Review of Phase II
Instream "Unimpaired" Flows in the Klamath River

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Balance Project Assignment 202009

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1. INTRODUCTION

1.1 Assignment

Balance Hydrologics ("Balance") was asked by the Yurok Tribe to review the technical merit and overall quality of the hydrological modeling presented in the Phase II Final Report entitled "Evaluation of Interim Instream Flow Needs in the Klamath River," prepared for the U.S. Department of the Interior by Thomas Hardy and Craig Addley, dated October 18, 2001.

Specifically, Balance was tasked to explain and evaluate the main assumptions and methodologies used to generate the unimpaired flow record at the Iron Gate Dam for the Phase II modeling effort. Once a critical mass of such information had been collected, Balance was asked to address specific questions regarding the disparity of data results from Phase I and Phase II reports, differences between unimpaired and 'natural' flows and recommend, if necessary, approaches which may improve the unimpaired flow record in the Phase II report.

Balance accepted this assignment with a relatively short timeframe for completion and this report, therefore, reflects a limited scope. We were also contending with mandated restrictions on email use by key federal agencies and with restrictions on the use of data from several studies. Due to these limitations we focused our review on a few of the key components of the hydrological modeling and centered our below discussion on these items. We may need to supplement our analysis at a later date.

1.2 Data sources

Several data sets and sources were used as input for the Phase II hydrological modeling. These exterior sources of data should reasonably also be examined to assess the overall quality of the hydrological modeling in Phase II. However, not all of these data could be obtained within the timeframe allowed for our analysis. Listed below are the data made available to us for review and additional data sources that we would have liked to review but to which did not have access or time to fully analyze:

Data Available

- "Evaluation of Interim Instream Flow Needs in the Klamath River - Phase II Final Report," October 18, 2001: prepared for the U.S. Department of the Interior by Thomas Hardy and Craig Addley

- "Hydrodynamic Modeling of Upper Klamath Lake," September 5, 2001: prepared for the U.S. Bureau of Reclamation by Philip Williams & Associates, Ltd.

- "Underlying Principles and Assumptions in the ADR Distribution Model," PowerPoint File, October 19, 1999: Jonathan La Marche, State of Oregon Department of Water Resources

- USBR net inflow records (1905-2001) for Upper Klamath Lake, supplied by Jim Bryant, Bureau of Reclamation, Klamath Basin Area Office

- Mean monthly unimpaired flows for different year types at Iron Gate Dam (output from MODSIM)

Data Not Available

- Accretion values at specific nodes between Upper Klamath Lake and Iron Gate Dam used in the MODSIM and Network 2 environment to estimate unimpaired flows (these data became available to us, but not in time to fully reduce and analyze for inclusion in this report)

1.3 Review limited to hydrological modeling of unimpaired flows

The Phase II Final Report is an extensive document that details three complex, watershed-scale modeling projects, which includes modeling several scenarios of hydraulic, hydrologic and habitat conditions in the Klamath River watershed. These models were integrated to make instream flow recommendations for the Klamath River below Iron Gate Dam. Through the integration of these three modeling components, several questions were explored, such as:

- Under what hydrologic conditions did the fish traditionally used by the Yurok people historically evolve?
- How do hydrodynamic patterns through specific reaches along Klamath River change at different discharges?
- Where are the fish habitat niches located in reaches during various flow events?

Our review, consisting of comments and recommendations, of the Phase II report is not comprehensive and is strictly limited to the hydrological modeling component of the project. Specifically, chapters titled Phase II, Phase II General Process, and portions of the Physical Processes chapter were examined in detail.

As Balance's scope did not include a review of the Phase II report in its entirety, it should be made clear that this review is in no way an attempt to examine and evaluate the other modeling efforts presented in the report.

1.4 Organization of this review

This review is organized topically and tries to highlight specific questions and / or key assumptions related to the hydrological modeling of unimpaired flows. We initially review the fundamental purpose of the unimpaired flows modeled in Phase II (what these flows represent and how they are paired with habitat models), as they ultimately formed the basis of the instream flow recommendations presented in the Phase II report.

Next, once the logic of the unimpaired hydrological modeling effort is explored, essential assumptions of the modeling project are discussed and grouped by modeling component. Analysis of these assumptions ultimately led to the comparison of the unimpaired hydrology used in the model to qualitative estimates of the pre-Project ‘natural’ hydrology that prevailed before widespread water diversion and dam construction commenced. The ‘natural’ hydrology of the Klamath system, especially in the Upper Klamath basin, likely differs from the simulated unimpaired hydrology generated in the Phase II report because of the hydrological parameters incorporated or not incorporated in the various models and the treatment of land use change and practices, ground water influences and sub-basin water contributions.

The unimpaired flow hydrology differs between the Phase I and Phase II reports due to the different approaches taken to estimate the flows. Therefore, these differences influence the instream flow recommendations that result from using these unimpaired flow estimates as relevant analogs for historical conditions. Balance was asked to assess possible reasons for this disparity and the relative magnitude of these differences.

Finally, we make a series of recommendations addressing areas of the Phase II hydrological modeling of unimpaired flows at Iron Gate Dam that could be strengthened with the incorporation of additional information.

2. SIGNIFICANCE OF UNIMPAIRED FLOW IN THE PROPOSED ALLOCATION

Unimpaired flow estimates formed the basis for selecting appropriate flow recommendations in the Phase II report. Therefore, the quality of these estimates in relation to the actual historical flows fish evolved under before significant landscape alteration is extremely important. Below, we briefly outline the major steps Hardy and Addley (and the supporting Technical Team) used to develop flow recommendations based on unimpaired flow estimates.

Monthly flow exceedence values created by simulated unimpaired flows at several stations were paired with habitat modeling for specific species to form a monthly habitat matrix. This matrix estimates the percent of maximum available habitat per species for a given month and at a given unimpaired flow exceedence. Fish species were then targeted for priority at different life stages (spawning, fry, juvenile) to maximize habitat. Monthly flow recommendations were made by using the unimpaired flows as an initial guide, then lowering the recommended flow to the lowest flow possible while attempting to maintain general habitat conditions required by prioritized species.

The seasonal shape of the unimpaired flow hydrograph was also considered in conjunction with specific monthly flow requirements to emulate historical flow conditions. The resultant recommended flows were then modeled using KPSIM to determine if recommended flows could be met in a variety of water year types and over all months by project operations. The results of this modeling effort showed that flow recommendations, with the exception of the 1994 water year, can generally be met by project operations.

Given the above logical steps that were employed in the Phase II report to formulate instream flow recommendations below Iron Gate Dam, we wish to again emphasize that the merit of the generated flow recommendations in Phase II rely on comprehensive and accurate unimpaired flow estimates. It should be noted that some inaccuracy is inherent to any method of flow estimation, especially in systems with many unknown parameters. However, it is still critical to examine these unknowns and how assumptions made about them may influence the resultant unimpaired flow estimates, which in turn directly affect the efficacy of the instream flow recommendations.

3. HISTORY OF FLOW ALTERATION

Streamflow in the main stem of the Klamath River and several major tributaries has been altered repeatedly throughout the last century (or earlier) in response to increased demand for irrigation, and to a lesser degree, power generation, municipal and industrial uses. One of the first landscape-altering projects was performed in the late 1880's when some of the wetland / marsh areas around the Lower Klamath Lake were drained and used for agriculture (Gearheart, 1995). Since this time, a series of dams and reservoirs have been constructed on the main stem and major tributaries of the Klamath River. Also, diversion canals of various sizes and land reclamation activities have proceeded within the basin in the last century, often under the aegis of the U.S. Bureau of Reclamation (USBR).

The unimpaired flows generated from the Phase II report attempt to reflect historical conditions before the above mentioned activities occurred in the Upper Klamath watershed.

4. UNIMPAIRED FLOWS AT IRON GATE DAM

This review focuses specifically on unimpaired flow estimates below Iron Gate Dam (the upstreammost station in Hardy and Addley's modeling environment). Phase II unimpaired flows at Iron Gate Dam were simulated using several models. First, the USBR estimated net inflows to Upper Klamath Lake using a mass balance equation. Philip Williams & Associates applied the USBR net inflow estimates along with consumptive use estimates prepared by Jonathan La Marche (ODWR) to simulate unimpaired outflows from Upper Klamath Lake using natural reef topography and the MIKE 11 model. The simulated outflows from Upper Klamath Lake were then input into the MODSIM model to estimate unimpaired flows below Iron Gate Dam in Hardy and Addley's Phase II. Various accretions were applied to account for flow differences between Upper Klamath Lake and Iron Gate Dam. The Network 2 computational network developed by the USGS to model Klamath River without any of the existing dams or alterations to the system was used with MODSIM for all unimpaired flow estimates above the Seiad station. The unimpaired flows model run was limited to the period of 1973 to 1997, the period for which the consumptive use data were calculated.

4.1 Net inflow estimates to Upper Klamath Lake

The U.S. Bureau of Reclamation (USBR) estimated monthly net inflow into Upper Klamath Lake from 1905 to present. This estimation relies on the basic assumption that inflow equals outflow plus change in storage ($I = O + \Delta S$). *Outflow* is based only on measurements at the 'A' Canal and the Link River Dam and *change in storage* is estimated based on area-capacity curves for the lake that were developed in 1920 from a limited sounding survey. Beginning in 1997, net inflow estimates were based on new area-capacity curves developed following a comprehensive bathymetric study. The "area" component of the area-capacity curve is determined from lake level measurements. Daily lake levels measured at three locations are applied to an algorithm that takes into account factors such as wind in order to calculate average lake elevation and surface area.

It is not clear how the USBR extended the inflow record back to 1905, since Link River Dam was not completed until 1920. However, for the purposes of the Phase II modeling effort, only net inflow estimates from 1973 to 1997 were used. This is the period of record for the consumptive use data set.

4.1.1 Analysis of USBR net inflow method

The USBR's net inflow method is a simple way to make rough estimates of inflow to Upper Klamath Lake. However, net inflow should not be confused with gross inflow, which is considerably larger and accounts for all water entering the lake. In addition, some assumptions within the method may lead to both under- and overestimates of inflows, with the balance most likely falling in the underestimation range. Therefore, use of this data to simulate unimpaired flows in the Klamath River may result in inaccurate estimates.

4.1.1.1 Outflows and Gross Inflow

As stated above, net inflow to Upper Klamath Lake is considerably less than gross inflow. While both parameters account for all types of potential water sources (e.g., stream and surface runoff; springs, seepage and other ground water; and direct precipitation), net inflow does not consider the full spectrum of potential outflows. Outflows at "A" Canal and Link River Dam are the only outflows considered in the net inflow estimates.

A more comprehensive model that estimates gross inflow would consider additional outflows in the $I = O + \Delta S$ equation. For example, in addition to the "A" Canal and the Link River Dam, there are approximately 22 private diversions that take water directly from Upper Klamath Lake. We do not have estimates of the amount of water in these diversions, nor do we have knowledge of the permitted and allowable rates. However, USBR staff mentioned that the private diversions may have a significant impact on lake levels particularly during summer months (Jim Bryant, personal communication). Rykbost (2001) reports Miller and Tash (1967) estimates for private agriculture diversions as 1.5 percent of outflows. Other outflows that should be considered include deep percolation from the lakebed into the ground water aquifer and evapotranspiration (including evaporation) from the lake surface. Evapotranspiration from the lake surface may account for over 20 percent of the outflow from the lake ([Miller and Tash, 1967] reported in Rykbost, 2001). Estimates of these additional outflows should be made to calculate gross inflows.

4.1.1.2 Area-Capacity Curves

The 1997 area-capacity curves for Upper Klamath Lake were developed following a comprehensive bathymetric study of the lake. The new curves predicted lower storage values for equivalent lake surface elevations than the previous curves that were based on the 1920 study. The decrease in storage capacity of the lake may be the result of sedimentation. It may also be an artifact of less accurate soundings and bathymetric measurements made in the original study. The decrease in lake capacity most likely occurred gradually over the period of record with sedimentation pulses taking place during above average precipitation years such as 1956, 1972 and 1984. Therefore, any resultant underestimates of net inflow due to the change in area-capacity were probably lower in magnitude for years early in the record compared to recent years.

4.1.1.3 Inflows

Finally, the USBR net inflow method does not distinguish between sources of inflow. We would like to note that the inflow factor in the $I = O + \Delta S$ equation includes: surface runoff in streams, inflow from Agency Lake, direct precipitation onto Upper Klamath Lake, and seepage from springs and other ground-water discharge into the lake.

Net inflows as calculated by the USBR for the period of 1905 to 2001 range from a low of 634.8 acre-feet in WY1931[1] to a high of 2,478.8 acre-feet in WY1956. WY1931 marks the near end of a 22 year dry period that extended from 1914 to 1936, whereas WY1956 is toward the end of the 1936 to 1958 wet cycle (Hecht and Kamman, 1996). Therefore, we can assume that net inflow estimates are somewhat reflective of long-term rainfall averages. A more careful comparison of net inflow estimates with precipitation records could yield information useful to the evaluation of consumptive use estimates in the region.

[1] Most hydrologic monitoring occurs for a period defined as a water year, which begins on October 1 and ends on September 30 of the named year. For example, water year 2001 (WY2001) began on October 1, 2000 and concluded on September 30, 2001.

4.2 Consumptive use modeling

Consumptive use estimates for the years of 1974 to 1997 formed one of the essential data components used to create the unimpaired flow hydrograph in the Phase II report. These estimates were calculated by Jonathan La Marche, from the State of Oregon Water Resources Department, as part of the Alternative Dispute Resolution (ADR) process for the Klamath Basin Adjudication in Oregon. These data and a summary PowerPoint presentation entitled "Underlying Principles and Assumptions in the ADR Distribution Model", dated October 19, 1999, were given to Balance by Leon Basdekas for the purpose of this review. Mike Belchik, of the Yurok Tribe technical staff, confirmed the availability of the data set for this review with recognition of its original ADR purpose[2]. We refer to this summary and accompanying data tables in all discussions below regarding consumptive use estimates. In addition, Balance staff have communicated with Jonathan La March via email for clarification of some specific points of analysis.

4.2.1 Method

Mr. La Marche's procedure to estimate consumptive use (CU) in the Upper Klamath Lake basin begins with an estimate of irrigated acreage and crop type. Irrigated acreage was determined by first summing the claimed and permitted acreage in the region. These numbers were then adjusted by comparing to several types of digital landuse coverage: Oregon State landuse and vegetation coverages, Oregon Water Resources Department places of use and points of diversion coverage, and output from the USGS Gap Analysis Program (GAP). A second adjustment to irrigate acreage was made based on field observations. Wetlands, marshes and sub-irrigated lands were subtracted from the total acreage. All agricultural acreage was treated as pasture. Mr. La Marche reported this as the major crop type in the basin and assumed it to a have similar crop coefficients to other types of agriculture in the region such as alfalfa.

The next step in the CU method involves comparing effective antecedent precipitation (EAP) in March of each year to the available water capacity (AWC) of soils in the basin. EAP was estimated as 80% of the October through March precipitation minus natural

[2] Disclaimer from Jonathan La Marche regarding written and verbal information: "Information Prepared for the Klamath Basin Alternative Dispute Resolution Process and is not admissible in legal proceedings, pursuant to ADR Operating Principle 7.2, without the consent of the affected participants, ADR Operating Principle 7.3.3(3)."

evapotranspiration (ET) occurring between October and March. The model assumes that the remaining 20% of precipitation is lost to runoff, deep percolation, and evaporation. Monthly ET values were determined using temperature records and Hargreaves equation. The AWC was computed for each sub-basin by reviewing soil characteristics reported in the county soil survey and rooting depths for pasture reported by the United Nations Food and Agriculture Organization (FAO). For example, AWC in the Sprague sub-basin was estimated at 7.0 inches. One of two computational scenarios to estimate monthly CU were possible depending on whether the EAP is greater than or less than the AWC.

The CU model assumes that growers maintain soil moisture at field capacity during the spring months, thereby loading soil moisture early in the irrigation season and reducing summer irrigation demand. At the end of the growing season, all of the soils' AWC has been utilized. Therefore, if March EAP is greater than AWC (EAP>AWC), saturated soil conditions are assumed and no irrigation occurs during March. In this scenario, CU during April and May is calculated as ET minus 80% of precipitation. From June through September, CU equals ET minus 80% of precipitation minus 33% of AWC (soil moisture use). In October, CU is ET minus 80% of precipitation.

If March EAP is less than AWC (EAP<AWC), March through May CU is calculated as ET plus 33% of the difference between EAP and AWC minus 80% of precipitation (soil moisture loading). June CU is ET minus 80% of precipitation and July through September CU is ET minus 80% of precipitation minus 33% of AWC (soil moisture use). Again, October CU is simply ET minus 80% of precipitation. Consumptive use equations by month for both scenarios are presented in Table 1.

Jonathan La Marche compared a hydrograph of the model output to limited data on return flows and canal diversions in the region with favorable results. These data suggest that more water is diverted for irrigation during spring months, thus supporting the assumption that fields are kept close to AWC during the spring with less irrigation in the summer.

4.2.2 Analysis of Method

We generally concur with several of the key assumptions in the consumptive use model. Efforts are typically made by growers to leave crop lands over winter in a condition that is favorable to capturing the maximum amount of snowmelt and winter season precipitation. The result is fields as close as possible to available water capacity in March. In addition, it is common practice for growers to apply more water during the spring season when water is plentiful. Thus, the shape of the La Marche's consumptive use hydrograph most likely represents actual applied water in the Upper Klamath basin. However, the magnitude of the estimates is probably less than actual water use. Factors that were not considered in Mr. La Marche's method such as land use and crop-planting changes over time, on-farm water use efficiencies, and efficiencies of conveyance systems can all significantly increase the actual amount of water consumed.

4.2.2.1 Applied Water Use vs. Consumptive Use

The most important consideration that was neglected in this analysis is the difference between consumptive use and applied water. The consumptive use method assumes all applied water in excess of crop needs (or consumptive use) percolates to the ground-water system and eventually returns to the Klamath River as flow[3]. Applied water refers to the amount of water that is removed from the source and it may differ significantly from consumptive use. Neglecting changes in available water capacity (and other storage) from year to year, **applied water** is the sum of consumptive use by the crop **plus** consumptive use of fallow ground in regular **plus** *water lost in conveyance* **plus** *water evaporated during application* rotation **plus** *deep and shallow percolation returns*. La Marche's CU method neglects water that evaporates from open conveyance channels and other components of the irrigation system. In addition, it should be noted that, while percolation returns eventually return to the river system, they are not available to support fish habitat while in transit.

4.2.2.2 ETAW

Evapotranspiration of applied water (in excess of that accounted for in crop consumptive) can occur during application as a result of inefficiencies in the irrigation

[3] This assumption neglects water lost from the system via pathways other than consumptive use. For example water is lost during transport to agricultural fields due to evaporation from open conveyance channels.

system. This can be a significant quantity of water in arid and windy climates such as the Upper Klamath basin. The sum of consumptive use and water lost during application is typically referred to as evapotranspiration of applied water (ETAW). Recent ETAW estimates for Siskiyou County, California were reported by Steve Orloff of University of California Agricultural Extension Services (http://www.snowcrest.net/siskfarm/wateff2.html). In this document, ETAW estimates for both flood and sprinkler irrigation systems are compared to evapotranspiration consumptive use estimates for a variety of crops. The difference between the two estimates is equal to the amount of water lost during application. As an example, pasture ETAW for a flood system is 3.7 acre-feet and 3.2 acre-feet for a sprinkler system, compared to an ET consumptive use estimate of 2.4 acre-feet. This suggests that 35% and 25% of applied water is lost during application to pasture from flood and sprinkler irrigation systems respectively. The low water efficiency on pasture land is reasonable when one considers that pasture is less lucrative than some other crops (i.e., onions, potatoes) and does not lend incentives for potentially expensive on-farm water conservation measures.

The above discussion indicates that more water may have been lost from irrigated acreage in the Upper Klamath basin than the consumptive use model predicts, again leading to a possible underestimation of the summer unimpaired flow simulations.

4.2.2.3 Deep Percolation

La Marche's consumptive use model assumes that all water applied in excess of consumptive use returns to the river as return flows within the irrigation season. While applied water that is not lost via ETAW does percolate into deep and shallow ground water aquifers, only a small portion of the water that percolates will return to the river within the month or season. The majority of the deep and shallow percolation returns will be delayed in transit and will not be available immediately for fish habitat needs. This oversight within the method has likely resulted in underestimates of consumptive use which translate to underestimates of unimpaired flows. In addition, the delay in deep and shallow percolation returns may be responsible in part for the shift in the existing annual hydrograph to higher flows earlier in the season compared to unimpaired flow estimates.

4.2.2.4 Other Issues

There are other assumptions in the consumptive use model that may also potentially lead to underestimates of water use in the Upper Klamath basin. For example, the model treats all irrigated acreage as pasture. While Jonathan La Marche reported that alfalfa is also planted in the basin, particularly in the area near Upper Klamath Lake, he chose to use only pasture to simplify the modeling effort (Jonathan La Marche, personal communication). In addition, his sources indicate that alfalfa has similar crop coefficients (a factor in ET and consumptive use) as pasture. This may be a good assumption for the period of record (1974 to 1997), however, we would like to note that the trend toward more water intensive crops such as onions and peppermint in the Klamath Project area (Smith and Rykbost, 2000) may be expanding to the Upper Klamath basin.

4.3 Modeled outflow from Upper Klamath Lake

Philip Williams & Associates was contracted by Utah State University and the USBR to model flows through Upper Klamath Lake using the MIKE 11 model. Their work is documented in the report, "Hydrodynamic Modeling of Upper Klamath Lake," dated September 5, 2001. Modeling of pre-Project flows consisted of revising the USBR net inflow simulation (discussed above) using a modified stage-storage relationship for Upper Klamath Lake. The revised net inflow and the consumptive use hydrographs developed by Jonathan La Marche were input into MIKE 11 to simulate water level and lake outflow estimates at the Link River Dam for the period of October 1973 to September 1997. Pre-Project outflow from the lake was simulated by incorporating the historical reef outlet structure. The profile of the natural reef was reconstructed using 2-foot contour maps produced from a bathymetry study conducted in 1920.

We did not have time within the scope of this report to thoroughly analyze PWA's modeling effort, however, the model output may underestimate unimpaired flows. PWA's model relies on consumptive use estimates and USBR net inflow estimates described above, and will, therefore, share some of the same underlying assumption and associated strengths / weaknesses.

4.4 Accretions between Link River Dam and Iron Gate Dam

Thus far, our review has focused on the methods and assumptions used to model the unimpaired flow hydrology above and through Upper Klamath Lake. Now the focus is turned to how unimpaired flows were modeled below Upper Klamath Lake, at the Link River Dam, to the Iron Gate Dam. This section of the Klamath River receives inputs from several tributaries and ground water sources (e.g. Shasta Valley and Butte Valley) and was once a part of a large wetland / marsh system, where water was transported between Klamath River and areas of Lower Klamath Lake, Tule Lake and the Lost River.

Accretion values, or water added to the Klamath River from tributaries, seeps and other sources, between Link River Dam and Iron Gate Dam incorporated in the Phase II modeling of unimpaired flows were generated from the MODSIM model at several nodes. These accretion values were calculated using mass balance equations, which often indirectly account for water lost to ground water storage, evaporation, evapotranspiration, etc. However, Balance did not examine the specific set of mass balance equations used in the Phase II MODSIM model so it is unclear to what extent such losses were included in the mass balance equations or what assumptions were made to estimate accretion values.

One known assumption made to estimate accretion values at specific nodes was that the hydrology of a particular tributary (or node) was the same now as it was before human alteration in the larger Klamath basin. Although MODSIM, and Network 2, removes dams and reservoirs to simulate unimpaired flows, it does not account for changes in land use or drainage in the watershed. It is important to note that land use has been altered, by land reclamation and agricultural activities, in the valleys between Upper Klamath Lake and Iron Gate Dam in a similar fashion as to what occurred in the watershed above Upper Klamath Lake. Therefore, existing flow conditions, even accounting for the removal of dams and reservoirs, would not accurately reflect historical pre-Project flows because consumptive use was not factored into the accretion estimates. This could cause the simulated Phase II unimpaired flows to be underestimated during the spring / summer months of irrigation season.

In total, approximately nine out of the twenty-five nodes were used in the model between the Link River Dam and the Iron Gate Dam to generate unimpaired flows. Nodes not used to model unimpaired flows were reservoirs or other features that did not exist before the Project. Total annual average accretion between the two stations equaled approximately 480,000 acre-feet per year. More specifically for comparison purposes, the annual average accretions gained between the USGS Keno gage and Iron Gate Dam equaled approximately 340,000 acre-feet per year. This number is approximately 23,500 acre-feet less than the annual average accretion values generated by CH2M Hill and used in the Balance (1996) report between the USGS gaging station at Keno and Iron Gate Dam. Because the CH2M Hill accretion values were derived from post-Project records (1960-1995) similar to the accretion values generated for Phase II, it is unclear without additional analysis of each method why this discrepancy exists (if this difference is even significant) and what are the main contributing factors for the difference. However, both likely underestimate spring and summer flows because neither method accounted for consumptive use in the side valleys below Upper Klamath Lake.

4.4.1 Lost River, Lower Klamath Lake, and Tule Lake

The Lost River system is located southeast of Upper Klamath Lake and includes Clear Lake, the Lost River, and Tule Lake. Lower Klamath Lake is currently linked to this system by constructed pathways, where water flows from Tule Lake to Lower Klamath Lake. Before human modification, these systems likely interacted seasonally during high precipitation events or during several-year episodes when the lakes were full and may have been actively spilling into the Klamath River.

The Lost River originates from Clear Lake, flows north, then west, then south, and terminates in Tule Lake. The Lost River Diversion Channel, a constructed channel, now transports water between the Lost River and Klamath River. This channel is designed such that water can be transported in either direction, however, flows are more frequently diverted from Klamath River to the Lost River, especially during irrigation season. Lower Klamath Lake was historically a very large wetland / marsh area that made up part of the Klamath River system to the south of Upper Klamath Lake.

Before historic alteration, the Lost River, Tule Lake and Lower Klamath Lake systems acted as sinks for high flows transported in the Klamath River. During large storm events, water overtopped the banks of Klamath River and utilized an expansive wetland floodplain and flowed through the Lost River Slough to Tule Lake (Rykbost, 2001). Similarly, high flows were transported from Klamath River to Lower Klamath Lake via the Klamath Straits and other pathways between Lake Ewauna and Keno (Weddell, 2000). It is reasonable to infer that under natural conditions the Lost River, Lower Klamath Lake and Tule Lake systems also acted as possible sources of water to the Klamath River via gradual releases of stored surface water when these lakes and associated wetlands were full and lake surface water elevations were higher than surface water elevations in the Klamath River. This would have occurred after individual winters with extremely high rainfall amounts or after a series of years with above-average precipitation.

4.4.1.1 Phase II treatment of the Lost River system

The Phase II hydrological modeling of unimpaired flows did not include any input from the Lost River system (including Tule Lake and Lower Klamath Lake) nor did it directly include potential water losses from Klamath River to these systems during high streamflow events. In recent correspondence with Leon Basdekas, we were informed that input values from the Lost River were set to zero when modeling the unimpaired flows because it was unclear how much and if any surface water was transported to the Klamath River from the Lost River historically, before significant alterations to the system occurred. The model, therefore, assumed no interaction between the systems to generate unimpaired flow estimates.

If the MODSIM model, used to simulate Phase II unimpaired flows, assumed that a channel exists as it does now (without an associated floodplain / slough / wetland system) it could possibly overestimate the amount of water historically moving downstream during high precipitation events or during high flows related to snowmelt (therefore, overestimating streamflow during the winter and early spring months). This overestimation takes two forms: a) water loss from the system via evaporation and evapotranspiration processes and b) reduction of peak flows during the winter season, where wetlands and floodplains release water gradually after a storm event and moderate flood flows.

5. UNIMPAIRED VS. 'NATURAL' FLOWS

Now that we have discussed the main methodologies and assumptions used to generate the unimpaired flows for the Phase II report and how these methods and/or assumptions likely over- or underestimated historical flows, we will address how the Phase II unimpaired flows specifically compare to 'natural' flows and the original Phase I unimpaired flow estimates.

Differences will exist between the simulated unimpaired flows generated for the Phase II report and 'natural' flows. For the purpose of this discussion, we define 'natural' flows to mean the flows occurring before European settlement significantly modified the Klamath River and surrounding watershed. 'Natural' flows, therefore, existed in the Klamath River system prior to the late 1800's. This poses a problem with estimating 'natural' flows because documented streamflow gaging by the USGS did not commence until 1905, so we have no directly measured data from the period before significant landscape alteration. Any form of unimpaired flow estimation, be it model generated or spatially and/or temporally interpolated from gaged data, will produce somewhat different streamflow values than the actual flows present before human modification ('natural' flows) because certain assumptions must be made to generate any type of estimate. Such assumptions will not reflect historical reality precisely. However, it is relevant and quite useful to qualitatively assess potential differences between the estimated unimpaired flows versus 'natural' flows and possible reasons and/or solutions for accounting for these differences.

5.1 Geologic Influences

The Upper Klamath basin is underlain by water-holding volcanic rocks, which historically sustained streamflow levels in Klamath River during seasonally dry months and longer periods of drought. The volcanic portions of the Klamath watershed contribute disproportionately large flows to the lower reaches of the river during the summer and during dry years (Balance, 1996).

The application of irrigation water on cropland changes the amount and the timing of ground water storage and discharge to surface streams, thereby affecting the overall shape of the annual hydrograph under 'natural' conditions. This creates a hydrograph with decreased flows during the summer and increased flows in the winter compared to the 'natural' hydrograph (Balance, 1996). Also, ground-water pumping has disrupted historical discharge patterns into the Klamath River system, most notably in the Shasta and Butte Valleys, but also locally elsewhere (c.f., Illian, 1970; Blodgett and others, 1988; Leonard and Harris, 1974; Hecht, 1998). Combined, these changes in the seasonal pattern of ground-water recharge and discharge are factors contributing to possible differences between 'natural' and unimpaired flows.

Finally, fine-grained deposits underlie historical wetlands and other valley-floor areas, often to levels well above the mapped extents of the former wetlands. Precipitation on the former wetlands and the fringing areas underlain by the fine-grained deposits would contribute to the flow of the river. At present, the combination of higher runoff rates from these areas and the greater drainage density associated with today's system of irrigation canals mean that storm flows enter the river much more rapidly. The nature of this change is similar in many respects to the hydrologic response observed during urbanization of agricultural lands elsewhere in the country, and it has similar effects such as more peaked runoff, with higher loads of sediment and other constituents entering the river system. Just as models with hourly or briefer time steps are needed to evaluate the urbanization effects of more runoff more rapidly conveyed to the streams, use of a time step shorter than a month will be needed to characterize and quantify this real and important difference between unimpaired and 'natural' flows.

5.2 Wetlands, marshes and floodplains

The areal extent of marsh and wetland systems in the Upper Klamath basin have been dramatically reduced since the late 1800's due to land reclamation and irrigation activities. It is estimated that over 60,000 acres of wetland have been lost in the Upper Klamath basin alone. Included in this loss of wetland habitat were "riparian wetlands", which occurred along river channels and flooded during overbank events. These wetlands attenuated floodwater and acted as small storage areas or sinks for water, where water was either consumed through evaporation or evapotranspiration or returned to the river system through return flow. Such riparian wetlands were especially prevalent along the Sprague River in the Upper Klamath basin (Gearheart, 1995).

Phase II unimpaired flow estimates differ from ‘natural’ flows because the Phase II simulated flows use the existing flow regime created by current land use practices as the baseline condition and only add consumptive use to alter these existing flows. This analysis, therefore, neglects the amount of wetlands present before human modification and disregards how large, wetland areas might have influenced the hydrology of the basin.

Under ‘natural’ conditions, large wetland areas served to decrease flows in the wet season and increase flows in the dry season (supplementing baseflows) because the wetlands, especially riparian wetlands, store water during high flow events. While some of the detained water would likely be consumed by evapotranspiration, the net addition to the Klamath River flows during the early (and perhaps late) summer would probably have been substantial.

Because the reduction in total wetland area resulting from land “reclamation” activities is not considered in the Phase II analysis, these hydrologic processes are not accounted for. Therefore, unimpaired flow estimates, compared to ‘natural’ conditions, likely overestimate wet season flows and underestimate dry season baseflows.

5.3 Lakes

In addition to these riparian wetland and floodplain systems, the lakes in the Klamath Basin have also been sizably reduced. Total lake size in the Klamath Basin, which includes Tule Lake, Clear Lake, Lower Klamath Lake and Upper Klamath Lake, has been reduced by more than 50% (USBR, 2002). The historical sizes of these lakes obviously fluctuated in response to climatic conditions, but did not vary as much as has been altered by humans.

To understand how reductions in lake sizes might affect the amount of water contributed to the Klamath River, it is necessary to compare how the surface areas of these lakes changed between pre-Project and present conditions. Appropriate rates of evaporation and evapotranspiration should be calculated using site-specific and preferably long-term data. From these two sets of data, rough estimates can be made regarding the total amount of evaporation occurring from historic lake surfaces in a given year or season. Factors that should be considered in such an analysis include long-term climate data, average lake depth, percent vegetation cover and general lake dynamics.

Balance conducted a limited initial analysis to estimate the amount of water historically lost to surface evaporation compared to current lake conditions. These estimates only considered evaporation from lake surface area, rather than the sum of evaporation and evapotranspiration, which would also consider changes in wetland area. Historic lake sizes were estimated by taking the average from USBR (2002) historical lake size data for Tule Lake, Clear Lake and Lower Klamath Lake. We obtained seasonal evaporation rates from the State of California Department of Water Resources (1974) for Clear Lake and Tule Lake. These rates were calculated from Class A evaporation pans at the sites for the months of April through October from 1948 to 1954 for Clear Lake and from 1962 to 1973 for Tule Lake. No direct estimates of evaporation rates were calculated for Lower Klamath Lake so we used the estimates for Tule Lake. Long-term climate data at Klamath Falls shows that the period from 1948 to 1954 was a slightly wetter than normal period for the area, while 1962 to 1973 encompassed a mixture of water year types (wet, dry and average). Temperatures (above, below or average) should also be explored to determine if the calculated evaporation rates may over- or underestimate normal years. However, given the time constraints of this project, an in-depth climate analysis was not feasible. Therefore, we consider the resultant seasonal evaporation amounts to be rough estimates only.

Total seasonal evaporation for Tule Lake, Clear Lake and Lower Klamath Lake was calculated by multiplying evaporation rates by surface area by a multiplier of 0.7. This multiplier is introduced because evaporation pans often overestimate the amount of lake evaporation. A different multiplier may deemed more appropriate at a later date, given additional information such as temperature, lake depth and/or vegetation data. Table 2 shows the historic and present lake sizes and the corresponding estimated seasonal evaporation. The total estimated difference between historical and current lake surface water evaporation rates is 375,782 acre-feet per season (April through October), suggesting that evaporation rates were historically higher. Again, we emphasize that this difference does not consider how the lakes, especially Lower Klamath Lake, typically functioned throughout the year and during wet versus dry years (see Section 5.3 below) in relation to water flows to and from the lakes. Therefore, we feel these issues should be further explored in order to understand how differences in seasonal evaporation between 'natural' and impaired conditions translate to more accurate unimpaired flow estimates.

5.4 Long-duration lake spilling

Historically, both Tule Lake and Lower Klamath Lake had the potential to experience long-duration spilling during winters with heavy rainfall. In these years, gradual water releases to Klamath River would likely occur during the spring and sometimes summer seasons due to gravity. If several years of above-average precipitation occurred in the basin, such releases could extend over several years and sustain baseflow during subsequent droughts. This interpretation is based on a) historical records of water outflow from the lakes to Klamath River (Weddell, 2000) and b) topographic maps showing similar historical lake boundary elevations for both Tule Lake and Lower Klamath Lake, both of which were significantly larger than current size. This is a topic that should continue to be explored, as interpretation of historical flow conditions would benefit from a better understanding of how these large lakes functioned hydrologically before land reclamation activities.

If such long-duration spilling events occurred historically, it is possible that fish populations experienced occasional, significantly higher spring (and potentially summer) baseflows under 'natural' conditions. Long-duration spills may conceivably have had a significant role in rebuilding brood-year stocks, which may have been depleted by events elsewhere in the watershed or through other sources of mortality.

6. PHASE I VERSUS PHASE II UNIMPAIRED MEAN MONTHLY STREAMFLOW

Unimpaired flows, representing the pre-Project hydrology of the Klamath basin, were estimated using two different methods in Phase I and Phase II. Phase I estimated unimpaired flows by using historical gaged streamflow data from the USGS station at Keno over the period of 1905 to 1912. A climate index was created by Balance (1996) and used in the Phase I hydrological modeling to account for above average climate conditions during the period that the historical gage was used to estimate unimpaired flows. Accretions from Keno to Iron Gate Dam were estimated from a model developed by CH2M Hill. This produced an unimpaired flow record at Iron Gate Dam, with mean monthly flows for a "normal" water year.

Phase II, however, used a set of models to simulate the unimpaired hydrology at Iron Gate Dam rather than a historical record. Unimpaired outflow from Upper Klamath Lake was modeled by PWA using net inflow estimates generated from the USBR and consumptive use estimates developed by Jonathan La Marche for the purpose of the Alternative Resolution Dispute process. Simulated outflow was used as input into the MODSIM flow model, created by the USGS and modified by the USU team, and accretion values were added at several nodes between Link River Dam and Iron Gate Dam to arrive at a simulated unimpaired flow record at the Iron Gate Dam.

It is expected that different methodologies will produce different unimpaired flow estimates due to the many uncertainties that are resolved and / or recognized in different ways to estimate pre-Project flows, whether using limited historical records or flow models.

To assess the differences between Phase I and Phase II unimpaired hydrologies, we look specifically at the mean monthly flow estimates at the Iron Gate Dam station for both methods (see Table 3). The most striking difference between the two estimates occurs during the late spring and summer months. Mean monthly unimpaired flows during the months of May through August are lower in the Phase II report than the Phase I report, which is interesting because Phase I was a product of an actual historical flow record (1905-1912), while Phase II used existing flow conditions in the absence of dams and reservoirs and added consumptive use values. Consumptive use is actually **highest** during the spring and summer months of difference, which may suggest that the consumptive use estimates used in the Phase II modeling may underestimate spring and summer water loss. The opposite trend occurs during the winter months, with higher unimpaired flows estimated by the Phase II report.

Several factors may be responsible for differences between the Phase I and Phase II unimpaired flow estimates:

- Phase I unimpaired flow estimates may be overestimated. The historical streamflow record, from 1905-1912, was measured during a period of above-average precipitation. This was accounted for by a climate index, but given the short time period of the record some inaccuracy is possible. However, this factor would affect the unimpaired annual flow hydrograph uniformly, rather than target (thereby overestimating) summer months only.

- Phase II unimpaired flow estimates may be underestimated for the spring and summer months. Assumptions made to model unimpaired flows for the Phase II report would tend to favor the underestimation of spring/summer flows, mainly due to using consumptive use rather than applied water to calculate "unimpaired flows," and due to smaller inefficiencies and additional losses not accounted for in the consumptive use model.

- Phase II unimpaired flow estimates may be overestimated for the fall and winter months. The hydrological modeling in Phase II does not directly account for floodplain and wetland storage of high flows during the winter prior to the advent of irrigated agriculture in the region.

One indicator suggesting that the consumptive use values may be underestimated is the slightly lower (relative to the surrounding fall/winter months) difference in mean monthly flows between Phase I and Phase II for October. Often, a second irrigation occurs during the month of October and if consumptive use estimates underestimate the amount of water consumed during irrigation activities, it should appear (to a lesser degree than the summer months) during October. Notice the difference between Phase II and Phase I for the month of September is +187 cfs, dips to +140 cfs for October, and climbs back up to +162 cfs for November.

7. CONCLUSIONS AND RECOMMENDATIONS

Based on our qualitative analysis of the basic assumptions and methodologies used to generate unimpaired flow estimates in the Phase II report, we arrive at several conclusions and recommendations.

Refer to Table 4 regarding the assumptions discussed below and how these assumptions may either over- or underestimate unimpaired flows at Iron Gate Dam.

- Phase II simulated unimpaired flows below Upper Klamath Lake at the Link River Dam are likely underestimated for the late spring and summer seasons.

    - The unimpaired flows below Upper Klamath Lake are computed by adding existing net inflows to the volume of water <u>consumptively used</u> by crops each month, rather than using the amount of water <u>applied</u> to the crops. Most of the applied water in excess of consumptive use eventually returns to the Klamath River system; however, it is not available for use by fish or in other instream functions while finding its way back to the stream network. Moreover, some of the applied water does not return to the stream system, evaporating from conveyance systems, farm ponds, or during irrigation, or percolating to ground-water bodies not rapidly connected to the stream system. In this region, evapotranspiration of applied water (ETAW) is often one-quarter to one-third greater than consumptive use, and sometimes more. While some of the applied water rapidly returns to streams, most of it does not. The difference between applied water and consumptive use should be added to consumptive use if it is desired to estimate unimpaired flows from historical and recent records.

    - Evapotranspiration from the Upper Klamath Lake surface was not explicitly considered as part of the outflow factor in the net inflow estimate equation. Up to 20% of the outflows from the lake can occur through evapotranspiration resulting in a significant change in net inflow calculations.

- Historical land-altering activities occurring in the Upper Klamath basin, such as land reclamation and agriculture, were likely also occurring downstream in Butte Valley and Shasta Valley. Therefore, modeling existing flow conditions for the reach of Klamath River between Link River Dam and Iron Gate Dam in the absence of dams and reservoirs alone will not accurately reflect 'natural' flows and will underestimate the amount of water added to the system, especially during the summer. Removing dams and diversions from the model does not account for changes in land use such as irrigation and the draining of wetlands. Instead, consumptive use estimates and other land use factors should be considered when modeling unimpaired flows for this reach to increase comparability between unimpaired and 'natural' flows.

- The Phase II model adjusts flows only for consumptive use in the Upper Klamath basin. By extension, similar adjustments should have been made for areas underlain by volcanic geology. No adjustments appear to have been made for the direct (diversion-related) effects of agriculture elsewhere in this part of the watershed, most notably in the Shasta River valley and in the Butte Basin – very large basins tributary to the Klamath River where outflows are now much lower than in the past [4]. Outflows from other smaller basins also merit adjustment.

- Unimpaired flows computed from adding in consumptive use do not recognize the effects of the much higher density of drainageways now prevailing. Currently, the drainageways carry off the high flows to Klamath River, without detaining them in the large wetlands, which once existed throughout the area. Storm runoff, which used to contribute to sustaining low flows later in the season now enters the river within hours or days, adding little to habitat. The monthly time step of the existing model masks this substantial effect which would become immediately apparent with a daily model. Adding the agricultural consumptive uses back into the model

[4] See, for example, Newcomb and Hart, 1958; Wood, 1960; Seymour, 1960; U.S. Dept of Interior, 1981; Blodgett and others, 1988; Hecht, 1998; Owens, 1998.

does nothing to adjust the computed unimpaired flows for the much more moderated runoff pattern which once prevailed. This is one important difference between ‘unimpaired’ and ‘natural’ flows.

- Additional research should be conducted to explore how the Lost River system interacted with Klamath River before these systems were significantly altered. This information would contribute greatly to our understanding of the ‘natural’ flow regime and could be incorporated into future modeling efforts.

- The gap between unimpaired and ‘natural’ can be narrowed if lake surface changes, lake dynamics, ground water movement and storage, geologic influences, wetland storage are further studied and considered when modeling unimpaired flows.

- If ‘unimpaired’ flows are used to guide instream-flow recommendations based on the premise that they more-closely recognize the needs of the instream resources, the special needs of the current stressed and depleted populations should continue to be recognized in planning flows to meet the needs of fish and other aquatic organisms.

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Table 1. Consumptive use equations developed by Jonathan La March for the Klamath Alternative Dispute Resolution.

Month	**Scenario 1: (March EAP > AWC)** Consumptive Use Equation	**Scenario 2: (March EAP < AWC)** Consumptive Use Equation
March	na, soils saturated	ET_{March} + 0.33(AWC - EAP) - $0.8*P_{March}$
April	ET_{April} - $0.8*P_{April}$	ET_{April} + 0.33(AWC - EAP) - $0.8*P_{April}$
May	ET_{May} - $0.8*P_{May}$	ET_{May} + 0.33(AWC - EAP) - $0.8*P_{May}$
June	ET_{June} - $0.8*P_{June}$	ET_{June} - $0.8*P_{June}$
July	ET_{July} - $0.8*P_{July}$ - 0.33*AWC	ET_{July} - $0.8*P_{July}$ - 0.33*AWC
August	ET_{August} - $0.8*P_{August}$ - 0.33*AWC	ET_{August} - $0.8*P_{August}$ - 0.33*AWC
September	$ET_{September}$ - $0.8*P_{September}$ - 0.33*AWC	$ET_{September}$ - $0.8*P_{September}$ - 0.33*AWC
October	$ET_{October}$ - $0.8*P_{October}$	$ET_{October}$ - $0.8*P_{October}$

Notes:
na = not applicable
ET = evapotranspiration
P = precipitation
EAP = effective antecedent precipitation = $0.8*P_{(October\ through\ March)}$ - $ET_{(October\ through\ March)}$
AWC = available water capacity

Table 2. Comparison of seasonal lake evaporation between historic and present conditions for Clear Lake, Tule Lake and Lower Klamath Lake

	Historic lake size[1]	**Present lake size**	**Pan evaporation**[2] (April through October)	**Estimated historic lake evaporation**[3] (April through October)	**Estimated present lake evaporation** (April through October)	**Difference** (Historic -Present)
	(acres)	*(acres)*	*(inches)*	*(acre-feet)*	*(acre-feet)*	*(acre-feet)*
Clear Lake	15,000	17,100	54.32	41,408	47,205	-5,797
Tule Lake	82,500	11,200	48.10	201,667	27,378	174,290
Lower Klamath Lake	89,500	4,700	48.10	218,779	11,489	207,290
					Total Difference	**375,782**

Notes:

[1] Historic and present lake sizes for Clear Lake, Tule Lake and Lower Klamath Lake were obtained from USBR (2002) and represent the average of the range given in the source, if the lake levels fluctuated seasonally and/or annually.

[2] Pan evaporation values were obtained from the State of California Department of Water Resources (1974) for Tule Lake and Clear Lake only. We estimated Lower Klamath Lake having similar evaporation rates as Tule Lake given their close proximity. Only the spring and summer months of April through October had full evaporation records at the sites and thus, evaporation was only estimated for these months for an average year.

[3] Evaporation pans often overestimate the amount of gross evaporation occurring on a lake or reservoir surface. To account for this, the pan evaporation amounts were scaled by 0.7 to compute the estimated historic and present seasonal evaporation. If Lower Klamath Lake and Tule Lake were extremely shallow historically and supported abundant marsh vegetation, the scaling factor could be raised to higher than 0.7.

Table 3. Comparison of Phase I and Phase II Mean Monthly Unimpaired Flow at Iron Gate Dam

Iron Gate Dam	**Phase I** (historical USGS gage data for Keno)	**Phase II** (model simulations)	**Phase II - Phase I**
Month	Mean Monthly Flows *(cfs)*	Mean Monthly Flows *(cfs)*	Difference[1] *(cfs)*
Oct	1536	1676	140
Nov	1809	1971	162
Dec	2358	2634	276
Jan	2827	3166	339
Feb	3331	3682	351
Mar	3604	3992	388
Apr	3857	3925	68
May	3627	3463	-164
Jun	2930	2735	-195
Jul	2147	1909	-238
Aug	1503	1455	-48
Sep	1370	1557	187

Notes:

[1]Negative values indicate that Phase I unimpaired monthly flow estimates are greater than Phase II estimates, which is shown in the months of May through August.

Table 4. Major assumptions of models used to generate unimpaired flows at Iron Gate Dam in the Phase II report and the potential effects of such assumptions on unimpaired flows compared to 'natural' flows

Net inflow estimates to Upper Klamath Lake	**Key factors**	**Over- or under-estimates unimpaired flow?**	**Season of influence**
Evapotranspiration/evaporation of water directly from lake	ET from lake could account for approximately 20% of total outflows. Oversight of this factor in the net inflow estimates (I = O + DS) leads to lower net inflows.	Under-estimation	All
Decrease in lake capacity	An old survey dating from 1920 was used to calculate the volume of water Upper Klamath Lake could hold. Only recently has the lake been re-surveyed. Inflow estimates do not account for decreased capacity.	Under-estimation	All
Exclusion of private diversions in outflow measurements	Twenty-two private diversions take water directly from Upper Klamath Lake and are not included in inflow estimations	Under-estimation	Spring/Summer
Increase in delta surface area	Increase in the amount of wetland vegetation in and around the lake, which would equate to higher consumptive use	Under-estimation	All
Consumptive use modeling			
On-farm efficiency	Water is lost to evaporation in open channel diversion canals	Under-estimation	Spring/Summer
On-farm efficiency	Application methods (sprinklers and flood irrigation) are not 100% efficient	Under-estimation	Spring/Summer
Return flow	All applied water not consumed is assumed to return to the Klamath River. The model does not consider water losses or delays as it passes through ground water storage and/or wells	Under-estimation	Spring/Summer
Lost River system			
Interaction between Klamath River and the Lost River, Tule Lake and Lower Klamath Lake	Storage of high flows in floodplains, wetlands and lakes	Over-estimation	Winter
Accretions between Upper Klamath Lake and Iron Gate Dam			
Water contributions from tributaries and seeps in Shasta Valley, Butte Valley and other small valleys	Post-Project hydrology that does not incorporate consumptive use was used to model the amount of water added to the Klamath River system between Link River Dam and Iron Gate Dam	Under-estimation	Spring/Summer