Compilation of information to Inform USFWS Principals on the Potential Effects of the Proposed Klamath Basin Restoration Agreement (Draft 11) on Fish and Fish Habitat Conditions in the Klamath Basin, with Emphasis on Fall Chinook Salmon

Introduction

In late 2007, the Regional Director (Region 8) of the US Fish and Wildlife Service (Service) requested technical staff from the Arcata Fish and Wildlife Office to evaluate the potential effects of the proposed Klamath Basin Restoration Agreement (KBRA- Draft 11) on fish and fish habitat conditions. Staff had been providing various technical analyses and assistance to Service managers for several months during negotiation of the draft KBRA prior to receiving this assignment. Following public release of Draft 11 of the KBRA in February, 2008, staff completed a draft compilation in April 2008, and provided it to settlement parties for review and comment. On April 11 and 12, 2008, technical and policy representatives of settlement parties met in Mt. Shasta, CA to critically discuss the analyses contained in the report, and written comments were subsequently provided by several parties. The current draft version (November 2009) incorporates many of these comments, as well as additional comments solicited from State and Federal agencies in November, 2009. In addition, staff relied extensively on subject matter experts from both within and outside of the Service to review sections of the report that pertain to their specific area of expertise.

The purpose of this report is to provide the Service managers involved in the on-going Klamath settlement negotiations with supporting information and documentation of the Service's technical staff analyses, data interpretations, and professional opinions relating to anticipated changes in fish production and fish habitat conditions that would occur as a result of implementation of the KBRA and the draft Klamath Hydroelectric Settlement Agreement (KHSA), collectively referred to hereafter as the Agreements. In completing this report, we attempted to clearly identify our level of confidence in the supporting data and subsequent analyses. As directed in this assignment, professional judgments of Service technical staff are provided with regard to potential outcomes of actions specified in the KBRA, particularly when existing data and/or associated analyses were not conclusive. In these cases, technical staff relied extensively on the published literature. Analyses, data interpretations, and professional opinions expressed in this document were derived on technical merit and therefore, do not address policy implications of the Agreements.

This document includes six separate, yet interrelated sections: water quantity, water quality, geomorphology and channel maintenance, fish health, fish production, and real-time water management. While the anticipated response of each of these factors to implementation of the KBRA is important to understand, they are all interrelated and these interrelations will be highly influenced by actions proposed under the KBRA. A thorough synthesis and integration of these disciplines as they relate to the KBRA is not provided in this document. However, sections within this document are ordered to allow concepts and conclusions made in previous sections to be referenced and built upon in subsequent sections of the document.

The primary focus of this report is the effects of the proposed Agreements on anadromous fish, and in particular, fall run Chinook salmon. The substantial body of existing information on fall run Chinook below Iron Gate Dam (IGD), as well as several existing peer-reviewed models that address habitats and production of fall run Chinook salmon, provide the basis for considerable in-depth analysis of potential effects in the lower Klamath River. Fewer tools are currently available for examining potential for successful re-occupancy of areas above IGD, but the existing information is sufficient for preliminary analyses. Analytical tools for coho salmon are much more limited, and are virtually non-existent for spring run Chinook, steelhead, and lamprey. As such, this report offers little analysis of the outcomes of the proposed Agreements on those taxa.

Regarding the Lost River and shortnose sucker species in Upper Klamath Lake and its tributaries, a considerable amount of life history information exists, but no available analyses or models specifically correlate or predict population performance with environmental variables. Therefore, our conclusions regarding the potential impacts of the Agreements on these two species are limited and general. The ongoing development of the Service's Recovery Plan for these two species should provide valuable additional information in the near future.

This report is not a comprehensive assessment of the potential effects of removing the PacifiCorp dam complex. As established in the Agreement in Principle signed in November 2008, and the Draft KHSA released in September 2009, more detailed evaluations will be conducted through a subsequent NEPA process and Secretarial Determination.

Assessments

I. Water Quantity

The Water Resources Program in the KBRA consists of schedules, plans, and other provisions that would substantially change the management of delivered water supply for irrigation and related uses in the upper Klamath Basin, Reclamation's Klamath Irrigation Project, and the National Wildlife Refuges. Assessments conducted in this report were based on the following assumptions detailed in Draft 11 of the KBRA released to the public in February 2008:

Upper Klamath Lake Wetlands Reconnection. Measures to increase water supply in Upper Klamath Lake include completion of the breaching of levees in the Williamson River Delta to add approximately 28,800 acre feet of storage; reconnecting Barnes Ranch and Agency Lake Ranch to Agency Lake to add approximately 63,700 acre feet of storage; and reconnecting BLM's Wood River Wetlands to Agency Lake to provide approximately 16,000 acre feet of storage.

Federal Klamath Irrigation Project. The KBRA establishes limitations on the quantity of water diverted from Upper Klamath Lake and the Klamath River for use by the Klamath Irrigation Project. The limitation would result in the availability of water for irrigation being about 10 to 26 % less than current demand in the driest years, with water availability for irrigation increasing on a sliding scale with increasingly wet conditions. The current pattern of agricultural water deliveries being higher in dry years than in wet years would be reversed.

Off Project Program. The KBRA establishes a process to increase annual inflow to Upper Klamath Lake by 30,000 acre feet through voluntary sale of surface water rights for irrigation, retirement of surface water rights for irrigation, or other means.

Real-time Water Management. The KBRA includes additional information sources and administrative structures to allow for real-time scientific adaptive management of water by fish managers for Upper Klamath Lake and the river below. The KBRA establishes a Technical Advisory Team that will develop an Annual Water Management Plan as a recommendation for the Secretary of the Interior. During each water year, the Technical Advisory Team would also recommend ongoing, real-time operations to adjust for changing environmental and biological conditions, enabling reintroduction of flow variability essential to riverine ecosystem function.

Refuges. The KBRA provides specific allocations and delivery obligations for water for the Lower Klamath and Tule Lake National Wildlife Refuges, increasing water availability and reliability above historical refuge use levels in most years.

Other (Drought, Emergency, Groundwater, Climate Change). These programs will focus on investigations and development and implementation of specific management actions to ensure the KBRA provides the best chance of enduring through unforeseen circumstances and unintended consequences. The KBRA offers the structure and potential to implement a functional drought plan, which has been insufficient under recent management.

Description of Klamath River Flow Schedules

Background. As part of on-going Klamath settlement negotiations in late 2007, a technical team of staff from the Service, NOAA Fisheries, and California Department of Fish and Game conducted iterative model simulations that incorporated differing flow and lake elevation targets, Klamath Irrigation Project delivery amounts, and model assumptions and assessed the biological effects of the various scenarios. The team relied extensively on flow-habitat relationships presented in Hardy Phase II habitat modeling study (Hardy et al. 2006a) developed for priority fish species and life stages in the Klamath River (Figure I-1).

Methods. The Technical Team assigned a priority life stage and species for each month of the year (Table I-1). Multiple species and life histories were considered in this process to ensure that, for example, a monthly flow recommendation for juvenile Chinook salmon in May would not have an adverse effect on coho salmon fry and/or steelhead juveniles within the same time step. The technical team then followed a series of steps described below, in applying the Hardy et al. (2006a) habitat-flow relationships developed for the IGD to Shasta River reach of the mainstem Klamath River (Figure I-1) to construct a flow schedule (ALT-X) for the priority species and life stages. Development of the ALT-X flow schedule is summarized below and in graphical form in Figure I-2. The ALT-X flow schedule was later modified into the ALT-X Yurok schedule that was used in the development of the WRIMS Run-32 Refuge model simulation (discussed later).

Step 1: A conservative approach using 80% of maximum habitat value was adopted by Team for developing instream flow recommendations. This approach is supported by previous instream flow studies for salmonids (Clipperton et al. 2002; Clipperton et al. 2003) as providing flows sufficient to cause negligible impacts to aquatic ecosystems (AEV and FOC 2007). Habitat values were calculated using a spreadsheet routine (Table I-2) based on linear interpolation of Hardy et al. (2006a) Phase II habitat outputs using suitability curves developed for R-Ranch, the representative site for the mainstem Klamath River reach located between IGD and the Shasta River. IGD discharges necessary to provide 80% of maximum habitat values were calculated for priority fish species and life stage for each monthly time step (Figure I-1). These were composited into one “priority species and life stage” curve representing the flows at IGD required by monthly time step to provide 80% of the maximum habitat value for the highest priority species and life stage (Table I-1; Step 1 of Figure I-2).

Step 2: Flow values represented in the composite “priority species and life stage” curve were averaged with each of five exceedence level flows from the Hardy et al. (2006a) Phase II modified estimates of Bureau of Reclamation’s unimpaired flows at IGD (USBR 2006). The resultant curves generated annual flow schedules for the 10, 30, 50, 70, and 90% exceedence levels that depict the shape of the natural flow regime for five water year types, thereby recognizing differences in water availability between years. (Exceedence equates to a probability derived from a specified historical period of record, that a specified flow magnitude will be met or exceeded. For example, flow associated with a 90% exceedence value would be expected to be equaled or exceeded 90% of the time over the period of record for the time step examined.)

Step 3: The flow regime developed in Step 2 displayed abrupt transitions between monthly time steps associated with changes in priority species and/or life stages between months. A running mean was used to smooth these irregularities in flow patterns for the October through April period. This method of averaging and smoothing resulted in a flow regime that mimics the shape of the natural hydrograph and was similar to the averaging and smoothing method used in development of the Hardy Phase I flow recommendations (Utah State University 1999).

Step 4: The smoothed monthly values were then compared to flow levels recommended in the Hardy et al. (2006a) Phase II report. For time steps where these flows exceeded the corresponding Hardy Phase II flow, they were adjusted down to the Hardy Phase II values. This occurred mostly in the spring of dry and critically dry water year types (i.e., 70% and 90% exceedence water years).

Biologists from the Yurok Tribe recommended an alternative to the ALT-X proposal, labeled the ALT-X Yurok flow schedule. The ALT-X Yurok schedule was designed to increase water storage in the fall and winter to increase the likelihood of filling Upper Klamath Lake. Filling the lake early in the water year increases the probability of spill and the availability of water to maximize, to the extent possible, river flows in the spring and early summer to provide habitat for Chinook salmon emergence and Chinook and coho salmon fry and juvenile rearing (Table I-1). March though June are key months for juvenile Chinook salmon in the Klamath River, and adequate flows are needed during these months to support progeny of mainstem spawners, as well as fry (<55mm) immigrating into the mainstem river from significant tributaries such as Bogus Creek and the Shasta and Scott rivers.

The ALT-X Yurok flow schedule would maintain flows between October through February at a steady, flat-lined state during dry inflow conditions (1,000 cfs for 90% exceedence and 1,100 cfs for 70% exceedence) and at levels reduced from the ALT-X schedule for the October to December period during higher inflow conditions (Figure I-3). The ALT-X Yurok flow schedule adopts the ALT-X flow schedule throughout the remainder of the water year.

The ALT-X Yurok flow schedule includes a static discharge approach to fall/winter flows (i.e., flat-line flows). While the conservative fall/winter flow period of the ALT-X Yurok flow schedule increases the likelihood of spill occurring later in the year, it does not provide flow variability through a substantial portion of the fall/winter period, nor does it mimic the natural flow regime as recommended throughout the current literature regarding instream flow management (Poff et. al. 1997). Differences in total flow volume between the ALT-X and ALT-X Yurok (and WRIMS Run 32 Refuge described later) flow schedules during this period are not of magnitude that would preclude an approach that would provide a desirable variability in fall/winter flows (Figure I-3). This, however, will rely on the strategy for implementation, which is discussed in Section 6 “Implementing the Water Allocation using Real-Time Management” of this report.

Model runs incorporating the various flow schedules were done to assess the feasibility of implementing alternatives, as gauged by deviations from river flow, lake elevation, and/or agricultural delivery targets. One of the significant benefits of the water allocation component of the KBRA lies in the flexibility it allows to adjust flow and lake elevation targets, as deemed appropriate and necessary by an interagency and Tribal team of scientists. In addition, following removal of PacifiCorp Project dams, frequent instantaneous fluctuations in flow are expected to occur due to the tributary accretions presently captured by the existing reservoirs. Later in this report, we discuss a potential model for implementing the water allocation proposed under the KBRA on a real-time daily basis that will minimize potential biological and physical problems associated with weekly, biweekly, and monthly steady-state flow regimes.

Description of Upper Klamath Lake Elevation Targets

Background. Biologists from the Service, Bureau of Reclamation, and Klamath Tribes developed a time series of water surface elevation targets (ALT-Y Lake schedule) to mimic the natural hydrology of Upper Klamath Lake, with proposed lake elevations rising and falling in synch with increasing and decreasing inflows. The Alt-Y Lake schedule establishes a continuous range of lake elevations based on inflow statistics for selected time steps (daily, weekly, or monthly). This management strategy is an improvement over existing lake elevation requirements that rely on water year type designations based on UKL inflow forecasts. Previously, changes in water year type designations have often dictated unnaturally abrupt changes in lake elevation requirements.

The ALT-Y Upper Klamath Lake target elevations listed in Table I-4 were derived to meet the current understandings of the life history and habitat requirements of endangered Lost River *Deltistes luxatus* and shortnose *Chasmistes brevirostris* suckers. These target elevations took into account benefits realized by proposed and recently accomplished projects to reconnect the Lower Williamson Delta, Barnes/Agency Lake Ranch, and Wood River Wetland to UKL; the removal of Chiloquin Dam; and continuation of upper basin restoration at the current or an accelerated rate. As lake elevations (and river flows) proposed under the KBRA are targets rather than requirements, a certain degree of flexibility will exist that will provide opportunities to strategically use basin storage to the benefit of aquatic species in both the lake and river. To successfully implement this adaptive management approach, research and monitoring of the environmental conditions that influence the survival of Lost River and shortnose suckers should be fully implemented. A better understanding of sucker population dynamics, life history tactics, and their habitat requirements will be invaluable in successfully implementing the proposed adaptive management process, in addition to guiding future restoration actions.

Winter/Spring. The goal of the lake elevation targets in the fall and winter months is to fill the lake. For most water years, the lake would reach its maximum elevation of 4,143 feet by May. Historically, February through June was the peak runoff period and high lake elevations were inherent. This hydrologic regime directly corresponds with the timing of the spawning migration of adult Lost River and shortnose suckers to shoreline habitats near the eastside spring areas of UKL and to tributary spawning streams, particularly the Williamson and Sprague Rivers. Spawning generally occurs from February-June and peaks in April and May. Filling the lake early in the water year ensures access to suitable lakeshore spawning habitats in addition to increasing the probability of achieving adequate lake levels through the summer.

Summer/Fall. Larval suckers begin to appear in the Lake in late March to early April, with peak abundance occurring in mid-May to mid-June. Larvae transform to juveniles by mid to late July. Lake fringe emergent vegetation is the primary habitat used by larval suckers and to a lesser extent by juvenile suckers. Juvenile suckers also utilize non-vegetated near shore areas with a variety of substrates types. Target elevations specified in the ALT-Y schedule are designed to keep lake levels from falling too quickly in June and July and to meet a minimum lake level of 4,140 feet at the end of July. When lake elevations drop below about 4,140 feet, vegetated habitats preferred by larval suckers and to a lesser extent, juvenile suckers, become dewatered and they must move to less desirable habitats. In late summer/early fall, the elevation of UKL at or above 4,138 feet allows juvenile suckers access to near shore non-vegetated habitat and adult suckers to offshore open water habitat with adequate depth (> 6 feet deep) and refugia areas, particularly Pelican Bay, which typically have better water quality than the main body of the lake at this time of year. This also facilitates the likelihood of refilling the lake by the following winter/spring.

WRIMS Run-32 Refuge Model

Background. At the request of technical staff representing participants in the settlement negotiations, Larry Dunsmoor of the Klamath Tribes performed iterative model simulations that incorporated differing flow and lake elevation targets, Klamath Reclamation Project delivery amounts, and asserted model assumptions. Model runs were performed during the early stages of the settlement negotiations using KPSIM, a Microsoft Excel based model initially developed in the late 1990's to address complex questions relating to relationships among flow requirements, minimum lake levels, inflow, agriculture, refuge demand, and management strategies for the Klamath Basin. To improve the performance and capabilities in modeling water balance in the Klamath Basin, the Water Resources Integrated Modeling System (WRIMS) was applied to the Klamath River Basin. WRIMS is generalized water resources simulation model specifically designed for evaluating alternatives in a Water Resources System and has been used extensively to simulate the State Water Project (SWP) and Central Valley Project (CVP) in California.

The WRIMS model reconfigured for the Upper Klamath Basin has recently been referred to as KLAMSIM (Appendix E of the KBRA). This WRIMS application is a hydrologic model used to simulate flows in the upper Klamath River under various management scenarios and allows for comparison of alternatives. The period of record for the Klamath WRIMS model analysis is water years 1961-2000. The model is primarily driven by Inflows to Upper Klamath Lake that are “hard-wired” into the system. Outputs of the model simulate what would have happened in the 1961-2000 period of record if flows, lake levels, agricultural diversions, among other factors, are varied from what occurred historically.

Outputs of KPSIM model runs and subsequently, WRIMS model runs were used to assess performance of model inputs and assumptions, as determined by close examination of deviations from model input targets. Model results were provided to the settlement parties for deliberation and negotiation. These parties, in turn, provided feedback to technical staff that helped guide completion of additional model runs. The WRIMS model run that represents the negotiated water allocation reached in the settlement process was labeled WRIMS Run-32 Refuge.

Model Inputs and Assumptions. The following model inputs were provided by Larry Dunsmoor of the Klamath Tribes (Model Update Matrix.pdf dated October 1, 2007) who performed the WRIMS Run-32 Refuge simulation, and are consistent with assumptions detailed in the Draft 11 of the KBRA. The flow schedule used in the WRIMS Run-32 Refuge simulation (Table I-3) deviated slightly from the ALT-X-Yurok flow schedule. We assume these small differences were due to interpolation between exceedence levels (Figure I-3). A schematic of the WRIMS model is provided in Figure I-4.

- Model run purpose and comments: Responds to long-standing request from National Wildlife Refuges to simulate a refuge demand schedule (see Lower Klamath National Wildlife Refuge allocation, below) that mimics the restricted Project allocation (see Klamath Irrigation Project allocation, below) – i.e., deliveries reduced in dry years and increased to full demand in wet years.
- Upper Klamath Lake (UKL) net inflow: Historical inflows for water years 1961-2000 plus a negotiated additional 30,000 acre feet (30 TAF).
- Wetland areas reconnected and larger storage capacity of UKL: Williamson River Delta (Tulana and Goose Bay), Agency Lake and Barnes ranches, Wood River Wetland.
- Klamath Irrigation Project allocation: Water from UKL always diverted at maximum potential allocation Mar-Oct: 330 TAF when March 1 inflow forecast is ≤287 TAF; 385 TAF when forecast is >567 TAF; linear interpolation between forecasts of 287 and 567 TAF. November- February deliveries are the same as the historical water years 1961-2000 period of record. Note that UKL inflow forecasts do not include the 30 TAF increase (Figure I-5).
- Lower Klamath National Wildlife Refuge allocation: 20% reduction April-October when March 1 UKL inflow forecast is ≤287 TAF; full delivery when the forecast is >567 TAF; allocation linear interpolation between forecasts of 287 and 567. Note that UKL inflow forecasts do not include the 30 TAF increase. Delivery set to higher priority than UKL or Iron Gate.
- Flood control curve: Most recent (2008) version provided by Reclamation, with minor modifications after consulting with Reclamation.
- Iron Gate flow targets: Targets selected based on cumulative winter or summer inflows to UKL through the previous time step. Inflow exceedence index was used to interpolate between WRIMS Run-32 Refuge flow targets.
- UKL level targets: ALT-Y targets selected based on cumulative winter or summer inflows to UKL through the previous time step. Inflow exceedences index (described below) was used to interpolate between ALT-Y lake elevation targets.

Inflow Exceedence Index. (Summarized from Dunsmoor 2007, Appendix A). Within the WRIMS Run-32 Refuge simulation, adaptations were made to better mimic hydrologic conditions of the upper basin that were used to assign UKL elevations and river flows referenced above. An Inflow Exceedence Index (IEI) was constructed as the basis of selecting lake level and river flow targets for each time step in the WRIMS model (Appendix A). This represents a significant improvement over reliance on simulations that go back in time through the historical record with perfect knowledge of the outcome of a particular water year. For example, the inflow characteristics for November and December are unknown in October of the same year. As a result, management of the river would most likely be conservative until there is a reasonable inflow forecast or until spill occurs from UKL.

Under the WRIMS Run-32 Refuge simulation, each water year was broken into two time segments - winter (October-March) and summer (April-September). The IEI is based on the cumulative net inflow to UKL from the beginning of the water year (October 1) through the previous time step. For example, in October the IEI equals the exceedence associated with net inflow to UKL in September. In November, the IEI equals the exceedence associated with the total net inflow to UKL from September through October. In December, the IEI equals the exceedence associated with the total net inflow to UKL from September through November. This process continues through the winter time segment. During summer time segment, the IEI was calculated as the exceedence associated with the net inflows into UKL from March through the previous time step. February through April, however, were conditioned on the NRCS 50% exceedence forecast for April-September. In the WRIMS Run-32 Refuge model, the IEI is calculated solely on the UKL net inflow for winter. Thereafter, the model relies on a look-up table for the NRCS forecast and if the forecast is drier (higher exceedence), the IEI changes to the exceedence associated with that forecast. The base period used for the NRCS forecast exceedences was water years 1961-2000.

The IEI is designed to help eliminate the effects of large fluctuations in the NRCS forecast over the April through June period. At times, however, the IEI process resulted in abrupt fluctuations in modeled river flow and lake elevations. These fluctuations reflect artifacts present in the historical records for water years 1961-2000, which often resulted from ESA established minimum lake elevations and river flows based on water year type classifications (four types for the lake, five types for the river). These historical changes in water year types often differed between the lake and river.

Once the IEI was calculated for a time step, the WRIMS model uses the IEI to select targets for river flows and lake levels for that time step (Table I-3 and Table I-4). The process was identical for both the river and lake. The WRIMS model interpolates flow and lake level targets that correspond to the calculated IEI using the river and lake targets. This process produces lake and river targets that vary within and between years according to the hydrologic pattern of inflows to UKL.

WRIMS Run-32 Refuge Model Outputs

Outputs of the WRIMS Run-32 Refuge simulation display performance over the historical period of record, water years 1961 through 2000. In the simulation, priority was set to agricultural deliveries to ensure that the fixed allocation to the Project was met over a variety of NRCS inflow forecasts between the periods March – October. River flows for the period of record and by time step were simulated at IGD (Table I-5, Appendix C). From these data, percentiles and exceedences were then calculated by monthly and bimonthly time steps (Table I-6). Upper Klamath Lake elevations were also simulated over the period of record (water years 1961-2000) and by time step (Table I-7). Percentiles and exceedences were calculated for UKL for monthly and bimonthly time steps (Table I-8).

Understanding Model Outputs. Before comparing the modeled outputs of flow and associated habitat value calculations, the following points should be understood:

1. The WRIMS model runs are limited to water years 1961-2000. This period of record was selected as it reflects current Project demands and construction and subsequent operation of IGD. However, the reader should understand that the smaller the data set used to develop flow exceedence probabilities, the greater the likelihood of the occurrence and magnitude of uncertainty in the outcome. This does not mean the model results are invalid. Instead, limitations of the data set should be acknowledged. For example, would a 100-year flood event be

captured within those 40 years? Maybe, maybe not. Are the 1992 and 1994 droughts expected to recur within the next 40 years? Again, maybe or maybe not. Did years occur historically that experienced higher or lower cumulative annual flows that are not represented by this period of record? It's quite possible that higher and/or lower flows occurred, but because we have no way to evaluate their frequency of occurrence, we did not include them in this modeling exercise. Therefore, the modeling reflects recent environmental conditions experienced in the Basin, with added positive benefits from restoration actions proposed under the KBRA.

2. Targets for the WRIMS Run-32 Refuge simulation, Hardy et al. (2006a) Phase II recommendations, ALT-X, and ALT-X Yurok are planning level flow schedules. In contrast, WRIMS Run-32 Refuge model outputs and historical Iron Gate flows for water years 1961-2000 represent flow outcomes of modeled simulations (WRIMS) and actual occurrences (historical). WRIMS Run-32 Refuge outputs and historical Iron Gate flows are useful to compare to one another since both depict spill events that exceed modeled and historical flow targets.

3. Much of the discussion of model outputs and habitat values rely on exceedence probabilities. As previously described, flow corresponding to a high exceedence value, for example 90%, would be expected to be equaled or exceeded 90% of the time, indicative of dry conditions. Conversely, a low exceedence flow is characteristic of wet conditions. Estimates of habitat availability for the different flow exceedences are based on the flow magnitude at the specific exceedence level (90, 70, 50, 30, and 10%) for the period of record.

4. When conditions in the basin are wet, reflected in the record as periods having a low exceedence, elevations specified in UKL flood elevation curves are reached; Project demands are met, which most often occurs at a time of year when demands are low to nonexistent; and water is sent down the river as spill.

5. Flow-habitat curves often depict increasing habitat availability with increasing discharge until a peak is reached at the apex of the curve (Figure I-1). Once discharge increases beyond this peak, habitat availability begins to drop. This is because high discharge events result in high velocities, to the point that spawning and rearing habitat may become unusable or greatly diminished. During extremely high flow events, young fish must either seek refuge, move to the edge of the flood plain or into tributaries (assuming they aren't at peak discharge also), or are forced to move downstream.

6. Notable decreases in habitat abundance occur during extremely high flow events when flow targets are exceeded, which are evident in the WRIMS Run-32 Refuge model outputs and historical IGD flow records for water years 1961-2000. Flow targets for Hardy et al. (2006a) Phase II, ALT-X, ALT-X Yurok, however, are static as they are planning schedules and therefore, do not reflect spill events or potential target shortfalls that may be reflected in model outputs. WRIMS Run-32 Refuge model outputs and historical IGD flow records provide greater insight than flow schedules on actual flows and associated habitat values as they incorporate high flow events and spill. Even if the Hardy Phase II baseflow recommendations were implemented, flows during the wet years would surpass the Phase II schedule and habitat values would, in some cases, be lower during spill events than those calculated for the flow recommendations. We note that the Hardy Phase II flows are baseflow targets and that higher flows associated with pulse or

overbank flows (i.e., spills) are also a component of the Hardy Phase II flow regime.

7. While flood flow events can diminish habitat availability, they are essential for geomorphic and channel maintenance processes that create and maintain quality and diversity in fish habitat conditions, a point well described by Hardy et al. (2006a) and the Trinity River Flow Evaluation (USFWS and HVT 1999). Therefore, managing flows exclusively to maximize habitat availability is not desirable.
8. Exceedence charts for flow provide a simplified, planning level perspective of how the river can function for a given water year. Flow exceedences and associated habitat availability values by species and life-stage, change daily, weekly, or monthly, depending on how time steps are partitioned. Exceedence charts provide a general idea of what is expected over a range of water year conditions for a particular time step. Under a real-time management scenario such as the IEI, exceedences are expected to change continuously in relation to the time step used. This practice would eliminate the need for water year types, with management of the lake and river becoming a continuous function of hydrologic conditions experienced in the basin.

Modeled River Flows. WRIMS Run-32 Refuge flow outputs at exceedence probabilities (10, 30, 50, 70 and 90%) at the Iron Gate gauging site were used to calculate the percent of maximum habitat availability that would be achieved for the reach between IGD and the Shasta River confluence (Figure I-6 - Figure I-10). These habitat availability values for the various flow exceedences were compared to flows and habitat values calculated for the WRIMS Run-32 Refuge flow targets, Hardy Phase II recommendations, and historical IGD discharge for water years 1961-2000. As previously mentioned, the WRIMS Run-32 Refuge flow outputs and historical water year 1961-2000 IGD discharges include spill above both the target values and allocation “rules”, which were modeled in the case of the WRIMS simulations or reflective of operational decisions in the historical IGD flow records (Appendix D).

IGD was managed historically (1962 to 1998) under a FERC minimum flow schedule for all water year types, with discharge from September 1 through April 30 designated at 1,300 cfs, May 1 through May 31 at 1,000 cfs, June 1 through July 31 at 710 cfs, and August 1 through August 31 at 1,000 cfs. Under this management regime, agriculture was typically given full deliveries except during the driest years, with differences between inflows, outflows, and deliveries reflected in UKL elevations. However, during the period 1962 through 1995, variances to the FERC minimum flows were allowed and river flows fell below the FERC minimum during 57 of the 408 (about 14%) months within this period (Trihey & Associates, Inc. 1996).

There are numerous periods during the fall and early winter months when historical IGD discharge exceeded the WRIMS Run-32 Refuge Outputs. These occurrences were due to the WRIMS R-32 Refuge Targets being purposely conservative, below the 1,300 cfs FERC minimums (September-December) forcing the modeled water to accumulate in UKL. This accumulation increased the probability of filling the lake to provide sucker spawning habitat availability and water storage, increased the probability of spill for channel and riparian maintenance purposes, and increased the availability of water to provide high spring flows, thereby increasing Chinook and coho salmon rearing habitat availability over values calculated for historical IGD flows.

In general, WRIMS Run-32 Refuge output flows exceed historical IGD flows and were similar to the Hardy et al. (2006a) Phase II recommendations for the 30% and higher exceedences during the critical Chinook salmon fry rearing months (March-April), and during Chinook (May) and coho salmon (June) juvenile rearing months. At these exceedences, modeled output flows also did reasonably well in meeting the WRIMS Run-32 Refuge flow targets (Figure I-6 - Figure I-10, Appendix B, C, D). At a 10% exceedence probability, the WRIMS Run-32 Refuge model flow outputs and historical IGD records for water years 1961-2000 were generally similar, but the difference varied between time steps within the March - June period. WRIMS Run-32 refuge output flows for this period were considerably higher than the Hardy Phase II recommendations for a 10% exceedence (Figure I-6 - Figure I-10, Appendix B, C), likely due to the Hardy et al. (2006a) values being a baseflow recommendation only and therefore, not reflecting spill.

WRIMS Run-32 Refuge model output flows were lower than Hardy Phase II recommendations in the fall and winter for dryer water years (Figure I-6 - Figure I-10, Appendix B, C), which can be explained by the different target flows used in the WRIMS Run-32 Refuge simulation and those of the Hardy Phase II recommendations. As previously discussed, lower fall and early winter flow targets were proposed in the ALT-X Yurok flow schedule (which were the basis for WRIMS Run-32 Refuge flows during these seasons) to help ensure that UKL would fill during drier years while still meeting Chinook salmon spawning needs, with stored water available to deliver to the river in the spring during the Chinook and coho salmon fry and juvenile rearing months. In addition, the Hardy Phase II recommendations did not address the needs of Upper Klamath Lake or deliveries to the Klamath Irrigation Project and the Refuge. Even so, habitat values for Chinook salmon spawning (October-November) and fry rearing (March-April) and Chinook (May) and coho salmon (June) juvenile rearing calculated for the Hardy Phase II recommended flows are worthwhile to compare to the other alternatives. For example, if habitat values estimated from the flow outputs of the WRIMS Run-32 Refuge model were found to vary significantly from habitat values calculated for the Hardy Phase II flow recommendations, these differences would be of concern. However, this was clearly not the case as described below.

Fish Habitat Predictions. Habitat values were calculated for the WRIMS Run-32 Refuge model flow outputs and expressed as a percentage of maximum habitat availability derived from the Hardy et al. (2006a) flow-habitat relation curves. Habitat values for WRIMS Run-32 Refuge model output flows were consistently higher than values calculated for historical water year 1961-2000 IGD flows for the March – May emergence and rearing life stages of Chinook salmon and June juvenile rearing period for coho salmon for exceedences greater than 10% (Figure I-6 - Figure I-10). At the 10% exceedence level, the difference in habitat values between the WRIMS Run-32 Refuge model output flows and the historical IGD flows varied considerably for the April-June period (Figure I-6 - Figure I-10, Appendix B and Appendix C). Habitat values calculated for the WRIMS Run-32 Refuge model output flows and Hardy Phase II recommendations for the March – April period differed little, if at all, for all exceedence levels with the exception of the March time step for a 10% exceedence level, in which case the habitat value for the Hardy Phase II flow was about 25% higher than the habitat value calculated for the WRIMS Run-32 Refuge model output flows (Figure I-6 - Figure I-10).

October-November Chinook salmon spawning habitat values for the WRIMS Run-32 Refuge model outputs were generally higher for the 10% exceedence level, similar for the 30, 50, and 70% exceedences, and less at the 90% exceedence level than values calculated for historical water years 1961-2000 IGD flows and the Hardy Phase II recommendations (Figure I-6 - Figure I-10). However, habitat values calculated for the Hardy Phase II baseflow recommendations may be lower in wetter water years because of spill that exceeds flows corresponding to the maximum habitat value. This topic is discussed later in more detail in the fish production section (Section V) of this report.

We also compared the habitat values calculated for WRIMS Run-32 Refuge model output for the critical spawning and rearing periods (October - November and March through June) to values estimated for the historical pre-Klamath Irrigation Project flows (Keno 1905-1912), Hardy Phase II recommendations, and historical (water years 1961-2000) IGD discharge (Table I-9). In this analysis, mean monthly flows at Keno between the years 1905 and 1912 (plus an additional 250 cfs added to account for accretions occurring between Keno Dam and IGD) were ranked, exceedence probabilities generated, and habitat values were calculated as explained above. Habitat values calculated for the WRIMS Run-32 Refuge model flow outputs for historical water years 1961-2000 and the Hardy Phase II flow recommendations were then compared to habitat values generated for the historical pre Klamath Irrigation Project flows by flow exceedences levels. For each exceedence level (10%, 30%, 50%, 70%, and 90%), counts were tallied to document the number of monthly time steps having habitat values that did not exceed the 70% habitat availability value. The 70% habitat value was selected *a priori* as the benchmark for comparison since habitat values for monthly time steps for the 10, 30, 50, 70, and 90% exceedence flow levels for the historical Keno plus 250 cfs scenario all exceeded 70% of the maximum habitat value, as determined based on the Hardy et al. (2006a) flow-habitat curves (Figure I-1). This analysis showed that under both WRIMS Run-32 Refuge modeled flow outputs and the Hardy Phase II recommendations that there were fewer monthly time steps having habitat values less than 70% than were observed for historical IGD discharge for water years 1961-2000 (Table I-9).

Modeled Lake Elevations. Comparisons were made between the WRIMS Run-32 Refuge lake elevations targets (ALT-Y), WRIMS Run-32 Refuge model outputs, and historical lake elevations for water years 1961-2000 (Figure I-11, Appendix E). In general, the WRIMS Run-32 Refuge model predicts the lake to fill to the targeted lake elevation (4,143 feet) for the majority of exceedence year types. Therefore, both Lost River and shortnose suckers should have unrestricted passage to their critical spawning locations. Some constraints may exist during the driest of years (>90% exceedence). However, outputs such as these presented in the form of exceedence graphs and tables do not represent an actual water year, but rather, a ranking of values for a particular time step. For example, if average monthly values were used in the calculations, there may be periods when actual elevations surpass the reported value.

There was a clear trend for the WRIMS Run-32 Refuge model outputs to be higher than the proposed ALT-Y targets throughout the fall and winter and during the majority of exceedences (Figure I-11). During wet to average water years (10-50% exceedence), this trend is likely a result of high inflows into UKL in combination with the conservative flow targets for the river. Once the lake reaches the flood curve elevation specified for a particular month (Figure I-12) releases at Link (outlet of UKL) will compensate for the rise and flows will increase. This exemplifies the opportunities to adaptively manage the lake and river on a real-time basis, as will be discussed later in this document (real-time management). For the months of April through July, the ALT-Y target lake elevation of 4,140 feet, which inundates emergent vegetative cover, was met during every exceedence level except for the driest year represented in the simulation (100% exceedence, not displayed in Figure I-11). Outputs of the WRIMS Run-32 Refuge simulation also predicted that lake elevations would not drop below 4,139 feet during late summer/early fall with the exception of September and October for a 90% exceedence year (Figure I-11). This should greatly facilitate refill of the lake by the following spring, and provide unrestricted access to tributaries and refugia areas during periods of adverse water quality.

Management During Drought

Background. The definition of drought is complex and highly influenced by perspective that may focus on meteorological, agricultural, hydrological, or socioeconomic aspects of a water shortage. For the purpose of the discussion below, we rely on the definition of drought provided by Warwick (1975):

> *"Drought is a condition of moisture deficit sufficient to have an adverse effect on vegetation, animals, and man over a sizeable area."*

Under this definition, the Klamath River has experienced frequent droughts, and in recent years, the frequency of drought has increased. A comparison of the flow-habitat relation curves (Figure I-1) of Hardy et al. (2006a) with the WRIMS Run-32 Refuge simulated flows for water years 1961-2000 (Table I-5), clearly demonstrate the need for an effective drought plan, especially for years like 1977, 1991, 1992, and 1994. Again, we view the periods of greatest concern for the mainstem Klamath River to be associated with adult Chinook salmon migration and holding (September), spawning (October-November) fry rearing (March-April), and juvenile rearing (May) periods and the coho and Chinook salmon juvenile rearing (June) period.

Salmonids evolved under oscillating cycles of wet and dry meteorological conditions that both have ecological importance. Flows represented by extremely high and low exceedences occurred naturally in the Klamath River and likely functioned as an important environmental stressor that helped in maintaining genetic diversity in fish populations (Hardy et al. 2006a). In the interim period leading up to dam removal, however, a conservative approach to managing river flows would be prudent. The physical process of removing the Klamath Hydropower dams will have short term impacts on aquatic biota, including salmonids, primarily as a result of high turbidity and sediment loads. Given this foreseeable impact, we suggest the drought plan be aggressive in reducing negative influence of low flows to fish production in the period leading up to and immediately following dam removal, with emphasis on maximizing survival of native aquatic species in the Klamath River. This approach, in combination with an effective reintroduction plan, would benefit re-colonization of anadromous species in the upper Klamath Basin and hasten restoration of ocean and in-river fishing opportunities.

Potential Influence of Climate Change. Climate change is expected to significantly affect water resources in the western United States by the mid-21st century (Leung et al. 2004; Barnett et al. 2008). Climate change is generally predicted to result in increased air and water temperatures, decreased water quality, increased evaporation rates, increased proportion of precipitation as rain instead of snow, earlier and shorter runoff seasons, and increased variability in precipitation patterns. Several studies have shown declining snowpack, earlier spring snowmelt, and earlier stream runoff in the western United States over the past few decades (Hamlet et al. 2005; Stewart et al. 2005; Knowles et al. 2006). Winter precipitation and snowpack have been shown to be strongly correlated with streamflow in the Pacific Northwest (Leung and Wigmosta 1999).

Increasing temperature trends are the major drivers of these observed trends, particularly at moderate elevations and relatively warm winter temperatures characteristic of the Pacific Northwest (Hamlet et al. 2005; Stewart et al. 2005). Temperatures are projected to continue increasing by about 0.2˚C per decade globally for the next two decades (IPCC 2007). Both the Oregon Climate Division 5 temperature dataset and the U.S. Historical Climatological Network temperature dataset for Crater Lake show increasing trends in winter temperatures since the 1970s. Present-day winter temperatures are as warm or warmer than at any other time during the last 80 to 100 years. Bartholow (2005) found that water temperatures in the Lower Klamath River have been increasing by about 0.5 C per decade since the 1960s. While projections of changes in precipitation with climate change vary widely among models (Gurshunov et al. 2007), some investigators report that increasing temperatures will result in decreasing April 1st snowpacks that will offset any precipitation increases in the region (McCabe and Wolock 1999; McCabe and Dettinger 2002; Hamlet et al. 2005).

Higher temperatures could also increase water use by agriculture because: (1) evapo-transpiration would be increased due to the physiological needs of the plants at higher temperatures and (2) increased evaporation rates requiring more water to be delivered to meet agriculture needs of the crops in the fields

A preliminary analysis of climatologic and hydrologic information for the Upper Klamath River Basin indicates UKL inflows, particularly baseflows (portion of streamflow that comes from groundwater and not runoff), have declined over the last several decades (Mayer 2008). Net inflow to UKL and tributary flow to UKL (an independent measure of inflow) are both strongly dependent on climate, particularly precipitation, as demonstrated in Mayer (2008). The April 1st snow water equivalent (SWE) in the southern Cascades has declined since the 1930s, based on data from two high elevation sites near Crater Lake (Mayer, 2008). Trends in the April 1st SWE at the two sites may be related to trends in winter temperature as well as precipitation. Part of the decline in baseflows is explained by decreasing precipitation but there may be other factors involved as well, including increasing temperatures and the resulting decrease in April 1st SWE; increasing evapotranspiration and consumptive use; or increasing surface water diversions or ground water pumping above the UKL.

Part of the decline in UKL net inflows and tributary flows is associated with trends in climate. The observed changes are consistent with regional observations of climate change-related phenomena throughout the western U.S. Other factors such as increased consumptive use or ground water pumping above the lake may also contribute to the decline. Regardless, implications of these declines are that there will be less water available in the system, particularly during the summer baseflow period. This potential climate-related decrease in water availability is of particular concern in the Klamath Basin given the increase in agricultural diversions and groundwater pumping that has occurred over the past several decades and the current pattern of agricultural demands and deliveries being greater in dry years than in wet years.

Climate change scenarios described above may directly affect biological resources in the Klamath Basin. These scenarios would exacerbate existing poor habitat conditions for suckers and anadromous species by degrading water quality, reducing snow-pack, and increasing agricultural water demand. Climate change would likely have gradual adverse effects on both suckers and salmon. However, these effects would be realized over a long time period while restoration of wetlands and water quality conditions and increased storage capacity are likely to occur more rapidly.

Under the KBRA, increases in funding, scope, magnitude and pace for completing restoration projects should help offset potential adverse influences of climate change on aquatic biota in the Basin. In addition, creation of added storage in the upper Klamath Basin will aid in capturing earlier spring runoff that may occur as a result of climate change, which could be used later in the year to provide water for channel maintenance and to provide fish habitats in UKL and the Klamath River.

Potential Effects of Drought on UKL Suckers. Conditions documented during the last three fish die-offs in UKL were characterized by higher than average temperatures (Wood et al. 2006). Because UKL is shallow, water temperatures tend to closely follow trends in air temperatures. Given this strong relationship, high air temperature events of even short duration result in increased water temperatures in the lake. Increased frequency, duration and intensity of high air temperatures could exacerbate current water quality conditions in UKL by increasing the occurrence of extreme summer water temperatures when die-offs are most likely to occur. Higher water temperatures could have multiple adverse effects on suckers including: (1) stressing standing crops of blue green algae *Aphanizomenon flos-aquae,* which may result in algal crashes following blooms and subsequent decreases in DO concentrations; (2) increasing respiration rates of all aquatic organisms, thus elevating DO consumption in the water column and sediments; and (3) reducing the DO holding capacity of water, which decreases as water temperature increase. Sucker growth rates might be increased for part of the year, but if temperatures lead to reduced water quality, the benefits could be negated by increased mortality due to poor water quality conditions.

Potential Effects of Drought on Anadromous Salmonids. Overall availability of water in the Upper Klamath Basin has a direct relation to IGD discharge under current management, and in the absence of additional storage, this general relationship would continue under the water allocation proposed in the KBRA. Low flows in the Klamath River, when coupled with hot, dry weather conditions, can influence water quality, fish habitat availability, fish susceptibility to infectious diseases, and subsequent prognosis for survival of infected individuals, among other potential effects. Maximum and daily mean water temperatures are elevated during drought periods due to the effects of increased ambient air temperatures, decreased thermal mass, increased travel time resulting from low flows, and decreased accretion from cool water tributaries. Anadromous species are also likely to be adversely affected by potential increases in winter flooding and reduced spring and fall flows that are projected to occur in northwestern rivers as a result from climate change (National Assessment Synthesis Team 2000). Earlier snowmelt and peak flows may also cause juveniles to reach the estuary earlier and at a reduced size, thereby decreasing their probability of survival.

In dry and critically dry water year types, flow management alternatives typically provide a “subsistence” level of protection. Hardy et al. (2006a) defines these “subsistence flows" as minimum stream flows needed to maintain tolerable water quality conditions and provide minimal aquatic habitat:

> *"At these flow exceedence ranges, water temperature affects in terms of increased risk associated with thermal stress, disease, and migration inhibition become a concern. We believe that these conditions naturally occurred within the mainstem Klamath River below IGD and they in fact represent an important environmental stressor for long-term population genetics…"*

We are cautiously mindful, however, that current populations of Klamath River anadromous salmonids, particularly wild stocks of coho and spring Chinook salmon and steelhead, are depressed and therefore, not at a point of resiliency at which increased environmental stressors are likely to benefit the genetic integrity of populations. Hardy et al. (2006a) also discuss the concept of establishing an ecological baseflow, or EBF, which they define as:

> *"a flow at which further human induced reductions in flow would result in unacceptable risk to the health of aquatic resources"* and later state that *"we have adopted an Ecological Base Flow that is equivalent to the monthly 95 percent exceedence levels."*

A water year classified as having a 95% inflow exceedence would, by definition, be a drought or an extreme drought. The importance of a functional plan to respond to drought conditions is addressed in the drought section (18.2.1) of the KBRA. Based on our analyses and the recommendations of Hardy et al (2006a) we stress the importance of having a well-defined, effective, and responsive drought plan in effect in the interim period leading up to and immediately following the physical process of dam removal.

We also recommend that the Technical Advisory Team that would be convened under the Agreement give further consideration to the EBF concept described by Hardy et al. (2006) in developing recommendations for inclusion in the drought plan and in managing Klamath River flows, particularly during the critical fry and juvenile rearing lifestage/time steps described in this report. Consideration of EBF monthly 95 % exceedence levels, however, should, be cognizant of the importance of reestablishing flow variability, preferably at daily time steps, that respond to real time environmental conditions, a concept strongly supported by Hardy (2008).

Recent studies have documented significant mortality in juvenile salmon and steelhead populations in the Klamath River resulting from disease, primarily caused by the endemic parasites *C. shasta* and *P. minibicornis* (Foott et al. 1999; KFHAT 2005; Chamberlain and Williamson 2006; Nichols and Foott 2006; Nichols et al. 2008). Disease-caused mortality increases with increasing water temperatures, which are elevated during drought conditions. In addition, habitat-induced mortality, a frequently used term in the USGS Salmon Production Model, SALMOD, increases with decreasing flows that would be anticipated under climate change. Under low flow conditions during the critical rearing period March – June, habitat bottlenecks for Chinook salmon fry result in premature downstream movement that increases the risk of predation, reduces feeding success, reduces fitness, and ultimately results in a lower survivorship of the cohort.

For example, an abrupt increase in disease-induced mortality of young-of-year Chinook salmon was observed in juvenile outmigrant trap catches at the Bogus, I-5, and Kinsman fish trap sites below IGD beginning on April 29, 2004 (Chamberlain and Williamson

2006). By early May 2004, mortality approached 50% for wild young-of-year Chinook salmon captured at the Kinsman, Happy Camp, and Persido Bar trap sites located further downstream. From June 2 to June 18, mortality observed in daily catches of Chinook salmon at the Kinsman site ranged between 51% and 88%. During this period, flows below IGD averaged 1,810 cfs for April, 1,290 cfs for May and dropped to 942 cfs for June, and daily mean flows ranged from 2,060 - 802 cfs.

In March through April 2005, daily mean discharge below IGD during was about 36% of average based on 44 years of record (1960-2004), and ranged from 808 to about 1,710 cfs. During this period, incidence of *C. shasta* and *P. minibicornis* infection in juvenile Chinook salmon captured at trap sites between I-5 Bridge (rkm 288) and Big Bar (rkm 81) steadily increased, reaching near 100% by early May (Nichols and Foott 2007). Daily mean flow increased from 1,900 cfs on May 4 to 3,430 cfs on May 5 and peaked at 5,380 cfs on May 18. For the weekly time strata immediately following the initiation of this spill event, incidence of *C. shasta* at the upper three trap sites steadily declined from an estimated 100% for the week of 11 May, down to 17% for the week of June 2. Indications are that low spring flows experienced in 2005 may have contributed to high incidence of infectious diseases in trap catches of Chinook salmon fry.

Importantly, conditions described above could likely be avoided given flexibility to manage flows provided under the KBRA, coupled with a functional and responsive drought plan. The need for a drought plan is emphasized considering the potential influence of climate change on water availability, flows, and water temperatures in the Basin.

Forecasting Drought. There may be clear indications in the hydrological records that can be used in combination with meteorological and run size forecasts to trigger implementation of a strategically designed drought plan to avert fish die-offs in the Klamath River. For example, during late June 2000, a large juvenile salmonid die-off occurred from diseases associated with ceratomyxosis and columnaris immediately following a decrease in IGD flows to approximately 1,050 cfs (Figure I-13). Even though this particular water year was classified as an Average Water Year type, the fish experienced drought conditions. The September 2002 adult die-off that resulted in mortality of a minimum estimate of 33,526 adult salmon and steelhead occurred when Iron Gate flows were approximately 760 cfs (Figure I-14, Guillen 2003a). The Service (Guillen 2003b) concluded that:

> *“Low river discharges apparently did not provide suitable attraction flows for migrating adult salmon, resulting in large numbers of fish congregating in the warm waters of the lower River. The high density of fish, low discharges, warm water temperatures, and possible extended residence time of salmon created optimal conditions for parasite proliferation and precipitated an epizootic of Ich and columnaris”.*

CDFG (2004) reported that “At least 33,000 adult salmon died during mid to late September 2002 in the lower 36 miles of river” and further stated that “The total fish-kill estimate of 34,056 fish was conservative and DFG analyses indicate actual losses may have been double that number” and that estimates from the USFWS mortality report “should be viewed as a minimum number of fish killed”, as indicated by Guillen (2003a).

Our analyses indicate that exceedence probabilities for the Williamson River could be used to forecast extreme droughts (i.e. water years 1992 and 1994). A 0.95 exceedence probability occurring during the March 16-31 time step, which equates to a flow of approximately 780 cfs or less, would result in a high likelihood that drought conditions would persist through September (Table I-10). In addition, preseason ocean abundance estimates for fall Chinook salmon used to forecast run size for the following fall are typically available in early March. Williamson River inflow exceedences probabilities and NRCS inflow forecasts in early April could be used to provide an early warning as to the need to implement drought plan contingency measures in May and June to avert juvenile die-offs. When coupled with the preseason adult salmon run size forecast, this information could also be used to implement drought measures to provide flows in mid- to late September and early October as deemed necessary to protect migrating adults. Actions such as those discussed above should be coordinated with flow management activities conducted under the Trinity River Restoration Program, which makes flow management recommendations for the upper Trinity River. In 2003 and 2004, increased fall flows were released into the Trinity River to reduce the likelihood of a fish die-off in the Lower Klamath River.

Balancing UKL Elevations and River Flows. The use of water for environmental purposes required balancing UKL elevations and flow releases from IGD in a fashion that would contribute to the restoration and sustainability of natural production of native fish species throughout the Klamath Basin. Following removal of the Klamath River dams, additional water is anticipated to become available within the reach between Keno and IGD because of tributary inflows, springs, decreased evaporation, etc., that is not necessarily accounted for or accurately represented in existing models. Following dam removal, water models currently used in the Basin will need to be revised and recalibrated to account for the significant hydrologic and landscape changes.

Water distribution between the lake and the river will be implemented under the KBRA using an adaptive management strategy. Adaptive management will provide fisheries managers the flexibility to make necessary adjustments in balancing lake elevations and river flows to ensure that critical life history stages of both suckers and salmon can be protected and enhanced on an annual basis, responding to current water availability, biological needs, and current status and health of these species. This adaptive process and the flexibility it provides will be particularly critical during the period within which the water allocation and restoration actions identified as assumptions in the WRIMS Run-32 Refuge model simulation are being phased in.

Potential consequences resulting from climate change are likely to make balancing UKL elevations and river flows increasingly challenging in the future. Higher temperatures would lead to higher winter runoff from the mountains as less precipitation would fall as snow and the diminished snowpack would melt earlier in the spring. Spring runoff and subsequent summer inflow may also be reduced. Under the current management regime in the Klamath Basin, these changes would likely have significant effects on fishes in UKL and the Klamath River, particularly in light of the increasing trend in agricultural water deliveries to the Klamath Irrigation Project coupled with the pattern in agricultural deliveries being higher in dry than in wet water years. However, implementation of the factors referenced in Table 1 of the Executive Summary of this report, among others listed in the KBRA, will help to counter adverse impacts that may result from climate change.

Tables and Figures

Table I-1. List of priority species and life stages agreed upon by the Technical Team (Appendix A) for computation of the 80% habitat values (Step 1, Figure I-2) and in assessing fish habitat availability for different model output flows.

Priority species/life stage	Oct	Nov	Dec	Jan	Feb[1]	Mar	Apr	May	Jun	July	Aug	Sep
Chinook spawning	X	X										
Chinook egg incubation (based on Chinook spawning HSC)			X	X								
Chinook fry					X	X						
Chinook fry/juveniles							X					
Chinook juveniles								X				
Coho juveniles									X			
Steelhead fry										X [2]		
Steelhead juveniles											X [2]	X [2,3]

[1] February is considered by the tech team as a transition month in which the priority species/life history phase transitions from incubation to Chinook fry and alelvins.
[2] High water temperatures, particularly during daylight hours, may cause habitat use to shift into thermal refugia.
[3] Conditions suitable for upstream migration were considered.

Table I-2. Example of the spreadsheet routine developed by USFWS to linearly interpolate habitat values, expressed as a percent of maximum habitat availability, from Iron Gate discharge. Habitat values were based on Hardy et al. (2006a) Phase II flow to habitat relation curves developed for the Iron Gate to Shasta reach of the mainstem Klamath River.

Time Step	**Insert Discharge**	Chinook Spawning	Chinook Fry	Chinook Juvenile	Coho Juvenile	Coho Fry	Steelhead Juvenile	Steelhead Fry
October	1,300	**98**	53	54	62	76	44	56
November	1,300	**98**	53	54	62	76	44	56
December	1,300	**98**	53	54	62	76	44	56
January	1,300	**98**	53	54	62	76	44	56
February	1,300	98	**53**	54	62	76	44	56
March 1-15	1,450	100	**58**	57	65	80	45	62
March 16-31	1,450	100	**58**	57	65	80	45	62
April 1-15	1,500	100	59	**58**	65	81	46	64
April 16-30	1,500	100	59	**58**	65	81	46	64
May 1-15	1,500	100	59	**58**	65	81	46	64
May 16-31	1,500	100	59	**58**	65	81	46	64
June 1-15	1,400	100	56	57	**65**	79	45	60
June 16-30	1,400	100	56	57	**65**	79	45	60
July 1-15	1,000	89	43	47	55	**66**	42	**44**
July 16-31	1,000	89	43	47	55	**66**	42	**44**
August	1,000	89	43	47	55	66	**42**	44
September	1,000	89	43	47	55	66	**42**	44

Species and Life Stage	Time Step	Percent of Maximum Habitat
Chinook Spawning and Incubation	October	98
Chinook Spawning and Incubation	November	98
Chinook Spawning and Incubation	December	98
Chinook Spawning and Incubation	January	98
Chinook Fry	February	53
Chinook Fry	March 1-15	58
Chinook Fry	March 16-31	58
Chinook Juvenile	April 1-15	58
Chinook Juvenile	April 16-30	58
Chinook Juvenile	May 1-15	58
Chinook Juvenile	May 16-31	58
Coho Juvenile	June 1-15	65
Coho Juvenile	June 16-30	65
Steelhead Fry	July 1-15	44
Steelhead Fry	July 16-31	44
Steelhead Juvenile	August	42
Steelhead Juvenile/Adult Passage	September	42

Table I-3. Flow targets (cfs) for Klamath River at Iron Gate Dam by year type specified in the WRIMS Run-32 Refuge Model. Settlement WRIMS model structure interpolates flow targets between the IEI exceedences in the column headings. For example, if the calculated IEI for Jan is 70%, then WRIMS calculates the river flow target corresponding to IEI=70% by linearly interpolating between 2,024 cfs and 1,100 cfs (Dunsmoor 2007, Appendix A).

Time Step	IEI = 5% (Wet)	IEI = 25% (Above Average)	IEI = 50% (Average)	IEI = 75% (Below Average)	IEI = 95% (Dry)
Oct	1300	1300	1300	1100	1000
Nov	1300	1300	1300	1100	1000
Dec	1300	1300	1300	1100	1000
Jan	2421	2223	2024	1100	1000
Feb	2831	2592	2353	1100	1000
Mar 1-15	3393	3116	2841	2350	1410
Mar 16-31	3393	3116	2841	2350	1410
Apr 1-15	3648	3346	3030	2260	1530
Apr 16-30	3648	3346	3030	2260	1530
May 1-15	3111	3111	2675	2050	1220
May 16-31	3111	3111	2675	2050	1220
Jun 1-15	2760	2660	2225	1635	1080
Jun 16-30	2760	2660	2225	1635	1080
Jul 1-15	1880	1830	1330	1070	840
Jul 16-31	1880	1830	1330	1070	840
Aug	1540	1335	1170	1005	895
Sep	1545	1430	1305	1160	1010

Table I-4. Upper Klamath Lake levels (corresponding to Alternative Y) and the associated IEI exceedence values used by settlement WRIMS runs as basis for interpolating to UKL targets corresponding to a calculated IEI (Dunsmoor 2007, Appendix A).

Time Step	IEI = 25% (Above Average)	IEI = 70% (Below Average)	IEI = 90% (Dry)	IEI = 99% (Critical)
Oct	4140.0	4139.0	4138.5	4138.0
Nov	4140.2	4139.5	4139.0	4138.4
Dec	4140.5	4140.1	4139.5	4138.9
Jan	4141.1	4140.8	4140.2	4139.6
Feb	4141.7	4141.6	4141.1	4140.6
Mar 1-15	4142.0	4142.2	4141.8	4141.3
Mar 16-31	4142.3	4142.4	4142.0	4141.5
Apr 1-15	4142.5	4142.6	4142.3	4141.8
Apr 16-30	4142.8	4142.8	4142.5	4142.0
May 1-15	4143.0	4142.8	4142.5	4141.8
May 16-31	4143.1	4142.7	4142.4	4141.6
Jun 1-15	4142.9	4142.4	4142.0	4141.2
Jun 16-30	4142.6	4142.1	4141.6	4140.8
Jul 1-15	4142.0	4141.6	4141.0	4140.3
Jul 16-31	4141.4	4141.0	4140.4	4139.8
Aug	4140.8	4140.2	4139.7	4139.1
Sep	4140.3	4139.5	4139.1	4138.5

Table I-5. WRIMS Run-32 Refuge model simulated flows at Iron Gate Dam for water years 1961-2000 (Dunsmoor 2007).

Water Year	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
1961	1,144	1,300	1,300	1,802	1,626	2,637	2,989	2,374	2,120	1,758	1,893	1,482	1,552	980	962	953	1,191
1962	1,269	1,193	1,297	1,877	1,651	2,482	2,500	2,203	3,097	2,222	2,372	1,703	1,425	841	795	813	986
1963	1,186	1,300	3,133	2,259	2,774	2,282	2,635	4,170	3,792	2,640	2,693	2,126	1,872	1,118	1,137	950	1,163
1964	1,210	1,289	1,300	1,987	2,016	2,403	2,387	1,816	3,015	2,214	2,093	1,752	1,823	1,114	1,083	930	1,049
1965	1,065	1,163	7,538	7,894	7,172	4,139	4,486	3,437	3,239	2,642	2,618	2,052	1,938	1,203	1,188	1,060	1,197
1966	1,185	1,300	1,300	2,215	2,402	2,635	2,687	2,274	2,718	2,242	2,105	1,599	1,473	900	920	817	1,067
1967	1,035	1,142	1,300	2,053	2,387	2,954	3,426	3,569	3,240	3,792	4,094	2,431	2,400	1,451	1,336	900	951
1968	1,062	1,025	1,056	1,091	1,376	2,693	3,066	2,142	1,698	1,249	1,377	1,074	986	717	732	884	1,069
1969	1,077	1,090	1,090	1,212	2,407	3,167	3,491	6,114	5,785	2,993	3,023	2,394	2,258	1,420	1,306	863	953
1970	1,102	1,108	1,166	5,905	4,607	3,826	4,100	2,388	1,763	2,074	2,143	1,624	1,511	929	905	777	993
1971	1,042	1,146	1,815	4,323	3,639	5,349	5,710	6,775	6,440	4,869	5,280	2,734	2,750	1,880	1,857	1,308	1,354
1972	1,288	1,300	2,035	2,869	5,203	10,383	10,636	4,305	3,958	2,778	2,795	2,067	1,759	1,162	1,158	1,188	1,199
1973	1,159	1,269	1,456	2,751	2,440	2,562	2,616	2,248	2,226	1,716	1,756	1,253	1,090	717	719	694	940
1974	1,123	1,300	3,233	6,057	3,548	5,499	5,860	7,062	6,702	3,060	3,197	2,446	2,101	1,526	1,624	1,331	1,298
1975	1,290	1,243	1,300	2,075	2,864	5,007	5,405	4,777	4,454	3,636	4,005	2,589	2,448	1,706	1,738	1,251	1,307
1976	1,300	1,300	2,226	2,409	2,589	3,023	3,058	2,863	2,254	2,134	2,132	1,610	1,507	937	959	1,112	1,269
1977	1,300	1,252	1,249	1,289	1,000	1,317	1,315	1,332	1,250	1,044	1,226	1,100	1,104	815	794	699	941
1978	975	1,108	1,742	4,059	3,114	3,778	4,074	3,985	3,651	2,709	2,659	1,943	1,678	1,027	1,019	818	1,119
1979	954	1,074	1,041	1,064	1,039	2,256	2,127	1,999	1,996	1,752	1,878	1,444	1,247	814	792	778	980
1980	1,058	1,168	1,228	2,517	3,488	2,820	3,120	2,351	2,187	2,012	2,114	1,631	1,528	945	922	775	979
1981	996	950	1,050	1,040	1,040	1,649	1,649	1,713	1,693	1,304	1,440	1,187	1,113	807	795	771	836
1982	919	1,075	3,486	2,611	7,807	5,539	5,894	6,186	5,827	2,880	2,914	2,206	1,981	1,437	1,529	1,184	1,197
1983	1,196	1,265	1,793	2,847	5,756	7,180	7,500	5,894	5,639	3,974	4,328	2,760	2,760	1,880	1,880	1,479	1,442
1984	1,300	1,449	6,130	3,345	3,748	6,037	6,412	5,586	5,220	3,443	3,792	2,747	2,648	1,686	1,613	1,353	1,467
1985	1,300	3,375	2,879	2,393	2,563	2,874	2,894	4,108	4,524	2,596	2,383	1,749	1,588	915	849	824	1,228
1986	1,146	1,247	1,300	2,178	7,130	6,595	6,866	3,253	2,975	2,588	2,404	2,054	1,804	1,161	1,127	833	1,151
1987	1,137	1,221	1,300	2,033	1,122	2,784	3,082	2,111	2,040	1,787	1,723	1,295	1,219	878	990	909	1,110
1988	1,065	996	1,062	1,131	1,537	2,026	2,350	1,632	1,632	1,439	1,549	1,301	1,377	988	937	835	952
1989	933	1,015	1,115	1,078	1,052	4,476	6,651	5,193	4,907	2,807	2,794	1,820	1,387	1,255	1,127	859	1,086
1990	1,145	1,150	1,111	1,054	1,015	1,542	2,811	1,807	1,552	1,673	1,755	1,437	1,430	961	963	955	1,107
1991	1,052	994	923	951	950	1,240	1,275	1,393	1,433	1,178	1,315	1,106	1,095	844	846	841	894
1992	816	828	861	850	809	1,012	1,003	1,045	1,006	793	819	672	616	484	496	414	478
1993	521	634	770	841	877	2,432	5,758	5,504	5,188	2,920	3,012	2,478	2,341	1,362	1,169	1,089	1,033
1994	1,076	981	974	954	928	1,228	1,133	1,165	1,107	908	1,040	882	838	599	542	453	537
1995	549	674	755	993	1,013	3,081	4,742	3,767	3,444	2,792	2,868	2,414	2,237	1,367	1,299	823	902
1996	940	882	1,026	2,908	8,966	4,507	4,846	3,846	3,566	3,009	3,223	2,366	2,136	1,347	1,287	930	1,069
1997	1,161	1,247	3,244	9,043	4,744	3,371	3,342	2,695	2,773	2,434	2,363	1,972	1,983	1,187	1,187	1,031	1,239
1998	1,255	1,300	1,286	3,028	3,938	4,752	5,148	4,821	4,474	5,458	5,735	2,647	2,656	1,835	1,835	1,258	1,259
1999	1,249	1,166	2,797	3,081	3,803	6,139	6,449	6,142	5,758	3,184	3,545	2,645	2,500	1,631	1,581	1,345	1,384
2000	1,300	1,300	1,272	2,606	3,713	3,248	3,535	3,579	3,318	2,575	2,560	1,868	1,674	988	978	780	1,165

Table I-6. Flow outputs (cfs) simulated by the WRIMS Run-32 Refuge model (model outputs), by percentiles and exceedence (Dunsmoor 2007).

Percentile	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August	September
0%	521	634	755	841	809	1,012	1,003	1,045	1,006	793	819	672	616	484	496	414	478
10%	931	943	969	989	995	1,520	1,616	1,608	1,540	1,242	1,371	1,105	1,094	798	786	763	902
30%	1,056	1,086	1,114	1,266	1,489	2,538	2,774	2,234	2,167	1,944	2,033	1,564	1,429	925	921	822	984
50%	1,130	1,167	1,300	2,197	2,501	2,988	3,384	3,345	3,168	2,581	2,393	1,844	1,676	1,071	1,051	892	1,097
70%	1,189	1,266	1,757	2,780	3,661	4,240	4,937	4,210	4,107	2,829	2,881	2,254	2,018	1,351	1,218	1,040	1,197
90%	1,300	1,300	3,234	4,481	5,894	6,048	6,470	6,117	5,761	3,651	4,014	2,646	2,515	1,688	1,636	1,310	1,311
100%	1,300	3,375	7,538	9,043	8,966	10,383	10,636	7,062	6,702	5,458	5,735	2,760	2,760	1,880	1,880	1,479	1,467

Exceedence	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
0%	1,300	3,375	7,538	9,043	8,966	10,383	10,636	7,062	6,702	5,458	5,735	2,760	2,760	1,880	1,880	1,479	1,467
10%	1,300	1,300	3,234	4,481	5,894	6,048	6,470	6,117	5,761	3,651	4,014	2,646	2,515	1,688	1,636	1,310	1,311
30%	1,189	1,266	1,757	2,780	3,661	4,240	4,937	4,210	4,107	2,829	2,881	2,254	2,018	1,351	1,218	1,040	1,197
50%	1,130	1,167	1,300	2,197	2,501	2,988	3,384	3,345	3,168	2,581	2,393	1,844	1,676	1,071	1,051	892	1,097
70%	1,056	1,086	1,114	1,266	1,489	2,538	2,774	2,234	2,167	1,944	2,033	1,564	1,429	925	921	822	984
90%	931	943	969	989	995	1,520	1,616	1,608	1,540	1,242	1,371	1,105	1,094	798	786	763	902
100%	521	634	755	841	809	1,012	1,003	1,045	1,006	793	819	672	616	484	496	414	478

Table I-7. Upper Klamath Lake elevations (ft) simulated (model outputs) by the WRIMS Run-32 Refuge model output of for water years 1961-2000 (Dunsmoor 2007).

Water Year	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
1961	4,139.67	4,140.47	4,141.56	4,141.59	4,142.70	4,142.90	4,143.00	4,142.87	4,142.82	4,142.66	4,142.47	4,142.14	4,141.78	4,141.21	4,140.62	4,140.00	4,139.52
1962	4,139.72	4,140.31	4,141.05	4,141.06	4,142.12	4,142.37	4,142.63	4,143.00	4,143.10	4,142.91	4,142.69	4,142.00	4,141.40	4,140.79	4,140.18	4,139.58	4,139.00
1963	4,140.63	4,141.50	4,141.90	4,141.66	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.13	4,143.14	4,142.43	4,141.81	4,141.27	4,140.70	4,139.91	4,139.52
1964	4,139.69	4,140.47	4,141.15	4,141.68	4,141.91	4,142.10	4,142.29	4,142.88	4,143.10	4,142.74	4,142.41	4,142.22	4,141.98	4,141.37	4,140.75	4,139.89	4,139.18
1965	4,139.15	4,139.95	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.06	4,142.88	4,142.72	4,142.25	4,141.82	4,141.26	4,140.68	4,140.19	4,139.63
1966	4,139.93	4,140.91	4,141.80	4,142.02	4,142.02	4,142.33	4,142.63	4,142.89	4,143.00	4,142.61	4,142.26	4,141.79	4,141.35	4,140.91	4,140.44	4,139.58	4,139.22
1967	4,139.16	4,139.97	4,141.30	4,142.01	4,142.65	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,142.79	4,142.39	4,141.62	4,140.84	4,139.75	4,138.99
1968	4,139.18	4,139.59	4,140.35	4,141.19	4,142.70	4,142.90	4,143.00	4,142.59	4,142.32	4,142.15	4,141.95	4,141.46	4,140.98	4,140.49	4,139.99	4,139.66	4,139.16
1969	4,139.24	4,139.98	4,140.81	4,142.25	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.07	4,143.04	4,142.57	4,142.14	4,141.41	4,140.66	4,139.64	4,139.02
1970	4,139.25	4,139.76	4,141.44	4,142.30	4,142.70	4,142.90	4,143.00	4,142.89	4,142.98	4,142.78	4,142.56	4,142.07	4,141.60	4,141.04	4,140.46	4,139.49	4,139.00
1971	4,139.15	4,140.70	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,142.94	4,142.68	4,142.03	4,141.38	4,140.21	4,139.84
1972	4,140.14	4,141.16	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.00	4,142.92	4,142.42	4,142.00	4,141.45	4,140.88	4,140.05	4,139.57
1973	4,139.93	4,140.69	4,141.90	4,142.30	4,142.70	4,142.85	4,143.00	4,142.86	4,142.73	4,142.44	4,142.13	4,141.55	4,140.99	4,140.50	4,140.01	4,139.21	4,138.84
1974	4,139.28	4,141.18	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.16	4,143.20	4,142.65	4,142.22	4,141.74	4,141.22	4,140.33	4,139.73
1975	4,139.76	4,140.30	4,141.33	4,141.94	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,142.80	4,142.46	4,141.91	4,141.32	4,140.45	4,139.92
1976	4,140.34	4,141.27	4,141.90	4,142.30	4,142.70	4,142.85	4,143.00	4,142.90	4,142.99	4,142.69	4,142.40	4,141.91	4,141.44	4,140.98	4,140.50	4,140.59	4,140.00
1977	4,139.96	4,140.42	4,140.84	4,141.14	4,141.81	4,142.06	4,142.32	4,142.06	4,141.84	4,141.91	4,141.93	4,141.58	4,141.20	4,140.57	4,139.93	4,139.11	4,138.83
1978	4,139.04	4,139.94	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,142.91	4,142.74	4,142.07	4,141.48	4,140.96	4,140.42	4,139.55	4,139.39
1979	4,139.36	4,139.68	4,140.33	4,141.38	4,142.31	4,142.59	4,142.93	4,142.92	4,142.93	4,142.83	4,142.69	4,141.99	4,141.34	4,140.76	4,140.17	4,139.43	4,138.94
1980	4,139.18	4,140.00	4,140.89	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.05	4,142.86	4,142.64	4,142.15	4,141.69	4,141.12	4,140.52	4,139.46	4,138.94
1981	4,139.00	4,139.50	4,140.44	4,141.20	4,142.38	4,142.59	4,142.82	4,142.83	4,142.86	4,142.68	4,142.48	4,141.91	4,141.35	4,140.76	4,140.14	4,139.11	4,138.46
1982	4,138.79	4,140.25	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.04	4,142.99	4,142.53	4,142.15	4,141.68	4,141.16	4,139.99	4,139.52
1983	4,139.84	4,140.61	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,142.95	4,142.69	4,142.10	4,141.50	4,140.67	4,140.05
1984	4,140.37	4,141.70	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,142.86	4,142.53	4,141.87	4,141.21	4,140.33	4,140.11
1985	4,141.01	4,141.70	4,141.90	4,141.99	4,142.19	4,142.47	4,142.77	4,143.00	4,143.10	4,142.69	4,142.35	4,141.85	4,141.38	4,140.76	4,140.17	4,139.57	4,139.66
1986	4,140.04	4,140.76	4,141.47	4,142.30	4,142.70	4,142.90	4,143.00	4,142.99	4,143.08	4,142.86	4,142.69	4,142.09	4,141.55	4,140.98	4,140.39	4,139.56	4,139.55
1987	4,139.98	4,140.57	4,141.17	4,141.47	4,142.70	4,142.90	4,143.00	4,142.89	4,142.80	4,142.39	4,141.99	4,141.59	4,141.20	4,140.94	4,140.67	4,139.86	4,139.29
1988	4,139.20	4,139.64	4,140.87	4,141.87	4,142.70	4,142.90	4,143.00	4,142.98	4,142.96	4,142.78	4,142.56	4,142.27	4,141.94	4,141.24	4,140.51	4,139.56	4,138.86
1989	4,138.81	4,139.91	4,140.53	4,141.31	4,142.13	4,142.90	4,143.00	4,143.00	4,143.10	4,143.00	4,142.92	4,142.29	4,141.80	4,141.07	4,140.33	4,139.63	4,139.39
1990	4,139.59	4,139.96	4,140.49	4,141.61	4,142.36	4,142.88	4,143.00	4,143.00	4,143.10	4,142.87	4,142.64	4,142.22	4,141.80	4,141.26	4,140.71	4,139.99	4,139.37
1991	4,139.33	4,139.64	4,139.97	4,140.74	4,141.36	4,141.77	4,142.16	4,142.21	4,142.25	4,142.24	4,142.19	4,141.76	4,141.32	4,140.80	4,140.27	4,139.27	4,138.52
1992	4,138.50	4,139.12	4,139.73	4,140.28	4,140.68	4,140.85	4,141.05	4,140.95	4,140.86	4,140.43	4,139.99	4,139.46	4,138.96	4,138.69	4,138.42	4,137.62	4,137.31
1993	4,137.66	4,138.46	4,139.41	4,140.25	4,141.04	4,142.53	4,143.00	4,143.00	4,143.10	4,143.07	4,143.04	4,142.70	4,142.37	4,141.62	4,140.89	4,139.88	4,139.18
1994	4,139.31	4,139.57	4,140.13	4,140.71	4,141.26	4,141.40	4,141.60	4,141.43	4,141.27	4,141.16	4,141.01	4,140.48	4,139.96	4,139.32	4,138.68	4,137.80	4,137.51
1995	4,137.76	4,138.57	4,139.30	4,140.87	4,142.27	4,142.90	4,143.00	4,143.00	4,143.10	4,143.14	4,143.16	4,142.67	4,142.20	4,141.52	4,140.83	4,139.55	4,138.84
1996	4,138.85	4,139.28	4,141.26	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.17	4,143.20	4,142.56	4,142.01	4,141.37	4,140.71	4,139.82	4,139.32
1997	4,139.41	4,140.26	4,141.90	4,142.30	4,142.70	4,142.75	4,142.81	4,142.91	4,143.00	4,142.76	4,142.55	4,142.31	4,142.05	4,141.50	4,140.93	4,140.15	4,139.68
1998	4,139.84	4,140.54	4,141.10	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,143.25	4,143.29	4,142.55	4,141.80	4,140.54	4,139.83
1999	4,140.01	4,141.55	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,142.82	4,142.48	4,141.84	4,141.20	4,140.59	4,140.02
2000	4,140.17	4,140.78	4,141.61	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,142.89	4,142.68	4,142.09	4,141.55	4,141.03	4,140.47	4,139.46	4,139.49

Table I-8. WRIMS Run-32 Refuge model output of UKL elevations by percentiles and exceedence (Dunsmoor 2007).

Percentile	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
0%	4137.66	4138.46	4139.30	4140.25	4140.68	4140.85	4141.05	4140.95	4140.86	4140.43	4139.99	4139.46	4138.96	4138.69	4138.42	4137.62	4137.31
10%	4138.81	4139.48	4140.11	4140.86	4141.77	4142.09	4142.32	4142.55	4142.31	4142.23	4141.99	4141.58	4141.18	4140.57	4140.00	4139.20	4138.80
30%	4139.18	4139.93	4140.86	4141.55	4142.34	4142.82	4143.00	4142.90	4142.99	4142.72	4142.48	4142.00	4141.42	4140.96	4140.41	4139.56	4139.00
50%	4139.39	4140.28	4141.31	4142.02	4142.70	4142.90	4143.00	4143.00	4143.10	4142.87	4142.69	4142.22	4141.80	4141.23	4140.64	4139.71	4139.34
70%	4139.87	4140.63	4141.90	4142.30	4142.70	4142.90	4143.00	4143.00	4143.10	4143.07	4143.04	4142.54	4142.08	4141.47	4140.83	4139.99	4139.56
90%	4140.18	4141.29	4141.90	4142.30	4142.70	4142.90	4143.00	4143.00	4143.10	4143.20	4143.20	4142.82	4142.49	4141.87	4141.23	4140.46	4139.93
100%	4141.01	4141.70	4141.90	4142.30	4142.70	4142.90	4143.00	4143.00	4143.10	4143.20	4143.20	4143.25	4143.29	4142.55	4141.80	4140.67	4140.11

Exceedence	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
0%	4,141.01	4,141.70	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,143.25	4,143.29	4,142.55	4,141.80	4,140.67	4,140.11
10%	4,140.18	4,141.29	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.20	4,143.20	4,142.82	4,142.49	4,141.87	4,141.23	4,140.46	4,139.93
30%	4,139.87	4,140.63	4,141.90	4,142.30	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,143.07	4,143.04	4,142.54	4,142.08	4,141.47	4,140.83	4,139.99	4,139.56
50%	4,139.39	4,140.28	4,141.31	4,142.02	4,142.70	4,142.90	4,143.00	4,143.00	4,143.10	4,142.87	4,142.69	4,142.22	4,141.80	4,141.23	4,140.64	4,139.71	4,139.34
70%	4,139.18	4,139.93	4,140.86	4,141.55	4,142.34	4,142.82	4,143.00	4,142.90	4,142.99	4,142.72	4,142.48	4,142.00	4,141.42	4,140.96	4,140.41	4,139.56	4,139.00
90%	4,138.81	4,139.48	4,140.11	4,140.86	4,141.77	4,142.09	4,142.32	4,142.55	4,142.31	4,142.23	4,141.99	4,141.58	4,141.18	4,140.57	4,140.00	4,139.20	4,138.80
100%	4,137.66	4,138.46	4,139.30	4,140.25	4,140.68	4,140.85	4,141.05	4,140.95	4,140.86	4,140.43	4,139.99	4,139.46	4,138.96	4,138.69	4,138.42	4,137.62	4,137.31

Table I-9. Habitat availability (expressed as a percentage of the maximum) on a monthly time step and by exceedence, for critical Chinook salmon spawning and rearing months for historical pre Klamath Irrigation Project Keno flows (1905-1912) with an added 250 cfs to roughly account for accretions between Keno Dam and Iron Gate Dam, Hardy et al. (2006a) Phase II flow recommendation (flow schedule), historical Iron Gate Dam (actual flows for water years 1961-2000), WRIMS Run-32 Refuge model outputs, and Real-Time Management (RTM, Section V) model outputs. Shaded periods indicate habitat availability less than 70%.

	Habitat availability (percent of maximum)					Count
	10%	30%	50%	70%	90%	
Historical Keno 1905-1912 (+250 cfs for accretions)						
October	93	100	100	98	98	0
November	88	97	98	99	100	0
March	99	100	98	93	88	0
April	99	87	85	83	78	0
May	98	89	87	79	73	0
June	91	83	78	75	71	0
					Total	0
Hardy Phase II flow recommendations						
October	99	100	100	100	100	0
November	84	88	93	98	100	0
March	99	100	100	87	57	1
April	96	92	81	69	58	2
May	89	84	76	65	52	2
June	81	77	73	66	57	2
					Total	7
Historical Iron Gate (water years1						
October	81	98	100	99	90	0
November	66	83	97	100	98	1
March	54	97	94	77	52	2
April	89	89	75	58	50	2
May	92	73	60	50	47	3
June	71	58	52	50	49	4
					Total	12
Run 32 Refuge model output						
October	98	96	94	91	86	0
November	98	97	95	92	86	0
March	71	98	99	94	62	1
April	92	94	84	68	58	2
May	91	78	72	64	54	2
June	77	72	68	65	57	3
					Total	8
Real-Time Management (RTM) model output						
	0	<1	<1	<1	<1	0
October	97	95	94	91	80	0
November	100	97	96	93	83	0
March	72	99	100	96	69	1
April	99	92	88	68	58	2
May	93	79	71	64	55	2
June	76	71	68	66	58	3
					Total	8

Table I-10. Probability table of Williamson River discharge exceedences. Note that when the March 16-31 time step has a 0.95 or greater exceedence probability, there is a high likelihood drought conditions persisting into late August, the onset of the fall Chinook salmon run. The highlighted row displays the first encounters of either 1992 or 1994 (drought years), by time step, and the associated day, exceedence (Exc) and flow (Q).

March 16-31					April 1-15				April 16-30				May 1-15				August 1-15				August 16-31			
Date	Year	Q	Rank	Exc	Date	Q	Rank	Exc	Date	Q	Rank	Exc	Date	Q	Rank	Exc	Date	Q	Rank	Exc	Date	Q	Rank	Exc
March 31, 1991	1991	803	602	0.94	April 10, 1991	839	561	0.93	April 27, 1991	726	548	0.91	May 6, 1990	662	546	0.91	August 7, 1990	376	556	0.93	August 20, 1991	380	602	0.94
March 17, 1991	1991	795	605	0.94	April 12, 1991	816	566	0.94	April 26, 1991	717	550	0.92	May 2, 1991	640	550	0.92	August 12, 1991	365	568	0.95	August 19, 1991	373	606	0.95
March 18, 1991	1991	791	607	0.95	April 1, 1991	812	567	0.94	April 24, 1977	708	553	0.92	May 7, 1990	635	551	0.92	August 14, 1991	365	568	0.95	August 17, 1991	366	607	0.95
March 19, 1991	1991	791	607	0.95	April 13, 1991	802	568	0.95	April 26, 1977	708	553	0.92	May 1, 1991	635	551	0.92	August 15, 1991	365	568	0.95	August 16, 1991	362	608	0.95
March 18, 1994	1994	782	609	0.95	April 2, 1994	774	569	0.95	April 16, 1994	706	555	0.92	May 6, 1994	634	553	0.92	August 13, 1992	316	571	0.95	August 28, 1992	347	609	0.95
March 19, 1994	1994	781	610	0.95	April 6, 1994	774	569	0.95	April 17, 1994	706	555	0.92	May 3, 1991	630	554	0.92	August 14, 1992	316	571	0.95	August 27, 1992	343	610	0.95
March 20, 1994	1994	779	611	0.95	April 14, 1991	765	571	0.95	April 18, 1994	702	557	0.93	May 4, 1991	630	554	0.92	August 15, 1992	313	573	0.95	August 31, 1992	341	611	0.95
March 16, 1994	1994	778	612	0.95	April 7, 1994	765	571	0.95	April 19, 1994	702	557	0.93	May 12, 1991	629	556	0.93	August 1, 1992	312	574	0.96	August 30, 1992	340	612	0.95
March 17, 1994	1994	772	613	0.96	April 9, 1994	763	573	0.95	April 25, 1991	701	559	0.93	May 8, 1991	626	557	0.93	August 11, 1994	312	574	0.96	August 29, 1992	337	613	0.96
March 21, 1994	1994	765	614	0.96	April 3, 1994	762	574	0.96	April 29, 1991	694	560	0.93	May 5, 1994	623	558	0.93	August 15, 1994	312	574	0.96	August 28, 1994	335	614	0.96
March 24, 1994	1994	764	615	0.96	April 5, 1994	762	574	0.96	April 16, 1991	686	561	0.93	May 7, 1994	622	559	0.93	August 2, 1992	310	577	0.96	August 31, 1994	331	615	0.96
March 23, 1994	1994	762	616	0.96	April 1, 1994	760	576	0.96	April 27, 1977	684	562	0.94	May 1, 1994	618	560	0.93	August 3, 1992	310	577	0.96	August 29, 1994	329	616	0.96
March 22, 1994	1994	756	617	0.96	April 8, 1994	760	576	0.96	April 18, 1991	682	563	0.94	May 11, 1991	615	561	0.93	August 7, 1992	308	579	0.96	August 30, 1994	327	617	0.96
March 25, 1994	1994	755	618	0.96	April 4, 1994	754	578	0.96	April 17, 1991	679	564	0.94	May 5, 1991	614	562	0.94	August 12, 1994	308	579	0.96	August 26, 1992	326	618	0.96
March 26, 1994	1994	748	619	0.97	April 11, 1994	748	579	0.96	April 24, 1991	679	564	0.94	May 4, 1994	612	563	0.94	August 6, 1992	307	581	0.97	August 27, 1994	323	619	0.97
March 31, 1994	1994	738	620	0.97	April 10, 1994	741	580	0.97	April 28, 1977	676	566	0.94	May 9, 1991	611	564	0.94	August 10, 1992	307	581	0.97	August 18, 1992	322	620	0.97
March 27, 1994	1994	737	621	0.97	April 12, 1994	728	581	0.97	April 19, 1991	676	566	0.94	May 8, 1994	609	565	0.94	August 12, 1992	307	581	0.97	August 16, 1992	321	621	0.97
March 30, 1994	1994	734	622	0.97	April 15, 1991	718	582	0.97	April 29, 1977	668	568	0.95	May 8, 1990	605	566	0.94	August 4, 1992	306	584	0.97	August 19, 1992	321	621	0.97
March 28, 1994	1994	724	623	0.97	April 13, 1994	709	583	0.97	April 20, 1994	668	568	0.95	May 3, 1994	604	567	0.94	August 5, 1992	306	584	0.97	August 17, 1992	320	623	0.97
March 29, 1994	1994	720	624	0.97	April 15, 1994	709	583	0.97	April 20, 1992	661	570	0.95	May 7, 1991	601	568	0.95	August 8, 1992	306	584	0.97	August 21, 1992	319	624	0.97
March 19, 1992	1992	628	625	0.98	April 14, 1994	704	585	0.97	April 21, 1994	661	570	0.95	May 10, 1991	601	568	0.95	August 9, 1992	306	584	0.97	August 20, 1992	317	625	0.98
March 18, 1992	1992	626	626	0.98	April 13, 1992	649	586	0.98	April 30, 1977	660	572	0.95	May 6, 1991	600	570	0.95	August 11, 1992	306	584	0.97	August 22, 1992	317	625	0.98
March 17, 1992	1992	625	627	0.98	April 14, 1992	630	587	0.98	April 27, 1994	655	573	0.95	May 2, 1994	596	571	0.95	August 14, 1994	305	589	0.98	August 23, 1992	313	627	0.98
March 16, 1992	1992	624	628	0.98	April 15, 1992	625	588	0.98	April 23, 1991	651	574	0.96	May 9, 1994	587	572	0.95	August 2, 1994	301	590	0.98	August 26, 1994	313	627	0.98
March 20, 1992	1992	624	628	0.98	April 1, 1992	607	589	0.98	April 30, 1991	649	575	0.96	May 9, 1990	576	573	0.95	August 13, 1994	301	590	0.98	August 24, 1992	311	629	0.98
March 21, 1992	1992	620	630	0.98	April 2, 1992	603	590	0.98	April 28, 1994	646	576	0.96	May 10, 1990	551	574	0.96	August 4, 1994	300	592	0.99	August 25, 1992	310	630	0.98
March 22, 1992	1992	619	631	0.98	April 12, 1992	591	591	0.98	April 22, 1991	643	577	0.96	May 10, 1994	551	574	0.96	August 5, 1994	300	592	0.99	August 25, 1994	310	630	0.98
March 23, 1992	1992	614	632	0.99	April 3, 1992	585	592	0.99	April 26, 1994	641	578	0.96	May 12, 1994	551	574	0.96	August 1, 1994	298	594	0.99	August 16, 1994	306	632	0.99
March 24, 1992	1992	611	633	0.99	April 4, 1992	571	593	0.99	April 20, 1991	639	579	0.96	May 11, 1994	537	577	0.96	August 3, 1994	298	594	0.99	August 24, 1994	302	633	0.99
March 25, 1992	1992	610	634	0.99	April 11, 1992	564	594	0.99	April 21, 1991	637	580	0.97	May 11, 1990	534	578	0.96	August 7, 1994	293	596	0.99	August 17, 1994	300	634	0.99
March 31, 1992	1992	609	635	0.99	April 7, 1992	560	595	0.99	April 16, 1992	633	581	0.97	May 13, 1994	530	579	0.96	August 10, 1994	293	596	0.99	August 23, 1994	300	634	0.99
March 26, 1992	1992	608	636	0.99	April 6, 1992	558	596	0.99	April 25, 1994	633	581	0.97	May 12, 1990	518	580	0.97	August 8, 1994	292	598	1.00	August 18, 1994	296	636	0.99
March 30, 1992	1992	607	637	0.99	April 5, 1992	557	597	0.99	April 19, 1992	631	583	0.97	May 14, 1994	518	580	0.97	August 9, 1994	289	599	1.00	August 22, 1994	296	636	0.99
March 28, 1992	1992	604	638	1.00	April 8, 1992	556	598	1.00	April 29, 1994	630	584	0.97	May 15, 1994	513	582	0.97	August 6, 1994	288	600	1.00	August 21, 1994	293	638	1.00

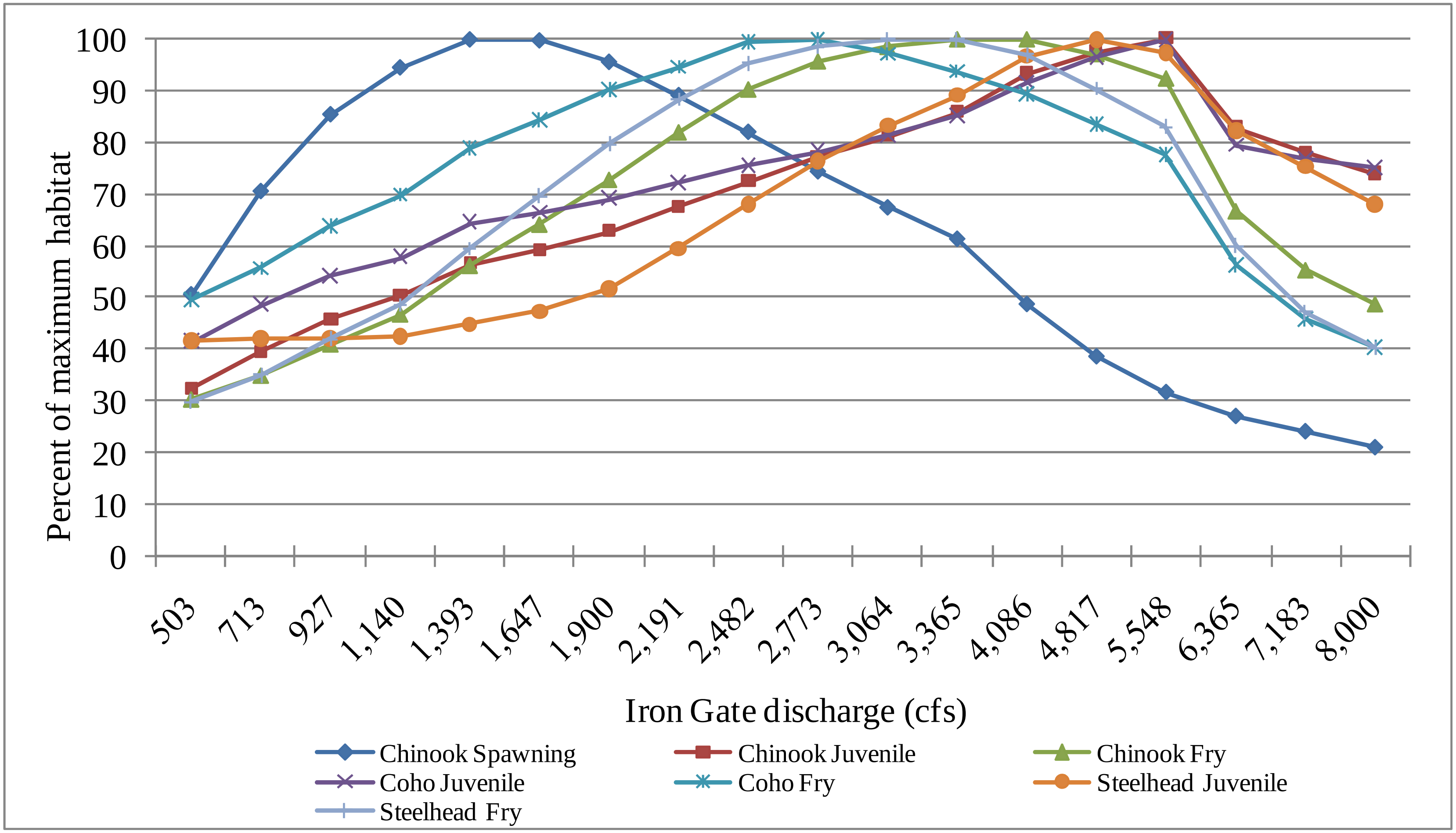


Figure I-1. Percent of maximum habitat in relation to discharge measure at Iron Gate Dam developed for the mainstem Klamath River, Iron Gate Dam to the Shasta River confluence. These relationships developed by Hardy et al. (2006a) were used by the Technical Team to assess the habitat values of alternative flow targets, model outputs, and historical conditions.

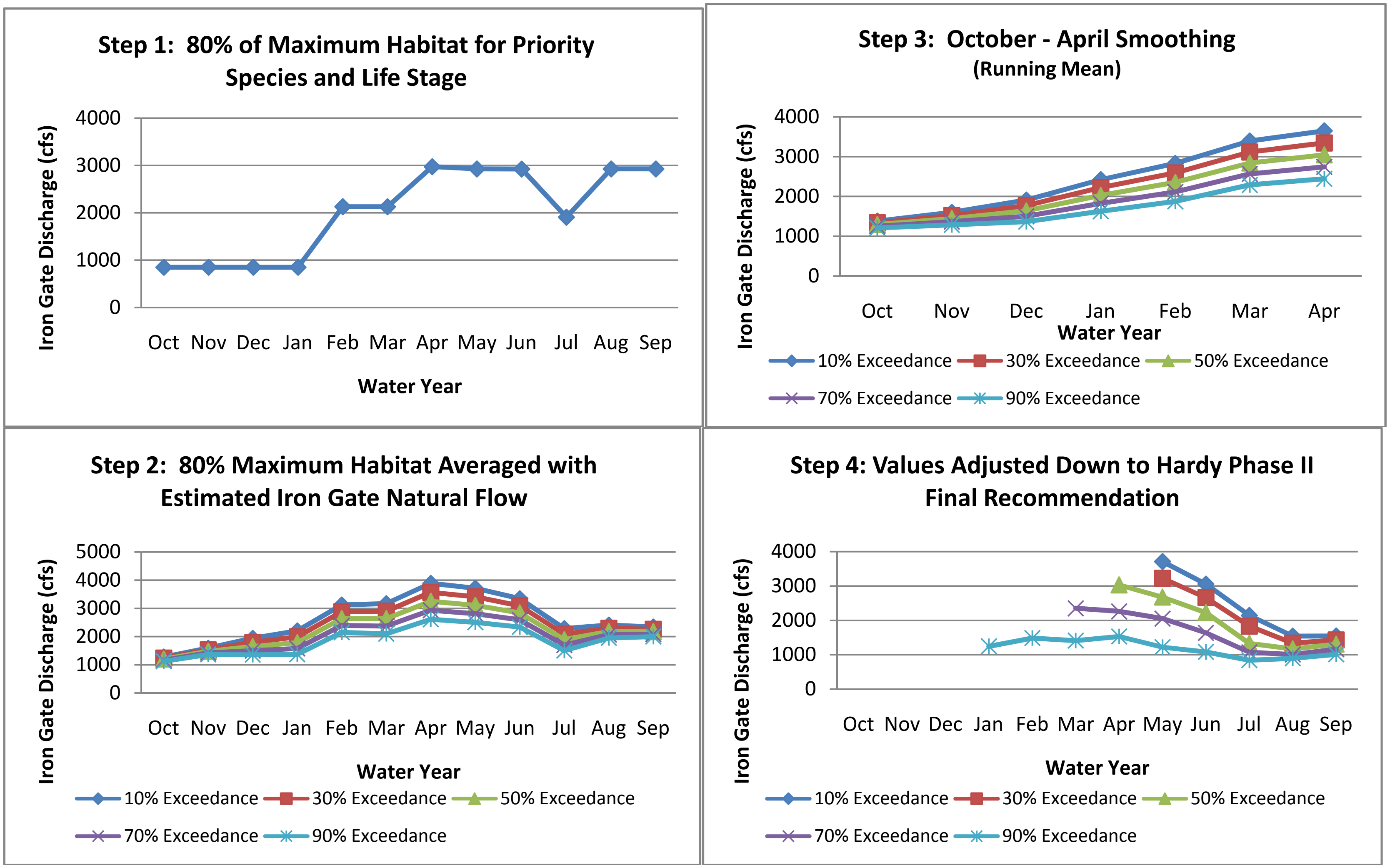
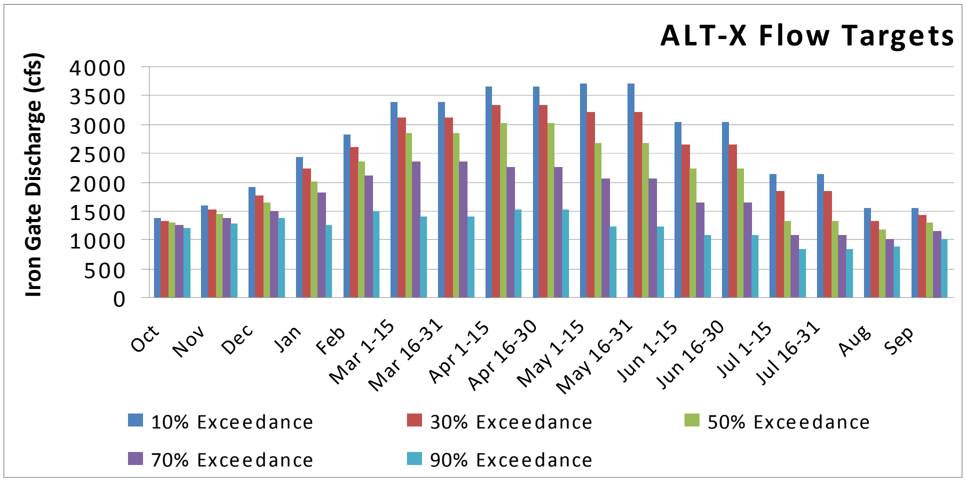
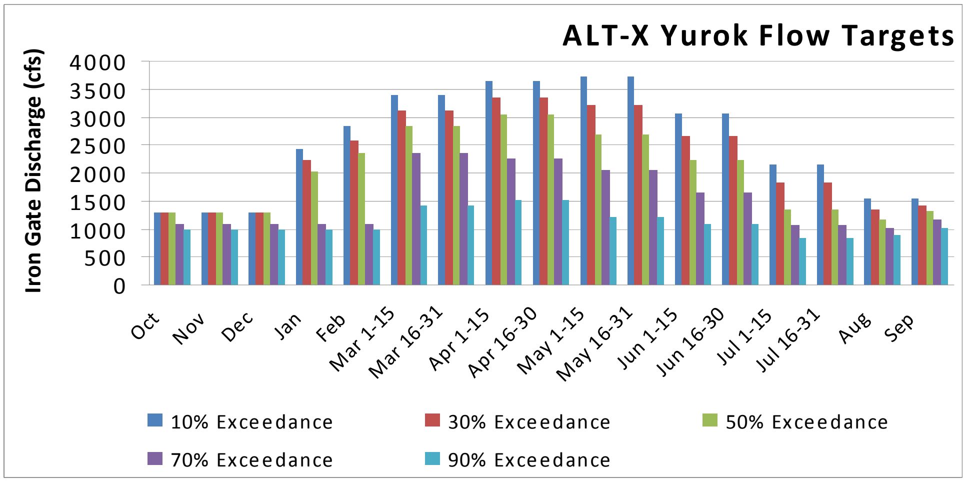


Figure I-2. Steps 1-4 used to develop the ALT-X flow regime.





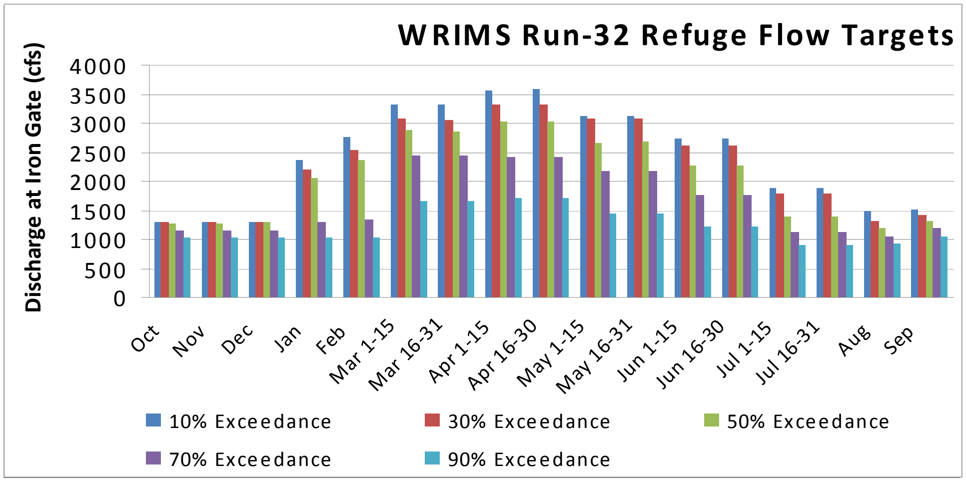


Figure I-3. Planning level flow targets for the ALT-X, ALT-X Yurok and WRIMS Run-32 Refuge alternatives, by exceedence level.

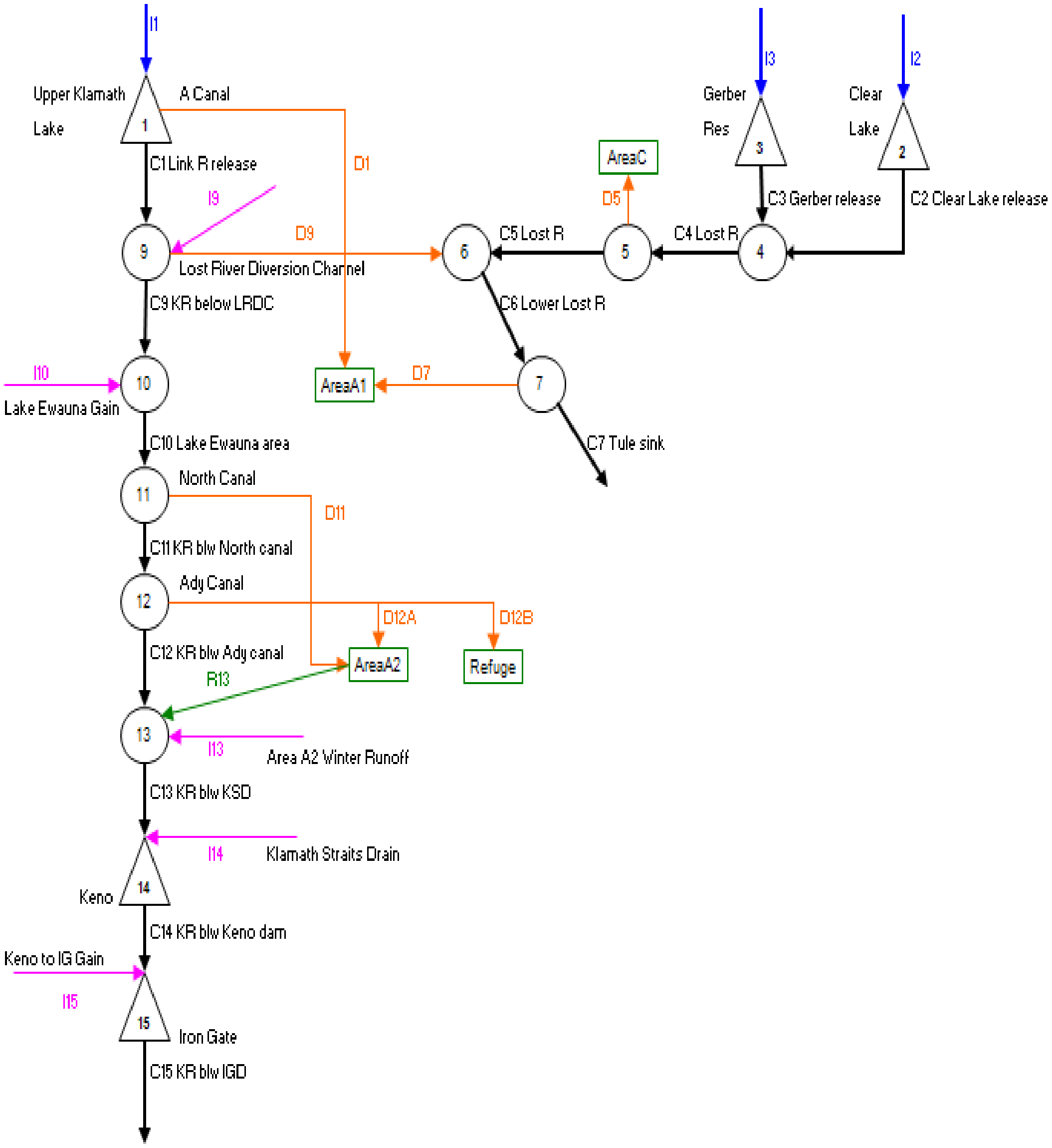
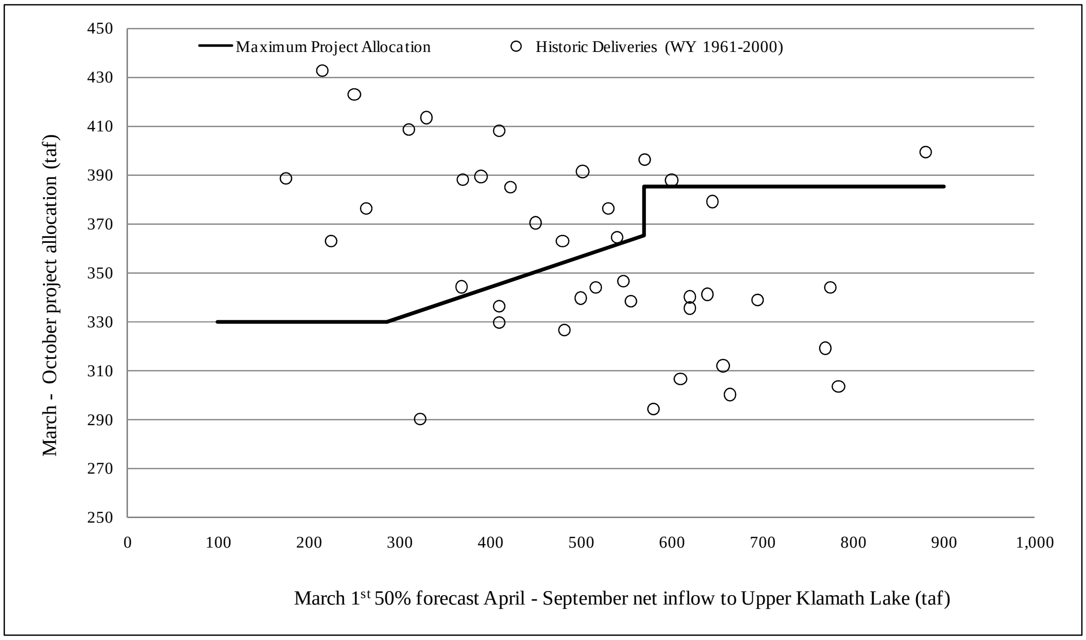


Figure I-4. WRIMS Run-32 Refuge model schematic showing model structure and demand nodes (provided by Nancy Parker, Reclamation 2007).



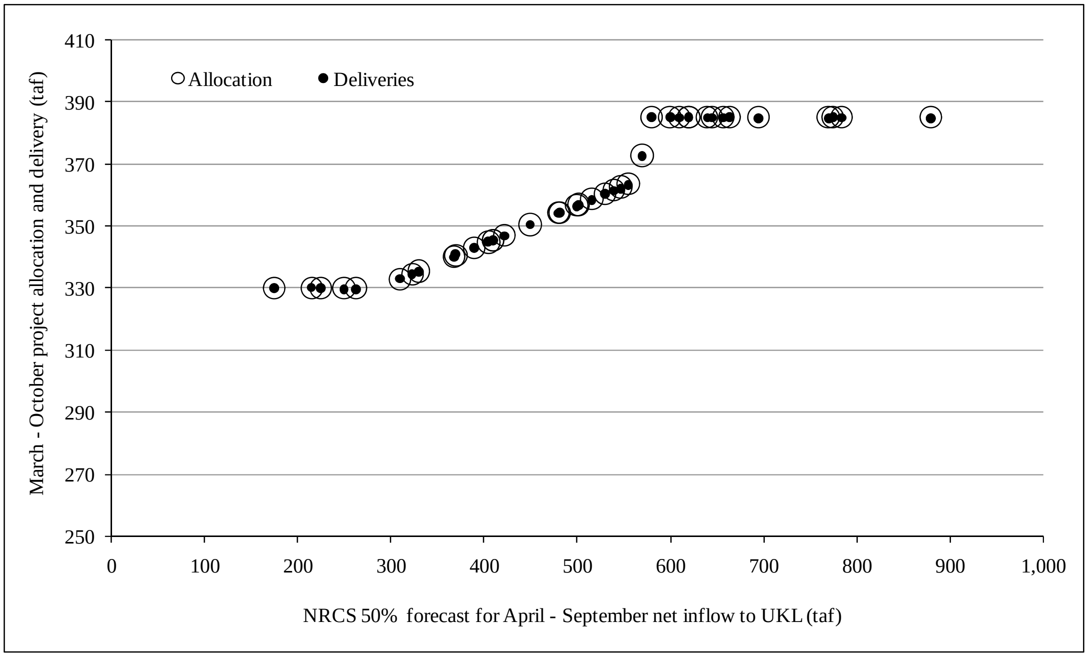
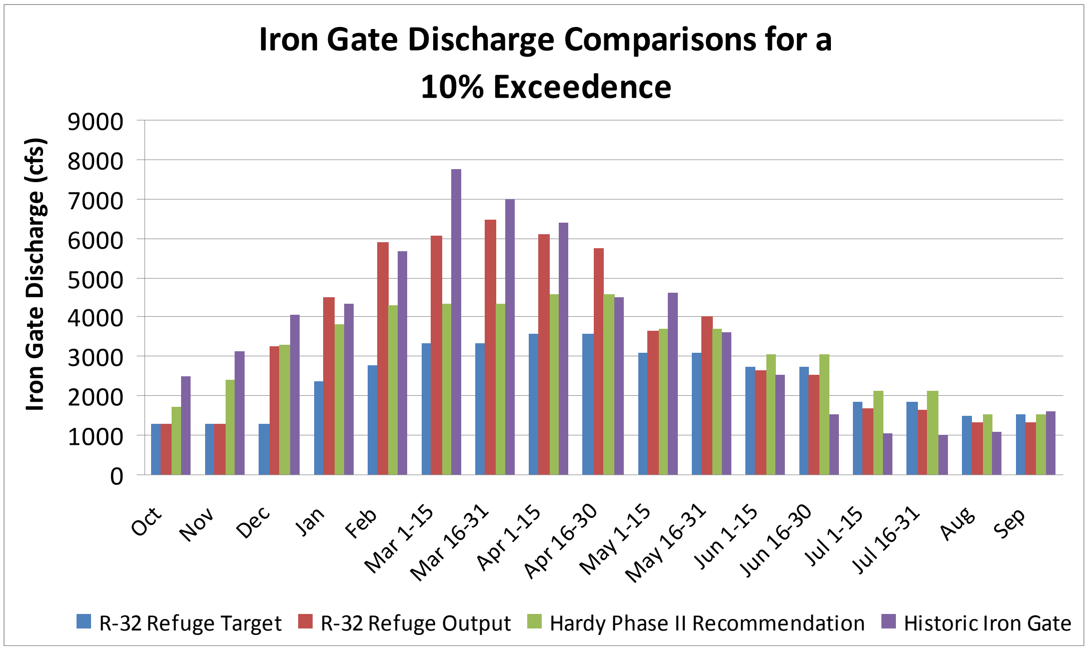


Figure I-5. Summary of March through October deliveries to the Klamath Irrigation Project for the historical period of record, water years 1961-2000 (top) and deliveries met in the WRIMS Run-32 Refuge simulation (bottom) under the water allocation proposed in the Klamath Basin Restoration KBRA. Graphs depict the conservative approach taken in the R-32 Refuge WRIMS simulation by assuming that it in average and wetter water years 1) the Klamath Project will take more water than it did historically and 2) the Project will use more water than it did historically.



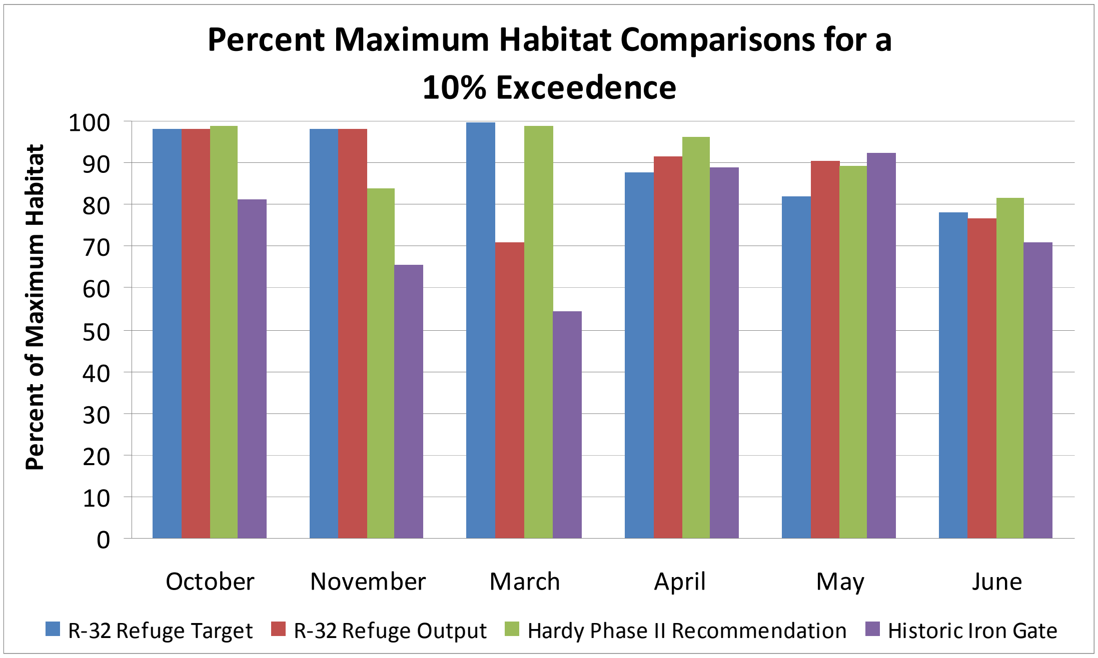


Figure I-6. Iron Gate discharge and resultant availability of spawning and rearing habitat for the WRIMS Run-32 Refuge flow schedule, WRIMS Run-32 Refuge model outputs, Hardy et al. (2006a) Phase II flow recommendations, and historical (water year 1961-2000) Iron Gate flow releases for a 10% exceedence flow level. Note that both the WRIMS Run-32 Refuge targets and Hardy Phase II recommendations are flow schedules and do not accurately portray spill events

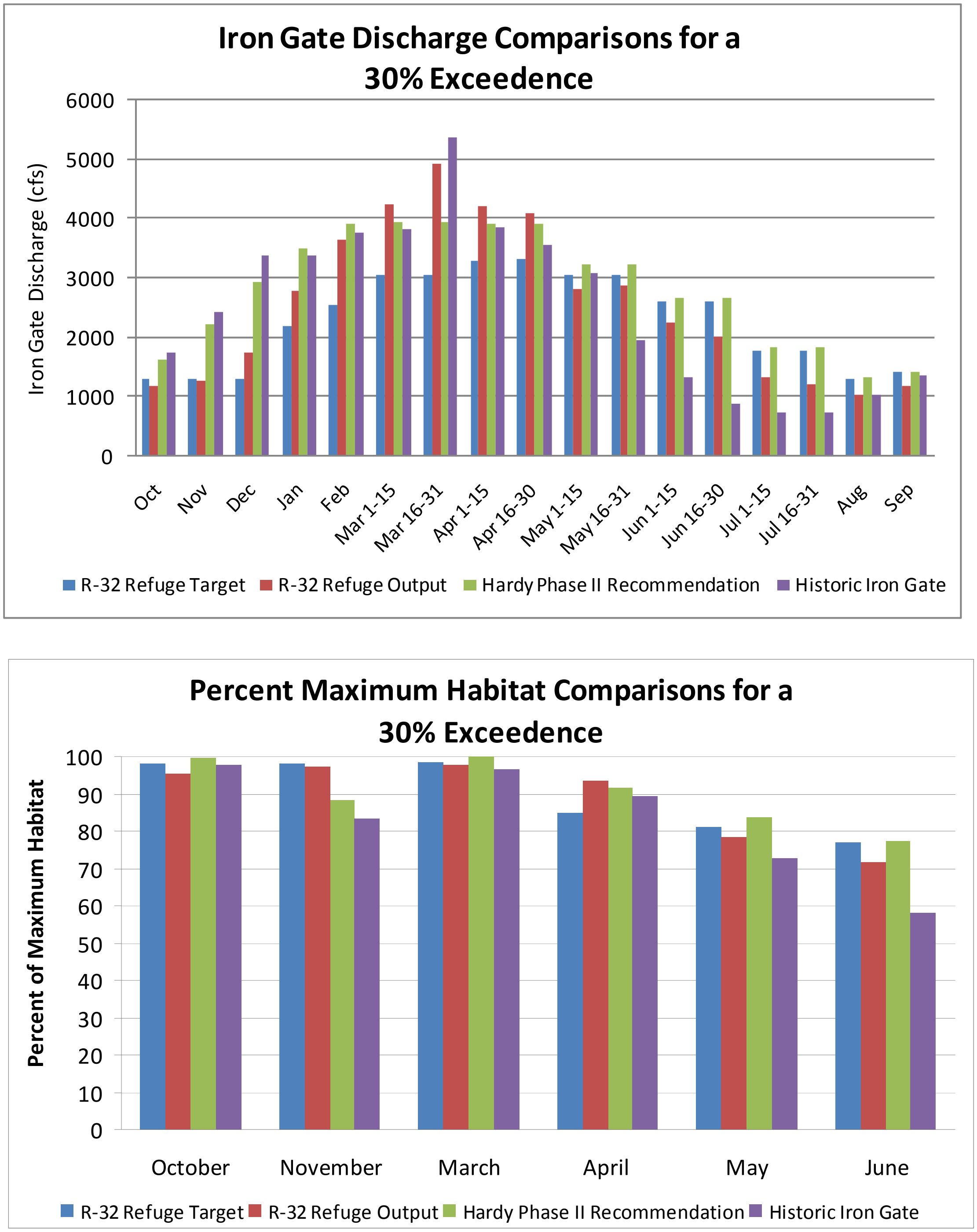
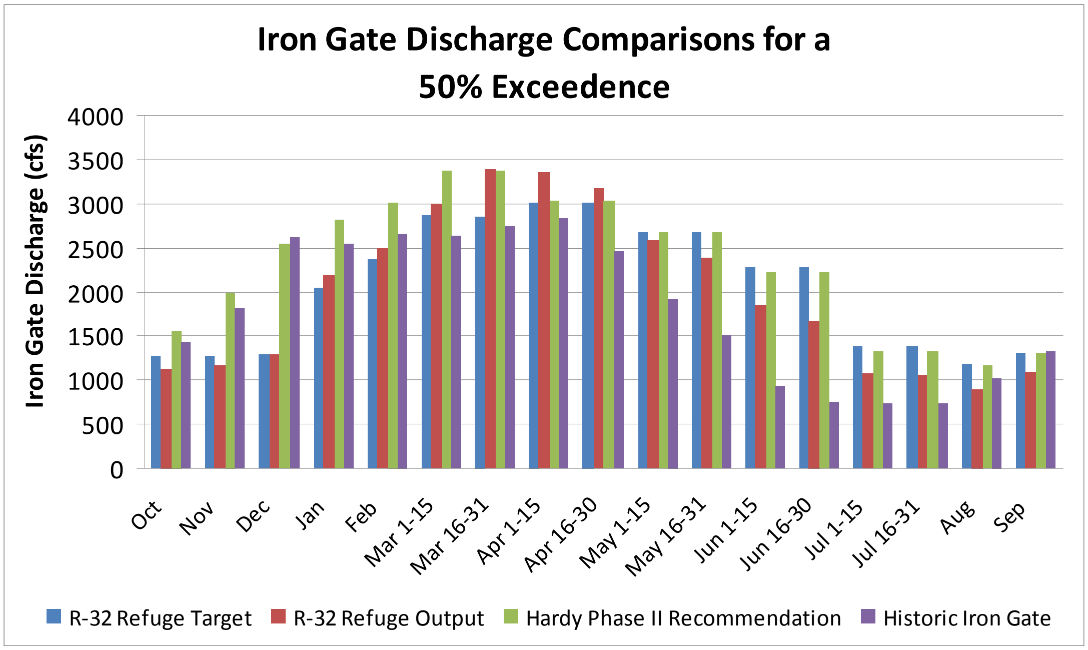


Figure I-7. Iron Gate discharge and resultant availability of spawning and rearing habitat for the WRIMS Run-32 Refuge flow target, WRIMS Run-32 Refuge model output, Hardy et al. (2006a) Phase II flow recommendation, and historical (water years 1961-2000) Iron Gate flow release for a 30% exceedence flow level. Note that both the WRIMS Run-32 Refuge targets and Hardy Phase II recommendations are flow schedules and do not accurately portray spill events.



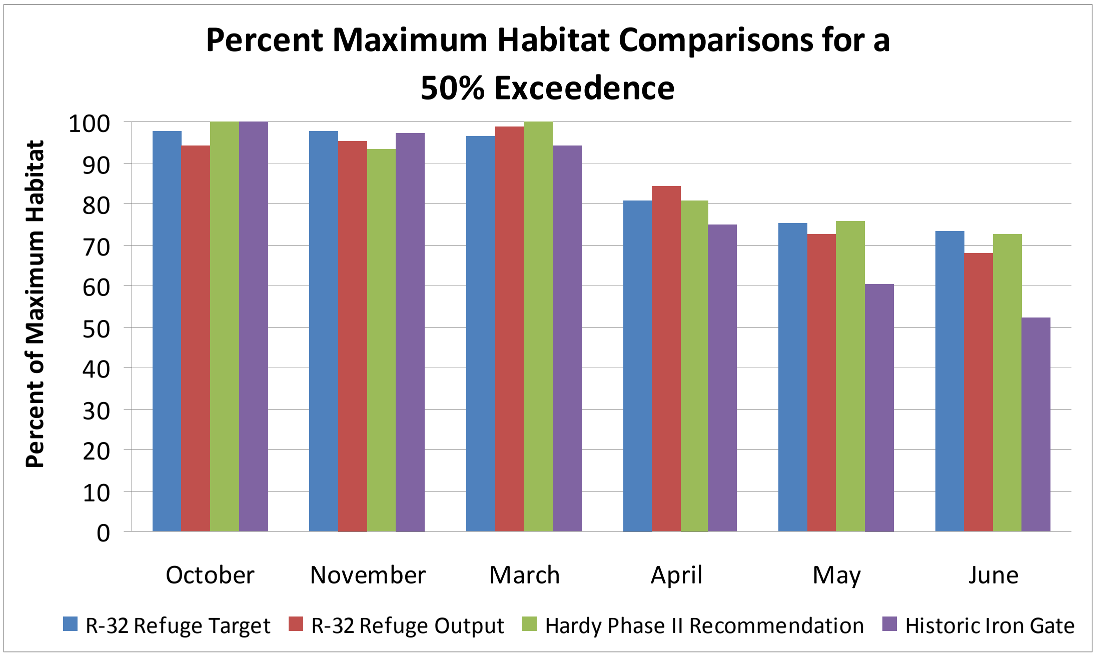
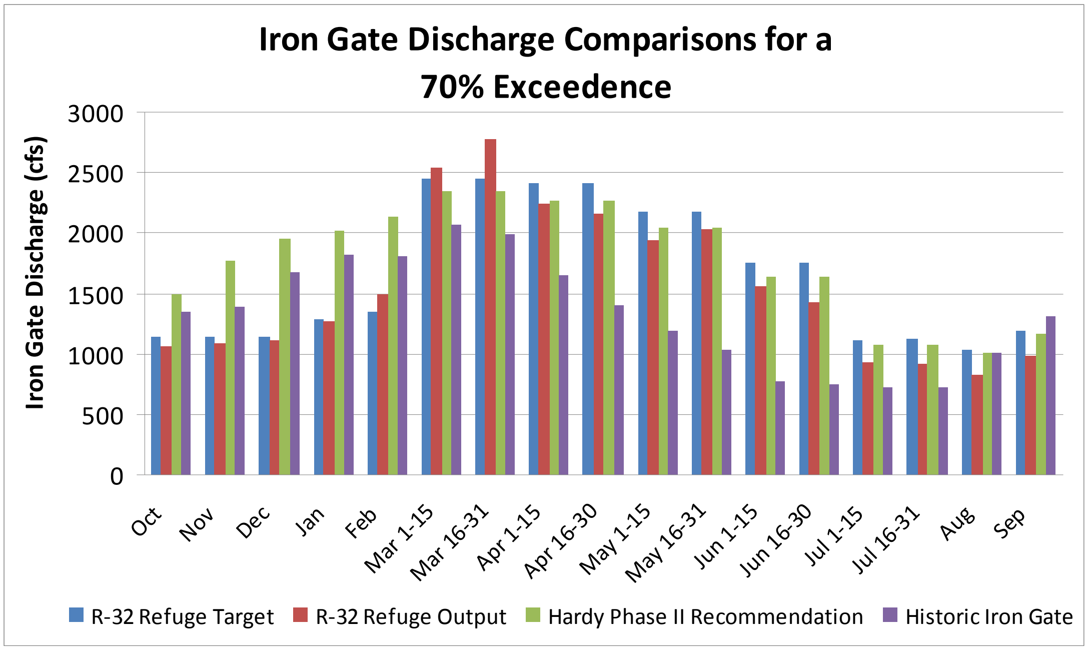


Figure I-8. Iron Gate discharge and resultant availability of spawning and rearing habitat for the WRIMS Run-32 Refuge flow target, WRIMS Run-32 Refuge model output, Hardy et al. (2006a) Phase II flow recommendation, and historical (water years 1961-2000) Iron Gate flow release for a 50% exceedence flow level. Note that both the WRIMS Run-32 Refuge targets and Hardy Phase II recommendations are flow schedules and do not accurately portray spill events.



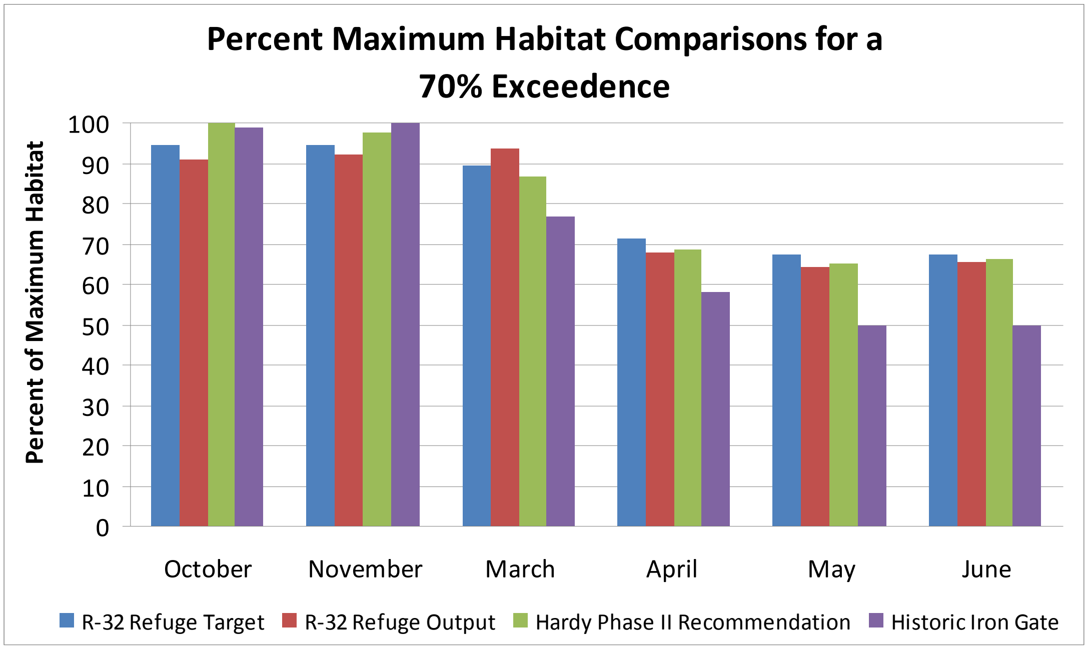
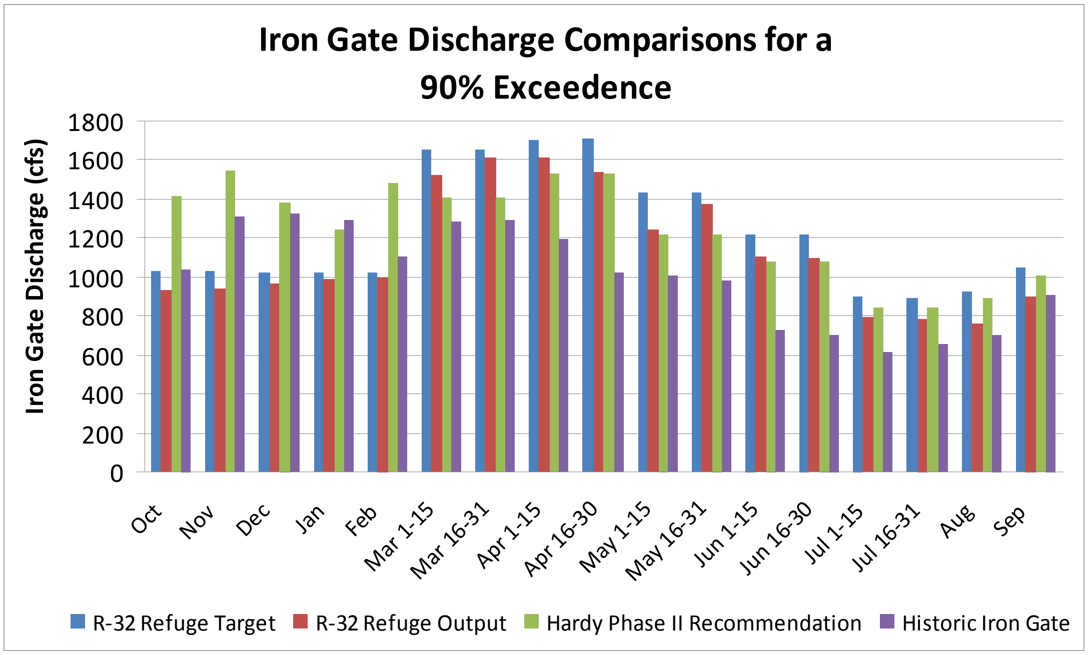


Figure I-9. Iron Gate discharge and resultant availability of spawning and rearing habitat for the WRIMS Run-32 Refuge flow target, WRIMS Run-32 Refuge model output, Hardy et al. (2006a) Phase II flow recommendation, and historical (water years 1961-2000) Iron Gate flow release for a 70% exceedence flow level. Note that both the WRIMS Run-32 Refuge targets and Hardy Phase II recommendations are flow schedules and do not accurately portray spill events.



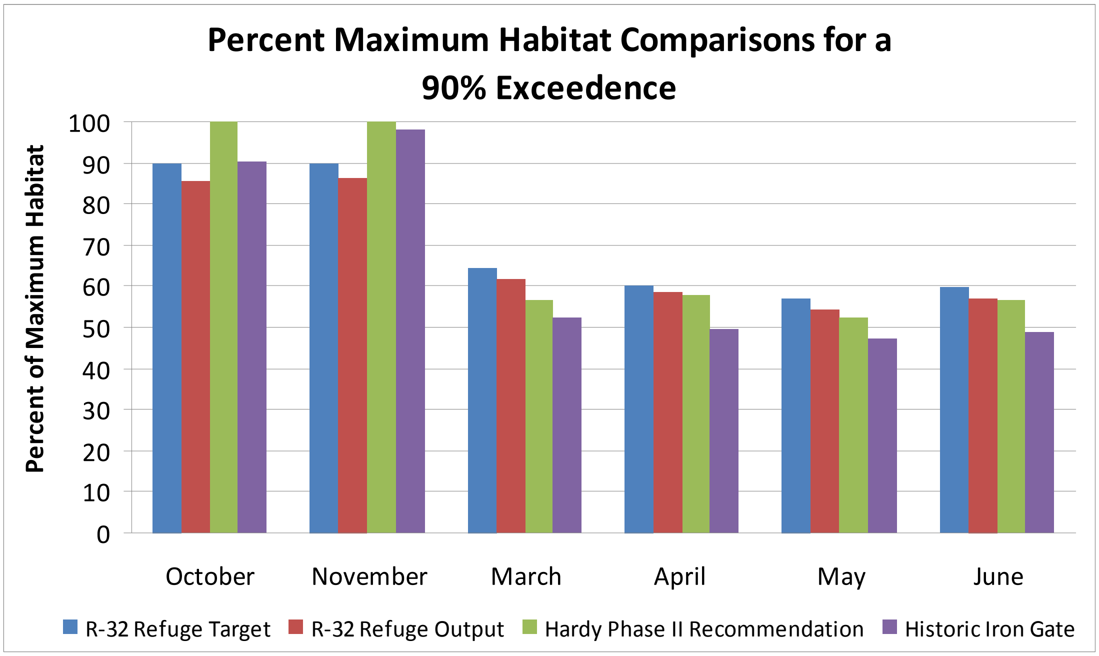
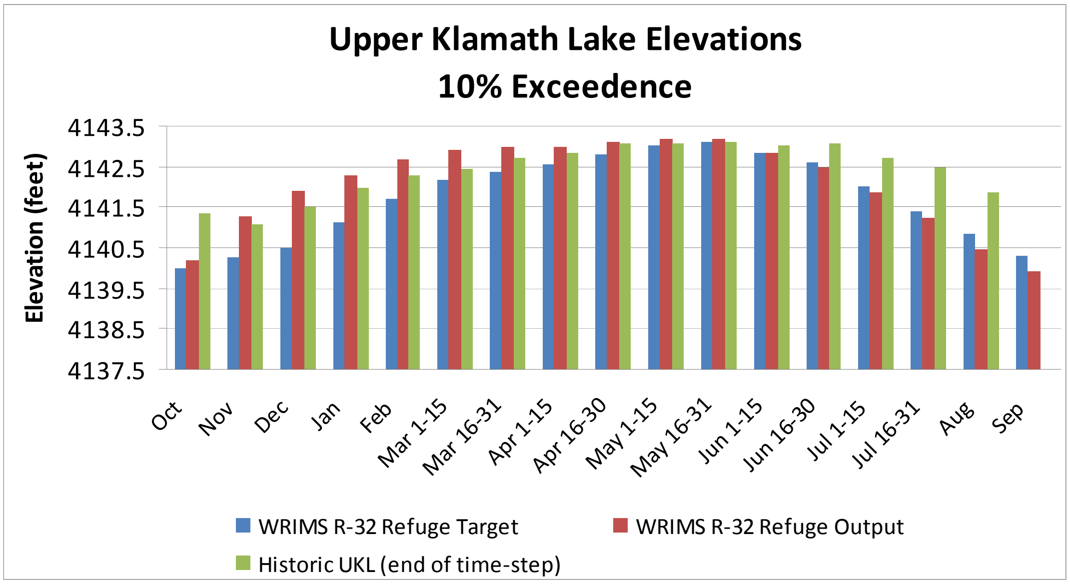


Figure I-10. Iron Gate discharge and resultant availability of spawning and rearing habitat for the WRIMS Run-32 Refuge flow target, WRIMS Run-32 Refuge model output, Hardy et al. (2006a) Phase II flow recommendation, and historical (water years 1961-2000) Iron Gate flow release for a 90% exceedence flow level. Note that both the WRIMS Run-32 Refuge targets and Hardy Phase II recommendations are flow schedules and do not accurately portray spill events.



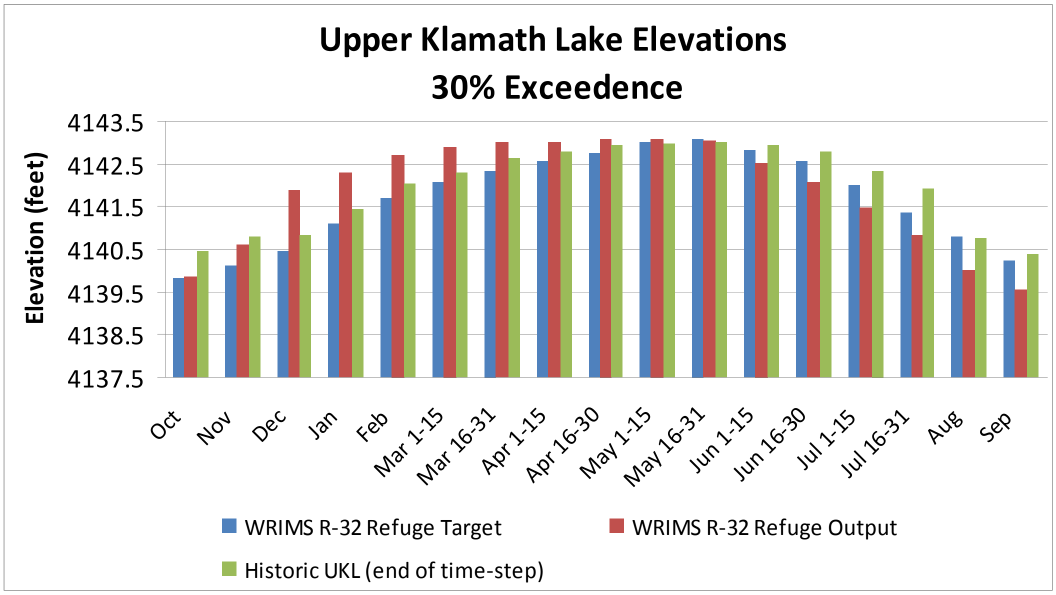
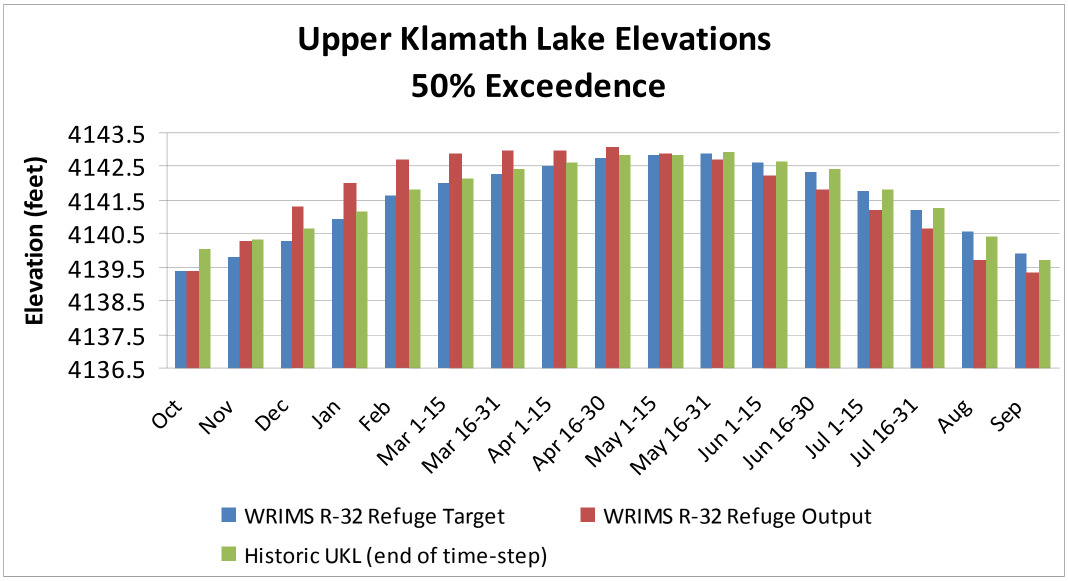


Figure I-11. Comparison of WRIMS Run-32 Refuge target (Alt-Y), WRIMS Run-32 Refuge model outputs, and historical water years 1961-2000 (end of time-step) lake elevations (feet above sea level) for Upper Klamath Lake by exceedence (10, 30, 50, 70, and 90%) and water year time-step.
(Continued on following pages).



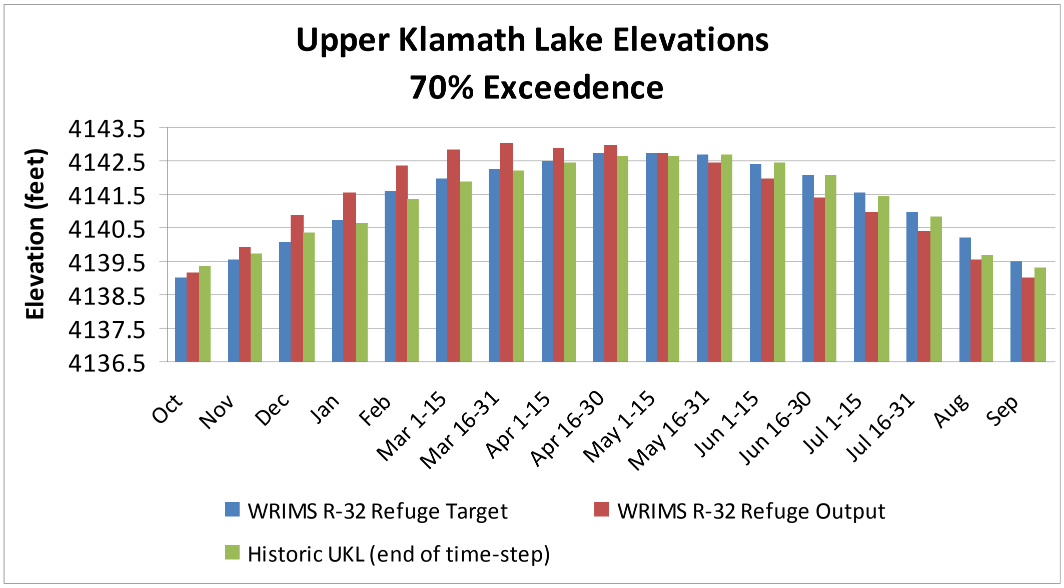


Figure I-11, continued. Comparison of WRIMS Run-32 Refuge target (Alt-Y), WRIMS Run-32 Refuge model outputs, and historical water years 1961-2000 (end of time-step) lake elevations (feet above sea level) for Upper Klamath Lake by exceedence (10, 30, 50, 70, and 90%) and water year time-step.

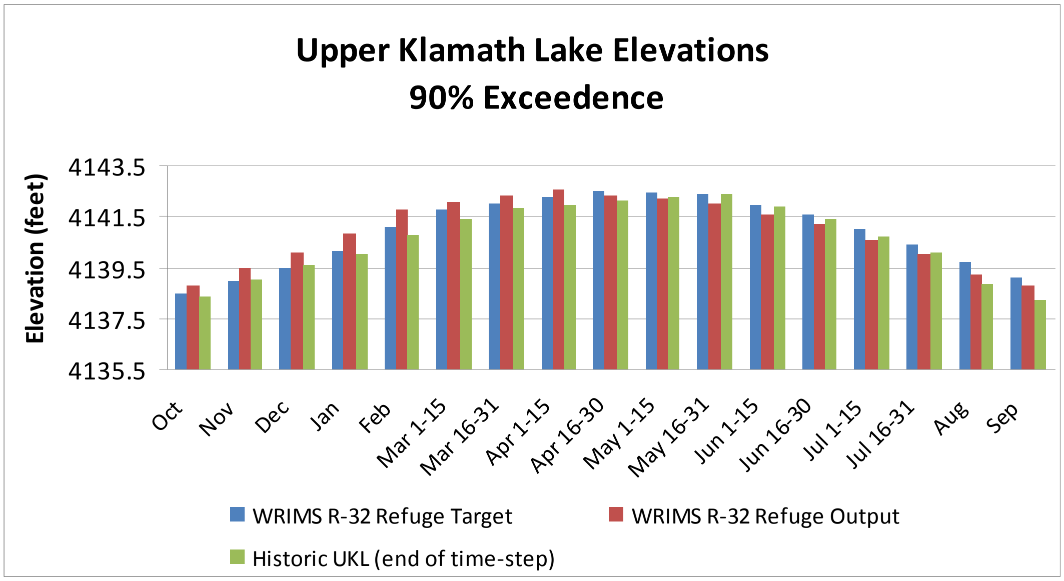


Figure I-11, continued. Comparison of WRIMS Run-32 Refuge target (Alt-Y), WRIMS Run-32 Refuge model outputs, and historical water years 1961-2000 (end of time-step) lake elevations (feet above sea level) for Upper Klamath Lake by exceedence (10, 30, 50, 70, and 90%) and water year time-step.

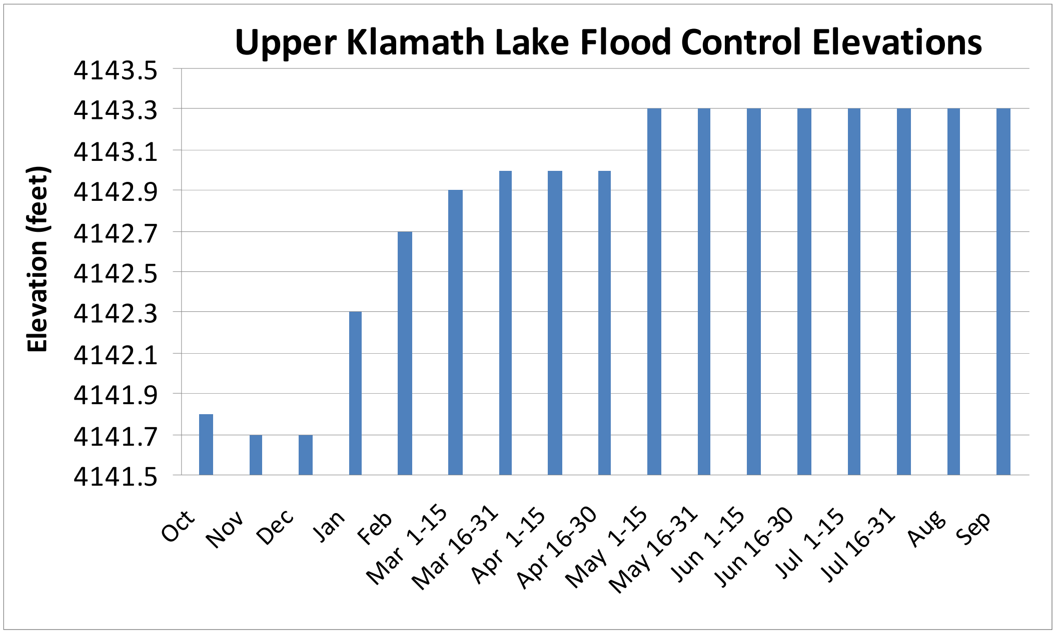


Figure I-12. Upper Klamath Lake flood elevation levels for time steps incorporated into the WRIMS Run-32 Refuge model simulation to define when spill would occur.

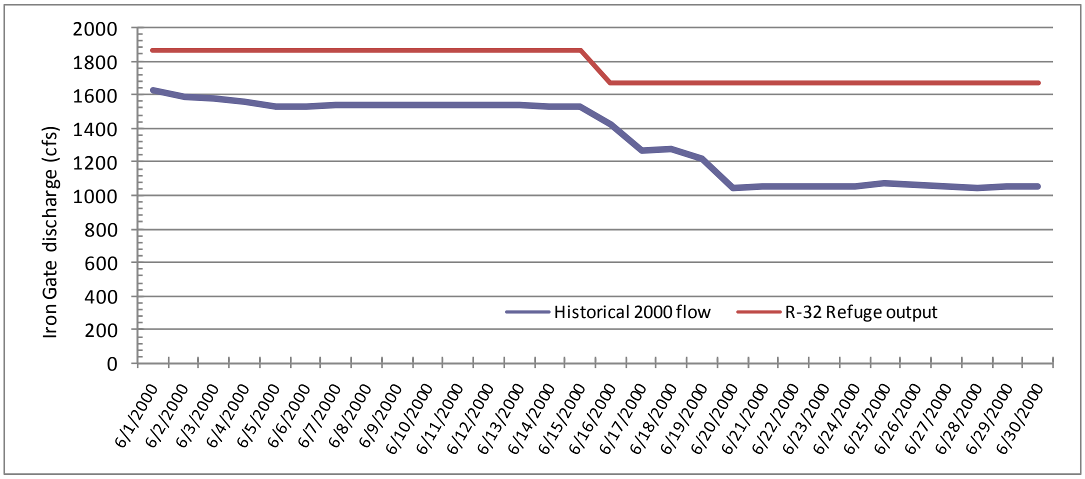


Figure I-13. Discharge below Iron Gate Dam contrasted with WRIMS Run-32 Refuge model flow outputs for June 2000. The decrease in flow to 1,050 cfs experienced in June 2000 was followed by a significant juvenile salmon die-off due to ceratomyxosis and columnaris.

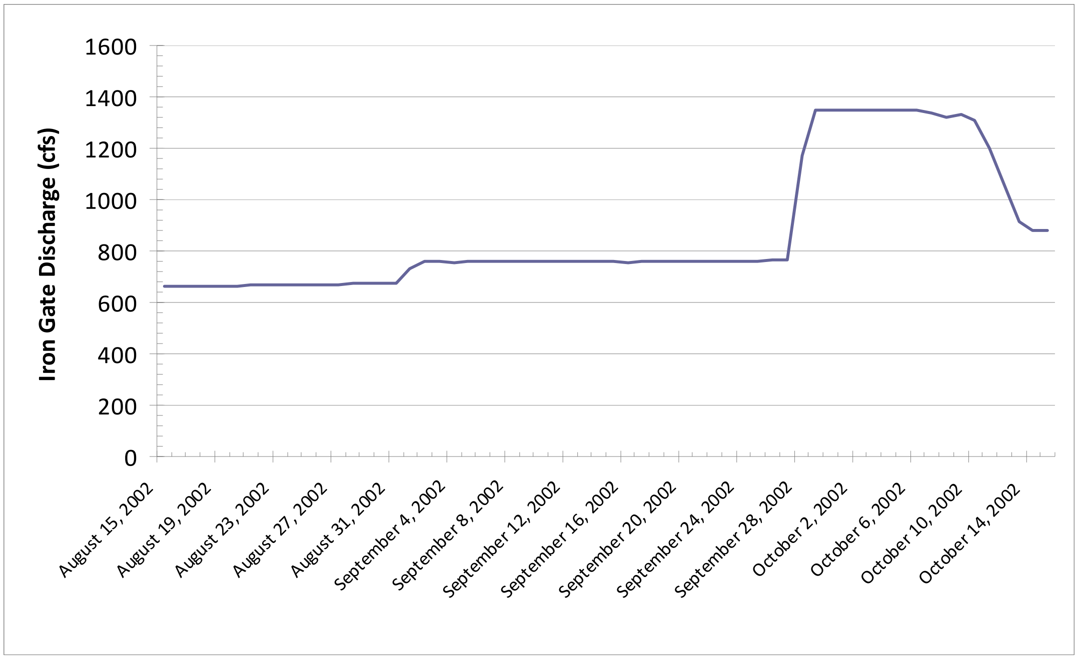


Figure I-14. Discharge below Iron Gate Dam between mid-August and mid-October, 2002, depicting flows of approximately 760 cfs during the September 19-28, 2002 die-off that resulted in mortality of over 33,000 adult salmon due to Ich and columnaris.

II. Water Quality

Under the pre dam removal phase of the Agreements, we assume that water quality conditions in the Klamath River are likely to improve slightly in response to regulatory and restoration actions, primarily through reductions in nutrient loading. However, the magnitude of improvement in water quality with the PacifiCorp Project dams in place and operational is not anticipated to be significant in comparison to benefits that would result from removal of existing hydropower reservoirs, which highly influence water quality conditions in the Klamath River (NRC 2003).

Pre Dam Removal

During the interim period leading up to dam removal, water quality conditions in the Klamath River are likely to improve slightly in response to regulatory and restoration actions, including interim measures proposed in the Draft KHSA, ongoing wetland restoration projects (e.g. dike removal on the Williamson Delta), and actions resulting from the Klamath River TMDL assessment, Clean Water Act Section 401 Certification, Section 7 consultations, etc. On-going regulatory processes and actions are also providing an improved understanding of water quality dynamics in the Basin, which will help direct future applied management actions (i.e. wetlands restoration, turbine venting) designed to improve water quality conditions. Potential changes in water quality conditions in the near future, however, are anticipated to be minor, largely because the continued operation of the PacifiCorp dam complex has the greatest single influence on water quality dynamics in the Klamath River below IGD (NRC 2003).

The Clean Water Act Section 401 certification is a regulatory process closely tied to the relicensing process of the Klamath Hydroelectric Project. Currently, and as part of the 401 certification application package to the State Board, PacifiCorp is experimenting with the use of epilimnion surface mixing devices to disturb algal blooms in the reservoirs (Copco and Iron Gate) and may in the near future implement other potential actions (e.g. turbine venting, algaecides, hypolimnetic oxygenation, and many more) to improve dissolved oxygen concentrations below PacifiCorp Project reservoirs to meet state standards (PacifiCorp 2008). Similarly, FERC (2007) has recommended the use of turbine venting at IGD to improve dissolved oxygen concentrations of water discharged into the river below the dam. However, many of these actions are being implemented only as pilot studies and it remains unclear as to whether these mitigation measures will be implemented in the future and if so, to what degree.

The mainstem Klamath River is listed under Section 303(d) of the Clean Water Act as an impaired water body for nutrients, dissolved oxygen, water temperature, and mycrocystin. While some of the above-mentioned water quality parameters may improve slightly as a result of management and restoration actions, remedial actions specific to the TMDL process have yet to be identified for the mainstem Klamath River. The TMDL process is jointly being developed by the Environmental Protection Agency, Oregon Department of Environmental Quality, and the California Regional Water Quality Control Board, and is expected to be completed by December 31, 2010. Following completion of the main TMDL document, an implementation plan will be drafted to identify specific actions designed to meet TMDL standards specified in the main TMDL document.

As our understanding of water quality and water dynamics within the Klamath system improves, Section 7 consultations may result in opportunities to improve water quality conditions. Measures in Biological Opinions could conceivably include actions to improve water quality. Prior to dam removal, the water allocation and implementation of real-time water management as proposed in the KBRA would likely have a positive influence on water quality. However, these improvements are expected to be minor because PacifiCorp Project reservoirs, which have the greatest influence on water quality in the Basin (NRC 2003), would still be in place and operational. With the reservoirs in place, water quality improvements made within and upstream of the Keno reach provided by the KBRA will be largely negated in the existing reservoirs and therefore, will not be fully realized below IGD.

Post Dam Removal

Background. Water quality in the Klamath River is highly dependent on flow quantities, point and non-point pollution sources, and hydraulic residence time (HRT). In the absence of PacifiCorp Project dams, hydrology of the river within this reach would more closely emulate pre dam conditions, with HRT substantially shortened from several weeks to less than a day. Restoration of the river channel in current Hydropower Project reaches, in combination with attendant stream flows, are expected to contribute positively to restoring the physical, chemical, and biological interactions that are critical to the integrity of the river ecosystem (Poff et al. 1997), including the necessary environmental conditions for restoration of viable fish populations.

Assessment of the interactions between physical, chemical, and biological variables in a reservoir/stream system is complex. To gain insight into how water quality has been influenced by the Hydropower Project reservoirs, PacifiCorp constructed a water quality model of the Project reservoirs and river segments between and below the PacifiCorp dam complex. This modeling effort has been valuable for improving our knowledge of the behavior of the system, as well as of the limitations of the model itself (FERC 2006). Model simulations include a hypothetical without Project dams alternative to describe baseline conditions from which to compare existing operations scenarios to determine potential Hydropower Project effects (PacifiCorp 2004). Of the water quality parameters modeled, we have the most confidence in the predicted thermal regimes that might result in the absence of PacifiCorp Project reservoirs. However, considerable uncertainty remains about the model’s ability to accurately simulate nutrient dynamics, DO and pH for the without Project dams alternative. Skepticism of the model’s ability to simulate nutrient dynamics, DO, and pH in the river system has been documented in the administrative record of comments on draft EIS relating to the relicensing of PacifiCorp’s Hydroelectric Project. Concerns focus primarily on the model’s deficiencies in accurately portraying nutrient dynamics within reservoirs, streams, and estuary for different water years, coupled with the application of the functionally uncalibrated and unvalidated model to investigate new alternatives, such as the without PacifiCorp Project dams alternative (Asarian and Kann 2006).

Thermal Regimes. The thermal regime of the Klamath River within the PacifiCorp Project area and below IGD has been considerably altered as a result of Project reservoir operations. Two independent water temperature models have been developed to assess the magnitude and timing of changes in thermal conditions between differing management alternatives. Outputs of these models have been useful in assessing various management alternatives, including the without PacifiCorp Project reservoirs alternative. The model developed for PacifiCorp by Deas and Orlob (1999) is based on hourly-time steps. The second model was developed by USGS Fort Collins Science Center as a plug-in module to the System Impact Assessment Model (SIAM) described by Bartholow et al. (2005), and employs daily time steps. Although past simulations conducted with these models may not incorporate flow patterns that specifically mimic those of the more contemporary WRIMS Run-32 Refuge alternative proposed under the KBRA, generalities of simulation results are useful to predict thermal regimes that may result under the without Project dams alternative. Simulations run by both of the models for with and without Project dams alternatives indicate that the primary influence Project reservoirs have on water temperature results from increased HRT and thermal mass (PacifiCorp 2004; Bartholow et al. 2005). In the absence of PacifiCorp Project reservoirs, HRT would be shortened from several weeks to a less than a day. In addition, the thermal lag (phase shift) resulting from storage of water in reservoir impoundments and associated increased thermal mass would be eliminated. Water temperatures would emulate variability inherent in local unregulated river systems, experiencing natural diurnal variations and becoming warmer earlier in the spring and early summer and cooler earlier in late summer and fall than what occurs presently

Bartholow et al. (2005) used their model to simulate annual water temperatures of the Klamath River over a 40-year period of record, water years 1962-2001. They found that with the dams in place and operational, water temperatures in the spring could be up to 2 to 4 °C cooler than those predicted by the model with the dams and impoundments hypothetically removed. However, the greatest influence of reservoir operations was predicted to occur from mid- to late August through November, when water temperatures below IGD were predicted to be between 2 and 7 °C warmer than predictions made by the without PacifiCorp Project reservoirs model. Within this time frame, the month of October exhibited the greatest temperature difference. Independent simulations conducted by PacifiCorp (2005) for a dry year (2002) for without PacifiCorp Project reservoirs indicate that water temperatures could be up to 7 °C cooler in August and 10°C cooler in early October at the present location of IGD than temperatures with the reservoirs operational (Figure II-1). Although the modeled year likely represents an extreme hydrological condition, modeling results between 2000 and 2004 show similar trends, albeit temperature differences between the with and without PacifiCorp Project alternatives were less extreme (FERC 2007).

Bartholow et al. (2005) found that PacifiCorp Project reservoirs resulted in a phase shift in water temperature in that the seasonal thermal signature was delayed by approximately 18 days. PacifiCorp's modeling (PacifiCorp 2004) also showed a similar phase shift in water temperatures that can be attributed to operation of PacifiCorp Project reservoirs. Simulations of water temperatures without the reservoirs in place by both models are similar and show that spatially, the temperature difference between the with and without dams alternatives is greatest below IGD, but can extend to 120 to 130 miles downstream of the present-day location of IGD. Without the reservoirs, Bartholow et al. (2005) showed a marked reduction of 4 to 5 °C in daily mean water temperatures in October to early November to at least 96 km below IGD (Figure II-2).

PacifiCorp (2004) has also shown that diurnal fluctuations would become broader and more variable for the without PacifiCorp Project dams alternative than for existing conditions with the reservoirs operational. In addition, removal of Project reservoirs would allow important tributaries (e.g. Spencer, Jenny, Fall, Shovel, Camp creeks, etc.) and coldwater springs such as those present below J.C. Boyle Dam and the

Powerhouse, to directly enter and flow unobstructed down the mainstem Klamath River. This would provide thermal diversity in the river in the form of intermittently-spaced thermal refugia, which would benefit various life stages of a variety of aquatic biota, including immigrating and emigrating adult and juvenile salmonids during warmer months of the year.

Bartholow et al. (2005) also compared temperature model simulations for with and without PacifiCorp Project dams alternatives to assess how the altered thermal regime has likely influenced thermal habitats of Chinook salmon. Bartholow found that restoring the thermal regime by removal of the Project reservoirs would benefit migrant, holding, and spawning adult Chinook salmon. Benefits derived from the colder thermal regime would include reduced disease incidence, increased swimming performance and increased gamete viability (Poole et al. 2001).

There are two lines of evidential data that support the hypothesis that the current warmer-than-historical thermal regime below Iron Gate Dam is having a negative effect on Chinook salmon production and that restoration of the cooler thermal regime has the potential to increase adult survival and egg viability during the early segment of the spawning period. Spawning survey data collected by the Service and Tribal partners from 2001 to 2007 (Gough and Williamson 2009 in review) show a higher pre-spawn mortality rate for female adult Chinook salmon in the IGD to Shasta River reach during the first two to three weeks of October than in subsequent survey weeks (Figure II-3), following the same general decreasing trend as weekly pre-spawn mortality counts. The overlap of high pre-spawn mortality and warmer-than-natural water temperatures in this reach provides evidence of an adverse thermal influence. Assuming this hypothesis is accurate, the relatively high pre-spawn mortality observed in the early phase of the run (Figure II-3) may decrease following dam removal in response to restoration of the Klamath River's thermal regime. In addition, Bartholow and Hendrickson (2006) reviewed 30 years of historical Chinook salmon egg fertility rate data collected at Iron Gate Hatchery and found reduced egg viability during the early as compared to later segments of the runs. They suggested thermal stress as a potential cause of the observed reduction in egg viability.

Differing views have been expressed as to the potential effects of warmer water temperatures that would occur in the spring and early summer in the absence of PacifiCorp Project reservoirs on juvenile salmonids in the Klamath River. Bartholow et al. (2005) suggest that warming of the Klamath River during the spring and early summer that would occur without the dams in place could potentially reduce the suitability of habitats necessary for rearing and outmigration of Chinook salmon. However, we speculate that earlier warming of the river system is likely to trigger juvenile salmonids to out-migrate earlier, thereby avoiding unsuitably warm water temperatures that are presently reached in late spring to mid-summer in most years. A predicted earlier outmigration in response to elevated water temperatures in the spring is supported by a large body of literature relating to increased growth rates and thermal response of emigrating salmonids (Hoar 1988). In addition, restoration of a variable thermal regime between February and June under the without PacifiCorp Project dams alternative would provide conditions conducive to support diversity in life history tactics inherent in viable salmon populations (Poff et al. 1997; Poole et al. 2001).

Dunsmoor and Huntington (2006) reviewed Bartholow et al. (2005) and analyzed current conditions (relicensing) and a dams out Alternative. While their results were consistent with those of Bartholow et al. (2005) regarding the benefits of dam removal and a revised thermal regime for adult migration, they suggest that dam removal may provide thermal benefits to juvenile Chinook salmon downstream of IGD. Among the reasons cited for disagreeing with Bartholow et al. (2005), Dunsmoor and Huntington (2006) believe that Bartholow's use of a degree-day metric to assess likely impacts to juveniles was unrealistic, primarily because it assumes juveniles would be occupying the river regardless of temperature. Dunsmoor and Huntington (2006) suggested that further study is warranted regarding this subject.

Influence of Nutrients on Dissolved Oxygen and pH. Concerns with the health of the river's aquatic biota focus mainly on the effect that nutrients have on primary productivity and the resulting potential to depress dissolved oxygen concentrations and increase pH. Under certain environmental conditions, some nutrients (e.g. ammonia) in sufficient quantities can cause direct harm to the aquatic biota (EPA 1999). In particular, un-ionized ammonia (NH_3) is recognized as being more toxic than ammonium (NH_4+), and fractions of these species are directly related to increased water temperature, pH, and ionic strength (EPA 1999). However, the conversion of reservoirs to a riverine environment would not likely result in conditions to support ammonia production or persistence at levels intolerable to salmonids (NRC 2003). Inorganic nitrogen concentrations observed in the Klamath Basin may support attainment of ammonia levels that can be hazardous to salmonids in slow moving, stratified environments such as the PacifiCorp Project reservoirs (FERC 2007, Section 3-113 to 3-121). However, conditions necessary to achieve high ammonia levels within the water column of a riverine environment like the Klamath River likely do not exist. High ammonia levels in the river would be avoided by high turbulence that re-aerates water and oxidizes ammonia to nitrate and by utilization by autotrophs (Campbell 2001; NRC 2003). Given this information, we conclude that DO and pH that result from primary productivity, rather than any particular nutrient, are likely the best parameters to assess the suitability of water quality to aquatic biota of the Klamath River.

Concerns have been expressed over reported relatively high ammonia concentrations in the Klamath River between IGD and the Shasta River (rkm 284) that suggest that ammonia could be a problem (PacifiCorp 2004; FERC 2007). PacifiCorp (2004) reported a mean ammonia concentration of 1.99 mg/L for water samples collected in October 2002 and 2004. In a closer review of these data, we discovered ammonia concentration values listed for data collected in 2004 to be 3.84 mg/L (filtered) and 2.03 mg/L (unfiltered), when Total Kjeldahl Nitrogen (TKN) was reported at 0.529 mg/L (filtered) and 0.571 mg/L (unfiltered). We consider these values to be erroneously high for several reasons. First, ammonia concentrations for filtered samples are substantially higher than for unfiltered samples, which is possible due to analytical error (e.g. reporting limit), but unrealistic in this case because of the large magnitude of the differences. Second, ammonia levels were considerably higher than TKN concentrations, which is also unrealistic since TKN is derived thru summation of the ammonia concentration and the organic N concentration (i.e.$TKN = NH_3 + Norg$). Lastly, these values appear as distinct outliers when compared to the distribution of ammonia concentration values reported for this site (Figure II-4). In the absence of these erroneous data points, all other ammonia values for this site are generally less than 0.16 mg/L and usually below detection level, or less than 0.1 mg/L. Thus, it is important to note that ammonia concentrations at this site, as well as below IGD, are generally low and concentrations of this constituent, as well as most other nutrients, tend to decrease with increasing downstream distance from the IGD (PacifiCorp 2004, FERC 2007).

The time period of the greatest concern with regard to low DO and high pH are the months of May through September, when primary productivity of the river is typically at its peak because of increased solar insolation and warmer water temperature regimes. During these months additional nutrients, in particular nitrogen from Lake Ewauna, could potentially increase productivity and result in depressed DO concentrations during the night and increased pH during the day, which could occur at levels harmful to aquatic organisms. Kann and Asarian (2005, 2007) also report these months as being a critical time period with regard to DO and pH. Monitoring with continuous monitors from 1996 to 1998 from Keno to Seiad, Campbell (2001) also observed the lowest DO concentrations occurred during mid-summer.

Additionally, Armstrong and Ward (2008) worked collaboratively with the Arcata Fish and Wildlife Office to evaluate nutrient data collected from the Klamath River from May to October from 2001 to 2006. They showed that phosphorus and nitrogen act similar to non-conservative nutrients that are assimilated during the warmer summer months, but react similar to conservative substances (i.e. total dissolved solids or specific conductance) during the colder months. Behaving as a conservative nutrient essentially indicates that the nutrient is not being utilized rapidly by the river system and is instead, being transported downstream. In this case, nutrients that are released during the periods outside of the summer critical period are likely transported to the Pacific Ocean without being utilized to any great extent within the Klamath environment and as such, ultimately have little to no effect on water quality (i.e. DO or pH) conditions in the river.

Nutrient Cycling. Kann and Asarian (2005, 2007) have shown that: 1) PacifiCorp Project reservoirs can seasonally be nutrient sources and/or nutrient sinks to the river system below; 2) PacifiCorp Project reservoirs can act as nutrient sources during the critical summer growing season; and 3) on an annual basis, there is typically a small net retention of total phosphorus and nitrogen in the PacifiCorp Project reservoirs. Data presented by Kann and Asarian (2005, 2007) highlight dynamics of the reservoirs that are not adequately addressed by PacifiCorp's model. Kann and Asarian (2005) suggest internal sediment loading and nitrogen fixation by cyanobacteria as two possible pathways for increased loading to occur during the summer months, the latter of which is supported by the extreme abundance of N-fixing cyanobacteria documented in PacifiCorp Project reservoirs in recent years (Kann and Corum 2007). This is important from a perspective of the potentially large contribution of nitrogen from the reservoirs to the river as well as the potential overall health issues related to toxic algae blooms to humans and aquatic biota of the river system.

Kann and Asarian (2005, 2007) found the combined Copco and Iron Gate reservoirs can act as sources of nitrogen during the spring/summer months, a critical time for rearing and outmigration of juvenile salmonids. The seasonal timing of the reservoirs functioning as a nitrogen source is important because during this time period, nutrients can drive primary productivity and elevate diel fluctuations in DO and pH, which in turn, can harm aquatic biota. This suggests that in the absence of the PacifiCorp Project reservoirs, nutrient loads would be less than those that currently occur with Project reservoirs in place. Further improvements in water quality are expected in response to restoration of natural riverine processes (i.e. assimilation and aeration) that would occur in the absence of Project reservoirs, which would further reduce nutrient levels and thereby improve water quality in the Klamath River (FERC 2007).

Dissolved Oxygen and pH. Simulations of water quality models by PacifiCorp (as shown in FERC 2007 and Figure II-5) and reported by USGS (Sharon Campbell, USGS, personal communication) show substantial improvements in DO under the without PacifiCorp Project dams alternative immediately downstream from IGD. Simulation results for without PacifiCorp Project conditions suggest DO concentrations could be increased by 3 to 4 mg/L during the summer and early winter (PacifiCorp 2005), a time when DO concentrations in water released from IGD can be substandard (e.g.<7 mg/L). This is not unexpected since removal of the Project dams and reservoirs would allow natural stream processes to occur. In particular, stream re-aeration has been shown to be a very important component of the dissolved oxygen kinetics of the Klamath River below Iron Gate dam (Ward and Armstrong 2009a in press). For this reason, as well as evidence that nutrient loads at Keno Dam can be quite similar to those at Iron Gate Dam during the growing season (See section above and Asarian and Kann 2006), we believe that DO concentrations below Keno Dam are likely to fall within the range of conditions that exist today in river reaches located well downstream of IGD. Within this region below Iron Gate Dam, water quality data (DO and pH) collected by the Service and cooperators from May through September over six years (2001 to 2006) from IGD to the mouth of the Klamath River have shown DO to be typically greater than 6 mg/L and pH to typically be between 7.5 and 9.0 (Table II-1, Ward and Armstrong 2009b in press). Typically, the lowest DO and highest pH was recorded immediately downstream of IGD. Campbell (2001) also reported only brief periods of DO below 5.5 mg/L below IGD from 1996 to 1998. In studies referenced above, it is likely that re-aeration in the river channel was a dominant factor in limiting the occurrence of low DO concentrations in the water column of the Klamath River.

Because Keno Dam would remain in place under the Agreements, the quality of water released from this shallow impoundment is expected to generally remain the same, unless measures are implemented by regulatory and/or remedial actions to reduce nutrient inputs or change nutrient dynamics within UKL and Lake Ewauna. As documented in recent years, nutrient dynamics in UKL and Lake Ewauna are variable and often result in periodic increases in nutrient loads and altered nutrient form (e.g. ammonia) transported to downstream reaches as a result of anoxic conditions that result from “crashes” in primary productivity (Sullivan et al. 2008; Sullivan et al. 2009). Anoxic conditions in Lake Ewauna typically occur in July or August in response to high organic loads from Upper Klamath Lake, high nutrients levels, high solar insolation, limited mixing of the water column, and warm weather, which results in severe oxygen demand (Sullivan et al. 2008; Sullivan et al. in press). Anoxic conditions in the water column can increase inorganic fractions of various nutrients (e.g. ammonia, ortho-phosphorus) from decomposition of organic matter and/or release from fine sediments, rendering them available for downstream transport. These episodic events and the resulting transport of elevated nutrient loads to downstream reaches will continue to occur until significant management actions are implemented to control the causative factors. Future modeling of nutrient dynamics in Lake Ewauna may provide valuable insights into possible management actions that could be taken to improve water quality within this reach (Sullivan et al. 2008), which would to some degree, improve water quality in downstream reaches. While episodic elevated nutrient loads would continue to be released from Keno Dam in the summer, re-aeration afforded by a functioning river channel below Keno Dam provided under the without Project dams alternative is likely to prevent these elevated nutrient loads or potential changes in water quality from becoming detrimental to biota.

Nutrient dynamics in stream channels are controlled by many abiotic and biotic factors that play a role in nutrient uptake (assimilation), nitrification, and denitrification (Kemp and Dodds 2001, Royer et al. 2004, Bernhardt et al. 2005). These dynamic processes are important to nutrient cycling and preventing periods of decreased water quality that result from current nutrient loads in the river. Inflow from tributaries and springs, which are currently captured in reservoirs, will also contribute towards improving water quality through dilution and thermal cooling, which may act to reduce primary productivity.

Restoration of the riverine thermal regime through removal of PacifiCorp Project reservoirs would also increase and “restore” diurnal swings in DO and pH in river reaches currently occupied by reservoirs, as well as those experienced below the current location of IGD. During the growing season, increased diurnal fluctuations in water temperature would increase photosynthesis during the afternoons, which would increase DO and pH. Likewise, during the night and early morning hours, DO and pH would be reduced because of the lack of photosynthesis. Again, however, we conclude that re-aeration afforded by the high stream gradient of the river system will override any strong oxygen demand imposed on the river by biochemical interactions (e.g. sediment oxygen demand and community respiration), thereby resulting in suitable conditions for aquatic biota. Results of model simulations reported by PacifiCorp for the without Project dams alternative (Figure II-5) also suggest re-aeration by the river is an important factor preventing poor DO conditions, even under conditions of high nutrient loading (Table II-1). The maximum daily pH observed during the growing season is expected to be lowered as a result of conversion from a lentic to a lotic environment under the dams out alternative. Upper Klamath Lake and PacifiCorp Project reservoirs have and continue to provide the necessary environmental conditions to promote dense accumulations of algae (e.g. *Aphanizomenon spp*) during the growing season that support high productivity and daily maximum pH values near 10.0 (NRC 2003) and are expected to continue to contribute to high loads to the Klamath River. In the absence of PacifiCorp Project reservoirs, however, riverine conditions such as increased water velocity and mixing would prevent dense accumulations of algae and associated high daily maximum pH (NRC 2003). In turn, lowered pH would lessen the potential for ammonia toxicity and improve overall suitability to aquatic organisms.

Blue Green Algae. Blue-green algae (BGA), known as cyanobacteria, are microscopic organisms that are naturally present in some lakes and streams. BGA can become abundant in warm, shallow, nutrient-rich, undisturbed surface water when exposed to high solar radiation. When this occurs, they can form blooms that discolor the water and can produce floating rafts or scums on the water surface. Some BGA produce toxins that could pose a health risk to people and animals when exposed to them in sufficient quantities. BGA blooms of *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* have been documented in Copco and Iron Gate Reservoirs from 2005 to 2007 (Kann and Corum 2005, Kann and Corum 2007; Kann 2007). In the absence of PacifiCorp Project reservoirs, the environmental conditions under which these species generally persist and thrive would be greatly diminished (FERC 2007). Huisman et al. (2004) demonstrated that potentially toxic *M. aeruginosa* dominate at low turbulent diffusivity (calm-stable conditions) when their flotation velocity exceeds the rate of turbulent mixing. As such, removal of PacifiCorp Project reservoirs and restoration to a riverine environment having a relatively high gradient and high degree of turbulence would prevent such blooms from occurring.

Algal blooms documented in the Klamath River in the past few years have been large, with toxin levels very high relative to the World Health Organization standards, often exceeding them by 10 to over 100 times (Kann and Corum 2005; Kann and Corum 2007). In addition to representing a public health hazard, high concentrations of BGA and toxins eventually are transported downstream as drift and have been reported to exist throughout the mainstem Klamath River below IGD (Kann and Corum 2005; Kann and Corum 2007). Kanz (2008) conducted a screening level analysis of accumulation of microcystin in yellow perch (*Perca flavescens*) from the reservoirs, Chinook salmon from Iron Gate Hatchery, and freshwater mussels (*Gonidea angulata*) from the Klamath River below IGD. He found bioaccumulation of the toxin to be transitory in nature, being present in tissues when the toxin and algal blooms are present and that depuration occurred in the absence of the toxin in the water. Kanz (2008) also suggested the toxin could have negative effects to fishes as well as mammals that consume the contaminated tissues. Landsberg (2002) reviewed the historical literature on the effects of harmful algal blooms on aquatic organisms and reported that *M. aeruginosa* can be toxic to fish and zooplankton. These findings suggest that high concentrations of this BGA and attendant toxins may be yet another stressor to the biotic community in the Klamath River, and that this environmental stressor can, in all likelihood, be dramatically reduced, potentially to naturally occurring non toxic levels, by removal of the PacifiCorp Project reservoirs.

Tables and Figures

Table II-1. Daily dissolved oxygen minima (A) and daily maximum pH (B) at several locations along the Klamath River below Iron Gate Dam (rkm 306) for the months of May through October from 2001 to 2006. Data collected with continuous datasonde recorders and finalized through detailed correction (adjustment) procedures (unpublished data, USFWS, Arcata, CA).

A	**Dissolved Oxygen (mg/L)**								
Monitoring Location: Distance from The Pacific Ocean (km)	306	285	231	207	162	95	70	65	11
Daily DO Minima (mg/L)	Cummulative Number of Days "Equal to or Less Than" the DO Minima								
12	663	293	268	571	568	587	681	612	606
11	663	293	268	571	559	587	676	612	599
10	663	293	268	571	550	578	638	594	567
9	651	292	252	558	507	527	550	481	459
8	534	231	201	443	436	344	395	298	293
7	281	130	97	217	215	62	87	77	108
6	106	8	26	29	30	3	4	3	2
5	28	0	3	1	1	0	0	0	0
4	5	0	0	0	0	0	0	0	0

B	**Hydrogen Ion Concentration (pH)**								
Daily pH Maxima	Cummulative Number of Days " Equal to or Greater Than" the pH Maxima								
7	712	293	302	588	594	596	676	633	526
7.1	711	293	302	588	594	596	676	633	526
7.2	709	293	302	588	594	596	676	633	526
7.3	696	293	302	588	594	596	676	633	526
7.4	679	293	302	588	594	596	676	633	525
7.5	669	293	302	588	594	596	676	633	525
7.6	654	293	302	588	594	596	676	633	522
7.7	635	293	302	588	594	596	676	633	513
7.8	606	293	302	588	591	596	675	624	505
7.9	577	292	302	587	587	589	668	617	486
8	548	291	302	577	578	561	648	601	465
8.1	511	291	302	562	562	496	625	575	439
8.2	464	290	300	543	541	387	579	542	393
8.3	395	285	291	508	466	283	489	443	312
8.4	345	274	272	432	365	191	398	305	260
8.5	287	259	230	357	255	110	320	182	179
8.6	217	241	179	276	170	52	223	86	125
8.7	183	216	114	197	86	19	96	23	53
8.8	135	175	69	149	53	6	27	4	2
8.9	94	129	21	80	22	3	1	2	0
9	54	85	5	21	9	2	0	0	0
9.1	27	36	2	6	1	1	0	0	0
9.2	7	14	0	0	0	0	0	0	0
9.3	3	4	0	0	0	0	0	0	0
9.4	0	1	0	0	0	0	0	0	0

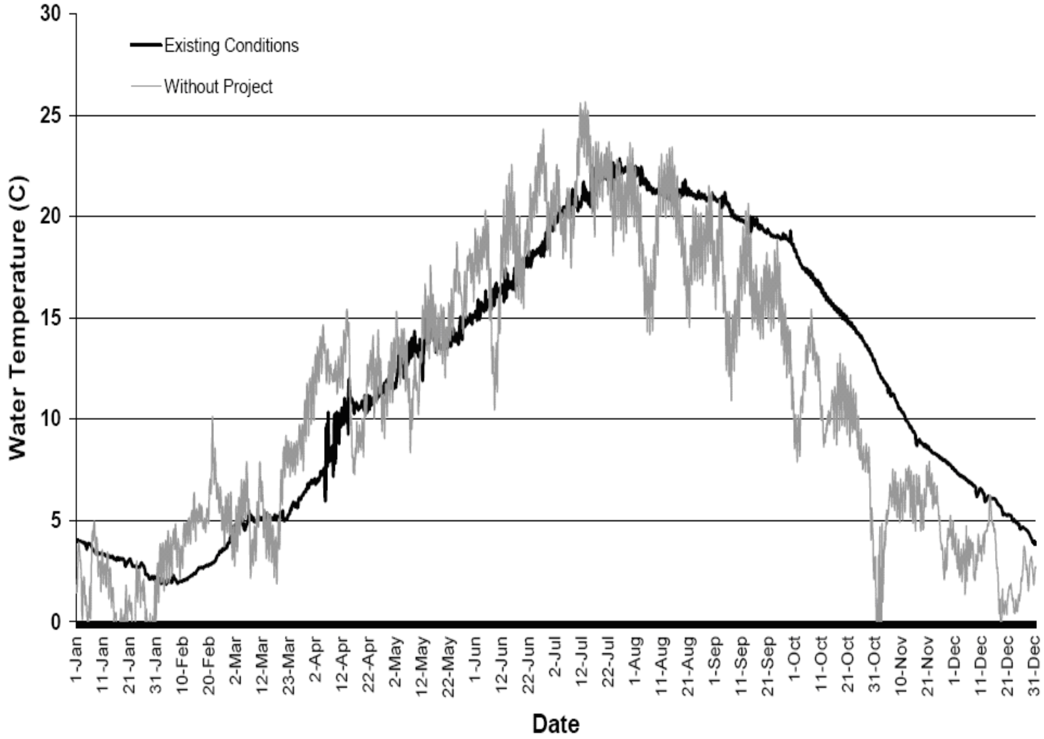


Figure II-1. Simulated hourly water temperature below Iron Gate dam (rkm 306) based on 2002 (defined as a dry water year) for existing conditions compared to hypothetical conditions without the existing Klamath Hydroelectric Project dams. (Source: FERC 2007; Figure 3-50, and PacifiCorp, response to AIR-AR-2, dated October 2005)

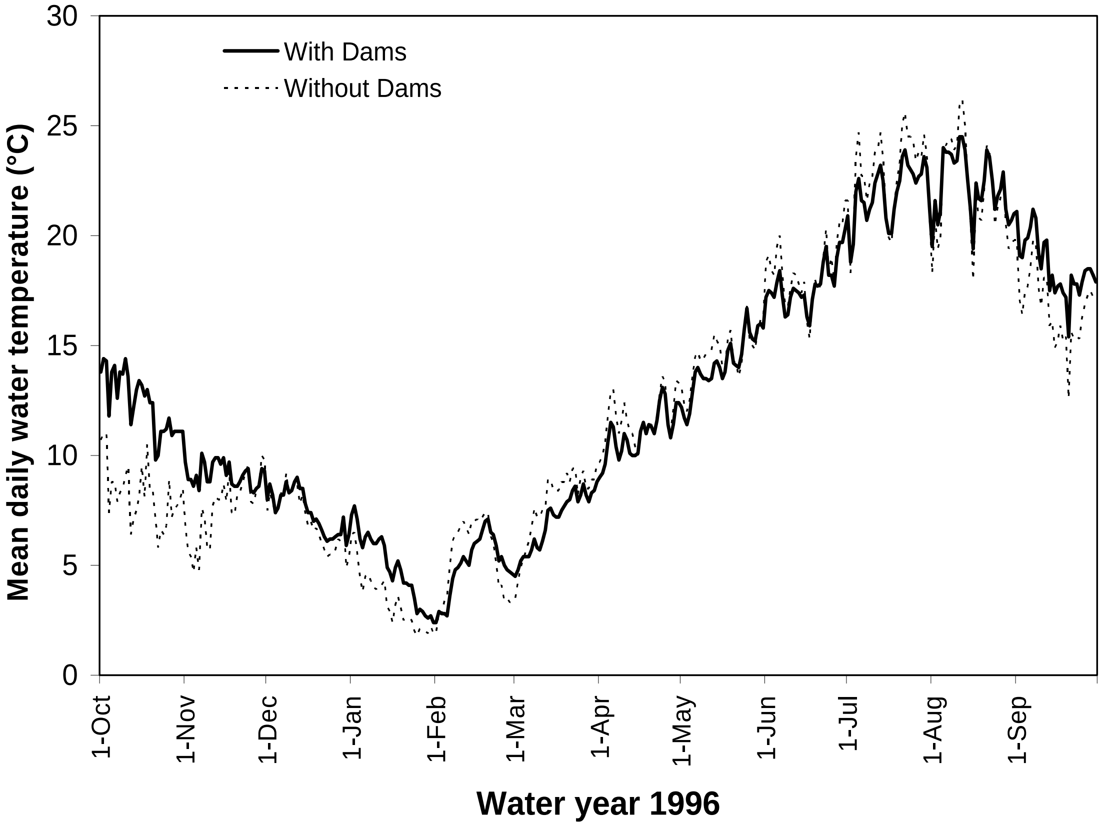


Figure II-2. Comparison of predicted daily mean water temperatures at Seiad Valley (rkm 214) in two different SIAM simulations for water year 1996.

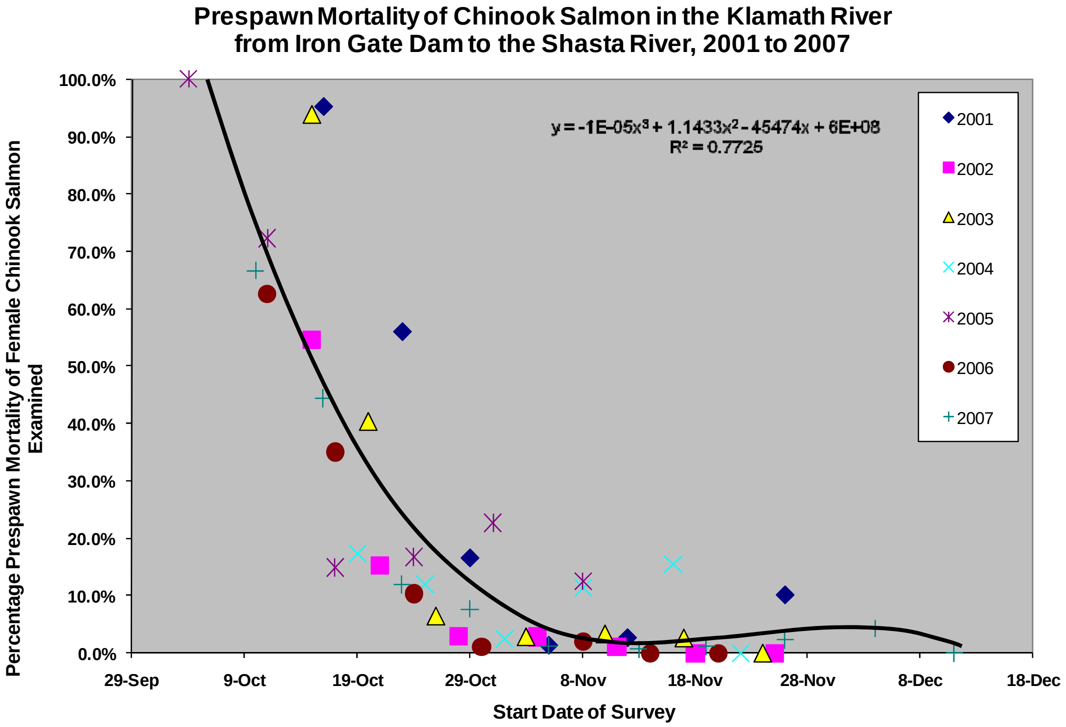


Figure II-3. Female Chinook salmon pre-spawn mortality rates in the mainstem Klamath River between Iron Gate Dam and the Shasta River 2001 to 2007. Data are presented for periods when sample sizes of fish examined exceeded 5 females (Gough and Williamson 2009, in review). Trend line shown for data pooled for all years.

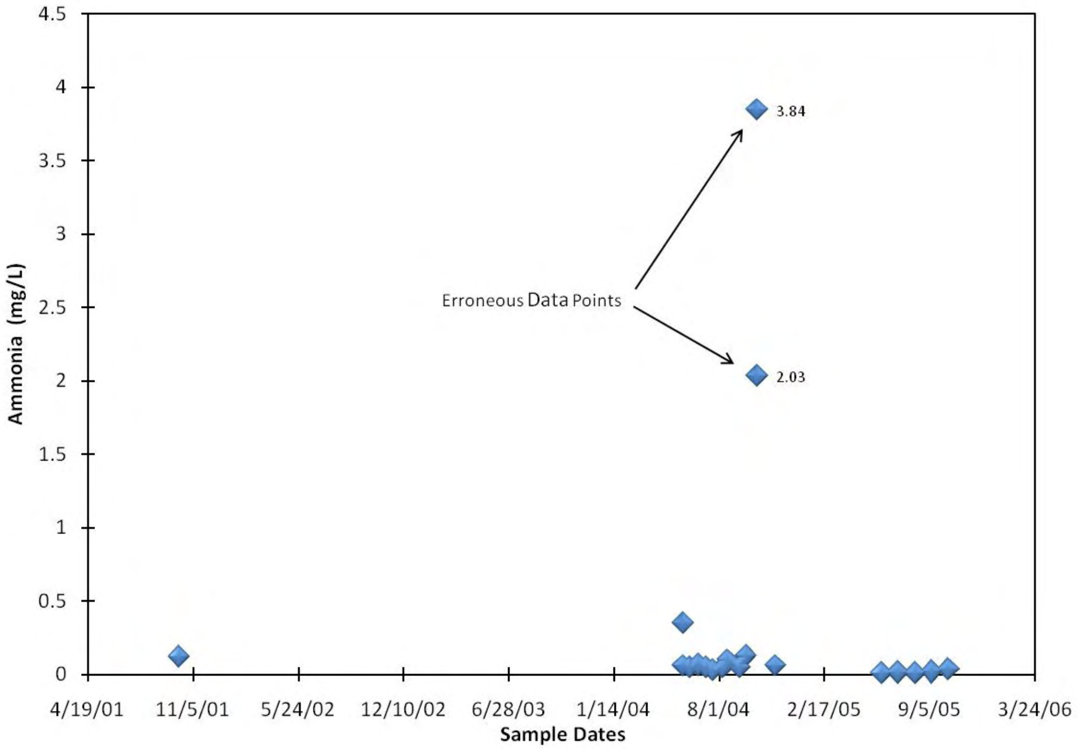


Figure II-4. Ammonia concentrations of Klamath River water samples collected immediately upstream of the Shasta River (rkm 284) by PacifiCorp and U.S. Fish and Wildlife Service from 2001 to 2005. Distribution of values identifies erroneous data as reported by PacifiCorp (2004). The minimum detection limit (MDL) for these samples was 0.1 mg/L and non-detects are reported here as 50% of the MDL.

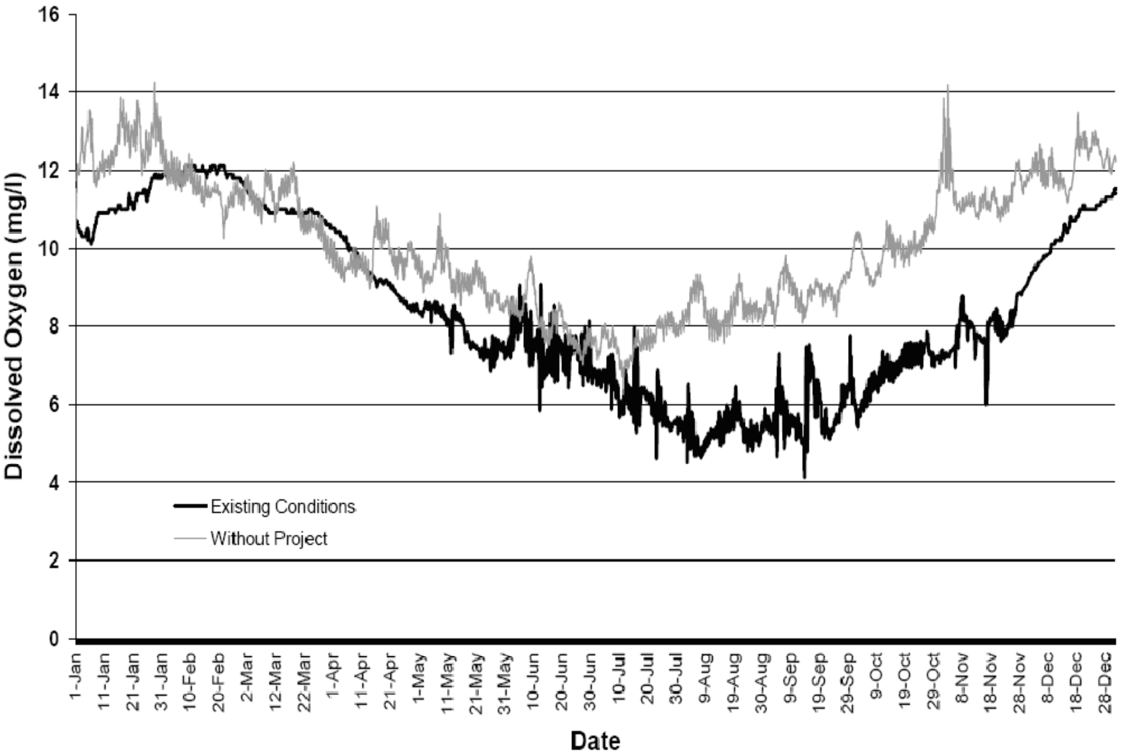


Figure II-5. Simulated hourly DO levels below Iron Gate dam based on the year 2002 (a dry year) for existing conditions compared to hypothetical conditions without the Klamath Hydroelectric Project dams (Source: FERC 2007; Figure 3-51 and PacifiCorp, response to AIR AR-2, dated October 17, 2005).

III. Geomorphology and Channel Maintenance

Overview

This section of the report provides a generalized overview of fluvial geomorphic processes, how these processes currently function within the Klamath Basin, and how they may be altered following removal of J. C. Boyle, Copco 1, Copco 2, and Iron Gate dams from the Klamath River. The volume of sediments stored behind the dams, the dynamics of sediment transport for different dam removal alternatives, and the potential biological effects of sediments liberated by the proposed dam removal on the Klamath River has been a topic of extensive study in recent years (Eilers and Gubala 2003; J.C. Headwaters, Inc. 2003; PacifiCorp 2004; GEC 2006; Shannon & Wilson, Inc. 2006; Stillwater Sciences 2008; Stillwater Sciences 2009; among others).

Sediment Supply and Transport. Rivers typically have three geomorphic zones: a production zone (steep, rapidly eroding headwaters), a transport zone (through which sediment is moved more or less without net gain or loss), and a deposition zone (Schumm 1977). The river channel within the transport zone can be viewed as a conveyor belt that moves erosion products downstream from the production zone to the deposition zone and ultimately, out to sea. As water flows from high elevations to sea level, mobilized sediment is transported downstream as either bedload, suspended load, or dissolved load. The largest component of the total sediment load is typically transported as suspended load, consisting of materials such as clay, silt, and sand held aloft in the water column by turbulence. This contrasts to bedload, which consists of sand, gravel, cobbles, and boulders that are transported by rolling, sliding, and bouncing along the bed (Leopold et al. 1964). Bedload ranges from a few percent of the total load in lowland rivers, to perhaps 15% in steep-gradient, mountainous rivers (Collins and Dunne 1990). Bedload, while a relatively small component of the total sediment load, is largely responsible for the formation of river channels and provides physical inert components, or building blocks of aquatic habitats that are critical for riverine life stages of aquatic biota (Kondolf 1997).

The rate of sediment transport depends on the availability and composition of the sediment load and the discharge of the river mobilizing the load. The transport rate typically increases as a power function of flow; that is, a doubling of flow typically produces more than a doubling in sediment transport (Kondolf 1997). The size of sediment mobilized often changes along the downstream gradient of a river system, changing from gravel, cobbles, and boulders in steep upper reaches to sands and silts in low-gradient downstream reaches. This decrease in size of mobilized particles along a stream's longitudinal gradient reflects, in part, a progressive decrease in particle size caused by weathering, abrasion, and sorting of materials by flowing water. The further sediments travel, the more weathered and sorted they become. Once suspended in the water column, fine particles such as clay can remain in suspension for extended periods of time, and be transported long distances.

Human disturbance of land from activities such as timber harvest, tilling, construction, etc. can dramatically increase erosion rates and may cause sediment loads to exceed a stream's transport capacity. Accelerated erosion in upper reaches of a catchment can affect a river system for many kilometers downstream of the sediment source. This influence can be observed for years or decades as the increased sediment loads propagate downstream through the river network (Kondolf 1997).

Sediment Deposition. A slow moving or still area in a waterway allows sediment deposition to occur. As such, pools exhibit a higher relative composition of fine sediment than riffles. In addition, flows within the mid-channel of a stream typically move at a higher velocity and therefore are capable of transporting larger substrates than water flowing nearer to the shore. In high velocity areas of a channel, small particles have a low probability of being entrained or settling out. In depositional zones of the channel, sand and gravel may be deposited and accumulate, forcing the channel to migrate. As a result, bars are established and the channel may become braided. Gravel bars may appear stable, but are often scoured by flood flow events and are replaced by sediments delivered from upstream sources. As vegetation establishes on bars, they become increasingly resistant to erosion or mobilization. In-channel deposits may also take the form of point bars, where sediments are deposited on the inside bends of meanders.

A river channel and its floodplain are dynamic features that constitute a single hydrologic and geomorphic unit characterized by frequent transfers of water and sediment between the two components. A lack of appreciation for connectivity between floodplains and the channel underlies many environmental problems in river management today (Kondolf 1997). When stream flow exceeds the channel’s capacity to contain that flow, water overflows onto the surrounding floodplain where large volumes of sediments settle out. Floodplains act as storage reservoirs for sediments through a repetitive process of deposition and subsequent release of sediments back into the channel. This process is triggered by bank erosion induced by high flows. Sediments stored on a floodplain are typically mobilized on a time scale of decades or centuries (Kondolf 1997). Successive flooding also creates natural levees or ridges of coarse sediment deposited on both banks of a stream. Natural levees may increase in elevation by accumulating sediments from repeated flood events and tend to be the highest elevation points on a floodplain. When water spills over natural levees onto the floodplain, the heaviest materials are deposited first followed by finer materials that can be carried further from the channel. Deposits of fine grained alluvium and detritus tend to hold water and drain slowly, creating wetland or soil conducive for establishment of riparian hardwoods. A notable function of backswamps is their ability to retain water, which may contribute to buffering the severity of flooding downriver.

All dams trap sediment to some degree, and most attenuate flood peaks and alter the seasonal distribution of flow that influenced pre dam channel morphology. These alterations disrupt physical processes and change the form and function of rivers above and below dams (Kondolf 1997; Trush et al. 2000) under which native flora and fauna evolved. Upstream of a typical dam, all bedload sediment and all or part of the suspended load may be deposited in the reservoir bed and upstream river reaches influenced by the reservoir backwater (Kondolf 1997). While water released downstream of dams may have the energy to mobilize sediment, the sediment supply is greatly reduced or absent. As a result, the hydraulic energy that was historically expended on transporting bedload is instead exerted on eroding the channel bed and banks resulting in changes to the particle size composition of the bed as gravels and finer materials are transported downstream. Over time, the lack of sediment input creates an armored layer, defined as a coarse lag deposit of large gravel, cobbles, or boulders that cannot be moved by future high flow events (Kondolf 1997).

Biological Effects. Excessive and chronic deposition of sediments that result from accelerated erosion rates can be detrimental to aquatic biota such as fish, benthic macroinvertebrates, and amphibians by altering their physiology and habitats at a magnitude and frequency interval that exceeds naturally occurring, sediment-induced disturbance rates. Potential impacts of fine sediment deposition on aquatic biota are extensive, including factors such as degradation of spawning and overwintering habitats and decreases in inter-gravel flow, residual pool volume, benthic invertebrate productivity and diversity, and primary productivity (Meehan and Bjornn 1991; Waters 1995; Owens et al. 2005; Stillwater Sciences 2009; among others).

Suspended sediment loads can also adversely affect aquatic species, with the degree of the effect dependent upon the concentration, composition of, and duration of exposure to the suspended materials (Newcombe and Jensen 1996). In addition to the impacts to aquatic habitats previously mentioned, suspended sediments may adversely impact aquatic species behaviorally (changes in migration, altered habitat use, impaired homing, etc.) and physiologically (stress, tissue damage, breathing impairment, reduced growth, mortality), (Newcombe and MacDonald 1991; Newcombe and Jensen 1996; USFWS 2004).

Just as too much sediment can be detrimental to aquatic species and their habitats, too little sediment can also have adverse biological effects. The increased particle size composition and armoring of the channel bed typically observed downstream of impoundments can diminish or eliminate spawning habitats. As a result, mitigation programs are sometimes implemented to supplement the gravel supply below dams to provide coarse sediment suitable for redd construction by spawning salmon and trout. In addition, bedload supply and transport is largely responsible for the creation and maintenance of dynamic and complex channel conditions (Kondolf 1997) that are essential to support an abundance and diversity of riverine biota.

Pre Dam Removal

Existing Condition Upstream of Iron Gate Dam. From its origin at Upper Klamath Lake to its mouth, the Klamath River is predominantly a non-alluvial, sediment supply-limited river flowing through generally mountainous terrain. Variability in local climate and geology are reflected in the geomorphic characteristics and flora of the river valley and reservoir shoreline slopes (Ayres Associates 1999). The broad volcanic landscape of the Upper Klamath Basin includes several river systems that flow into Upper and Lower Klamath Lakes, Agency Lake, Tule Lake, Clear Lake, Lake Ewauna, an extensive system of marshes, and a series of low-gradient connective river reaches and sloughs (Philip Williams & Associates, Ltd. 2009). The combination of diking, conversion of marshland, and regulation of river outflows have fundamentally changed the hydrology and hydraulic performance of the upper and lower watersheds. While the upper basin has a large contributing watershed area (about 2.9 million acres), it does not contribute significant amounts of coarse sediment to the mainstem Klamath River because the natural configuration of lakes and marshes in the upper basin captures sediments before they are contributed to the river (Philip Williams & Associates, Ltd. 2009).

Keno Reservoir is located at the downstream end of the upper basin. Formed by Keno Dam, the reservoir inundates a relatively low gradient, meandering section of the Klamath River. Keno Reservoir is managed to maintain a constant water surface level to facilitate water diversions to adjacent agricultural canals. General topography, dredging, diking, and channelization have resulted in a stable channel configuration for Keno Reservoir, characterized as having a grass-lined, moderately sinuous channel with little visible current. Upstream of the reservoir, the river is broad, meandering, and is flanked by wetlands. Downstream of the constricted Keno Gorge, steep topography of the Klamath River corridor abruptly gives way to gentle slopes where J. C. Boyle Reservoir is located (Philip Williams & Associates, Ltd. 2009). It is likely that the reach of the Klamath River now inundated by J. C. Boyle Reservoir once provided salmonid spawning habitat. Spencer Creek, historically a salmon-producing tributary to the Klamath River (Hamilton et al. 2005), enters J. C. Boyle Reservoir near its upstream extent.

A significant proportion of the Klamath River is diverted at J.C. Boyle for power generation. Minimal flows are passed down the mainstem Klamath River below the dam through what has been referred to as the “Bypass Reach”. A regulatory minimum flow of 100 cfs is required to be released from J. C. Boyle Dam to provide instream flow for fish. A series of springs in the riverbed between the dam and the J. C. Boyle Powerhouse contribute an estimated average of 225 cfs of cold spring water to the river, resulting in a relatively constant, regulated flow of approximately 325 cfs during summer months (BLM 2003). One, both, or neither of the J. C. Boyle Powerhouse turbines may be used to generate electricity at any given time, with operation of turbines dependent upon energy demand and water availability. When the daily mean flow of the river is less than 3,300 cfs, the facility produces power during periods of peak energy demand (PacificCorp 2000). When the turbines are not being operated, inflow to J. C. Boyle Reservoir is stored for later use. The channel within the peaking reach downstream of the J. C. Boyle Powerhouse is characterized as having high velocities (during peaking releases), lacking in sediment supply, and consists of a broad, plane-bed channel with scattered boulders. The river gradient decreases downstream of Spring Island at 351 and terraces along the river are wide and conspicuous, particularly in the area of Frain Ranch (Philip Williams & Associates, Ltd. 2009).

Prior to dam construction, the Klamath River in area of the Frain Ranch likely consisted of alternating pool and riffle habitats with wide floodplain terraces. The area’s relatively low channel gradient is indicative of having zones of sediment deposition that create quality spawning habitats for salmonids and resident trout. Land clearing and channel modifications reduced the complexity of the channel and floodplain in this 8-km reach which once likely contained more side channels, alternating pools, bars, runs, and riffles than are currently present and would have contributed to habitat complexity (Philip Williams & Associates, Ltd. 2009). Further downriver, the broad floodplains adjacent to the river in the Copco Ranch area (currently in agriculture) likely provided conditions to support an extensive riparian forest. The reach of the Klamath River currently inundated by Copco Reservoir was a broadly meandering river with backwaters and side channels. This reach had an alluvial and depositional character with alternating pool and riffle formations (Figure III-1). The river channel is progressively constricted by volcanic bluffs (remnants of older flows) in the downstream half of the Copco Reservoir reach. However, despite these outcrops and valley constrictions, the mile of river upstream of the mouth of Ward’s Canyon (about rkm 320) was apparently slow and deep (Philip Williams & Associates, Ltd. 2009). Further downriver, the Copco 2 Reservoir and bypass reach is a steep and boulder-strewn reach of river containing abundant pocket water in a canyon setting.

Based on available aerial photographs taken prior to dam construction, the channel morphology of the river inundated by Iron Gate Reservoir appears fairly similar to reaches below IGD. An exception lies in the 4.8-km reach immediately upstream of the dam where the river valley was generally wider with a lower gradient than in the 4.8-km reach downstream of the dam. We also suspect the input of sediments from Jenny Creek played an important role in creation of channel complexity in this reach. Similarly, the channel and floodplain of Camp Creek at its confluence with the river included multiple channels and islands and riparian vegetation of varying ages (Philip Williams & Associates, Ltd. 2009).

Existing Condition Downstream of Iron Gate Dam.

Channel Morphology. The Klamath River from IGD to the Scott River is in a relatively confined valley. Below the dam, the presence of mature riparian vegetation near the water's edge suggests the river has not migrated laterally or vertically (aggraded or degraded) for a period equal to or less than the age of mature trees in the area (Ayers Associates 1999). In recent years, Service crews have observed and documented evidence of fossilized bars and degradation of the channel in this reach (Figure III-2 and Figure III-3). Islands that existed prior to IGD have persisted, and in some cases have even grown in size. Many of these alluvial features within the first 13 km downstream of IGD appear to be relic features, their forms possibly fixed by the disruption of river processes that came about with construction of the Copco I Dam in 1918 (Ayers Associates 1999).

A review of historical aerial photographs taken between 1955 and 2001 suggests that the basic planform of the river at the reach scale has been static over that period (PacifiCorp 2004). Ayers Associates (1999) used aerial photographs to determine that riparian vegetation patterns and locations have remained fairly constant over the past 50 to 60 years. They found evidence at a smaller scale, however, that prominent stands of vegetation had been removed or damaged by major floods, with reestablishment taking significant periods of time. Photos taken during the drought period from 1986 to 1994 and shortly thereafter depict extensive colonization and encroachment of vegetation onto bar surfaces. The general lack of mature riparian vegetation on bars and low terraces along most of the river suggests that many alluvial features and associated riparian vegetation communities within this reach remain dynamic (Hardy et al. 2006a) and are evidence of the effects of frequent flood flows (Ayers Associates 1999),.

Tributaries located downstream of IGD continue to deliver coarse bed materials in sufficient quantity and quality necessary to support significant spawning of fall Chinook salmon in the mainstem Klamath River (Figure III-4). Abundance of spawning fall Chinook salmon in the reach between IGD and the Shasta River has in recent years exceeded 10,000 fish (Gough and Williamson in review; CDFG 2008; Figure III-5). The success of mainstem spawning and presence and distribution of spawning gravels downstream of tributaries and pools and in riffles within this reach indicate that spawning gravels have been replenished following the numerous peak flow events recorded since the construction of IGD in 1962 (Figure III-6). However, it is unclear if the quantity, quality, and location of suitable spawning substrates have substantially changed from pre-IGD conditions (Hardy et al. 2006a).

Aquatic Vegetation. During the drought period from 1986 to 1994, aquatic vegetation became well established within the river below IGD (Ayers Associates 1999). Filamentous algae and submerged vegetation encroached well into the river channel and became fairly dense. Depending on annual low-flow conditions, emergent vegetation such as reeds, grasses, and cattails became well established in shallow areas having low flow velocities (Figure III-7). The proliferation of aquatic vegetation during this period presumably occurred in response to prolonged periods of relatively low, stable flows of nutrient rich water, coupled with deposition and retention of fine-grained sediments.

Ayers Associates (1999) determined that the flood events of 1997 removed substantial amounts of vegetation from the channel, leaving only small colonies positioned along the channel margins and other protected areas. These remaining patches of aquatic macrophytes were observed at several locations, primarily in reaches upstream of the confluence of the Scott River, and were associated with features that created areas of low velocity such as protected bank margins, inside of bends, coarse-grained relict in-channel mining debris (large cobbles and boulders), or low bedrock benches and bedrock outcrops along the river margins. The small, localized pockets of low-velocity water created by these features allow fine sediments to fall out of suspension and create protected substrates for germination and growth of aquatic macrophytes (Ayres and Associates 1999). Although the proliferation of the aquatic vegetation can largely be attributed to water quality and hydrologic variables, retention of fine sediments contributes to the expansion of colonies when flow conditions are conducive. Extensive recolonization of aquatic vegetation present in the river has been particularly evident during drier years and years experiencing minimal peak winter/spring flows. Juvenile outmigration fish trapping operations become inundated with aquatic vegetation when these conditions occur (Figure III-8).

Sediment Transport. Ayres and Associates (1999) examined the incipient motion (the initiation of motion of the bed material by hydrodynamic forces) for riffles and pools below IGD. Below a critical level of shear stress, the hydraulic forces are insufficient to mobilize sediment and it remains stationary. Above the critical level, hydraulic forces can act to mobilize the channel bed. By comparing the critical stress of the sediment with the hydraulic shear stress created by the flow, an assessment of the stability and mobility of bed material was made for specific reaches and flow conditions. The critical shear stress was computed by hydrologic reach to determine the flows necessary to produce incipient motion for riffles and pools (D50 for riffles, D50 and D84 for pools; Table III-1). Ayres and Associates (1999) investigated the frequency of incipient motion using a 36-year period of record (water years 1962-1997). Incipient motion conditions of magnitude to flush pools and rework riffles occurred about every two to three years, except during periods of drought in the late 1970s, 1980s and early 1990s (Figure III-9). It is also important to note that depending on the time of year and distance downstream of IGD, the effects of IGD flows on sediment mobilization can be overshadowed by significant tributary accretions downstream. For example, USGS gage data recorded for January 1, 1997, reported discharge at IGD at 18,500 cfs, while discharge at Orleans located 209 km downstream of IGD was 233,000 cfs. As such, the frequency of flows that meet incipient motion criteria increases with distance downstream of the dam as a progressively lower portion of the river is regulated by IGD, and thus experiences a greater frequency of flooding.

Below IGD downstream to Seiad Valley (rkm 214), where the majority of salmon spawning occurs, pool flushing flows that scoured the D50 sized materials are expected to be exceeded about 65% of the years at Site #4 and 40% of the years at Sites #5 and #6 (Table III-1). Mobilization of sediment finer than very coarse sand (D84) from Sites #4, #5, and #6 is not expected to occur during drought years, and is expected to occur at Site #4 less than 20% for average water years (Ayers Associates 1999).

Post Dam Removal

Geomorphic Response. An analysis of information previously developed for PacifiCorp indicates that approximately 20.4 million cubic yards of sediment is trapped in three of four reservoirs considered for removal. Retention of sediments in Copco 2 is negligible (GEC 2006). The investigation found that reservoir drawdown and removal of the dams would cause sediment in the path of river flow to erode nearly instantaneously when exposed to moving water. Depending on discharge, suspended sediment would travel to the ocean within approximately four days after being eroded and mobilized (GEC 2006). Eroding sediments would dramatically increase suspended sediment concentrations immediately downstream of IGD for the period of time required to draw down the reservoirs (Figure III-10). Pulses or “waves” of high suspended sediment concentrations would occur from knick point sediment erosion to form a newly emerging river channel as reservoir water surface elevations are drawn down. Following drawdown, sediment eroded from the riverbanks and from overbank would continue to produce waves of elevated suspended sediment levels, but would do so at much lower concentrations than anticipated to occur during reservoir drawdown (Grant 2004; GEC 2006; Stillwater Sciences 2009).

The evolution of the new channel within low gradient reaches in the PacifiCorp Project reach and downstream of IGD would likely initiate with multiple channels of degradation and widening, followed by lateral movement and incision until a quasi-equilibrium, stable state is reached as the river reaches its original grade and a dominant, mainstem channel persists. The time required for the channel to reach equilibrium condition (months, years, or decades) would be highly dependent upon the rate of dam removal and frequency, magnitude and duration of hydrologic events.

The rate of geomorphic response to dam removal would depend on the magnitude and duration of high flows within a year, the sequences of high geomorphic-effective flows across years, the composition and amount of bedload materials entering the river, and the effectiveness of flows at mobilizing and redistributing fine and coarse sediment throughout the river including materials currently stored within PacifiCorp Project reservoirs (Hart et al. 2002). Predicting the extent and length of time necessary for a complete geomorphic response is challenging due to the spatial (downstream influence) and temporal (flow magnitude between and across years) scales in which the physical processes would occur following dam removal (Hart et al. 2002). This will be a subject of intensive study in the period leading up to dam removal.

The transport rate of suspended sediment during the drawdown period (Figure III-10) is anticipated to stabilize shortly after draw down is complete, with significantly smaller pulses of sediment waves accompanying storms during the bank stabilization and re-vegetation period (Stillwater Sciences 2008). Morphological effects will be driven by the supply of sediment and the frequency and magnitude of flows to transport that sediment. Following removal of the dams, coarse sediment (gravel or larger) stored behind the dams would be mobilized and transported downstream of IGD in quantities that far exceed amounts transported since the construction of the dams. Along with fines liberated by dam removal, coarse sediments may have short-term impacts such as filling of pools, covering of roughness elements, fining of the bed, and large-scale morphological adjustments such as braiding or change in the river planform (Figure III-11). Downstream sediment delivery will occur as a series of pulses of sorted material starting with fines, then sand, followed by coarse material driven by the occurrence and magnitude of storms up river (Figure III-12).

Fines are expected to intrude into the gravel, settle in the bed of pools, and deposit along the margin of channel followed by coarse material. The filling and smoothing of the channel bed and burial of the bed roughness over time will be followed by re-incision and sorting of the material deposited. However, sediment released for a “blow and go” approach to dam removal could exhibit limited sorting (Grant 2004).

The morphology of the channel below the dam removal sites will dictate where released materials are likely to settle out (Grant 2004; Figure III-13). Given the Klamath’s bedrock canyon morphology and limited occurrence of broad alluvial reaches, the majority of the liberated sediment would be transported downstream with subsequent storms (Stillwater Sciences 2008) as was observed following removal of Marmot Dam on the Sandy River (Grant 2009).

While the coarse sediment deficit is anticipated to be alleviated with dam removal, Hardy and Addley (2001) also recommend flood flows to restore fluvial processes necessary for the rehabilitation of the channel and associated riparian community. A current study by U.S.G.S. Fort Collins Science Center (Holmquist –Johnson and Milhous, in review) should contribute to our understanding of the effects of the water allocation proposed in the KBRA on flood flow intervals, which can be addressed by the Technical Advisory Team through the adaptive management process provided under the KBRA.

We expect geomorphic conditions below IGD will improve following dam removal and implementation of the water allocation proposed in the KBRA. Connectivity between the various historically significant sources of sediment supply to the mainstem Klamath River will be reestablished.

WRIMS R-32 Refuge Flow Effects. The flow targets specified in the WRIMS R-32 Refuge model were developed, in part, to store additional water in UKL during fall and early winter months to increase the likelihood of spill events occurring in the late winter and early spring (Figure I-6 - Figure I-10, Appendix B and Appendix C). We explored the influence of this shift in the annual hydrograph on sediment mobilization by comparing annual maximum discharges of the WRIMS R-32 Refuge model outputs to historical IGD flow data for water years 1961-2000. To facilitate this comparison, we averaged historical daily mean Iron Gate discharge data within monthly or bi-weekly time steps specified in the WRIMS model. We then plotted the annual maximum time-step specific mean discharges for WRIMS R-32 Refuge and historical IGD data for water years 1961-2000 and assessed the frequency of occurrence of exceeding thresholds identified for mobilization of fines (in riffles and in pools) and gravels reported by Ayers Associates (1999) (Figure III-9). We found that the annual maximum flows of WRIMS R-32 Refuge model outputs and historical IGD data averaged within time steps exceeded the mobilization threshold for fines in riffles 83 and 85%, and fines in pools 17 and 18% of the years within the 40-year period of record, respectively. In contrast, the threshold for gravel mobilization reported by Ayers Associates (1999) was only exceeded during one year (1972) of the 40-year period of record (Figure III-9). These analyses, however, are based on mean values calculated for each time step, rather on than daily mean or instantaneous values, which would experience much higher fluctuations than monthly or biweekly time steps, particularly under real-time management operations such as the methodology described in Section VI of this report.

Examination of historical IGD flow data and WRIMS R-32 Refuge model outputs for the period of record 1960-2000 graphically depict the additional flow being released under the WRIMS simulation during the late winter and spring months as compared to historical IGD flow releases (Figure I-6 - Figure I-10, Appendix B, C). We anticipate that the higher flows modeled in WRIMS R-32 Refuge during the late winter and spring months, when combined with tributary accretions below Keno that are currently being regulated, will increase the frequency of flows that mobilize sediment.

The increase in sediment mobilization events are anticipated to have a positive effect on the aquatic environment, such as decreasing the retention of fines associated with the establishment of excessive aquatic vegetation below IGD and adversely affecting micro-habitats occupied by polychaete worms (*Manayunkia speciosa*). Polychaetes have been identified as an intermediate host of the fish pathogens *C. shasta* and *P. minibicornis,* which have been attributed to significant juvenile Chinook and Coho salmon mortalities in the Klamath River (see Section IV Fish Health). During drought years, managed peak flows of sufficient magnitude and duration along with piggybacking on natural hydrologic events could be implemented to deter the establishment of aquatic vegetation and disrupt the life cycle of fish pathogens and their polychaete host.

Channel and Riparian Maintenance Flows:

High frequency flow events (2-year recurrence interval) serve many in-channel functions including transport of bedload. Established riparian vegetation however, responds to much lower frequency flow events (10 or 20 year floods). Rathburn et.al. (2009) suggest a flow magnitude equating to a 25-year flood event as a target for generating riparian canopy gaps, creating regenerative early seral stage habitat, enhancing biogeochemical processes, maintaining habitat heterogeneity, and possibly disrupting the coarse bed-surface layer and scouring pools to maintain fish overwinter habitat. These hydrologic events are infrequent occurrences that overtop riverbanks, contribute to floodplain development and maintenance, and provide lateral connectivity to off-channel habitats (Hardy et al. 2006a). Some aquatic species thrive during high-flow water years, while other species do well during years of drought. Generalist species flourish under wide-ranging flow conditions. NRC (2008) concluded that high flows route coarse sediments, build bars, erode banks, flush fine sediments, scour vegetation, and undercut and topple large woody riparian vegetation, all of which contribute to the dynamics and channel processes that characterize the salmon-rearing streams of the western United States. Typically, anadromous salmonids have successful year-classes during normal to below-normal water years when flow conditions don’t result in mobilization of spawning gravels during the spawning, incubation, and fry-rearing seasons. High flows during wet years scour pools, recruit large woody debris, flush fine sediments, and build bars that lead to favorable habitat conditions the year following (NRC 2008).

Ayers Associates (1999) concluded that because of limited storage capacity, IGD has not reduced annual peak flows to downstream reaches. Flow augmentations for flushing purposes was not recommended during normal years since flushing of sediment from pools and riffles occurs relatively frequently (Figure III-14).

We recommend that environmental flows as suggested by Rathburn et.al. (2009) should be maintained under the 2-year and 25-year peak flow recurrence intervals. For the 2-year peak flow return interval, we used the median value for the return years 1.5 and 2.5, which equated to a peak discharge of 5,900 cfs. For the 25-year return interval, we calculated a peak discharge of 20,500 cfs. Under the water allocation proposed in the KBRA, the frequency, magnitude, and duration of peak flows in the Klamath River are expected to meet channel maintenance needs. However, peak flow regimes could be altered by the creation of additional storage and out-of-basin water transfers, which differ in that stored water could be used to recreate peak flow events whereas water transferred out-of-basin cannot.

Case Study - Marmot Dam, Sandy River

The removal sequence of the four Klamath dams continues to be a matter of great discussion and debate. Recently, the removal of the 45 feet high and 165 feet wide Marmot Dam on the Sandy River in Oregon resulted in the largest sediment release (one million cubic yards) accompanying any dam removal to date. As stated by Dr. Gordon Grant of Pacific Northwest Research Station/USDA Forest Service Forest Science Laboratory (Grant 2009), in reference to the Marmot Dam removal:

> *“This was a rare opportunistic field experiment, a chance to study one of the biggest unknowns in river geomorphology: how a large, energetic river digests a mammoth meal of sediment. The overriding scientific question on everyone’s minds was what would happen to the sediment after the river was unleashed.”*

The primary management concerns associated with removal of Marmot Dam were the potential that sediments transported downstream would have a direct, adverse affect on fish or bury their habitats, and on the flooding potential of downstream property. Results of computer modeling provided a range of predictions of sand and gravel deposition under various scenarios. However, sediments stored above the dam were transported downstream quickly, on a timetable that surpassed expectations based on model outputs. In addition, sediments released by the removal of Marmot Dam were reported to have minimal adverse affects on fish habitats or create conditions that would induce flooding of downstream properties. Removing Marmot Dam demonstrated the power of an energetic river to rapidly and efficiently redistribute the expansive volumes of unconsolidated sediment stored behind the dam given favorable hydrologic conditions. Most of the channel changes occurred upstream of a bedrock gorge, with only limited changes downstream. The Marmot Dam removal exemplifies that under the right set of conditions, dam removal can be an effective strategy for restoring ecosystem function and connectivity of large rivers and improving conditions for threatened and endangered species, while causing minimal, short-term impacts.

Conclusions

In summary, the release of up to 20.4 million cubic yards of sediment trapped behind the Klamath dams will function as a significant disturbance event. We believe that the initial suspended sediment concentrations during drawdown would be extremely high, with the majority of materials remaining in suspension and reaching the Pacific Ocean in approximately four days as reported by Stillwater Sciences (2009). Small amounts of fine sediment would settle along stream margins and other low-velocity areas within the active channel. We also anticipate that sediment would move down the river in waves following successive storms as the channel, currently inundated by the reservoirs, reoccupy their original planform and grade. Sediments will distribute both longitudinally and horizontally as a function of discharge and river channel velocities. The distribution of fine and coarse sediment will be highly dependent upon the frequency, magnitude, duration and rate of change of hydrologic events during and immediately following drawdown of the reservoirs. Coarse materials will follow the fines, covering up many of the areas that were inundated, and this process will sequentially continue down the river until the river cuts back to its original grade (Figure III-15).

We believe dam removal in combination with implementation of the WRIMS R-32 Refuge water allocation proposed under the KBRA will have a positive influence on channel morphology and subsequent maintenance, and that these benefits greatly outweigh the potential short-term negative effects. We expect fish populations to sustain only minor impacts as salmonids and non salmonids in the affected area would likely find of refuge in areas such as off-channel habitats, tributaries, and river reaches upstream of the uppermost reservoir. In addition, we believe these sediment waves will have a direct adverse effect on the polychaetes with direct mortality of worms occurring from physical displacement and smothering by sediment deposition. Additional effects to the polychaete microhabitat would occur upon dam removal due to hydraulic shifts at the microhabitat scale due to diurnal fluctuations of flow associated with day and night (thawing and freezing, and evaporation and transpiration) that would no longer be controlled by IGD. The aquatic and terrestrial environment would also greatly benefit by restoring the dynamics of a riverine environment.

Tables and Figures

Table III-1. Incipient motion criteria for riffles and pools for the Klamath River survey sites (Ayers Associates 1999).

Incipient Motion Criteria for Riffles

Survey Site Reference	River Mile	D_{50} (ft)	Critical Shear Stress (lb/ft^2)	Discharge required to initiate motion (cfs)
Site # 1, Blue Creek	16	0.18100	0.65100	147,000
Site #2, Sandy Bar	77	0.27100	0.97800	59,000
Site #3, Happy Camp	106	0.59100	2.13000	33,500
Site #4, Portuguese Creek	128	0.28100	1.01000	16,500
Site #5. Beaver Creek	161	0.28100	1.01000	13,200
Site #6, Little Bogus Creek	187	0.28100	1.01000	9,800

Incipient Motion Criteria for Pools

Survey Site Reference	River Mile	D_{50} (ft)	Critical Shear Stress (lb/ft^2)	Discharge required to produce "flushing" flows at 2*t_c (cfs)
Site # 1, Blue Creek	16	0.00328	0.01590	13,300
Site #2, Sandy Bar	77	0.00125	0.00603	3,200
Site #3, Happy Camp	106	0.00085	0.00412	1,600
Site #4, Portuguese Creek	128	0.00164	0.00794	2,300
Site #5. Beaver Creek	161	0.00230	0.01100	2,600
Site #6, Little Bogus Creek	187	0.00328	0.01590	2,500

Incipient Motion Criteria using D84 (2mm) for Pools

Survey Site Reference	River Mile	Discharge required to produce "flushing" flows at 2*t_c (cfs)
Site # 1, Blue Creek	16	25,000
Site #2, Sandy Bar	77	14,500
Site #3, Happy Camp	106	6,200
Site #4, Portuguese Creek	128	6,600
Site #5. Beaver Creek	161	6,000
Site #6, Little Bogus Creek	187	5,400

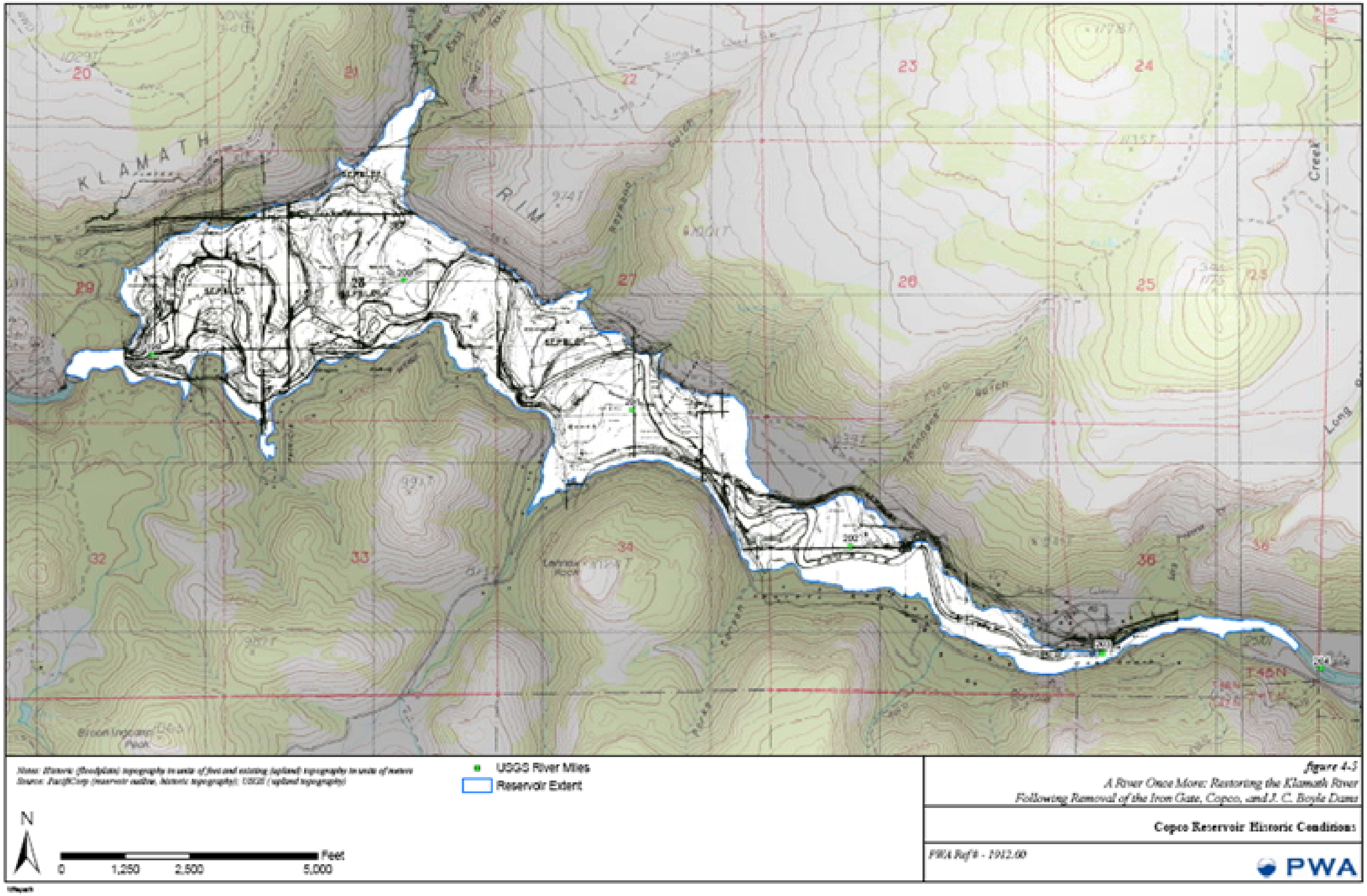


Figure III-1. Klamath River currently inundated by Copco Reservoir (Philip Williams & Associates, Ltd. 2009)

Figure III-2. Fossilized bars below IGD, indicative of a lack of coarse sediment (USFWS photo).

Figure III-3. Evidence of possible channel degradation below IGD (USFWS photo).

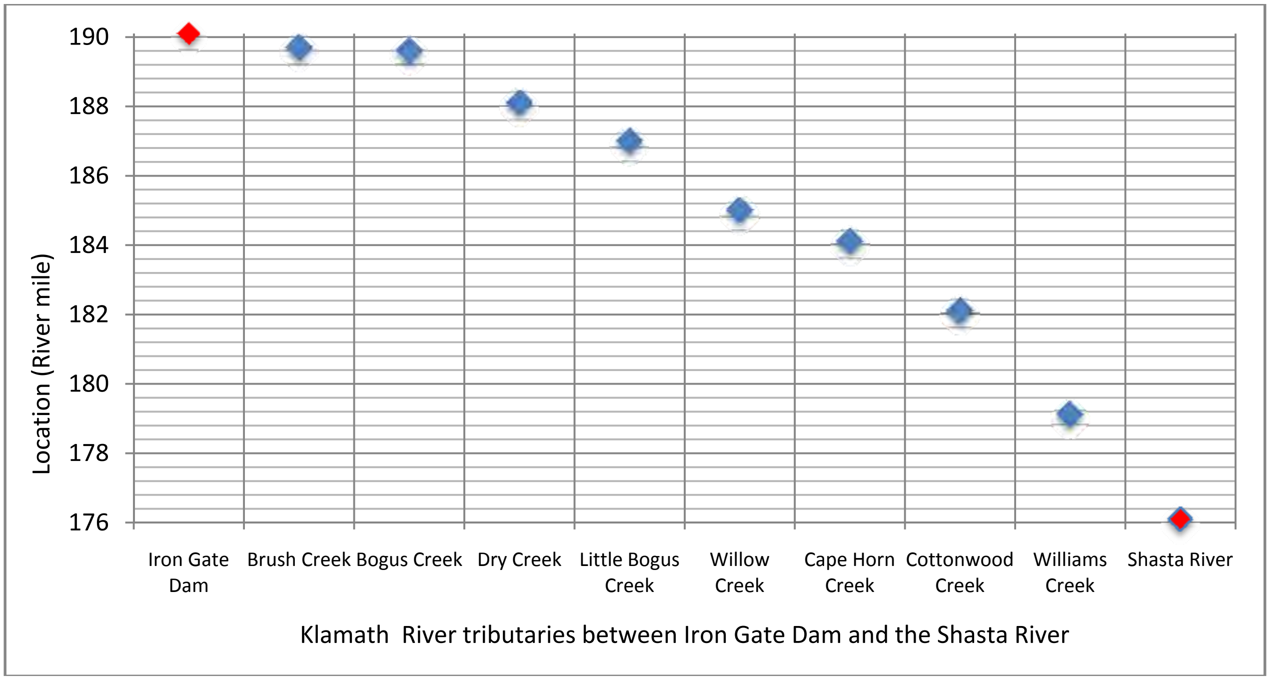


Figure III-4. Tributaries that supply bedload to the mainstem Klamath River between Iron Gate Dam and the Shasta River.

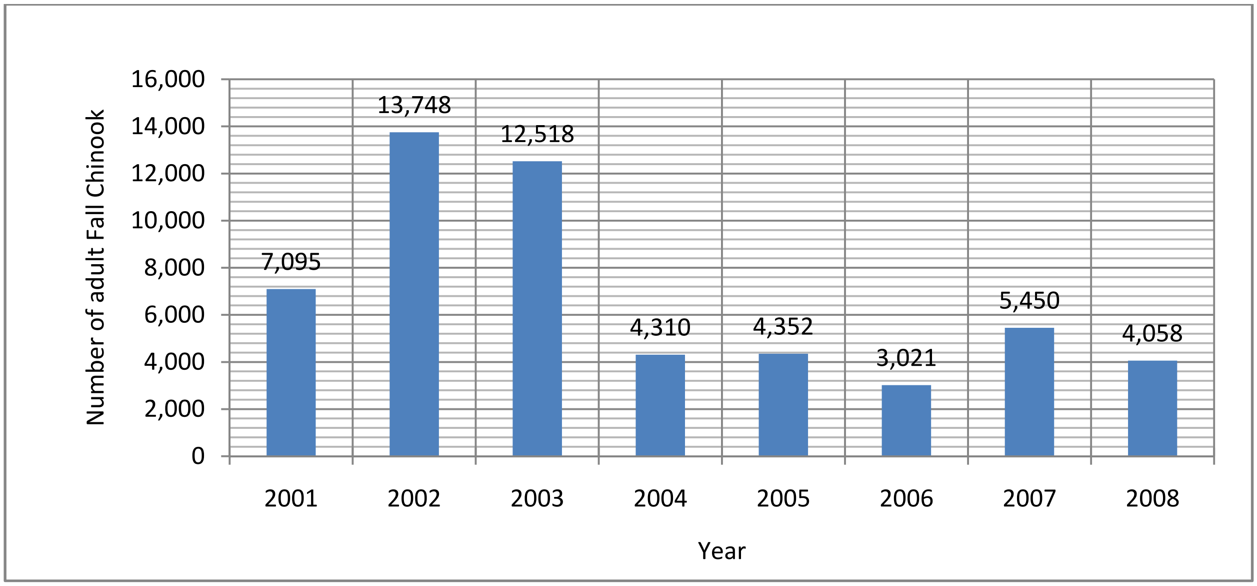


Figure III-5. Numbers of Klamath River Fall Chinook salmon that spawned in the mainstem between Iron Gate Dam and the mouth of the Shasta River during years 2001-2008 (Gough and Williamson in review).

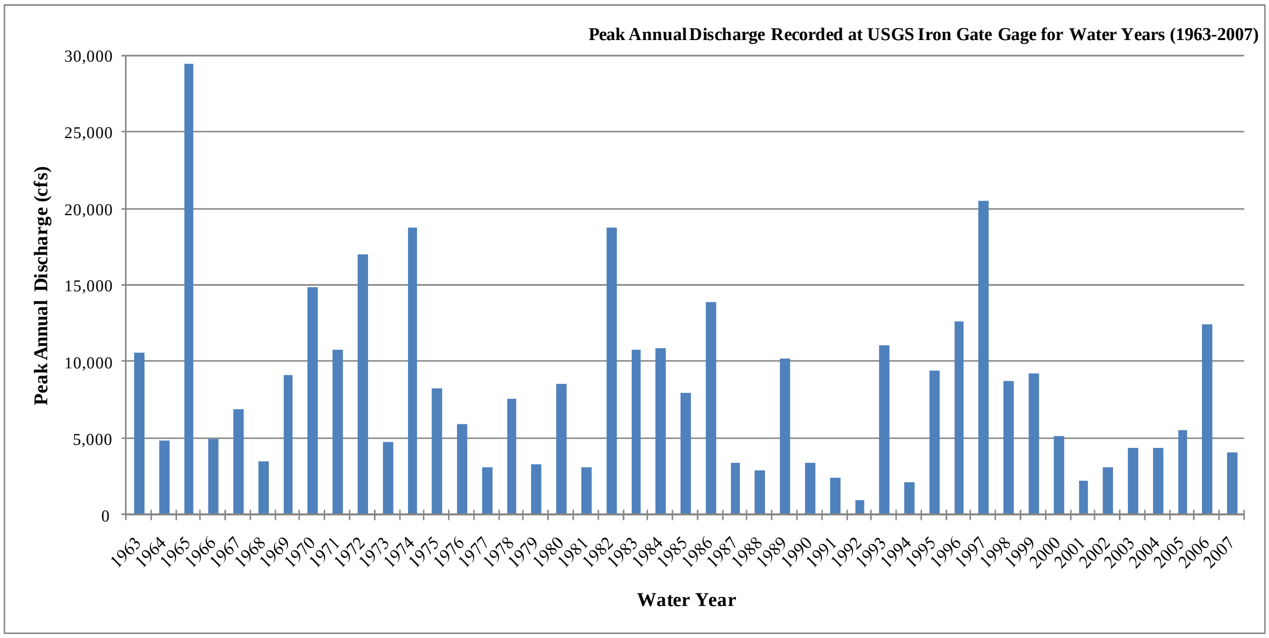


Figure III-6. Annual peak discharge (cfs) for the years 1963-2007 measured at the USGS gage station 11516530 located on the mainstem Klamath River below Iron Gate Dam.

Figure III-7. Aquatic vegetation observed on the Klamath River below Iron Gate Dam (2005 USFWS photo)

Figure III-8. Juvenile outmigration trap located below Iron Gate Dam, inundated with aquatic vegetation (2004 USFWS photo).

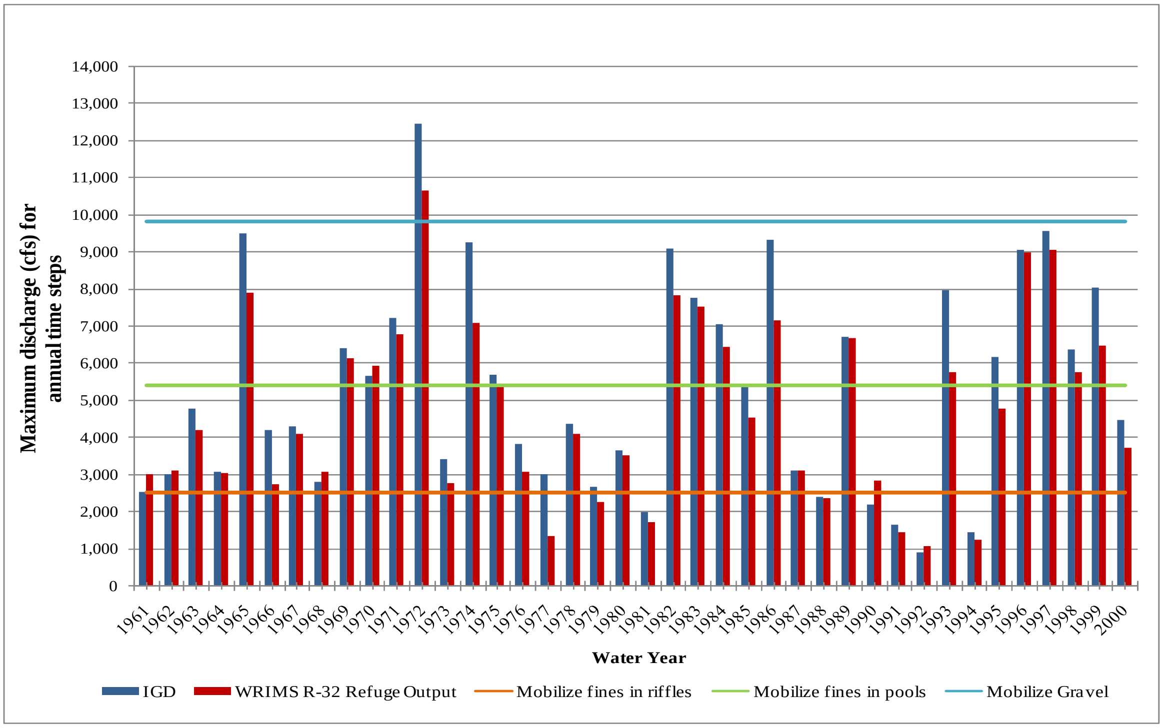


Figure III-9. Iron Gate (water years 1961-2000) and WRIMS R-32 Refuge Output maximum annual discharge (cfs) based on time step flows and comparisons to Ayres and Associates (1999) sediment mobilization flow thresholds.

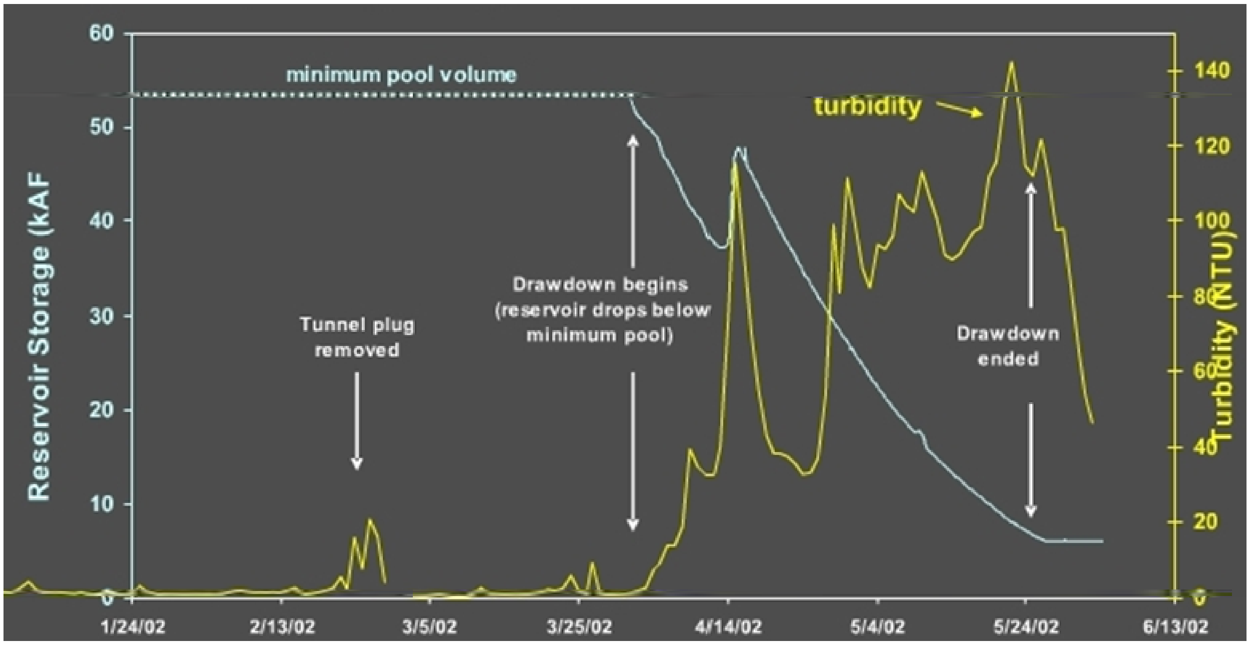


Figure III-10. Cougar Reservoir (South Fork McKenzie River, Oregon) storage (kAF) and turbidity (NTU) displaying the increase in turbidity during draw down (Grant 2004).

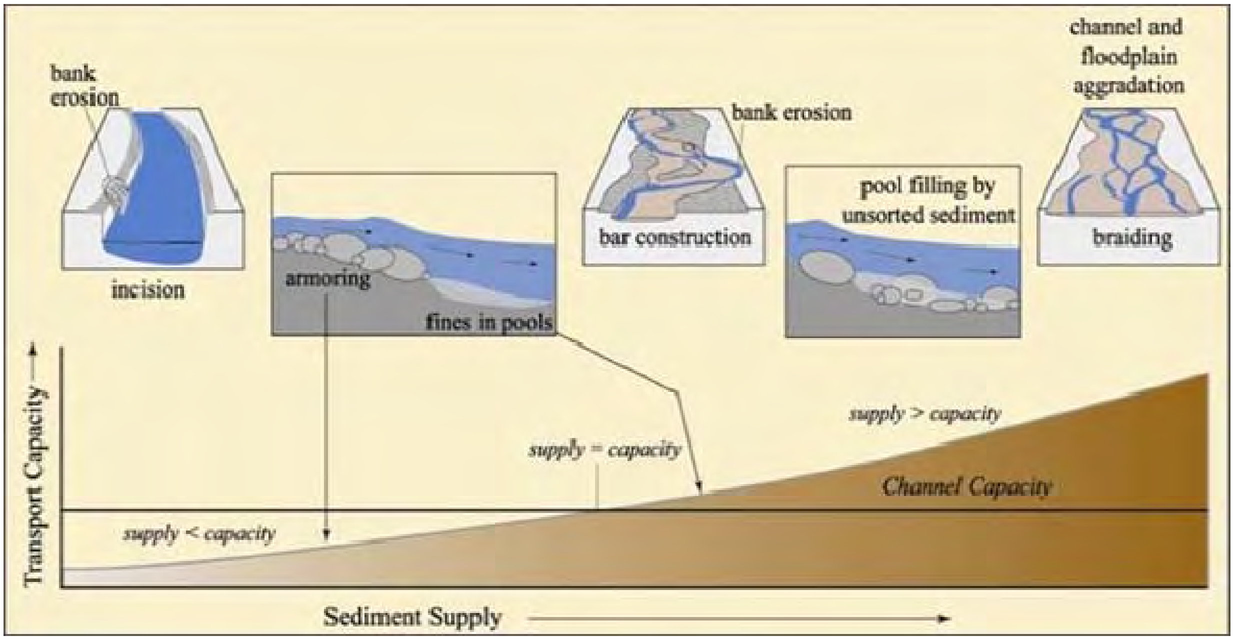


Figure III-11. Sediment supply versus river transport capacity (Grant 2004).

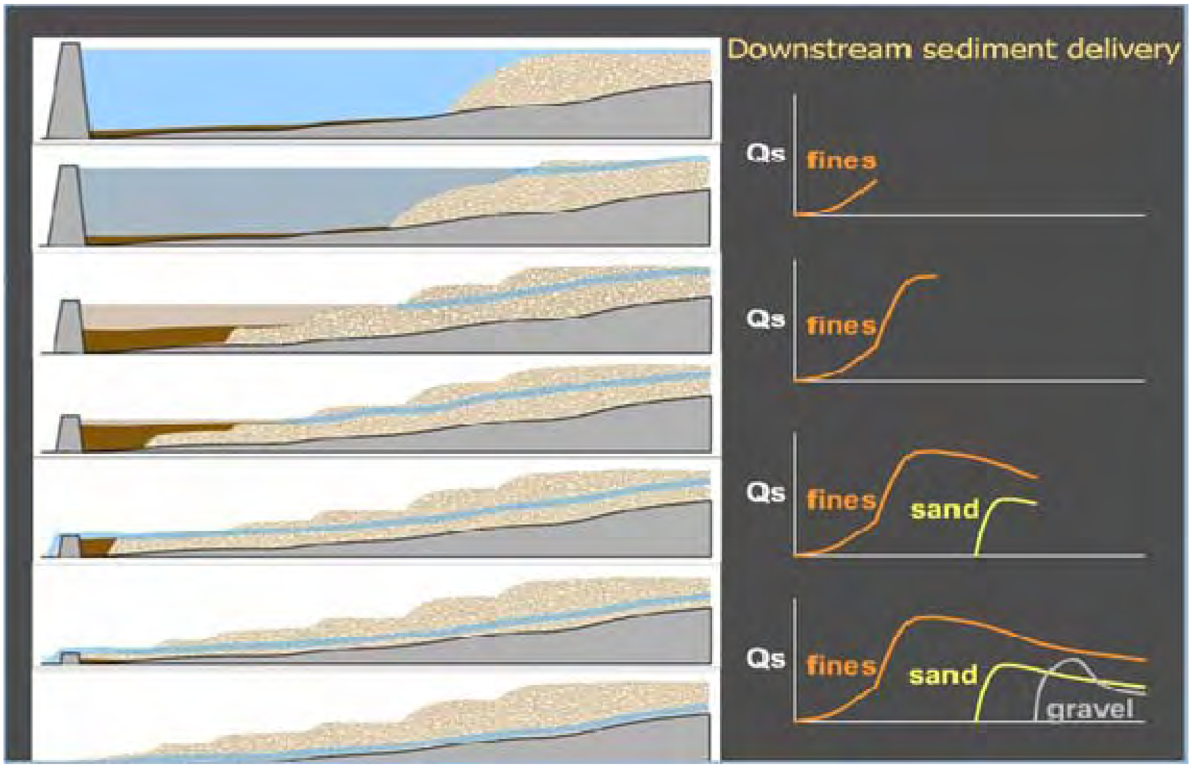


Figure III-12. Sorted sediment delivered downstream from large dam removal (Grant 2004).

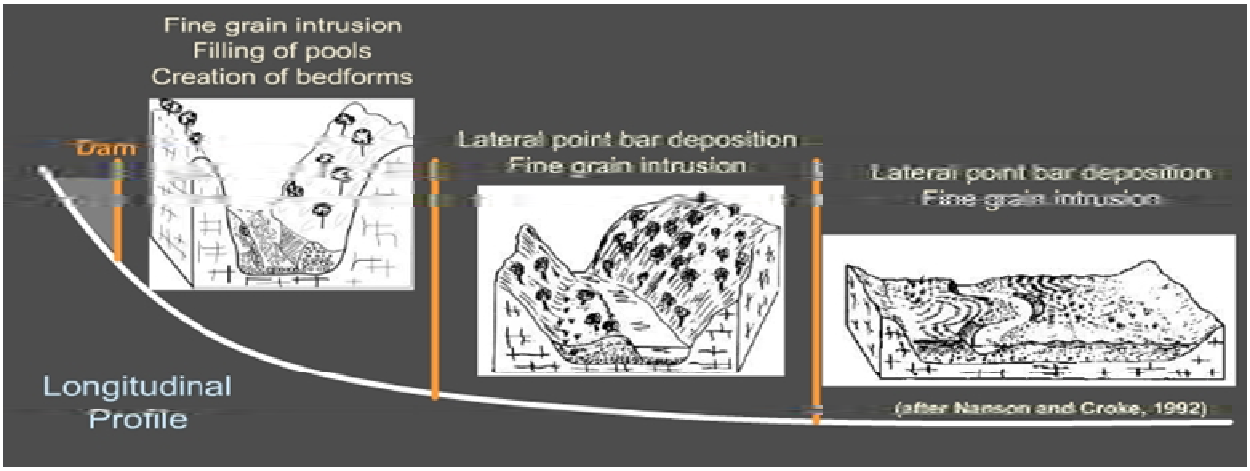


Figure III-13. Channel response of sediment based on channel morphology (Grant 2004).

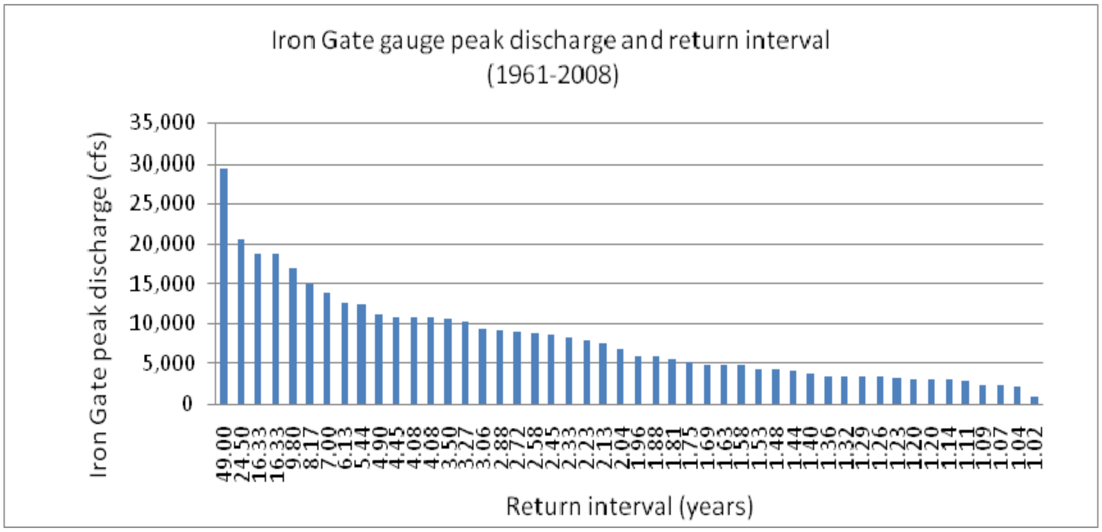


Figure III-14. Annual peak flow return interval below Iron Gate Dam for the period of record water years 1961-2008 (USGS gage number 11516530).

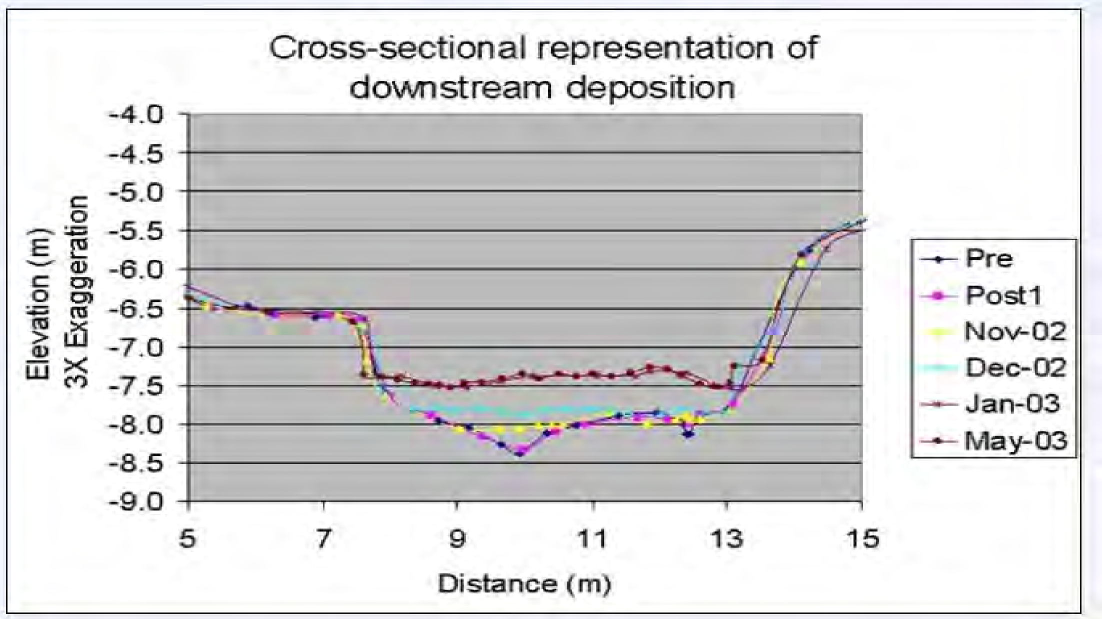


Figure III-15. Cross sectional representation of the New Year's Eve, 2002 Maple Gulch (Rouge River Basin, OR) deposition event and subsequent incision back to original channel form (Grant 2004).

IV. Fish Health Implications

Pre Dam Removal

Fish Diseases in the Klamath River. Certain fish pathogens are widespread in the mainstem Klamath River. The most noted fish health incident in the Basin in recent years was the September 2002 adult fish die-off in the lower river. Guillen (2003a) reported a minimum of 32,533 fall Chinook salmon, 629 steelhead, and 344 coho salmon perished during this event, which resulted from a combination of below average streamflow, high water temperature, high adult escapement, and an epizootic columnaris (*Flavobacterium columnare*) and Ich (*Ichthyophthirius multifiliis*) outbreaks (Guillen 2003b). The 2002 disease outbreak was also exacerbated by high fish densities as these pathogens are transmitted from fish to fish (Guillen 2003b). CDFG (2004) reported that “At least 33,000 adult salmon died” during the event and “that actual losses may have been double that number”. It is important to note that estimates from the USFWS mortality report “should be viewed as a minimum number of fish killed” (Guillen 2003a).

The Service and its many partners have documented high infection rates in emigrating juvenile Chinook and coho salmon, primarily by one or both myxozoan parasites, *C. shasta*, and *P. minibicornis*. Fish health studies conducted from 1995 to present by the Service (Foott et al. 1999; Nichols and Foot 2006; Nichols et al. 2007) and Oregon State University (Stocking et al. 2006; Stocking and Bartholomew 2007) have consistently documented high infection incidence in the Klamath River during the spring and summer. For example, Nichols and Foott (2006) estimated up to 45% of natural origin juvenile fall Chinook salmon passing by the Big Bar outmigrant trap were infected with *C. shasta* and 94% with *P. minibibornus*.

While native salmonids exposed to low doses of *C. shasta* (and presumably *P. minibicornis*) exhibit some degree of resistance (Ching and Munday 1984; Bartholomew et al. 2001), even native fishes can become overwhelmed by the presence of high infectious doses, resulting in a diseased state (Ratliff 1981; Ching and Munday 1984; Bartholomew 1998; Foott et al. 2006, Stone et al. 2008). Fish that display clinical symptoms of disease are more prone to perish due to increased susceptibility to other pathogens, greater susceptibility to predation, and a compromised osmoregulatory system that is critical for successful entry into seawater (S. Foott personal communication).

The first extensive surveys for *C. shasta* occurred in the Klamath River basin in the late 1980s (Hemmingsen et al. 1988; Buchanan et al. 1989; Hendrickson et al. 1989), although its presence had been documented as early as 1968 (Schafer 1968). No information exists on how prevalent these parasites were immediately before and immediately after construction of PacifiCorp Project dams. Recent information however, has documented abnormally high infection prevalence in native salmonids below IGD, which indicate that a host-parasite imbalance exists in that area (Stocking et al. 2006). Studies employing caged sentinel fish at fixed locations (Stocking et al. 2006; J. Bartholomew personal communication) and quantification of the parasite in water samples (Hallett and Bartholomew 2006) have narrowed the focus of the area most affected by disease to approximately the reach between I-5 and Seiad Valley in the Lower Klamath River, and in the Williamson River above UKL.

Ceratomyxa shasta and *P. minibicornis* are assumed to have co-evolved with the salmon species they infect in the Klamath River. This co-evolution of parasites and their salmonid hosts should persist over time at relatively low level virulence equilibrium, given relative consistency in the environmental conditions in which this equilibrium evolved (Toft and Aeschilimann 1991; Esch and Fernandez 1993). However, when environmental conditions are significantly altered, the abrupt change typically favors the parasite because of its shorter generation time and greater genetic variation as compared to that of the host (Webster et al. 2007). In other words, the parasite is quicker to adapt to environmental changes than the host, causing the parasite-host equilibrium to become out of balance. This imbalance in the parasite-host equilibrium may be expressed as elevated infection rates in the host organisms over naturally-occurring equilibrium (background) levels, consistent with the high infections levels observed in juvenile Chinook salmon populations in the lower Klamath River below IGD.

Life Cycle of Parasites. The life cycles of *C. shasta* and *P. minibicornis* are complicated. Both parasites have been documented to be dependent upon salmonids and a freshwater polychaete as alternate hosts to perpetuate their life cycle (Bartholomew et al. 1997; Bartholomew et al. 2006; Bartholomew et al. 2007; Figure IV-1). Actinospores are released from the freshwater polychaete worm into the water column and infect fish on contact. Neither horizontal (fish to fish), nor vertical (fish to egg) transmissions have been documented under laboratory conditions, suggesting that the worm host is necessary for completion of the life cycle. After the infected fish host dies, myxospores are released back into the water column to infect polychaete worm and complete the life cycle. However the complete life cycle, especially as it relates to the ecology of the polychaete host, is not fully understood.

Despite the complexity, having two different hosts involved in the life cycles of these parasites may offer enhanced opportunity for management intervention. The life cycles of *C. shasta* and *P. minibicornis* continue to be a focus of study by the Oregon State University, Humboldt State University, Tribes, and the Service, with the goal of identifying management actions that may be implemented to interfere with a segment or segments of the life cycles to bring the parasite-host equilibrium back into balance.

Polychaete Abundance and Distribution. Polychaetes are widely distributed throughout the mainstem Klamath River. In tributaries to the Klamath River located downstream of IGD, surveys have shown polychaete worms to be either absent, or their distribution is to lower tributary reaches immediately upstream of their confluence with the Klamath (Stocking 2006; Stocking and Bartholomew 2007; Wilzback and Cummins 2007). Polychaetes are most prevalent in low velocity areas such as runs, pools, and riffle edge habitats and fine benthic organic matter (Stocking 2006; Stocking and Bartholomew 2007; Wilzback and Cummins 2007). Stocking (2006) found that transitional areas between the river and its downstream receiving reservoir, known as a reservoir inflow zone, can have exceptionally high densities of polychaetes, which is consistent with other published literature referenced by Stocking.

At this time, the distribution of polychaetes above UKL has not been completely described. Surveys conducted by Stocking (2006) documented the presence of polychaetes in the Williamson River, the dominant inflow tributary to Upper Klamath Lake. The infective stage of the parasite, as determined by sentinel studies employing susceptible strains of salmonids, has been documented to occur in the Williamson River upstream to rkm 38 (Hemmingsen et al. 1988; J. Bartholomew personal communication) and in Agency Lake (Hemmingsen et al. 1988), suggesting that the polychaete host is present in these areas. However, Hemmingsen et al. (1988) and Buchanan et al. (1989) were unable to induce mortality from ceratomyxosis in rainbow trout in other areas above Upper Klamath Lake (e.g. upper Williamson River (rkm 74 and upstream), Wood River (rkm 14), and Fort Creek (rkm 2). While not conclusive, results from these studies indicate that the distribution of the polychaetes or infectivity within polychaetes above Upper Klamath Lake may be confined to lower mainstem river reaches.

Post Dam Removal

Hydrology and Polychaete Abundance and Distribution. Restoration of the hydrologic function of the river system is paramount to creating habitat diversity and maintaining biophysical attributes of a river system (Stanford et al. 1996; Poff et al. 1997). Although implementation of the Agreements will not fully restore the natural hydrologic regime of the Klamath River, it would result in a flow pattern that mimics pre dam conditions, having greater intra- and inter-annual variability than exists today. Creating diversity in flows and water temperatures and providing flexibility to manage flows to respond to real-time climatic and biological conditions (discussed in Section VI) will be made possible by the KBRA. Restoring these dynamic conditions in the Klamath River will create instability and disturbance in microhabitat conditions that would be expected to reduce polychaete populations (Stocking and Bartholomew 2007) and presumably, reduce infection rates within polychaete populations.

The stable, monotypic, nutrient- and diatom-rich flow conditions that occur immediately below IGD provide an optimal environment for production of filter-feeding benthic invertebrates such as *M. speciosa* (Wilzbach and Cummins 2007). Fluctuating flows that mimic, albeit to a lesser degree, conditions experienced under a natural flow regime, would mimimize the occurrence of monotypic stable flow conditions in which polychaete worms are known to proliferate. The concept of mimicking the shape and function of the natural hydrograph in response to changes in environmental conditions is widely accepted as the most ecologically defensible approach to managing flows (Stanford et al. 1996; Poff et al. 1997; Richter et al. 2003). Under the KBRA, the Technical Advisory Team would have flexibility to integrate flow variability and natural flow-induced disturbance into management of the Klamath River. In the following section of this report (Section VI), we present one possible method that would achieve this goal.

Removal of the Klamath River dams would eliminate the existing reservoir inflow zones, thereby eliminating these densely colonized areas. However, the importance of reservoir inflow zones to the overall population of polychaetes and the imbalance in the parasite-host equilibrium is currently unknown. Although dam removal would likely eliminate large colonies associated with reservoir inflow zones, high density populations of polychaetes can occur in other habitats and thus, the response of infectivity to new sources of myxospores from immigrating salmonids within these remaining polychaete populations following dam removal is uncertain (also see Genetic Variation in *C. shasta* below).

Thermal Regimes and Polychaete Abundance and Distribution. The restored thermal regime would also influence the distribution and colonization of the river channel by polychaetes. We conclude that the greater thermal diversity that will be experienced following removal of the PacifiCorp Project dams and reservoirs is likely to result in greater invertebrate diversity and less favorable environmental conditions for production and survival of a single species (Poff et al. 1997) such as the polychaete. Warmer water during the spring and summer may result in rapid growth and colonization by polychaetes, but densities of the species may be reduced by other invertebrates that prey upon the polychaetes (K. Cummins personal communication.). In contrast, cooler water temperatures during the early fall and winter would likely result in reduced polychaete colonization rates.

Hydrology and Actinospore Abundance and Distribution. The influences of a restored hydrologic regime on actinospore dispersion are difficult to assess because of limited information. A restored hydrologic regime would likely result in events that would distribute the actinospore load along an expanded section of the mainstem Klamath River. It is also likely that the resultant increased distribution of infected polychaetes would result in a concomitant increase in the dispersion of actinospores. Similarly, increased Klamath River flows during the spring out migration period (May through June) could act to reduce actinospore transmission efficiency (S. Foott personal communication) and increased river volume may act to dilute actinospore concentrations.

Potential benefits could also be derived from greater flow variations that would occur during the winter or early spring. Removal of PacifiCorp Project dams would facilitate the occurrence of higher peak flows and restoration of mid-sized (gravel) sediment input below IGD that could scour or deposit bedload over polychaete colonies and their habitats, thereby reducing actinospore loads in the following spring.

Thermal Regimes and Actinospore Abundance and Distribution. The dynamics of actinospore development and release into the environment is not well known and is worthy of future study in the Klamath Basin. Our current limited knowledge indicates that actinospore production and release into the environment is positively associated with water temperature; when water temperatures approach 10°C in spring, replication and release of actinospores increases (J. Bartholomew, personal communication). During late summer there is a decrease in actinospore release. In fall, levels begin to increase until water temperatures decrease below 10˚C. As such, warmer water temperatures that may occur within the current location of PacifiCorp Project reservoirs and immediately below IGD during spring and summer could result in an increased rate of actinospore production and an earlier or prolonged release period. However, overall actinospore production is dependent on total abundance of infected polychaetes, which as described previously and below (Hydrology and Myxospore Abundance and Distribution), is anticipated to decrease following the removal of the Klamath River dams. Conversely, cooler temperatures in the fall may result in decreased magnitude or a shortened period of actinospore release.

Ratliff (1981) hypothesized that delays in out-migration and higher water temperatures as a result of Columbia River impoundments may amplify losses from ceratomyxosis due to longer and later exposure times. There is a chance that earlier warming of the Klamath River that would occur in the spring as a result of dam removal could stimulate early actinospore release from polychaetes. However, fish emigration is likely to occur earlier in the season with a warmer thermal regime because fish will likely have grown faster. In this case, and if actinospore release is stimulated by warmer water temperatures, we conclude that the restored thermal regime will coincide with a restored emigration pattern and perhaps improved rearing/emigration in downstream reaches afforded by higher tributary contributions of flow that dilute spore concentrations and lessen the risk of infection. Restoration of the thermal regime will provide a diversity of thermal habitats that should help balance the parasite distribution and abundance in the river system.

Hydrology and Myxospore Abundance and Distribution. Removal of the PacifiCorp Project dams is likely to alter the distribution of myxospores by dispersing concentrations of adult salmon and resident trout found below IGD, which likely function as reservoirs of myxospores. A contemporary theory is that the passage barrier created by IGD and the shared location of the Iron Gate Fish Hatchery has concentrated the density of spawning adult salmon in the IGD to Scott River reach, thereby exacerbating release of infectious myxospores within this reach. S. Foott (2007 unpublished data) found adult Chinook salmon to have a high level of parasite infection (>70%) below the dam. Stocking et al. (2006) also found that polychaetes residing below IGD exhibited high infection prevalence (4.9 to 8.3%) as compared to polychaetes above IGD (0.27%). This study suggests that the greater abundance of myxospores released by dense concentrations of spawning salmon within this reach result in higher infection rates in polychaetes, which proliferate in this relatively stable reach. However, it’s also possible that concentrated spawning conditions within this reach could shift upriver to the reach below Keno with the removal of the PacifiCorp dams, with a concomitant upstream shift in the current zone experiencing high infectivity.

Uncertainty remains as to the overall influence that dam removal may have on the distribution and abundance of myxospores. However, it is likely that there will be a shift in myxospore distribution in response to the increased dispersion of spawning adult salmonids and resident trout that will result from dam removal. It has been hypothesized that crowded spawning conditions that exist below IGD could shift upriver to below Keno Dam, creating a “hotspot” infection zone similar to what presently exists in the Beaver Creek area. However, unlike IGD, which is a total fish passage barrier, bidirectional passage will be provided at Keno Dam and as such, we do not anticipate major concentrations of spawning adult Chinook salmon directly below the dam as observed below IGD. We also expect that further evaluation of disease would be included in plans for reintroduction of anadromous fish species upstream of Keno Dam.

Restoration of dynamic flows in the Klamath River, in particular, higher flows during the late winter and spring, may also reduce the infection rates within polychaetes. Higher stream flows are likely to flush the parasites (i.e. myxospores) from the mainstem river channel (J. Bartholomew personal communication). Myxospores are negatively buoyant (J. Bartholomew personal communication) and as such, are likely to accumulate on the bottom of the stream channel. These accumulations would be susceptible to being mobilized and subsequently transported within or out of the main channel during high flow events.

Thermal Regimes and Myxospore Abundance and Distribution. Restoration of the Klamath’s historical pre Hydropower Project thermal regime (at times, between 7 to 10 °C cooler than existing conditions, (FERC 2007) would have a pronounced influence on the system’s biota and aquatic ecosystem processes, and will likely influence the ecology of the polychaete worms and may reduce replication rates of myxospores in host immigrant adult salmon and resident salmonids. Udey et al. (1975) found disease replication to be temperature dependent; when water temperatures decrease, replication of parasites decrease. In turn, reduced concentration of myxospores shed from hosts may result in decreased infection rates in polychaetes. Current research is aimed at improving our understanding of myxospore production and release timing.

Genetic Variation in *C. shasta*. Genetic variants of *C. shasta* have recently been discovered in the Klamath River basin by Oregon State University (Atkinson and Bartholomew, in preparation). To date, they have identified four unique genotypes (Type 0, I, II, and III), three of which exhibit a host preference. Type 0 appears to be specific to native steelhead and in-basin rainbow trout; Type I infects native Chinook salmon; Type II prefers native coho salmon; and the Type III variant occurs at low prevalence and is thought to be non-specific. At present, the presence of Types 0, II, and III has been documented in the IGD, with Type II (coho salmon specific) persisting at low levels on out-of-basin stocked rainbow trout (Atkinson, personal communication) as a host. The Type I genotype (Chinook salmon specific) has yet to be observed upstream of IGD. This genotype would be reintroduced above the current site of IGD with dam removal and anadromous fish reintroduction, but would affect only Chinook salmon. Dam removal and anadromous fish reintroduction may also result in the redistribution of the Type 0, II, and III genotypes already detected above IGD. However, the life cycle of these host-specific variants would only persist in areas of the river where polychaetes are present. Even in light of this developing research, we believe that infection levels in salmonids are likely to be low relative to current conditions documented below IGD for reasons previously discussed.

Water Quality and Fish Health. The overall influences of nutrient concentrations on general water quality (e.g. DO and pH) to the health of fish are expected to improve over current conditions (see the Water Quality Section of this document). For example, we expect that DO concentrations in several reaches below PacifiCorp Project dams would increase resulting in potentially less stress to the biotic community and improved health of salmonids. The abundance of mainstem Klamath River thermal refugia habitats (coldwater tributaries and springs) available to anadromous fishes in the basin would increase considerably following dam removal, which would help ameliorate stressful conditions for fish and other biota. For example, Boyle (1976) reported numerous springs in the valley prior to inundation by the PacifiCorp Project reservoirs that would create thermal diversity in the system.

Population Level Effects of Diseases. The effects of disease on salmonid populations in the Klamath Basin have not been well described. Recent studies have shown that the elevated incidence levels of infectious diseases are adversely affecting freshwater production of Chinook and coho salmon smolts in the Klamath River, but the degree to which populations are affected is unknown. Disease-induced mortality of juvenile downstream migrant salmon may not necessarily have a significant population level affect during years of diminished ocean productivity, which may limit ocean carrying capacity for salmonids. During years of poor ocean productivity, density-dependent survival in the marine environment may limit abundance of salmon populations rather than freshwater production. Conversely, during years where ocean productivity is high and survival is not significantly influenced by density dependent mortality in the ocean, high mortality of juvenile salmon in the river and the resultant decrease in the abundance of smolts entering the ocean due to disease-induced mortality, directly affect ocean abundance of Klamath stocks. In turn, lower ocean abundance is likely to result in decreased harvest opportunity and potentially, decreased spawning escapement to the Klamath Basin.

Figures

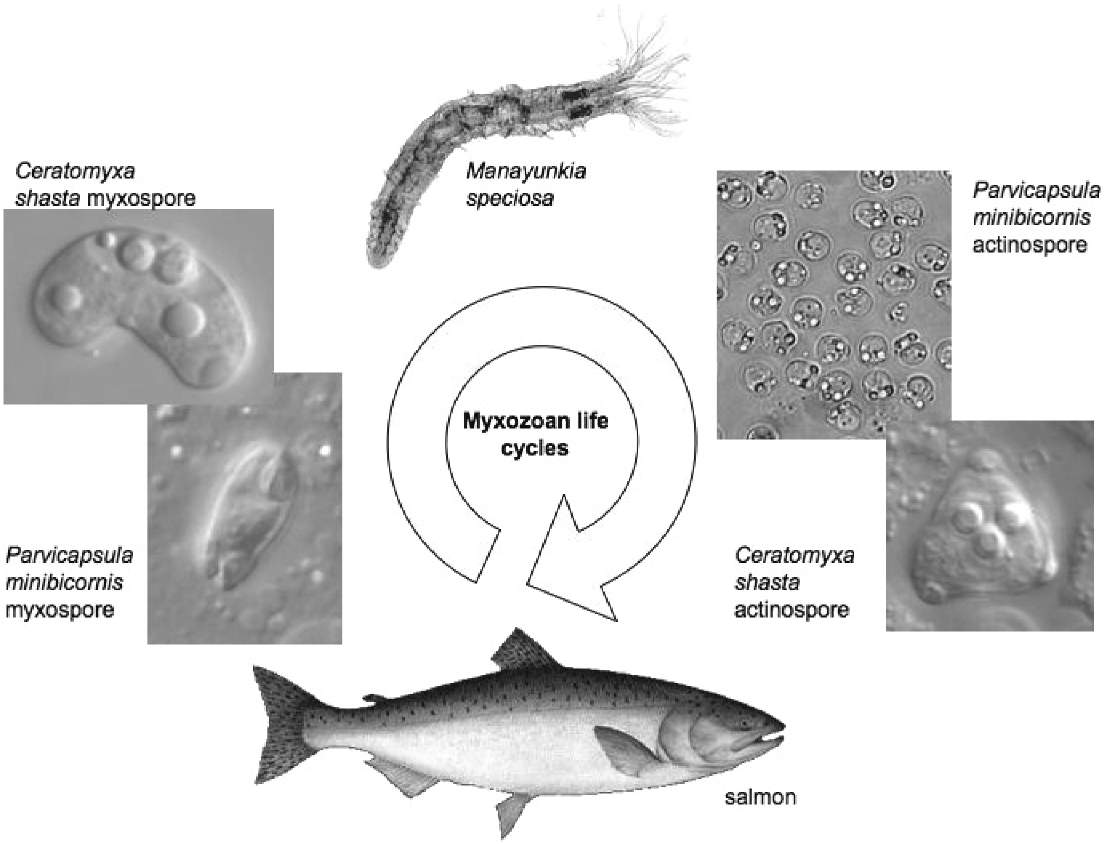


Figure IV-1. The life cycle of *Ceratomyxa shasta* and *Parvicapsula minibicornis* (graphic provided with permission from J. Bartholomew, Oregon State University). *Manayunkia speciosa* is a freshwater polychaete worm and intermediate host of both parasites

V. Potential Change in Fish Production

Pre dam Removal

Background. Our analyses on potential changes in fish production focused primarily on juvenile fall Chinook salmon due to the availability of an existing production model developed for the Klamath River. To conduct the analyses, the Service requested USGS Fort Collins Science Center to implement the decision support system, Systems Impact Assessment Model (SIAM) to corroborate the information produced by the WRIMS model, Reclamation’s water planning model for the Klamath Basin, and to predict changes in water temperature and production of juvenile fall Chinook salmon that would occur below IGD under various water management alternatives being evaluated in negotiations of the KBRA. SIAM is a multi-component planning model (Figure V-1) that was specifically designed to test performance of proposed water management alternatives as to their feasibility (i.e., is it possible?) and effectiveness (i.e., how well does it work compared to status quo or other alternatives?) (Bartholow et al. 2003). SIAM is not an "operations" model that will provide information for daily river system management.

The fish production model (SALMOD) within SIAM has been parameterized for the Klamath using an extensive volume of information extracted from the literature, data collected in the Klamath River and in neighboring systems, and information reached by consensus from a large group of experienced fisheries staff from State, Federal, Commercial, and Tribal entities. SALMOD is a weekly time-step model that begins with the onset of spawning and continues through the duration of outmigration of juveniles. As fall run Chinook salmon spawning in the Klamath River begins in mid-October, the biological year has been set to begin October 1, which coincides with the beginning of the water year used in management.

Previous analyses indicate that SALMOD consistently reproduces trends in fall Chinook salmon production in the Klamath River from IGD to the confluence of the Scott River (Bartholow and Henriksen 2006). However, SALMOD has not been calibrated or validated and as such, accuracy of the model in predicting the number of fish or fish production for any day, week, year, or season is unknown. SALMOD does predict relative changes in fish production that may result from changes in flow, habitat, and water temperature. As such, we conclude that SALMOD provides reasonable comparative estimates of fish production between simulations that can be attributed to changes in these parameters. Sensitivity analyses of SALMOD results indicate the main driver for fall Chinook salmon production in the Klamath River is available habitat (controlled by channel shape and flow), followed by flow and water temperature (Bartholow and Henriksen 2006). More specifically, Bartholow and Henriksen (2006) plotted the availability of habitat for specific life stages of fall Chinook salmon as a function of flow (Figure V-2). This plot demonstrates that in the SALMOD model, spawning habitat is maximized at flows between about 750 to 1,800 cfs and declines relatively rapidly thereafter as flows exceed about 1,700 to 1,800 cfs. The model predicts rearing habitat for fry and smolts is maximized between flows of 4,500 and 7,500 cfs. These relationships are crucial in understanding production estimates generated by SALMOD.

Objectives. USGS was first asked to compare hydrology predictions of SIAM to those of WRIMS and assess how closely outputs of the two models agree with one another with regard to river flow and reservoir storage. Although the two models are unlikely to predict the same exact values for any given day in a water year within the specified period of record (water years 1961-2000), we expected general agreement in bulk water amounts on a monthly or annual basis and established *a priori* that any discrepancy greater than ± 10% would be viewed in more detail and possible errors in either of the two models be identified and corrected.

The second task asked of USGS was to configure SIAM to emulate specific WRIMS model runs, duplicate the WRIMS runs, and then estimate change in water temperature and fish production from the historical water year 1961-2000 baseline to accompany hydrology model predictions, which are WRIMS's only output parameter. Although these simulations use historical water year data, anticipated restoration activities and augmentations to Upper Klamath Lake inflow were factored into model runs to more accurately depict future conditions likely under the KBRA prior to dam removal. The expectation was that having a variety of both meteorological and hydrological conditions, as reflected in the period of record for water years 1961-2000, would provide a range of conditions that might be expected in the future.

Methods

Model Comparison. Specific changes were made to the SIAM model (version 4.15) to emulate the hydrology of the WRIMS model and generate simulations using the same inflow, water storage, downstream flow deliveries, water surface elevation targets, IGD flow release targets, agricultural and Refuge demands provided in WRIMS. To provide results similar to WRIMS model runs, the following priorities were used: agricultural demands received the highest priority (19) and Iron Gate demand was set as the lowest priority (30) with the rest of the nodes, including Upper Klamath Lake, given a priority of 20 in all simulations. The NRCS March 1st forecast was used to determine the exceedence year for SIAM simulations incorporating the Hardy et al. (2006a) Phase II, Alt X, and Alt X, Yurok flow schedules as model inputs.

The resulting version of SIAM was renamed “Settlement SIAM” and was applied to simulations, including WRIMS Run-31, WRIMS Run-32-Refuge, and other alternatives where water temperature and fish production values were desired in addition to water management predictions. A historical baseline of fall Chinook salmon production was simulated using the standard version of SIAM (version 4.15), which emulated WRIMS fairly well if Upper Klamath water surface elevation and Iron Gate flow release targets were entered into the appropriate target fields in the model.

Production Estimates. The second task assigned to USGS was to provide estimates of water temperature and fall Chinook salmon production for various water management alternatives and/or flow schedules under consideration in negotiations relating to the KBRA. Those were:

- WRIMS Run-32 Refuge; water management alternative
- ALT-X; flow schedule and UKL water surface elevation targets
- ALT-X-Yurok; flow schedule and UKL water surface elevation targets
- Hardy et al. (2006a) Phase II; flow schedule

- Historical Baseline; simulation of historical conditions from water years 1961-2000

To eliminate variability induced by annual differences in run size, spawning escapement was maintained at a constant value for all simulations. Simulations were compared to the historical baseline estimates (water years 1961-2000) and converted to a percent difference from fish production value predicted by the Settlement SIAM model on an annual basis. Significant deviation from historical baseline production estimates was established at ± 10 %. Production estimates generated by Settlement SIAM for the different alternatives that differ by less than 10% of the historical baseline estimate or each other for a given year should be interpreted as not differing significantly from each other. It should also be noted that the historical baseline simulation was generated using the standard SIAM v. 4.15, representing historical conditions and operations of the Klamath System from water years 1961-2000. All other simulations were performed using the Settlement SIAM model, which incorporates additional storage and inflows that have been proposed under the KBRA or have been recently implemented for Upper Klamath Lake by Reclamation and others.

Results

Model Comparison. USGS was not able to independently compare WRIMS and SIAM outputs directly, because to our knowledge, a WRIMS simulation that recreates both historical flows and UKL elevations has not been performed. However, USGS was able to compare how well Settlement SIAM emulated WRIMS R-32 Refuge IGD flows (Figure V-3). The Settlement SIAM model simulation was configured to emulate the WRIMS model simulation as closely as possible. Although some minor deviations in IGD flows are visible from the graph, trends are similar, indicating that the Settlement SIAM and WRIMS models produce output flows at IGD that are similar to one another. The difference in mean monthly flow predicted at IGD by the two models averaged 1.7% (about 100 cfs) for the period of record (Table V-1). This, however, does not mean that the USGS modified SIAM model and the Reclamation model reproduce the Klamath Basin hydrology accurately (or inaccurately); rather, they reproduce Klamath Basin hydrology similarly. USGS has determined that the unmodified SIAM model does reproduce the historical hydrology of the Klamath Basin to within 1% (root mean square = 54 cfs) compared to the IGD USGS gage over a 45-year period of record, water years 1961-2005 (Flug and Scott 1997). The two models' apparent agreement is likely rooted in independent calibration and validation, resulting in reproduction of the hydrology of the Klamath Basin as accurately as possible for each of the two models. Since the modified SIAM model and WRIMS model were both based on previously calibrated and validated models, we assume that the accuracy of both models is carried through to the modified versions.

Change in Water Temperature. In general, differences in water temperature between the historical baseline and Settlement SIAM simulations calculated using WRIMS R-32 Refuge model outputs were within the SIAM model confidence interval for temperature of ± 1 °C (Hanna and Campbell 1999). Seasonally, the difference between predicted SIAM temperatures and Settlement SIAM temperatures ranged from 0.3° C in the winter, 0.7 °C in spring and summer to 1 °C in the fall. There are a variety of metrics within SIAM that can provide further insight into differences in water temperature, which are currently being examined more closely to help inform the Secretarial Determination. However, given the small differences in modeled water temperatures for the various model runs, we chose not to present water temperature results for any of the fish production simulations.

Production Estimates. Production estimates of juvenile Chinook salmon varied considerably between alternatives and across years within alternatives (Figure V-4). Because graphs with 5 or 7 traces of 40 points each are difficult to visualize and understand, we summarized the most salient model results in graphical and tabular form to provide resource managers with a useable means for assessing differences among simulations from the large body of model runs that USGS conducted.

In general, years where modeled historical production of fall Chinook salmon was low provided the greatest opportunity for improvement under any of the alternative flow schedules. Conversely, in years where modeled historical production was high, there was little difference in the change in production for the alternatives. Percent change in production from the historical water years 1961-2000 baseline and Run-32 Refuge simulation for the 10 highest historical production years (upper 25th percentile) averaged about +6 % and for the 10 lowest historical production years (lower 25th percentile), about +45 % (Table V-2). Percent change in production from the historical baseline and the Hardy et al. (2006a) Phase II simulations for the 10 highest historical production years averaged about -7% and about +50 % for the 10 lowest historical production years (Table V-2).

To further explore these modeling results/outputs, we plotted the percent change in annual estimates of simulated production of juvenile fall Chinook salmon from historical baseline that would result from implementation of the WRIMS Run-32 Refuge and Hardy et al. (2006a) Phase II flow schedules, as predicted by Settlement SIAM. We observed imperfect negative correlation in the relation between fish production modeled for the historical water years 1961-2000 water year baseline and for model runs incorporating the WRIMS Run-32 Refuge and Hardy et al. (2006a) Phase II flow schedules (Figure V-5). Modeled gains in fish production under both Run-32 Refuge and Hardy Phase II runs were greatest for low-to-mid historical production years and the magnitude of change for these years was highly variable (Figure V-6 through Figure V-9). For years where the modeled historical production was high, potential for improvement under either of these flow schedules was consistently low. This is because in historically high production years, habitat availability modeled in SALMOD was at or near the maximum values, providing little to no opportunity for improvement in predicted production.

Fall Chinook salmon production estimates calculated for simulations incorporating the Hardy et al. (2006a) Phase II, Alt X, Alt X Yurok, and WRIMS Run-32 Refuge flow schedules varied considerably from the historical 1961-2000 water year baseline, and to a much lesser degree, between one another for a given year (Figure V-4). In years when modeled fish production increased significantly over historical baseline predictions (>10 % over baseline, Figure V-4), improvements in production often occurred as a result of increased flows in the spring and/or reduction in intensity and/or frequency of fall spills. Early fall spills reduced estimates of adult spawning habitat availability, while increases in spring flows over historical baseline conditions resulted in increased fry and juvenile rearing habitat availability. For 1985, for example, simulations independently incorporating the four flow schedules all predicted a >140 % increase in fish production over the historical baseline estimate (Figure V-8). In water year 1985, historical flows below IGD averaged 5,254 cfs during November. At that flow level, spawning habitat availability calculated in SALMOD is low (Figure V-2). In all other simulations (WRIMS Run 32- Refuge, Alt-X, Alt-X-Yurok and Hardy et al. (2006a) Phase II), this fall spill was reduced and resulting predictions in fish production increased significantly over the historical baseline.

In 1993 and 1995, production estimates for the baseline hydrograph are high (Figure V-9). Water year 1993 ranks as the third highest and 1995 as the highest annual production estimate for the historical water year 1961-2000 simulations. The baseline hydrographs for these two years provided at or near the maximum habitat availability for the various life stages of fall Chinook salmon (Figure V-2). If flows are at a level that correspond to the maximum habitat area at the proper time periods, regardless of whether the simulation is for the historical baseline or some other water management alternative, production predictions will be maximized. Deviations from maximum value of habitat area curves reduce production estimates. As such, it appears that when conditions historically were “ideal” in terms of habitat availability, it is difficult to improve fish production further by altering the hydrograph.

In 1969, 1993, and 1995 simulations incorporating the Hardy et al. (2006a) Phase II flow schedule resulted in more than a 10% reduction in estimated production from the historical 1961-2000 water year baseline. Factors contributing to the modeled decrease in production from historical conditions include high fall flows that limit spawning habitat in 1969, resulting in higher egg superimposition mortality compared to the historical baseline. In 1995, higher flows in the fall and lower flows in the spring, as compared to the historical baseline, yielded higher egg mortality and reduced rearing habitat in the spring. In 1993, the historical baseline hydrology produced the third highest modeled fish production estimate for the 40-year period of record, so altering the hydrology for this water year in any manner was unlikely to significantly improve this already high production year. This point is valid for all of the simulations, not just the comparison with the Hardy et al. (2006a) Phase II flow schedule.

Water year simulations using the Hardy et al. (2006a) Phase II flow schedule occasionally resulted in a lower production estimate than for the historical 1961-2000 water year baseline. This most often occurred because of the use of an inaccurate NRCS March 1st forecast. Accuracy of the NRCS forecast in predicting the actual exceedence year type was poor for some water years. For example, in 1969 the NRCS forecast was for a 4.6% exceedence year, whereas the exceedence calculated from historical data was about 24%. This resulted in the Hardy Phase II flows applied in the Settlement SIAM simulations to be substantially greater than the WRIMS Run-32 Refuge flows (Figure V-10). As discussed previously in Section I, the WRIMS Run-32 Refuge simulation incorporates an Inflow Exceedence Index as the basis of selecting lake level and river flow targets for each time step rather than being dependent on the NRCS forecast. Furthermore, the difference between 1969 production estimate for the Hardy Phase II simulation and estimates calculated using the Alt X and Alt X Yurok flow schedules (which also use the NRCS forecast to determine exceedence year type) were primarily due to the higher flow targets for the fall/winter months in the Hardy Phase II schedule for wet water year types as compared to targets for the Alt X and Alt X Yurok flow schedules (Table V-3).

We further assessed anticipated improvements in fish production by ranking predicted historical fish production values for the period of record (water years 1961-2000) and categorizing them as being high (10 of 40 years, >75th percentile), moderate (20 of 40 years, 25th - 75th percentile), or low (10 of the 40 years, <25th percentile) production years. Transition points between these groupings were then applied to ranked lists of Settlement SIAM simulated production estimates. For the various Settlement SIAM simulations, the number of years in the 40-year period of record that would fall into the high production category was predicted to shift upward from 10 years to between 17 to 18 years (Figure V-11). Fish production is also benefited by decreasing the number of years when low fish production is predicted to occur. The number of years when low production was estimated for the five different water management schedules within the 40-year period of record was reduced from 10 years down to 3 or 4 years out of the 40-year historical baseline. In essence, implementing any of the alternative flow schedules was predicted to reduce low production years by 2/3 in the future. Reducing the average occurrence of low production years from 1 out of every 4 years downward to 1 out of every 10 years is particularly significant given the dominant 3 to 4 year life cycle of fall Chinook salmon in the Klamath Basin. This reduction in the frequency of low production years does not preclude the possible occurrence of one or more low production brood years that subsequently negatively influence the forecasted annual run strength and harvestable surplus target for a given year. It does, however, greatly decrease the probability that a series of low production years would occur back to back, which would suppress future escapements and subsequent production and fishery opportunities. The probability of occurrence of two consecutive low production years based on the historical data, is 0.063 (0.25 x 0.25), assuming independence between years. The alternative water management scenarios that reduce the occurrence of low production years to 4-in-40 years and 3-in-40 years result in the probability of occurrence of two consecutive low production years of 0.010 and 0.006, respectively. Again, these probabilities assume independence between consecutive water years, which is unlikely when considering wet and dry hydrologic cycles and cycles of marine productivity. Depending on the strength of correlation of hydrologic and marine conditions between consecutive years, especially for years having low production, the probabilities for the occurrence of consecutive low production years would likely be higher.

Modeled Lake Elevations. Because ESA listed species are present in both Upper Klamath Lake and in the Klamath River below Iron Gate Dam, the life cycle needs of both lake suckers and anadromous fishes must be carefully considered by resource managers in developing water management alternatives. Although all of the water management alternatives or flow and water surface elevation target schedules have the potential to improve anadromous fish production, the dependence of suckers on seasonal habitats that are related to water surface elevation in Upper Klamath Lake introduces the need to consider UKL storage and lake levels in addition to downstream flows.

As was noted earlier, statistical relationships between habitat parameters and sucker population performance have not been demonstrated. Over the past decade, several UKL surface level management regimes have been in place, each based on certain rationales related to sucker habitat. For instance, in the 2001 Biological Opinion for listed suckers in UKL, the Service mandated monthly UKL levels because they provided access to habitat at key seasons for different life stages. The NRC (2002, 2004) found little empirical support for applying these particular lake levels as ESA mandates, but also recognized that lake levels were important for access by suckers to spawning and rearing habitat, and for summer refugial habitat. Subsequently, the Service's 2008 Biological Opinion approved a more complex set of lake level prescriptions proposed by

Reclamation that also was designed to provide seasonal habitats for suckers under various exceedences.

For the purposes of this exercise, to demonstrate relative performance of various model runs against a habitat standard, we evaluated the various modeling results against the monthly UKL levels specified in the Service's 2001 Biological Opinion. We chose this readily available and relatively simple measure for illustrative purposes only, recognizing that additional research and future regulatory applications will likely produce different standards for actual management application.

Water surface elevations of UKL simulated by Settlement SIAM were assessed by recording the number of occurrences that the minimum lake elevations specified in the 2001 Biological Opinion was not met in simulation outputs of mean monthly lake elevations over the 40-year period of record. Upper Klamath Lake water surface elevations were substantially lower under the Hardy simulation than those modeled under either the historical baseline or the WRIMS Run-32 Refuge simulation (Figure V-12). The number of times that specified monthly elevations were not met ranged from 5 to 69 for the Settlement SIAM simulations and occurred 9 times for the historical 1961-2000 water year baseline run using SIAM. Of the various flow alternatives, the simulation implementing the Hardy et al. (2006) Phase II flow schedule yielded the greatest number (69) of occurrences when the monthly water surface elevation was less than the 2001 Biological Opinion minimum level.

It is important to recognize that the Hardy Phase II flow recommendations used in the Settlement SIAM simulations were, as described by Hardy et al. (2006a):

> *"made based on the ecological needs of the Lower Klamath River and anadromous fish in particular" and that the Hardy Phase II study was "not commissioned to undertake any 'optimization' or flow balancing to meet competing water demands".*

Hardy et al. (2006a) further state that their flow recommendations

> *"provide a frame of reference to support decision making within the policy arena, where trade-offs between downstream flow needs versus beneficial out-of-stream uses upstream, including Upper Klamath Lake elevations necessary to protect and recover the endangered Klamath sucker will likely be debated".*

The SIAM settlement (Alt X, Alt X Yurok, and WRIMS 32 Refuge) alternatives each embodied attempts to accomplish balancing of UKL levels with flows for anadromous fish production below Iron Gate Dam, and thus, in our opinion, represent more feasible approaches to actual management of the various demands.

Post Dam Removal

Anadromous Fish Habitat above Iron Gate Dam. Fish habitats in the Upper Klamath Basin have been inaccessible to anadromous fishes since 1918 when Copco 1 Dam was constructed. Removal of the Project dams as proposed in the Draft KSHA would reestablish production of anadromous fish species to much of its historical range in the Klamath Basin (Table V-4). Over 676 km (420 miles) of interconnected river and stream channels currently exist upstream of IGD that would provide functional spawning and rearing habitats for anadromous fish species, including spring and fall Chinook and coho salmon, steelhead, and Pacific lamprey, following removal of PacifiCorp Project dams (Huntington 2006). In addition, an estimated range of 98-379 km (60-235 miles) of potential habitat exists in the Upper Basin that could be rehabilitated into a functional condition for use by anadromous fish species.

We estimated distances of historical anadromous fish habitat within the Klamath River mainstem, historical side channels, and tributaries that are currently inundated by the Klamath reservoirs by overlaying historical topography maps with current NAIP imagery. Contour maps of the reservoirs were obtained from Bathymetry and Sediment Classification of the Klamath Hydropower Project Impoundments by J. C. Headwaters, Inc (2003). The reservoirs analyzed included Iron Gate, Copco, and J. C. Boyle and mainstem distance values were compared with results provided by Philip Williams & Associates, Ltd. (2009) and the U.S.G.S. National Hydrography Dataset (NHD) Artificial Lines. Based on this analysis, we estimated that 27.4 km of mainstem Klamath River, about 2 km of side channels, and 6.7 km of tributaries would be reestablished that are currently inundated by Project reservoirs (Table V-5 and Table V-6).

Dam removal would decrease the likelihood of the occurrence of redd superimposition by allowing spawning adults that currently concentrate below IGD (Magneson 2006; Magneson et el. 2008; Magneson 2008; Figure V-13), to disperse upriver, thereby having potential to improve adult to juvenile production ratios. The range of dispersal of anadromous spawning following dam removal would likely be widespread and is anticipated to include historical key spawning areas in the mainstem Klamath River currently inundated by Iron Gate and Copco reservoirs, the Sprague and Williamson rivers, as well as numerous small tributaries. Dispersal of the concentrated spawning that currently occurs below IGD is also likely to reduce the resultant high concentrations of fry and juvenile salmonids that currently exist downstream of IGD, potentially benefiting outmigrant wild stocks of anadromous fishes from the Bogus Creek and the Shasta and Scott rivers through reduced competition for food and space. This is in addition to benefits that would result from increased water quality (Section II) and potential reductions in disease-induced mortality (Section IV).

The total estimated length of river and stream channels opened to anadromy under the Agreements is particularly significant for juvenile salmonids, which have been reported to be closely associated with stream banks and proximity to escape cover (Beechie and Liermann 2005; Hardy et al. 2006b; Stutzer et al. 2006). We calculated a coarse approximation of habitat gains for salmon fry upstream of IGD by doubling the stream distance under the assumption that 1 km of added accessible channel would equate to 2 km of additional bank habitat (676 km increase in channel distance times 2 stream banks = 1,352 km of bank habitat, excluding side channels, mid-channel islands, etc).

In addition, greater than 676 km of river and stream channels important for the production of macroinvertebrates would become available as rearing and feeding areas for juvenile salmonids. This gross estimate is likely low as it does not account for invertebrate production in reaches considered recoverable (Huntington 2006) or reaches located upstream of fish passage barriers, a portion of which would be transported downstream in the drift into reaches used by anadromous species. Potential increases in food availability, in combination with changes in water temperatures that more closely resemble the historical pre-development thermal regime, are likely to increase the size of smolts at ocean entry, which has been shown to increase estuary/ocean survival (Jokikokko et al. 2006; Muir et al. 2006)

Dam removal provides a high likelihood for spring Chinook salmon to become reestablished in the upper Klamath River and potentially, be restored as the once dominant Chinook salmon run in the Basin (Gatschet 1890; Spier 1930; Hume in Snyder 1931). Historically, adult spring Chinook salmon migrated upstream of the current location of IGD in the spring and over-summered in large holding pools in the mainstem Klamath River and tributaries fed by cool spring water and/or high elevation snow melt. Iron Gate Hatchery maintained a remnant spring Chinook salmon population for a short period of time after construction of IGD. However, the lack of adequate holding facilities and high water temperatures resulted in unsuccessful spawning of the last 17 adults in 1978 (CDFG 1982; Shaw et al. 1997). Following construction of PacifiCorp Project dams, summer holding habitats for adult spring Chinook in the mainstem Klamath River were restricted to the few locations having cool water tributary inputs into large confluence pools such as below Happy Camp (about 130 km downstream of IGD) and possibly the confluence with Bluff Creek (227 km below IGD).

Production potential of Chinook salmon and steelhead has been estimated by various authors for different reaches of the Klamath River above Iron Gate Dam (Table V-4). These estimates vary by author and by reach, but potential gains are consistently significant. Fortune et al. (1966) based estimates of adult capacity on the abundance of spawning habitat above the dams. Chapman (1981) based his estimates of adult capacity on a type of instream flow study. However, subsequent to these two studies, extensive habitat restoration has occurred in the Upper Klamath Basin. While these two studies are considered contemporary, the authors' estimates of production potential (Table V-4) are likely to be conservative because of recent habitat improvements that have been implemented.

Under the DRAFT Oregon Department of Fish and Wildlife Restoration Plan (Oregon Department of Fish and Wildlife 2008) anadromous fish would recolonize habitat naturally without intervention/movement of fish. If monitoring reveals that recolonization is not occurring or is doing so too slowly, managers have the option to pursue active reintroduction of anadromous fish.

Given the significant changes in habitat availability in the Klamath Basin, a reevaluation of the Klamath fall Chinook salmon harvest management plan will be required to evaluate the natural spawner escapement floor, ocean and in-river harvest, and other issues, such as the development of a comprehensive spring Chinook salmon harvest management.

Benefits for Federally-Listed Coho Salmon. Historical habitats of Klamath River coho salmon, part of the federally listed SONCC (Southern Oregon/Northern California Coast) coho ESU (Evolutionarily Significant Unit), were significantly reduced when Project dams were constructed (Williams et al. 2006). Dam removal would provide access to suitable coho salmon tributaries such as Spencer, Fall, Beaver, Deer, Shovel, Negro, Scotch, and Jenny creeks, mainstem Klamath River habitats located upstream of IGD, and cold water refugia below J.C. Boyle Dam. Benefits of dam removal to the ESU extend beyond the additional numerical abundance of habitat provided by dam removal. In general, as habitat availability and abundance increases for an ESU, the risk of extinction to the species is reduced. Reestablishing coho salmon above the current site of IGD will increase both the quantity and diversity of habitats available to the Klamath coho salmon population, which is likely to improve the ability of the population within the ESU, and the ESU as a whole, to persist (McElhany et al. 2000), with the intent of recovery and potential reestablishment of fishing opportunities.

Fish Habitat Below Iron Gate Dam. Adult spawning and juvenile rearing habitat gains above IGD, as provided under the Agreements, are in addition to gains that would result below IGD in response to implementation of the KBRA's water allocation. Based on analyses presented previously, we conclude that the production potential of fall Chinook salmon would significantly improve prior to dam removal in years resembling low and average historical production years in response to implementing the water allocation proposed in the KBRA. In years where modeled historical production was high, potential for improvement under both Run-32 Refuge and Hardy et al. (2006a) Phase II flow schedules was consistently low as habitat availability modeled in SALMOD was at or near the maximum values (Figure V-4). With the removal of Klamath River dams, this habitat-induced bottleneck to production would be greatly reduced, creating opportunity to increase production over that experienced in historically high production years. In general, gains in habitat availability and associated production potential that would occur as a result of removal of the Klamath River dams, including the reestablishment of spring Chinook and coho salmon and steelhead in the upper basin, far exceed gains that could be achieved below IGD through manipulation of flows alone.

Tables and Figures

Table V-1. Mean difference and associated descriptive statistics between average monthly flow releases at Iron Gate Dam modeled by WRIMS Run-32 Refuge and Settlement SIAM for water years 1961-2000.

Mean difference	100.6 cfs
Standard Error	4.8 cfs
Median	77.8 cfs
Mode	11.1 cfs
Standard Deviation	105.8 cfs
Minimum	<0.2
Maximum	1166.0
Count	480
Confidence Level (95.0%)	9.5

Table V-2. Summary statistics for the historical 1961-2000 water year baseline SIAM simulations and the WRIMS Run-32 Refuge and Hardy Phase II Settlement SIAM simulations, grouped by 25 percentiles of historical production. Simulations estimate juvenile production in the reach between Iron Gate Dam and the Scott River for different Klamath River flow scenarios with the PacifiCorp Hydropower Project in place.

Historical production rank (water years 1961-2000)	% historical median		WRIMS Run-32-Refuge (% change from historical baseline)		Hardy Phase II (% change from historical baseline)	
	Mean	SE	Mean	SE	Mean	SE
31-40 (lowest 25%)	35	51.8	45	42.5	50	38.5
21-30	12	7.5	10	14.4	7	13.4
11-20	24	2.3	6	6.8	3	11.4
1-10 (highest 25%)	40	8.2	6	6.8	-7	8.8

Table V-3. Schedule of flow releases from Iron Gate Dam for a 10% exceedence year by monthly time steps for fall/winter months.

Flow Schedule	Nov	Dec	Jan	Feb
Hardy Phase II	2460	3385	3990	4475
Alt X	1601	1910	2421	2831
Alt X Yurok	1300	1300	2421	2831

Table V-4. Estimates by various authors of the potential of habitat to support anadromous spawning adults, by species, in the Klamath River above IGD (methodology differed by author, check source information for specifics). These estimates do not take into account habitat in Upper Klamath Lake (UKL) or habitat currently inundated by PacifiCorp Project reservoirs.

Above UKL	Species	Pre Hydropower Project historical potential	Recent potential	Source
	Chinook Salmon	111,200[1]	--	Huntington 2006
	Chinook Salmon	>10,000[2]	--	CDFG 1990
Above Iron Gate Dam				
	Chinook Salmon	--	21,200[1]	Huntington 2004
	Chinook Salmon	--	9,200	Fortune et al. 1966
	Chinook Salmon	--	18,000	Chapman 1981[4]
	Steelhead	--	8,600[1]	Huntington 2004
	Steelhead	--	7,500	Fortune et al. 1966
	Steelhead	--	9,500	Chapman 1981[4]
PacifiCorp Project reach				
	Chinook Salmon	--	13,406[3]	FERC 2007

[1] These are returns; the assumption is based on 100 percent dam passage and 100 percent reservoir survival, and no harvest.

[2] Spring Chinook salmon only from Williamson and Sprague Rivers.

[3] Fall Chinook only; corrected from FERC 2007 based on FERC Order 381 (Federal Energy Regulatory Commission 1963).

[4] As adjusted in Huntington (2004).

Table V-5. Estimated distance (in km) of Klamath River mainstem habitat currently inundated by PacifiCorp Project reservoirs (FWS = Service, PWA = Philip Williams & Associates, Ltd. (2009), NHD = U.S.G.S. National Hydrography Dataset.

Reservoir	FWS distance	FWS side channels*	PWA distance	NHD distance
Iron Gate	10.96		11.08	10.51
Copco	11.05	1.99	11.08	7.84
JC Boyle	5.35		5.43	5.34

*Side channels were analyzed in the historical Copco topography map.

Table V-6. Distance (in km) of major tributaries currently inundated by PacifiCorp Project reservoirs, and the estimated total number of tributaries flowing into each reservoir, based on USGS National Hydrography Dataset.

Reservoir	Distance (km)	Potential Tributaries (count)
Iron Gate	4	52
Copco	2.43	18
JC Boyle	0.3	19

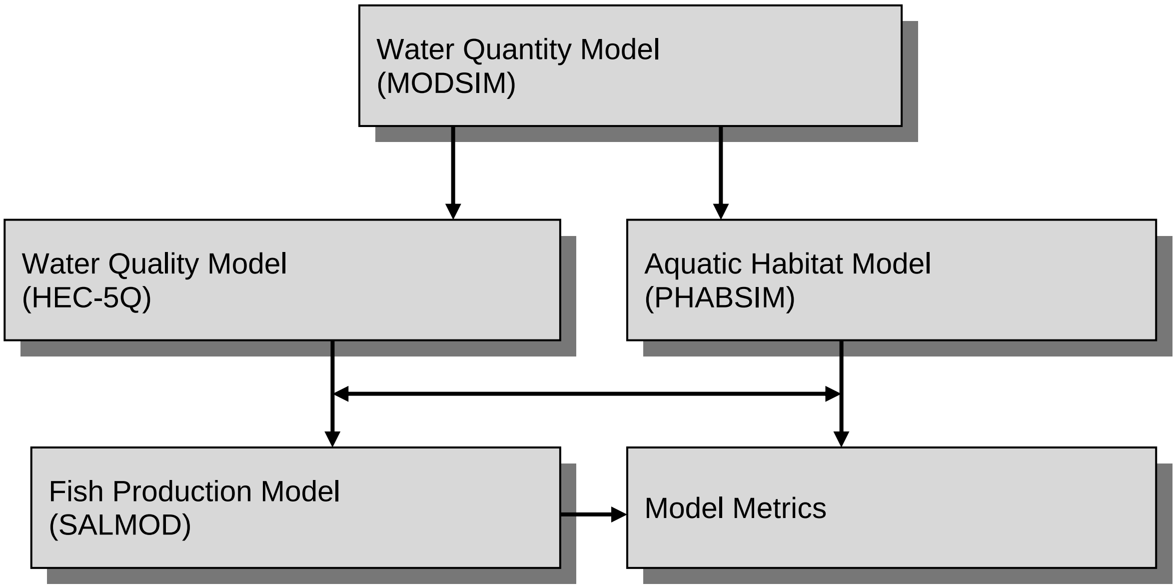


Figure V-1. Various components of the Systems Impact Assessment Model (SIAM).

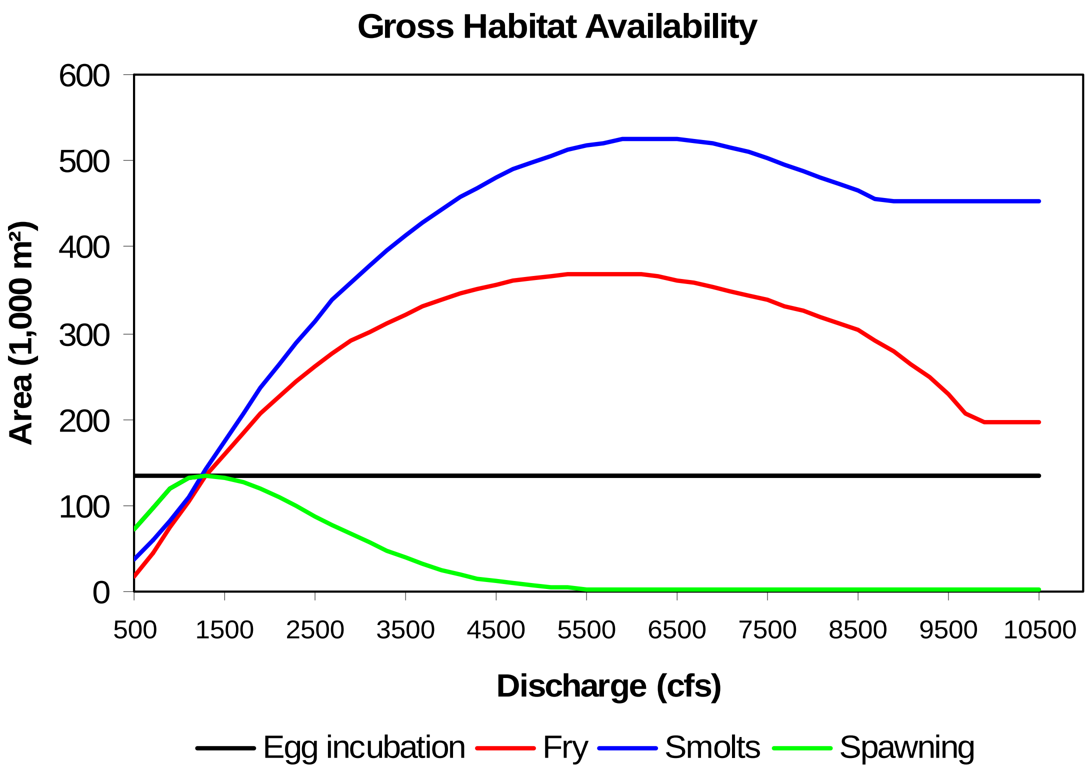


Figure V-2. The relationship between habitat availability and flow in the Klamath River in the Iron Gate Dam to Scott River reach for four life stages of fall Chinook salmon (Bartholow et al. 2003). Note that availability of egg incubation habitat is based on the maximum value for spawning habitat and is assumed to be static over different flow levels.

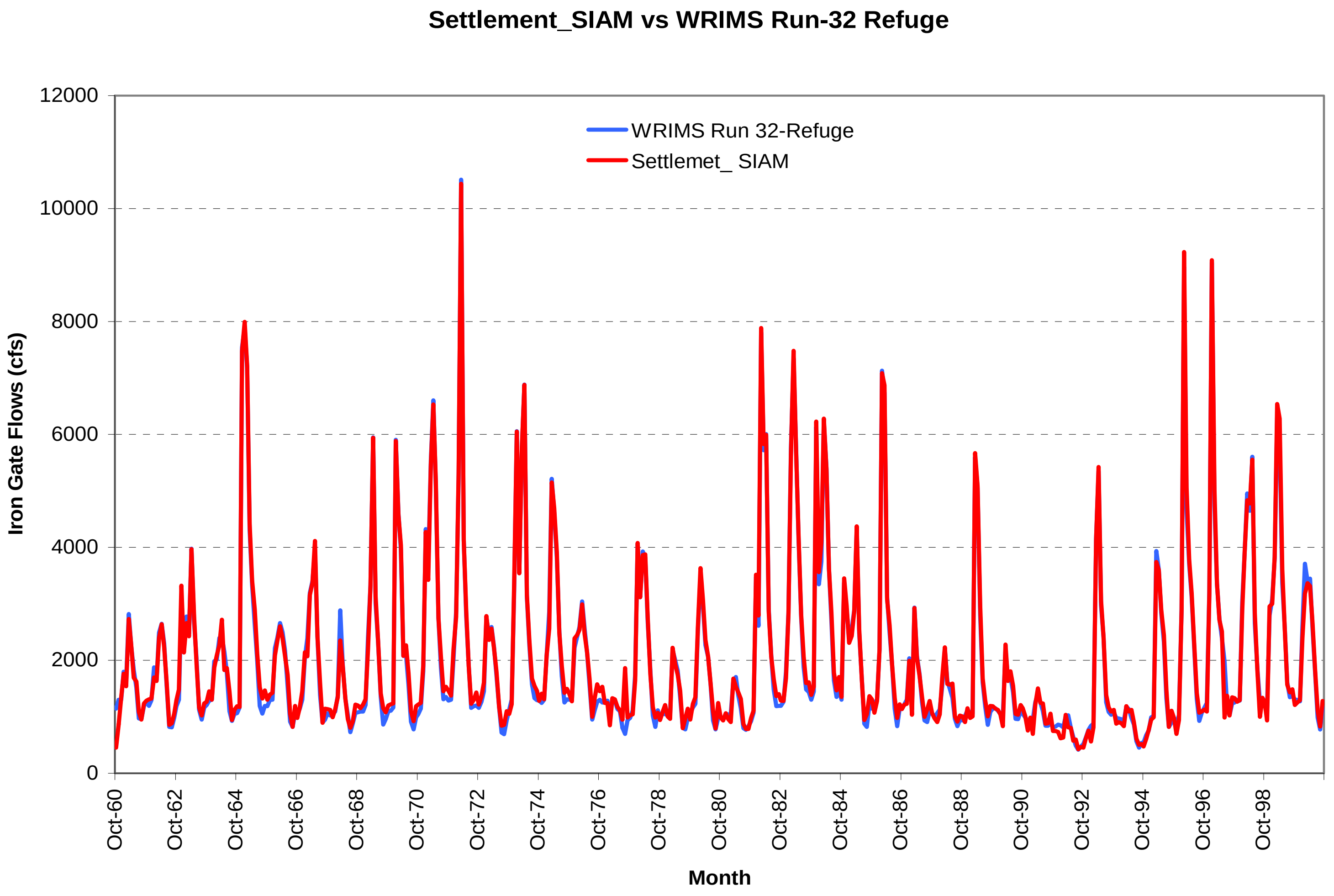


Figure V-3. Comparison of water management simulations below Iron Gate Dam using two models; USGS specially configured Settlement SIAM and Reclamation's WRIMS.

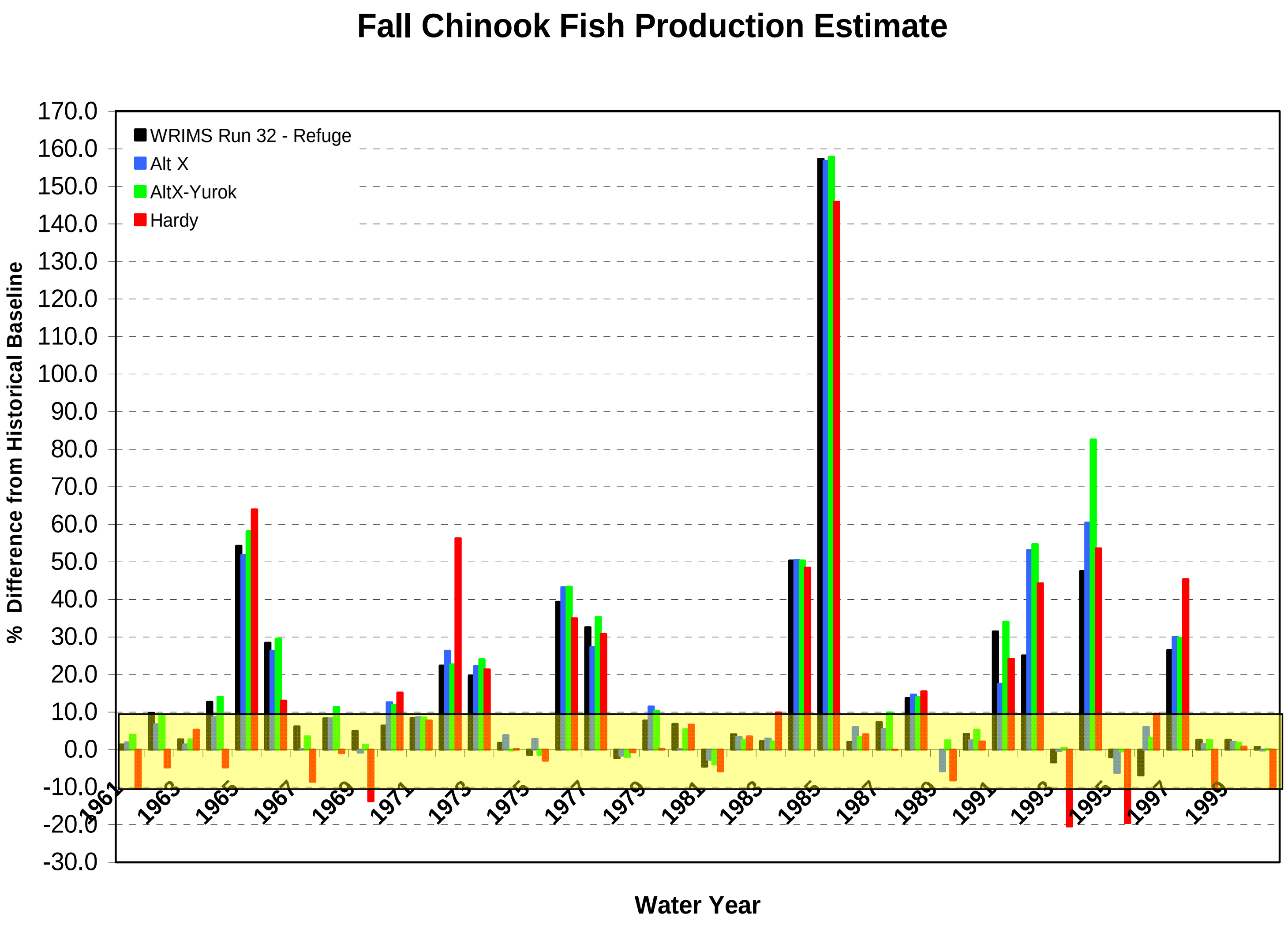
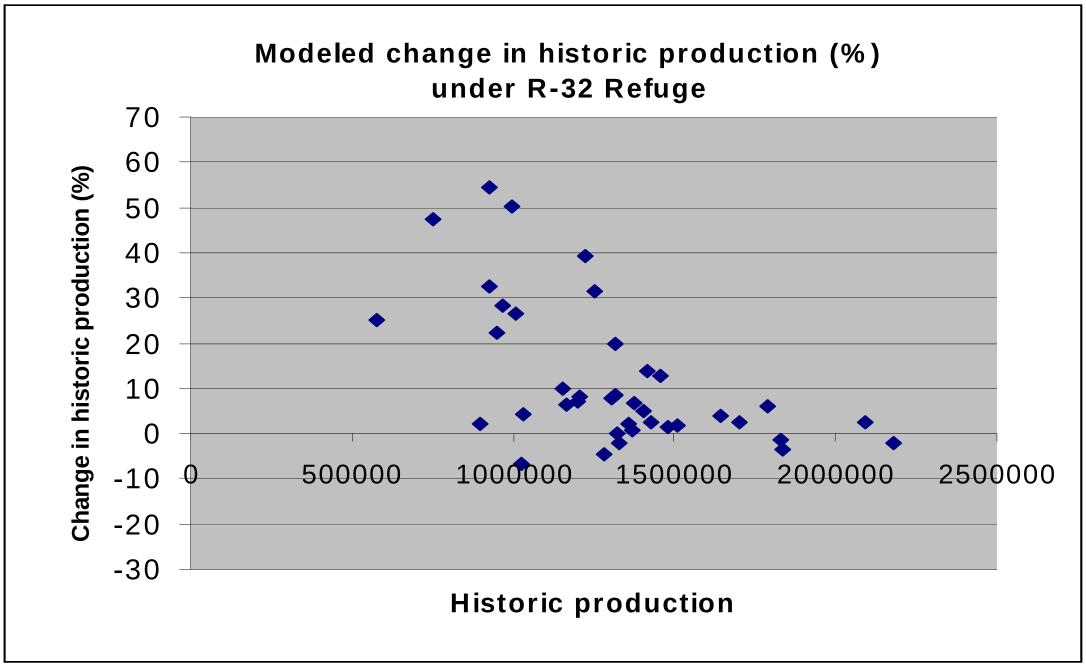


Figure V-4. Comparison of the difference (%) in fish production predicted from the historical 1961-2000 water year baseline under four model simulations having differing flow schedules (alternatives). The shaded area between ± 10% indicates model predictions that are not significantly different from the historical baseline. Simulations were generated by the SIAM/SALMOD model for the reach between Iron Gate Dam and the Scott River to describe interim conditions prior to removal of the PacifiCorp dams.



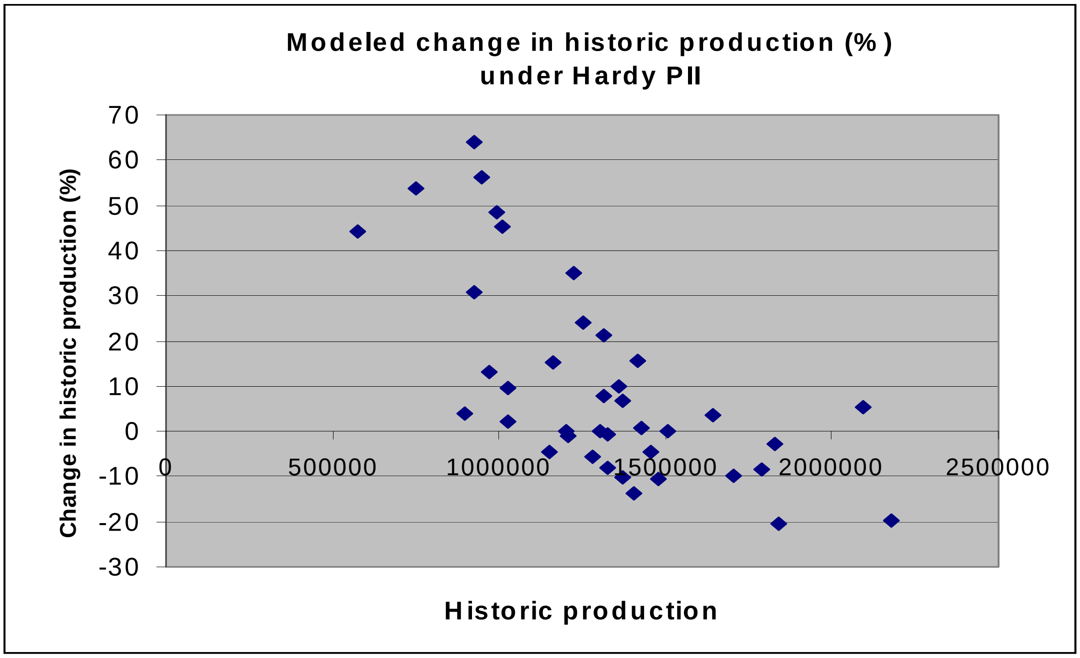


Figure V-5. Estimated change in production of juvenile fall Chinook salmon from historical 1961-2000 water year baseline under the Run-32 Refuge and Hardy et al. (2006a) Phase II flow schedules. Simulations were generated by the SIAM/SALMOD model for the reach between Iron Gate Dam and the Scott River to describe interim conditions prior to removal of the PacifiCorp dams.

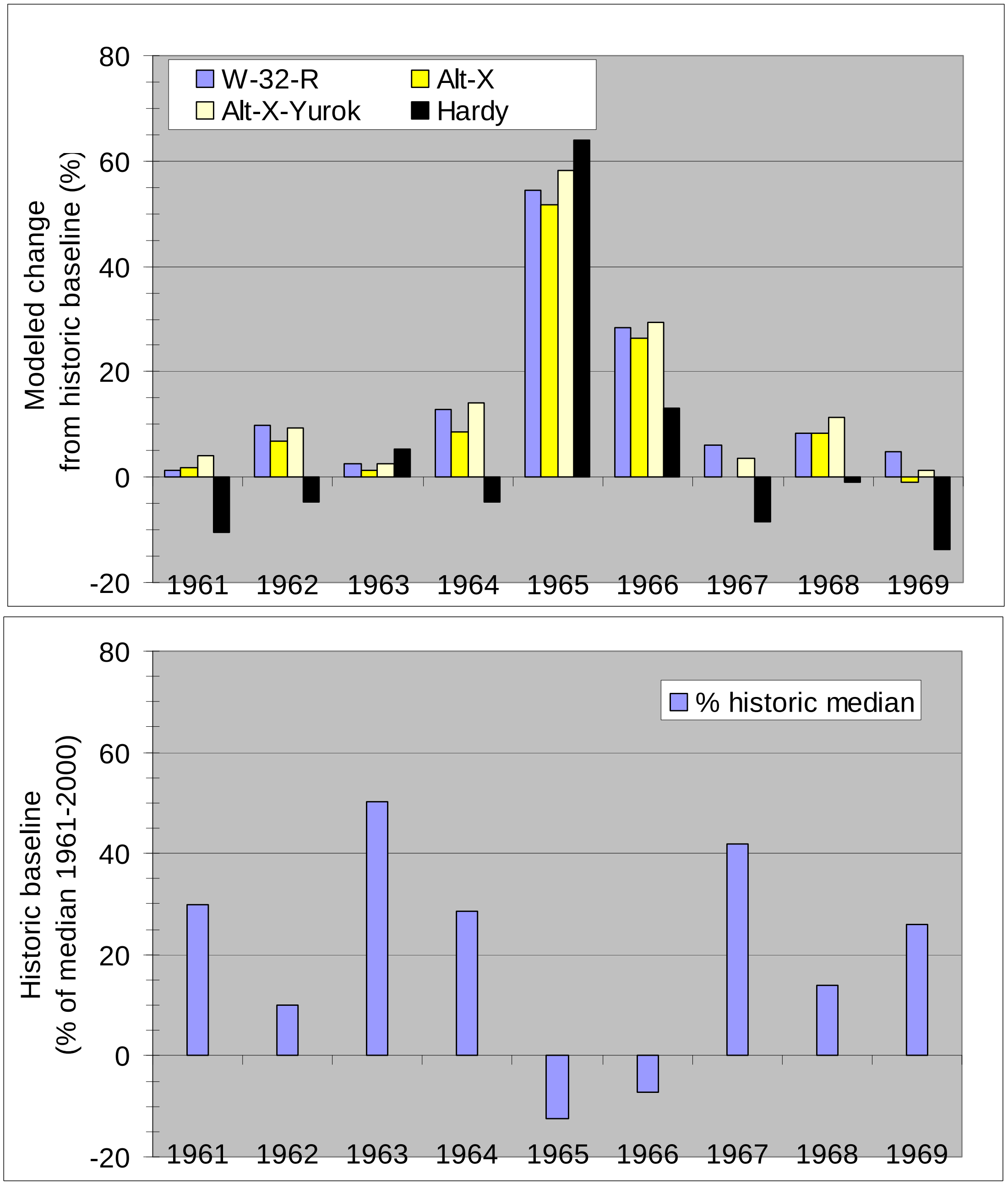


Figure V-6. Estimated change in production of juvenile fall Chinook salmon from historical baseline under four flow alternatives considered in negotiations of the Klamath Basin Restoration Agreement for water years 1961-1969. For reference, annual historical productions estimates are provided, expressed as the difference (%) from the historical median, water years 1961-2000. Simulations were generated by the SIAM/SALMOD model for the reach between Iron Gate Dam and the Scott River to describe interim conditions prior to removal of the PacifiCorp dams.

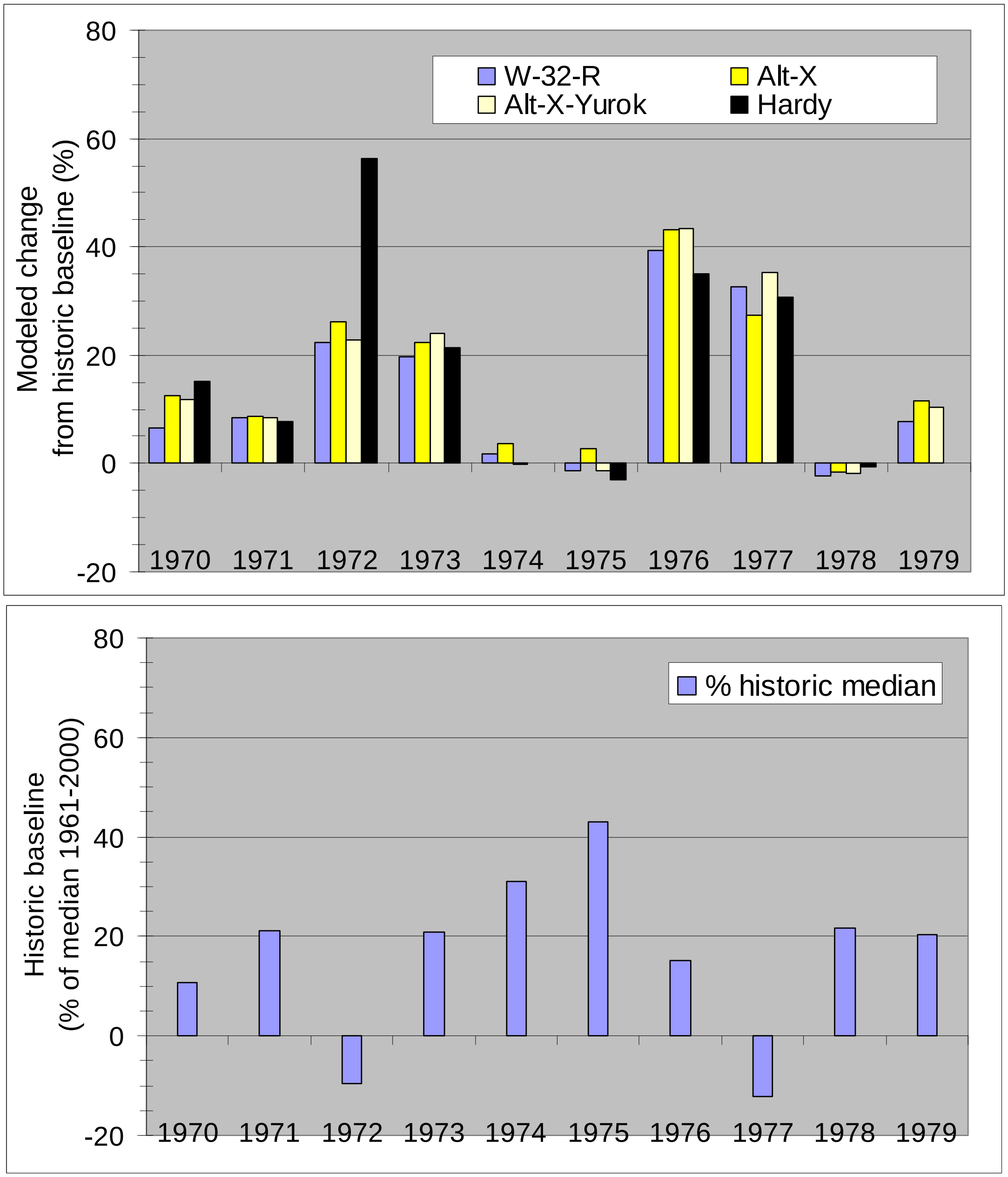


Figure V-7. Estimated change in production of juvenile fall Chinook salmon from historical baseline under four flow alternatives considered in negotiations of the Klamath Basin Restoration Agreement for the water years 1970-1979. For reference, annual historical productions estimates are provided, expressed as the difference (%) from the historical median, water years 1961-2000. Simulations were generated by the SIAM/SALMOD model for the reach between Iron Gate Dam and the Scott River to describe interim conditions prior to removal of the PacifiCorp dams.

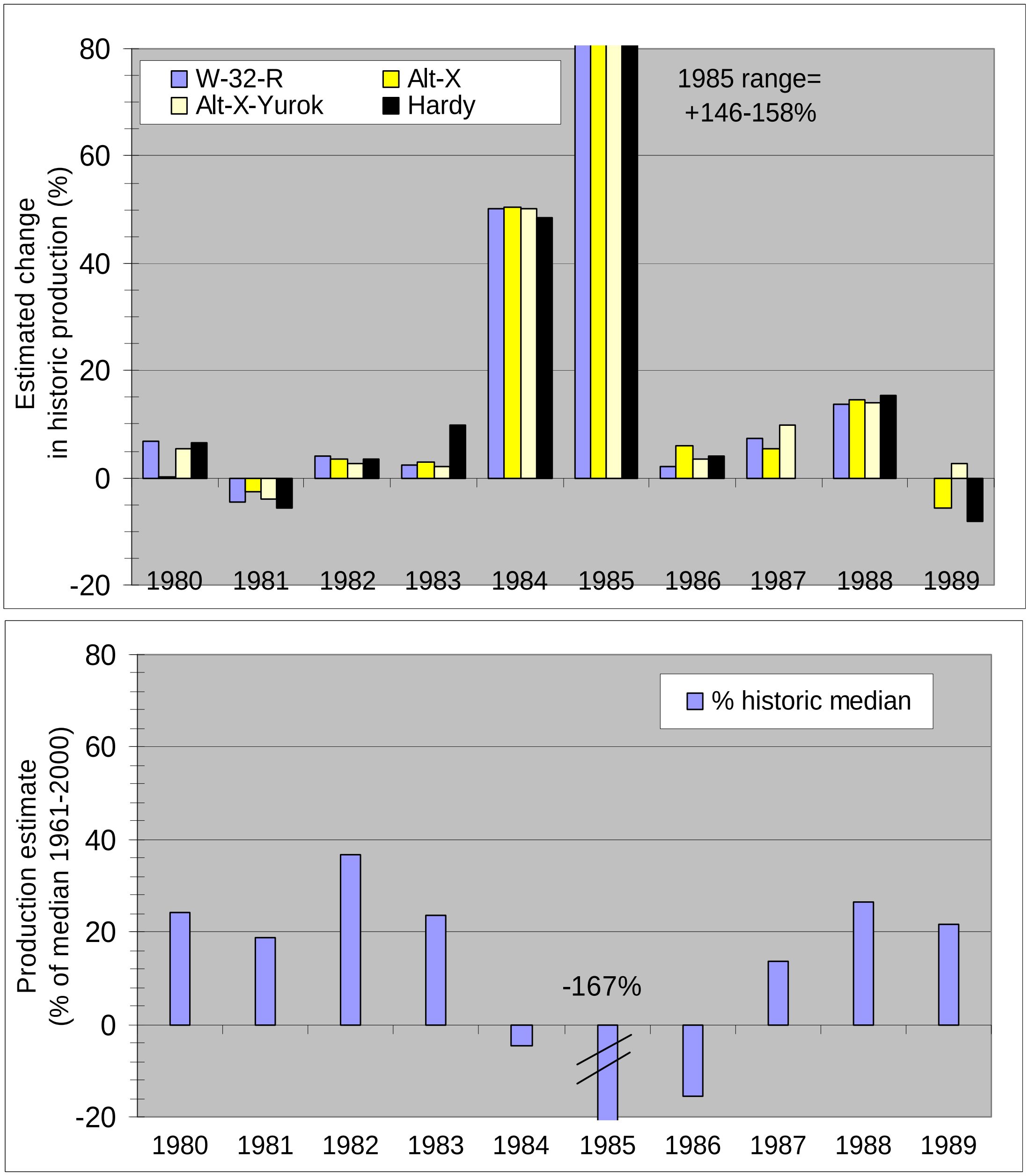


Figure V-8. Estimated change in production of juvenile fall Chinook salmon from historical baseline under four flow alternatives considered in negotiations of the Klamath Basin Restoration Agreement for water years 1980-1989. For reference, annual historical productions estimates are provided, expressed as the difference (%) from the historical median, water years 1961-2000. Simulations were generated by the SIAM/SALMOD model for the reach between Iron Gate Dam and the Scott River to describe interim conditions prior to removal of the PacifiCorp dams.

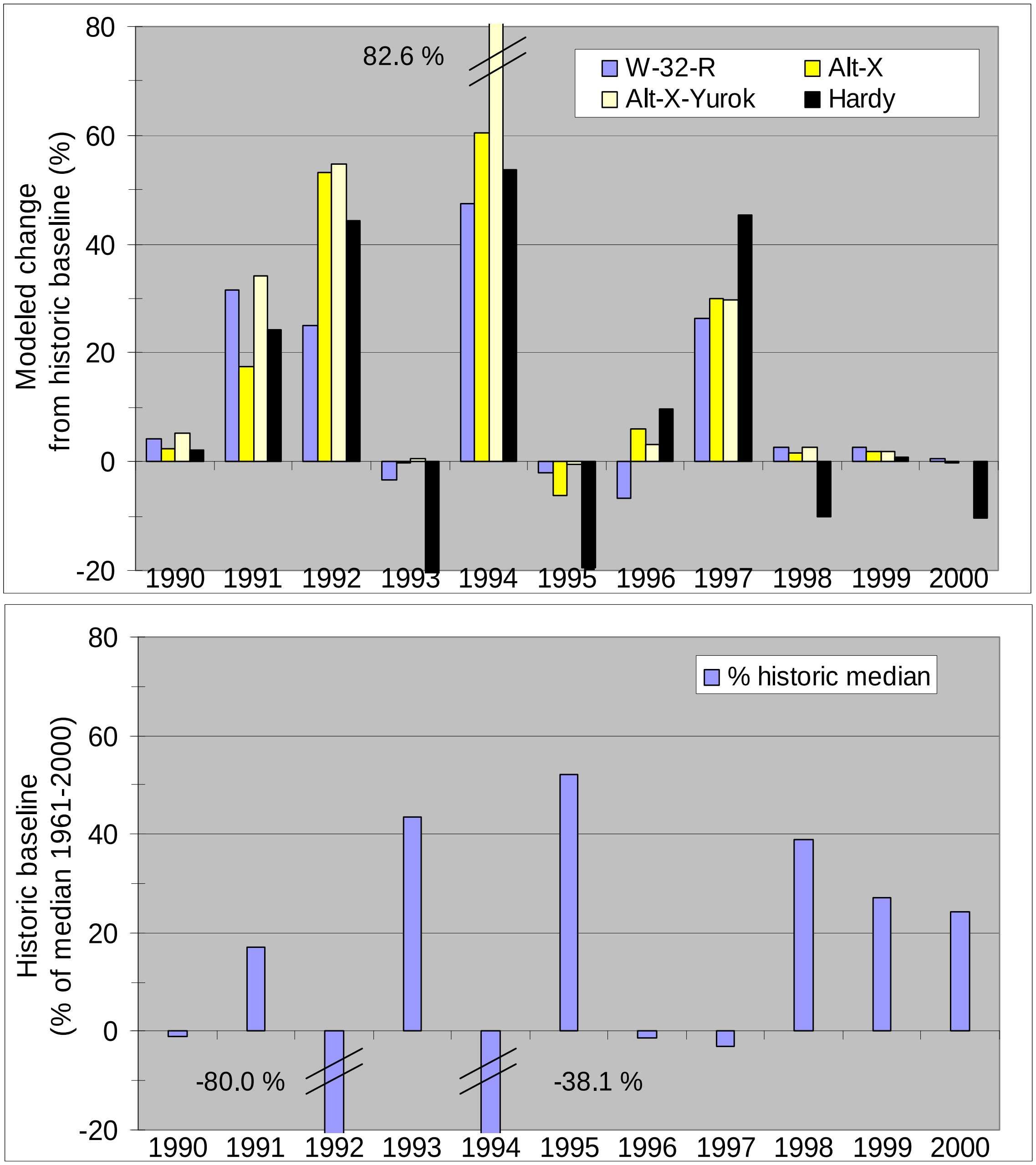


Figure V-9. Estimated change in production of juvenile fall Chinook salmon from historical baseline under four flow alternatives considered in negotiations of the Klamath Basin Restoration Agreement for water years 1990-2000. For reference, annual historical productions estimates are provided, expressed as the difference (%) from the historical median, water years 1961-2000. Simulations were generated by the SIAM/SALMOD model for the reach between Iron Gate Dam and the Scott River to describe interim conditions prior to removal of the PacifiCorp dams.

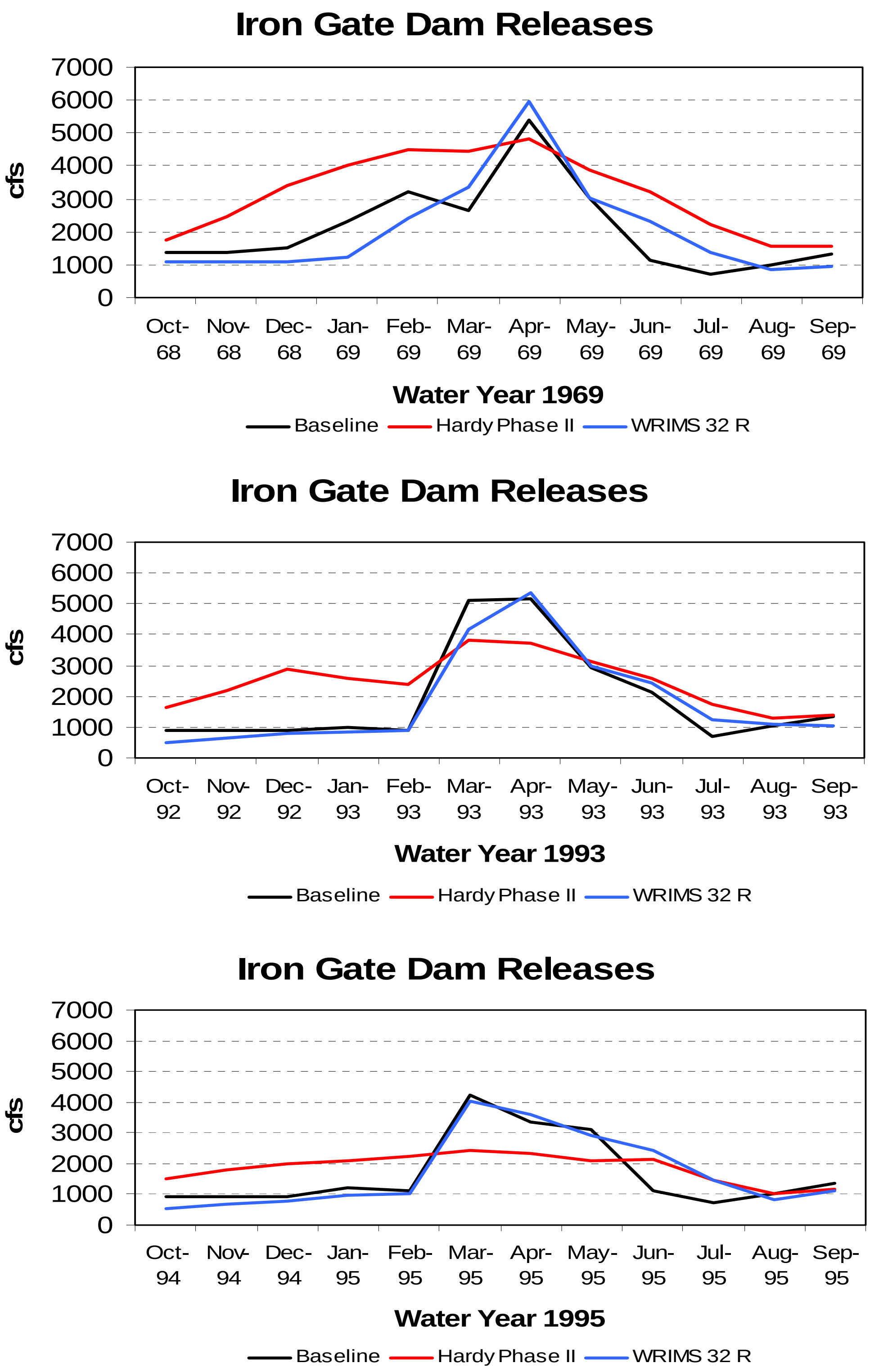
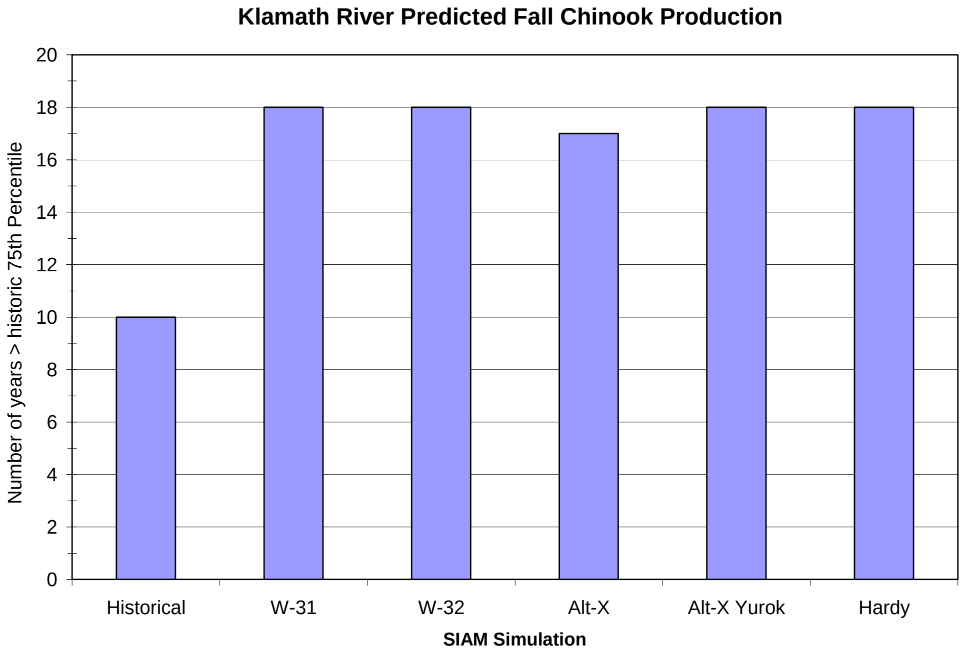


Figure V-10. Comparison of Settlement SIAM model outputs of flow releases from Iron Gate Dam for water years 1969, 1993, and 1995.



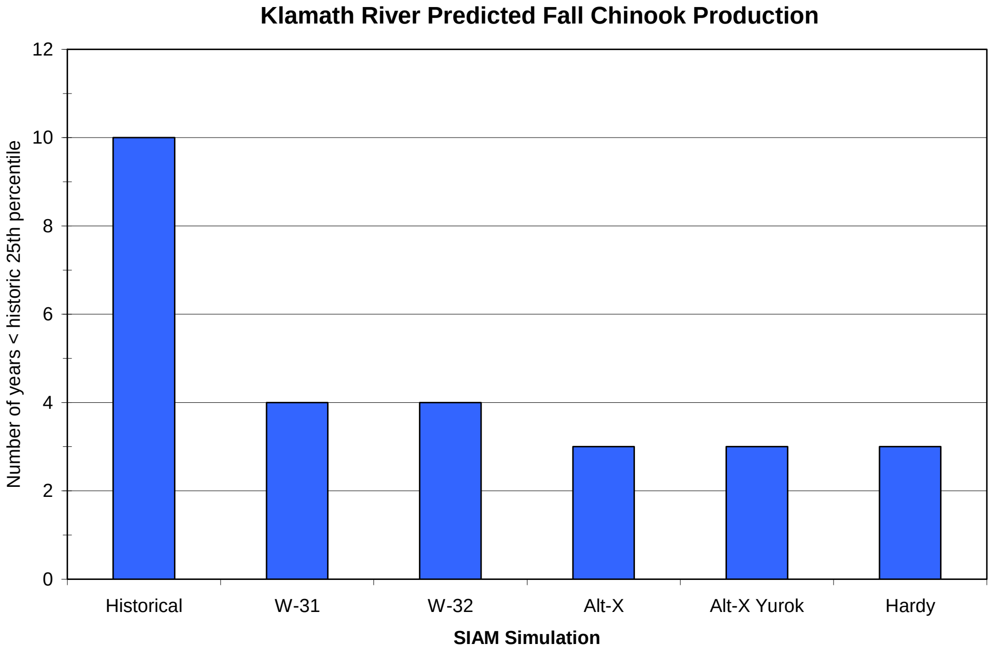


Figure V-11. Number of years when fish production was estimated by SIAM (historical simulation) and Settlement SIAM (various alternative flow schedules) to be greater than the 75th percentile (top) and less than the 25th percentile (bottom) of the historical baseline for water years 1961-2000 (WRIMS Run 31 = W-31, WRIMS Run-32 Refuge = W-32). Simulations were generated for the reach between Iron Gate Dam and the Scott River to describe interim conditions prior to removal of the PacifiCorp dams.

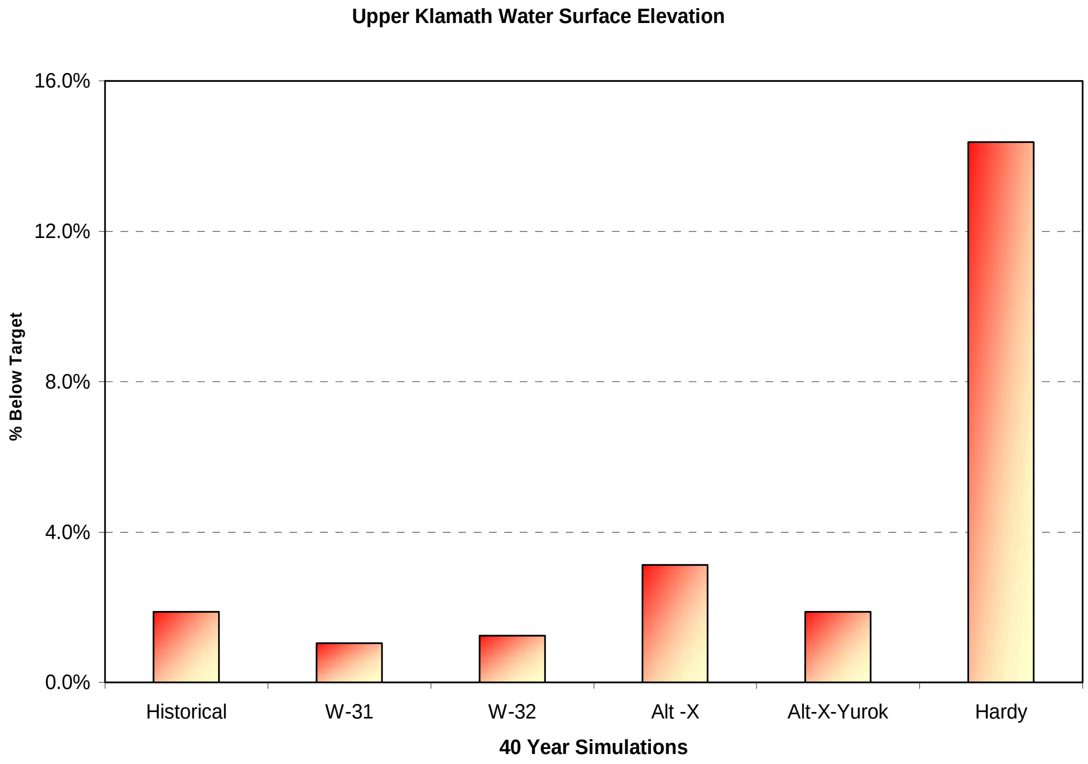


Figure V-12. Percentage of monthly time steps over the 40 year period of record (water years 1961-2000) when water surface elevations predicted by SIAM (historical simulation) and Settlement SIAM (various alternative flow schedules) in Upper Klamath Lake would not meet levels specified in the 2001 Biological Opinion for lake suckers (WRIMS Run 31 = W-31, WRIMS Run-32 Refuge = W-32).

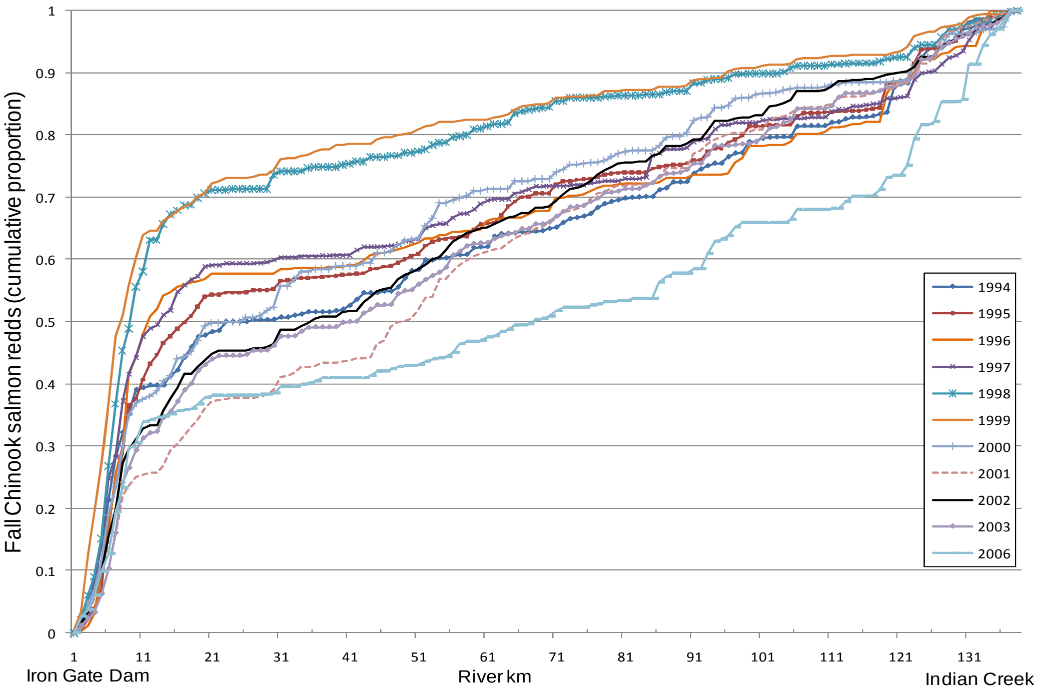


Figure V-13. Cumulative proportion of fall Chinook salmon redds by river kilometer between Iron Gate Dam and Indian Creek on the mainstem Klamath River for survey years 1994-2003 and 2006.

VI. Implementing the Water Allocation using Real-Time Management

Reducing Operational Effects

Background. The draft KBRA proposes to establish a Technical Advisory Team (TAT) with responsibility to make recommendations for management of lake levels and river flows, but does not specify methodologies for use by the TAT. The Real-Time Management (RTM) application presented here could achieve two goals. First, this RTM process provides a potentially feasible example of a process for the TAT to apply in implementing the water allocation proposed in the KBRA in real time. Second, implementation of the RTM process is essential to reestablish important processes and functions of the natural hydrograph, including the timing, frequency, magnitude, duration, and rate of change in flows in a manner that responds to changing environmental conditions. This proposed RTM method provides managers with a methodology and decision support tool for determining flow releases to the Klamath River based on real-time environmental conditions, which is otherwise difficult early in the water year given the uncertainty in water availability forecasts It relies on the Williamson River as a hydrologic indicator of flows in the mainstem Klamath River, as recommended by the NRC (2008) and supported by Hardy (2008, Appendix F), and is consistent with management of regulated rivers that is widely supported in the literature (Poff et al. 1997; Annear et al. 2004; Hardy et al. 2006a; NRC 2008; Trush 2007; Hardy 2008; Appendix F).

Pacific salmon evolved in an environment that was historically in a constant state of flux. During their freshwater life phases, salmon experience stream flows that vary from year to year in response to annual climatic trends, seasonally in response to reoccurring annual weather patterns, and daily as a result of local or upstream climatic events. Incorporating this natural flow variability into flow regulation operations is challenging and therefore, often overlooked. Instead, operation plans are reduced to a consolidated flow schedule having monthly or even seasonal time steps. Current operational practices and or physical constraints may limit operation of dams, gates, turbines, etc. on an hourly or daily basis. However, modification of current practices and infrastructure are conceivable and should be a incorporated into the implementation phase of the KBRA.

Instream flow practitioners and stream ecologists strongly promote dam operations that rely extensively on hydrologic conditions experienced in the basin that result in flow patterns that mimic the shape and function of the natural hydrograph under which the aquatic biota evolved. For example, in a recent analysis on Klamath River hydrology conducted by the Natural Research Council (NRC 2008), the authors' state:

> *"One argument for considering a "natural flow regime" is that it better reflects the requirements of the assemblage of species rather than individual species of concern"; "Flows at the mouth of the Williamson River are affected by privately managed irrigation diversions, but given the large total flow in the Williamson, the hydrograph has predominantly natural features" and ; "The committee concludes that Hardy et al. (2006a) should have used daily flows or at least weekly flows for making instream flow recommendations, because monthly time steps are likely to produce erroneous results. To address this shortcoming, the*

> *committee recommends that consideration be given to streamflow disaggregation modeling as a means for obtaining daily streamflow data while preserving the statistical attributes of the estimated monthly flows.“*

Implementation of a flow schedule that incorporates natural flow variability and associated stream function back into regulated rivers is supported by the Instream Flow Council (Annear et al. 2004):

> *“IFC Flow Variability Statement: Instream flow prescriptions should provide inter- and intra-annual variable flow patterns that mimic the natural hydrograph (magnitude, frequency, duration, timing, rate of change) to maintain or restore processes that sustain natural riverine characteristics.”*

Similarly, in a document specific to the KBRA, Trush (2007) stated:

> *“Reliance on mean monthly stream flows, and exceedence probabilities of these mean monthly stream flows, divorced researchers from the reality of variable stream flows in the mainstem Klamath that a single Chinook salmon fry, for example, might experience over several months or even within a month. An effective ecological analysis of stream flows cannot be accomplished using monthly, biweekly, or average exceedence probability curves because none of these sufficiently portray the within-year and between-year flow variability. Each annual hydrograph uniquely influences the aquatic ecosystem, including salmon and steelhead. Our Chinook fry emerging from the gravel on February 15 isn’t exposed to an averaged fluvial environment described via a probability distribution, but a fluvial environment specific to that day’s streamflow. As our fry’s life unfolds, its immediate success - surviving yet another day – will depend in large part on how good former days were. An ecological analysis sensitive to day-to-day influences is best accommodated by annual daily average hydrographs.”*

Analyses and modeling efforts conducted in the technical development realm of the settlement process, many of which are summarized in this report, rely extensively on bi-weekly or monthly time steps. Flow schedules such as ALT-X, ALT-X Yurok, Hardy et al. (2006a) Phase II recommendations, and WRIMS Run-32 Refuge flow targets and corresponding habitat value calculations are planning level tools used to simulate outcomes and compare alternatives. While monthly flow tables are useful for planning purposes, flow implementation should be accomplished in a manner that addresses the biological importance of daily flow variability. Recent guidance provided by the Natural Research Council (NRC 2008) suggests that:

> *“Although monthly flow values can be useful for general river-basin planning, they are not useful for ecological modeling for river habitats, because the monthly average masks important discharge values that may exist only for a few days or even less. In short, planners operate on a monthly basis, but fish live on a daily basis.”*

The KBRA proposes to provide a fixed allocation of water to the Klamath Irrigation Project and Refuge, with the remaining water, and additional water created through increased storage and land idling, allocated to meet the needs of fish species in UKL and the Klamath River. The division of water between the lake and the river will be implemented using an adaptive management approach that will provide flexibility in implementing river flows and maintaining lake elevations; a progressive approach new to Klamath water management.

Recent Operations. Recent management of flow releases from IGD is the result of a decision-making paradigm governed by priorities, commitments, and uncertainty. Current priorities have been identified as UKL elevations and IGD flow releases dictated through ESA processes, providing full deliveries to the Klamath Irrigation Project in an undefined amount (including higher demand in dry years than in wet years), and flows necessary to meet needs of Tribal Trust species. Adherence to these priorities, in combination with the uncertainty in the water supply and agricultural demands early in the water year (prior to the availability of reliable water supply forecasts), have resulted in a conservative approach to IGD flow releases. Storage in UKL is maximized while maintaining ESA required minimum flow releases from IGD until flood curve lake elevations are reached, at which time spill occurs. For example, flows in the Klamath River below IGD remained relatively constant at the minimum levels identified in NOAA Fisheries 2002 Biological Opinion from early September 2004 until early May 2005, at which point IGD spilled (Figure VI-1). Under this type of management regime, inter- and intra-annual variability in flow patterns in the reach below IGD are diminished and the flow pattern in the resultant hydrograph deviates from the shape of the natural hydrograph with respect to magnitude, frequency, duration, timing, and rate of change necessary to maintain or restore processes that sustain natural riverine characteristics and biota.

Recent flow releases from IGD have been dictated by minimum jeopardy threshold flow levels established in NOAA Fisheries 2002 Biological Opinion (NOAA Fisheries 2002), which are subject to change with future reconsultation and subsequent release of a new Biological Opinion by NOAA Fisheries. The current schedule used to determine flow minimum flow releases from IGD (NOAA Fisheries 2002) specifies IGD discharge for monthly time steps for five water year types determined based on NRCS forecasts (Table VI-1). To implement ESA required flows and lake elevations, Reclamation relies on the NRCS forecast for the April through September period to categorize the year into a water year type. A high level of uncertainty and variability, however, exists for the NRCS forecasts (Figure VI-2). While the accuracy of forecasts increases near the end of the rain and snow season (typically around July), accuracy may be low in the beginning of the water year. Uncertainty in the forecast early in the water year has resulted in highly conservative management of flow releases from IGD during periods critical for the production of Chinook and coho salmon.

Under current management, water year types in the Klamath Irrigation Project may be adjusted based on net inflow calculations into Upper Klamath Lake, which are calculated using the simple equation:

$$\text{Net Inflow} = \text{Outflow} - \text{Change in UKL Elevation}$$

Net inflow estimates are accumulated through the April through September irrigation season and are used as the basis of reclassifying water year type if changes in the NRCS forecast are deemed necessary. Using this methodology, however, daily inflow estimates are highly variable and can exhibit negative values, even when inflows from the Williamson River, a major tributary to UKL, remain relatively stable. Error in calculations of UKL inflow can likely be attributed to a combination of factors, including limited accounting of accretions from tributaries, springs, seeps, freshets and agricultural runoffs; private diversions directly from UKL; and variations in evaporation and transpiration due to meteorological conditions and measurement error of the Link River Dam and A-canal outflows. In addition, changes in wind or atmospheric pressure gradients can create a short-period oscillation in water surface elevations, known as a seiche, which can influence the accuracy of UKL elevation measurements. Due to the relatively large surface area of UKL, a small change in lake elevation measurement can result in a large difference in calculated inflow.

Need for Real-Time Management. Variations in daily stream flow are influenced by a variety of factors, including 1) precipitation (snow and rain); 2) freeze and thaw cycles; 3) seasonal trends such as fall freshets, spring runoff or shallow groundwater influenced mid-summer baseflows; 4) dry soil conditions versus a spring high groundwater table and high soil moisture content; and 5) high transpiration rates in spring-summer months versus low transpiration rates during vegetative dormant periods in fall and winter. Much of natural variability in stream flow is lost in regulated rivers such as the Klamath and instead, extended periods of stable minimum flows occur. This creates a shift in the hydrograph that deviates from the shape of the natural hydrograph under which the aquatic species evolved. Flows on the Klamath River in the winter/spring are frequently managed to maximize storage while flows released to the river are managed at ESA minimums. Because of the winter/spring emphasis on filling UKL to flood curve capacity, the lake is frequently at maximum capacity when spring snowmelt naturally occurs, causing the annual peak flow to shift to the spring when inflow exceeds the capacity to store additional water and spill occurs (e.g. water year 2005; Figure VI-1).

The WRIMS Run-32 Refuge simulation, which incorporate the Dunsmoor (2007) IEI (Appendix A), moves closer to implementation of flows based on ambient climatic conditions and events. As addressed by the IEI, future management proposed under the KBRA eliminates the use of water year types and instead, relies on an operations process that incorporates continuous updates based on hydrologic indicators (i.e., inflow) that reflect current climatic conditions. Based on this understanding, the IEI methodology should be further refined and used to implement the proposed water allocation detailed in the KBRA. An example of a daily real-time management process is provided below.

Implementing WRIMS Run-32 Refuge in Real Time

Background. We propose a process for implementing WRIMS Run-32 Refuge model outputs that allocates river flows below IGD on a daily basis to reflect real-time hydrologic conditions experienced in the Upper Basin. The goal of the real-time management application and resultant RTM flows is to reestablish important functions of the natural hydrograph, including the timing, frequency, magnitude, duration, and rate of change in flows. This RTM process would eliminate the need for designation of flow schedules by water year type, and instead relies on real-time Williamson River daily discharge values to dictate daily flows at IGD. Management of the river would become a continuous function based on current hydrologic conditions experienced in the Upper Basin. The RTM process proposed herein would restore patterns in Klamath River flows to a regime resembling unregulated, natural river systems while providing a method for implementing the water allocation proposed in the KBRA.

RTM Hydrologic Indicator. The Williamson River was selected as the real-time hydrologic indicator stream for the upper Klamath Basin, as recommended by the Natural Research Council (NRC 2008). Selection was based on the Williamson River's long term gauging data set, large watershed area, large contribution to UKL inflow, and, recognition as stated by NRC (2008) that "…*given the large total flow in the Williamson, the hydrograph has predominantly natural features*."

We compared flows recorded at the gage site on the Williamson River below its confluence with the Sprague River to flows measured at the gage site on the Klamath River below IGD for water years 1970-2000. However, similarities in the responsiveness of flows to changing environmental conditions such as rain and snowmelt events between the two gauge sites was difficult to assess, primarily because of the extensive water management that occurs between the two sites as part of Reclamation and PacifiCorp Project operations. Williamson River flows are typically retained in UKL by Link River Dam to maximize lake storage and Link River flows are managed by PacifiCorp for power generation within the Hydropower Project and then reregulated by IGD to meet FERC minimums (1962-1995) and more recently, Klamath River instream flow requirements specified by NOAA Fisheries (2002). To account for these operational deviations from the natural hydrographs, Williamson River and Iron Gate gage data were plotted on a discontinuous basis, excluding days having daily mean discharge at the Iron Gate gage less than 3,000 cfs, which is the approximate outlet works capacity of Link River Dam and turbine hydraulic capacity of PacifiCorp's facility. The resulting plots demonstrate that under conditions described above when UKL and PacifiCorp Project Reservoirs storage is maximized, discharge from IGD mimics the hydrologic pattern of daily mean discharge for the Williamson River (Figure VI-3). The signature of flow events experienced on the Williamson River that occur in response to rain and snowmelt events is evident in flows experienced below IGD. Therefore, we concur with the recommendation of the NRC (2008) in that daily mean discharge measured at the Williamson River gage site is an appropriate indicator of hydrologic conditions at IGD and suitable for calculating daily, real-time management flow requirements for the Klamath River gage site downstream of IGD.

Development of RTM Application*.* The Williamson River historical flow data set was obtained from the U.S. Geological Survey National Water Information System: Web Interface for the Gauging Station (11502500) - Williamson River below Sprague River, near Chiloquin, OR Database:

http://waterdata.usgs.gov/or/nwis/dv?cb_00060=on&format=rdb&begin_date=1960-10-01&end_date=2000-09-30&site_no=11502500&referred_module=sw

The historical daily dataset covered the period 1917-2007. However, we truncated the dataset to the October 1, 1960 to September 30, 2000 (water years 1961-2000) to maintain consistency with inputs and outputs of the WRIMS Run-32 Refuge model run. The 40 years of daily records were binned into the monthly and biweekly time steps used in the WRIMS Run-32 Refuge simulation, ranked, and exceedence probabilities generated using the equation:

$$P = 100 * [M / (n+1)]$$

Where:

P = probability that a given flow will be equaled or exceeded (% of time)

M = ranked position on the listing (dimensionless)

n = number of events for a period of record (dimensionless)

WRIMS R-32 Refuge RTM flows were calculated on a daily basis for the Iron Gate gage site for water years 1961-2000 using the Williamson River daily exceedence values and the WRIMS Run-32 Refuge flow outputs by time step and exceedence (Table I-6) using the following interpolation equation:

$$QK_W = QK_H - [(EK_H - E_W) * (QK_H - QK_L) / (EK_H - EK_L)]$$

Where:

QK_W = WRIMS R-32 Refuge RTM flow

EKH = Known nearest higher exceedence (Table I-6)

EW = Known Williamson River time-step specific exceedence (Table VI-2)

QKH = Known discharge for nearest higher exceedence (Table I-6)

EKL = Known nearest lower exceedence (Table I-6)

QKL = Known discharge for nearest lower exceedence (Table I-6)

This use of the common exceedence value creates a hydrologic link between the Williamson River daily flows and the estimated WRIMS Run-32 Refuge RTM flows at the IGD gage site.

It is assumed that the use of WRIMS Run-32 Refuge flow outputs to derive historical daily flows maintains the balance expressed in the WRIMS R-32 Refuge outputs for UKL elevations, deliveries to agriculture, and Klamath River flows. This assumption is currently being assessed by USGS Fort Collins Science Center using the MODSIM component of the SIAM model.

RTM Example. In this example, an instantaneous discharge for the Williamson River on March 08, 2008, of 771 cfs, was obtained from the USGS Williamson Gauging Station - (11502500): http://waterdata.usgs.gov/or/nwis/uv?11502500.

This discharge value was then located on the Williamson River exceedence probability table for the time step March 1-15, resulting in an exceedence probability of 0.94 or a 94% exceedence value (Table VI-2). The 94% exceedence value and a table of WRIMS Run-32 Refuge outputs by exceedence and time step (Table I-6) were used to interpolate the RTM flow (QKw) for the IGD site (1,307.7 cfs). An example of the interpolation in tabular form for the March 1-15 time step and the 0.94 exceedence probability is provided in Table VI-3.

In summary, the example for the March 8, 2008 Williamson River flow reading of 771 cfs equated to an exceedence value of 94%, which was interpolated to a RTM flow of 1,307.7 cfs. The 94% exceedence value reflects low flow conditions for that time step (March 1-15); i.e. a flow that was exceeded 94% of the time over the 40 years of record for that time step. Despite the low inflow, under past operations, if snowpack and snow moisture content were high, the forecast would dictate an “above average” or “wet” water year type designation and higher flows would be released from IGD, which may drop UKL elevations at a time important for sucker life history needs. The RTM process would eliminate this potential scenario by keeping the IGD flows relative to the Williamson River daily inflow exceedence values. With the initiation of runoff driven by snowmelt, the Williamson exceedence would decrease triggering releases of higher RTM IGD flows. In addition, ramping rates would also be indicative of the Williamson River's hydrologic values.

We developed a Microsoft Access application that automates the above referenced interpolations and worksheet lookup procedures. The current date and Williamson River discharge are entered into this application and the associated Williamson River exceedence value for that time step and corresponding instantaneous WRIMS Run-32 Refuge RTM IGD discharge and total daily discharge in acre feet are automatically calculated (Figure VI-4). Note that Williamson River discharges above and below the range observed in the period of record provided in Table I-6 by time step and exceedence, were set to the respective highest or lowest flow.

RTM Performance Tests. We developed a separate Microsoft Access application to display the daily WRIMS Run-32 Refuge RTM values, historical IGD flow, and the historical Williamson River flows for user-defined date ranges between the water years 1961 to 2000. This application also calculates and displays the accumulated total discharge in acre feet (Figure VI-5). The user also can zoom in on particular periods of interest by changing the start and end dates and obtain both flow and acre-feet information for that period.

The RTM application tracked the Williamson River's daily hydrograph on a real-time basis and reflected many of the freshets that were not observed in the outputs of the WRIMS Run-32 Refuge model outputs There were occurrences where RTM peak flows greatly exceeded WRIMS Run-32 Refuge model output, but followed the trace of the historical 1961-2000 water year IGD discharge. Operational constraints limit the capability to control these peak flow events, which occur as "run of the river" and mimic the shape of the natural hydrograph (Figure VI-6, Figure VI-7). In addition, both low and high flow events calculated for the RTM methodology are bounded within the limits of WRIMS Run-32 Refuge model outputs, which could be improved by increasing the number WRIMS Run-32 Refuge's exceedence outputs (i.e. every 5%) and decreasing the span of time steps to weekly rather than bi-weekly or monthly. This modification would provide greater variability in flow, which is otherwise diminished by averaging flows by the longer time steps provided in the WRIMS Run-32 Refuge model. For example, the first week in October is typically drier than the last week of October. Using weekly time steps and an increased number of exceedences would capture these differences.

We compared flows by water year types (dry, below average, average, and above average, and wet) between historical (1961-2000 water years) Iron Gate, WRIMS Run-32 Refuge and RTM (Figure VI-8). WRIMS Run-32 Refuge model output and RTM flows both increase discharge and habitat availability during the critical months of March through June over historical conditions. The Dry and Below Average charts exemplify past management practices when higher flows were released in the fall and subsequently curtailed in the spring to store water, even though juvenile salmon habitat needs are the greatest during this period.

Total annual discharge of water (acre feet) expended by RTM simulations, WRIMS Run-32 Refuge model outputs, and historical IGD flows was calculated for water years 1961 to 2000 (Figure VI-9). Total discharge (acre feet) averaged by time step for water years

1961-2000 differed little between the WRIMS Run-32 Refuge and RTM simulations (negative 21,788 acre feet) and to a slightly greater degree, between the WRIMS R-32 Refuge and historical IGD releases (negative 90,217 acre feet, Figure VI-10). The majority of differences in total annual discharge between WRIMS R-32 Refuge flows and RTM flows and between WRIMS R-32 Refuge and historical IGD releases can be explained by higher fall flows and spill events not being fully represented in the WRIMS R-32 Refuge model outputs. The difference between WRIMS Run-32 Refuge flow outputs and historical IGD flows in September is due to the 1,300 cfs IGD FERC minimum, which was not a requirement in the WRIMS Run-32 Refuge model. Other differences were attributed to spill events. However, spill can be "run of the river", with little opportunity to be managed.

Habitat values based on flows for specific exceedence levels were very similar between WRIMS Run-32 Refuge outputs and RTM simulations, which was anticipated since WRIMS Run-32 Refuge outputs were used to derive the RTM flows. These values were also compared to the Hardy Phase II recommendations for the critical October - November spawning and March - June rearing periods (Figure VI-11). Overall, modeled outputs of both WRIMS Run-32 Refuge and the RTM compared well with the Hardy Phase II flow schedule, with the largest differences occurring during periods of spill in wet years and during the fall spawning period of dry water years. As stated earlier in this document, modeled flows, such as RTM and WRIMS Run-32 Refuge include spill events that can decrease total availability of spawning habitat, whereas flow schedules such as Hardy Phase II and ALT-X are planning level schedules used as targets in modeling applications.

Summary. Since RTM is a daily representation of the WRIMS Run-32 Refuge modeling exercise, similar accounting of water over the period of record is expected. RTM is an adjustment to the distribution of flow within the period of record (water years 1961-2000), which minimizes the effects of management on IGD flow releases by redistributing the historical Klamath River flows at IGD to mimic the historical daily hydrology of the Williamson River based on associated exceedences. Once these exceedence relationships were established, we were able to calculate RTM flow projections for water years 2001-2007 (Figure VI-12) based on Williamson River daily discharge exceedence and WRIMS Run-32 Refuge outputs by exceedence for water years 1961-2000. The Service is currently working with the Stockholm Environment Institute to refine this methodology.

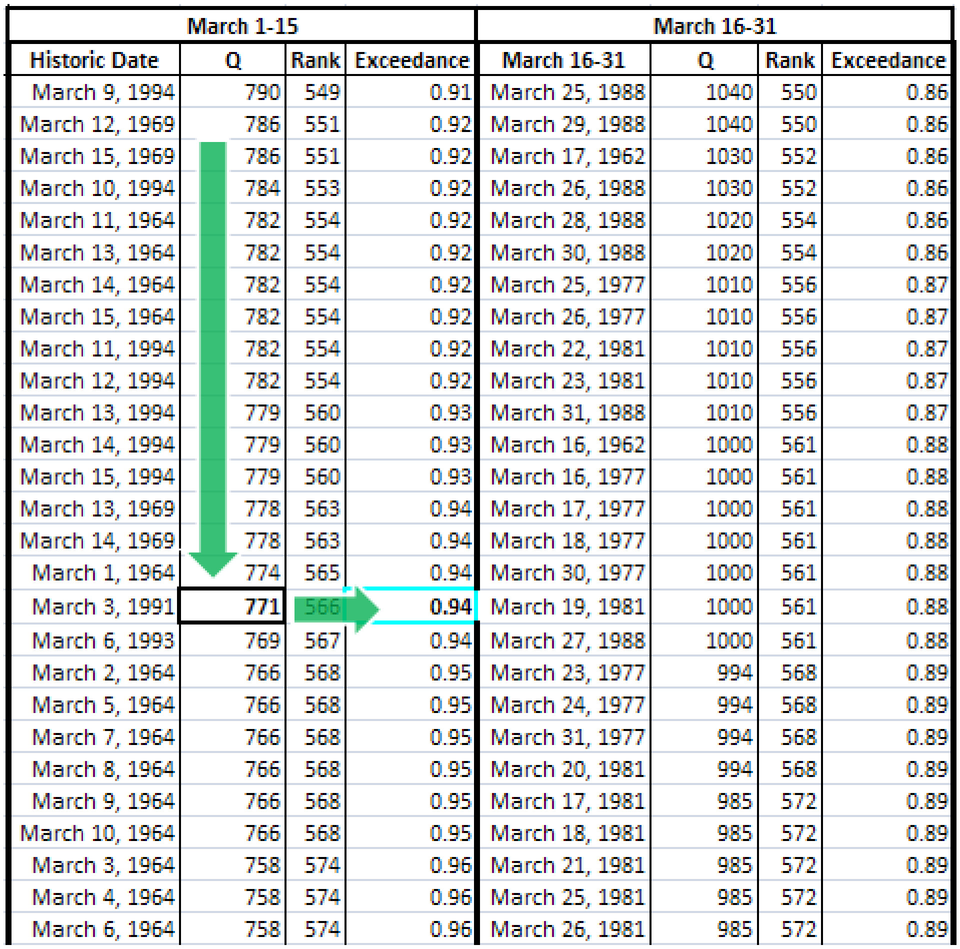
Under the current management regime, discharge on the Williamson River increases and decreases in response to precipitation and runoff events, while historical flows at IGD often remain constant at ESA required minimum levels until the elevation of UKL elevation reaches a level specified in flood control curves that triggers spill. Using the WRIMS Run-32 Refuge model outputs that incorporated IEI in addition to an RTM function such as the one described here, flows could be managed to mimic UKL inflow patterns, as recommended by the NRC (2008). This would represent a major shift in management of the river, moving from a regulated pattern of flow to one that mimics the natural hydrograph. For example, in revisiting water year 2005 (Figure VI-13), implementing the WRIMS Run-32 Refuge RTM would have increased flows earlier in the spring, providing habitat for fry salmon during this critical life history stage.

Tables and Figures

Table VI-1. Recommended long-term Iron Gate Dam discharge by water year type specified in NOAA Fisheries 2002 Biological Opinion (NOAA 2002).

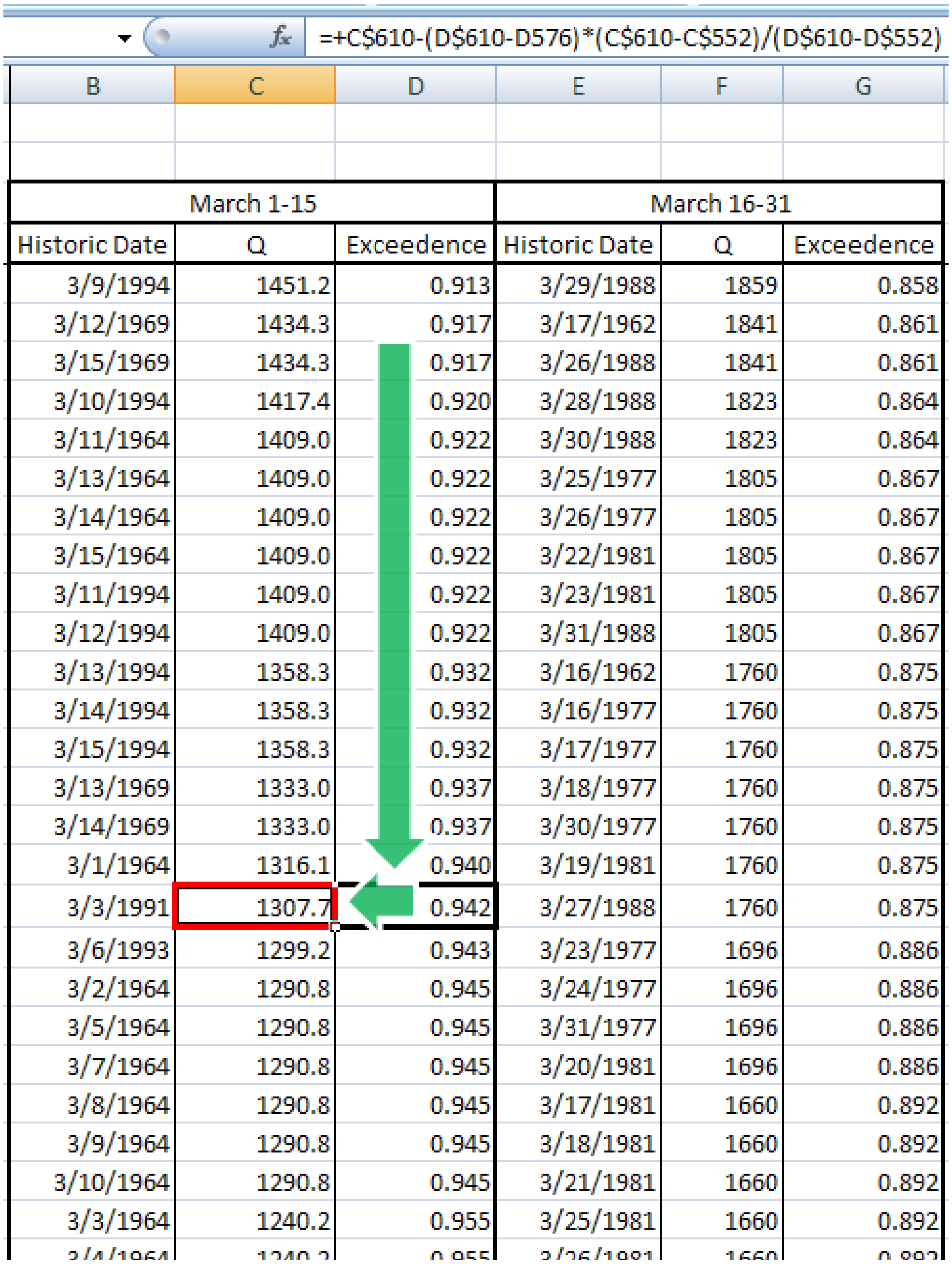
Month	Dry	Below average	Average	Above average	Wet
October	1,300	1,300	1,300	1,300	1,300
November	1,300	1,300	1,300	1,300	1,300
December	1,300	1,300	1,300	1,300	1,300
January	1,300	1,300	1,300	1,300	1,300
February	1,300	1,300	1,300	1,300	1,300
March	1,450	1,725	2,750	2,525	2,300
April	1,500	1,575	2,850	2,700	2,050
May	1,500	1,400	3,025	3,025	2,600
June	1,400	1,525	1,500	3,000	2,900
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

Table VI-2. Excerpt of ranked daily Williamson River flows and exceedence probabilities for the March 1-15 time step for water years 1961-2000. In this example, the average daily flow of the Williamson River on March 08, 2008 was obtained from the USGS Station-1502500 (771 cfs) and used to look up the exceedence probability (0.94) over the period of record for the March 1-14 time step.



March 1-15				March 16-31			
Historic Date	Q	Rank	Exceedance	March 16-31	Q	Rank	Exceedance
March 9, 1994	790	549	0.91	March 25, 1988	1040	550	0.86
March 12, 1969	786	551	0.92	March 29, 1988	1040	550	0.86
March 15, 1969	786	551	0.92	March 17, 1962	1030	552	0.86
March 10, 1994	784	553	0.92	March 26, 1988	1030	552	0.86
March 11, 1964	782	554	0.92	March 28, 1988	1020	554	0.86
March 13, 1964	782	554	0.92	March 30, 1988	1020	554	0.86
March 14, 1964	782	554	0.92	March 25, 1977	1010	556	0.87
March 15, 1964	782	554	0.92	March 26, 1977	1010	556	0.87
March 11, 1994	782	554	0.92	March 22, 1981	1010	556	0.87
March 12, 1994	782	554	0.92	March 23, 1981	1010	556	0.87
March 13, 1994	779	560	0.93	March 31, 1988	1010	556	0.87
March 14, 1994	779	560	0.93	March 16, 1962	1000	561	0.88
March 15, 1994	779	560	0.93	March 16, 1977	1000	561	0.88
March 13, 1969	778	563	0.94	March 17, 1977	1000	561	0.88
March 14, 1969	778	563	0.94	March 18, 1977	1000	561	0.88
March 1, 1964	774	565	0.94	March 30, 1977	1000	561	0.88
March 3, 1991	**771**	566	**0.94**	March 19, 1981	1000	561	0.88
March 6, 1993	769	567	0.94	March 27, 1988	1000	561	0.88
March 2, 1964	766	568	0.95	March 23, 1977	994	568	0.89
March 5, 1964	766	568	0.95	March 24, 1977	994	568	0.89
March 7, 1964	766	568	0.95	March 31, 1977	994	568	0.89
March 8, 1964	766	568	0.95	March 20, 1981	994	568	0.89
March 9, 1964	766	568	0.95	March 17, 1981	985	572	0.89
March 10, 1964	766	568	0.95	March 18, 1981	985	572	0.89
March 3, 1964	758	574	0.96	March 21, 1981	985	572	0.89
March 4, 1964	758	574	0.96	March 25, 1981	985	572	0.89
March 6, 1964	758	574	0.96	March 26, 1981	985	572	0.89

Table VI-3. Daily Iron Gate exceedence probabilities and associated discharges, by time step, were interpolated from the WRIMS Run-32 Refuge outputs. In this example, the Williamson River on March 8, 2008 had an exceedence probability of 0.94, which was used to determine the RTM discharge of 1,307.7 cfs at IGD.



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=+C$610-(D$610-D576)*(C$610-C$552)/(D$610-D$552)
```

March 1-15			March 16-31		
Historic Date	Q	Exceedence	Historic Date	Q	Exceedence
3/9/1994	1451.2	0.913	3/29/1988	1859	0.858
3/12/1969	1434.3	0.917	3/17/1962	1841	0.861
3/15/1969	1434.3	0.917	3/26/1988	1841	0.861
3/10/1994	1417.4	0.920	3/28/1988	1823	0.864
3/11/1964	1409.0	0.922	3/30/1988	1823	0.864
3/13/1964	1409.0	0.922	3/25/1977	1805	0.867
3/14/1964	1409.0	0.922	3/26/1977	1805	0.867
3/15/1964	1409.0	0.922	3/22/1981	1805	0.867
3/11/1994	1409.0	0.922	3/23/1981	1805	0.867
3/12/1994	1409.0	0.922	3/31/1988	1805	0.867
3/13/1994	1358.3	0.932	3/16/1962	1760	0.875
3/14/1994	1358.3	0.932	3/16/1977	1760	0.875
3/15/1994	1358.3	0.932	3/17/1977	1760	0.875
3/13/1969	1333.0	0.937	3/18/1977	1760	0.875
3/14/1969	1333.0	0.937	3/30/1977	1760	0.875
3/1/1964	1316.1	0.940	3/19/1981	1760	0.875
3/3/1991	1307.7	0.942	3/27/1988	1760	0.875
3/6/1993	1299.2	0.943	3/23/1977	1696	0.886
3/2/1964	1290.8	0.945	3/24/1977	1696	0.886
3/5/1964	1290.8	0.945	3/31/1977	1696	0.886
3/7/1964	1290.8	0.945	3/20/1981	1696	0.886
3/8/1964	1290.8	0.945	3/17/1981	1660	0.892
3/9/1964	1290.8	0.945	3/18/1981	1660	0.892
3/10/1964	1290.8	0.945	3/21/1981	1660	0.892
3/3/1964	1240.2	0.955	3/25/1981	1660	0.892
3/4/1964	1240.2	0.955	3/26/1981	1660	0.892

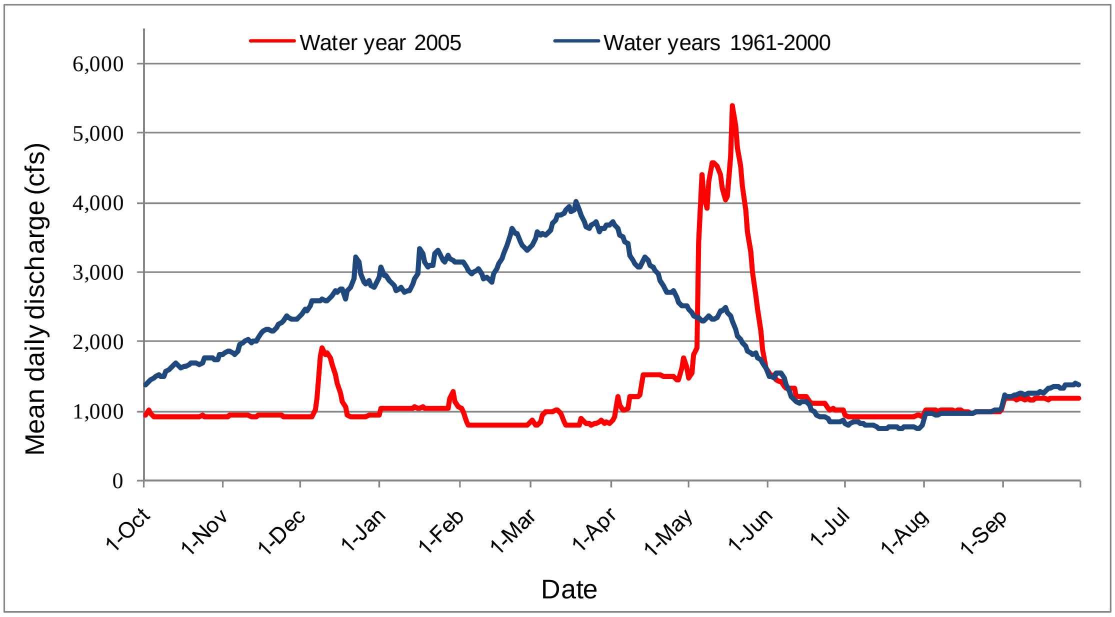


Figure VI-1. Daily mean discharge measured at the Iron Gate gauge for water year 2005 and water years 1961-2000 pooled, between October 1 and September 30.

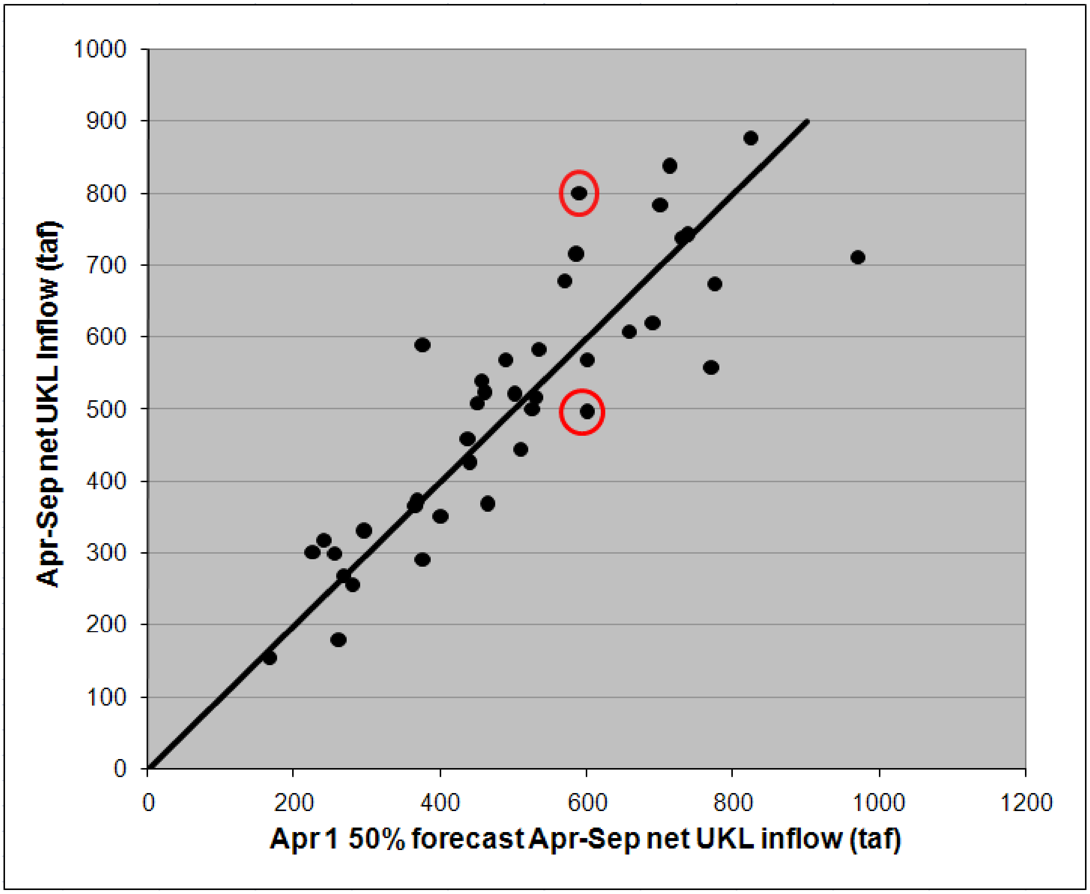


Figure VI-2. Recent management of minimum UKL elevations and Klamath River flows is based on the April 1-September 30 NRCS forecast, as plotted above against actual inflow in thousand acre feet (taf). The red circles demonstrate that in some years, uncertainty in forecast can be large, which can lead to erroneous water year type designations and subsequent over or under allocations in implementing lake elevations and river flows.

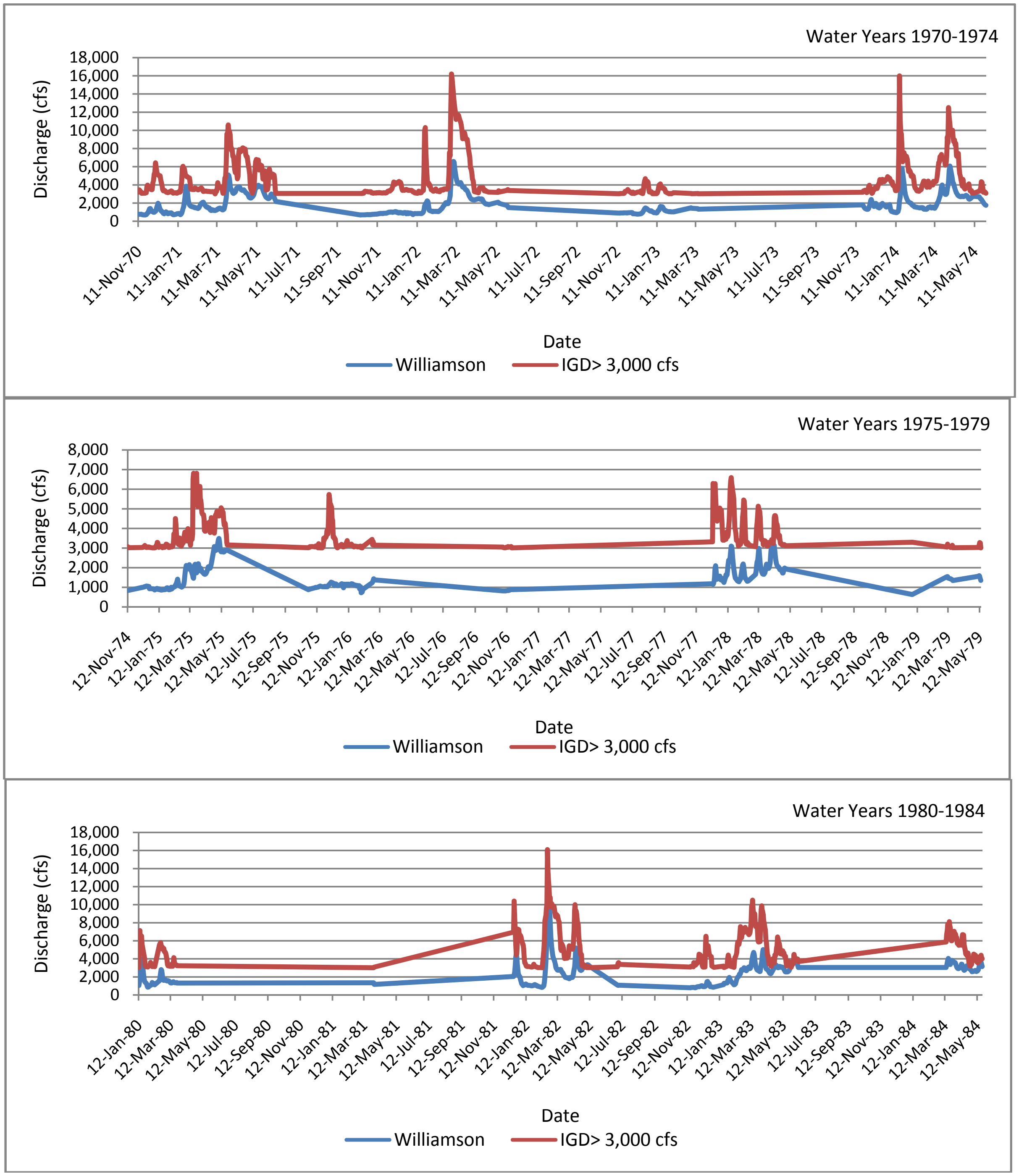
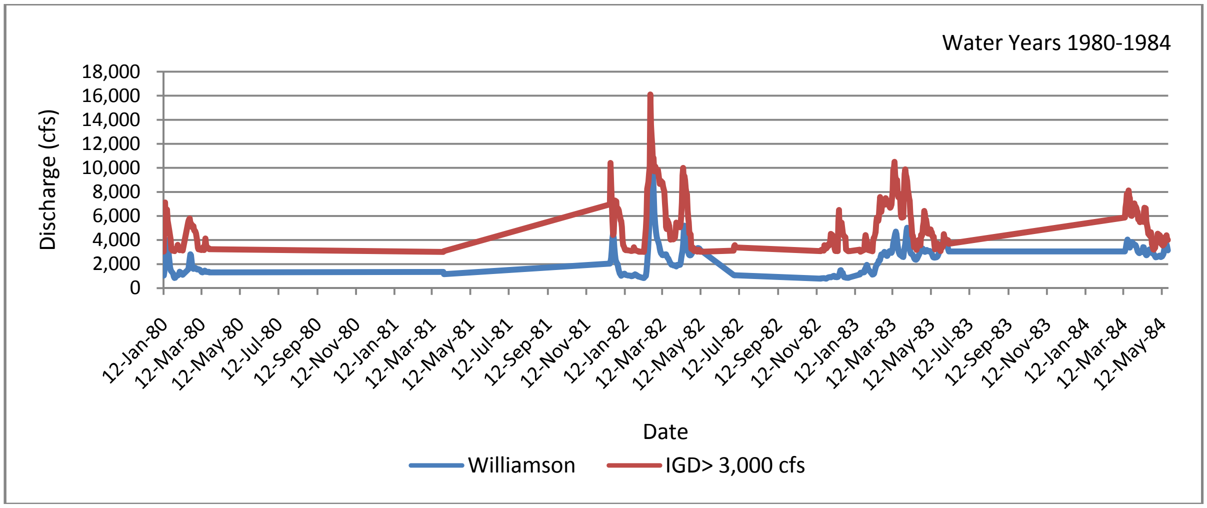


Figure VI-3. Comparisons of discharge for Williamson River below its confluence with the Sprague River at USGS Gage 11502500 and 11516530 Klamath River below Iron Gate Dam by water year. Data presented are discontinuous, including only periods when Klamath River discharge at the Iron Gate gage was greater than 3,000 cfs.



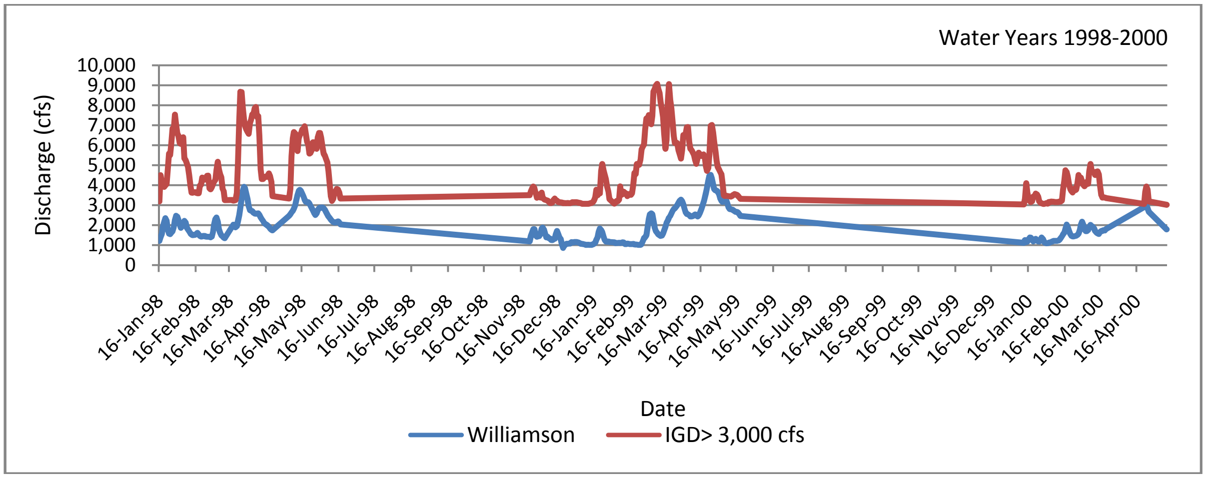
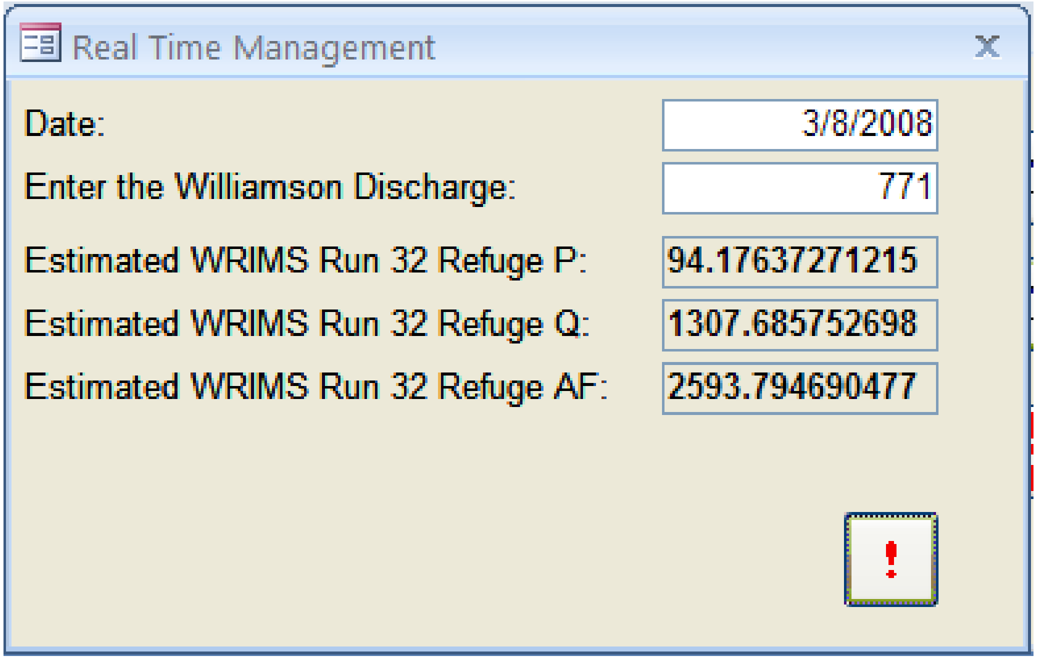


Figure VI-3, continued. Comparisons of discharge for Williamson River below its confluence with the Sprague River at USGS Gage 11502500 and 11516530 Klamath River below Iron Gate Dam by water year. Data presented are discontinuous, including only periods when Klamath River discharge at the Iron Gate gage was greater than 3,000 cfs.



Date: 3/8/2008

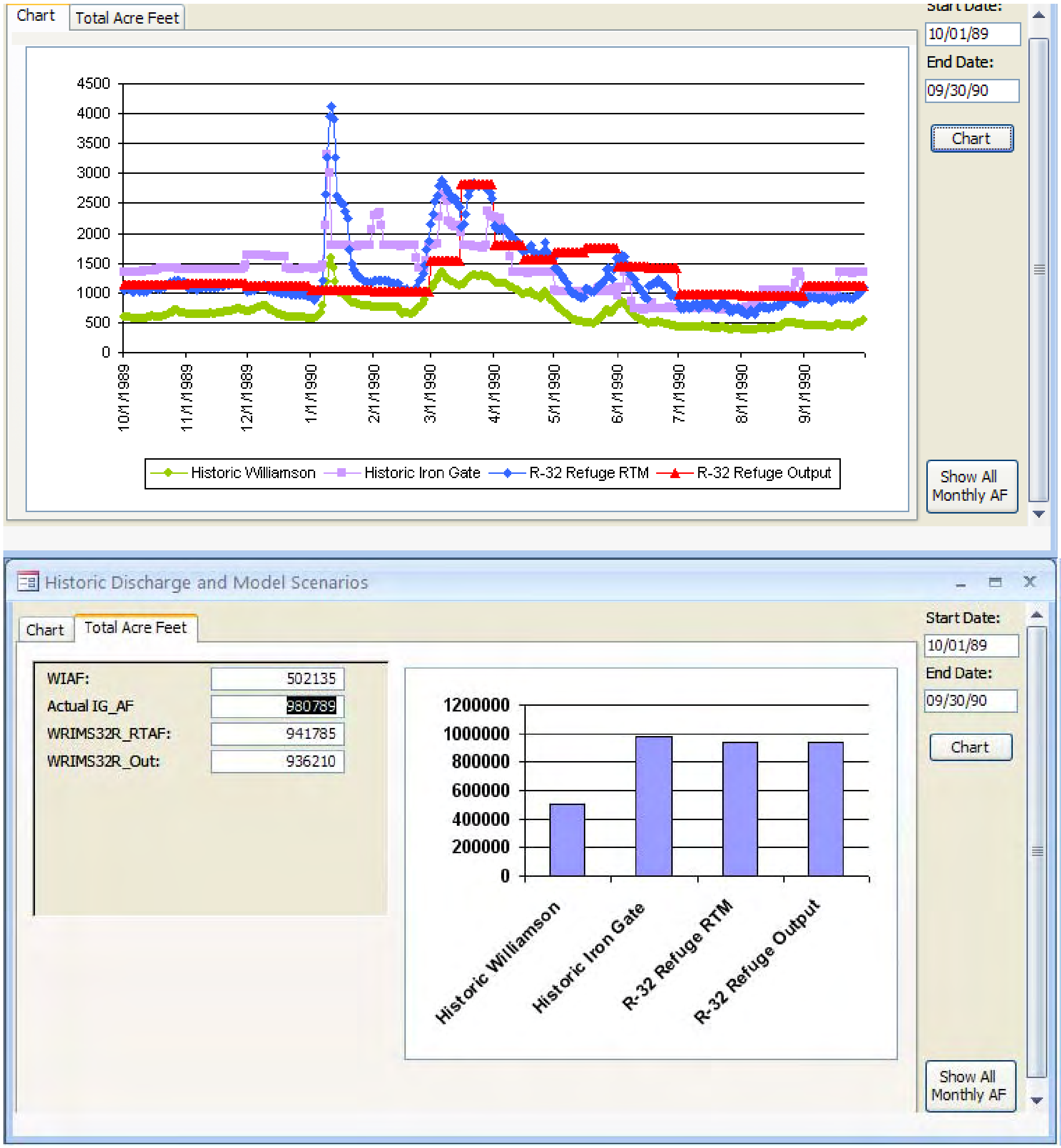
Enter the Williamson Discharge: 771

Estimated WRIMS Run 32 Refuge P: 94.17637271215

Estimated WRIMS Run 32 Refuge Q: 1307.685752698

Estimated WRIMS Run 32 Refuge AF: 2593.794690477

Figure VI-4. Example of an output display from the Microsoft Access routine used to implement WRIMS Run-32 Refuge model outputs in real time. In this example, the date and Williamson River discharge of 771 cfs are entered and the program calculates the exceedence probability (.094), the corresponding WRIMS Run-32 Refuge flow (Q) associated with that exceedence for the March 1-15 time step, and the total daily discharge, in acre feet.



Start Date: 10/01/89
End Date: 09/30/90

Start Date: 10/01/89
End Date: 09/30/90

WIAF:	502135
Actual IG_AF	980789
WRIMS32R_RTAF:	941785
WRIMS32R_Out:	936210

Figure VI-5. RTM database interface display of daily flows (top) and total annual discharge in acre feet (bottom) for historical Williamson River, historical Iron Gate, Run-32 Refuge model output, and RTM for water year 1990 (10/01/1989- 09/30/1990).

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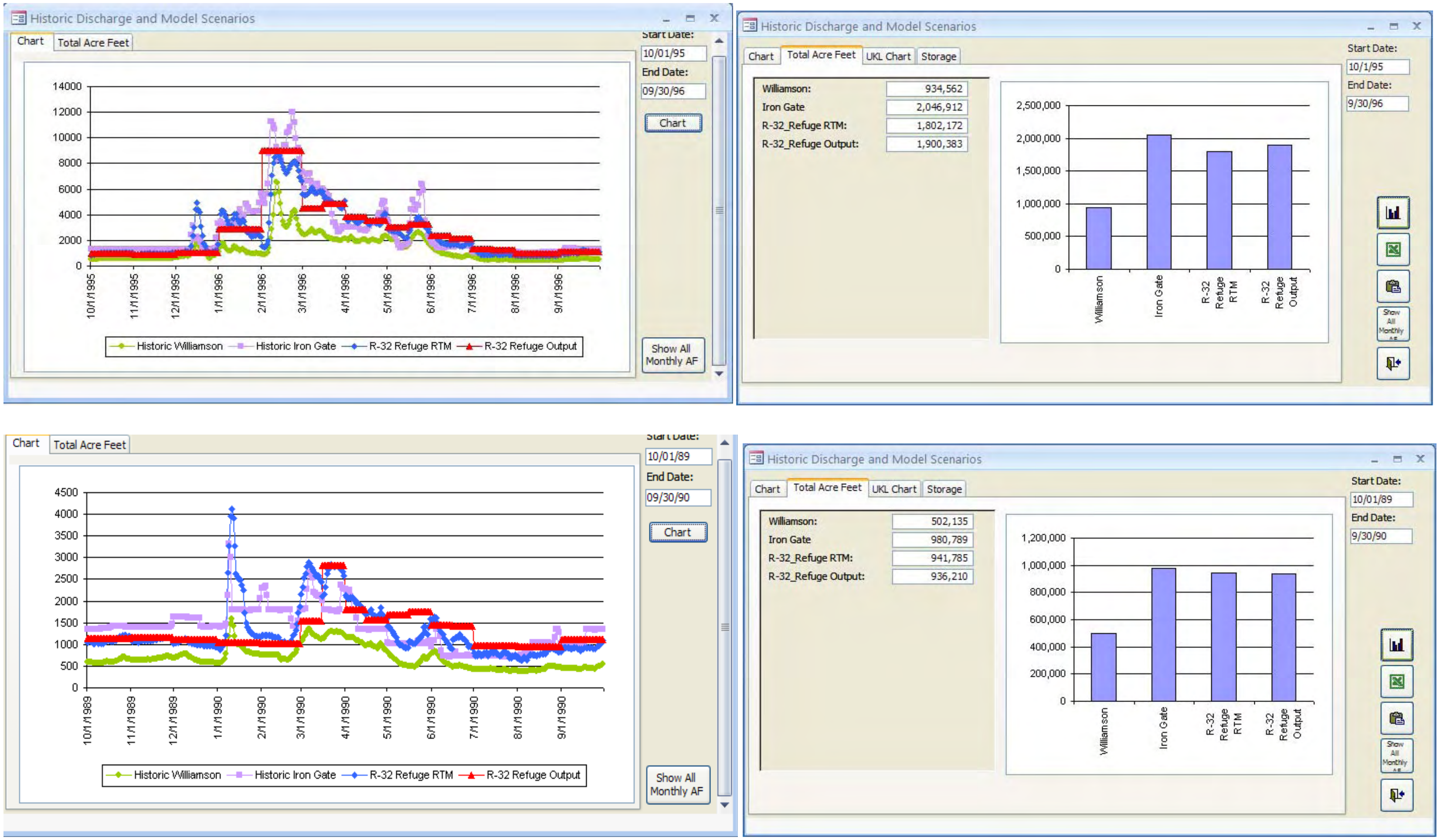


Top left: Start Date: 10/01/95 End Date: 09/30/96

Top right: Start Date: 10/1/95 End Date: 9/30/96

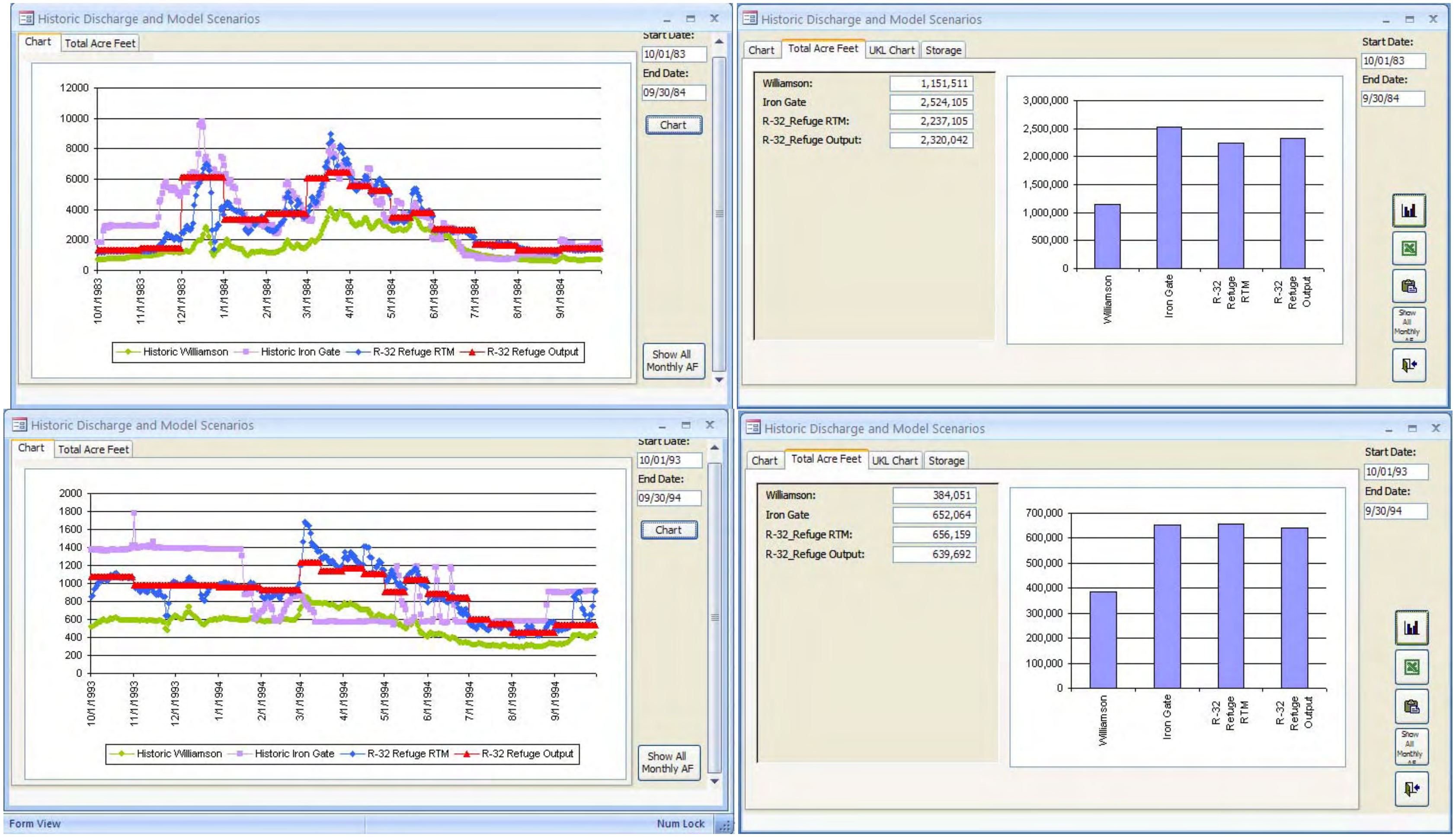
Williamson:	934,562
Iron Gate	2,046,912
R-32_Refuge RTM:	1,802,172
R-32_Refuge Output:	1,900,383

Bottom left: Start Date: 10/01/89 End Date: 09/30/90

Bottom right: Start Date: 10/01/89 End Date: 9/30/90

Williamson:	502,135
Iron Gate	980,789
R-32_Refuge RTM:	941,785
R-32_Refuge Output:	936,210

Figure VI-6. RTM database interface display comparing daily flows (left) and total annual discharge in acre feet (right) for the historical Williamson River, historical Iron Gate, Run-32 Refuge RTM, and Run-32 Refuge model outputs. The top charts represent an above average water year (1996), and the bottom charts represent a below average water year (1990).



Start Date: 10/01/83
End Date: 09/30/84

Start Date: 10/01/83
End Date: 9/30/84

Williamson:	1,151,511
Iron Gate	2,524,105
R-32_Refuge RTM:	2,237,105
R-32_Refuge Output:	2,320,042

Start Date: 10/01/93
End Date: 09/30/94

Start Date: 10/01/93
End Date: 9/30/94

Williamson:	384,051
Iron Gate	652,064
R-32_Refuge RTM:	656,159
R-32_Refuge Output:	639,692

Figure VI-7. RTM database interface display comparing daily flows (left) and total annual discharge in acre feet (right) for the historical Williamson River, historical Iron Gate, Run-32 Refuge RTM, and Run-32 Refuge model outputs. The top charts represent a wet water year (1984), and the bottom charts represent a dry water year (1994).

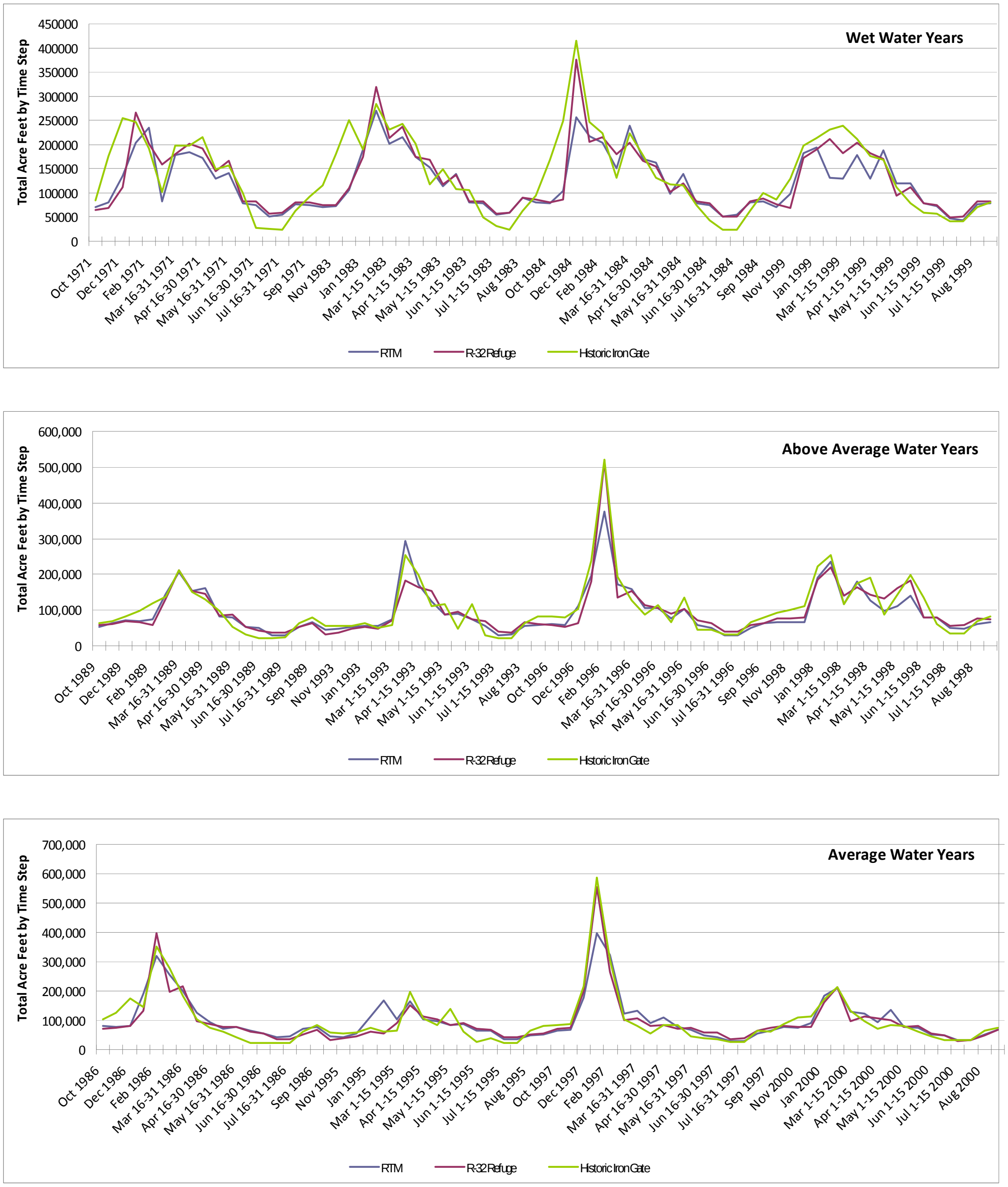


Figure VI-8. Comparison of discontinuous outputs of WRIMS Run-32 Refuge and RTM with historical Iron Gate discharge for the four most recent years within the period of record (water years 1961-2000) categorized as Wet, Above Average, and Average Water Year types.

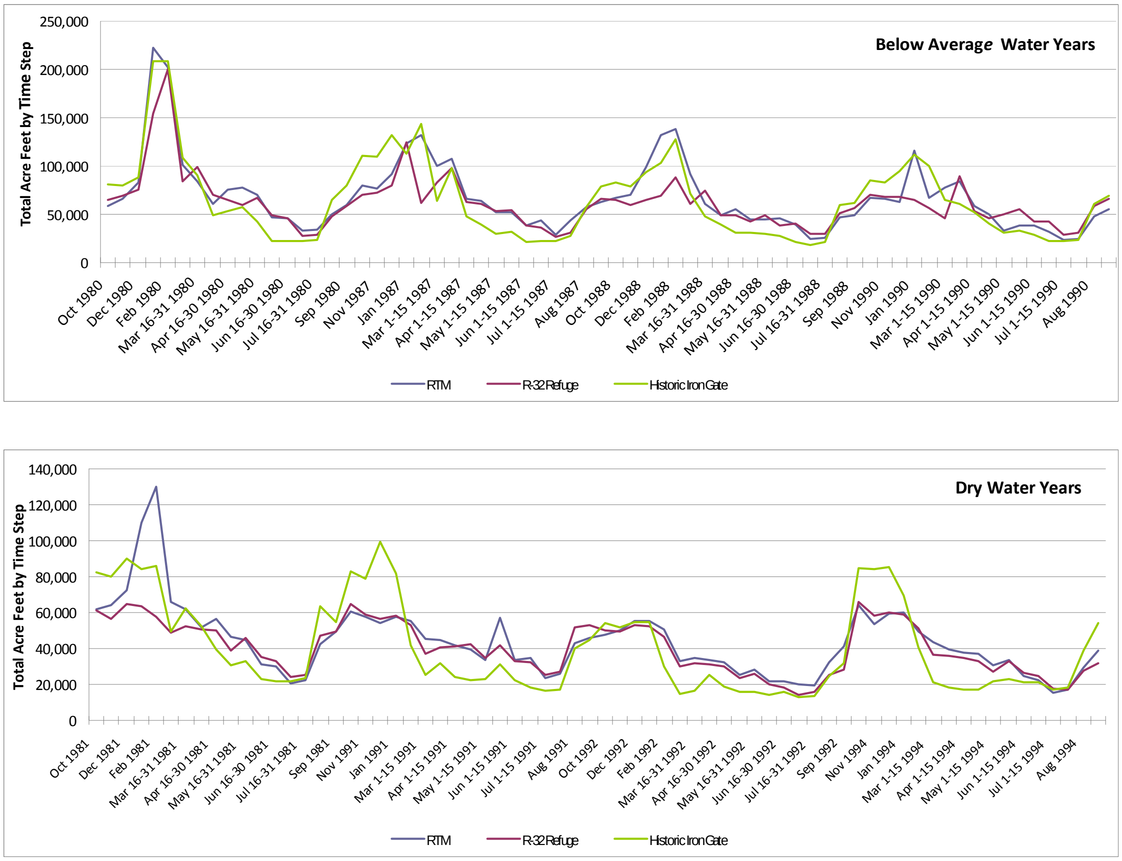


Figure VI-8, continued. Comparison of discontinuous outputs of WRIMS Run-32 Refuge and RTM with historical Iron Gate discharge for the four most recent years within the period of record (water years 1961-2000) categorized as Below Average and Dry Water Year types.

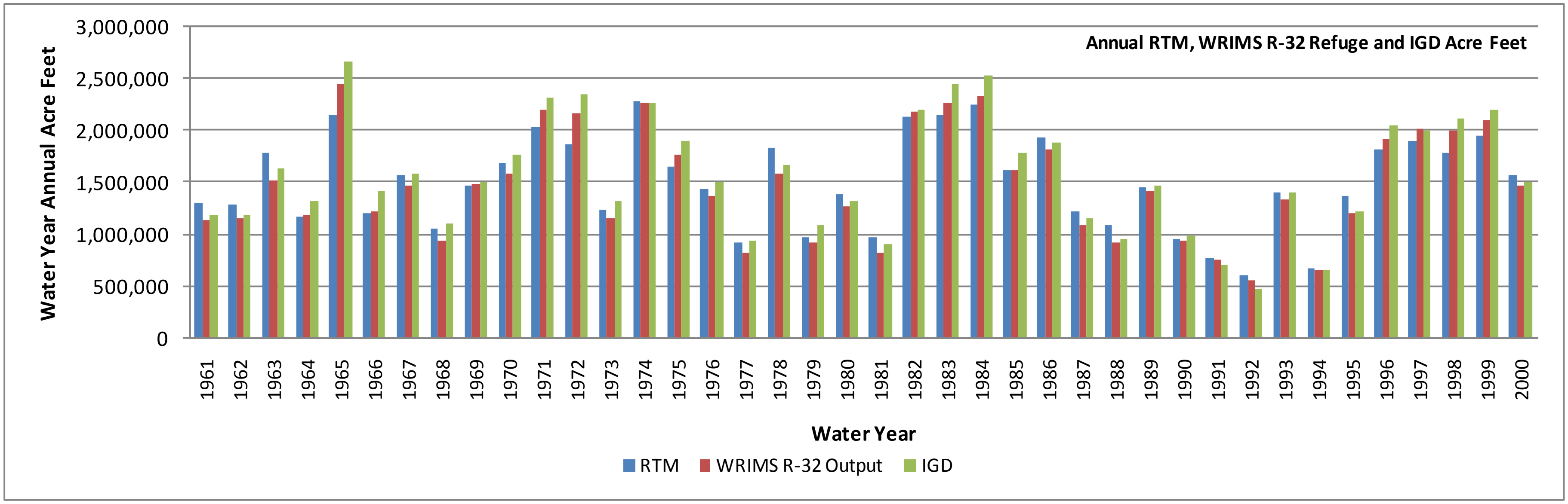
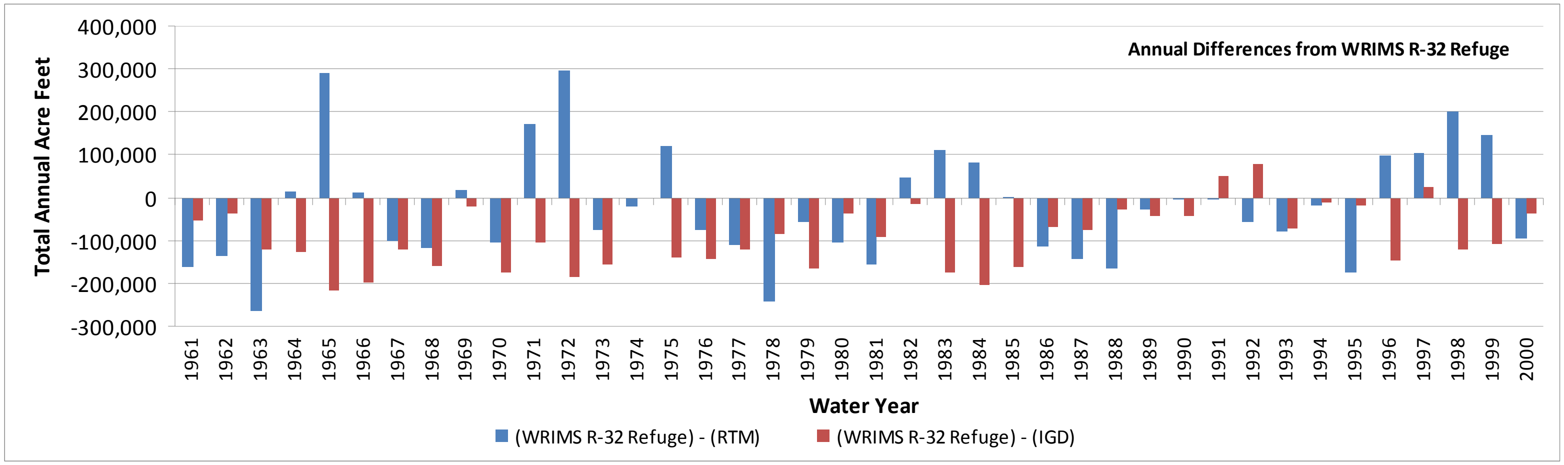


Figure VI-9. Total annual discharge (acre feet) estimated for RTM and WRIMS Run-32 Refuge model output, and actual IGD releases for the water years 1961-2000.



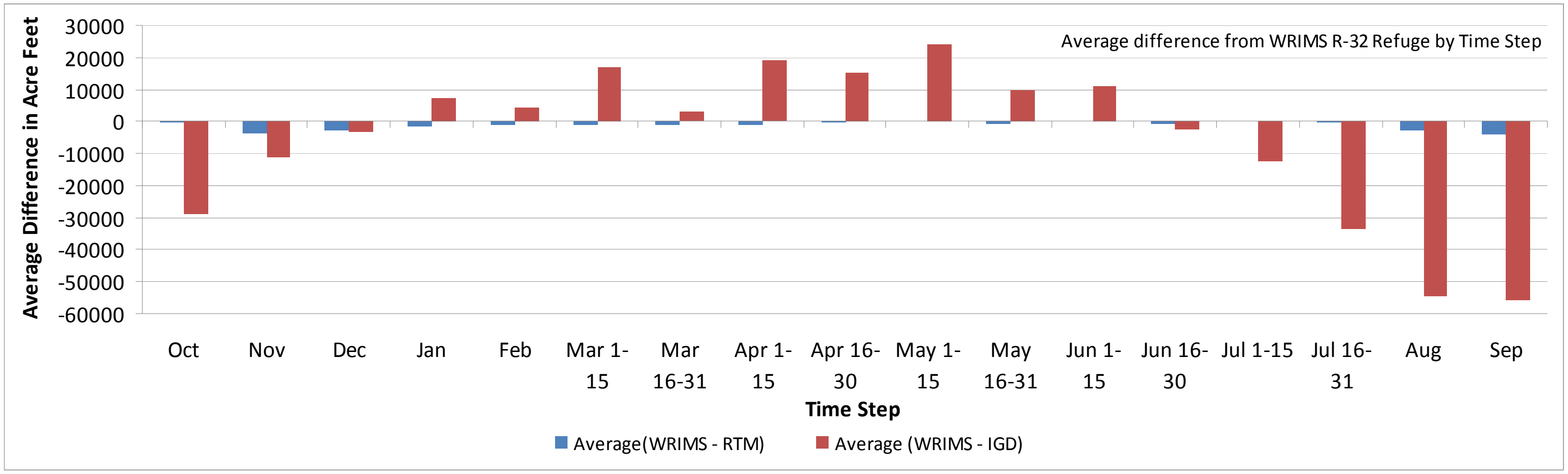
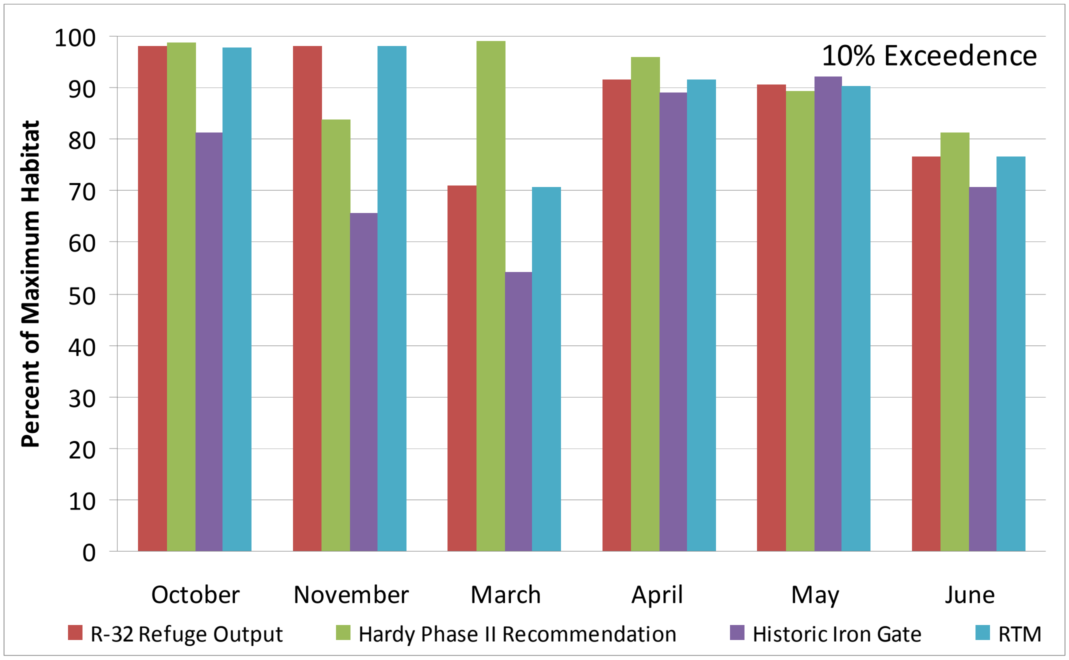


Figure VI-10. Differences in total accumulated discharge between WRIMS Run-32 Refuge outputs and RTM flows and WRIMS Run-32 Refuge outputs and historical Iron Gate flows calculated annually (top) and averaged by time steps for water years 1961-2000 (bottom).



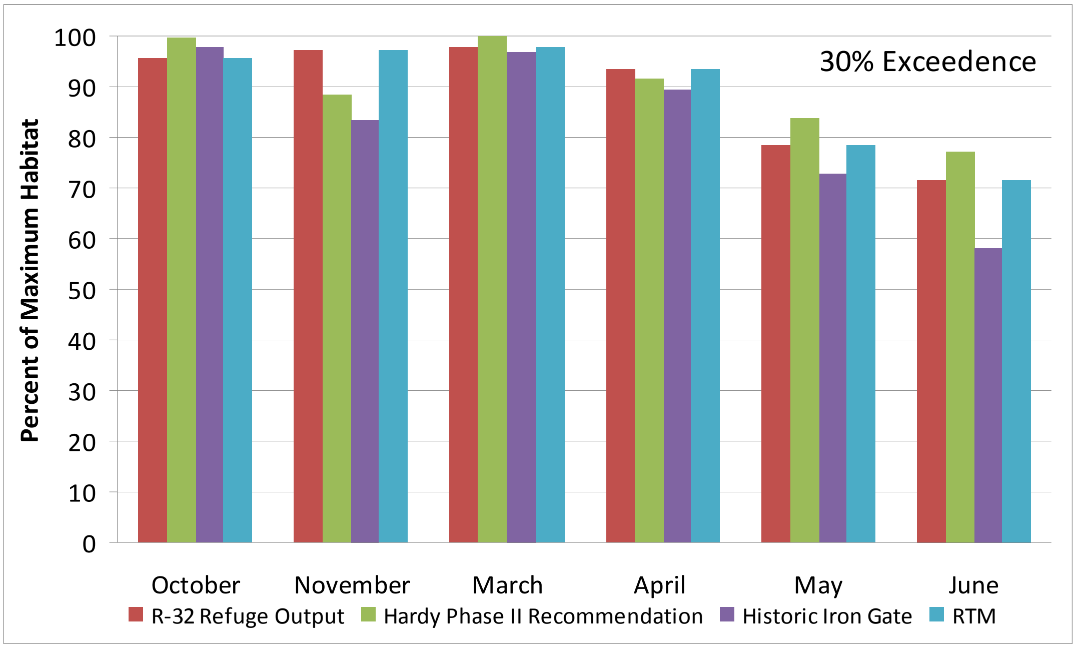
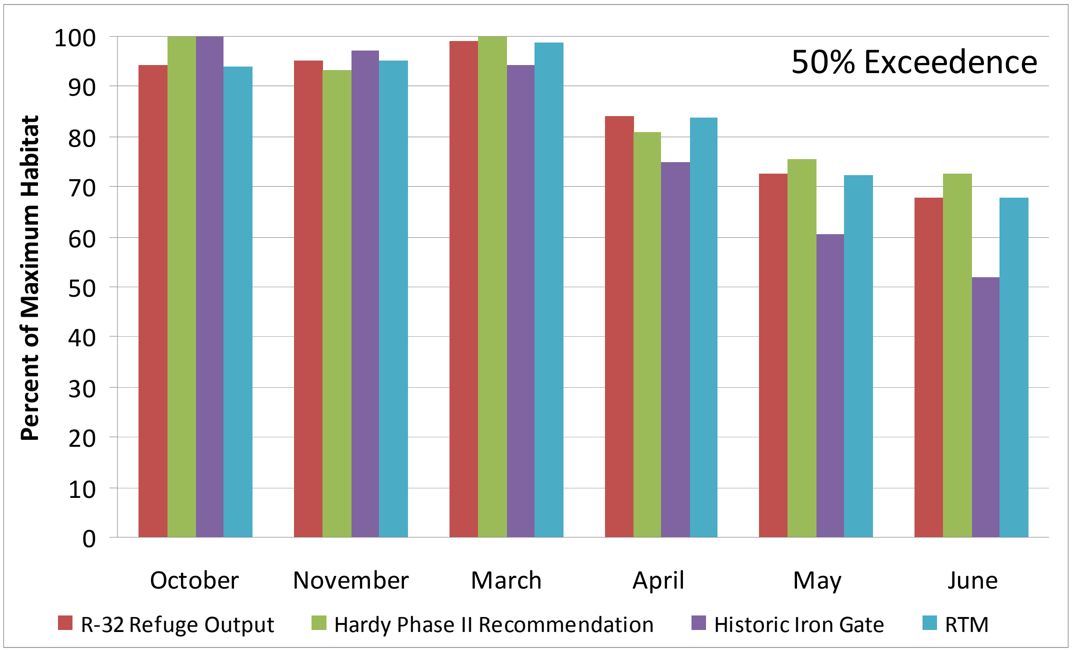


Figure VI-11. Habitat availability values calculated for Hardy et al. (2006a) Phase II recommendations, WRIMS Run-32 Refuge flow outputs and the RTM flows by flow exceedence during the critical Chinook salmon spawning (October – November) and juvenile salmon rearing periods March – June.



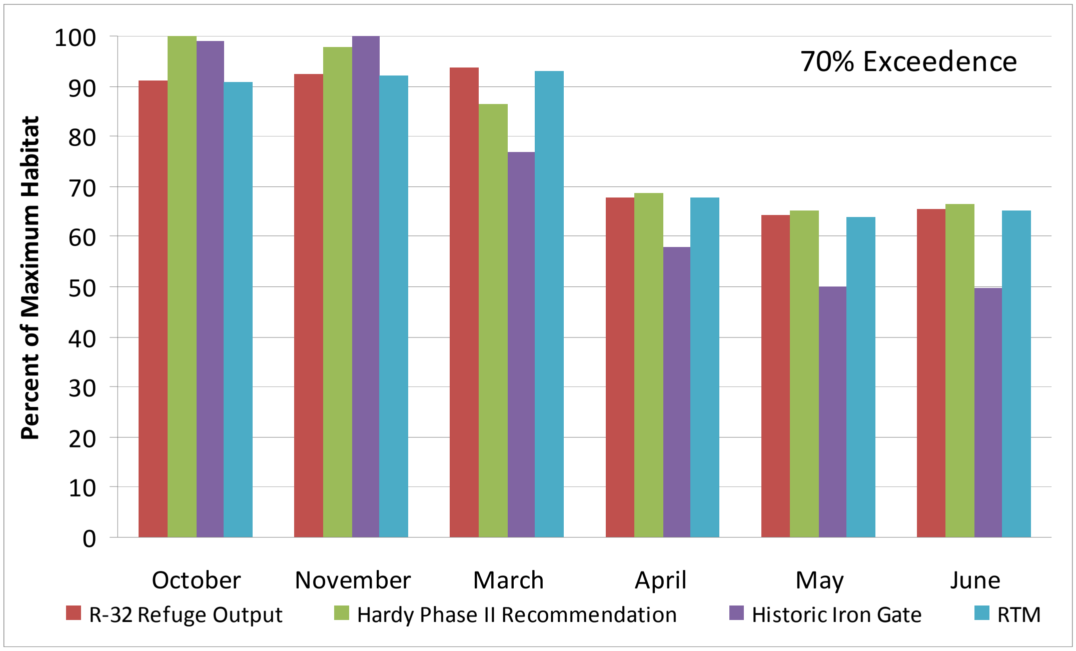


Figure VI-11, continued. Habitat availability values calculated for Hardy et al. (2006a) Phase II recommendations, WRIMS Run-32 Refuge flow outputs and the RTM flows by flow exceedence during the critical Chinook salmon spawning (October – November) and juvenile salmon rearing periods March – June.

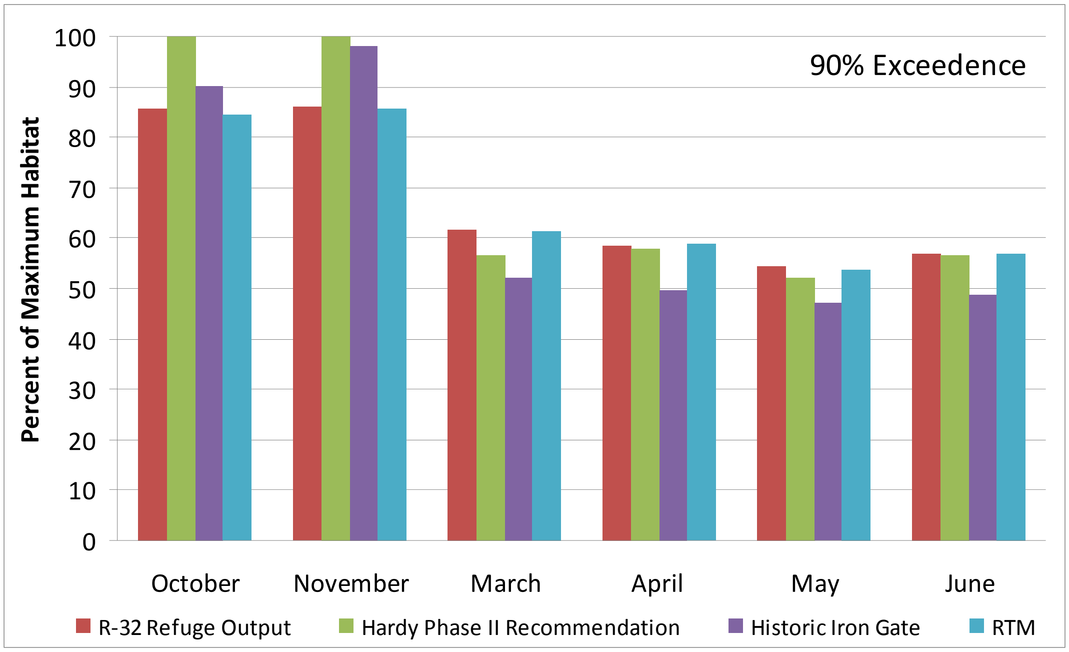
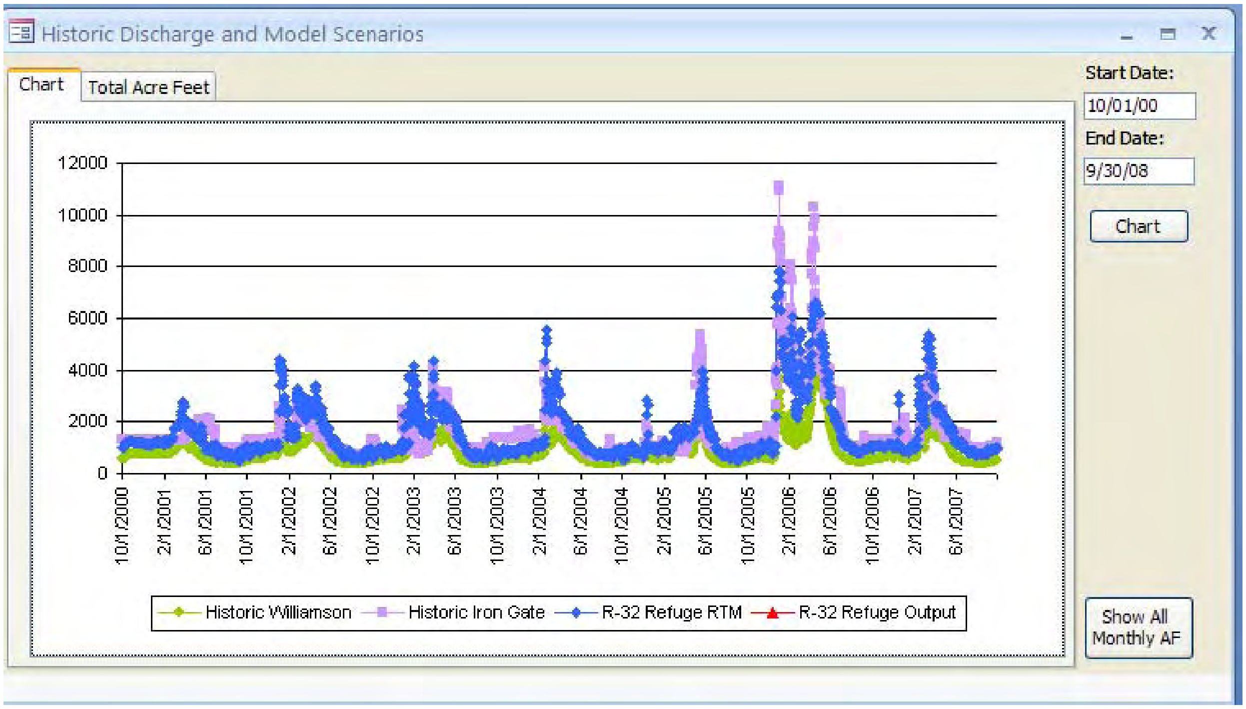


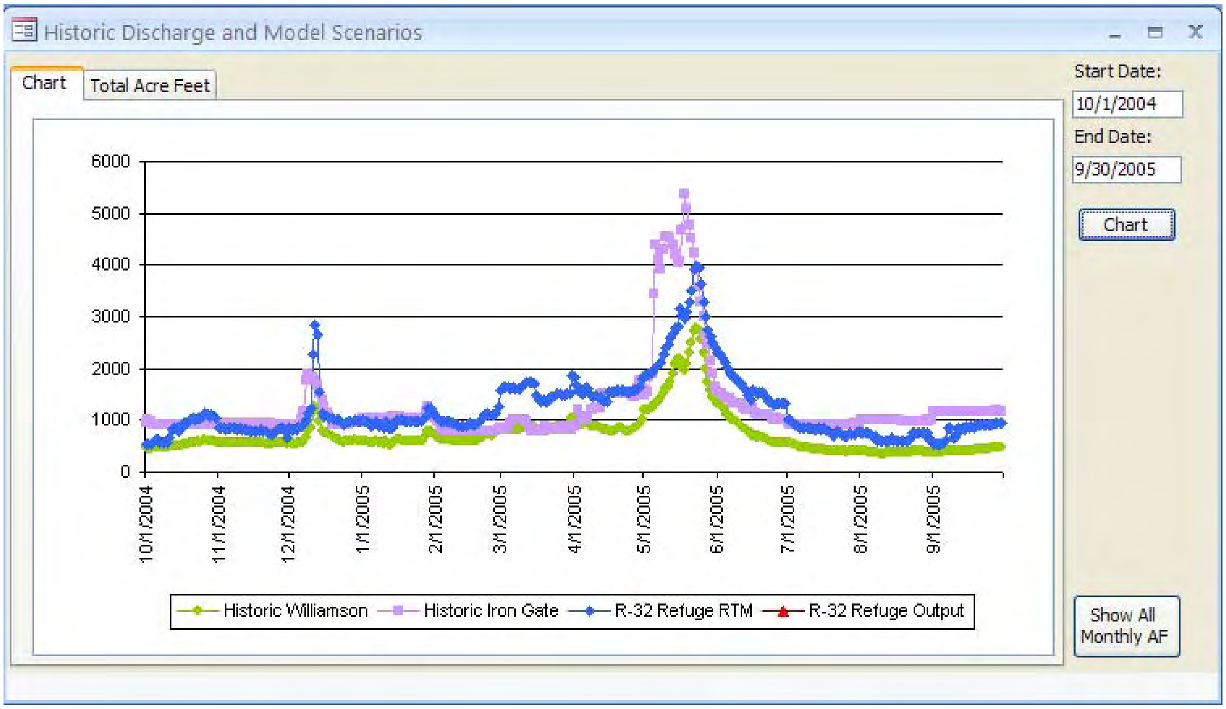
Figure VI-11, continued. Habitat availability values calculated for Hardy et al. (2006a) Phase II recommendations, WRIMS Run-32 Refuge flow outputs and the RTM flows by flow exceedence during the critical Chinook salmon spawning (October – November) and juvenile salmon rearing periods March – June.



Start Date: 10/01/00

End Date: 9/30/08

Figure VI-12. Daily RTM database interface display calculated for the October 1, 2000 to September 30, 2007, a period outside range of water years used in the WRIMS Run-32 Refuge model simulation.



Start Date: 10/1/2004

End Date: 9/30/2005

Figure VI-13. RTM database interface display comparing daily average flows for historical Williamson River, historical Iron Gate, WRIMS Run-32 Refuge RTM, and WRIMS Run-32 Refuge model outputs for water year 2005.

Technical Conclusions

Our analyses indicate that implementing the KBRA's water allocation plan would benefit the restoration of anadromous salmonids prior to the removal of PacifiCorp Project dams. However, quantitative gains in fish habitat and associated production potential that would result from dam removal, including the reestablishment of spring and fall Chinook and coho salmon, steelhead, and Pacific lamprey upstream of the current site of IGD, exceed gains that could be achieved below IGD through manipulation of flows alone. The water allocation plan specified in the KBRA would also contribute to maintaining water levels in Upper Klamath Lake that, in combination with restoration activities listed in the KBRA, will benefit listed sucker populations. Removal of PacifiCorp Project dams and subsequent reestablishment of Basin connectivity and variable stream flows in the Klamath River are expected to contribute significantly towards restoration of the physical, chemical, and biological processes and interactions that are essential to a functional aquatic ecosystem.

The timing and magnitude of improvements to fish production will largely depend on the time required to implement the full suite of restoration and management actions identified in the Agreements. This suite of actions includes, but is not limited to, removal of the PacifiCorp Hydroelectric Project dams, implementation of the proposed water allocation, completion of restoration projects, water rights retirement, ground water monitoring, development and implementation of a drought plan, increased storage in upper Klamath Lake, improvements in water quality resulting from dam removal and habitat restoration, implementation of an adaptive process incorporating real-time management, and implementation of the reintroduction plan.

As described in Section 9.1.1. of the KBRA, the purpose of the KBRA's Fisheries Program is to restore and sustain natural production of fish species throughout the Klamath River Basin. Specifically, this program,

> *"...establishes conditions that, combined with effective implementation of the Water Resources Program in Part V, will contribute to the natural sustainability of fisheries and Full Participation in Harvest Opportunities, as well as the overall ecosystem health of the Klamath River Basin…"*

The collective professional opinion of lead technical staff that contributed to this report concur that removal of Iron Gate, Copco 1 and 2, and J. C. Boyle dams and implementation of the water allocation specified in the KBRA will benefit sucker populations and contribute greatly to the restoration of anadromous fishes, as needed to support full participation in ocean and in-river harvest opportunities and ceremonial needs of Tribes. When viewed in combination with the implementation of an effective drought plan, dam removal, and other restoration actions identified in of the Executive Summary, it is the professional judgment of the authors that the KBRA water and fish programs, would over time, achieve the Agreement's stated goal of restoring the "*natural sustainability of fisheries and full participation in harvest opportunities, as well as the overall ecosystem health of the Klamath River Basin*". The timing and magnitude of improvements, however, will largely depend on the time required to implement the full suite of restoration and management actions identified in the KBRA (Table 1 Executive Summary).

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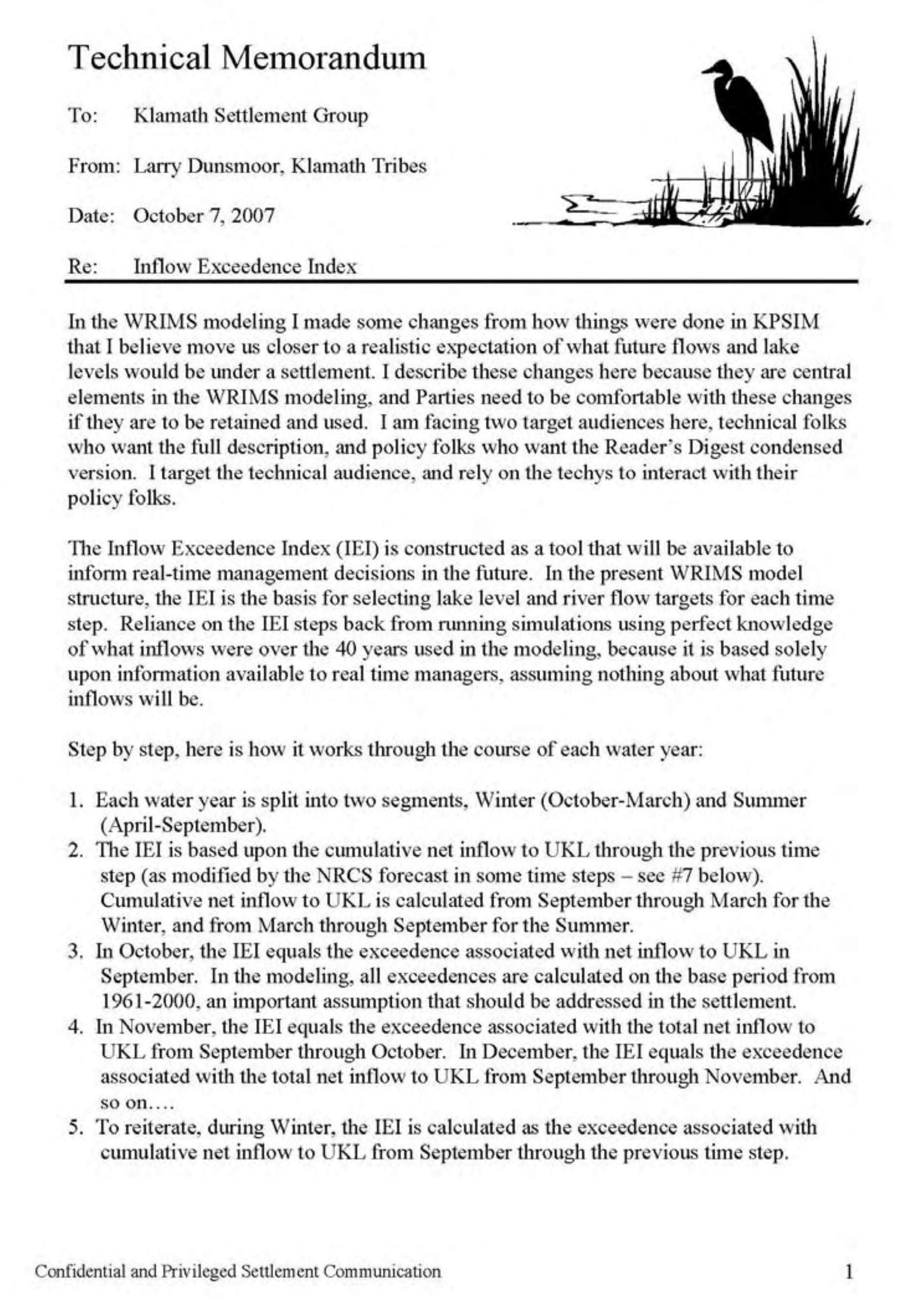
Appendices

Appendix A. Technical memo describing the Exceedence Index (IEI) developed by L. Dunsmoor, Klamath Tribes.



Technical Memorandum

To: Klamath Settlement Group

From: Larry Dunsmoor, Klamath Tribes

Date: October 7, 2007

Re: Inflow Exceedence Index

In the WRIMS modeling I made some changes from how things were done in KPSIM that I believe move us closer to a realistic expectation of what future flows and lake levels would be under a settlement. I describe these changes here because they are central elements in the WRIMS modeling, and Parties need to be comfortable with these changes if they are to be retained and used. I am facing two target audiences here, technical folks who want the full description, and policy folks who want the Reader's Digest condensed version. I target the technical audience, and rely on the techys to interact with their policy folks.

The Inflow Exceedence Index (IEI) is constructed as a tool that will be available to inform real-time management decisions in the future. In the present WRIMS model structure, the IEI is the basis for selecting lake level and river flow targets for each time step. Reliance on the IEI steps back from running simulations using perfect knowledge of what inflows were over the 40 years used in the modeling, because it is based solely upon information available to real time managers, assuming nothing about what future inflows will be.

Step by step, here is how it works through the course of each water year:

1. Each water year is split into two segments, Winter (October-March) and Summer (April-September).
2. The IEI is based upon the cumulative net inflow to UKL through the previous time step (as modified by the NRCS forecast in some time steps – see #7 below). Cumulative net inflow to UKL is calculated from September through March for the Winter, and from March through September for the Summer.
3. In October, the IEI equals the exceedence associated with net inflow to UKL in September. In the modeling, all exceedences are calculated on the base period from 1961-2000, an important assumption that should be addressed in the settlement.
4. In November, the IEI equals the exceedence associated with the total net inflow to UKL from September through October. In December, the IEI equals the exceedence associated with the total net inflow to UKL from September through November. And so on….
5. To reiterate, during Winter, the IEI is calculated as the exceedence associated with cumulative net inflow to UKL from September through the previous time step.

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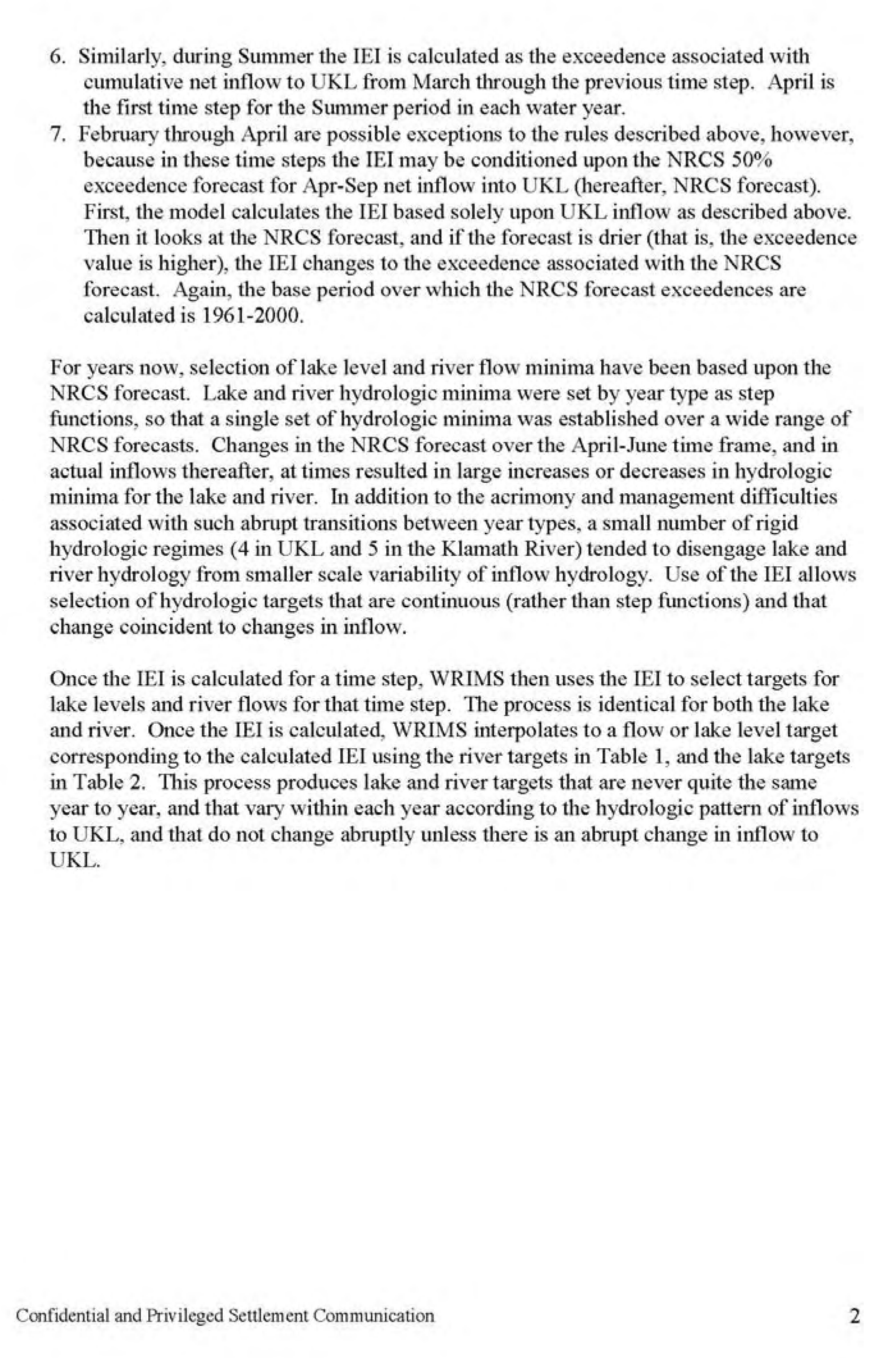


6. Similarly, during Summer the IEI is calculated as the exceedence associated with cumulative net inflow to UKL from March through the previous time step. April is the first time step for the Summer period in each water year.
7. February through April are possible exceptions to the rules described above, however, because in these time steps the IEI may be conditioned upon the NRCS 50% exceedence forecast for Apr-Sep net inflow into UKL (hereafter, NRCS forecast). First, the model calculates the IEI based solely upon UKL inflow as described above. Then it looks at the NRCS forecast, and if the forecast is drier (that is, the exceedence value is higher), the IEI changes to the exceedence associated with the NRCS forecast. Again, the base period over which the NRCS forecast exceedences are calculated is 1961-2000.

For years now, selection of lake level and river flow minima have been based upon the NRCS forecast. Lake and river hydrologic minima were set by year type as step functions, so that a single set of hydrologic minima was established over a wide range of NRCS forecasts. Changes in the NRCS forecast over the April-June time frame, and in actual inflows thereafter, at times resulted in large increases or decreases in hydrologic minima for the lake and river. In addition to the acrimony and management difficulties associated with such abrupt transitions between year types, a small number of rigid hydrologic regimes (4 in UKL and 5 in the Klamath River) tended to disengage lake and river hydrology from smaller scale variability of inflow hydrology. Use of the IEI allows selection of hydrologic targets that are continuous (rather than step functions) and that change coincident to changes in inflow.

Once the IEI is calculated for a time step, WRIMS then uses the IEI to select targets for lake levels and river flows for that time step. The process is identical for both the lake and river. Once the IEI is calculated, WRIMS interpolates to a flow or lake level target corresponding to the calculated IEI using the river targets in Table 1, and the lake targets in Table 2. This process produces lake and river targets that are never quite the same year to year, and that vary within each year according to the hydrologic pattern of inflows to UKL, and that do not change abruptly unless there is an abrupt change in inflow to UKL.

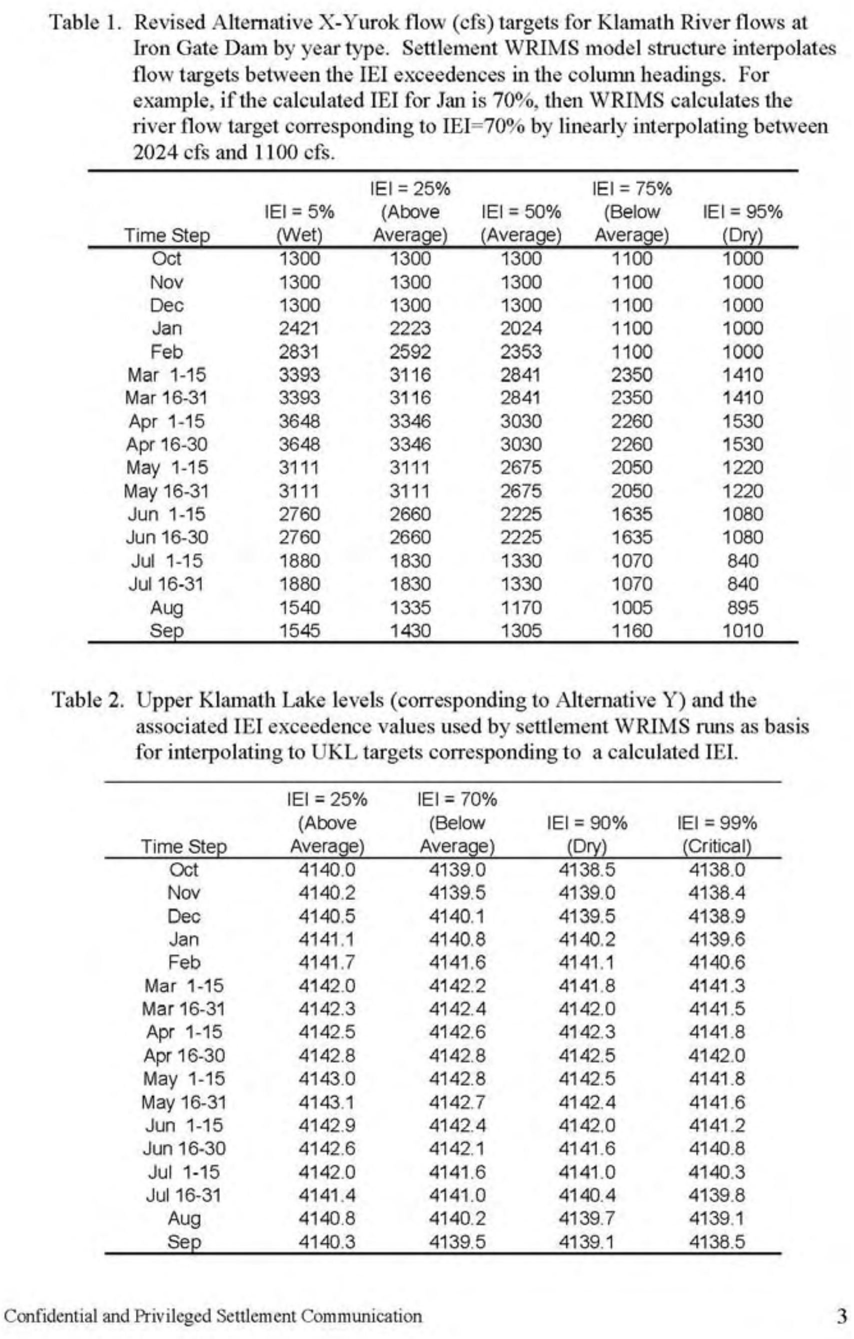


Table 1. Revised Alternative X-Yurok flow (cfs) targets for Klamath River flows at Iron Gate Dam by year type. Settlement WRIMS model structure interpolates flow targets between the IEI exceedences in the column headings. For example, if the calculated IEI for Jan is 70%, then WRIMS calculates the river flow target corresponding to IEI=70% by linearly interpolating between 2024 cfs and 1100 cfs.

Time Step	IEI = 5% (Wet)	IEI = 25% (Above Average)	IEI = 50% (Average)	IEI = 75% (Below Average)	IEI = 95% (Dry)
Oct	1300	1300	1300	1100	1000
Nov	1300	1300	1300	1100	1000
Dec	1300	1300	1300	1100	1000
Jan	2421	2223	2024	1100	1000
Feb	2831	2592	2353	1100	1000
Mar 1-15	3393	3116	2841	2350	1410
Mar 16-31	3393	3116	2841	2350	1410
Apr 1-15	3648	3346	3030	2260	1530
Apr 16-30	3648	3346	3030	2260	1530
May 1-15	3111	3111	2675	2050	1220
May 16-31	3111	3111	2675	2050	1220
Jun 1-15	2760	2660	2225	1635	1080
Jun 16-30	2760	2660	2225	1635	1080
Jul 1-15	1880	1830	1330	1070	840
Jul 16-31	1880	1830	1330	1070	840
Aug	1540	1335	1170	1005	895
Sep	1545	1430	1305	1160	1010

Table 2. Upper Klamath Lake levels (corresponding to Alternative Y) and the associated IEI exceedence values used by settlement WRIMS runs as basis for interpolating to UKL targets corresponding to a calculated IEI.

Time Step	IEI = 25% (Above Average)	IEI = 70% (Below Average)	IEI = 90% (Dry)	IEI = 99% (Critical)
Oct	4140.0	4139.0	4138.5	4138.0
Nov	4140.2	4139.5	4139.0	4138.4
Dec	4140.5	4140.1	4139.5	4138.9
Jan	4141.1	4140.8	4140.2	4139.6
Feb	4141.7	4141.6	4141.1	4140.6
Mar 1-15	4142.0	4142.2	4141.8	4141.3
Mar 16-31	4142.3	4142.4	4142.0	4141.5
Apr 1-15	4142.5	4142.6	4142.3	4141.8
Apr 16-30	4142.8	4142.8	4142.5	4142.0
May 1-15	4143.0	4142.8	4142.5	4141.8
May 16-31	4143.1	4142.7	4142.4	4141.6
Jun 1-15	4142.9	4142.4	4142.0	4141.2
Jun 16-30	4142.6	4142.1	4141.6	4140.8
Jul 1-15	4142.0	4141.6	4141.0	4140.3
Jul 16-31	4141.4	4141.0	4140.4	4139.8
Aug	4140.8	4140.2	4139.7	4139.1
Sep	4140.3	4139.5	4139.1	4138.5

Appendix B. Alt X, Alt X Yurok, WRIMS Run-32 Refuge, and Hardy et al. (2006a) planning level flow targets, WRIMS Run-32 Refuge model flow outputs and historical (1961-2000 water years) Iron Gate discharge, by exceedence. Highlighted areas represent key months for Chinook salmon spawning and Chinook and coho salmon rearing.

Time step	10%					
	Alt X	Alt X Yurok	Run-32 Refuge Target	Run-32 Refuge Output	Hardy Phase II Recc.	Historical Iron Gate
Oct	1379	1300	1300	1300	1715	2511
Nov	1601	1300	1300	1300	2415	3152
Dec	1910	1300	1300	3234	3280	4062
Jan	2421	2421	2373	4481	3835	4348
Feb	2831	2831	2765	5894	4285	5656
Mar 1-15	3393	3393	3322	6048	4355	7748
Mar 16-31	3393	3393	3322	6470	4355	6995
Apr 1-15	3648	3648	3573	6117	4585	6381
Apr 16-30	3648	3648	3574	5761	4585	4495
May 1-15	3710	3710	3111	3651	3710	4618
May 16-31	3710	3710	3111	4014	3710	3608
Jun 1-15	3055	3055	2735	2646	3055	2523
Jun 16-30	3055	3055	2736	2515	3055	1526
Jul 1-15	2140	2140	1868	1688	2140	1050
Jul 16-31	2140	2140	1867	1636	2140	1016
Aug	1540	1540	1486	1310	1540	1094
Sep	1545	1545	1514	1311	1545	1612

Appendix B, continued. Alt X, Alt X Yurok, WRIMS Run-32 Refuge, and Hardy et al. (2006a) planning level flow targets, WRIMS Run-32 Refuge model flow outputs and historical (1961-2000 water years) Iron Gate discharge, by exceedence. Highlighted areas represent key months for Chinook salmon spawning and Chinook and coho salmon rearing.

	30%					
Time step	Alt X	Alt X Yurok	Run-32 Refuge Target	Run-32 Refuge Output	Hardy Phase II Recc.	Historical Iron Gate
Oct	1337	1300	1300	1189	1645	1761
Nov	1522	1300	1300	1266	2220	2425
Dec	1774	1300	1300	1757	2945	3389
Jan	2223	2223	2184	2780	3510	3395
Feb	2592	2592	2547	3661	3925	3770
Mar 1-15	3116	3116	3061	4240	3940	3837
Mar 16-31	3116	3116	3060	4937	3940	5368
Apr 1-15	3346	3346	3307	4210	3930	3854
Apr 16-30	3346	3346	3315	4107	3930	3567
May 1-15	3225	3225	3068	2829	3225	3082
May 16-31	3225	3225	3066	2881	3225	1969
Jun 1-15	2660	2660	2617	2254	2660	1324
Jun 16-30	2660	2660	2612	2018	2660	893
Jul 1-15	1830	1830	1777	1351	1830	756
Jul 16-31	1830	1830	1775	1218	1830	750
Aug	1335	1335	1316	1040	1335	1041
Sep	1430	1430	1416	1197	1430	1369

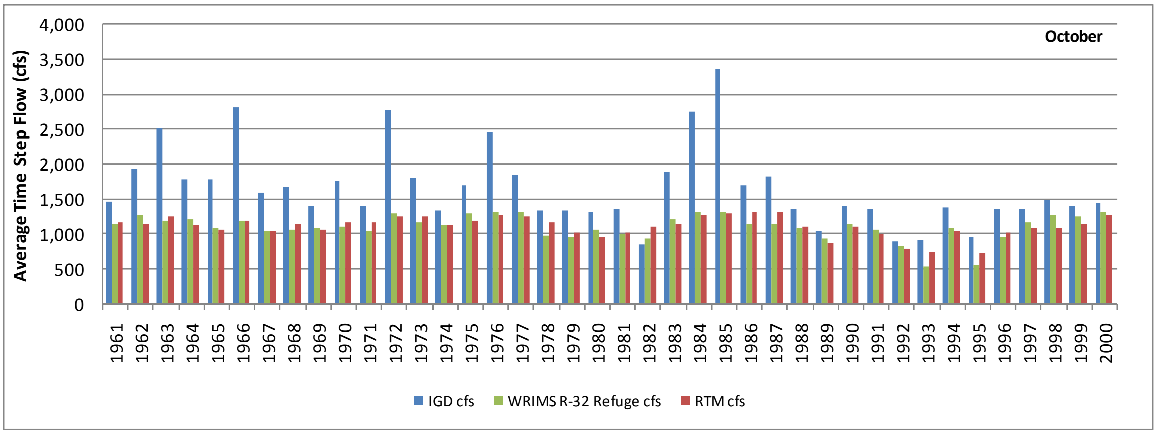
	50%					
Time step	Alt X	Alt X Yurok	Run-32 Refuge Target	Run-32 Refuge Output	Hardy Phase II Recc.	Historical Iron Gate
Oct	1294	1300	1280	1130	1565	1430
Nov	1443	1300	1278	1167	2000	1805
Dec	1638	1300	1300	1300	2545	2615
Jan	2024	2024	2043	2197	2820	2554
Feb	2353	2353	2376	2501	3015	2659
Mar 1-15	2841	2841	2868	2988	3380	2639
Mar 16-31	2841	2841	2852	3384	3380	2745
Apr 1-15	3030	3030	3020	3345	3030	2835
Apr 16-30	3030	3030	3017	3168	3030	2458
May 1-15	2675	2675	2667	2581	2675	1917
May 16-31	2675	2675	2672	2393	2675	1514
Jun 1-15	2225	2225	2270	1844	2225	931
Jun 16-30	2225	2225	2270	1676	2225	756
Jul 1-15	1330	1330	1383	1071	1330	736
Jul 16-31	1330	1330	1384	1051	1330	733
Aug	1170	1170	1187	892	1170	1029
Sep	1305	1305	1318	1097	1305	1332

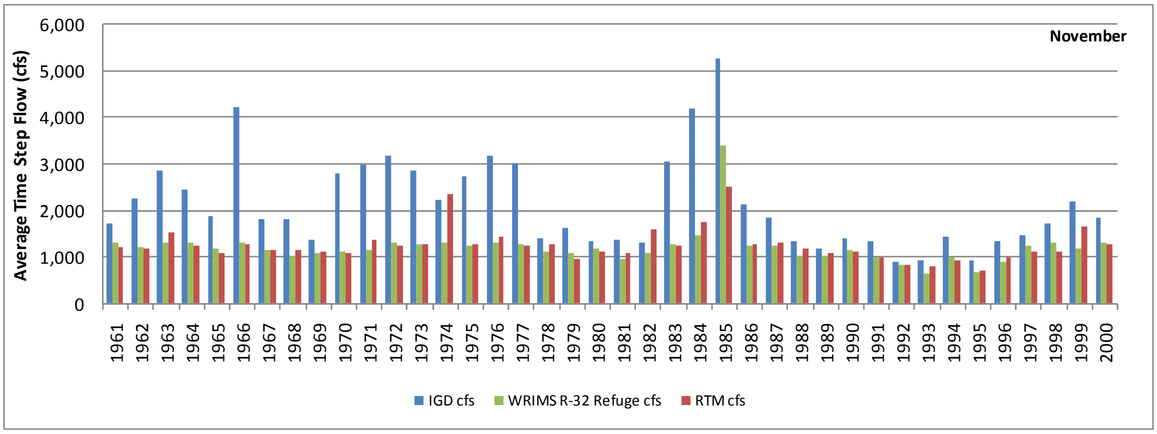
Appendix B, continued. Alt X, Alt X Yurok, WRIMS Run-32 Refuge, and Hardy et al. (2006a) planning level flow targets, WRIMS Run-32 Refuge model flow outputs and historical (1961-2000 water years) Iron Gate discharge, by exceedence. Highlighted areas represent key months for Chinook salmon spawning and Chinook and coho salmon rearing.

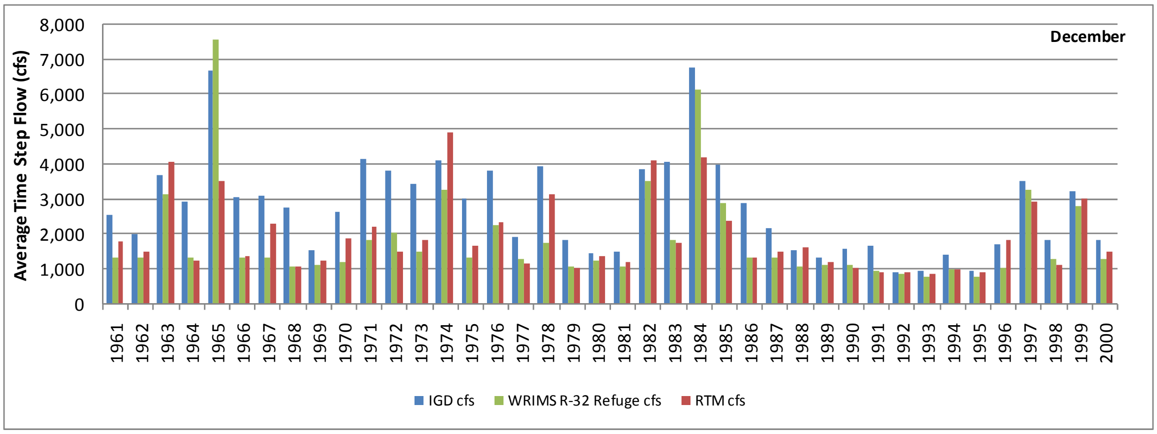
	70%					
Time step	Alt X	Alt X Yurok	Run-32 Refuge Target	Run-32 Refuge Output	Hardy Phase II Recc.	Historical Iron Gate
Oct	1251	1100	1142	1056	1490	1345
Nov	1363	1100	1141	1086	1775	1390
Dec	1502	1100	1137	1114	1950	1682
Jan	1825	1100	1286	1266	2015	1827
Feb	2114	1100	1348	1489	2135	1806
Mar 1-15	2350	2350	2448	2538	2350	2065
Mar 16-31	2350	2350	2448	2774	2350	1998
Apr 1-15	2260	2260	2412	2234	2260	1647
Apr 16-30	2260	2260	2412	2167	2260	1398
May 1-15	2050	2050	2176	1944	2050	1188
May 16-31	2050	2050	2169	2033	2050	1039
Jun 1-15	1635	1635	1752	1564	1635	767
Jun 16-30	1635	1635	1751	1429	1635	742
Jul 1-15	1070	1070	1119	925	1070	721
Jul 16-31	1070	1070	1122	921	1070	724
Aug	1005	1005	1038	822	1005	1014
Sep	1160	1160	1189	984	1160	1304

	90%					
Time step	Alt X	Alt X Yurok	Run-32 Refuge Target	Run-32 Refuge Output	Hardy Phase II Recc.	Historical Iron Gate
Oct	1207	1000	1028	931	1415	1037
Nov	1284	1000	1027	943	1545	1306
Dec	1366	1000	1024	969	1380	1324
Jan	1245	1000	1025	989	1245	1292
Feb	1485	1000	1024	995	1485	1105
Mar 1-15	1410	1410	1655	1520	1410	1283
Mar 16-31	1410	1410	1655	1616	1410	1294
Apr 1-15	1530	1530	1705	1608	1530	1191
Apr 16-30	1530	1530	1709	1540	1530	1021
May 1-15	1220	1220	1428	1242	1220	1010
May 16-31	1220	1220	1428	1371	1220	979
Jun 1-15	1080	1080	1218	1105	1080	732
Jun 16-30	1080	1080	1217	1094	1080	702
Jul 1-15	840	840	896	798	840	611
Jul 16-31	840	840	895	786	840	654
Aug	895	895	922	763	895	701
Sep	1010	1010	1046	902	1010	906

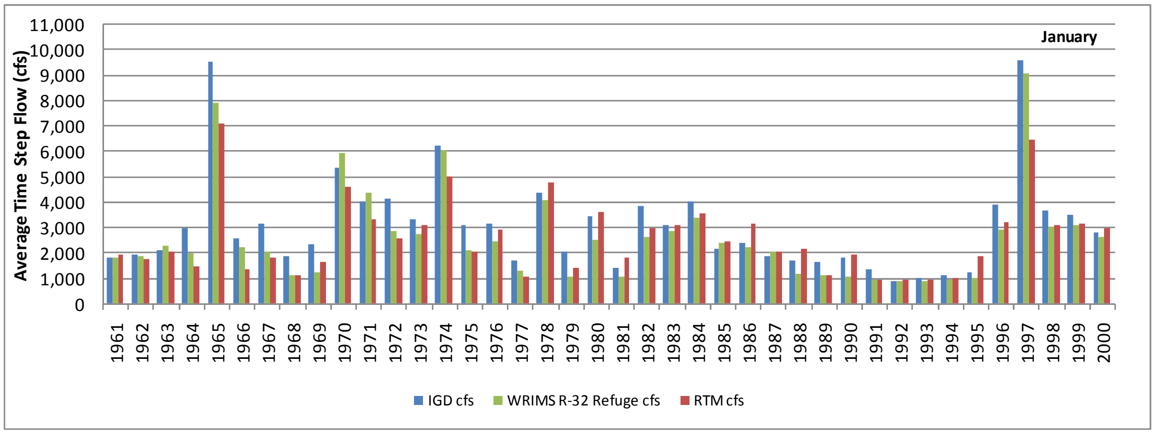
Appendix C. Comparison of the average flow, by time step, for the historical Iron Gate records, WRIMS Run-32 Refuge model simulation outputs, and real-time management process (RTM) for the period of record, water years 1961-2000.

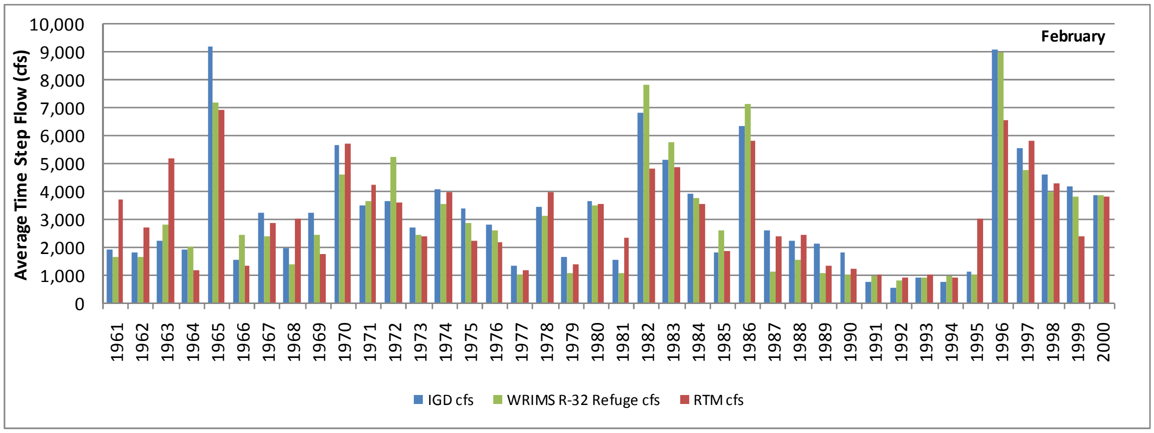


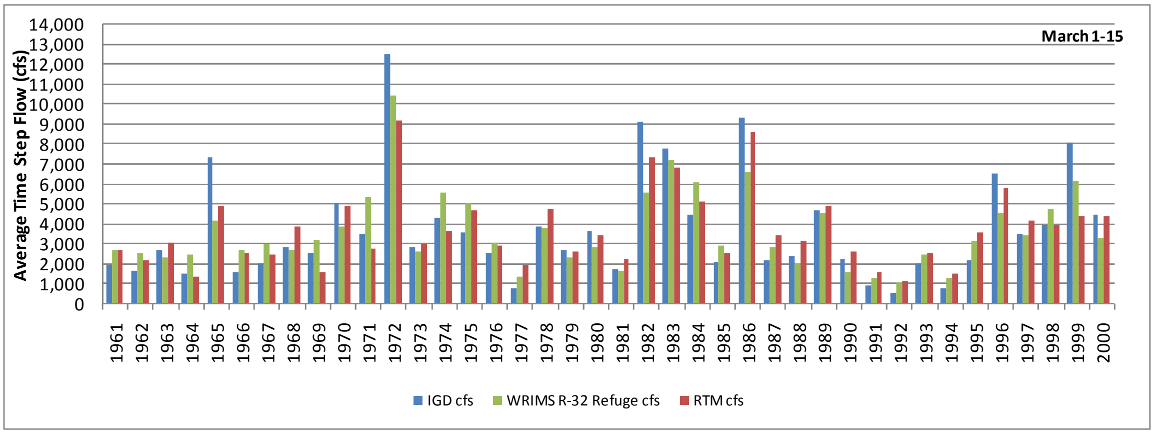




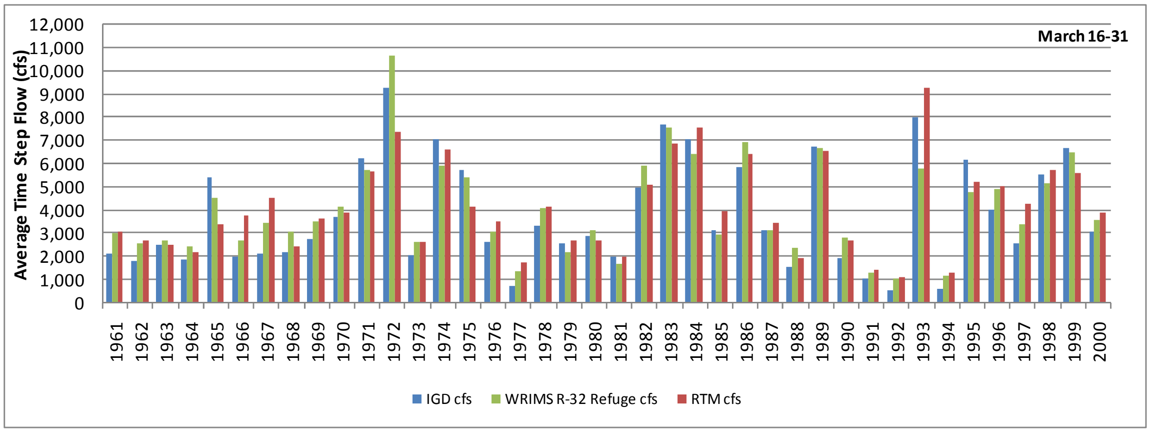
Appendix C, continued. Comparison of the average flow, by time step, for the historical Iron Gate records, WRIMS Run-32 Refuge model simulation outputs, and real-time management process (RTM) for the period of record, water years 1961-2000.

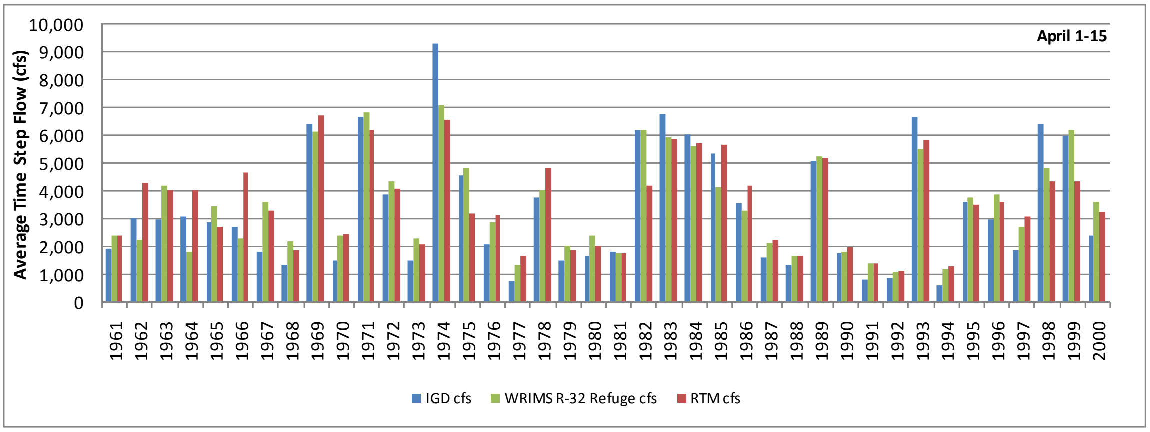


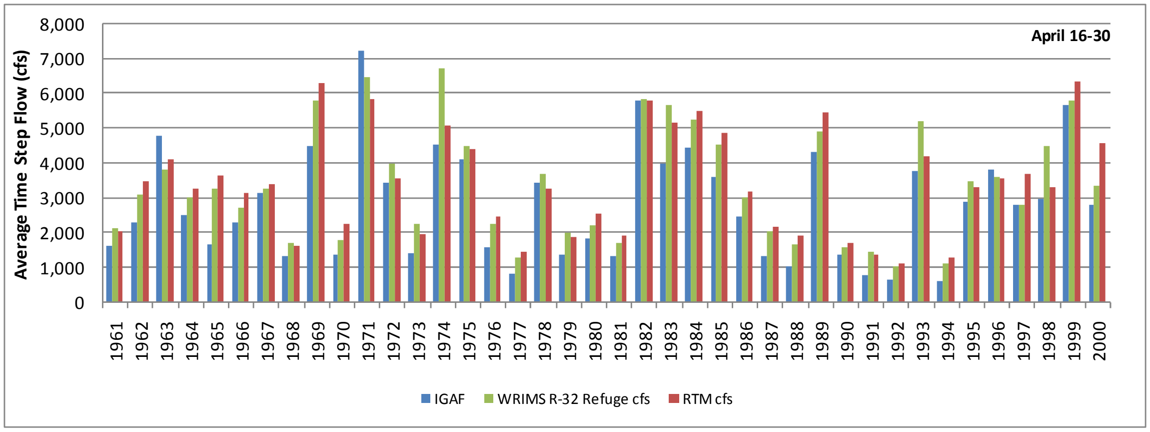




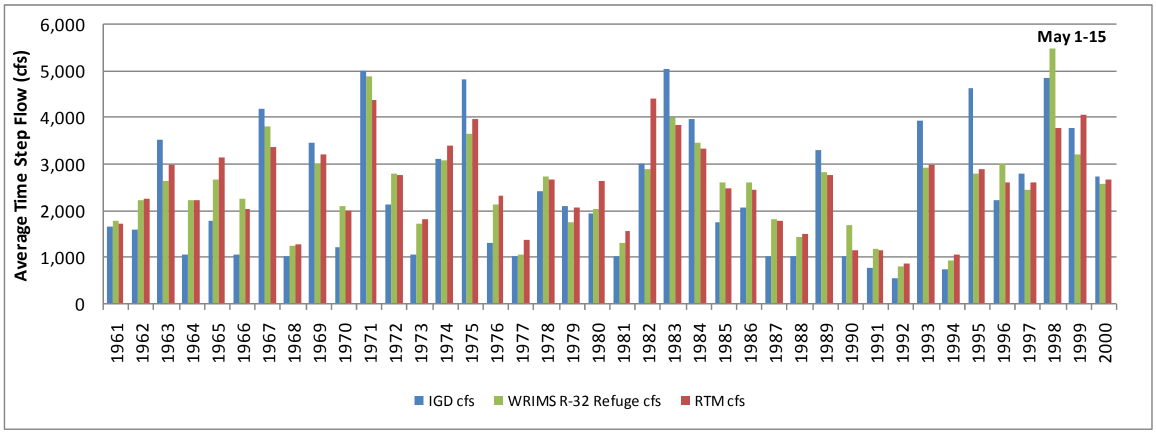
Appendix C, continued. Comparison of the average flow, by time step, for the historical Iron Gate records, WRIMS Run-32 Refuge model simulation outputs, and real-time management process (RTM) for the period of record, water years 1961-2000.

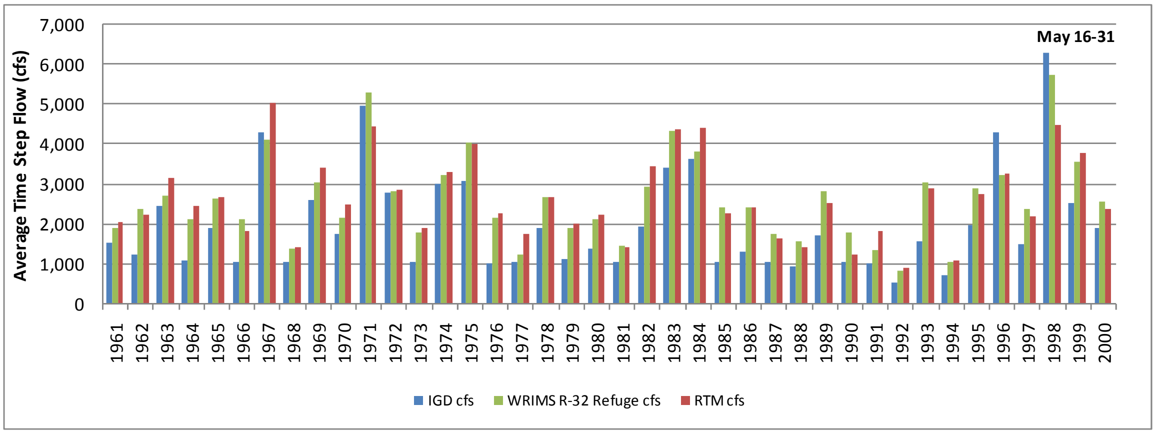


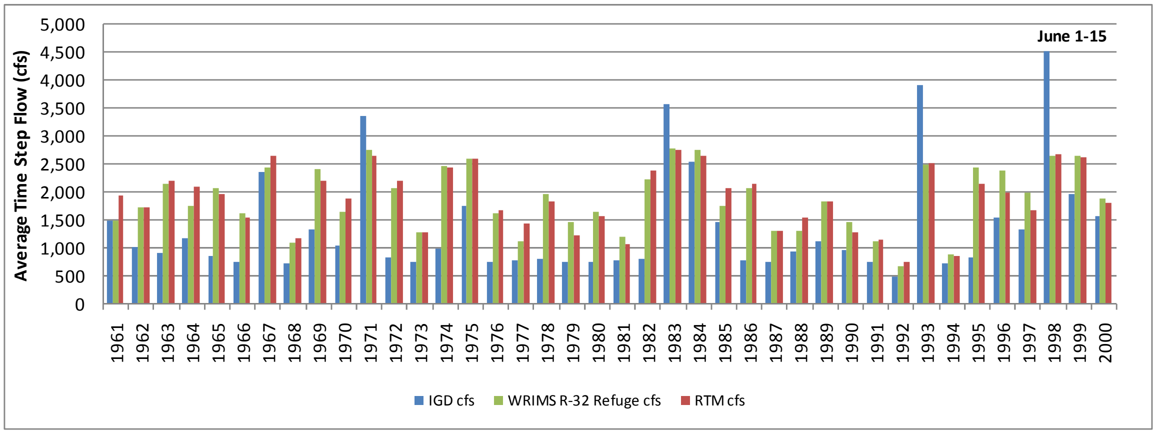




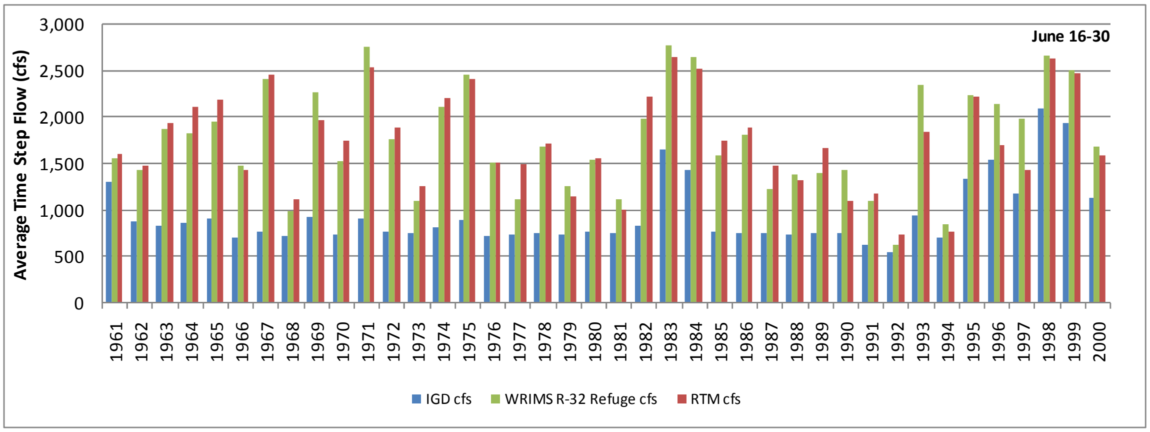
Appendix C, continued. Comparison of the average flow, by time step, for the historical Iron Gate records, WRIMS Run-32 Refuge model simulation outputs, and real-time management process (RTM) for the period of record, water years 1961-2000.

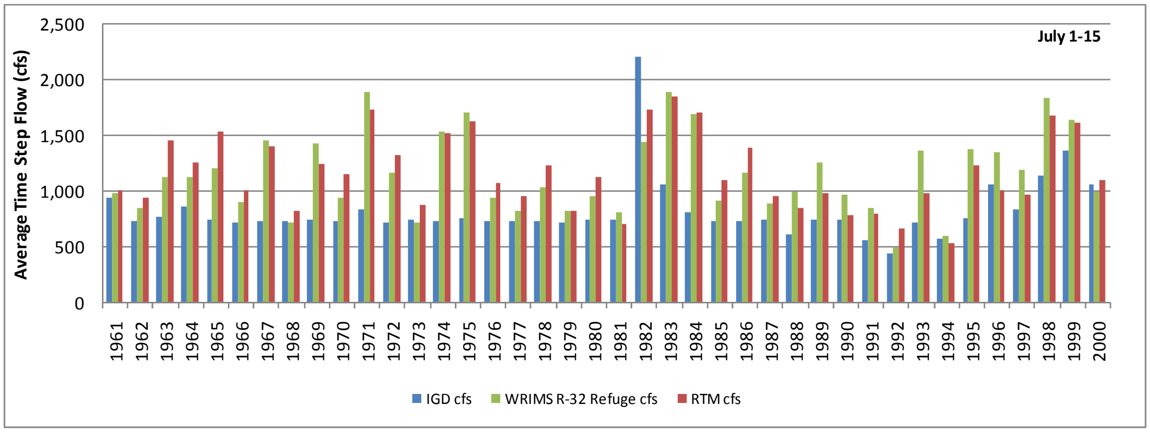


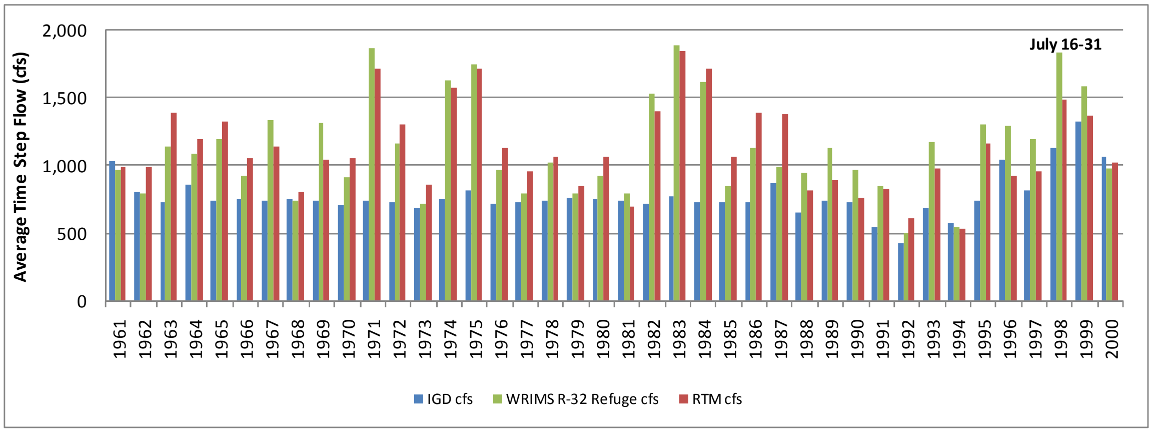




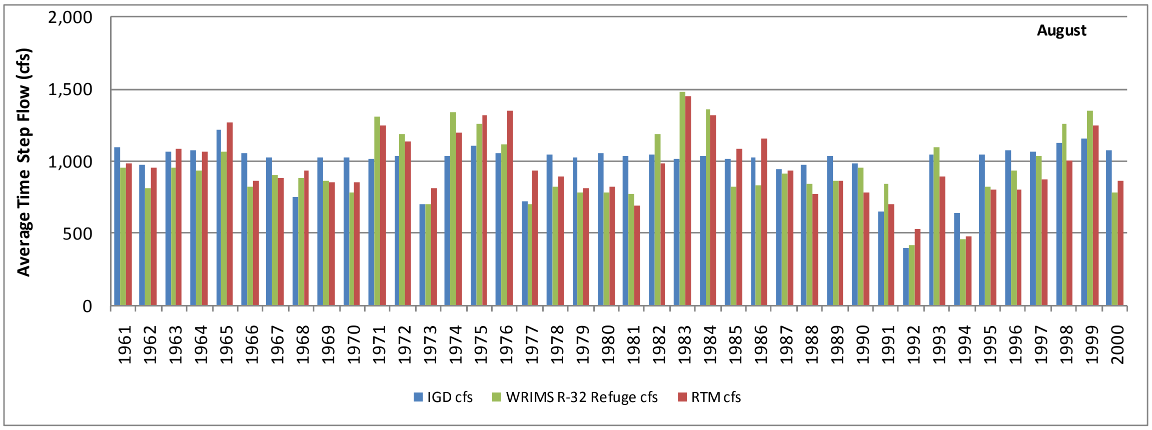
Appendix C, continued. Comparison of the average flow, by time step, for the historical Iron Gate records, WRIMS Run-32 Refuge model simulation outputs, and real-time management process (RTM) for the period of record, water years 1961-2000.

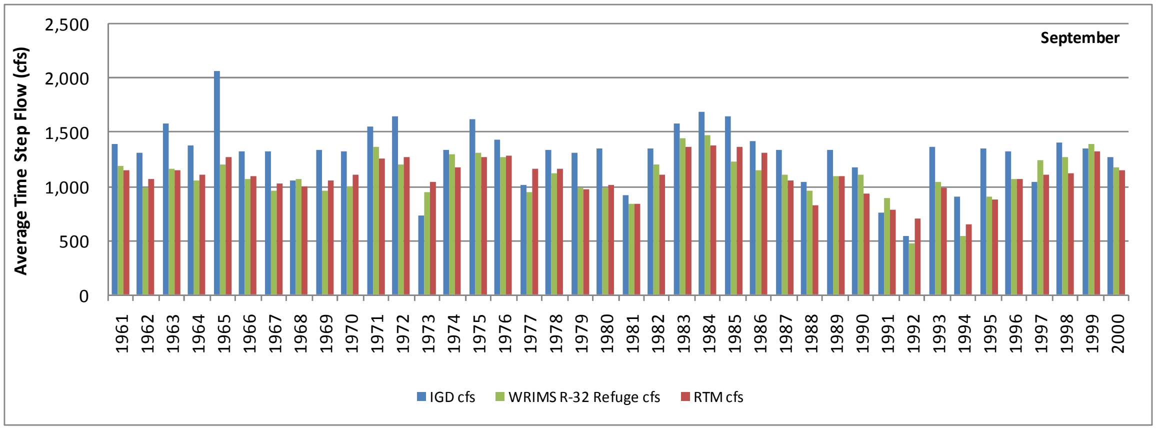






Appendix C, continued. Comparison of the average flow, by time step, for the historical Iron Gate records, WRIMS Run-32 Refuge model simulation outputs, and real-time management process (RTM) for the period of record, water years 1961-2000.





Appendix D. Average historical flows (cfs) by time step recorded at the USGS Klamath River below Iron Gate Dam, CA gage (a) and difference between WRIMS R-32 Refuge model simulated flows and historical Iron Gate Dam flows (b) for water years 1961-2000.

(a) Historical Average Flows at USGS Iron Gate Dam Gage (cfs)

Water Year	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
1961	1,461	1,716	2,524	1,773	1,906	1,910	2,094	1,913	1,599	1,640	1,514	1,480	1,295	940	1,023	1,094	1,382
1962	1,907	2,253	1,985	1,907	1,769	1,599	1,748	2,985	2,284	1,573	1,211	987	870	725	804	968	1,309
1963	2,511	2,852	3,661	2,103	2,189	2,669	2,435	2,942	4,741	3,489	2,420	891	823	758	729	1,058	1,574
1964	1,761	2,425	2,908	2,936	1,953	1,439	1,811	3,067	2,493	1,048	1,074	1,159	851	856	857	1,073	1,369
1965	1,774	1,876	6,653	9,489	9,150	7,306	5,368	2,835	1,629	1,765	1,887	838	893	738	737	1,208	2,052
1966	2,798	4,188	3,040	2,554	1,546	1,558	1,981	2,693	2,271	1,053	1,018	728	696	714	743	1,052	1,313
1967	1,574	1,796	3,069	3,099	3,212	1,987	2,101	1,781	3,135	4,174	4,283	2,337	755	721	732	1,016	1,311
1968	1,654	1,805	2,725	1,870	1,997	2,790	2,148	1,311	1,300	1,019	1,018	712	703	727	742	747	1,048
1969	1,382	1,356	1,498	2,287	3,204	2,527	2,745	6,381	4,444	3,457	2,590	1,320	922	738	730	1,023	1,332
1970	1,745	2,773	2,615	5,327	5,656	5,017	3,682	1,495	1,330	1,188	1,714	1,017	719	722	705	1,020	1,310
1971	1,379	2,953	4,122	4,016	3,447	3,441	6,214	6,639	7,205	5,001	4,946	3,353	896	828	731	1,014	1,541
1972	2,753	3,152	3,777	4,100	3,770	12,447	9,219	3,854	3,429	2,125	2,748	810	764	712	725	1,029	1,640
1973	1,791	2,827	3,389	3,292	2,659	2,817	1,998	1,458	1,377	1,042	1,026	744	747	731	682	701	725
1974	1,333	2,221	4,076	6,177	4,065	4,261	6,995	9,254	4,495	3,082	2,995	966	807	730	744	1,030	1,327
1975	1,688	2,708	3,002	3,085	3,361	3,567	5,667	4,507	4,079	4,792	3,044	1,744	883	744	811	1,098	1,612
1976	2,432	3,156	3,805	3,132	2,885	2,540	2,592	2,047	1,578	1,283	1,003	749	717	718	717	1,054	1,428
1977	1,827	2,986	1,894	1,656	1,336	725	724	728	794	1,010	1,019	759	725	719	720	718	1,014
1978	1,322	1,390	3,903	4,348	3,435	3,837	3,314	3,731	3,422	2,403	1,875	801	742	730	734	1,041	1,326
1979	1,329	1,623	1,824	2,027	1,644	2,639	2,555	1,455	1,326	2,083	1,098	742	721	709	756	1,022	1,304
1980	1,308	1,337	1,435	3,395	3,747	3,634	2,843	1,647	1,799	1,917	1,354	740	756	741	750	1,051	1,348
1981	1,342	1,343	1,465	1,364	1,541	1,667	1,958	1,767	1,325	1,025	1,039	767	735	739	733	1,033	916
1982	852	1,306	3,836	3,810	6,777	9,077	4,904	6,179	5,763	3,011	1,914	793	815	2,194	712	1,039	1,345
1983	1,874	3,021	4,062	3,075	5,123	7,748	7,619	6,755	3,952	5,005	3,383	3,545	1,637	1,053	763	1,014	1,567
1984	2,746	4,167	6,735	4,013	4,024	4,427	7,038	5,981	4,403	3,942	3,608	2,523	1,423	796	728	1,030	1,674
1985	3,353	5,254	3,976	2,142	1,764	2,065	3,119	5,323	3,567	1,730	1,026	1,434	755	721	723	1,011	1,645
1986	1,675	2,129	2,859	2,365	6,332	9,312	5,795	3,512	2,458	2,064	1,294	760	742	727	729	1,015	1,405
1987	1,801	1,844	2,143	1,827	2,579	2,161	3,101	1,601	1,305	1,010	1,016	732	748	741	859	935	1,332
1988	1,341	1,331	1,517	1,682	2,296	2,386	1,494	1,309	1,021	1,025	924	931	726	611	654	974	1,038
1989	1,037	1,166	1,324	1,605	2,125	4,627	6,690	5,041	4,310	3,283	1,702	1,098	744	741	739	1,035	1,337
1990	1,382	1,400	1,541	1,812	1,806	2,190	1,896	1,742	1,347	1,021	1,043	959	746	736	724	979	1,168
1991	1,345	1,324	1,621	1,334	747	849	993	801	754	761	979	741	612	547	542	647	749
1992	879	873	889	888	543	501	521	843	636	525	501	476	536	429	427	398	538
1993	904	915	914	1,011	910	1,953	7,962	6,619	3,763	3,901	1,529	3,883	934	705	680	1,039	1,359
1994	1,375	1,414	1,387	1,127	730	712	572	569	574	741	714	706	702	572	575	636	906
1995	937	909	944	1,191	1,105	2,143	6,151	3,583	2,853	4,618	1,969	827	1,320	756	735	1,040	1,350
1996	1,345	1,337	1,682	3,885	9,354	6,519	4,009	2,955	3,795	2,204	4,288	1,538	1,526	1,050	1,037	1,065	1,316
1997	1,346	1,461	3,494	9,553	5,545	3,447	2,553	1,863	2,791	2,784	1,466	1,324	1,163	831	809	1,058	1,035
1998	1,483	1,703	1,798	3,618	4,558	3,914	5,467	6,357	2,967	4,825	6,247	4,495	2,084	1,128	1,122	1,119	1,395
1999	1,398	2,171	3,207	3,475	4,163	8,018	6,649	5,932	5,636	3,760	2,486	1,948	1,921	1,359	1,314	1,149	1,341
2000	1,430	1,822	1,822	2,792	3,816	2,239	1,520	1,191	1,398	1,361	954	782	563	529	532	538	638

(b) WRIMS R-32 Refuge model simulated flows minus historical Iron Gate Dam flows (in cfs).

Water Year	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
1961	-317	-416	-1,224	29	-281	727	895	462	521	118	379	3	257	40	-61	-140	-191
1962	-638	-1,060	-688	-30	-119	883	751	-782	813	648	1,161	716	555	116	-9	-155	-323
1963	-1,325	-1,552	-528	156	585	-388	200	1,228	-949	-849	273	1,235	1,050	359	408	-108	-411
1964	-551	-1,135	-1,608	-949	64	964	577	-1,250	522	1,166	1,019	593	972	258	225	-144	-319
1965	-709	-712	885	-1,595	-1,978	-3,167	-882	603	1,610	876	731	1,214	1,045	465	451	-148	-855
1966	-1,613	-2,888	-1,740	-339	856	1,077	706	-419	447	1,189	1,087	871	777	185	177	-235	-246
1967	-539	-654	-1,769	-1,046	-825	967	1,325	1,787	105	-382	-188	94	1,645	730	604	-116	-359
1968	-592	-780	-1,669	-780	-622	-97	918	830	398	229	360	362	283	-10	-10	137	21
1969	-304	-266	-408	-1,075	-797	640	746	-267	1,341	-464	433	1,074	1,336	682	576	-160	-379
1970	-642	-1,665	-1,449	577	-1,049	-1,191	418	894	433	886	429	607	792	207	200	-242	-317
1971	-338	-1,808	-2,307	307	192	1,908	-504	136	-764	-132	335	-619	1,854	1,051	1,126	294	-187
1972	-1,465	-1,852	-1,742	-1,231	1,433	-2,063	1,417	451	529	653	47	1,258	995	450	434	160	-440
1973	-632	-1,558	-1,933	-541	-219	-256	619	790	849	674	730	509	342	-14	37	-6	215
1974	-210	-921	-842	-120	-517	1,239	-1,135	-2,192	2,207	-22	202	1,480	1,294	796	880	301	-29
1975	-398	-1,465	-1,702	-1,011	-497	1,441	-262	269	375	-1,156	961	845	1,565	962	927	153	-305
1976	-1,132	-1,856	-1,579	-723	-295	483	466	816	676	852	1,129	861	790	219	242	58	-160
1977	-527	-1,734	-645	-367	-336	592	591	604	456	34	207	341	379	96	75	-19	-73
1978	-347	-282	-2,160	-290	-321	-60	759	255	229	306	784	1,141	936	297	285	-223	-208
1979	-376	-549	-783	-963	-605	-383	-428	544	670	-331	780	702	526	104	36	-244	-324
1980	-250	-168	-207	-878	-259	-814	278	704	388	95	760	891	772	204	172	-276	-369
1981	-346	-392	-415	-324	-502	-18	-309	-53	367	279	401	420	378	67	62	-262	-80
1982	67	-231	-351	-1,199	1,030	-3,537	990	7	64	-132	1,000	1,414	1,166	-757	817	146	-148
1983	-679	-1,755	-2,269	-228	634	-568	-118	-861	1,687	-1,031	945	-785	1,123	827	1,118	465	-125
1984	-1,446	-2,718	-606	-668	-275	1,611	-625	-395	817	-499	184	224	1,225	890	885	323	-207
1985	-2,053	-1,879	-1,097	251	799	809	-225	-1,215	958	866	1,357	314	833	194	126	-187	-417
1986	-528	-882	-1,559	-187	798	-2,717	1,071	-259	517	524	1,109	1,294	1,063	435	398	-182	-254
1987	-664	-624	-843	206	-1,458	623	-19	511	735	777	707	564	471	137	131	-27	-221
1988	-276	-335	-455	-551	-759	-360	856	323	611	413	624	370	651	377	283	-139	-86
1989	-105	-151	-208	-527	-1,073	-151	-39	151	597	-476	1,092	722	643	515	388	-176	-251
1990	-237	-250	-430	-758	-791	-648	915	65	205	651	712	479	685	226	239	-24	-61
1991	-293	-331	-698	-384	203	391	282	593	679	417	336	364	483	298	304	194	145
1992	-63	-46	-28	-38	266	511	482	201	370	269	318	196	80	55	69	16	-61
1993	-383	-281	-145	-170	-32	479	-2,204	-1,115	1,425	-981	1,483	-1,405	1,407	657	489	50	-326
1994	-299	-433	-413	-172	198	516	561	596	532	167	326	177	135	27	-33	-183	-368
1995	-388	-235	-189	-198	-92	938	-1,409	184	591	-1,826	898	1,587	918	611	564	-217	-447
1996	-405	-455	-657	-978	-387	-2,012	838	891	-229	805	-1,064	828	610	297	251	-136	-248
1997	-185	-214	-249	-509	-801	-76	789	832	-18	-350	897	648	820	355	378	-27	204
1998	-229	-403	-512	-590	-620	838	-319	-1,536	1,507	633	-512	-1,848	572	707	713	139	-136
1999	-149	-1,005	-409	-395	-360	-1,879	-200	210	122	-576	1,058	697	580	272	267	196	43
2000	-130	-522	-551	-186	-103	1,009	2,015	2,389	1,921	1,214	1,607	1,086	1,111	460	446	242	526

Appendix E. Historical Upper Klamath Lake elevations by end of time steps (a) and WRIMS R-32 Refuge model simulated flows minus historical Upper Klamath Lake elevations (b) for water years 1961-2000.

(a) Historical Upper Klamath Lake elevations (ft)

Water Year	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
1961	4,138.6	4,139.5	4,140.0	4,140.1	4,141.4	4,141.9	4,142.4	4,142.5	4,142.6	4,142.5	4,142.4	4,142.1	4,141.8	4,141.1	4,140.4	4,139.6	4,139.0
1962	4,138.9	4,139.0	4,139.5	4,139.4	4,140.8	4,141.4	4,142.1	4,142.4	4,142.8	4,142.9	4,143.0	4,142.6	4,142.1	4,141.4	4,140.8	4,140.0	4,139.2
1963	4,140.3	4,140.5	4,140.8	4,140.6	4,142.4	4,142.5	4,142.7	4,142.8	4,143.0	4,143.0	4,143.0	4,142.6	4,142.3	4,141.9	4,141.5	4,140.6	4,140.0
1964	4,140.0	4,140.3	4,139.9	4,139.7	4,140.2	4,140.8	4,141.4	4,141.8	4,142.2	4,142.3	4,142.4	4,142.6	4,142.8	4,142.4	4,141.9	4,141.2	4,140.5
1965	4,140.2	4,140.7	4,143.5	4,143.0	4,142.2	4,141.6	4,141.1	4,141.7	4,142.3	4,142.6	4,142.9	4,142.9	4,143.0	4,142.7	4,142.5	4,142.2	4,141.5
1966	4,140.8	4,139.7	4,139.6	4,139.5	4,140.3	4,141.1	4,141.9	4,142.1	4,142.4	4,142.4	4,142.4	4,142.2	4,142.0	4,141.6	4,141.2	4,140.1	4,139.7
1967	4,139.4	4,140.0	4,140.2	4,140.4	4,140.6	4,141.3	4,142.0	4,142.4	4,142.9	4,143.0	4,143.0	4,143.0	4,143.0	4,142.5	4,142.0	4,140.9	4,140.2
1968	4,140.2	4,140.2	4,139.8	4,140.2	4,141.8	4,142.0	4,142.1	4,141.9	4,141.7	4,141.5	4,141.4	4,140.9	4,140.4	4,139.7	4,139.1	4,138.9	4,138.6
1969	4,138.6	4,139.5	4,140.4	4,141.3	4,141.4	4,141.9	4,142.4	4,142.7	4,143.0	4,143.0	4,143.1	4,143.1	4,143.1	4,142.6	4,142.2	4,141.2	4,140.5
1970	4,140.6	4,139.9	4,140.8	4,142.4	4,142.2	4,142.3	4,142.4	4,142.7	4,143.0	4,143.1	4,143.2	4,142.9	4,142.7	4,142.2	4,141.7	4,140.5	4,139.9
1971	4,140.1	4,140.7	4,140.4	4,141.2	4,141.8	4,142.2	4,142.7	4,142.6	4,142.6	4,142.8	4,143.0	4,143.0	4,143.1	4,142.9	4,142.7	4,141.9	4,141.8
1972	4,141.3	4,141.2	4,140.8	4,140.3	4,142.1	4,142.1	4,142.2	4,142.5	4,142.8	4,142.9	4,143.0	4,143.0	4,143.0	4,142.6	4,142.2	4,141.6	4,141.1
1973	4,141.2	4,141.1	4,141.2	4,141.3	4,141.7	4,142.0	4,142.3	4,142.4	4,142.6	4,142.5	4,142.4	4,141.8	4,141.3	4,140.7	4,140.1	4,139.1	4,139.1
1974	4,139.6	4,141.2	4,141.5	4,142.0	4,142.2	4,142.4	4,142.6	4,142.7	4,142.7	4,142.9	4,143.0	4,143.0	4,142.9	4,142.7	4,142.5	4,141.9	4,141.5
1975	4,141.4	4,141.0	4,140.9	4,140.8	4,141.4	4,141.8	4,142.2	4,142.4	4,142.7	4,142.8	4,143.0	4,143.0	4,143.1	4,142.9	4,142.7	4,142.1	4,141.6
1976	4,141.4	4,141.2	4,140.9	4,140.9	4,141.3	4,141.7	4,142.1	4,142.4	4,142.6	4,142.7	4,142.7	4,142.5	4,142.2	4,141.8	4,141.4	4,141.8	4,141.5
1977	4,141.4	4,140.8	4,140.8	4,140.9	4,141.5	4,142.1	4,142.7	4,142.6	4,142.5	4,142.6	4,142.7	4,142.5	4,142.2	4,141.5	4,140.8	4,139.8	4,139.5
1978	4,139.6	4,140.5	4,141.1	4,141.5	4,141.8	4,142.2	4,142.5	4,142.7	4,142.9	4,142.9	4,143.0	4,142.7	4,142.4	4,142.0	4,141.6	4,140.5	4,140.4
1979	4,140.3	4,140.4	4,140.6	4,141.2	4,141.9	4,142.2	4,142.4	4,142.6	4,142.8	4,142.8	4,142.7	4,142.1	4,141.4	4,140.7	4,140.0	4,138.9	4,138.2
1980	4,138.4	4,139.4	4,140.6	4,141.7	4,142.2	4,142.4	4,142.5	4,142.8	4,143.1	4,143.0	4,143.0	4,142.8	4,142.6	4,142.0	4,141.4	4,140.0	4,139.4
1981	4,139.4	4,139.7	4,140.6	4,141.3	4,142.4	4,142.6	4,142.8	4,142.9	4,143.0	4,142.9	4,142.8	4,142.2	4,141.6	4,140.8	4,140.1	4,138.4	4,137.6
1982	4,138.3	4,140.0	4,141.8	4,141.5	4,142.9	4,142.7	4,142.4	4,142.5	4,142.6	4,142.8	4,143.0	4,143.1	4,143.3	4,142.9	4,142.5	4,141.6	4,141.4
1983	4,141.4	4,141.0	4,140.7	4,141.1	4,142.1	4,142.2	4,142.4	4,142.6	4,142.8	4,143.0	4,143.1	4,143.0	4,142.9	4,142.8	4,142.6	4,142.3	4,142.0
1984	4,141.4	4,141.0	4,140.8	4,141.1	4,141.7	4,142.1	4,142.6	4,142.7	4,142.9	4,142.9	4,143.0	4,143.0	4,143.0	4,142.7	4,142.3	4,141.8	4,141.8
1985	4,141.4	4,140.9	4,140.4	4,140.8	4,141.6	4,142.1	4,142.6	4,142.8	4,143.0	4,143.0	4,143.0	4,142.7	4,142.4	4,141.8	4,141.2	4,140.5	4,140.6
1986	4,140.9	4,141.1	4,140.7	4,141.6	4,142.7	4,142.7	4,142.6	4,142.7	4,142.8	4,142.9	4,143.1	4,142.8	4,142.6	4,142.0	4,141.5	4,140.4	4,140.4
1987	4,140.5	4,140.8	4,140.9	4,141.5	4,141.9	4,142.2	4,142.6	4,142.6	4,142.7	4,142.5	4,142.2	4,141.9	4,141.6	4,141.3	4,141.0	4,140.1	4,139.3
1988	4,139.1	4,139.4	4,140.6	4,141.4	4,142.0	4,142.4	4,142.7	4,142.8	4,143.0	4,142.9	4,142.9	4,142.7	4,142.5	4,141.7	4,140.9	4,139.5	4,138.7
1989	4,138.7	4,139.9	4,140.6	4,141.1	4,141.3	4,141.9	4,142.5	4,142.7	4,142.9	4,143.0	4,143.1	4,142.7	4,142.3	4,141.6	4,140.9	4,139.9	4,139.6
1990	4,139.9	4,140.3	4,140.6	4,141.4	4,141.7	4,142.2	4,142.7	4,142.8	4,142.8	4,142.8	4,142.7	4,142.4	4,142.1	4,141.4	4,140.7	4,139.6	4,138.9
1991	4,138.8	4,139.0	4,138.8	4,139.5	4,140.4	4,141.1	4,141.7	4,141.9	4,142.2	4,142.3	4,142.4	4,142.0	4,141.5	4,140.9	4,140.3	4,139.0	4,138.2
1992	4,138.2	4,139.0	4,139.7	4,140.3	4,140.9	4,141.4	4,141.8	4,141.7	4,141.7	4,141.2	4,140.7	4,140.1	4,139.5	4,139.1	4,138.8	4,137.7	4,137.4
1993	4,137.6	4,138.3	4,139.3	4,140.0	4,140.9	4,141.8	4,142.7	4,142.8	4,143.0	4,143.2	4,143.3	4,143.0	4,142.7	4,142.1	4,141.5	4,140.5	4,139.5
1994	4,139.6	4,139.7	4,139.9	4,140.6	4,141.4	4,141.8	4,142.2	4,142.2	4,142.1	4,142.1	4,142.0	4,141.4	4,140.8	4,139.9	4,139.0	4,137.5	4,136.8
1995	4,136.9	4,137.8	4,138.6	4,140.3	4,142.0	4,142.3	4,142.7	4,143.0	4,143.2	4,143.2	4,143.1	4,143.1	4,143.1	4,142.7	4,142.2	4,140.7	4,139.7
1996	4,139.4	4,139.6	4,141.3	4,141.9	4,142.3	4,142.5	4,142.6	4,142.9	4,143.1	4,143.1	4,143.1	4,142.7	4,142.2	4,141.5	4,140.8	4,139.7	4,139.0
1997	4,139.0	4,139.9	4,141.6	4,141.8	4,142.0	4,142.3	4,142.5	4,142.8	4,143.1	4,143.0	4,142.9	4,142.5	4,142.2	4,141.7	4,141.3	4,140.4	4,140.2
1998	4,140.3	4,140.9	4,141.1	4,142.0	4,142.1	4,142.4	4,142.7	4,142.8	4,143.0	4,143.1	4,143.1	4,143.1	4,143.0	4,142.5	4,142.0	4,140.7	4,140.0
1999	4,140.3	4,141.3	4,141.5	4,141.7	4,142.0	4,141.9	4,141.8	4,142.0	4,142.3	4,142.6	4,142.9	4,142.7	4,142.5	4,141.9	4,141.3	4,140.8	4,140.3
2000	4,140.5	4,140.8	4,141.5	4,142.1	4,142.3	4,142.3	4,142.4	4,142.8	4,143.2	4,143.1	4,143.0	4,142.5	4,142.1	4,141.4	4,140.8	4,139.4	4,139.6

(b) WRIMS R-32 Refuge model simulated flows minus historical Upper Klamath Lake elevations (ft).

Water Year	October	November	December	January	Febuary	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	Jul y 1-15	July 16-31	August	September
1961	1.03	0.94	1.58	1.53	1.35	1.03	0.60	0.37	0.23	0.16	0.07	0.04	-0.02	0.12	0.24	0.44	0.52
1962	0.80	1.32	1.54	1.65	1.36	0.94	0.54	0.57	0.33	0.01	-0.35	-0.57	-0.70	-0.65	-0.61	-0.40	-0.20
1963	0.30	1.05	1.12	1.03	0.35	0.37	0.29	0.16	0.12	0.16	0.18	-0.21	-0.50	-0.63	-0.79	-0.72	-0.48
1964	-0.34	0.16	1.30	2.03	1.76	1.35	0.94	1.13	0.95	0.46	0.00	-0.38	-0.81	-0.98	-1.16	-1.29	-1.32
1965	-1.02	-0.79	-1.60	-0.72	0.52	1.26	1.90	1.32	0.80	0.32	-0.14	-0.67	-1.16	-1.48	-1.82	-2.04	-1.87
1966	-0.83	1.17	2.22	2.48	1.70	1.21	0.72	0.74	0.62	0.23	-0.11	-0.40	-0.67	-0.69	-0.75	-0.49	-0.48
1967	-0.25	0.00	1.06	1.60	2.09	1.64	1.03	0.59	0.24	0.25	0.16	-0.25	-0.65	-0.88	-1.12	-1.15	-1.21
1968	-1.03	-0.65	0.58	0.97	0.92	0.95	0.87	0.68	0.64	0.61	0.55	0.56	0.59	0.74	0.89	0.80	0.56
1969	0.67	0.45	0.45	0.98	1.33	1.03	0.62	0.32	0.11	0.03	-0.05	-0.52	-0.96	-1.22	-1.50	-1.51	-1.48
1970	-1.31	-0.18	0.66	-0.10	0.50	0.60	0.59	0.21	0.02	-0.28	-0.60	-0.85	-1.08	-1.16	-1.27	-0.96	-0.90
1971	-0.95	0.02	1.55	1.12	0.95	0.70	0.35	0.40	0.55	0.44	0.24	-0.08	-0.39	-0.87	-1.35	-1.70	-1.96
1972	-1.12	-0.07	1.06	2.02	0.65	0.77	0.78	0.49	0.30	0.08	-0.12	-0.59	-0.97	-1.12	-1.29	-1.57	-1.53
1973	-1.28	-0.39	0.75	0.97	0.98	0.84	0.69	0.43	0.18	-0.03	-0.25	-0.29	-0.31	-0.19	-0.07	0.07	-0.26
1974	-0.36	-0.03	0.36	0.32	0.54	0.52	0.40	0.34	0.37	0.29	0.20	-0.31	-0.70	-0.95	-1.25	-1.55	-1.77
1975	-1.63	-0.72	0.48	1.11	1.35	1.13	0.80	0.56	0.41	0.37	0.23	-0.24	-0.65	-0.98	-1.36	-1.60	-1.68
1976	-1.07	0.07	1.05	1.42	1.45	1.19	0.93	0.54	0.35	0.03	-0.28	-0.55	-0.79	-0.84	-0.92	-1.21	-1.50
1977	-1.39	-0.35	0.04	0.23	0.31	-0.04	-0.37	-0.52	-0.64	-0.70	-0.81	-0.88	-0.98	-0.90	-0.83	-0.67	-0.67
1978	-0.56	-0.56	0.80	0.84	0.89	0.75	0.51	0.31	0.21	-0.02	-0.24	-0.63	-0.94	-1.04	-1.16	-0.99	-1.01
1979	-0.96	-0.67	-0.29	0.20	0.41	0.42	0.50	0.28	0.09	0.07	0.00	-0.06	-0.07	0.06	0.17	0.58	0.74
1980	0.82	0.58	0.34	0.59	0.50	0.53	0.46	0.20	-0.01	-0.14	-0.31	-0.60	-0.86	-0.87	-0.92	-0.55	-0.46
1981	-0.35	-0.24	-0.13	-0.08	0.00	-0.02	-0.02	-0.06	-0.09	-0.17	-0.27	-0.28	-0.27	-0.08	0.08	0.73	0.86
1982	0.52	0.24	0.09	0.76	-0.17	0.25	0.56	0.47	0.47	0.23	0.00	-0.59	-1.10	-1.18	-1.31	-1.61	-1.88
1983	-1.57	-0.43	1.20	1.21	0.64	0.70	0.65	0.41	0.27	0.23	0.10	-0.06	-0.23	-0.67	-1.12	-1.67	-1.95
1984	-1.03	0.75	1.06	1.23	0.99	0.77	0.45	0.28	0.21	0.25	0.20	-0.13	-0.44	-0.78	-1.12	-1.45	-1.69
1985	-0.35	0.80	1.53	1.24	0.57	0.34	0.13	0.19	0.12	-0.30	-0.65	-0.87	-1.05	-1.07	-1.06	-0.96	-0.94
1986	-0.83	-0.30	0.82	0.70	0.01	0.24	0.37	0.26	0.25	-0.08	-0.36	-0.71	-1.00	-1.04	-1.11	-0.85	-0.85
1987	-0.49	-0.24	0.32	0.02	0.81	0.68	0.44	0.25	0.09	-0.07	-0.23	-0.32	-0.41	-0.39	-0.37	-0.19	-0.01
1988	0.08	0.20	0.28	0.47	0.66	0.52	0.28	0.15	0.01	-0.12	-0.29	-0.38	-0.51	-0.41	-0.35	0.02	0.16
1989	0.15	0.01	-0.02	0.24	0.81	1.01	0.53	0.30	0.16	-0.02	-0.19	-0.41	-0.50	-0.52	-0.56	-0.25	-0.21
1990	-0.27	-0.30	-0.09	0.25	0.62	0.64	0.27	0.22	0.27	0.10	-0.06	-0.17	-0.27	-0.13	0.01	0.35	0.47
1991	0.58	0.63	1.17	1.27	0.95	0.71	0.46	0.28	0.09	-0.04	-0.20	-0.19	-0.19	-0.09	0.00	0.28	0.32
1992	0.32	0.16	0.07	0.02	-0.26	-0.52	-0.75	-0.79	-0.82	-0.76	-0.71	-0.61	-0.49	-0.42	-0.35	-0.10	-0.09
1993	0.07	0.14	0.14	0.24	0.17	0.77	0.35	0.17	0.08	-0.08	-0.25	-0.28	-0.29	-0.45	-0.60	-0.57	-0.32
1994	-0.31	-0.10	0.19	0.16	-0.09	-0.37	-0.59	-0.73	-0.85	-0.90	-0.99	-0.92	-0.85	-0.60	-0.36	0.28	0.71
1995	0.83	0.77	0.72	0.60	0.32	0.56	0.27	0.03	-0.11	-0.01	0.06	-0.44	-0.91	-1.14	-1.38	-1.19	-0.86
1996	-0.58	-0.27	-0.03	0.45	0.39	0.44	0.38	0.15	0.02	0.06	0.07	-0.09	-0.16	-0.13	-0.12	0.16	0.32
1997	0.43	0.40	0.27	0.48	0.69	0.49	0.30	0.11	-0.09	-0.21	-0.30	-0.23	-0.18	-0.24	-0.32	-0.21	-0.52
1998	-0.47	-0.33	-0.01	0.29	0.56	0.49	0.32	0.18	0.14	0.15	0.06	0.16	0.25	0.04	-0.18	-0.19	-0.17
1999	-0.25	0.26	0.39	0.63	0.75	1.04	1.23	0.96	0.78	0.61	0.34	0.13	-0.04	-0.04	-0.05	-0.18	-0.28
2000	-0.31	-0.06	0.16	0.25	0.45	0.56	0.56	0.20	-0.07	-0.21	-0.34	-0.45	-0.51	-0.40	-0.32	0.11	-0.11

Appendix F. Summary document titled “ Support for the Klamath Settlement Agreement” dated April 23, 2008 by Dr. Thomas B. Hardy, as presented to the Klamath settlement participants at the April 10, 2008 Klamath Settlement science meeting in Mt. Shasta, CA.

Support for the Klamath Settlement Agreement

Dr. Thomas B. Hardy

April 23, 2008

I wish to express thanks to the Klamath Settlement Science Team for having made their time and expertise available to me to allow a detailed evaluation of the science and rationale behind the proposed Settlement Agreement. In particular, Mike Belchik, Nick Hetrick, Tom Shaw, and Larry Dunsmoor spent considerable time with me going over the technical details that underpin the Settlement Agreement and in particular, the expected flow regimes. My review of the technical work underpinning the Settlement Agreement was greatly facilitated by the USFWS 'White Paper' authored by N. J. Hetrick, T. A. Shaw, P. Zedonis, and J. P. Polos of the Arcata Fisheries Program of the USFWS. This document in conjunction with several full days of technical discussions by the principal authors in Arcata allowed a detailed and comprehensive review to be completed prior to the discussions held in Mt. Shasta on April 10th and 11th.The opportunity for open discussion provided during the science meetings on April 10th and 11th were also very helpful and served to reinforce my opinion to support the Settlement Agreement.

My initial concerns that precluded me from supporting the Settlement Agreement were broadly centered on the following main points:

1. Apparent lack of variation in winter and spring flows over a wide range of water year types.
2. Apparent sustained low flows below 1000 cfs during the later summer and early fall.
3. The potential affects of groundwater pumping on stream flows.
4. Uncertainty on the relationship between the Drought Management Plan and river flows during extreme drought conditions.
5. Other Factors

Prior to addressing each of these major issues, I want to commend the parties for their clear understanding of the technical basis behind the Hardy Phase II recommendations that served as the starting point for their evaluation of flow regimes. As noted in Hardy et al., (2006) the exceedence based flow recommendations (Base Flows) were target flows and did not incorporate any considerations of Upper Klamath Lake levels necessary for support of its endangered species nor the balancing necessary to consider beneficial out-of-stream uses of Klamath water for both agriculture and the wildlife refuge. It was also beyond the scope of that work to fully consider tributaries, dam removal, and restoration actions throughout the basin now being contemplated under the Settlement Agreement. The other components of the Hardy Phase II recommended flow regime associated with overbank and pulse flows and

Ecological Base Flows (i.e., 95 percent exceedence flows) were also recognized and considered in their evaluation of the Settlement flows as noted below. My detailed review of the technical information made it readily apparent that the flow regimes being considered under the Settlement Agreement are clearly an extension of the Hardy Phase II recommended flow regimes that reflect the necessary balance for agriculture, refuge deliveries, target lake elevations for the endangered Klamath Lake suckers, flood control curve, increased storage capacity of Upper Klamath Lake and factor in reasonable and achievable restoration actions both within Klamath Lake and upstream tributaries.

Apparent lack of variation in winter and spring flows over a wide range of water year types

My discussions with several individuals working on the Settlement Agreement made it clear to me that many people in the Klamath Basin do not necessarily understand the subtle difference between the various components of the flow recommendations provided in Hardy Phase II. One component, the 'Base Flow' recommendations, is represented by the exceedence flow based table (i.e., Table 27). These flow recommendations are target flows on a monthly basis by water year type that focus on providing variable habitat conditions for the anadromous species and other aquatic resources in the river. Flows associated with exceedence ranges lower than about the 10 percent level (i.e., high flows that are equaled or exceeded only 10 percent of the time) are superseded by the Hardy Phase II Overbank and Pulse Flow recommendations. In that context, it is not appropriate to be concerned with the prediction of available physical habitat values even if these higher flows would indicate reductions in available habitat as some individuals have expressed. As emphasized in the Hetrick et al. (2008) "whitepaper":

> "Even if the Hardy Phase II baseflow recommendations were implemented, flows during the wet years would surpass the Phase II schedule and habitat values would, in some cases, be lower during spill events than those calculated for the flow recommendations. We note that the Hardy Phase II flows are baseflow targets and that higher flows associated with pulse or overbank flows (i.e., spills) are also a component of the Hardy Phase II flow regime", and that "While flood flow events can diminish habitat availability, they are essential for geomorphic and channel maintenance processes that create and maintain quality and diversity in fish habitat conditions, a point well described by Hardy et al. (2006)."

Overbank and pulse flows that exceed the Hardy Phase II Base Flow recommendations are necessary for the physical, chemical, and biological processes of channel maintenance and riparian maintenance flows that create and maintain the habitats associated with the target Base Flow recommendations. As noted in the Hardy Phase II report, the existing infrastructure of the Klamath Basin does not unduly impact these higher flow regimes. More importantly, the Real Time Management (RTM) analyses of the Settlement flows presented by Hetrick et al. (2008) as a potential method of implementing the water allocation proposed under Settlement show that these flow events will also be maintained given the management objectives of filling the lake early in the spring under both the flood control and target lake elevations for suckers. This will result in the high probability of lake spills over a wide range of water year types. My concern in the initial review of the Settlement Agreement was the apparent lack of variation in the winter and spring flows over a wide range of water year types as reflected in the WRIMS model flow duration summaries provided for my review. This was the only technical information that I had access to at the time of my initial review. During my detailed technical review, it became apparent that the WRIMS model outputs do not necessarily reflect anticipated daily flows within the river that would be achieved under the Settlement Agreement given the nature of that model (i.e., a planning tool) and how flows would be managed under the proposed RTM Operations tool. The detailed analysis conducted by Hetrick et al. (2008) clearly show for example, in many water years during the winter and spring periods, the WRIMS monthly time step would indicate a flow at Iron Gate on the order of 5,000 cfs while the RTM-based analysis shows Upper Klamath Lake in spill mode, with predicted flows at Iron Gate Dam more on the order 10,000 to 20,000 cfs. These differences in projected flow regimes are attributed to the nature of the WRIMS model structure, monthly time step, and conservative nature of the modeling assumptions. A careful comparison between the RTM-based analysis versus the WRIMS modeling show that on an annual basis, the total volume of water released within the Klamath River is similar for most years. However, the expected flow outcomes of the RTM model are expected to maintain both overbank and pulse flow characteristics as recommended in the Hardy Phase II work. Based on this review of the RTM-based flows, this approach should be explored further and refined as necessary to meet ecological objectives for river flows. In my opinion, the RTM-based flow management under the constraints of water deliveries, flood control, and target lake elevations for suckers will still result in adequate variation of winter and spring flow regimes and meet the required ecological flow regime characteristics of both overbank and pulse flows. The RTM analyses also demonstrated to me that over the intermediate ranges of water year types (i.e., 10 to 90 percent exceedence ranges) that expected daily flow regimes are within acceptable levels of the Hardy Phase II target flow recommendations given the required balancing with target lake elevations critical to the endangered sucker.

Apparent sustained low flows below 1000 cfs during the later summer and early fall

The other component of the flow regime highlighted in the Hardy Phase II recommendations relate to the Ecological Base Flow recommendations, and my concerns of allowing flows below 1000 cfs during the late summer and early fall due to the increased ecological risk from temperature and disease factors under existing conditions. However, it should be noted that the Base Flow recommendations (Table 27 in Hardy Phase II), that the flow recommendations during July and August at exceedences greater than about 75 percent are in fact lower than 1000 cfs. What was critical to understand is that the Hardy Phase II concerns over the ecological risk from disease and thermal affects when flow fall below 1000 cfs were driven by the conditions with the dams in place. What became clear from the extended review of the technical work in the Settlement Agreement in conjunction with the work of Dumsmoor as part of the FERC relicensing of PacifiCorp facilities is that these conditions are anticipated to significantly improve with dam removal. My own assessment of anticipated channel conditions in the Copco to Iron Gate Dam reach in conjunction with the improved water quality and temperature regimes lessen these concerns under Settlement flow regimes. It is my opinion that the cold water refugia that will exist from tributaries and large springs in this reach as well as the anticipated shift in the thermal regime is anticipated to reverse the 2-3 week shift in run timing currently experienced in the main stem Klamath. Once the dams are removed, it may be that lower flow releases from Keno will result in improved thermal conditions in specific reaches due to lack of thermal dilution associated with existing reservoir conditions. These combined factors have led me to believe that the threshold flow at which significant concerns over thermal and disease factors will drop well below 1000 cfs to something on the order of 700 to 800 cfs.

Another significant factor in this regard is related to the Drought Management Plan that is a key element of the Settlement Agreement. My discussions with the technical team have clearly shown that this plan is critical in addressing flow regime changes when critical drought conditions are being experienced in the basin. Under the assumption that the Drought Management Plan will be required and completed as part of the Settlement Agreement and that the plan will result in compromises for both in river and out-of-stream diversions it is an equitable tradeoff within the context of the Settlement Agreement for addressing aquatic resource needs both within the main stem Klamath River and sucker needs within Upper Klamath Lake.

The potential affects of groundwater pumping on stream flows

In my initial review of the Settlement Agreement I raised concerns regarding the potential affects of groundwater pumping on stream flows. Discussions with the technical personnel and statements by the Oregon Department of Water Resources during the April 10th and 11th meetings in Mt. Shasta have clarified this issue. It is evident that setting the groundwater pumping to levels in existence in 2000, setting a 6 percent reduction in flow in any of several critical springs around Upper Klamath Lake important for the Klamath Lake suckers and enforcement of Oregon laws that govern curtailment of groundwater pumping if stream flows are affected will provide the necessary protections for over utilization of groundwater resources in the basin. It is recognized that both monitoring and enforcement will need to be adequately addressed.

Uncertainty on the relationship between the Drought Management Plan and river flows during extreme drought conditions

An initial concern in my review of the Settlement Agreement and limited technical material provided on the WRIMS modeling was related to projected flows at high exceedence levels (i.e., > 90 percent) where late summer and early fall flows were reported as low as 400 to 500 cfs. Based on my review of the RTM analysis and a better understanding of the assumptions made in these model runs, I am convinced that flows of these magnitudes are likely underestimating actual river flows. As was noted previously, the RTM-based analysis of flows clearly show higher flows than that projected by the WRIMS runs on a daily basis and that the estimated evaporation from the existing reservoirs (~ 8,000 ac-feet/year) were not added into the projected modeled WRIMS flows. This is not to suggest flows during critical drought years are expected to be low, but that these flows are not as low as being projected under the WRIMS runs and do not reflect flows that will be anticipated under the Drought Management Plan.

Other Factors

Several other factors that came to light as part of my opportunity to discuss the technical basis of the Settlement Agreement are worth noting. I believe that monitoring diversion of water for the Klamath Project to the point of diversion is an important element of the Settlement Agreement. This will ensure that the proposed flow volumes are being met with the implementation of that water use in the hands of the water users. I believe that this will result in more efficient use of the available water as evidenced by improved agricultural practices in other basin to which I am familiar. I also believe that the increased habitat availability to suitable stream habitats not only within the main stem Klamath River above Iron Gate Dam but also in upper basin tributaries will result in improved productive capacity for the entire system. This view is strongly supported by analyses conducted by Hetrick et al. (2008) which show increased outmigrant production from the system under Settlement Agreement flow regimes even prior to dam removal. I am also confident that the water quality and temperature modeling conducted for the 'no dam' conditions by Dunsmoor and Mike Deas show vastly improved conditions for the main stem Klamath River and is supported by both the bioenergetics modeling and salmon production modeling reported in Hardy Phase II.

Although a policy issue, I am now more comfortable that the proposed work anticipated under the Settlement Agreement on both the Implementation Plan and Drought Management Plan are in fact required to be completed in order for the Settlement Agreement to remain in place. This eliminates my initial concern that these elements were left uncompleted prior to being able to support the Settlement Agreement.

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