Application of the Systems Impact Assessment Model (SIAM) to Fishery Resource Issues in the Klamath River, California

By Sharon G. Campbell, John M. Bartholow, and John Heasley

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
Flow rate		
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Application of the Systems Impact Assessment Model (SIAM) to Fishery Resource Issues in the Klamath River, California

By Sharon G. Campbell[1], John M. Bartholow[2], and John Heasley[3]

Abstract

At the request of two offices of the U.S. Fish and Wildlife Service (FWS) located in Yreka and Arcata, Calif., we applied the Systems Impact Assessment Model (SIAM) to analyze a variety of water management concerns associated with the Federal Energy Regulatory Commission (FERC) relicensing of the Klamath hydropower projects or with ongoing management of anadromous fish stocks in the mainstem Klamath River, Oregon and California. Requested SIAM analyses include predicted effects of reservoir withdrawal elevations, use of full active storage in Copco and Iron Gate Reservoirs to augment spring flows, and predicted spawning and juvenile outmigration timing of fall Chinook salmon. In an effort to further refine the analysis of spring flow effects on predicted fall Chinook production, additional SIAM analyses were performed for predicted response to spring flow release variability from Iron Gate Dam, high and low pulse flow releases, the predicted effects of operational constraints for both Upper Klamath Lake water surface elevations, and projected flow releases specified in the Klamath Project 2006 Operations Plan (April 10, 2006).

Results of SIAM simulations to determine flow and water temperature relationships indicate that up to 4° C of thermal variability can be attributed to flow variations, but the effect is seasonal. Much more of thermal variability can be attributed to air temperature variations, up to 6° C. Reservoirs affect the annual thermal signature by delaying spring warming by about 3 weeks and fall cooling by about 2 weeks. Multi-level release outlets on Iron Gate Dam would have limited utility; however, if releases are small (700 cfs) and a near-surface and bottom-level outlet could be blended, then water temperature may be reduced by 2–4° C for a 4-week period during September. Using the full active storage in Copco and Iron Gate Reservoir, although feasible, had undesirable ramifications such as earlier spring warming, loss of hydropower production, and inability to re-fill the reservoirs without causing shortages elsewhere in the system. Altering spawning and outmigration timing may be important management objectives for the salmon fishery, but difficult to implement. SIAM predicted benefits that might occur if water temperature was cooler in fall and spring emergence was advanced;

KEYWORDS: Klamath River, thermal regime, anadromous fish, multi-level intake, selective withdrawal, reservoirs, flows, water management, fall Chinook salmon

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however, model simulations were based on purely arbitrary thermal reductions. Spring flow variability did indicate that juvenile fall Chinook rearing habitat was the major biological ‘bottleneck’ for year class success. Rearing habitat is maximal in a range between 4,500 and 5,500 cfs below Iron Gate Dam. These flow levels are not typically provided by Klamath River system operations, except in very wet years. The incremental spring flow analysis provided insight into when and how long a pulse flow should occur to provide predicted fall Chinook salmon production increases. In general, March 15th – April 30th of any year was the period for pulse flows and 4000 cfs was the target flow release that provided near-optimal juvenile rearing habitat. Again, competition for water resources in the Klamath River Basin may make implementation of pulsed flows difficult.

Introduction

At the request of two offices of the U.S. Fish and Wildlife Service (FWS) located in Yreka and Arcata, Calif., we applied the Systems Impact Assessment Model (SIAM) to analyze a variety of water management concerns associated with the Federal Energy Regulatory Commission (FERC) relicensing of the Klamath hydropower projects or with ongoing management of anadromous fish stocks in the mainstem Klamath River, Oregon and California. The Yreka FWS specifically asked for SIAM analysis of the predicted effects of reservoir withdrawal elevations, use of full active storage in Copco and Iron Gate Reservoirs to augment spring flows, and predicted spawning and juvenile outmigration timing of fall Chinook salmon. In an effort to further refine the analysis of spring flow effects on predicted fall Chinook production, the Arcata FWS requested analysis of predicted response to spring flow release variability from Iron Gate Dam, high and low pulse flow releases, and a specific analysis of the predicted effects of operational constraints for both Upper Klamath Lake water surface elevations and projected flow releases specified in the Klamath Project 2006 Operations Plan (April 10, 2006). This report presents the results of SIAM modeling to address these FWS requests for technical assistance in 2006.

Flowing out of southern Oregon into northern California, the Klamath River once supported large runs of Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and other economically and culturally important cold water fishes. Hydropower development, agricultural diversions, habitat alterations, land use practices, commercial fishing, hatchery influences, disease, and climatic fluctuations have all been named as potential factors in the decline the fishery (Brown and others, 1994). Despite restoration efforts, salmon populations have continued to decline since the late 1970s (National Research Council, 2004).

Water temperatures are crucially important in the physiology and survival of all cold-blooded aquatic organisms and have been considered an obstacle to recovering anadromous fish on the mainstem Klamath River (California State Senate, 1963; U.S. Department of the Interior, 1985; Klamath River Basin Fisheries Task Force, 1991). Temperatures in the Klamath River appear to be elevated with respect to geographic regions either immediately to its north or south, in part because the river’s headwater is the large, shallow Upper Klamath Lake (UKL) located in an interior basin isolated from more moderate Pacific weather (Bartholow, 2005). There are four hydropower facilities on the Klamath River below UKL all having near-surface rather than hypolimnetic withdrawal structures. Below the lowest mainstem dam (and the current upstream limit of salmon migration), temperatures regularly exceed 22–26°C in the summer and fall, a range known to be stressful for salmonids at a minimum (Myrick and Cech, 2004) and likely either acutely lethal or exclusionary (Richter and Kolmes, 2005). Based on newly collected information (J. Bartholomew and S. Foote, personal commun., 2006, when water temperatures reach 10°C in the spring the virulence of *Ceratomyxa shasta,* an endemic myxosporean protozoan parasite afflicting salmonids of the Pacific northwest also begins to increase (Bartholomew, 1998). *C. Shasta* is quite lethal to juvenile salmonids in certain sections of the Klamath River prior to their emigration to the ocean (Foott and others, 1999).

There has been substantial work exploring the degree to which flow management and dam removal might be expected to alter mainstem water temperatures. One modeling tool developed by the U.S. Geological Survey Fort Collins Science Center (USGS-FORT) is the Systems Impact Assessment Model (SIAM) (Bartholow and others, 2005). This decision support system model incorporates a water quantity, water quality, and fish production component in a Windows-based user interface and is available for download along with a 45-year database and user documentation at *http://www.fort.usgs.gov/Products/Software/*.

Campbell and others (2001) evaluated several water management alternatives using SIAM including changes in agricultural deliveries relative to historical conditions, hypothetical changes to release levels at Iron Gate Dam to simulate mid-level and low-level outlet discharge on predicted water, and changes in reservoir storage in UKL and Iron Gate Dam Reservoir. That modeling effort indicated that temperature changes of approximately ±2°C from the historical baseline would accompany such management alternatives. In general, Campbell and others (2001) found that predicted thermal effects were limited both spatially and temporally, and that careful analysis and in-depth evaluation of different hydrologic conditions that more fully describe water quality changes at multiple locations on the Klamath River should be performed prior to implementation of specific management alternatives. Bartholow and others (2004) found that, if managed with the historical flows, dam removal would shift the timing of the annual thermal signature an average of 18 days earlier in the year, but would not appreciably alter annual maximum or minimum temperatures. Such a temporal shift would likely benefit adult fall Chinook during their fall spawning migration but, depending on how life history timing was affected, might potentially harm salmon rearing in the spring. Deas (2000) explored a wide variety of water management options for Iron Gate Reservoir operations and retrofit using the WQRRS reservoir model (Water Quality for River-Reservoir Systems software), but focused largely on the warmest summer months. Deas concluded that only modest thermal benefits (1–2°C reductions) were possible through the summer (June–August) and then only if selective withdrawal were combined with increased reservoir storage. PacifiCorp (2005) also examined options for selective withdrawal using the CE-QUAL-W2 model in an unpublished report. This report examined a single year and maintained historical flow conditions, concluding that thermal benefits of selective withdrawal were quite modest (approximately 1°C), short term (maximum two weeks), and did not propagate far downstream. None of the above work explored the full range of possibilities in controlling water temperatures in a wide variety of hydrologic and meteorologic conditions if existing management constraints (for example, minimum instream flows, reservoir storage conventions) were not applied, nor did they assume use of full active reservoir storage.

The role that dam releases (flows) influence predictions of fish production is generally known, especially how the amount of suitable habitat changes with flow have been relatively well defined for portions of the Klamath River mainstem below Iron Gate Dam (Bartholow and Henriksen, 2006). However, iterative model runs to determine incremental effects of changing flow seemed desirable, in order to determine the relative benefits of providing specific ranges of flow, both temporally and spatially, for fall Chinook salmon life stages. The FWS charged USGS with a series of SIAM evaluations of both flow and temperature, and specified various means for altering each parameter in the modeling exercises.

Our goals were to explore and understand the full limits of temperature and flow control potentially available to river management while keeping the current suite of hydropower facilities in place. There were several explicit actions that could be applied singly or in combination to manipulate mainstem water temperatures, to alter the flow regime, to manipulate reservoir storage, and (or) to make structural modifications to the dams' intake works. There are a greater variety of flow alterations that were explored in an attempt to quantify their effects on fish production predictions. We addressed these independent objectives in this report by applying a decision support model, SIAM, and other modeling tools such as the fish production model, SALMOD, to predict the range of temperature and flow alterations that could be under man's influence. We did not evaluate the potential of increasing reservoir capacity.

Study Area

The Klamath Basin spans the Oregon-California state line (fig. 1). Annual inflows to UKL average 1,666×10^6 m^3 but are highly variable, ranging from 708 to 2,615×10^6 m^3. Some inflows are diverted to the Bureau of Reclamation's Klamath Project, a large reclaimed wetland now used for agriculture. After development of agricultural lands, the mainstem Klamath River releases now range from 488 to 2,213×10^6 m^3 per year. Downstream return flows combine with other flows from the watershed to yield flow releases below the most downstream dam, Iron Gate, that average 1,915×10^6 m^3 per year (range from 572 to 3,286×10^6 m^3).

Along with Iron Gate Dam and Reservoir, constructed in 1962, there are three other hydropower facilities on the mainstem Klamath River: Link Dam controlling UKL (1921), J.C. Boyle Dam (1958), and twin Copco facilities (1918 and 1925), all taking advantage of the relatively steep gradient through the Klamath Mountains (fig. 2). Iron Gate re-regulates Copco's peaking operations. The Federal Energy Regulatory Commission (FERC) stipulated a minimum flow schedule below Iron Gate mandated by Endangered Species Act requirements in the license for the hydropower project that expired in 2006. Under the FERC schedule, minimum flows below Iron Gate are 1,300 cfs from September through April, 1,000 cfs in May and August, and 710 cfs in June and July. There are two additional small reservoirs, Keno and Lake Euwana, used to control water surface elevations for additional off-stream uses. All of these facilities collectively preclude anadromous fish from using historic spawning and rearing habitat in the upper Klamath Basin (Hamilton and others, 2005).

A summary of reservoir capacities (table 1) highlights the relative importance of UKL for water management. In table 1, maximum storage values refer to the total reservoir capacity, dead storage is the unusable volume below existing intake structures, and the difference, active storage, is the manageable volume of water in each reservoir. As can be seen, UKL dominates systemwide storage. The 1962–2001 operating storage volumes in table 1 represent volumes actively used during this period. These somewhat smaller storage values result from present-day operations that meet agricultural deliveries, provide hydraulic head for hydropower generation, maintain water levels and habitat for fish in UKL, and support instream flows below Iron Gate Dam. Hydraulic residence times in table 1 were computed from the maximum storage for each reservoir divided by a range of low, average, and high monthly flows from the 1962–2001 period of record (Bartholow and others, 2004).

Although UKL is large, it has an average depth generally less than 3 m and wind-induced mixing (Wood and others, 1996) making it unsuitable for multi-level intakes to provide temperature control. All the reservoirs below UKL are small, relatively shallow (mean depths ≤19 m; maximum depths ≤51 m), have release structures located in the epilimnion, and have short hydraulic residence times (table 1). These reservoirs do stratify during the summer, however, the volume of cool water below each reservoir's thermocline is limited.

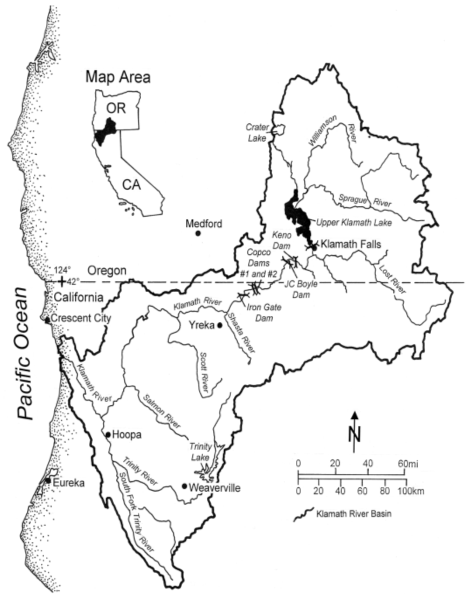

Figure 1. Study area map from Bartholow and others (2004).

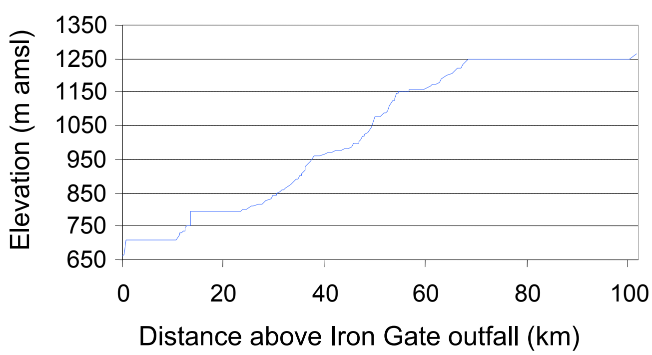

Figure 2. Water surface gradient, in meters above mean sea level, along the Klamath River from Iron Gate's outfall (km 0) to UKL (km 101.7), with the horizontal profiles denoting reservoirs.

Table 1. Reservoir storage volumes and calculated hydraulic residence times for a range of storage definitions and a range of flows on the mainstem Klamath River. Asterisk denotes hydropower facility. From Bartholow and others (2004).

Reservoir	Maximum storage (106 m^3)	Dead storage (106 m^3)	Active storage (106 m^3)	Operating storage 1962–2001 (106 m^3)	Computed hydraulic residence time (days) low – average – high
UKL (UKL)–Link River Dam*	776.8	176.3	600.5	276.5	45.8 – 170.2 – 400.5
Lake Ewauna	1.2	0	1.2	0.1	0.1 – 0.9 – 4.4
Keno Reservoir	22.8	0	22.8	4.3	1.1 – 5.7 – 64.7
J.C. Boyle Reservoir* (Topsy Lake)	4.2	0	4.2	1.9	0.2 – 0.9 – 4.9
Copco Lake*	57.8	0	36.3	34.5	2.5 – 11.0 – 59.4
Copco #2 Forebay*	0.1	0	0.1	0	0.0 – 0.0 – 0.1
Iron Gate Reservoir*	72.5	15.7	56.8	28.7	3.1 – 13.8 – 74.4
Total storage	935.4	192.0	721.9	346.0	---
Total system residence time (days)	All storage bodies				52.8 – 202.5 – 608.4
	All storage below UKL				7.0 – 32.3 – 207.9

Methods

SIAM analyses included:

1. effects of changing flow on water temperature;
2. potential to change temperature by changing Iron Gate Reservoir release depth;
3. potential to change water temperature by manipulating Copco and Iron Gate Reservoir water storage volume;
4. potential to alter spawn timing if the thermal regime were changed in some fashion;
5. potential to change outmigration timing for young-of-the-year (YOY) fall Chinook if spring temperatures were altered;
6. predicted effects of spring flow variability on estimated outmigration success; and
7. incremental spring flow variability and predicted effects on outmigration success.

In some analyses, only the fish production model component, SALMOD, was used, and in all SIAM analyses, an iterative modeling tool was used to run the model multiple times to seek the set of flows and temperatures that yielded the greatest predicted number of outmigrants for each set of water management alternatives.

Data exploration based solely on measured water temperature data proved difficult and inconclusive when attempting to separate the effects of flow from those of ambient meteorology and antecedent reservoir conditions. For this reason, and because our objective dealing with structural modifications could not be addressed using measured data, we elected to use simulation models to answer our questions.

Water Quantity and Quality Models

An off-the-shelf network water quantity simulation model, MODSIM (Labadie, 1988; Dai and Labadie, 2001), was applied to the Klamath River Basin to evaluate potential water management alternatives. The MODSIM program is a planning model used for interconnected and managed water systems with numerous reservoirs, diversions, and return flows. The model realistically allocates water using a prioritization algorithm that considers reservoir operating rules and physical constraints, instream flow requirements, and agricultural or other demands. Using historical monthly flow and reservoir operations records, MODSIM simulates river and reservoir operation from UKL downstream to the Pacific Ocean. The Klamath's major tributaries (Shasta, Scott, Salmon, and Trinity Rivers) were modeled only as inflows using USGS gage records at or near their confluences with the Klamath. Details of this MODSIM model calibration and application may be found in Flug and Scott (1998).

We used another publicly available model, HEC-5Q (U.S. Army Corps of Engineers, 1986), to simulate mean daily water temperature given Klamath River flows and reservoir operations from MODSIM. The HEC-5Q program is a one-dimensional model that simulates water quality in reservoirs vertically from the surface to the bottom and longitudinally in rivers. Mean monthly flows were converted to equal daily values by dividing by the number of days in each month (disaggregated) and then combined with daily average meteorological data including air and dew point temperatures, wind speed, precipitation and cloud cover. Flow and meteorology inputs then drive the HEC-5Q model in simulating all four Klamath River hydropower reservoirs in series. Single-day time step constraints in HEC-5Q required simplifying J.C. Boyle Reservoir's and Copco #2's forebay to river reaches because these small reservoirs had short hydraulic residence times that became computationally unstable under high flow conditions.

The uniform monthly flow disaggregation represented stable flow conditions well, but it was somewhat less descriptive of conditions during winter peak flow events and necessarily introduced steps at month boundaries. Fortunately, model tests verified that the simple disaggregation we used had only a negligible effect on release temperatures below the reservoirs due to their homogenizing effects. For example, we compared Iron Gate release temperatures for two simulations for a wet year (1982), one using mean daily flows from the disaggregation and one using measured daily flows to capture larger amplitude day-to-day flow variations when they occurred. The maximum single-day difference in predicted release temperatures was 0.8°C in February, though the average absolute daily difference was 0.1°C, leading us to conclude that using simple disaggregation would not prejudice our results. A complete description of the HEC-5Q numerical modeling methods, data requirements, and details of the Klamath River model calibration and application may be found in Hanna and Campbell (2000).

Both of these widely used models, MODSIM and HEC-5Q, were seamlessly coupled using a user-friendly interface, SIAM (Bartholow and others, 2005). The SIAM program greatly facilitated much of the analysis dealing with the assessment of alternative flow regimes, but it did not allow the detailed user control necessary to evaluate alternative reservoir intake placement and blending options. Expert intervention was required to carefully specify HEC-5Q's inputs controlling these model capabilities.

Model Calibration and Validation

Details of independently calibrating and validating (confirming) both MODSIM and HEC-5Q for the Klamath River have been reported elsewhere (Flug and Scott, 1998; Hanna and Campbell, 2000) and are only summarized here. The MODSIM program was calibrated for the years 1970–79 because this period contained relatively complete data records representing a variety of low, average, and high water supply years. Model calibration was considered excellent, with less than 0.1 percent difference in flows on an annual basis at three USGS gaging locations. Validation focused on the period 1980–89, also containing a representative mix of hydrologic years, and was commendable with average monthly and yearly flow differences well below 1.0 percent. Over the full period used for simulation, the root mean squared error (RMSE) between the simulated daily flows passed to the HEC-5Q model disaggregated from MODSIM and measured daily flows below Iron Gate was 34 cfs (ranging from 5 cfs in November to 74 cfs in September).

The HEC-5Q model was calibrated for 1996 and validated using 1997 and 1998 data sets, again dictated by the availability of good in-reservoir and in-river data. The model performed well with r^2 values of 0.85 to 0.97 when predicted and measured values were compared, depending on the year, and mean absolute errors of 0.9 to 1.0°C. However, the model performed somewhat less well for the entire 43 year data set, with a mean absolute error of about 1.8°C depending on the geographic location, though the r^2 values remained quite high (for example, $r^2 = 0.96$, $n = 7354$, $p < 0.001$ below Iron Gate Dam). Mean absolute error was better than average immediately below Iron Gate on an annual basis, 1.3°C, with individual absolute monthly errors ranging from 0.9°C in August to 1.7°C in February. Measured water temperature data were intermittent during the bulk of the historical record (roughly 1963 to 1980), with changes in measurement techniques during the period, potentially explaining some differences. However, because temperature predictions for any single day at any single location contain more uncertainty (±1.8°C), in this paper we limit our conclusions to general trends indicative of longer time scales over multiple years.

SALMOD, the fall Chinook salmon fish production component of SIAM, remains "unverified" because, to date, sufficient data have not been collected to provide an independent data set to compare against another data set and perform a traditional model calibration/verification procedure. USGS held a workshop with Klamath Basin resource managers, stakeholders, and Tribal participants in October, 2006, to parameterize the SALMOD model, using a collective best evidence approach. A sensitivity analysis for the model was performed to determine those factors most sensitive to change. The results were reported in Bartholow and Henriksen (2006) and have been incorporated into the current version of SIAM. In general, predictions of fall Chinook salmon production are considered valid where flow and/or temperature are varied because any changes in population estimates can be attributed to those driving factors. USGS also specifies that differences between simulation predictions must exceed ±10%, an estimate of the model confidence interval.

Model Application

Flow-Only Manipulation Scenarios

To achieve our first objective, we ran the SIAM model specifying a series of fixed flow releases from Iron Gate Dam for each month of the year through a range of 500 to 2,500 cubic feet per second (cfs) in 200 cfs increments. We did this for all water years in our historical database (1961–2003) to make sure that model results captured the full range of daily meteorological conditions throughout this period. In so doing, the MODSIM model "tried" to do everything necessary in the way of basinwide water management to guarantee delivery of the prescribed flow. The model sometimes used different strategies to deliver the requested amount of water in different months. For example, in some months the model might have altered reservoir storage from historical conditions, in others it may have modified diversions, and in yet others it may have used a combination of methods. However, in a few cases the model simply could not supply the higher monthly flows requested when water supply conditions were too low. (In fact, the reason we only evaluated flows up to 2,500 cfs is because at higher flows the results from too many simulations became infeasible, generally during the summer months except in the very wettest years). When these situations occurred, the model generated results for a lesser amount of water and we disregarded the model's corresponding water temperature predictions. When requested flows were feasible, we recorded both the mean monthly Iron Gate release temperature (average of the mean daily temperatures for all days in that month) and the single highest value of the daily mean for each month in each year.

We also used our simulation results to address two related issues. First, from the simulations we performed, we captured spring and fall trends for the first date(s) in the spring when Iron Gate temperatures for three consecutive days exceeded 10°C and 15°C and for the last date in the fall when they exceeded 20°C for three consecutive days. The benchmarks 10°C and 15°C were chosen as indicators of the initiation of conditions that are stressful for the rearing life stage of juvenile salmon (McCullough, 1999; U.S. Environmental Protection Agency, 2003), 10°C because of its association with increased virulence of endemic bacterial or parasitic disease (Udey and others, 1975; Bartholomew, 1998), and 15°C to represent the approximate upper limit of optimum juvenile growth (Richter and Kolmes, 2005). The 20°C benchmark was chosen for similar reasons; temperatures above this level are associated with spawning migration blockages in many rivers (Richter and Kolmes, 2005). We only recorded instances when release temperatures were above their respective thresholds for three consecutive days to eliminate situations when uncharacteristic single-day meteorological events might trigger higher water temperatures far in advance of more enduring conditions.

The SIAM software has the ability to run a simulation with the hydrology for one water year coupled with the meteorology from another year to test the sensitivity of either. As a double-check on our findings from the above simulations that used 43 years of historical meteorology, we ran SIAM using the 43-year historical hydrology coupled with a single average year's meteorology. In other words, in the first set of simulations both flows and meteorology were varied, while the second set of simulations varied only flows. Our expectation was that by comparing year-to-year changes in monthly average temperature, we would get a different estimate of the magnitude of thermal variation due solely to "normal" variations in the annual flow regime. This technique, then, is simply a second method of assessing release temperature effects attributable to variation in discharge alone; it also allowed us to make simulations with flows above the 2,500 cfs cap we used previously.

Structural Modification Scenarios

To explore the potential effects of modifying reservoir withdrawal structures, we ran some preliminary experiments using SIAM to see if release temperatures from the Copco facility could significantly influence the ultimate release temperatures downstream from Iron Gate. We found no appreciable differences (0.0 to <0.5°C, depending on the time of year and specific hydrologic conditions) in Iron Gate release temperatures given potential variation in Copco's release temperature, so we excluded this possibility from further consideration. Focusing our attention on Iron Gate Dam, we concentrated on the month of September for two reasons. First, unpublished model results had identified September as having the greatest potential for temperature control because of the large difference in temperatures between the stratified reservoir and rapidly changing ambient air temperatures. Furthermore, as we learned from the previous simulations, September water temperature is affected by seasonal cooling as the fall equinox approaches, and therefore, is not conducive to temperature control through flow changes alone. Second, we chose September because of its importance in "setting up" mainstem temperatures during the fall Chinook salmon spawning season. In other words, reservoir releases and management during September have a bearing on early-October releases. Water temperatures are currently marginal during early-October spawning, likely resulting in adult or egg mortality (Bartholow and others, 2004). Spawning seems to require water temperatures less than 18.9°C (Bell, 1973; McCullough, 1999). Cooling elevated mainstem water temperatures for this important activity might help increase salmon production either by reducing temperature-related mortality, by allowing spawning to occur earlier in the fall (potentially allowing earlier outmigration of juveniles the following spring before the onset of thermally modulated disease mortality), or reducing in vivo egg mortality. There is also some evidence of egg viability impairment for early spawned eggs collected by the Iron Gate Hatchery (K. Rushton, personal commun., 2006). Though similar analyses could be conducted for other months, only those months exhibiting marked reservoir stratification (approximately 1°C/m) would be suitable candidates.

Unlike more contemporary reservoir water quality models, the version of HEC-5Q we used did not have the capability to directly simulate a true multi-level intake. However, careful examination of the simulated reservoir profiles in September indicated a difference of only about 0.1°C between water at the spillway when the reservoir was full and the current intake elevation just 24.4 ft below the spillway. We assumed, then, that water going over the spillway could be used as a surrogate for water discharged through the current intake elevation, recognizing that the exact hydraulic characteristics might not be the same as for a submerged orifice. Then, because HEC-5Q can mix water from the spillway and one other port, we had the flexibility we needed to simulate blending water from different intake elevations.

We used SIAM to generate release temperatures below Iron Gate dam for each of nine unique water year types representing different combinations of water supply (*wet* = >75th percentile, *average* = 50th percentile, *dry* = <25th percentile) and meteorological conditions (*cool* = June air temperature average of ~16°C; *average* = June air temperature average of ~18°C; *warm* = June air temperature average of ~20°C). These nine year types (wet cool, wet average, wet warm, average cool, average average, average warm, dry cool, dry average, and dry warm) are important because they establish the reservoir's September 1 thermal profiles. However, our nomenclature for year types refers to the general characterization of an entire water year, not any specific month such as September. We chose nine year types solely to make sure we had covered a variety of antecedent reservoir conditions (and because we have used these year types in other analyses). Thus, our results may be viewed as a type of sensitivity analysis.

Each of these nine year types were paired with seven blending scenarios for two intake elevations, one mid-level and one bottom release, 89.5 ft and 155.6 ft below the surface, respectively. The last permutation was two flow rates, one 1,300 cfs (the current FERC minimum flow) and 700 cfs. Finally, the various permutations were compared to a baseline simulation using the reservoir's current intake elevation and the average historical September discharge of 1,330 cfs, resulting in a total of 253 simulations.

Reservoir Storage Scenarios

The FWS requested that SIAM be utilized to evaluate the use of full active storage in Copco and Iron Gate Reservoirs to determine potential fisheries benefits. Although both Copco and Iron Gate Reservoirs are usually operated in near-full condition, each reservoir can be drawn down to the level of the outlet for the hydropower plant. In Copco the outlet is located at 2,571 ft MSL (mean sea level) and has a reservoir storage capacity of 17,488 acre-ft. Copco's maximum elevation is 2,607.5 ft MSL, where it has a reservoir storage capacity of 46,867 acre-ft. Total active storage has been estimated as 29,379 acre-ft for Copco Reservoir. Iron Gate Dam outlet is located at 2,299 ft MSL, with water storage of 35,533 acre-ft. The maximum storage elevation is 2,328 ft MSL, with a reservoir storage capacity of 58,794 acre-ft. Total active storage has been estimated as 23,261 acre-ft for Iron Gate Reservoir. Total active storage in both reservoirs is estimated at approximately 52,000 acre-ft (52,640 acre-ft). To translate into discharge, the total active storage was calculated (52,000 acre-ft/1.98)/30 days to equal 875.4 cfs per day for a 30 day month.

Using 52,000 acre-ft as the full active storage (FAS), we evaluated a variety of hydrological and meteorological year types using historical simulations of those year types as baseline; we configured the model runs to use FAS over a two-month period at 26,000 acre-ft per month and then to use the entire FAS over a single month. The two-month simulations used FAS during March and April for each year. The single month simulations were performed for March, April, May, June, August, and September for each year type. Results of simulations were compared to historical baseline model runs for the same year type.

- Wet hydrological years were 1971, 1982, and 1998. Those water years correspond to cool, average, and warm meteorological years, respectively.
- Average hydrological years were 1976, 1995, and 1985. Those water years correspond to cool, average, and warm meteorological years, respectively.
- Dry hydrological years were 1981, 1988, and 1977. Those water years correspond to cool, average, and warm meteorological years, respectively. These year/meteorology combinations were used throughout the various scenario analyses.

Using this matrix of hydrological and meteorological years provides a full range of conditions that have occurred in the Klamath Basin during the past 45 years.

An historical baseline simulation was run for each year using default settings for the SIAM decision support model. The exceptions to default settings were

- not applying disease related fish mortality,
- removing tributary fish from the SALMOD ".sup" file, and
- using 15.9°C as the mortality temperature for fry.

The SIAM model is calibrated to within ±1 percent for predicted flow volume, and within ± 0.6°C at Iron Gate Dam. Simulations using FAS were configured by adding the extra storage volume to the Iron Gate Dam flow target values for the appropriate months and by constraining the SIAM model to deliver those flows by assigning the highest priority for water demand in the system, while priorities for Copco and Iron Gate Reservoir storage were assigned the lowest priority in the system. In general, these were the only required simulation configuration options that had to be made to achieve the desired results. Because we wanted to determine the effects of using the additional storage volume in either March and April or in single months, deviations from the baseline simulation in other months were corrected by entering the historical amount of flow released from Iron Gate Dam and re-running the simulation until the simulation most closely duplicated historical conditions, except for the month or months were FAS usage was desired. There were a few deviations from the baseline in agricultural diversions upstream of Copco and Iron Gate Reservoirs, but they were usually <50 cfs in total for one or two months.

Spawn Timing Scenarios

The FWS, citing evidence that indicates that the hydroelectric dams cause warmer water temperatures in the fall and delayed spring warming (Bartholow, 2005), requested that the SALMOD fish production model be used to examine the effects of changing the timing of fall Chinook spawning to begin in early September instead of October. The hypothesis being tested was that cooling fall water temperatures would allow fall Chinook to immigrate and spawn earlier in the fall. SIAM was used to model a hypothetical shift in spawn timing to determine whether this shift would yield higher predicted fish production. The model generated flow and temperature data input files to SALMOD for each of nine water year types: 1982 (wet/avg), 1971 (wet/cool), 1998 (wet/warm), 1995 (avg/avg), 1976 (avg/cool), 1985 (avg/warm), 1988 (dry/avg), 1981 (dry/cool), 1977 (dry/warm).

Thirteen scenarios were set up for running SALMOD outside of SIAM. These were:

- Baseline runs using the flow and temperature files generated by SIAM.
- Cooling stream temperatures by 2°C during October.
- Shifting the beginning of the biological year to the first of September and providing no stream temperature cooling.
- Shifting the beginning of the biological year to the first of September, setting the Iron Gate flow to 700 cfs during September, and cooling stream temperatures by 3°C in September.
- Shifting the beginning of the biological year to the first of September, setting the Iron Gate flow to 700 cfs during September, and cooling stream temperatures by 2°C in both September and October.
- Setting minimum emergence temperature to zero, thus eliminating its threshold effect.
- Eliminating minimum emergence temperature threshold and allowing migration immediately following emergence.
- Shifting the beginning of the biological year and associated spawning back two weeks with no stream cooling.
- Shifting the beginning of the biological year and associated spawning back two weeks with 2°C stream cooling during the shift period.
- Shifting the beginning of the biological year and associated spawning back two weeks with 3°C stream cooling during the shift period.
- Shifting the beginning of the biological year and associated spawning back three weeks with no stream cooling.
- Shifting the beginning of the biological year and associated spawning back three weeks with 2°C stream cooling during the shift period.
- Shifting the beginning of the biological year and associated spawning back three weeks with 3°C stream cooling during the shift period.

Temperature and flow adjustments were made directly to the temperature and flow input files for SALMOD. Longitudinal accretions and heat flux were assumed to be maintained. The biological year timing was modified by shifting the temperatures and flows in the SALMOD input files. The following variables were recorded for each scenario:

1. migration start date;
2. migration end date;
3. total number of juvenile fall Chinook salmon outmigrating;

4. total number of instream juvenile fall Chinook salmon;
5. total number of fall Chinook salmon exposed to ≥10°C;
6. percent of instream juvenile fall Chinook salmon exposed to ≥10°C;
7. percent of juvenile fall Chinook salmon migrating;
8. average weights of migrating juvenile fall Chinook salmon;
9. total egg mortality; and
10. total juvenile fall Chinook salmon mortality.

The number of predicted out-migrating fall Chinook salmon is highly sensitive to the emergence temperature in the SALMOD model. Simulations were run for each scenario while varying the emergence temperature from 3°C to 8°C (current emergence temperature) and relaxing the emergence temperature completely (ET = 0°C). A total of 116 simulations were run.

Spring Flow Variability Scenarios

Another resource management issue expressed by FWS is how spring flow variability might influence Chinook salmon production in the Klamath River. A SIAM modeling analysis was used to examine the effect of spring flow variability on predicted Chinook salmon production in the mainstem of the Klamath River. The following procedures were used to conduct this analysis:

- SIAM was run for the entire period of record (1961–2003) to generate the flow input file for SALMOD.
- The biological year for the fall Chinook life cycle was divided into months and significant seasons (fall, winter, and spring). Fall consisted of October and November, winter of December through February, and spring of March through May. The values in the SALMOD flow input file were summarized to identify years with low, average, and high flows. A low flow year (1992), average flow year (1967), and a high flow year (1983) were selected from the values.
- SIAM was run to generate baseline fish production values for the low flow year (1992), average flow year (1967), and high flow year (1983).
- Flow analysis values were generated for each month (October through May) and season (fall, winter, and spring). Additional runs were made for the March–April time period. SALMOD was run for each flow analysis where flow was varied from 500 cfs to 10,000 cfs by 500 cfs increments. Temperatures were not coupled to flows and were always set to the baseline values. Fish production (number of juvenile outmigrants) and percent difference from baseline fish production were recorded. This was repeated for each of the flow year types. These simulations were repeated for SALMOD configured with no tributary fish. This was done to isolate the effects of flow variability on mainstem production only. A total of 903 simulations were made.
- Using predicted “best” seasonal flows for low flow years (1992), a series of simulations were run where spring flows of 1,500 cfs, 2,000 cfs, 3,000 cfs, and 4,000 cfs were applied for one to thirteen consecutive weeks beginning the first week of March. The percent difference from baseline production results were recorded for each flow and number of consecutive weeks.

Incremental Spring Flow Scenarios

In an effort to further refine the analysis of spring flow effects on predicted fall Chinook production, three additional analyses were conducted at the request of FWS. These additional analyses included the following:

1. SIAM was used to predict fall Chinook production, defined as the number of out-migrating fish, in response to flow releases from Iron Gate Dam. In this analysis Iron Gate release flows were varied from 500 to 3,500 cfs at 500 cfs increments for durations ranging from 2 to 14 weeks. The period of analysis was defined as that period from February 15 to May 31. Previously, analyses were conducted using the SALMOD model alone where flows were varied and stream temperature was held to baseline values. These analyses indicated that maximum predicted fish production was attained for spring flows of 3,000 to 4,000 cfs throughout the spring analysis period (February 15–May 31). In this current analysis, a base flow of 4,000 cfs was applied during the spring period with variable flows (500, 1,000, 1,500, 2,000, 2,500, 3,000, and 3,500 cfs) applied during cumulative two week intervals beginning February 15. For example, a 500 cfs flow was applied from February 15–February 28 and 4,000 cfs from March 1–May 31. Then 500 cfs from February 15–March 15 and 4,000 cfs from March 16–May 31 and so on. These simulation regimes were applied for a low flow year (1992), average flow year (1967), and a high flow year (1983). A total of 150 scenarios were simulated. Predicted fall Chinook production, agriculture water deliveries, water levels for Iron Gate Reservoir, Copco Lake, and UKL, Iron Gate release flows, Iron Gate release temperatures, fry habitat mortality, fry temperature mortality, juvenile habitat mortality, juvenile temperature mortality, and total juvenile mortality were recorded for each simulation. To help clarify the results, an additional set of simulations were performed where the average spring flow (March–May) for each year type was used as a base flow instead of 4,000 cfs. The flows that were used were: 600 cfs for low flow years (1992), 2,900 cfs for average flow years (1967), and 5,700 cfs for high flow years (1983).
2. SIAM was used to predict fall Chinook production in response to low and high pulse flows during the spring period (February 15–May 31). Analysis of pulse flows was conducted for a low flow year (1992) only. The effect of pulse flows during average or high flow years is minimal. For high pulse flow scenarios, a base flow of 600 cfs (approximate average flow during 1992 spring months) was applied during the spring period. Pulse flows of 3,000 cfs and 6,000 cfs were applied for two week intervals (February 15–February 28, March 1–March 15, etc.) throughout the spring period. Only one pulse per run was applied. Three additional simulations were made using a pulse duration of one month (March, April, and May). Predicted fall Chinook production, Iron Gate release flows, Iron Gate release temperatures, and UKL elevations were recorded for each simulation. A total of thirty simulations were made. Low pulse simulations were made following the same procedures as for high pulse simulations with the base flow set to 3,000 cfs and the pulse flow set to 500 cfs.
3. To better understand how relationships between spring flow and fish production fit within the operational constraints of the Klamath Project, the following scenarios were simulated using UKL elevation targets and Iron Gate release flows from the Klamath Project 2006 Operations Plan (April 10, 2006):

- An optimum flow of 3,000 cfs at Iron Gate Dam was applied during the spring period (February 15–May 31). Iron Gate flows had the highest priority followed by Iron Gate Reservoir and Copco Lake storage and then UKL elevations. This would result in the Iron Gate flow targets being met, Iron Gate Reservoir and Copco Lake levels kept high enough to provide temperature buffering, and the majority of the water coming from UKL. This scenario was applied to a low flow year (1992).

- The UKL elevation targets from the 2006 Operations Plan were applied for a low flow year (1992). Priorities were set so that the UKL targets would be met and agricultural deliveries would be made. Iron Gate release flows had the lowest priority.
- The UKL elevation targets from the 2006 Operations Plan were applied for a low flow year (1992). Priorities were set so that the UKL targets would be met and agricultural deliveries would not be made. Iron Gate release flows had the lowest priority.
- The UKL elevation targets from the 2006 Operations Plan were reduced by one foot and applied for a low flow year (1992). Priorities were set so that the UKL targets would be met and agricultural deliveries would not be made. Iron Gate release flows had the lowest priority.
- The UKL elevation targets from the 2006 Operations Plan were reduced by two feet and applied for a low flow year (1992). Priorities were set so that the UKL targets would be met and agricultural deliveries would not be made. Iron Gate release flows had the lowest priority.
- An optimum flow of 3,500 cfs at Iron Gate Dam was applied during the spring period (February 15–May 31). Iron Gate flows had the highest priority followed by Iron Gate Reservoir and Copco Lake storage and then UKL elevations. This would result in the Iron Gate flow targets being met, Iron Gate Reservoir and Copco Lake levels kept high enough to provide temperature buffering, and the majority of the water coming from UKL. This scenario was applied to an average flow year (1967).
- The UKL elevation targets from the 2006 Operations Plan were applied for an average flow year (1967). Priorities were set so that the UKL targets would be met and agricultural deliveries would be made. Iron Gate release flows had the lowest priority.
- The UKL elevation targets from the 2006 Operations Plan were applied for an average flow year (1967). Iron Gate release targets from the 2006 Operations Plan were applied. Priorities were set so that the UKL targets would be met and agricultural deliveries would be made. Iron Gate release flows had the lowest priority.
- An optimum flow of 3,500 cfs at Iron Gate Dam was applied during the spring period (February 15–May 31). Iron Gate flows had the highest priority followed by Iron Gate Reservoir and Copco Lake storage and then UKL elevations. This would result in the Iron Gate flow targets being met, Iron Gate Reservoir and Copco Lake levels kept high enough to provide temperature buffering, and the majority of the water coming from UKL. This scenario was applied to a high flow year (1983).
- The UKL elevation targets from the 2006 Operations Plan were applied for a high flow year (1983). Priorities were set so that the UKL targets would be met and agricultural deliveries would be made. Iron Gate release flows had the lowest priority.
- The UKL elevation targets from the 2006 Operations Plan were applied for a high flow year (1983). Iron Gate release targets from the 2006 Operations Plan were applied. Priorities were set so that the UKL targets would be met and agricultural deliveries would be made. Iron Gate release flows had the lowest priority.
- The UKL elevation targets from the 2006 Operations Plan were applied for a high flow year (1983). Iron Gate release targets were set to the optimum flows of 3,500 cfs. Priorities were set so that the UKL targets would be met and agricultural deliveries would be made. Iron Gate release flows had the lowest priority.

Tables 2 and 3 show the operational criteria for UKL elevation and flows at Iron Gate Dam used in these SIAM simulations.

Table 2. Lake elevation operational criteria for UKL. Source: Klamath Project 2006 Operations Plan.

Month	Water year type and elevation (ft)			
	Above average	Below average	Dry	Critical dry
March 31	4142.5	4142.7	4141.7	4142.0
April 30	4142.9	4142.8	4142.2	4141.9
May 31	4143.1	4142.7	4142.4	4141.4
June 30	4142.6	4142.1	4141.5	4140.1
July 31	4141.5	4140.7	4140.3	4138.9
August 31	4140.5	4139.6	4139.0	4137.6
September 30	4139.8	4138.9	4138.2	4137.1
October 31	4139.7	4138.8	4138.2	4137.3
November 30	4140.3	4139.0	4139.0	4138.1
December 31	4141.0	4138.8	4139.7	4138.9
January 31	4141.5	4139.5	4140.3	4140.1
February 28	4141.9	4141.7	4140.4	4141.1

Table 3. Klamath River operational criteria for flows at Iron Gate Dam. Source: Klamath Project 2006 Operations Plan.

Month	Water year type and flow (cfs)				
	Wet	Above average	Average	Below average	Dry
April	2,050	2,700	2,850	1,575	1,500
May	2,600	3,025	3,025	1,044	1,500
June	2,900	3,000	1,500	1,525	1,400
July	1,000	1,000	1,000	1,000	1,000
August	1,000	1,000	1,000	1,000	1,000
September	1,000	1,000	1,000	1,000	1,000
October	1,300	1,300	1,300	1,300	1,300
November	1,300	1,300	1,300	1,300	1,300
December	1,300	1,300	1,300	1,300	1,300
January	1,300	1,300	1,300	1,300	1,300
February	1,300	1,300	1,300	1,300	1,300
March	2,300	2,525	2,750	1,725	1,450

Results and Discussion

Flow-Only Manipulation Scenarios

Figures 3 and 4 most effectively summarize what we found in terms of the potential to affect water temperature by flow management alone. Figure 3 clearly shows two things. First, discharge alone, as characterized by the vertical variation in the fitted trend lines in these monthly graphs, accounts for up to 4°C of the variation in release temperature depending on the month (range = 0.0–4.0°C). Ambient meteorology, as characterized by the vertical column of dots surrounding the trend lines, has more of an influence on release temperatures—up to 6°C (range = 4.0–6.0 °C).

Second, increasing Iron Gate releases through the 500 to 2,500 cfs range does influence release temperatures, but the effect is seasonally dependent and may be counter-intuitive. For example, increasing flows generally decreases mean monthly release temperatures for the months of November through February, but increases temperatures from June through August. Most of these months with discernable trends reveal an asymptotic relationship between discharge and temperature, but for the

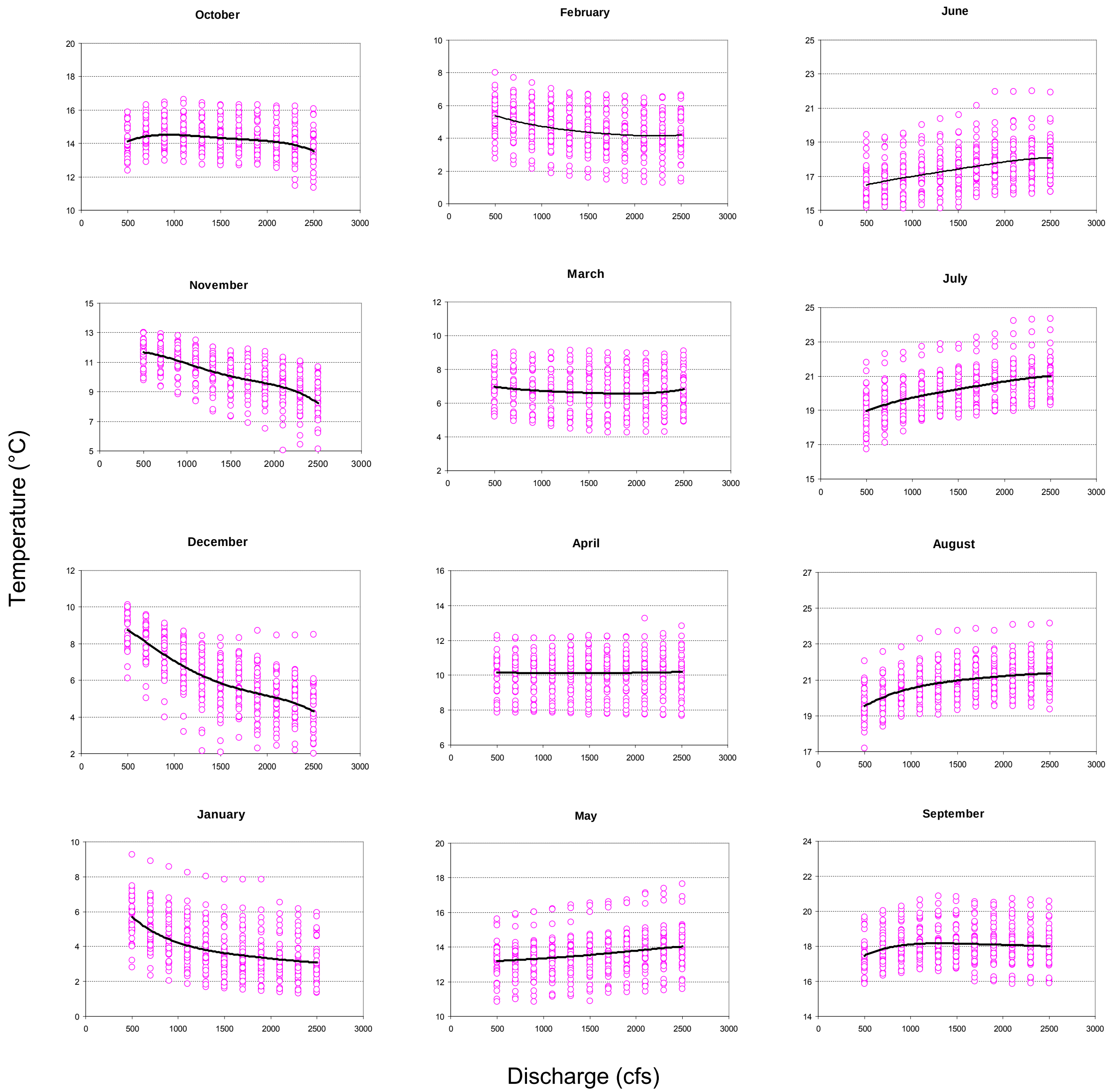

Figure 3. Relationship between monthly Iron Gate releases and mean monthly temperature of that release for each month of the water year in the flow-only scenarios. Trend lines are simple polynomial fits. Note that the y-axis scales differ between plots but always span 10°C. Outliers represent a few years with exceptional meteorological conditions.

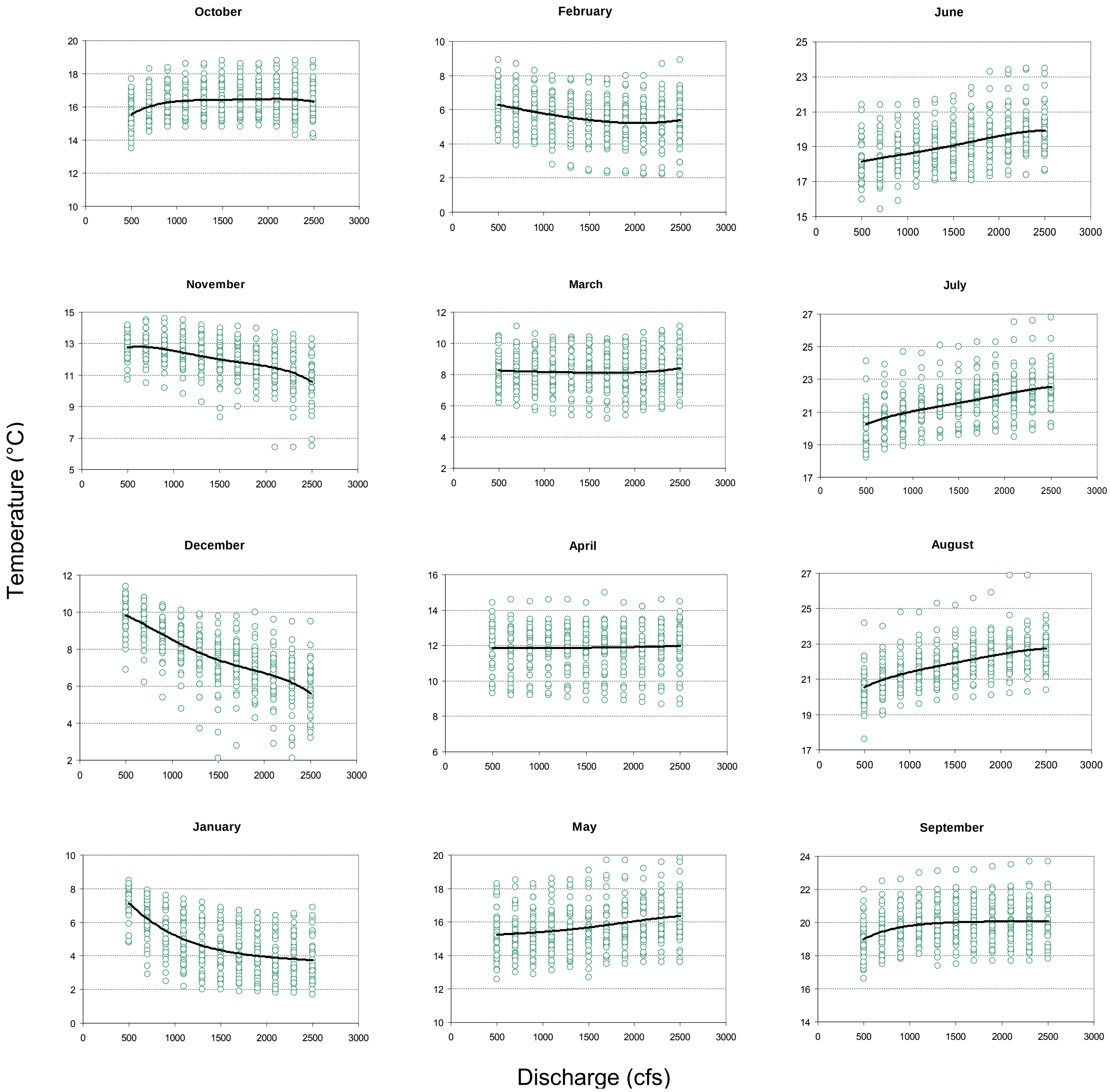

Figure 4. Relationship between monthly Iron Gate releases and maximum monthly temperature of that release for each month of the water year in the flow-only scenarios. Trend lines are simple polynomial fits. Note that the y-axis scales differ between plots, but always span 10°C. Outliers represent a few years with exceptional meteorological conditions.

months when ambient air temperatures are changing most rapidly (for example, March and September), trends appear to have either a slight convex or concave shape. There appears to be little relationship between flow and temperature during March through May and September through October, perhaps because ambient air temperature is rapidly warming or cooling seasonally.

Results for maximum monthly water temperature (fig. 4) largely mirrored mean monthly water temperatures. Likewise, simulation results for a location 98 km (61 mi) downstream at the USGS Seiad gage (not shown here) were quite similar even though there are two large intervening tributaries, the Shasta and Scott Rivers. Discharge alone accounts for up to 4°C of the variation in maximum release temperature, depending on the month (range = 0.1–4.1 °C). Ambient meteorology, as in mean temperature release, has more influence on maximum temperature release—up to 7.5°C (range = 5.0–7.5°C).

Figure 5 illustrates the same phenomenon by collectively indicating the length of the summer period with potentially stressful water temperatures. Figure 5a shows the first date in each of the various simulations when water temperatures exceed for three consecutive days in the spring the 10°C threshold associated with higher incidence of juvenile salmonid disease. Only the very highest flows we tested seem to affect when this temperature is exceeded, pushing the date earlier in the year by about 7 days. However, the range of dates for onset of temperatures >10°C seemed to decrease as flow increased. For example, at 500 cfs, the range for temperatures >10°C was March 21– May 26 — a total of 66 days. At 2,500 cfs, the range was narrower, from March 21–May 12 — a total of 44 days. We speculate that at lower flows, ambient air temperatures are the major driver for water temperature and vary considerably from year to year. At higher flows, the influence of Upper Klamath Lake propogates downstream and reservoir processes become the major driver for variation in water temperature.

Figure 5b is similar, but keyed to the 15°C optimum juvenile Chinook growth threshold, again exceeded for three consecutive days. This graph shows that increasing flows through the range we examined advances the river's warming in late spring by about 9 days. Again the range of dates is greater at lower flow than at higher flow (fig. 5b).

Figure 5c shows the last date that temperatures exceed 20°C for three consecutive days in the fall when adult Chinook are migrating upstream to spawn. In this case, effects of flow on temperature timing appear pronounced only at the lower discharge levels and indicate that reducing flows advances the date at which stressful temperatures cease by about 10 days. There is some evidence that, historically, fall Chinook spawning occurred earlier in the year, but additional dams such as J.C. Boyle (1953) and Iron Gate (1961) have gradually resulted in spawning occurring later in the fall than it did historically (Snyder, 1931).

Recall that we wished to double-check our results using a somewhat different technique. Running SIAM with historical hydrology and a single meteorological year revealed that water management practices over the last 45 years of record were associated with only small water temperature fluctuations, ±1.0°C immediately below Iron Gate dam and ±0.67°C 98 km (61 mi) downstream at the USGS Seiad gage site. Month-to-month variations differed between the two sites, but both showed the largest deviations in July and December. Though the two techniques we employed are not directly comparable, these small temperature changes (≤1°C) are indicative that flow alone has a small influence on Iron Gate release temperatures.

Structural Modification Scenarios

Simulation results intended to mimic a multi-level intake structure for Iron Gate Dam predicted cooling release temperatures below Iron Gate dam by 3–5°C by the end of September, but outcomes

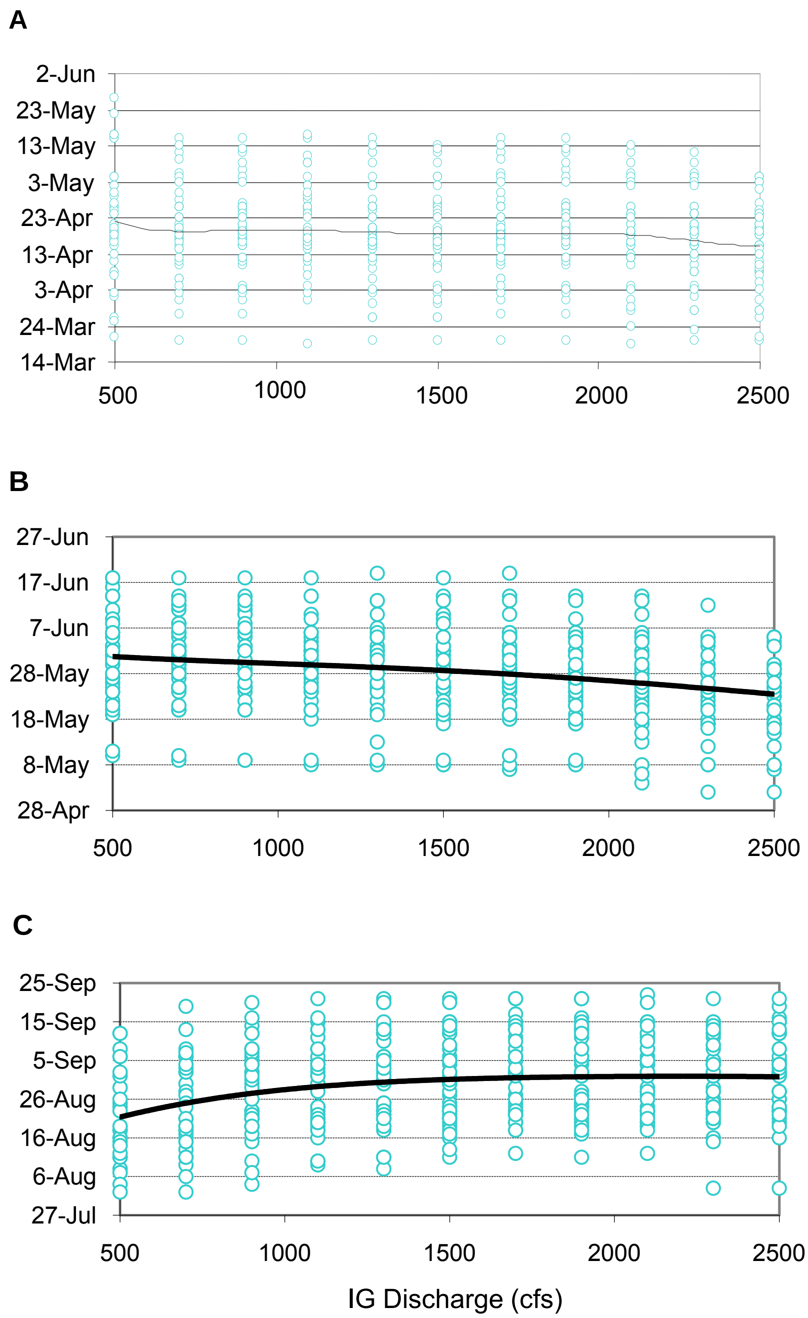

Figure 5. Relationship between seasonal Iron Gate releases and (A) the first date release temperatures exceed 10°C for three consecutive days, (B) the first date release temperatures exceed 15°C for three consecutive days, and (C) the last date they exceed 20°C. Trend lines are simple polynomial fits to the results from flow-only scenarios. Y-axis intervals are 10 days.

varied considerably depending on the specific combination of flow rate and blending elevations. Releasing 1,300 cfs through the hypothetical lower elevation intakes, whether blended with near-surface releases or not, always destratified the reservoir by the end of September, resulting in month-end river temperatures higher than those predicted if no alteration in intake elevation was made. Without blending, reducing flows from 1,300 cfs to 700 cfs extended the period of cooler water delivery, but still resulted in elimination of the thermocline by September 30. However, blending from either the mid- or bottom-level intakes allowed significant cooling (2–3°C) and maintained thermal stratification, albeit less pronounced, at the end of September.

Table 4 summarizes simulation results for the 700 cfs blending scenarios. Differences in September mean monthly predicted release temperatures from the baseline condition range from -1.0°C to -4.6°C, indicating that temperatures could be cooled by as much as 4.6°C in some situations. The average predicted cooling over all years ranged from -1.9°C to -2.9°C. Predicted mean monthly September release temperature ranged from 13.6°C to 20.9°C. The lowest predicted mean September temperature occurred using an equal blending of the bottom intake with the spillway in 1977 (13.6°C), an overall warm year. The maximum predicted average monthly release temperature occurred in the 250 cfs/450 cfs (intake/spill) mid-level blend in 1998 (20.9°C), an overall warm year. Across all year types, predicted September release temperatures averaged 15.9°C to 16.9°C.

In-river temperatures are important at the end of September as the fall Chinook spawning season gets underway. The middle section of table 4 illustrates the performance of the various blending options we simulated. Release temperatures ranged from 14.5°C for a 250/450 bottom release blend in 1977 to 20.6°C in the 350/350 bottom-level blend in 1998. Predicted water temperatures at the lower intake elevations we simulated at the end of September are an indicator of potential cooling capacity carried into early October. For example, in the 1981, 1988, 1977, and 1976 scenarios, predicted September 30 reservoir profile temperatures at the intake elevation for both mid- and bottom-level intake simulations with a blending ratio of 250/450 were 0.5°C to 3.8°C cooler than the predicted September 30 blended release for the same years. Noting this, we developed a simple metric to help gage potential cooling ability computed from the ratio of predicted temperature at the intake elevation divided by the blended release temperature at the end of September—the higher the value, the greater the potential to provide cooler release temperatures into October, that is, the greater the volume of cool water remaining in Iron Gate Reservoir. All of the 250/450 mid- and bottom-level blending scenarios predicted potential cooling capacity, although this capacity was greater in some years than others (dry years).

Figure 6 shows predicted Iron Gate release temperatures during September for the baseline and mid-level intake scenarios averaged across all nine year types. As can be seen, the baseline condition, drawing primarily epilimnetic water, exhibits gradual cooling as ambient air temperatures cool the system. Unblended mid-level releases (1,300 and 700 cfs) result in predictions of immediate and dramatic cooling at the beginning of September, but warm quickly by mid-month as the cool water Iron Gate Reservoir pool is depleted. In contrast, the blended release scenarios provide less dramatic and relatively stable predicted temperatures during the entire month of September.

Figure 7 shows the predicted Iron Gate release temperatures during September for the baseline and bottom-level intake scenarios averaged across all nine year types. As in figure 6, the two unblended simulations (1,300 and 700 cfs) show an initial cooling in early September followed by substantial warming in mid-month, while the blended bottom level simulations predict relatively stable September temperatures compared to the baseline. In both figures 6 and 7, the 250/450 and the 350/350 blending ratio scenarios, for a total of 700 cfs discharge, predict the greatest capability to maintain thermal stability throughout the month.

Table 4. Simulation results for 700 cfs blending scenarios. Release temperatures are in-river values below Iron Gate Dam. Blended flows are given in cfs; all temperature values, both absolute and differences, are in degrees Celsius.

Water year Hydrology Meteorology	1981 Dry Cool	1988 Dry Avg.	1977 Dry Warm	1976 Avg. Cool	1995 Avg. Avg.	1985 Avg. Warm	1971 Wet Cool	1982 Wet Avg.	1998 Wet Warm	Average across years
Blend (Level) *Intake/Spill*										
September mean monthly release temperature difference (blend minus baseline)										
250/450 (Bottom)	-3.5	-3.7	-3.4	-2.8	-2.2	-1.6	-1.2	-2.0	-1.6	-2.4
250/450 (Mid)	-2.7	-3.0	-2.7	-2.2	-1.6	-1.1	-0.8	-1.5	-1.2	-1.9
350/350 (Bottom)	-4.3	-4.6	-4.2	-3.1	-2.5	-1.7	-1.3	-2.3	-1.7	-2.9
350/350 (Mid)	-3.4	-3.8	-3.4	-2.5	-1.9	-1.4	-1.0	-1.8	-1.4	-2.3
September mean monthly release temperature										
250/450 (Bottom)	14.9	15.8	14.4	15.2	16.7	15.7	17.2	16.7	20.5	16.3
250/450 (Mid)	15.6	16.5	15.0	15.8	17.3	16.2	17.6	17.2	20.9	16.9
350/350 (Bottom)	14.0	14.9	13.6	14.9	16.5	15.5	17.1	16.4	20.3	15.9
350/350 (Mid)	14.9	15.8	14.4	15.5	17.0	15.9	17.4	16.9	20.6	16.5
September 30 blended release temperature										
250/450 (Bottom)	15.2	16.0	14.5	16.7	17.8	16.1	17.0	17.2	20.5	16.8
250/450 (Mid)	15.8	16.6	14.9	16.8	17.9	16.1	16.6	16.8	20.1	16.8
350/350 (Bottom)	15.7	16.7	15.2	17.5	18.6	16.3	17.1	17.4	20.6	17.2
350/350 (Mid)	16.2	17.2	15.4	17.1	18.3	16.1	16.5	16.9	20.1	17.1
September 30 reservoir profile temperature at bottom- or mid-level intake elevation										
250/450 (Bottom)	11.7	12.2	11.3	14.9	16.7	15.5	16.7	17.0	20.4	15.2
250/450 (Mid)	14.0	14.0	13.2	16.3	17.7	15.2	15.5	15.7	18.8	15.6
350/350 (Bottom)	14.2	15.2	13.9	17.0	18.5	16.1	16.8	17.3	20.5	16.6
350/350 (Mid)	16.1	16.6	15.1	16.6	18.0	15.3	15.6	15.8	19.0	16.5
Potential cooling power (1 - intake temp / blended temp) on September 30										
250/450 (Bottom)	0.23	0.24	0.22	0.11	0.06	0.04	0.02	0.01	0.00	0.10
250/450 (Mid)	0.11	0.16	0.11	0.03	0.01	0.06	0.07	0.07	0.06	0.08
350/350 (Bottom)	0.10	0.09	0.09	0.03	0.01	0.01	0.02	0.01	0.00	0.04
350/350 (Mid)	0.01	0.03	0.02	0.03	0.02	0.05	0.05	0.07	0.05	0.04

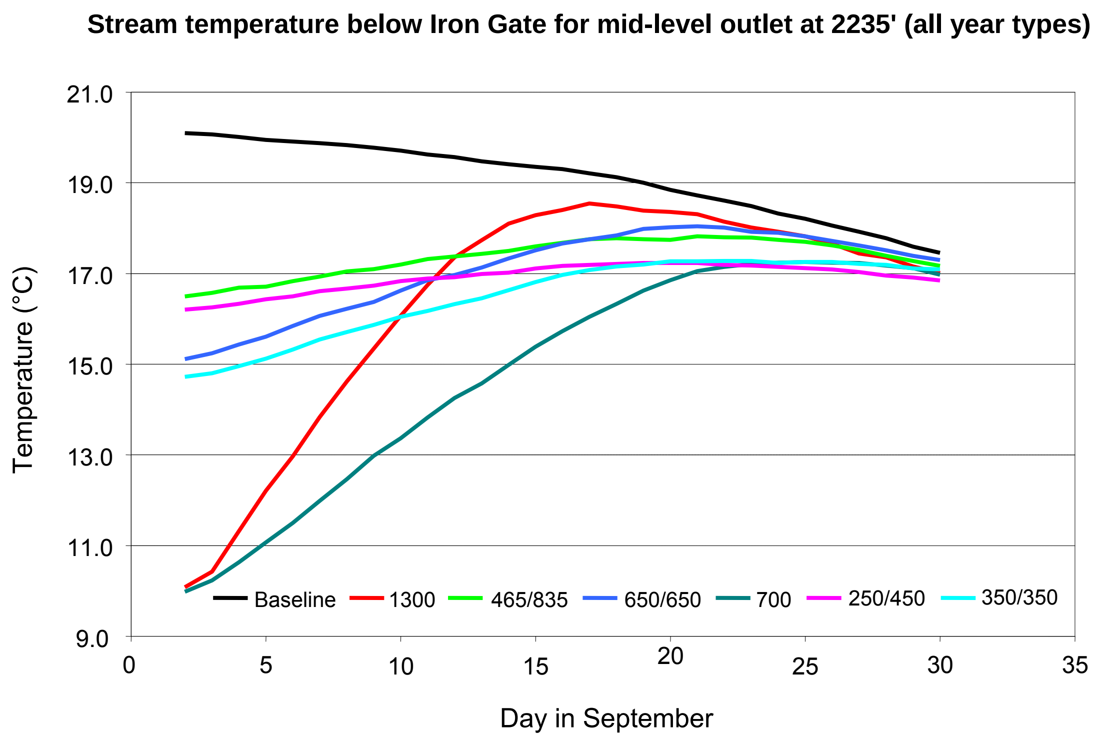

Figure 6. Iron Gate release temperatures during September for the baseline and mid-level intake scenarios averaged across all nine year types for the structural modification scenarios. Legend gives mid-level outlet flows/spill from epilimnion, all in cfs.

For these scenarios, we have only provided temperature results immediately below Iron Gate Dam. At some distance downstream, predicted temperatures are unlikely to differ substantially from the historical baseline as they will reach thermal equilibrium with ambient air temperatures. This distance will vary with discharge, but in one simulation we examined, a 700 cfs release blended 250/450 using the bottom-level intake, the predicted average September temperature was still 2.5°C cooler than the baseline scenario downstream at the Scott River confluence about 75 km (47 mi) below Iron Gate Dam.

Reservoir Storage Scenarios

In general, the results of providing 52,000 acre-ft, the approximate volume of full active storage (FAS) in Copco and Iron Gate Reservoirs in March and April predict little benefit to fall Chinook salmon below Iron Gate Dam. Table 5 is a summary of the difference from the baseline for each of the combined March and April simulations. The exceptions were predicted for dry hydrological years. In those water year types, using FAS in Copco and Iron Gate Reservoirs to provide spring flow augmentation may provide some benefits to fall Chinook salmon.

Simulations were run for these same hydrological and meteorological year types with FAS used in just one month of the water year. Positive effect was predicted only for two dry year simulations. Because simulation results for other single months were not significantly different from the baseline, they are not presented here. Our opinion on fish production predictions is that if the variation is within ±10 percent, then there is no significant difference from the baseline. The ±10 percent is a rule of thumb utilized in a variety of technical and scientific fields. We apply this to the fish production

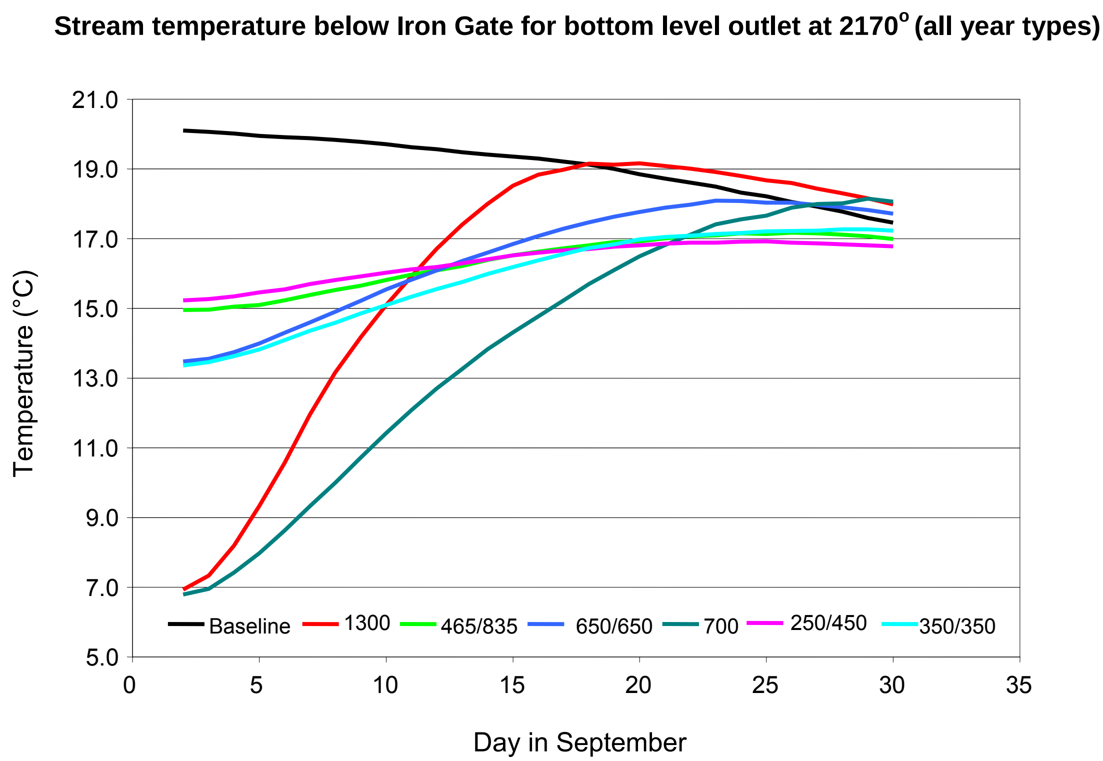

Figure 7. Iron Gate release temperatures during September for the baseline and bottom-level intake scenarios averaged across all nine year types for the structural modification scenarios. Legend gives bottom-level outlet flows/spill from epilimnion, all in cfs.

Table 5. Summary of predicted fry, pre-, and immature smolt production comparing baseline and March and April flow augmentation simulations for nine hydrological and meteorological year types.

	Hydrological type	Meteorological type	Baseline	March & April	Percent change
1981	Dry	Cool	376465	378757	0.6%
1988	Dry	Average	370409	388590	4.9%
1977	Dry	Warm	210777	298035	41.4%
1976	Average	Cool	325119	317133	-2.5%
1995	Average	Average	400396	402813	0.6%
1985	Average	Warm	242672	228881	-5.7%
1971	Wet	Cool	400369	392571	-1.9%
1982	Wet	Average	402683	386550	-4.0%
1998	Wet	Warm	407813	405061	-0.7%

predictions because the SALMOD model remains un-calibrated. Therefore, only comparisons between simulations where flow and temperature parameters are varied can be considered indicative of an effect of either of the two parameters on fish production if they differ by more than±10 percent. Only the March and April combined simulation and the March only simulations resulted in predictions of fish production in excess of ±10 percent. Table 6 summarizes the results of these comparisons for the month of March.

In a dry, warm water year like 1977, use of FAS in Copco and Iron Gate Reservoirs might increase fish production by as much as 17 percent (table 6). However, as we discuss later on, maintaining these reservoirs at near or full capacity may have some water quality benefits in most years that would preclude use of FAS as a management technique except in occasional circumstances.

In general, reservoir refill in FAS simulations did not occur. Copco and Iron Gate Reservoirs priority were set to the lowest in the system and therefore, in the SIAM model, the reservoirs had no "incentive" to refill. If the reservoir priority was increased in a simulation, the reservoirs refilled in one month at the expense of discharge below Iron Gate Dam. Another analysis will be required to determine whether the reservoir could refill after FAS usage in a given year or over the historical period of record. There are several options that can be explored to determine whether it is feasible to refill the reservoirs while still meeting UKL biological opinion water surface elevation targets for lake suckers and irrigation delivery demands.

If a bottom outlet were utilized in some temperature management scheme for Iron Gate Dam, then dissolved oxygen (DO) concentration may present a different water quality concern. The SIAM program predicts dissolved oxygen concentration, but the confidence interval for that estimation is ±2.0 mg/L. As a general estimation of the potential for dissolved oxygen concentrations below Iron Gate Dam to be adversely affected by bottom releases from the reservoir, we might assume that a mixing of 0.0 mg/L DO in 250 cfs of release water and 8.0 mg/L DO in 450 cfs might result in release water DO of 5.33 mg/L. This is below the North Coast Regional Water Quality Control Board (NCRWQCB) standard of 8 mg/L by 2.27 mg/L. Natural re-aeration will occur in the downstream direction, but there is an additional re-aeration technology that could address that DO deficit. The Tennessee Valley Authority has successfully used a variety of high-performance aerating weirs for DO improvement (Hauser and Morris, 1995). These weirs can increase DO by 2 mg/L during operation.

The FWS also requested an evaluation of the National Oceanic and Atmospheric Administration biological opinion, (NOAA, 2002) (BO) flow schedule to determine whether use of FAS could help meet flow targets at Iron Gate Dam in a variety of water year types. We did a preliminary analysis

Table 6. Summary of predicted fry, pre-, and immature smolt production comparing baseline and March flow augmentation simulations for nine hydrological and meteorological year types.

	Hydrological type	Meteorological type	Baseline	March	Percent change
1981	Dry	Cool	376465	371712	-1.3%
1988	Dry	Average	370409	377257	1.8%
1977	Dry	Warm	210777	246801	17.1%
1976	Average	Cool	325119	326724	0.5%
1995	Average	Average	400396	403496	0.8%
1985	Average	Warm	242672	228488	-5.8%
1971	Wet	Cool	400369	399038	-0.3%
1982	Wet	Average	402683	384088	-4.6%
1998	Wet	Warm	407813	409293	0.4%

using dry, average, and wet year simulations using the BO flow schedule (National Oceanic and Atmospheric Administration, 2002). Because the wet year flow schedule is actually less than the average year schedule, we used the average year schedule for the high flow simulation in those months where flows were lower (March, April, May, and June).

A dry year (1988), an average year (1986), and a wet year (1982) were simulated using values from the BO modified flow schedule, as discussed above for the wet year simulation, as targets for Iron Gate Dam release. Iron Gate demand priority was given the highest in the system and, where required, flow targets were enforced in the model. In all three simulations, flow targets at Iron Gate Dam were met, but only by shorting agricultural deliveries in addition to using FAS.

In the dry year simulation (1988), three irrigation diversions located between Upper Klamath Lake and Keno Reservoir—the Lost River, North Canal, and Ady Canal—were shorted a total of 31,591 acre-ft. In the average year simulation (1986), A Canal (irrigation diversion above Upper Klamath Lake outlet), North Canal, and Ady Canal were shorted 77,437 acre-ft. In the wet year simulation (1982), Copco and Iron Gate Reservoirs were shorted by 27,000 acre-ft early in the water year and A Canal, North Canal, and Ady Canal were shorted 69,577 acre-ft later in the water year, for a total of 101,626 acre-ft in addition to FAS. For the dry year simulation, FAS provided 62 percent of the total shortage and agricultural deliveries provided 38 percent. For the average year simulation, FAS provided 40 percent of the total shortage and agricultural deliveries provided 60 percent. For the wet year simulation FAS provided 34 percent of the total shortage while agricultural deliveries and reservoir storage provided 66 percent. As specified, the Klamath water bank, which relies primarily on foregone irrigation and groundwater pumping as an alternate irrigation source, was not included in these simulations. However, if a Klamath water bank of 100,000 acre-ft were included, then it may be possible to achieve the BO flow schedule below Iron Gate Dam for dry and average years. Although the wet year predicted shortage exceeds both FAS and a Klamath water bank of 100,000 acre-ft, there may still be some potential to distribute the flow shortage among various water uses.

Simulations that attempted to apportion the shortages of the average year BO flow schedule for Iron Gate Dam releases were performed for dry, average, and wet years (fig. 8). In a dry year (1988), the shortage to agricultural deliveries was 31,591 acre-ft in addition to using FAS in Copco and Iron Gate Reservoirs (simulation name = 1988BOFLOWS) for a total shortage of 83,591 acre-ft. Sharing the shortage among reservoir storage, Iron Gate releases, and agriculture (fig. 8) results in a total shortage of 59,474 acre-ft including FAS. The hydrograph is slightly reshaped, with most of the shortage in agricultural deliveries occurring in February (12,474 acre-ft to the Lost River Diversion) and usage of FAS shifted to August and September. The effect on the number of predicted fall Chinook juvenile outmigrants is positive in both the 1988BOFLOWS and the 1988BOFLOW2 simulations compared to the 1988BASELINE simulation. The predicted number of outmigrants increases from 370,409 for the baseline to 403,357 (10.7 percent) in the BOFLOWS simulation and further increases to 409,921 (12 percent) in the BOFLOW2 simulation with the slightly reshaped hydrograph. In this instance, for a dry year, all agricultural diversion shortages and refill of both Copco and Iron Gate Reservoirs might be accomplished through use of the Klamath water bank of 100,000 acre-ft.

In an average year type (1986) a similar exercise was performed. In this simulation (1986BOFLOWS), total agricultural shortages were 77,437 acre-ft in addition to FAS usage for a total shortage of 129,437 acre-ft. This exceeds a hypothetical water bank of 100,000 acre-ft. By reshaping the hydrograph slightly (fig. 9), the total shortage is reduced to 86,828 acre-ft, with 36,828 acre-ft coming from the Lost River Diversion in March and the remainder in FAS usage. In this simulation (1986BOFLO2) excess water in March was diverted into a hypothetical off-stream storage (agricultural

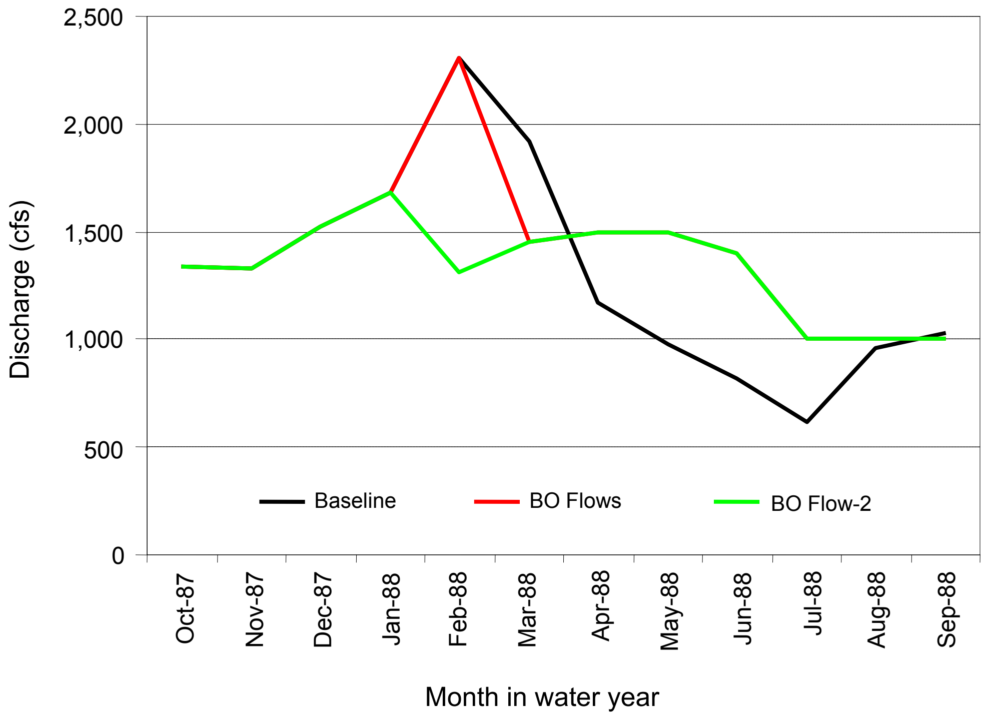

Figure 8. Comparison of the 1988 water year hydrographs predicted in simulations for historical conditions (Baseline), Biological Opinion flows (BO Flows), and Biological Opinion flows with agricultural diversion shortages apportioned (BO Flow-2).

diversions for A Canal, Lost River Diversion, North Canal, and Ady Canal), and returned to the Klamath River via the Lost River Diversion and Klamath Straits Drain later in the water year. Approximately 298,188 acre-ft was diverted, stored, and retrieved using this off-stream storage mechanism. Both Copco and Iron Gate Reservoirs refilled in the following month (April), although there was a small storage usage in Iron Gate Reservoir of 8,000 acre-ft in May. For these three simulations of an average water year, the effect on the predicted number of fall Chinook juvenile outmigrants was also positive in both the 1986BOFLOWS and the 1986BOFLO2 simulations compared to the 1986BASELINE simulations. The predicted number of outmigrants increases from 396,295 for the baseline to 401,447 (1.3 percent) in the BOFLOWS simulation and further increases to 478,280 (21 percent) in the BOFLO2 simulation with the reshaped hydrograph (fig. 9). Again, in this average year simulation, all agricultural diversion shortages and refill of both Copco and Iron Gate Reservoirs might be accomplished through use of a hypothetical water bank of 100,000 acre-ft and off-stream storage that captures excess spring runoff.

The wet year type simulation (1982) was challenging. In this wet year the hydrograph showed a substantial peak in discharge in the spring that exceeded BO flow targets in every month of the year except June (fig. 10). Total shortages to agriculture (A Canal, North Canal, and Ady Canal) were 77,437 acre-ft in June, July, and August, in addition to shortages in Copco and Iron Gate Reservoir in October of 27,000 acre-ft and FAS in those same reservoirs in June for a total of 153,626 acre-ft. As in

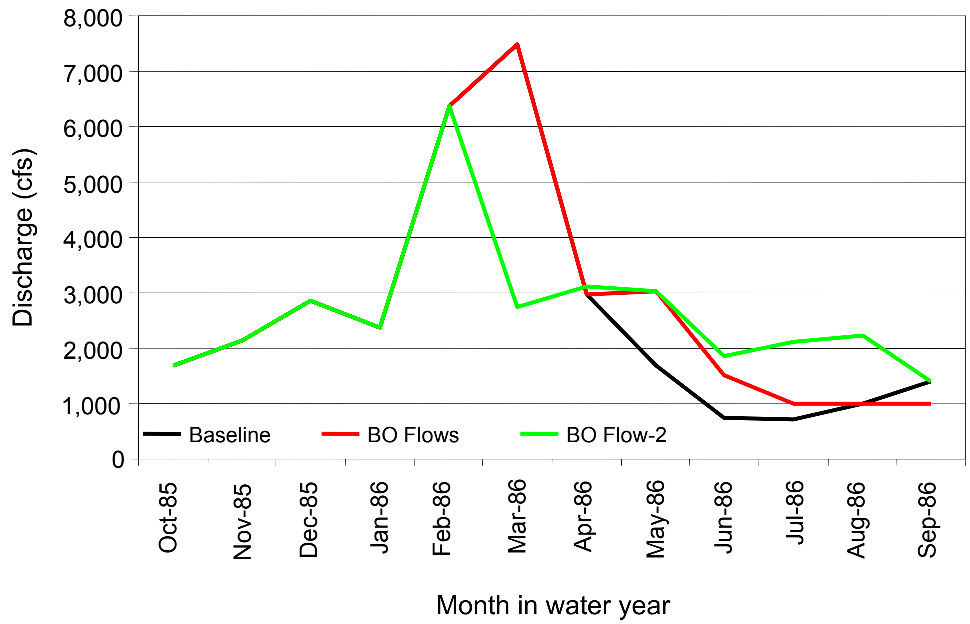

Figure 9. Comparison of the 1986 water year hydrographs predicted in simulations for historical conditions (Baseline), Biological Opinion flows (BO Flows), and Biological Opinion flows with agricultural diversion shortages apportioned (BO Flow-2).

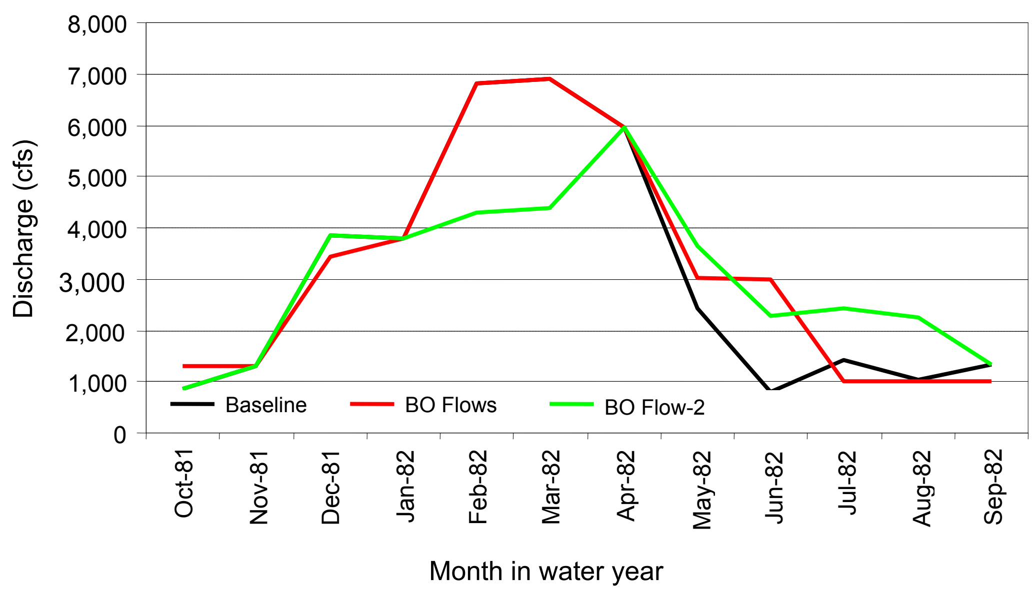

Figure 10. Comparison of the 1982 water year hydrographs predicted in simulations for historical conditions (Baseline), Biological Opinion flows (BO Flows), and Biological Opinion flows with agricultural diversion shortages apportioned (BO Flow-2).

the average year simulations, the issue is spring runoff discharge. In the 1982BASELINE and 1982BOFLOWS traces shown in figure 10, peak spring flows are approximately 7,000 cfs. Storing some of that discharge off-stream reshapes the hydrograph to provide more water in the summer. In the 1986BOFLO2 simulation excess water in February and March was diverted into a hypothetical off-stream storage (agricultural diversions for A Canal, Lost River Diversion, North Canal, and Ady Canal) and returned to the Klamath River via the Lost River Diversion and Klamath Straits Drain later in the water year. As in the 1986 simulations, approximately 298,188 acre-ft was diverted, stored and retrieved using this off-stream storage mechanism. In both the average and wet year BOFLO2 simulations, discharge below Iron Gate in the spring exceeds the 2,000 cfs level (fig. 10) indicated in the run-timing exercise where little further gain in the number of fall Chinook juvenile outmigrants was predicted. The total shortage predicted in the 1982BOFLO2 simulation was 49,896 acre-ft in the Lost River Diversion in February, when peak flows were being diverted to off-stream storage. In that instance, no shortage actually occurred and FAS in Copco and Iron Gate Reservoirs was not utilized. The use of the Klamath water bank would also not be required in this wet year simulation. For these three simulations of a wet water year, the effect on the predicted number of fall Chinook juvenile outmigrants was also positive in both the 1982BOFLOWS and the 1982BOFLO2 simulations compared to the 1986BASELINE simulations. The predicted number of juvenile outmigrants increases from 402,683 for the baseline, to 405,501 (<1 percent) in the BOFLOWS simulation and further increases to 423,409 (5.2 percent) in the BOFLO2 simulation with the reshaped hydrograph (fig. 10). In this wet year simulation, essentially no shortages were predicted and FAS in Copco and Iron Gate Reservoirs was not required. The hydrograph was reshaped using off-stream storage that captured excess spring runoff.

Spawning and Outmigration Timing Analysis Using SALMOD

Cooling the river below Iron Gate Dam during the current spawning period results in little predicted gain in fish production for the current emergence temperature of 8°C. Emergence temperature less than 8°C results in slightly depressed fish production predictions. Cooling river temperatures in the fall seems to offer little advantage to predicted fish production under the current life cycle timing for Klamath River mainstem fall Chinook in the SALMOD model.

Creating conditions in which fall Chinook would spawn in September instead of October may improve predicted fish production. If the life cycle timing is shifted without changing river temperatures, predicted fish production would drop significantly (approximately a 50–75 percent reduction), attributed to increased water temperature during spawning. The predicted temperature increase results in increased *in vivo*, incubation, and temperature mortality of eggs. Cooling river temperatures by 2°C to 3°C during September and October could result in less egg mortality in the fall but egg/alevins would be exposed to mortality factors longer in the spring while waiting for the river to warm up to emergence temperature. Juvenile fish could not migrate earlier and thus would still be exposed to disease-conducive temperatures. Predicted fish production may actually be depressed under those conditions. There is some question among researchers as to the numerical value of emergence temperature and whether or not it is actually a trigger mechanism for emergence. If you lower the emergence temperature (ET) in the SALMOD model, predicted fish production approaches a 41 to 58 percent increase at ET = 3°C. Juvenile fish could migrate earlier and may not be exposed to mortality associated with higher temperatures. Baseline production increased by 12.5 percent when the temperature was changed from ET = 8°C to ET = 3°C. The fall cooling scenarios resulted in a production increase of 52 percent at ET = 7°C, 76 percent at ET = 6°C, and 97 percent at ET = 3°C versus production at ET = 8°C.

An additional analysis of spring flow levels was made using the SALMOD model with disease mortality included (fig. 11). The SIAM program was used to generate flow and temperature data input files to SALMOD for each of nine water year types. Simulations were made with SALMOD outside of SIAM where March, April, and May flows were varied from 500 to 10,000 cfs in increments of 500 cfs for each year type. Flow adjustments were made directly to the flow input file for SALMOD. The number of predicted outmigrating fish was recorded for each flow value. A total of 60 runs were made for each year type for a total of 540 runs. The results of these analyses indicated that little improvement in predicted fish production could be made by increasing spring flows above 2,000 cfs. As the SALMOD model is currently configured, the effects of temperature related disease mortality greatly outweighed any improvements in fish habitat in these simulations.

The SIAM program and the SALMOD fish production module do not have the capability to directly emulate spring flushing flow because no relationship between fish outmigration and flow has been developed for Klamath River anadromous fish. In general, there is a window of temperatures when instream fall Chinook salmon juveniles are between emergence and disease exposure (fig. 12). If ET were 6°C and the onset of temperatures favoring disease exposure was 10°C, over the 43 year period of record for SIAM, the average number of days for this temperature range is 36. If ET is 8°C, then the average number of days for this temperature range is 16. The average date for a weekly mean average temperature of 6°C is March 9, for 8°C, March 29, and the average date for a weekly water temperature of 10°C is April 14. With an ET of 8°C and the onset of favorable conditions for disease exposure of 10°C, outmigrating juvenile fall Chinook salmon have just 15 days, on the average, to move downstream to the mouth of the Klamath River within the 8–10°C thermal window. We also looked at travel time versus discharge. Mike Deas (Watercourse, Inc., personal commun., 2004 estimates travel time from Iron Gate Dam to the Scott River as 1–2 days depending on flow. At 600 cfs, travel time was estimated at 45.8 hours, and at 4,000 cfs, travel time was estimated at 22.1 hours. Spring discharge from Iron Gate Dam is generally 1,200 cfs or greater, indicating that it may be possible to move downstream at least 47 miles in about 1–1.5 days.

The fry emergence and juvenile out-migration issue revolves around the assumption that the series of PacifiCorp dams is known to extend the summer's warm water 2–3 weeks in the fall, potentially resulting in "excess" mortality to both adults and *in vivo* eggs (Bartholow and others, 2005). Fall Chinook historically spawned earlier than at present (Snyder, 1931), though there is some question about whether spring Chinook may have "biased" this timing estimate, and it is plausible that if at least some of the larger existing hydropower dams were removed, especially Iron Gate Dam, spawning might again occur 2–3 weeks earlier. This earlier spawning period in turn might result in juvenile fish emerging and outmigrating earlier than at present, potentially prior to widespread disease outbreaks in the spring associated with water temperatures >10°C. If true, this could result in improved freshwater Chinook production.

There are two parameters in SALMOD that directly control fry emergence and juvenile migration timing. These are

1. minimum emergence temperature—fry do not emerge below this temperature threshold; and
2. starting week for seasonal juvenile migration—migration cannot begin before this time.

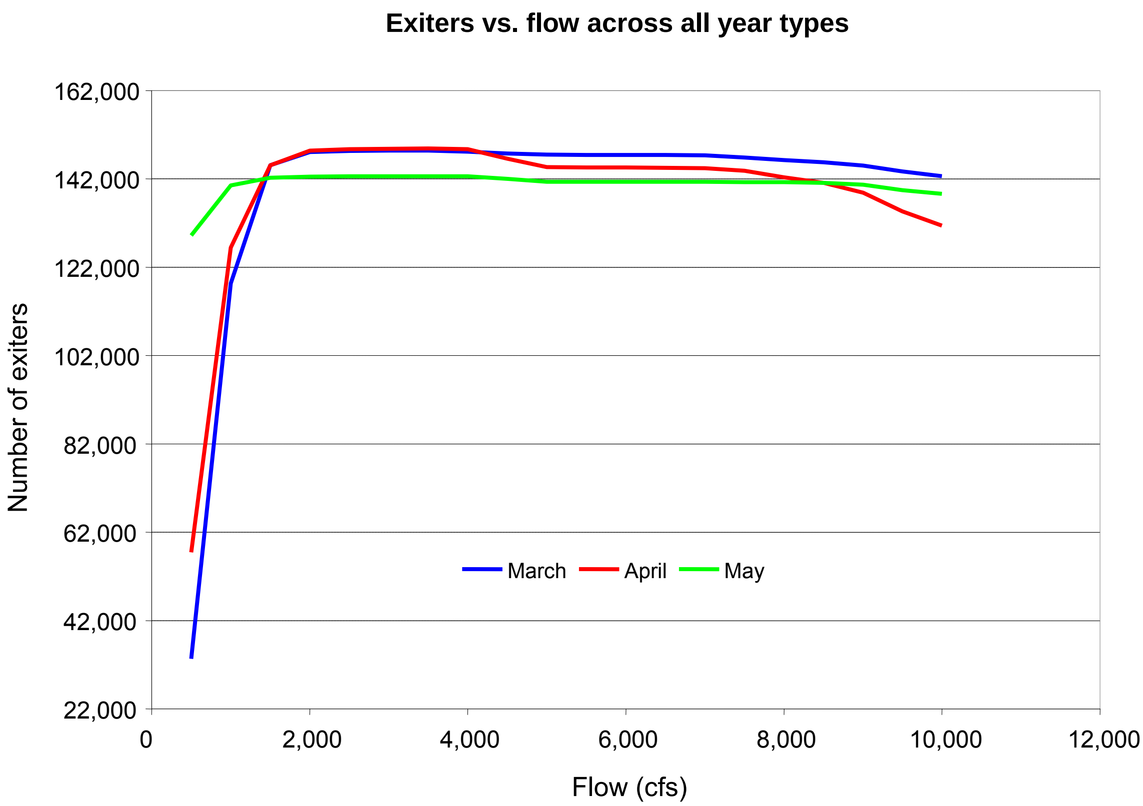

Figure 11. Summary of the predicted average number of fall Chinook salmon exiters at varying discharges during March, April, and May for nine different simulations.

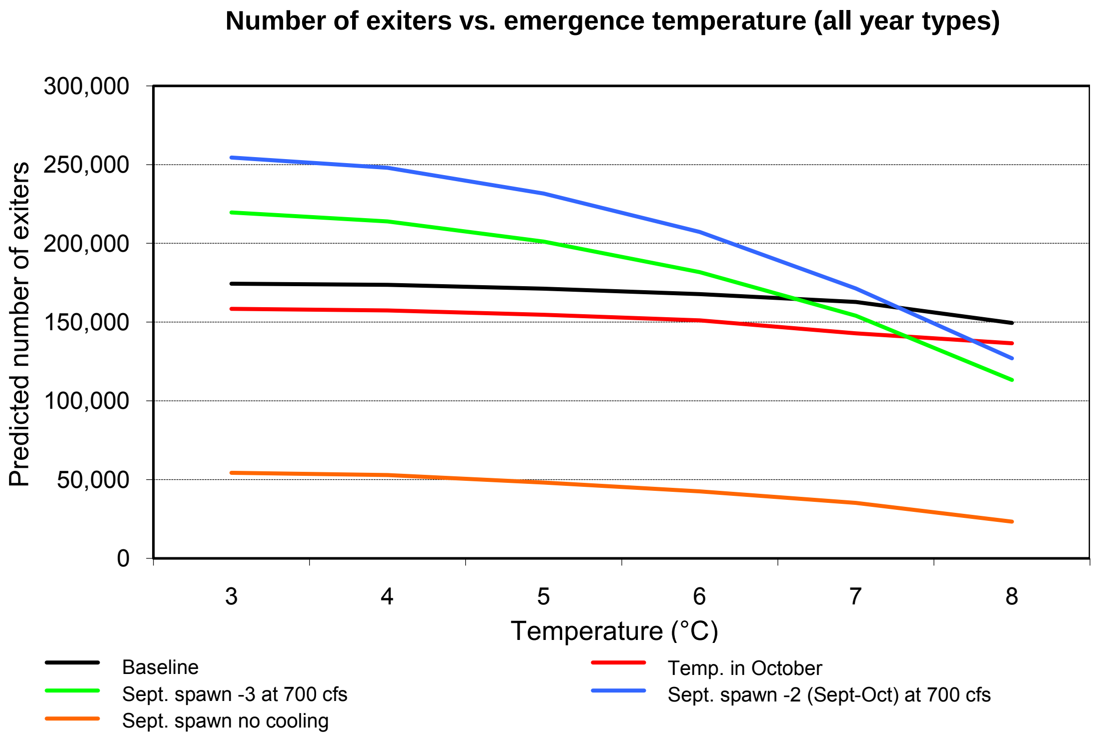

Figure 12. Number of predicted fall Chinook salmon exiters versus emergence temperature for the spawning and out-migration timing SIAM simulations.

The current settings for these parameters (8°C and the week beginning March 4) result in model predictions showing a narrow temporal distribution of juvenile fish with little variability with respect to water year type (table 7). There is increasing evidence, though not universally accepted, that no minimum emergence temperature threshold exists and that migration may begin as soon as fry emerge (Brannon and Beer, University of Washington, personal commun., 2004). If these parameters remained in effect, shifting the spawning time back a few weeks would have little effect on emergence, migration timing, and ultimate fall Chinook production. These restrictive controls were removed for this analysis by setting emergence temperature to 0°C and allowing migration to occur as soon as emergence begins. This resulted in model output with much broader temporal distributions for instream juveniles as well as migrating juveniles. In addition, these distribution patterns were much more sensitive to stream temperatures. That is, cooler stream temperatures in September resulted in earlier predicted emergence times and longer migration periods.

Shifting the spawning period back by two to three weeks can result in exposure to much warmer stream temperatures during the early weeks of spawning (table 7). This can result in higher predicted *in vivo* mortality rates for eggs. In addition, fall Chinook are unlikely to change their spawning behavior if stream temperatures remain the same in September. Cooling the stream in the fall by 2–3°C either by dam removal or temperature control devices may help to mitigate this mortality. Cooling the stream will result in higher rates of predicted emergence (more fish emerge sooner) as well as higher production. Cooling the stream by 3°C had a slightly more beneficial effect on SALMOD's predicted production than cooling the stream by 2°C.

Table 7. SALMOD emergence timing and migration results for nine year types and a variety of spawning and temperature conditions.

Water year:	1981	1988	1977	1976	1995	1985	1971	1982	1998	Average
October spawning										
Migration start week	15	17	18	23	22	23	18	15	22	19.2
Migration start date	1/14	1/28	2/4	3/11	3/4	3/11	2/4	1/14	3/4	2/11
Migration end week	37	40	39	39	38	37	37	37	38	38
Migration end date	6/17	7/8	7/1	7/1	6/24	6/17	6/17	6/17	6/24	6/24
Total exiters	1,834,024	1,603,807	823,504	887,584	1,707,677	176,691	1,053,960	1,991,702	1,331,515	1,267,829
Number of juvenile fish produced	25,709,092	21,425,122	11,090,587	11,216,806	22,042,077	2,648,866	13,897,288	26,324,742	14,583,511	16,548,677
Number of fish exposed to temperatures >10°C	3,550,545	3,604,607	3,375,510	3,619,958	4,095,719	1,779,749	5,405,137	3,094,539	4,050,115	3,619,542
Percent exposed	13.8	16.8	30.4	32.3	18.6	67.2	38.9	11.8	27.8	28.6
Percent survival for juvenile fish	7.1	7.5	7.4	7.9	7.7	6.7	7.6	7.6	9.1	7.6
Average exiter weight (g)	1.2	1.1	1.1	0.9	1.2	0.8	1.0	1.2	1.1	1.1
Spawning start 2 weeks early with 2°C cooling										
Migration start week	14	14	14	18	17	17	14	14	16	15.3
Migration start date	12/23	12/23	12/23	1/20	1/28	1/13	12/23	12/23	1/6	12/30
Migration end week	39	41	41	40	41	38	38	38	40	40
Migration end date	6/16	6/30	6/30	6/23	7/15	6/9	6/9	6/9	6/23	6/16
Total exiters	1,889,926	2,328,004	1,184,078	1,407,325	2,258,963	626,835	1,945,724	2,307,311	1,668,926	1,735,232
Number of juvenile fish produced	28,278,421	35,982,027	19,090,000	20,369,181	30,057,752	10,852,365	27,021,640	32,877,210	19,980,092	24,945,410
Number of fish exposed to temperatures >10°C	1,778,533	1,934,272	1,862,999	2,880,803	2,655,007	2,766,145	4,321,052	1,682,855	2,784,727	2,518,488
Percent exposed	6.3	5.4	9.8	14.1	8.8	25.5	16.0	5.1	13.9	11.7
Percent survival for juvenile fish	6.7	6.5	6.2	6.9	7.5	5.8	7.2	7.0	8.4	6.9
Average exiter weight (g)	1.3	1.2	1.2	1.1	1.4	1.0	1.1	1.3	1.2	1.2
Spawning start 3 weeks early with 2°C cooling										
Migration start week	14	14	14	14	14	14	14	14	17	14.3
Migration start date	12/23	12/23	12/23	12/16	12/16	12/16	12/23	12/23	1/6	12/23
Migration end week	39	41	41	41	41	39	39	39	41	40
Migration end date	6/16	6/30	6/30	6/23	6/23	6/9	6/9	6/9	6/23	6/16
Total exiters	1,497,546	2,391,263	1,321,073	1,492,398	2,349,914	1,088,057	1,998,185	2,345,155	1,289,097	1,752,521
Number of juvenile fish produced	24,868,415	39,139,723	22,557,465	24,178,898	32,106,206	18,411,067	29,752,020	34,833,303	16,606,926	26,939,336
Number of fish exposed to temperatures >10°C	1,155,109	1,438,681	1,217,823	2,030,356	1,953,318	3,001,334	3,120,382	1,210,764	1,744,419	1,874,687
Percent exposed	4.6	3.7	5.4	8.4	6.1	16.3	10.5	3.5	10.5	7.7
Percent survival for juvenile fish	6.0	6.1	5.9	6.2	7.3	5.9	6.7	6.7	7.8	6.5
Average exiter weight (g)	1.5	1.3	1.2	1.2	1.5	1.1	1.2	1.4	1.3	1.3

The SALMOD output showed that spawning three weeks earlier produced more fish than spawning two weeks earlier or spawning in October if adequate cooling occurs (table 7). Spawning two weeks earlier increased predicted production even without cooling. Predicted emergence times are on average four weeks earlier for the early spawning scenarios than for spawning in October. For years with warm fall stream temperatures, emergence occurred as much as eight weeks earlier. Although the migration start date was earlier, the end date remained the same. The average predicted migration start was mid February for October spawning. Migration began in late December for the early spawning scenarios. The migration period ended in mid to late June for all scenarios. The SALMOD model predicted larger numbers of juvenile fish spread out over longer periods of time for the early spawning scenarios. Mortality for these fish was reduced by 3 to 7 percent. Twenty nine percent of fish produced from October spawning were exposed to stream temperatures greater than 10°C (at temperatures above 10°C disease is more prevalent). The amount of fish exposed to these temperatures dropped to 12 and 8 percent for the scenarios where spawning occurred two and three weeks early. The predicted number of juvenile outmigrants (exiters) was 38 percent higher for the early spawning scenarios. In addition, the average weight of migrating juveniles was predicted to be 13 to 22 percent greater for those fish produced from early spawning. This may result in potentially higher downstream survival rates.

Klamath Spring Flow Variability Analysis

Klamath Historical Flows

Over the 43-year historical period of record, SIAM simulated flows below Iron Gate Dam that varied between 395 cfs and 12,568 cfs. The average simulated flows below Iron Gate for fall (October–November), winter (December–February), and spring (March–May) were 2,034 cfs, 3,488 cfs, and 3,365 cfs, respectively. The average minimum simulated flows for these periods were 975 cfs, 948 cfs, and 740 cfs. Average maximum flows were 4,630 cfs, 10,590 cfs, and 6,917 cfs.

Upon review of the monthly flow output from SIAM, flows during water year 1992 (low flow year) most closely matched the simulated minimum annual and spring flows for the 43-year period of record.

Average annual and spring flows for the 43-year period of record were best represented by the flows simulated for water year 1967 (average flow year). The simulated annual and spring flows of water year 1983 (high flow year) most closely fit the average simulated maximum annual and spring flows for the 43-year period of record. Table 8 shows the baseline flows for each season in each flow year type.

Table 8. Average seasonal flows (cfs) for each flow year type.

Season	Fall		Winter			Spring		
Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Low (1992)	951	1,006	1,053	1,016	749	688	877	623
Ave. (1967)	1,699	2,123	3,551	3,671	3,575	2,546	3,091	4,615
High (1983)	2,176	3,369	,4630	4,054	6,905	9,404	6,352	5,137

Figures 13 and 14 illustrate the average annual and average seasonal flow for each year in the 43-year period for the baseline simulation. In figure 13, it appears that 6 years in the historical period of record shown here were very dry, with annual flows below Iron Gate Dam averaging less than 1,500 cfs. High flow was observed in 7 years of the historical period of record.

Figure 14 describes the seasonal variability of flows associated with spawning (fall), egg incubation (winter), and rearing (spring) of juvenile fall Chinook salmon in the Klamath River. The occurrence of runoff events in all three seasons and the lack of runoff events in the fall season over the last 18 years (1986–2003) are apparent. This is the longest period consistently lacking runoff events for a season within the historical period of record. The trace for fall flows in figure 14 indicates that the average seasonal flow below Iron Gate Dam never exceeded 2,000 cfs for that 18-year period. These extended periods when natural spates are not evidenced may indicate extended drought or management practices that tend to reduce the amplitude of runoff events. From a fisheries perspective, low stable flows may have undesirable consequences, such as the buildup of fines in gravels, which makes them unsuitable spawning habitat. The additional fines can also provide a substrate for aquatic vegetation that may provide habitat for organisms acting as intermediate hosts for the spores of disease organisms that infect life stages of salmonids present in the Klamath River.

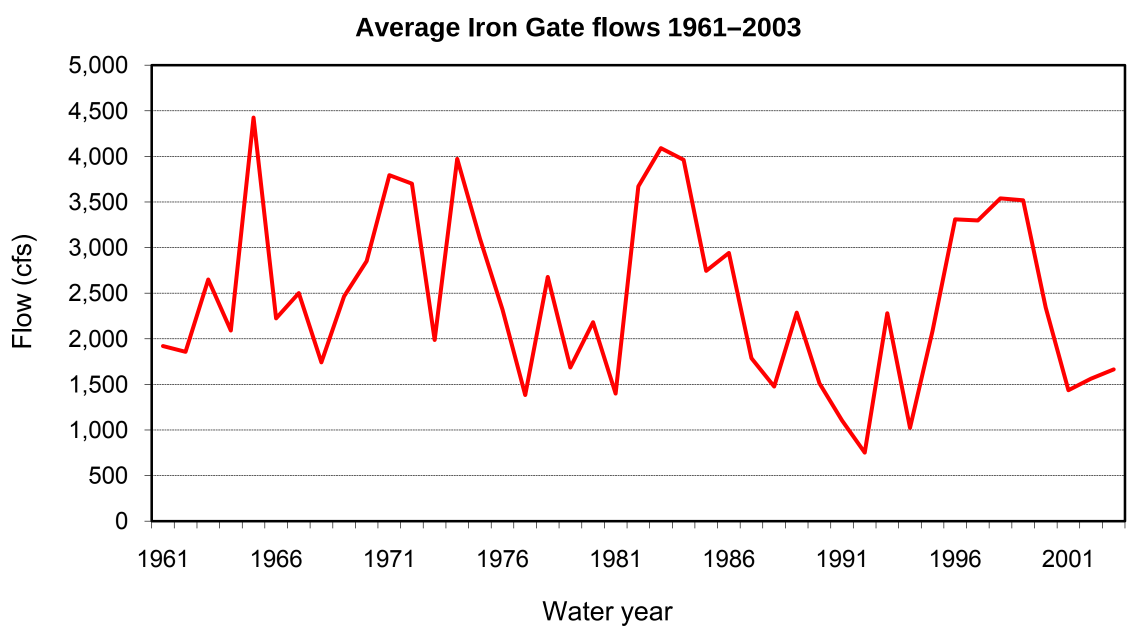

Figure 13. Average Iron Gate flows 1961–2003.

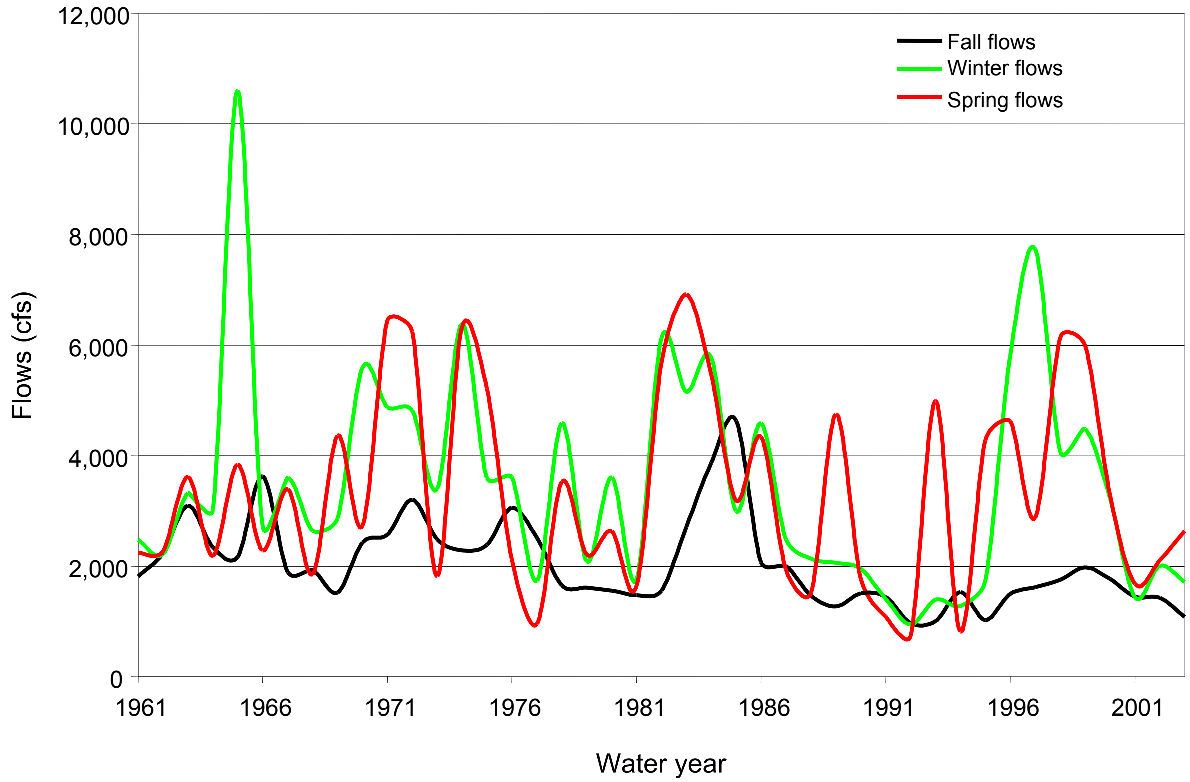

Figure 14. Average seasonal Iron Gate flows 1961–2003.

Low Flow Years (1992)

Figure 15 shows the seasonal flow effects for low flow years. Flows above 1,000 cfs in the fall resulted in a decreasing trend in simulated fish production as flow approached 7,000 cfs. Flows of 3,500 and 7,000 cfs exhibited decreases in fish production ranging from -10 to -65 percent during the fall season resulted in the elimination of spawning habitat in the SIAM/SALMOD compared to the historical baseline fish production prediction. Iron Gate Dam flows above 3500 cfs during the fall season result in the elimination of spawning habitat in the SIAM/SALMOD model. Flows during the winter months, December–February, had little effect on simulated fish production during low flow years. Simulated fish production steadily improved for spring flows between 1,000 and 4,500 cfs. Production estimates were 118 percent greater than baseline simulations for flows of 4,000 to 4,500 cfs during the March–May period. Flows above 4,500 cfs resulted in a decline in rearing habitat and thus a reduction in the amount of improvement in simulated fish production in this low flow simulation. The majority of the improvement in fish production estimates was attributable to flows in March and April. Maintaining these flows in May added only a few percent to simulated fish production. In terms of the number of outmigrating fish predicted by SALMOD, the maximum number of outmigrating fish, at 4,000 cfs, was 7.34 times that for the flow (500 cfs) that predicted the minimum number of outmigrating fish.

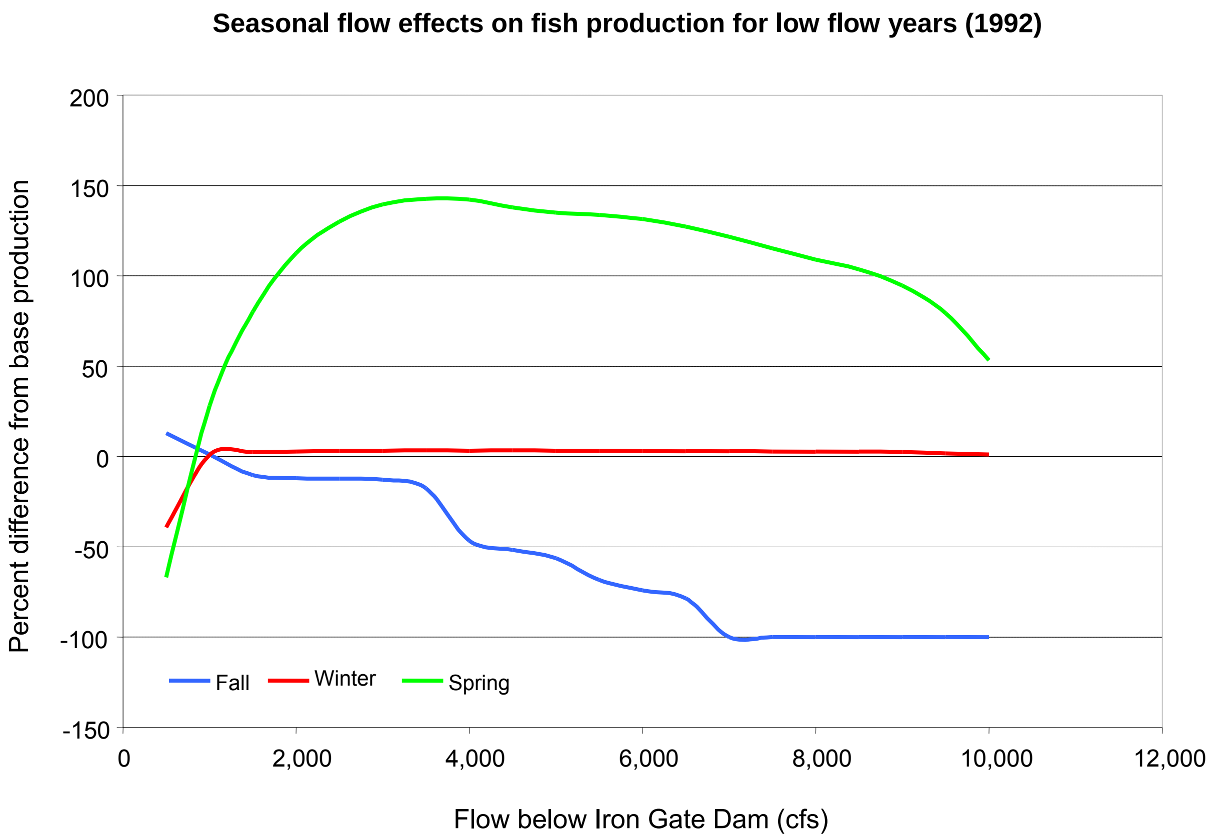

Figure 15. Seasonal flow effects on simulated fish production for low flow years (1992).

Average Flow Years

Figure 16 shows the seasonal flow effects for average flow years. Simulated fish production remained essentially unchanged for fall flows of 1,000 to 2,500 cfs. As flows increased above 2,500 cfs, production declined drastically as flows increased and spawning habitat was reduced in the model. Habitat restriction can occur at even lower flows (500 cfs) for other habitat types. Flows between 1,500 and 4,000 cfs during winter months (December–February) had little effect on simulated fish production during average flow years. Production gradually declines to levels 5 percent below baseline for flows from 4,500 to 10,000 cfs. Spring flows (March–May) less than 3,000 cfs reduce simulated fish production by 5 to 89 percent below baseline. There was a slight improvement in production for flows of 3,500 to 6,000 cfs. Spring flows above 6,000 cfs resulted in declining simulated fish production due to decreasing rearing habitat availability. In terms of the number of outmigrating fish predicted by SALMOD, the maximum number of outmigrating fish, at 4,000 cfs, was 9.2 times that for the flow (500 cfs) predicting the minimum number of outmigrating fish.

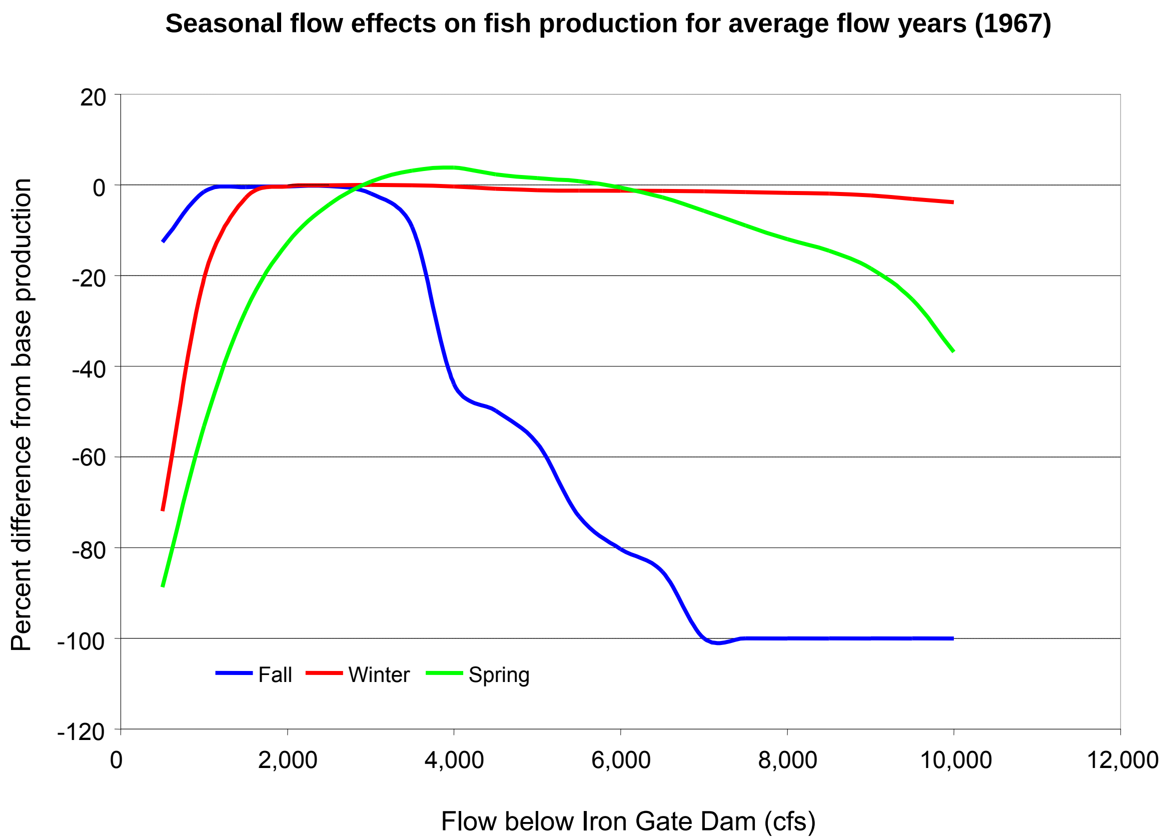

Figure 16. Seasonal flow effects on simulated fish production for average flow years.

High Flow Years

Figure 17 shows the seasonal flow effects for high flow years. Fall flows of approximately 1,500 to 3,000 cfs had little effect on simulated fish production. Flows above 3,000 cfs in the fall resulted in a steady decline (10 to 78 percent below baseline) in simulated fish production due to loss of spawning habitat at higher flows. Winter flow variability had little effect on simulated fish production at any flow during high flow years. During high flow years, spring flows above 1,400 cfs increased simulated fish production to a peak value at 4,000 cfs that was 55 percent above that of the baseline run. Simulated fish production declined as flows were increased above 4,000 cfs due to loss of rearing habitat. In terms of the number of outmigrating fish predicted by SALMOD, the maximum number of outmigrating fish, at 4,000 cfs, was 9.65 times that for the flow (500 cfs) predicting the minimum number of outmigrating fish.

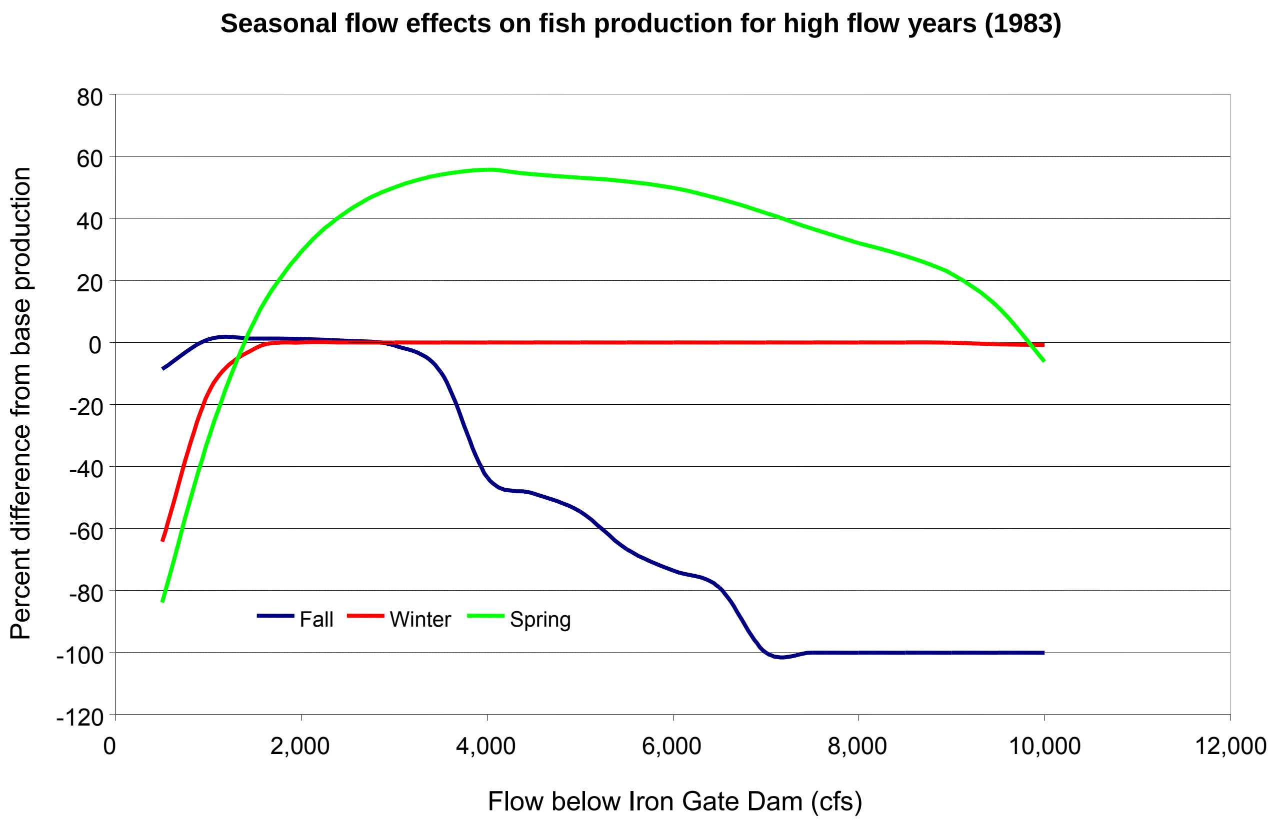

Figure 17. Seasonal flow effects on simulated fish production for high flow years.

Effect of Tributary Fish

The addition of tributary fish increases the proportion of juvenile mortality due to habitat availability. It also increases total simulated juvenile mortality by about 6 percent. As a result, the influence of flow variability on simulated fish production is reduced by about 17 to 30 percent depending on the type of flow year. Spring flows of about 4,000 cfs during low flow years resulted in a 118 percent increase in simulated fish production over baseline with tributary fish included. This increase is compared to 142 percent improvement without tributary fish. Including tributary fish in the simulation is more realistic but potentially masks the effects of fall flow variability on egg production; therefore, simulations with and without tributary fish were conducted.

To assess the impact of spring flow magnitude and duration on simulated fish production, spring flows were varied from 1,500 to 4,000 cfs for one to thirteen weeks beginning the first week of March of a low flow year (1992). Figure 18 shows the effect of spring flow magnitude and duration on simulated fish production for the low flow year 1992. These results show that increases in improvement are small after the end of April (9 weeks). The level of improvement varies from 35 to 52 percent as the flow increases from 1,500 to 4,000 cfs for the first nine weeks.

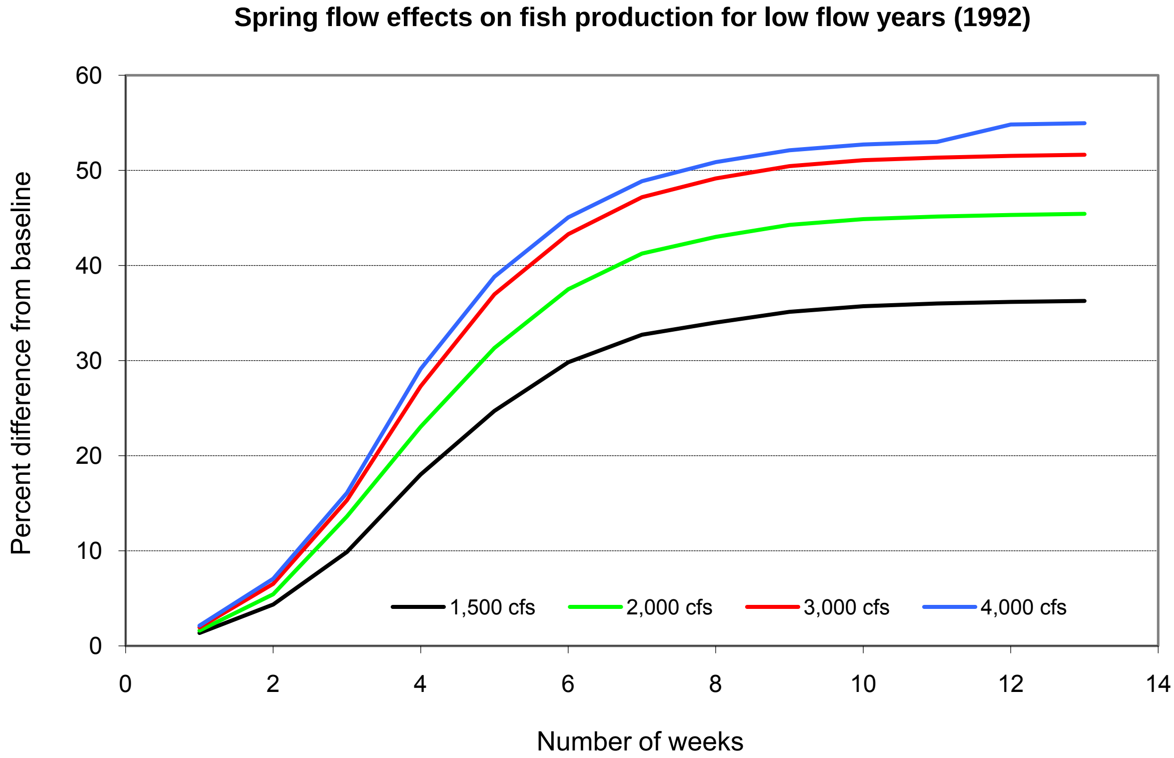

Figure 18. Varying spring flow effects on predicted fish production for low flow years.

Spring Incremental Flows Analysis Results

Low Flow Years

Figure 19 is an example of how the incremental flow simulations were configured. In this example for 1992, a low flow year, there were two baselines: from February 15 to May 31, one provided 4,000 cfs and the other provided 600 cfs. Fish production estimates for the two baseline simulations represented the starting condition against which other pulsed flows were compared.

Figure 20 focuses in on the February–May period of the pulsed flow simulations to illustrate how these simulations differed from one another. The discharge from Iron Gate Dam ranged from 500 cfs during the entire period to 4,000 cfs for the entire period, with simulations that began by using short periods of varying flow for short time increments (pulsed flows) and continued with progressively longer intervals.

Figure 21 illustrates the effect on fish production of the spring pulse flows at the 4,000 cfs level. Flows applied during the first four weeks of the spring season (February 15 to March 15) had little effect on predicted fish production, regardless of whether the base flow was 4,000 cfs or 600 cfs, although the total production for the 4,000 cfs baseline was 40 percent greater than the total production predicted for the 600 cfs baseline (figs. 21 and 22). During this period, habitat in the

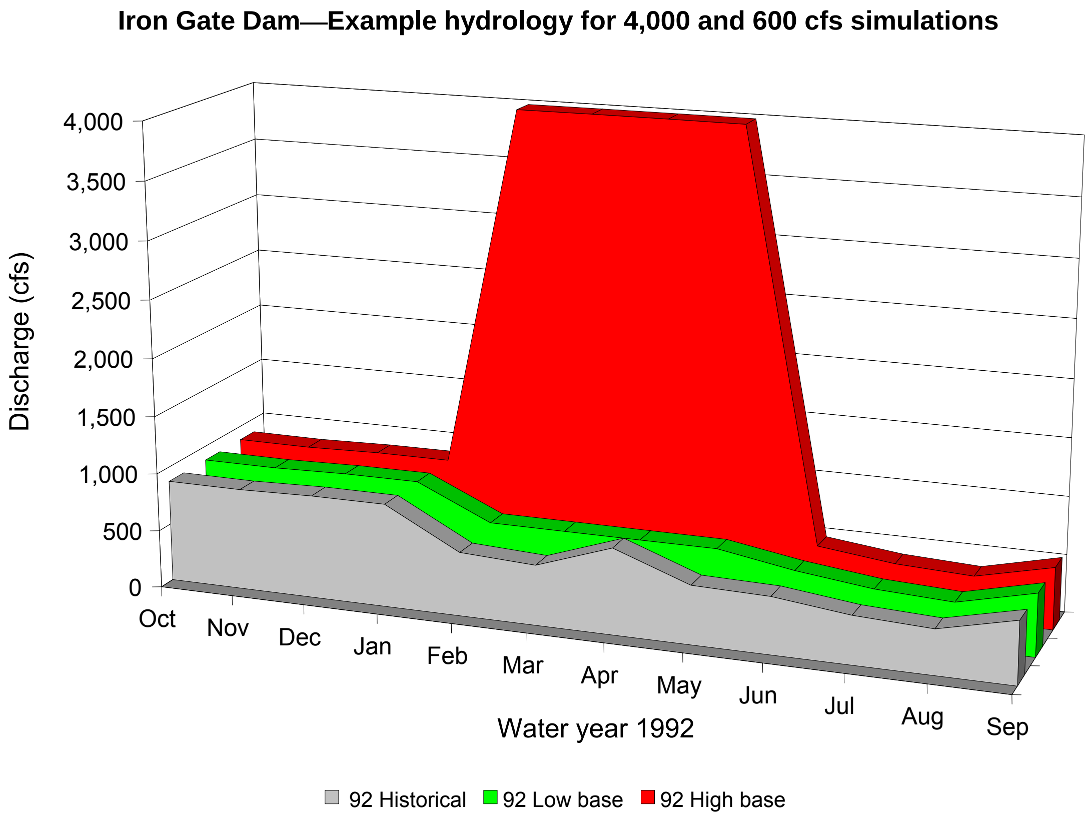

Figure 19. Hydrology for two simulations compared to historical conditions for water year 1992. The two simulations were identical to the historical except during the period February 15 to May 31.

mainstem apparently is adequate at all flows for the number of juveniles present during this time period; tributary fish have not entered the river to compete for available habitat. Pulsed flows applied during May also have little impact on fish production as most of the fall Chinook juveniles have migrated and habitat is once again adequate for the number of fish present.

The predicted effect of reducing spring flows to 500, 1,000, or 1,500 cfs from a baseline of 4,000 cfs on juvenile fish production is substantial. Reducing spring flows to 500 cfs from a 4,000 cfs baseline results in an approximate 50 percent decrease in fish production estimates (fig. 21). Reducing the flow to 1,000 cfs decreases predicted fish production by 20 percent, and a reduction to 1,500 cfs decreases predicted fish production by 10 percent. The duration of reduced flows has maximal effect at about 10 weeks, although the decreases in fish production estimates are evident at 4 weeks and marked at 6 weeks. In these simulations, reduced flows between 2,000 cfs and baseline (4,000 cfs) have minimal impact, perhaps indicating that the habitat for the number of fish present is adequate when flows approach 2,000 cfs in this set of simulations for a low flow year.

In figure 22, the baseline number of fall Chinook juveniles is substantially less because the baseline flows are 600 cfs rather than 4,000 cfs as previously shown in figure 21. The effect of increasing spring flows in increments of 500 cfs begins to become apparent after about 6 weeks for all except the initial 500 cfs increment. Even 1,000 cfs for 10 weeks increases estimated fish production by 25 percent. When flows are increased to 1,500 cfs for 10 weeks, fish production

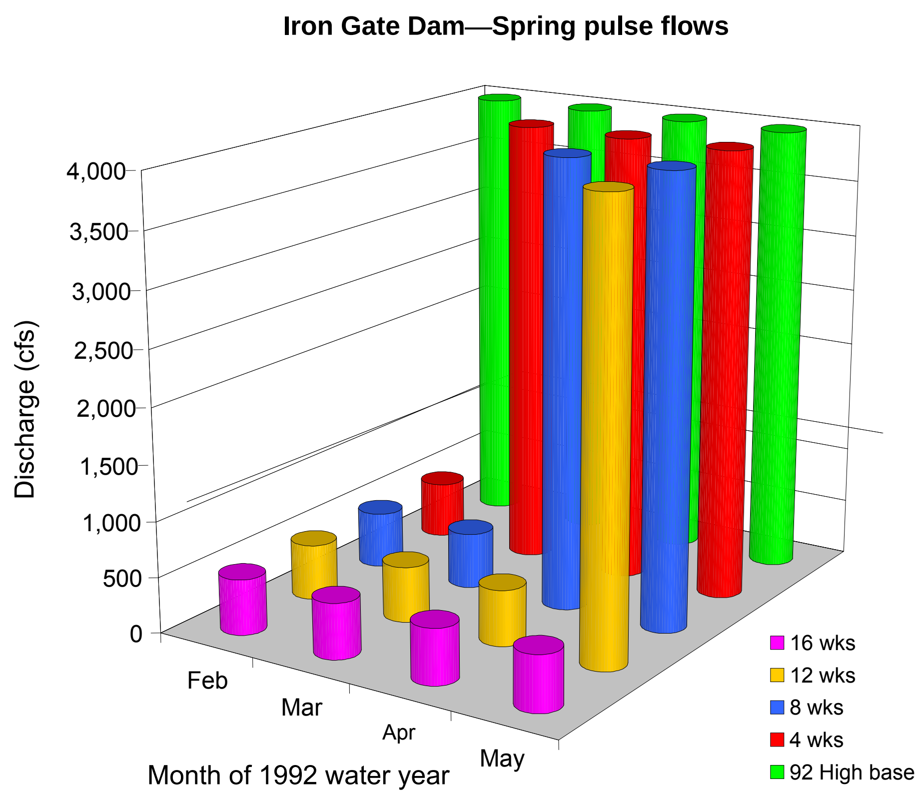

Figure 20. An example of pulsed flows during the February–May period showing delivery of just 500 cfs for 4, 8, 12, and 16 weeks. Monthly intervals are shown for visual clarity and convenience.

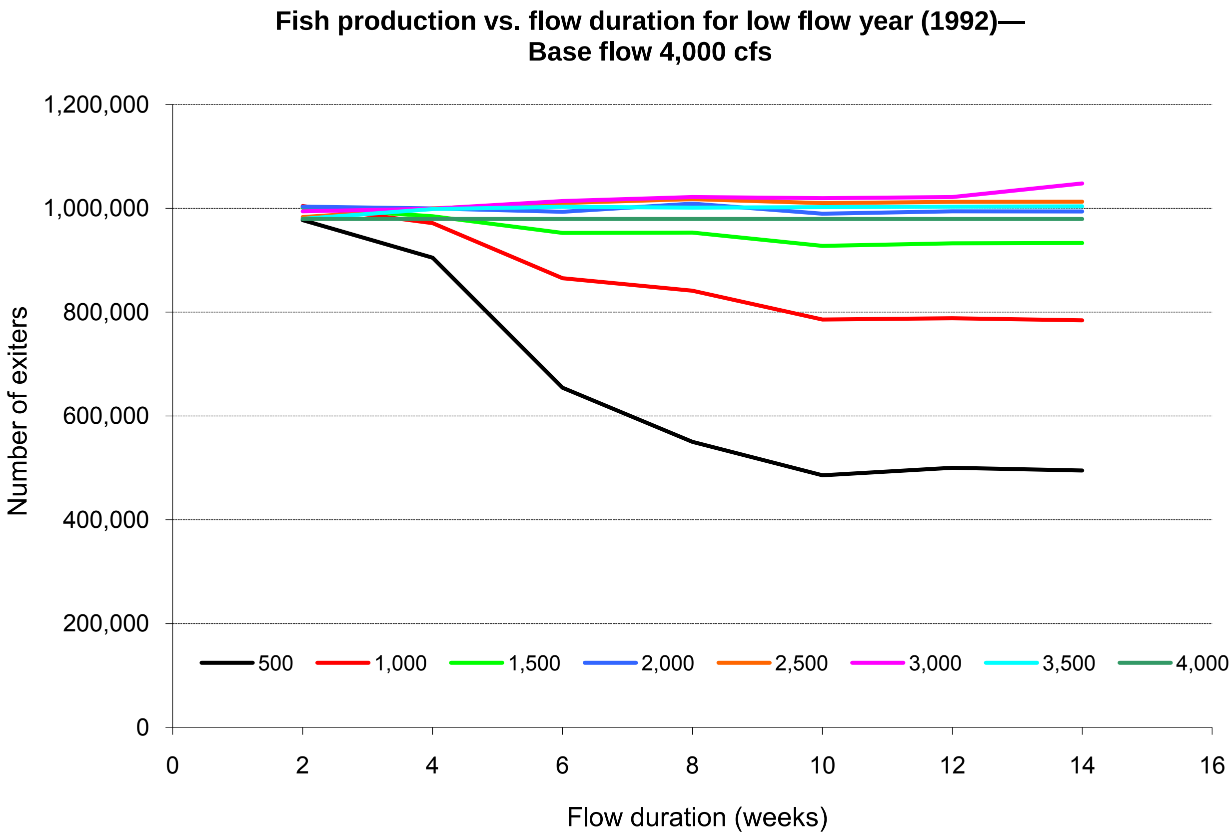

Figure 21. Number of fall Chinook juveniles predicted by simulations of altering spring flows from 4,000 cfs in increments of 500 cfs for durations of 2 to 14 weeks (February 15 through May 31).

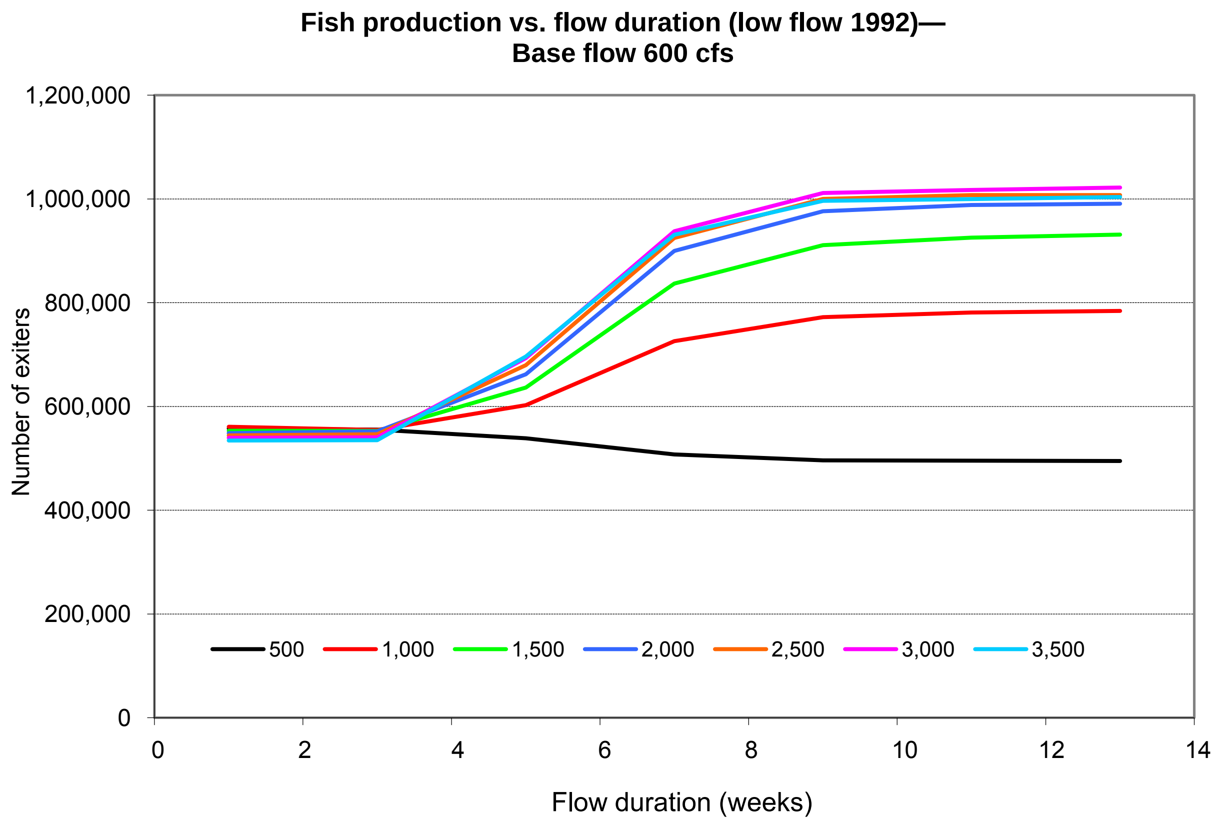

Figure 22. Number of fall Chinook juveniles predicted by simulations of altering spring flows from 600 cfs in increments of 500 cfs for durations of 2 to 14 weeks (February 15 through May 31).

estimates are increased by 36 percent, and when 2,000 cfs is provided, fish production estimates are nearly the same as the 4,000 cfs simulation. From this information, we may be able to infer that in times when the water supply is limited, a 10-week duration of flows of 1,500–2,000 cfs could have substantial positive effects on fall Chinook juvenile production.

Flow has its greatest impact on predicted fish production during the period from March 15 to April 30. Figure 23 is a 3D representation of the effects of flow and flow duration on simulated fish production. Note that the 600 cfs baseline is used as the starting estimate of fish production. As the flow duration increases to 4 weeks (March 15) the estimate of production begins to increase substantially, with peak values for fish production occurring at about 10 weeks (April 30). In a low flow year when the water supply is limited, the provision of spring pulse flows during this period, for as much as can be allocated (1,500 to 3,500 cfs, if possible), may have the most beneficial effect on estimated fish production.

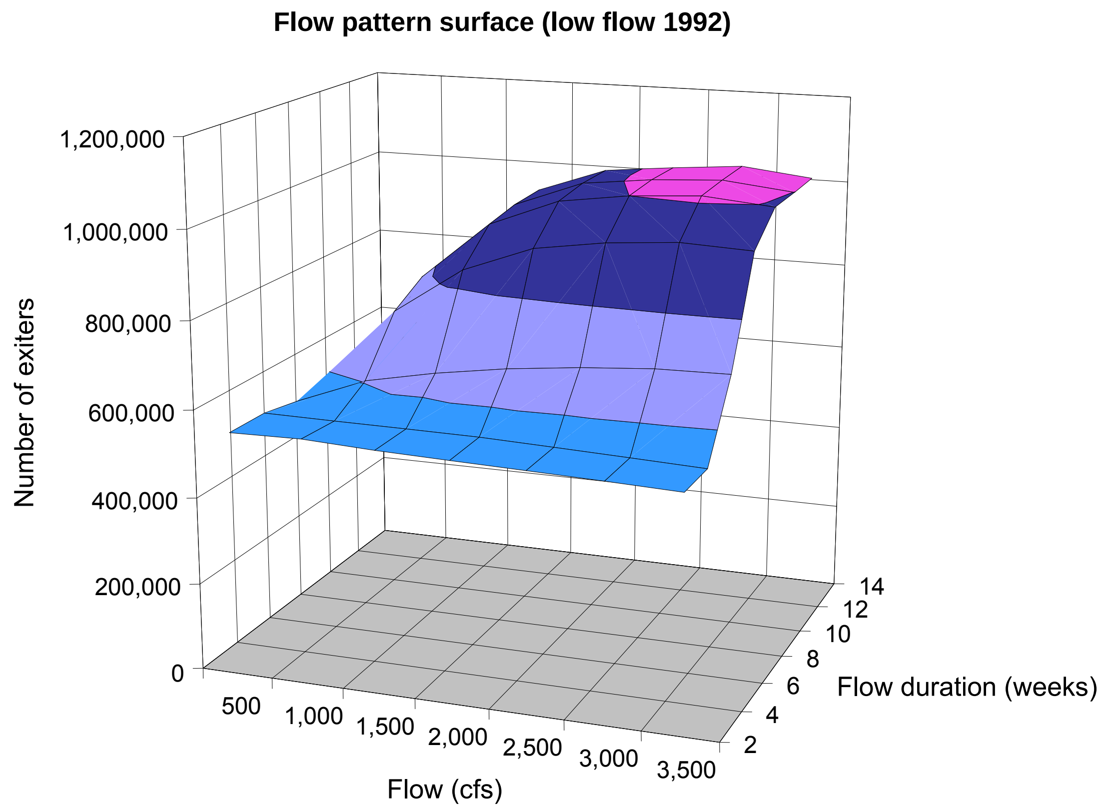

Figure 23. Flow pattern surface for low flow years illustrating both duration and flow effects on estimated fish production (March 15 through June 15).

Habitat and temperature-induced mortality have the greatest influence on simulated fish production for the Klamath River. Disease mortality has been implemented through the temperature mortality functions by increasing the mortality rate once water temperature exceeds 10°C. Habitat-induced mortality makes up the bulk of total simulated juvenile fish mortality, representing 68.3 percent of total mortality during flows of 3,000 cfs, and 91.5 percent during flows of 500 cfs. In contrast, temperature-induced mortality represents 27.1 percent and 6.4 percent, respectively, of total simulated fish mortality. Spring flow apparently influences simulated fish production primarily through its impact on juvenile fish rearing habitat. An exception to this can occur if, during a simulation, all of the full active storage (FAS) in Copco and Iron Gate Reservoirs is used to augment spring flows downstream of Iron Gate Dam. The water stored in Copco and Iron Gate Reservoirs represents a temperature buffer for water coming from the relatively warm UKL. If this buffer is removed by using all of the active storage to augment flows, predicted river temperatures downstream of Iron Gate Dam may increase as much as 0.75ºC. The increase in water temperature would result in higher predicted temperature mortality at this time of year (March 15–April 30) and a reduction of predicted fish production of up to 20 percent for low flow conditions. The temperature buffer described in the model can be maintained by limiting the use of Iron Gate and Copco FAS and maintaining the water surface to within the top three or four feet of the reservoirs.

Higher fall flows result in greater predicted spawning habitat (47 percent), thus resulting in much lower superimposition mortality (table 9). In addition, river temperatures below Iron Gate averaged 1.3ºC lower at 1,200 cfs than for the lower flows. Lower water temperatures delayed predicted egg maturation and resulted in higher fry number estimates, thus allowing more juvenile fish to migrate out of the area for the low flow simulation.

The SIAM simulation predicts that spring flows of 3,000 cfs will produce the most fish during low flow years. However, this is not a 'real world' option because applying spring flows of 3,000 cfs during low flow years would cause UKL to be drawn down to an elevation of 4,135 ft (spillway crest) by the end of May, well below the minimum elevation for lake suckers (4,141.4 ft). As a modeling exercise, application of lower flows in fall and winter were implemented but that only raised the lake level by 0.4 feet. Similarly, shutting off all agricultural deliveries only raised the lake level by 1 ft. Table 9 shows the decrease in predicted fish production from reducing spring flows from 3,000 to 500 cfs. Even supplying flows of 1,000 cfs results in a significant increase in predicted fish production over the low flow year (1992) baseline. Again, these simulations were model exercises to determine whether mandated BO lake levels and irrigation deliveries could be met in a very dry year and whether any management options might exist. Figure 24 shows UKL levels through the spring months (February–June) for each of the spring flows simulated. None of the flows will allow both agricultural deliveries and UKL minimum elevations to be met. When agricultural deliveries are shut off, flows up to 1,500 cfs can be released from Iron Gate Dam while meeting UKL minimum levels. Figure 25 shows UKL elevations for spring flows when agricultural deliveries are not made.

Table 9. Decrease in predicted fish production as flows are reduced in low flow years.

Spring flow (cfs)	Percent reduction from optimum (3,000 cfs)	Percent over baseline (avg. spring flow = 587 cfs)
2,500	<1.0%	82.2%
2,000	2.2%	80.0%
1,500	8.6%	68.8%
1,000	21.1%	45.7%
500	50.1%	-7.7%

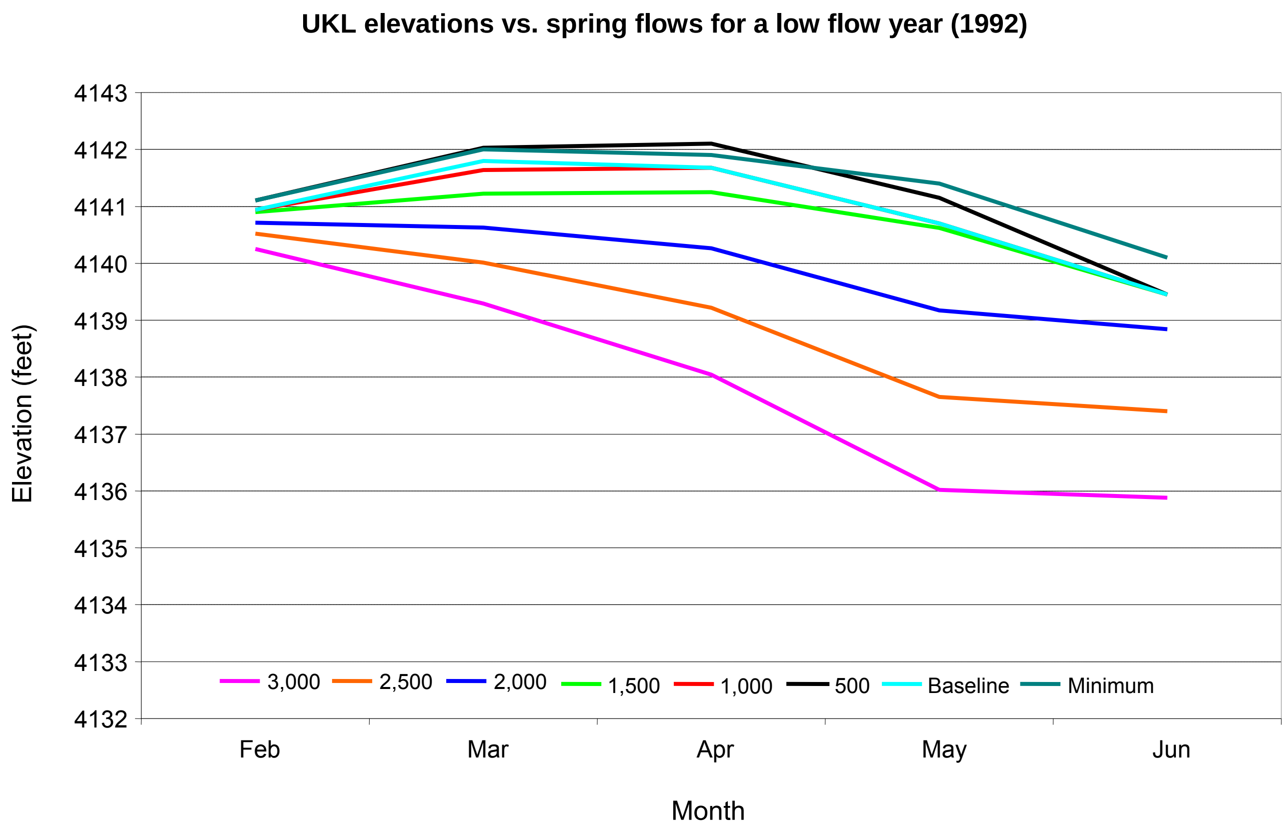

Figure 24. UKL elevations for spring flows with agricultural deliveries in low flow years.

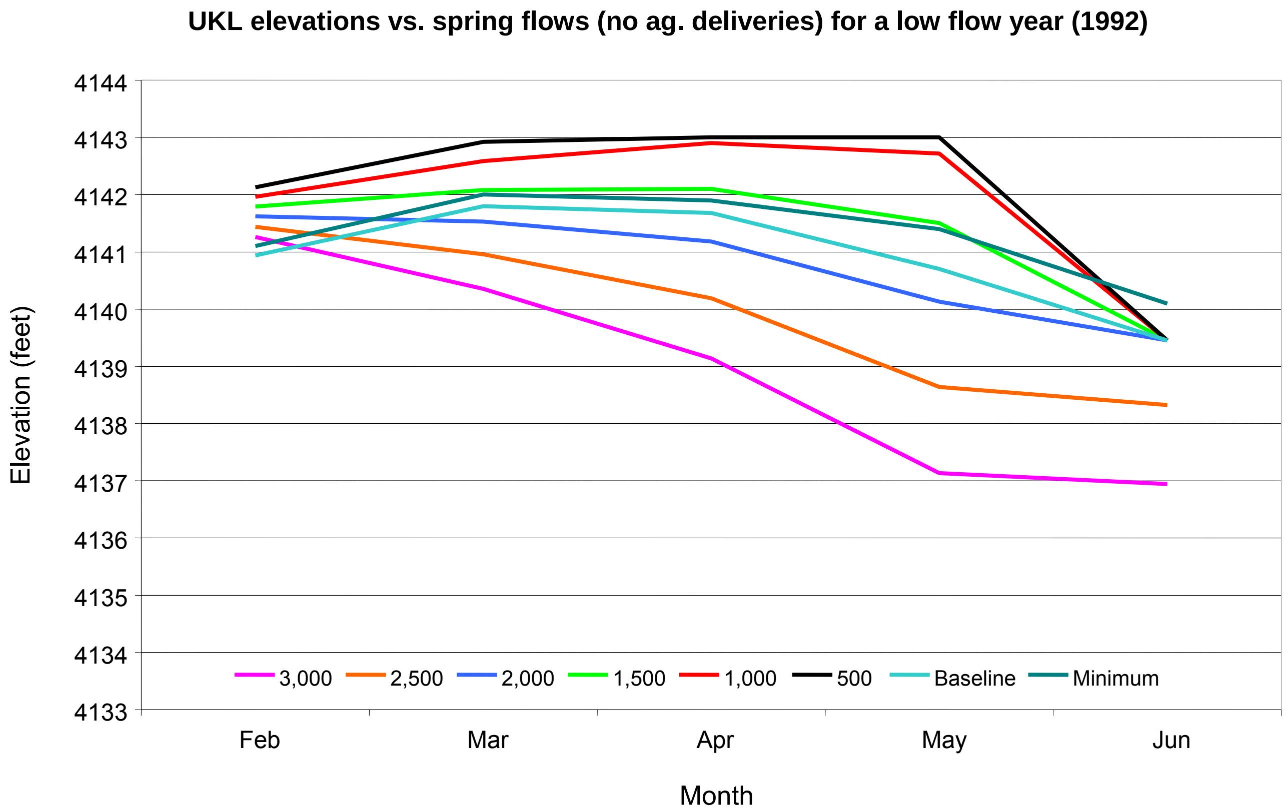

Figure 25. UKL elevations for spring flows without agricultural deliveries in low flow years.

Average Flow Years

Figure 26 shows the effects of varying flows incrementally from a base flow of 2,900 cfs during average flow years. Like low flow years, flows applied during the first four weeks of the spring season (February 15 to March 15) had little effect on predicted fish production. Fish habitat in the mainstem appears adequate at all flows for the number of juveniles there during this time period. Tributary fish have not entered the river to compete for available habitat. Flows applied during May also have little impact on fish production, as most of the fish have migrated and habitat is once again adequate for the number of fish present.

Flow has its greatest impact on predicted fish production during the period from March 15 to April 30 (weeks 4–10). Figure 27 is a 3D representation of the effects of flow and flow duration on simulated fish production. This figure shows the effects of flow timing as well. Because the base flow is higher, the effect of duration at low flows is greater than that for low flow years.

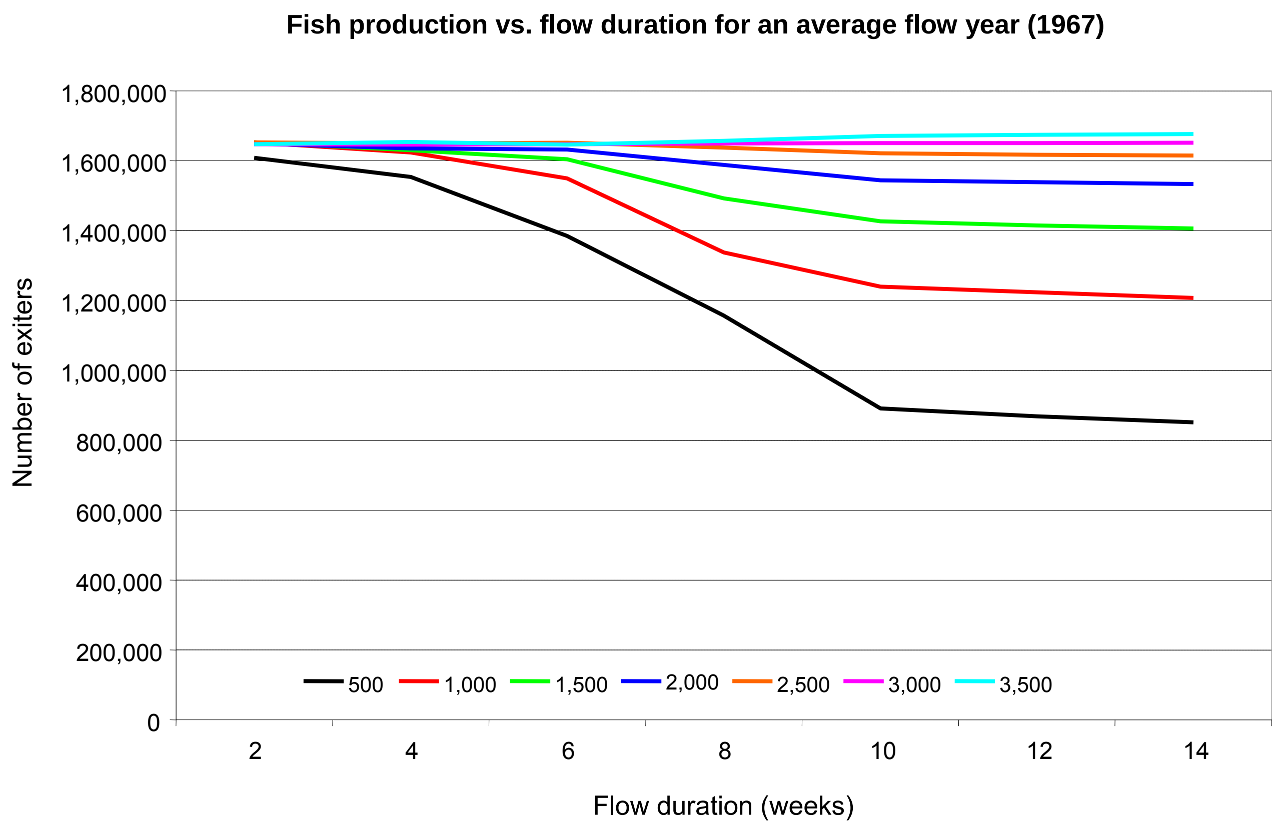

Figure 26. Number of fall Chinook juveniles predicted by simulations of altering spring flows from 2,900 cfs in increments of 500 cfs for durations of 2 to 14 weeks (February 15 through May 31).

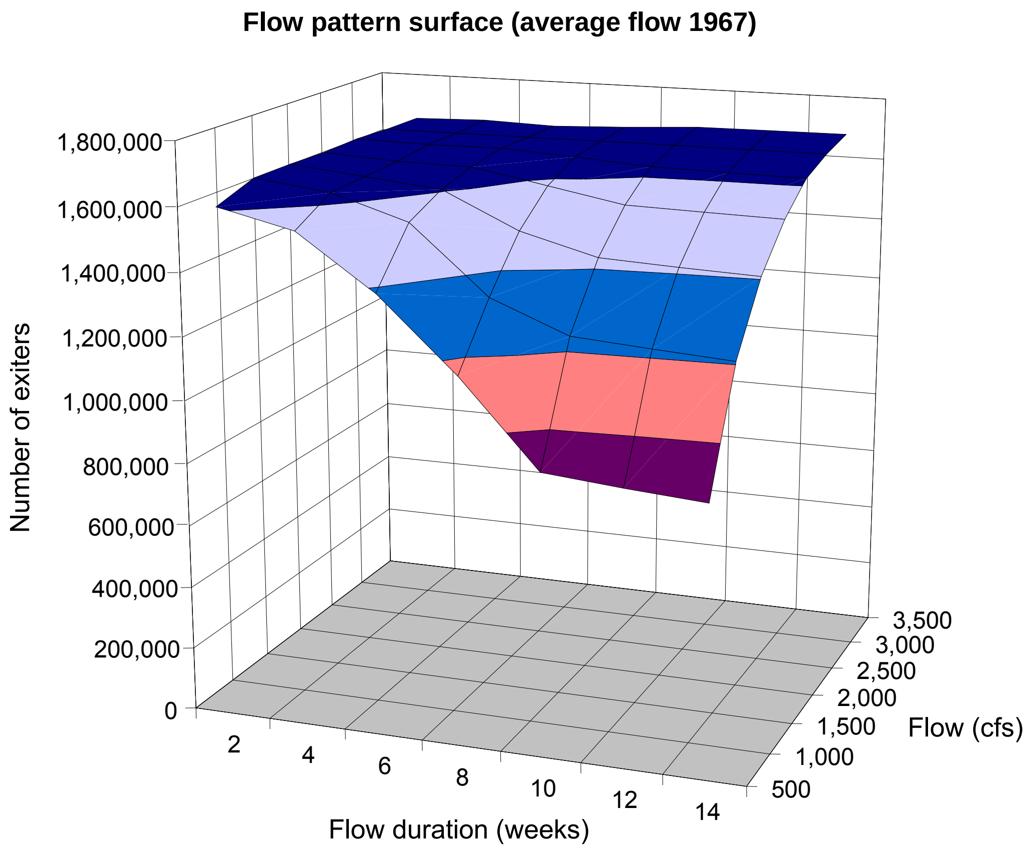

Figure 27. Flow pattern surface for average flow years illustrating both duration and flow effects on estimated fish production from February 15 through May 31.

As previously discussed, predicted habitat and temperature mortality have the greatest influence on simulated fish production for the Klamath River. Of these mortality factors, predicted habitat-induced mortality makes up the bulk of total simulated juvenile fish mortality, representing 78.1 percent of total mortality during flows of 3,500 cfs, and 87.4 percent during flows of 500 cfs. In contrast, predicted temperature mortality represents 14.9 percent and 9.1 percent, respectively, of total simulated fish mortality.

The SIAM simulation predicts that spring flows of 3,500 cfs will produce the most fish during average flow years. Applying spring flows of 3,500 cfs during average flow years can be maintained by allowing UKL to be drawn down to an elevation of 4,142.2 ft by the end of May, a half foot below the minimum elevation for lake suckers (4,142.7 ft). Table 10 shows the decrease in predicted fish production from reducing spring flows from 3,500 to 500 cfs. Augmenting flows beyond those released in 1967 results in only a slight improvement in predicted fish production. Figure 28 shows UKL levels through the spring months (February–June) for each of the spring flows simulated. Flows above 2,000 cfs will not allow UKL minimum elevations to be met while providing full agricultural delivery demands. When agricultural deliveries are shut off, flows up to 2,500 cfs can be released from Iron Gate Dam and UKL minimum levels can be met (fig. 29).

Table 10. Decrease in predicted fish production as flows are reduced in average flow years.

Spring flow (cfs)	Percent reduction from optimum (3,500 cfs)	Percent over baseline (avg. spring flow = 2,910 cfs)
3,000	1.1%	3.4%
2,500	4.0%	0.4%
2,000	8.6%	-4.4%
1,500	16.7%	-12.9%
1,000	28.8%	-25.5%
500	51.2%	-49.0%

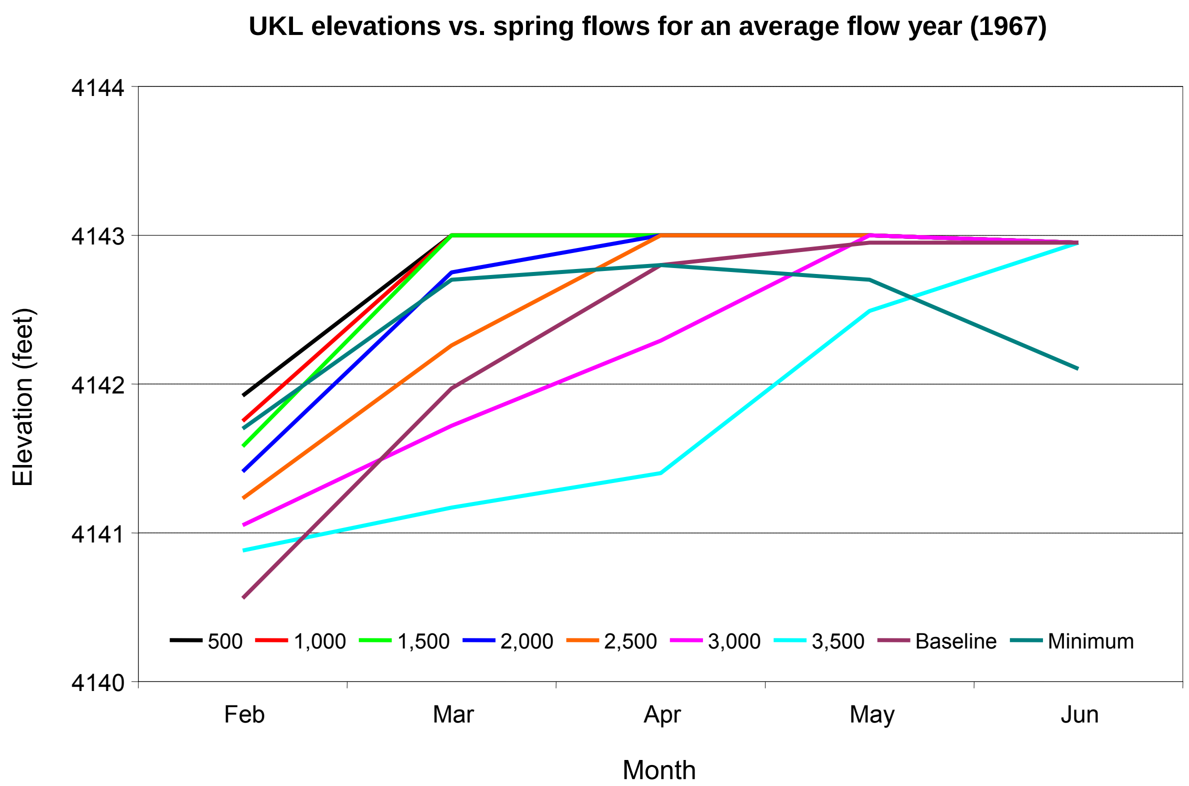

Figure 28. UKL elevations for spring flows with agricultural deliveries in average flow years.

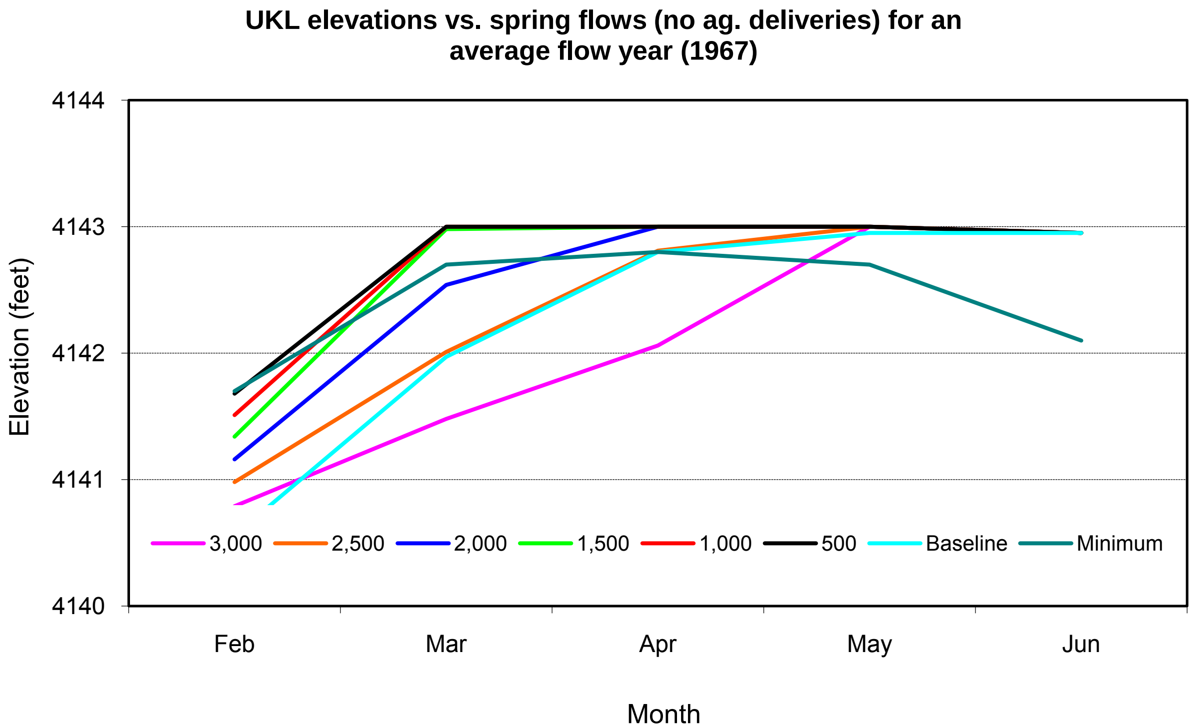

Figure 29. UKL elevations for spring flows without agricultural deliveries in average flow years.

High Flow Years

Figure 30 shows the effect of varying flows incrementally for a base flow of 5,700 cfs during high flow years. Like low and average flow years, flows applied during the first four weeks of the spring season (February 15 to March 15) had little effect on predicted fish production, apparently because fish habitat in the mainstem is adequate at all flows for the number of juveniles present, and tributary fish have not entered the river to compete for available habitat. Flows applied during May also have little impact on fish production, as most of the fish have migrated and habitat is once again adequate for the number of fish present.

Flow has its greatest impact on predicted fish production during the period from March 15 to April 30 (weeks 4–10). Figure 31 is a 3D representation of the effects of flow and flow duration on simulated fish production. This figure shows the effects of flow timing as well. The flow pattern surface is much flatter than that for low or average flow years (x-axis scale starts at 800,000 rather than 0), indicating that predicted fish production is less sensitive to changes in spring flow or duration for high flow years because the base flow is so much greater than in low or average flow years. There is no table accompanying the results for high flow years because the decrease in estimates of fish production as the base flow was reduced was relatively small (<22 percent at 500 cfs).

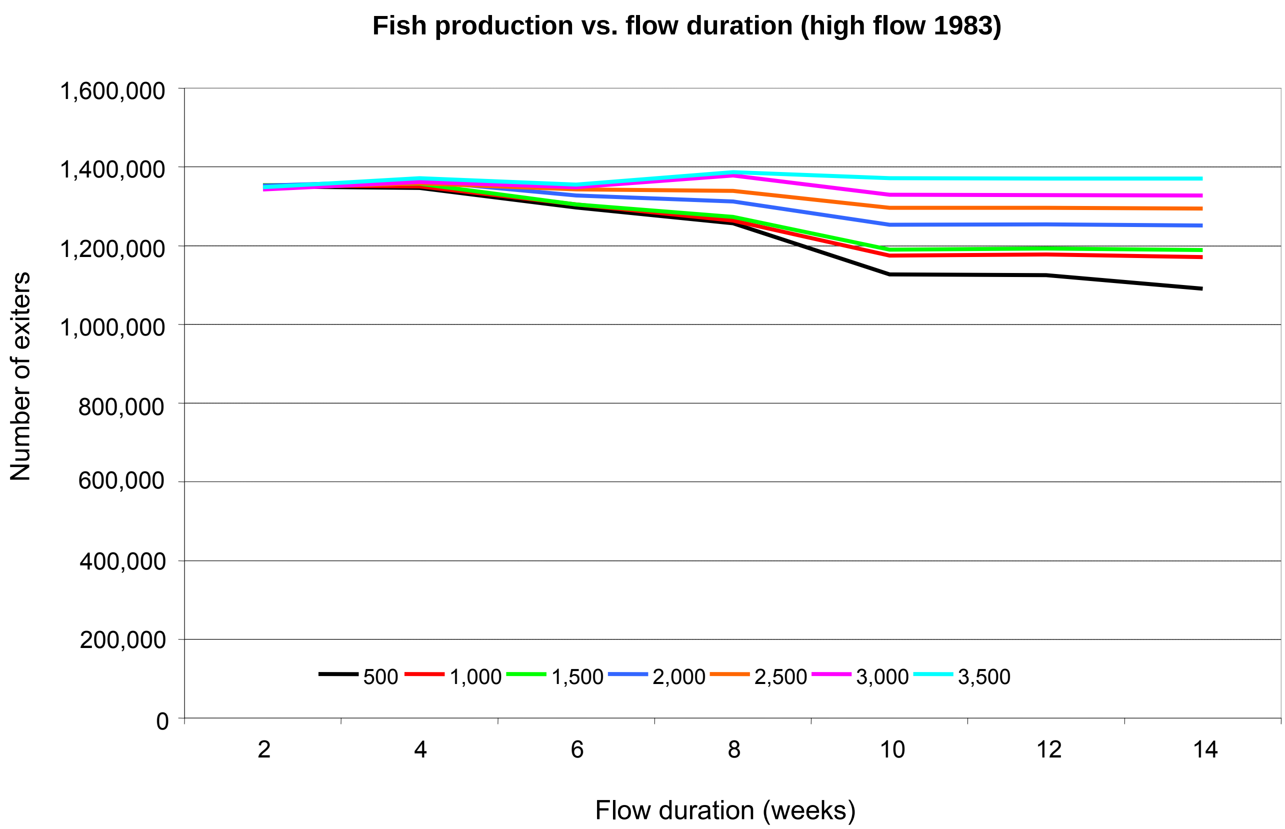

Figure 30. Number of fall Chinook juveniles predicted by simulations of altering spring flows from 5,700 cfs in increments of 500 cfs for durations of 2 to 14 weeks (February 15 through May 31).

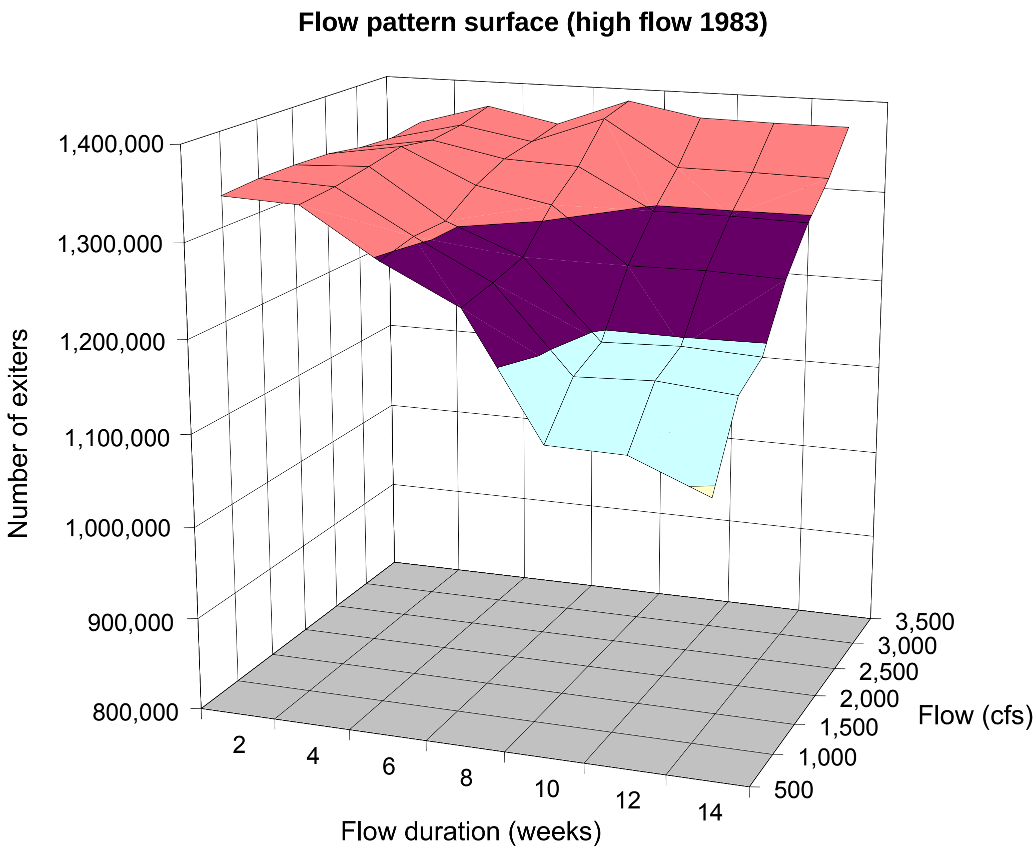

Figure 31. Flow pattern surface for high flow years illustrating both duration and flow effects on estimated fish production (February 15 through May 31).

Of the two main mortality factors, predicted habitat-induced mortality makes up the bulk of total simulated juvenile fish mortality, representing 72.2 percent of total mortality during flows of 3500 cfs, and 80.9 percent during flows of 500 cfs. In contrast, predicted temperature mortality represents 22.7 percent and 14.6 percent, respectively, of total simulated fish mortality.

The SIAM simulation predicts that spring flows of 3,500 cfs will produce the most fish during high flow years. Applying spring flows of 3,500 cfs during high flow years allows the UKL minimum elevations for lake suckers to be met both with and without agricultural deliveries. Figure 32 shows the UKL elevations for spring flows of 3,500 cfs compared to the minimums and baseline with agricultural deliveries.

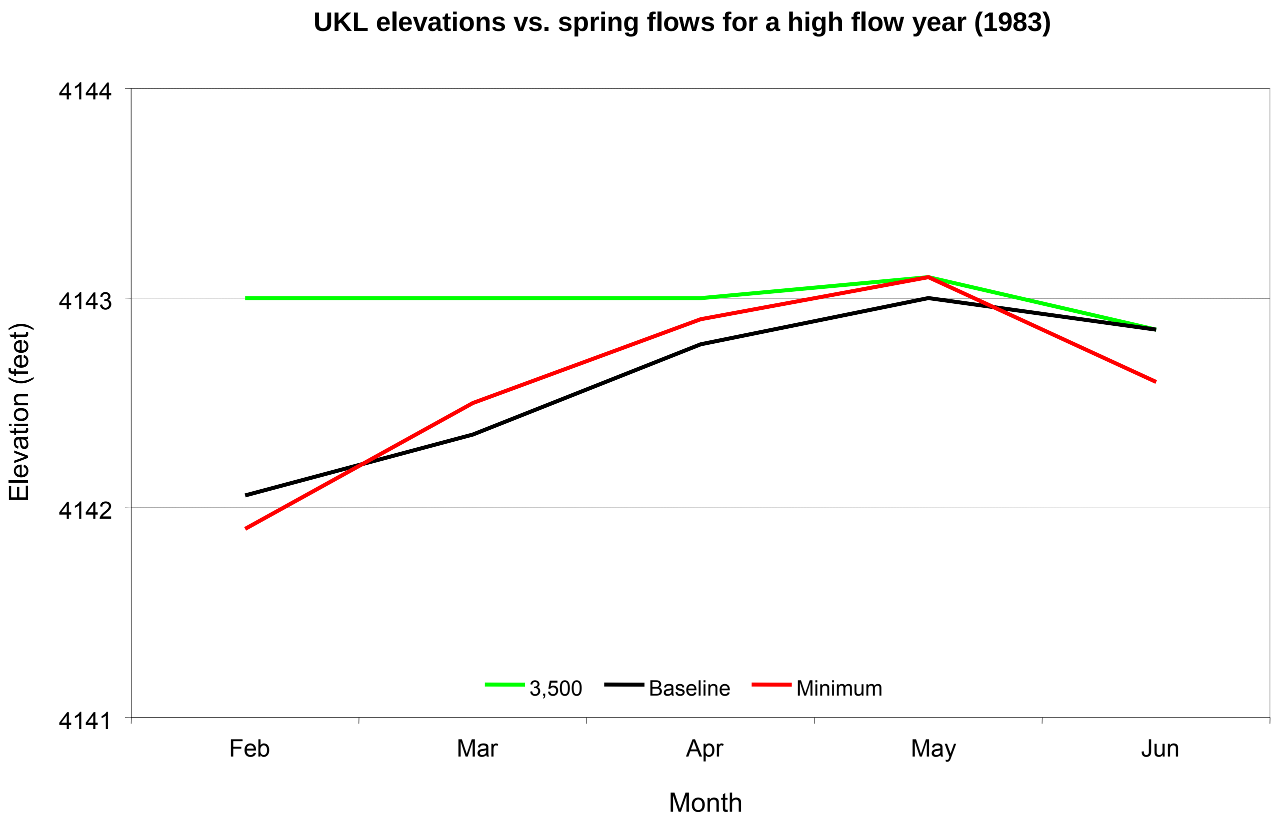

Figure 32. UKL elevations for spring flows with agricultural deliveries in high flow years.

Pulse Flow Simulations

Application of two-week pulses of 500 cfs during the spring (February 15–May 31) resulted in a 0.5 to 35.5 percent reduction in predicted fish production, depending on when pulse flows occurred. The greatest impact occurred during each of the two-week periods from March 16 to April 15. The least impact occurred during the month of May. Predicted fish production was reduced by 40 percent for a four-week pulse of 500 cfs in March, 38.9 percent in April, and 1.3 percent in May. Figures 33 and 34 show the response of predicted fish production to two- and four-week pulses of 500 cfs compared to a baseline spring flow of 3,000 cfs during the period from February 15 to May 31.

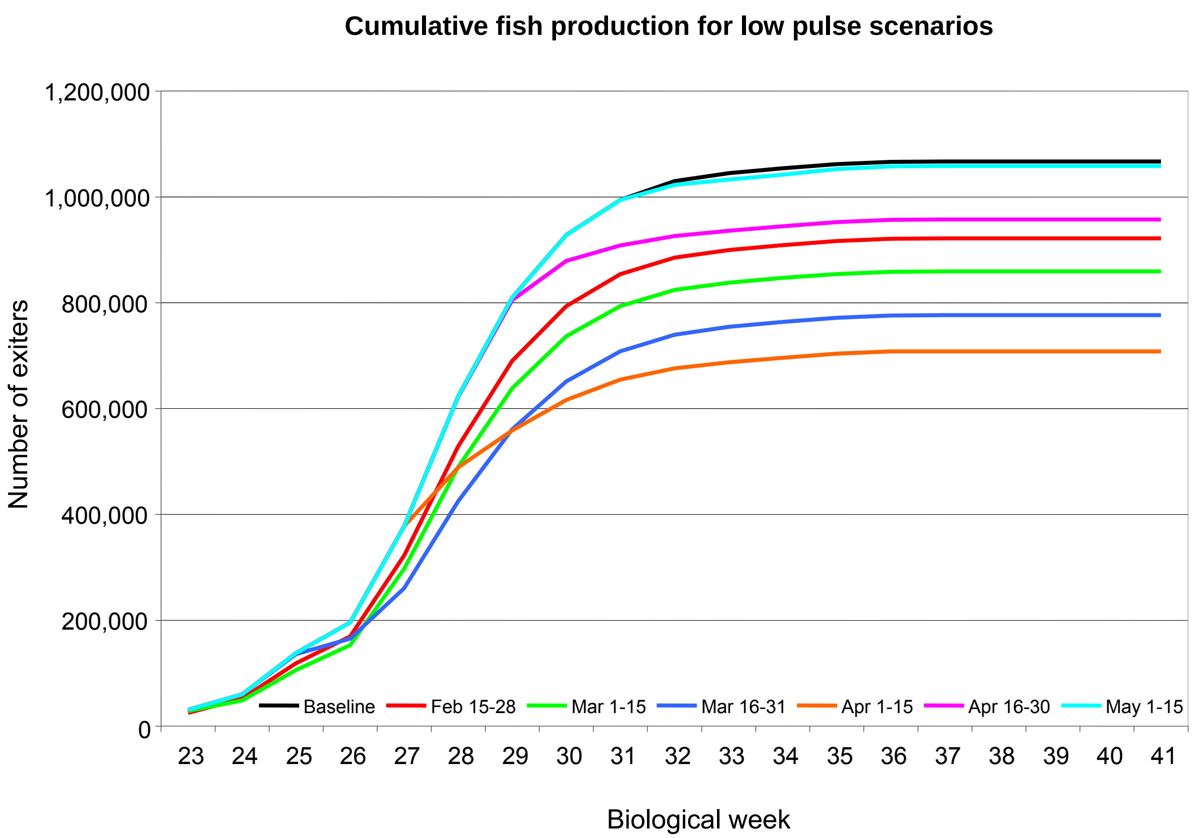

Figure 33. Predicted cumulative fish production for 500 cfs pulses of two weeks' duration.

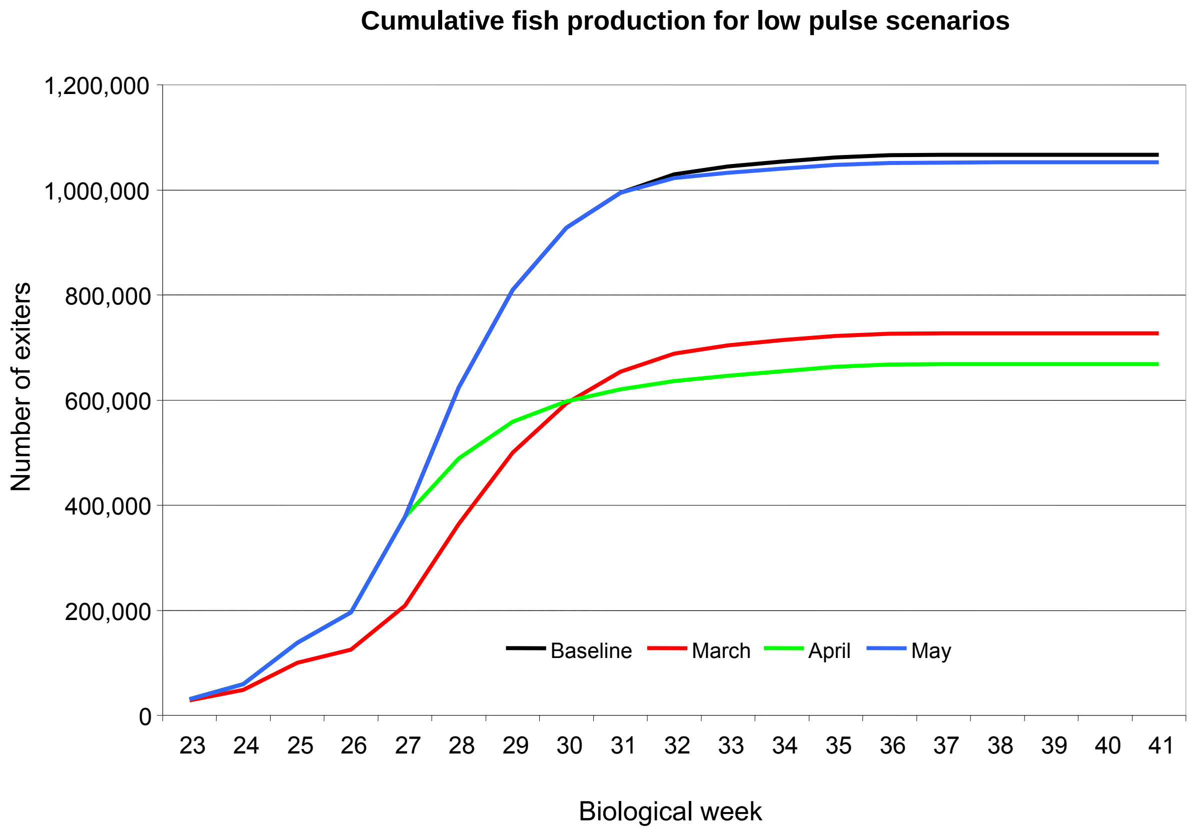

Figure 34. Predicted cumulative fish production for 500 cfs pulses of four weeks' duration.

The application of a 3,000 cfs pulse for two weeks during a low flow (600 cfs) spring season resulted in a response in simulated fish production ranging from a 5.2 percent decrease to an 18 percent increase compared to that predicted for flows of 600 cfs over the entire spring season (February 15–May 31). Decreases in predicted fish production occurred during the period from February 15 to March 15. Pulses applied in April resulted in the largest increases. The application of a 3,000 cfs pulse for four weeks resulted in an increase in predicted fish production of 1.2 to 30.3 percent depending on timing of pulse flows. Again, application of the pulse in April resulted in the greatest increase, followed by March and then May. Figures 35 and 36 show the response of predicted fish production to two- and four-week pulses of 3,000 cfs compared to a baseline spring flow of 600 cfs during the period from February 15 to May 31.

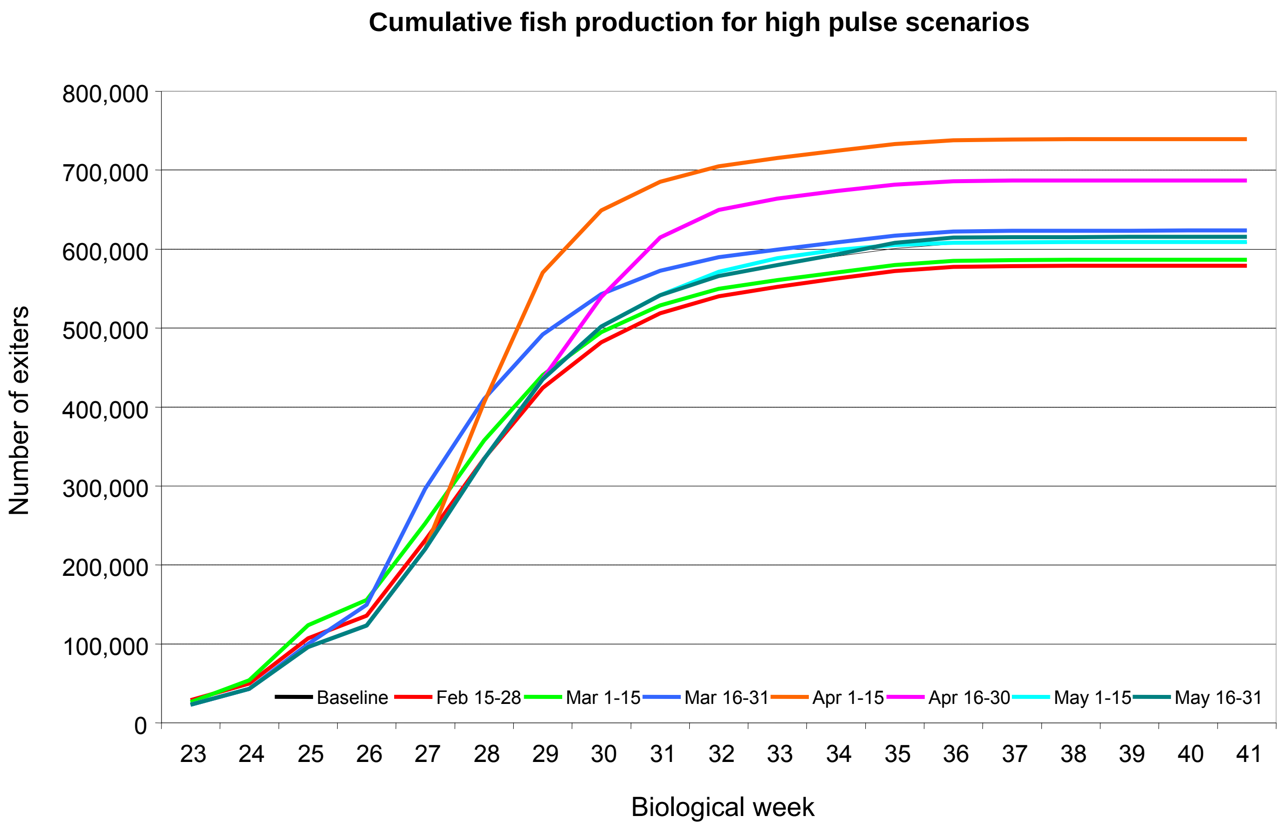

Figure 35. Predicted cumulative fish production for 3,000 cfs pulses of two weeks' duration.

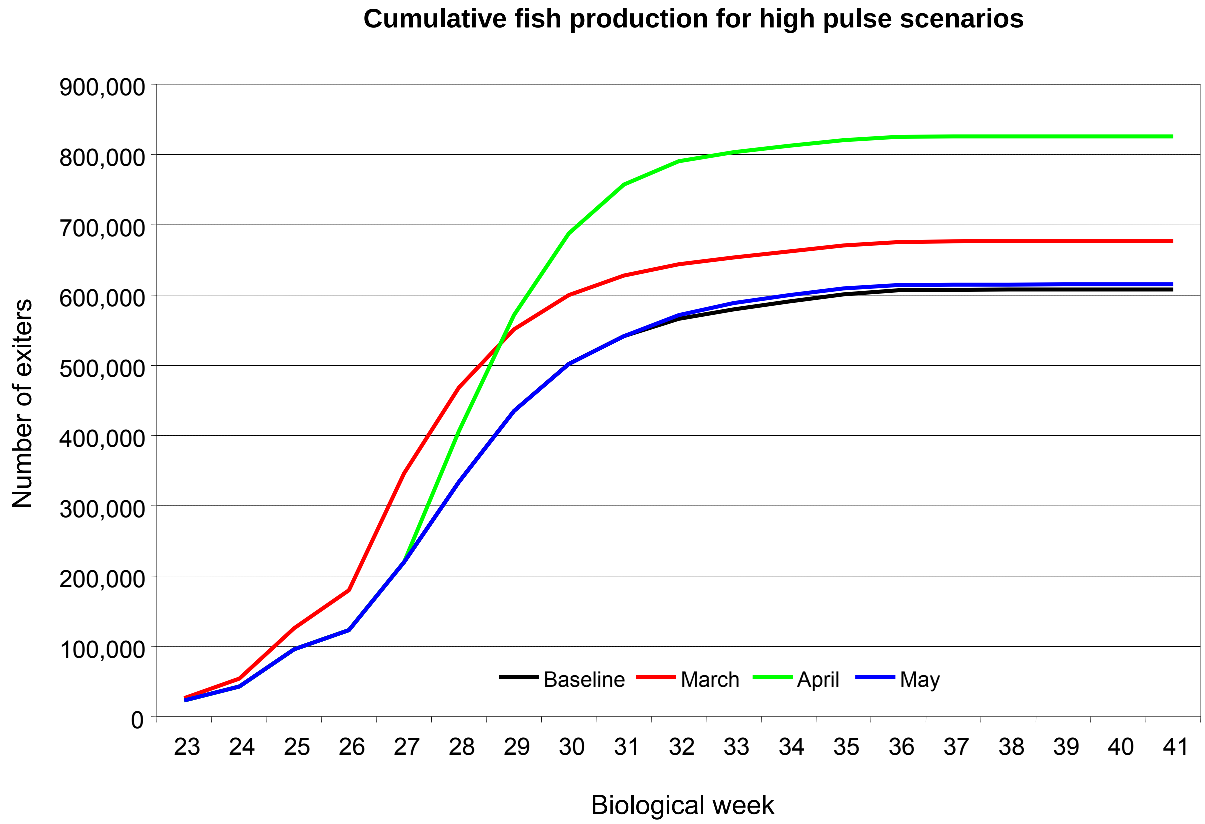

Figure 36. Predicted cumulative fish production for 3,000 cfs pulses of four weeks' duration.

The application of a 6,000 cfs pulse for two weeks during a low flow (600 cfs) spring season resulted in a response in simulated fish production ranging from a 12.3 percent decrease to an 11.9 percent increase compared to that predicted for flows of 600 cfs over the entire spring season. Decreases in predicted fish production occurred during the periods from February 15 to March 31 and May 1 to May 15. Pulses applied in April resulted in the largest increases although not as great as for pulses of 3,000 cfs. A 6,000 cfs pulse had the most positive impact during April while a pulse in May had little effect. Figures 37 and 38 show the response of predicted fish production to two- and four-week pulses of 6,000 cfs compared to a baseline spring flow of 600 cfs during the period from February 15 to May 31.

2006 Operations Plan Scenarios

Low Flow Years

Maintaining optimum spring flows of 3,000 cfs during low flow years results in the lowering of UKL elevations well below the minimums established for lake suckers. A reduction in predicted fall Chinook production of 66.1 percent of that for optimum flows occurs when minimum UKL elevations are maintained and agricultural deliveries are made. This decrease is reduced to 34 percent when agricultural deliveries are not made. Relaxing the UKL minimums by 1 or 2 ft as well

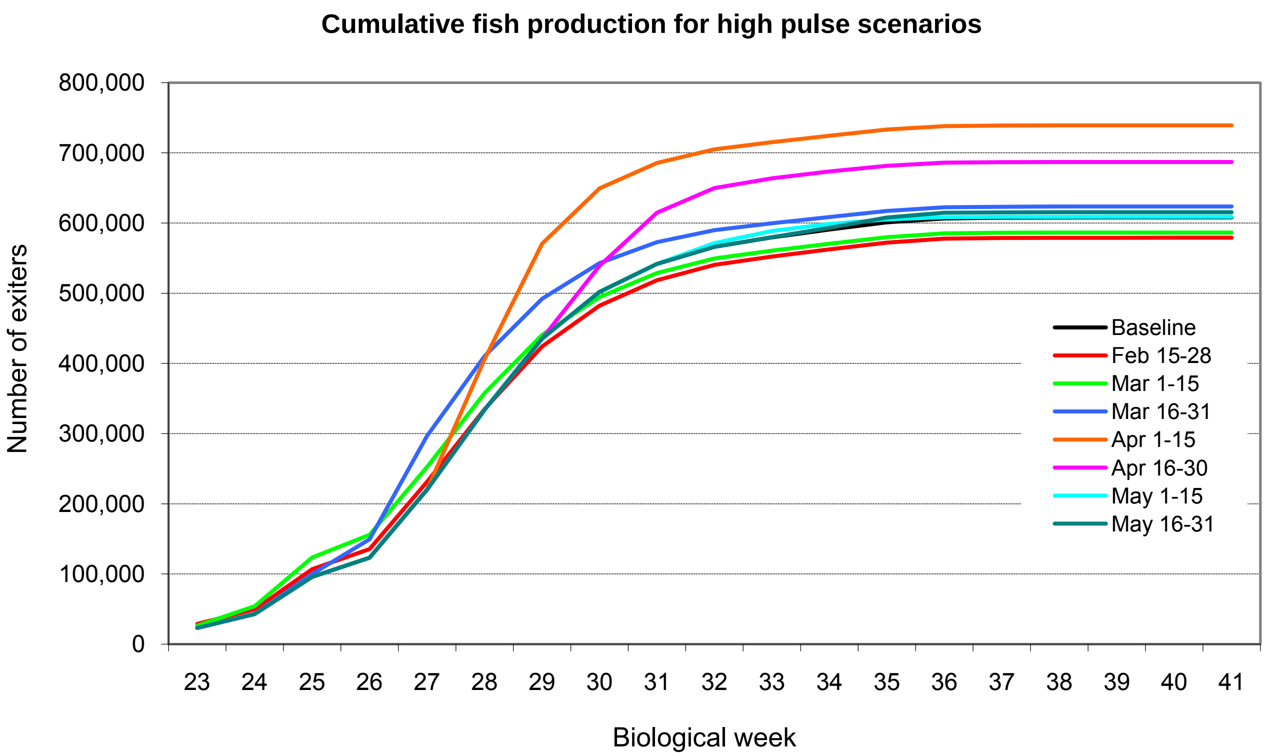

Figure 37. Predicted cumulative fish production for 6,000 cfs pulses of two weeks' duration.

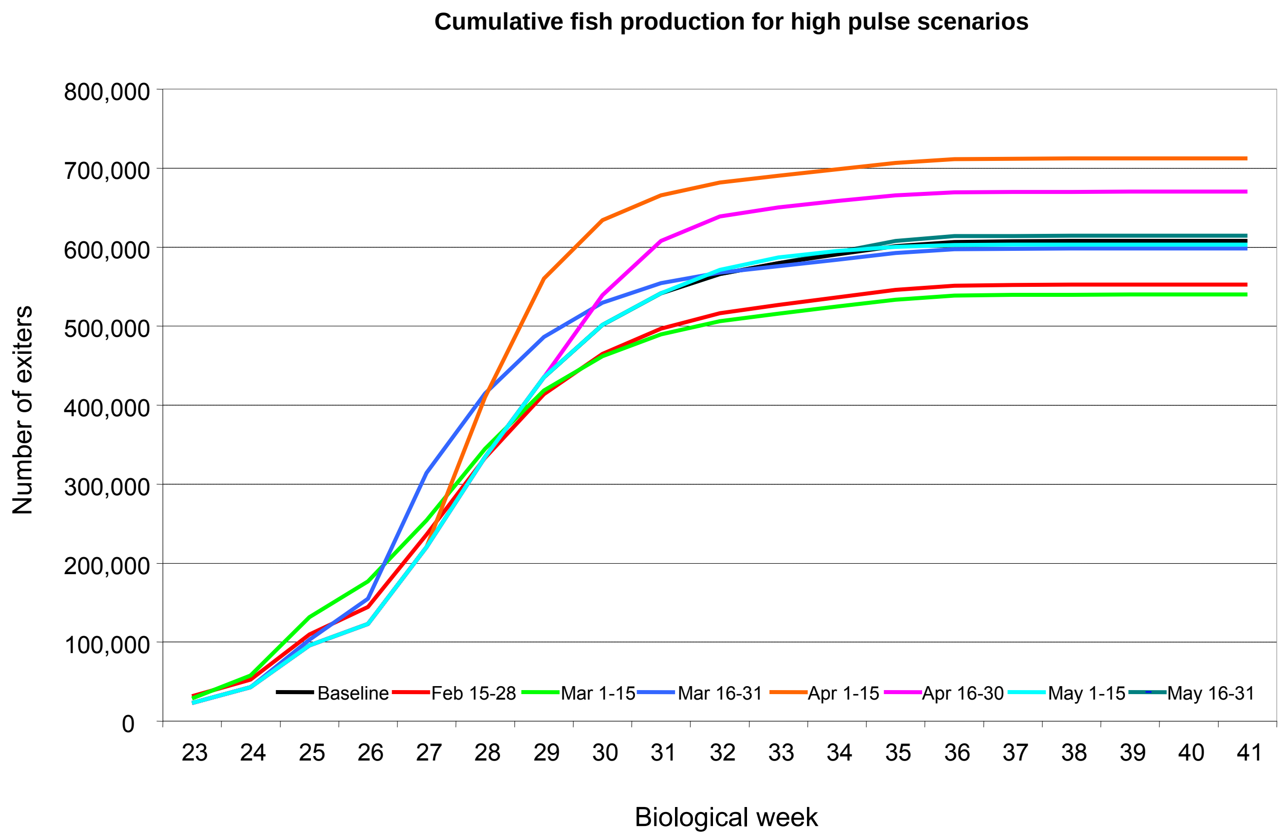

Figure 38. Predicted cumulative fish production for 6,000 cfs pulses of four weeks' duration.

as shutting off agricultural deliveries further lessened the decrease in production from predicted maximum fish production to 11.1 percent and 3.9 percent, respectively.

Figure 39 shows the predicted effect on cumulative fish production of maintaining UKL at different elevations.

During an average flow year, predicted cumulative fish production for the following scenario—using spring flows of 3,500 cfs, maintaining UKL minimum elevations only, and limiting Iron Gate discharge to the 2006 Klamath Project Operations Plan values (along with UKL minimums)—was within ±3.5 percent of the baseline. Figure 40 shows predicted cumulative fish production for these three scenarios for average flow years. Maintaining UKL minimums and allowing excess water to be sent downstream results in a decrease in predicted cumulative fish production of 38.8 percent over an optimum flow of 3,500 cfs during high flow years. Restricting Iron Gate discharge to those values in the Operations Plan reduces that decrease to 12.5 percent. If water is discharged from Iron Gate Dam at 3,500 cfs for the spring period, the simulated cumulative fish production is within 2 percent of that associated with the optimum flow schedule.

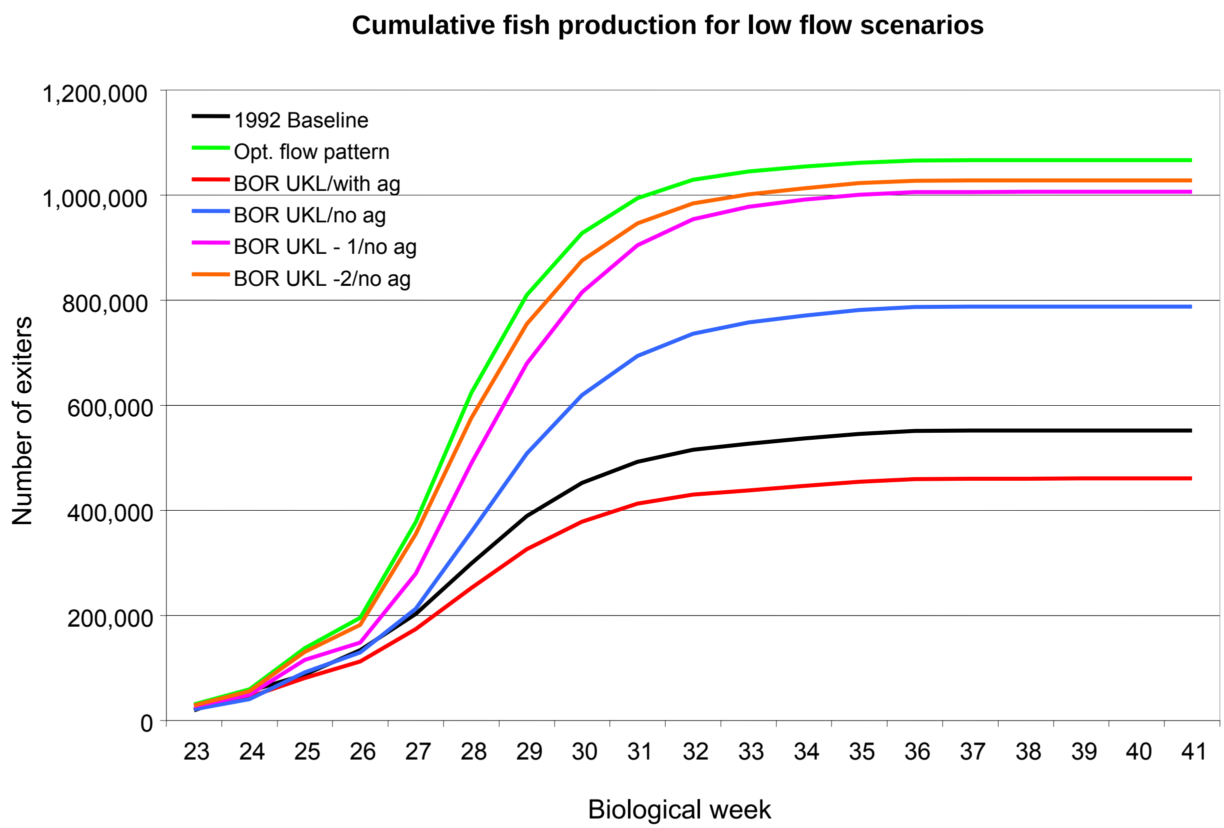

Figure 39. Predicted cumulative fish production for different Klamath Project management scenarios.

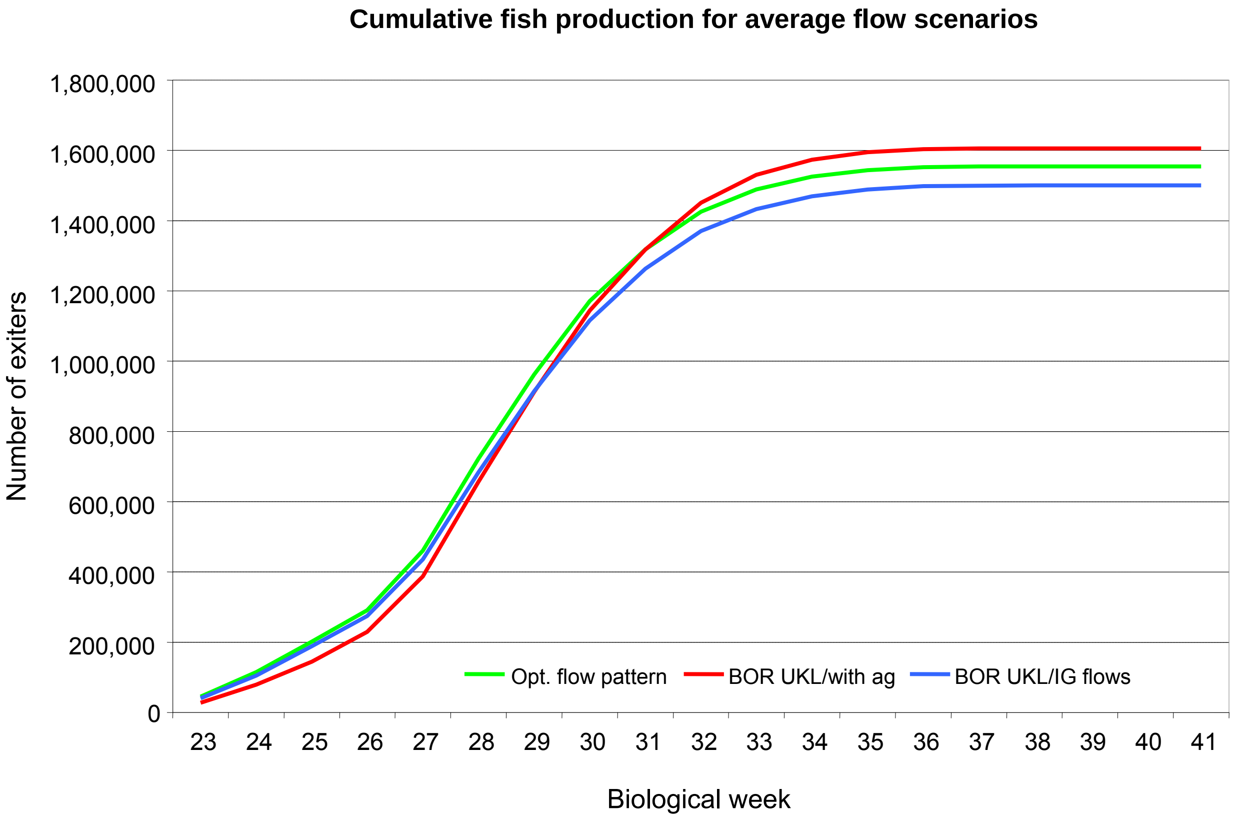

Figure 40. Predicted cumulative fish production for three average flow year scenarios.

Conclusions

Flow-Only Manipulation

What is the effect of potential discharge variation on water temperatures below Iron Gate Dam? Results from simulations that varied only flow confirm the conclusion of Campbell and others (2001) that reservoir operations and flow management are likely to yield only small effects on water temperatures in the Klamath River below Iron Gate Dam. Figures 3 and 4 illustrate that the thermal effect due to discharge alone (as captured by the trend lines) is much less than the thermal effect induced by the historical interannual meteorological variability (as captured by the predicted dispersion around the trend lines). Reducing flows from 2,500 cfs to 500 cfs was shown to postpone warming to 15°C in the spring and hasten the date at which temperatures cool below 20°C in the late summer, in effect shortening the high-temperature summer season by about 7 days in the spring and 9 days in the fall (average derived from trend lines in the bottom two graphs of figure 5). Such information may be useful in light of the warming and consequent lengthening of the high temperature season that has occurred in the Klamath Basin over the last 40 years (Bartholow, 2005). Though we did not evaluate monthly flows greater than 2,500 cfs because too many of our simulations ran out of water when this flow was maintained year-round, it would not be difficult to do on a case by case basis as warranted. In general, figure 3 provides a good indication of the expected direction and magnitude of change.

Are these potential release temperature changes important? It is apparent that during certain times of the year, releasing more water below Iron Gate would generally be expected to increase water temperatures while during other months the effects are to cool the stream. In yet other months, there is virtually no discernable effect. When they occur, temperature changes may be up to 4°C due solely to flow variation but the incremental effect of flow variation is relatively small. For example, increasing flows in June may be expected to increase water temperatures by only 0.41°C per 500 cfs increment. These temperature differences would be even smaller farther below Iron Gate. In context, the simulated mean June temperature below Iron Gate over the 43-year period was 17.7°C (ranging from 15.5 to 21.7°C). Some individual measured (not simulated) maximum daily values have been recorded as high as 22.0°C in June. When water temperatures are relatively cool (or perhaps even average) for this time of year, a small temperature increase may pose less of a biological problem than when temperatures are already far outside an optimum growth range, if not acutely lethal, for salmonids rearing in or migrating through the mainstem Klamath River (Richter and Kolmes, 2005).

What are the mechanisms responsible for the trends apparent in the results of the flow-only simulations? Unlike the thermal response of systems with large reservoirs having significant volumes of hypolimnetic (cold-water) storage, the fundamental response of Iron Gate release temperature to discharge on the mainstem Klamath River appears related to how much (and how quickly) water from UKL homogenizes water temperatures downstream. In other words, as flows increase down the mainstem, UKL's release temperature increasingly governs downstream reservoir and river temperatures and reduces the thermal lag induced by the downstream reservoirs. Thus, any water management decision meant to address downstream river temperatures, either for rearing juvenile salmon or upstream migrating adults, must pay attention to water temperatures in UKL. Though short term (2–3 week) temperature modifications may be achieved through reservoir and flow management, the long-term thermal signature will be governed by the dominant thermal source—UKL. Residence time through the downstream reservoirs is insufficient to provide much more thermal buffering than the approximate 18-day phase delay found by Bartholow and others (2004), though the delay interval will depend on flow rate and downstream reservoir volumes. Evidence of this conclusion may be inferred by looking at the unblended 700 and 1,300 cfs traces in figures 6 and 7 that illustrate exhaustion of the cool water pool in approximately two weeks time.

So what controls UKL release temperatures? Wood and others (1996) investigated the relationship between water surface elevations in UKL and selected water quality variables. They concluded that the temperature of this large (363 km^2, or 140 mi^2) but generally shallow (mean depth 2–3 m, or 6–10 ft, depending on elevation) lake is unlikely to be a function of lake level. Instead, UKL's water temperature dynamic was found to be strongly influenced by air temperature with a time lag of only a few days. Knowing this, is it possible to develop potentially useful management guidance? Continuing with the above line of reasoning, it is logical to ask when, and by how much, are water temperatures emanating from UKL generally warmer than Iron Gate release temperatures. A graph of measured (not simulated) mean weekly water temperature differences is shown in figure 41.

Weekly measured temperature differences

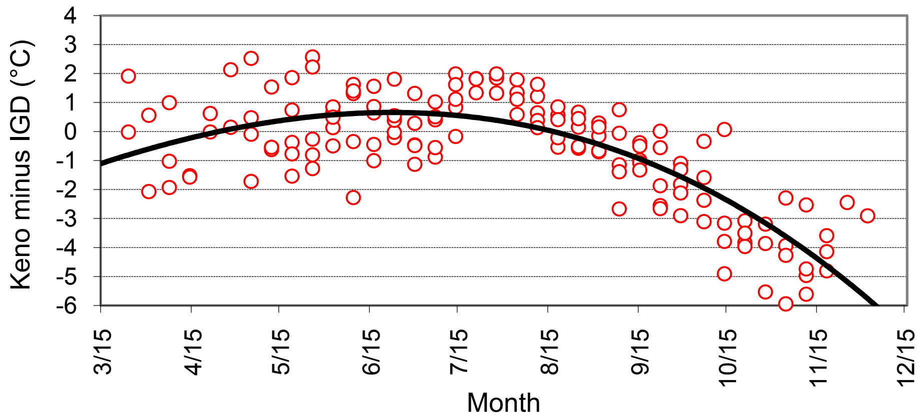

Figure 41. Measured mean weekly water temperature differences, from data collected by USGS and partner agencies from 1996 to 2001. Plotted values are the Keno, OR., temperature 37.5 km (23.3 mi) below UKL minus Iron Gate release temperatures. Solid trend line is a simple polynomial fit. Temperature data were not sampled regularly at both stations, especially from mid-winter to early spring.

There is considerable scatter in the figure, but generally speaking, releases from UKL tend to be warmer than Iron Gate releases from early May to late August. UKL releases are cooler the remainder of the year, especially after mid-September. When UKL releases are warmer than Iron Gate's releases, it will be difficult to cool the river below Iron Gate for more than about two weeks, if at all, because the only source of colder water readily available is that stored in Iron Gate Reservoir. Conversely, when UKL temperatures are typically below Iron Gate release temperatures, September and October for example, one might expect that increasing mainstem flows would have a substantial cooling effect such as that evident in November (fig. 3). The lack of sensitivity in September and October is likely due to both the buffering provided by hypolimnetic pool early in the fall and the general lag times we have discussed. Once Iron Gate turns over sometime in mid-October, the thermocline is destroyed and upstream inflow temperatures can more readily dominate outflow temperatures.

We had hypothesized that higher flow volumes would supplant ambient meteorological effects as the dominant factor controlling release temperatures such that increasing flows from 500 to 2,500 cfs would reduce or dampen the range of resulting release temperatures, if not their absolute values. This did not prove to be the case. In fact, there is some indication in figures 3 and 4 that just the opposite occurs from September through December, even though it was often impossible to supply very high flows in times of drought. A partial explanation for this may be what we mentioned earlier, namely that high flows more efficiently transport UKL release temperatures downstream, and these releases are themselves more thermally variable because of UKL's rapid response to ambient meteorological conditions. Low flows, in contrast, result in stabilizing release temperatures due to higher reservoir residence time. What we cannot yet explain is why other months do not exhibit this behavior to the same degree. Reservoir interflow or density currents through the reservoirs may play a role. However, an even more careful examination of figures 3 and 4 suggest that although the range of release temperatures may not dampen at higher flows, their absolute maxima may in some cases. For example, focusing on the October graph in figure 3, the absolute maxima across the range of flows appears to reach an asymptote, whereas the absolute minima exhibit a decline. This model prediction could bear additional scrutiny.

In retrospect, the maximum monthly water temperatures did not prove to be a useful metric in assessing the flow-only simulation results. This is because when seasonal temperatures are increasing, the maximum monthly water temperature is very likely to be at or near the end of each month, whereas when seasonal temperatures are decreasing, the maximum monthly water temperatures are likely to be at or near the beginning of each month. For this reason, we believe that the mean monthly temperatures are a better metric to use in discerning functional relationships. However, mean monthly water temperatures are not immune from their own set of problems. Though they nicely integrate the results, mean monthly water temperatures are not fully independent of modeled conditions in the previous month.

What opportunities might there be in controlling release temperatures by modifying the dams' intake works? Scoping revealed that biologically meaningful temperature changes seemed possible only in the fall, by reducing flows below currently prescribed minimum flows and only by blending water from near the surface with lower-level intakes. Blending water from two different depths in Iron Gate Reservoir during September could have the potential to keep temperatures in a more favorable range for fall Chinook salmon spawning under a wide range of hydrologic and meteorologic conditions, but not all. The exception was a single year, 1998, when predicted mean monthly release temperatures exceeded the likely upper limit for spawning, 18.9°C, but not necessarily for adult migration. Blending was also predicted to result in cooler end-of-month releases. In general, all of the intake and spillway blending simulations produced a release temperature below 18.9°C, again with the exception of a single year, 1998. If unblended water was abruptly released from lower in Iron Gate's pool, release temperatures during September would exhibit a very abrupt cooling followed by an abnormal warming trend through the month instead of the typical cooling trend. From a fisheries perspective, being able to provide relatively uniform river temperatures for spawning fall Chinook salmon may be more desirable than providing a much cooler temperature at the beginning of September that increases rapidly for the remainder of the month.

All uses of simulation models must recognize uncertainty. Because one of our objectives was to increase the range of alternatives examined, we relaxed recent operational constraints and applied the models outside the range of conditions for which they had been calibrated. Unlike simple statistical models, physically-based models like those we used are commonly considered more trustworthy, or robust, in extrapolating outside the calibration domain. However, almost by definition, because our simulations explored water management options and structural modifications that have not been tried, we can offer no conclusive proof of their accuracy. For the flow-only scenarios, the models are consistent with the measured data. Figure 42 focuses on September's flow vs. temperature predictions with an overlay of measured data. One can see that it would be difficult to derive a statistically meaningful trend from the measured data alone. We also acknowledge that not every option we simulated may be physically or institutionally possible, especially under extreme water supply or water demand conditions. For example, figure 42 illustrates that in this managed river mean monthly flows were confined to a range of 700 cfs or above 2,100 cfs for the month of September during the period of record (1961–2003). In fact, the FERC flow target for the month of September below Iron Gate Dam is approximately 1,300 cfs, and therefore the data are clustered around that value simply because flow releases are managed to achieve that value in many years.

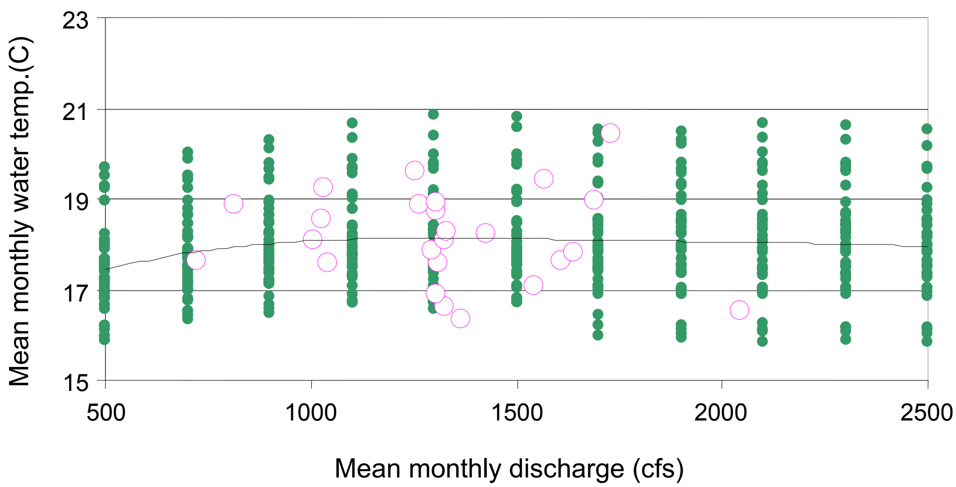

Figure 42. Measured mean monthly water temperatures (open circles) superimposed on September's flow vs. Iron Gate release temperature plot from figure 3 from the flow-only scenarios.

Structural Modification

For the structural modification scenarios, we acknowledge more uncertainty. HEC-5Q was once a state-of-the-art reservoir model and remains in widespread use today in spite of no longer being publicly supported (Deas and Lowney, 2000). However, other reservoir operations models (for example, CE-QUAL-W2; Cole and Buchak, 1995) have largely superseded HEC-5Q in simulating detailed multi-level intake structures because of superior near-field hydrodynamics, especially in smaller reservoirs (such as Iron Gate) where longitudinal temperature gradients may be important. During calibration, we deliberately gave more weight to model accuracy for release temperature from the existing structure and paid less attention to matching the reservoir's thermal structure. Nonetheless, our results are intended to improve understanding of the Klamath River system and offer information to those who will make water management decisions. Our modeling is intended to evaluate water management options at a *planning* level. Though we believe HEC-5Q continues to be quite capable of predicting the approximate magnitudes and trends of alternative reservoir operations and intake designs, we acknowledge that given the expense of any contemplated retrofit, our assessment of the multi-level withdrawal scenarios should be independently confirmed using a contemporary reservoir operations model. The CE-QUAL-W2 model of Iron Gate Reservoir assembled (PacifiCorp, 2005) could be applied for scenarios similar to those we have evaluated.

It is possible that innovative water management alternatives and/or multi-level intake retrofits at Iron Gate Dam could have beneficial effects on water temperature for salmon for some distance downstream during certain months of the year, particularly early fall. In both cases, potential temperature improvements would generally be less than 4°C and of relatively short duration (approximately two to four weeks) as Iron Gate's cool water pools are depleted. However, mitigating elevated water temperatures is but one element needing attention on the Klamath River. In this paper we have ignored the effects of flow modifications on other environmental components important in the life history of Chinook salmon. For example, river flows are known to impact the amount of fish habitat available for spawning, rearing, and migration (Stalnaker and others, 1995) and potentially disease prevalence or virulence. Any water management decisions should integrate both flow and water quality (water temperature at a minimum) into a mix that addresses the desired goals. Though we have illustrated potential thermal benefits of reducing flows below current FERC-stipulated minimums in September, such flows may not be acceptable for other reasons. Further, alterations to dissolved oxygen and potential impacts to cool water delivery to the existing fish hatchery would likely accompany any increase in hypolimnetic releases. Assessing the full suite of benefits, costs, and consequences of both flow and temperature modifications is well beyond the scope of this report.

Reservoir Storage

Using SIAM to explore the potential of using FAS in Copco and Iron Gate Dam Reservoirs as an additional source of water for spring flows was feasible. However, increasing discharge from Iron Gate Dam by approximately 200 cfs for up to a month could result in several potentially adverse consequences. First, a positive predicted response (increased production over the historical baseline) was observed only in dry, warm years and in the March–April or March-only simulations. Second, using the FAS may eliminate the thermal buffer that the reservoirs can provide and lead to increased water temperatures and increased mortality for juvenile fall Chinook salmon life stages in most of the simulation results. Third, since there was no incentive in the SIAM model to re-fill the reservoirs, in most simulations, the reservoir water surface remained at minimum pool for the remainder of the simulation period. In the real world, that would result in undetermined losses of power generation revenue. Finally, if the model is forced to re-fill the reservoirs after using the FAS, then flows below Iron Gate Dam are reduced for one month to allow the water surface elevation to come up to full pool. As a potential management technique, reservoir storage can be utilized under very limited or otherwise special circumstances, but as a long-term or habitual source of spring flow augmentation, it appears that the adverse consequences may well outweigh the benefits for fall Chinook salmon downstream of Iron Gate Dam

Spawning and Outmigration Timing

The spawning and outmigration timing modeling analysis was a classic model gaming exercise intended to explore a “what if” scenario. What if water temperatures were cooled in some fashion, such as removing dams, using groundwater pumping or off-stream cooler water sources? SALMOD analysis results indicated that if cooler water temperatures were available in the Klamath River below Iron Gate Dam in September, then greater fish production could result compared to the current October spawning period. If fish spawned in September in these simulations, then emergence also occurred earlier, by as much as 8 weeks, with outmigration beginning in late December. The SALMOD model also predicted the juvenile fall Chinook life stage temporal occupancy period would be extended. Thermal mortality could be reduced by 3–7 percent and exposure to spring temperature exceeding 10°C would be reduced by 8–12 percent. The overall results of advancing spawning, emergence, and outmigration were to increase predicted fish production by 38 percent and to increase the average weight of migrating juveniles by 13–22 percent. If more fish and bigger fish were produced, then perhaps the ocean survival rate would also increase.

Although we have discussed how the river might be cooled using multi-level outlets, particularly in September, whether fall Chinook salmon could take advantage of those altered thermal conditions is another issue. Iron Gate Dam is 305.7 km (190 river miles) upstream from the river mouth and the cooling effect of a multi-level outlet would persist for only a portion of that 305.7 river kilometers. USGS estimates of downstream cooling (Bartholow and others, 2004) indicates that significant cooling (>1 °C) would be unlikely to persist downstream to the Seiad Valley stream gage. Fall Chinook salmon preparing to spawn in the Klamath River would have to pass through a zone of water temperature at or above the maximum tolerance limit of 18.9 °C (Bell, 1973; McCullough, 1999), travel upstream for distances of up to 241+ km (150+ miles) from the ocean to reach river segments that provided cooler conditions for spawning. However, for a long-term management objective, reducing water temperature in the Klamath River in September may have some benefits for fall Chinook salmon production, if they could take advantage of the improved spawning conditions.

Spring Flow Variability

In general, flows that are restricted to <2,000 cfs during October and November produce the best predicted fish production by providing the most spawning habitat. In the various simulations of flow in the Klamath River, simulated fish production appeared to be relatively insensitive to flow levels during the winter months (December–February). During low flow year simulations, any increase in flows above 1,000 cfs during the spring months (March–May) resulted in significant improvements (20 to 118 percent) in fish production over baseline predictions. Simulation results for all year types indicate that spring flows of approximately 4,000 cfs maximize predicted fish production.

In the fish production model, SALMOD, flow variability primarily affects habitat availability. Fall flow influences spawning habitat while spring flow influences juvenile rearing habitat. Differences in simulated fish production were very sensitive to spring flow levels. The ratio of maximum (4,000 cfs simulation) to minimum (500 cfs simulation) predicted out-migrating fish numbers was 7.3 to 9.7 for all flow year types. In other words, 4,000 cfs in any year type resulted in 7.3 to 9.7 times the number of predicted out-migrating fish.

Results of various simulations may indicate that the relative insensitivity of simulated fish production to winter flow levels greater than 1,000 cfs offers the opportunity to conserve water during those months (December–February) for later release in the spring. However, the ability to regulate spring flows to levels 4,000 cfs or less may not be possible during high flow years due to the lack of storage capability on the Klamath. Results also indicated that improvements in simulated fish production over that for baseline conditions can be achieved even at higher than optimum flows. Low flow year type simulations indicated that significant improvements in predicted fish production may be achieved with flows as low as 1,500 cfs during March and April.

Incremental Spring Flows

SIAM simulations where pulsed flows were applied during the period from February 15–March 15 had minimal effect on predicted fish production for all flow year types. Pulsed flows have their greatest impact on simulated fish production during the period from March 15–April 30 in all flow year types. Flows applied during May have minimal effect on predicted fish production for all flow year types. The simulations all indicated that the 6 week period from mid-March to the end of April was the temporal period for juvenile rearing habitat that could yield the most benefit for water usage. Flows of 4,000 cfs or as close to that discharge as can be provided, in any flow year type, consistently result in increased fish production estimates over baseline historical simulations where the discharge is either less or significantly greater than 4,000 cfs. Providing 4,000 cfs for that period equates to approximately 484,000 AF of water. Over the historical period, from 1961–2005, the average discharge for Iron Gate Dam in March and April was 3,128 cfs or approximately 260,125 AF of water. Looking at the habitat provided for several fall Chinook life stages at varying discharges in figure 43, 4,000 cfs could provide 17–27 percent more gross habitat availability than a discharge of 3,000 cfs for fry and smolt life stages of fall Chinook salmon. Throughout the historical period, flows during the period March 15–April 30 were at or above 4,000 cfs in 19 of the 45 years of record. In just one of those years, did the flows during the March–April 30 period exceed 8,500 cfs (1965) where rearing habitat begins to decrease for both fry and smolt life stages of fall Chinook salmon (fig. 43). The predicted gains in fish production in dry hydrological year types can be very substantial, increasing by a factor of roughly 7–9 times greater than at flows of 500–1,000 cfs. As shown in figure 43, habitat availability at 500 cfs is minimal. Increasing flow to 1,500 cfs nearly doubles the amount of juvenile rearing habitat compared to 500 cfs. Although habitat availability is not the complete suite of life stage requirements needed to support fall Chinook salmon production within the SALMOD model, it is the greatest determining factor for survival. It does appear, through repeated simulations, that the SALMOD model is predicting fish production trends similar to observed trends (California Department of Fish and Game, 2004) even though absolute numbers of fish actually produced in the Klamath River may be substantially different from model predictions.

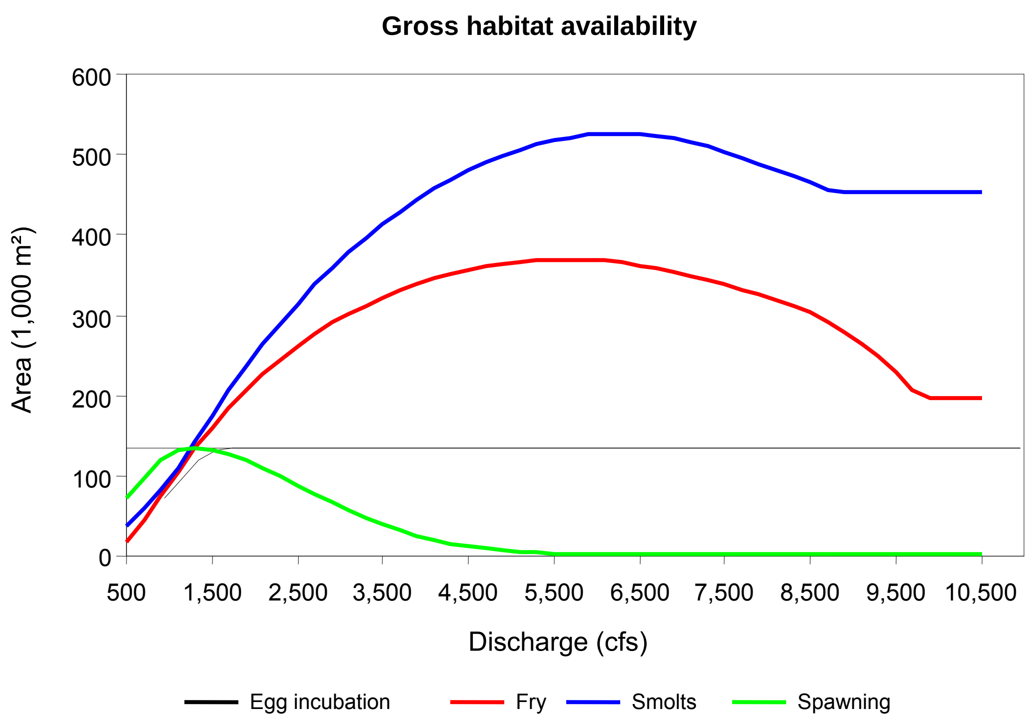

Figure 43. Habitat availability in the Klamath River from Iron Gate Dam to the confluence of the Scott River for four life stages of fall Chinook salmon (after Bartholow and Henriksen, 2006).

Provision of 4,000 cfs from March 15–April 30 may not be possible in a real world scenario, even in average to above average years because augmenting spring flows above 2,000 cfs may not allow UKL water surface elevations to be maintained when agricultural deliveries are made. The FWS Biological Opinion (U.S. Fish and Wildlife Service, 2001) for UKL specifies water surface elevation targets at certain times of the year to protect the endangered lake suckers. It is painfully apparent that in most years, the water supply cannot meet the resource demands for all of the water uses in the Klamath Basin. As an example of competing needs for limited resources, SIAM modeling of the Bureau of Reclamation's Klamath Project 2006 Operation Plan found that maintaining UKL to the levels described in the Plan during low flow years could reduce predicted fall Chinook production by 34 to 66 percent depending on whether agricultural deliveries were met or not.

Setting and achieving long-term restoration goals and objectives for the ESA species in UKL and downstream in the Klamath River is a complex and difficult challenge for Federal, State, County, municipal, and private sector resource management entities. Modeling does not provide absolute answers about how much water should be allocated to which resource use, but it can indicate how much water is needed for some resource use and provide guidance in how to minimize shortages. Models can also assist managers to make the most of limited water supply by defining critical temporal periods, the duration of pulse flows or reduced flows, and provide yardsticks to determine how much might be lost or gained if certain water management strategies are implemented.

USGS does not advocate any particular water management strategy or recommend any water supply allocation. The SIAM decision support system is intended to be an objective modeling tool that managers can utilize to quickly asses the relative merits of water management alternatives and guide decisions about water resource use in a complex network that involves multiple needs for that limited resource in the Klamath River.

Acknowledgments

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