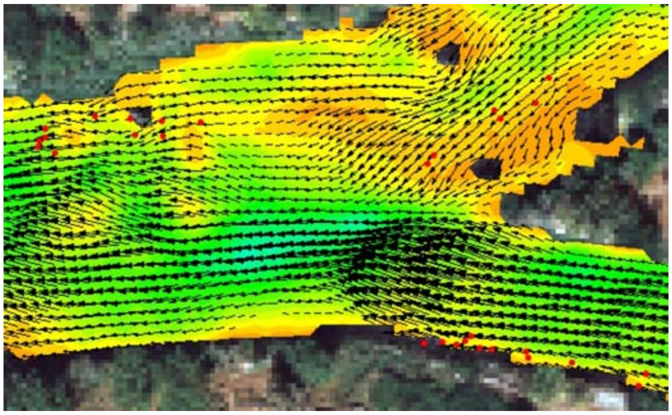


Figure 117. Simulated velocity vectors at RRanch at a flow of 1340 cfs.

These results also suggest that other types of integrated habitat modeling for steelhead juveniles that incorporates metrics to quantify the velocity shelter patterns based on the distribution and pattern of the velocity vectors would likely show improved results.

It is clear from an examination of these results that there is generally good agreement between predicted and observed habitat utilization but less so than other species and life stages. Steelhead juvenile locations generally match up well with the overall spatial mosaic of predicted habitat availability at these sites although we are likely under predicting the amount of habitat. Results of the simulations generally work better in the absence of the effects of large roughness elements such as ’boulder fields’ and isolated boulders that are underrepresented by the resolution of the computational mesh. This is apparent in the fish distribution and simulated habitat shown at the bottom right and upper right of Figures 115 through 117.

We believe that in general, the simulations of available habitat will have a bias to slightly under estimate the amount of usable habitat at a given discharge only to the extent that ‘boulder fields’ contribute significantly to the overall habitat availability within a given study site. It is evident in many of the remaining examples that the type of conditions highlighted at the RRanch study site above are not evident at other study locations in the river.

Figures 118 through 123 show predicted habitat suitability (i.e., combined suitability at each node) versus the spatial location of steelhead juveniles collected at different flow rates and various study sites where observation data was available.

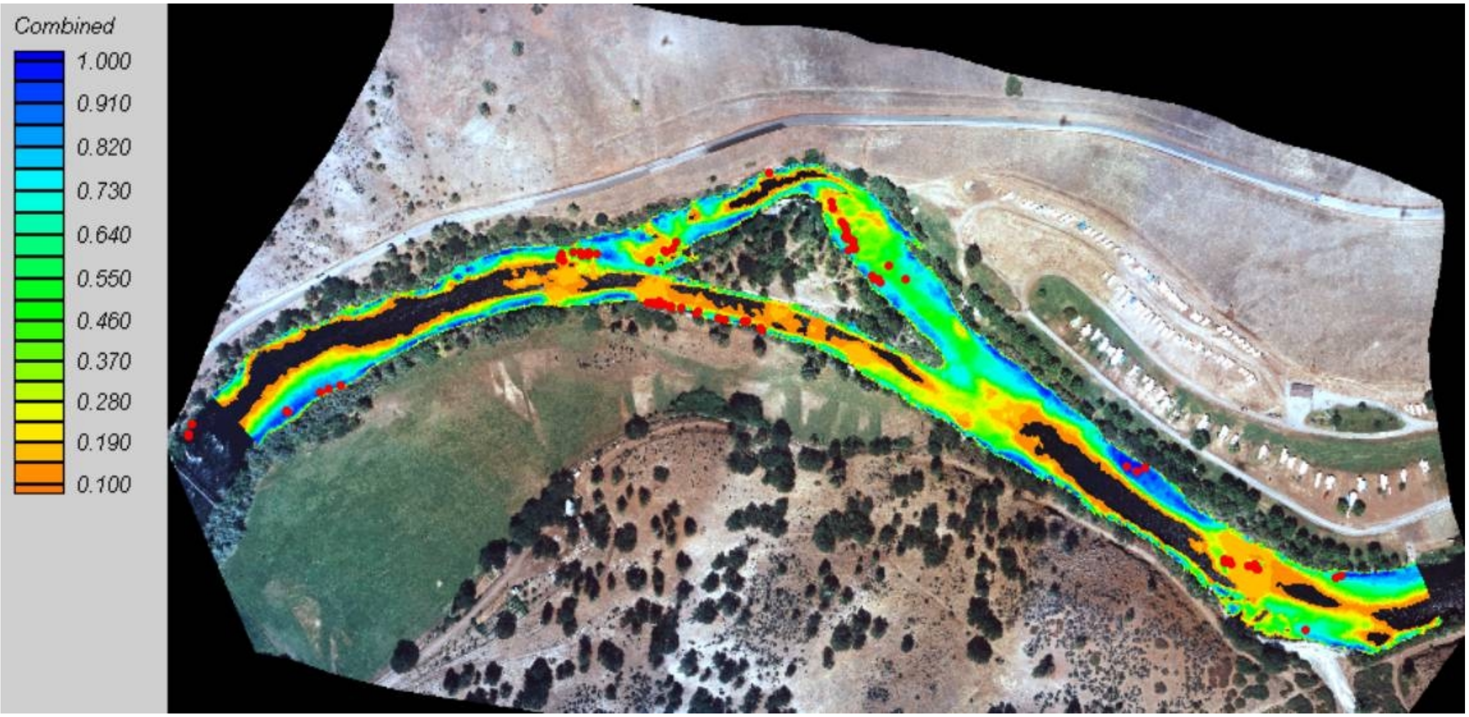


Figure 118. Suitability of predicted habitat versus observed juvenile locations for steelhead within the Rranch study site. Fish collections were made at approximately 1340 cfs. Fish at far lower left are outside computational mesh.

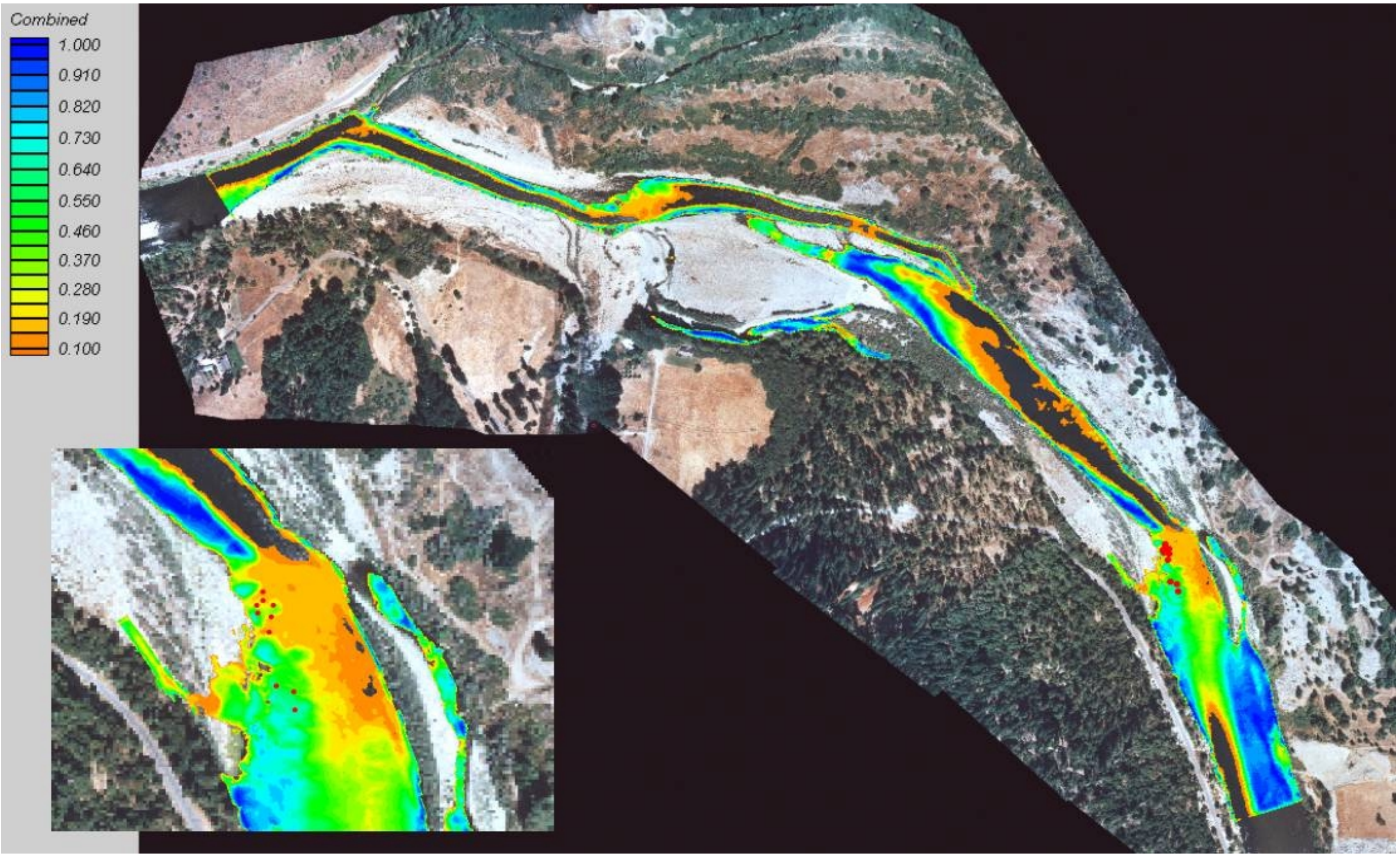


Figure 119. Suitability of predicted habitat versus observed juvenile locations for steelhead within the Seiad study site. Fish collections were made at approximately 1500 cfs. Simulated flows are approximately 1450 cfs.

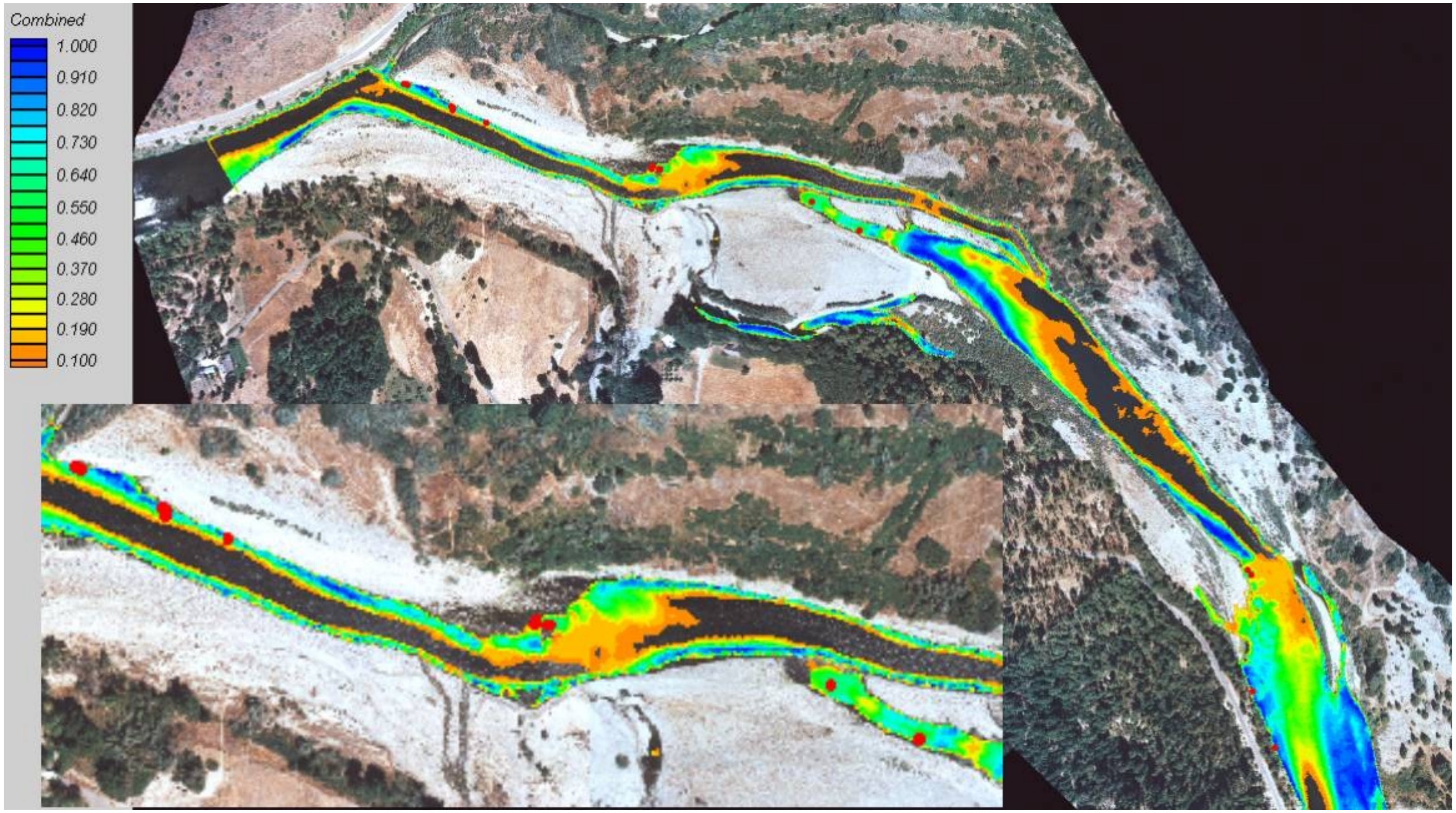


Figure 120. Suitability of predicted habitat versus observed juvenile locations for steelhead within the Seiad study site. Fish collections were made at approximately 1625 cfs.

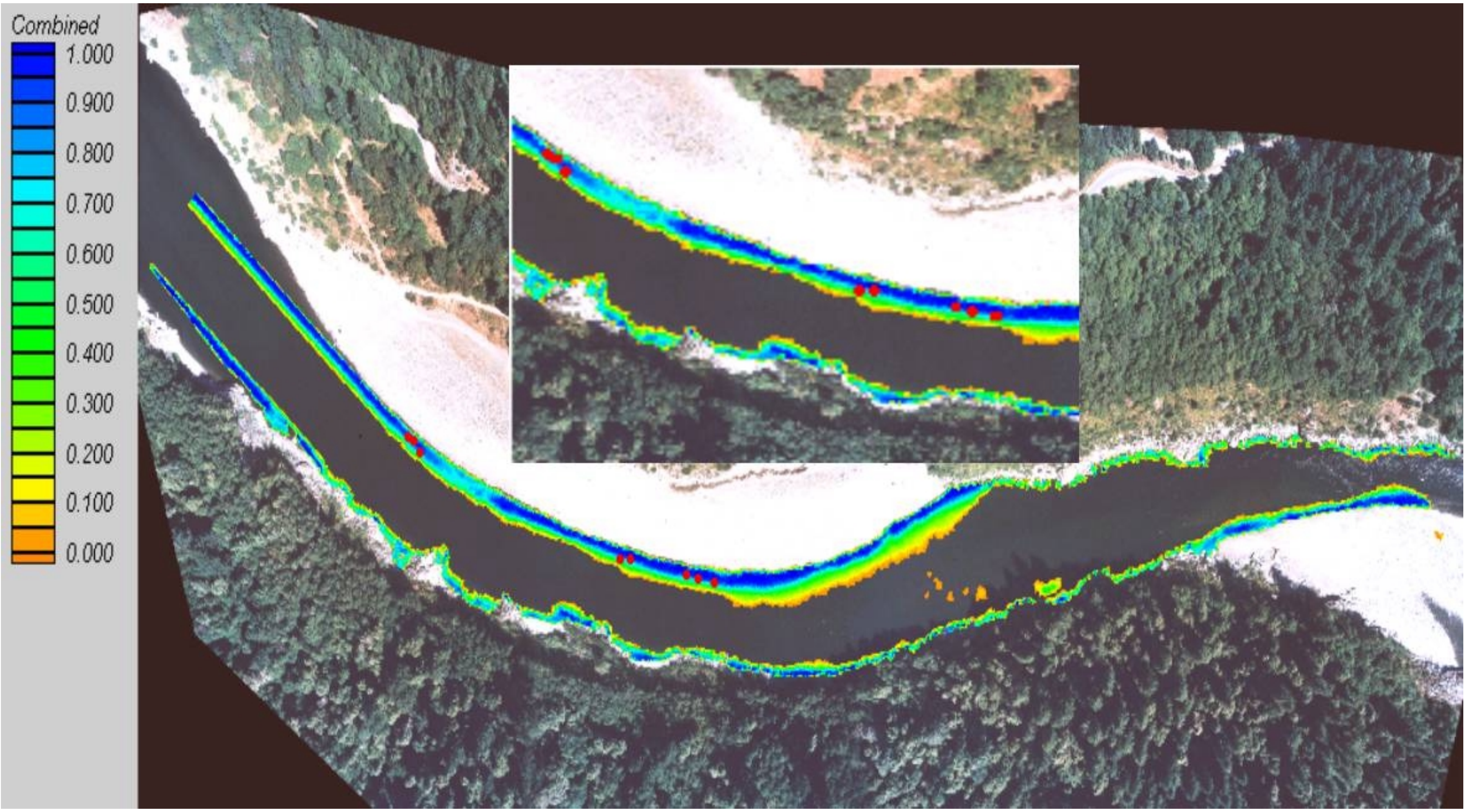


Figure 121. Suitability of predicted habitat versus observed juvenile locations for steelhead within the Young's Bar study site. Fish collections were made at approximately 2825 cfs. Simulated flow is approximately 3140 cfs. High value habitat will shift toward the center of the stream at observed fish flow.

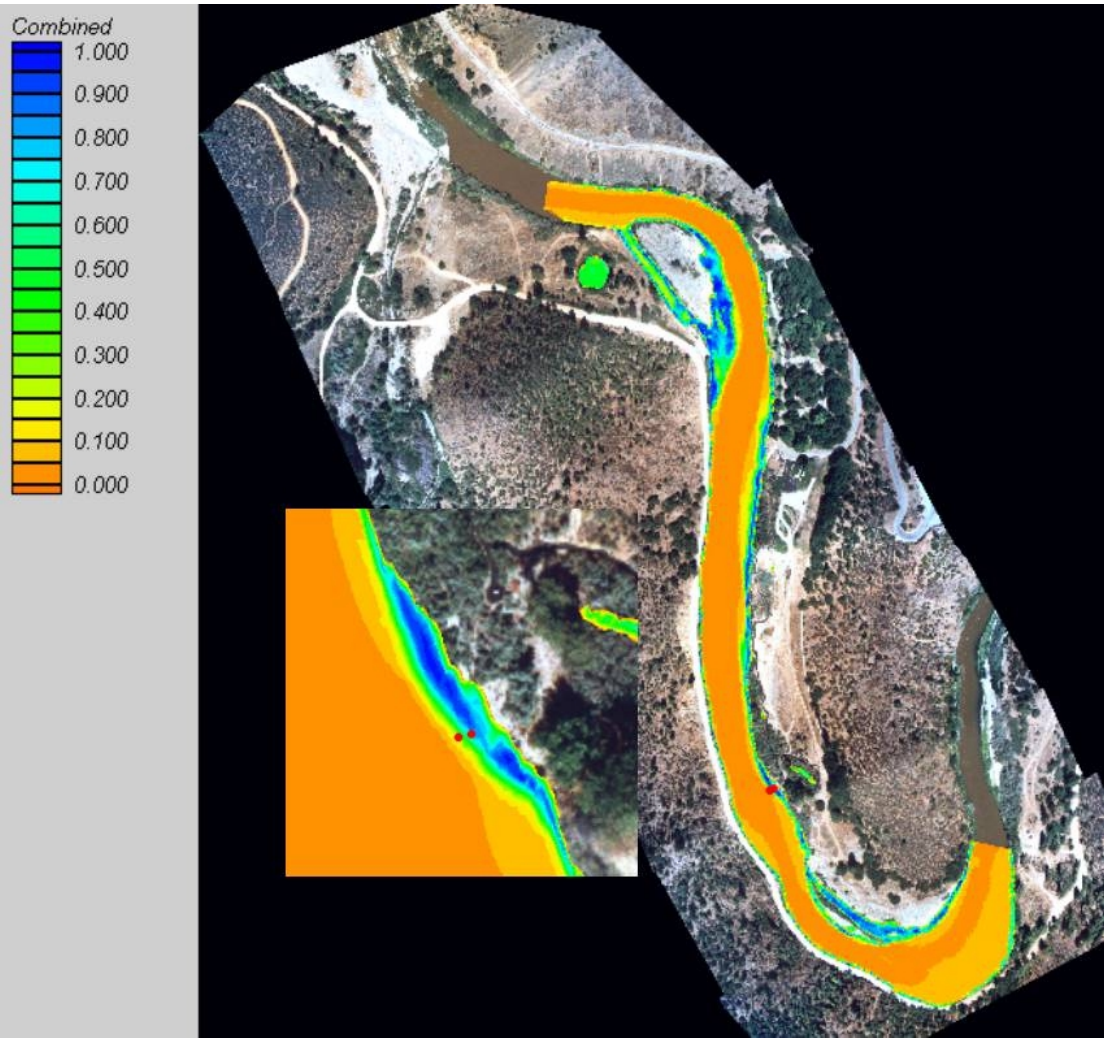


Figure 122. Suitability of predicted habitat versus observed juvenile locations for steelhead within the Trees of Heaven study site. Fish collections were made at approximately 6000 cfs. Simulated flow is approximately 5860 cfs. High value habitat will shift toward the center of the stream at observed fish flow. Note: Darkest brown habitats are essential no value habitats.

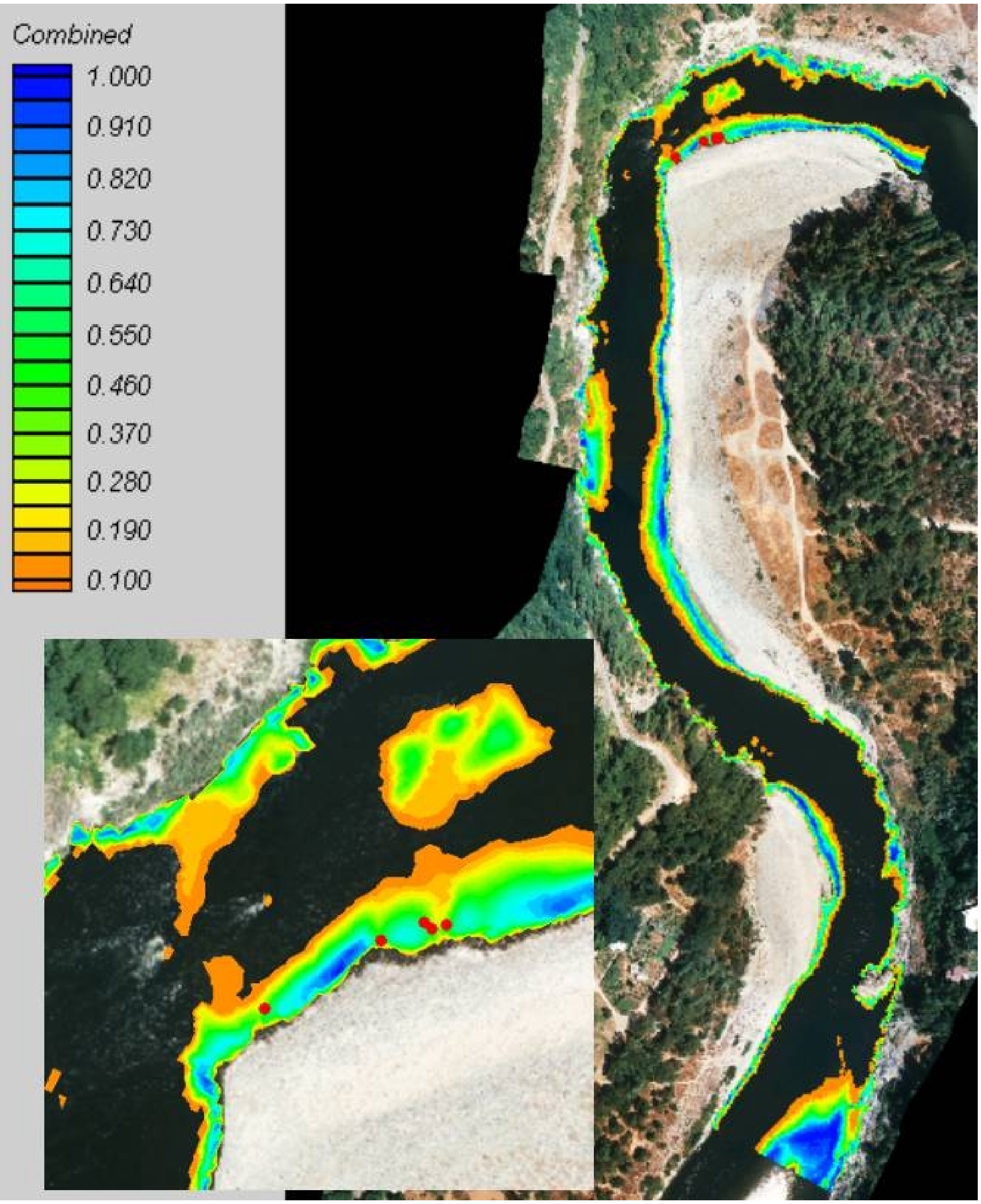


Figure 123. Suitability of predicted habitat versus observed juvenile locations for steelhead within the Orleans study site. Fish collections were made at approximately 2225 cfs.

River Reach Level Habitat Results

As was noted previously, the site-specific habitat modeling at each USU 2-dimensional study site was ‘scaled’ to the reach level by assigning reach level weightings to each node based on the nodes assigned mesohabitat classification. These results are comparable to the reach level habitat versus discharge relationships derived from the USGS/USFWS 1-dimensional based habitat modeling reported earlier. Differences are to be expected given the basic differences between the computational representation (i.e., cross section versus three-dimensional topography) of the channel and the associated hydraulic and habitat modeling algorithms. This is discussed more later in the report.

Figures 124 through 127 provide the reach level relationships between habitat and discharge for the four reach level segments used in this analysis. Figures 128 through 131 provide this same information where the habitat has been normalized for each species and life stage to the percent of maximum habitat.

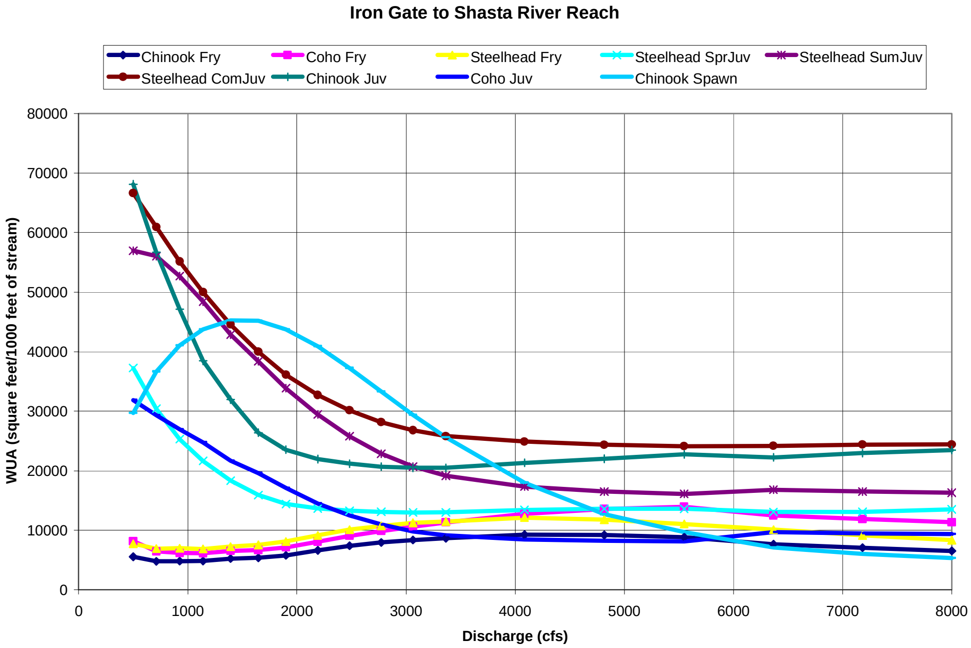


Figure 124. Relationship between available habitat and discharge for each species and life stage for the Iron Gate to Shasta River reach.

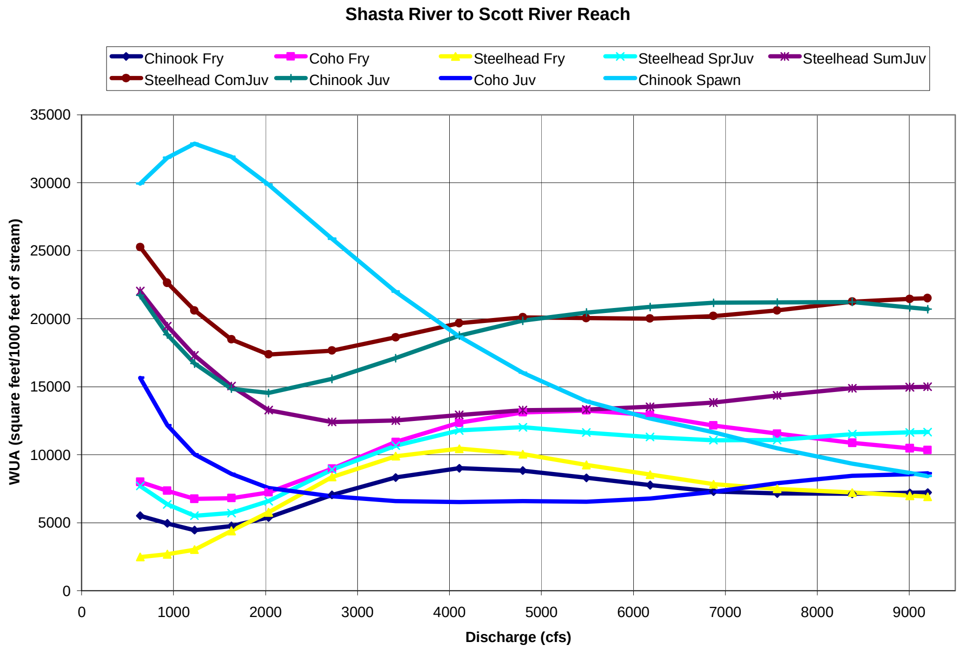


Figure 125. Relationship between available habitat and discharge for each species and life stage for the Shasta River to Scott River reach.

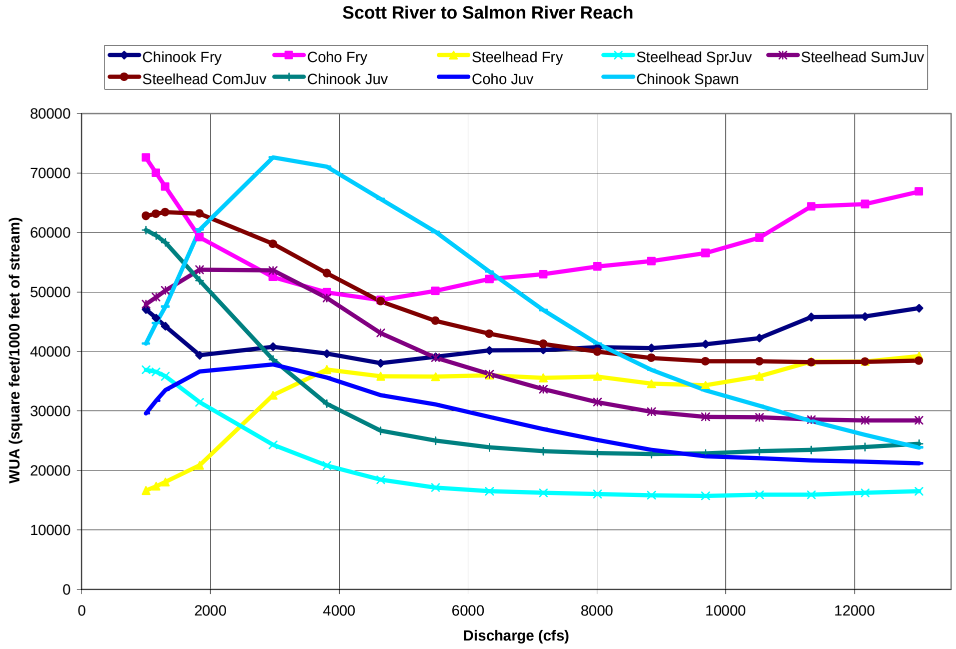


Figure 126. Relationship between available habitat and discharge for each species and life stage for the Scott River to Salmon River reach.

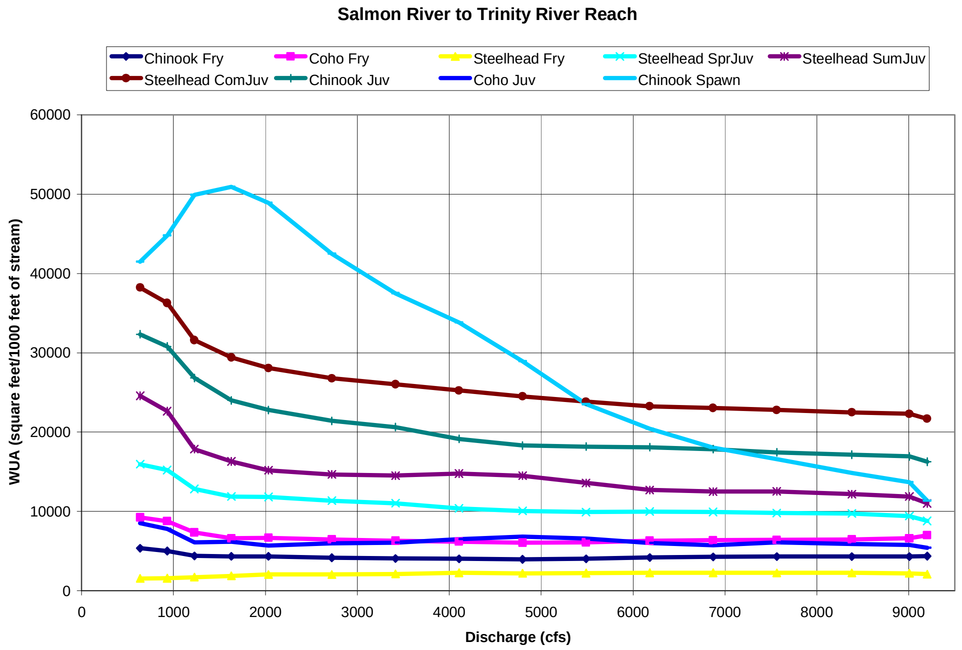


Figure 127. Relationship between available habitat and discharge for each species and life stage for the Salmon River to Trinity River reach.

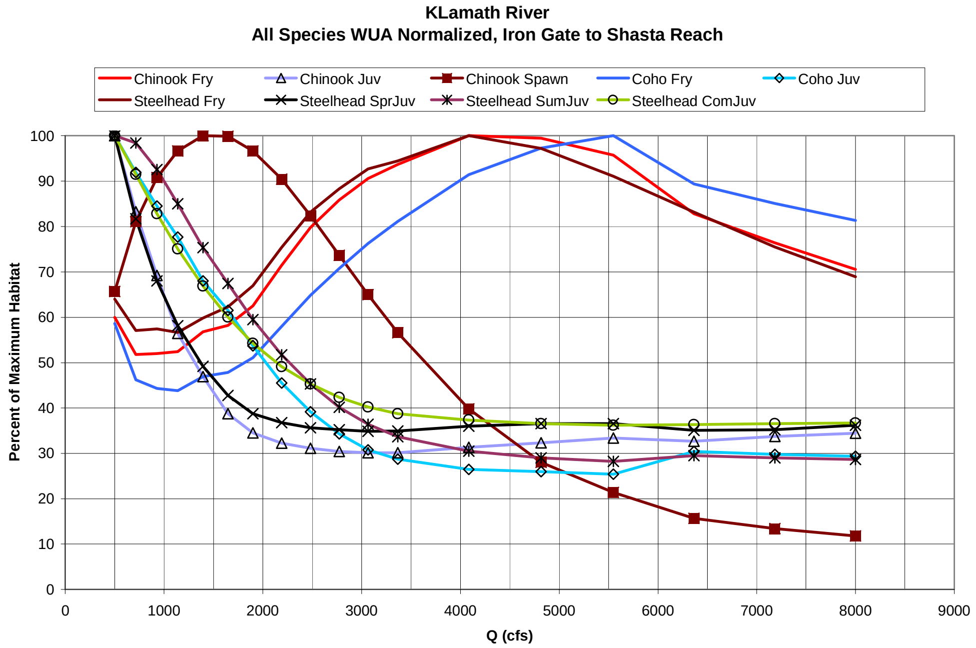


Figure 128. Relationship between percent of maximum habitat and discharge for each species and life stage for the Iron Gate to Shasta River reach.

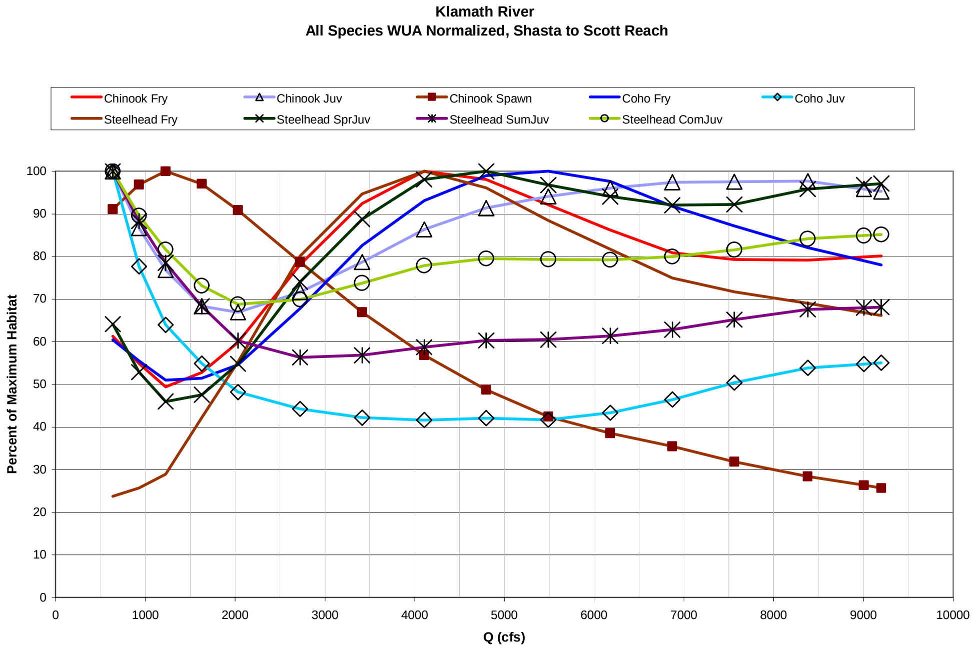


Figure 129. Relationship between percent of maximum habitat and discharge for each species and life stage for the Shasta River to Scott River reach.

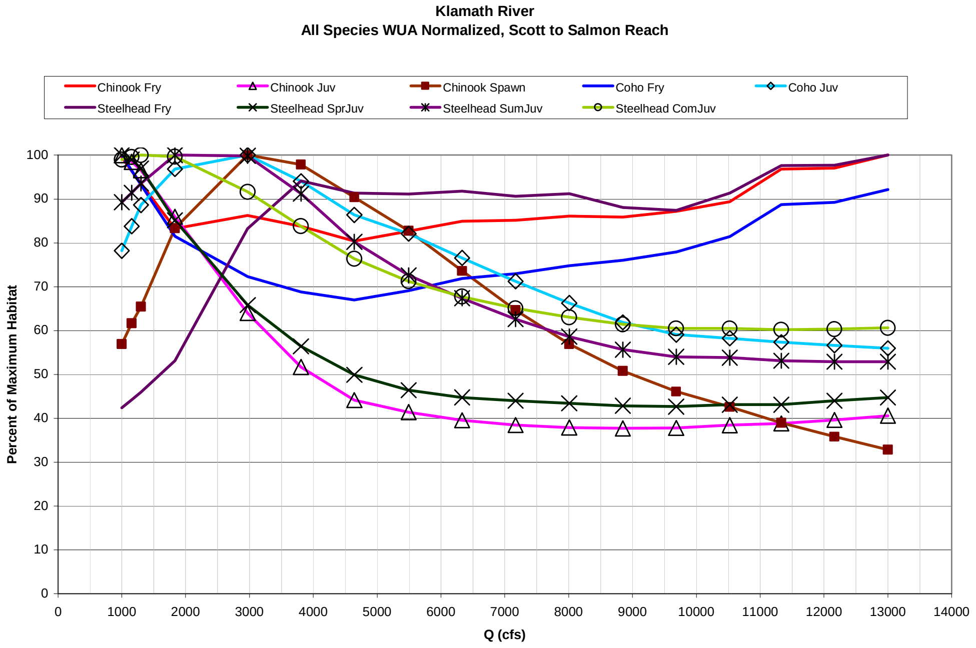


Figure 130. Relationship between percent of maximum habitat and discharge for each species and life stage for the Scott River to Salmon River reach.

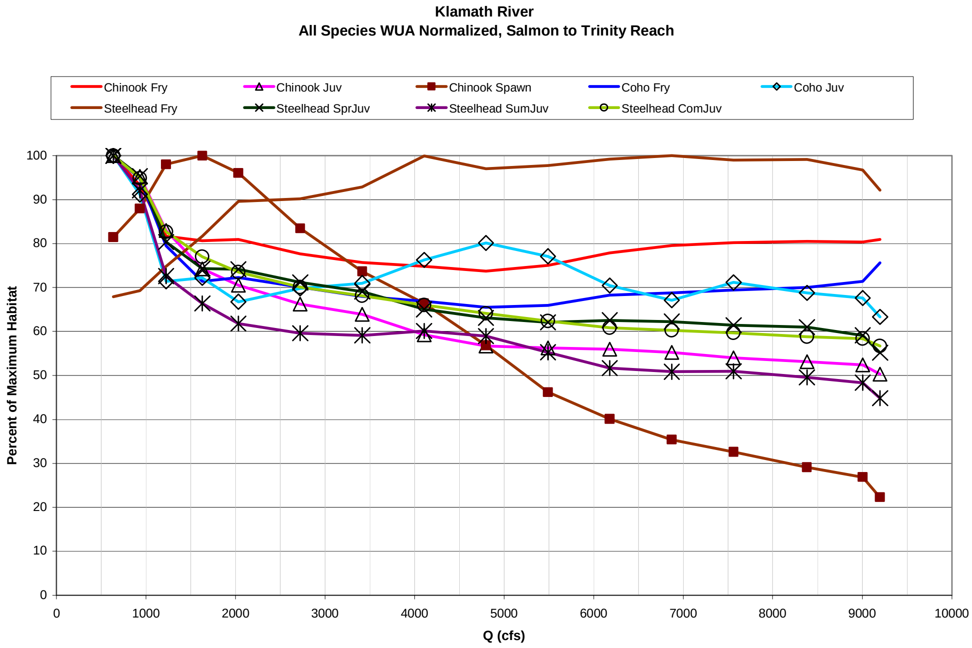


Figure 131. Relationship between percent of maximum habitat and discharge for each species and life stage for the Salmon River to Trinity River reach.

Study results for the Trinity to estuary reach are not reported due to the poor hydraulic model performance at the Youngs Bar study site (see 2-dimensional hydraulic modeling).

Comparison of 1-dimensional versus 2-dimensional Modeling Results

USGS/USFWS based 1-dimensional modeling results for the two reach level segments represented by the Iron Gate to Shasta River and the Shasta River to Scott River can be compared with the USU derived results using 2-dimensional hydraulic modeling. This comparison is intended to highlight both similarities and differences that arise out of the different approaches to field data collection, hydraulic modeling, and the way habitat is computed. Each technique approaches the modeling using different objectives and assumptions. Both approaches produce valid modeling results as demonstrated by the various validation steps described previously.

A comparison of Figures 88 and 131 for the Iron Gate to Shasta River reach based on the percent of maximum habitat relationships over the same flow ranges for the USGS/USFWS and USU study results shown similar overall relationships in the habitat versus discharge functions. These differences between the 1-dimensional and the 2-dimensional based results are attributed to the linkage between the field based cross section representation of the mesohabitats, the way in which these results are scaled to the reach total, and differences in how the mesohabitat proportions are calculated at the reach level. A cross section within a specific mesohabitat type only provides a single estimate of the width of the feature while in the 2-dimensional representation the explicit changes in channel width for each mesohabitat are utilized. Secondly, the mesohabitat weighting used in the 2-dimensional habitat modeling are derived from area calculations rather than longitudinal distances. Another factor is that in the hydraulic simulations based on the 2-dimensional model, the area of each mesohabitat unit changes differently compared to the cross section view at different flow rates. The area is explicitly determined by the interplay between the water surface elevation and the associated area of each mesohabitat unit represented spatially by the topography within the channel rather than by a fixed single width associated with the cross section data sets.

The normalized habitat relationships are fundamentally similar in terms of the functional relationships and the flow ranges at which the maximum habitat conditions are predicted for the different species and life stages. The more ‘jagged’ appearance in the 1-dimensional modeling results represents an underlying ‘artifact’ of the velocity simulations when employing more than one velocity calibration set in the hydraulic simulations. This is a common occurrence in PHABSIM and an expected result for these simulations (see Hardy 2000 for a discussion on this phenomenon). In the 2-dimensional hydraulic simulations, velocities are not used in the calibration process of the model and therefore these simulations are not affected by this ‘artifact’.

Both sets of simulations show expected habitat response functions that match well with field based observations for fry and spawning life stages as well as producing consistent results in terms of the juvenile life stages. We consider the results for both modeling approaches to represent valid but independent estimates of the flow versus habitat relationships within these two reaches. We also considered that the observed differences are within expected ranges of variability given the nature and differences in the respective modeling approaches from our experience in other systems.

Bioenergetics and Developmental Based Habitat Modeling

The following section of the report examines temperature related issues in light of bioenergetics and developmental issues associated with egg incubation, emergence, and growth through the spring and early summer period. The analyses focus on salmonids and chinook in particular.

Spawning, Emergence and Growth

Water temperature can be considered a “master control factor” in the ecology of aquatic organisms. Water temperature affects both the physiology and behavior of poikilothermic species (e.g., fish). In fish for example, temperature regimes influence migration, egg maturation, spawning, incubation success, growth, inter- and intraspecific competitive ability, and resistance to parasites, diseases, and pollutants (Armour 1991; McCullough 1999). In the Klamath River, water temperature has been implicated as a limiting factor for anadromous fish. Of particular concern are the potential impacts of increased temperatures due to reservoirs and water withdrawls. Bartholow (1995) identified high fall and early spring temperatures as critical time periods potentially affecting fall chinook salmon. Development of eggs and alevins and growth of fry are particularly sensitive to temperature. To identify the effects of various flow regimes on temperature and chinook development, hydrology and water temperature model runs for each flow scenario based on the 39 year simulation period (1961-1999) were used to calculate relative emergence timing and growth of fry to outmigration. For these simulations, the analysis was confined to the Iron Gate to Shasta River reach. In this instance, the analyses used a ‘no project’ simulation based on Upper Klamath Lake net inflows to extend the simulation period of record.

Incubation and Emergence

To generate a relative analysis of water temperature on the rate of development of chinook salmon eggs from fertilization to emergence we identified an approximate mean spawning time from USFWS spawning survey data (Tom Shaw, Pers. Comm.). The approximate mean date of spawning was October 25. We then used this starting date to calculate the maximum, minimum, and mean number of days to emergence for each of the flow scenarios over the 39 year simulation period. Daily temperature units (degree days) required for emergence were approximated as 1600 temperature units (°F) (Piper et al. 1982; T.D. Beacham, Pers. Comm.). Clearly, the beginning time for egg development (spawning date) and the exact number of degree-days for emergence can vary with various temperature regimes. However, we used a fixed spawning time and constant 1600 temperature units for emergence, to simplify the analysis between different flow regimes. Suitable temperatures during incubation were assumed to be between approximately 5 and 14 °C; significant mortality occurs outside this temperature window (McCullough 1999).

The minimum, maximum, and average number of days required for emergence for each of the scenarios are provided in Table 44. Table 44 also shows the number of days during the 39 years that temperatures during incubation were below or above the 5 to 14 °C incubation temperature window. Each of the flow scenarios take approximately 175 days to reach 1600 degree days (°F) except the No Project scenario which takes 15 days longer. Colder fall temperatures in the No Project scenario increased the emergence time.

The average number of days in each year that exceed the 5 and 14 °C incubation temperature window is 69 to 70 for all scenarios except for the No

Project scenario, which is 60 days. The number of days colder than the window range from 27 to 28, except for the No Project scenario, which is 45 days.

Table 44. Summary of days below and above 5 and 14 degrees C during the incubation period of Oct 25 -March 13 for all years for all flow alternatives. Also Average, maximum, and minimum number of days to reach 1600 degree days (F) for emergence.

Criteria	ESA_P1	Ferc_ESA	No Project	USGS
average days <= 5C	27	27	45	28
Max days <=5C	45	46	65	46
Min days <=5C	0	0	0	0
average days >=14C	69	70	60	70
Max days >=14C	72	72	72	72
Min days >=14C	39	39	0	39
average days that meet both criteria	97	97	105	98
max days that meet both criteria	117	118	133	118
min days that meet both criteria	39	39	0	39

Days to reach 1600 degree days for all alternative for all years

	ESA_P1	Ferc_ESA	No Project	USGS
average days to reach 1600 dd	173	176	190	176
max days to reach 1600 dd	201	201	201	201
min days to reach 1600 dd	127	125	150	123

Growth of Fry

We modeled approximate growth of fry following emergence using the Wisconsin bioenergetics model. Food consumption was estimated by roughly calibrating a proportion of maximum consumption (P-value) to observed growth and temperature data from 1993 (Tom Shaw, Pers. Comm.). The parameters used for the bioenergetics mass balance equations were the default parameters for chinook salmon (Stewart and Iberra 1991). Following calibration of the P-value, a typical beginning growth/emergence date of March 14 was assumed (Tom Shaw, Pers. Comm.) and growth for each water year and flow scenario was modeled through May 31 (approximate date of outmigration). Outmigration typically occurs when fish reach 55 mm or approximately 1.8 grams. A weight versus length relationship was generated from field data (Tom Shaw, Pers. Comm.). Figure 132 shows this relationship.

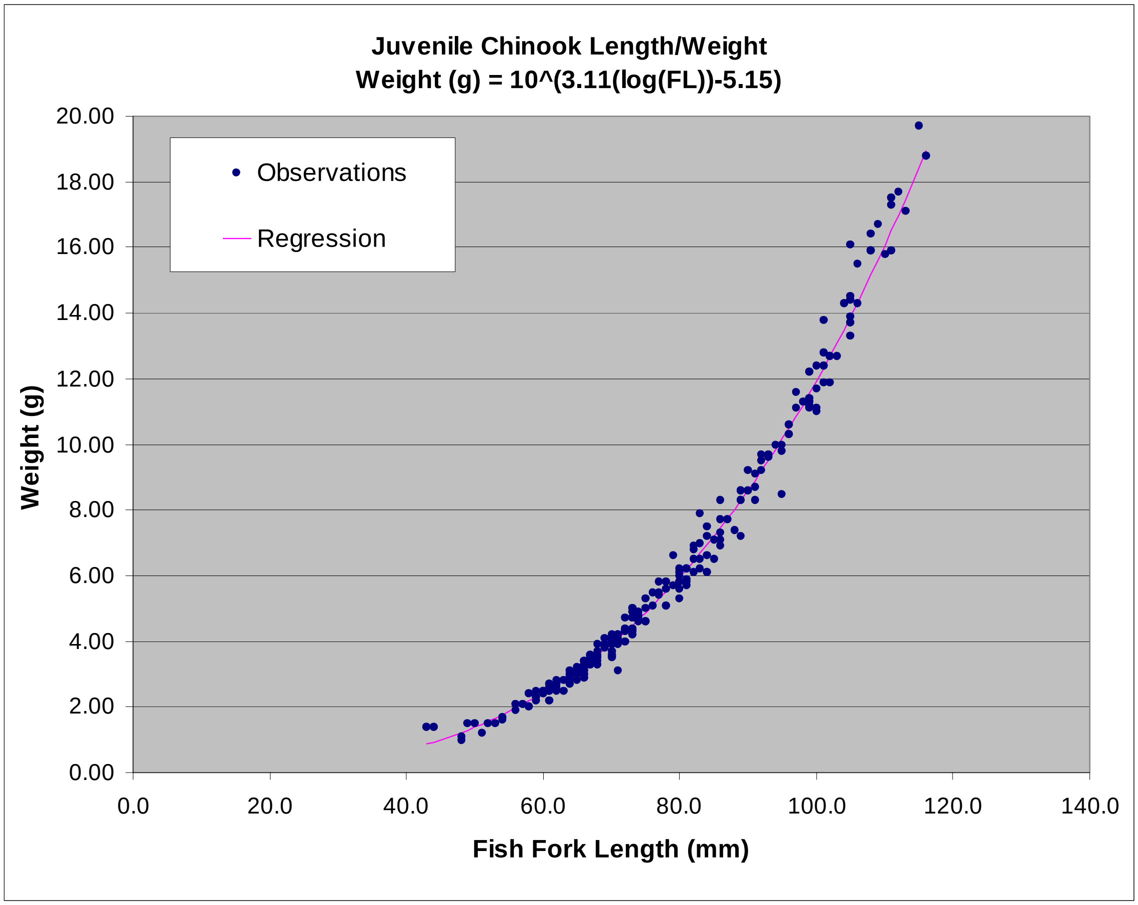


Figure 132. Fork length (mm) versus weight (g) for Klamath Chinook (Tom Shaw, unpublished data).

The approximate P-value calibration is shown in Figure 133. Mean fish size versus time to emergence is plotted for measured fish lengths from 1993 field data. The field data are uncertain in terms knowing the specific date since emergence. They simply reflect the date of field sampling, not the date since emergence (Tom Shaw, Pers. Comm.). Ascertaining time from emergence for the field data is particularly difficult due to the uncertain source of fish in the sampling data (i.e., tributaries or mainstem). For analysis purposes, chinook size at emergence is assumed to be 33 mm or 0.37 grams on March 14. Clearly there is some discrepancy between the measured data and the calibration P-value growth data; however, we use the two together as an “order of magnitude” validity check. The P-value used for the analysis was 0.76.

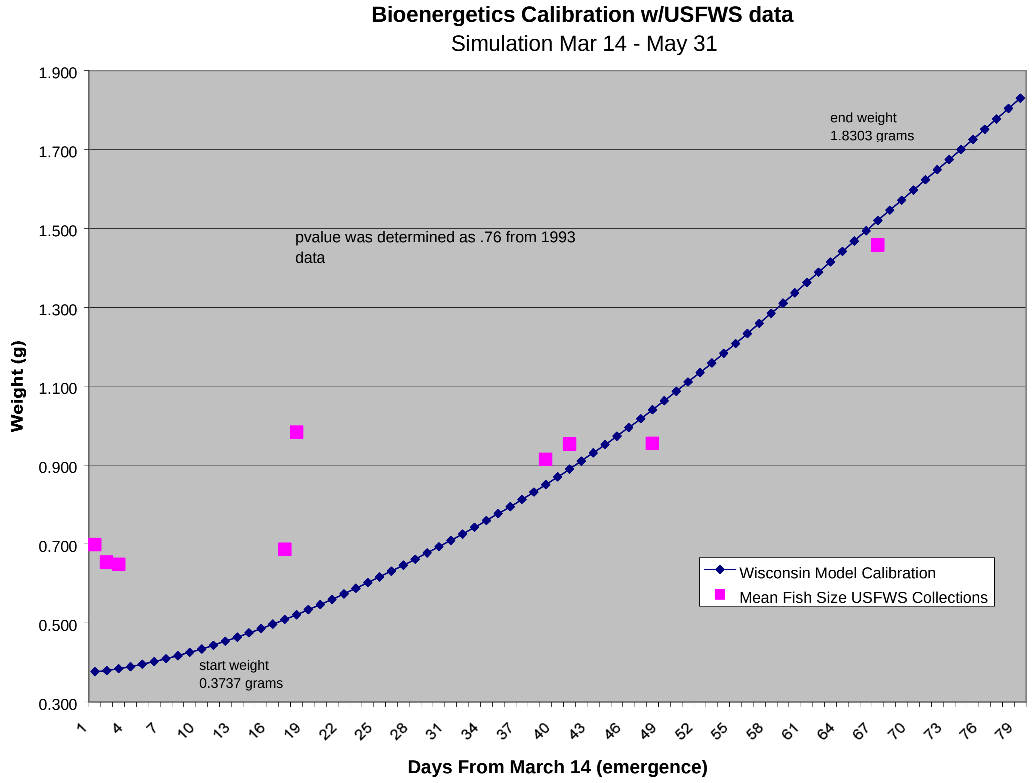


Figure 133. Bioenergetics P-value calibration data. Start date is March 14 (emergence), start weight 0.37 grams, and P-value 0.76. Measured fish sizes are from USFWS sampling data (see text for discussion).

Modeled growth for each of the water years and flow scenarios were summarized for comparative purposes. The average, minimum, and maximum fish sizes on May 31 are shown in Table 45. Very little difference occurs between flow scenarios and fish growth. Slightly warmer temperatures during the March 14 – May 31 period for the No Project scenario result in slightly faster growth. Under the No Project scenario fish reach 55 mm (1.83 g) just after May 31 about 4 days faster than other flow scenarios.

Table 45. Chinook fry summary growth by flow scenario from emergence assumed to be from March 14 to May 31.

	ESA_P1		FERC_ESA		No Project		USGS Historic	
	weight (g)	length (mm)	weight (g)	length (mm)	weight (g)	length (mm)	weight (g)	length (mm)
average	1.60	52.78	1.58	52.55	1.73	54.11	1.59	52.70
max	1.95	56.14	1.95	56.18	1.96	56.29	1.96	56.25
min	1.25	48.79	1.25	48.78	1.40	50.58	1.24	48.66

The effects on emergence timing and growth rate to outmigration between the flow scenarios are relatively small except for the incubation/emergence with the No Project scenario that exhibits colder temperatures during the fall months and 15 days longer emergence on average. The No Project scenario also exhibits slightly warmer temperatures during spring (March 14 - May 31) and as a result chinook fry grow slightly faster reaching 55 mm about 4 days sooner than other flow scenarios. In total the No Project scenario has approximately 10 days later outmigration than the other flow scenarios.

Bioenergetics Modeling of Fry and Juvenile Salmonids

The model used in this study was developed by Addley (1993). The following section is adapted from Addley (1993) and Guensch et al., (2001). The later reference can be consulted for results on the field validation of the model, while Ludlow and Hardy (1996) compare this approach to HSC based modeling. Addley and Hardy (1999) discuss its integration and application within the context of multidisciplinary assessment frameworks in large river systems.

This model simulates the Net Energy Intake (NEI) for a drift feeding salmonid by calculating gross energy intake (GEI), which is the total prey energy a fish can consume in a given time, and then subtracting energy losses. Energy losses consist of metabolic costs, digestive costs, and non-assimilated energy costs. Metabolic costs include routine basal metabolism while maintaining a station in the current and prey capture costs. Digestive cost is the energy required to digest prey. Non-assimilated energy is energy egested in feces, and excreted as ammonia and urea in urine. NEI is calculated by:

$$NEI = GEI - CC - SC - F_d - U - F \qquad (1)$$

where:

CC is the prey capture cost,
SC is the stationary swimming and basal metabolic cost,
F_d is the digestion cost,
U is energy lost in urine, and
F is the non-assimilated energy lost in feces.

Calculation of GEI for a fish in a given position involves determination of the maximum capture area (MCA [m^2]), which is then multiplied by the drift-energy density and the water velocity. Calculation of MCA assumes the fish maintains a holding position in the current and makes forage attempts for drifting prey (Figure 134).

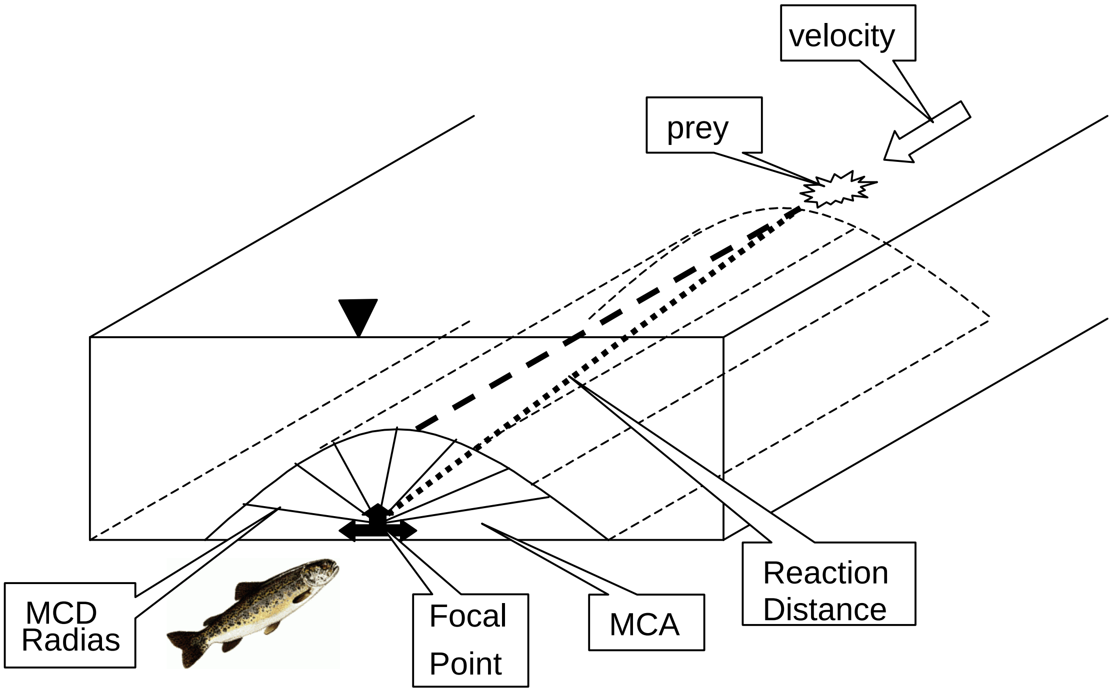


Figure 134. Diagram showing geometric variables in MCA calculation.

The *MCA* is a semicircular area that is perpendicular to the fish's orientation (i.e. perpendicular to velocity field), within which the fish can capture prey before it drifts past. The radius of the MCA semicircle is the maximum capture distance (*MCD* [m]), and is calculated from the combination of reaction distance, water velocity, and the fish's potential swimming speed. Note the *MCD* is not constant in all radial directions from the fish's focal point. It can be smaller vertically than laterally for example, because of increased water velocity higher in the water column. Specifically, *MCD* is determined by setting the time required for drift to pass the fish from its maximum reaction distance upstream equal to the time required for the fish to intercept the prey. This process results in the following equation for MCD:

$$MCD = \sqrt{\frac{RD^2 * (VMAX^2 - V^2_{mean})}{V^2_{prey} + VMAX^2 - V^2_{mean}}} \qquad (2)$$

where:

RD is the reaction distance of the fish (cm),
V_{prey} is the velocity of the prey(m s^{-1}),
V_{mean} is the mean water velocity along the *MCD* radii (m s^{-1}), and

VMAX is the swimming speed used to capture prey. For example the 60-minute maximum sustainable swimming speed of the fish (m s^{-1}) or calculation of the most efficient swimming velocity could be used for this value. For a detailed derivation of this expression see Addley (1993).

Reaction distance is a function of fish size (Dunbrack and Dill 1983; Schmidt and O'Brien 1982), prey size (Confer and Blades 1975; Vinyard and O'Brien 1976; Confer et al. 1978; Henderson and Northcote 1985; Schmidt and O'Brien 1982; Dunbrack and Dill 1983), light levels (Confer et al. 1978; Kettle and O'Brien 1978; Levine et al. 1979; Henderson and Northcote 1985; Lazzaro 1987), and turbidity (Vinyard and O'Brien 1976; Confer et al. 1978). Addley derived the following implicit equation relating prey length and fish length to daytime reaction distance from the empirical data of Dunbrack and Dill (1983).

$$PL = \left(RD^2 + 50 * RD\right) * \frac{\left(1 + 5.8 * e^{-0.34*FL}\right)}{1725} \qquad (3)$$

In equation 3, *PL* is the prey length (mm) and *FL* is the fish length (cm). The reaction distances derived from expression 3 are then adjusted for turbidity within the model using equation 4 (adapted from Barrett et al. 1992):

$$RD' = \frac{RD * \left(-2.27 * TURB + 100\right)}{100} \qquad (4)$$

where:

TURB is the turbidity (NTU).

The MCA is then calculated as the sum of the incremental areas associated with each MCD as follows:

$$MCA = \sum_{j=1}^{m} \frac{d\theta}{2} * MCD_j^2 \qquad (5)$$

Where:

$d\theta$ is an incremental angle equal to 0.314 radians and is perpendicular to the flow vectors and the fish. We used m=10 to provide a half circle shaped capture window with θ ranging from 0.0 to 3.14 radians.

The idealized *GEI* (GEI^*) is then computed from the following:

$$GEI^* = \sum_{i=1}^{n} MCA_i * V_{mean_i} * DD_i * PE_i \qquad (6)$$

where, *DD* and *PE* are the drift density (prey ft^{-3}) and energy content (J $prey^{-1}$) for the i^{th} prey size, respectively. GEI^* is the energy passing through the *MCA* if all prey are captured. This of course is not possible because at high drift densities other prey items pass during a foraging attempt. In addition, not all foraging attempts are successful. Therefore, the *GEI** is adjusted as follows for these influences to obtain actual *GEI*:

$$GEI = \frac{GEI^* * PC * T_w}{T_w + T_f} \tag{7}$$

where:

PC is the probability of successful capture,
T_w is the average time waiting to feed (s), and
T_f is the duration of a forage attempt (s).

Rearranging equation 7 into the terms of the original variables results in:

$$GEI = \frac{MCA * V_{mean} * DD * PE * PC}{1 + t_f * MCA * V_{mean} * DD} \tag{8}$$

To obtain the net energy input, this *GEI* equation is adjusted for assimilation losses, capture costs, and swimming costs. The swimming cost at the focal position (*SC*) is calculated with expression 9 adopted from Stewart (1980)

$$SC(J/h) = 1.4905 * FWT^{(0.784 * e^{(0.068 * T)})} * e^{((0.0259 - 0.0005 * T) * \frac{FV}{30.48})} \tag{9}$$

where:

FWT is the fish weight (g),
T is the water temperature (^{o}C), and
FV is the focal velocity (cm s^{-1}).

The capture cost (*CC*) is then given by:

$$CC_i(J/prey) = 6/3600 * SCOST(VMAX) * TC_i\,. \tag{10}$$

The subscript *i* indicates the prey class, 3600 (s hr^{-1}) is a conversion factor, and *TC* is the estimated time of capture (s prey^{-1}) for prey class *i*. The cost of steady swimming at VMAX is multiplied by 6 to estimate capture costs because the dynamic action involved in prey capture is more costly than steady swimming. The *PE* term is replaced by the energy term incorporating assimilation losses (E [j prey^{-1}]) with the capture costs subtracted. Elliott (1976) estimated assimilation losses to be at least 25 – 30% of energy intake. Therefore, we used *E* = 0.58**PE* for a conservative estimate. The resulting NEI equation is:

$$NEI(J/t) = \frac{\sum_{i=1}^{n} MCA_i * V_{mean_i} * DD_i * (E_i - CC_i) - SC}{1 + \sum_{i=1}^{n} t_{fi} * MCA_i * V_{mean_i} * DD_i}\,. \tag{11}$$

The NEI equation (equation 11) is essentially the same form as the Holling disk equation (Holling 1959) with the swimming cost subtracted. The model evaluates NEI with equation 11, at each grid point representing hydraulic properties, temperature, and invertebrate drift density by size class. Table 46 lists the final set of model equations and where necessary clarification comments.

The basic model was integrated with the 2-dimensional hydraulic model output for the estimation of the NEI associated with each node in the computational mesh at a given flow rate. The hydraulic model solutions were modified for input to the bioenergetics model to simulate the capture area oriented perpendicular to the direction of the velocity vector at each computational mesh node location using the following procedure.

At each computational node, we interpolated the depth and velocity at eleven 'new' nodes perpendicular to the velocity vector at that node location. The interpolation consisted of creating velocities and depths at these eleven points (five new nodes spaced 1 foot apart on each side of the original mesh node). The interpolated depths and velocities were used as input for the bioenergetic model. The bioenergetic model was then run for simulated flow results at each site with site-specific temperatures (derived from HEC5Q as described below), macroinvertebrate drift density (see Table 27), and the following species. The species specific length versus weight equations were developed from empirical data as shown in Figures 135 through 137. The following equations were utilized in the bioenergetics analysis from the regression results. The length for each species indicated refers to the length utilized in the bioenergetics modeling.

Steelhead (160 mm): $Weight(g) = 10^{(3.107 * \mathrm{Log}(FL(mm)) - 5.153)}$

Chinook (40 mm): $Weight(g) = 10^{(3.11 * Log(FL(mm)) - 5.15)}$

Coho (115 mm): $Weight(g) = 10^{(3.2 * Log(FL(mm)) - 5.3266)}$

Table 46. Equations used in the net energy intake (NEI) model (Addley 1993).

Parameter & Units	Equation/Calculation Method	Discussion and Citations
NEI_i ($J \bullet hr^{-1}$)	$NEI = \dfrac{\sum_{i=1}^{n} MCA_i \cdot V_{ave\,i} \cdot DD_i \cdot PC_i \cdot (E_i - CC_i) - SC}{1 + \sum_{i=1}^{n} t_{f\,i} \cdot MCA_i \cdot V_i \cdot DD_i}$	Net energy intake rate based on possible gross energy intake minus energy costs and losses for each prey class i.
MCD_{ij} (ft)	$MCD_{ij} = \sqrt{\dfrac{RD_i^2 (V_{\max}^2 - V_{mean_j^2})}{V_{\max}^2 + V_p - V_{mean_j^2}}}$	Maximum capture distance, calculated in the plane transverse and perpendicular to the fish by an iterative computer program where $V_{mean\ j}$ = mean velocity along MCD_{ij} (calculated within the computer program) and RD_i is the reaction distance for prey size i
V_{max} ($ft \bullet s^{-1}$)	$V_{\max} = 13.86 \left(\dfrac{21.42 - T}{3.92} \right)^{0.24} e^{0.24\left(1-\left(\frac{21.42-T}{3.92}\right)\right)} TL^{0.63}$	Maximum sustained fish velocity equation derived from Brett & Glass (1973) T=temperature (°C) TL=total length (cm) .
RD_i (ft)	$PL_i = (RD_i^2 + 50\ RD_i)(\dfrac{1 + 5.8\ e^{-.034(FL)}}{1725})$	Reaction distance equation derived from data of Dunbrack & Dill (1983) where PL_i = prey length (mm), RD_i = reaction distance (cm), and FL = total fish length (mm)
RD_i'(ft)	$RD_i' = \dfrac{RD_i(-2.27 \cdot TURB + 100)}{100}$	Reaction distance from equation above adjusted for turbidity (TURB) with equation adapted from Barrtett et al. (1992).
$V_{mean\ ij}$	Computed within computer program from velocity data.	Average velocity along MCD radian j for prey class i.
MCA_i (ft^2)	Area circumscribed by the arc created by connecting the ends of the MCD_i radians in the plane transverse and perpendicular to the fish (calculated with a computer program)	Maximum capture area at a location given water depth, water velocity, and channel morphology
$V_{ave\ i}$ ($ft \bullet s^{-1}$)	Computed within computer program from velocity data.	Average water velocity in the MCA for prey class i.
DD_i ($prey \bullet ft^3$)	Site specific emperical data	Measured daytime drift density in for each prey size i
PC_i	Assume probability of capture equals 1.0	Probability of successful prey capture
PE_i ($J \bullet prey^{-1}$)	$PE_i = 0.3818 (PL_i)^{2.46}$	Prey energy derived from Smock (1980) and Cummins and Wuycheck (1971), where PL_i = prey length (mm).
E_i ($J \bullet prey^{-1}$)	$0.58\ PE_i$	Energy assimilated (gross energy intake minus 14% for food digestion and 28% for losses due to excretion and feces) .

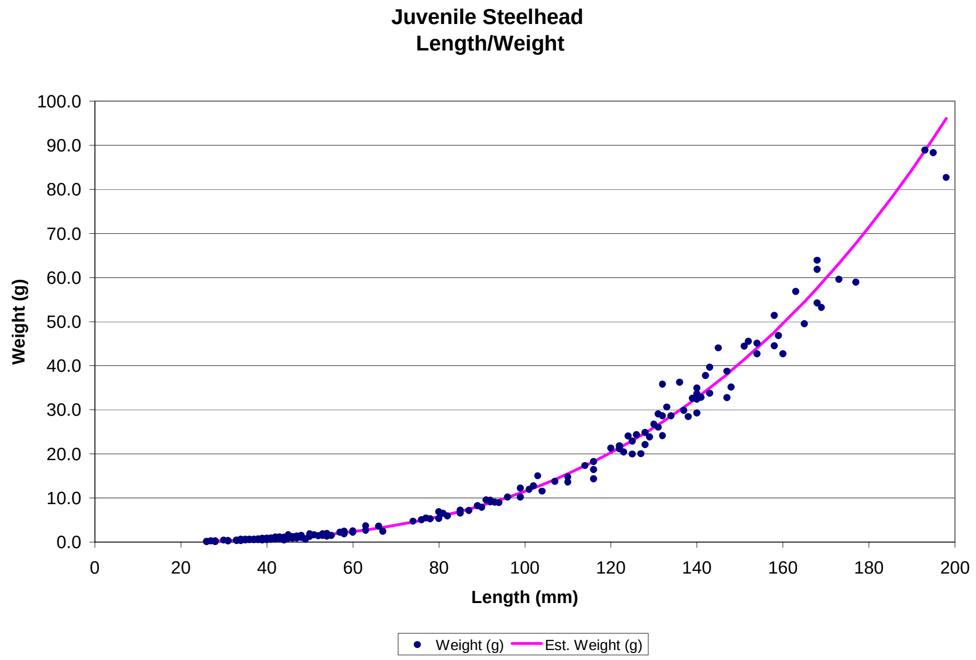


Figure 135. Relationship between size and weight for steelhead used to develop the species-specific growth equations for use in the bioenergetics model.

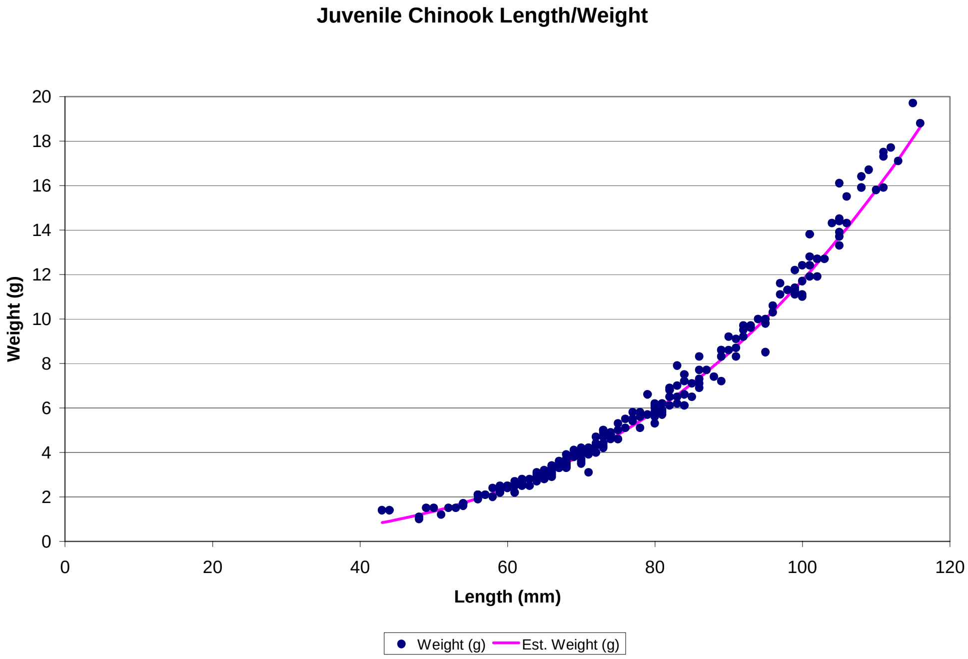


Figure 136. Relationship between size and weight for chinook used to develop the species-specific growth equations for use in the bioenergetics model.

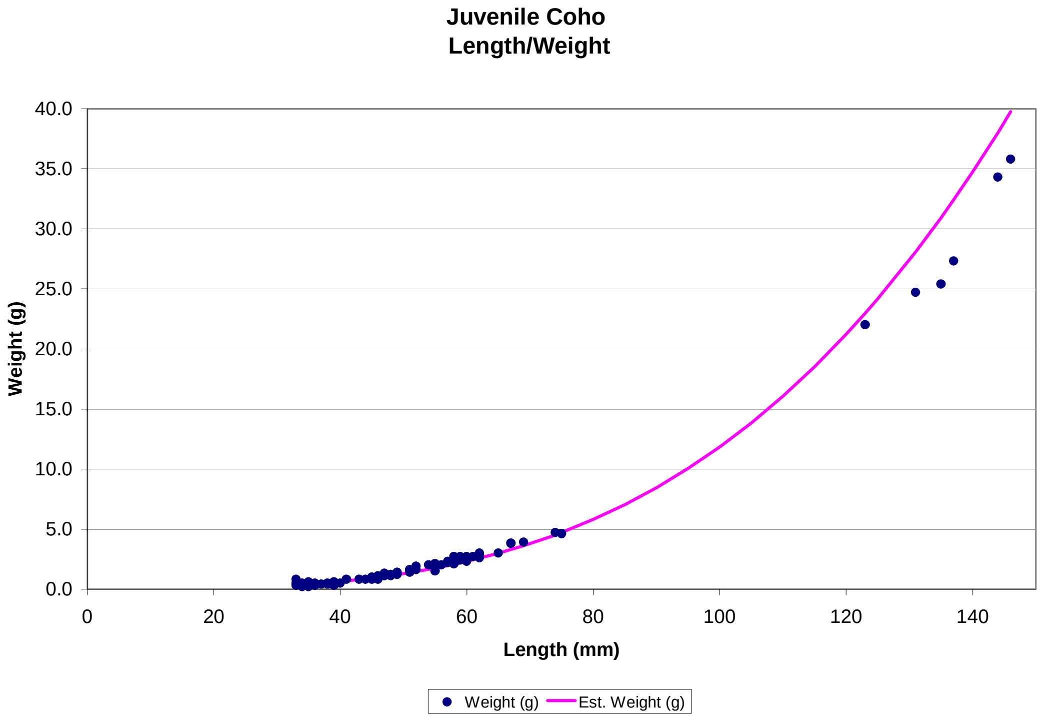


Figure 137. Relationship between size and weight for coho used to develop the species-specific growth equations for use in the bioenergetics model.

Although the fitted relationship for coho appears to under predict the weight at the upper size ranges, we felt that the relationship is adequate for the size coho used in our analysis (i.e., 115mm). Additional data on weight for fish greater than 80 mm would be valuable to improve this relationship.

The sizes used in the analysis for each species were selected based on the length frequency of fish observations obtained from work on the development of HSC and fish location observations for the habitat modeling validation described previously. Temperatures were selected to represent the average conditions during spring associated with chinook fry use in the river. Steelhead and coho juveniles used the average temperature during the July through September period to correspond with the late summer outmigration from tributaries and late summer rearing period in the main stem Klamath River (see Table 22).

The invertebrate densities, distribution of the invertebrate densities by size classes, and the temperature used in the simulations at each study site are provided in Table 47. The invertebrate densities were obtained from the sampling results at each study site (see Table 27). The temperatures were estimated from the HEC5Q model simulation results at each site under existing conditions (i.e., USGS historical operations scenario as described previously).

The size class for each species and ‘life stage’ were selected to represent the ‘average’ size during the simulation period.

Table 47. Field derived or simulated bioenergetics model input parameters used in the simulations at each study site.

RRanch								
	Invert Density	Percent Distribution by Size						
	per cubic foot	11 mm	9 mm	7 mm	5 mm	3 mm	1 mm	Temp C
	0.080	0.018	0.009	0.014	0.213	0.502	0.244	20.54
Trees of Heaven								
	Invert Density	Percent Distribution by Size						
	per cubic foot	11 mm	9 mm	7 mm	5 mm	3 mm	1 mm	Temp C
	0.081	0.064	0.014	0.020	0.262	0.363	0.277	20.64
Brown Bear								
	Invert Density	Percent Distribution by Size						
	per cubic foot	11 mm	9 mm	7 mm	5 mm	3 mm	1 mm	Temp C
	0.023	0.508	0.025	0.139	0.220	0.090	0.018	20.77
Seiad								
	Invert Density	Percent Distribution by Size						
	per cubic foot	11 mm	9 mm	7 mm	5 mm	3 mm	1 mm	Temp C
	0.050	0.021	0.009	0.001	0.077	0.537	0.355	20.44
Rogers Creek								
	Invert Density	Percent Distribution by Size						
	per cubic foot	11 mm	9 mm	7 mm	5 mm	3 mm	1 mm	Temp C
	0.022	0.155	0.018	0.000	0.082	0.372	0.373	20.56
Orleans								
	Invert Density	Percent Distribution by Size						
	per cubic foot	11 mm	9 mm	7 mm	5 mm	3 mm	1 mm	Temp C
	0.022	0.155	0.018	0.000	0.082	0.372	0.373	20.72
Saints Bar Rest								
	Invert Density	Percent Distribution by Size						
	per cubic foot	11 mm	9 mm	7 mm	5 mm	3 mm	1 mm	Temp C
	0.028	0.03	0.003	0.016	0.087	0.684	0.180	20.49

Chinook Fry (40mm)

The bioenergetics model for chinnok fry (i.e., 40 mm) and these associated data at the RRanch study site were used to compute the NEI response surface over a range of combined depth and velocity. The response surface for this species and life stage (i.e., size) at other study sites based on the input data in Table 46 will result in small or at best moderate shifts left or right in this basic relationship based on the combination of drift availability and temperature differences. This response surface (Figure 138) clearly shows the upper threshold for velocities at about 1.5 feet/second and optimal velocities at around 0.5 feet per second. Below this velocity the NEI surface also shows a rapid decline.

These results in terms of the velocity dimension of the response surface are very similar to the site-specific HSC relationship for chinook fry velocity (see Figure 47). The response surface also shows that NEI rapidly increases up to a depth of about 1.2 feet and then becomes insensitive to further increases in depth. This is somewhat different from the site-specific chinook fry depth HSC (see

Figure 48). The HSC show depths to be optimal around 1.0 foot and then the depth suitability declines at both higher and lower depth values. We attribute this difference between the two modeling approaches to the following factor. At present, there is no mechanistic ‘behavioral’ component within the bioenergetics model to factor in the selection of shallow water for predator avoidance (or, for example, other behavioral issues such as surface feeding). The observed strong associations of chinook fry with vegetative escape cover in the main stem Klamath was discussed in the HSC section of the report. This association with shallow, vegetation escape cover, in part, accounts for the truncated depth suitability reflected in Figure 48. The incorporation of predation avoidance (e.g., distance to escape cover) within the bioenergetics model is feasible but was beyond the scope of this effort. It would be possible to just simply limit the usable depths in the bioenergetics model based on the observed empirical HSC data. Because the velocity suitability of the bioenergetics model is very similar to the HSC criteria, limiting depths based on the HSC criteria, however, produces bioenergetics results nearly identical those obtained by simply using the HSC criteria.

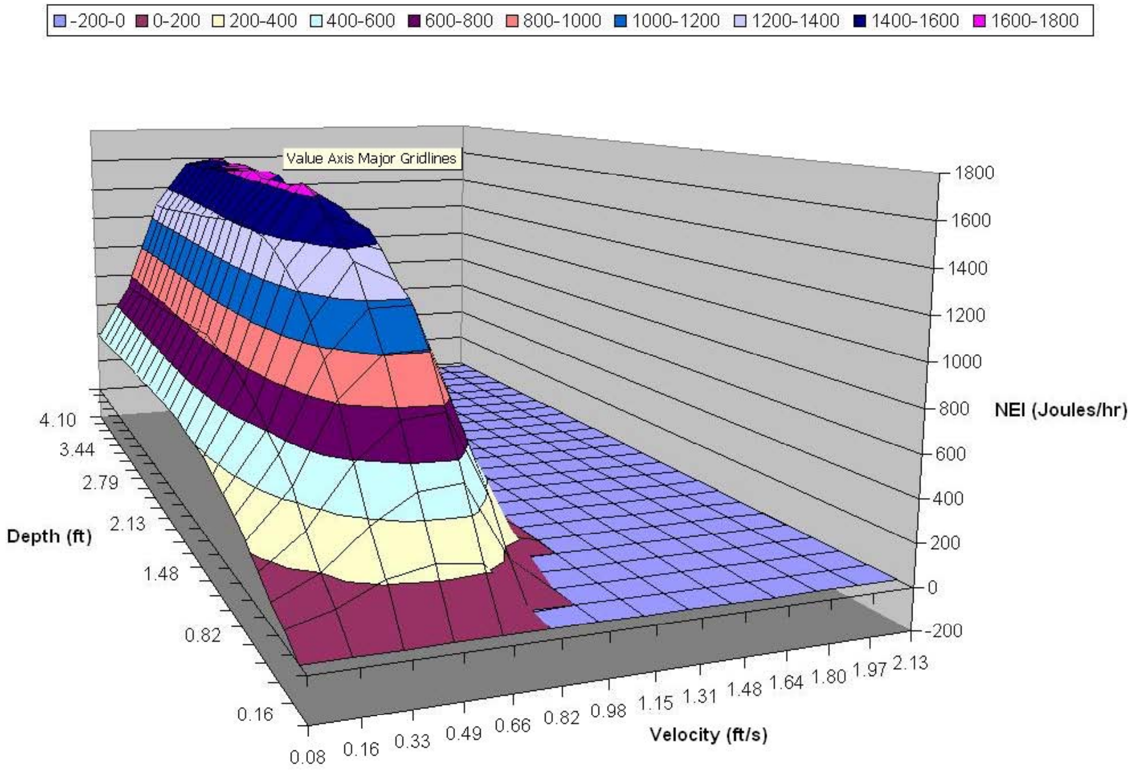


Figure 138. Chinook 40 mm total length NEI response surface for depth and velocity based on temperature and drift characteristics for the RRanch study site.

To illustrate chinook fry habitat based strictly on energetics (i.e., no truncation of depth suitability due to predation avoidance) we modeled a range of flows that could be present when chinook fry are in the system. The spatial distribution of chinook fry (40 mm) at the RRanch 1342, 2500, and 5226 cfs are shown in Figure 1

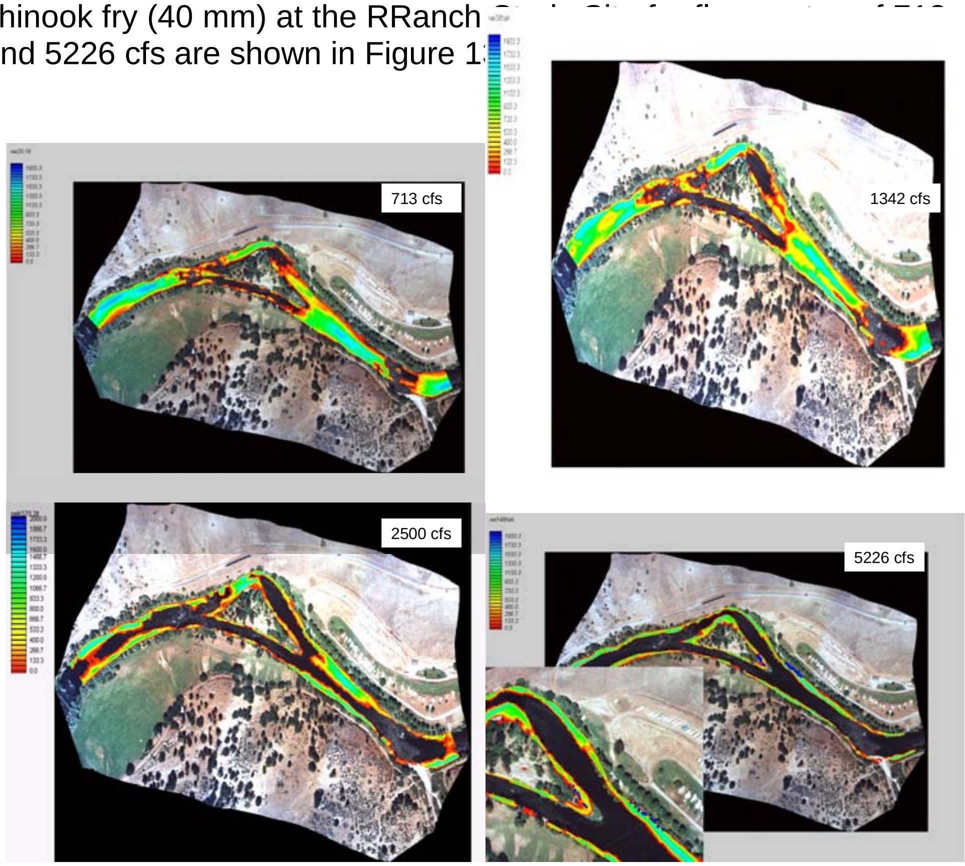


Figure 139. Chinook fry (40 mm) NEI magnitude and spatial distributions at the RRanch study site for flow rates of 713, 1342, 2500, and 5226 cfs.

The amount and distribution of positive NEI areas within the study site remain relatively constant over the range of simulated flow rates between approximately 700 to 1300 cfs and encompass a large proportion of the main channel. The areas that are not energetically favorable (i.e., negative) are indicated by the lack of color in the image. From a purely energy flow perspective, these results indicate that large areas of the channel are suitable at lower flow rates compared to the amount of suitable areas at the two higher flow rates. The primary factor in the spatial distribution and amount of suitable habitat at the lower flow rate is related to the fact that the modeling results do not incorporate key behavioral constraints that actually make these areas unusable (i.e., availability of escape cover).

Finally, the simulated conditions at the flow rates for 2500 and ~5200 cfs show an important result. At a flow rate of 2500 cfs the velocities within the main channel are beginning to become sufficiently high that the energetically favorable areas are now confined to the river margins. This is even more evident at 5200 cfs. This is ecologically important in that it constrains energetically favorable conditions in contact with escape cover at the stream margins and ‘excludes’ access to the main river channel. This is also interesting in light of the estimated unimpaired mean monthly flows during the March to early June period, which range between 4000 and 2500 cfs at this study site (see Figure 37). This period corresponds to chinook fry rearing at this study site (see Table 29). This spatial linkage between favorable energetic locations and proximity to escape cover is considered a critical factor in the successful rearing for chinook fry (and similar sized life stages of other species).

Steelhead Juvenile (160mm)

The bioenergetics model for steelhead juvenile (i.e., 160 mm) and the associated data at the RRanch study site were used to compute the NEI response surface over a range of combined depth and velocity. The response surface for this species and life stage (i.e., size) at other study sites based on the input data in Table 46 will result in small or at best moderate shifts left or right in this basic relationship based on the combination of drift availability and temperature differences. This response surface (Figure 140) clearly shows the upper threshold for velocities near 2.3 feet/second and optimal velocities at around 1.3 feet per second. Below this velocity the NEI surface also shows a rapid decline.

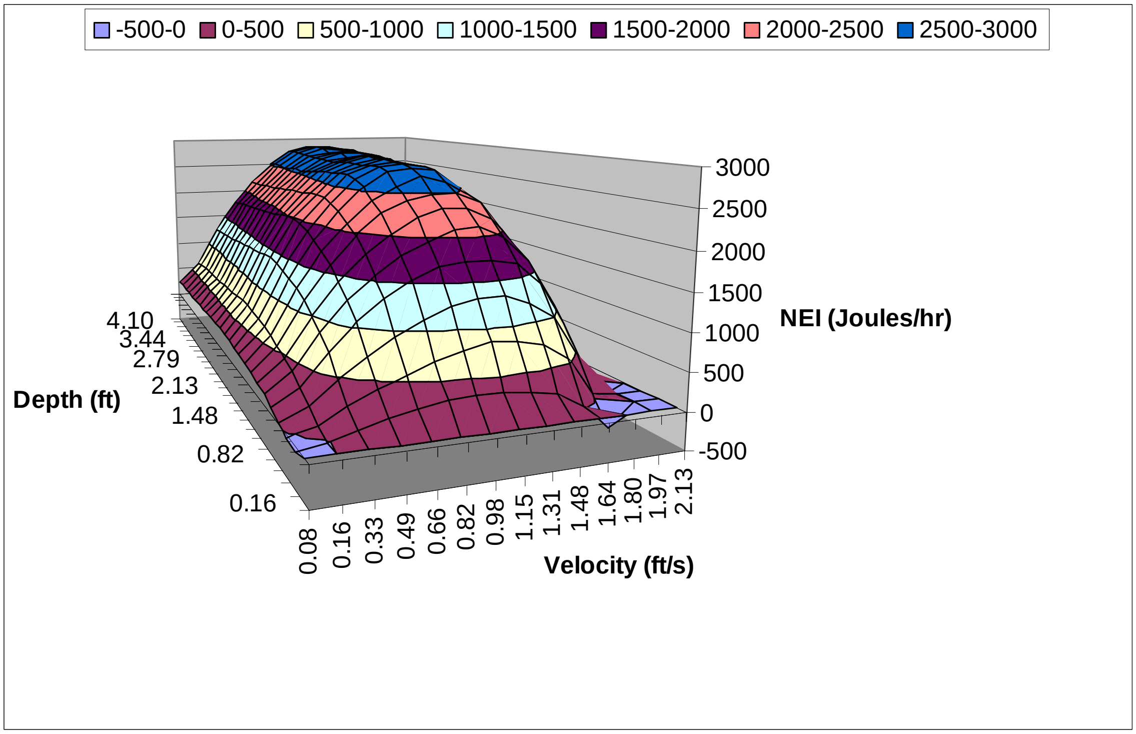


Figure 140. Steelhead 160 mm total length NEI response surface for depth and velocity based on temperature and drift characteristics for the RRanch study site.

These results in terms of the velocity dimension of the response surface are very similar to the site-specific HSC relationship for summertime steelhead velocity (see Figure 51). The temperature used in the simulations more closely reflects the collection conditions associated with summertime steelhead HSC than spring or combined seasonal HSC results. The response surface also shows that NEI rapidly increases up to a depth of about 1.2 feet and then becomes relatively insensitive to further increases in depth. The rising portion of the NEI response surface matches the site-specific summertime steelhead depth HSC (see Figure 52) in this regard. However, the HSC show that the depth suitability declines at higher depth values. We attribute this ‘decline’ in the depth HSC to be reflective of both predation avoidance behavior (i.e., use of shallower water) as well as the potential for depth limitations associated with surface feeding behavior on drift. These are known factors in other salmonid species. Our own analysis of prey recognition distance (i.e., reaction distance) based on the prey size distribution in the Klamath River strongly suggests that 90 percent of the prey sizes in the Klamath River are only observable at a distance of approximately 1.0 to 2.0 feet. Thus surface feeding would largely be limited to shallow water. The observation data in the HSC for steelhead indicate that the addition of a depth restriction in the bioenergetics model may be warranted at a future date.

Coho Juvenile (115mm)

The bioenergetics model for coho juvenile (i.e., 115 mm) and the associated data at the RRanch study site were used to compute the NEI response surface over a range of combined depth and velocity. This response surface (Figure 141) clearly shows the upper threshold for velocities near 2.0 feet/second and optimal velocities at the 0.9 to 1.0 feet per second range. Below this velocity, the NEI surface also shows a rapid decline with very little NEI associated with zero velocity (i.e., lower left corner of Figure 141).

These results in terms of the velocity dimension of the response surface are very similar to the envelope HSC relationship for summertime steelhead velocity (see Figure 75). The envelope HSC for velocity extends the suitability range to 2.5 feet per second but at very low suitabilities. The response surface also shows that NEI rapidly increases up to a depth of about 1.2 feet and then becomes insensitive to further increases in depth. The rising portion of the NEI response surface is similar to the envelope depth HSC (see Figure 76). Although not strongly represented by the few available coho HSC used in the development of the envelope HSC, the depths decline from optimal values around 2.5 feet to zero suitability at 5.5 feet. We believe this ‘decline’ in the depth HSC to be ‘real’ and reflective of both predation avoidance behavior (i.e., use of shallower water) as well as the potential for depth limitations associated with surface feeding behavior on drift as noted above. This comparison also suggests that the addition of a depth restriction in the bioenergetics model may be warranted.

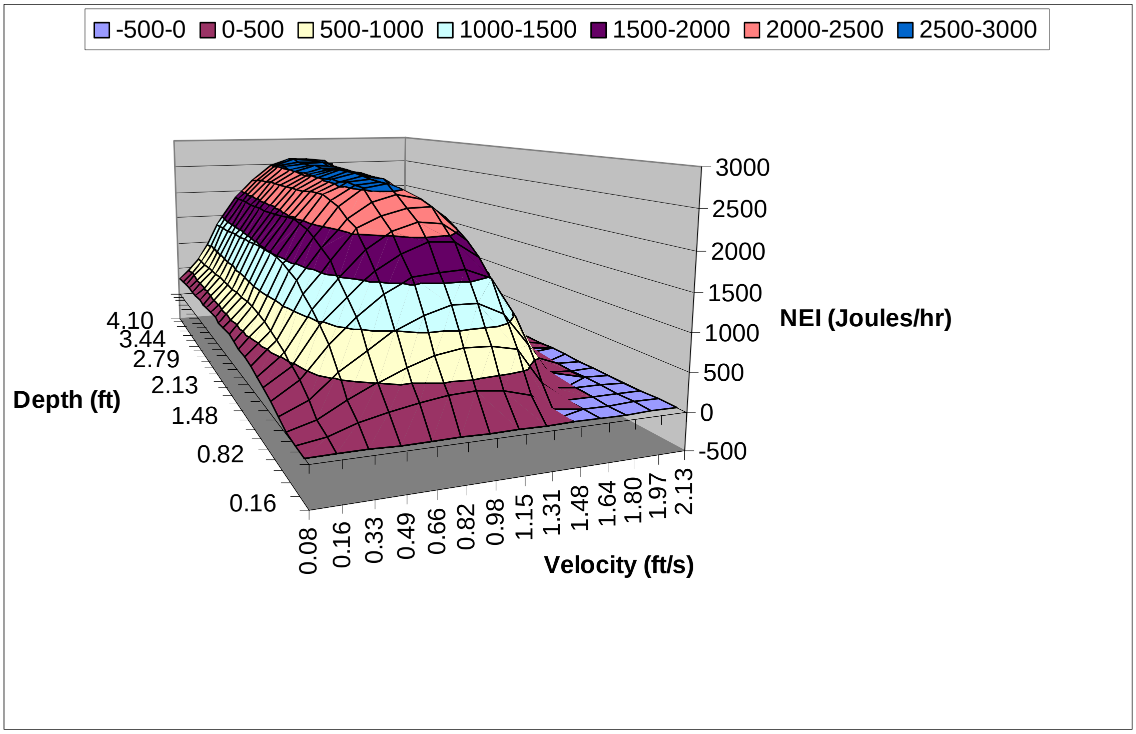


Figure 141. Coho 115 mm total length NEI response surface for depth and velocity based on temperature and drift characteristics for the RRanch study site.

Study Site Specific Bioenergetics Results

Appendix B contains NEI surface plots for selected flow rates at each study reach for chinook, steelhead, and coho simulations. These examples are provided for comparative purposes to the physical habitat HSC based modeling. Although we had anticipated that this modeling approach might reflect juvenile fish distributions ‘better’ than the HSC based modeling, the similarity of the NEI response surface and the HSC tended to yield equivalent results. Also as noted in the discussions for each species above, the incorporation of a depth and/or distance to escape cover component to the bioenergetics modeling needs to be explored further. This was beyond the scope of existing resources and budget for this project.

The NEI simulations however, were valuable as a form of HSC validation, especially for the velocity curves. The results infer the importance of incorporating behavioral requirements of young life stages in the modeling of available habitat. This is particularly true for the association of escape cover for fry life stages as implemented in the physical habitat modeling approaches using the HSC criteria as discussed above.

Chemical Processes

In this section of the report, the water quality and temperature modeling results are discussed. As was noted earlier, the HEC-5Q water quality modeled was adapted by the USGS for use within SIAM and was the tool used to generate results for use in the Phase II assessments.

Water Quality (Temperature) Modeling using SIAM

Within the MODSIM and HEC5Q portions of SIAM several preset flow scenarios and associated computational networks are available. Network 2 is designed to model the river without any of the existing dams or alterations to the system (this is no longer supported by the USGS). The HEC5Q portion of Network 2 is based upon a 30-day month, 360-day year, with water quality output on a daily time-step. Note that MODSIM (flow) in Network 2 is a monthly time step for the period of record. Daily flows are derived in SIAM by dividing the monthly values by 30. Network 3 includes all dams and alterations to the system and produces output from Upper Klamath Lake to the estuary. The HEC5Q output changes in Network 3 to a standard month, 365-day year, with no February 29th. The output is still a daily time step and MODSIM flow output is still monthly.

SIAM provides a graphical interface to view results and comparisons between alternatives that are modeled using the same network. However, further data reduction was necessary using Microsoft's Excel spreadsheets as part of our evaluations. This was required to allow for a comparison between Network 2 and 3 outputs with their different time step accounting and enhanced our ability to observe trends differently than the SIAM interface allowed.

In our applications of SIAM we found that the user needs to evaluate the simulations carefully given the following observed behavior in the HEC5Q model:

1. Negative water temperatures as low as –5.3 C^o were obtained. HEC5Q has an error of plus or minus, 0.5 C^o. SIAM or HEC5Q does not correct any negative values to 0 C^o, or account for the heat of fusion for ice creation (USGS, Blair Hanna). The SIAM interface 'screens' these values but they are retained in the simulation output from HEC5Q.

2. Positive water temperatures as high as 120 C^o could be obtained <u>before</u> the model would "crash". This served as a warning that the model was being pushed/forced past its capability, or that an unrealistic flow scenario was input.

3. If a reservoir volume was adjusted too low, or a flow regime was attempted that forced the residence time in the reservoir to

violate HEC5Q's requirement of a residence time being greater than 1 day, results similar to number 2 above could be obtained.

4. SIAM is limited in returning visual warnings of violations of preset limits or requirements for MODSIM and HEC5Q. The modeler must be vigilant in screening outputs for erroneous results, and knowledge of the Klamath River System is required.

5. The current linkage between MODSIM and HEC5Q cannot accurately model the reach from Upper Klamath Lake to Iron Gate Dam for five water year types with different operating criteria when modifications are attempted through the SIAM interface.

The reader is directed to the Hydrology modeling section of the report above for a detailed description of our use of the MODSIM and HEC5Q models implemented for the scenario evaluations.

QA/QC of Model Simulation Results

As part of our QA/QC evaluations of the temperature (and flow) modeling to determine if the model was producing reasonable results, we systematically checked model outputs for all simulated scenarios. This included screening for excessively high or low temperatures, and expected within year fluctuations in temperature values. QA/QC evaluations also examined the simulations to check that the program maintained a minimum Upper Klamath Lake storage that matched the 4139-foot elevation selected for Upper Klamath Lake minimums. This check also ensured that no upper extremes in lake storage values were generated. Finally, flows generated at Iron Gate (and other node locations) were examined for unrealistic simulated values prior to using the results.

The No_Project scenario was difficult to compare to the other alternatives. The No_Project scenario uses Network 2 (360-day year) and all other alternatives use Network 3 (365 day year) for modeling. This different time step accounting required an adjustment in the No_Project results to represent a 365-day year for a systematic comparison. This was achieved by the following steps:

Temperature

The No_Project scenario used a 30-day month (Feb included). This was standardized to match output using Network 3 by adding a 31st of the month and interpolating the required value between the 30th and the 1st day of the next month. In February, the two extra days were eliminated. A 365-day year was produced.

Flow

Both the Network 2 and Network 3 flow outputs are based upon total volume for the month. The daily values were obtained by dividing the total by the number of days in a month represented by the specific Network (30-days for Network 2 or the standard calendar for Network 3). Standardizing flow values between networks was accomplished using the same procedure as described for temperature above.

Temperature Run-Sum Calculations

Simulation results for temperature were summarized using a run-sum analysis. This type of analysis counts the number of events ('sum') that exceed some threshold criteria and tracks the length or 'run' for each event. Run-sum water temperature calculations were based upon the following:

1. Chronic events occur when water temperatures equal or exceed 16 C^o for seven or more consecutive days.
2. Acute events are associated with water temperatures equal or greater than 22 C^o.

These definitions were adopted by the USGS in SIAM and are primarily used as a relative index to compare water temperature simulation results between scenarios.

Comparison of Modeled Scenario Temperatures

The simulated daily temperature results from 1974 to 1997 water years for modeled scenarios at each USU study site (see Table 19) are presented in this section. Note that Saints Rests Bar data has been omitted. In addition, for the unimpaired no project scenario, only results between Iron Gate Dam and Seiad are available since the HSC5Q model network file for this scenario stops at the Seiad gage (see Hydrology section).

Simulated Daily Temperature Time Series

The daily simulation results for each station for all scenarios are provided in Appendix C. Figure 142 through 145 show the results for the Iron Gate study site, which is illustrative of the remaining stations. During most years, the chronic threshold for water temperature (i.e., 16 C) was violated almost continuously during June, July, and August for all flow scenarios. There is also an apparent slight upward trend in the temperature over the last decade that is associated with the meteorological data in the HEC5Q data sets. The results are consistent with the findings of Bartholow (1995) and generally support the conclusion that during low flow summer periods the conditions in the Klamath main stem are likely marginal for anadromous species due to elevated temperature.

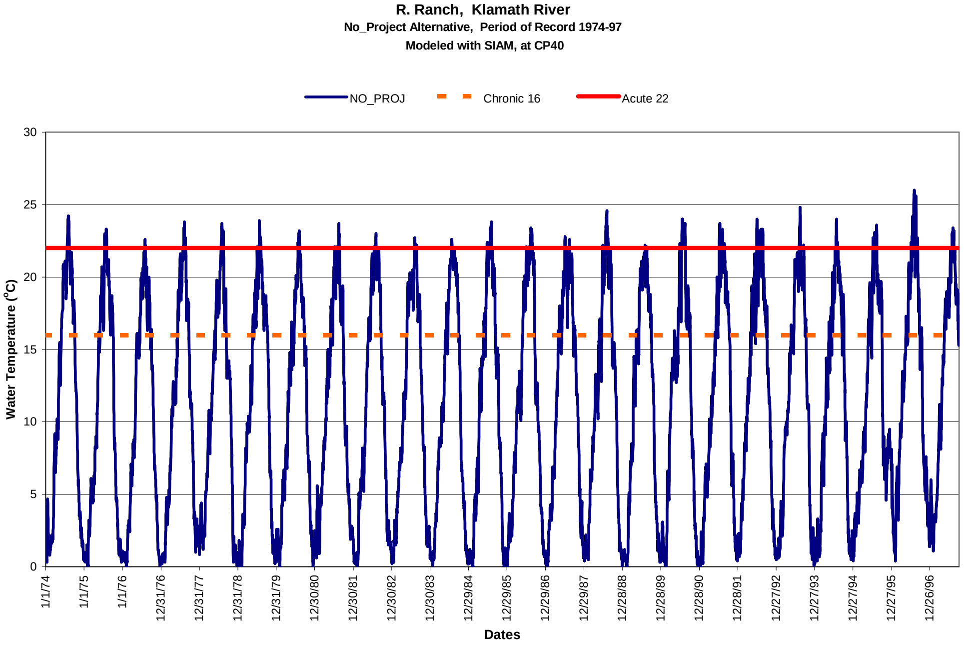


Figure 142. Daily mean temperatures at Iron Gate for the unimpaired no project scenario (1974 to 1997 water years).

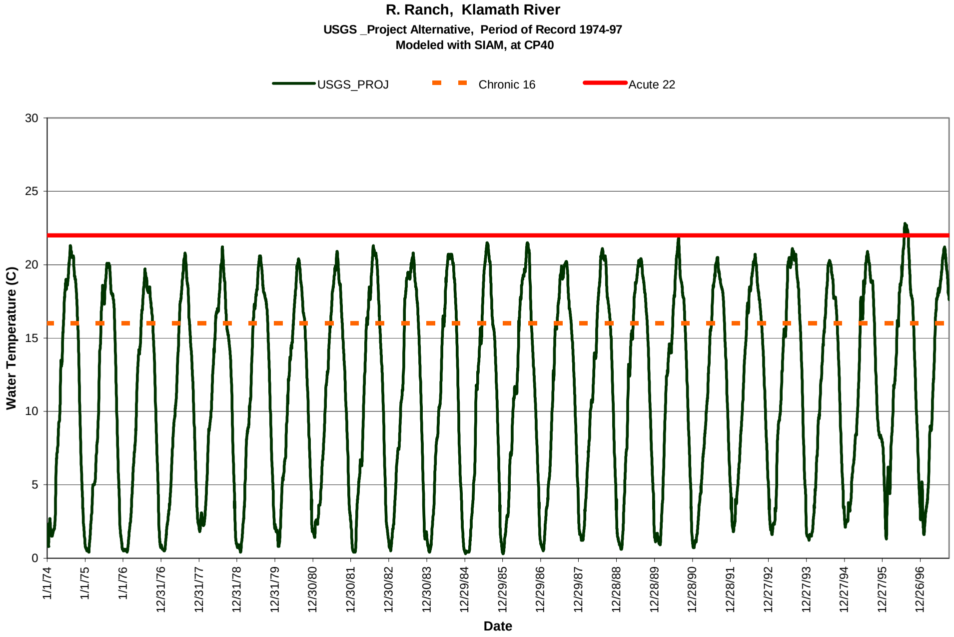


Figure 143. Daily mean temperatures at Iron Gate for the USGS Historical project operations (1974 to 1997 water years).

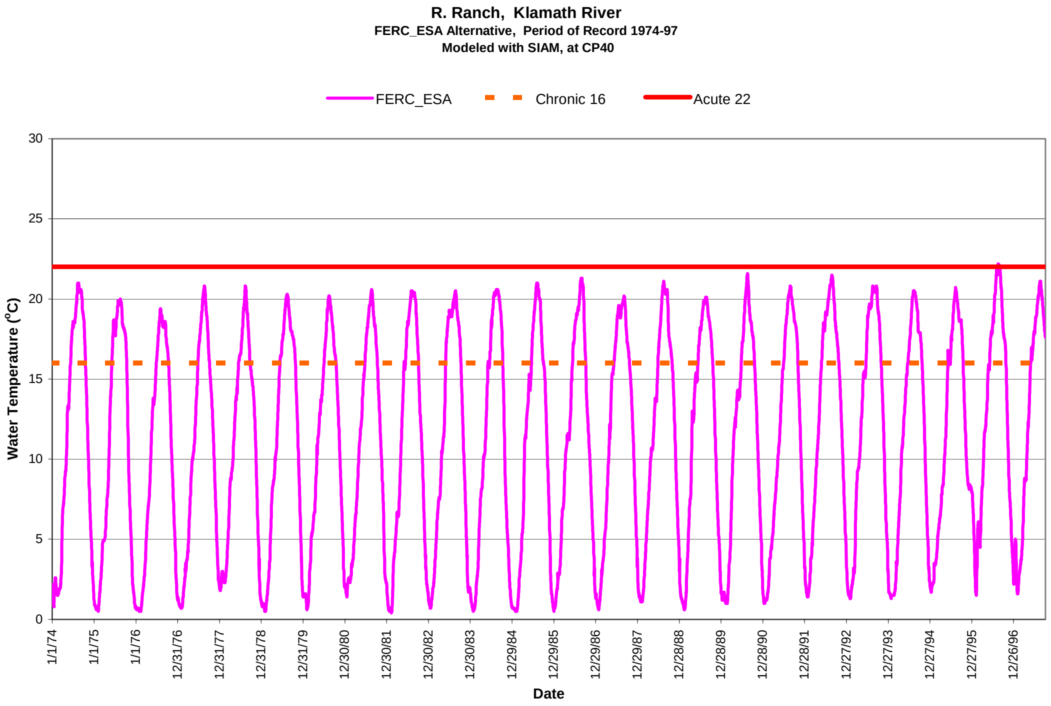


Figure 144. Daily mean temperatures at Iron Gate for the FERC_ESA scenario (1974 to 1997 water years).

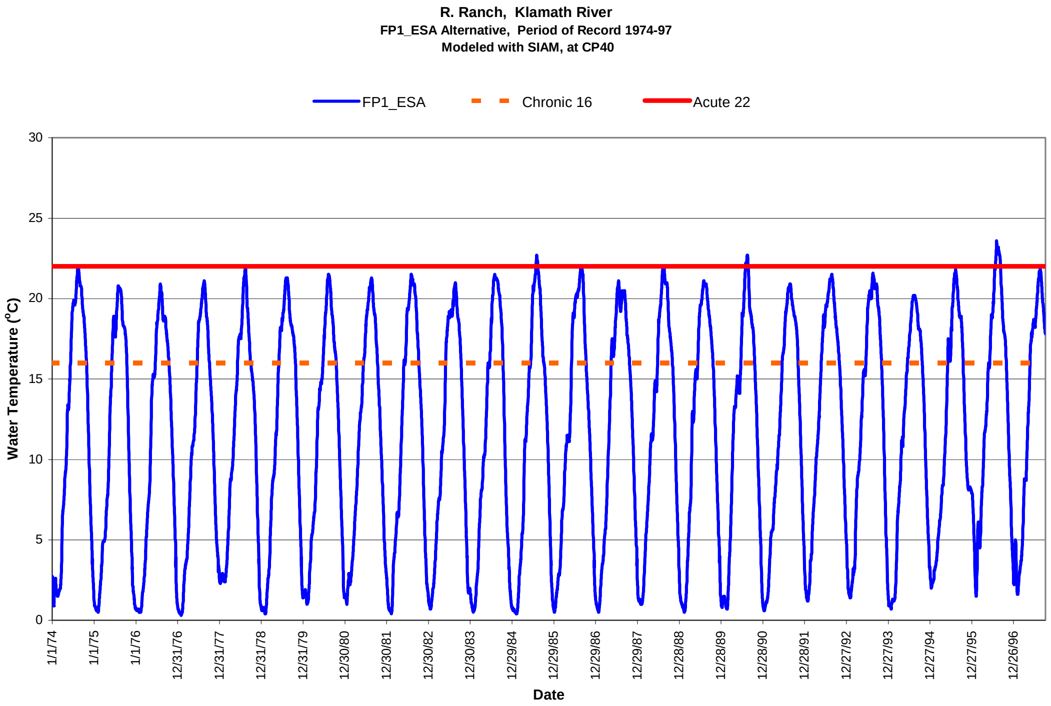


Figure 145. Daily mean temperatures at Iron Gate for the FP1_ESA scenario (1974 to 1997 water years).

Simulated Mean Monthly Temperatures

The simulation results of daily temperatures from 1974 to 1997 for each station were used to compute the long-term mean monthly temperatures for each scenario. These results are presented in Figures 146 to 152. The corresponding tabular data that includes the monthly mean, standard deviation, maximum, and minimum temperatures are provided in Appendix D.

The results for the unimpaired no project flows suggest that the average monthly temperatures immediately below Iron Gate are slightly warmer than the other scenarios, including existing conditions, (~2 C) during the spring and summer period. However, it is difficult to attribute a strong significance to these results given the uncertainties in the modeling of pre-project conditions in Upper Klamath Lake and upstream of Iron Gate. However, the results during the October through December period are sufficiently large that likely the main stem in this reach was indeed cooler existing conditions as shown in the results. The results also show that below the Trees of Heaven site (below the confluence of the Shasta River) that the mean monthly summer temperatures are essentially the same for all scenarios (see the results at the Brown Bear study site). The influence of the Scott River inflows under the unimpaired flow scenario is readily apparent in the much lower year round mean monthly temperatures observed at Seiad.

Iron Gate

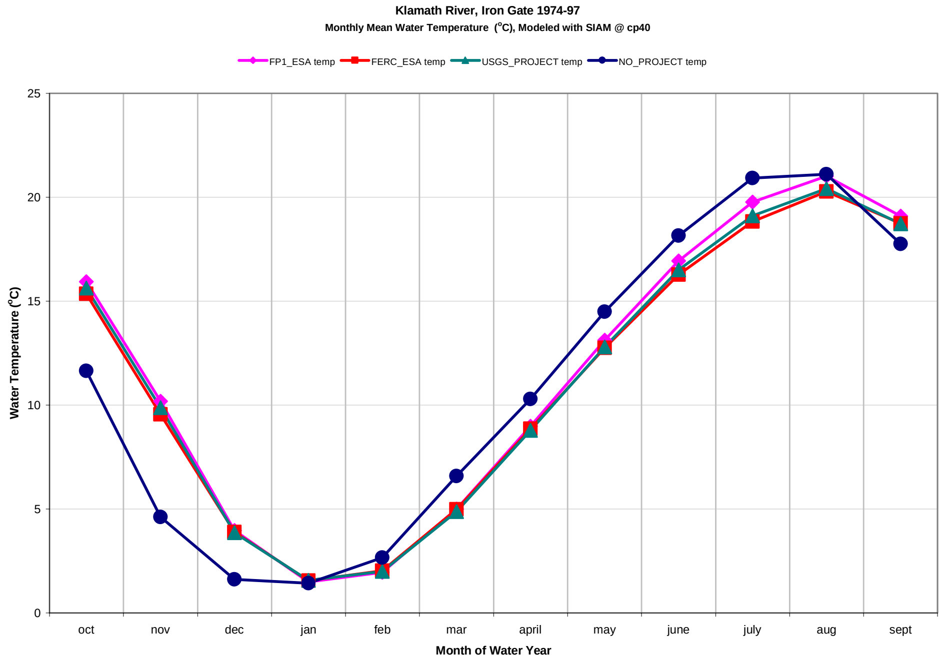


Figure 146. Mean monthly temperatures at Iron Gate for all simulated scenarios (1974 to 1997 water years).

Trees of Heaven

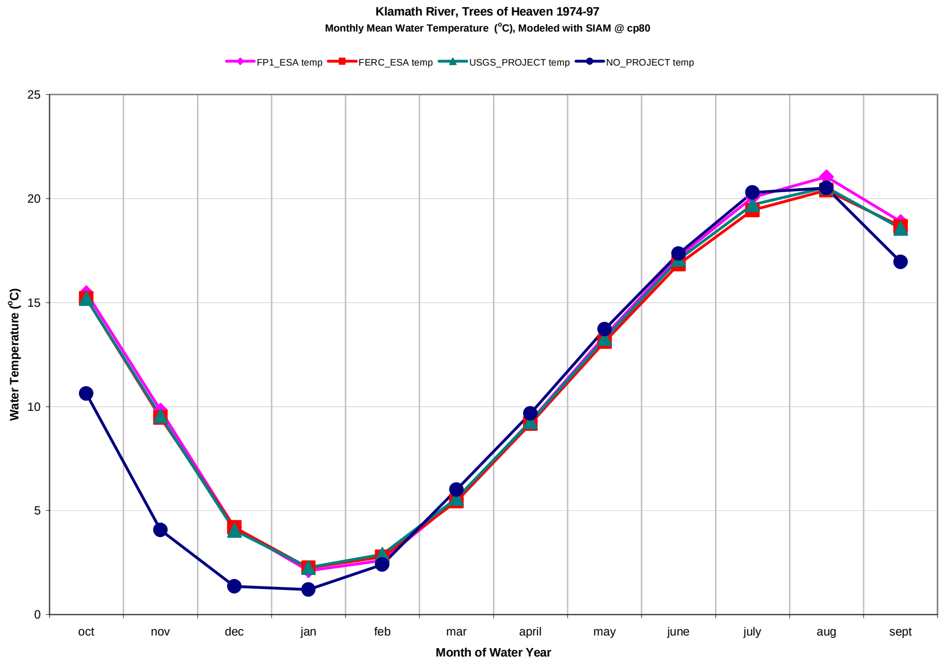


Figure 147. Mean monthly temperatures at Trees of Heaven for all simulated scenarios (1974 to 1997 water years).

Brown Bear

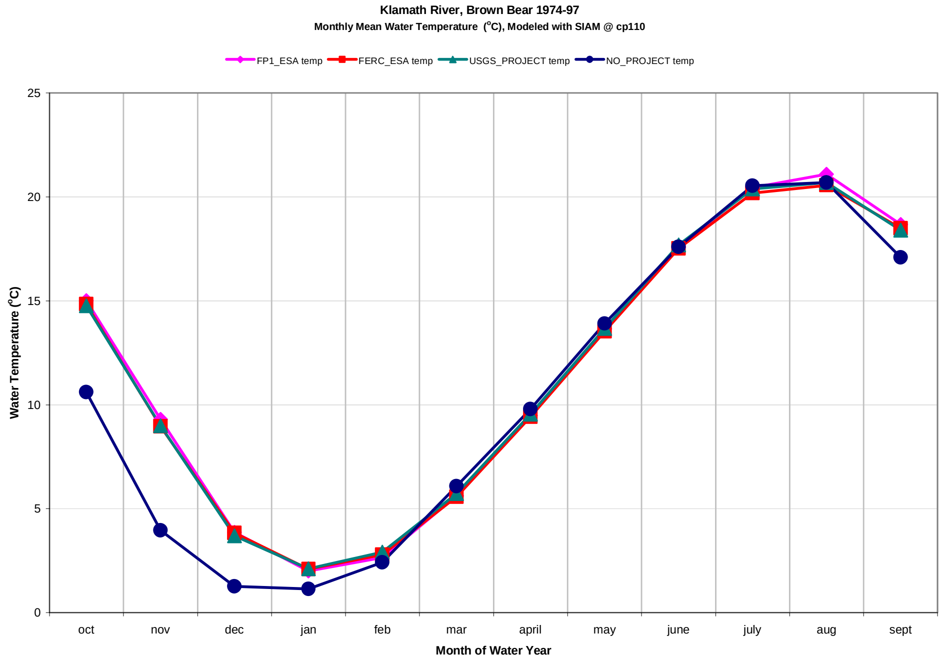


Figure 148. Mean monthly temperatures at Brown Bear for all simulated scenarios (1974 to 1997 water years).

Seiad

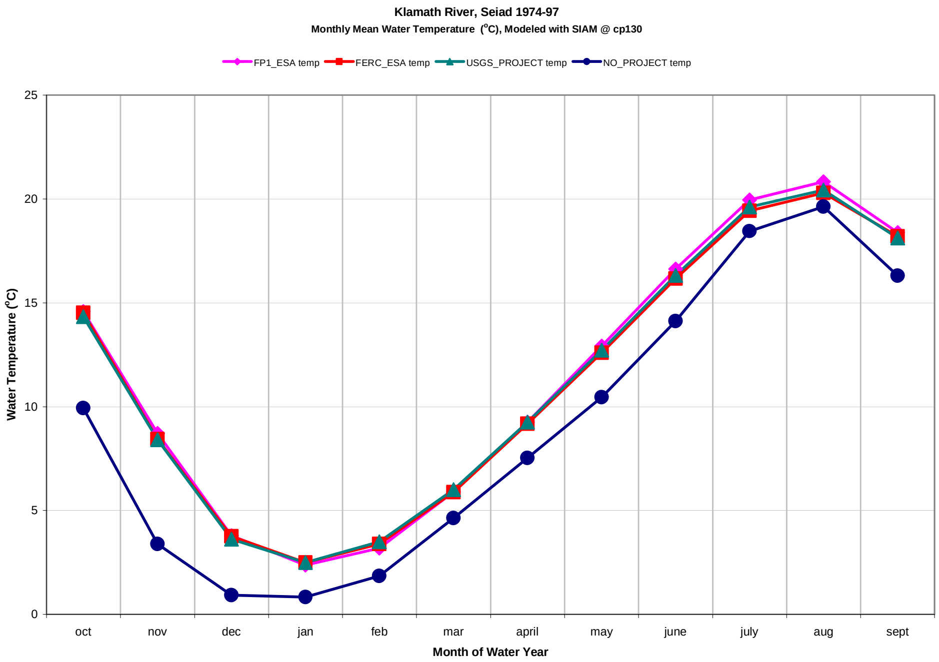


Figure 149. Mean monthly temperatures at Seiad for all simulated scenarios (1974 to 1997 water years).

Rogers Creek

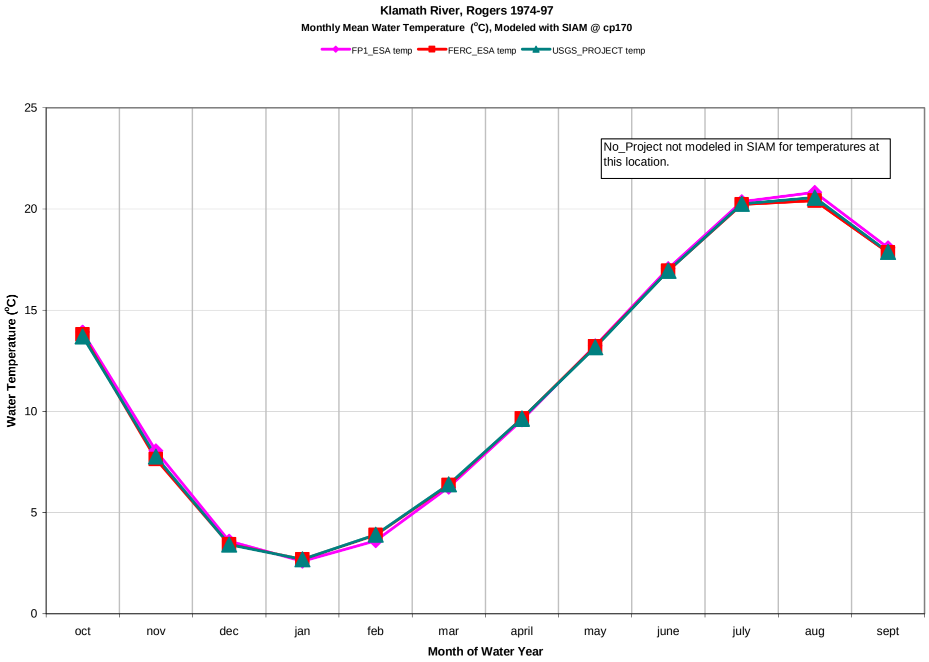


Figure 150. Mean monthly temperatures at Rogers Creek for all simulated scenarios (1974 to 1997 water years).

Orleans

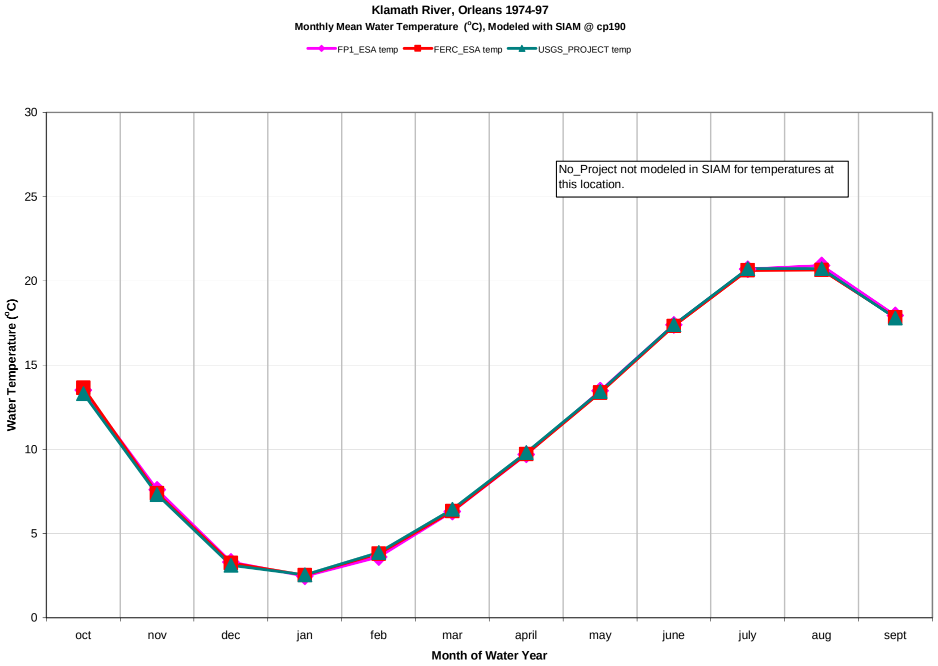


Figure 151. Mean monthly temperatures at Orleans for all simulated scenarios (1974 to 1997 water years).

Saints Rest Bar

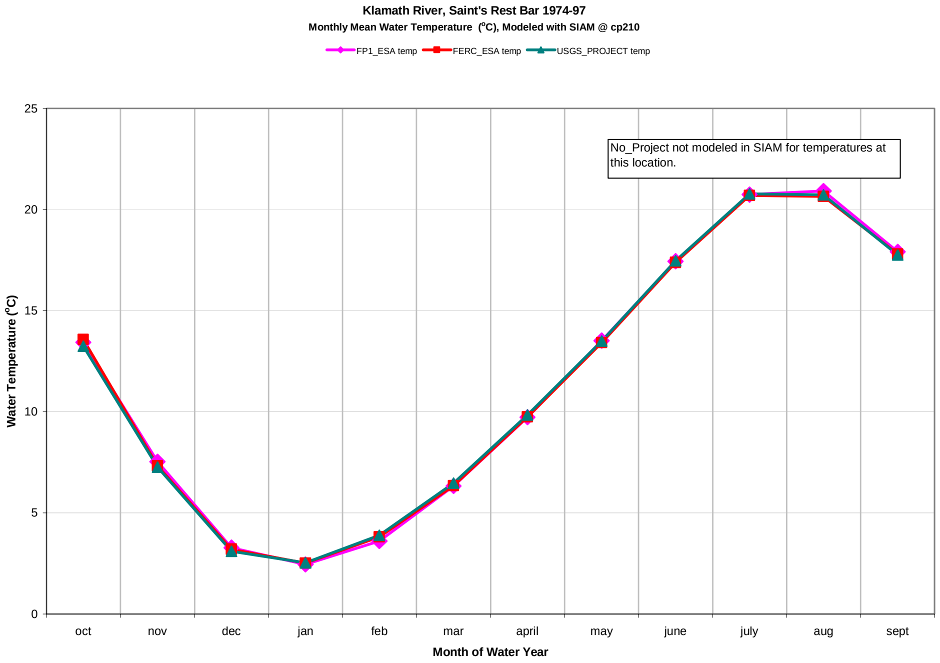


Figure 152. Mean monthly temperatures at Saints Rest Bar for all simulated scenarios (1974 to 1997 water years).

Run Sum Analysis of Chronic and Acute Temperatures

Table 48 contains the run sum length analysis for both acute and chronic temperatures based on each of the flow scenarios at each of the study sites. These results for the Iron Gate to Seiad reach are interesting in light of the unimpaired no project scenario comparisons. The unimpaired average mean daily temperatures are lower than all scenarios and are attributed to the lower winter temperatures (see Figures 146 through 152). This is also reflected in the lower total number of days above 16 C. The unimpaired results show a greater number of events above 16 C but they are considerably less in terms of their average length. The maximum length of events greater than 16 C is also smaller than other scenarios. Average temperatures associated with these events show very little variation between scenarios (i.e., +/- 1 C).

A comparison of the acute event results also show that the unimpaired flow scenario had the greatest number of days and number of events above 22 C. However, the average length of the acute events was generally shorter in the upper reaches of the main stem. With the exception of the FERC_ESA scenario, the unimpaired scenario also had the lowest maximum length of acute events immediately below Iron Gate and was generally similar to other scenarios below the Shasta River. The implications of these results are discussed further in the instream flow recommendations.

Table 48. Run sum length analysis of daily temperatures for each flow scenario at each study site.

Klamath River, Mean Daily Water Temperature (°C), Modeled with SIAM
Period of Record 1974-97 (8668 Days)

Location	Alternative	All		Chronic Events >16 °C						Acute Events > 22 °C				
		Max Mean Daily Temperature (°C)	Average Mean Daily Temperature (°C)	# of Days > 16° C	Events > 16° C (1 or more days)	Ave. Length of Events >16° C (days)	Max Length of Events >16° C (days)	Chronic Events >= 7 Days >16° C (days)	Average Temp of Events >16° C	# of Days > 22° C	Acute Events > = 22° C (1 or more days)	Ave. Length of Events >22° C (days)	Max Length of Events >22° C (days)	Average Temp of Events >22° C
Iron Gate CP40*	FP1_ESA	23.6	11.5	3165	29	109.1	161	25	19.2	99	8	12.4	44	22.5
	FERC_ESA	22.2	11.2	2963	27	109.7	151	25	18.8	15	2	7.5	8	22.1
	USGS_PROJ	22.8	11.2	3030	29	104.5	144	27	18.8	38	1	38.0	38	22.4
	N0_PROJECT	26	11.0	2937	76	41.3	129	40	19.7	442	78	4.6	22	22.9
Trees of Heaven CP80*	FP1_ESA	23.5	11.7	3134	39	84.6	158	28	19.3	116	21	5.5	45	22.5
	FERC_ESA	22.2	11.2	2969	28	106.0	152	25	18.8	17	2	8.5	9	22.0
	USGS_PROJ	23.2	11.6	3058	58	55.0	141	27	19.0	45	8	5.6	12	22.5
	N0_PROJECT	25.4	10.5	2668	81	29.5	119	45	19.3	259	59	4.4	17	22.8
Brown Bear CP110*	FP1_ESA	24.4	11.7	3097	70	42.6	140	30	19.4	208	53	3.7	19	22.6
	FERC_ESA	24.2	11.6	3062	89	33.3	139	35	19.2	108	37	2.9	12	22.5
	USGS_PROJ	24.3	11.6	3069	76	37.6	141	36	19.3	167	52	2.9	12	22.6
	N0_PROJECT	25.7	10.5	2698	95	25.5	111	50	19.5	313	71	3.7	16	22.9
Seiad CP130*	FP1_ESA	24.1	11.4	2861	74	35.1	136	31	19.2	175	50	3.3	17	22.6
	FERC_ESA	23.7	11.3	2772	88	29.8	115	44	18.9	83	32	2.8	10	22.4
	USGS_PROJ	24.2	11.3	2769	86	26.5	116	38	19.0	128	42	2.4	10	22.6
	N0_PROJECT	24.7	9.1	2001	109	18.0	68	44	18.8	117	34	3.2	14	22.8
Rogers CP170*	FP1_ESA	25.1	11.5	2854	114	26.9	118	44	19.4	286	73	3.2	14	22.8
	FERC_ESA	24.9	11.4	2797	129	23.1	114	58	19.3	256	72	2.8	12	22.8
	USGS_PROJ	25.1	11.4	2785	129	22.8	114	53	19.3	278	75	3.0	12	22.9
	N0_PROJECT	This location not supported for the No_Project Scenario in SIAM												
Orleans CP190*	FP1_ESA	26.2	11.5	2845	135	19.0	115	52	19.6	394	114	2.7	9	23.0
	FERC_ESA	26.1	11.5	2804	150	18.6	96	61	19.5	256	72	2.8	12	22.8
	USGS_PROJ	26	11.5	2803	140	18.3	95	61	19.6	404	120	2.5	8	23.1
	N0_PROJECT	This location not supported for the No_Project Scenario in SIAM												
Saint's Rest Bar CP210*	FP1_ESA	26.2	11.5	2844	131	23.5	116	52	19.6	401	121	2.6	9	23.0
	FERC_ESA	26.2	11.5	2806	150	18.6	96	59	19.6	393	122	2.4	8	23.1
	USGS_PROJ	26.1	11.5	2800	148	17.9	95	62	19.6	424	126	2.7	9	23.1
	N0_PROJECT	This location not supported for the No_Project Scenario in SIAM												

* SIAM control point designation that corresponds to the USU study site at this location

Instream Flow Recommendations

In this section of the report, the results from the two-dimensional site-specific analyses are used to recommend instream flows for each river reach in the main stem Klamath River from Iron Gate Dam to below the Trinity River. When evaluating these instream flow recommendations, we remind the reader that the overall objective of the Phase II study is to make revised flow recommendations that will maximize the potential to meet recovery and sustainability of the anadromous species and other aquatic resources in the Lower Klamath River. Recommendations are provided to the Department of Interior in light of these Phase II objectives. The study results could be used to consider other management objectives such as trade-offs between different flow regimes representing various other management and/or policy objectives. This will undoubtedly include potential trade-offs between ESA driven lake elevations in Upper Klamath Lake versus the downstream needs of the anadromous species and other potential demands on the water resources in the basin. The evaluation of alternative policy or management objectives for recommending alternative instream flow regimes was not within the purview of this effort and was beyond the scope of the Phase II study.

We have approached the development of flow recommendations from the premise that they should attempt to mimic the seasonal pattern and general magnitude of the natural flow hydrograph for a given water year type. The recommendations should also ensure that the underlying characteristic of the flow hydrograph varies between water year types (i.e., 90 through 10 percent exceedence flows). This logically follows from the previous discussions on the ecological basis of instream flow regimes or more succinctly from ‘the natural flow paradigm’ (e.g., Poff et al., 1997). This is particularly important since the main analytical assessments conducted in Phase II rely primarily on physical habitat simulations. As such, these modeling efforts do not incorporate all the physical, chemical, and biological processes or their linkages within a river ecosystem. Use of the physical habitat results was made in light of their inherent limitations to define or necessarily ‘protect’ these processes. The instream flow recommendations were made in light of both physical habitat as well as factors that are more generally related to physical, chemical, and biological processes.

From a physical habitat perspective, we approached the flow recommendations from the objective to maximize habitat conditions if possible for target species and life stages. We recognized that under any ‘natural’ flow regime, ‘optimal’ or maximum habitat conditions do not necessarily occur for a given species or life stage in any or all locations or for all time periods. One component of our flow recommendations targeted habitat conditions that are similar in characteristics to those found under the unimpaired flow regime on a seasonal basis and its inherent variability by water year type.

Reference Conditions: Unimpaired No Project Simulated Flows and Habitat

In Phase II, we relied on simulated hydrology to estimate the unimpaired flows at Iron Gate Dam as an alternative to the adjusted gage data used in Phase I. We believe that this simulated hydrology represents the best available information for estimating flow (and habitat) 'reference conditions' below Iron Gate Dam under unimpaired flow conditions for the purposes of this study. Figure 153 shows the 10 to 90 percent monthly exceedence flows below Iron Gate (SIAM CP40 see Figure 5). This has been plotted on an annual rather than water year basis to emphasize the seasonal (i.e., winter, spring, summer and early fall) characteristics of the monthly flows.

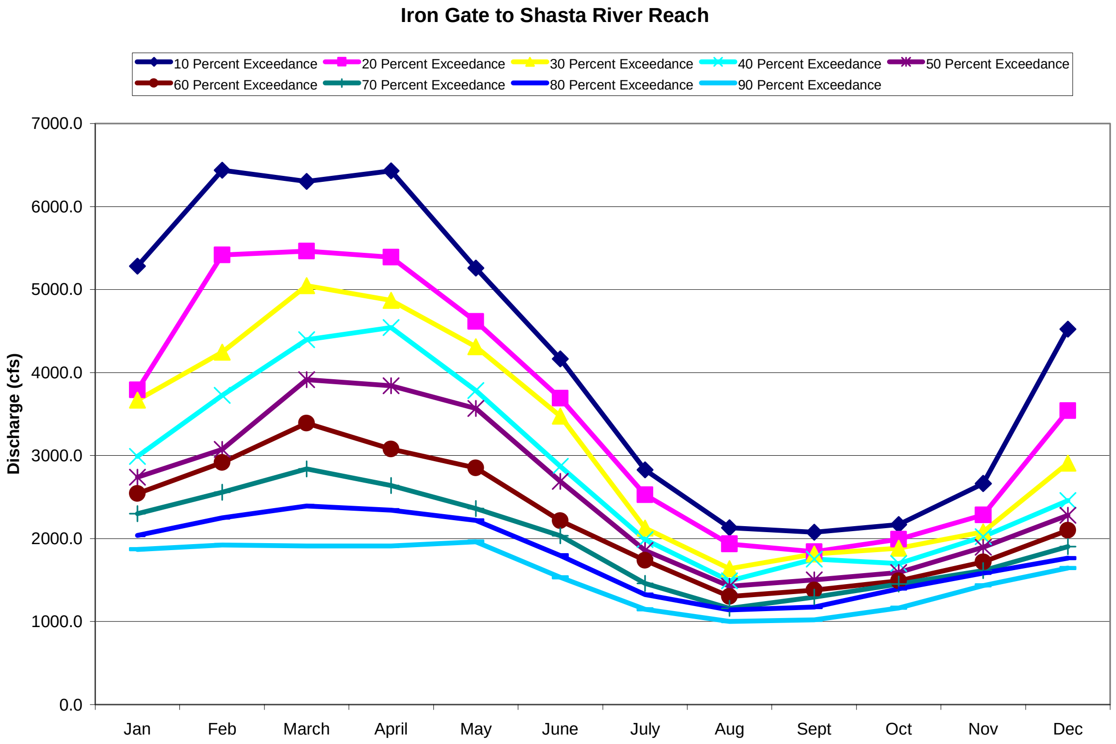


Figure 153. Monthly flows associated with the 10 to 90 percent exceedence ranges below Iron Gate Dam (SIAM CP40 see Figure 5).

There are certain characteristics of the hydrograph shown in Figure 153 that were considered in the recommendation process in Phase II. We view the overall trend in the progressive lengthening of the runoff signature with decreasing exceedence values (i.e., higher flows) during the December to June period to be an inherent property of the Klamath River hydrograph. As runoff volume proportionally increases, the runoff period lengthens and magnitudes of the flows increase. We attempted to retain this more variable characteristic of the flow regime during this period in formulating our flow recommendations. The simulation results for the summer period show a markedly different characteristic with a narrow range of flow variability. This ‘stability’ in the summer and early fall flow regimes has been noted by other investigators (Balance Hydrologics, (1996), USGS (1996)) as a characteristic of the Klamath River. We also strived to retain this characteristic in our flow recommendations during this period.

We recognize that the results shown are derived from simulation modeling with their attendant assumptions and data sources, and therefore these estimated flow results are not exact. They have been used as a tool to characterize the hydrograph in a manner that lends itself to establishing instream flows that conceptually links the seasonal and inter-annual variability of the hydrograph to the ecological requirements of the target species (e.g., monthly periodicity). Although a number of different statistical representations of the hydrology were examined (e.g., see USGS 1996, Balance Hydrologics 1996, mean monthly flows, etc) the use of flow exceedence ranges was also selected to be compatible with the USBR Klamath Project operations model (KPSIM). As noted previously, this modeling tool sets water year definitions based on water year type exceedence forecasts. This allows for the evaluation of the results from an existing decision framework in terms of water year classifications.

The habitat modeling results at the reach level (i.e., percent of maximum habitat) represents a ‘theoretical’ relationship between flow and habitat availability. However, these results can only be interpreted in light of the specific hydrology associated with a given study reach. Integration of the unimpaired hydrology and physical habitat simulation results allows the establishment of a habitat ‘reference condition’ for each target species and life stage for these flow conditions. The integration of hydrology and habitat results was undertaken for each target species and life stage for each monthly flow exceedence level. The inclusion or exclusion of a specific target species and life stage for a given month within a river reach was based on the monthly species periodicity results developed for the study (see Table 29).

The physical habitat availability was accomplished by selecting a monthly flow value at a given exceedence level and then interpolating the habitat from the percent of maximum habitat versus discharge relationship (e.g., see Figure 128) for a given study reach. This was repeated for each month for each exceedence range and for each life stage present according to the species periodicity for that river reach.

These estimates of habitat availability (as percent of maximum habitat) in each monthly for each exceedence flow range were then considered to represent the best estimate of habitat reference conditions associated with the unimpaired flows for each river reach. Since, the reach level habitat results were obtained by weighting study site results over the entire river reach (see Figure 5), the simulated flows associated with the midpoint of each river reach were used in the calculations. Utilizing the reach midpoint hydrology was considered the least biased approach for estimating the reach level habitat values versus using either the starting or the ending river reach hydrology.

Flow Recommendation Methodology

The development of the instream flow recommendations was simplified by the construction of a composite monthly habitat matrix that associated a single ‘priority’ species and life stage to each month. The species and life stage priority system for each month was based on the presence of chinook spawning, followed by chinook fry, coho fry, steelhead fry, and then steelhead juveniles. This ‘rank ordering’ of the species and life stages was derived based on input from the Technical Team and stressed the importance of protecting each successive life history phase (i.e., spawning/incubation, fry, then juveniles) using the monthly species periodicities for each river reach. Discussions with the Technical Team also considered the relative importance between chinook, coho, and steelhead on a monthly basis in terms of their utilization of the main stem, timing of outmigration from tributaries, and overall status of the various species within the basin.

The basic procedure used to assign the priority species to a month was to designate chinook spawning as a priority in the October through January period. Chinook fry was then assigned as the priority during the February through May period. Most chinook fry begin to outmigrate from the Iron Gate to Shasta River reach in late May or early June, so coho fry were assigned to the month of June. Steelhead fry were then assigned to July followed by ‘summer’ steelhead 1^+ in August and September. The monthly composite habitat matrix was then derived by computing the percent of maximum habitat for chinook spawning, chinook fry, coho fry, steelhead fry, and ‘summer’ steelhead 1^+ based on the estimated monthly unimpaired flows at each flow exceedence level.

These results for the Iron Gate to Shasta River reach based on the species and life stage periodicity are provided in Table 49. Each species and life stage has been color coded for clarity. Lighter shading indicates lower expected use (or importance) within this reach for that particular month and was a factor in the development of the monthly composite habitat matrix illustrated in Table 50, which retains the color associations for species in Table 49.

Table 49. Percent of maximum habitat based on the estimated unimpaired flows for chinook spawning, chinook fry, coho fry, steelhead fry, and 'summer' steelhead 1$^+$ in the Iron Gate to Shasta River reach.

Chinook Spawning	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	24	15	16	15						91	77	33
20	47	23	22	23						95	88	53
30	50	37	26	28						97	93	70
40	67	48	35	32						99	94	83
50	75	65	44	45						100	97	88
60	81	69	56	65						100	99	92
70	87	80	72	78						100	100	97
80	94	89	85	86						100	100	98
90	97	96	96	96						97	100	100
Chinook Fry	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	97	82	84	82	97	100						
20	97	96	96	97	100	97						
30	96	100	98	99	100	95						
40	89	97	100	100	97	87						
50	85	91	98	98	95	84						
60	81	88	94	91	87	72						
70	75	81	87	83	76	67						
80	67	73	77	76	72	61						
90	62	63	63	63	64	58						
Coho Fry	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10		89	90	89	99	92						
20		100	100	99	96	86						
30		93	98	97	93	83						
40		86	94	95	87	73						
50		76	89	88	84	69						
60		73	81	77	72	59						
70		66	72	68	62	54						
80		59	63	62	59	50						
90		52	51	51	53	47						
Steelhead Fry	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10				83	94	100	89	74	72			
20				92	98	97	84	68	66			
30				97	99	95	74	62	65			
40				98	98	90	69	61	64			
50				98	96	87	66	60	61			
60				93	89	76	64	59	60			
70				86	80	71	61	57	59			
80				79	76	65	59	57	57			
90				67	69	61	57	57	57			
Steelhead 1+ Summer	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10						30	39	53	55			
20						32	44	59	61			
30						33	53	68	62			
40						39	57	72	64			
50						42	61	74	72			
60						51	65	79	76			
70						56	73	84	79			
80						63	78	85	84			
90						71	85	90	89			

Table 50. Monthly composite habitat matrix based on priority species and life stages in the Iron Gate to Shasta River reach.

Composite Matrix	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	24	82	84	82	97	92	89	53	55	91	77	33
20	47	96	96	97	100	86	84	59	61	95	88	53
30	50	100	98	99	100	83	74	68	62	97	93	70
40	67	97	100	100	97	73	69	72	64	99	94	83
50	75	91	98	98	95	69	66	74	72	100	97	88
60	81	88	94	91	87	59	64	79	76	100	99	92
70	87	81	87	83	76	54	61	84	79	100	100	97
80	94	73	77	76	72	50	59	85	84	100	100	98
90	97	63	63	63	64	47	57	90	89	97	100	100

🟨 chinook spawning
🟩 chinook fry
🟦 coho fry
🟪 steelhead fry
🟧 steelhead 1+

This composite monthly habitat matrix was then used as an initial guide in selecting recommended flows for a given month at the various exceedence levels as described below.

Selection of recommended monthly flows at each exceedence level involved an iterative process that compared computed habitat for a target flow rate against the reference habitat for the priority species and life stage in a given month. Target flows were incrementally lowered from the unimpaired flow while attempting to 'improve' or retain the same general habitat magnitude as the reference habitat condition. The extent that flows could be adjusted and still achieve an equivalent (or improved) reference habitat value was highly dependent on the habitat versus discharge relationship for a given species and life stages over specific flow ranges.

Once a target flow regime at an exceedence level was determined, adjustments in the monthly flows were made in order to preserve the underlying seasonal shape of the unimpaired flow hydrograph. Specifically this involved retaining the approximate magnitude changes month-to-month reflected in the unimpaired hydrology at each exceedence level. This step also included the evaluation of the relative differences between monthly flows at different exceedence flow levels to ensure that a rational relationship was retained between different exceedence levels (i.e., water year types). This was approached by examining the month-to-month and exceedence-to-exceedence changes in flow for the unimpaired flow regimes and adjusting the target flows to retain this relative difference.

When this final set of adjustments were made, the results for other species and life stages were compared to their respective reference habitat conditions. Based on this review of other species and life stages, no additional adjustments to the flows were deemed necessary in all cases. The final set of recommended target flows at each exceedence flow level were also plotted and compared against the unimpaired flow regime to verify that no irrational results had been obtained (i.e., the recommended flows preserved the seasonal and exceedence flow characteristics of the hydrograph).

The flow recommendation process noted above also included a consideration of the water temperature results for the various flow scenarios. We consider that the existing state of the summer and early fall temperature regime in the main stem Klamath River to be sufficiently stressful (i.e., almost continual exposure to chronic temperature levels regardless of exceedence flow levels) that flow rates during this period were not recommended lower than 1000 cfs under any circumstance. This flow is approximately equivalent to the 90 percent exceedence flow during August and September under estimated unimpaired flow conditions. Unimpaired flows during this period only range between 1000 cfs and ~ 2100 cfs (i.e., the 10 percent exceedence). Our assessment of the temperature simulation results is that flows below 1000 cfs exacerbates these deleterious temperature conditions and places the anadromous species at greater ecological risk. Additional temperature modeling underway by U.C. Davis that incorporates the Shasta River will help in future evaluations but were not available for use in this study.

Iron Gate Dam to Shasta River Reach

The estimated unimpaired monthly flows for each exceedence level below Iron Gate Dam (CP 40) are provided in Table 51. These values were derived from the MODSIM outputs within SIAM.

Table 51. Simulated unimpaired monthly flows for the Iron Gate to Shasta River Reach for the 10 to 90 percent exceedence flow levels.

Exceedence	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	5282	6439	6302	6430	5259	4163	2829	2131	2076	2169	2664	4522
20	3792	5416	5463	5391	4613	3690	2528	1935	1843	1991	2284	3541
30	3666	4245	5045	4869	4313	3473	2129	1639	1813	1885	2081	2910
40	2990	3724	4394	4541	3785	2870	1986	1490	1754	1700	2020	2460
50	2738	3072	3913	3841	3568	2689	1854	1425	1503	1589	1897	2282
60	2541	2914	3389	3078	2848	2216	1739	1300	1377	1492	1717	2100
70	2299	2559	2838	2637	2361	2033	1462	1158	1296	1450	1613	1903
80	2037	2249	2390	2342	2218	1797	1325	1141	1174	1394	1584	1762
90	1871	1922	1909	1908	1962	1533	1148	1004	1021	1163	1434	1643

The corresponding percent of maximum habitat associated with each priority species and life stage is provided in Table 50 (see above). These flows and associated habitat values were used in the procedure described above to derive the monthly flow recommendations for the Iron Gate to Shasta River Reach at the 10 to 90 percent exceedence ranges and are provided in Table 52.

Table 52. Percent of maximum habitat for the recommended monthly flows in the Iron Gate to Shasta River Reach at each exceedence flow level.

Composite Matrix	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	38	99	96	97	100	87	78	63	61	97	90	53
20	51	100	99	100	100	81	74	68	66	98	93	68
30	68	95	100	100	97	73	69	73	70	100	95	85
40	76	91	98	97	94	67	64	77	73	100	97	90
50	85	85	94	93	91	61	61	81	77	100	99	94
60	90	79	88	85	82	55	60	86	82	99	100	98
70	94	72	77	72	69	50	58	90	86	97	100	100
80	99	63	66	63	62	48	57	90	88	97	99	100
90	100	58	58	58	58	46	57	90	90	96	97	99

🟨 chinook spawning
🟩 chinook fry
🟦 coho fry
🟪 steelhead fry
🟧 steelhead 1+

The corresponding difference in the percent of maximum habitat between the unimpaired and recommended flow regimes for each month at each exceedence flow level is provided in Table 53.

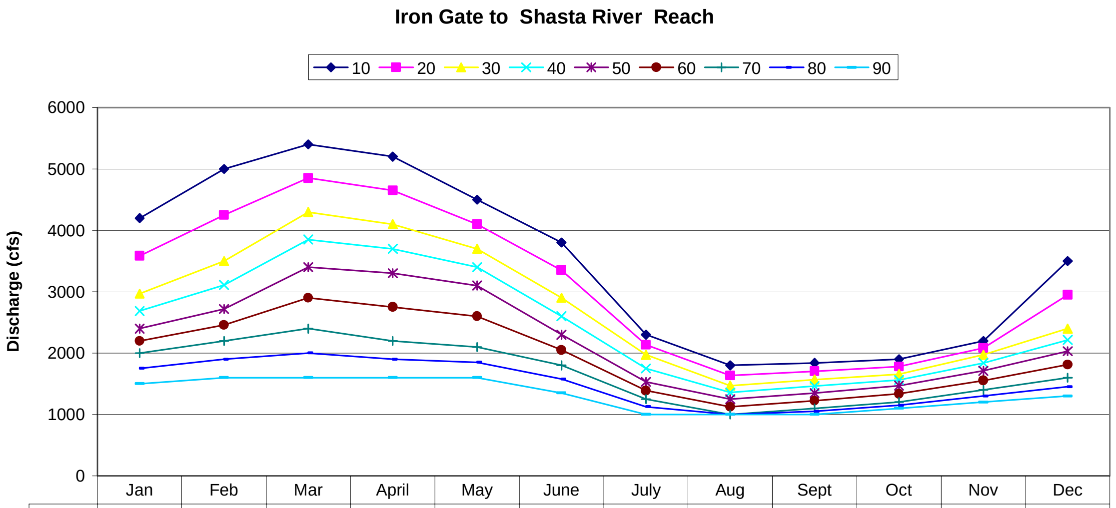
Table 53. Difference between percent of maximum habitat for unimpaired and recommended flow regimes in the Iron Gate to Shasta River Reach.

Composite Matrix	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	14	16	13	15	2	-5	-11	9	7	6	13	21
20	5	3	3	3	0	-5	-10	9	4	3	5	16
30	18	-5	2	1	-3	-9	-5	5	8	3	2	15
40	9	-6	-2	-3	-3	-5	-5	4	9	1	3	7
50	10	-6	-5	-5	-4	-8	-5	6	5	0	2	6
60	10	-9	-6	-5	-5	-4	-4	7	6	-1	1	5
70	7	-10	-9	-11	-8	-4	-2	6	7	-3	0	3
80	5	-11	-12	-13	-11	-2	-2	5	4	-3	-1	2
90	3	-5	-5	-5	-6	-1	0	0	1	-1	-3	-1

🟨 chinook spawning
🟩 chinook fry
🟦 coho fry
🟪 steelhead fry
🟧 steelhead 1+

In this instance, the ‘balancing’ between habitat magnitudes and retention of the overall shape in the month-to-month and exceedence-to-exceedence flow patterns resulted in a slightly greater reduction of habitat values relative to the unimpaired reference conditions at the 70 and 80 percent exceedence flow levels during the February to May period compared to other exceedence levels. This was considered an ‘equitable’ tradeoff to maintain the characteristic of the underlying hydrograph properties.

The corresponding monthly instream flow recommendations at each exceedence flow level are provided in Figure 154.



	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	4200	5000	5400	5200	4500	3800	2300	1800	1840	1900	2200	3500
20	3585	4250	4850	4650	4100	3350	2135	1635	1705	1780	2085	2950
30	2970	3500	4300	4100	3700	2900	1970	1470	1570	1660	1970	2400
40	2685	3110	3850	3700	3400	2600	1750	1360	1460	1565	1840	2215
50	2400	2720	3400	3300	3100	2300	1530	1250	1350	1470	1710	2030
60	2200	2460	2900	2750	2600	2050	1390	1125	1225	1335	1555	1815
70	2000	2200	2400	2200	2100	1800	1250	1000	1100	1200	1400	1600
80	1750	1900	2000	1900	1850	1575	1125	1000	1050	1150	1300	1450
90	1500	1600	1600	1600	1600	1350	1000	1000	1000	1100	1200	1300

Figure 154. Recommended monthly instream flows below Iron Gate Dam at each exceedence flow level.

The recommended flow regimes can be compared to the unimpaired flow regimes shown in Figure 153. This comparison shows that both the seasonal and intra-annual flow variability of the recommended flows ‘mimic’ the unimpaired flow regime while retaining close agreement with the predicted amounts of available physical habitat (see Table 53).

Shasta to Scott River Reach

The estimated unimpaired flows for the middle of this reach (CP 100) were used for the calculation of the reference habitat conditions. These flows are provided in Table 54.

Table 54. Simulated unimpaired monthly flows for the Shasta River to Scott River Reach for the 10 to 90 percent exceedence flow levels (middle of reach).

Exceedence	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	7593	8313	7519	7743	6427	4828	3082	2273	2238	2416	3355	6491
20	5243	7340	7028	6187	5430	4424	2956	2120	2086	2212	2569	4356
30	4579	5138	6265	5858	4947	3788	2404	1717	1940	2115	2413	3479
40	3516	4576	5644	5272	4228	3117	2107	1560	1897	1900	2368	2849
50	3336	3746	4770	4606	4043	2998	1974	1539	1603	1776	2251	2712
60	2951	3353	3892	3690	3398	2582	1845	1410	1456	1657	1918	2474
70	2658	2921	3323	2961	2670	2259	1544	1210	1386	1614	1842	2164
80	2539	2715	2751	2649	2459	1986	1401	1200	1229	1569	1796	2041
90	2156	2219	2149	2098	2180	1636	1202	1021	1059	1277	1634	1884

The monthly composite habitat matrix was generated for this river reach using the same process and priority life stages as discussed above. The priority species and life stage associated with a given month was modified to reflect the differences in the monthly species and life stage periodicities unique to this reach (see Table 29). In this instance, chinook fry were extended to June in lieu of using coho fry.

The composite habitat matrix associated with the unimpaired flows for the Shasta to Scott River Reach is provided in Table 55. This table retains the same color scheme as the Iron Gate to Shasta River reach.

The recommended flows in the Shasta to Scott River Reach were initially evaluated by adding the reach gains to the recommended flows below Iron Gate Dam (CP 40) that corresponded to the control point at the middle of this river reach (i.e., CP 100). This process of propagating the Iron Gate to Shasta River reach recommendations downstream was utilized to assess if the flow recommendations could be achieved by maintaining hydrologic continuity between the reaches if possible. The corresponding composite habitat matrix at the reach level is provided in Table 56 and Table 57 shows the difference compared to the unimpaired habitat values.

Table 55. Monthly composite habitat matrix based on priority species and life stages in the Shasta River to Scott River Reach for unimpaired flows (middle of reach).

Composite Matrix	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	39	73	77	76	87	100	90	70	70	70	57	41
20	45	78	81	90	98	99	88	71	71	73	67	50
30	48	99	89	96	99	92	71	77	73	75	70	56
40	56	100	97	99	97	81	59	81	74	80	71	63
50	57	92	100	100	96	78	54	81	80	84	73	65
60	62	86	94	91	87	68	50	85	83	87	80	69
70	65	77	86	78	71	56	41	89	85	88	82	74
80	68	72	73	70	63	47	35	90	89	89	83	76
90	74	55	52	50	53	38	28	96	95	96	88	81

🟨 chinook spawning
🟩 chinook fry
🟪 steelhead fry
🟧 steelhead 1+

Table 56. Monthly composite habitat matrix based on priority species and life stages in the Shasta River to Scott River Reach based on reach gains added to the Iron Gate to Shasta River Reach recommended flows (middle of reach).

Composite Matrix	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	42	88	84	80	90	100	80	73	72	72	66	44
20	47	97	85	94	99	96	71	76	75	76	68	53
30	51	95	96	99	100	90	60	81	77	79	69	58
40	58	94	100	100	98	80	53	84	81	83	73	60
50	59	85	98	97	91	72	47	85	84	86	75	69
60	62	83	91	88	82	62	41	89	86	90	79	74
70	69	83	79	73	73	52	37	95	89	93	83	79
80	72	73	68	57	55	42	28	94	92	95	87	81
90	80	48	47	45	46	34	27	95	95	97	91	88

🟨 chinook spawning
🟩 chinook fry
🟪 steelhead fry
🟧 steelhead 1+

Table 57. Difference between percent of maximum habitat for unimpaired and recommended flow regimes in the Shasta River to Scott River Reach (middle of reach).

Composite Matrix	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	3	15	6	4	3	0	-10	3	2	2	9	3
20	2	18	4	4	1	-2	-17	5	4	3	1	3
30	3	-4	7	3	0	-3	-11	3	4	4	-1	2
40	3	-6	3	1	1	-1	-5	3	7	3	3	-3
50	2	-7	-2	-3	-5	-6	-7	4	4	2	2	4
60	0	-3	-3	-3	-4	-6	-9	4	2	3	-1	5
70	4	7	-7	-5	2	-4	-4	5	4	5	1	5
80	4	1	-5	-13	-8	-4	-7	4	4	6	4	5
90	5	-7	-5	-5	-7	-4	-2	-1	0	1	4	8

chinook spawning
chinook fry
steelhead fry
steelhead 1+

Based on this comparison we felt the maintaining hydrologic continuity between these reaches provided a reasonable basis to factor into the flow recommendations. We recognize that the estimated reach gains in MODSIM are impacted by depletions within the Shasta River and that they can be improved once additional flow depletion analyses are completed as part of ongoing studies. This is clearly illustrated in Figure 155, which depicts the flow regime immediately below the Shasta River derived by adding the reach gains to the instream flow recommendations for the Iron Gate to Shasta River Reach.

This figure clearly illustrates that adjustments to the flow regime for some months and flow exceedence levels were required to obtain a rational flow regime for the instream flow recommendations. These preliminary values were adjusted using the same basic procedure as followed in the Iron Gate to Shasta River Reach in order to derive the final instream flow recommendations for this reach. These values are provided in Figure 156.

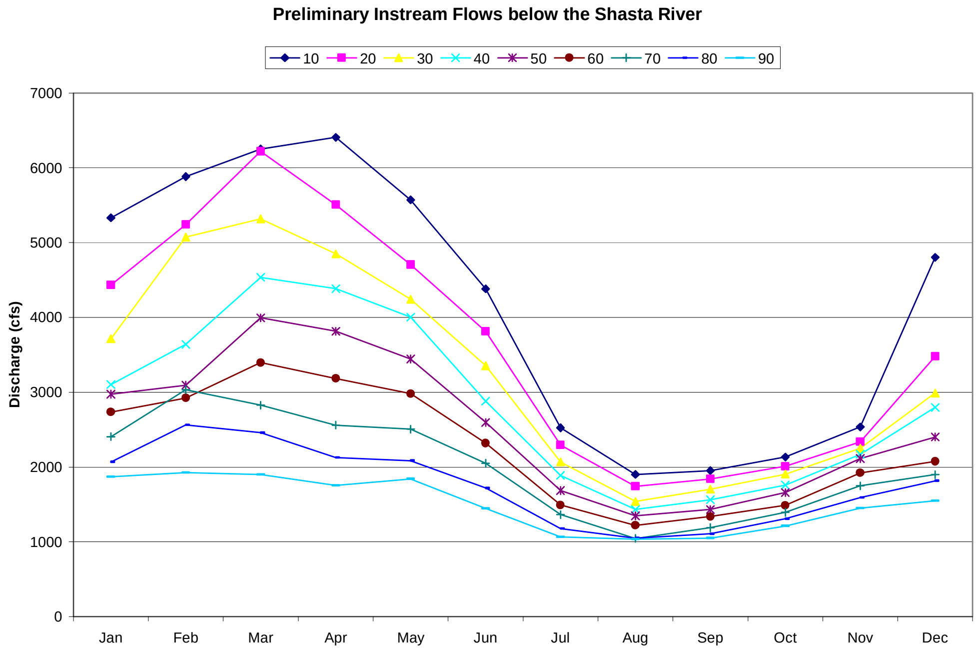
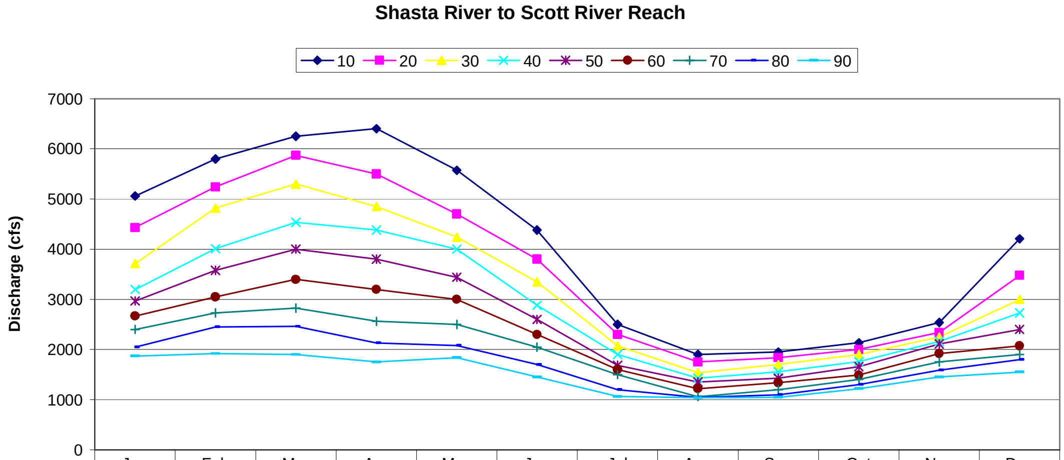


Figure 155. Monthly flows below the Shasta River based on reach gains added to the flow recommendations in the Iron Gate to Shasta River Reach.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	5060	5800	6250	6400	5570	4380	2500	1900	1950	2135	2540	4210
20	4430	5240	5870	5500	4700	3800	2300	1750	1840	2000	2340	3480
30	3715	4820	5300	4850	4240	3350	2070	1540	1700	1900	2250	3000
40	3200	4010	4535	4380	4000	2880	1900	1430	1560	1760	2160	2730
50	2970	3580	4000	3800	3440	2600	1685	1350	1430	1660	2110	2400
60	2670	3050	3400	3200	3000	2300	1600	1220	1340	1490	1920	2075
70	2400	2730	2825	2560	2500	2045	1500	1060	1200	1400	1750	1900
80	2050	2450	2460	2130	2080	1700	1200	1050	1100	1300	1590	1800
90	1870	1920	1900	1750	1840	1452	1065	1035	1050	1220	1450	1550

Figure 156. Recommended instream flows below the Shasta River at each exceedence flow level.

Scott River to Salmon River Reach

The estimated unimpaired flows for the middle of this reach (CP 160) were used for the calculation of the reference habitat conditions. These flows are provided in Table 58.

Table 58. Simulated unimpaired monthly flows for the Scott River to Salmon River Reach for the 10 to 90 percent exceedence flow levels (middle of reach).

Exceedence	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	19723	20625	15395	14523	12441	9185	4245	2745	2646	3023	7839	16914
20	11596	12320	13798	11717	10524	6837	3840	2513	2476	2911	5053	10707
30	10214	10852	13222	10693	9380	6154	3245	2122	2276	2484	4495	6739
40	8441	9305	11055	9488	7061	4747	2696	1981	2138	2315	3326	5584
50	5391	6789	8886	8107	6581	4350	2486	1744	1829	2096	2636	3989
60	5063	6275	6565	6060	6224	3974	2384	1665	1677	1989	2297	3630
70	4696	5295	5877	4876	4407	3332	1968	1445	1613	1840	2232	3190
80	4269	4247	4774	4411	3622	2806	1857	1389	1389	1701	2123	2692
90	2998	3566	3657	3531	3254	2124	1438	1129	1178	1426	2045	2646

The monthly composite habitat matrix was generated for this river reach using the same process and priority life stages as discussed above. The priority species and life stage associated with a given month was modified to reflect the differences in the monthly species and life stage periodicities unique to this reach (see Table 29). In this instance, chinook fry were extended to June in lieu of using coho fry.

The composite habitat matrix associated with the unimpaired flows for the Scott River to Salmon River Reach is provided in Table 59. Note that in Table 59, '#N/A' indicates that the unimpaired flows were outside the simulated flow range used in the physical habitat simulations and therefore these values were not able to be computed. This table retains the same color scheme as the Iron Gate to Shasta River reach.

The recommended flows in the Scott River to Salmon River Reach were initially evaluated by adding the reach gains to the recommended flows below the Shasta River (CP 80) that corresponded to the control point at the middle of this river reach (i.e., CP 160). The corresponding composite habitat matrix at the reach level is provided in Table 60 and Table 61 shows the difference compared to the unimpaired habitat values.

Table 59. Monthly composite habitat matrix based on priority species and life stages in the Scott River to Salmon River Reach for unimpaired flows. (Note: #N/A means flows were beyond habitat simulation ranges).

Composite Matrix	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	#N/A	#N/A	#N/A	#N/A	#N/A	97	78	91	92	100	58	#N/A
20	#N/A	#N/A	#N/A	#N/A	#N/A	82	80	93	93	99	89	#N/A
30	39	#N/A	#N/A	#N/A	97	75	80	96	95	97	94	71
40	52	97	#N/A	97	85	69	78	97	96	96	100	85
50	87	81	96	93	79	70	77	98	98	94	98	98
60	89	76	79	74	75	73	77	99	99	91	95	99
70	92	69	73	69	69	77	75	100	99	86	95	100
80	95	70	69	69	75	77	75	100	100	81	94	99
90	100	75	75	75	77	74	73	99	99	73	92	99

🟨 chinook spawning
🟩 chinook fry
🟪 steelhead fry
🟧 steelhead 1+

Table 60. Monthly composite habitat matrix based on priority species and life stages in the Scott River to Salmon River Reach based on reach gains added to the Shasta River Reach recommended flows (middle of reach). (Note: #N/A means flows were beyond habitat simulation ranges).

Composite Matrix	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	#N/A	#N/A	#N/A	#N/A	#N/A	92	80	95	95	99	76	#N/A
20	#N/A	#N/A	#N/A	#N/A	100	78	80	97	96	97	93	50
30	42	#N/A	#N/A	100	97	72	79	98	97	95	97	66
40	49	95	95	95	84	69	78	98	98	94	99	88
50	65	96	90	87	77	71	76	99	99	93	99	92
60	91	82	83	75	70	74	76	100	99	88	99	98
70	94	72	70	69	68	77	75	99	100	79	97	100
80	99	69	68	72	74	76	73	99	99	75	92	99
90	99	75	74	75	77	73	73	99	99	72	84	95

🟨 chinook spawning
🟩 chinook fry
🟪 steelhead fry
🟧 steelhead 1+

Table 61. Difference between percent of maximum habitat for unimpaired and recommended flow regimes in the Scott River to Salmon River Reach (middle of reach). (Note: #N/A means flows were beyond habitat simulation ranges).

Composite Matrix	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	#N/A	#N/A	#N/A	#N/A	#N/A	-4	2	4	3	0	18	#N/A
20	#N/A	#N/A	#N/A	#N/A	#N/A	-4	0	4	3	-2	4	#N/A
30	3	#N/A	#N/A	#N/A	0	-3	-1	1	2	-2	3	-4
40	-3	-1	#N/A	-3	-1	0	-1	1	2	-2	-1	3
50	-22	14	-5	-6	-2	1	-1	1	1	-1	1	-6
60	2	6	4	0	-6	2	-1	1	1	-3	4	-1
70	1	3	-3	0	-1	0	0	-1	0	-7	2	0
80	4	-1	0	3	-1	-1	-1	0	0	-7	-2	0
90	0	0	-1	0	0	-1	0	0	0	-1	-8	-3

🟨 chinook spawning
🟩 chinook fry
🟪 steelhead fry
🟧 steelhead 1+

These results illustrate the inherent uncertainty in the existing flow accretions estimated within the MODSIM module of SIAM. The low negative habitat value in January for chinook spawning (i.e., -22 percent) is due to an ‘abnormally’ low relative value in the accretions between at the 50 percent flow exceedence value compared to the accretions at the 60 and 40 percent values. This apparent discrepancy in the estimated flows was taken into account during the flow recommendation process by adjusting the recommended flows to retain a rational magnitude between adjacent months and adjacent exceedence levels. This is illustrated further by an examination of Figure 157, which depicts the flow regime immediately below the Scott River derived by adding the reach gains to the instream flow recommendations for the Shasta River Reach.

This figure clearly illustrates that some adjustments to the flow regime for some months and flow exceedence levels were required to obtain a rational flow regime for the instream flow recommendations. These preliminary values were adjusted using the same basic procedures described previously. The final recommended instream flow values immediately below the Scott River are provided in Figure 158.

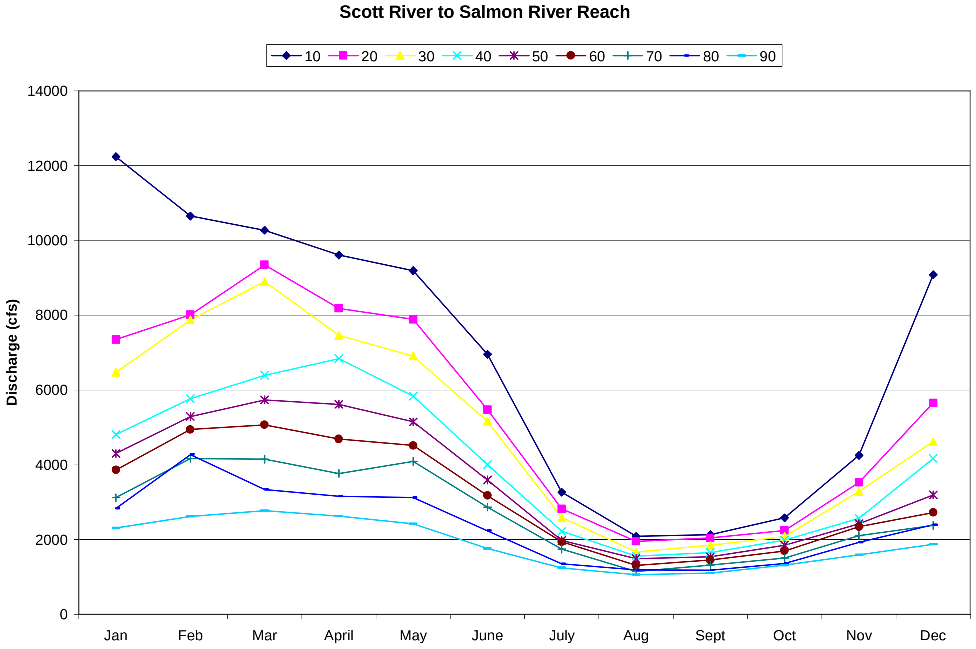
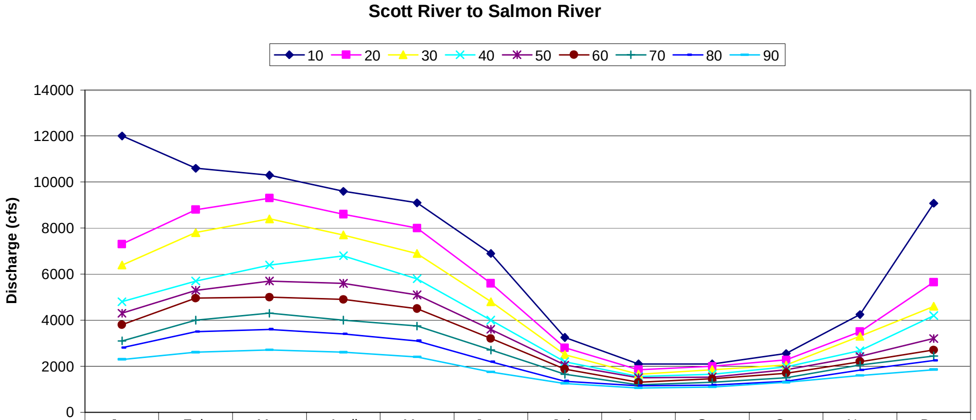


Figure 157. Monthly flows below the Scott River based on reach gains added to the flow recommendations in the Shasta River to Scott River Reach.



	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	12000	10600	10300	9600	9100	6900	3250	2100	2100	2550	4250	9075
20	7300	8800	9300	8600	8000	5600	2800	1850	2000	2275	3500	5650
30	6400	7800	8400	7700	6900	4800	2500	1650	1850	2050	3300	4600
40	4800	5700	6400	6800	5800	4000	2200	1550	1650	1975	2675	4200
50	4300	5300	5700	5600	5100	3600	2050	1500	1525	1850	2425	3200
60	3800	4950	5000	4900	4500	3200	1875	1300	1450	1700	2200	2700
70	3100	4000	4300	4000	3750	2700	1650	1200	1300	1500	2050	2450
80	2800	3500	3600	3400	3100	2200	1350	1150	1175	1350	1825	2250
90	2300	2600	2700	2600	2400	1750	1250	1050	1100	1300	1600	1850

Figure 158. Recommended instream flows below the Scott River at each exceedence flow level.

Salmon River to Trinity River Reach

The estimated unimpaired flows for the middle of this reach (CP 190) were used for the calculation of the reference habitat conditions. These flows are provided in Table 62.

Table 62. Simulated unimpaired monthly flows for the Salmon River to Trinity River Reach for the 10 to 90 percent exceedence flow levels.

Exceedence	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	34460	34963	26537	23239	20800	15147	5863	3373	3228	4076	14569	31486
20	19747	22863	22939	19452	18165	11274	5141	3156	2909	3976	8561	19554
30	17341	17594	21607	17751	15931	8987	4496	2778	2757	3035	7939	10560
40	15349	14982	17915	15133	11185	7328	3591	2647	2423	2771	4740	9651
50	8981	11791	13983	12348	10032	6407	3199	2109	2206	2647	3209	6219
60	8403	9981	10987	9992	9624	6026	3058	1983	2084	2482	2962	5467
70	7408	8351	9236	8239	6962	4777	2611	1807	1838	2234	2840	4803
80	6580	7398	7878	7219	5575	3592	2401	1726	1652	1885	2728	3677
90	4359	5565	6047	5374	4906	2960	1869	1377	1403	1662	2547	3259

The monthly composite habitat matrix was generated for this river reach using the same process and priority life stages as discussed above. The priority species and life stage associated with a given month was modified to reflect the differences in the monthly species and life stage periodicities unique to this reach (see Table 29). In this instance, chinook fry were extended to June in lieu of using coho fry.

The composite habitat matrix associated with the unimpaired flows for the Salmon River to Trinity River Reach is provided in Table 63. Note that in Table 63, '#N/A' indicates that the unimpaired flows were higher than the simulated flow range used in the physical habitat simulations and therefore these values were not able to be computed. This table retains the same color scheme as the Iron Gate to Shasta River reach.

The recommended flows in the Salmon River to Trinity River Reach were initially evaluated by adding the reach gains to the recommended flows below the Scott River (CP 130) that corresponded to the control point at the middle of this river reach (i.e., CP 160). The corresponding composite habitat matrix at the reach level is provided in Table 64 and Table 65 shows the difference compared to the unimpaired habitat values.

Table 63. Monthly composite habitat matrix based on priority species and life stages in the Salmon River to Trinity River Reach for unimpaired flows. (Note: #N/A means flows were beyond habitat simulation ranges).

Composite Matrix	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	#N/A	#N/A	#N/A	#N/A	#N/A	92	99	89	90	98	30	#N/A
20	#N/A	#N/A	#N/A	#N/A	#N/A	85	99	91	93	97	72	#N/A
30	#N/A	#N/A	#N/A	#N/A	92	85	96	94	94	89	79	52
40	28	92	#N/A	92	84	92	89	95	96	84	99	62
50	68	86	90	87	82	94	85	99	98	82	92	95
60	74	82	84	82	82	96	84	99	99	79	88	99
70	85	88	84	88	93	99	81	100	99	75	86	100
80	92	91	90	92	99	89	80	100	100	68	84	95
90	99	99	96	100	99	84	78	#N/A	#N/A	62	80	92

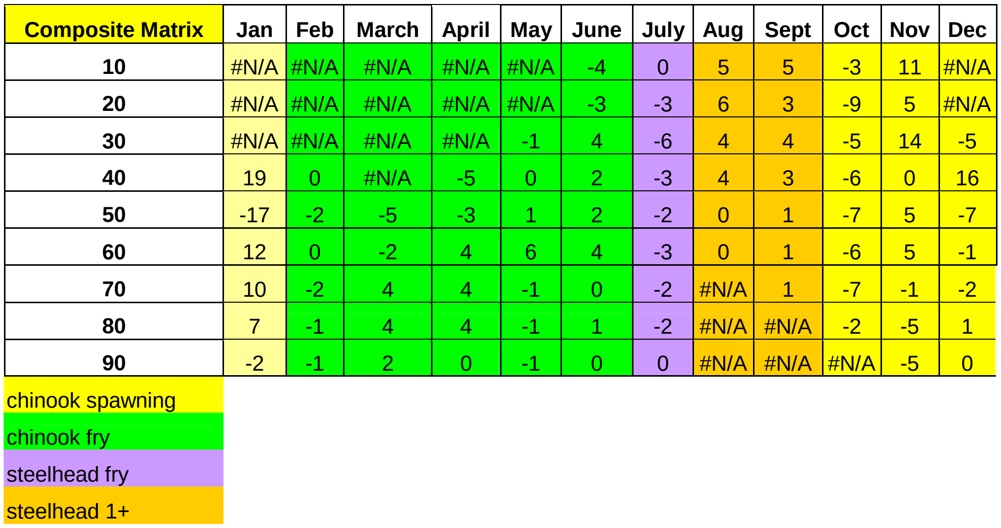
🟨 chinook spawning
🟩 chinook fry
🟪 steelhead fry
🟧 steelhead 1+

Table 64. Monthly composite habitat matrix based on priority species and life stages in the Salmon River to Trinity River Reach based on reach gains added to the Scott River Reach recommended flows (middle of reach). (Note: #N/A means flows were beyond habitat simulation ranges).

Composite Matrix	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
10	#N/A	#N/A	#N/A	#N/A	#N/A	88	98	94	95	94	41	#N/A
20	#N/A	92	#N/A	92	92	82	96	96	96	88	78	32
30	29	92	92	92	91	89	90	98	98	84	94	47
40	47	91	90	87	84	93	85	99	99	79	100	77
50	51	84	85	84	83	96	82	99	99	75	97	87
60	86	82	82	87	88	100	81	99	100	73	93	98
70	95	86	88	92	91	99	80	#N/A	100	68	84	98
80	99	91	93	96	98	89	78	#N/A	#N/A	65	78	96
90	97	98	98	100	98	83	78	#N/A	#N/A	#N/A	75	92

🟨 chinook spawning
🟩 chinook fry
🟪 steelhead fry
🟧 steelhead 1+

Table 65. Difference between percent of maximum habitat for unimpaired and recommended flow regimes in the Salmon River to Trinity River Reach (middle of reach). (Note: #N/A means flows were beyond habitat simulation ranges).



Composite Matrix	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	#N/A	#N/A	#N/A	#N/A	#N/A	-4	0	5	5	-3	11	#N/A
20	#N/A	#N/A	#N/A	#N/A	#N/A	-3	-3	6	3	-9	5	#N/A
30	#N/A	#N/A	#N/A	#N/A	-1	4	-6	4	4	-5	14	-5
40	19	0	#N/A	-5	0	2	-3	4	3	-6	0	16
50	-17	-2	-5	-3	1	2	-2	0	1	-7	5	-7
60	12	0	-2	4	6	4	-3	0	1	-6	5	-1
70	10	-2	4	4	-1	0	-2	#N/A	1	-7	-1	-2
80	7	-1	4	4	-1	1	-2	#N/A	#N/A	-2	-5	1
90	-2	-1	2	0	-1	0	0	#N/A	#N/A	#N/A	-5	0

chinook spawning
chinook fry
steelhead fry
steelhead 1+

Figure 159 depicts the flow regime immediately below the Salmon River derived by adding the reach gains to the instream flow recommendations for the Scott River Reach.

This figure clearly illustrates that some adjustments to the flow regime for some months and flow exceedence levels were required to obtain a rational flow regime for the instream flow recommendations. These preliminary values were adjusted using the same basic procedures described previously. The final instream flow recommended values immediately below the Salmon River are provided in Figure 160.

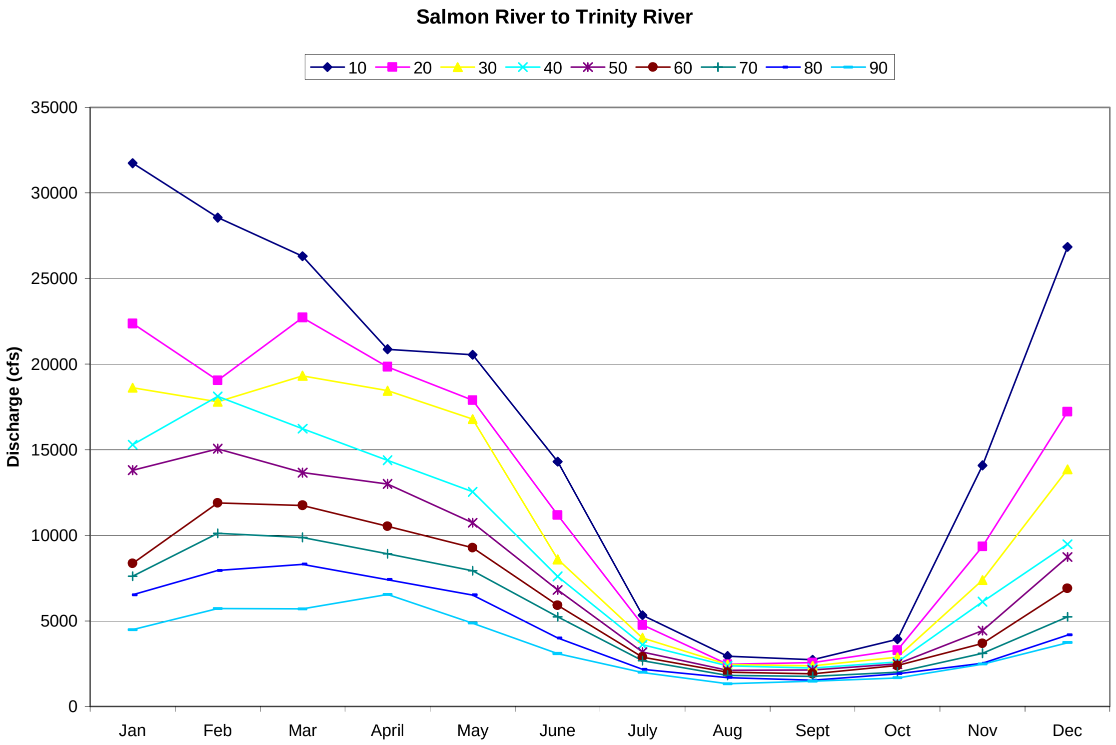
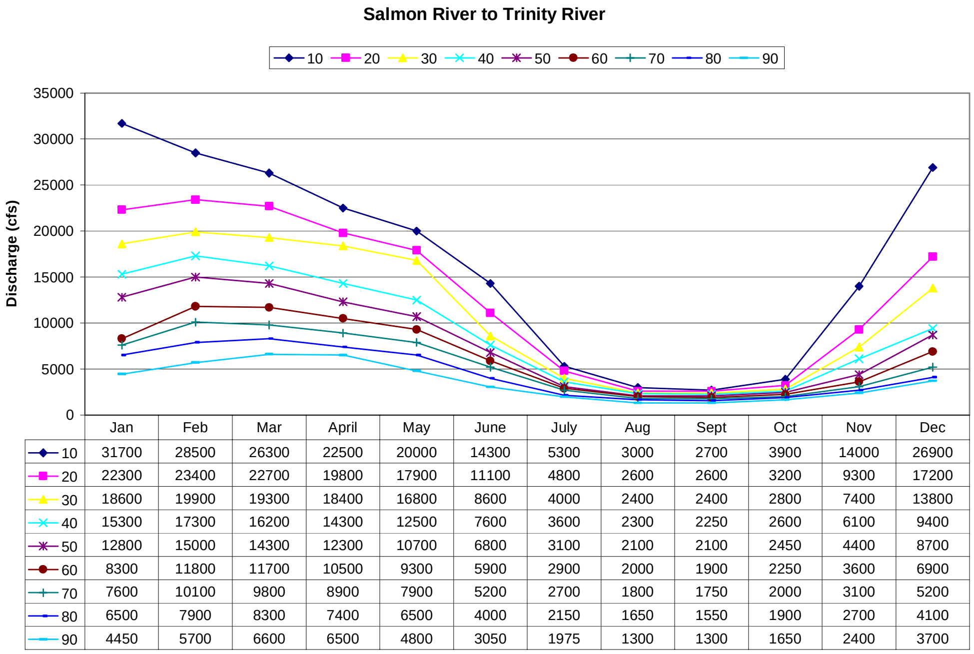


Figure 159. Monthly flows below the Salmon River based on reach gains added to the flow recommendations in the Scott River Reach.

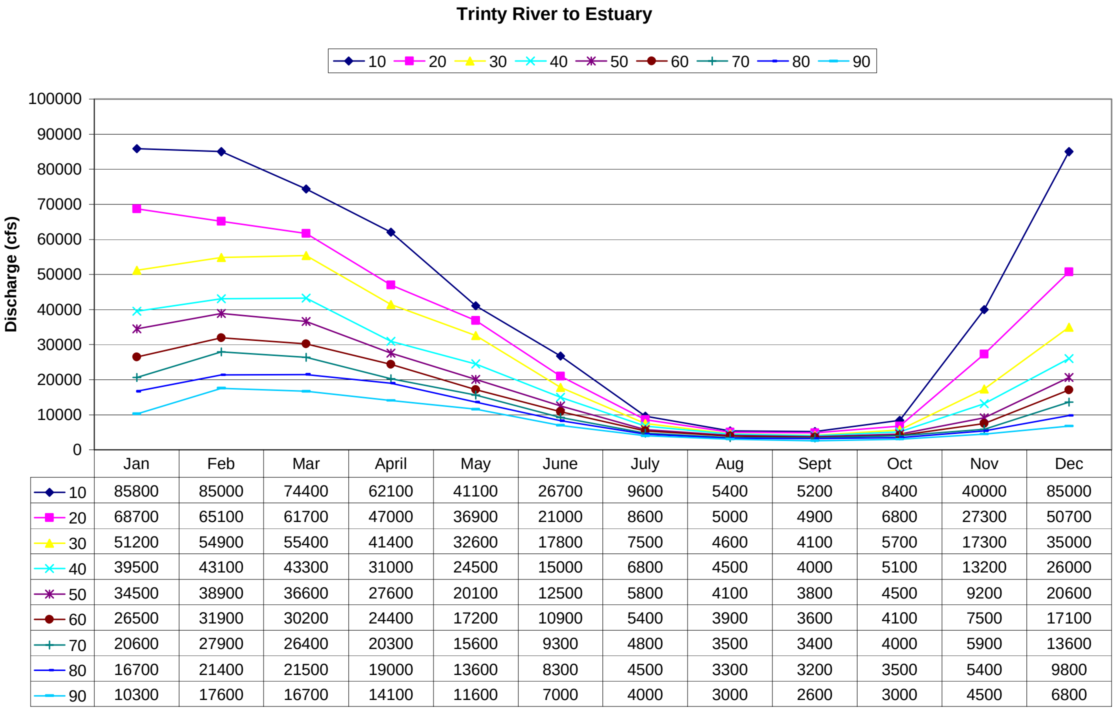


	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
◆ 10	31700	28500	26300	22500	20000	14300	5300	3000	2700	3900	14000	26900
■ 20	22300	23400	22700	19800	17900	11100	4800	2600	2600	3200	9300	17200
▲ 30	18600	19900	19300	18400	16800	8600	4000	2400	2400	2800	7400	13800
× 40	15300	17300	16200	14300	12500	7600	3600	2300	2250	2600	6100	9400
✱ 50	12800	15000	14300	12300	10700	6800	3100	2100	2100	2450	4400	8700
● 60	8300	11800	11700	10500	9300	5900	2900	2000	1900	2250	3600	6900
+ 70	7600	10100	9800	8900	7900	5200	2700	1800	1750	2000	3100	5200
▬ 80	6500	7900	8300	7400	6500	4000	2150	1650	1550	1900	2700	4100
▬ 90	4450	5700	6600	6500	4800	3050	1975	1300	1300	1650	2400	3700

Figure 160. Recommended instream flows below the Salmon River at each exceedence flow level.

Trinity River to Estuary Reach

As noted previously in the report, no habitat simulations were conducted for this river reach due to inadequate performance of the hydraulic model for the downstream most study site. However, flow recommendations are made for this river reach using the same procedure for other reaches to propagate the recommended flows from the Salmon River to Trinity River Reach. The corresponding instream flow recommendations are shown in Figure 161.



	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	85800	85000	74400	62100	41100	26700	9600	5400	5200	8400	40000	85000
20	68700	65100	61700	47000	36900	21000	8600	5000	4900	6800	27300	50700
30	51200	54900	55400	41400	32600	17800	7500	4600	4100	5700	17300	35000
40	39500	43100	43300	31000	24500	15000	6800	4500	4000	5100	13200	26000
50	34500	38900	36600	27600	20100	12500	5800	4100	3800	4500	9200	20600
60	26500	31900	30200	24400	17200	10900	5400	3900	3600	4100	7500	17100
70	20600	27900	26400	20300	15600	9300	4800	3500	3400	4000	5900	13600
80	16700	21400	21500	19000	13600	8300	4500	3300	3200	3500	5400	9800
90	10300	17600	16700	14100	11600	7000	4000	3000	2600	3000	4500	6800

Figure 161. Recommended instream flows below the Trinity River at each exceedence flow level.

Flow Recommendation Implementation

An objective of the Phase II study was to develop instream flow recommendations for different water year types. In Phase I, we relied on the definition of five water year types based on net inflow to Upper Klamath Lake and this operational definition was retained in Phase II (see Hydrology section). However, as the results in the previous section indicate, we have actually developed flow recommendations associated with ‘nine’ water year types and as will be discussed below, we are recommending that these results be used to specify instream flow regimes as a ‘continuous function’ rather than only five water year types. Our motivation for this approach is illustrated by the following example.

Instream flow requirements for the previously defined five-water year types were derived by assigning required flows below Iron Gate Dam using the following exceedence values:

• Extremely Wet	10 percent exceedence
• Wet	30 percent exceedence
• Average	50 percent exceedence
• Dry	70 percent exceedence
• Critically Dry	90 percent exceedence

These recommended instream flow requirements below Iron Gate Dam for each of these five water year types were then used to simulate Klamath Project Operations using KPSIM. In these simulations, we used the USFWS 2000 Biological Opinion Upper Klamath Lake water surface elevations and the historical net inflows to Upper Klamath Lake. For this analysis, we used the project operations over the 1961 to 1997 period of record.

Table 66 shows a summary of river flows below Iron Gate Dam for these simulation results. Values in red indicate that the target flows could not be met, non-zero values indicate flows in excess of the recommended flows, and a zero value indicates that the flow release equaled the target flow (i.e., the flow recommendation). When examining these results, it should be noted that the 'discrepancy' between the target instream flow recommendations and the flow values derived from the simulations are related to project operations, year-to-year variation in Upper Klamath Lake inflows, and carry over storage between years. This simulation was also undertaken to check whether the Phase II recommended flows could be physically met over a long-term set of simulated historical net inflows to Upper Klamath Lake. This analysis confirmed that the project could be operated to achieve these recommendations in all but 19 of the 468 simulated months in this period of record. It is important to note that for these simulations rely on the net inflows to Upper Klamath Lake (i.e., existing depletions are included).

The corresponding KPSIM Upper Klamath Lake demands, shortages, and inflows for this simulated period are provided in Figure 162. These data show effect of the recommended flow regime on agricultural and refuge demands.

Table 66. KPSIM simulation results for flows at Iron Gate Dam based on the Phase II flow recommendations by five water year types.

Water Year	Oct	Nov	Dec	Jan	Feb	Mar 1-15	Mar 16-31	Apr 1-15	Apr 16-30	May 1-15	May 16-31	Jun 1-15	Jun 16-30	Jul 1-15	Jul 16-31	Aug	Sep
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(256.0)	(256.0)	(221.4)	(221.4)	(236.4)	(236.4)	(170.1)	(170.1)	(156.8)	(150.4)
1991	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	0.0	0.0	0.0	8.1	189.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(26.3)	(1.1)	(21.0)
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1979	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.0	0.0	530.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1987	0.0	433.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1970	0.0	0.0	16.0	3773.5	1718.7	1456.9	1496.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	0.0	0.0	589.8	2129.8	1430.7	583.9	623.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	0.0	0.0	468.5	0.0	59.0	214.5	254.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1966	364.2	1250.5	201.2	0.0	0.0	0.0	0.0	0.0	44.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	0.0	0.0	806.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(44.2)	(20.5)	(25.4)
1976	0.0	728.7	432.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	0.0	122.1	3059.4	6820.5	1917.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	0.0	246.7	0.0	418.3	4139.7	3305.8	3302.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	(146.4)	(156.8)	(168.8)	(89.2)	(343.7)	(293.6)	(293.6)	0.0	73.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	0.0	0.0	0.0	1979.2	785.9	191.9	188.1	3.2	322.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	0.0	0.0	5089.1	5687.5	4171.5	778.2	774.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	2444.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	0.0	55.6	1557.2	6163.3	1312.7	1309.0	13.6	351.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	805.0	599.3	937.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	1025.0	1265.4	1381.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(40.5)	0.0
1972	0.0	140.1	0.0	0.0	0.0	4977.7	5925.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	988.8	701.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	0.0	0.0	882.9	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	0.0	7.1	0.0	1463.2	159.5	438.3	434.5	0.0	86.8	1097.7	1116.8	0.0	0.0	0.0	0.0	0.0	0.0
1982	0.0	641.6	4745.2	1392.4	4737.6	1331.1	1327.4	1260.9	1599.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.0	1022.9	2923.0	4058.8	376.5	1119.5	1115.8	2196.1	2534.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999	0.0	695.1	492.9	122.4	0.0	0.0	0.0	0.0	598.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	690.9	2574.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1971	0.0	404.5	2156.3	2310.8	0.0	0.0	0.0	0.0	67.5	81.4	100.6	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	766.4	0.0	573.9	1895.3	1891.6	0.3	315.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min	(146.4)	(156.8)	(168.8)	(89.2)	(343.7)	(293.6)	(293.6)	(256.0)	(256.0)	(221.4)	(221.4)	(236.4)	(236.4)	(170.1)	(170.1)	(156.8)	(150.4)
Average	31.9	254.8	695.1	851.7	668.7	443.9	491.2	97.9	171.2	24.6	25.5	(6.1)	(6.1)	(4.4)	(6.2)	(5.6)	(5.0)
Max	1025.0	2444.8	5089.1	6820.5	6163.3	4977.7	5925.9	2196.1	2534.2	1097.7	1116.8	0.0	0.0	0.0	0.0	0.0	0.0

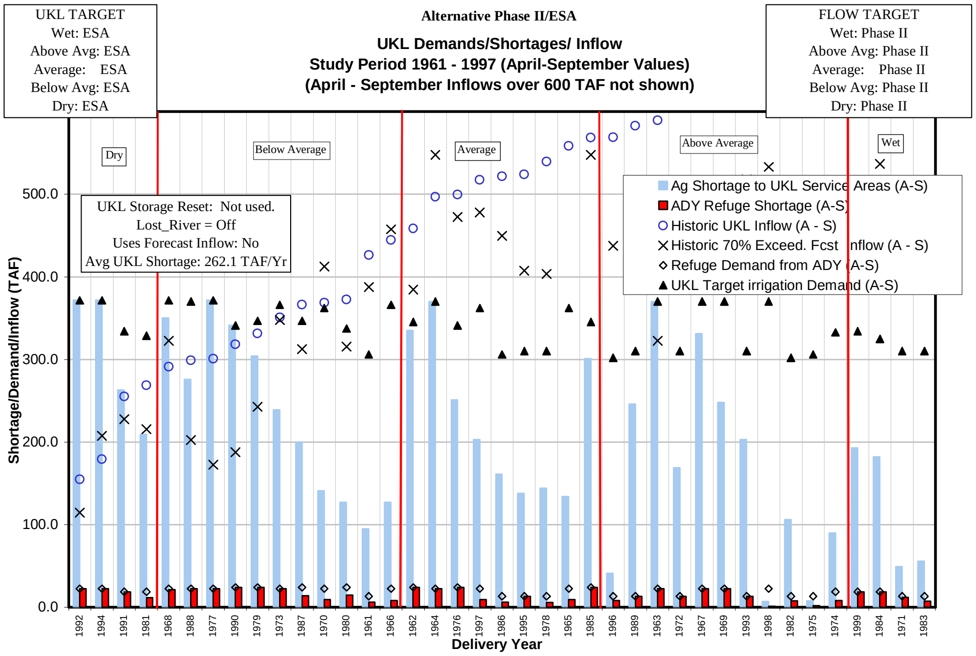


Figure 162. Upper Klamath Lake demands, shortages, and inflows using the Phase II instream flow recommendations for five water year types.

The simulated flows derived from the KPSIM modeling for these recommendations were then used to calculate the associated percent of maximum habitat for all species and life stages. These values for the priority species and life stages are shown in Table 67. This also provides a comparison of the percent of maximum habitat for the other flow scenarios described in the hydrology section (i.e., FERC, USGS historical, and Phase I).

Table 67. Percent of maximum habitat for priority species and life stages (see text) in the Iron Gate to Shasta River Reach for various flow alternatives.

Extremely Wet WY	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Unimpaired	24	82	84	82	97	92	89	53	55	91	77	33
Phase II	25	74	86	96	100	93	74	68	66	98	73	21
USGS Historical	24	81	76	94	98	58	57	88	68	78	47	41
FERC_ESA	26	74	81	96	94	60	57	90	79	99	93	94
Phase I	26	74	83	96	94	73	64	77	75	94	93	100

Wet WY	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Unimpaired	50	100	98	99	100	83	74	68	62	97	93	70
Phase II	54	97	100	97	94	67	64	77	73	100	95	78
USGS Historical	59	96	100	98	90	44	57	89	77	99	93	56
FERC_ESA	70	96	98	100	72	45	57	90	79	56	86	72
Phase I	76	96	100	98	90	59	64	77	75	100	97	88

Average WY	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Unimpaired	75	91	98	98	95	69	66	74	72	100	97	88
Phase II	69	91	94	93	91	61	61	81	77	100	98	93
USGS Historical	93	79	91	84	58	57	57	89	78	99	93	56
FERC_ESA	92	76	91	81	52	57	57	90	79	95	100	98
Phase I	84	90	91	93	90	77	64	77	75	100	99	93

Dry WY	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Unimpaired	87	81	87	83	76	54	61	84	79	100	100	97
Phase II	90	72	77	72	69	50	58	90	86	97	100	100
USGS Historical	100	58	75	57	52	57	57	90	87	99	99	100
FERC_ESA	100	58	80	55	52	57	98	90	79	99	99	100
Phase I	84	90	91	88	84	69	61	83	77	100	100	93

Criticaly Dry WY	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Unimpaired	97	63	63	63	64	47	57	90	89	97	100	100
Phase II	100	58	58	58	58	46	57	90	90	96	97	99
USGS Historical	95	52	53	52	52	58	58	99	95	89	90	91
FERC_ESA	99	55	55	55	52	57	57	90	79	99	99	99
Phase I	100	63	87	58	57	57	57	100	94	91	95	99

The results in Figure 162 clearly illustrate that effect of specifying a single instream flow regime to a water year type that in actuality covers a range of inflow volumes. In essence, approximately half the time, the inflows will be higher and half the time the inflows will be lower than the index water year classification (i.e., the midpoint of each water year class). Therefore, at the upper end of a water year interval, instream flows are met and shortages are minimized. At the bottom end of a water year interval, the instream flows are met at the ‘expense’ of increased shortages. This also in effect reduces the intra-annual variability in the hydrology around these five water year based instream flow recommendations.

Alternatively, we propose that the instream flow recommendations can be used to specify the flow releases based on the computed inflow exceedence level. This could be accomplished by a simple linear interpolation of the instream flow requirements using the exceedence flow level recommendations provided in this report. This would have the advantage of a continuous scale in the required instream flows that are directly linked to inflow volumes to Upper Klamath Lake. This would provide the basis for a more ecologically oriented flow regime that preserves greater intra-annual variability than achievable under a five-water year classification scheme. It also has the advantage of reducing apparent shortages associated with other water demands over the lower half of each ‘water year’ interval. These reduction in shortages would occur since the instream flow requirement moves up or down according to inflow volume rather than remaining at a fixed level over a broad range of inflows for a single water year classification.

We also recommend that a ‘unidirectional’ mode of operation be implemented for ramping flow releases between successive monthly flow targets. The ‘ramping rate’ should be tied to expected inflow volume and next sequential monthly flow target such that changes in the between day flows should occur approximately a week period. This could be accomplished by computing the expected change in inflow volumes at Iron Gate Dam including the increase or decrease in the target instream flow regime and dividing this flow volume by seven. This would then set the approximate daily change in flows to ramp up or down to meet the next sequential flow target. Operational limitations at Iron Gate Dam also need to be considered since flow control is limited by turbine and spill gate capacities when computing these desired transitional flows.

Summary

The Phase II study relied on site-specific physical habitat modeling and estimated unimpaired hydrology below Iron Gate Dam to recommend instream flows for each river reach. The study utilized state-of-the-art field data collection strategies and habitat modeling. The study results are considered to represent the best available science upon which to make instream flow recommendations or evaluation of alternative flow allocation strategies. However, the evaluation of alternative flow allocation strategies was not part of the Phase work plan and is beyond the scope of this effort.

The study results based on physical habitat modeling implemented several unique approaches that involved distance to escape cover in the habitat simulations. Both the site-specific HSC and habitat modeling approach were validated based on predicted versus observed habitat use by different species and life stages within the main stem Klamath River where these data were available. For several species and life stages (i.e., chinook juvenile, coho fry, and steelhead fry) a procedure for developing envelope HSC from literature-based curves was developed. This general approach was validated by comparisons of habitat simulation results between envelope derived HSC and the available site-specific HSC for chinook spawning, chinook fry, and steelhead 1^+ summertime.

Hydraulic simulations were conducted using a two-dimensional hydraulic simulation algorithm and three-dimensional channel topographies over extensive study reaches. These hydraulic simulations and corresponding spatial representation of the study reaches provided improved hydraulic simulations of velocities for the habitat modeling. This approach also relied on the integration of substrate and vegetation mapping results in GIS that greatly enhanced the process of habitat model development and validation.

Phase II relied on estimated unimpaired hydrology below Iron Gate Dam. These simulated unimpaired conditions are considered to represent the best available estimates of unaltered flows below Iron Gate Dam. These simulated results were used in conjunction with the habitat modeling results for target species and life stages to provide an estimate of monthly habitat availability over a range of flow exceedence levels. These reference conditions were then used in an iterative procedure to develop reach specific monthly flow recommendations for five water year types.

The flow recommendations also considered the simulation of water temperature profiles below Iron Gate Dam. These results supported the findings in Phase I that flows should remain above ~ 1000 cfs during the later summer and early fall period. Temperature conditions during this period remain at or above chronic temperature exposure rates and reducing flows below 1000 cfs is considered to increase the ecological risk to the anadromous species in the main stem Klamath River.

These flow recommendations are intended to meet the objectives of Phase II to provide flows necessary for recovery and to meet other objectives of the Department of Interior including tribal trust and ESA issues. Although the flow recommendations are provided specific for five water year types, results (i.e., recommendations) were generated for the 10 to 90 percent exceedence flow ranges. The intent was to provide greater flexibility on associating the variability in water year type definitions to finer increments rather than the larger range of flows associated with the existing USBR 4 water year types or the five used in our assessments. This would allow a better match between actual water forecast volumes and an appropriate scaling of the instream flows. This should be explored further in future study efforts.

Recommendations

Based on the technical assessments conducted as part of Phase II the following recommendations were identified:

1. Due to problems with the field data, site characteristics, and hydraulic modeling performance at the study site below the Trinity River, additional data at this site involving expanded topography upstream of the existing site boundary should be considered. This would permit the integration of this data with the existing topography and calibration data sets to permit habitat modeling in this lower reach of the main stem Klamath River. An additional study site nearer the estuary would also provide better resolution of the habitat versus discharge characteristics by expanding the characterization for this section of the river.
2. Additional data on fish observations at each of the study sites should continue on a seasonal basis. This is particularly true for steelhead fry, coho fry, and coho juveniles. These data would be important to ultimately improve the envelope base habitat suitability curves or development of site-specific habitat suitability curves for these species and life stages. The revised curves could then be used to refine or update the flow recommendations for each river reach.
3. Additional work on the water quality modeling of the main stem is critical. We believe that extending the water quality model developed by Dr. Mike Deas to encompass the entire main stem would be the best approach. This model is computationally better suited to address the critical temperature issues than the analytical capabilities of the HEC5Q model in SIAM.
4. We also believe that a more refined Klamath Project Operations model should be explored. The refinement should allow the instream flow targets at Iron Gate Dam to be adjusted to a specific value based on the

cumulative inflow into Upper Klamath Lake over the October to March period and then adding the April forecast values to define the water year type. The water year type would be defined by the associated inflow exceedence curve. This exceedence value could then be used with the 10 to 90 percent exceedence flow based instream flow recommendations to assign the target flow regime below Iron Gate Dam. This could be accomplished by a simple linear interpolation of the results. This has the advantage of eliminating the large discrete jumps in the instream flow regimes inherent in the five-water year type classification. As the water forecasts were updated each month, then a revised instream flow schedule could be computed based on the revised exceedence forecast. This type of system would better track the changes in seasonal hydrology and not hold flow unnecessarily high(or low) when updated forecasts become available. We feel this would represent a more ecologically favorable characteristic to the flow regimes below Iron Gate Dam.

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Appendix B - Net Energy Surface Plots

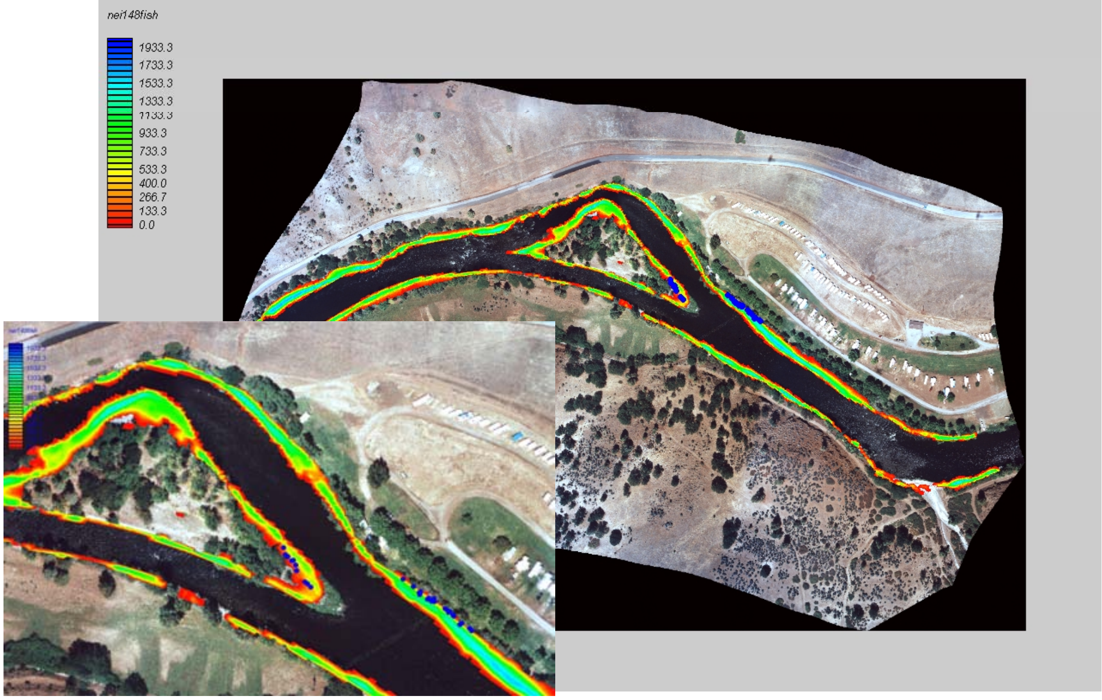

Figure B1. NEI Magnitude, with fish observations, for RRanch, Chinook 40mm at 148cms.

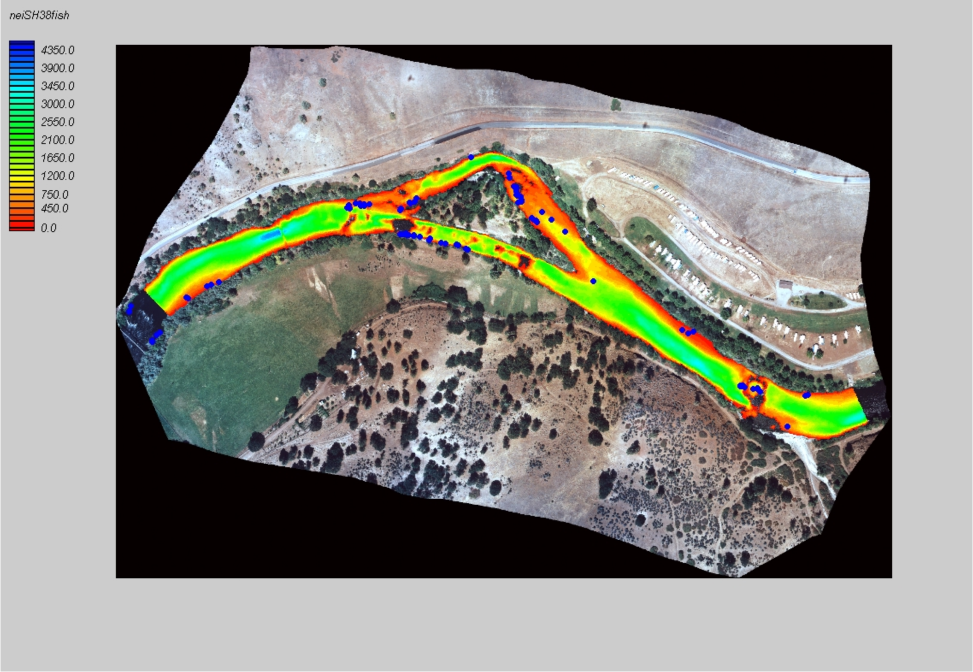

Figure B2. NEI Magnitude, with fish observations, for RRanch, Steelhead 160mm at 38cms.

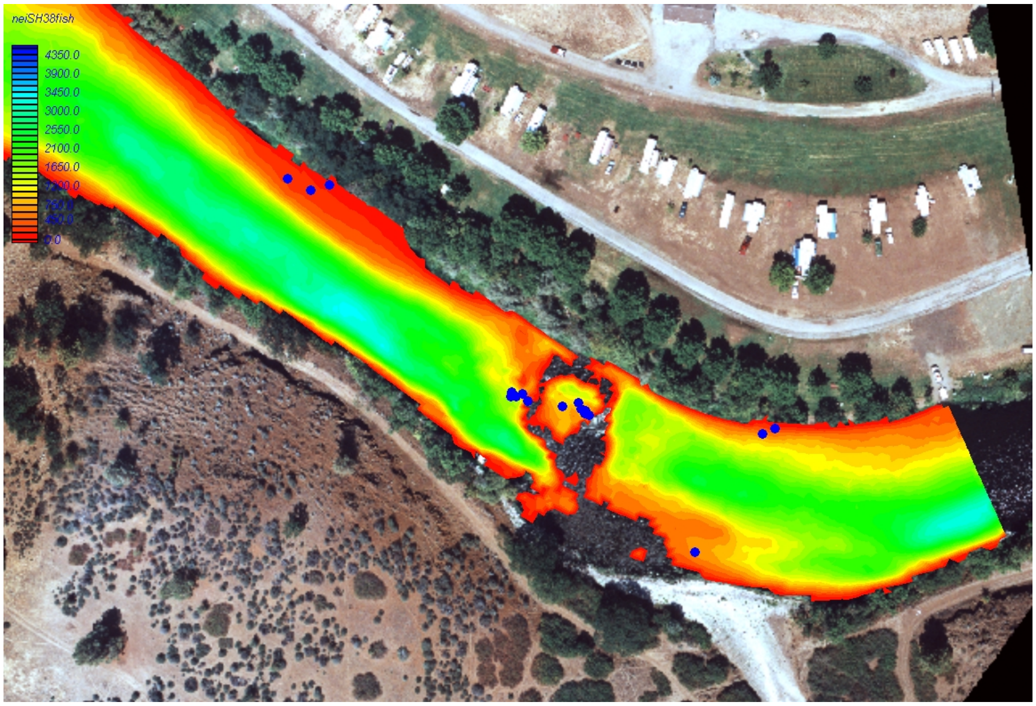

Figure B3. NEI Magnitude, with fish observations, for RRanch, Steelhead 160mm at 38cms (zoom).

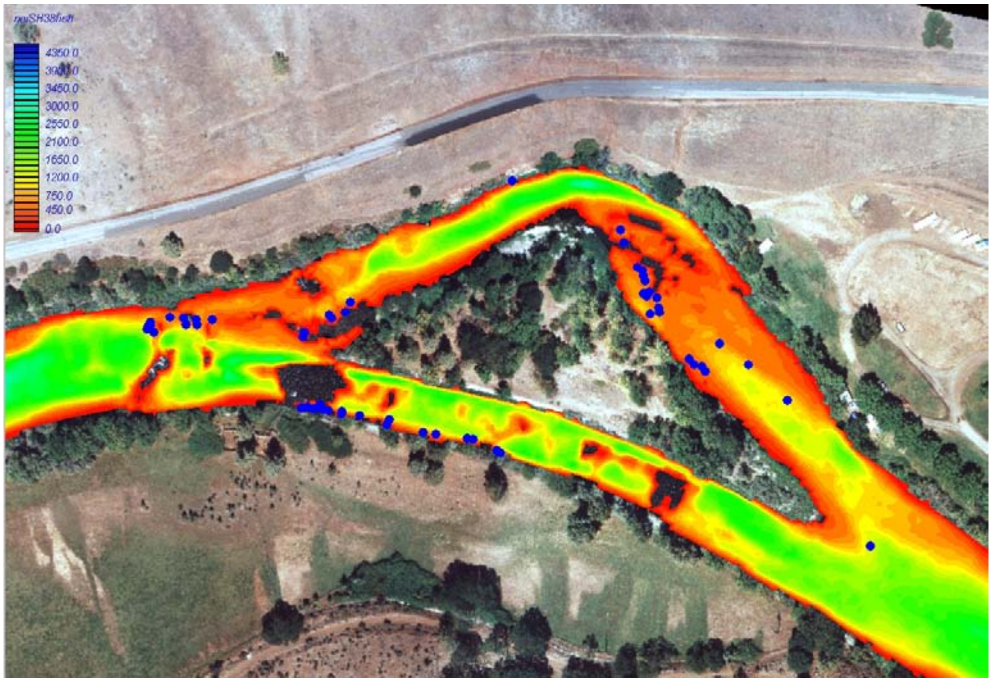

Figure B4. NEI Magnitude, with fish observations, for RRanch, Steelhead 160mm at 38cms (zoom).

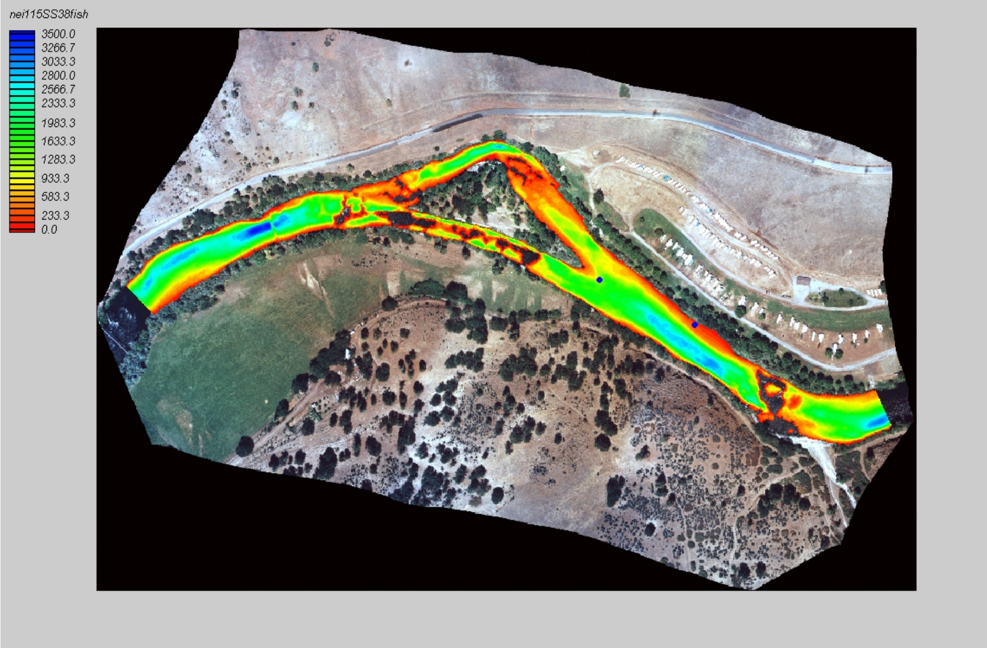

Figure B5. NEI Magnitude, with fish observations, for RRanch, Coho 115mm at 38cms.

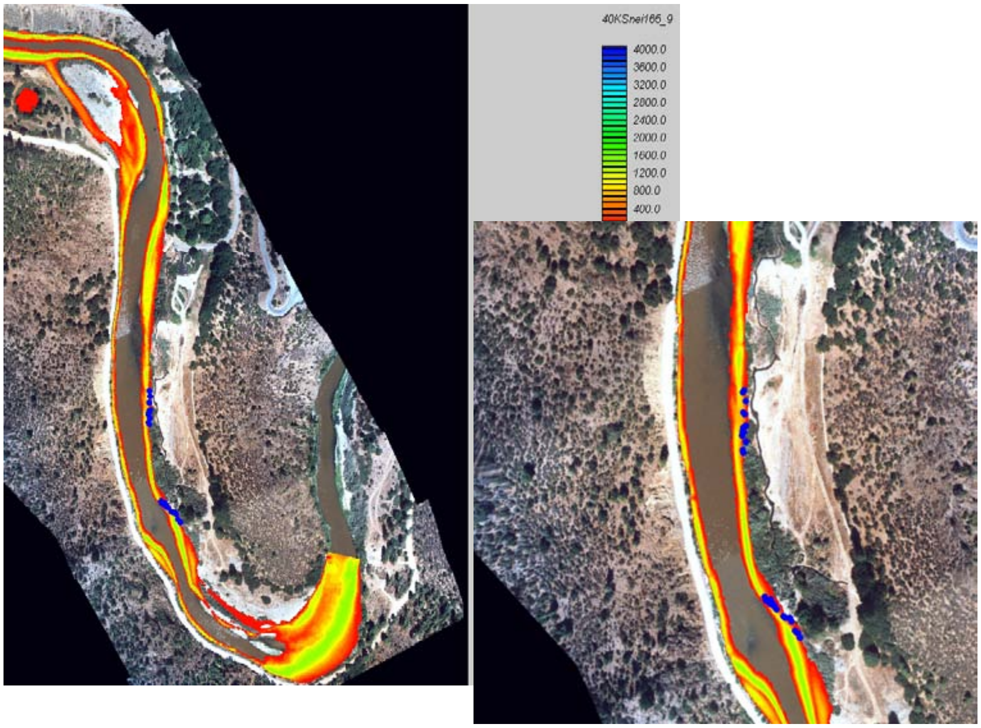

Figure B6. NEI Magnitude, with fish observations for Tree of Heaven, Chinook 40mm at 165.9cms.

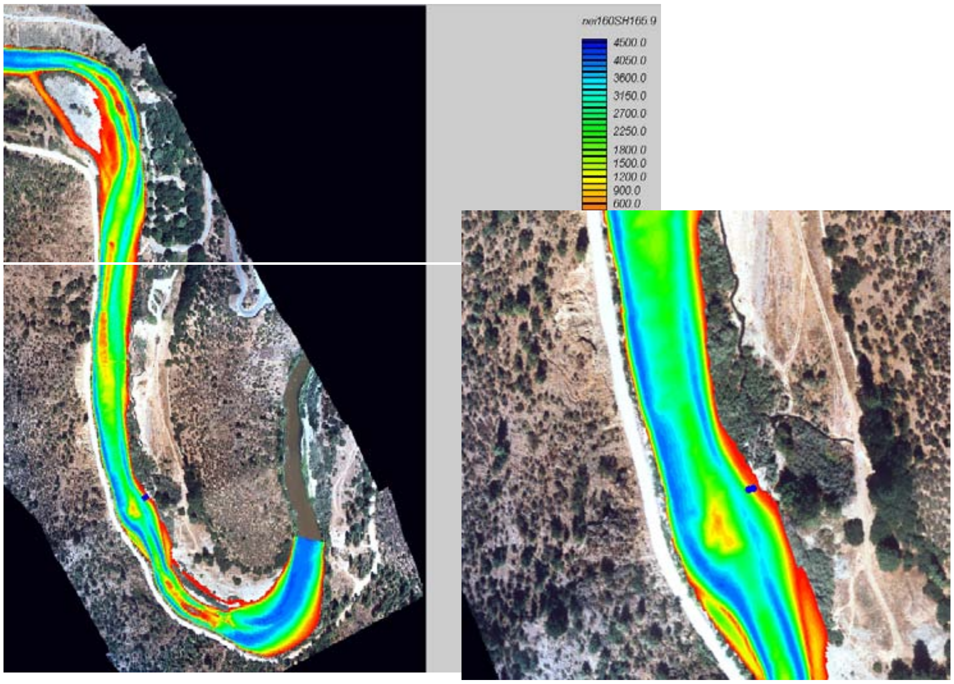

Figure B7. NEI Magnitude, with fish observations, for Tree of Heaven, Steelhead 160mm at 165.9cms.

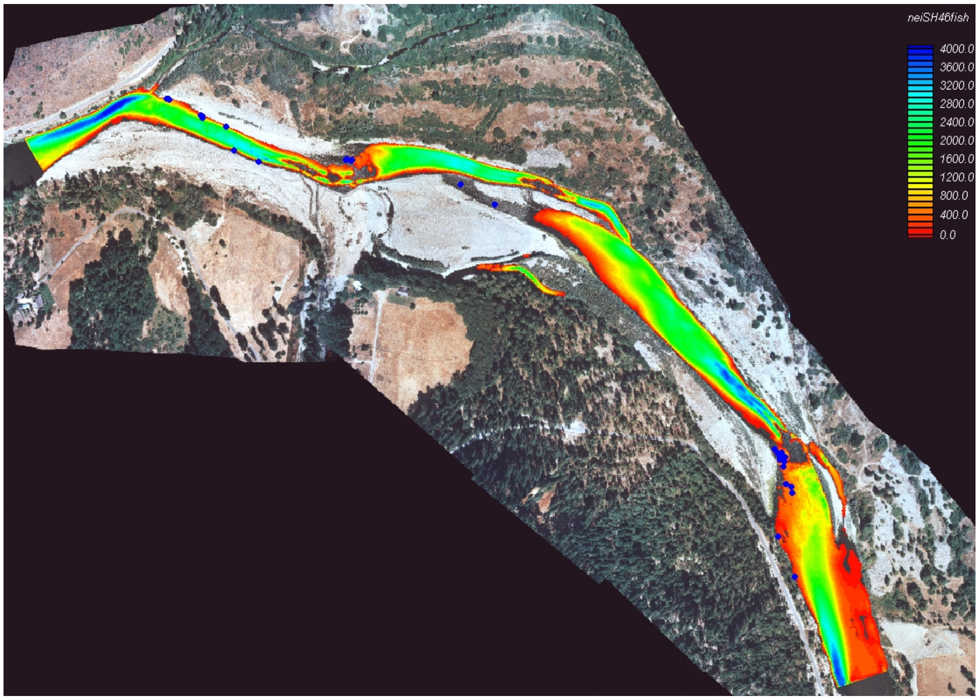

Figure B8. NEI Magnitude for Seiad, with fish observations, Steelhead 160mm at 48cms

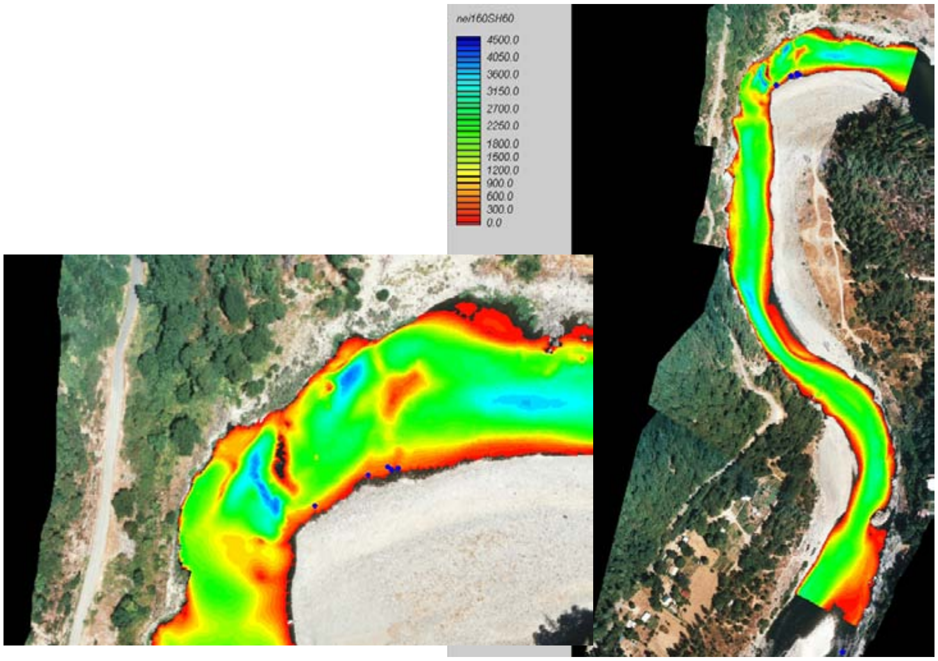

Figure B9. NEI Magnitude for Orleans, with fish observations, Chinook 40mm at 90.56cms.

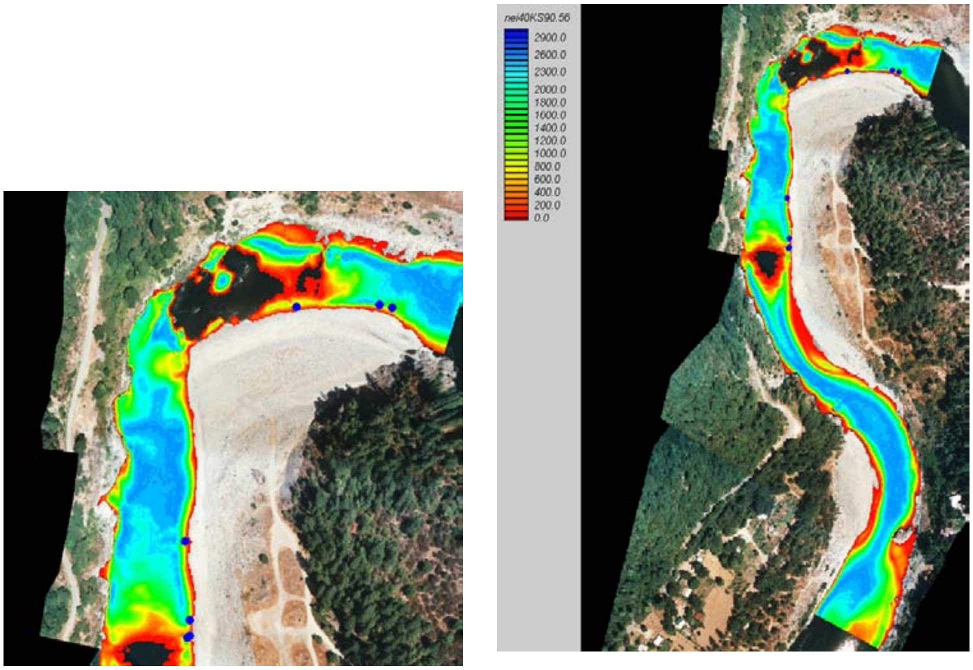

Figure B10. NEI Magnitude for Orleans, with fish observations, Steelhead 160mm at 60cms.

Appendix C – Simulated Temperature Profiles

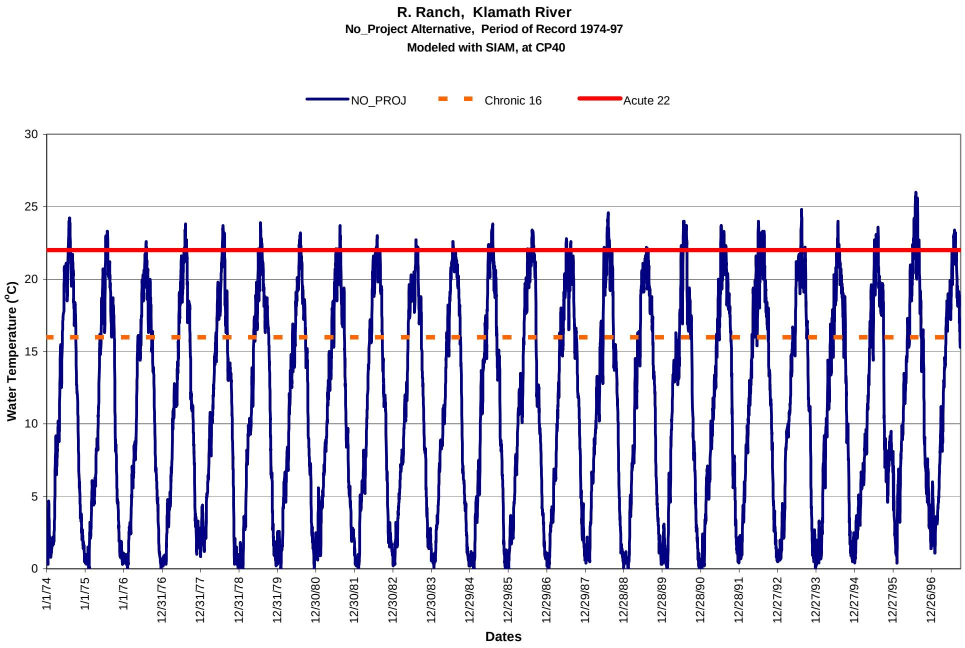

Figure C1. Daily mean temperatures at Iron Gate for the unimpaired no project scenario (1974 to 1997 water years).

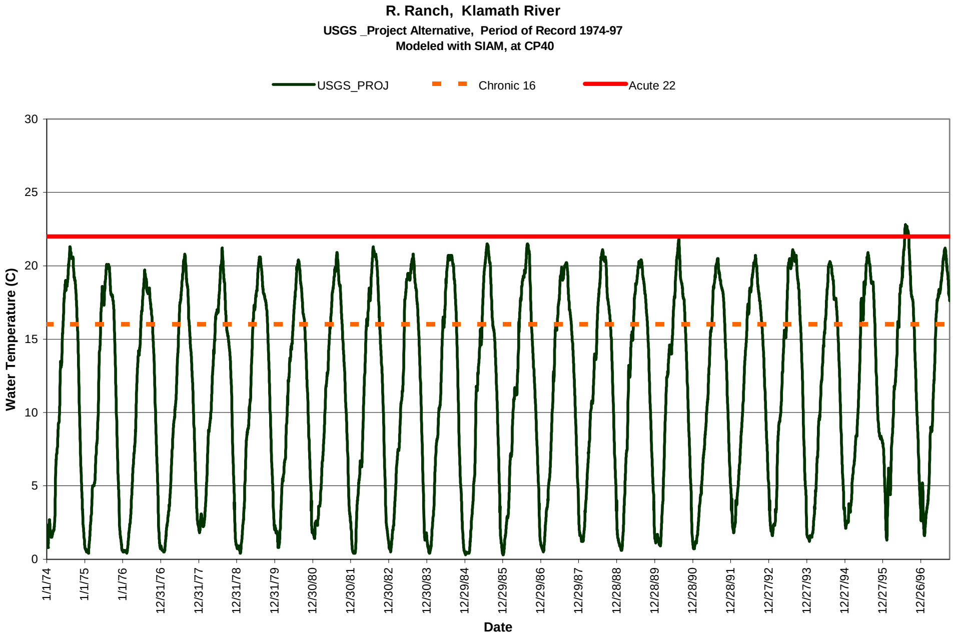

Figure C2. Daily mean temperatures at Iron Gate for the USGS Historical project operations (1974 to 1997 water years).

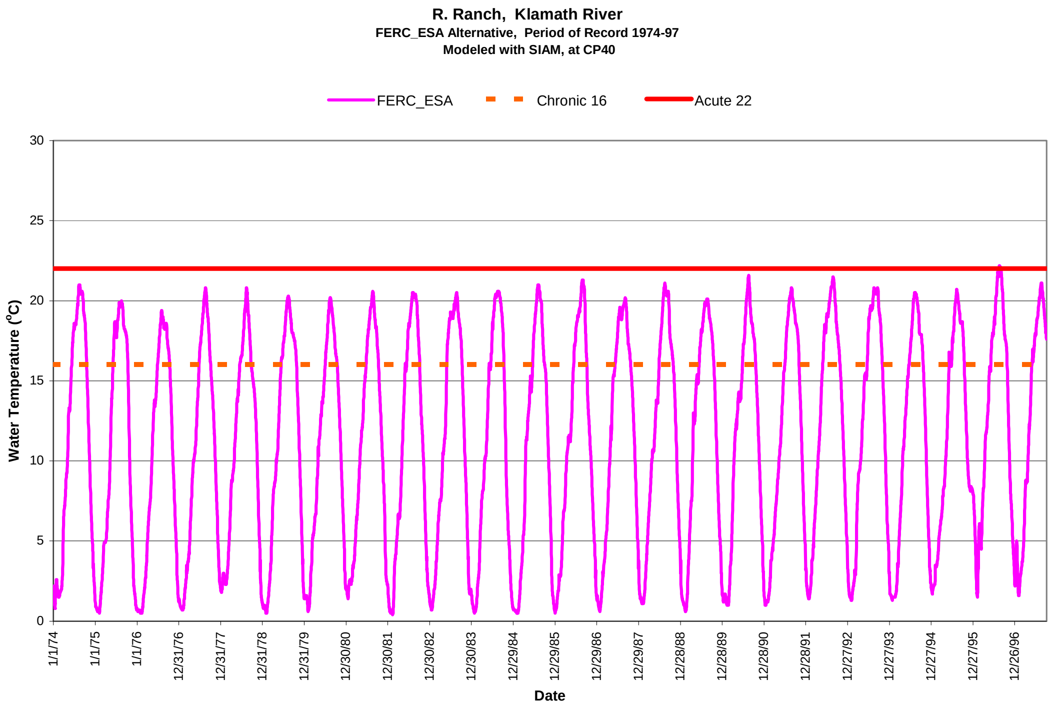

Figure C3. Daily mean temperatures at Iron Gate for the FERC_ESA scenario (1974 to 1997 water years).

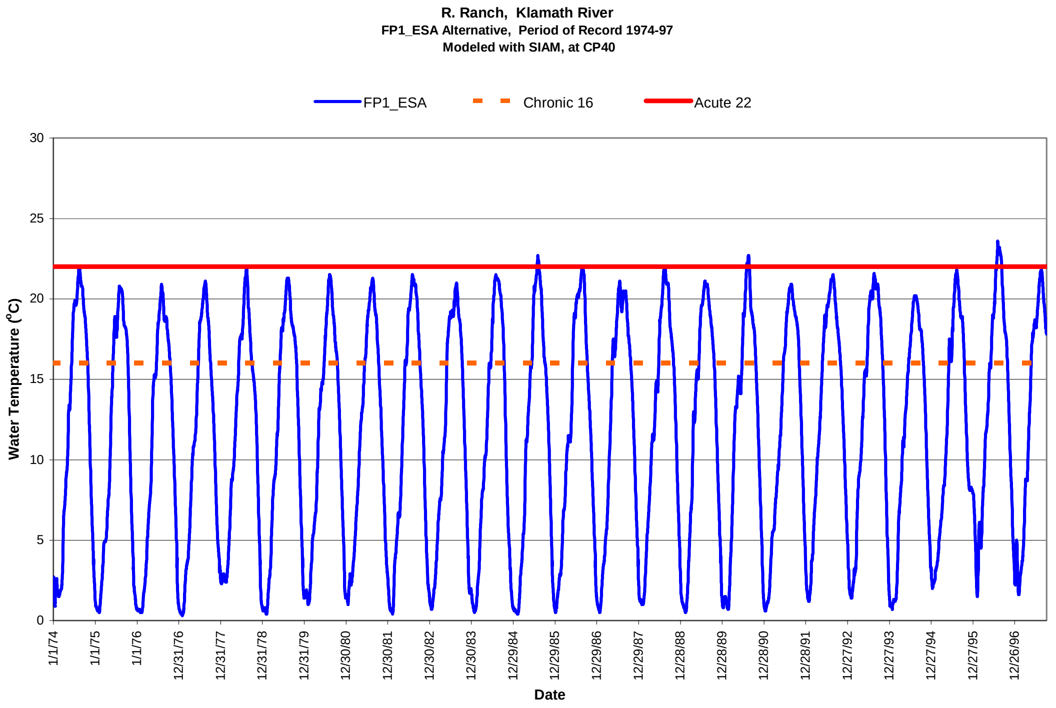

Figure C4. Daily mean temperatures at Iron Gate for the FP1_ESA scenario (1974 to 1997 water years).

Trees of Heaven

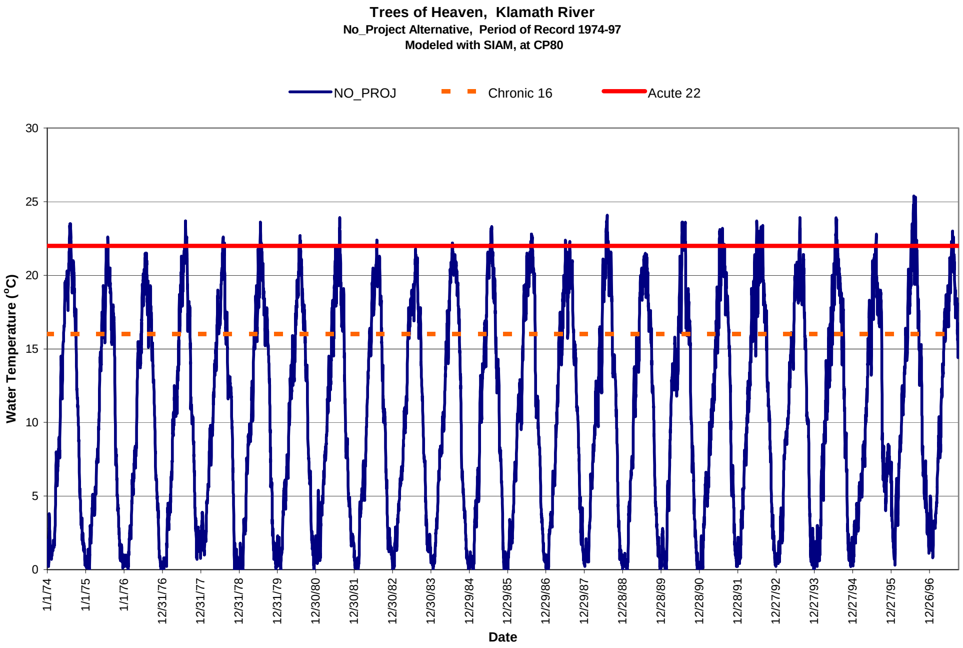

Figure C5. Daily mean temperatures at Trees of Heaven for the unimpaired no project scenario (1974 to 1997 water years).

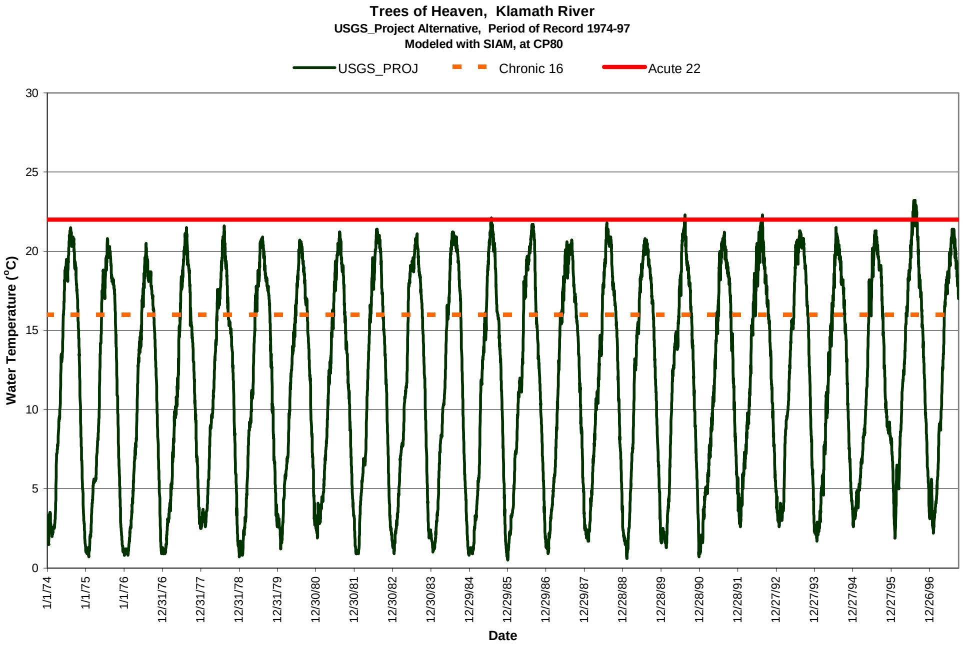

Figure C6. Daily mean temperatures at Trees of Heaven for the USGS Historical project operations (1974 to 1997 water years).

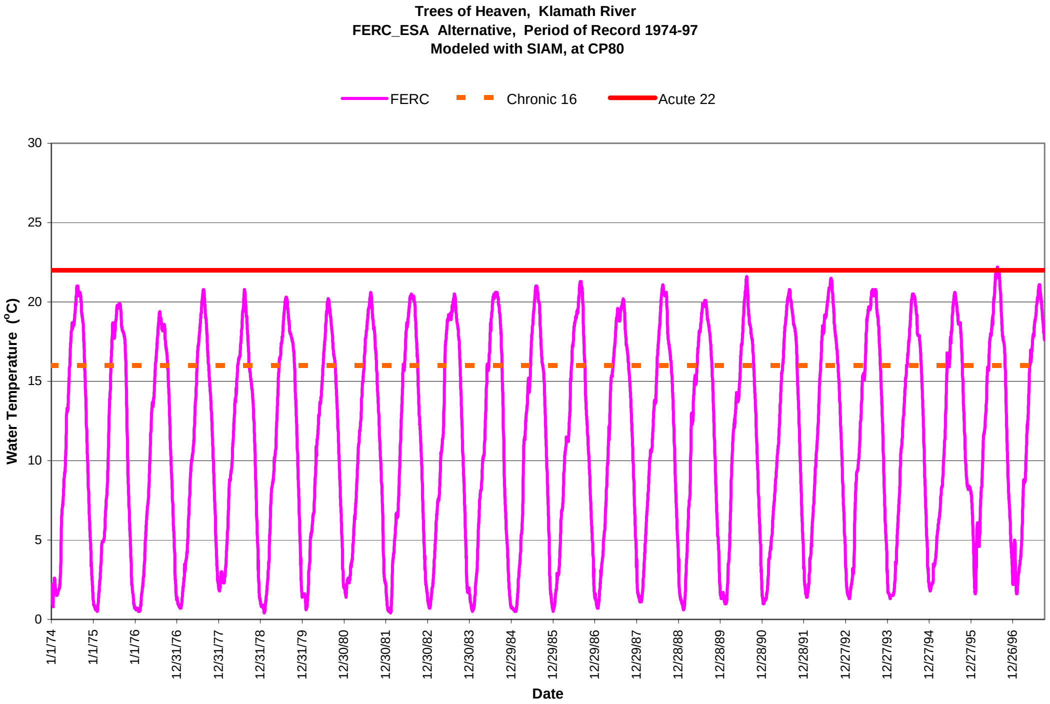

Figure C7. Daily mean temperatures at Trees of Heaven for the FERC_ESA scenario (1974 to 1997 water years).

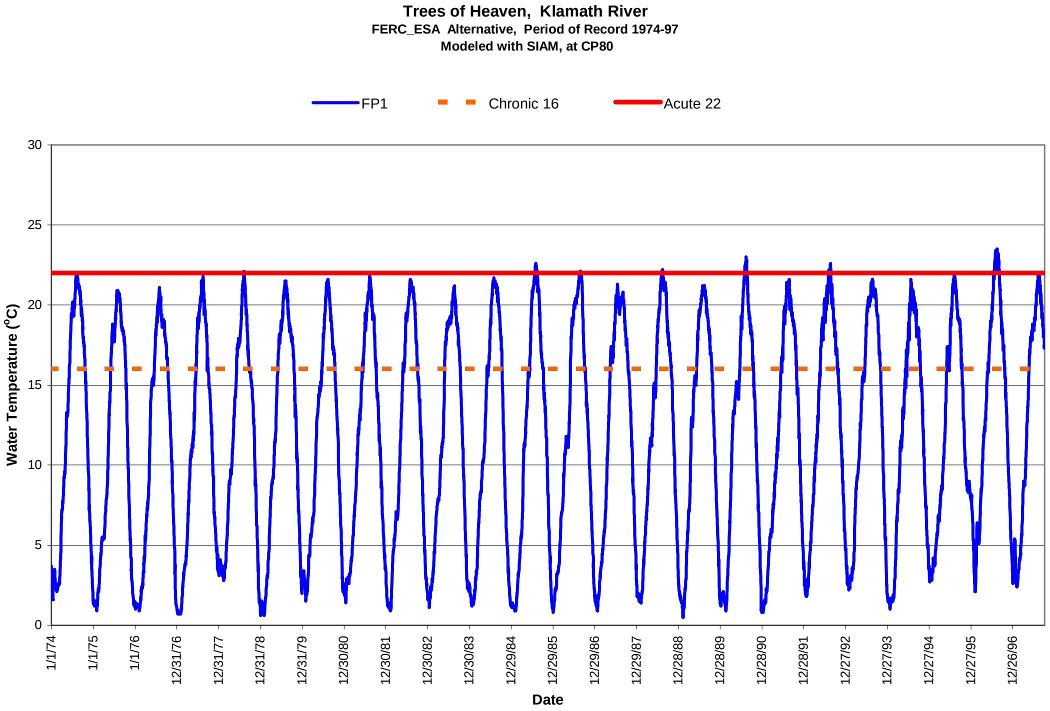

Figure C8. Daily mean temperatures at Trees of Heaven for the FP1_ESA scenario (1974 to 1997 water years).

Brown Bear

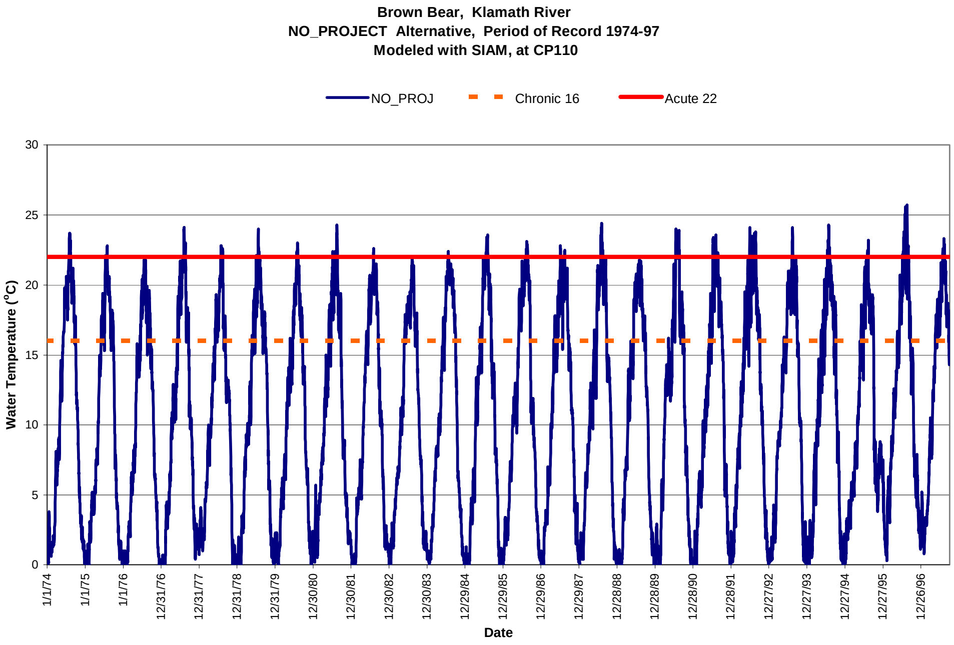

Figure C9. Daily mean temperatures at Brown Bear for the unimpaired no project scenario (1974 to 1997 water years).

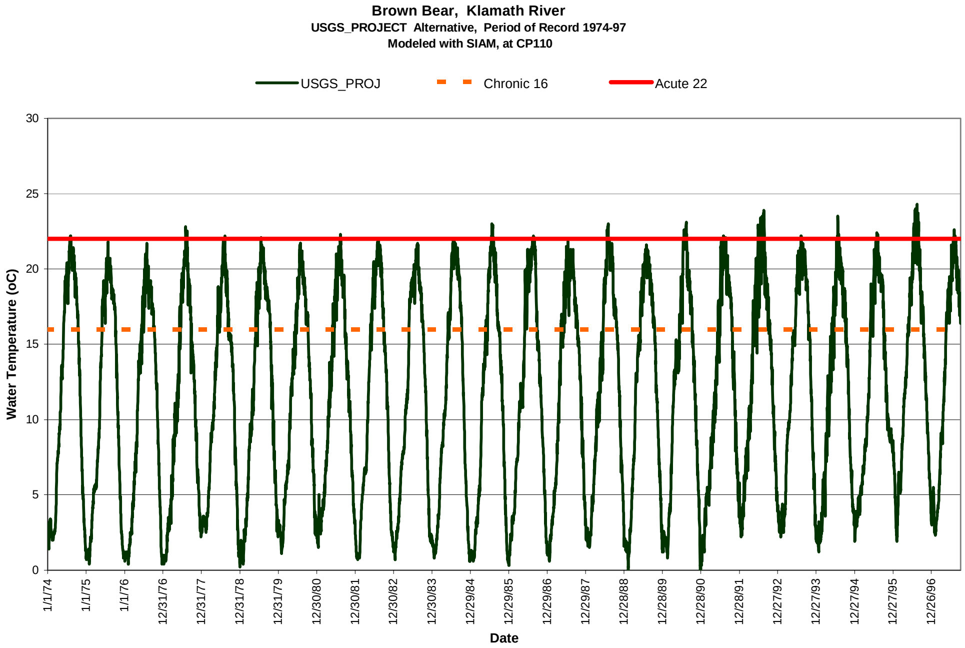

Figure C10. Daily mean temperatures at Brown Bear for the USGS Historical project operations (1974 to 1997 water years).

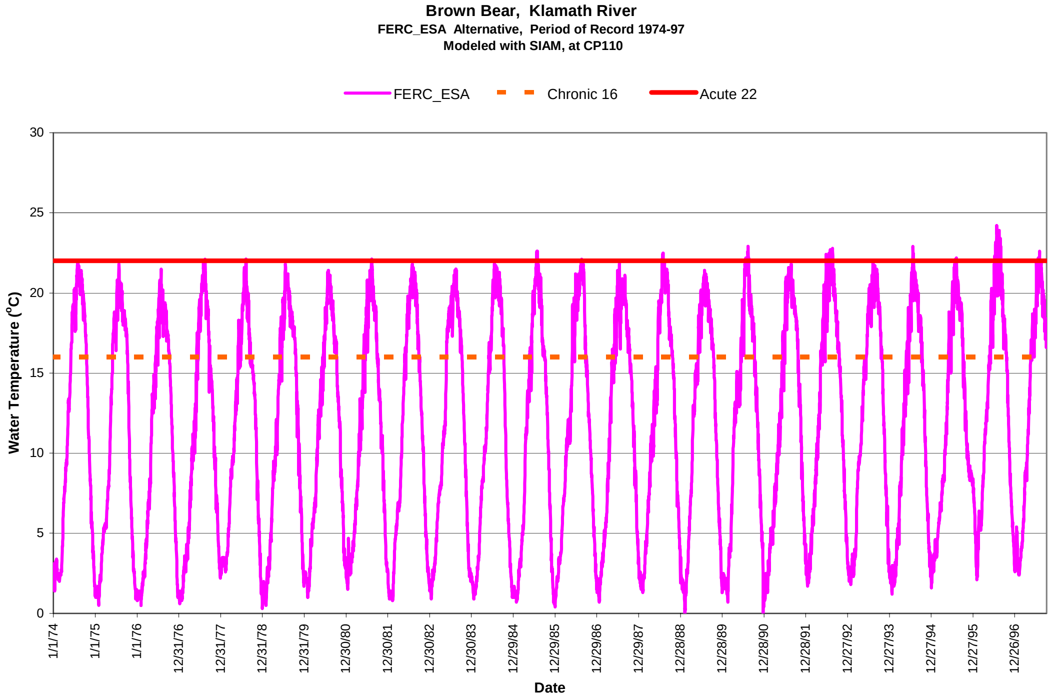

Figure C11. Daily mean temperatures at Brown Bear for the FERC_ESA scenario (1974 to 1997 water years).

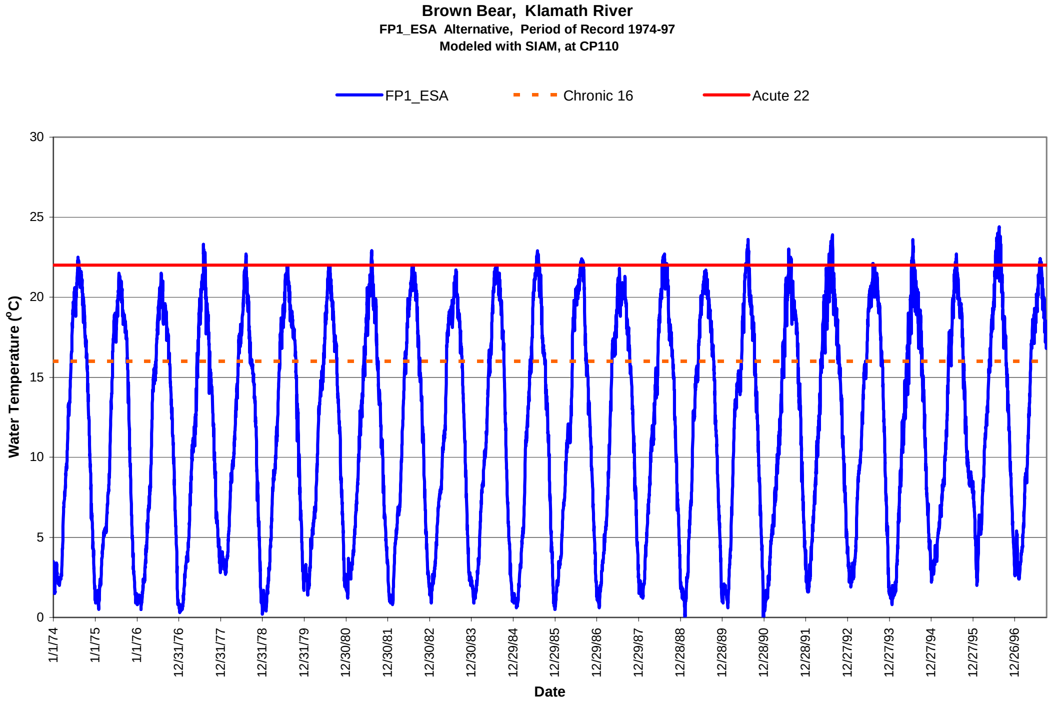

Figure C12. Daily mean temperatures at Brown Bear for the FP1_ESA scenario (1974 to 1997 water years).

Seiad

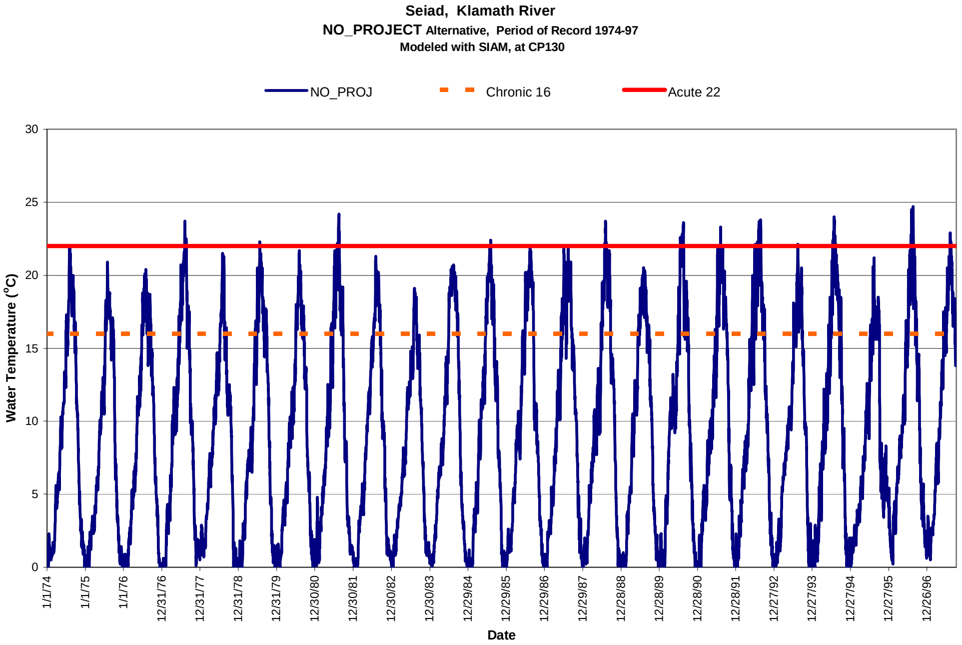

Figure C13. Daily mean temperatures at Seiad for the unimpaired no project scenario (1974 to 1997 water years).

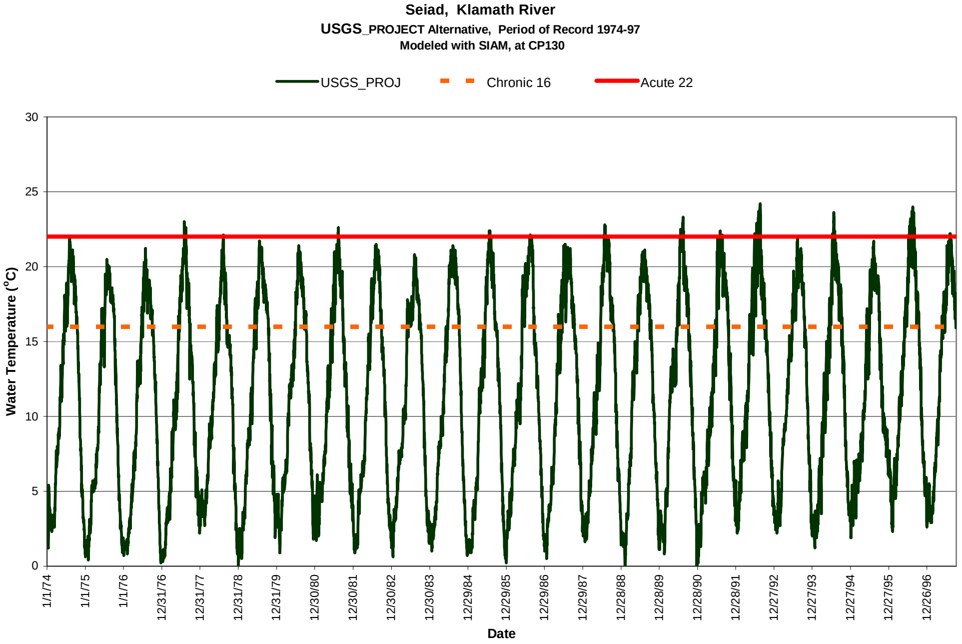

Figure C14. Daily mean temperatures at Seiad for the USGS Historical project operations (1974 to 1997 water years).

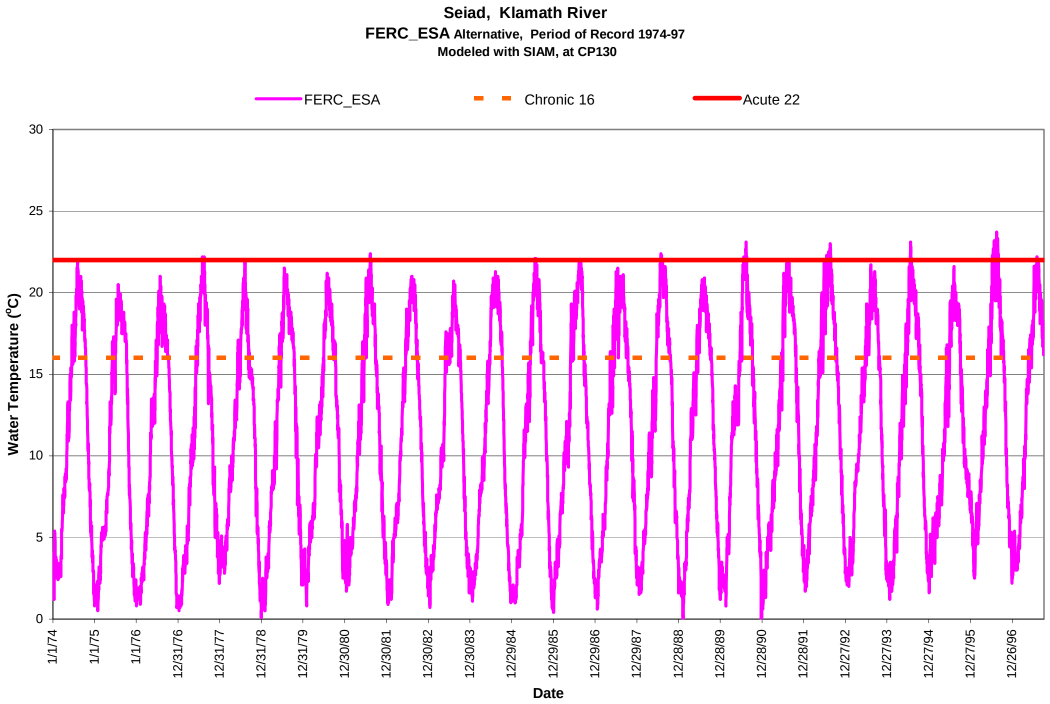

Figure C15. Daily mean temperatures at Seiad for the FERC_ESA scenario (1974 to 1997 water years).

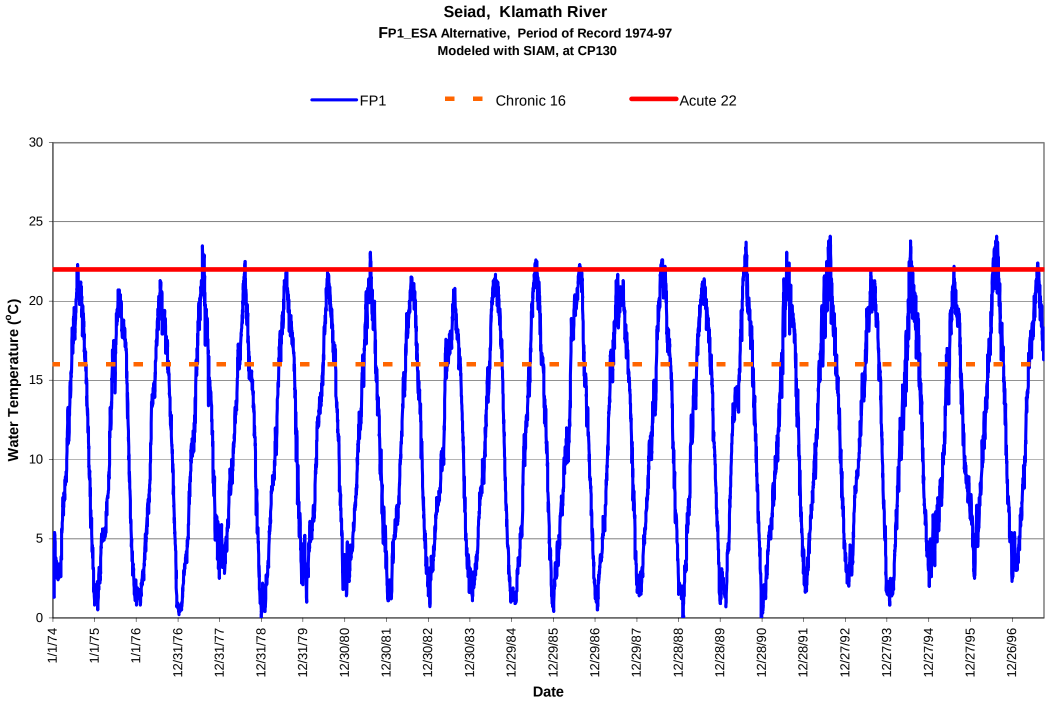

Figure C16. Daily mean temperatures at Seiad for the FP1_ESA scenario (1974 to 1997 water years).

Rogers Creek

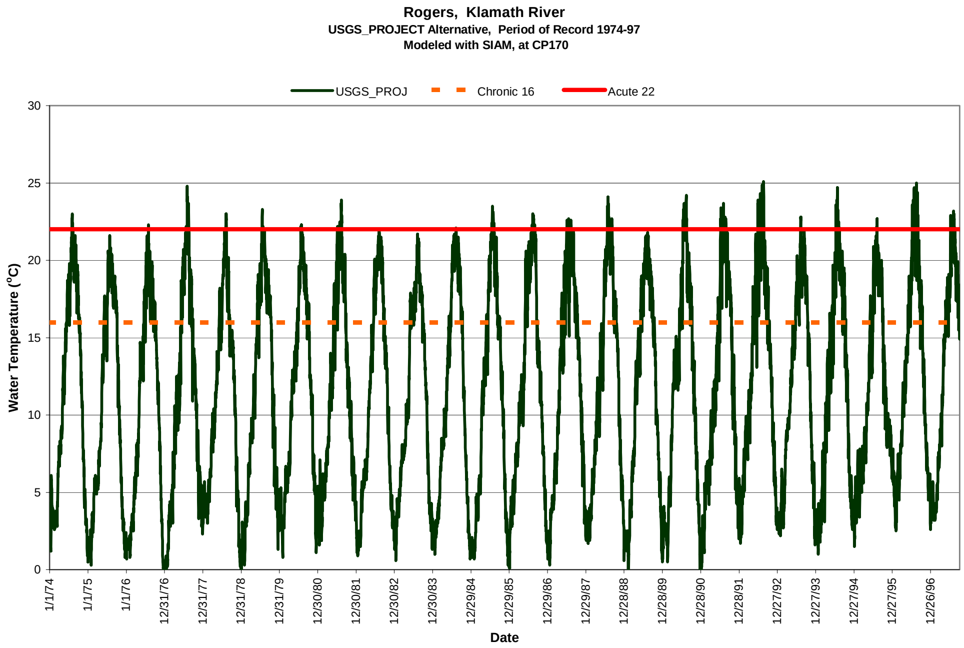

Figure C17. Daily mean temperatures at Rogers Creek for the USGS Historical project operations (1974 to 1997 water years).

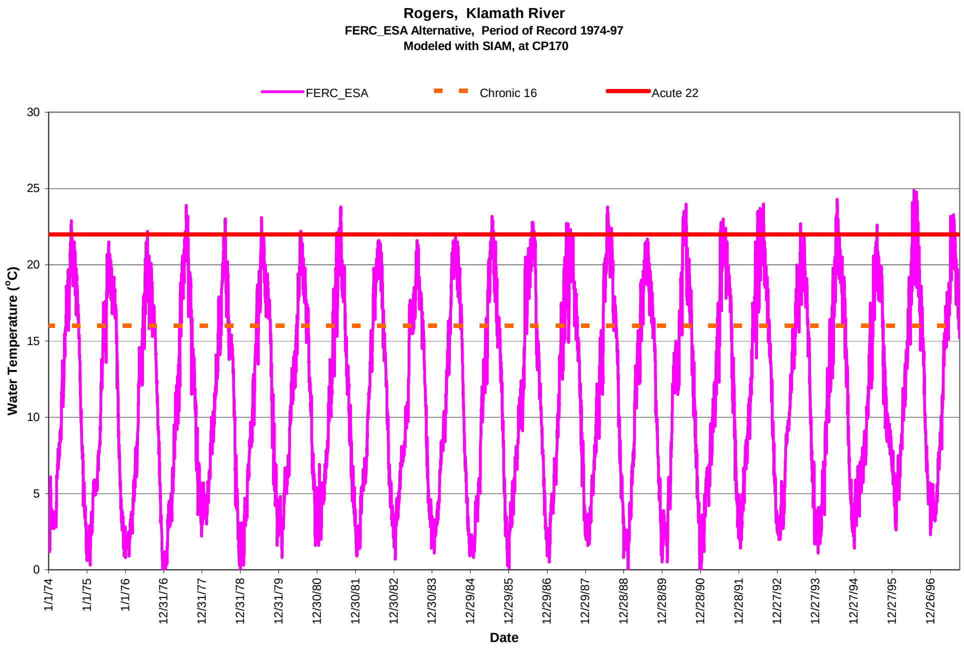

Figure C18. Daily mean temperatures at Rogers Creek for the FERC_ESA scenario (1974 to 1997 water years).

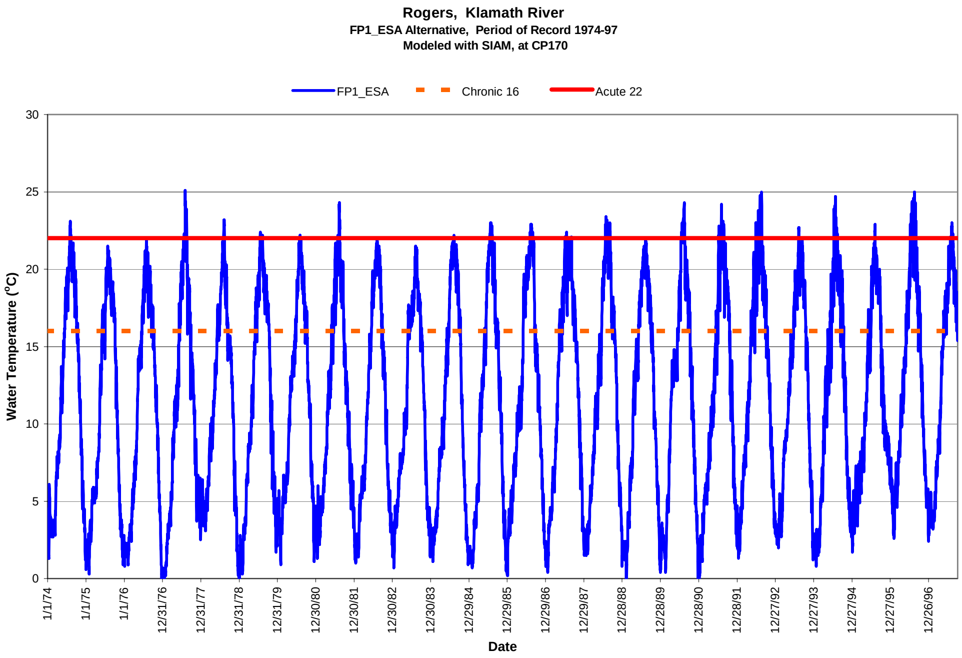

Figure C19. Daily mean temperatures at Rogers Creek for the FP1_ESA scenario (1974 to 1997 water years).

Orleans

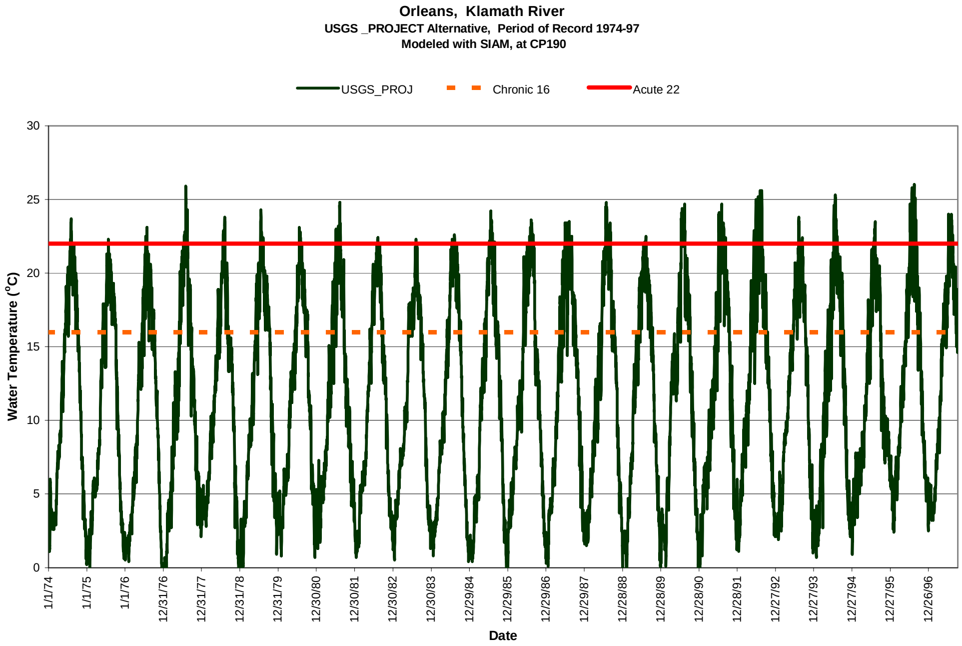

Figure C20. Daily mean temperatures at Orleans for the USGS Historical project operations (1974 to 1997 water years).

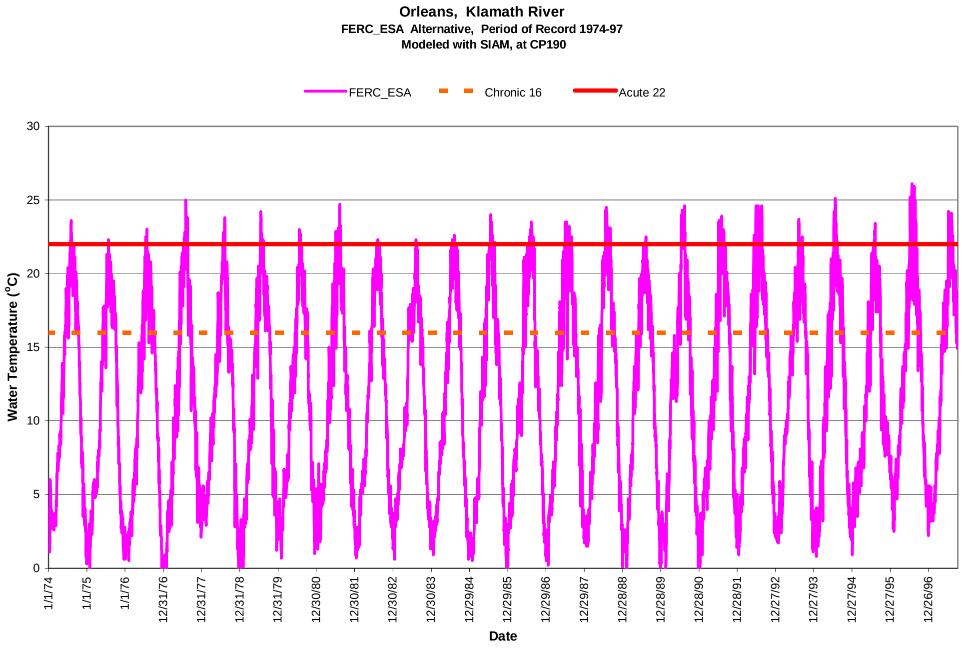

Figure C21. Daily mean temperatures at Orleans for the FERC_ESA scenario (1974 to 1997 water years).

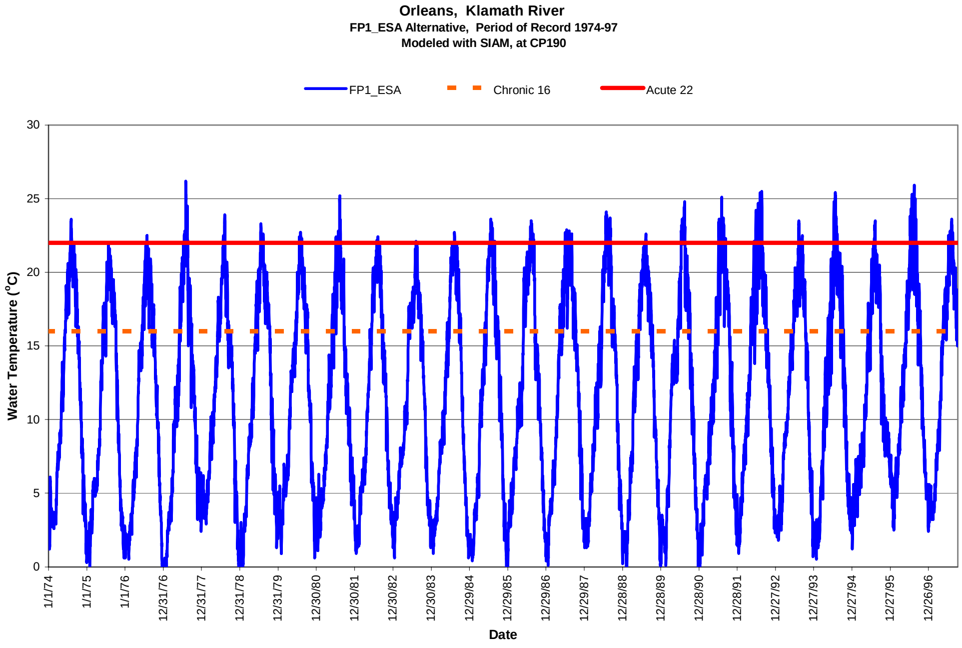

Figure C22. Daily mean temperatures at Orleans for the FP1_ESA scenario (1974 to 1997 water years).

Saints Rest Bar

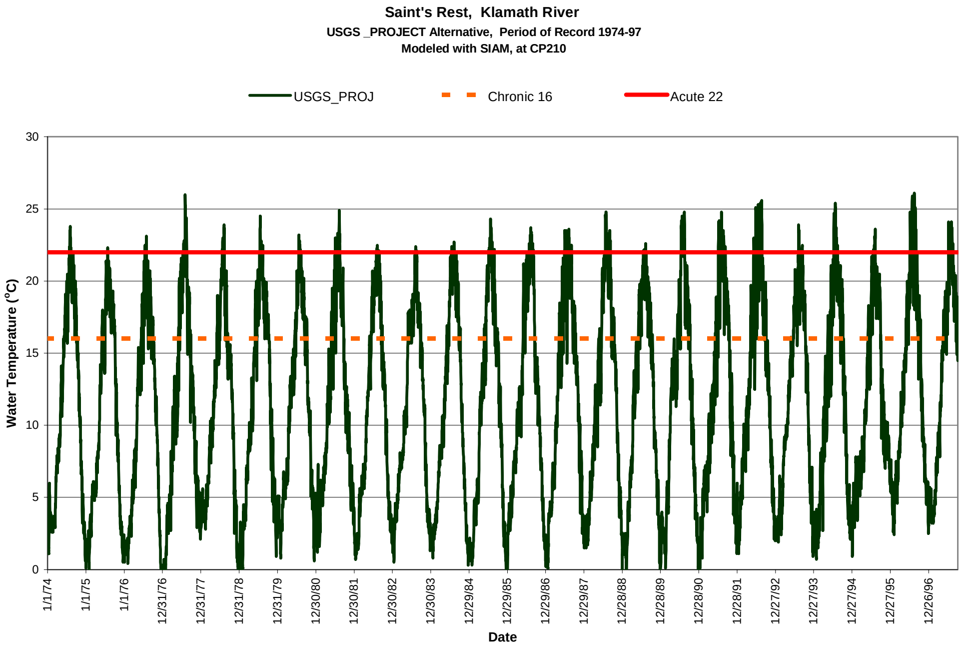

Figure C23. Daily mean temperatures at Saints Rest Bar for the USGS Historical project operations (1974 to 1997 water years).

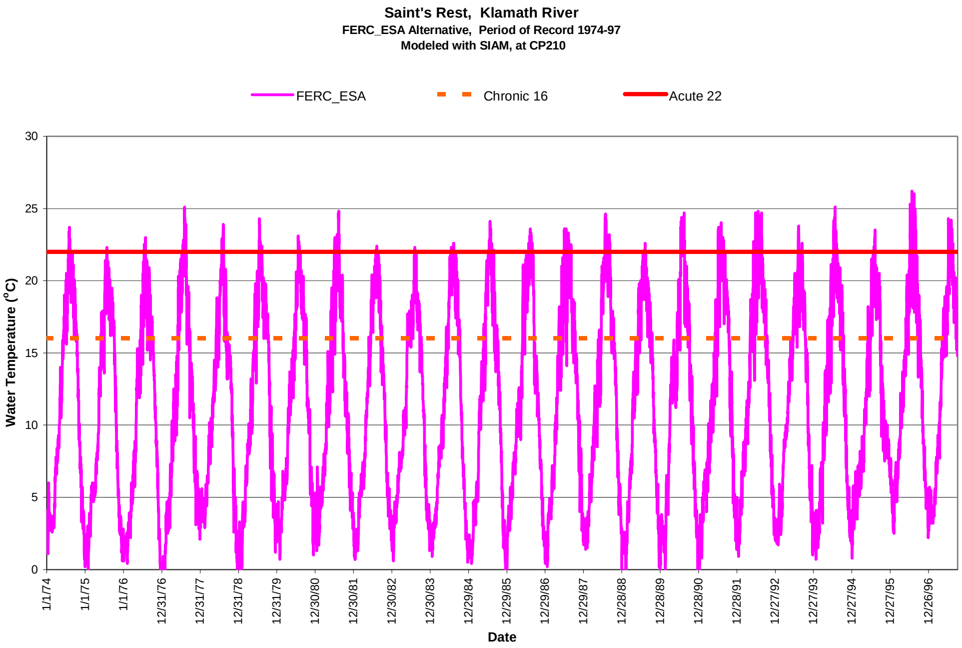

Figure C24. Daily mean temperatures at Saints Rest Bar for the FERC_ESA scenario (1974 to 1997 water years).

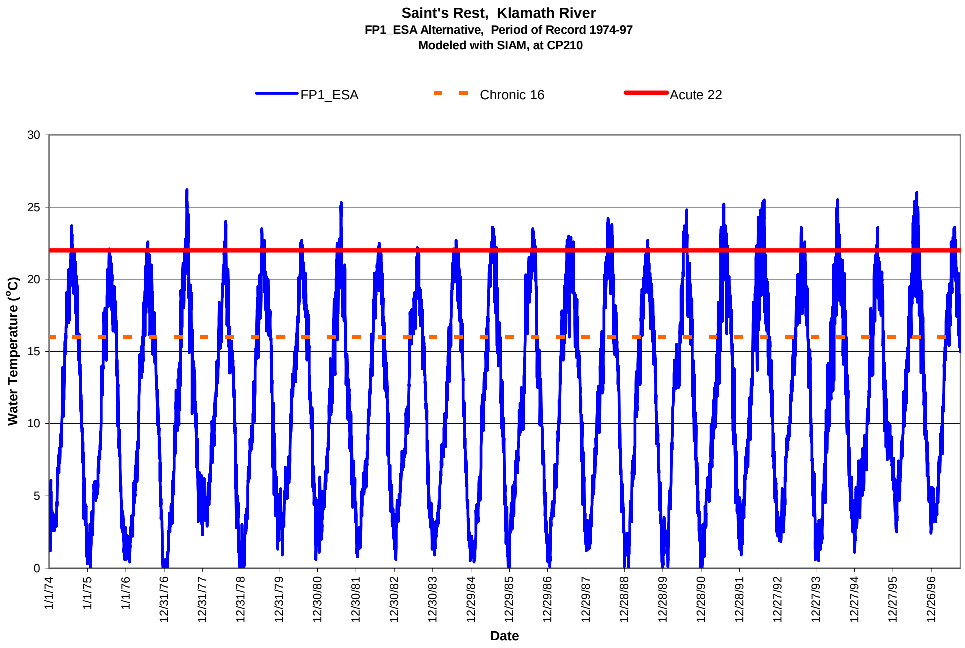

Figure C25. Daily mean temperatures at Saints Rest Bar for the FP1_ESA scenario (1974 to 1997 water years).

Appendix C - Simulated Water Temperatures Statistics

Klamath River, Iron Gate
Water Temperature, Period of Record 1974-97
Modeled with SIAM, cp40 (location in SIAM corresponding to Iron Gate)

Alternative	Month	n	Mean Daily Water Temperature (°C)			
			Mean	StDev	Max	Min
No_Project	Oct	713	11.6	2.9	18.1	5.2
	Nov	690	4.6	2.3	11.2	0.2
	Dec	713	1.6	1.6	9.5	0.0
	Jan	744	1.4	1.2	7.1	0.0
	Feb	672	2.7	1.7	7.3	0.0
	Mar	744	6.6	1.9	11.5	1.8
	April	720	10.3	2.1	16.2	5.2
	May	744	14.5	2.0	19.9	8.6
	June	720	18.1	2.0	24.0	12.8
	July	744	20.9	1.5	25.7	16.3
	Aug	744	21.1	1.6	26.0	16.3
	Sept	720	17.7	2.0	22.7	11.2
USGS_With_Project	Oct	713	15.6	1.7	19.1	10.1
	Nov	690	9.9	2.7	15.8	2.7
	Dec	713	3.9	2.4	10.0	0.4
	Jan	744	1.6	1.2	7.7	0.3
	Feb	672	2.0	1.1	6.2	0.4
	Mar	744	4.9	1.6	8.8	1.8
	April	720	8.8	1.8	13.2	4.4
	May	744	12.8	1.9	17.3	8.2
	June	720	16.5	1.5	19.3	11.8
	July	744	19.1	1.0	22.8	16.1
	Aug	744	20.4	0.7	22.8	19.1
	Sept	720	18.7	1.1	22.1	15.5
FERC_ESA	Oct	713	15.4	2.0	19.2	8.5
	Nov	690	9.6	2.6	15.5	2.6
	Dec	713	3.9	2.2	9.3	0.5
	Jan	744	1.5	1.1	7.7	0.5
	Feb	672	2.0	1.1	6.1	0.4
	Mar	744	5.0	1.6	8.9	1.7
	April	720	8.9	1.7	13.0	4.6
	May	744	12.8	1.8	17.2	8.1
	June	720	16.3	1.5	19.3	12.1
	July	744	18.8	1.0	21.8	16.1
	Aug	744	20.3	0.7	22.2	18.8
	Sept	720	18.7	1.1	21.5	15.6
FP1_ESA	Oct	713	15.9	1.8	19.5	9.9
	Nov	690	10.2	2.6	16.1	3.2
	Dec	713	4.0	2.3	10.0	0.6
	Jan	744	1.5	1.2	7.8	0.3
	Feb	672	1.9	1.1	6.1	0.4
	Mar	744	5.0	1.6	8.8	1.7
	April	720	9.0	1.8	13.3	4.9
	May	744	13.1	1.9	17.5	8.0
	June	720	16.9	1.5	20.4	12.5
	July	744	19.8	1.0	23.4	16.9
	Aug	744	21.0	0.8	23.6	19.2
	Sept	720	19.1	1.1	22.4	15.9

Klamath River, Trees of Heaven

Water Temperature, Period of Record 1974-97

Modeled with SIAM, cp80 (location in SIAM corresponding to Trres of Heaven)

Alternative	Month	n	Mean Daily Water Temperature (°C)			
			Mean	StDev	Max	Min
No_Project	Oct	713	10.6	2.7	16.9	4.7
	Nov	690	4.1	2.1	10.1	0.0
	Dec	713	1.4	1.4	8.4	0.0
	Jan	744	1.2	1.1	6.0	0.0
	Feb	672	2.4	1.5	6.8	0.0
	Mar	744	6.0	1.8	10.9	1.5
	April	720	9.7	2.1	15.8	4.7
	May	744	13.7	2.0	19.6	7.9
	June	720	17.4	2.0	23.7	12.0
	July	744	20.3	1.6	24.8	15.4
	Aug	744	20.5	1.7	25.4	15.3
	Sept	720	16.9	2.1	21.7	10.3
USGS_With_Project	Oct	713	15.2	1.7	19.1	10.0
	Nov	690	9.5	2.5	15.1	2.9
	Dec	713	4.1	2.2	9.2	0.5
	Jan	744	2.3	1.2	8.0	0.7
	Feb	672	2.9	1.2	6.9	0.6
	Mar	744	5.6	1.5	9.8	2.5
	April	720	9.3	1.7	13.2	5.3
	May	744	13.3	1.8	17.9	8.5
	June	720	17.1	1.5	20.5	12.2
	July	744	19.7	1.1	23.2	16.5
	Aug	744	20.5	0.8	23.2	18.8
	Sept	720	18.6	1.2	21.8	15.3
FERC_ESA	Oct	713	15.2	1.9	19.2	8.8
	Nov	690	9.5	2.4	15.1	2.9
	Dec	713	4.2	2.0	9.2	0.8
	Jan	744	2.2	1.1	8.0	0.8
	Feb	672	2.8	1.1	6.4	0.6
	Mar	744	5.5	1.5	9.1	2.3
	April	720	9.2	1.7	13.1	4.8
	May	744	13.1	1.8	17.7	8.4
	June	720	16.8	1.5	20.5	12.3
	July	744	19.4	1.0	22.6	16.0
	Aug	744	20.4	0.7	22.7	18.7
	Sept	720	18.7	1.2	21.4	15.5
FP1_ESA	Oct	713	15.5	1.7	19.4	9.8
	Nov	690	9.8	2.4	15.4	3.4
	Dec	713	4.2	2.1	9.2	0.8
	Jan	744	2.1	1.2	8.1	0.6
	Feb	672	2.6	1.1	6.4	0.5
	Mar	744	5.5	1.5	9.3	2.3
	April	720	9.3	1.8	13.4	5.3
	May	744	13.4	1.9	18.0	8.4
	June	720	17.2	1.5	20.5	12.8
	July	744	20.1	1.0	23.4	17.6
	Aug	744	21.0	0.8	23.5	19.4
	Sept	720	18.9	1.2	22.0	15.8

Klamath River, Brown Bear
Water Temperature, Period of Record 1974-97
Modeled with SIAM, cp110 (location in SIAM corresponding to Brown Bear)

Alternative	Month	n	Mean Daily Water Temperature (^oC)			
			Mean	StDev	Max	Min
No_Project	Oct	713	10.6	2.8	17.2	4.7
	Nov	690	4.0	2.2	10.1	0.0
	Dec	713	1.3	1.5	8.7	0.0
	Jan	744	1.1	1.1	5.8	0.0
	Feb	672	2.4	1.6	7.2	0.0
	Mar	744	6.1	1.8	11.2	1.4
	April	720	9.8	2.2	16.4	4.6
	May	744	13.9	2.1	20.1	8.1
	June	720	17.6	2.1	24.3	11.8
	July	744	20.5	1.7	25.2	15.3
	Aug	744	20.7	1.8	25.8	15.2
	Sept	720	17.1	2.2	22.3	10.0
USGS_With_Project	Oct	713	14.8	1.9	19.2	9.5
	Nov	690	9.0	2.4	14.7	2.7
	Dec	713	3.7	2.1	9.4	-0.9
	Jan	744	2.1	1.2	7.8	0.3
	Feb	672	2.9	1.3	7.6	-0.3
	Mar	744	5.7	1.6	10.8	2.4
	April	720	9.5	1.8	14.3	5.4
	May	744	13.7	2.0	19.0	8.8
	June	720	17.7	1.7	22.9	12.5
	July	744	20.4	1.3	24.0	15.8
	Aug	744	20.7	1.1	24.3	18.0
	Sept	720	18.4	1.4	21.7	13.1
FERC_ESA	Oct	713	14.8	2.0	19.2	8.7
	Nov	690	9.0	2.3	14.7	2.7
	Dec	713	3.8	2.0	8.9	-0.4
	Jan	744	2.1	1.1	7.8	0.5
	Feb	672	2.8	1.2	6.4	-0.2
	Mar	744	5.6	1.5	9.7	2.2
	April	720	9.4	1.8	13.8	5.2
	May	744	13.5	1.9	18.7	8.7
	June	720	17.5	1.7	22.4	12.5
	July	744	20.2	1.3	24.2	15.5
	Aug	744	20.6	1.0	23.9	17.9
	Sept	720	18.5	1.3	21.5	13.8
FP1_ESA	Oct	713	15.0	1.9	19.5	9.6
	Nov	690	9.3	2.4	15.0	3.0
	Dec	713	3.9	2.1	9.1	-0.6
	Jan	744	2.0	1.2	7.9	0.3
	Feb	672	2.6	1.2	6.4	-0.3
	Mar	744	5.6	1.6	9.8	2.2
	April	720	9.5	1.8	14.0	5.3
	May	744	13.7	1.9	18.7	8.7
	June	720	17.6	1.5	21.8	12.9
	July	744	20.5	1.2	24.0	17.2
	Aug	744	21.1	1.1	24.4	18.3
	Sept	720	18.7	1.3	22.1	14.0

Klamath River, Seiad
Water Temperature, Period of Record 1974-97
Modeled with SIAM, cp130 (location in SIAM corresponding to Seiad)

Alternative	Month	n	Mean Daily Water Temperature (^{o}C)			
			Mean	StDev	Max	Min
No_Project	Oct	713	9.9	2.7	16.7	4.0
	Nov	690	3.4	2.0	9.6	0.0
	Dec	713	0.9	1.1	6.2	0.0
	Jan	744	0.8	0.8	4.8	0.0
	Feb	672	1.9	1.2	5.7	0.0
	Mar	744	4.6	1.4	8.6	1.0
	April	720	7.5	1.7	12.3	3.6
	May	744	10.5	1.8	16.1	5.5
	June	720	14.1	2.5	22.0	8.8
	July	744	18.4	2.2	24.0	12.5
	Aug	744	19.6	2.0	24.7	14.2
	Sept	720	16.3	2.2	21.7	9.4
USGS_With_Project	Oct	713	14.3	1.9	18.9	9.1
	Nov	690	8.4	2.2	14.2	2.8
	Dec	713	3.6	1.9	9.1	-1.3
	Jan	744	2.5	1.3	7.7	0.2
	Feb	672	3.5	1.5	8.4	-0.4
	Mar	744	6.0	1.5	10.7	2.5
	April	720	9.3	1.7	14.1	5.2
	May	744	12.7	1.9	17.8	8.0
	June	720	16.3	1.8	22.2	11.6
	July	744	19.6	1.6	23.6	13.9
	Aug	744	20.4	1.2	24.2	17.5
	Sept	720	18.1	1.5	21.8	12.5
FERC_ESA	Oct	713	14.5	2.0	19.0	8.5
	Nov	690	8.4	2.2	14.2	2.7
	Dec	713	3.8	1.8	8.9	-0.9
	Jan	744	2.5	1.2	7.8	0.5
	Feb	672	3.4	1.3	7.1	-0.3
	Mar	744	5.9	1.4	9.9	2.4
	April	720	9.2	1.7	14.1	5.1
	May	744	12.6	1.8	17.9	7.9
	June	720	16.2	1.8	21.9	11.5
	July	744	19.4	1.5	23.2	13.9
	Aug	744	20.3	1.1	23.7	17.5
	Sept	720	18.2	1.4	21.6	13.2
FP1_ESA	Oct	713	14.6	1.9	19.2	9.3
	Nov	690	8.7	2.3	14.4	3.2
	Dec	713	3.8	1.9	8.9	-1.0
	Jan	744	2.4	1.3	7.8	0.2
	Feb	672	3.2	1.4	7.1	-0.4
	Mar	744	5.9	1.4	9.9	2.4
	April	720	9.2	1.7	13.9	5.1
	May	744	12.9	1.9	18.0	7.9
	June	720	16.6	1.7	21.6	12.3
	July	744	20.0	1.3	23.8	15.4
	Aug	744	20.8	1.2	24.1	17.9
	Sept	720	18.4	1.4	22.2	13.4

Klamath River, Rogers

Water Temperature, Period of Record 1974-97

Modeled with SIAM, cp170 (location in SIAM corresponding to Rogers)

Alternative	Month	n	Mean Daily Water Temperature (^{o}C)			
			Mean	StDev	Max	Min
No_Project	Oct	713	Water temperatures are not modeled by SIAM at this location for the No_Project.			
	Nov	690				
	Dec	713				
	Jan	744				
	Feb	672				
	Mar	744				
	April	720				
	May	744				
	June	720				
	July	744				
	Aug	744				
	Sept	720				
USGS_With_Project	Oct	713	13.7	2.1	19.0	7.9
	Nov	690	7.8	2.2	13.9	2.4
	Dec	713	3.4	1.9	9.3	-3.4
	Jan	744	2.7	1.5	7.8	-0.4
	Feb	672	3.9	1.6	9.3	-1.0
	Mar	744	6.4	1.5	11.6	2.5
	April	720	9.7	1.9	14.9	5.2
	May	744	13.2	2.1	19.0	8.3
	June	720	17.0	2.1	23.9	11.6
	July	744	20.3	1.8	24.7	13.6
	Aug	744	20.6	1.6	25.1	16.6
	Sept	720	17.9	1.8	22.7	10.9
FERC_ESA	Oct	713	13.8	2.2	19.1	7.3
	Nov	690	7.7	2.2	13.9	2.2
	Dec	713	3.4	1.9	9.1	-3.4
	Jan	744	2.7	1.4	7.8	-0.4
	Feb	672	3.9	1.5	8.1	-1.0
	Mar	744	6.4	1.5	10.8	2.4
	April	720	9.7	1.8	15.0	5.2
	May	744	13.2	2.0	20.5	8.2
	June	720	17.0	2.1	23.5	11.5
	July	744	20.2	1.8	24.9	14.3
	Aug	744	20.4	1.5	24.8	16.6
	Sept	720	17.9	1.7	22.4	11.5
FP1_ESA	Oct	713	13.9	2.1	19.3	8.1
	Nov	690	8.0	2.2	14.1	2.6
	Dec	713	3.6	1.9	9.2	-3.0
	Jan	744	2.6	1.5	7.8	-0.3
	Feb	672	3.6	1.5	7.5	-1.0
	Mar	744	6.3	1.5	10.6	2.4
	April	720	9.6	1.8	14.7	5.2
	May	744	13.2	2.0	18.9	8.2
	June	720	17.1	1.9	23.0	12.4
	July	744	20.4	1.6	24.7	14.9
	Aug	744	20.8	1.5	25.1	16.9
	Sept	720	18.1	1.7	23.0	11.6

Klamath River, Orleans
Water Temperature, Period of Record 1974-97
Modeled with SIAM, cp190 (location in SIAM corresponding to Orleans)

Alternative	Month	n	Mean Daily Water Temperature (^oC)			
			Mean	StDev	Max	Min
No_Project	Oct	713	Water temperatures are not modeled by SIAM at this location for the No_Project.			
	Nov	690				
	Dec	713				
	Jan	744				
	Feb	672				
	Mar	744				
	April	720				
	May	744				
	June	720				
	July	744				
	Aug	744				
	Sept	720				
USGS_With_Project	Oct	713	13.3	2.3	19.2	7.0
	Nov	690	7.3	2.3	13.7	1.7
	Dec	713	3.1	2.0	9.2	-5.0
	Jan	744	2.5	1.5	7.6	-1.1
	Feb	672	3.9	1.7	9.4	-1.6
	Mar	744	6.5	1.6	12.0	2.3
	April	720	9.8	2.0	15.2	5.2
	May	744	13.5	2.2	19.8	8.3
	June	720	17.4	2.3	25.0	11.4
	July	744	20.7	2.0	25.8	13.6
	Aug	744	20.7	1.9	26.0	16.0
	Sept	720	17.8	2.0	23.4	10.3
FERC_ESA	Oct	713	13.7	2.3	19.2	7.1
	Nov	690	7.4	2.2	13.7	1.6
	Dec	713	3.2	2.0	9.0	-5.2
	Jan	744	2.5	1.5	7.6	-1.1
	Feb	672	3.8	1.5	8.2	-1.6
	Mar	744	6.3	1.5	11.1	2.2
	April	720	9.7	1.9	15.2	5.1
	May	744	13.4	2.2	19.5	8.2
	June	720	17.3	2.3	24.6	11.3
	July	744	20.6	2.0	26.1	13.6
	Aug	744	20.7	1.8	25.9	15.9
	Sept	720	17.8	2.0	23.1	10.7
FP1_ESA	Oct	713	13.5	2.3	19.4	7.1
	Nov	690	7.6	2.3	13.9	1.8
	Dec	713	3.3	2.0	9.1	-4.6
	Jan	744	2.5	1.5	7.6	-0.8
	Feb	672	3.6	1.6	7.6	-1.6
	Mar	744	6.3	1.5	11.0	2.2
	April	720	9.7	1.9	14.9	5.1
	May	744	13.5	2.1	19.5	8.2
	June	720	17.4	2.0	24.2	12.2
	July	744	20.7	1.7	25.4	14.7
	Aug	744	20.9	1.8	26.2	16.3
	Sept	720	18.0	2.0	23.7	10.8

Klamath River, Saint's Rest Bar
Flow and Water Temperature, Period of Record 1974-97
Modeled with SIAM, cp210 (location in SIAM corresponding to Saint's Rest Bar)

Alternative	Month	n	Mean Daily Water Temperature (°C)			
			Mean	StDev	Max	Min
No_Project	Oct	713	Water temperatures are not modeled by SIAM at this location for the No_Project.			
	Nov	690				
	Dec	713				
	Jan	744				
	Feb	672				
	Mar	744				
	April	720				
	May	744				
	June	720				
	July	744				
	Aug	744				
	Sept	720				
USGS_With_Project	Oct	713	13.2	2.4	19.1	6.9
	Nov	690	7.3	2.3	13.6	1.6
	Dec	713	3.1	2.0	9.3	-5.3
	Jan	744	2.5	1.5	7.6	-1.1
	Feb	672	3.9	1.7	9.4	-1.7
	Mar	744	6.5	1.6	12.0	2.3
	April	720	9.8	2.0	15.2	5.1
	May	744	13.5	2.2	19.9	8.3
	June	720	17.5	2.3	25.1	11.4
	July	744	20.8	2.0	25.9	13.6
	Aug	744	20.7	1.9	26.1	15.9
	Sept	720	17.8	2.0	23.5	10.2
FERC_ESA	Oct	713	13.4	2.4	19.4	7.0
	Nov	690	7.5	2.3	13.8	1.7
	Dec	713	3.3	2.0	9.1	-4.8
	Jan	744	2.5	1.5	7.6	-0.9
	Feb	672	3.6	1.6	7.7	-1.7
	Mar	744	6.3	1.5	11.0	2.2
	April	720	9.7	1.9	14.9	5.1
	May	744	13.5	2.1	19.6	8.2
	June	720	17.4	2.1	24.3	12.1
	July	744	20.7	1.7	25.5	14.7
	Aug	744	20.9	1.8	26.2	16.2
	Sept	720	17.9	2.0	23.8	10.7
FP1_ESA	Oct	713	13.6	2.3	19.2	7.0
	Nov	690	7.3	2.2	13.7	1.5
	Dec	713	3.2	2.0	9.0	-5.5
	Jan	744	2.5	1.5	7.6	-1.2
	Feb	672	3.8	1.5	8.2	-1.7
	Mar	744	6.4	1.5	11.2	2.2
	April	720	9.8	1.9	15.3	5.1
	May	744	13.4	2.2	19.6	8.2
	June	720	17.4	2.4	24.7	11.3
	July	744	20.7	2.0	26.2	13.6
	Aug	744	20.7	1.8	26.0	15.8
	Sept	720	17.8	2.0	23.2	10.5