Effects of sediment release following dam removal on the aquatic biota of the Klamath River

Final Technical Report

Prepared for
State Coastal Conservancy
Oakland, California

Prepared by
Stillwater Sciences
Arcata, California

January 2009

Acknowledgments

Development of this report would not have been possible without the input and thoughtful expertise of numerous researchers working in the Klamath River basin, who were very generous in providing guidance for this work. We are very grateful and appreciative to all those who gave us their time, and would like to acknowledge the following: Annie Manji (CDFG), Barry McCovey Jr. (Yurok Tribe), Boyd Kynard (BK-Riverfish), Brian Cluer (NMFS), Chuck Huntington (Clearwater Bio Studies), Craig Tucker (Karuk Tribe), Daniel Erickson (Pew Institute for Ocean Science), Dan Gale (Yurok Tribe), Dave Hillemeier (Yurok Tribe), Greg Susich (USGS), Greg Stutzer (USFWS), James Simondet (NMFS), Joel Van Eenennaam (University of California Department of Animal Science), John Hamilton (USFWS), Joshua Israel (University of California Department of Animal Science), Joshua Strange (Yurok Tribe), Kimball Rushton (CDFG), Mark Hampton (CDFG), Michael Belchik (Yurok Tribe), Monica Hiner (Yurok Tribe), Stan van der Wetering (Siletz Tribe), Steve Lindley (NOAA), Susan Corum (Karuk Tribe), Thomas Payne (Thomas Payne & Associates), Tom Lisle (Redwood Sciences Laboratory), Tom Shaw (USFWS), Toz Soto (Karuk Tribe), Wade Sinnen (CDFG), and in particular Michael Bowen (State Coastal Conservancy).

Suggested citation:

Stillwater Sciences. 2009. Effects of sediment release following dam removal on the aquatic biota of the Klamath River. Technical report. Prepared by Stillwater Sciences, Arcata, California for State Coastal Conservancy, Oakland, California. January. 185 pp.

Effects of sediment release following dam removal on the aquatic biota of the Klamath River

Executive Summary

Introduction

Four dams on the Klamath River are under consideration for removal: Iron Gate, Copco 1 and 2, and J.C. Boyle. These dams are located between river miles 196 and 225 in Oregon (J.C. Boyle) and California (Iron Gate, Copco 1 and 2), downstream of the Upper Klamath Lake. Dam removal options currently under consideration would result in 1.3–2.9 million metric tons of fine sediment (sand, silt, and finer) being transported into downstream reaches of the Klamath River (Stillwater Sciences 2008), resulting in high suspended sediment loads, which can result in deleterious effects on aquatic habitats and species. This report first summarizes Stillwater Sciences's analyses of the physical properties and concentrations of suspended sediment likely to result from sediment releases. It then focuses on the potential biological effects of sediment release on aquatic habitats and species if the dams were to be removed. In addition, opportunities to reduce the impacts of dam removal were explored, and recommendations are presented based on our analysis. The long-term benefits of dam removal (although assumed crucial to recovery of the aquatic biota) were not analyzed as a part of this study.

Summary of Sediment Modeling Results

The primary impact on aquatic habitat from dam removal is predicted to result from the release of fine sediment when the reservoirs are drawn down in preparation for their eventual removal — there is little sediment release after the drawdown is complete. Because of that, when we refer to "dam removal" in this report, we are specifically addressing the effects of the fine sediment released during reservoir drawdown. Based on sediment modeling results (Stillwater Sciences 2008), release of sediment from behind Iron Gate Dam during reservoir drawdown is expected to result in increases in suspended sediment and turbidity for four to eight months following initial reservoir drawdown. Increases in daily average total suspended sediment concentrations (TSS hereafter) are predicted to fluctuate during dam removal, ranging from approximately 50 ppm (parts per million by mass [one ppm is approximately 1 mg/l]) with spikes up to approximately 38,000 ppm that can last between days and weeks depending on the location within the basin, and the hydrological conditions in the basin during removal.

In order to arrive at an optimum reservoir drawdown scenario, Stillwater analyzed more than 70 different drawdown scenarios with multiple variables, such as different start dates, drawdown rates, and other variables. This analytical approach was designed to meet multiple objectives: (1) to shorten the duration of high TSS levels resulting from reservoir drawdown; (2) to avoid secondary high Spring TSS pulses resulting from reservoirs refilling during drawdown; (3) to avoid high TSS levels during peak migration periods for anadromous salmonids and other aquatic resources, and; (4) to maintain the structural integrity of earthen embankment dams and other structures associated with the Klamath River Project. As a result of this analysis a preferred reservoir drawdown scenario has been identified that starts the drawdown of both Copco 1 and Iron Gate reservoirs on 6 November at a rate of 1 ft/day. This rate subsequently increases to 6 ft/day on 15 November, employing the existing diversion tunnel at the Iron Gate Dam and a proposed Copco 1 bottom outlet of approximately 200 square ft constructed prior to reservoir drawdown. This approach results in minimal sediment releases prior to 15 November, but allows a higher drawdown rate by 15 November. That increased drawdown rate commencing on 15 November results in high suspended sediment levels during peak drawdown. Simulated maximum TSS for the period prior to 15 November is generally less than 1,000 ppm at the Iron Gate station and less than 500 ppm in the lower Klamath River. Simulated TSS for the winter period is predicted to be high, with daily averages over 30,000 ppm at Iron Gate station under some hydrologic conditions, and over 10,000 ppm under some hydrologic conditions in the lower river. Under this scenario, simulated maximum TSS for the following spring and summer is generally less than 2,000 ppm at the Iron Gate station, and less than 500 ppm in the lower river.

Approach to Biological Analysis

A set of objective criteria and a vetting process were used to select focal species for the various analyses. The following focal species were selected for analysis:

- Chinook salmon (fall and spring) (*Oncorhynchus tshawytscha*)
- Coho salmon (*O. kisutch*)
- Steelhead (summer and fall/winter)/rainbow trout (*O. mykiss*)
- Coastal cutthroat trout (*O. clarki clarki*)
- Pacific lamprey (*Lampetra tridentata*)
- Green sturgeon (*Acipenser medirostris*)

A worst-case scenario for discussion of potential population responses was analyzed using the TSS and duration predictions from Stillwater Sciences (2008) in conjunction with Newcombe and Jensen's (1996) "severity of ill effects indices". Because little scientific literature on the effects of suspended sediment on Pacific lamprey and green sturgeon exists, these results could not be directly related to Newcombe and Jensen's (1996) indices, but a qualitative discussion is provided for these species based on available information.

Results of Biological Analyses

Modeled suspended sediment dynamics following dam removal differ significantly between years of varying hydrological conditions. In general, impacts on life stages present during fall and winter are potentially more severe if dam removal occurs during a dry year. This elevated risk occurs when reservoirs would be less inundated, more sediment would be exposed earlier in the year, and thus fine sediment would be more readily eroded and transported downstream. Conversely, a wet year drawdown may result in more severe impacts on life stages present during the following spring. This elevated risk is caused by the potential for reservoirs to remain inundated during winter drawdown, delaying the transport of fine sediment until spring when reservoir levels are low enough to expose sediment deposits.

All focal species have numerous life stages that rely on habitat in the mainstem Klamath River, thus making them susceptible to impacts from the predicted elevated levels of TSS that would be released in three seasons (winter, spring and summer). Effects of predicted exposure to TSS range from sublethal avoidance behavior and physiological stress to direct mortality rates of up to 60%, depending on durations and concentrations of exposure. In some cases, sublethal effects such as physiological stress may interact with other environmental factors in the basin (e.g., temperature and disease) to increase mortality rates. However, despite these predicted impacts, complete mortality is not expected for any species or life stage. The primary mitigating factor is that all species analyzed have extensive temporal and spatial distribution within the basin, which is expected to facilitate survival during dam removal, and a strong recovery subsequent to dam removal. In particular, the use of tributaries for spawning and rearing, the use of other off-channel habitat for over-wintering, rearing in the lower river or estuary, and life histories that include mature adults in the ocean, is predicted to buffer the short-term impacts of TSS in the mainstem.

The main impacts of sediment releases following dam removal are anticipated to be focused on species and life stages distributed mainly in the mainstem Klamath River during winter and spring peaks in TSS, particularly in the mid-to upper river. A summary of impacts and predicted population response is provided below for each focal species, based on life-history timing and distribution in the basin.

Fall-run Chinook salmon**:** Impacts on fall-run Chinook salmon are predicted to be greatest for the minority of the existing run that spawns in the mainstem Klamath River. The most important factors mitigating impacts related to a sediment pulse on fall-run Chinook salmon are the mixed age classes represented in the escapement each year, and the wide distribution of the population in tributaries. Overall, it appears that impacts will be short-term, and the population will fully recover within five years after dam removal.

Spring-run Chinook salmon: Impacts on spring-run Chinook salmon are predicted to be greatest for upstream-migrating adults and outmigrating smolts during spring. However, most adults return to the Trinity River, and thus will experience a significantly diluted TSS due to flow accretion from upstream tributaries. No spawning occurs in the mainstem, and there is great plasticity in life histories for rearing juveniles. Overall, a relatively rapid recovery to pre-dam removal stock levels is predicted, although protection of the Salmon River sub-population will be a key to recolonizing habitat upstream of Iron Gate Dam.

Coho salmon**:** Impacts on coho salmon are predicted to be greatest for the minority (<12% or 3,600 in an average year) of the run that has not reached tributary habitat prior to dam removal. However, the majority of the adult coho salmon migrants will have reached tributary spawning habitat prior to dam removal and will be protected from sediment releases. Overall, the wide distribution, and use of tributaries by coho salmon juvenile and adults should result in only short-term effects and facilitate recovery of the population.

Summer and winter steelhead**:** Impacts on summer and winter steelhead are predicted to be greatest for the portion of the adults migrating to spawn in tributaries upstream of the Trinity River, and for the smolts produced from those tributaries. However, the wide spatial distribution of steelhead in the Klamath basin means that much of the population will avoid severe impacts of TSS by remaining in tributaries for extended rearing, or using the Klamath River mainstem farther downstream. Overall, the summer and winter steelhead populations are anticipated to be highly affected by removal, but have life history characteristics that should allow a strong recovery.

Coastal cutthroat trout**:** Impacts on coastal cutthroat trout are predicted to be greatest for juveniles and migrating adults, since these fish are more likely to be in the mainstem or estuary during dam removal. Overall, the broad spatial distribution of coastal cutthroat trout, combined with their heavy use of tributaries, should allow them to avoid or recover quickly from the TSS disturbances associated with dam removal.

Pacific lamprey**:** Because of their long freshwater residency, impacts on Pacific lamprey are predicted for multiple year classes. However, due to their wide spatial distribution in the Klamath basin, straying behavior, and high fecundity, Pacific lamprey are anticipated to recover relatively quickly from dam removal impacts.

***Green sturgeon*:** Impacts on green sturgeon are predicted to be greatest for life stages occurring in the mainstem Klamath River, including migrating adults during spring, incubating eggs, and rearing juveniles. However, the ability of the population to recover from the loss of juvenile production is expected to be high because the majority (~75%) of the population (subadult and adult) will be in the ocean during removal; they have high fecundity, are long-lived (up to 40 years), and are able to spawn multiple times; and the current population appears strong and stable.

Recommendations to reduce impacts

Although the populations of all focal species are expected to recover in the long term, the following measures are recommended to support the survival of individuals during dam removal, and facilitate a stronger population recovery in the short term.

Protection of weak year classes

To ensure that there are strong year classes of fall Chinook salmon in the ocean capable of rapid recolonization of habitat following dam removal, the year class strength should be predicted. If the two year classes preceding implementation of dam removal are weak, we note that the impacts of dam removal could be more dramatic and subsequent recovery prolonged. During periods of low abundance or poor ocean conditions, we recommend that managers consider the increased risk of dam removal to fall Chinook salmon. It may be appropriate for managers to emphasize mitigation measures or management actions to protect weak year classes. We also recommend annual monitoring of natural adult coho salmon returns to better predict year class strength, and recommend that dam removal be conducted in a year of a strong year class to provide a greater opportunity for the population to recover from the effects of removal.

Management of annual harvest

We recommend that harvest managers (federal, state, and tribal) consider the impacts of dam removal in determining allowable harvest during the time of dam removal. Special protection (e.g., reduced or no harvest) may be appropriate for the component of populations that may spawn in the mid-Klamath River, where impacts on adults and smolts are expected to be especially high. In addition, components of the run headed for tributary habitat are particularly crucial to the ability of species to survive the impacts of dam removal. For currently unregulated fisheries, we recommend that harvest managers consider the impacts of dam removal, and possibly consider proactive and/or voluntary restrictions during dam removal, or temporary regulations tailored to species of interest.

Capture of adults or juveniles

The recommendation to reduce impacts by directly capturing adults is a based on considering the trade-off between the proportion of the population susceptible to some level of impacts from dam removal in comparison with the feasibility and potential impacts from capturing and handling fish. After discussions with biologists studying aquatic species in the Klamath River, we concluded that it is not feasible to capture enough adults or juveniles to off-set impacts, and the stress and injuries from capture and handling would likely result in abrasions, infections, and fungal outbreaks during holding. Therefore measures such as capturing adults or juveniles and either trucking or holding them are not recommended. The one exception is for fall-run Chinook salmon, for which we recommend that managers consider salvaging mainstem-spawning adults during the fall prior to dam removal. However, the appropriateness of this recommendation partially depends on the degree of hatchery influence in the mainstem spawning proportion of the fall-run Chinook salmon population.

Increase fall and spring instream flows

We recommend releasing water in fall and spring during dam removal to mimic the natural hydrograph that would have existed in the Klamath River during a “wet year” prior to the USBR project, consistent with recommendations in NAS (2004). Increased flows during fall are predicted to increase fall-Chinook salmon spawning in tributaries, increase the proportion of the coho salmon escapement in tributaries prior to dam removal, facilitate juvenile coho and steelhead migration downstream and into off-channel habitat, and encourage the outmigration of post-spawned adult green sturgeon prior to dam removal. Increased flows during spring are predicted to increase the survival of upstream migrating adult spring-run Chinook salmon, as well as outmigrating salmon juveniles and smolts. However, if the water year during dam removal is dry, managers will need to balance the benefits of increased flows against the risk of impacts to the remainder of the basin if less water is available later in the year.

Habitat quality in tributaries

The dependence of Chinook and coho salmon, steelhead and resident trout, Pacific lamprey, and amphibians and reptiles on tributaries for spawning and rearing is a key life-history feature that is anticipated to reduce impacts during dam removal, and to facilitate the recovery of these species. In addition, the use of tributary habitat as refuge during winter is an important behavior that will aid the survival of juvenile coho salmon, steelhead, and cutthroat trout during peak TSS concentrations. Therefore we recommend efforts in tributaries that continue to increase instream flows, reduce sediment input, increase habitat complexity, and remove migration barriers.

Table of Contents

Tables

Figures

1 INTRODUCTION

1.1 Background

Four dams on the Klamath River are under consideration for removal: Iron Gate, Copco 1 and 2, and J.C. Boyle. These dams are located between river miles 196 and 225 in Oregon (J.C. Boyle) and California (Iron Gate, Copco 1 and 2), downstream of the Upper Klamath Lake (Figure 1). Preliminary analyses indicate that there are approximately 11.5–15.3 million m$_3$ (15 to 21 million yd$_3$) of deposits stored within the reservoirs impounded by these four dams (Eilers and Gubala 2003, Gathard Engineering Consulting [GEC] 2006) that contain approximately 7.4 million metric tons of fine sediment (Stillwater Sciences 2008). Dam removal options currently under consideration would result in 1.2–2.9 million metric tons of fine sediment (sand, silt and finer) being transported into downstream reaches of the Klamath River (Stillwater Sciences 2008), resulting in high suspended sediment loads and localized short-term sediment deposition, both of which can result in deleterious effects on aquatic habitats and species. This report first summarizes Stillwater Sciences' analyses of the physical properties and concentrations of suspended sediment likely to result from sediment releases. It then focuses on the potential biological effects of sediment release on aquatic habitats and species if the dams were to be removed, and recommends actions of specific measures to avoid or reduce the impacts from the sediment release.

1.2 Overview of Preferred Reservoir Drawdown Scenario

The recommended dam drawdown and removal project alternative in GEC (2006) calls for the removal of J.C. Boyle and Copco 2 dams prior to the removal of Copco 1 and Iron Gate Dams (Figure 1). J.C. Boyle Reservoir contains less than 4% of the total sediment deposits, while minimal deposit is found upstream of Copco 2 Dam, and thus, their removal will result in relatively minor sediment release downstream. Following the removal of J.C. Boyle and Copco 2 dams, a concurrent drawdown of Copco 1 and Iron Gate reservoirs will be conducted in preparation for the removal of the two remaining dams so that impacts from the release of portions of the reservoir deposits will be concentrated for a minimal duration. Drawdown of Copco 1 Reservoir will be facilitated by constructing a gated outlet structure near the bottom of Copco 1 Dam, while the existing diversion tunnel in Iron Gate Dam will be used for its drawdown. Because only a small amount of coarse sediment is deposited upstream of the dams, the primary impact on aquatic habitat from "dam removal" is predicted to result from the release of fine sediment when the reservoirs are drawn down in preparation for their eventual removal while sediment deposition downstream of the dam is predicted to be minimal. Therefore, when we refer to "dam removal" in this report, we are specifically addressing the effects of the fine sediment released during reservoir drawdown.

To further refine the concurrent drawdown alternative recommended by GEC (2006), Stillwater Sciences conducted sediment transport simulations to examine sediment transport dynamics following the initiation of reservoir drawdown under different options and hydrologic scenarios. Based on the modeling results and geotechnical considerations, Stillwater Sciences (2008) recommended constructing the Copco 1 bottom outlet structure with a gated opening of approximately 18.2 m^2 (200 ft^2), and starting drawdown of Copco 1 and Iron Gate reservoirs on 6 November at a rate of 0.3 m/day (1 ft/day), then increasing the drawdown to 1.8 m/day (6 ft/day) on 15 November. Details of the sediment transport modeling and modeling results can be found in Stillwater Sciences (2008); a brief summary is provided below.

1.3 Summary of Sediment Model Results

DREAM-1 is one of the two **D**am **R**emoval **E**xpress **A**ssessment **M**odels developed for simulation of sediment transport following dam removal (Cui et al. 2006a, 2006b), and was designed for application under conditions in which the sediment deposit in the reservoir upstream of the dam under consideration for removal is composed primarily of non-cohesive fine sediment (i.e., sand and finer). For this study, the DREAM-1 model was modified to incorporate the site-specific conditions of the project (e.g., reservoir storage curves, outlets capacity curves) to allow for a simulation of the reservoir drawdown process. Modeling results include time-series of channel aggradation, bedload flux, and the increase in daily-averaged suspended sediment concentration compared to background condition (referred to as TSS hereafter) in the river downstream of the dams.

1.3.1 Suspended sediment concentration and duration following reservoir drawdown

As discussed above, the preferred alternative starts the reservoir drawdown process on 6 November at a rate of 0.3 m/day (1 ft/day) and increases it to 1.8 m/day (6 ft/day) on 15 November (Stillwater Sciences 2008). Starting the 0.3 m/day (1 ft/day) drawdown earlier than 6 November could result in higher than 2,000 ppm (parts per million by mass, which is approximately 1 mg/l) suspended sediment concentration prior to 15 November (Stillwater Sciences 2008). Fourteen (14) runs (Runs 44 through 52 and 54 through 58) were conducted for the preferred drawdown alternative using the hydrologic conditions starting on 6 November that represent (in order of decreasing wetness) the wettest water year in the recorded history (1983), a wet year in the recorded history (1970), the seven post-1984 wettest years (1998, 1996, 1985, 2005, 1986, 1999, and 1997), the post-1984 average year (2003) with approximately 50% exceedance probability, and the four post-1984 driest years (1994, 1991, 1992 and 2002) based on Klamath River runoff at the Iron Gate station for the period of 15 November through 31 December. In these runs, the Copco 1 outlet is assumed to have a gated opening of 18.2 m_2 (196 ft_2, or 14 by 14 ft). Simulated suspended sediment concentrations downstream of Copco 1 Dam and at the Iron Gate (USGS #11516530), Seiad Valley (USGS #11520500), and Orleans (USGS #11523000) gaging stations, and sediment fluxes at the Iron Gate and Orleans stations, are presented in Stillwater Sciences (2008). Simulated numbers of days with suspended sediment concentrations exceeding specified values at Iron Gate, Seiad Valley, and Orleans stations are presented in Tables 1–3, respectively. In addition to Iron Gate, Seiad Valley, and Orleans gaging stations, suspended sediment concentration at Klamath gaging station (USGS #11530500) is calculated based on simulated suspended sediment concentration at Orleans gaging station and discharge records at both Orleans and Klamath gaging stations, whenever discharge records are available. The calculated number of days with suspended sediment concentrations exceeding specified values at Klamath gaging station is provided in Table 4. Simulated suspended sediment concentrations for three periods are discussed below.

Table 1. Simulation results for the number of days with suspended sediment concentration exceeding specified values at the Iron Gate Station following drawdown.

Period	Calendar year to start drawdown	1998[b] (Run 44)	1996 (Run 45)	1985 (Run 46)	2005 (Run 47)	1986 (Run 48)	1999 (Run 49)	1997 (Run 50)	2003 (Run 51)	1994 (Run 52)	1991 (Run 54)	1992 (Run 55)	2002 (Run 56)
		(Post-1984 wettest year)	(Post-1984 2nd wettest year)	(Post-1984 3rd wettest year)	(Post-1984 4th wettest year)	(Post-1984 5th wettest year)	(Post-1984 6th wettest year)	(Post-1984 7th wettest year)	(Post-1984 average year, 50% exceedance probability)	(Post-1984 3rd driest year, 10% exceedance probability)	(Post-1984 driest year)	(Post-1984 2nd driest year)	(Post-1984 4th driest year)
6–15 Nov.	> 100 ppm[a]	3	2	4	2	3	4	3	2	1	1	1	1
	> 500 ppm	2	1	2	1	1	2	2	1	0	0	0	0
	> 1,000 ppm	0	0	1	0	0	1	0	0	0	0	0	0
	> 2,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0
15 Nov–21 Mar.	> 100 ppm	65	49	63	44	64	53	55	65	88	76	73	82
	> 500 ppm	36	33	51	33	46	46	46	53	68	67	63	76
	> 1,000 ppm	29	30	39	26	40	39	41	51	56	61	56	56
	> 2,000 ppm	23	22	22	25	32	34	35	48	42	55	48	40
	> 3,000 ppm	18	19	17	22	26	27	29	34	33	48	39	31
	> 5,000 ppm	9	14	12	17	17	19	18	23	23	37	31	25
	> 10,000 ppm	3	6	3	8	4	5	5	7	13	21	16	13
	> 20,000 ppm	0	1	0	1	0	1	1	1	6	5	3	5
	> 30,000 ppm	0	0	0	1	0	0	0	1	1	1	2	2
	> 40,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0
22 Mar–5 Nov	> 100 ppm	67	64	10	61	10	13	21	0	0	0	0	0
	> 500 ppm	3	9	7	16	3	2	2	0	0	0	0	0
	> 1,000 ppm	0	2	2	6	1	1	0	0	0	0	0	0
	> 2,000 ppm	0	0	0	2	0	0	0	0	0	0	0	0
	> 3,000 ppm	0	0	0	2	0	0	0	0	0	0	0	0
	> 5,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0

a. Parts per million (ppm) is equivalent to milligrams per liter (mg/l);

b. Results for Runs 57 and 58, which used the discharge records from 1970 (a historical wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results.

Table 2. Simulation results for the number of days with suspended sediment concentration exceeding specified values at the Seiad Valley Station following drawdown.

Period	Calendar year to start drawdown	1998[b] (Run 44)	1996 (Run 45)	1985 (Run 46)	2005 (Run 47)	1986 (Run 48)	1999 (Run 49)	1997 (Run 50)	2003 (Run 51)	1994 (Run 52)	1991 (Run 54)	1992 (Run 55)	2002 (Run 56)
		(Post-1984 wettest year)	(Post-1984 2nd wettest year)	(Post-1984 3rd wettest year)	(Post-1984 4th wettest year)	(Post-1984 5th wettest year)	(Post-1984 6th wettest year)	(Post-1984 7th wettest year)	(Post-1984 average year, 50% exceedance probability)	(Post-1984 3rd driest year, 10% exceedance probability)	(Post-1984 driest year)	(Post-1984 2nd driest year)	(Post-1984 4th driest year)
6–15 Nov	> 100 ppm[a]	3	2	3	2	3	3	3	2	1	1	1	1
	> 500 ppm	1	0	1	0	1	1	1	0	0	0	0	0
	> 1,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0
15 Nov–21 Mar.	> 100 ppm	52	47	61	42	57	51	53	63	80	72	69	75
	> 500 ppm	31	28	48	27	44	41	44	51	53	61	57	46
	> 1,000 ppm	26	22	31	22	35	37	37	48	43	57	47	33
	> 2,000 ppm	17	17	22	21	30	32	32	34	26	48	35	24
	> 3,000 ppm	9	12	16	16	24	23	23	20	20	39	24	19
	> 5,000 ppm	7	6	10	10	12	18	16	11	16	28	16	14
	> 10,000 ppm	0	3	3	4	3	4	3	5	9	9	8	9
	> 20,000 ppm	0	0	0	1	0	0	0	1	2	2	3	2
	> 30,000 ppm	0	0	0	0	0	0	0	1	0	0	0	0
	> 40,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0
22 Mar–5 Nov	> 100 ppm	39	51	9	45	6	13	13	0	0	0	0	0
	> 500 ppm	1	1	2	10	1	1	0	0	0	0	0	0
	> 1,000 ppm	0	0	0	4	0	0	0	0	0	0	0	0
	> 2,000 ppm	0	0	0	1	0	0	0	0	0	0	0	0
	> 3,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0

a. Parts per million (ppm) is equivalent to milligrams per liter (mg/l);
b. Results for Runs 57 and 58, which used the discharge records from 1970 (a historical wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results.

Table 3. Simulation results for the number of days with suspended sediment concentration exceeding specified values at the Orleans Station following drawdown.

Period	**Calendar year to start drawdown**	**1998[b] (Run 44)**	**1996 (Run 45)**	**1985 (Run 46)**	**2005 (Run 47)**	**1986 (Run 48)**	**1999 (Run 49)**	**1997 (Run 50)**	**2003 (Run 51)**	**1994 (Run 52)**	**1991 (Run 54)**	**1992 (Run 55)**	**2002 (Run 56)**
		(Post-1984 wettest year)	(Post-1984 2nd wettest year)	(Post-1984 3rd wettest year)	(Post-1984 4th wettest year)	(Post-1984 5th wettest year)	(Post-1984 6th wettest year)	(Post-1984 7th wettest year)	(Post-1984 average year, 50% exceedance probability)	(Post-1984 3rd driest year, 10% exceedance probability)	(Post-1984 driest year)	(Post-1984 2nd driest year)	(Post-1984 4th driest year)
6–15 Nov	> 100 ppm[a]	3	2	3	1	3	3	3	2	0	0	1	0
	> 500 ppm	1	0	1	0	1	1	1	0	0	0	0	0
	> 1,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0
15 Nov–21 Mar.	> 100 ppm	42	34	59	36	46	50	48	51	60	68	59	55
	> 500 ppm	20	19	33	21	38	37	36	37	33	54	41	30
	> 1,000 ppm	12	14	23	19	32	31	26	26	23	48	27	26
	> 2,000 ppm	7	10	15	13	23	22	16	18	19	33	20	19
	> 3,000 ppm	3	7	9	11	14	9	7	13	15	24	16	16
	> 5,000 ppm	0	4	7	7	6	5	5	9	10	14	10	13
	> 10,000 ppm	0	0	3	0	1	1	0	3	2	5	4	5
	> 20,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0
22 Mar–5 Nov	> 100 ppm	28	9	8	30	2	8	2	0	0	0	0	0
	> 500 ppm	0	0	0	4	0	0	0	0	0	0	0	0
	> 1,000 ppm	0	0	0	2	0	0	0	0	0	0	0	0
	> 2,000 ppm	0	0	0	0	0	0	0	0	0	0	0	0

a. Parts per million (ppm) is equivalent to milligrams per liter (mg/l);

b. Results for Runs 57 and 58, which used the discharge records from 1970 (a historical wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results.

Table 4. Calculated number of days with suspended sediment concentration exceeding specified values at the Klamath station following drawdown, based on simulated results at the Orleans station and the discharge records at both Orleans and Klamath stations.

Period	Calendar year to start drawdown	1998[b] (Run 44)	1996 (Run 45)	1985 (Run 46)	2005 (Run 47)	1986 (Run 48)	1999 (Run 49)	1997 (Run 50)	2003 (Run 51)	1994 (Run 52)	1991 (Run 54)	1992 (Run 55)	2002 (Run 56)
		(Post-1984 wettest year)	(Post-1984 2nd wettest year)	(Post-1984 3rd wettest year)	(Post-1984 4th wettest year)	(Post-1984 5th wettest year)	(Post-1984 6th wettest year)	(Post-1984 7th wettest year)	(Post-1984 average year, 50% exceedance probability)	(Post-1984 3rd driest year, 10% exceedance probability)	(Post-1984 driest year)	(Post-1984 2nd driest year)	(Post-1984 4th driest year)
6–15 Nov	> 100 ppm[a]	2	N/A	2	1	2	2	1	2	0	0	0	0
	> 500 ppm	0		0	0	0	0	0	0	0	0	0	0
15 Nov–21 Mar.	> 100 ppm	32		50	27	45	47	39	47	35	59	48	40
	> 500 ppm	11		21	20	32	31	26	21	20	46	23	23
	> 1,000 ppm	5		14	13	26	21	14	17	15	36	20	21
	> 2,000 ppm	3		8	10	11	8	6	13	10	19	15	16
	> 3,000 ppm	1		6	6	4	4	4	9	5	13	10	15
	> 5,000 ppm	0		3	1	1	1	0	6	0	6	4	9
	> 10,000 ppm	0		1	0	0	0	0	0	0	0	0	2
	> 20,000 ppm	0		0	0	0	0	0	0	0	0	0	0
22 Mar–5 Nov	> 100 ppm	3		6	19	1	2	1	0	0	0	0	0
	> 500 ppm	0		0	1	0	0	0	0	0	0	0	0
	> 1,000 ppm	0		0	0	0	0	0	0	0	0	0	0

a. Parts per million (ppm) is equivalent to milligrams per liter (mg/l);

b. Results for Runs 57 and 58, which used the discharge records from 1970 (a historical wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results.

1.3.1.1 Fall (from the date of initial drawdown to 15 November)

Simulated maximum TSS for the period prior to 15 November is generally less than 1,000 ppm at the Iron Gate station except for Runs 46 and 49 (starting drawdown on 6 November 1985) with a one-day TSS that exceeds 1,000 ppm, but is less than 2,000 ppm (Table 1). This corresponds to a probability of less than 6% that 1,000 ppm will be exceeded according to post-1984 hydrologic conditions. At the Seiad Valley and Orleans stations, simulated TSS values for all the runs are less than 1,000 ppm (Tables 2 and 3). At the Klamath station (Table 4), calculated TSS values are less than 500 ppm for all the runs.

1.3.1.2 Winter (15 November to 21 March)

Simulated TSS for the winter period is high for all model runs (Tables 1–4). At the Iron Gate station, maximum TSS exceeds 10,000 ppm for all the runs and exceeds 30,000 ppm in some runs. At the Seiad Valley station, maximum TSS exceeds 10,000 ppm for all runs, but exceeds 30,000 ppm in only one run. At the Orleans station, eight of the 12 runs have maximum TSS that exceed 10,000 ppm (but are less than 20,000 ppm). At the Klamath station, two runs have a maximum TSS that exceeds 10,000 ppm (but are less than 20,000 ppm).

1.3.1.3 Spring (after 21 March)

Simulated maximum TSS for the following spring is generally less than 1,000 ppm at the Iron Gate station (Table 1), less than 500 ppm at the Seiad Valley station (Table 2), and less than 100 ppm at the Orleans and Klamath stations except for one run (Run 47 that starts drawdown on 6 November 2005) (Tables 3–4). For Run 47, the simulated maximum TSS is between 2,000 and 5,000 ppm at the Iron Gate station, between 1,000 and 3,000 ppm at the Seiad Valley station, between 500 and 2,000 ppm at the Orleans station, and between 500 and 1,000 ppm at the Klamath station.

1.3.1.4 Dynamics in wet years versus dry years

Modeled suspended sediment dynamics following dam removal differ significantly among years of varying hydrological conditions. In general, Copco 1 and Iron Gate reservoirs start to refill with the arrival of the first winter high flow event, which effectively stops erosion of the reservoir deposits. As a result, wet years are generally characterized by less fine sediment release in winter and more fine sediment release in the following spring. This is because the winter high flow in wet years generally arrives earlier and lasts longer, leaving more sediment in the reservoirs for spring erosion. In contrast, more sediment will be eroded from the reservoirs in winter during dry years. This is due to the generally later arrival and shorter duration of winter high flows which leave the reservoir deposits exposed and more prone to erosion. As a result, dry years are generally characterized by higher winter and lower spring suspended sediment events.

1.3.2 Potential effects of suspended sediment on aquatic habitat

In addition to analyzing suspended sediment, Stillwater Sciences (2008) also assessed the potential for sediment deposition downstream of Iron Gate Dam, temporary loss of pool habitat, and fine sediment infiltration into salmon redds following dam removal. Based on simulation results indicating that there will be minimal sediment deposition downstream of Iron Gate Dam following dam removal, and in combination with flume experimental results of Wooster et al. (2008) and theoretical analysis of Cui et al. (2008), Stillwater Sciences (2008) concluded that potential pool filling is expected to be small, and recovery from potential fine sediment infiltration and pool filling will be quick. Therefore persistent, chronic (e.g., > 1 year) effects due to the release of reservoir deposits are not anticipated.

2 APPROACH TO BIOLOGICAL ANALYSIS

2.1 Selection of Focal Species

A set of objective criteria and a vetting process were used to select focal species for the various analyses, as illustrated in Figure 2. The methodical application of criteria to a pool of candidate species facilitated a comparison of the species, which clarified and simplified the process of selecting a suite of focal species. The selection process included the following considerations:

1. Species historically existed (i.e., is native) and currently exists within the Klamath River basin downstream of Iron Gate Dam, and within the area of primary impact (i.e., upstream of the confluence with Trinity River).
2. Species is listed or proposed for listing under the Federal or State Endangered Species Act.
3. Species is not listed, but meets other criteria, such as high economic or public interest value, or is believed to be a strong indicator in aquatic communities.
4. Available information on species is sufficient to allow at least a qualitative assessment of dam removal impacts.

Based on this process, the following focal species were selected for analysis:

- Chinook salmon (fall and spring) (*Oncorhynchus tshawytscha*)
- Coho salmon (*O. kisutch*)
- Steelhead (summer and fall/winter)/rainbow trout (*O. mykiss*)
- Coastal cutthroat trout (*O. clarki clarki*)
- Pacific lamprey (*Lampetra tridentata*)
- Green sturgeon (*Acipenser medirostris*)

Impacts on other aquatic species such as aquatic macroinvertebrates and amphibians were assessed, but were discussed in less detail than focal species.

2.2 Summary of Review of Information on Effects of Suspended Sediment

To analyze the potential effects of dam removal on focal species populations, we reviewed model predictions of anticipated sediment releases following dam removal, and available scientific literature to characterize the effects of TSS on individuals. Based on model predictions, release of sediment from behind Iron Gate Dam during its removal is expected to result in increases in suspended sediment and turbidity for 4 to 8 months following dam removal. Total suspended sediment concentrations are predicted to range from less than 50 ppm to more than 38,000 ppm with peaks having durations from days to weeks. Concentrations of suspended sediment are expected to be higher in reaches of the Klamath River located closer to the point of origin of the sediment (i.e., the former site of the dam) and to decline in a downstream direction. Concentrations would be further reduced downstream of the Klamath River's confluence with major tributaries such as the Scott, Salmon, and Trinity rivers. Higher concentrations would likely occur during high-flow periods lasting from a few days to a few weeks. As both adult and juvenile anadromous salmonids of different species are present in the Klamath River throughout the year, all life stages would be exposed to increased suspended sediment concentrations and turbidity resulting from dam removal.

Based on review of the scientific literature, the most commonly observed effects of suspended sediment on salmonids include the following: (1) avoidance of turbid waters in homing adult anadromous salmonids, (2) avoidance or alarm reactions by juvenile salmonids, (3) displacement of juvenile salmonids, (4) reduced feeding and growth, (5) physiological stress and respiratory impairment, (6) damage to gills, (7) reduced tolerance to disease and toxicants, (8) reduced survival, and (9) direct mortality (Newcombe and Jensen 1996). Information on both concentration and duration of suspended sediment is important for understanding the potential severity of its effects on salmonids (Newcombe and MacDonald 1991). Herbert and Merkens (1961) stated that "there is no doubt that many species of fresh-water fish can withstand extremely high concentrations of suspended solids for short periods, but this does not mean that much lower concentrations are harmless to fish which remain in contact with them for a very long time." Effects of suspended sediment on fish may be increased if toxics or other stressors (e.g., water temperature, disease) are present as well. This report considers these other factors qualitatively, but not quantitatively, in assessing the impacts of a sediment pulse to the population.

Determining the concentrations that cause direct lethal effects in salmonids has generally been based on laboratory studies experimenting with exposures to concentrations of suspended sediment over 1,000 ppm and usually much higher. According to Sigler et al. (1984), "yearling and older salmonids can survive high concentrations of suspended sediment for considerable periods, and acute lethal effects generally occur only if concentrations exceed 20,000 ppm (see reviews by Cordone and Kelly 1961; Sorenson et al. 1977)." For 36-hour exposures using juvenile Chinook and sockeye salmon, Newcomb and Flagg (1983) reported 10% mortality at concentrations of 1,400 ppm, 50% mortality at 9,400 ppm, and 90% mortality at 39,400 ppm. Concentrations of 82,000 ppm resulted in 60% mortality after 6 hours exposure. Estimated concentrations of 207,000 ppm resulted in 100% mortality in one hour. Stober et al. (1981) reported mortality rates of 50% for juvenile Chinook and coho salmon exposed to 500–1,000 ppm for 96 hours; however. From the results of these and other studies, it appears that relatively short-term exposures to increases in TSS concentrations under 500–600 ppm would not likely result in substantial direct mortality to either juvenile or adult anadromous salmonids in the Klamath River. If the duration of exposure is extended, however, some direct mortality may be expected. Exposures of 19 days to TSS concentrations of 90–270 ppm and higher have been reported as resulting in mortality to juvenile rainbow trout by Herbert and Merkens (1961). Less information is available on the effects of suspended sediment or turbidity on newly emerged salmonid fry (Sigler et al. 1984).

Egg-to-emergence survival of salmonids spawning downstream of the Iron Gate Dam site may be substantially reduced by fine sediment settling out of the water column and into substrates. Extended exposures to suspended sediment have been reported to result in significant mortality to eggs of salmonids at concentrations of less than 200 ppm (Cederholm et al. 1981, Langer 1980, Shaw and Maga 1943, Slaney et al. 1977, Turnpenny and Williams 1980, all as cited in Newcombe and Jensen 1996).

Sublethal effects on adult and juvenile salmonids that may affect their spawning success or survival have been reported in the range of 100–500 ppm. Physiological indicators of stress have been noted in adult and juvenile salmonids exposed to concentrations less than or approaching 500 ppm. Such indicators have included increases in plasma glucose levels (Servizi and Martens

1987, 1992), changes to blood cell count and blood chemistry (Redding and Schreck 1982), gill tissue damage (Herbert and Merkens 1961), "coughing" behavior (Hughes 1975, Servizi and Martens 1992), increased rate of respiration (McLeay et al. 1987), and reduced tolerance to toxic substances (McLeay et al. 1987). Suspended sediment and turbidity may also cause behavioral changes in salmonids. Juvenile salmonids may show avoidance of areas with higher suspended sediment concentrations (Servizi and Martens 1992), or may emigrate or be displaced downstream when exposed to increased suspended sediment (McLeay et al. 1987). Exposures to concentrations <500 ppm have also been reported as interfering with adult Chinook salmon homing to natal streams (Whitman et al. 1982). The most commonly reported effects of concentrations in the range of 100–500 ppm are reduced feeding and reduced growth rate of juvenile salmonids (McLeay et al. 1987, Noggle 1978, Sigler et al. 1984, Sykora et al. 1972). Long-term exposure to even relatively low concentrations of suspended sediment may also have this effect (Sykora et al. 1972). These sublethal effects are collectively referred to in this report as "sublethal physiological stress."

The size of suspended sediment particles may affect the severity of effects on fish, in addition to the concentration and duration of exposure. Servizi and Martens (1987) found increased lethal effects of Fraser River sediments on juvenile sockeye salmon (*Oncorhynchus nerka*) with increasing particle size. Newcombe et al. (1995 as cited in Newcombe and Jensen 1996) also noted increased mortality (80–100%) for juvenile rainbow trout associated with an acute episode of silty (0.10–0.17 mm) water discharge, and Newcombe and Jensen (1996) note that the level of mortality is much less severe (about 0–10%) for other similar events in which the particle sizes were smaller.

Observations of the effects of acute peaks in TSS in natural settings is lacking, due to the obvious logistical constraints of field-based studies during extreme events. However, in large, high gradient rivers in erosive terrain such as the Klamath River, fish regularly experience chronic turbidity and spikes in TSS that approach the sublethal concentrations reported in laboratory studies. During large winter storms or following landslides in the Klamath River basin, numerous tributaries and the mainstem have been observed to experience extremely high suspended sediment loads, approaching concentrated debris torrents (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008). Although measurements of TSS during these peak events have not been possible to date, infrequent sampling in the mid-Klamath River near Orleans often detected TSS levels over 4,000 ppm during winter storms (USGS station #11523000), and TSS in the South Fork Trinity has been recorded as high as 21,000 ppm during a large flood (USGS station # 11527000). Overall, these observations indicate that natural TSS events occur in the Klamath River, and fish populations appear capable of surviving and recovering from them. For example, Pacific lamprey and other species have been observed to migrate during the peak of moderate to high turbidity events. Juvenile coho and Chinook salmon have also been commonly observed at outmigrant traps migrating as high flows decrease, indicating their survival through such events (T. Soto, Fisheries Biologist, Karuk Tribe, unpublished data, 2008).

2.3 Analysis of Biological Effects of Dam Removal on the Klamath River

We evaluated the impacts of a sediment pulse on focal species populations using the analysis of TSS released during dam removal described above in Section 1.3, based on the documented potential effects of TSS reviewed above in Section 2.2. Impacts to species are anticipated to be primarily from the release of TSS. Sediment transport analysis conducted by Stillwater Sciences (2008) concluded that the amount of pool filling will be small, based on the minimal predicted reach-averaged sediment deposition downstream of the dam. Flume experiments indicated that pool topography will persist, and if pool infilling occurs, it will be short lived prior to returning to pre-sediment release topography. This report is focused on the potential impacts associated with TSS following dam removal and measures to reduce TSS impacts; the long-term benefits of dam removal (although assumed crucial to recovery of the aquatic biota) were not analyzed here.

This analysis of the biological effects associated with dam removal is based on an examination of the "worst-case scenario" for each life stage based on the years modeled, rather than an analysis of the probability of such a scenario occurring. For some species and life stages a dry year was the worst-case scenario (e.g., coho salmon adults), while for other life stages a wet year was the worst-case scenario (e.g., coho salmon smolts). Since the analysis was conducted for each life stage, it is assumed in a worst-case scenario that both dry year and wet year conditions could occur (which is not actually possible).

The approach used was to analyze the worst-case scenario modeled (to be conservative for the species), and assumes that if the worst case does not result in severe impacts on the population, more benign scenarios would be even more protective of the species. For example, based on Shannon & Wilson, Inc. (2006), the average particle size for all core samples collected from Iron Gate Reservoir was extremely small (approximately 0.015 mm), and therefore the impacts of TSS are likely to be less severe than reported here (Newcombe and Jensen 1996). In addition, although not every potential hydrologic scenario was modeled in Stillwater Sciences (2008), the relationship between wet and dry years causing predictable effects during winter or spring is fairly strong, and it seems unlikely that a more severe case could have been modeled.

Our analysis uses Newcombe and Jensen's (1996) approach of calculating the severity of impacts based on concentration and duration of exposure as estimated by the DREAM-1 model runs. (note that rather than using Newcombe and Jensen's [1996] TSS unit of measure "mg/l", this report uses an equivalent unit of ppm). Potential population-level impacts of suspended sediment released from dam removal activities for a given species not only depend on their abundance, distribution, and life stages present, but also on the timing, duration, and concentration of suspended sediment released. Newcombe and Jensen (1996) reviewed and synthesized 80 published reports of fish responses to suspended sediment in streams and estuaries and established a set of equations to calculate "severity of ill effect" indices for various species and life stages based on the duration of exposure and concentration of suspended sediment present. The indices used by Newcombe and Jensen (1996) have become a standard for selecting management-related turbidity and suspended sediment criteria (e.g., Walters et al. 2001). Predicted maximum concentration and duration of TSS were calculated based on specific life history stage timing information for each species using DREAM-1 model results, rather than the generic distinction of seasons shown in Tables 1–4. Using the fourteen (14) DREAM-1 model run discussed in Section 1.3.1 above, results in relation to Newcombe and Jensen's (1996) severity of ill effects indices (Table 5), TSS concentrations and durations (based on life-history timing) were compared with the distribution of salmonid species found within the mainstem Klamath River to obtain a worse-case scenario for discussion of potential population responses.

Table 5. Scale of the severity of ill effects associated with excess suspended sediment (based on Newcombe and Jensen 1996).

Severity	Category of effect	Description
0	Nill effect	• No behavioral effects
1	Behavioral effects	• Alarm reaction
2		• Abandonment of cover
3		• Avoidance response
4	Sublethal effects	• Short-term reduction in feeding rates • Short-term reduction in feeding success
5		Minor physiological stress: • Increase in rate of coughing • Increased respiration rate
6		• Moderate physiological stress
7		• Moderate habitat degradation • Impaired homing
8		Indications of major physiological stress: • Long-term reduction in feeding rate • Long-term reduction in feeding success • Poor condition
9	Lethal effects	Reduced growth rate: • Delayed hatching • Reduced fish density
10		• 0–20% mortality • Increased predation of effected fish
11		• >20–40% mortality
12		• >40–60% mortality
13		• >60–80% mortality
14		• >80–100% mortality

Because little scientific literature on the effects of suspended sediment on Pacific lamprey and green sturgeon exists, these results could not be directly related to Newcombe and Jensen's (1996) indices, but a qualitative discussion is provided for these species based on available information. For the purpose of this report, durations were considered to be the total number of days of exposure for a given TSS level within a specified life-stage period, and were not necessarily continuous within that period. These durations were then compared with Newcombe and Jensen's (1996) severity indices for a discussion of prolonged effects on aquatic resources.

The background levels of TSS in the Klamath River basin during winter can fluctuate from less than 10 ppm (S. Corum, Water Resources Coordinator, Karuk Tribe, unpublished data) to over 2,000 ppm during moderate rain events (USGS station #11523000). However, long-term data on background TSS in the Klamath River basin are not available, and these moderate rain-driven events are not predictable as they do not directly correlate to water discharge in the river. Thus, DREAM-1 simulation presented in Stillwater Sciences (2008) predicted the increases of TSS over the background TSS. Our analysis in this report uses these predicted increases of TSS as a surrogate of the TSS values by ignoring the background levels. There are two reasons that this is a reasonable approximation: 1) a large amount of sediment will be released during dam removal, causing suspended sediment concentration orders of magnitude higher than the background condition during the peak sediment release periods, and as a result, the background TSS can be considered negligible during the year of dam removal; and 2) during periods when dam removal is not contributing large amounts of sediment, and the TSS from the erosion of reservoir deposits is comparable to or lower than the background levels of TSS, the impact to aquatic biota from the TSS can be expected to be fairly minor, and thus, additional consideration becomes unnecessary. If long-term data on background TSS in the Klamath River basin became available, it would provide an opportunity to confirm that these are reasonable approximations, but probably not change the conclusions of the analysis.

This analysis also highlighted aspects of life-history timing and distribution that could make some species and life stages either more or less susceptible to the effects of dam removal and sediment release in the mainstem Klamath River. Based on key aspects of susceptibility, opportunities to reduce the impacts of dam removal were explored, and measures are recommended based on our analysis. These recommendations were developed primarily to address biological impacts, and did not take into account all feasibility and social concerns that would need to be considered in a detailed dam removal plan. They are also based on assuming continuation of all other current management activities in the basin, including hatchery operations.

3 RESULTS OF BIOLOGICAL ANALYSIS

3.1 Fall-run Chinook Salmon

Salmon populations are classified according to the Evolutionarily Significant Unit (ESU). Two Chinook salmon ESUs occur in the Klamath River basin—the Southern Oregon and California Coastal (SOCC) ESU, which spawns in the mainstem Klamath River from its confluence with the Trinity River to the ocean, and the Upper Klamath and Trinity Rivers ESU, which spawns in the upstream portion of the basin (Myers et al. 1998). Both ESUs were last determined to not warrant listing in September of 1999 (NMFS 1999). Currently, these two ESUs are considered to encompass all runs of Chinook salmon in the Klamath River basin, including both fall- and spring-runs. This section focuses on fall-run Chinook salmon, and Section 3.2 below focuses on the spring-run. Fall-run Chinook salmon of both hatchery and wild origin are primarily found in the mainstem Klamath River, large tributaries such as the Trinity, Shasta, Scott, and Salmon rivers, and Blue, Bogus, Elk, and Indian creeks (NRC 2004) (Figure 3).

3.1.1 Life history

There appear to be three life history types for fall-run Chinook salmon in the Klamath River basin (Sullivan 1989):

- Type I (smolts enter ocean within a few months of emergence in early spring)
- Type II (smolts enter ocean in autumn or early winter)
- Type III (smolts enter ocean in spring at age-1+[1])

Based on scale analysis by Sullivan (1989), fall-run Chinook salmon in the Klamath River basin appear to primarily exhibit a Type I or II life history, with only a few exhibiting Type III. The Type I life history appears to be prevalent for adults returning at ages 2–4. Type II appears to be most prevalent for age-4 returns, though still common for ages 2 and 3 (Sullivan 1989). Type III is uncommon for all ages, representing <4% of all 3- and 4-year-old adults sampled.

Adult fall-run Chinook salmon begin entering the lower Klamath River in August, with peak migration typically occurring between early September and late October (Table 6; NRC 2004). Fall-run Chinook salmon adults typically reach the spawning grounds two to four weeks following river entry (USGS 1998, as cited in NRC 2004; Strange 2007).

---

[1] A fish emerging in spring is designated age-0 until January 1st of the following year, and then is designated age-1+ for the entire year until January 1st of the next year, when it would be designated age-2+.

Table 6. Life-history timing of fall-run Chinook salmon in the Klamath River basin downstream of Iron Gate Dam. Peak activity is indicated in black.

Life stage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Type I																								
Incubation	▨	▨	▨	▨	▨	▨	▨													▨	▨	▨	▨	▨
Emergence[1]			▨	▨	▨	▨	▨																	
Rearing					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			
Juvenile outmigration[2,3,4,5]							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			
Adult migration[6, 7,8]														▨	▨	▨	■	▨	▨	▨				
Spawning[9,10,11,12]																				■	▨	▨		
Type II																								
Rearing					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Juvenile outmigration[2, 13]																	▨	▨	▨	▨	▨	▨		
Type III																								
Rearing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile outmigration[2, 13]			▨	▨	▨	▨	▨																	

[1] USGS (1998, as cited in NRC 2004); [2] Scheiff et al. (2001); [3]Chesney 2000; [4]Chesney and Yokel 2003; [5]Voight and Gale 1998); [6]NAS (2004, as cited in FERC 2006); [7] USGS (1998, as cited in NRC 2004); [8]Strange (2007); [9] Shaw et al. (1997); [10] Magneson (2006); [11] Lau (CDFG, pers. comm., 1996, as cited in Shaw et al. 1997); [12] Hampton (2002); [13] Wallace 2004

Spawning fall-run Chinook salmon typically peaks in late October and substantially declines by the end of November (Shaw et al. 1997). Although spawning surveys on the mainstem Klamath River are not typically conducted in December, there is evidence of spawning in the mainstem into early December in some years (Magneson 2006), and of adults holding in the mainstem in mid-December. For example, adults holding near the Scott River were observed in snorkel surveys as late as mid-December, from 1993 to 1995 (Lau, CDFG, pers. comm., 1996, as cited in Shaw et al. 1997). Upstream migration into the Shasta River may occur as late as the end of November, as evidenced by observations at weir[2] operations in the lower Shasta River in 2001 by Hampton (2002).

Based on spawning timing, eggs and alevins are typically in the gravel from October through February, and fry (<50 mm fork length [FL]) begin emerging from early February through early April, with peaks in emergence varying annually (USGS 1998, as cited in NRC 2004). Fry often emerge earlier in some tributaries than in the mainstem (USGS 1998, as cited in NRC 2004). For example, fry in the Shasta River emerge as early as January (USGS 1998, as cited in NRC 2004). There is probably some downstream movement of fry into the mainstem Klamath River from the tributaries during the winter, but the extent to which this occurs is unknown due to the difficulty of sampling during the winter.

Fall-run Chinook salmon fry are documented to migrate to the mainstem Klamath River from some of the larger tributaries in March, April, and May (Chesney 2000, Chesney and Yokel 2003, Voight and Gale 1998). Peak outmigration of fry (most <45 mm FL) in the Shasta River occurred during March of 2000 and 2002 (Figure 4; Chesney 2000, Chesney and Yokel 2003), and in the Scott River from late-March to early-April in 2002 (Figure 3, Chesney and Yokel 2003). Numbers of fry outmigrating from Blue Creek appeared to be fairly consistent through both April and May of 1996, while in Hunter Creek peak outmigration of age 0+ fish was observed in May of 2006 (Voight and Gale 1998).

---

[2] Barrier built across a stream to divert fish into a trap.

Age-0+ juveniles (>50 mm FL) are present in the main stem of the Klamath River in April and May, based on the timing of outmigration from tributaries. There was substantial outmigration of age-0+ juveniles from the Shasta River in April and May of 2000 and 2002 (Chesney 2000, Chesney and Yokel 2003). Peak outmigration of age-0+ juveniles in the Scott and Trinity rivers typically occurs later—June in the Scott River (Chesney 2000, Chesney and Yokel 2003), and June through August in the Trinity River (Figures 4–5; Scheiff et al. 2001, Naman et al. 2004). Age-0+ juveniles are also typically captured in the estuary beginning in April and May, based on electrofishing studies by Wallace (2004).

In the mainstem Klamath River, peak outmigration of age 0+ smolts associated with the Type I life-history occurs in June and July, based on outmigrant data from the Big Bar trap run by USFWS (Figure 6; Scheiff et al. 2001). By comparing outmigration timing in the Shasta and Scott rivers, it appears that there may be substantial mainstem rearing of age-0+ juveniles from April through July before smolting (Figure 4). Based on surveys of mainstem pools at the mouths of creeks in 2001, most age 0+ juveniles have departed from the Klamath River by August and September, indicating that the Type II life history is primarily in the tributaries (T. Shaw, USFWS, unpublished, 2002, as cited in NRC 2004).

Type II age 0+ smolts outmigrate from the mainstem Klamath River from September to November (Scheiff et al. 2001), with fewer smolts found in the estuary by the end of September or October (Wallace 2004). The largest smolts are usually observed in the Klamath River mainstem and estuary during this period.

The Type III life history (outmigration at age 1+) is uncommon. Type III juveniles overwinter in the mainstem Klamath River or its tributaries and outmigrate in early spring (possibly as early as late winter) as yearlings (Shieff et al. 2001). Age 1+ smolts have been captured in the estuary as late as May by Wallace (2004), but it was unknown whether these belonged to the spring or fall run. However, juvenile hatchery fall-run Chinook were also captured in the estuary during this period in the year following their release.

3.1.2 Distribution

Fall-run Chinook salmon are distributed throughout the Klamath River downstream of Iron Gate Dam, and in its tributaries (Figure 3). The tributaries with the largest spawning populations are the Trinity River (36%), Bogus Creek (11%), Shasta River (7%), Scott River (7%), and the Salmon River (3%) based on long-term averages of escapement data from 1978 to 2002 (FERC 2006). Typically, only a small portion of the fall run spawns in the mainstem Klamath River (a long-term average of 4% of the total escapement, including returning hatchery fish) (FERC 2006). However, there have been years with as few as 580 spawners (3% of total escapement), and years with as many as 22,000 spawners (23% of total escapement) in the mainstem Klamath River (FERC 2006), and in 2002 a high of nearly 32% of naturally-produced fish spawned in the mainstem Klamath River. However, typically less than 10% of naturally-produced fall-run Chinook spawn in the mainstem Klamath River in any given year (FERC 2006). Within the mainstem Klamath River, spawning occurs from Iron Gate Dam (RM 310.3) to the confluence with Indian Creek (RM 173.8), with the highest densities of redds typically found from Iron Gate Dam to the confluence with the Shasta River (RM 288) (Magneson 2006) (Figure 3).

The majority of fall-run Chinook salmon rearing occurs in tributaries to the Klamath River (Figure 3; CDFG 2003). Detailed information on fry distribution in the Klamath River basin is lacking, but inferences can be made about the distribution of early life-history stages based on distribution of spawning, as discussed below. Large numbers of fry rear the Shasta River, Scott River, Hunter Creek, and Blue Creek, and migrate to the mainstem Klamath River during spring (Chesney 2000, Chesney and Yokel 2003) (Figure 3). It appears that many of these fry rear in the mainstem before smolting.

Limited numbers of age-0+ juveniles are observed in both the mainstem Klamath River and Trinity River in the fall (Figures 5–6). Most of these fish probably outmigrate during the fall as Type II smolts; however, some may rear in the mainstem until the following spring. Age 0+ smolts are captured in the fall at outmigrant traps in the Trinity River (Scheiff et al. 2001), in mid-Klamath tributaries (T. Soto, Fisheries Biologist, Karuk Tribe, unpublished data 2008), as well as in the Klamath River estuary (Wallace 2004). There is not much data on yearling rearing distribution due to the difficulty of sampling in winter; however, a small number of Type III fish outmigrate from tributaries and the mainstem during spring as yearlings (Scheiff et al. 2001). It is assumed that these fish rear primarily in the tributaries during summer and in tributaries and in the mainstem during winter.

3.1.3 Potential population responses

We evaluated potential impacts of TSS on the fall-run Chinook salmon population using the DREAM-1 model results for maximum average daily TSS values by water year type for each life stage (Figures 7–11). This analysis focused on the implications of DREAM-1 model runs 44 (wettest case scenario) and 54 (driest case scenario) for the life-history timing and distribution of fall-run Chinook salmon (Figures 12–17). Impacts on adults are potentially more severe if dam removal occurs during a dry year (e.g., run 54), when more sediment could be exposed earlier in the year since the reservoirs would be less inundated, and thus fine sediment is more readily transported downstream. Conversely, impacts on outmigrating juveniles are potentially more severe if dam removal occurs during a wet year (e.g., run 44), when the reservoir could be inundated during winter, delaying the transport of fine sediment until spring when reservoir levels are low enough to expose sediment deposits.

Because adult fall-run Chinook salmon migrate upstream during fall and typically finish spawning by late November, upstream-migrating adults are not generally found in the mainstem during the proposed period of dam removal (Table 6). Those adults remaining in the mainstem prior to entering tributaries are expected to be exposed to short durations of TSS nearing 1,000 ppm, and longer durations of over 150 ppm (Table 7). It is possible that adults may respond to these exposures by increasing the rate of migration into the tributaries as avoidance behavior, as is well documented for juvenile salmonids (e.g., Sigler et al. 1984, Servizi and Martens 1992), and was observed for upstream-migrating Chinook salmon and coho salmon adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008).

Table 7. Potential for risk to fall-run Chinook salmon life stages based on anticipated exposure to TSS.

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Adult upstream migrants headed for tributaries (15 July to 31 October)	> 150	One week	8	Based on examination of modeled dry years (worst-case scenarios) at Iron Gate Station	Upstream migrant exposure likely limited to first two weeks of November.
	> 1,000	One day	8		
Spawning (15 October to 30 November) Incubation (15 October to 15 April) Emergent fry (1 February to 15 April)	> 10,000	> One month	NA	Based on examination of modeled dry years (worst-case scenarios) at Iron Gate Station	Cumulative effects of TSS on multiple life stages are not explicitly addressed by Newcombe and Jensen's (1996) severity index. However, due to long-term (> 2 weeks) exposure of spawners, incubating eggs, and emergent fry to TSS >10,000, all spawning in the mainstem are assumed to result in 100% mortality.
Type I Outmigration (1 April to 5 November)	> 100	One week	8	Based on examination of modeled wet years (worst-case scenarios) at Iron Gate Station	Assumes that rearing occurs in tributaries, and all outmigrants are in lower river by late fall, so that primary impact occurs during spring.
	> 4,000	One day	9		
Type II outmigration (1 September to 30 November)	>8,000	Two weeks	11	Based on examination of modeled dry years (worst-case scenarios) at Iron Gate Station.	Assumes that rearing occurs in tributaries, and outmigration from upper Klamath continues into fall.
	> 38,000	One day	10–11		
Type III outmigration (1 February to 15 April)	> 3,000	Two weeks	11	Based on examination of modeled wet years (worst-case scenarios) at Iron Gate Station	Assumes that rearing occurs in tributaries.
	> 15,000	One day	10		

[1] Predicted maximum concentration and duration of TSS was calculated from life history stage timing information shown based on DREAM-1 model results.

[2] Based on Newcombe and Jensen (1996) severity index (Table 5).

If the dams are removed during a dry year, the fall-run Chinook salmon spawning in the mainstem are likely to be exposed to long durations (>2 weeks) of concentrations over 10,000 ppm, and potentially one day with concentrations over 30,000 ppm (Figure 5). If dam removal does not occur during a dry year, the duration and concentration of exposure are predicted to be much lower (Tables 1–4). Assuming a "worst-case scenario" (i.e., removal occurs during a dry year), mortality rates of 20 to 40% are anticipated (Table 7). These impacts on adults, in addition to the cumulative impacts on multiple life stages (eggs and emergent fry) of chronic exposure to TSS greater than at least 3,000 to 10,000 ppm (Table 1), are anticipated to result in no production (Table 7) from redds in the mainstem during the year of dam removal.

Much of the overall impact on fall-run Chinook salmon will depend on the relative proportion of fall-run mainstem-spawning Chinook salmon during the year of drawdown. A higher proportion of mainstem spawners within the overall population will translate to a higher level of adverse impact. Conversely, a lower proportion of mainstem spawners will result in a lower level of impact. As discussed in Section 3.1.2 above, typically, only a small portion of the fall run spawns in the mainstem Klamath River (a long-term average of 4% of the total escapement, including returning hatchery fish) (FERC 2006), but proportions have been higher in other years, and appears weakly correlated with flows in the Klamath River (Figure 18). Since during years of lower flows it appears that a larger proportion of naturally-produced adults spawn in the mainstem there is an additional potential impact of a greater potential effect on fall-run Chinook salmon during drier water years. Based on well documented avoidance behavior of juvenile salmonids to TSS (e.g., Sigler et al. 1984, Servizi and Martens 1992), it is possible that in reaction to the low concentrations of TSS initially released on 6 November, a higher proportion of adults will spawn in tributaries to avoid TSS. In addition, due to the presence and location of the Iron Gate Fish Hatchery, many of the mainstem spawning fall-run Chinook salmon anticipated to be at risk from dam removal are believed to be hybridized with hatchery fish, and thus not likely to be genetically unique.

For this analysis, impacts on incubating eggs of mainstem spawners are assumed to be lethal. The sediments released during dam removal will likely be primarily conveyed as wash load and will not fall out of suspension; however, that fraction of sediments that intrude into the spawning gravels will carry high concentrations of very fine sediment. It is possible that these sediments will adhere to the chorion[3] of the egg (Greig et al. 2005, Levasseur et al. 2006) and smother and kill the eggs. The degree to which sediments will adhere to the egg is affected by the properties (e.g., angularity) of the minerals comprising the sediments. A bioassay using reservoir sediments and Chinook salmon eggs from the hatchery could be conducted to assess the likelihood of egg smothering occurring in the Klamath River. Even if egg smothering does occur, it may be that there is already high egg mortality for fall-run mainstem spawners due to low dissolved oxygen (DO) in the water released from Iron Gate Reservoir in November and a potentially very high biological oxygen demand (BOD) in the gravels due to deposited and decaying phytoplankton also derived from the reservoir. If egg mortality is currently high, the population-level effect of the sediment release would be greatly reduced. Fortunately, the effect of fine sediment on spawning success is unlikely to persist beyond the first year. Sediment transport analysis conducted by Stillwater Sciences (2008) concluded that fine sediment infiltration is expected to be limited to a shallow depth near the bed surface, which can be readily flushed during a high flow event after the fine sediment supply in the former reservoir area is exhausted, or would removed by the redd construction activities of spawning fish in subsequent years.

---

[3] The outermost membrane of an incubating egg.

The impacts of a sediment pulse on each of the three life history types of fall-run Chinook salmon vary. The Type I life history will potentially be exposed to the pulse of suspended sediment predicted to occur during spring. However, based on the TSS concentrations and durations predicted, even if dam removal occurs during a wet year (worst-case scenario), direct mortality is not anticipated. It is likely that other factors in the basin, such as interactions with disease and water temperature in conjunction with reduced feeding and growth, will result in mortality of some proportion of outmigrants, or reduced size at ocean entry with subsequent reduced marine survival (Bilton 1984). The impact is likely to be greater for later migrating smolts, but based on observed migrant timing many should be in the lower river prior to spring sediment pulses (Figure 6). It is predicted that by the time the first sediment pulse occurs on 6 November, any Type I outmigrants from the previous year's production are typically in the estuary, and will be far enough downstream to avoid harmful TSS concentrations (Figures 15–17).

Some Type II age 0+ smolts may be directly affected by suspended sediment, but the effect would be restricted to later-migrating individuals, since most Type II juveniles rear in tributaries and outmigrate during early fall, after the spring pulse of suspended sediment. It is predicted that by the time the first sediment pulse occurs on 6 November, any Type II outmigrants from the previous year's production will typically be in the estuary, and which should be far enough downstream to avoid harmful TSS concentrations (Figure 10; Figures 15–17). However, for outmigrants that are leaving tributaries in the mid-Klamath River and continuing their migration into late-fall (which does occur for some individuals), the pulse of sediment in late November could be lethal and cause up to 40% mortality (Table 7).

Type III juveniles are rare in the Klamath basin. Type III individuals typically rear in tributaries, and outmigrate during later winter (February through early-April), when sediment concentrations are predicted to be relatively lower (Figure 11). Some Type III individuals are also assumed to outmigrate from tributaries during fall and over-winter in the lower Klamath River prior to outmigrating in the early spring. During the driest years modeled, there could be long durations (> 2 weeks) of concentrations over 3,000 ppm, resulting in direct mortality of smolts from the previous year's production of up to 40% (Table 7).

Overall, the impact from dam removal on fall-run Chinook salmon smolts is expected to be minor because of the variable life histories, the large majority of age 0+ juveniles that rear in tributaries and migrate to the mainstem only later in the spring and summer, and because many of the fry outmigrating to the mainstem come from tributaries in the mid- or lower Klamath, where TSS concentrations will be diluted. In addition, impacts are distributed between two year classes, rather than being cumulative within a single year class. Therefore, the Type II and Type III progeny of adults that successfully spawned in tributaries during the year of dam removal will produce smolts that outmigrate to the ocean a year after the spring pulse of sediment, and should not have significantly reduced fitness attributable to dam removal.

To evaluate the potential worst-case effects of dam removal, we used data on actual age-specific adult escapements to the Klamath River (Prager and Mohr 1999) and estimated the reduction in 3-year olds, 4-year olds, and 5-year olds that might have occurred if the sediment pulse had taken place on three different dates in the past. Although mortality of smolts from the fall-run Chinook salmon population spawning during the year of dam removal was not expected to be significant, an analysis of the impacts of a sediment pulse on the population was conducted based on assuming some mortality of the smolt population (possibly from interactions with disease or other factors). The dates were chosen to represent periods of relatively low, medium, and high escapements. We made the following assumptions based on data discussed above:

1. Thirty-two (32) percent of the fall-run escapement spawns in the mainstem. This is the highest proportion observed, with the average proportion being 4 percent (including returning hatchery fish).
2. There is a 100 percent mortality of eggs deposited in the mainstem, although it is possible that the effects on egg survival will be minimal.
3. The percent loss of the total eggs deposited in the basin will result in the same percent reduction of the returning adults from that year class. This also assumes density-dependent mortality is similar in the mainstem and tributary habitats. If egg survival is already low in the mainstem relative to the tributaries, Assumption #3 will exaggerate the effects of losing the mainstem production.
4. Fall-run Chinook salmon that spawn in tributaries produce natural-origin smolts (i.e., not hatchery releases) vulnerable to sediment impacts. As an assumed worst-case scenario, and including potential for mortality from interactions with disease or increased ocean mortality resulting from smolting at a small size, mortality of natural-origin smolts produced from tributaries is assumed to be 66% from smolt stage to ocean entry.

The results of the analysis are summarized in Table 8. Based on the stock-recruitment relationship developed by Prager and Mohr (1999), the reduction in the number of spawners that would occur under the worst-case scenario would only be evident for three years of direct impact from a given sediment pulse. The largest factor mitigating the impacts of a sediment pulse on fall-run Chinook salmon is the mixed age classes represented in the escapement each year, resulting in a proportion of each year class in the ocean. In this worst-case scenario, the average percent reduction in escapement for the three simulations is 33% three years after dam removal, 32% four years after dam removal, and around 1% five years after dam removal. Since impacts on adults are potentially greater during a dry year, and impacts on smolts greater in a wet year, it is likely that regardless of the hydrological year in which dam removal occurs, there will be impacts on fall-run Chinook salmon during either adult or juvenile outmigration life stages. However, since impacts on smolts have a greater potential to affect the recovery of the population, a wet year would have more of an effect on the population than a dry year. Overall, it appears that the impacts on fall-run Chinook salmon will be short-term, and that the population will fully recover within five years after dam removal.

Table 8. Impacts of sediment release on subsequent escapement if dam removal had occurred in years of relatively low (1976), medium (1983), and high (1988) escapements. Years with impact are shown in **bold font**.

Brood year	Observed escapement	Estimated escapement based on year of impact		
		1976	1983	1988
1979	41,980	**32,954**	41,980	41,980
1980	29,430	**21,919**	29,430	29,430
1981	37,930	**37,346**	37,930	37,930
1982	42,120	42,120	42,120	42,120
1983	37,360	37,360	37,360	37,360
1984	20,990	20,990	20,990	20,990
1985	33,580	33,580	33,580	33,580
1986	124,190	124,190	**51,392**	124,190
1987	135,030	135,030	**92,915**	135,030
1988	100,640	100,640	**99,402**	100,640
1989	58,850	58,850	58,850	58,850

Brood year	Observed escapement	Estimated escapement based on year of impact		
		1976	1983	1988
1990	21,630	21,630	21,630	21,630
1991	15,870	15,870	15,870	**12,687**
1992	17,080	17,080	17,080	**10,438**
1993	23,690	23,690	23,690	**23,559**

3.1.4 Recommendations for reducing impacts

Overall, sediment impacts on fall-run Chinook salmon following dam removal are not anticipated to be severe. It is recommended that managers consider the following measures to help reduce impacts on the population, and support a strong recovery:

- Attempt to conduct dam removal during a year with a strong fall-run Chinook salmon year class, and if not, provide extra protection for weak year classes from the impacts of dam removal.
- Consider dam removal impacts in the management of annual harvest.
- Consider salvaging mainstem-spawning fall-run Chinook salmon adults from the Klamath River.
- Increase fall and spring instream flows.
- Improve habitat conditions (e.g., increased instream flows, habitat restoration) in Klamath River tributaries, especially during the year prior to dam removal.
- Postpone the release of hatchery smolts until early summer.

3.1.4.1 Protection of weak year classes

The largest factor mitigating the impacts of a sediment pulse on fall-run Chinook salmon is the mixed age class structure represented in the escapement each year. The mixed age class results in a proportion of each year class persisting in the ocean, which thereby avoid impacts related to dam removal, providing for a quicker and stronger recovery. If dam removal occurs in years following weak year classes, there will be less fish in the ocean to buffer the potential effect of dam removal. For example, in 1986 there were few age 4 or 5 year old returns, and thus greater percent reduction in escapement if dam removal had occurred during the year that the age 3 year class was produced (1984, Table 8).

A strategy for ensuring that there are strong year classes in the ocean is to use the predicted year class abundance estimate from the Pacific Fisheries Management Council's Salmon Technical Team (STT) analysis. The STT annually predicts the ocean abundance to set harvest levels; this prediction is based upon linear regressions used to relate ocean abundance estimates of age-3, age-4, and age-5 Chinook salmon on 1 September to that year's river run size estimates of age-2, age-3, and age-4 Chinook salmon, respectively (PFMC 2008). Harvest levels were initially established from stock/recruit analysis conducted in the mid-1980s, but have subsequently been re-evaluated with additional data by the stock-recruitment model of Prager and Mohr (1999) and the STT (PFMC 2005). Harvest of Klamath River fall-run Chinook salmon is managed by the Pacific Fisheries Management Council (PFMC) under its Pacific Coast Salmon Fishery Management Plan (FMP). Prior to 2007 the PFMC recommended a minimum escapement goal of 35% of the total adult returns, with an exception requiring zero harvest when projected stock abundance is less than 35,000 natural spawners (an "escapement floor" or Conservation Alert Standard) (NMFS 2007). More recently, PFMC introduced Amendment 15 to the FMP, which proposed "to allow limited harvest of Klamath River fall-run Chinook (KRFC) in ocean salmon fisheries during years that might otherwise be closed because of a projected shortfall in the KRFC conservation objective of 35,000 naturally spawning adults (PFMC 2007)."

Based on the FMP conservation objective of 35,000 naturally spawning adults, as well as professional judgment, we consider escapements below around 25,000 to be "weak" year classes, although this definition is not based on extensive quantitative data. If the two year classes preceding implementation of dam removal are weak, we note that the impacts of dam removal could be more dramatic and subsequent recovery prolonged. During periods of low abundance or poor ocean conditions, we recommend that managers consider the increased risk of dam removal to fall Chinook salmon. It may be appropriate for managers to emphasize mitigation measures or management actions to protect weak year classes.

3.1.4.2 Management of annual harvest

We recommend that during the year of dam removal, harvest managers consider the potential impacts of dam removal on fall-run Chinook salmon in setting harvest allocations, especially if overall escapement is predicted to be low (see recommendation to protect weak year classes above). More stringent management of harvest as a means to reduce impacts of dam removal is also consistent with the Elwha River restoration plan (Ward et al. 2008), which reflects an agreement between Washington State and local tribes to curtail all in-river fisheries for a period of 5 years when active removal of the Elwha Dam begins. Harvest managers should assess the extent to which proximity to the Iron Gate Fish Hatchery has resulted in hybridization with mainstem spawning, fall-run Chinook salmon. If a significant proportion of genetically unique mainstem spawners exists, then protecting them from subsequent harvest may be a high priority. Conversely, if the population is highly hybridized, such protections may not be warranted.

3.1.4.3 Fish salvage in the mainstem

We recommend salvaging mainstem-spawning fall-run Chinook salmon be considered. This would likely entail capturing upstream-migrating adults during early November before dam removal, holding and spawning them at Iron Gate Hatchery, and releasing their progeny during the spring following peaks in sediment pulses. It may also be feasible to release adults upstream of Iron Gate Dam into potential spawning tributaries rather than holding them. We recommend accomplishing the salvage operation with the installation of a temporary upstream migration weir located in the mainstem upstream of the Shasta River, which could be operated from about late August through October when flows are low, and prior to dam removal impacts. This appears to be feasible, as similar weirs are operated seasonally in the Trinity River in conditions of higher flow, and equally stable channel configurations. To sort migrants believed to be spawning in the mainstem from those returning to Iron Gate Hatchery or Bogus Creek, it is recommended that 100% of the progeny of the year class (or classes) expected to be affected be marked (e.g., adipose fin-clipped) as outmigrant smolts. Capture efficiency at Bogus Creek is anticipated to be high, and it is assumed that it is feasible for all smolts released from Iron Gate Hatchery could to be marked. In years of high production, it may not be feasible to capture a high percentage of smolts from Bogus Creek.

These efforts may only accomplish the rescue of a few thousand adults, and will likely have adverse effects on the adults salvaged. However, mainstem spawners and their progeny are at a very high risk for complete mortality, so we believe that the risk associated with handling mortality is justifiable. However, it is not certain if the mainstem spawning component of the population is genetically "unique" enough to warrant salvage efforts. Although the fall-run Chinook salmon that spawn in the mainstem Klamath River downstream of Iron Gate Dam are distributed in a location that makes them likely candidates to recolonize habitat upstream of Iron Gate Dam after dam removal, genetically they are likely introgressed to some degree with hatchery stock, which may affect their suitability for recolonization. Although no current fish management reintroduction plan exists, we recommend that any actions to hold or release fall-run Chinook salmon be consistent with long-term reintroduction efforts.

3.1.4.4 Increase fall and spring flows

Analysis of the mainstem natural spawner fraction versus flow suggests that, generally, increased numbers of naturally produced fall-run Chinook salmon adults spawn in the mainstem during years when fall flows are low (Figure 18). Although the association is weak, and other factors likely affect the number of mainstem spawners, increased flows during fall prior to dam removal are recommended to potentially increase the rate of migration of fall-run Chinook salmon into tributaries, and thus reducing the proportion of fish directly exposed to TSS during dam removal. We recommend water managers consider releasing water in fall during dam removal to mimic the natural hydrograph that would have existed in the Klamath River during a "wet year" prior to the USBR project, consistent with recommendations in NRC (2004). However, if the water year during dam removal is dry, managers will need to balance the benefits of increased flows during fall with the risk of impacts to the basin if less water is available during the following spring. Increases in fall flows are assumed to be most successful if conducted synchronously with increased flows in regulated tributaries, as would occur under natural conditions. Increased fall flows in the Shasta and Scott rivers, for example, are thought to be key triggers to "pull" adult Chinook salmon out of the mainstem and encourage their migration upstream into tributaries. The timing and implementation of these flow releases should take into consideration the hydrograph of unregulated tributaries. Doing so will ensure that adults that are attracted up the mainstem by increasing fall flows are not blocked from accessing their natal streams due to natural low flow conditions.

In addition, to decrease risk of other sources of mortality on fall-run Chinook salmon beyond that caused by elevated TSS, increased fall flows from the Trinity River should be considered if conditions are present for a repeat of the 2002 adult fish kill that occurred in the mainstem Klamath River, which was attributed to disease-causing pathogens. Primary conditions that led to the outbreak of the ever-present disease pathogens *Ichthyophthirius multifilis* (*Ich*) and *Flabobacterium columnare* (*columnaris*) were low flows, elevated water temperatures, and relatively high densities of adult Chinook salmon in the lower river. Criteria have been developed by the Trinity Management Council to identify when conditions are present for the consideration of triggering a pulse flow from the Trinity River (USFWS 2004). It is recommended that these criteria be reconsidered during the year(s) that dam removal is planned to occur.

Under natural, unregulated conditions, a spring flow pulse occurred in the Klamath River and in its tributaries (NRC 2004). This historical feature of the hydrograph is thought to increase the survival of salmon juvenile outmigrants and smolts through several mechanisms, including decreased infection of *Ich* among juveniles, decreased residency time in the mainstem prior to smolting, and increased habitat availability in the mid-Klamath River (Hardy et al. 2006), especially in the reach between Shasta River and Scott River where survival is particularly poor

(Beeman et al. 2007, 2008). Impacts from a potential pulse of sediment during spring would be expected to result in further increases in rates of mortality. As with fall flows, spring pulse flows would be most beneficial for salmon smolts if released synchronously with increased flows in regulated tributaries. We recommend that water managers increase spring flows during the year of dam removal in the Klamath River mainstem and regulated tributaries to reduce the impacts of dam removal on outmigrating smolts.

3.1.4.5 Habitat quality in tributaries

The dependence of fall-run Chinook salmon on tributaries for spawning and rearing is a key life-history feature that is anticipated to reduce impacts on them during dam removal, and to facilitate their recovery. Therefore we recommend actions to improve habitat quality in tributaries to aid fall-run Chinook salmon's ability to survive dam removal. Detailed recommendations for improving habitat quality in tributaries in provided in Section 3.3.4.2, and are anticipated to benefit fall-run Chinook salmon as well as other species.

3.1.4.6 Hatchery release timing

We recommend hatchery managers consider adjusting the timing and/or magnitude of hatchery releases during the year of drawdown to avoid mortality associated high TSS events during dam removal. This may include reducing the number of smolts released during the spring and increasing the number of sub-yearlings that are released during the fall.

3.2 Spring-run Chinook Salmon

Two Chinook salmon ESUs occur in the Klamath River basin—the Southern Oregon and Coastal (SOCC) ESU, which spawns in the mainstem Klamath River from its confluence with the Trinity River to the ocean, and the Upper Klamath and Trinity Rivers ESU, which spawns in the upstream portion of the basin (Myers et al. 1998). Both ESUs were last determined to not warrant listing in September of 1999 (NMFS 1999). This section focuses on spring-run Chinook salmon, and Section 3.1 above focuses on the fall-run. Although wild spring-run Chinook salmon in the Klamath River system differs from fall-run Chinook genetically, as well as in terms of life history and habitat requirements (NRC 2004), both runs are included within these ESUs (Myers et al. 1998). It is believed that the Salmon River population of spring-run Chinook salmon may be the last wild population in the Klamath River system (NRC 2004). Trinity River spring-run Chinook salmon are composed mostly of naturally spawning fish of hatchery origin (NRC 2004); although the South Fork Trinity River may have a component of wild fish.

3.2.1 Life history

There appears to be three life history types for spring-run Chinook salmon in the Klamath River basin based on Sullivan (1989):

- Type I (smolts enter ocean within a few months of emergence)
- Type II (smolts enter ocean in autumn or early winter)
- Type III (smolts enter ocean in spring at age-1+)

Wild spring-run Chinook salmon in the Klamath River appear to consist primarily of Type II life history, based on scale analyses of adults returning from 1990 to 1994 in the Salmon River

(Olson 1996) as well as otolith analyses[4] of Salmon River fry and adults (Sartori 2006b). The Type III life history is also a component of the overall population, although apparently not nearly as prevalent as the Type II. In the South Fork Trinity River, the vast majority of fish were also identified as outmigrating as age-0 in the spring, or autumn, and not rearing over the winter (Table 9) (Dean 1995). There are apparently some age-1 outmigrants (age-1 defined as having overwintered in freshwater and presumably outmigrating greater than one year after emergence) in the Klamath River basin, but it appears not nearly to the same extent as age-0 outmigrants.

Based on scale analyses, Olson (1996) found that 7.1% of adults returning to the Salmon River from 1990 to 1994 exhibited a Type III life history. Based on scale analyses of adults returning in 1991 and 1992, Dean (1995) noted that 10–12% of returning adults exhibited a Type III life history in the South Fork Trinity River. Age-1 juvenile outmigration in the South Fork Trinity River has been observed to occur from mid-winter through spring (Table 9), with the latest outmigrant captured on 9 April (Dean 1994, 1995). Olson did not find any age-1 juvenile outmigrants in the Salmon River, but he did not trap during the winter or early spring.

Table 9. Life-history timing of spring-run Chinook salmon in the Klamath River basin downstream of Iron Gate Dam. Peak activity is indicated in black.

Life stage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Type I																								
Incubation[1]	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	▨	▨	▨	▨	▨	▨
Emergence[1, 2]					▨	▨	■	■	▨	▨	▨													
Rearing					▨	▨	▨	▨	▨	▨														
Juvenile outmigration[1]							■	■	■	■														
Adult migration in mainstem1[1,3,11]						▨	▨	▨	▨	▨	▨	▨												
Adult entrance into tributaries[1,11]									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
Spawning[7, 8]																	▨	▨	■	▨				
Type II																								
Rearing					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			
Juvenile outmigration[1, 9, 10 ,11]																			■	■	▨			
Type III																								
Rearing					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile outmigration[1, 10, 11]		▨	▨	▨	▨	▨	▨	▨	▨	▨														

[1] Olson (1996); [2] West 1991; [3] Tuss et al. (1990, as cited in Olson 1996), [4] NAS (2004, as cited in FERC 2006); [5] Barnhart (1994); [6] NRC (2004); [7] Dean (1995a); [8] Sartori 2006a; [9] Sullivan (1989), [10] Dean (1994); [11] Dean (1995)

Adult spring-run Chinook salmon begin entering the Klamath River as early as February (Tuss et al. 1990, as cited in Olson 1996), and continue freshwater entry for the duration of the spring season (NRC 2004, Barnhart 1994). Adults entering the Klamath River hold in pre-spawning holding pools for the spring (NRC 2004). Spring-run Chinook salmon adults were previously thought to hold for major periods of the summer in the mainstem Klamath River; however, extensive radio telemetry records indicate that most upstream-migrating adults pass through the mainstem and stage in holding pools in or near key tributaries (e.g., Blue Creek, Trinity and Salmon rivers) before water temperatures reach around 22ºC (usually early July) (J. Strange, Fisheries Biologist, Yurok Tribe, unpublished data, 2007). There may be extensive holding at least through April and into May, based on known holding timing in the South Fork Trinity River and the Salmon River. It appears that fish start to hold in the South Fork Trinity and Salmon rivers by May and June, respectively (Dean 1995 and Olson 1996), and adults are not typically

---

[4] Annual marks deposited in scales or otoliths (ear bone) used to determine fish age.

observed in the lower Klamath until late-March (Tuss et al. 1990, as cited in Olson 1996). Adults spawn in the Salmon River from mid-September to late-October (Sartori 2006a). Spawning in the South Fork Trinity River occurs from September through early November (Dean 1995).

Incubation occurs primarily from September to mid-January, based on estimated 50% hatch timing from Olson (1996), but may extend into June in some years. Emergence takes place from March and continues until early-June (West 1991). Olson (1996) reported that peak fry emergence in the Salmon River occurs in April. Age-0 juveniles rearing in the Salmon River emigrate at various times of the year, with one of the peaks of outmigration occurring in April through May (Olson 1996), which would be considered Type I life history. Olson (1996) further noted that outmigrating fish captured during this period consisted entirely of smaller fish (mean <60 mm FL). However, based on outmigrant trapping from April to November in 1991 at three locations in the South Fork Salmon River, Olson (1996) reported that greatest peak in outmigration of age-0 juveniles (69%) was in mid-October, which would be considered Type II life history. Based on scale analyses of spawners in the upper South Fork Salmon River, Olson (1996) concluded that the majority (84.3%) of returning adults have a Type II life history. Scale circuli[5] patterns of adults with an identified Type II life history were consistent with those from juveniles outmigrating in mid-October. Sullivan (1989) reported that outmigration of Type II age-0 juveniles can occur as late in the year as early-winter. It is unclear what the outmigration pattern is for age-0 spring-run Chinook juveniles on the Trinity River is because differentiation between spring and fall race juveniles has not been documented; however, on the South Fork Trinity River, outmigration occurs in late-April and May with a peak in May (Dean 1994, 1995). It can be assumed that age-0 juveniles in the South Fork Trinity River that do not outmigrate during this period remain in the stream to rear. This is because age-1 juveniles have been found to outmigrate from the South Fork Trinity River during the following spring (Dean 1994, 1995).

It is unclear how much time outmigrating age-0 juveniles spend in the Klamath River mainstem and estuary before entering the ocean. Sartori (2006b) did identify a period of increased growth (estimated mean of 24 days) just prior to reaching an estuarine environment based on otolith analyses of returning adults to the Salmon River, but this period was never clearly linked to mainstem residence. From March to May, there were fair numbers of age-1 juvenile outmigrants captured in the Klamath River estuary (Wallace 2004). Most were identified to be hatchery age-1 juvenile fall-run Chinook salmon, but nearly half were identified to be of natural origin, based on tag expansions. It seems likely that at least some of these natural origin fish were spring-run Chinook outmigrants.

3.2.2 Distribution

Spring-run Chinook salmon in the Klamath River basin are distributed mostly in the Salmon and Trinity rivers (Figure 19). Adults entering the mainstem Klamath River in winter and spring presumably hold in the Klamath River mainstem, as there are no indications of fish entering either the Salmon River or South Fork Trinity River during this time period. Flows are typically relatively high during this period, and thus little sampling takes place, so it is difficult to evaluate where fish are actually holding. Adults have, however, been observed in the Klamath River below Weitchpec from late-March to mid-June (Tuss et al. 1990, as cited in Olson 1996). Temperatures are typically cooler in the winter and spring, and there may be greater extent of holding than in the summer.

---

[5] Annual marks deposited in scales used to determine age of fish.

Spring-run Chinook salmon spawn in both the Trinity and Salmon river systems (Figure 19). In the Trinity River, spawning distribution includes the mainstem and the South Fork Trinity River, although it is assumed that most Trinity River spawners are of hatchery origin (NRC 2004). In the Salmon River sub-basin, spawning for spring-run Chinook salmon occurs above the confluence of the North and South Forks (P. Brucker, Salmon River Restoration Council, pers. comm., as cited in Sartori 2005). Based on data for both jacks and adults (hatchery and natural) from the mainstem Trinity River (KRIS 2004a), Salmon River (KRIS 2004b), and South Fork Trinity River (KRIS 2004c) from 1992 to 2001, on average around 5% of the escapement returns to the Salmon River, with the remainder returning to the Trinity River system (including South Fork Trinity River). The Salmon River contributions to the overall escapement ranged from 1 to 20%, and from 2 to 35% of the natural escapement; note however that the Trinity River escapement estimate of "natural" fish could include large numbers of hatchery strays. If there are large numbers of Trinity River hatchery strays, then the Salmon River fraction of natural escapement would be even higher than what is reported here. No spawning has been observed in the mainstem Klamath River (Shaw et al. 1997).

Rearing of age-0 juveniles likely occurs in the mainstem Klamath River, although it appears that the majority rear in their natal streams (i.e., Salmon and Trinity rivers). It is unclear to what extent Trinity River age-0 spring-run Chinook salmon rear in the mainstem Trinity or Klamath rivers, as trapping studies have not differentiated between spring and fall races. There were relatively small numbers of age-1 juveniles captured in the estuary in spring as compared with age-0 juveniles (Wallace 2004).

It appears that at least a portion of the populations in the Salmon River (7.1% of returning adults based on Olson 1996) and South Fork Trinity River (10–12% of returning adults based on Dean 1995) overwinter in freshwater, and outmigrate as age-1 fish. Age-1 juveniles are present in the tributaries, mainstem, and estuary as they outmigrate. Based on scale analyses by Olson (1996) and Dean (1994, 1995), it appears that the majority of age-1 juvenile outmigration occurs during the spring. This is consistent with Wallace (2004) who noted that age-1 juveniles were typically captured in the estuary during spring; however, it is unclear what proportion of these fish were actually spring-run. Based on tag expansions, Wallace (2004) identified many age-1 fall-run Chinook salmon to be hatchery origin, but nearly half were identified to be of natural origin. It seems likely that at least some portion of these natural origin fish were spring-run Chinook outmigrants that were rearing in the mainstem Klamath River or estuary.

Sartori (2006a) analyzed otolith data for the juvenile outmigration period from August through October, and identified 18 of 59 otoliths as similar to samples taken from known spring-run Chinook salmon (not fall-run Chinook salmon) spawning grounds, confirming that spring-run Chinook salmon are outmigrating to the mainstem Klamath River during the fall, as is regularly observed in mid-Klamath tributaries (T. Soto, Fisheries Biologist, Karuk Tribe, unpublished data 2008). Based on direct observation in tributary pools, Chinook salmon age-0 juveniles are decreasing in abundance in the mainstem Klamath River during late summer, but are still present in substantial numbers (T. Shaw, USFWS, unpublished data 2002, as cited in NRC 2004), suggesting extended mainstem rearing into the fall. Juvenile Chinook salmon were still present in over 40% of pools sampled in September; however, it is difficult to say what proportion of these fish are spring-run versus fall-run without genetic analyses. In addition, it is also likely that juveniles spend at least some time in the estuary prior to ocean entry. Based on adult otolith analysis, Sartori (2006b) estimated mean residence time in estuarine habitats to be 104 days; however, Sartori (2006b) acknowledged that entry into the estuarine environment could not be truly identified, but had to be assumed based on a change in otolith patterns.

3.2.3 Potential population response

We evaluated potential impacts of TSS on the spring-run Chinook salmon population using the DREAM-1 model results for maximum average daily TSS values by water year type for each life stage (Figures 20–23). This analysis focused on the implications of DREAM-1 model runs 44 (wettest case scenario) and 54 (driest case scenario) for the life-history timing and distribution of spring-run Chinook salmon (Figures 24–29). Because of the run timing of adults, and the predominance of smolt outmigration in the spring and fall, impacts on the population are potentially more severe if dam removal occurs during a wet year (e.g., run 44), when the reservoir could be inundated early during winter, which would delay the erosion of reservoir deposits until spring when reservoir levels are low enough to expose sediment deposits.

Adult spring-run Chinook salmon typically enter and migrate up the Klamath River during March through June (Table 9), and thus the entire adult population is anticipated to be affected by the spring pulse of TSS. Although the majority (>90%) of adults return to the Trinity River and will be exposed to lower concentrations due to dilution, those adults returning to the Salmon River could be exposed to peak TSS concentrations over 350 ppm (Figure 20) if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a month over 50 ppm (Table 10). Overall the impacts are expected to be sublethal, including major physiological stress (Table 10). Stressed adults are assumed to be more susceptible to disease, possibly increasing pre-spawn mortality, unless exposure causes avoidance behavior and early entrance into tributary habitat as was observed for upstream migrating Chinook salmon and coho salmon adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008), and is consistent with observed avoidance behavior of juvenile salmonids to TSS (Sigler et al. 1984, Servizi and Martens 1992). In some wet years modeled a pulse of sediment also occurs during summer (July), when spring-run Chinook salmon are typically holding in tributaries, and therefore not anticipated to be affected. Since no spring-run Chinook salmon spawning occurs in the mainstem Klamath River, incubating eggs are not anticipated to be affected by acute turbidity.

Table 10. Potential for risk to spring-run Chinook salmon life stages based on anticipated exposure to TSS.

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Adult upstream migrants headed for tributaries (1 March to 30 June)	> 50	One month	8	Based on examination of modeled wet years (worst-case scenarios) at Orleans Station	Majority of adults enter Trinity River, and will be exposed to lower concentrations.
	> 150	One week	8		
	>350	One day	8		
Spawning	Because no spring-run Chinook salmon spawning occurs in the mainstem Klamath River, spawners, incubating eggs, and emergent are not anticipated to be affected by dam removal.				
Incubation					
Emergent fry					

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Type I outmigration (1 April to 31 May)	> 100	One week	8	Based on examination of modeled wet years (worst-case scenarios) at Orleans station.	Majority of juveniles outmigrate from Trinity River, and will be exposed to lower concentrations.
	> 200	One day	6–7		
Type II outmigration (1 October to 15 November)	> 20	One week	6	Based on examination of modeled dry years (worst-case scenarios) at Orleans Station.	Assumes that rearing occurs in tributaries, and outmigration from mid-Klamath continues into fall.
	> 2,500	One day	9		
Type III outmigration (15 January to 31 May)	> 50	One month	8	Based on examination of modeled wet years (worst-case scenarios) at Orleans Station.	Majority of juveniles outmigrate from Trinity River, and will be exposed to lower concentrations.
	> 500	Two weeks	9		
	> 5,000	One day	9		

[1] Predicted maximum concentration and duration of TSS was calculated from specific life history stage timing information for each species using DREAM-1 model results.

[2] Based on Newcombe and Jensen (1996) severity index (Table 5).

Most late winter and rearing of Type I and II life histories is thought to occur in tributaries (West 1991; Dean 1994, 1995) reducing likelihood of exposure in the mainstem. Downstream migration of Type I to the mainstem and ocean occurs in April and May (Table 9), which is after most predicted impacts from the winter sediment releases, and before potential impacts from a late spring sediment pulse predicted to occur in wet years (Figure 21). It appears that even during wet years, analyzed outmigrants from the Salmon River would be exposed to peak daily concentrations less than 250 ppm, a week of concentrations over 100 ppm, with outmigrants from the Trinity River exposed to even lower concentrations (Figure 27). This exposure is anticipated to result in some sublethal moderate to major physiological stress, which in association with other environmental factors in the basin (e.g., water temperatures, exposure to disease) could lead to some mortality or reduced fitness at a later life stage.

Age-0 juveniles of the Type II life history rear in the lower Klamath River mainstem or estuary into early November. Potentially, there may be large numbers of juveniles produced from the year class preceding the year of dam removal reaching the estuary in early to mid-November, based on peak migration in mid-October (Olson 1996) and a mean residence time in "optimal" freshwater habitat of 24 days (Sartori 2006b). It is not totally clear where these fish go after they leave the Salmon and Trinity rivers, but based on otolith data for the Salmon River, residence time in estuary-type habitat is estimated to be as long as 3.5 months (Sartori 2006b). If rearing time in estuary-type habitat is actually overestimated, and Sartori's (2006b) estimates of estuarine residence include rearing in nearshore environments rather than just the estuary, and thus actual estuarine residence time is short (i.e., <3 weeks), it may be possible that the majority of Type II juvenile outmigrants will have reached the ocean prior to dam removal in early November. Those juveniles remaining in the estuary during dam removal could experience one-day exposures of over 1,500 ppm during a wet year (Table 10; Figure 22), with anticipated physiological stress including reduce growth rates. Since this is near the end of their outmigrant timing, fish exposed to this pulse of TSS may simply migrate to the ocean and avoid impacts, consistent with observed avoidance behavior of juvenile salmonids to TSS (Sigler et al. 1984, Servizi and Martens 1992).

The life history type most likely to be affected is the Type III, since freshwater rearing is the longest in duration for these fish (Table 9). If overwintering of juveniles in the mainstem Klamath River does occur, these fish would be affected by TSS during winter peak TSS concentrations. Age-1+ juveniles rearing or outmigrating during winter and early spring would be exposed to up to month of concentrations over 50 ppm, and possibly a day over 10,000 ppm in a wet year, with anticipated mortality sublethal major physiological stress (Table 10). Based on scale analyses, at most around 17% of the escapement is from the Type III life history and could be affected. However, at least some proportion of winter rearing occur in tributaries (West 1991; Dean 1994, 1995) reducing the duration of exposure, and most Type III outmigrants enter the mainstem at the Trinity River, where TSS concentrations of TSS are predicted to be more dilute.

The overall effect of dam removal to the spring-run population is not anticipated to be significant. Although most of the escapement could be exposed to TSS during a wet year, most adults return to the Trinity River, where sediment releases are predicted to be diluted by significant accretion from upstream tributaries. In addition, since there is no spawning in the mainstem, impacts on spawning, eggs, fry, and most rearing is also protected. Although the Type III life history could be directly affected, significantly mortality is not anticipated, and most outmigrants are not Type III. This highlights that the plasticity of the population, with three life history types, should result in the protection of most production and relative rapid recovery to pre-dam removal stock levels, even under a variety of sediment release scenarios.

3.2.4 Recommendations for reducing impacts

Overall, sediment impacts on spring-run Chinook salmon following dam removal are not anticipated to be severe. Measures such as trapping and capturing adult or smolt Chinook salmon and either trucking or holding them, have been considered, but are not recommended. The following measures are recommended:

- Consider dam removal impacts in the management of annual harvest.
- Increase spring instream flows.
- Improve habitat conditions (e.g., increased instream flows, habitat restoration) in the South Fork Trinity and Salmon rivers.

3.2.4.1 Management of annual harvest

Current harvest regulations limit harvest within much of the mainstem Klamath River, and portions of the mainstem Trinity River. We recommend that during the year of dam removal, harvest managers consider the potential impacts of dam removal on spring-run Chinook salmon. Specifically, we recommend harvest managers consider continuing to reduce the potential harvest of the component of the run that may spawn in the Salmon River, which is a key sub-population for recovery of the overall population, and will be crucial to help recolonize habitat upstream of Iron Gate dam after dam removal. More stringent management of harvest as a means to reduce impacts of dam removal is also consistent with the Elwha River restoration plan (Ward et al. 2008), which reflects an agreement between Washington State and local tribes to curtail all in-river fisheries for a period of 5 years when active removal of the Elwha Dam begins.

3.2.4.2 Increase spring flows

The rate of spring-run Chinook salmon migration appears to be related to flows in the Klamath River and tributaries (Strange 2007). Under natural, unregulated flow conditions, a spring pulse of flow occurred in the Klamath River and in its tributaries (NRC 2004). We recommend water managers increase spring flows consistent with the natural hydrograph for a wet year in all regulated tributaries of the Klamath basin, as well as the mainstem Klamath River during the year of dam removal to increase the rate of migration of spring-run Chinook salmon upstream into key tributaries (i.e., Salmon River). We also recommend the spring flow pulse to increase survival of outmigrating smolts, as described in Section 3.1.4.4. Note that the Type II outmigrating smolts would also benefit from the increased fall instream flows described in Section 3.1.4.4, which could increase their rate of downstream migration, allowing them to leave the Klamath basin prior to dam removal.

3.2.4.3 Conditions in South Fork Trinity and Salmon rivers

The dependence of spring-run Chinook salmon on the Salmon River and South Fork Trinity River for spawning and rearing is a key life-history feature that is anticipated to reduce impacts on them during dam removal, and to facilitate their recovery. Therefore, all actions taken to improve habitat conditions in these tributaries are recommended to aid spring-run Chinook salmon's ability to survive dam removal. Detailed recommendations for improving habitat quality in tributaries are provided in Section 3.3.4.2, and are anticipated to benefit spring-run Chinook salmon in addition to other species. However, efforts to enhance habitat conditions in the Salmon River upstream of the confluence of the North and South Forks, and South Fork Trinity River are recommended in particular due to the concentration of the natural, spring-run escapement occurring there.

3.3 Coho Salmon

The Southern Oregon/Northern California coho salmon ESU was federally listed as threatened on 6 May 1997 (NMFS 1997). The threatened status of Southern Oregon/Northern California coho salmon was reaffirmed in NMFS' final listing determination issued on 28 June 2005 (NMFS 2005). The Southern Oregon/Northern California coho salmon ESU includes all naturally spawned populations between Punta Gorda, California and Cape Blanco, Oregon, a designation area encompassing the Trinity and Klamath river basins (NMFS 1997). Critical habitat for coho salmon was designated on 5 May 1999 and includes all reaches of all rivers, including tributaries and estuarine habitat, between the Elk River in Oregon and the Mattole River in California (NMFS 1999). Habitat located on tribal lands on the lower Trinity River was not included as critical habitat.

The vast majority of coho salmon that spawn in the Klamath River basin are believed to be of hatchery origin. Indirect estimates indicate 90% of adult coho salmon in the system return directly to hatcheries or spawning grounds in the immediate vicinity of hatcheries (Brown et al. 1994). Most natural spawning appears to occur in tributaries of the Klamath River below Weitchpec (Wallace 2004) (Figure 30). In the Trinity River, 97% of spawners are estimated to be of hatchery origin (USFWS/Hoopa Valley Tribe [HVT] 1999). The largest spawning escapement appears to be in the Trinity River; Estimated escapements from 1997 to 2002 ranged from 239 to 51,826 fish (KRIS 2004d). In contrast, from 1930 to 2002, the Shasta River has typically had less than 400 spawners, with ≤30 fish from 1985 to 2000 (KRIS 2004e). Redd surveys on the Scott

River identified 212 redds in the 2001/2002 spawning season (FERC 2006). Escapement data for the mainstem Klamath River and other tributaries does not appear to be available.

3.3.1 Life history

Adult coho salmon enter the Klamath River between late-September and mid-December, with peak upstream migration occurring between late-October and mid-November (Table 11; NRC 2004). Spawning generally occurs within a few weeks following arrival at spawning grounds (NRC 2004). Based on data from Maurer (2002), timing of coho entrance into Scott Creek appears to peak by late-November, with most spawning occurring in early-December.

Table 11. Life-history timing of coho salmon in the Klamath River basin downstream of Iron Gate Dam. Peak activity is indicated in black.

Life stage (citations)	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Incubation	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								▨	▨	▨	▨
Emergence[1,2,3]				▨	■	■	■	■	▨	▨	▨	▨	▨											
Rearing[4]	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile redistribution[5]																			▨	▨	▨	▨		
Juvenile outmigration[6, 7, 8 9, 10]				▨	▨	▨	■	■	■	■	▨	▨												
Adult migration[9]																		▨	▨	■	■	▨	▨	
Spawning[9, 11]	▨	▨																			■	■	■	■

[1] CDFG (2000, unpubl. data, as cited in NRC 2004); [2] CDFG (2001, unpubl. data, as cited in NRC 2004); [3] CDFG (2002, unpubl. data, as cited in NRC 2004); [4] Sandercock (1991);[5] T. Soto, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008; [6]Scheiff et al. (2001); [7] Chesney and Yokel (2003); [8] T. Shaw (USFWS, unpubl. data, 2002, as cited in NRC (2004); [9] NRC (2004); [10]Wallace (2004); [11] Maurer (2002)

Coho salmon fry emerge from redds beginning in late February (CDFG 2000, 2001, 2002, all unpubl. data, as cited in NRC 2004). Peak emergence occurs in March and April, although fry are observed through June and early-July (CDFG 2000, unpubl. data, as cited in NRC 2004). Coho salmon typically rear in streams for one year (Sandercock 1991). In the Shasta River, fry and juvenile outmigration peaks in early-April and mid-May, respectively, indicating that these fish may rear in the mainstem Klamath River after outmigration from the Shasta River. Outmigrant trapping in the Trinity River suggests that fry and juveniles also outmigrate to the mainstem Klamath River in the spring (Scheiff et al. 2001). In the Scott River, fry and juvenile outmigration appears to occur later in the spring, and into the summer (Chesney and Yokel 2003), but these fish probably spend less time in the mainstem prior to outmigration. Few juveniles are observed in pools at the mouths of tributaries in the mainstem by early fall (T. Shaw, USFWS, unpubl. data, 2002, as cited in NRC 2004). Significant migration of age-0 juveniles occurs in the fall (October through November), typically during the first rainfall and freshet of the season (T. Soto, Fisheries Biologist, Yurok Tribe, unpublished data 2008).

Juveniles smolt and migrate downstream from tributaries into the mainstem Klamath River from February through mid-June with a peak in April and May (USFWS, unpublished data, 1998, as cited in NRC 2004; Chesney and Yokel 2003; Scheiff et al. 2001; NRC 2004), and appears to coincide with the descending limb of the spring hydrograph (NRC 2004). Outmigrant trapping results from 2002 reported by Chesney and Yokel (2003) indicate that smolts outmigrate from March to early-July in the Shasta River, and from late-March to late-May in the Scott River. In 2001, peak emigration occurred later in the Shasta River (late-April) as compared with the Scott River (late-March), although there were very few (<10) smolts captured in the Scott River (Chesney and Yokel 2003). In the Trinity River, coho salmon smolts were typically captured from early-May to mid-June (Scheiff et al. 2001). Smolts appear to move downstream rather quickly; Wallace (2004) reported that numbers of coho salmon smolts in the Klamath River estuary peaked in May, the same month as peak outmigration. Wallace (2004) also observed a significant decrease in estuary presence by June and July, suggesting a brief residence time prior to ocean entry.

3.3.2 Distribution

Coho salmon are distributed throughout the Klamath River downstream of Iron Gate Dam, and in its tributaries (Figure 30). Most coho salmon in the Klamath River basin spawn in tributaries (Trihey and Associates 1996). Most fry and juvenile rearing also occurs in tributaries (NRC 2004). Rearing has also been observed in tributary confluence pools in the mainstem Klamath River (T. Shaw, USFWS, unpublished data, 2002, as cited in NRC 2004). Low densities of juveniles in the mainstem during early fall (August and September) has been associated with high mortality rates related to poor water quality (NRC 2004), and, although some juveniles do rear in the mainstem, it appears that most production occurs in tributaries.

Emergent fry are likely to be distributed in or near redds at spawning locations in the tributaries. Important coho salmon habitat identified by NMFS (2002) includes (Figure 30):

- Four large tributaries, including the Shasta, Scott, Salmon, and Trinity rivers;
- Six small tributaries entering the Klamath River between Iron Gate Dam and Seiad Valley;
- Thirteen (13) small tributaries between Seiad Valley and Orleans; and
- Twenty-seven (27) small tributaries between Orleans and the mouth of the Klamath River.

The majority of natural coho smolt production appears to occur in tributaries of the Klamath River downstream of Weitchpec (Wallace 2004). Blue Creek and Hunter Creek are two other known producers of natural coho salmon in the lower Klamath River that make a substantial contribution to production (Voight and Gale 1998). Substantial spawning also occurs in the Trinity, Shasta, Scott, and Salmon rivers (FERC 2006). Coho salmon have also been observed to spawn in side channels, tributary mouths, and shoreline margins of the mainstem Klamath River from Beaver Creek (RM 161) downstream to Independence Creek (RM 94) (Trihey and Associates 1996).

Juvenile rearing and smolt production occurs from all tributaries where spawning occurs. In addition, significant migration of age-0 juveniles occurs in the fall (October through November), with many juveniles emigrating from tributaries in the mid-Klamath, including Shasta, Scott and Salmon rivers, as well as small tributaries in the mid-Klamath including, Independence, China, Dylan, Thompson, and Stanshaw creeks. These outmigrations typically take place during the first rainfall and freshet of the season (T. Soto, Fisheries Biologist, Yurok Tribe, unpublished data 2008). In fall 2007, juvenile coho salmon PIT tagged during this emigration were detected migrating upstream into tributaries (including some that were dry during summer), off-channel ponds, and other winter refuge habitat in the lower Klamath River (near or within the estuary), including Waukell, Panther, Hunter, and McGarvey creeks (M. Hiner, Fisheries Biologist, Yurok Tribe, unpublished data, 2008). This migration upstream out of the mainstem Klamath River occurs on an annual basis mostly in October and November, with less movement in December.

3.3.3 Potential population response

We evaluated potential impacts of TSS on the coho salmon population using the DREAM-1 model results for maximum average daily TSS values by water year type for each life stage (Figures 31–34). This analysis focused on the implications of DREAM-1 model runs 44 (wettest case scenario) and 54 (driest case scenario) for the life-history timing and distribution of coho salmon (Figures 35–37). Impacts on adults are potentially more severe if dam removal occurs during a dry year (e.g., run 54), when more sediment could be exposed earlier in the year since the reservoirs would be less inundated, and thus fine sediment would be more readily transported downstream. Conversely, impacts on outmigrating juveniles are potentially more severe if dam removal occurs during a wet year (e.g., run 44), when the reservoir could be inundated during winter, delaying the transport of fine sediment until spring when reservoir levels are low enough to expose sediment deposits.

Dam removal may have a direct effect on returning adult coho salmon. Adult coho salmon enter the Klamath River between late September and mid-December, with peak upstream migration occurring between late October and mid-November. Therefore, the later portion of the coho salmon run could be within the mainstem during the initial peak of sediment released during dam removal (Figures 35–37). If dam removal occurs during a dry year, adults that don't reach tributary habitat prior to early-November are anticipated to be exposed to long durations (>2 weeks) of concentrations over 8,000 ppm, and potentially a day with concentrations over 38,000 ppm (Table 12). If dam removal does not occur during a dry year, duration and concentration of exposure are predicted to be much lower (Tables 1–4). Assuming a "worst-case scenario" (i.e., removal occurs during a dry year), mortality rates of up to 40% are anticipated (Table 12). If removal occurs during a dry year, impacts could also be exacerbated by later run timing, potentially increasing the proportion of the run in the mainstem after 6 November.

Table 12. Potential for risk to coho salmon life stages based on anticipated exposure to TSS.

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Adult upstream migrants (15 September to 15 December)	>8,000	Two weeks	11	Based on examination of modeled dry years (worst-case scenarios) at Iron Gate Station	Upstream migrant exposure likely limited to last two weeks of November
	> 38,000	One day	11		
Spawning	> 10,000	> One month	NA	Based on examination of modeled dry years (worst-case scenarios) at Iron Gate Station	Cumulative effects of TSS on multiple life stages are not explicitly addressed by Newcombe and Jensen's (1996) severity index. However, due to long-term (> 2 weeks) exposure of spawners, incubating eggs, and emergent fry to TSS >10,000, all spawning in the mainstem are assumed to result in 100% mortality.
Incubation					
Emergent fry					

Life history stage (timing)	**Anticipated magnitude (ppm)[1]**	**Anticipated duration based on sediment pulse and life-history timing**	**Index of anticipated impact on individuals in mainstem[2]**	**Sediment analysis notes**	**Other biological considerations**
Age-1+ juveniles during winter (15 November to 21 March)	>3,000	One month	11	Based on examination of modeled dry years (worst-case scenarios) at Iron Gate Station	Many juveniles over winter in lower river or migrate to off-channel habitat and thus avoid impacts
	>8,000	Two weeks	11		
	> 38,000	One day	10		
Age-0+ juveniles during summer (22 March to 14 November)	> 1,000	One month	11	Based on examination of modeled wet years (worst-case scenarios) at Iron Gate Station	Exposure to juveniles rearing in mainstem could occur during summer for age-0+ if removal occurs during a wet year
	> 4,000	One day	9		
Juvenile outmigrants (1 February to 15 June)	> 400 ppm	Two weeks	9	Based on examination of modeled wet years (worst-case scenarios) at Seiad Valley	Exposure to juvenile outmigrants could occur during most of the spring outmigration
	>1,500	One day	8		

[1] Predicted maximum concentration and duration of TSS was calculated from specific life history stage timing information for each species using DREAM-1 model results.

[2] Based on Newcombe and Jensen (1996) severity index (Table 5).

Coho salmon adults entering lower Klamath tributaries are not likely to be significantly affected by dam removal, since most will be out the mainstem by early-November, and TSS is predicted to be more diluted in the lower River (e.g., Klamath Station on Figure 31). The number of coho salmon adults ultimately exposed to TSS from dam removal will be those adults that either spawn in the mainstem, or those fish returning to upper Klamath River tributaries (e.g., Bogus Creek), mid-Klamath tributaries (e.g., Shasta and Scott rivers), or Iron Gate Hatchery that have not migrated from the mainstem at the onset of dam removal (6 November). Based on an analysis combining both hatchery and naturally-produced coho salmon, an average of 16 coho salmon (<1% of total escapement) spawn in the mainstem (although uncertainty exists because observations during winter are challenging). Typically, around 4,000 coho salmon adults enter either upper or mid-Klamath tributaries, and 1,500 return to the Iron Gate Hatchery. Based on run timing, it appears that about 35% of these fish will have left the mainstem by the time sediment from dam removal is released (Table 13). Therefore, overall, it appears that less than 12% (3,600 in an average year) of the total Klamath basin adult escapement will be in the mainstem and directly affected by the release. However, escapement varies considerably between years, and the overall impact could be higher if dam removal is during a year with poor returns. Most of these fish are anticipated to be naturally-produced (68%, based on Table 13), since it appears that hatchery-origin fish have a slightly early run timing. For example, Gale et al. (1998) have observed an entry period from early-October into January in lower Klamath River tributaries, and Wietkamp et al. (1995) suggests an even broader period from late-August to mid-January, although in the mainstem near these lower Klamath River tributaries TSS is predicted to be more dilute (e.g., Klamath Station, Figure 31). On average, approximately 27% of the naturally-produced adult escapement would be affected to differing degrees (depending on distribution in the mainstem).

Table 13. Average annual escapement for coho salmon with estimated number of fish vulnerable to TSS impacts in the mainstem Klamath River following dam removal, based on data from 2001 to 2004.

Reach destination	Average annual escapement (proportion of total run)	Average number in mainstem following dam removal (fraction of run)	Proportion hatchery origin	Source notes
Iron Gate Hatchery	1,500 (0.05)	660 (0.44)	0.78	IGH (2008), Hampton (2005a, as cited in Ackerman et al. 2006)
Lower Klamath tributaries	646 (0.02)	323 (0.50)	0.10	Ackerman et al. (2006) Fraction of run in mainstem is a professional judgment value based on Blue Creek data (Gale et al. 1998); hatchery proportion professional judgment based on no observations of hatchery influence.
Middle Klamath tributaries	2,166 (0.07)	1,429 (0.66)	0.15	Ackerman et al. (2006)
Trinity River	25,123 (0.80)	1,256 (0.05)	0.80	D. Hillemeier, Yurok Tribal Fisheries Program and W. Sinnen, CDFG, as cited in Ackerman et al. (2006).
Upper Klamath mainstem	16 (0.0)	16 (1.00)	0.27	Magneson and Gough (2006) Assumed same hatchery proportion as for Bogus Creek, based on data from Hampton (2005c, as cited in Ackerman et al. 2006).
Upper Klamath tributaries	1,875 (0.06)	1,500 (0.80)	0.27	Ackerman et al. (2006). Fraction in mainstem based on Bogus Creek run timing (Hampton 2005c, as cited in Ackerman et al. 2006). Assumed same hatchery proportion as for Bogus Creek, based on data from Hampton (2005c, as cited in Ackerman et al. 2006).
Total Klamath River basin run	31,325 (1.0)	5,184 (0.17)	0.74	Values summed or averaged across reaches.

The approximately 12% of the adult run that could be exposed to sediment releases following dam removal may be further reduced due to adult coho salmon behavior. Based on well documented avoidance behavior of juvenile salmonids to TSS (e.g., Sigler et al. 1984, Servizi and Martens 1992), it is possible that the response to TSS in the fall might be increased rate of migration into the tributaries as an avoidance behavior, as was observed for upstream migrating Chinook salmon and coho salmon adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm. August 2008).

Because spawning in the mainstem is not common for coho salmon (Figure 30), it is unlikely that dam removal will directly affect egg or alevin development, with the exception of the redds created by the few coho salmon that are observed to spawn there. However, for those coho salmon that do spawn in the mainstem, the cumulative impacts on multiple life stages (adults, eggs, emergent fry) of chronic exposure to TSS greater than 10,000 ppm are anticipated to result in no production (i.e., 100% mortality of incubating eggs through emergent fry; Table 12).

Although most fry rearing is believed to occur in tributaries, age-0+ juveniles are observed outmigrating from tributaries in late spring and early summer. Juveniles produced from tributaries and rearing in the mainstem during the summer following dam removal could be exposed to TSS of over 1,000 ppm for a month if dam removal occurs during a wet year (Table 12). Under this scenario, mortality rates up to 40% are anticipated, including reduced feeding and growth rates (Table 12). These impacts, in addition to exposure to diseases and the elevated temperatures currently observed in the mainstem Klamath River during summer, would likely have the cumulative effect of high mortality for these individuals. There could also be long-term effects on marine survival as well, if those fish suffering physiological stress survive the summer, but smolt at a smaller size (Bilton et al. 1982, Hemmingsen et al. 1986).

Age-1+ juveniles (progeny from the year class prior to dam removal) that have either survived rearing conditions during summer, or outmigrated from tributaries during fall, rearing in the mainstem during winter of dam removal could be exposed to concentrations equal to those of upstream-migrating adults, with potential mortality rates up to 40% (Table 12). However, it appears that many of these juveniles are migrating to the lower Klamath River and avoiding conditions in the mainstem by using tributary and other off-channel habitat during winter, thus lowering their exposure and potential mortality, a pattern that is likely to be even more pronounced as juveniles attempt to avoid increased TSS (Sigler et al. 1984, Servizi and Martens 1992). The peak in the fall downstream migration is in October and November, and thus many of the juveniles should either be out of the mainstem when initial pulses in sediment occur, or far enough downstream to avoid peak TSS concentrations.

It appears that most juveniles rear in tributaries or off-channel habitat during winter, and will not be affected until migrating to the ocean as smolts. If dam removal occurs during a wet year (e.g., model runs 45 and 48 of Figure 34), there could be an adverse effect for smolts, since the peak of outmigration appears to be in April and May coinciding with a predicted spring turbidity spike (Figures 35–38). The impact is likely to be greater if the pulse happens later (April or May) rather than earlier (March), since there are increasing numbers of smolts reaching the mainstem Klamath River in April and May. It appears that most natural origin smolts outmigrate to the mainstem Klamath during April and May (Wallace 2004), and would therefore be vulnerable to turbidity effects in the spring. Wallace (2004) hypothesized that pre-smolts likely spend at least a month in the mainstem, and would thus be susceptible to turbidity during spring. However, even during the most severe years analyzed, peak TSS concentrations are typically less than 500 ppm (Table 12), and only during one dry year modeled was there durations of more than a day over 1,000 ppm (Table 12). The concentrations and durations predicted during spring outmigration are in the range that are anticipated to result in sublethal effects, such as reduced feeding and growth rates, and other signs of physiological stress. Therefore, coho smolts exposed to turbidity would be expected to suffer physiological stress, and mortality rates are not anticipated to be significant (Table 12). However, coho salmon smolts outmigrating from the Klamath River near Iron Gate Dam have mortality rates of around 35 to 70% (Beeman et al. 2007, 2008), which in conjunction with reduced feeding and growth could result in high mortality of outmigrants. Studies on coho salmon mortality rates (based on radio-tagged releases) are only based on a few years of data, but so far it appears that survival is higher for wild fish than for hatchery fish. This differential in survival is (1) associated with the length of residency in the mainstem prior to migrating (fish that enter the mainstem later have higher survival), (2) may be related to discharge (in some instances migrants had higher survival when flows in mainstem were higher), and (3) is much lower in the upper Klamath River (most mortality occurs upstream of confluence with Scott River). There could also be a longer-term effect on the year class if fish smolt at a smaller size with consequent reduced marine survival.

The overall effect of dam removal on the coho salmon population is not expected to be significant, despite direct mortality to a proportion of some life stages. A decrease, but not elimination, in production of coho salmon from two year classes is likely. For example, if a turbidity spike occurs during dam removal in November of 2010, juveniles rearing in the mainstem from the 2010 year class would be affected, as would adults from the 2011 year class. A spring turbidity spike in 2011 will have an additional impact on the 2010 age-0 fry and 2010 smolts. However, the likelihood of significant loss of the adult escapement or smolt production is low (Table 12). A proportion of the potential smolt production and a large proportion of the adult population would likely be in tributaries or off-channel habitat by mid-November, or low enough in the basin to avoid high concentrations of TSS (Figure 35). In addition, impacts are distributed between two year classes, rather than being cumulative on one year class. Therefore, the proportion of adults that successfully spawn in tributaries during the year of dam removal will produce smolts that will outmigrate to the ocean a year after the spring pulse of sediment, and should not have reduced fitness associated with dam removal. Since impacts on adults are potentially greater during a dry year, and impacts on smolts greater in a wet year, it is likely that regardless of the hydrological year in which dam removal occurs there will be impacts on coho salmon during either adult or juvenile outmigration life stages. In addition, escapement varies considerably between years, and the overall impact could be higher if dam removal is during a year with poor returns. In general, the wide distribution, and use of tributaries of coho salmon juvenile and adults should allow moderate production under even a worst-case scenario, and therefore, recovery of the population should not be significantly limited by short-term impacts associated with dam removal.

3.3.4 Recommendations for reducing impacts

Overall, sediment impacts on coho salmon following dam removal are not anticipated to be severe. Measures such as trapping and capturing adult or smolt coho salmon and either trucking or holding them, have been considered, but are not recommended. The following measures are recommended:

- Increase fall and spring instream flows.
- Improve habitat conditions (e.g., increased instream flows, habitat restoration) in Klamath River tributaries, especially during the year prior to dam removal.
- Postpone the release of hatchery smolts until early summer.

3.3.4.1 Increased fall and spring flows

Analysis of fall-Chinook salmon mainstem natural spawner fraction versus flow indicates that more naturally-produced adults spawn in the main stem during years when fall flows are low (Figure 18). Similarly, migration of coho salmon adults into tributaries also appears to be affected by flow, with earlier tributary entrance times observed in Blue Creek during years with high flows during fall (Figure 38; Gale et al. 1998). Based on limited data in Blue Creek (Gale et al. 1998) and Shasta River (Hampton 2002, Hampton 2005b, as cited in Ackerman et al. 2006), tributary entrance timing in the lower to middle Klamath River appears to be related to the timing of the first substantial fall flow event (Figures 38–40), and entrance into Bogus Creek has also been associated with the first major change in daily discharge at the Klamath River below Iron Gate Dam gage (although a strong relationship between flow and migration has not been observed in other upper Klamath River tributaries). Coho salmon migration has been observed (but not quantified) in relation to pulse flow events in the Shasta River as well (M. Hampton, Fisheries Biologist, CDFG, per comm.., 2007). In addition, significant downstream migration and redistribution of age-0 juveniles into winter habitat occurs in the fall during the first rainfall and freshet of the season (T. Soto, Fisheries Biologist, Yurok Tribe, unpublished data, 2008), which if it occurs before dam removal would allow these fish to avoid the initial pulse of sediment.

Increased flows in Klamath River, and especially in regulated tributaries during fall, prior to dam removal, are recommended to potentially increase the rate of migration of fall-run Chinook salmon, and coho salmon into tributaries, thus reducing the proportion of fish directly exposed to TSS during dam removal. We recommend releasing water in fall during dam removal to mimic the natural hydrograph that would have existed in the Klamath River during a "wet year" prior to the USBR project, consistent with recommendations in NAS (2004). However, if the water year during dam removal is dry, managers will need to balance the benefits of increased flows with the risk of impacts to the remainder of the basin if less water is available later in the year. Increases in fall flows are assumed to be most successful if conducted synchronously with increased flows in regulated tributaries, as would occur under natural conditions. Increased fall flows in the Shasta and Scott rivers, for example, are thought to be key triggers or cues to "pull" adult coho salmon out of the mainstem and encourage their migration upstream into tributaries. The timing and implementation of these flow releases, which would require cooperation with water managers in the tributaries, should take into consideration the hydrograph of unregulated tributaries to ensure that coho salmon adults that are attracted up the mainstem by increasing fall flows are not blocked access their natal streams due to natural low flow conditions. Fall flows (from the Trinity River) are also believed to be an effective management tool to decrease infection and mortality of coho salmon adults from the ciliated protozoan *Ichthyophthirius multifiliis* (*Ich*) in the lower mainstem Klamath River.

Under natural, unregulated conditions, a spring pulse of flow occurred universally in the Klamath River and in its tributaries (NRC 2004). This main feature of the hydrographs is thought to increase the survival of coho salmon juvenile outmigrants and smolts through several mechanisms, including decreased infection of *Ich* among juveniles, decreased residency time in the mainstem prior to smolting, and increased habitat availability in the mid-Klamath River (Hardy et al. 2006), especially in the reach between Shasta River and Scott River where survival is particularly poor (Beeman et al. 2007, 2008). Based on radio-tagged smolt releases of Beeman et al. (2007, 2008), coho salmon smolts migrating from the upper Klamath River downstream of Iron Gate Dam currently have mortality rates of around 35 to 70%, with higher rates for fish with longer residency times in the mainstem prior to smolting. Impacts from a potential pulse of sediment during spring would be expected to result in further increases in rates of mortality. As with fall flows, spring pulse flows would be most beneficial for coho salmon smolts if released synchronously with increased flows in regulated tributaries. Chesney et al. (2007, as cited in Ericksen et al. 2007) observed that springtime (typically in April) increases in water diversions and agricultural operations appeared to increase water temperature and decrease available habitat, apparently leading to a pulse in outmigration of fry and juveniles into the mainstem Klamath River. In some tributaries with unregulated flows, improved habitat conditions could increase both rearing time (decreasing residence in mainstem prior to migration), and possibly facilitate higher growth rates allowing fish to enter the mainstem at a larger size. It is also possible that increased instream flows in some tributaries (e.g., Shasta River) could allow later emigration timing, as well as increasing the dilution of TSS in the mainstem. We recommend water managers increase spring flows during the year of dam removal in the Klamath River mainstem and regulated tributaries to reduce the impacts of dam removal.

3.3.4.2 Habitat quality in tributaries

The dependence of coho salmon on tributaries for spawning and rearing is a key life-history feature that is anticipated to reduce impacts on them during dam removal, and to facilitate their recovery. We recommend that restoration activities in the Klamath River basin be viewed not as separate from actions from dam removal, but integral to the success of reducing the impacts of dam removal, and crucial to facilitate a healthy and strong recovery of populations. Programs such as the Klamath River Basin Conservation Area Restoration Program (USFWS 2005), the Salmon River Subbasin Restoration Strategy (Elder et al. 2002), and the Klamath River Coho Salmon Recovery Plan (NMFS 2007) are examples of ongoing efforts to restore habitat, restore instream flows, and increase fish access. All actions taken to improve habitat quality in tributaries are recommended to aid coho salmon's ability to survive dam removal, and to increase their recovery in general. Mid-Klamath river tributaries, including the Shasta and Scott rivers, are currently providing most of the production of coho salmon from the Klamath River upstream of Orleans (Figure 30). It is probable that these fish, in closest proximity to Iron Gate Dam are both the most likely to be affected by TSS during dam removal and to contribute to the recolonization of habitat upstream of the dams post removal. We recommend the following measures, consistent with the detailed recommendations of NRC (2004):

- Reestablish cool summer flows in tributaries (including Shasta and Scott rivers). In some locations (e.g., Park Creek, tributary to Shasta River or Rail Creek, tributary to Scott River), this may be accomplished by providing land owners with a groundwater well or compensation for water rights, thus allowing dedicated water rights to be directed to instream flow. In other locations (e.g., Big Springs Creek, tributary to Shasta River), riparian restoration, channel construction, and fencing are predicted to decrease instream water temperatures and improve rearing habitat quality. In other locations, tailwater capture systems or additional points of water diversion could improve water quality and increase instream flows without affecting the volume of water rights (A. Manji, Statewide FERC Coordinator, CDFG, pers. comm., August 2008).
- Remove or provide for effective passage (e.g., replacing flashboards with alternative diversion methods, upgrading ineffective fish ladders, channel reconstruction in aggraded channels) at all small dams and diversions throughout the distribution of salmonids in tributaries. Many of the key barriers in the Klamath River basin are included in the California Fish Passage Assessment Database (CalFish Portal 2008). Specific examples of known barriers include: (1) Park Creek (tributary to the Shasta River), where a culvert on a levee road is a partial barrier for adult coho salmon, Chinook salmon, and steelhead to 28 miles of habitat, (2) an earthen dam on Rail Creek (tributary to Scott River), (3) numerous gravel push-up dams used for water diversions on tributaries to the Scott River, (4) an aggraded channel at the confluence of Shackleford Creek (tributary to Scott River), and (5) a CalTrans culvert on Mill Creek (tributary to East Fork Scott River) (A. Manji, Statewide FERC Coordinator, CDFG, pers. comm., August 2008).
- Ensure that prescriptions for land-use practices (timber management, road construction, agriculture/grazing, and residential and infrastructure development) are sufficiently stringent to prevent physical degradation of tributary habitat.
- Reduce impairment of spawning habitat through reductions in the delivery of fine sediment from timber management, agriculture, livestock, or other human activities.

Habitat enhancement efforts in the lower Klamath River tributaries are also crucial, since most of the natural production of coho salmon within the Klamath basin is believed to result from tributaries downstream of the confluence with the Trinity River, and since juveniles produced from throughout the basin use lower Klamath tributaries and off-channel habitat to rear during winter (increasing ability to avoid adverse conditions in the mainstem). In the early 1990s, the State Coastal Conservancy began working with Simpson Timber Company (now Green Diamond Resource Company), the Yurok Tribe, and others to identify causes of impairment and recommend actions for remediation. Initial reports (e.g., Balance Hydrologics 1995) determined that the main cause of habitat impairment in the tributaries was sedimentation resulting particularly from intensive logging and unregulated road building on unstable slopes from the 1950s through the 1970s. Funded in part by the Conservancy and others, multi-year restoration efforts have been implemented to remediate human-caused sediment sources from 30 tributary sub-basins within the lower Klamath River basin. It is highly recommended that these efforts continue to maintain and enhance habitat for coho salmon in tributaries, thus increasing resiliency to disturbances in the mainstem Klamath River. In addition, focused efforts to increase over-wintering habitat, such as expanded efforts to create rearing ponds in Waukell Creek, should help provide refuge for coho salmon, steelhead, cutthroat trout, and other species during dam removal.

3.3.4.3 Hatchery release timing

We recommend that hatchery managers adjust the timing of hatchery releases during the year of dam removal, although it would be out of synch with natural life-history timing. If smolts are released later in the spring (e.g., mid-May), survival is anticipated to be higher based on current conditions (Beeman et al. 2007, 2008), as well as avoiding the peak in spring release of sediment in the year following dam removal.

3.3.4.4 Protection of weak year classes

Annual monitoring of natural adult coho salmon returns is currently not adequate to establish a good record of year-class strength (NRC 2004). However, based on available data, it does appear that there are very likely years of strong year classes (e.g., 2004, 2007), and years of weak year classes (e.g., 2002, 2005). We recommend that consistent monitoring of tributaries be conducted for adults and outmigrating juveniles to establish a record of year class strength. The timing of dam removal should then take into account year class strength of naturally produced coho salmon. We recommend that dam removal be conducted in a year of at least one, if not a series of strong year classes, to provide a greater opportunity for the population to recover from the effects of removal.

3.4 Summer Steelhead

This section addresses spring/summer steelhead; fall and winter steelhead are addressed below in Section 3.5. Some sources refer to this run as a "summer" run (i.e., Moyle 2002, NRC 2004, USFWS 1998, Papa et al. 2007), while others refer to it as a "spring" run (Hopelain 1998). In this document, this run will be referred to as a "summer" run. Klamath Basin summer steelhead and winter steelhead populations both belong to the Klamath Mountain Province (KMP) Evolutionary Significant Unit. In a 2001 status review, NMFS determined that KMP steelhead did not warrant ESA listing (NMFS 2001a), despite acknowledging that their numbers are declining and they are in danger of extinction (Busby et al. 1994). In addition to genetic differences (Papa et al. 2007), summer steelhead differ from the other runs by run timing, sexual maturity upon freshwater entry, incidence of repeat spawning, and incidence of the half-pounder life-history (described below). Within the Klamath River basin summer steelhead population there are considerable behavioral (Hopelain 1998) and genetic (Papa et al. 2007) differences from the other runs.

3.4.1 Life history

Summer steelhead enter the Klamath river earlier than either the fall or winter-runs, and unlike the other runs, enter sexually immature (Barnhart 1994, Moyle 2002). Although data are limited, it is believed that summer steelhead adults enter the mainstem Klamath River from March to June (Table 14) (Hopelain 1998), and migrate to cooler tributaries (Barnhart 1994, Moyle 2002). Summer steelhead adults appear to migrate rapidly once entering freshwater and appear to hold longer than other runs. This contention is supported indirectly by observed run timing on the New River in 1994 (tributary to the Trinity River). Summer steelhead entry into the New River ranged from late March to mid-July, with a peak in late June (USFWS 1996, as cited in USFWS 1998). They have also been observed during snorkel surveys in several Klamath River tributaries during July through September (Dean 1995, USFWS 1998). There is a greater incidence of repeat spawning for summer steelhead, 40–64% as compared with 18–48% for fall run, and 31% for winter-run (Hopelain 1998).

Table 14. Life-history timing of summer steelhead in the Klamath River basin downstream of Iron Gate Dam. Peak life history periods are shown in black.

Life stage (citations)	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Incubation	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨											▨	▨
Emergence[1]						▨	▨	▨	▨	▨	▨	▨												
Rearing[2, 3]	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile outmigration[3, 4, 5]							■	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Half-pounder residence[4, 6, 7]	▨	▨	▨	▨	▨	▨										▨	▨	▨	▨	▨	▨	▨	▨	▨
Adult migration in mainstem[4]					▨	▨	▨	▨	▨	▨	▨	▨												
Adult holding in tributaries[1, 5, 8, 9]													▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Spawning[1, 10]	▨	▨	▨	▨																			▨	▨
Run-backs[5]						▨	▨	■	▨	▨														

[1] PacifiCorp 2004; [2] NRC 2004; [3] PacifiCorp 2004; [4] Hopelain 1998; [5] Wallace 2004; [5] USFWS 1998; [6] CDFG 1988, as cited in USFWS 1998; [7] NRC 2004; [8] USFWS 1996, as cited in USFWS 1998; [9] Dean 1995; [10] Klamath River Stock Identification Committee (KRSIC) 1993, as cited in USFWS 1998

All steelhead runs share the "half-pounder" life-history pattern, in which an immature fish emigrates to the ocean in the spring, returns to the river in the fall, spends the winter in the river, then emigrates to the ocean again the following spring (Busby et al. 1994, Moyle 2002). Half-pounders enter freshwater from approximately mid-August to mid-October, with peak entry occurring during the last week in August to mid-September (CDFG 1988, as cited in USFWS 1998). Half-pounders typically utilize the mainstem Klamath River, although they also use larger tributaries such as the Trinity River during the fall (Dean 1994, 1995). Half-pounders that overwintered in freshwater during the previous winter typically outmigrate in March. The incidence of half-pounders appears to vary greatly, depending on the population of summer steelhead in the basin (Hopelain 1998). Most data on observations of half-pounders is not run-specific, to our knowledge. The half-pounder life history does not appear to be as prominent for the summer run when compared with the fall run. Hopelain (1998) found that only 32% of summer steelhead adults (17 adults in all) in the North Fork Trinity River exhibited a half-pounder life history, in comparison with 94% for upper Klamath River fall steelhead (406 adults);

however, 100% of all summer steelhead adults in Clear Creek (7 adults) exhibited a half-pounder life history.

Spawning probably occurs slightly earlier for summer steelhead than for the other runs, with timing thought to be from December through February (Table 14) (KRSIC 1993, as cited in USFWS 1998). Adult steelhead downstream migrants (run-backs) are thought to migrate to the ocean from mid-March to late May, based on steelhead emigration in New River, tributary to the Trinity River (USFWS 1998).

Age-0, 1, and 2 juveniles all rear to some extent in the mainstem during fall. Run-type has not been identified for juveniles observed in the mainstem Klamath River to our knowledge. It is assumed that summer-run fish have a similar life-history pattern to observed steelhead juveniles, presumably of different run types. In tributaries to the Klamath River above Seiad Creek, it appears that large numbers of age-0 and 1 juveniles leave tributaries and enter the mainstem in spring and summer, and that these fish are likely rearing in the mainstem before leaving as age-2 outmigrants (CDFG 1990a, 1990b, as cited in USFWS 1998). Upstream of the Trinity River confluence, around 13% of rearing juveniles (run is unknown) are age-0, 47% are age-1, 37% age-2, and 3% are age-3 (Scheiff et al. 2001). Similar proportions occur in Trinity River. Age-0 steelhead were also observed rearing in the upper mainstem Klamath River from mid-May through mid-October (CDFG 1990a, 1990b, both as cited in USFWS 1998). Rearing also takes place in tributaries to the Klamath River, as well as the estuary during fall. Based on rotary screw trapping[6] in the Trinity River through October or November, age-0, 1, and 2 juvenile outmigrants were all captured as late as early December (Scheiff et al. 2001). Assuming that these fish reached the Klamath River mainstem shortly thereafter, mainstem Klamath River rearing occurred throughout the entire fall period (and for the entire year for age-0 outmigrants). Juveniles are also captured in the estuary as late as September and October, when sampling ends (Wallace 2004). Juveniles were also captured at the Big Bar rotary trap on the mainstem Klamath River from mid-September to mid-December (USFWS 1998).

Summer steelhead juveniles share a similar life-history pattern to fall and winter steelhead, with over 90% smolting at age-2 (Hopelain 1998). Smolts appear to outmigrate throughout the entire fall period, with smolts captured in the estuary during the entire sampling period (typically from May to September, although sometimes as late as October) (Wallace 2004), and from mid-September to mid-December at the rotary screw trap at Big Bar (USFWS 1998). It appears, however, that peak smolt outmigration occurs earlier than fall (i.e., in April, May, or June), based on estuary captures (Wallace 2004).

3.4.2 Distribution

Summer steelhead are distributed throughout the Klamath River downstream of Iron Gate Dam, and in its tributaries (Figure 41). Spawning distribution is thought to be upstream of typical winter steelhead spawning areas, but where coho salmon are likely to be present (NRC 2004). Spawning is primarily in tributaries, and based on direct observation is believed to include the following streams: Bluff Creek, Red Cap Creek, Dillon Creek, Clear Creek, Indian Creek, Elk Creek, Wooley Creek, Salmon River, South Fork Trinity River, North Fork Trinity River, New River, and Canyon Creek (Roelofs 1983). Based on analysis of available escapement data from 1978 through 1997, on average around 53% of the population spawn in tributaries to the Klamath River upstream of the confluence with the Trinity River. It is believed that summer steelhead

---

[6] Rotary screw traps capture downstream migrating fish by sampling a portion of the water column.

adults are fairly rare above Seiad Creek, due to high water temperatures (Kent Bulfinch, California In-River Sport Fishing Community Representative, pers. comm., 1996, as cited in NRC 2004). Half-pounders appear to travel upstream along with fall-run Chinook salmon during their fall spawning migration (USFWS 1998).

Juveniles rear in the mainstem Klamath River, tributaries to the Klamath, or the estuary. It is thought that juveniles rearing in tributaries are typically distributed near spawning locations, typically upstream of winter steelhead distribution, although probably sympatric with coho salmon (NRC 2004). Based on analysis of available outmigrant trapping data (including Scheiff et al. 2001, Chesney 2000, Chesney and Yokel 2003), a little over half of the production of juveniles (of all runs) appears to be produced from tributaries upstream of the confluence with the Trinity River, consistent with spawning distribution (although there is much annual variation). There appears to be substantial mainstem rearing of steelhead juveniles into September, with 88% of pools surveyed containing steelhead, as compared with only 41% for Chinook salmon juveniles and 3% for coho salmon juveniles (T. Shaw, USFWS, unpublished material, 2002, as cited in NRC 2004).

A significant migration of age-0 juvenile steelhead are observed migrating upstream into tributaries (including some that were dry during summer), off-channel ponds, and other winter refuge habitat in the lower Klamath River (near or within the estuary), including Waukell, Panther, Hunter, and McGarvey creeks (M. Hiner, Fisheries Biologist, Yurok Tribe, unpublished data, 2008). This migration upstream out of the mainstem Klamath River occurs annually, mostly in October and November, but also in December through February. Smolts are captured in the mainstem and estuary throughout this period as well, although the peak outmigration is typically in spring and summer (USFWS 1998, Wallace 2004).

3.4.3 Potential population response

We evaluated potential impacts of TSS on the summer steelhead population using the DREAM-1 model results for maximum average daily TSS values by water year type for each life stage (Figures 42–46). This analysis focused on the implications of DREAM-1 model runs 44 (wettest case scenario) and 54 (driest case scenario) for the life-history timing and distribution of summer steelhead (Figures 47–52). Impacts on adults are potentially more severe if dam removal occurs during a dry year (e.g., run 54), when more sediment could be exposed earlier in the year since the reservoirs would be less inundated, and thus fine sediment is more readily transported downstream. Conversely, impacts on outmigrating juveniles are potentially more severe if dam removal occurs during wet years (e.g., run 44), when the reservoir could be inundated during winter, delaying the transport of fine sediment until spring when reservoir levels are low enough to expose sediment deposits.

The entire adult summer steelhead escapement is anticipated to be affected by the spring pulse of TSS, since adults typically enter and migrate up the Klamath River during March through June (Table 14). In addition, mature adults returning to the ocean (“run-backs”) from the preceding year’s escapement migrate downstream after spawning during this same period. Although around 47% of adults return to the Trinity River or tributaries downstream and will be exposed to lower concentrations due to dilution, those adults returning to tributaries upstream of the Trinity River could be exposed to peak TSS concentrations over 700 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a month over 50 ppm (Table 15). Overall the impacts are expected to be sublethal, including major physiological stress (Table 15). Stressed adults are assumed to be more susceptible to disease, possibly increasing pre-spawn mortality, unless exposure causes avoidance behavior and early entrance into tributary habitat, as was observed for upstream-migrating Chinook salmon and coho salmon adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008), and is consistent with observed avoidance behavior of juvenile salmonids to TSS (Sigler et al. 1984, Servizi and Martens 1992). In some modeled wet years, a pulse of sediment also occurs during summer (July), when summer steelhead are typically holding in tributaries, and therefore would not be affected.

Table 15. Potential for risk to summer steelhead life stages based on anticipated exposure to TSS.

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Adult upstream migration and run-backs (1 March to 30 June)	> 50	One month	8–9	Based on examination of modeled wet years (worst-case scenarios) at Seiad Valley Station	Proportion enters Trinity River, and will be exposed to lower concentrations
	> 150	Two weeks	8		
	> 700	One day	8		
Half-pounder residence (15 August to 31 March)	> 1,000	One month	10	Based on examination of modeled dry years (worst-case scenarios) at Seiad Valley Station	Proportion enters Trinity River, and will be exposed to lower concentrations
	> 3,000	Two weeks	11		
	> 30,000	One day	11		
Spawning	Because no steelhead spawning occurs in the mainstem Klamath River, spawners, incubating eggs, and emergent are not anticipated to be affected by dam removal.				
Incubation					
Emergent fry					
Rearing (All year)	> 1,000	One month	11	Based on examination of modeled dry years (worst-case scenarios) at Seiad Valley Station	Many juveniles rear in lower mainstem or estuary where TSS concentrations will be lower
	> 3,000	Two weeks	11		
	> 30,000	One day	10–11		
Juvenile outmigration (1 April to 30 June)	> 150	One week	8	Based on examination of modeled wet years (worst-case scenarios) at Seiad Valley Station	Many juveniles outmigrate from lower mainstem where TSS concentrations will be lower
	> 500	One day	7–8		

[1] Predicted maximum concentration and duration of TSS was calculated from specific life history stage timing information for each species using DREAM-1 model results.

[2] Based on Newcombe and Jensen (1996) severity index (Table 5).

Adult summer-run half-pounders typically enter the mainstem and hold from around mid-August through March (Table 14), and thus would be affected by sediment released during both fall and winter. Although some half-pounders are observed to hold in the Trinity River or other tributaries, half-pounders in the mainstem upstream of the Trinity River could be exposed to peak TSS concentrations over 30,000 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a month over 1,000 ppm (Table 15). Overall the impacts are expected to be lethal, with mortality rates as high as 40% (Table 15). Stressed adults are also assumed to be more susceptible to disease, possibly increasing pre-spawn mortality, unless exposure causes avoidance behavior and entrance into tributary habitat, as was observed for upstream-migrating Chinook salmon and coho salmon adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008). On average, 32% of summer steelhead adults returning to the North Fork Trinity River are half-pounders (Hopelain 1998). Since no summer steelhead salmon spawning occurs in the mainstem Klamath River, incubating eggs are not anticipated to be affected by dam removal.

Juvenile summer steelhead rear in the mainstem Klamath River, tributaries to the Klamath, or the estuary. Since most (over 90%) of steelhead juveniles smolt at age-2, those juveniles outmigrating from tributaries to rear in the mainstem will be susceptible to fall, winter, and spring sediment releases. Based on captures in tributaries and the mainstem, it appears than around 40% of the population rears in tributaries until age-2, and thus will only be susceptible to the spring pulse while outmigrating. The approximately 60% of the rearing population that outmigrates as age-0 or age-1 and rears for extended periods in the mainstem upstream of Trinity River could be exposed to peak TSS concentrations over 30,000 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a month of TSS concentrations over 1,000 ppm (Table 15). Overall the impacts are expected to be lethal, with mortality rates as high as 40% (Table 15). For the approximately 47% outmigrating from the Trinity River, exposures are anticipated to be less (Figure 43), but some mortality would still be expected (up to 20%). However, it appears that many of these juveniles are avoiding conditions in the mainstem by using tributary and other off-channel habitat during winter, lowering their exposure and potential mortality. The peak in the migration out of the mainstem is in fall, and thus many of the juveniles should either be out of the mainstem when initial pulses in sediment occur, or they may migrate out of the mainstem later in the winter (as occurs for steelhead juveniles) when concentrations increase.

Summer steelhead outmigrating in spring as age-2 smolts in the mainstem upstream of the Trinity River could be exposed to peak TSS concentrations over 500 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a week over 150 ppm (Table 15). Overall the impacts are expected to be sublethal, including major physiological stress (Table 15). By fall these fish are typically in the estuary or in off-channel habitat, where TSS concentrations are more dilute (Figure 44). Approximately 47% of smolts outmigrate from the Trinity River, and will be exposed to lower concentrations, with one-day peaks less than 200 ppm (Figure 44).

The impacts of a sediment pulse on summer steelhead could be significant, particularly for the portion of the population, spawning in tributaries upstream of the Trinity River. For that portion of the population impacts are anticipated for at least six year classes, including adult run-backs, adults (including half-pounders), age-0 or juveniles rearing in the mainstem, and age-2 smolts outmigrating down the mainstem. However, the wide spatial distribution of steelhead in the Klamath basin means that many portions of the population will avoid severe impacts of TSS by remaining in tributaries for extended rearing, or using the Klamath River mainstem farther downstream where TSS concentrations are anticipated to be more dilute (e.g., 47% spawn in tributaries in and downstream of the Trinity River), or migrating out of the mainstem into tributaries and off-channel habitat during winter. In addition, the life history variation of steelhead means that although numerous year classes will be affected, not all individuals in any given year class will be affected. For example, the year class represented by the adults directly affected by dam removal will have had some proportion (around 30%) return the year before as half-pounders. In addition, a proportion of the escapement that spawns successfully will rear for long enough in tributaries to not only avoid the year of dam removal, but may not enter the mainstem until up to two years following dam removal. The high incidence of repeat spawners among the summer run steelhead (ranging from 40 to 64%, Hopelain 1998) is also anticipated to increase resiliency to dam removal impacts. Overall, the summer steelhead population is anticipated to be highly affected by removal, but has life history characteristics that should allow a strong recovery.

3.4.4 Recommendations for reducing impacts

Overall, sediment impacts on summer steelhead following dam removal are potentially severe. Measures such as capturing adult or juvenile steelhead and either trucking or holding them have been considered, but are not recommended. In the Klamath River basin, current fishing regulations only allow hatchery steelhead to be retained, so harvest management is unlikely to influence the impacts of dam removal. We recommend hatchery managers release smolts early in the spring to avoid the late spring pulse of sediment. In addition, improved habitat conditions (e.g., habitat restoration) in tributaries appear to be the most likely measure to reduce impacts of dam removal.

The dependence of summer steelhead on tributaries for spawning and rearing is a key life-history feature that is anticipated to reduce impacts on them during dam removal, and to facilitate their recovery. If the carrying capacity of habitat in the tributaries were increased by improving habitat complexity, it is possible that fewer individuals would migrate to the mainstem for rearing, and thus avoid impacts during removal. In addition, a significant migration of juvenile steelhead upstream into tributaries occurs during fall and winter.

Therefore, all actions taken to improve habitat quality in tributaries are recommended to aid steelhead's ability to survive dam removal, and to increase their recovery in general. In particular, efforts taken in Bluff Creek, Red Cap Creek, Dillon Creek, Clear Creek, Indian Creek, Elk Creek, Salmon River, South Fork Trinity River, North Fork Trinity River, New River, and Canyon Creek would benefit steelhead (and in most cases coho salmon as well). Summer steelhead are most likely to benefit from improved habitat conditions and off-channel rearing habitat with implementation of measures described in Section 3.3.4.2 for coho salmon.

3.5 Winter Steelhead and Rainbow Trout

Moyle (2002) described two runs, a winter and a summer run for the Klamath River basin, but Barnhart (1994), Hopelain (1998), USFWS (1998), and Papa et al. (2007) identified three runs (i.e., summer, fall, and winter) for the Klamath River basin. In this report, we refer to both the fall and winter-runs as "winter steelhead," and only make a distinction between the two runs when it is pertinent. Klamath basin summer steelhead and winter steelhead populations both belong to the Klamath Mountain Province (KMP) Evolutionary Significant Unit. In a 2001 status review, NMFS determined that KMP steelhead did not warrant ESA listing (NMFS 2001a), despite acknowledging that their numbers are declining and they are in danger of extinction (Busby et al. 1994).

This section considers both winter steelhead and rainbow trout of the same subspecies *Oncorhynchus mykiss irideus*, and does not include redband trout (*Oncorhynchus mykiss newberrii*). The vast majority of existing information addresses steelhead rather than resident coastal rainbow trout. This section primarily addresses steelhead, but it is assumed that juvenile rearing in freshwater will be similar for both the resident and anadromous forms of coastal rainbow trout.

3.5.1 Life history

In contrast to summer-run steelhead, the winter-run are sexually mature upon freshwater entry (Papa et al. 2007). Fall-run steelhead adults typically enter the Klamath River from July to October and winter-run steelhead adults typically enter from November through March (Table 16) (Hopelain 1998, USFWS 1998). In some years, nearly 100% of fall-run steelhead adults migrate into tributaries and out of the Klamath River mainstem by early November (Sinnen et al. 2006). However, migration timing of fall steelhead varies considerably between years, and in many years entry into the upper Klamath River (including Iron Gate Hatchery and Shasta River) continues into late December (CDFG 1982a, 1983, 1985, 1987, 1993, CDFG unpublished data, all as cited in USFWS 1998; Dean 1994). Comparing the peak of freshwater entry for fall steelhead based on estuary captures (typically late September; CDFG 1988, as cited in USFWS 1998) with the peak of entry at Iron Gate Hatchery (late-October to mid-November; CDFG 1982a, 1982b, 1983, 1985, 1987, 1993, all as cited in USFWS 1998; Dean 1994) and tributaries such as the Scott and Shasta rivers (mid-October; CDFG, unpublished data, as cited in USFWS 1998), it appears that holding in the mainstem for fall steelhead adults ranges from only a few weeks to nearly two months in the mainstem Klamath River. The peak of the run in the Trinity River also tends to occur in October and November, based on data from the Junction City and Willow Creek weirs (Dean 1994, 1995). It appears that fall steelhead adults utilize the mainstem Klamath River above Seiad Creek from September to December, and that winter steelhead adults utilize the same area from late December through mid-April (USFWS 1998). Holding patterns have not been identified directly, although fall steelhead adults can potentially hold in the mainstem Klamath River for several weeks.

Table 16. Life-history timing of fall-and winter-run steelhead and rainbow trout in the Klamath River basin downstream of Iron Gate Dam. Peak life history periods are shown in black.

Life stage (citations)	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Incubation	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
Emergence[1, 2]						▨	▨	▨	▨	▨	▨	▨												
Rearing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile outmigration							■	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Half-pounder residence[1, 3, 4, 5, 6, 7, 8]	▨	▨	▨	▨	▨	▨											▨	▨	▨	▨	▨	▨	▨	▨
Fall-run adult migration[9, 10, 11]													▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Winter-run adult migration	▨	▨	▨	▨	▨	▨															▨	▨	▨	▨
Spawning[1, 12, 13]	▨	▨	■	■	■	■	▨	▨	▨															
Run-backs[14]					▨	▨	▨	▨	▨	▨														

[1] NRC (2004); [2] Dean (1994); [3] Busby et al. (1994), [4] Moyle (2002); [5] CDFG (1988, as cited in USFWS 1998); [6] T. Kisanuki (USFWS, pers. comm., 1997); [7] USFWS (1979); [8] B. Claypole (Klamath River guide, pers. comm., 1996, as cited in USFWS 1998); [9] CDFG (1982a, 1983, 1985, 1987, 1993, CDFG unpublished data, all as cited in USFWS 1998; Dean 1994); [10] Hopelain (1998); [11] USFWS (1998); [12] KRSIC (1993, as cited in USFWS 1998); [13] West et al. (1990); [14] Nels Brownel (USFS, pers. comm., 1997, as cited in USFWS 1998)

Winter steelhead primarily spawn in tributaries, but also spawn in the mainstem, with peak spawn timing in February and March (ranging from January to April) (NRC 2004). In general, spawn timing of fall steelhead ranges from February through April, and from January through April for winter steelhead (KRSIC 1993, as cited in USFWS 1998). Spawning in tributaries to the Klamath River upstream of Seiad Creek occurs from mid-March to early May (West et al. 1990). Adults may repeat spawning in subsequent years after returning to the ocean.

Although there are little data on downstream migration of spawned adults, winter steelhead have been captured in May near the mouth of Beaver Creek (RM 259) (N. Brownel, USFS, pers. comm., 1997, as cited in USFWS 1998).

Fry emerge in spring (NRC 2004), with fry observed in outmigrant traps in Bogus Creek and Shasta River from March through mid-June (Dean 1994). Some juveniles rear in the mainstem during fall, and likely to some extent in the winter and spring. It is unclear if fish rearing in the mainstem during fall make migrations back into tributaries during winter, but age-0 and 1 year old juveniles have been captured in the mainstem until the end of trapping season in mid-December (USFWS 1998). Age-0 steelhead were also observed rearing in the upper mainstem Klamath River mainstem from mid-May through mid-October (CDFG 1990a, 1990b, both as cited in USFWS 1998), and juveniles have also been captured in the estuary as late as September and October (when sampling ended) (Wallace 2004).

In tributaries to the Klamath River above Seiad Creek, age-0 and 1 juveniles have been captured in outmigrant traps in spring and summer (CDFG 1990a, 1990b, as cited in USFWS 1998), which means that these fish are likely rearing in the mainstem before leaving as age-2 outmigrants. Upstream of the Trinity River confluence, around 13% of rearing juveniles (run is unknown) are age-0, 47% are age-1, 37% age-2, and 3% are age 3 (Scheiff et al. 2001). Similar proportions occur in Trinity River. Age-0 steelhead have been captured leaving the Shasta River and Bogus Creek from mid-April through early July, and age-1 steelhead were observed from January through June. Age-1 and 2 juveniles are typically captured in April and May at both the Big Bar rotary trap on the mainstem Klamath and the Willow Creek rotary trap on the Trinity River, and it is not uncommon for age-0 fish to be captured in May as well (Scheiff et al. 2001). Based on rotary screw trapping in the Trinity River, age-0, 1, and 2 juvenile outmigrants were all captured as late as early December (Scheiff et al. 2001). In addition, there is evidence of downstream migration of age-1 and 2 juveniles in tributaries such as Bogus Creek and Shasta River as early as mid-January and throughout the entire trapping season ending in June (CDFG 1990a, 1990b, as cited in USFWS 1998). Age-3+ juveniles are only captured in small numbers, but are typically captured from April to June in the mainstem Klamath River, and from April to May in the mainstem Trinity River. Peak abundance of juveniles in the estuary typically occurs in May and June (Wallace 2004).

Juvenile outmigration appears to primarily occur between May and September with peaks between April and June, although smolts are captured in the estuary as early as March and as late as October (Wallace 2004). Age-2 juveniles were the most common life history type based on scale analyses of returning adults, representing 86% of adult returns, in comparison with only 10% for age-1 juveniles and 4% for age 3 juveniles (Hopelain 1998).

3.5.2 Distribution

Winter steelhead are distributed throughout the Klamath River downstream of Iron Gate Dam, and in its tributaries (Figure 53). Klamath River fall and winter steelhead primarily spawn in tributaries such as the Trinity, Scott, Shasta, and Salmon rivers. Although NRC (2004) suggests that there may be some spawning in the mainstem Klamath River, there have been no observations in the mainstem above Seiad Creek (USFWS 1998) or documentation of spawning at any location within the mainstem. Escapement data on winter steelhead is lacking, primarily because of the logistical challenges of sampling adults during winter (NMFS 2001b, as cited in FERC 2006). Based on examination of limited available datasets, it appears that greater than 80% of adults return to tributaries upstream of the confluence with the Trinity River.

Half-pounders typically utilize the mainstem Klamath River until leaving the following March (NRC 2004), although they also utilize larger tributaries such as the Trinity River (Dean 1994, 1995). Half-pounders are seen as far up in the mainstem as Beaver Creek from December through February (Bob Claypole, Klamath River guide, pers. comm., 1996, as cited in USFWS 1998). This life-history pattern is common within all tributaries, although it appears to be dominant for fall-run spawners in the mainstem Klamath River tributaries upstream of Weitchpec (mean incidence of 94% of all returning adults), and in the mainstem Trinity River (80% of returning adults) (Hopelain 1998). Winter-run steelhead apparently have a much lower incidence of the half-pounder life history in comparison with fall-run (18% compared with a mean of 94% based on 5 Klamath tributaries upstream of Weitchpec) (Hopelain 1998).

Half-pounders typically return to the river in September, and the majority reside in the lower Klamath River through March before returning to the ocean (NRC 2004). As the fall progresses, half-pounders appear to travel upstream along with fall-run Chinook salmon during their spawning migration (USFWS 1998). Half-pounders are also common in the Trinity River, although they typically represent a small fraction of all steelhead that are sampled at either the Junction City or Willow Creek weirs, possibly because they may be able to swim through the spaces between weir bars. In some years, they have represented over 20% of the steelhead entering Trinity River Hatchery, although this percentage likely includes resident trout (Dean 1994, 1995). The percentage exhibiting this life-history pattern appears to be influenced by spawning location. Hopelain (1998) found that nearly 80% of spawners in the mainstem Trinity River exhibited a half-pounder life history, although much lower percentages were determined for spawners in the North Fork and South Fork Trinity rivers (32% and 35%, respectively).

Fry and juveniles rear in the mainstem Klamath River, in tributaries to the Klamath River, and in the estuary. Based on analysis of available outmigrant trapping data (including Scheiff et al. 2001, Chesney 2000, Chesney and Yokel 2003) a little over half of the production of juveniles (from all runs of steelhead) appear to be produced from tributaries upstream of the confluence with the Trinity River, although there is much annual variation. Large numbers of juveniles outmigrate from the Scott and Shasta rivers in early July (Chesney 2000, Chesney 2002, Chesney and Yokel 2003). There appears to be substantial mainstem rearing of steelhead juveniles into September, with 88% of pools surveyed containing steelhead, as compared with only 41% for Chinook salmon juveniles and 3% for coho salmon juveniles (T. Shaw, USFWS, unpublished material, 2002, as cited in NRC 2004). A significant migration of age-0 juvenile steelhead migrate upstream into tributaries (including some that were dry during summer), off-channel ponds, and other winter refuge habitat in the lower Klamath River (near or within the estuary), including Waukell, Panther, Hunter, and McGarvey creeks (M. Hiner, Fisheries Biologist, Yurok

Tribe, unpublished data, 2008). This migration upstream out of the mainstem Klamath River occurs annually mostly in October and November, but also in December through February.

3.5.3 Potential population response

We evaluated potential impacts of TSS on the winter steelhead population using the DREAM-1 model results for maximum average daily TSS values by water year type for each life stage (Figures 54–59). This analysis focused on the implications of DREAM-1 model runs 44 (wettest case scenario) and 54 (driest case scenario) for the life-history timing and distribution of winter steelhead (Figures 60–65). Impacts on adults are potentially more severe if dam removal occurs during a dry year (e.g., run 54), when more sediment could be exposed earlier in the year since the reservoirs would be less inundated, and thus fine sediment is more readily transported downstream. Conversely, impacts on outmigrating juveniles are potentially more severe if dam removal occurs during a wet year (e.g., run 44), when the reservoir could be inundated during winter, delaying the transport of fine sediment until spring when reservoir levels are low enough to expose sediment deposits.

Dam removal is anticipated to have a direct effect on returning adult winter steelhead. Adults enter the Klamath River in late summer and fall, and migrate and hold in the mainstem Klamath River through fall and winter. These adults could be exposed to peak TSS concentrations over 30,000 ppm if removal occurs during a dry year (worst-case scenario of the conditions modeled), and up to a month over 1,000 ppm (Table 17). Overall the impacts are expected to be lethal, with mortality rates up to 40% (Table 17). Stressed adults are also assumed to be more susceptible to disease, possibly increasing pre-spawn mortality, unless exposure causes avoidance behavior and early entrance into tributaries, as was observed for upstream migrating Chinook salmon and coho salmon adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm. August 2008), which is consistent with observed avoidance behavior of juvenile salmonids to TSS (Sigler et al. 1984, Servizi and Martens 1992). A little less than 20% of returning adults return to Trinity River or tributaries downstream, where TSS concentrations (and thus effects) are expected to be more benign because of dilution. In addition, winter-run steelhead enter the Klamath River slightly later than fall-run steelhead (Table 16), and thus although steelhead migration timing is variable, in many years nearly all of the fall-run may be into tributary habitat prior to sediment releases in November, and over half of the winter-run population may begin migration after impacts from November and early December sediment releases (Figures 60–62).

Table 17. Potential for risk to winter steelhead life stages based on anticipated exposure to TSS.

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Adult upstream migration (1 July to 31 March)	> 1,000	One month	10	Based on examination of modeled dry years (worst-case scenarios) at Seiad Valley Station	
	> 3,000	Two weeks	11		
	> 30,000	One day	11		
Half-pounder residence (15 August to 31 March)	> 1,000	One month	10	Based on examination of modeled dry years (worst-case scenarios) at Seiad Valley Station	
	> 3,000	Two weeks	11		
	> 30,000	One day	11		
Spawning	Because no steelhead spawning occurs in the mainstem Klamath River, spawners, incubating eggs, and emergent are not anticipated to be affected by dam removal.				
Incubation					
Emergent fry					
Adult run-backs (1 March to 30 May)	> 150	Two weeks	8	Based on examination of modeled wet years (worst-case scenarios) at Seiad Valley Station	
	> 600	One day	8		
Rearing (all year)	> 1,000	One month	11	Based on examination of modeled dry years (worst-case scenarios) at Seiad Valley Station	Many juveniles rear in lower mainstem or estuary where TSS concentrations will be lower
	> 3,000	Two weeks	11		
	> 30,000	One day	10–11		
Juvenile outmigration (1 April to 15 December)	> 150	One week	8	Based on examination of modeled wet years (worst-case scenarios) at Seiad Valley Station	Many juveniles outmigrate from lower mainstem where TSS concentrations will be lower
	> 500	One day	7–8		

[1] Predicted maximum concentration and duration of TSS was calculated from specific life history stage timing information for each species using DREAM-1 model results.

[2] Based on Newcombe and Jensen (1996) severity index (Table 5).

Most spawning occurs in tributaries, and thus this life stage is protected from direct effects of dam removal (production from any mainstem spawning that does occur is assumed to suffer 100% mortality). Mature adults returning to the ocean ("run-backs") from the preceding year's escapement migrate downstream after spawning during late winter and spring. These adults could be exposed to peak TSS concentrations over 600 ppm if removal occurs during a dry year (worst-case scenario of the conditions modeled), and up to two weeks over 150 ppm (Table 17). Overall the impacts are expected to be sublethal, including major physiological stress (Table 17).

Adult summer run half-pounders typically enter the mainstem and hold from around mid-August through March (Table 16), and thus would be affected by sediment release during both fall and winter. Although some half-pounders are observed to hold in the Trinity River or other tributaries, half-pounders in the mainstem upstream of the Trinity River could be exposed to peak TSS concentrations over 30,000 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a month over 1,000 ppm (Table 17). Overall the impacts are expected to be lethal, with mortality rates as high as 40% (Table 17). The proportion of half-pounders varies by location, with around 30% of the run in the South Fork and North Fork Trinity returning as half-pounders, and as much as 80% of the escapement in the mainstem Trinity River.

Juveniles rear in the mainstem Klamath River, tributaries to the Klamath, or the estuary. Since most (over 90%) of steelhead juveniles smolt at age-2, those juveniles outmigrating from tributaries to rear in the mainstem will be susceptible to fall, winter, and spring sediment releases. Based on captures in tributaries and the mainstem, it appears that around 40% of the population rears in tributaries until age-2, and thus will only be susceptible to the spring pulse while outmigrating. The approximately 60% of the rearing population that outmigrate as age-0 or age-1 and rear for extended periods of the time in the mainstem upstream of Trinity River could be exposed to peak TSS concentrations over 30,000 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a month over 1,000 ppm (Table 17). Overall the impacts are expected to be lethal, with mortality rates as high as 40% (Table 17). For the approximately 47% outmigrating from the Trinity River, exposures are anticipated to be less (Figure 55), but mortality would still be expected (up to 20%). However, it appears that many of these juveniles are avoiding conditions in the mainstem by using tributary and other off-channel habitat during winter, which in the presence of elevated TSS may occur even more commonly (Servizi and Martens 1992), lowering their exposure and potential mortality. The peak in the migration out of the mainstem is in fall, and thus many of the juveniles should either be out of the mainstem when initial pulses in sediment occur, or they migrate out of the mainstem later in the winter (as occurs for steelhead juveniles) when concentrations increase.

Winter steelhead outmigrating in spring as age-2 in the mainstem upstream of the Trinity River could be exposed to peak TSS concentrations over 500 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled), and up to a week over 150 ppm (Table 17). Overall the impacts are expected to be sublethal, including major physiological stress (Table 17). By fall these fish are typically observed in the estuary, where TSS concentrations are more dilute (Figure 56). The approximately 47% of smolts outmigrate from the Trinity River will be exposed to lower concentrations, with one-day peaks less than 200 ppm (Figure 56).

The impacts of a sediment pulse on winter steelhead could be significant, particularly for the portion of the population spawning in tributaries upstream of the Trinity River. For that portion of the population impacts are anticipated for at least six year classes, including adult run-backs, adults (including half-pounders), age-0 or juveniles rearing in the mainstem, and age-2 smolts outmigrating down the mainstem. However, the wide spatial distribution of steelhead in the Klamath basin means that many portions of the population will avoid severe impacts of TSS by remaining in tributaries for extended rearing, migrating out of the mainstem into tributaries or off-channel habitat, or using the Klamath River mainstem farther downstream where TSS concentrations are anticipated to be more dilute. In addition, the life history variation of steelhead means that although numerous year classes will be affected, not all individuals in any given year class will be affected. For example, the year class represented by the adults directly affected by dam removal will have had some proportion (around 20 to 80%) return the year before as half-pounders. Also, some proportion of both the fall- and winter-runs are expected to migrate upstream to tributaries either before, or following the primary impacts from sediment release. In addition, a proportion of the progeny of the escapement that spawns successfully will rear for long enough in tributaries to not only avoid the year of dam removal, but may not enter the mainstem until up to two or three years following dam removal. The incidence of repeat spawners among the winter-run steelhead (ranging from 18 to 48% for fall run, and 31% for winter-run; Hopelain 1998) is also predicted to increase resiliency to dam removal impacts. Fall- and winter-run steelhead are considered by NMFS to be in low abundance and at some risk of extinction (Busby et al. 1994). Therefore, loss of substantial numbers of any life stage could increase the risk of extinction. Overall, the winter steelhead population is anticipated to be highly affected by removal, but has life history characteristics that should allow a strong recovery.

3.5.4 Recommendations for reducing impacts

Overall, sediment impacts on winter steelhead following dam removal are potentially severe. Measures such as capturing adult or juvenile steelhead and either trucking or holding them have been considered, but are not recommended. In the Klamath River basin, current fishing regulations only allow hatchery steelhead to be retained, so harvest management is unlikely to influence impacts of dam removal. We recommend hatchery managers release smolts early in the spring to avoid the spring pulse of sediment. In addition, improved habitat conditions (e.g., habitat restoration) in tributaries appear to be the most likely measure to reduce impacts of dam removal.

The dependence of winter steelhead on tributaries for spawning and rearing is a key life-history feature that is anticipated to reduce impacts on them during dam removal, and to facilitate their recovery. If the carrying capacity of habitat in the tributaries were increased by increasing habitat complexity, it is possible that fewer individuals would migrate to the mainstem for rearing, and thus avoid impacts during removal. In addition, a significant migration of juvenile steelhead upstream into tributaries is observed during fall and winter.

Therefore, all actions taken to improve habitat quality in tributaries are recommended to aid steelhead ability to survive dam removal, and to increase their recovery in general. In particular, efforts taken in Bluff Creek, Red Cap Creek, Dillon Creek, Clear Creek, Indian Creek, Elk Creek, Wooley Creek, Salmon River, South Fork Trinity River, North Fork Trinity River, New River, and Canyon Creek would benefit steelhead (and in most cases coho salmon as well). Winter steelhead are most likely to benefit from improved habitat conditions and off-channel rearing habitat with implementation of measures described in Section 3.3.4.2 for coho salmon.

3.6 Coastal Cutthroat Trout

Coastal cutthroat trout (*Oncorhynchus clarki clarki*) are known to occur downstream of Iron Gate Dam, primarily within smaller tributaries of the Klamath River mainstem (NRC 2004), but also within tributaries to the Trinity River (Moyle et al. 1995). Klamath River coastal cutthroat trout belong to the Southern Oregon California Coast ESU. In a 1999 status review, NMFS determined that the Southern Oregon California Coast ESU did not warrant ESA listing (Johnson et al. 1999). Based on recent data, adult abundance in lower Klamath River tributaries and the estuary appears be increasing (Johnson et al. 1999). Redband trout (*Oncorhynchus mykiss newberrii*) and bull trout (*Salvelinus confluentus*) both potentially occur upstream of Iron Gate Dam, but are not observed downstream (Buchanan et al. 1991).

3.6.1 Life history

Although cutthroat trout have not been extensively studied in the Klamath basin, it has been noted that their life history is similar to fall and winter steelhead in the Klamath River (NRC 2004). Both resident and anadromous life histories are observed in the Klamath River basin. Anadromous adults enter the river to spawn in the fall, and juveniles may spend anywhere from one to three years in freshwater to rear. Juveniles outmigrate during April through June, at the same time as Chinook salmon juvenile downstream migration (Hayden and Gale 1999, as cited in NRC 2004; Moyle 2002). Juveniles also appear to spend at least some time rearing in the estuary. Wallace (2004) found that estuary residence time ranged from 5 to 89 days, with mean of 27 days, based on a mark-recapture study. The mouth of Hunter Creek, located in the upper estuary, experienced particularly high recapture rates. Peak captures of cutthroat in the estuary tends to occur in May and June, although cutthroat trout tend to be common from May through September, with occasional captures as early as March.

Sea-run adults may either return in summer to feed, or return in September or October to spawn and/or possibly overwinter (NRC 2004). Moyle (2002) noted that upstream migration in northern California spawning streams tends to occur from August to October after the first substantial rain.

Generally, spawning of anadromous and resident coastal cutthroat trout may occur from September to April, based on observations of ripe or nearly ripe females from captured fish (Moyle 2002). Sampling for adult salmonids in the Klamath River rarely takes place from December through April, and it is conceivable that adults in the Klamath River may exhibit a similar range in spawning patterns. Gale et al. (1998) observed adult anadromous coastal cutthroat trout in Blue Creek as late as early December, when their sampling ended.

3.6.2 Distribution

Coastal cutthroat trout are distributed primarily within smaller tributaries to the lower 22 miles of the Klamath River mainstem above the estuary (NRC 2004), but also within tributaries to the Trinity River (Moyle et al. 1995). It is generally believed that most sea-run adults never leave the estuary for the ocean, or remain close to the coast within low-salinity plumes of large rivers (Trotter 1997). Most populations in California are believed to migrate primarily between rivers and estuaries or between small and large streams (Gerstung 1997).

Spawning typically occurs in headwater tributaries of larger streams during the fall, winter, or spring (Moyle 2002). A significant migration of juvenile cutthroat occurs upstream into tributaries (including some that were dry during summer), off-channel ponds, and other winter refuge habitat in the lower Klamath River (near or within the estuary), including Waukell, Panther, Hunter, and McGarvey creeks (M. Hiner, Fisheries Biologist, Yurok Tribe, unpublished data, 2008). This migration upstream out of the mainstem Klamath River occurs annually through the fall and winter.

3.6.3 Potential population response

So little is known about the spatial and temporal distribution of adult coastal cutthroat trout in the Klamath River that it is difficult to say whether these fish are likely to be vulnerable to increased TSS concentrations following dam removal or not. Based on the observations of cutthroat migrating to upper reaches of tributaries to spawn, and the presumption that they either overwinter or spawn late in the winter, these fish will not be affected by winter peaks in TSS. Limited data from Blue Creek (Gale et al. 1998) seem to support this presumption, with large numbers of cutthroat trout adults observed in Blue Creek throughout November and into early December. These data suggest that a turbidity spike in late November would not affect adults that are either overwintering or spawning in tributaries. The effects of turbidity on the population will depend heavily on what fraction of the adults actually spawns or overwinters in the mainstem.

The suspended sediment releases in spring would likely affect the cutthroat juveniles and migrating adults, since these fish are more likely to be in the mainstem or the estuary by that time. Adults would likely be vulnerable whether they are utilizing the estuary or a low-salinity coastal plume. The only life stage that might avoid completely avoid these effects is juveniles rearing in tributaries. In addition, it appears that many juveniles are avoiding conditions in the mainstem by using tributary and other off-channel habitat during winter, lowering their exposure and potential mortality. Overall, the broad spatial distribution of coastal cutthroat trout, combined with their heavy use of tributaries, should allow them to avoid or recover from the TSS disturbances associated with dam removal.

3.7 Pacific Lamprey

At least four, and possibly five or six species of lamprey occur in the Klamath River system (Kostow 2002, FERC 2006, PacifiCorp 2006), including:

- Pacific lamprey (*Lampetra tridentata*),
- Pit-Klamath brook lamprey (*L. lethophaga*),
- Klamath River lamprey (*L. similis*),
- Miller Lake lamprey (*L. minima*),
- a nonparasitic species, unofficially named "Lost River lamprey" (*L. foletti*), and
- a parasitic species, unofficially named "Klamath Lake lamprey".

Of these species, only resident Klamath River lamprey and anadromous Pacific lamprey are present downstream of Iron Gate Dam (PacifiCorp 2004, FERC 2006). Pacific lamprey, along with three other lamprey species, was petitioned for ESA listing in 2003 (Nawa 2003). Although the USFWS halted species status review in December 2004 due to inadequate information (NMFS 2004), efforts to list Pacific lamprey are anticipated to resume as more information is obtained.

Scientific literature and data on the life history, habitat requirements, and distribution of lamprey species of the Klamath River basin are limited. However, basic life histories and habitat requirements of lampreys are similar to the Pacific lamprey, for which much more information exists; and therefore Pacific lamprey was chosen as the focal species. If basic patterns in distribution differ between the species (e.g., Klamath River lamprey are found in more abundance directly downstream of Iron Gate Dam), then impacts could vary from those discussed in this study.

3.7.1 Life history

Adult Pacific lamprey have been observed entering the Klamath River throughout the year (Table 18); however, peak upstream migration occurs from December through June (Larson and Belchik 1998, PacifiCorp 2004). After returning to fresh water and completing partial migration, Pacific lamprey are thought to hold for nearly a year prior to spawning (Kostow 2002).

Table 18. Life-history timing of Pacific lamprey in the Klamath River basin downstream of Iron Gate Dam. Peak activity is indicated in black.

Life stage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Incubation[2, 3]						▨	▨	▨	▨	▨	▨	▨	▨	▨										
Rearing[3, 4]	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile outmigration[1,4]	▨	▨	▨	▨	▨	▨	▨	▨	▨	■	■	▨	▨	▨	▨	▨	▨	▨	■	■	■	■	■	■
Adult migration[2, 3, 5]	■	■	■	■	■	■	■	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	■	■
Spawning[3, 4, 5, 6, 7]						▨	▨	▨	▨	▨	▨	▨												

[1] Includes both ammocoete and eyed juvenile outmigration, [2] Larson and Belchik (1998), [3] FERC (2006), [4] Scheiff et al. (2001), [5] Kostow (2002), [6] CH2M Hill (1985), [7] PacifiCorp (2004)

Adult spawning in the mainstem Klamath River occurs from mid-March through mid-July (FERC 2006, GEC 2006). Spawning in the Trinity River and in its tributaries has been observed to occur from April through June (CH2M Hill 1985), and it is believed that these adults die soon after spawning (Kostow 2002, PacifiCorp 2004).

Egg incubation lasts from two to four weeks depending on water temperature, and occurs from mid-March through July (Larson and Belchik 1998, FERC 2006, Brumo 2006). After hatching, ammocoetes[7] remain in redd gravels for another two to three weeks before passively migrating downstream to low-velocity habitats dominated by silt and sand substrates (Kostow 2002, FERC 2006, Brumo 2006). Ammocoetes then burrow into the stream bottom and live as filter-feeders for from 2 to 10 years (depending on species), before outmigrating to the ocean (Larson and Belchik 1998, Kostow 2002, PacifiCorp 2004). Scheiff et al. (2001) found that the majority of ammocoetes were captured in outmigrant traps located in the Klamath and Trinity rivers between April through July. Scheiff et al. (2001) also noted that the majority of juveniles were captured in late May and early June at the Big Bar trap on the Klamath River and in October through December at the Willow Creek trap on the Trinity River, although juveniles were captured at both sites during all seasons. Pacific lamprey can spend from 1 to 3 years in the ocean before returning to their natal streams (Beamish 1980, FERC 2006, GEC 2006).

3.7.2 Distribution

Pacific lamprey are present in the mainstem Klamath River and tributaries below Iron Gate Dam and in the Trinity, Salmon, Shasta, and Scott river basins (Figure 66; CH2M Hill 1985, Hardy and Addley 2001, NRC 2004). Trapping efforts conducted by Scheiff et al. (2001) in 1997–2000 in the Trinity River at Willow Creek and in the mainstem Klamath River just upstream of the Trinity River confluence indicated that approximately 66% of juvenile outmigrants from the basin were captured in the Klamath River, with the remainder produced in the Trinity River. There are

---

[7] Ammocoetes are the larval stage of lampreys.

also observations of Pacific lamprey spawning in the mainstem Klamath River, Scott River (in large numbers), and in numerous tributaries to the lower Klamath River downstream of the confluence with the Trinity River (B. McCovey, Fisheries Biologist, Yurok Tribe, unpublished data 2007; T. Soto, Fisheries Biologist, Karuk Tribe, unpublished data 2008) (Figure 66). Based on observations and available habitat, most ammocoete rearing likely occurs in the Salmon, Scott, and Trinity rivers, as well as in the mainstem Klamath River. The Klamath River upstream of the Shasta River appears to have less available spawning and rearing habitat, and Pacific lamprey are not regularly observed there.

3.7.3 Potential population responses

We evaluated potential impacts of TSS on the Pacific lamprey population using the DREAM-1 model results for maximum average daily TSS values by water year type for each life stage (Figures 67–68). This analysis focused on the implications of DREAM-1 model runs 44 (wettest case scenario) and 54 (driest case scenario) for the life-history timing and distribution of Pacific lamprey (Figures 69–71). Because of a protected period of adult migration and juvenile rearing, the overall effects of TSS on Pacific lamprey following dam removal will vary depending on whether removal is conducted during a wet year or a dry year, but will be severe in either case. Anadromous Pacific lamprey enter the Klamath River basin throughout the year, although their numbers peak in early winter, and thus a large proportion of the adult run could be directly impacted by dam removal from sediment released during fall, winter, and spring, with one-day exposures over 38,000 ppm, and up to a month over 3,000 ppm (Table 19). The effect of TSS on Pacific lamprey is not known, but based on adult salmonids, mortality rates of up to 40% are predicted for exposed adults. However, around 44% of the escapement returns to the Trinity River and in its tributaries. These individuals will be exposed to lower concentrations while in the mainstem downstream of Trinity River, and many may avoid impacts by entering the Trinity River prior to dam removal.

Table 19. Potential for risk to Pacific lamprey life stages based on anticipated exposure to TSS, assuming similar effects as for salmonids.

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Adult migration, rearing juveniles, outmigrants (all year)	> 8,000	One week	9	Based on examination of modeled dry years for winter, and wet years for spring (worst-case scenarios) at Iron Gate Station	Many lamprey migrate and rear in lower Klamath River, where TSS concentrations will be less, and a worst-case scenario of both a wet and dry year are mutually exclusive
	> 3,000	One month	11		
	> 38,000	One day	11		
Spawning 1 April to 30 June)	> 400	One week	9	Based on examination of modeled wet years (worst-case scenarios) at Iron Gate Station	Many lamprey spawn in lower Klamath River, where TSS concentrations will be less
	> 150	One month	9		
	> 1,500	One day	8–9		

[1] Predicted maximum concentration and duration of TSS was calculated from specific life history stage timing information for each species using DREAM-1 model results.

[2] Based on Newcombe and Jensen (1996) severity index (Table 5).

Based on the documented multi-year rearing of Pacific lamprey ammocoetes in the mainstem Klamath River, increased suspended sediment resulting from dam removal has the potential to impact multiple year classes of rearing ammocoetes, with one-day exposures greater than 38,000 ppm (Figure 67), and up to a month over 3,000 ppm. Lamprey are reported to have an intermediate tolerance of increased siltation and turbidity (Zaroban et al. 1999) and it is not known how increased sediment loads would affect ammocoete survival. Salmonid juveniles are predicted to have mortality rates up to 40% at these exposures, but because Pacific lamprey ammocoetes seek fine sediment deposits for rearing, they are expected to remain buried during spikes in suspended sediment and avoid severe impacts during sediment releases following dam removal. However, ammocoetes are filter-feeders, so at a minimum reduced growth rates are expected, with the likelihood of some mortality.

Overall, because multiple year classes of lamprey rear in the mainstem Klamath River at any given time, and since adults migrate upstream over the entire year, effects on Pacific lamprey could be severe. However, the wide spatial distribution of lamprey in the Klamath basin, including spawning and rearing in mid-Klamath River tributaries such as the Scott River, and around 44% in the Trinity River alone, should mean that many individuals will avoid the most severe sediment pulses. In addition, Pacific lamprey are considered to have low fidelity to their natal streams (FERC 2006), and may not enter the mainstem Klamath River if environmental conditions are unfavorable. Migration into Trinity River and other lower Klamath River tributaries may increase during the year of dam removal. Similarly, straying behavior following dam removal should encourage re-colonization and the recovery of the Klamath River component of the population. Pacific lampreys have extremely high fecundity, ranging from 11,400 to 174,000 eggs per female (Kan 1975, as cited in Kostow 2002), and therefore there is a high potential to “re-seed” depleted habitats relatively quickly (assuming damaged spawning habitats recover and survival is relatively high). In addition, increased habitat availability and reestablishment of natural sediment dynamics following dam removal are likely to help reduce the impacts of dam removal for any Pacific lamprey in the mainstem that survive initial sediment releases.

3.7.4 Recommendations for reducing impacts

Overall, sediment impacts on Pacific lamprey following dam removal are potentially severe. Measures such as capturing adults either trucking or holding them have been considered, but are not recommended. The following measures are recommended:

- Consider dam removal impacts in the management of annual harvest.
- Improve habitat conditions (e.g., increased instream flows, habitat restoration) in Klamath River tributaries, especially during the year prior to dam removal.

3.7.4.1 Management of annual harvest

In the Klamath River basin, lamprey harvest is regulated by CDFG and the Klamath Basin Tribes. Although there are no seasonal restrictions or limit on catch; flows, weather conditions, and fishing methods with a relatively low catch per effort may ensure that the Pacific lamprey catch is fairly minimal in any given year. Non-tribal harvest of Pacific lamprey appears to be limited, and would likely remain so after dam removal. However, protection of Pacific lamprey in key spawning tributaries such as the Scott River is anticipated to be important in facilitating strong recovery and recolonization of habitat upstream of Iron Gate Dam following dam removal. Protection of Pacific lamprey spawning in the mainstem Klamath River is also important because these individuals will be most directly affected by dam removal. Therefore harvest managers may want to consider appropriate restrictions on Pacific lamprey harvest during the year of dam removal.

3.7.4.2 Habitat quality in tributaries

The dependence of lamprey on tributaries for spawning and rearing is anticipated to reduce impacts on their populations during dam removal, and to facilitate their recovery. If the carrying capacity of rearing habitat in tributaries were increased by improving habitat complexity, it is possible that fewer individuals would migrate to the mainstem, thus avoiding impacts during removal. Therefore, all actions taken to improve habitat quality in tributaries are recommended to aid Pacific lamprey in their ability to survive dam removal, and to increase their recovery in general.

Restoration activities aimed at improving anadromous salmonid habitats described for coho salmon in Section 3.3.4.2—specifically those that increase channel complexity and riparian habitats—are expected to also help Pacific lamprey. Specific actions and management strategies that will likely benefit lamprey in tributaries include the following: restoration of riparian and floodplain habitats; reduction of entrainment and impingement through installment of adequate irrigation ditch/diversion screening; reduction of night diversions; avoidance of rapid dewatering of rearing habitats and spawning gravels; and reduction of unfavorably high water temperatures during egg development through increased instream flows.

3.8 Green Sturgeon

Green sturgeon (*Acipenser medirostri*) in the Klamath River basin are included in the Pacific-northern Distinct Population Segment (DPS), which also includes coastal spawning populations from the Eel River north to the Klamath and Rogue rivers. Klamath River basin is the principal spawning stream for green sturgeon in California (Moyle 2002). NMFS (2006) determined that the Pacific-northern DPS did not warrant listing as threatened or endangered. However, uncertainties in the population structure and status led NMFS to designate them as a Species of Concern. White sturgeon are also occasionally observed, but are not thought to be endemic, and thus are not discussed here.

3.8.1 Life history

Adult green sturgeon enter the Klamath River system from late February through late July (Table 20; KRBFTF 1991, NRC 2004, Moyle 2002, PacifiCorp 2004, CALFED ERP 2007). Yurok Tribe gill net captures in the mainstem Klamath River from the mouth to RM 72 (just upstream of the Trinity River) for 1999–2003 document that adults are present from 21 March to 2 July, but 88% of adult green sturgeon were captured from 1 April to 1 June (Van Eenennaam et al. 2006). Benson et al. (2007) used radio and sonic telemetry to track movements and migration patterns of green sturgeon in the Klamath River system and found that upstream spawning migrations occurred from April through June for the period 2002–2004. Spawning occurs from March to July, with peak activity occurring from mid-April to mid-June (Emmett et al. 1991, as cited in CALFED ERP 2007; NRC 2004; FERC 2006).

Table 20. Life-history timing of green sturgeon in the Klamath River basin downstream of Iron Gate Dam. Peak activity is indicated in black.

Life stage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Incubation/emergence[1]					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨									
Rearing[1, 2, 3]	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Juvenile outmigration[4, 5, 6, 7, 8]										▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
Adult migration[1, 2, 9, 10, 11, 12, 13]				▨	▨	▨	■	■	■	■	▨	▨	▨	▨										
Spawning[2, 3, 4, 13]					▨	▨	▨	■	■	■	■	▨	▨	▨										
Post-spawning adult holding[13]										▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		

[1] CALFED ERP (2007), [2] NRC (2004), [3] FERC (2006), [4] Emmett et al. (1991, as cited in CALFED ERP 2007), [5] CH2M Hill (1985), [6] Hardy and Addley (2001), [7] Scheiff et al. (2001), [8] Belchik (2005, as cited in CALFED ERP 2007), [9] KRBFTF (1991), [10] Moyle (2002), [11] PacifiCorp (2004), [12] Van Eenennaam et al. (2006), [13] Benson et al. (2007)

Green sturgeon in the Klamath River sampled during their spawning migration ranged in age from 16 to 40 years (Van Eenennaam et al. 2006). It believed that in general, green sturgeon have a life span of at least 50 years, and spawn every four years on average after around age-16, for a total of around eight spawning efforts in a lifetime (Klimley et al 2007).

Benson et al. (2007) found that after spawning, most sturgeon held in deep pools in the mainstem Klamath and Trinity rivers from June through November for an average of 150–170 days (range of 116–199 days). Post-spawning adult emigration has been associated with the timing of winter rains (CALFED ERP 2007). Benson et al. (2007) reported that the majority of post-spawning adults outmigrated in the fall and winter after summer holding, and appeared to be triggered by increasing discharge. Results of tracking studies by Benson et al. (2007) indicated that 18% of post-spawning adults outmigrated in the spring during 2003–2004 monitoring.

Green sturgeon egg development and early larval rearing in the mainstem Klamath River and mainstem tributary reaches occurs during late spring and early summer when water temperatures are relatively low due to snowmelt and food availability is high (CALFED ERP 2007).

Juvenile green sturgeon may rear for one to three years in the Klamath River system before they outmigrate to the estuary and ocean (NRC 2004, FERC 2006, CALFED ERP 2007), usually during summer and fall (Emmett et al. 1991, as cited in CALFED ERP 2007; CH2M Hill 1985; Hardy and Addley 2001). Green sturgeon juveniles are reported to have rapid growth, and are capable of entering the ocean at young ages (Allen and Cech 2007, as cited in Klimley et al. 2007). Rearing for more than one year is rarely observed in the mid-Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008). Scheiff et al. (2001) reported that juvenile outmigrants were captured from mid-May through as late as mid-October.

3.8.2 Distribution

Green sturgeon spawn primarily in the lower 67 miles of the mainstem Klamath River (downstream of Ishi Pishi Falls), in the Trinity Rivers upstream to Greys Falls, and potentially in the lower Salmon River upstream to Wooley Creek (Figure 72) (KRBFTF 1991, Adams et al. 2002, Benson et al. 2007). Adult green sturgeon spawn in deep pools with strong bottom currents (Beamesderfer and Webb 2002, NRC 2004, CALFED ERP 2007). Adult green sturgeon were reported from the South Fork Trinity River up until 1964, but are no longer believed to occur in this reach (KRBFTF 1991, CH2M Hill 1985).

Scheiff et al. (2001) reported that for the period 1997–2000, trapping in the Trinity River at Willow Creek and in the mainstem Klamath River just upstream of the Trinity River confluence showed that approximately 71% of juvenile outmigrants were captured in the Klamath River trap while only 29% were captured in the Trinity River trap. In the lower 10 km of the Salmon River, two juvenile green sturgeon were collected in October 1996 (CALFED ERP 2007), suggesting that some spawning and rearing may occur there. Juveniles typically spend one to four years in fresh or estuarine habitats before ocean entry (Beamsesderfer and Webb 2002). Male sturgeon spend 15 years in the ocean, whereas female sturgeon may spend 17 years in the ocean prior to returning to spawn (Adams et al. 2002). In their study of reproductive conditions of Klamath River green sturgeon, Van Eenennaam et al. noted that the youngest age for a mature female and male sampled was 14 and 16, respectively, although the majority (180 of 200) of the mature sturgeon sampled were males of 15–28 years and females of 19–34 years.

3.8.3 Potential population response

We evaluated potential impacts of TSS on the green sturgeon population using the DREAM-1 model results for maximum average daily TSS values by water year type for each life stage (Figures 73–76). This analysis focused on the implications of DREAM-1 model runs 44 (wettest case scenario) and 54 (driest case scenario) for the life-history timing and distribution of green sturgeon (Figures 77–79). Because of the spring migration of adults, impacts are potentially more severe if dam removal occurs during a wet year (e.g., run 44), when the reservoir could be inundated during winter, delaying the transport of fine sediment until spring when reservoir levels are low enough to expose sediment deposits. However, because of extended rearing that includes the winter period, dry years (e.g., run 54) also have high potential to affect rearing juveniles.

Adult green sturgeon enter the Klamath River beginning in late February, and would be exposed to sediment released during spring (most severe in a wet year). Adults returning to the upper extent of their range (Ishi Pishi Falls in the mainstem, RM 67; Figure 72) could be exposed to peak TSS concentrations over 1,000 ppm if removal occurs during a wet year (worst-case scenario of the conditions modeled; Figure 73), and up to a month over 50 ppm (Table 21). Overall, the impacts of TSS on green sturgeon are not known. Based on salmonid adults, effects would be expected to be sublethal, including major physiological stress (Table 21) and reductions in feeding. However, reduced feeding may not be a severe effect for green sturgeon, which typically withstand long periods of deprivation during spawning migration (EPIC et al. 2001, as cited in CDWR 2003). Green sturgeon spawn on average every four years, so up to 75% of the mature adult population may remain in the ocean during the year of dam removal, which is consistent with observations of spawning return intervals in the Rogue River (Erickson and Webb 2007; D. Erickson, Fisheries Biologist, Pew Institute for Ocean Science, pers. comm., August 2008). In addition, green sturgeon are believed to not undergo spawning migrations if environmental conditions are less than optimal (CALFED ERP 2007). Webb and Erickson (2007) observed that a proportion of the mature adults that entered the Rogue River returned downstream without spawning, and this behavior is also observed in white sturgeon (J. Van Eenennaam, Research Associate, University of California Department of Animal Science, pers. comm., August 2008). With increased TSS in the Klamath River, an additional proportion of the mature population may not migrate upstream from the ocean during the year of dam removal, or may enter in March or April when concentrations are expected to be lower, but this behavior is not currently documented in the Klamath River (J. Israel, Research Associate, University of California Department of Animal Science, pers. comm., August 2008).

Table 21. Potential for risk to green sturgeon life stages based on anticipated exposure to TSS, assuming similar effects as those reported for salmonids.

Life history stage (timing)	Anticipated magnitude (ppm)[1]	Anticipated duration based on sediment pulse and life-history timing	Index of anticipated impact on individuals in mainstem[2]	Sediment analysis notes	Other biological considerations
Adult migration and spawning 15 February to 31 July)	> 50	One month	8	Based on examination of modeled wet years (worst-case scenarios) at Orleans Station	Adults may not enter Klamath River if water quality is poor
	> 150	Two weeks	8		
	> 1,000	One day	8		
Post-spawning adult holding (15 May to 30 November)	> 1,000	Two weeks	10	Based on examination of modeled wet years (worst-case scenarios) at Orleans Station	Adults are observed to outmigrate during first flow event, so exposure to fall TSS could be reduced
	> 8,000	One week	11		
	> 17,000	One day	10-11		
Incubation and emergence (1 March to 15 August)	> 150	> Two weeks	NA	Based on examination of modeled wet years (worst-case scenarios) at Orleans Station	All spawning in the mainstem is assumed to result in 100% mortality
Juvenile rearing (all year)	> 1,000	One month	10	Based on examination of modeled dry years (worst-case scenarios) at Orleans Station	Many sturgeon spawn in lower Klamath River, where TSS concentrations will be less. Extended rearing not common.
	> 3,000	Two weeks	11		
	> 20,000	One day	11		
Juvenile outmigration (15 May to 15 October)	> 50	One month	8	Based on examination of modeled wet years (worst-case scenarios) at Orleans Station	
	> 150	Two weeks	9		
	> 400	One day	7		

[1] Predicted maximum concentration and duration of TSS was calculated from specific life history stage timing information for each species using DREAM-1 model results.
[2] Based on Newcombe and Jensen (1996) severity index (Table 5).

Green sturgeon females are broadcast spawners that lay thousands of adhesive eggs that settle into the spaces between cobble substrates (Moyle et al. 2002; Emmett et al. 1991, as cited in CALFED ERP 2007). It is generally believed that silt prevents eggs from adhering to one another, and causes mortality (EPIC 2001, as cited in CDWR 2003). Exposed rock and cobble may be reduced by fine sediment deposition, and incubating eggs could experience long-term (> one month) exposures of TSS over 50 ppm, and it is therefore assumed that increased fine sediment deposition resulting from dam removal would cause all production from the mainstem to be lost (J. Van Eenennaam, Research Associate, University of California Department of Animal Science, pers. comm., August 2008).

After spawning, green sturgeon hold in mainstem pools in the Trinity and Klamath rivers from June through November. In the mainstem Klamath River, holding adults (from the previous year's escapement) could be exposed to high concentrations of TSS during the fall of dam removal. Post-spawning adult emigration has been associated with the timing of winter rains (CALFED ERP 2007), and Benson et al. (2007) reported outmigration appeared to be triggered by increasing discharge. Therefore if a fall increase in flows (natural or managed) occurs it could result in the outmigration of adult green sturgeon prior to impacts associated with dam removal.

Based on green sturgeon rearing patterns, there could be at least three year classes of juveniles rearing in the mainstem Klamath River during dam removal, and in the upper extent of their range in the mainstem they could be exposed to maximum one-day TSS concentrations of nearly 20,000 ppm (Figure 74), and up to a month over 1,000 ppm. Although the effects of TSS on juvenile sturgeon are unknown, based on effects on juvenile salmonids these exposures would be expected to result in up to 40% mortality. However, juvenile green sturgeon exposed to high suspended sediment in the Connecticut River had no apparent physiological stress, whereas several other sturgeon species suffered gill infections during these events (B. Kynard, Fisheries Biologist, BK-Riverfish, pers. comm., August 2008). In addition, green sturgeon eggs sampled in the Klamath River by Van Eenennaam et al. (2006) were the largest recorded for a north American sturgeon, likely allowing production of large juveniles well adapted to fast growth and having shorter residence time in the river (Van Eenennaam et al. 2006). This is consistent with observations that rearing for more than one year appears to be rare in the mid-Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008), which is consistent with less extensive feeding opportunities in the lower Klamath River compared with systems such as the Sacramento River delta, or the Columbia River estuary (J. Van Eenennaam, Research Associate, University of California Department of Animal Science, pers. comm., August 2008). Around 30% of the production in the basin appears to occur in the Trinity River, and thus that component of the population would be protected from sediment impacts associated with dam removal. Rearing in the estuary is also common, where TSS concentrations are predicted to be lower.

Green sturgeon in the mainstem Klamath River could be severely affected by dam removal. Losses in the mainstem are anticipated for at least five year classes, including adults, incubation, and age-1, 2, and 3 juveniles. The ability of the population to recover from the loss of juvenile production is expected to be high based on the majority of the population (subadult and adult) being in the ocean during removal, which would be able to return during the spring following dam removal to spawn. In addition, the approximately 30% of the population spawning and rearing in the Trinity and Salmon rivers during dam removal will buffer against losses to all year classes in the Klamath River. Much of the spawning and rearing of green sturgeon occurs downstream of the Trinity River, where sediment concentrations are predicted to be much lower, and thus mortality may not be as high as estimated. Because green sturgeon are long-lived and are able to spawn multiple times, the loss of one year class and impacts on other year classes may have little influence on the population as a whole over time. Without accurate population estimates of the green sturgeon population in the Klamath River, it is difficult to predict how long recovery might take. Van Eenennaam et al. (2006) carefully suggests that the Klamath River green sturgeon population appears strong and stable, while cautioning against conclusions based on short time frames relative to their life history.

3.8.4 Recommendations for reducing impacts

Overall, sediment impacts on green sturgeon following dam removal are potentially severe. After discussions with biologists studying sturgeon in the Klamath River, we concluded that it is not feasible to capture enough of the adult spawning migration to off-set impacts; wild-caught sturgeon do not readily feed in captivity; and the stress and injuries from capture and handling would likely result in abrasions, infections, and fungal outbreaks during holding (J. Van Eenennaam, Research Associate, University of California Department of Animal Science, pers. comm., August 2008; J. Israel, Research Associate, University of California Department of Animal Science, pers. comm., August 2008). Therefore measures such as capturing adults and either trucking or holding them are not recommended. The following measures are recommended:

- Consider dam removal impacts in the management of annual harvest.
- Increase fall instream flows.

3.8.4.1 Management of annual harvest

The Klamath River supports the largest spawning population of green sturgeon in California (Moyle 2002), and evidence from the Yurok Tribal salmon gillnet fishery suggests that it has been relatively stable in recent years (Van Eenennaam 2006). Because of the wide-ranging nature of green sturgeon (Moyle 2002), individuals from the Klamath River population were harvested in multiple areas (Adams et al. 2002, Moyle 2002), and excessive fishing pressure along with inappropriate slot limits have been cited as potential threats to west coast populations (Adams et al. 2002, Erickson and Webb 2007). In recent years, however, harvest of green sturgeon has been prohibited in Oregon, California, and Washington sport fisheries, as well as Columbia River and Willapa River commercial fisheries. In-river tribal harvest still occurs annually as a by-product of the Yurok Tribe salmon gillnet fishery. We recommend tribal managers consider whether potential measures are feasible and warranted to limit bycatch of green sturgeon during the period leading up to and after dam removal as a potential strategy to help mitigate the short- and long-term impacts of dam removal.

3.8.4.2 Fall pulse flow release

Adult post-spawning migration occurring in the fall and winter appears to be linked to increased stream discharge from the onset of precipitation (Benson et al. 2007, CALFED ERP 2007) which may represent a viable means of removing post-spawned adult fish from the system. Benson et al. (2007) reported that the majority of adult green sturgeon outmigrating during the first major flow event of the season entered the estuary within 1–2 days when discharge increased in excess of 100–200 $m^3 s^{-1}$. Benson et al. (2007) also recorded an adult male green sturgeon that left the summer holding location and outmigrated to the estuary prior to the onset of precipitation, which was attributed to a management decision to increase discharge (from 53 to 70 $m^3 s^{-1}$) from Iron Gate Dam. This fish was also shown to have resumed summer holding when these flow releases (for a duration of two weeks) were decreased until the first rainfall of the season. It is likely that the majority of adult fish would voluntarily outmigrate from the system if flows were increased prior to dam removal activities. Although sturgeon have typically migrated downstream prior to the primary impacts in mid-November, it is recommended that a fall flow release be used to ensure that adults are out of the system prior to dam removal.

Therefore, increased flows during fall prior to dam removal are recommended to potentially increase the rate of downstream migration of green sturgeon out of the Klamath River, thus reducing the proportion of fish directly exposed to TSS during dam removal. We recommend releasing water in fall during dam removal to mimic the natural hydrograph that would have existed in the Klamath River during a "wet year" prior to the USBR project, consistent with recommendations in NAS (2004). However, if the water year during dam removal is dry, managers will need to balance the benefits of increased flows during fall with the risk of impacts to the basin if less water is available during the following spring. Increases in fall flows are assumed to be most successful if conducted synchronously with increased flows in regulated tributaries, to help create enough of a pulse of water to encourage outmigration.

3.9 Other Aquatic Species

As discussed in Section 2.1, a set of objective criteria and a vetting process were used to select focal species for the various analyses (as illustrated in Figure 1). By using these criteria, only a fraction of the aquatic species found in the Klamath Basin watershed were selected as focal species for the purposes of this document; however, the suspended sediment caused by dam removal will likely affect other (non-focal) aquatic species as well. Most of these species did not meet the selection criteria because either they were not native to the Klamath River basin, occurred far enough downstream to avoid primary impacts, or there was no scientific literature on suspended sediment tolerance levels (e.g., invertebrates), especially for short durations of high concentrations. General potential implications of suspended sediment from dam removal on non-focal aquatic species are described below.

3.9.1 Estuary fish species

Estuary fish species regularly documented to occur in the Klamath River estuary (Moyle 2002, NRC 2004, PacifiCorp 2004) include:

- Pacific herring (*Clupea pallasii*)
- Longfin smelt (*Spirinchus thaleichthys*)
- Eulachon (*Thaleichthys pacificus*)
- Topsmelt (*Atherinops affinis*)
- Shiner perch (*Cymatogaster aggregata*)
- Arrow goby (*Clevelandia ios*)
- Starry flounder (*Platichthys stellatus*)

Based on a summary of potential effects of dam removal on hydrology and water quality of the Klamath River estuary (Stillwater Sciences, in prep.), elevated suspended sediment loads are expected in the lower Klamath River and the estuary following dam removal, which in addition to causing high TSS (>300 mg/L) and turbidity in the water column, may alter estuarine sediment deposits and the frequency and duration of mouth closure, and potentially reduce the volume of the cooler salt water wedge that periodically forms during summer months. However, the estuary is anticipated to experience lower concentrations of dam removal-related TSS than in areas farther upstream. Overall estuary fish species are expected to survive impacts of dam removal, and recover in the long-term.

3.9.2 Other native fish species

Other native fish species documented to occur downstream of Iron Gate Dam (Moyle 2002, NRC 2004, PacifiCorp 2004) include:

- Klamath largescale sucker (*Catostomus snyderi*)
- Shortnose sucker (*Chasmistes brevirostris*)
- Lost River sucker (*Deltistes luxatus*)
- Klamath smallscale sucker (*Catostomas rimiculus*)
- Klamath tui chub (*Gila bicolor*)
- Blue chub (*Gila coerulea*)
- Klamath speckled dace (*Rhinichthys osculus klamathensis*)
- Threespine stickleback (*Gasterosteus aculeatus*)
- Brook stickleback (Culaea inconstans)
- Sharpnose sculpin (*Clinocottus acuticeps*)
- Coastrange sculpin (*Cottus aleuticus*)
- Prickly sculpin (*Cottus asper*)
- Marbled sculpin (*Cottus klamathensis*)
- Klamath Lake sculpin (*Cottus princeps*)
- Slender sculpin (*Cottus tenuis*)
- Pacific staghorn sculpin (*Leptocottus armatus*)

Most of these species have a life history that includes partial or extended rearing the mainstem Klamath River, and thus will be affected by TSS following dam removal. However, these species have typically evolved in large rivers, regularly experience elevated TSS loads, have components of their life history in tributary habitat, and are also distributed in the Trinity River. Therefore impacts are predicted to occur, but recovery is anticipated. In 1991, a chemical spill occurred in the upper Sacramento River, killing all aquatic life in the river for 36 miles downstream of the spill (CTC 1996). Although the effects of this spill were instantaneous and aquatic species were not able to avoid lethal effects (i.e., more severe than predicted for Klamath River during dam removal), it serves as an indication of how species react to a massive disturbance. Long-term monitoring demonstrated that following the disturbance, aquatic species were able to recover in a relatively short span of time (e.g., 5 years for salmonid species) due to natural reseeding of the affected reach from species migrating from upstream and tributary reaches, as well as from downstream reaches during spawning migrations, and a one-time small release of hatchery juveniles (CTC 1996; T Payne, Fisheries Biologist, Thomas R. Payne and Associates, pers. comm., August 2008). In addition, the native fish that occur most predominantly in the mainstem Klamath River (e.g., Klamath largescale sucker) are anticipated to immediately benefit from increased habitat following dam removal.

3.9.3 Non-native fish species

Many non-native fish species are documented to occur in the Klamath River basin downstream of Iron Gate Dam (Moyle 2002, NRC 2004, PacifiCorp 2004), including:

- American shad (*Alosa sapidissima*)
- Surf smelt (*Hypomesus pretiosus*)

- Golden shiner (*Notemigonus crysoleucas*)
- Fathead minnow (*Pimephales promelas*)
- Goldfish (*Carassius auratus*)
- Yellow bullhead (*Ameiurus natalis*)
- Brown bullhead (*Ameiurus nebulosus*)
- Black bullhead (*Ameiurus melas*)
- Channel catfish (*Ictalurus punctatus*)
- Kokanee (*Oncorhynchus nerka*)
- Brown trout (*Salmo trutta*)
- Brook trout (*Salvelinus fontinalis*)
- Arctic grayling (*Thymallus arcticus*)
- Sacramento perch (*Archoplites interruptus*)
- Green sunfish (*Lepomis cyanellus*)
- Pumpkinseed (*Lepomis gibbosus*)
- Bluegill (*Lepomis macrochirus*)
- Largemouth bass (*Micropterus salmoides*)
- Smallmouth bass (*Micropterus dolomieui*)
- Spotted bass (*Micropterus punctulatus*)
- White crappie (*Pomoxis annularis*)
- Black crappie (*Pomoxis nigromaculatus*)
- Yellow perch (*Perca flavescens*)

The impacts of a sediment pulse on non-native fish species are not well understood, but are of high concern. It is generally believed that actions taken to restore the mainstem Klamath River and in its tributaries, including dam removal, will benefit native fish adapted to natural conditions more than the non-native fish species.

3.9.4 Amphibians and reptiles

Special-status amphibians and reptiles potentially occurring in the mainstem Klamath River basin downstream of Iron Gate Dam include:

- Foothill yellow-legged frog (*Rana boylii*) (California species of special concern)
- Northwestern pond turtle (*Clemmys marmorata marmorata*) (USDA Forest Service sensitive species)

Other native amphibians and reptiles potentially occurring in the mainstem Klamath River downstream of Iron Gate Dam include:

- Western toad (*Bufo boreas*)
- Coastal giant salamander (*Dicamptodon tenebrosus*)
- Pacific treefrog (*Pseudacris regilla*)
- Northern red-legged frog (*Rana aurora*)
- Oregon garter snake (*Thamnophis atratus hydrophilus)*

Non-native species may also occur, including bullfrog. Frogs and toads prefer slow water areas, and are found in mainstem rivers, such as the Klamath River, only in edge water and backwater areas. Most amphibian egg deposition and rearing likely occur in tributaries and off-channel areas. Northwestern pond turtles that occur in mainstem riverine areas are generally concentrated in side-channels and backwaters, and generally move to off-channel habitats, such as oxbows, during high flows (Holland 1994, as cited in Ashton et al. 1997; Ashton et al. 1997). They lay their eggs in holes that they dig on land, and so their egg life stage would not be affected by sediment in the river.

Some frog species lay eggs in fall after the first rains (e.g., red-legged frog), and other species lay eggs in late spring as flows decline (e.g., yellow-legged frog). For either life history, sediment released during dam removal is assumed to suffocate and cause 100% mortality of all eggs deposited in the mainstem under a worst-case scenario. All tadpoles in the mainstem are also assumed to suffer from direct exposure to TSS, and from reduced food availability if silt covers their food source (algae and diatoms) or affects the primary production of algae. All post-metamorphic frogs, as well as turtles and snakes, are assumed to be able to move out of the mainstem during peak TSS concentrations and avoid impacts of TSS. For post-metamorphic amphibian life stages, turtles, and snakes, impacts are anticipated to be indirect, with a potential decrease in food supply if macroinvertebrate populations decrease during dam removal. Overall, based on the wide spatial distribution of amphibians and reptiles, and primary use of off-channel habitat and tributaries, populations are expected to avoid severe impacts from dam removal, and recover quickly.

4 SUMMARY OF RECOMENDATIONS TO REDUCE IMPACTS

Although the populations of all species are expected to recover in the long-term, sediment impacts on focal species following dam removal are potentially severe for some life stages in the short-term. The following species and life stages are particularly vulnerable to the short-term impacts of dam removal:

- Mainstem-spawning fall-run Chinook salmon;
- Late migrating adult coho salmon;
- Adult summer and winter steelhead;
- Migrating adult coastal cutthroat trout;
- Mainstem rearing juvenile salmonids;
- Outmigrant salmonid smolts;
- All life stages of Pacific lamprey in mainstem; and
- All life stages of green sturgeon in mainstem.

These species and life stages were of particular consideration in developing management recommendations to reduce the impacts of dam removal. The "Recommendations for reducing impacts" subsections in Section 3 above describe potential actions to benefit each particular species or life stage. For management priorities geared towards a particular species or life stage, please refer to these species-specific recommendations above. We also synthesized all recommendations to develop general recommendations to inform a comprehensive dam removal program. These recommendations were developed primarily based on biological impacts, and did not take into account all feasibility and social concerns that would need to be considered in a detailed dam removal plan. In the summary below, the species that would be expected to benefit from each recommended action are italicized to emphasize the relevance of the recommendations to the runs of concern.

4.1 Protection of Weak Year Classes

As described in detail in Section 3.1.4.1, the largest factor mitigating the impacts of a sediment pulse on *fall-run Chinook salmon* is the mixed age class structure represented in the escapement each year, resulting in a proportion of each year class in the ocean. A strategy for ensuring that there are strong year classes in the ocean capable of rapid recolonization of habitat following dam removal is to predict the year class strength using the stock-recruitment model of Prager and Mohr (1999). If the two year classes preceding implementation of dam removal are weak, we note that the impacts of dam removal could be more dramatic and subsequent recovery prolonged. During periods of low abundance or poor ocean conditions, we recommend that managers consider the increased risk of dam removal to fall Chinook salmon. It may be appropriate for managers to emphasize mitigation measures or management actions to protect weak year classes. Similar opportunities have not been identified for other species, for which either escapement does not include multiple year classes (e.g., spring Chinook salmon), or no model is available (e.g., green sturgeon and Pacific lamprey) to predict year class strength

As described in detail in Section 3.3.4.4, annual monitoring of natural adult *coho salmon* returns is currently not adequate to establish a good record of year-class strength (NRC 2004). We recommend that consistent monitoring of tributaries be conducted for adults and outmigrating juveniles to establish a record of year class strength. We recommend that dam removal be conducted in a year of at least one, if not a series of strong year classes, to provide a greater opportunity for the population to recover from the effects of removal. .

4.2 Management of Annual Harvest

We recommend that during the year of dam removal, harvest regulators consider the potential impacts of dam removal, especially the component of the run that may spawn in the mid-Klamath River, where impacts on adults and smolts are expected to be especially high. In addition, components of the run headed for tributary habitat are particularly crucial to the ability of species to survive the impacts of dam removal. For those species that are not regulated (e.g., *Pacific lamprey*), or harvested as a by-product of another fishery (e.g., *green sturgeon*), we recommend pro-active or voluntary regulations be considered to increase their protection. Appropriate regulatory management during the year of dam removal could include reduced (or no) harvest of all or portions of adult escapement, or reduced harvest within specific geographical locations (e.g., within tributaries). There are no numeric data that support a specific target of escapement to survive the impacts of dam removal, so it is not possible to recommend a precise reduction in harvest to ensure recovery following dam removal. However, elevated TSS associated with dam removal is anticipated to result in at least some mortality on multiple life stages of most species, and presumably the larger the populations, the more resilient they will be to disturbance. Recommendations for more stringent management of harvest as a means to reduce impacts of dam removal is also consistent with the Elwha River restoration plan (Ward et al. 2008), which reflects an agreement between Washington State and local tribes to curtail all in-river fisheries for a period of 5 years when active removal of the Elwha Dam begins.

4.3 Capture of Adults or Juveniles

After discussions with biologists studying aquatic species in the Klamath River, we concluded that it is not feasible to capture enough adults or juveniles to off-set impacts, and the stress and injuries from capture and handling would likely result in abrasions, infections, and fungal outbreaks during holding. Therefore, measures such as capturing adults or juveniles and either trucking or holding them are not recommended. The one exception is for *fall-run Chinook salmon*, for which we recommend measures to salvage mainstem-spawning adults (described in detail in Section 3.1.4.3). These efforts may only accomplish the rescue of a few thousand adults, and will likely have adverse effects on the adults handled. However, mainstem spawners and their progeny are at a very high risk for complete mortality. Although most *fall-run Chinook salmon* do not spawn in the mainstem, those that do spawn there are a unique component of the population that may be particular well adapted to recolonize habitat upstream of Iron Gate Dam after dam removal. Although no current fish management reintroduction plans exist, we recommend that any actions to hold or release fall-run Chinook salmon be consistent with long-term reintroduction efforts.

4.4 Increase Fall and Spring Instream Flows

We recommend increasing instream flows during the fall and spring of dam removal to mimic the natural hydrograph that would have existed in the Klamath River during a “wet year” prior to the USBR project. However, if the water year during dam removal is dry, managers will need to balance the benefits of increased flows during fall with the risk of impacts to the basin if less water is available during the following spring. Increases in flows in the mainstem Klamath River are assumed to be most ecologically beneficial if conducted synchronously with increased flows in regulated tributaries, as would occur under natural conditions. Increased flows during fall are predicted to increase *fall-run Chinook salmon* spawning in regulated tributaries (described in detail in Section 3.1.4.4), increase the proportion of the *coho salmon* escapement in tributaries prior to dam removal (described in detail in Section 3.3.4.1), facilitate juvenile *coho salmon* and *steelhead* migration downstream and into off-channel habitat (described in detail in Section 3.3.4.1 and 3.4.4), and encourage the outmigration of *fall-run Chinook salmon* smolts and post-spawned adult *green sturgeon* (described in detail in Section 3.1.4.4 and 3.8.4.2) prior to dam removal. The timing and implementation of these flow releases should take into consideration the hydrograph of unregulated tributaries to ensure that access to natal streams by *coho salmon* adults that are attracted up the mainstem due to high fall flows is not blocked due to natural low flow conditions in the tributaries. In addition, increased flows during fall (from the Trinity River) are also believed to be an effective management tool to decrease infection and mortality of adult migrating salmon from the ciliated protozoan *Ichthyophthirius multifiliis*. Increased flows during spring are predicted to increase the survival of upstream migrating adult *spring-run Chinook salmon* (described in detail in Section 3.2.4.2), as well as outmigrating salmon juveniles and smolts.

4.5 Habitat Quality in Tributaries

The dependence of *Chinook* and *coho salmon*, *steelhead* and *coastal cutthroat trout*, *Pacific lamprey*, *amphibians*, and *reptiles* on tributaries for spawning and rearing is a key life-history feature that is anticipated to reduce impacts on them during dam removal, and to facilitate their recovery. In addition, the use of tributary habitat as refuge during winter is a key behavior that will aid the survival of juvenile *coho salmon, steelhead,* and *cutthroat trout* during peak TSS concentrations.

The importance of tributary streams to recovery of stocks was made clear during the 1991 chemical spill in the upper Sacramento River, which killed all aquatic life in the river for 36 miles downstream of the train derailment (CTC 1996). Although the effects of this spill were instantaneous and aquatic species were not able to avoid lethal effects (i.e., more severe than predicted for Klamath River during dam removal), aquatic species were able to recover in a relatively short span of time (e.g., 5 years for salmonid species) due to natural reseeding of the affected reach from species migrating from upstream and tributary reaches, as well as from downstream reaches during spawning migrations (CTC 1996; T Payne, Fisheries Biologist, Thomas R. Payne and Associates, unpublished data, 2008).

As described in detail in Section 3.3.4.2, we recommend that the following measures be considered, which are consistent with the recommendations of NRC (2004), including:

- Reestablishment of cool summer flows in tributaries (including Shasta and Scott rivers).
- Removal of barriers or other provisions for effective passage at (e.g., replacing flashboards with alternative diversion methods, upgrading ineffective fish ladders, channel reconstruction in aggraded channels) all small dams and diversions throughout the distribution of salmonids in tributaries.
- Ensuring prescriptions for land-use practices (timber management, road construction, agriculture/grazing, and residential and infrastructure development) are sufficiently stringent to prevent physical degradation of tributary habitat.

- Reducing impairment of spawning habitat through reductions in the delivery of fine sediment from timber management, agriculture, livestock, or other human activities.
- Implementing habitat enhancement efforts in the lower Klamath River tributaries, including off-channel habitat.

4.6 Hatchery Release Timing

We recommend hatchery managers adjust the timing of hatchery releases during the year of dam removal, although for some species it would be out of synch with natural life-history timing. If fish are released earlier in the spring (e.g., April), survival is anticipated to be increased by avoiding the late spring release of sediment in the year following dam removal, with the exception of *coho salmon* smolts which are likely to benefit from a late spring release timing (as described in detail in Section 3.3.4.3).

5 REFERENCES

Ackerman, N. K., B. Pyper, I. Courter, and S. Cramer. 2006. Estimation of returns on naturally produced coho to the Klamath River - review draft. Klamath coho integrated modeling framework technical memorandum #1 of 8. Prepared by Cramer Fish Sciences, Gresham, Oregon for Bureau of Reclamation, Klamath Basin Area Office, Klamath Falls, Oregon.

Adams, P. B., C. B. Grimes, J. E. Hightower, S. T. Lindley, and M. L. Moser. 2002. Status review for North American green sturgeon, *Acipenser medirostris*. National Marine Fisheries Service, Santa Cruz, California.

Allen, P. J., and J. J. Cech. In press (2007). Age/size effects on juvenile green sturgeon, *Acipenser medirostris*, oxygen consumption in saline environment. Environmental Biology of Fishes.

Ashton, D. T., A. J. Lind, and K. E. Schlick. 1997. Western pond turtle (*Clemmys marmorata*). Natural history. Prepared by USDA Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, California.

Balance Hydrologics, Inc. 1995. Background report and strategic workplan for watershed restoration planning: lower Klamath River, California. Report Prepared for State of California, Coastal Conservancy, Oakland, California.

Barnhart, R. A. 1994. Salmon and steelhead populations of the Klamath-Trinity Basin, California. Pages 73-97 *in* T. J. Hassler, editor. Klamath Basin fisheries symposium. California Cooperative Fishery Research Unit, Humboldt State University, Arcata.

Beamesderfer, R. C. P., and M. A. H. Webb. 2002. Green sturgeon status review information. S. P. Cramer and Associates, Gresham, Oregon.

Beamish, R. J., and T. G. Northcote. 1989. Extinction of a population of anadromous parasitic lamprey, *Lampetra tridentata*, upstream of an impassable dam. Canadian Journal of Fisheries and Aquatic Sciences 46: 420-425.

Beeman, J. W., G. M. Stutzer, S. D. Juhnke, and N. J. Hetrick. 2007. Survival and migration behavior of juvenile coho salmon in the Klamath River relative to discharge at Iron Gate Dam, 2006. Final report. Prepared by U.S. Geological Survey, Cook, Washington and U.S. Fish and Wildlife Service, Arcata California for U.S. Bureau of Reclamation, Mid-Pacific Region, Klamath Basin Area Office, Klamath Falls, Oregon.

Beeman, J., S. Juhnke, G. Stutzer, and N. Hetrick. 2008. Survival and migration behavior of juvenile coho salmon in the Klamath River relative to discharge at Iron Gate Dam, 2007. Draft report. Prepared by U.S. Geological Survey, Western Fisheries Research Center, Cook, Washington, and U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California for U.S. Bureau of Reclamation, Klamath Basin Area Office, Klamath Falls, Oregon.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society, Bethesda, Maryland.

Belchik, M. 2005. Adult green sturgeon (*Acipenser medirostris*) migration, movements, and habitat use in the Klamath River, California, 2002-2004. Published abstract. Symposium and 39th Annual Meeting, California-Nevada Chapter, American Fisheries Society.

Benson, R. L., S. Turo, and B. W. McCovey. 2007. Migration and movement patterns of green sturgeon (*Acipenser medirostris*) in the Klamath and Trinity rivers, California, USA. Environmental Biology of Fishes 79: 269-279.

Bilton, H. T. 1984. Returns of Chinook salmon in relation to juvenile size at release. Canadian Technical Report of Fisheries and Aquatic Sciences 1245. Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, Nanaimo, British Columbia.

Bilton, H. T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Canadian Journal of Fisheries and Aquatic Sciences 39: 426-447.

Brown, L. R., P. B. Moyle, and R. M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. North American Journal of Fisheries Management 14: 237-261.

Brumo, A. F. 2006. Spawning, larval recruitment, and early life survival of Pacific lampreys in the South Fork Coquille River, Oregon. Master's thesis. Oregon State University, Corvallis, Oregon.

Buchanan, D., A. Hemmingsen, D. Bottom, P. Howell, R. French, and K. Currens. 1991. Native trout project. Fish research project F-136-R. Oregon Department of Fish and Wildlife, Portland, Oregon.

Busby, P. J., T. C. Wainwright, and R. S. Waples. 1994. Status review for Klamath Mountains Province steelhead. NOAA Technical Memorandum NMFS-NWFSC-19. National Marine Fisheries Service, Seattle, Washington.

CALFED ERP (CALFED Ecosystem Restoration Program). 2007. Green sturgeon (*Acipenser medirostris*). In Delta regional ecosystem restoration implementation plan. Draft report. CALFED ERP (California Department of Fish and Game, NOAA Fisheries, U.S. Fish and Wildlife Service, California Bay-Delta Authority, and ERP Science Board), Sacramento, California.
http://www.delta.dfg.ca.gov/erpdeltaplan/docs/cm_Risk%20Model_Green%20Sturgeon_Edited_10_31_06.pdf

CalFish Portal. 2008. California Fish Passage Assessment Database (PAD) project. Funded by the Coastal Conservancy in collaboration with California Department of Fish and Game, and the Pacific States Marine Fisheries Commission, Sacramento, California. CalFish; a California Cooperative Anadromous Fish and Habitat Data Program website.
http://dnn.calfish.org/FishPassageAssessment/tabid/97/Default.aspx.

CDFG (California Department of Fish and Game). 1982a. Iron Gate salmon and steelhead hatchery, 1978-79. Administrative report no. 82-22. CDFG, Inland Fisheries Division, Arcata, California.

CDFG. 1982b. Iron Gate salmon and steelhead hatchery, 1980-81. Administrative report no. 82-20. CDFG, Inland Fisheries Division, Arcata, California.

CDFG. 1983. Iron Gate salmon and steelhead hatchery, 1981-82. Administrative report no. 84-1

CDFG. 1985. Iron Gate salmon and steelhead hatchery, 1983-84. Administrative report No. 85-01

CDFG. 1987. Iron Gate salmon and steelhead hatchery, 1984-85. Administrative report No. 87-6.

CDFG. 1988. A four year summary of seining/tagging operations in the lower Klamath River with emphasis on mature fall Chinook salmon, coho salmon, and steelhead trout, 1984 through 1987. Draft report. CDFG, Inland Fisheries Division, Arcata, California.

CDFG. 1990a. Juvenile salmonid sampling within the Klamath-Trinity Basin, 1984. Draft report. CDFG, Inland Fisheries Division, Arcata, California.

CDFG. 1990b. Distribution, abundance, fork length and coded-wire tag recovery data for juvenile anadromous salmonids within the Klamath-Trinity Basin, 1985. Draft report. CDFG, Inland Fisheries Division, Arcata, California.

CDFG. 1993. Iron Gate salmon and steelhead hatchery, 1991-92. Administrative report no. 93-2.

CDFG. 2003. Klamath River Basin fall Chinook salmon spawner escapement, in-river harvest 16 and run-size estimates 1978-2002. CDFG, Arcata, California.

CDWR (California Department of Water Resources). 2003. Matrix of life history and habitat requirements for Feather River fish species: green sturgeon. Oroville FERC Relicensing (Project No. 2100), SP-F3.2 Task 2, SP-F21 Task 1, interim report. Prepared by CDWR, Sacramento, California.

Cederholm, C. J., L. M. Reid, and E. O. Salo. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, Washington. Pages 38-74 *in* Salmon-spawning gravel: A renewable resource in the Pacific Northwest? Report No. 39. State of Washington Water Research Center, Washington State University, Pullman, and the University of Washington, Seattle.

CH2M Hill. 1985. Klamath River basin fisheries resource plan. Prepared for U.S. Department of the Interior.

Chesney, W. R. 2000. Study 3a1, Shasta and Scott River juvenile steelhead trapping, 2000. Annual report. Prepared by California Department of Fish and Game, Steelhead Research and Monitoring Program, Yreka, California.

Chesney, W. R. 2002. Shasta and Scott river juvenile salmonid outmigrant study, 2000-2001. Annual report. Prepared by California Department of Fish and Game, North Coast Region, Redding, California.

Chesney, W. R., and E. M. Yokel. 2003. Shasta and Scott River juvenile salmonid outmigrant study, 2001-2002. Project 2a1. Steelhead Research and Monitoring Program annual report. Prepared by California Department of Fish and Game, North Coast Region, Redding, California.

Chesney, W. R., B. J. Cook, W. B. Crombie, H. D. Langendorf, and J. M. Reader. 2007. Shasta and Scott river juvenile salmonid outmigrant study. Final report and appendices. Prepared by California Department of Fish and Game, Anadromous Fisheries Resource Assessment and Monitoring Program.

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevin. Bulletin 18. International Pacific Salmon Fisheries Commission, New Westminster, British Columbia, Canada.

Cordone, A. J., and D. W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. California Fish and Game 47: 189-228.

Cramer, S. P., I. I. Courter, R. Ericksen, C. Justice, T. Nickelson, and B. Pyper. 2007. Klamath coho life-cycle model. Draft version 1.1 model report. Prepared by Cramer Fish Sciences, Gresham, Oregon for The Bureau of Reclamation, Klamath Basin Area Office, Klamath Falls, Oregon.

CTC (Cantara Trustee Council). 1996. 1996 annual report. Prepared by CTC, Redding, California.

Cui, Y., C. Braudrick, W. E. Dietrich, B. Cluer, and G. Parker. 2006b. Dam Removal Express Assessment Models (DREAM). Part 2: Sample runs/sensitivity tests. Journal of Hydraulic Research 44: 308-323.

Cui, Y., G. Parker, C. Braudrick, W. E. Dietrich, and B. Cluer. 2006a. Dam Removal Express Assessment Models (DREAM). Part 1: Model development and validation. Journal of Hydraulic Research 44: 291-307.

Cui, Y., J. K. Wooster, P. F. Baker, S. R. Dusterhoff, J. S. Sklar, and W. E. Dietrich. In press (2008). Theory of find sediment infiltration into immobile gravel bed. Journal of Hydraulic Engineering.

Dean, M. 1994. Life history, distribution, run size, and harvest of spring Chinook salmon in the south fork Trinity River Basin. Chapter VII - job VII in Trinity River Basin monitoring project 1991-1992.

Dean, M. 1995. Life history, distribution, run size, and harvest of spring Chinook salmon in the south fork Trinity River Basin. Chapter VII - job VII in Trinity River Basin monitoring project 1992-1993.

Eilers, J. M., and C. P. Gubala. 2003. Bathymetry and sediment classification of the Klamath Hydropower Project impoundments. Prepared by J. C. Headwaters, Inc. for PacifiCorp, Portland, Oregon.

Elder, D., B. Olson, A. Olson, J. Villeponteaux, and P. Brucker. 2002. Salmon River subbasin restoration strategy: steps to recovery and conservation of aquatic resources. Prepared by Klamath National Forest, Yreka California and Salmon River Restoration Council, Sawyers Bar, California for the Klamath River Basin Restoration Task Force.

Emmett, R. L., S. L. Stone, S. A. Hinton, and M. E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries. Volume 2: Species life history summaries. ELMR Report No. 8. NOS/NOAA Strategic Environmental Assessment Division, Rockville, Maryland.

EPIC (Environmental Protection Information Center), Center for Biological Diversity, and Waterkeepers Northern California. 2001. Petition to list the North American green sturgeon as an endangered or threatened species under the Endangered Species Act. Prepared by Environmental Protection Information Center, Garberville, California; Center for Biological Diversity, San Francisco, California; and Waterkeepers Northern California, San Francisco, California.

Erickson, D. L., and M. A. H. Webb. 2007. Spawning periodicity, spawning migration, and size at maturity of green sturgeon, *Acipenser medirostris*, in the Rogue River, Oregon. Environmental Biology of Fishes 79: 255-268.

Ericksen, R. P., S. P. Cramer, I. I. Courter, and K. Arendt. 2007. Simulation of the life cycle of Klamath coho from adult entry to summer rearing. Review draft. Klamath coho integrated modeling framework technical memorandum series. Technical Memorandum #8 of 8. Prepared by Cramer Fish Sciences, Gresham, Oregon submitted to the Bureau of Reclamation, Klamath Basin Area Office, Klamath Falls, Oregon.

FERC (Federal Energy Regulatory Commission). 2006. Licensing for the continued operation of PacifiCorp's Klamath Hydroelectric Project, located principally on the Klamath River, in Klamath County, Oregon and Siskiyou County, California, FERC project no. 2082. Draft environmental impact statement. Prepared by FERC, Office of Energy Projects, Washington, D.C.

Gale, D. B., T. R. Hayden, L. S. Harris, and H. N. Voight. 1998. Assessment of anadromous fish stocks in Blue Creek, lower Klamath River, California, 1994-1996. Technical report no. 4. Prepared by the Yurok Tribal Fisheries Program, Klamath, California.

GEC (Gathard Engineering Consulting). 2006. Klamath River dam and sediment investigation. Appendix F: aquatic species use table. Prepared by GEC, Seattle, Washington.

GEC. 2007. Evaluation of alternatives to reservoir lowering start date from those proposed in November 2006. Federal Energy Regulatory Commission report. Prepared by GEC, Seattle, Washington.

Gerstung, E. R. 1997. Status of coastal cutthroat trout in California. Pages 43-56 *in* J. D. Hall, P. A. Bisson and R. E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Proceedings of a symposium. American Fisheries Society, Oregon Chapter, Corvallis.

Greig, S. M., D. A. Sear, D. Smallman, and P. A. Carling. 2005. Impact of clay particles on the cutaneous exchange of oxygen across the chorion of Atlantic salmon eggs. Journal of Fish Biology 66: 1681-1691.

Greig, S. M., D. A. Sear, and P. A. Carling. 2007. A review of factors influencing the availability of dissolved oxygen to incubating salmonid embryos. Hydrological Processes 21: 323-334.

Hampton, M. 2002. Summary of Chinook and coho salmon observations in 2001 Shasta River fish counting facility, Siskiyou County, California. California Department of Fish and Game, Yreka, California.

Hampton, M. 2004. Shasta River fish counting facility, Chinook and coho salmon observations in 2003, Siskiyou County, CA. California Department of Fish and Game, Yreka, California.

Hampton, M. 2005a. Recovery of Chinook and coho salmon at Iron Gate Hatchery, October 2, 2004 to December 20, 2004. Klamath River Project. California Department of Fish and Game.

Hampton, M. 2005b. Shasta River fish counting facility, Chinook and coho salmon observations in 2004, Siskiyou County, CA. California Department of Fish and Game, Yreka, California.

Hampton, M. 2005c. Bogus Creek salmon studies. California Department of Fish and Game, Yreka, California.

Hardy, T. B., and R.C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River. Phase II. Final report. Prepared for U.S. Department of the Interior, Washington, D.C..

Hardy, T. B., R. C. Addley, and E. Saraeva. 2006. Evaluation of instream flow needs in the lower Klamath River; phase II. Final report. Prepared by Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah for U.S. Department of the Interior.

Hayden, T. R., and D. B. Gale. 1999. Juvenile salmonid emigration monitoring from the Hunter Creek Basin, lower Klamath River, California, 1996-1997. Technical report 6. Prepared by Yurok Tribal Fisheries Program, Biological Monitoring Division, Klamath, California.

Hemmingsen, A. R., R. G. Sheldon, and R. D. Ewing. 1986. Comparison of adult returns to a hatchery from subyearling and yearling coho salmon released at similar sizes and different times. North American Journal of Fisheries Management 6: 204-208.

Herbert, D. M. W., and J. C. Merkens. 1961. The effects of suspended mineral solids on the survival of trout. International Journal of Air and Water Pollution 5: 46-55.

Holland, D. C. 1994. The western pond turtle: habitat and history. Final Report DOE/BP-62137-1. Bonneville Power Administration, Portland, Oregon.

Hopelain, J. S. 1998. Age, growth, and life history of Klamath River basin steelhead trout (*Oncorhynchus mykiss irideus*) as determined from scale analysis. Administrative report no. 98-3 Prepared by California Department of Fish and Game, Inland Fisheries Division, Sacramento, California.

Hubbs, C. L. 1971. Lampetra (*Entosphenus*) lethophaga, new species, the nonparasitic derivative of the Pacific lamprey. Transactions of the San Diego Natural History Society 16: 125-164.

Hughes, G. M. 1975. Coughing in the rainbow trout (*Salmo gairdneri*) and the influence of pollutants. Revue Swiss de Zoologie 82: 47-64.

Johnson, O. W., M. H. Ruckelshaus, W. S. Grant, F. W. Waknitz, A. M. Garrett, G. J. Bryant, K. Neely, and J. J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-37. National Marine Fisheries Service, Seattle, Washington.

Kan, T. T. 1975. Systematics, variation, distribution, and biology of lampreys of the genus Lampetra in Oregon. Doctorate dissertation. Oregon State University, Corvallis, Oregon.

Klimley, A. P., P. J. Allen, J. A. Israel, and J. T. Kelly. 2007. The green sturgeon and its environment: introduction. Environmental Biology of Fishes 79: 187-190.

Koski, K. V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams. Master's thesis. Oregon State University, Corvallis.

Kostow, K. 2002. Oregon lampreys: natural history, status, and analysis of management issues. Oregon Department of Fish and Wildlife, Portland.

KRBFTF (Klamath River Basin Fisheries Task Force). 1991. Long range plan for the Klamath River Basin Conservation Area Fishery Restoration Program. Prepared by KRBFTF, Yreka, California with assistance from William M. Kier Associates, Sausalito, California.

KRIS (Klamath Resource Information System). 2004a. Chinook (spring) Trinity hatchery/natural escapement 1978-2002. Website. http://www.krisweb.com/krisklamathtrinity/krisdb/webbuilder/mt_ct10.htm [Accessed 7 August 2008].

KRIS. 2004b. Chinook spring-run population 1980-2002. Website. http://www.krisweb.com/krisklamathtrinity/krisdb/webbuilder/sa_ct8.htm [Accessed 7 August 2008].

KRIS. 2004c. Chinook (spring) SF Trinity 1992-2002. Website. http://www.krisweb.com/krisklamathtrinity/krisdb/webbuilder/st_c10.htm [Accessed 7 August 2008].

KRIS. 2004d. Coho adult population above Willow Creek. Website. http://www.krisweb.com/krisklamathtrinity/krisdb/webbuilder/mt_c15.htm [Accessed 7 August 2008].

KRIS. 2004e. Adult coho at Shasta Racks 1930-2002. Website. http://www.krisweb.com/krisklamathtrinity/krisdb/webbuilder/sh_c15.htm [Accessed 7 August 2008].

KRSIC (Klamath River Stock Identification Committee). 1993. Salmon and steelhead populations of the Klamath-Trinity Basin. Prepared by KRSIC for Klamath River Task Force.

Langer, O. E. 1980. Effects of sedimentation on salmonid stream life. Environment Canada. Environmental Protection Service, unpublished report. North Vancouver, British Columbia.

Larson, Z. S., and M. R. Belchik. 1998. A preliminary status review of eulachon and Pacific lamprey in the Klamath River Basin. Prepared by Yurok Tribal Fisheries Program, Klamath, California.

Levasseur, M., N. E. Bergeron, M. F. Lapointe, and F. Berube. 2006. Effects of silt and very fine sand dynamics in Atlantic salmon (*Salmo salar*) redds on embryo hatching success. Canadian Journal of Fisheries and Aquatic Sciences 63: 1450-1459.

Magneson, M. 2006. Mainstem Klamath River fall Chinook salmon spawning survey 2005. Arcata fisheries data series report DS 2006-05. Prepared by U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Magneson, M., and S. A. Gough. 2006. Mainstem Klamath River coho salmon redd surveys 2001 to 2005. Arcata fisheries data series report DS 2006-7. Prepared by U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Maurer, S. 2002. Scott River watershed adult coho salmon spawning survey, December 2001 - January 2002. Prepared for USDA Forest Service, Klamath National Forest, Scott River Ranger District, Fort Jones, California.

McLeay, D. J., I. K. Birtwell, G. F. Hartman, and G. L. Ennis. 1987. Responses of Arctic grayling (*Thymallus arcticus*) to acute and prolonged exposure to Yukon placer mining sediment. Canadian Journal of Fisheries and Aquatic Sciences 44: 658-673.

Moyle, P. B. 2002. Inland fishes of California. Revised edition. University of California Press, Berkeley.

Moyle, P. B., R. M. Yoshiyama, J. E. Williams, and E. D. Wikramanayake. 1995. Fish species of special concern in California. Final report. Prepared by Department of Wildlife and Fisheries Biology, University of California, Davis for California Department of Fish and Game, Inland Fisheries Division, Rancho Cordova.

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of Chinook salmon from Washington, Idaho, Oregon, and California. NOAA technical memorandum NMFS-NWFSC-35. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington.

Nakamoto, R. J., T. T. Kisanuki, and G. H. Goldsmith. 1995. Age and growth of Klamath River green sturgeon (*Acipenser medirostris*). Project 93-FP-13. U.S. Fish and Wildlife Service, Coastal California Fish and Wildlife Office, Arcata, California.

Naman, S. W., S. Turo, and T. Hayden. 2004. Juvenile salmonid monitoring on the lower Trinity River, California, 2001. Technical report number TR-04-1 Prepared by Yurok Tribal Fisheries Program, Trinity River Division, Hoopa, California.

Nawa, R. 2003. A petition for rules to list: Pacific lamprey (*Lampetra tridentata*); river lamprey (*Lampetra ayresi*); western brook lamprey (*Lampetra richardsoni*); and kern brook lamprey (*Lampetra hubbsi*) as threatened or endangered under the Endangered Species Act. Letter to U.S. Fish and Wildlife Service, Department of the Interior, Washington, D.C.

NCRWQCB (North Coast Regional Water Quality Control Board). 2006. Desired salmonid freshwater habitat conditions for sediment-related indices. NCRWQCB, Santa Rosa, California.

Newcomb, T. W., and T. A. Flagg. 1983. Some effects of Mt. St. Helens volcanic ash on juvenile salmon smolts. Marine Fisheries Review 45: 8-12.

Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16: 693-727.

Newcombe, C. P., and D. D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11: 72-82.

Newcombe, C. P., B. Sheperd, G. Hoyer, and M. Ladd. 1995. Documentation of a fish kill (juvenile rainbow trout: *Oncorhynchus mykiss*) in Bellevue Creek (near Mission, Kelowna, British Columbia, Canada), caused by silty water discharge. Habitat Protection Occasional Report. British Columbia Ministry of Environment, Lands and Parks, Habitat Protection Branch.

NMFS (National Marine Fisheries Service). 1997. Endangered and threatened species: threatened status for southern Oregon/northern California coast evolutionarily significant unit (ESU) of coho salmon. Federal Register 62: 24588-24609.

NMFS. 1999a Designated critical habitat; proposed critical habitat for nine evolutionarily significant units of steelhead in Washington, Oregon, Idaho, and California. Federal Register 64: 5740-5754.

NMFS. 2001a. Endangered and threatened species: final listing determination for Klamath Mountains Province steelhead. Federal Register 66: 17845-17856.

NMFS. 2001b. Reevaluation of the status of Klamath mountain province steelhead. Prepared by West Coast Biological Review Team.

NMFS. 2002. Biological opinion, Klamath Project operations. Prepared by NMFS, Southwest Regional Office, Long Beach, California.

NMFS. 2004. Endangered or threatened wildlife and plants; 90-day finding on a petition to list three species of lamprey as threatened or endangered. Federal Register 69: 77158-77167.

NMFS. 2005. Endangered and threatened species; final listing determinations for 16 ESUs of West Coast salmon, and final 4(d) protective regulations for threatened salmonid ESUs. Federal Register 70: 37160-37204.

NMFS. 2006. Endangered and threatened species; revision of species of concern list, candidate species definition, and candidate species list. Federal Register 71: 61022-61025.

NMFS. 2007. Endangered and threatened wildlife and plants; fisheries off west coast states and in the Western Pacific; Amendment 15. Federal Register 93: 27276-27280.

Noggle, C. C. 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. Master's thesis. University of Washington, Seattle.

NRC (National Research Council). 2004. Endangered and threatened fishes in the Klamath River Basin: causes of decline and strategies for recovery. The National Academies Press, Washington, D.C.

ONHIC (Oregon National Heritage Information Center). 2007. Data system search for rare, threatened and endangered animals in the vicinity of upstream of your Klamath River project. Requested by Jennifer Aspittle, Stillwater Sciences, Arcata, California.

Olson, A. 1996. Freshwater rearing strategies of spring Chinook salmon (*Oncorhynchus tshawytscha*) in Salmon River tributaries, Klamath Basin, California. Master's thesis. Humboldt State University, Arcata, California.

PacifiCorp. 2004. Klamath Hydroelectric Project (FERC project no. 2082): fish resources. Final technical report Prepared by PacifiCorp, Portland, Oregon.

Papa, R., J. A. Israel, F. Nonnis Marzano, and B. May. 2007. Assessment of genetic variation between reproductive ecotypes of Klamath River steelhead reveals differentiation associated with different run-timings. Journal of Applied Ichthyology 23: 142-146.

PFMC (Pacific Fishery Management Council). 2003. Pacific Coast salmon plan. Fishery management plan for commercial and recreational salmon fisheries off the coasts of Washington, Oregon and California as revised through amendment 14. Prepared by PFMC, Portland, Oregon.

PFMC. 2005. Klamath River fall Chinook stock-recruitment analysis. Prepared by Pacific Fishery Management Council, Salmon Technical Team, Portland, Oregon.

PFMC. 2007. Final environmental assessment for Pacific Coast salmon plan amendment 15: an initiative to provide for de minimis fishing opportunity for Klamath River fall-run Chinook salmon. Prepared by the Pacific Fishery Management Council and National Marine Fisheries Service, Portland, Oregon.

PFMC. 2008. Stock abundance analysis for 2008 ocean salmon fisheries. Preseason Report I. Prepared by Pacific Fishery Management Council, Portland, Oregon.

Prager, M. H., and M. S. Mohr. 1999. Population dynamics of Klamath River fall Chinook salmon: stock-recruitment model and simulation of yield under management. Prepared by National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz/Tiburon Laboratory, Tiburon, California for Klamath Fisherey Management Council.

Quigley, D. 2005. Scott River watershed adult coho spawning ground surveys, November 2004-January 2005. Prepared by Siskiyou Resource Conservation District, Etna, California for U.S. Fish and Wildlife Service and California Department of Fish and Game.

Ratliff, D. E., and P. J. Howell. 1992. The status of bull trout populations in Oregon. Pages 10-17 *in* P. J. Howell and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. American Fisheries Society, Oregon Chapter, Corvallis.

Roelofs, T. D. 1983. Current status of California summer steelhead (*Salmo gairdneri*) stocks and habitat, and recommendations for their management. Report to USDA Forest Service, Region 5.

Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 397-445 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, B.C.

Sartori, J. C. 2006a. Identification of migratory juvenile Chinook salmon from the Salmon River drainage, northern California. Technical report. Prepared by U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Sartori, J. C. 2005. Microstructural natal signature of spring Chinook salmon otoliths from the Salmon River drainage, northern California. Technical report number TR2005-01. Prepared by U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Sartori, J. C. 2006b. Comparative otolith microstructural analysis of adult, juvenile, and fry life stages of Salmon River spring Chinook salmon of northwestern CA. Technical report. Prepared by U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Scheiff, A. J., J. S. Lang, and W. D. Pinnix. 2001. Juvenile salmonid monitoring on the mainstem Klamath River at Big Bar and mainstem Trinity River at Willow Creek 1997-2000. Annual report of the Klamath River Fisheries Assessment Program. Prepared by U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

Sear, D. A., P. A. Carling, and S. M. Greig. 2005. Fine sediment accumulation in spawning gravels and the effects on interstitial flow. Pages 808-812 *in* D. J. Lastra and P. V. Martinez, editors. Fifth international symposium on ecohydraulics: aquatic habitats: analysis and restoration. IAHR, Madrid, Spain.

Servizi, J. A., and D. W. Martens. 1987. Some effects of suspended Fraser River sediments on sockeye salmon (*Oncorhynchus nerka*). Pages 254-264 *in* H. D. Smith, L. Margolis and C. C. Wood, editors. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96. Department of Fisheries and Oceans, Ottawa.

Servizi, J. A., and D. W. Martens. 1992. Sublethal responses of coho salmon (*Oncorhynchus kisutch*) to suspended sediments. Canadian Journal of Fisheries and Aquatic Sciences 49: 1389-1395.

Shaw, P. A., and J. A. Maga. 1943. The effect of mining silt on yield of fry from salmon spawning beds. California Fish and Game 29: 29-41.

Shannon & Wilson, Inc. 2006. Sediment sampling, geotechnical testing and data review report: segment of Klamath River, Oregon and California. Prepared by Shannon & Wilson, Inc., Seattle, Washington for California Coastal Conservancy, Oakland, California.

Shaw, T. A., C. Jackson, D. Nehler, and M. Marshall. 1997. Klamath River (Iron Gate Dam to Seiad Creek) life stage periodicities for Chinook, coho, and steelhead. Prepared by U.S. Fish and Wildlife Service, Coastal California Fish and Wildlife Office, Arcata, California.

Sigler, J. W., T. C. Bjornn, and F. H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Transactions of the American Fisheries Society 113: 142-150.

Slaney, P. A., T. G. Halsey, and A. F. Tautz. 1977. Effects of forest harvesting practices on spawning habitat of stream salmonids in the Centennial Creek watershed, British Columbia. Fish Management Report No. 73. Mineral, Recreation and Conservation, British Columbia.

Sorenson, D. L., M. M. McCarthy, E. J. Middlebrooks, and D. B. Porcella. 1977. Suspended and dissolved solids effects on freshwater biota: a review. Research Report E. T. A.-600/3-77-042. Environmental Protection Agency, Office of Research and Development.

Stillwater Sciences. 2008. Klamath River dam removal study: sediment transport DREAM-1 simulation. Technical report. Prepared by Stillwater Sciences, Arcata, California for California Coastal Conservancy, Oakland, California.

Stillwater Sciences. In preparation. Dam removal and Klamath River water quality: a synthesis of the current conceptual understanding and an assessment of data gaps. Technical memorandum. Prepared by Stillwater Sciences, Berkeley, California for California Coastal Conservancy, Oakland, California.

Stober, Q. J., B. D. Ross, C. L. Melby, P. A. Dinnel, T. H. Jagielo, and E. O. Salo. 1981. Effects of suspended volcanic sediment on coho and Chinook salmon in the Toutle and Cowlitz rivers. Technical Completion Report FRI-UW-8124. University of Washington, Fisheries Research Institute, Seattle.

Strange, J. 2007. Adult Chinook salmon migration in the Klamath River Basin. 2005 Sonic Telemetry Study final report. Prepared by Yurok Tribal Fisheries Program, Klamath, California and University of Washington, School of Aquatic and Fishery Science, Seattle, Washington, in collaboration with Hoopa Valley Tribal Fisheries, Hoopa, California.

Sullivan, C. M. 1989. Juvenile life history and age composition of mature fall Chinook salmon returning to the Klamath River, 1984-1986. Master's thesis. Humboldt State University, Arcata, California.

Sykora, J. L., E. J. Smith, and M. Synak. 1972. Effect of lime neutralized iron hydroxide suspensions on juvenile brook trout (*Salvelinus fontinalis Mitchill*). Water Resources 6: 935-950.

Trihey and Associates. 1996. Instream flow requirements for tribal trust species in the Klamath River. Concord, California.

Trotter, P. C. 1997. Sea-run cutthroat trout: life history profile. Pages 7-15 *in* J. D. Hall, P. A. Bisson and R. E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Proceedings of a symposium. American Fisheries Society, Oregon Chapter, Corvallis.

Turnpenny, A. W. H., and R. Williams. 1980. Effects of sedimentation on the gravels of an industrial river system. Journal of Fish Biology 17: 681-693.

Tuss, C., J. Polos, and D. Wills. 1990. Klamath-Trinity River Basin spring Chinook salmon stock evaluation and run size forecast. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California.

USFWS (U.S. Fish and Wildlife Service). 1979. Hoopa Valley Indian Reservation - inventory of reservation waters, fish rearing feasibility study and a review of the history and status of anadromous fishery resources of the Klamath River Basin. Prepared by USFWS, Arcata Fish and Wildlife Office, Arcata, California.

USFWS. 1996. Trinity River fisheries assessment program. Investigations in New River. Progress report FY 1994 and 1995 Prepared by USFWS, Arcata Fish and Wildlife Office, Arcata, California.

USFWS. 1998. Klamath River (Iron Gate Dam to Seiad Creek) life state periodicities for Chinook, coho, and steelhead. Prepared by USFWS, Coastal California Fish and Wildlife Office, Arcata, California.

USFWS. 2004. Fall flow monitoring plan 2004 – recommendation to the Trinity Management Council. Memorandum. Prepared by USFWS, Arcata, California for USFWS California/Nevada Operations Office, Sacramento, California.

USFWS. 2005. Klamath River Basin Conservation Area Restoration Program, working to restore anadromous fisheries of the Klamath River basin. FY 2005 Annual report. Prepared by U. S. Fish and Wildlife Service, Yreka Fish and Wildlife Office,Yreka, California for the Klamath River Basin Fisheries Task Force.

USFWS, and HVT (Hoopa Valley Tribe). 1999. Trinity River flow evaluation. Final report. Prepared by USFWS, Arcata Fish and Wildlife Office, Arcata, California and HVT, Hoopa, California.

USGS (U.S. Geological Survey). 1998. Status of listed species and recovery plan development June Sucker Chasmistes liorus-endangered, Utah. Prepared by USGS, Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

Van Eenennaam, J. P., J. Linares, S. I. Doroshov, D. C. Hillemeier, T. E. Willson, and A. A. Nova. 2006. Reproductive conditions of the Klamath River green sturgeon. Transactions of the American Fisheries Society 135: 151-163.

Voight, H. N., and D. B. Gale. 1998. Distribution of fish species in tributaries of the lower Klamath River: an interim report, FY 1996. Technical Report No. 3. Yurok Tribal Fisheries Program, Habitat Assessment and Biological Monitoring Division.

Voight, H., and D. McCanne. 2002. Regional estimation of juvenile coho abundance in tributaries to the lower Klamath River. Two year report, 2000-2001. Yurok Tribal Fisheries Program, Klamath, California.

Voight, H., and D. McCanne. In preparation. Regional estimation of juvenile coho abundance in tributaries to the lower Klamath River. Three year report, 2002-2004. Yurok Tribal Fisheries Program, Klamath, California and Humboldt State University, Arcata, California.

Wallace, M. 2004. Natural vs hatchery proportions of juvenile salmonids migrating through the Klamath River Estuary and monitor natural and hatchery juvenile salmonid emigration from the Klamath River Basin. July 1, 1998 through June 30, 2003. Final performance report. Federal Aid in Sport Fish Restoration Act. Project no. F-51-R-6. Arcata, California.

Ward, L., P. Crain, B. Freymond, M. McHenry, D. Morrill, G. Pess, R. Peters, J. A. Shaffer, B. Winter, and B. Wunderlich. 2008. Elwha River fish restoration plan- developed pursuant to the Elwha River Ecosystem and Fisheries Restoration Act, Public Law 102-495. NOAA Technical memorandum, NMFS-NWFSC-90. U.S. Department of Commerce, Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA.

Webb, M. A. H., and D. L. Erickson. 2007. Reproductive structure of the adult green sturgeon, *Acipenser medirostris*, population in the Rogue River, Oregon. Environmental Biology of Fishes 79: 305-314.

West, J. R. 1991. A proposed strategy to recover endemic spring-run Chinooks salmon populations and their habitats in the Klamath River Basin. Prepared by USDA Forest Service, Pacific Southwest Region, Yreka, California.

West, J. R., O. J. Dix, A. D. Olson, M. V. Anderson, S. A. Fox, and J. H. Power. 1990. Evaluation of fish habitat conditions and utilization in Salmon, Scott, Shasta, and Mid-Klamath sub-basin tributaries. Annual report for interagency agreement 14-16-0001-89508. Prepared by USDA Forest Service, Klamath National Forest, Yreka, California and Shasta Trinity National Forest, Weaverville, California.

Whitman, R. P., T. P. Quinn, and E. L. Brannon. 1982. Influence of suspended volcanic ash on homing behavior of adult Chinook salmon. Transactions of the American Fisheries Society 111: 63-69.

Whyte, J. N. C., R. J. Beamish, N. G. Ginther, and C. E. Neville. 1993. Nutritional condition of the Pacific lamprey (*Lampetra tridentata*) deprived of food for periods of up to two years. Canadian Journal of Fisheries and Aquatic Sciences 50: 591-599.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. Technical memorandum NMFS-NWFSC-24. Prepared by National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, Seattle, Washington.

Wooster, J. K., S. Dusterhoff, Y. Cui, L. Sklar, W. E. Dietrich, and M. Malko. 2008. Sediment supply and relative size distribution effects on fine sediment infiltration into immobile gravels. Water Resources Research 44: W03424, doi:10.1029/2006WR005815.

Wooster, J. K., Y. Cui, J. G. Venditti, J. T. Minear, S. Dusterhoff, R. Humphries, P. Nelson, W. E. Dietrich, and L. Sklar. In preparation. Channel response to fine and coarse sediment pulses at varying spatial scales in a flume with forced pool-riffle morphology.

Zaroban, D., M. Mulvey, T. Maret, R. Hughes, and G. Merritt. 1999. Classification of species attributes for Pacific Northwest freshwater fishes. Northwest Science 73: 81-93.

Figures

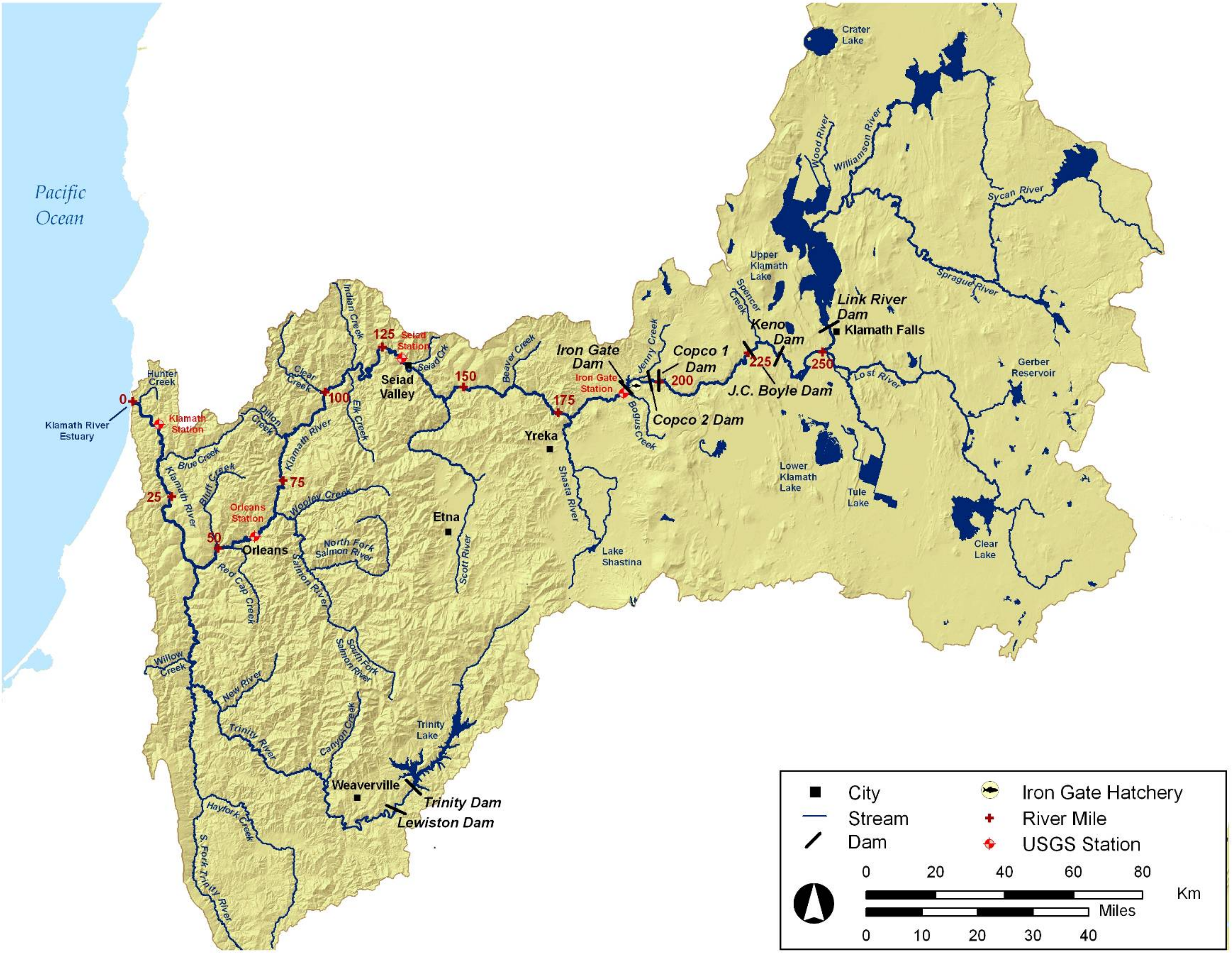

Figure 1. Klamath River basin.

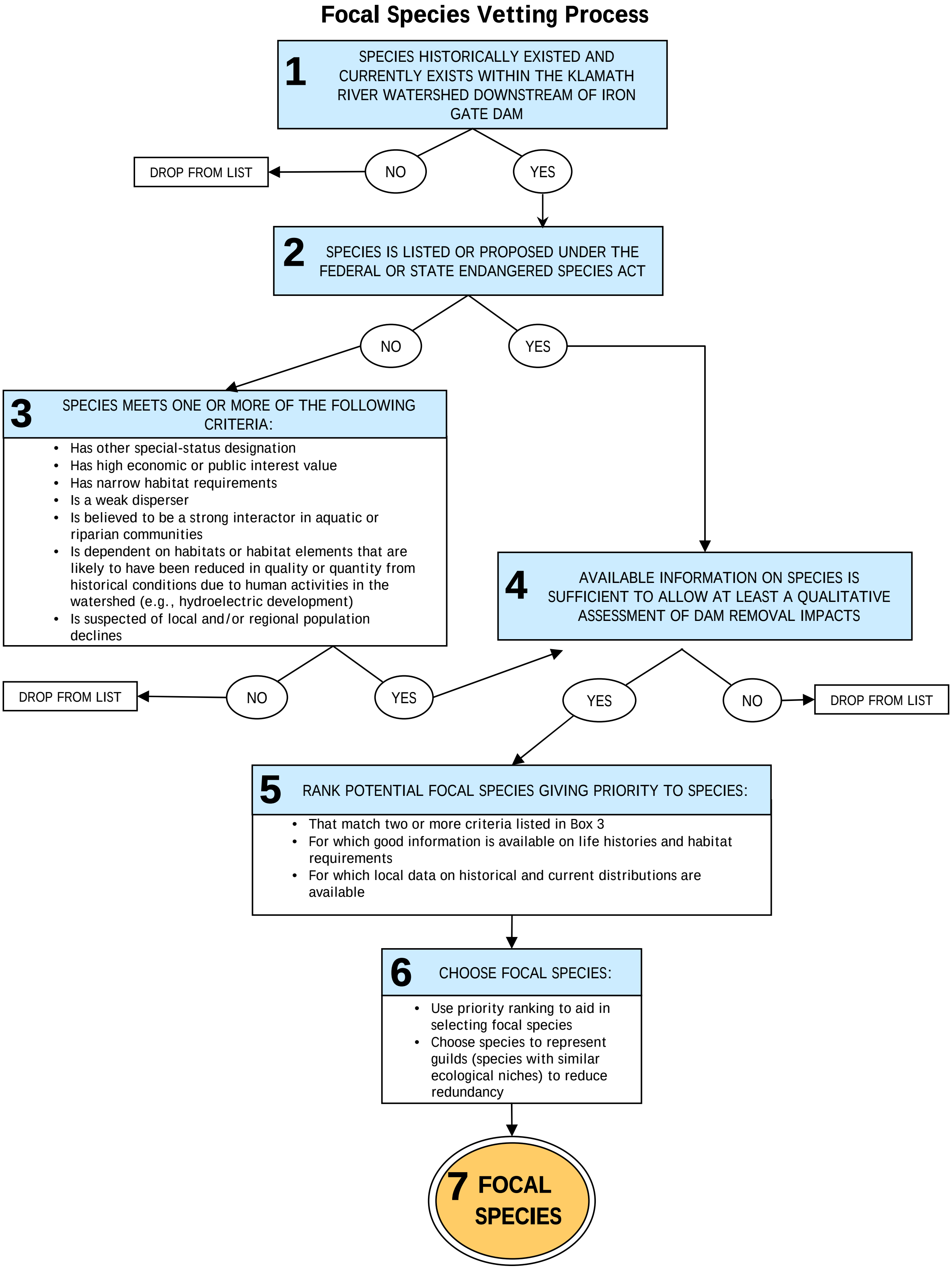

Figure 2. Focal species vetting process.

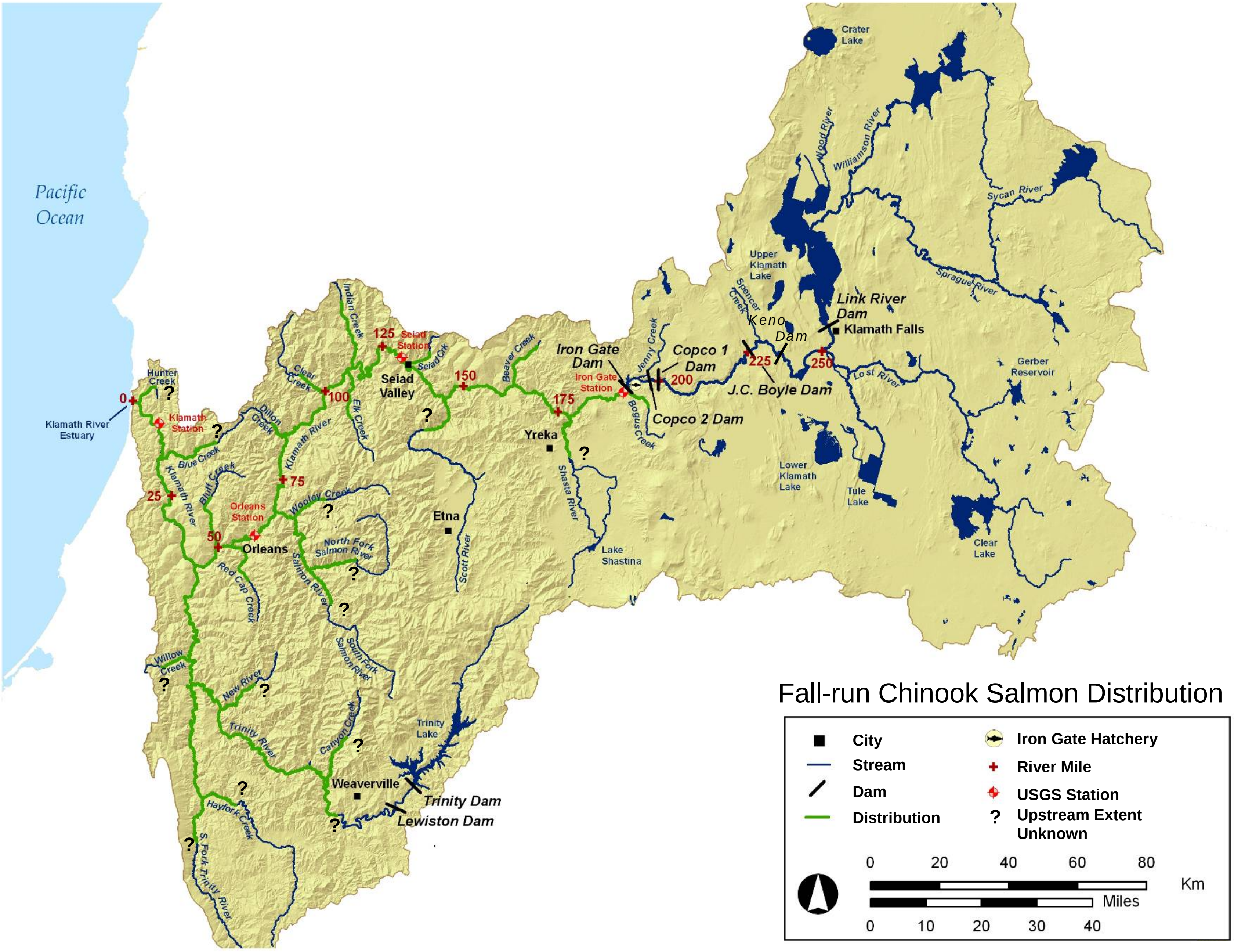

Figure 3. Fall-run Chinook salmon distribution in the Klamath River basin.

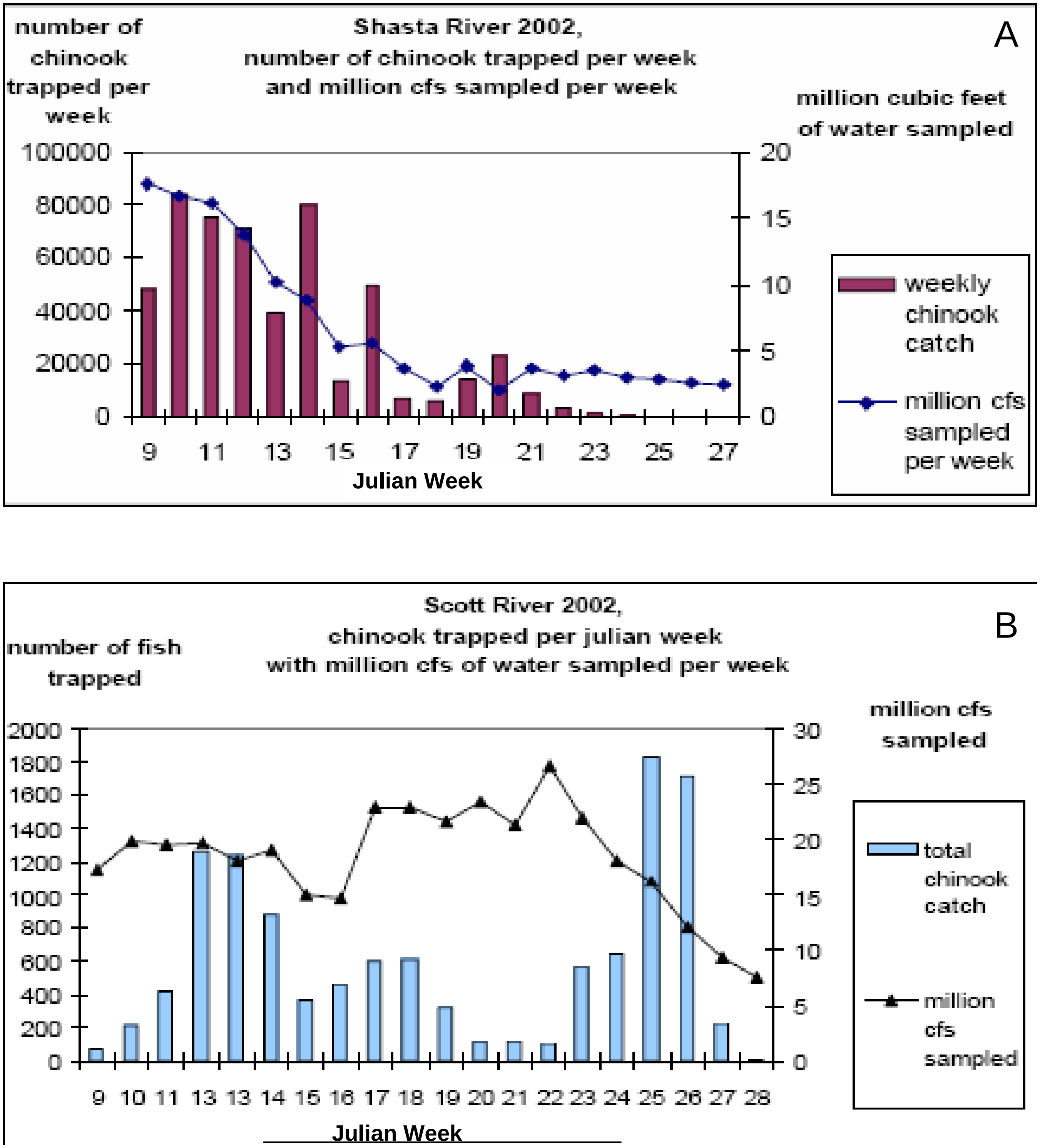

Figure 4. Emigration timing of Chinook salmon in the Shasta River (A) and the Scott River (B) in 2002 (from Chesney and Yokel 2003).

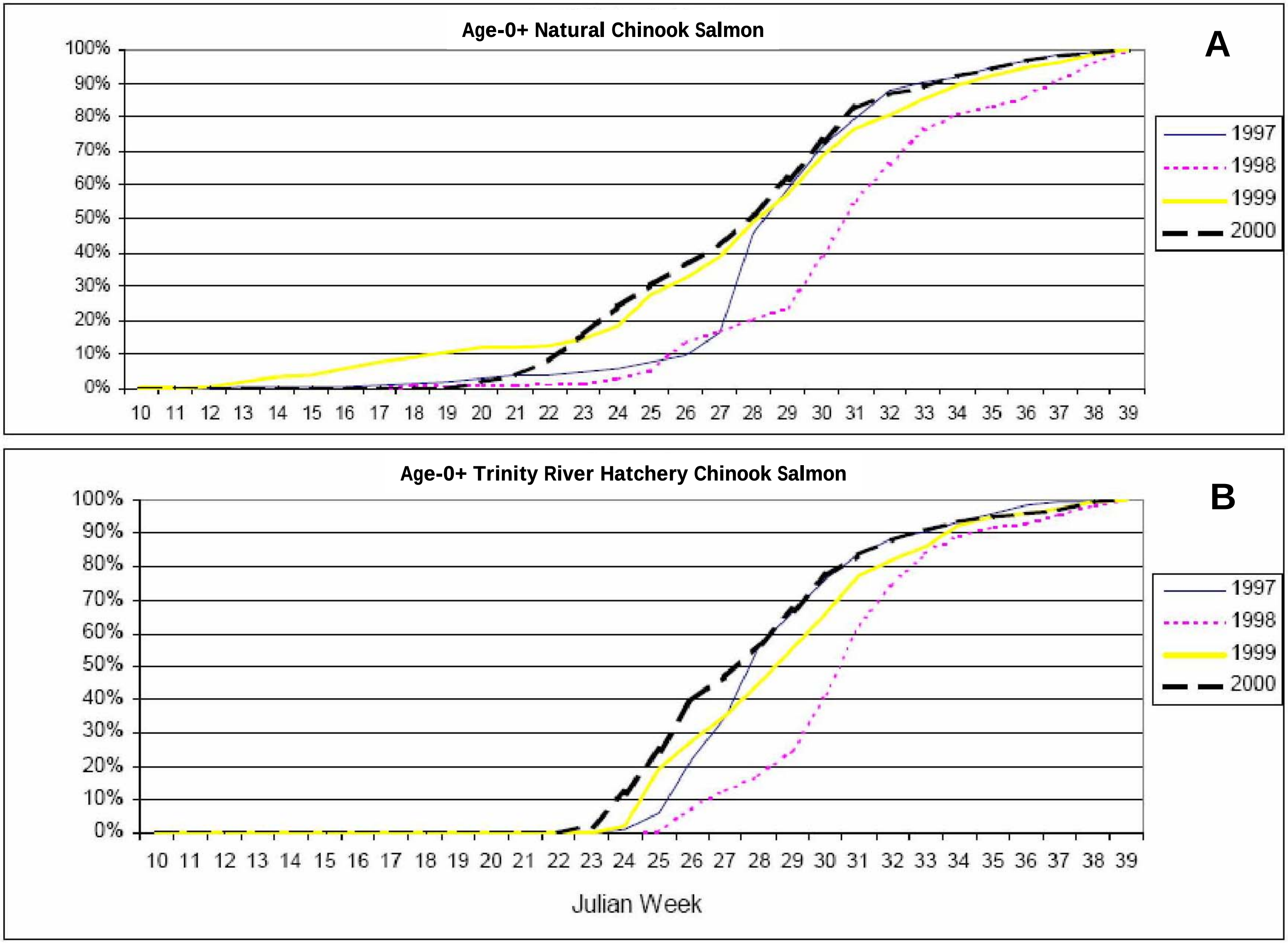

Figure 5. Emigration timing of natural (A) and hatchery releases (B) of Chinook salmon in the Trinity River at the Willow Creek outmigration trap from 1997 to 2000 (from Scheiff et al. 2001).

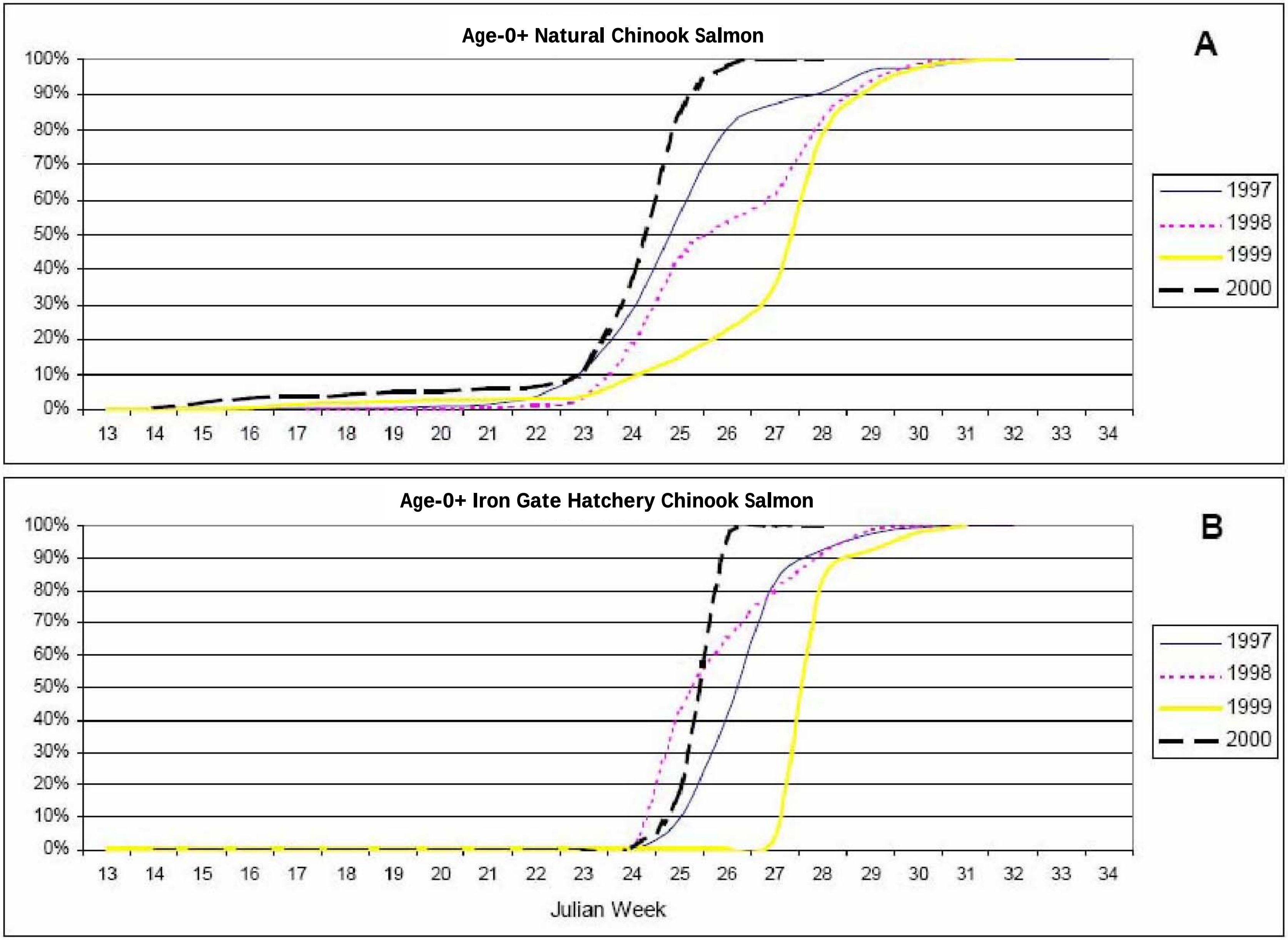

Figure 6. Emigration timing of natural (A) and hatchery releases (B) of Chinook salmon in the Klamath River at the Big Bar outmigration trap from 1997 to 2000 (from Scheiff et al. 2001).

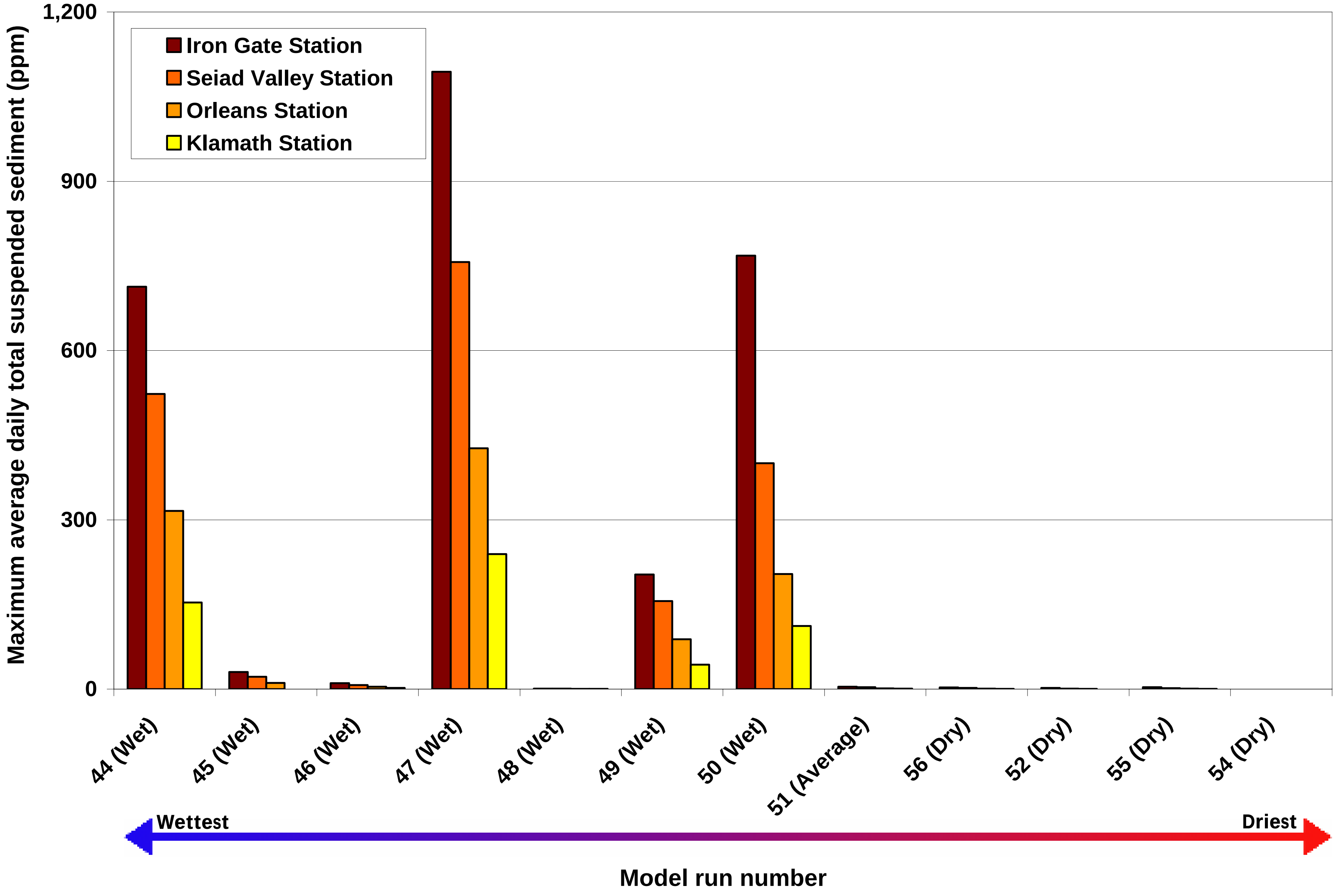

Figure 7. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 July through 31 October (the period of fall-run Chinook salmon adult migration).

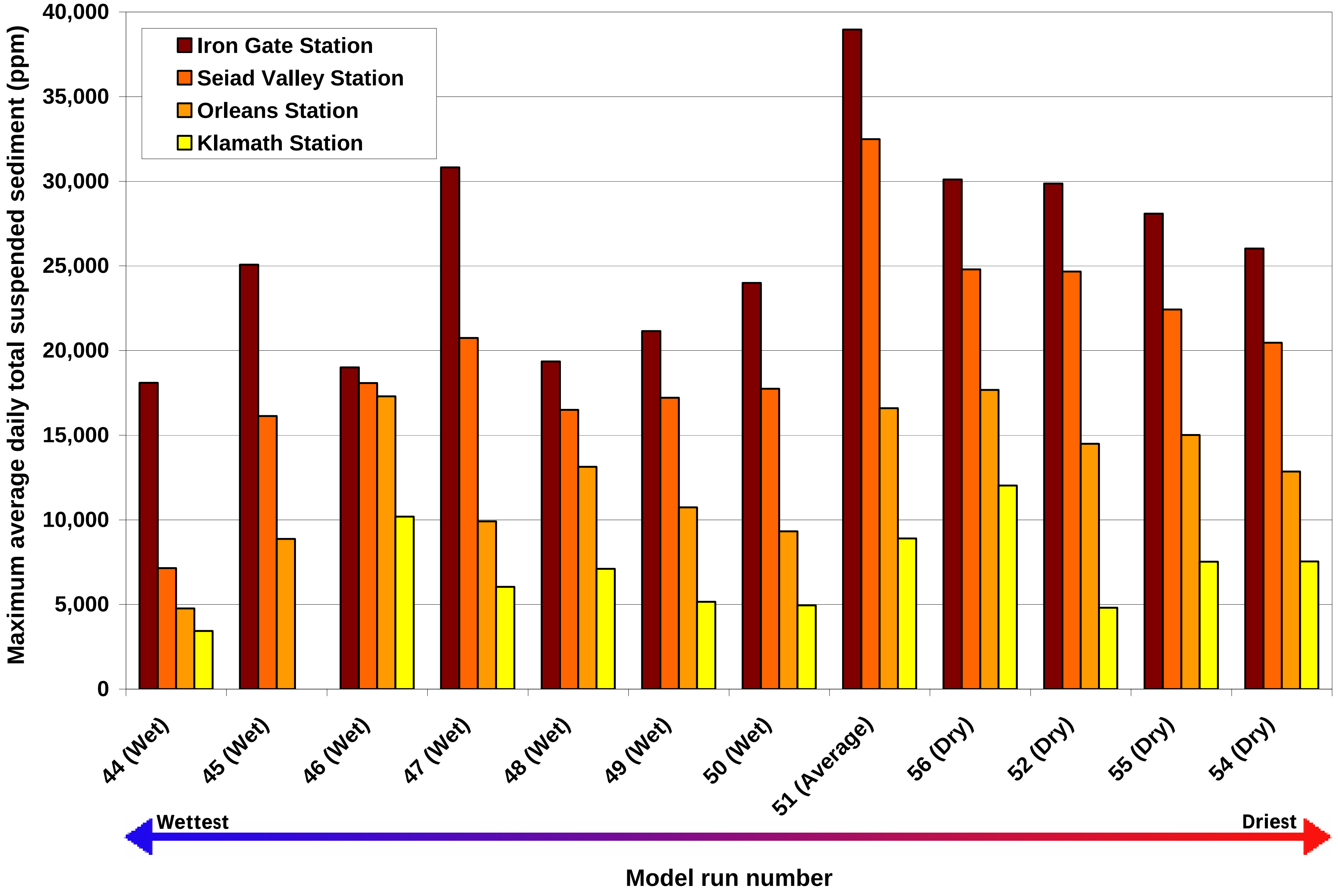

Figure 8. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 October through 30 November (the period of fall-run Chinook salmon spawning).

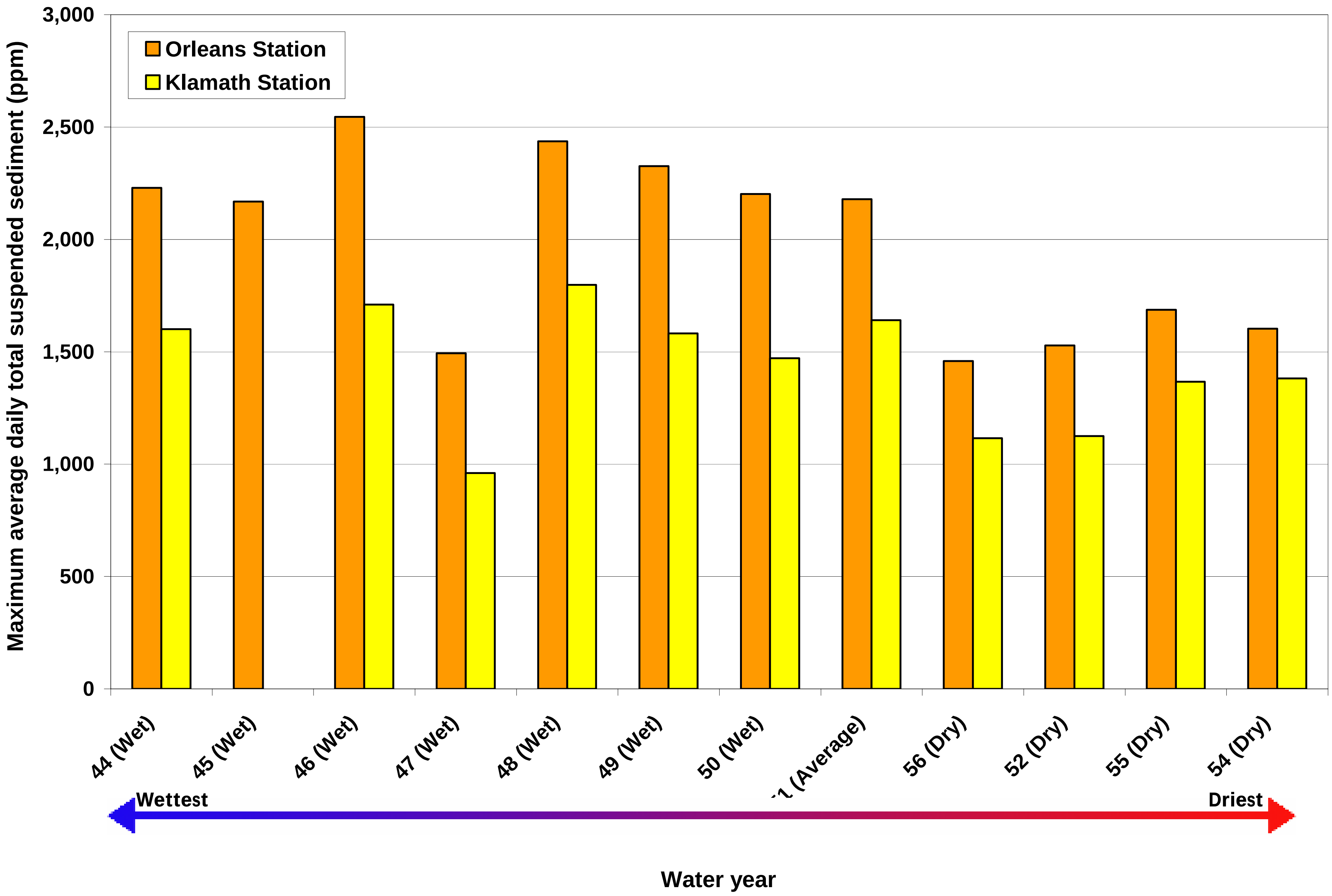

Figure 9. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 April through 15 November (the period of Type I fall-run Chinook salmon juvenile outmigration assuming that all juveniles are in the lower river by 6 November).

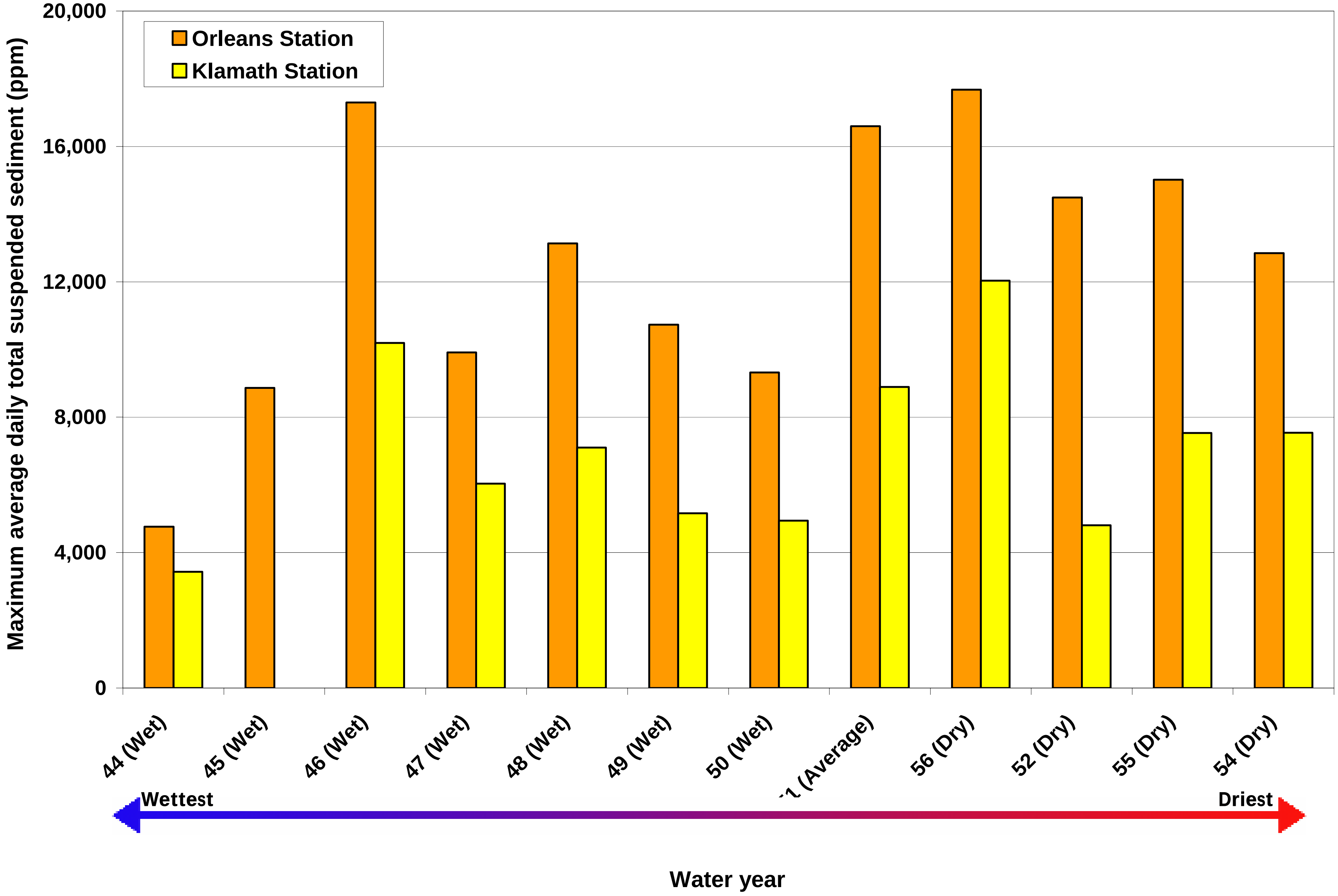

Figure 10. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 September through 31 October (the period of Type II fall-run Chinook salmon juvenile outmigration).

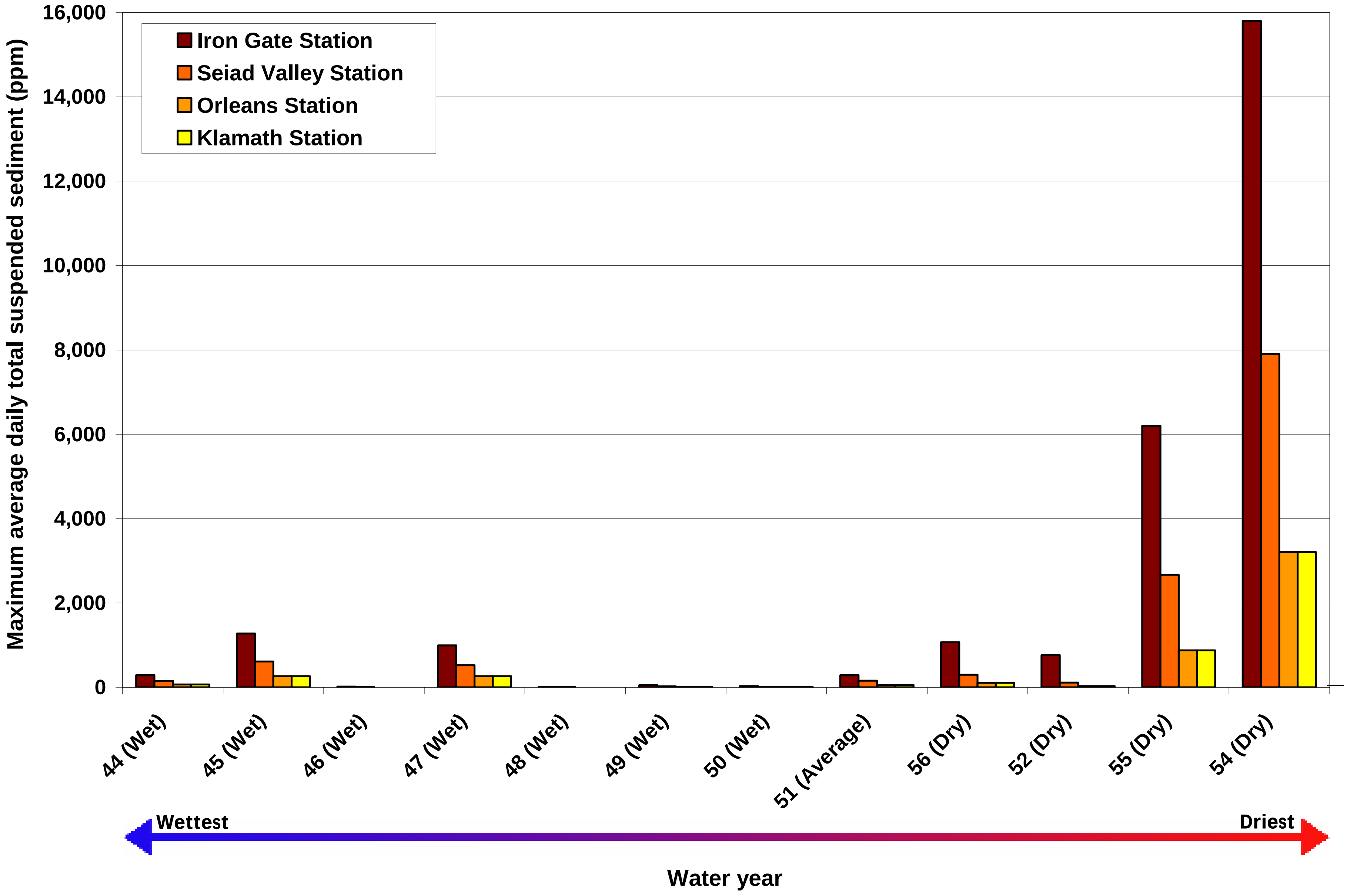

Figure 11. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 February through 15 April (the period of Type III fall-run Chinook salmon juvenile outmigration).

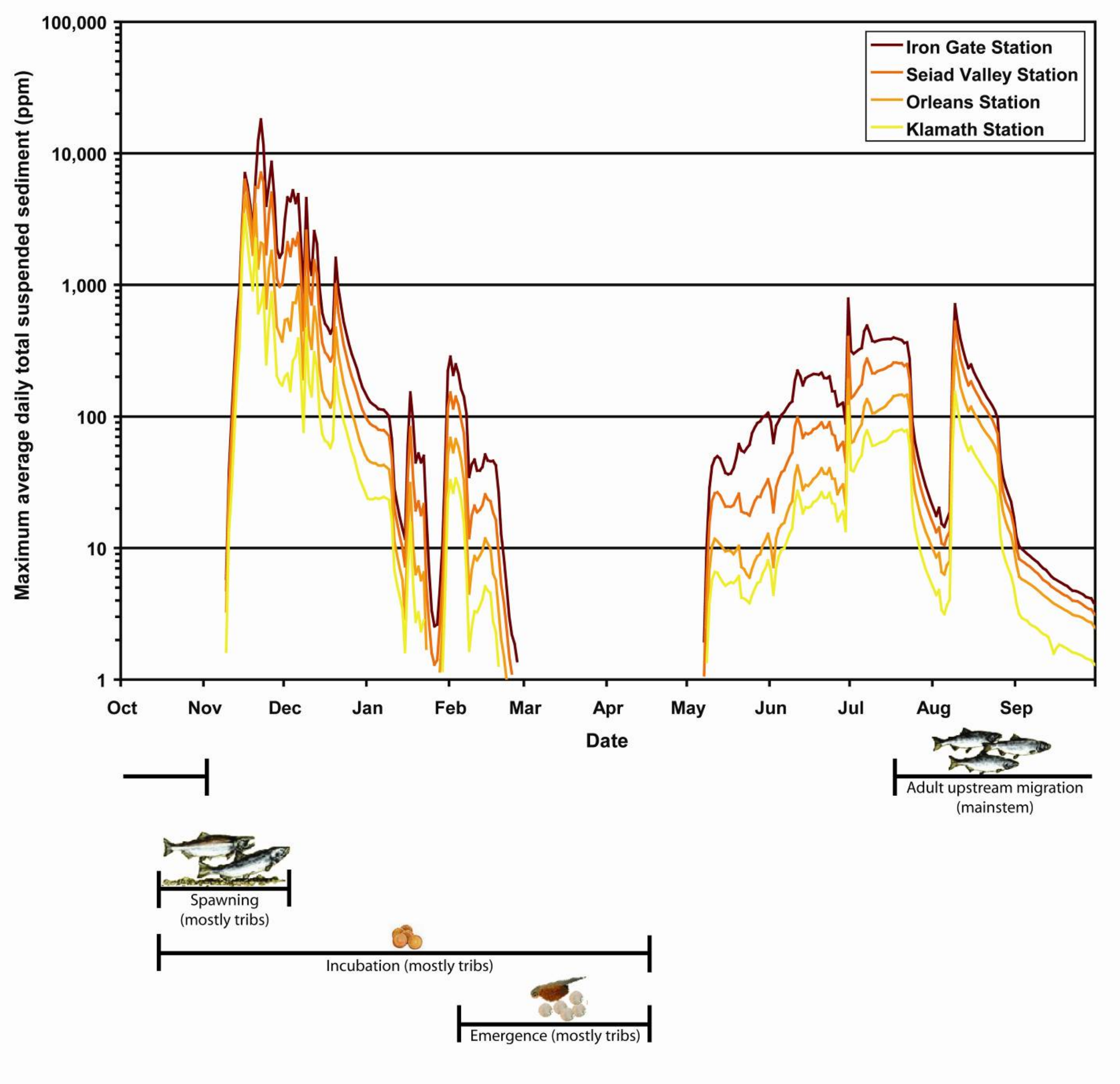

Figure 12. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with fall-run Chinook salmon adult upstream migration, spawning, incubation, and emergence life-history timing.

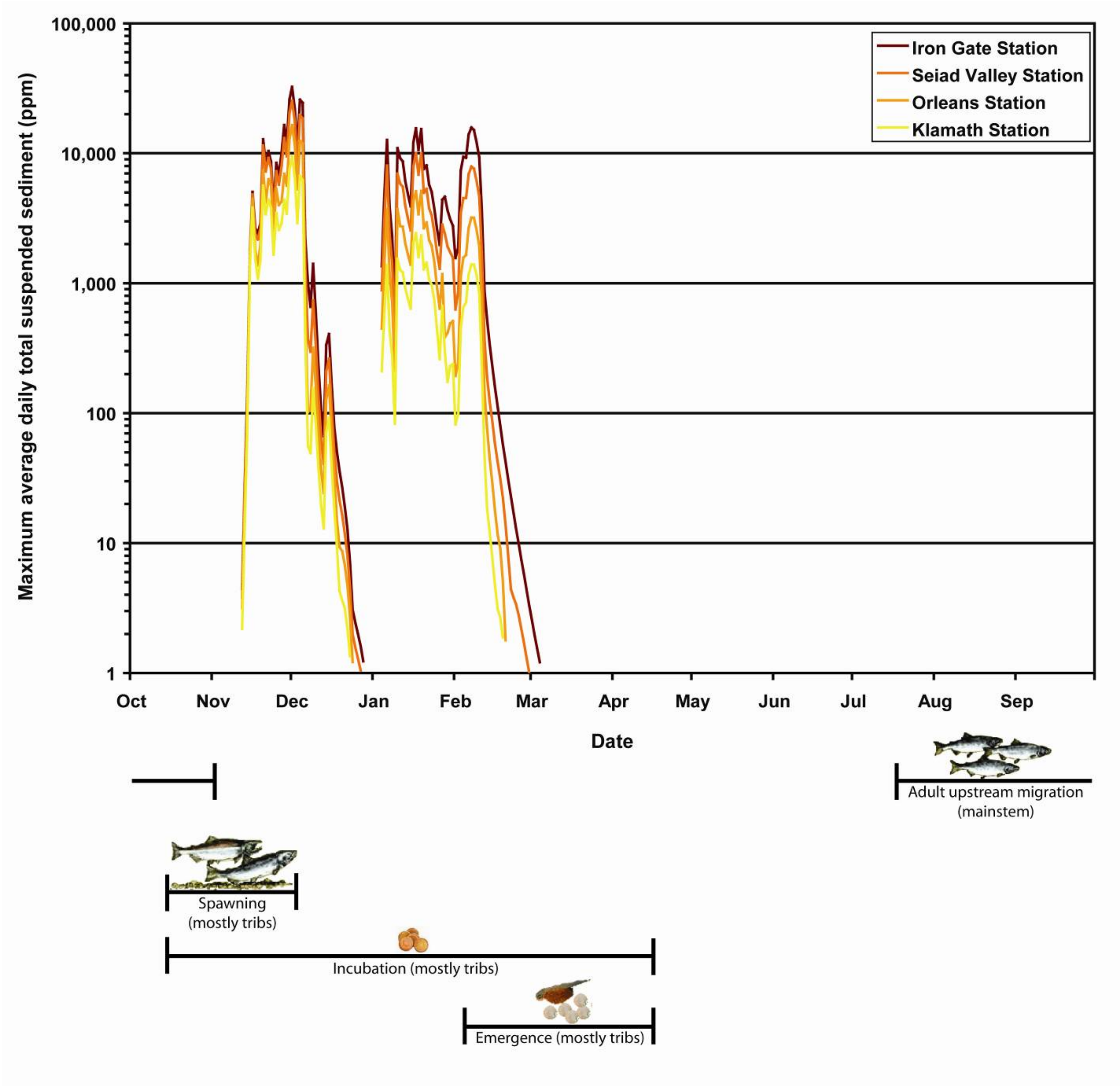

Figure 13. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with fall-run Chinook salmon adult upstream migration, spawning, incubation, and emergence life-history timing.

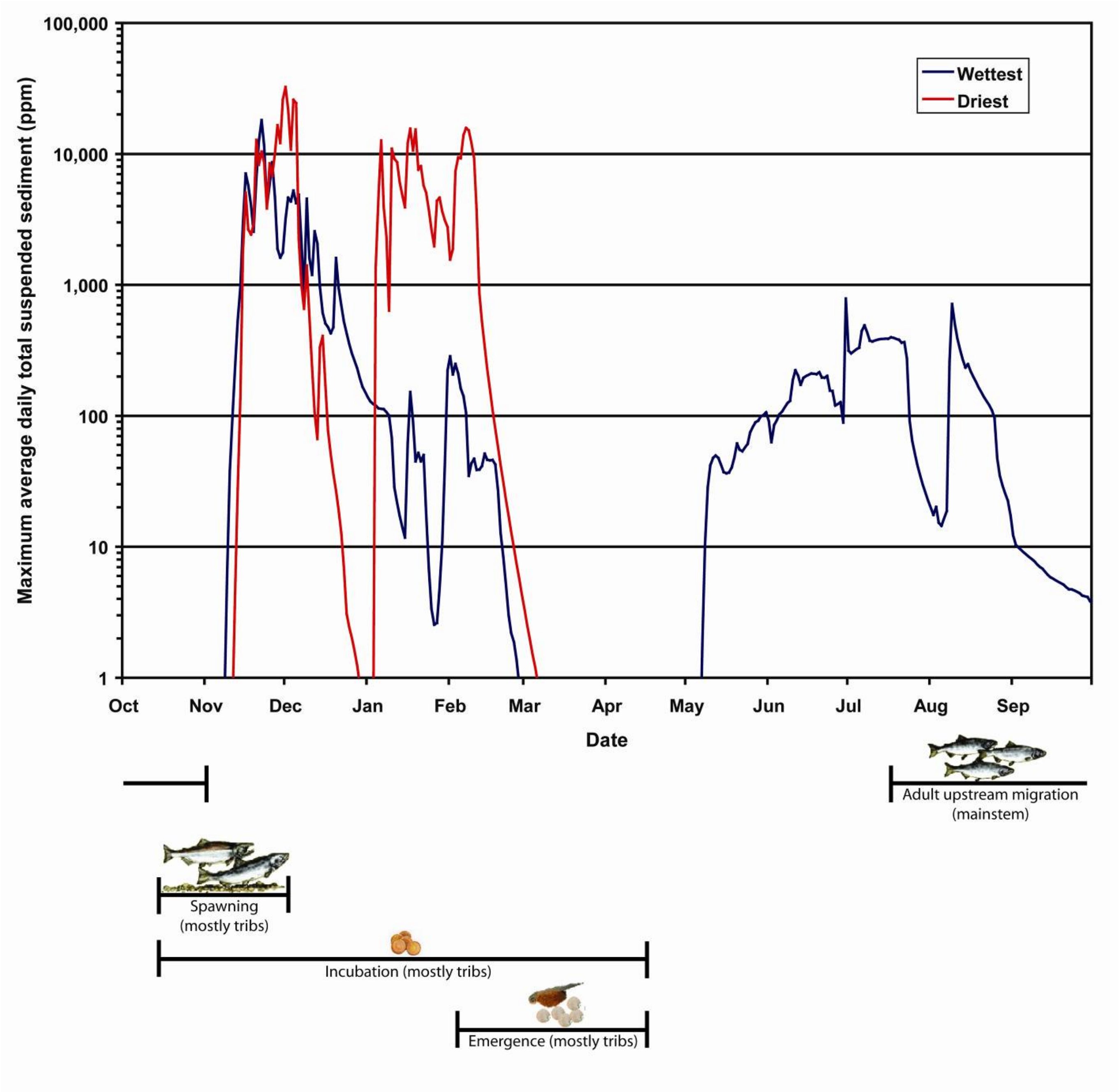

Figure 14. Average daily total suspended sediment concentrations in the Klamath River at the Iron Gate Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with fall-run Chinook salmon adult upstream migration, spawning, incubation, and emergence life-history timing.

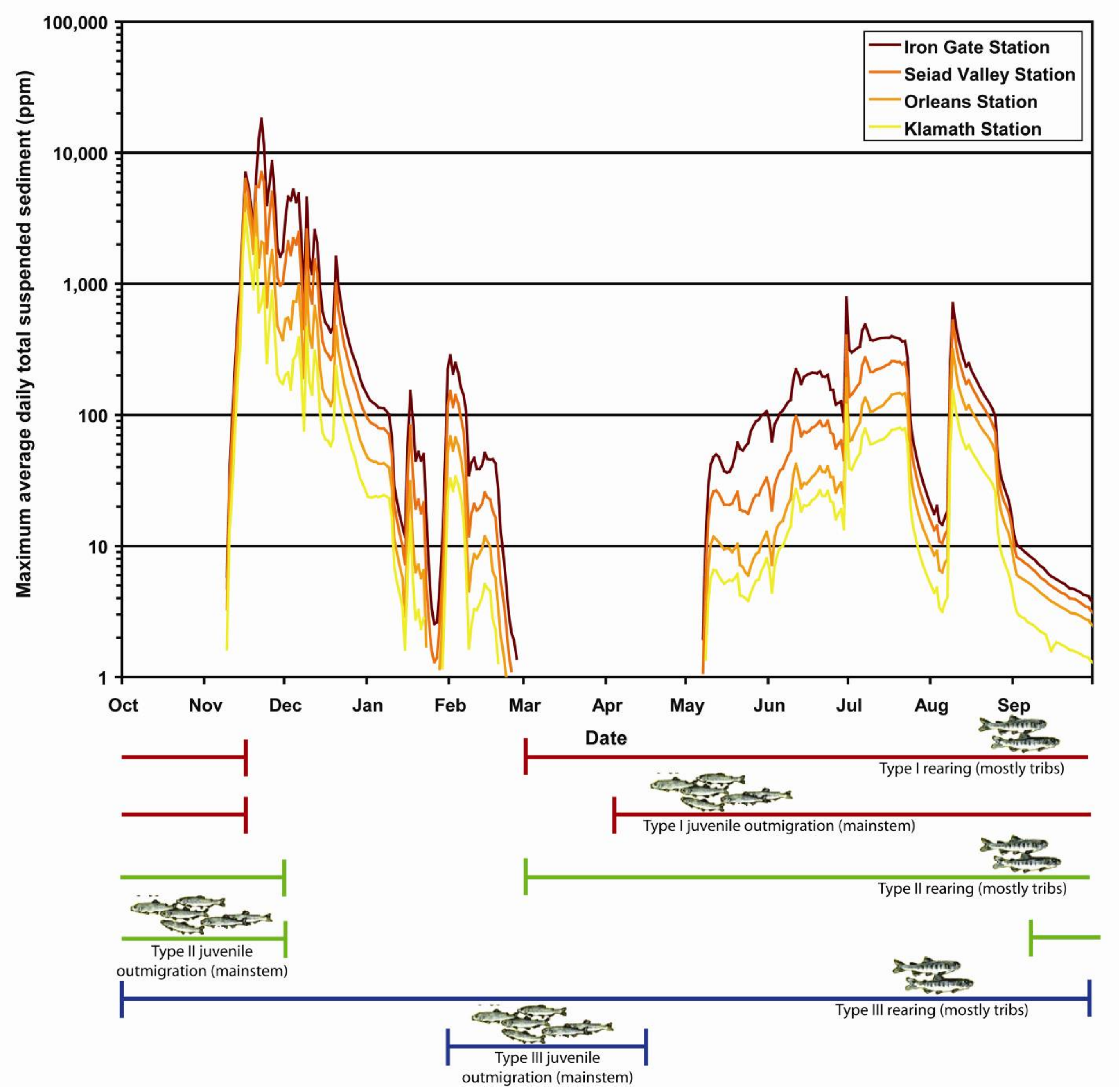

Figure 15. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with fall-run Chinook salmon juvenile rearing and outmigration life-history timing.

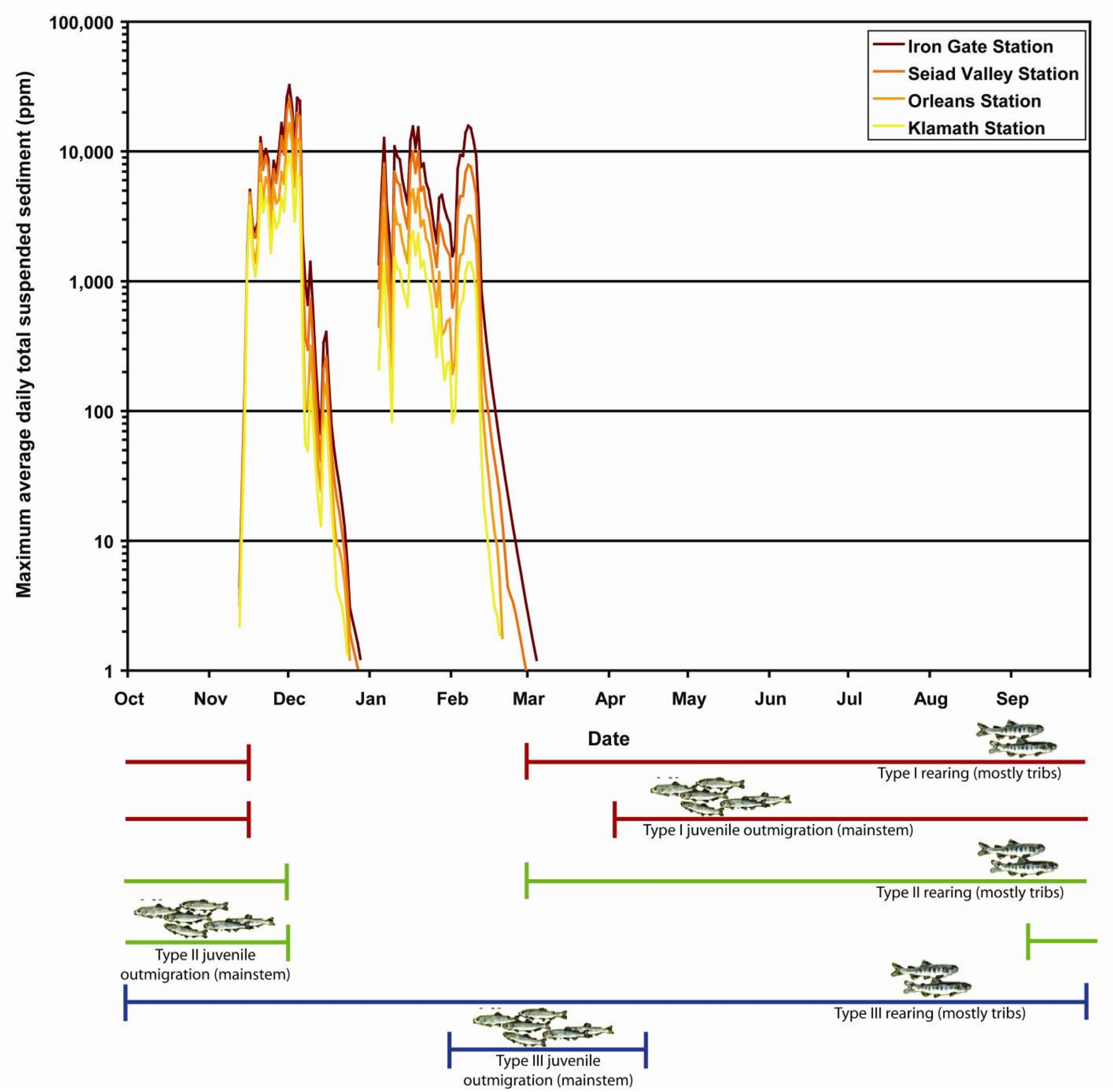

Figure 16. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with fall-run Chinook salmon juvenile rearing and outmigration life-history timing.

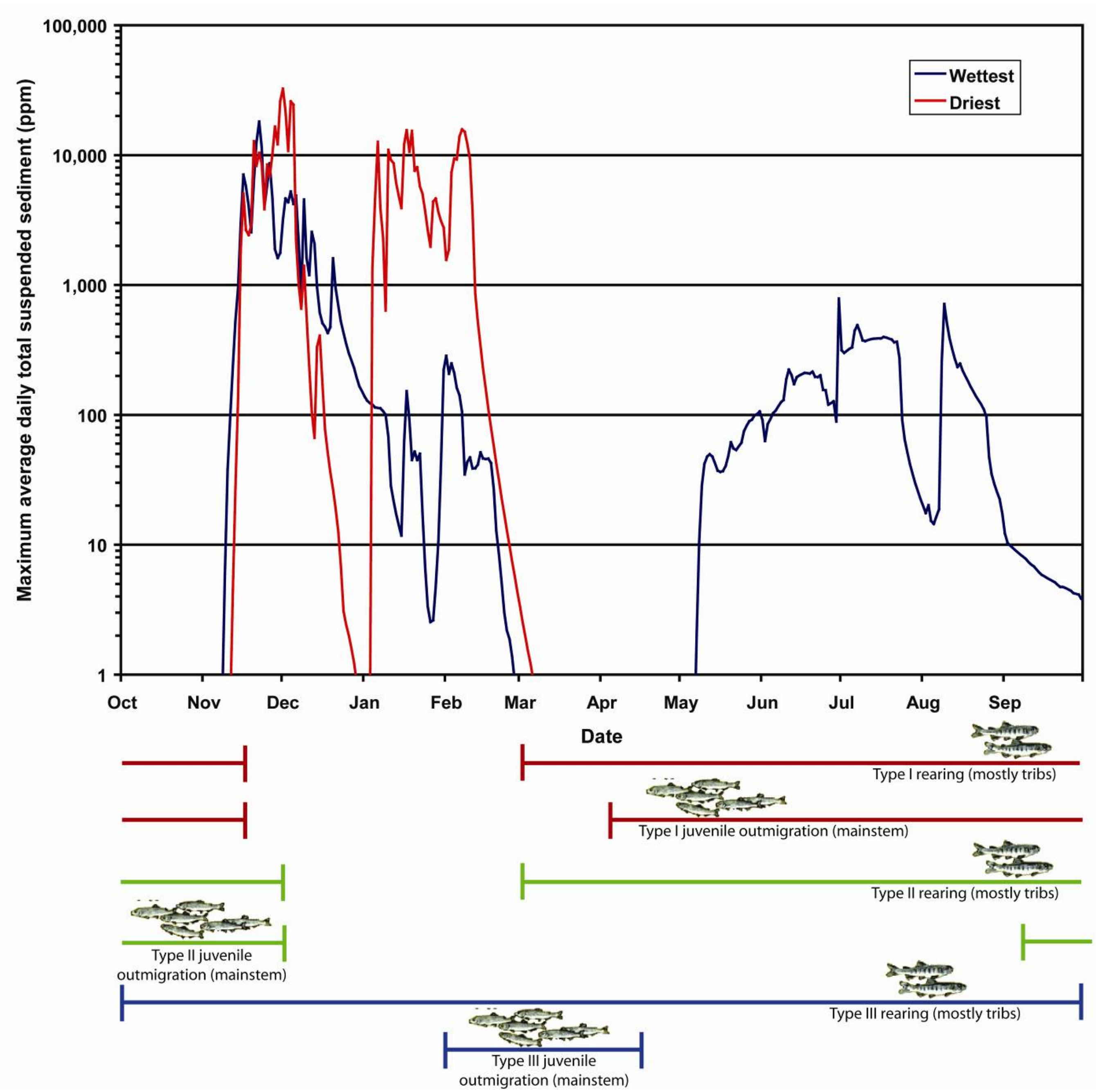

Figure 17. Average daily total suspended sediment concentrations in the Klamath River at the Iron Gate Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with fall-run Chinook salmon juvenile rearing and outmigration life-history timing.

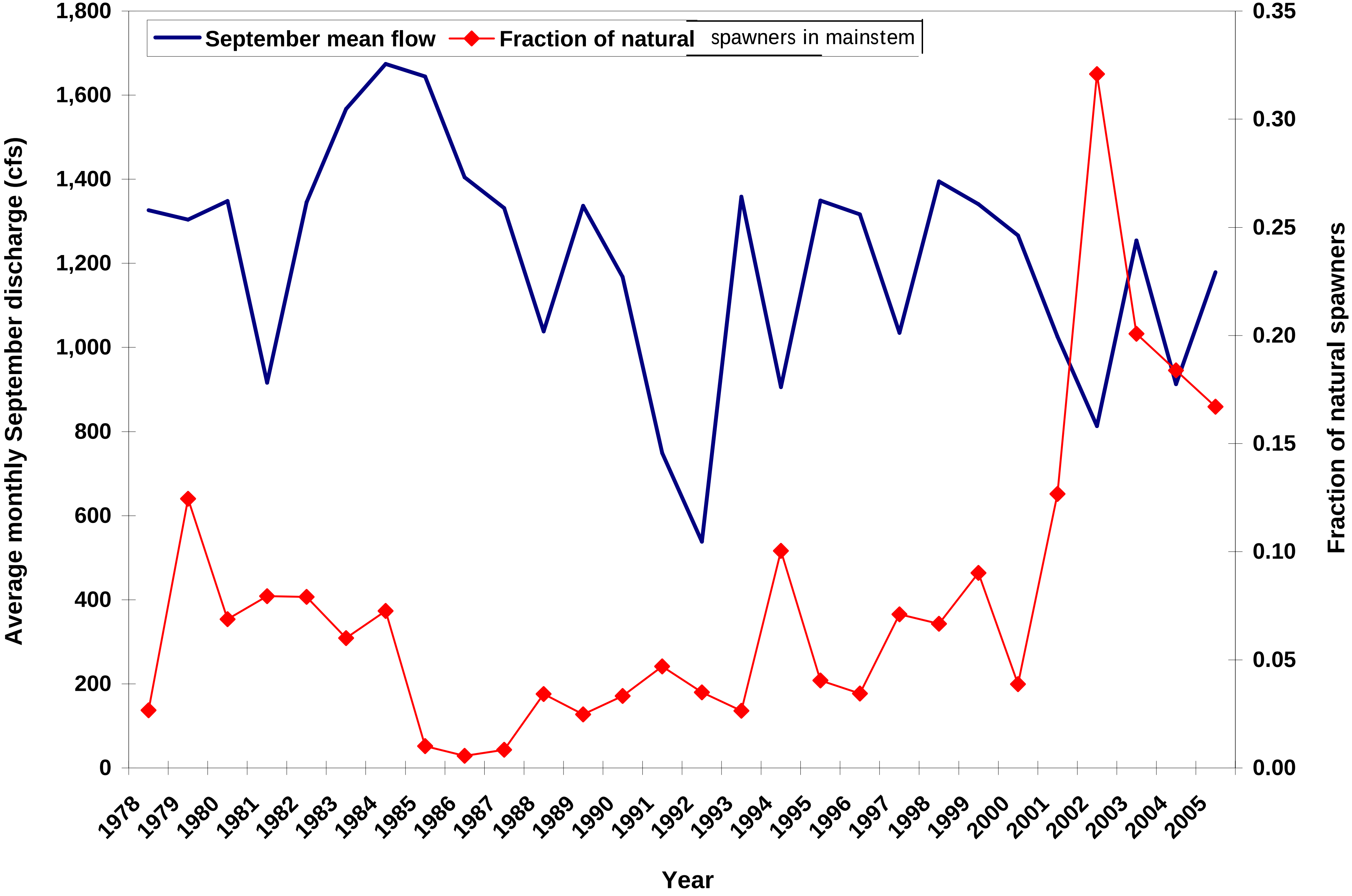

Figure 18. Fraction of natural spawners in the mainstem Klamath River in relation to mean monthly discharge for September at the Iron Gate station for 1978-2005 (based on CDFG 2003 as reported in FERC 2006).

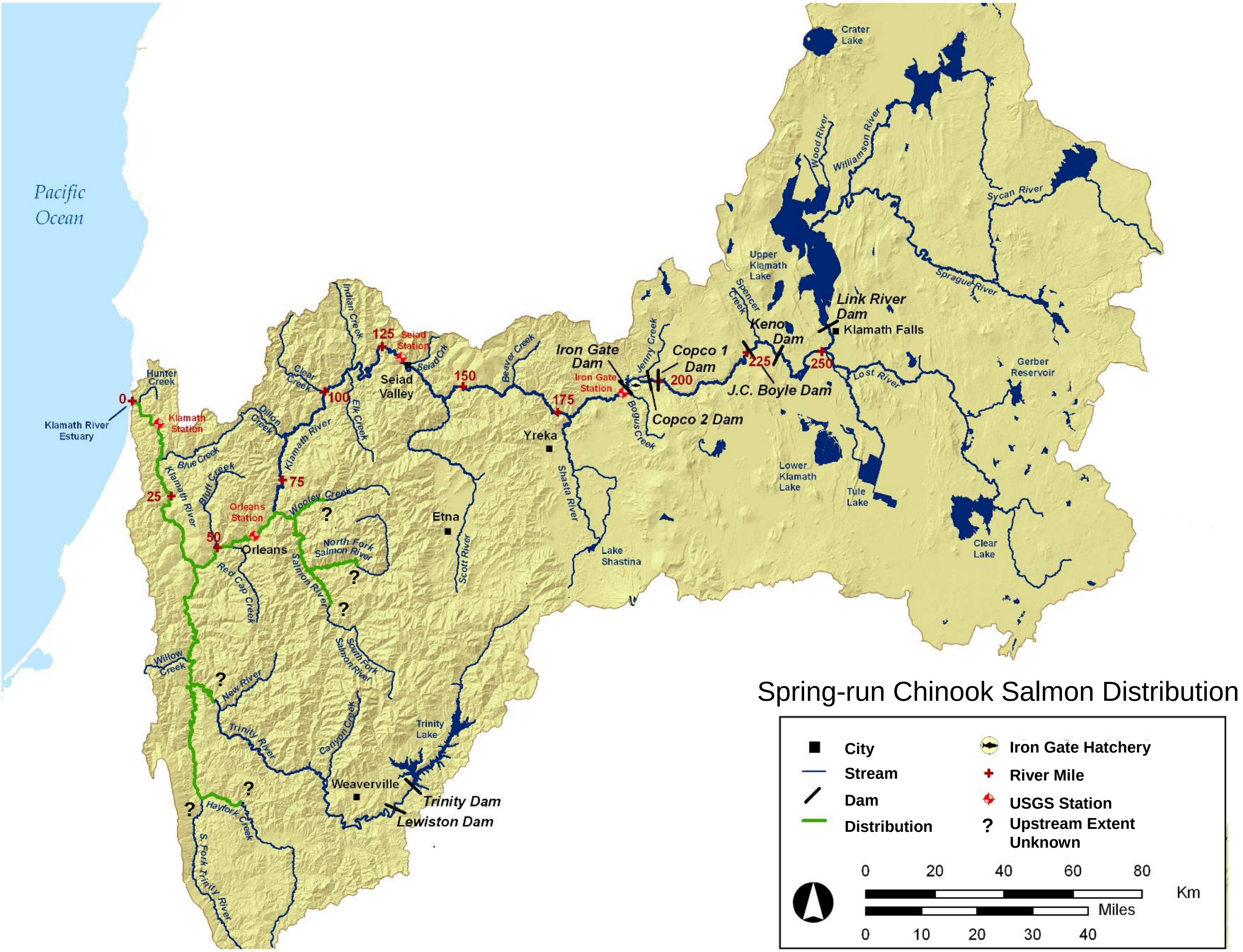

Figure 19. Spring-run Chinook salmon distribution in the Klamath River basin.

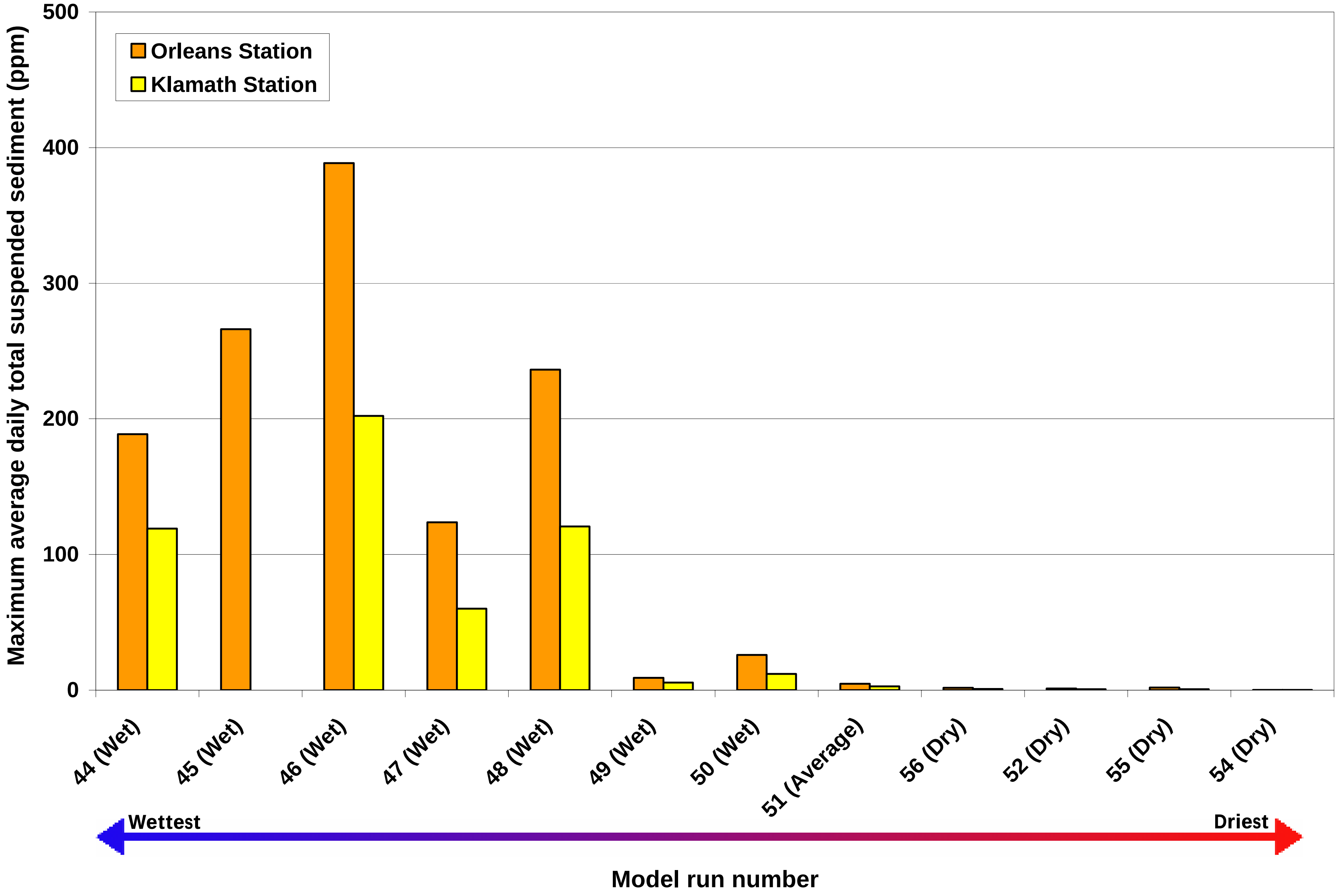

Figure 20. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 March through 30 June (the period of adult spring-run Chinook salmon upstream migration).

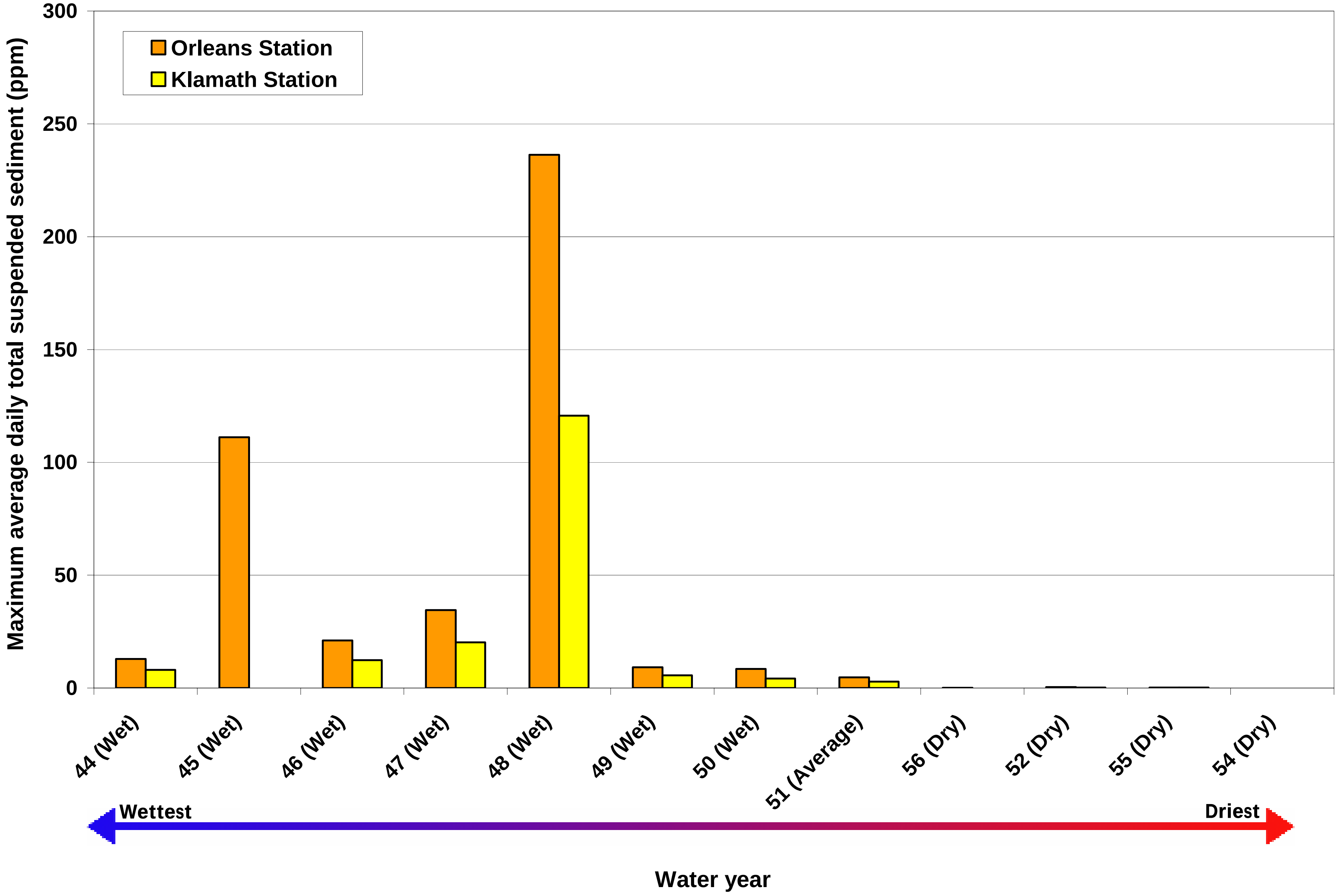

Figure 21. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 April through 31 May (the period of Type I spring-run Chinook salmon juvenile outmigration).

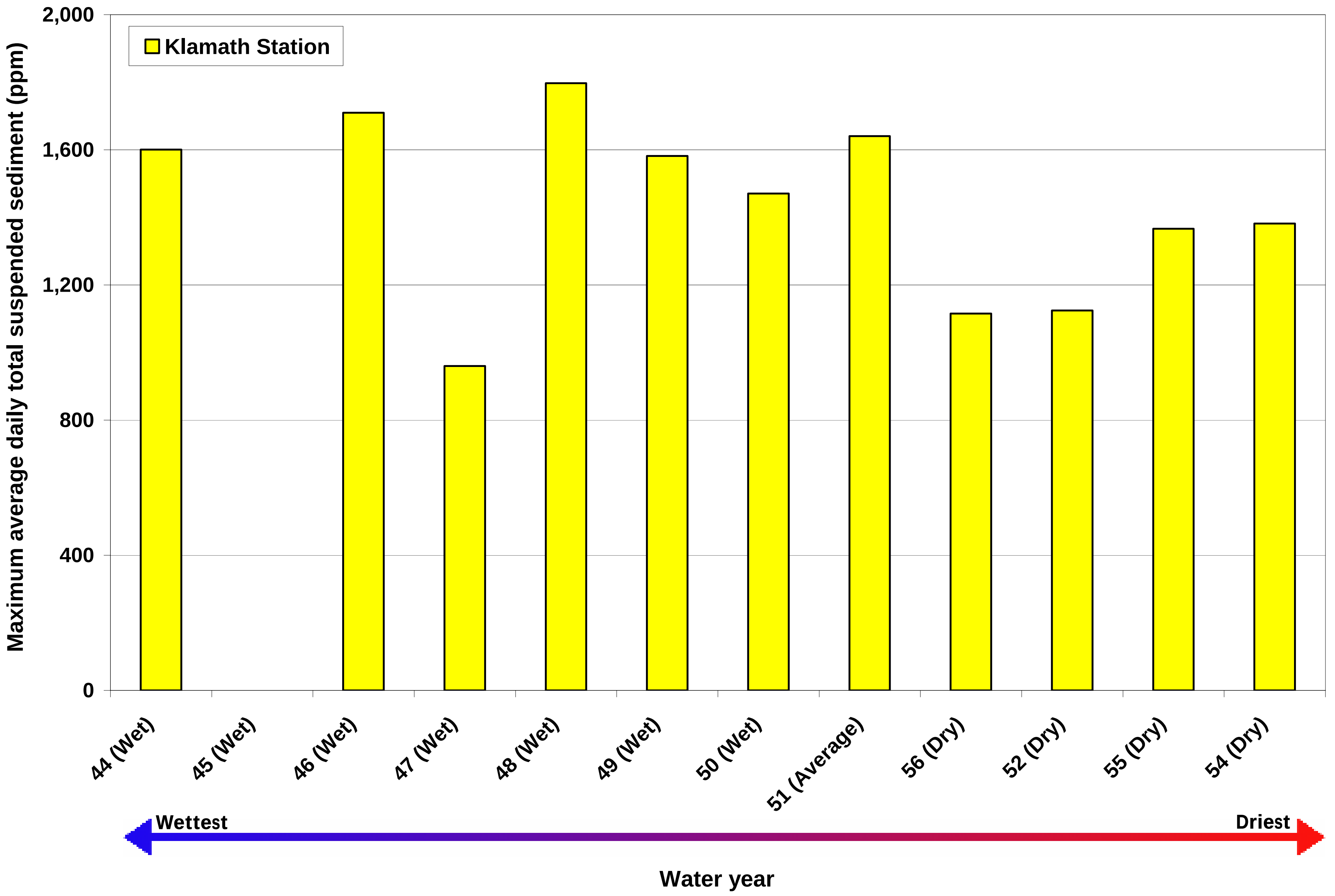

Figure 22. Maximum average daily total suspended sediment by water year type in the Klamath River at Klamath station based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 October through 15 November (the period of Type II spring-run Chinook salmon juvenile outmigration assuming that all juveniles are in the lower river by 6 November).

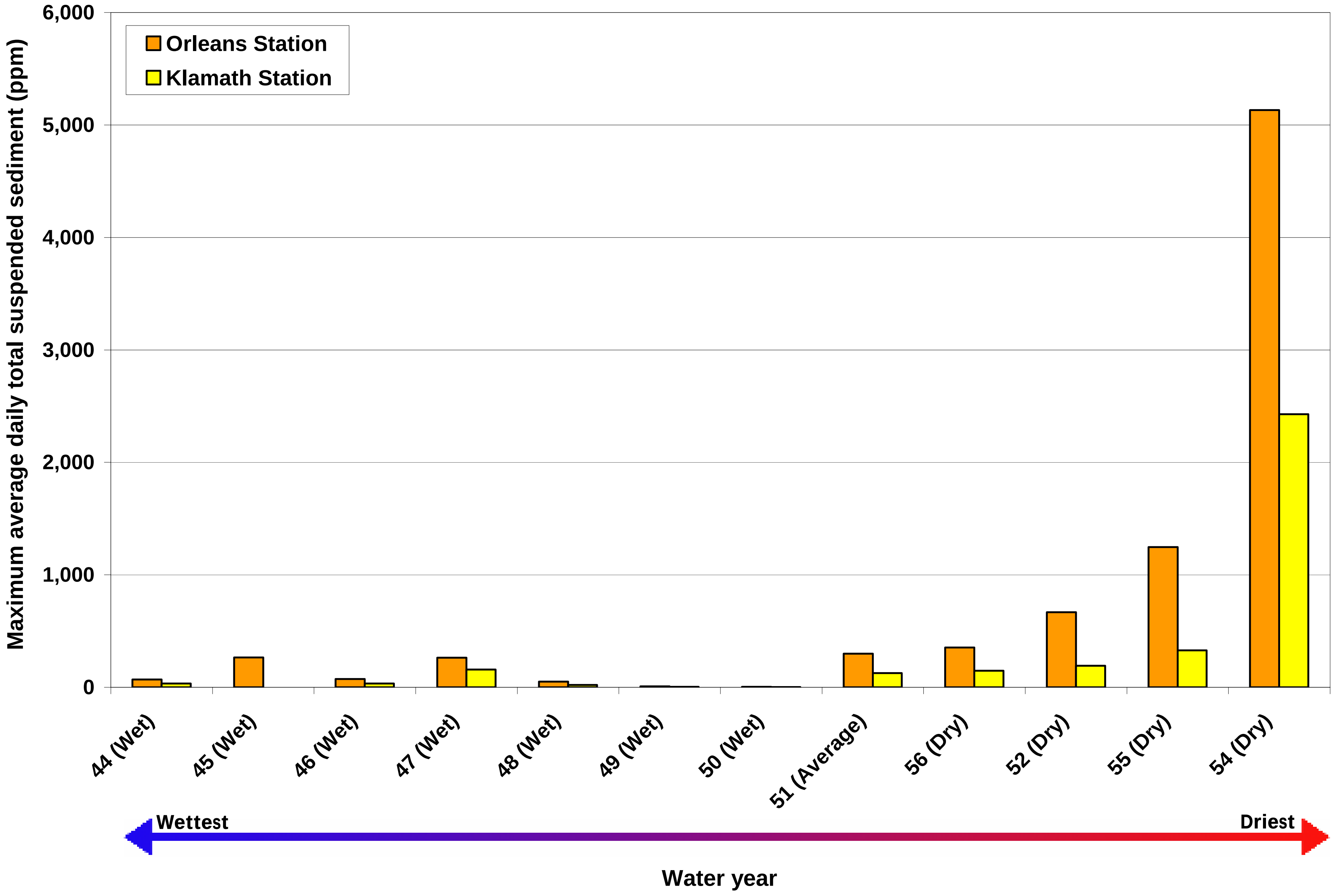

Figure 23. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 January through 31 May (the period of Type III spring-run Chinook salmon juvenile rearing and outmigration).

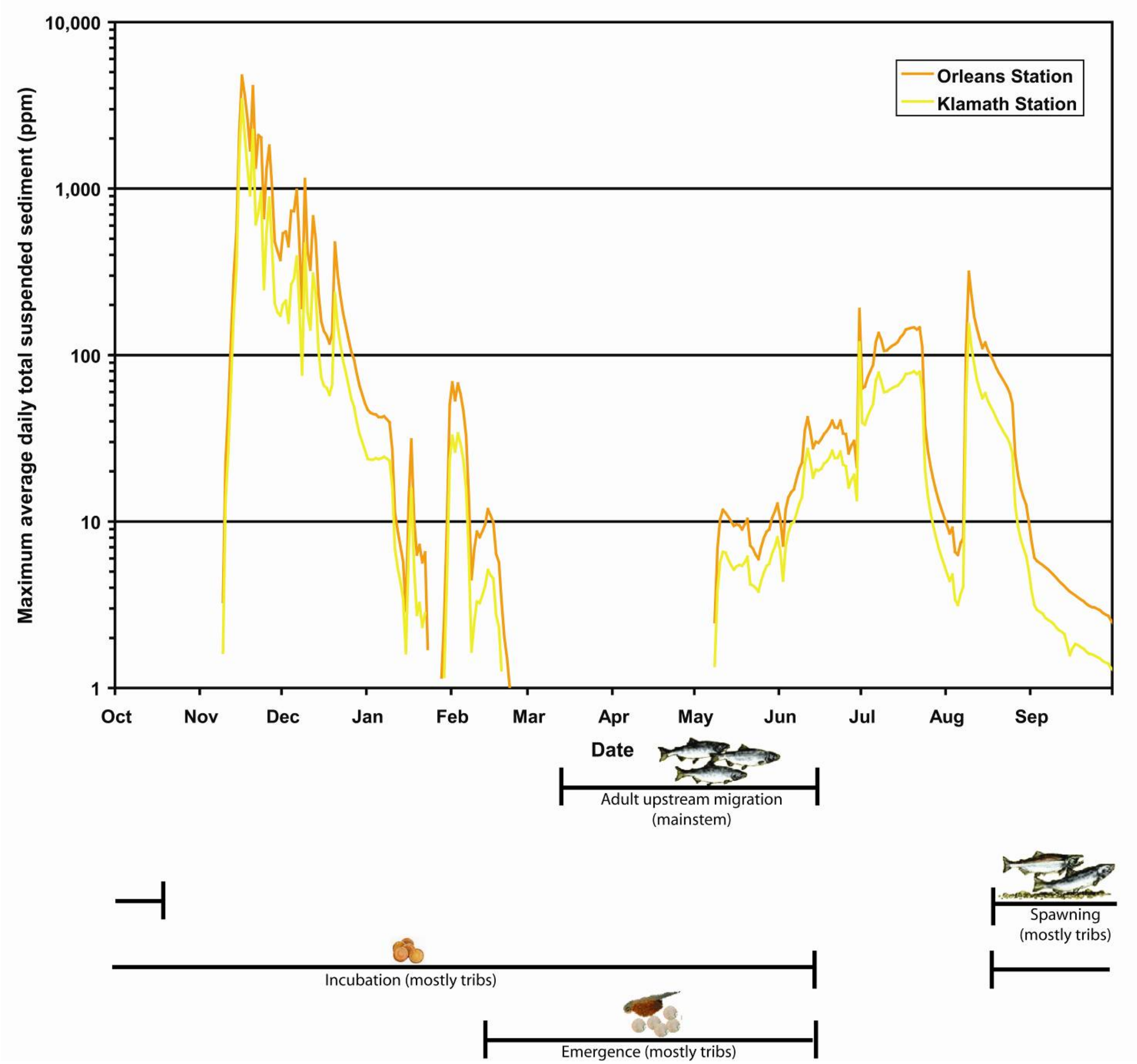

Figure 24. Average daily total suspended sediment concentrations in the Klamath River downstream of Orleans based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with spring-run Chinook salmon adult upstream migration, spawning, incubation, and emergence life-history timing.

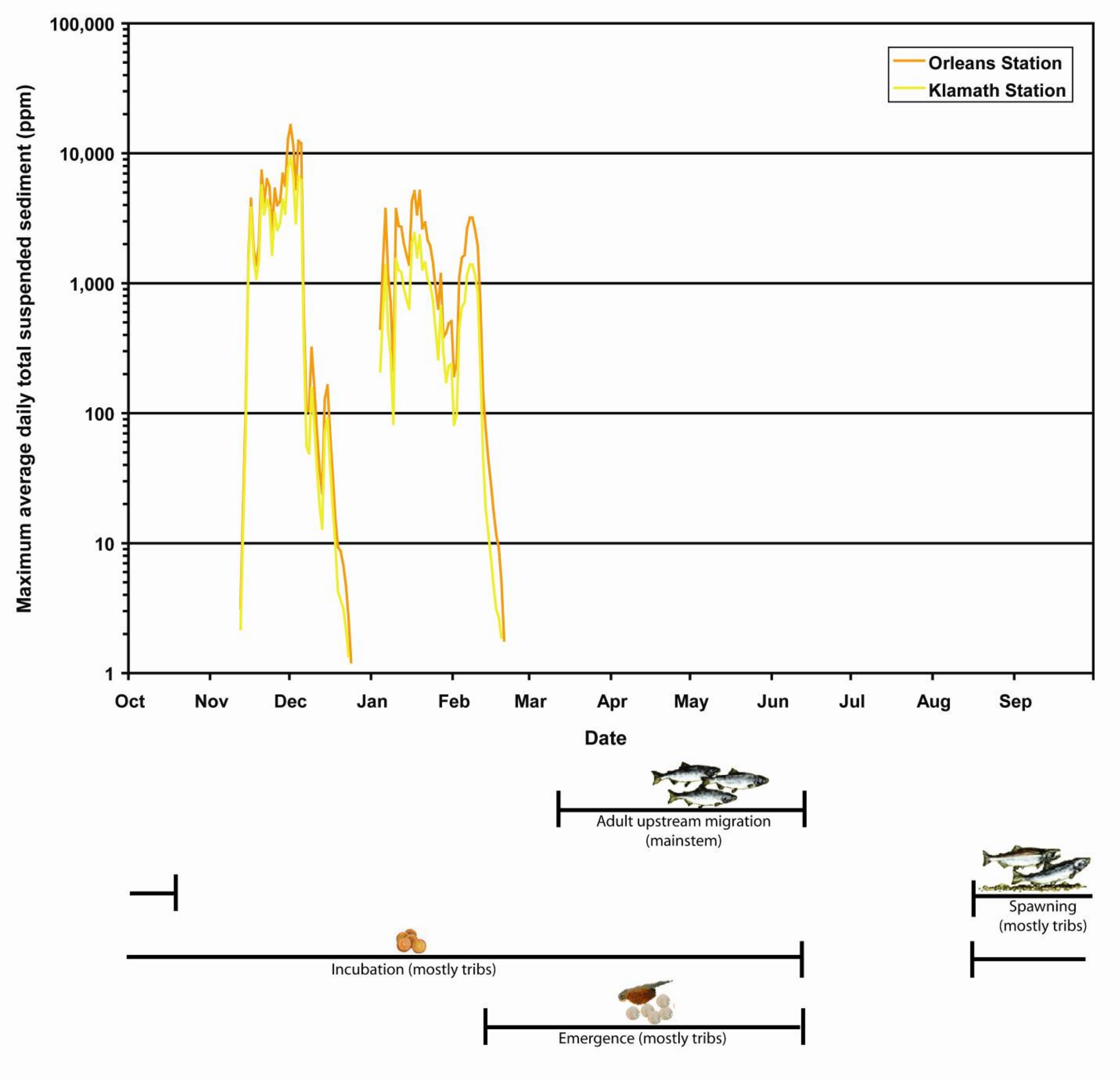

Figure 25. Average daily total suspended sediment concentrations in the Klamath River downstream of Orleans based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with spring-run Chinook salmon adult upstream migration, spawning, incubation, and emergence life-history timing.

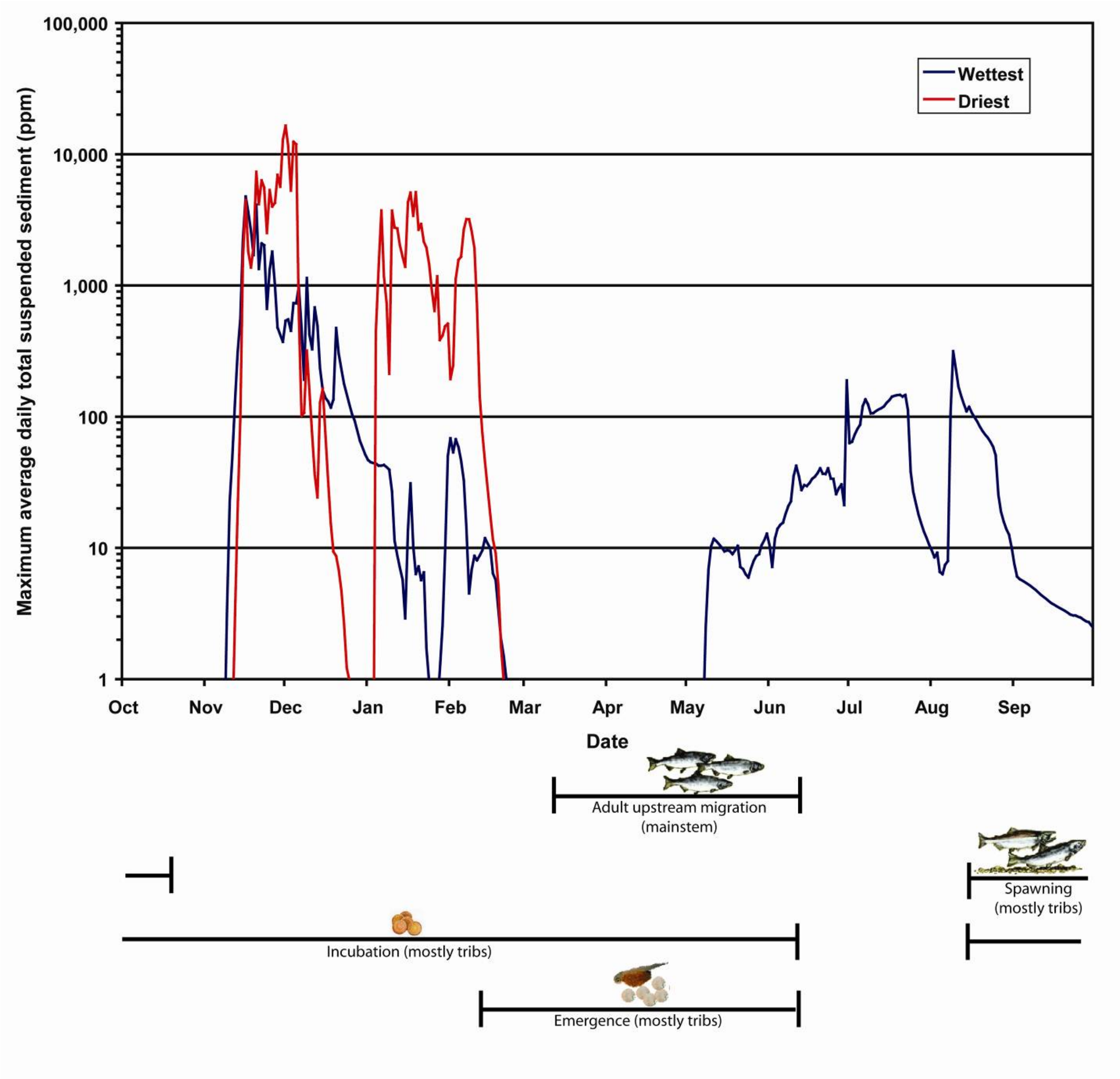

Figure 26. Average daily total suspended sediment concentrations in the Klamath River at the Orleans Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with spring-run Chinook salmon adult upstream migration, spawning, incubation, and emergence life-history timing.

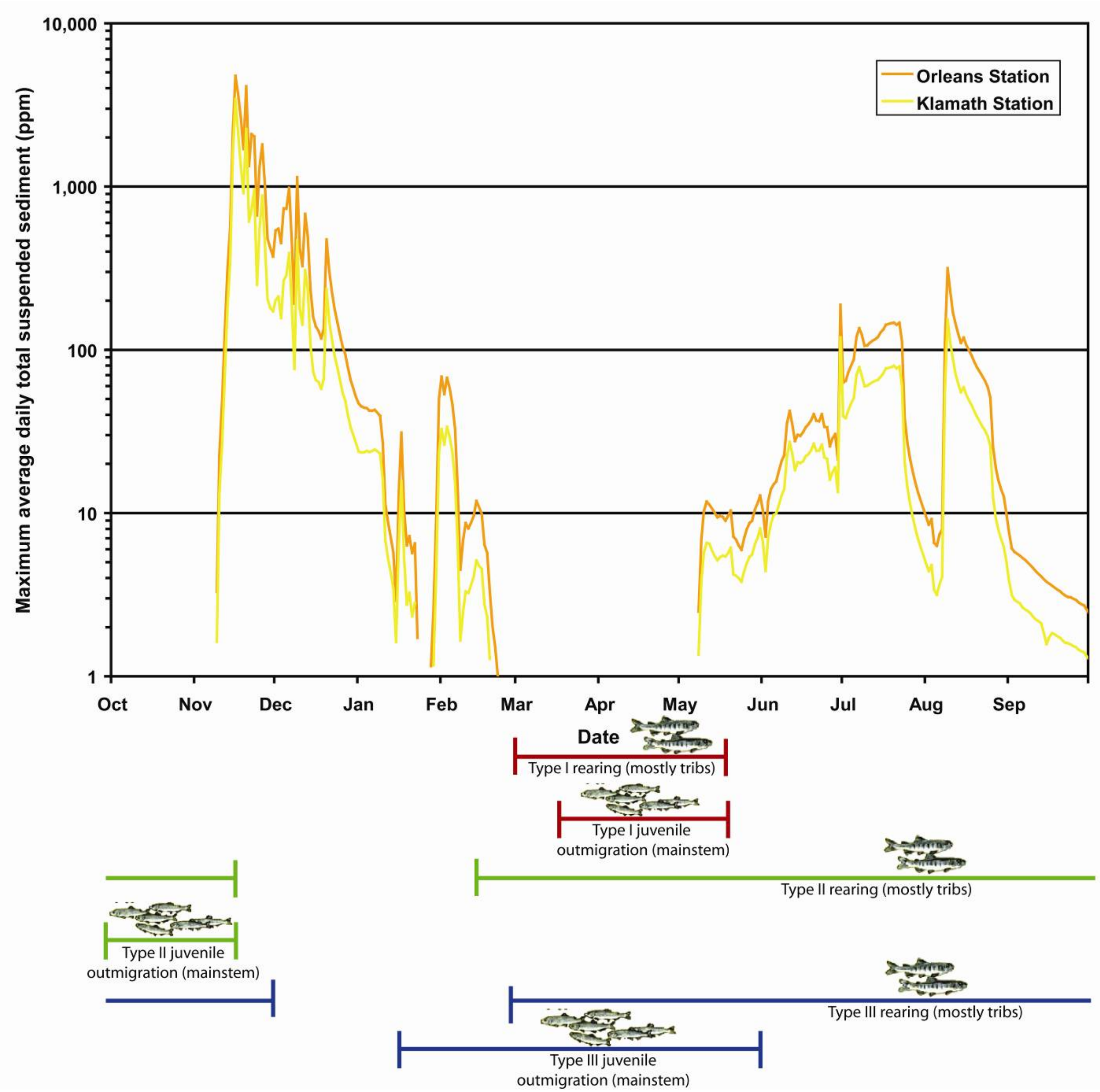

Figure 27. Average daily total suspended sediment concentrations in the Klamath River downstream of Orleans based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with spring-run Chinook salmon juvenile rearing and outmigration life-history timing.

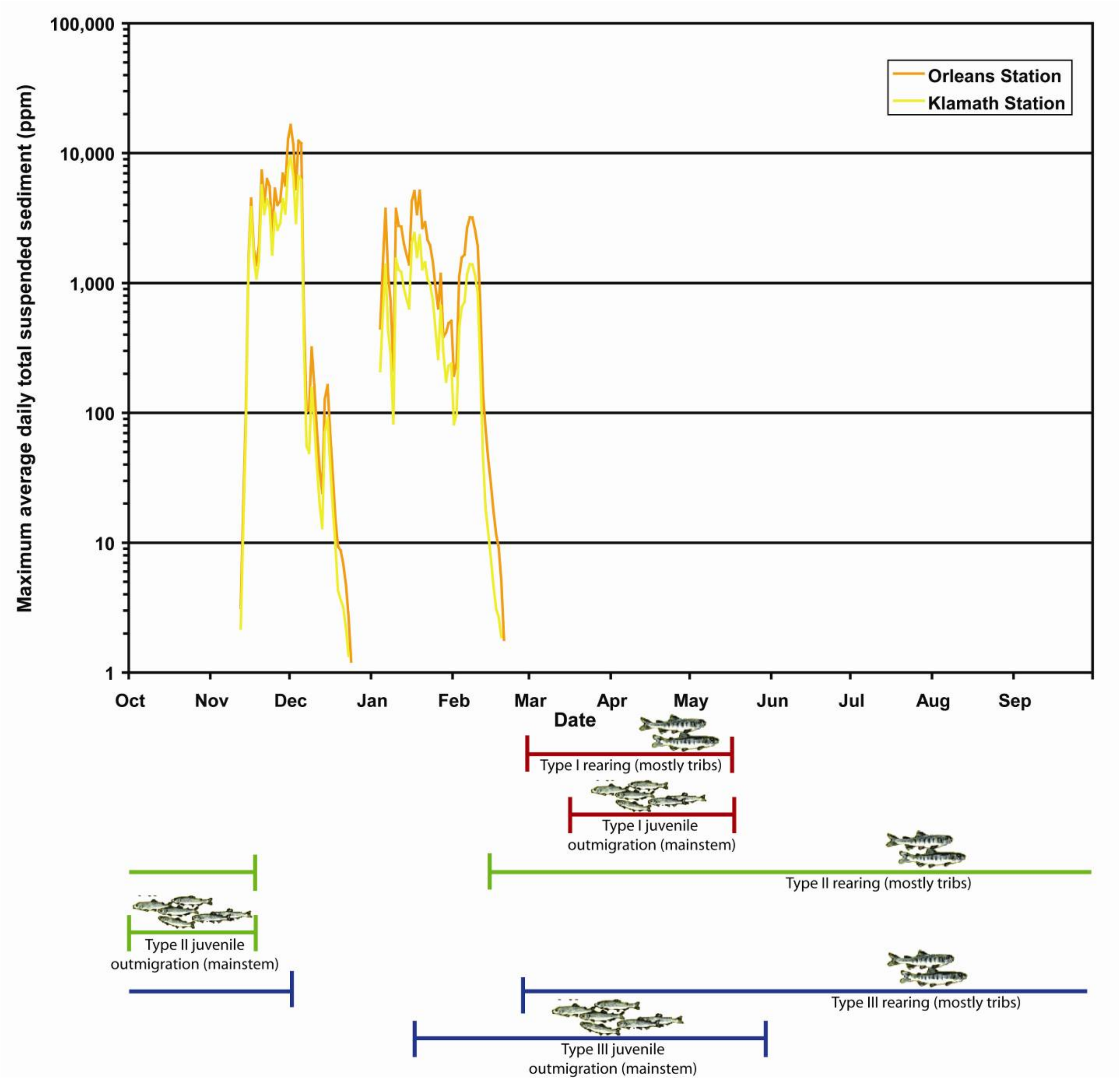

Figure 28. Average daily total suspended sediment concentrations in the Klamath River downstream of Orleans based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with spring-run Chinook salmon juvenile rearing and outmigration life-history timing.

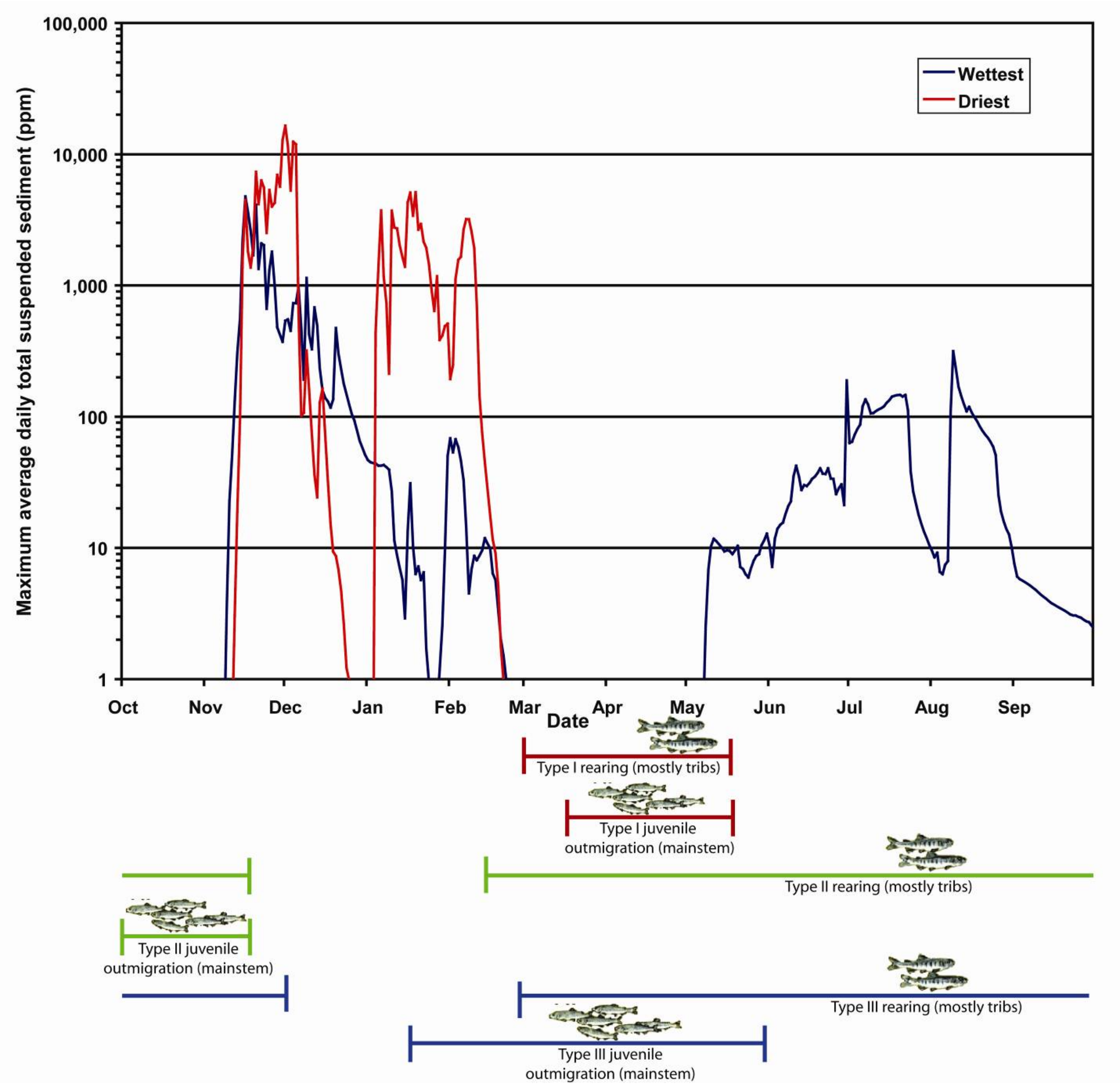

Figure 29. Average daily total suspended sediment concentrations in the Klamath River at the Orleans Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with spring-run Chinook salmon juvenile rearing and outmigration life-history timing.

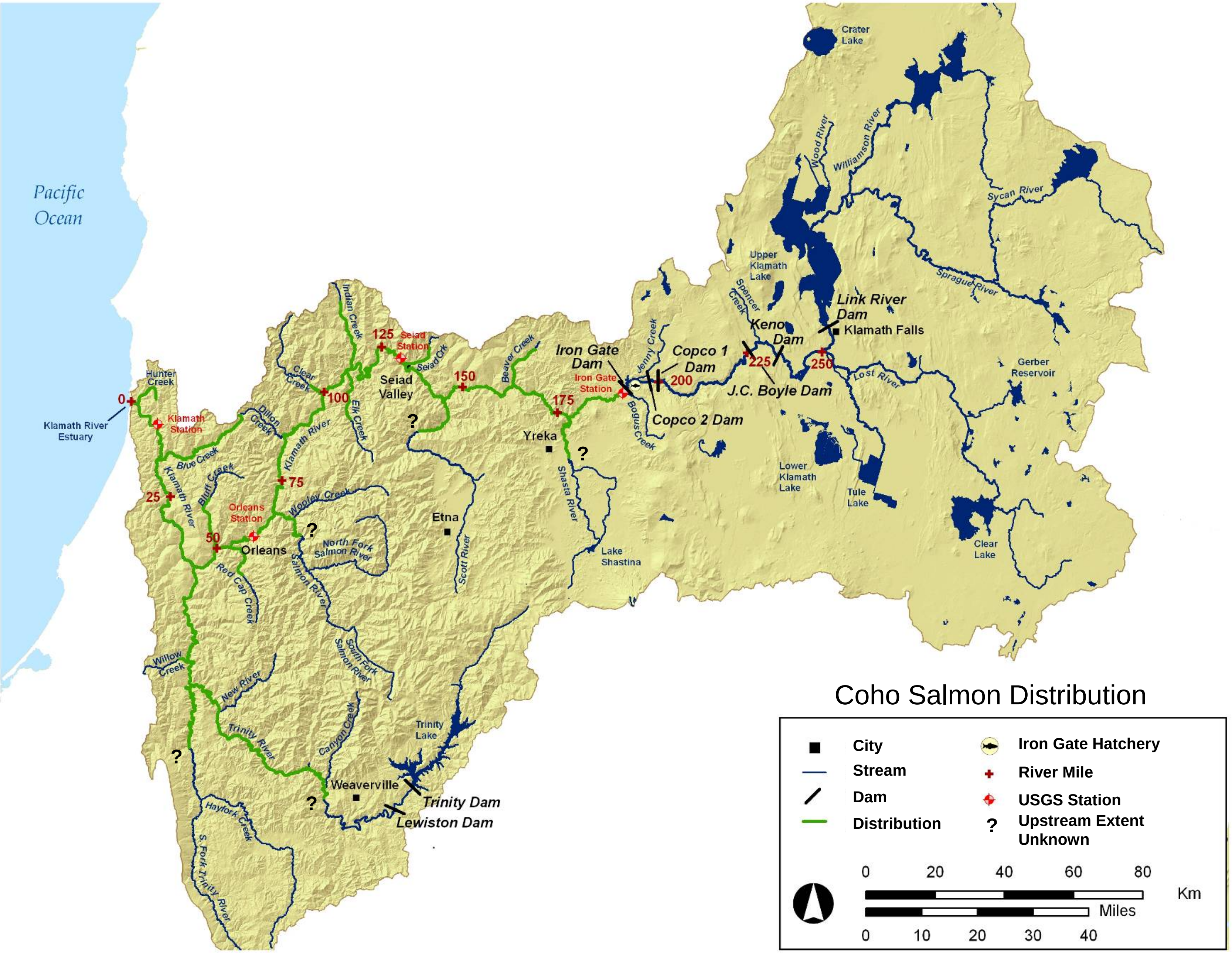

Figure 30. Coho salmon distribution in the Klamath River basin. Coho are also distributed in numerous other small tributaries downstream of Iron Gate Dam.

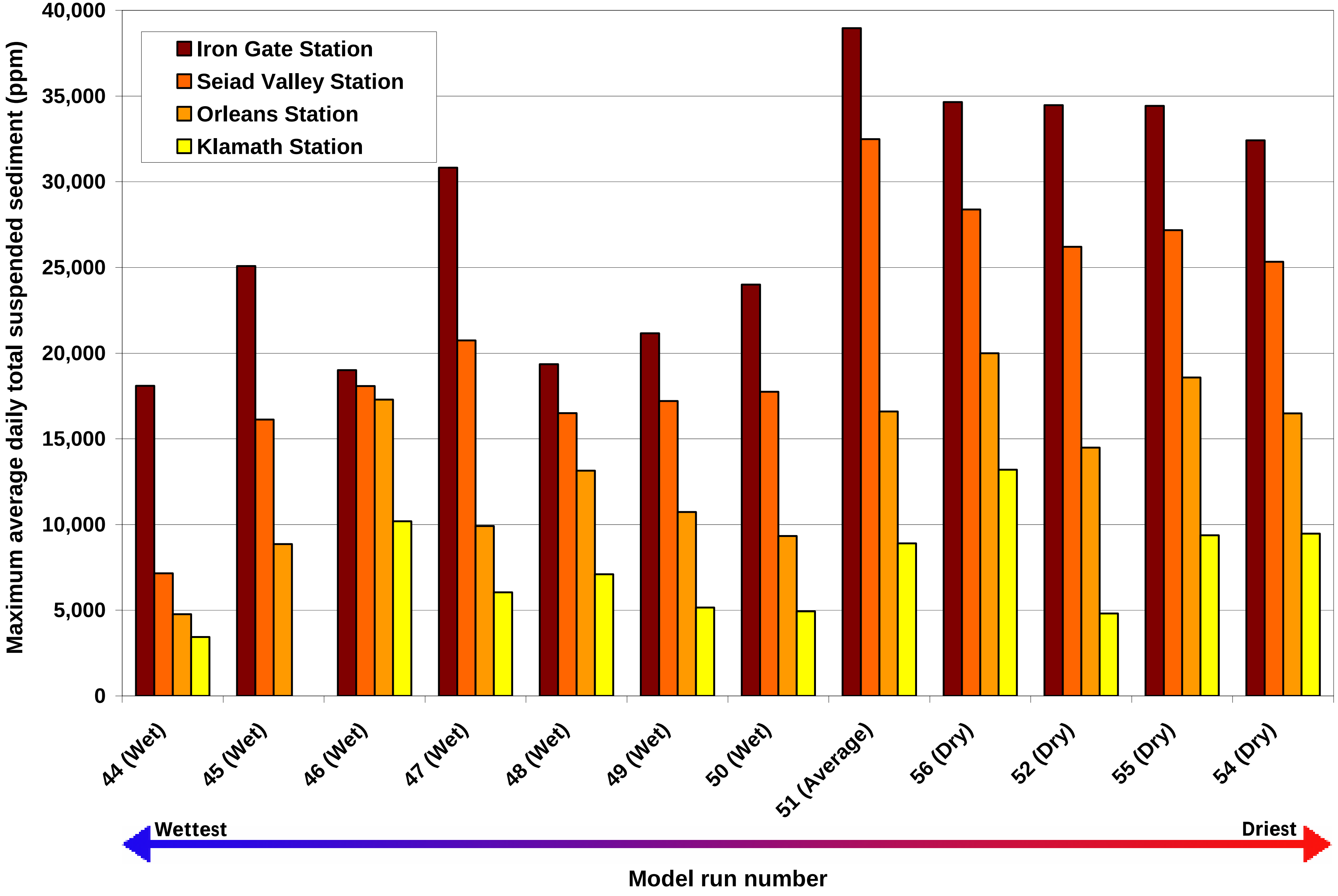

Figure 31. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 September through 31 January (the period of adult coho salmon upstream migration and spawning).

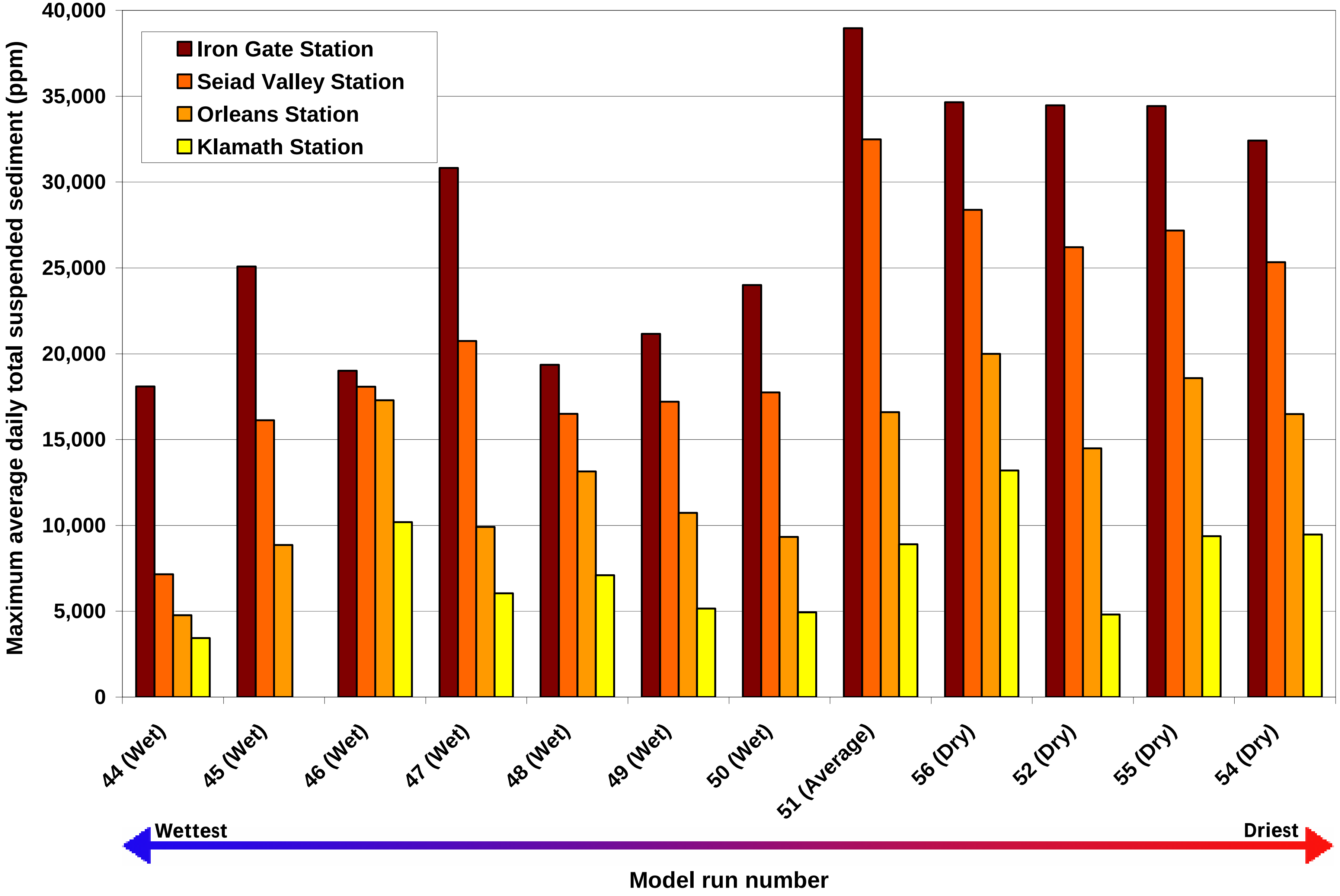

Figure 32. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 November through 21 March (the period of coho salmon winter rearing).

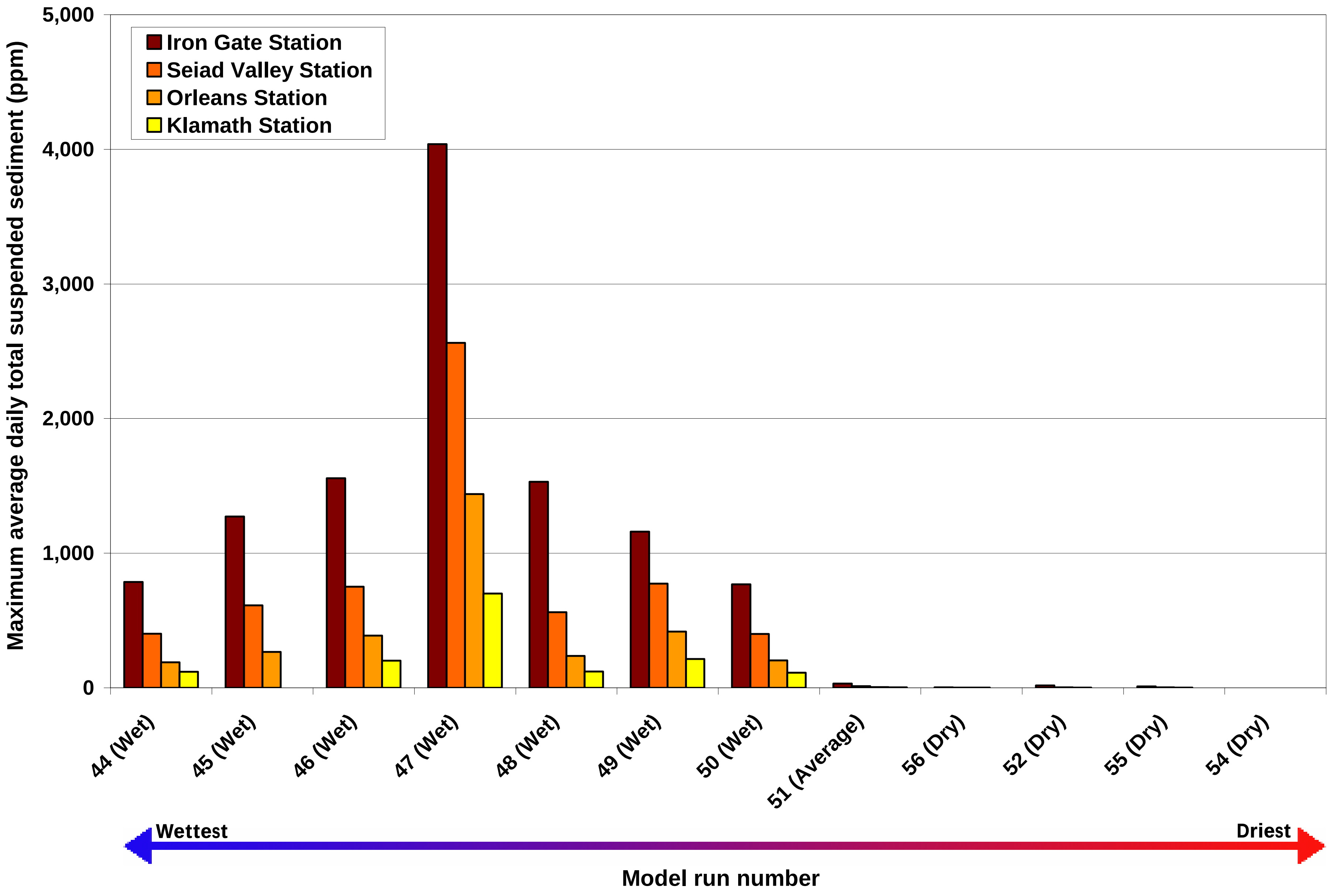

Figure 33. **Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 22 March through 31 July (the period of coho salmon summer rearing).**

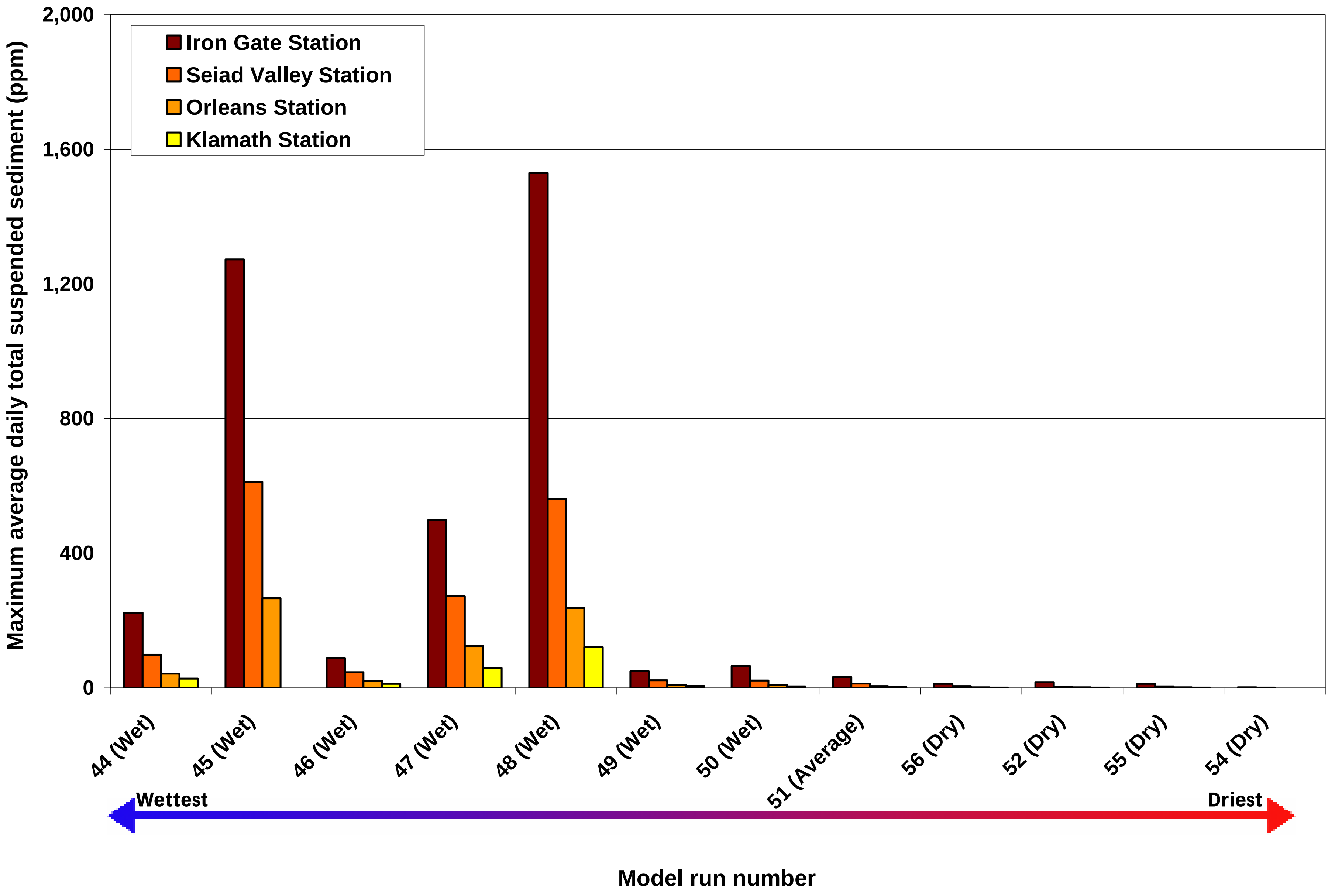

Figure 34. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of the Scott River confluence based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 February through 15 June (the period of coho salmon juvenile outmigration).

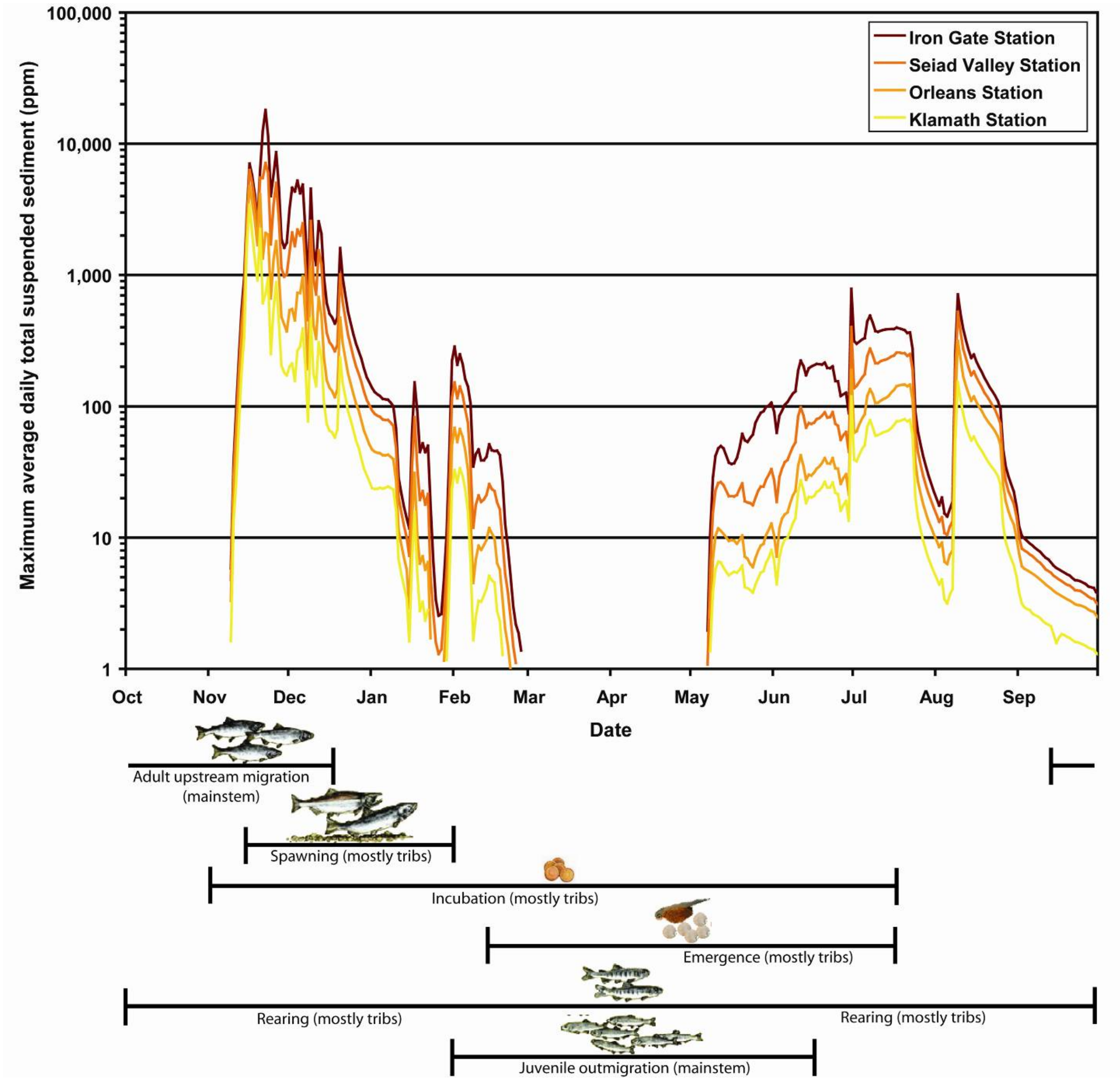

Figure 35. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with life-history timing for coho salmon.

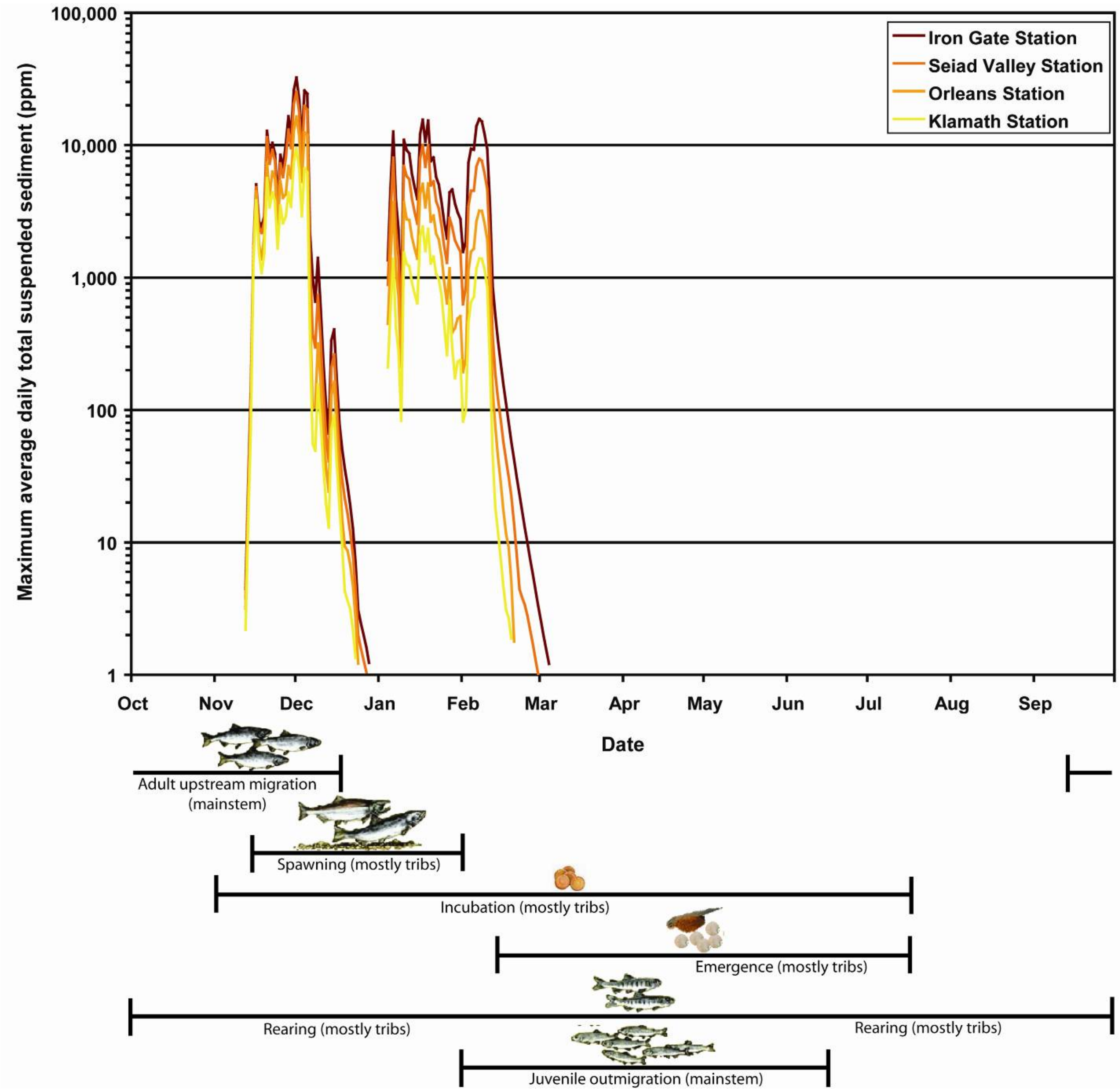

Figure 36. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with life-history timing for coho salmon.

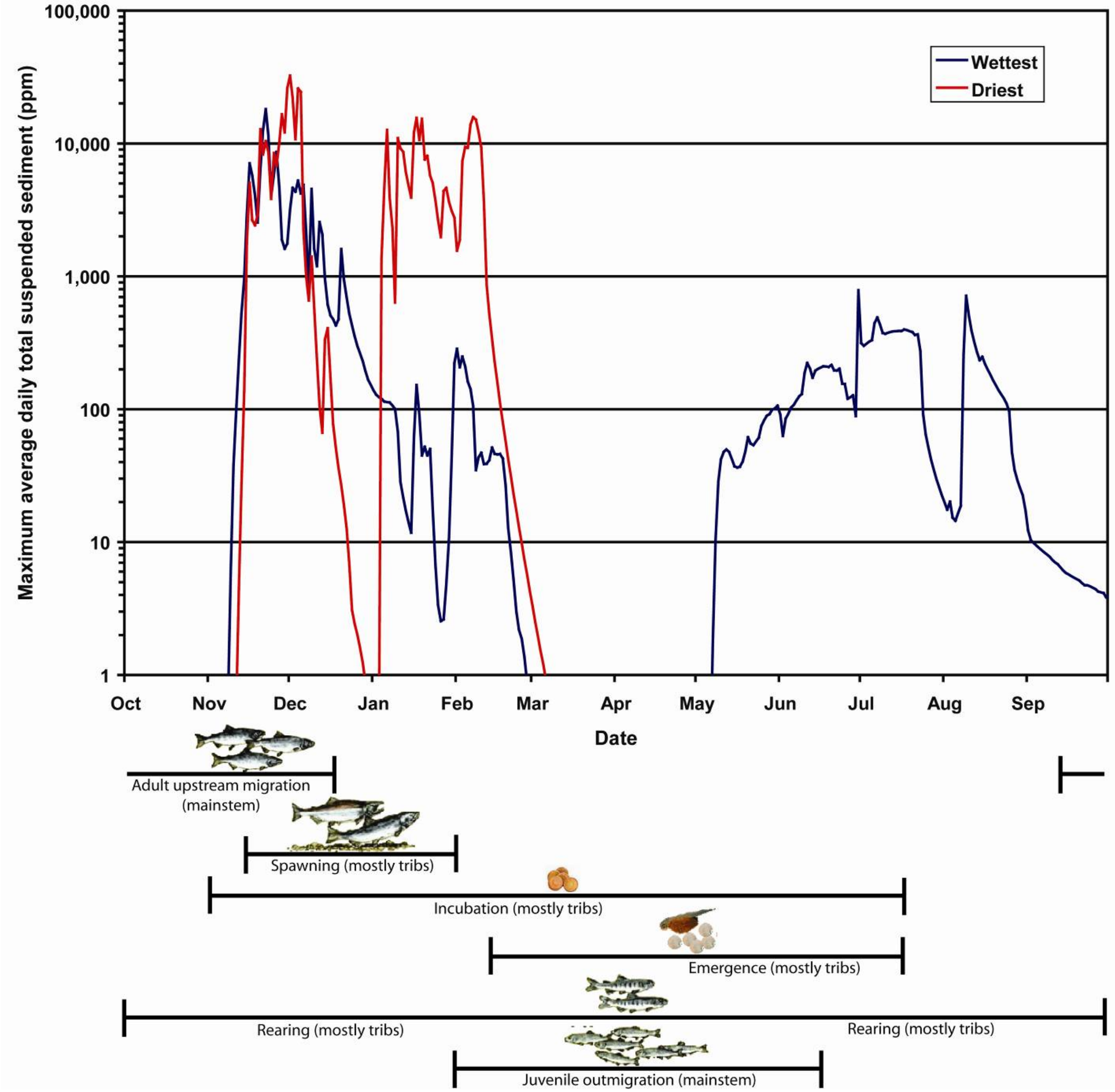

Figure 37. Average daily total suspended sediment concentrations in the Klamath River at the Iron Gate Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with life-history timing for coho salmon.

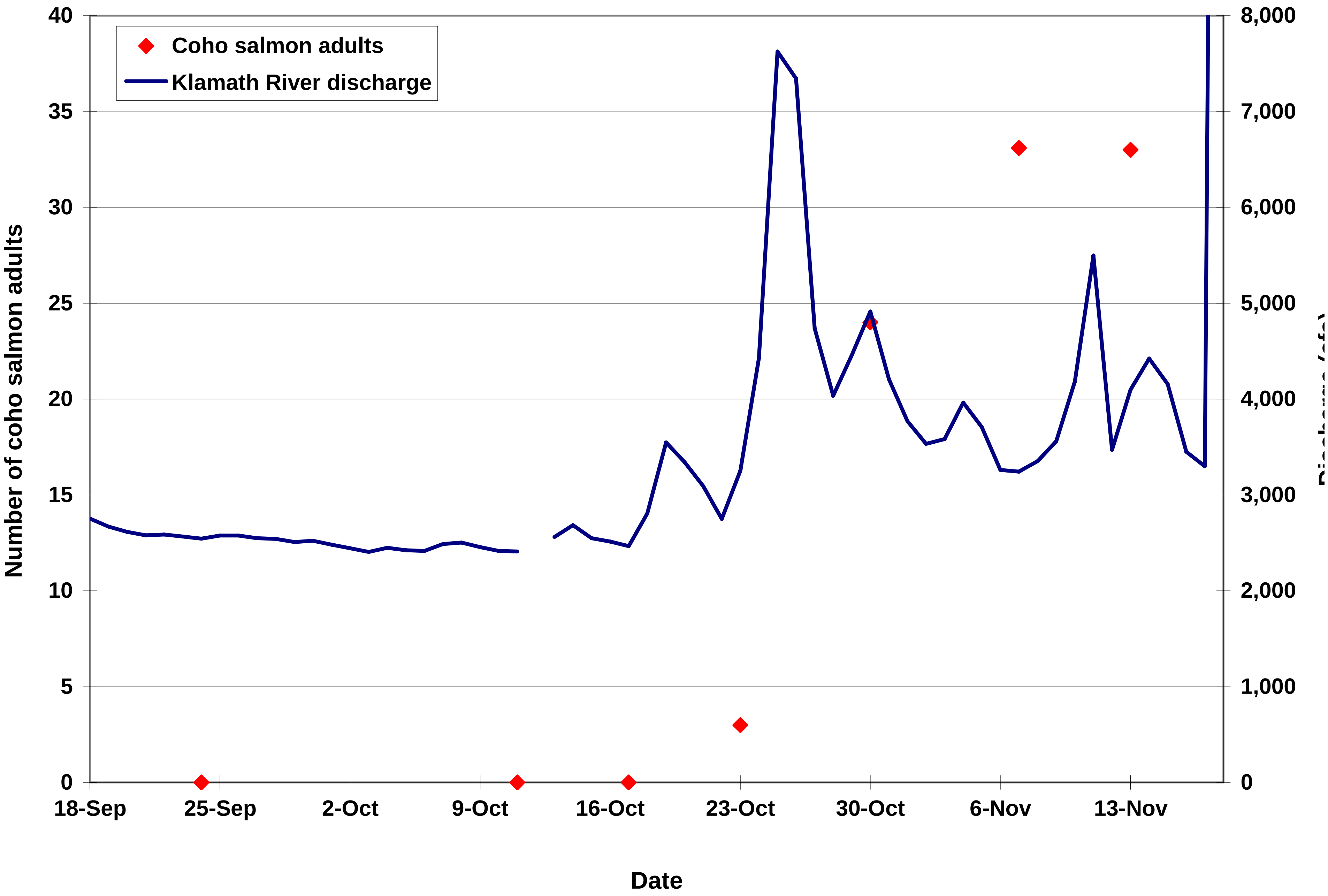

Figure 38. Number of coho salmon adults migrating upstream in Blue Creek as reported by Gale et al. (1998) in relation to average daily discharge at the California Department of Water Resources Klamath River near Klamath (Turwar Creek) station for the period 18 September through 18 November 1996.

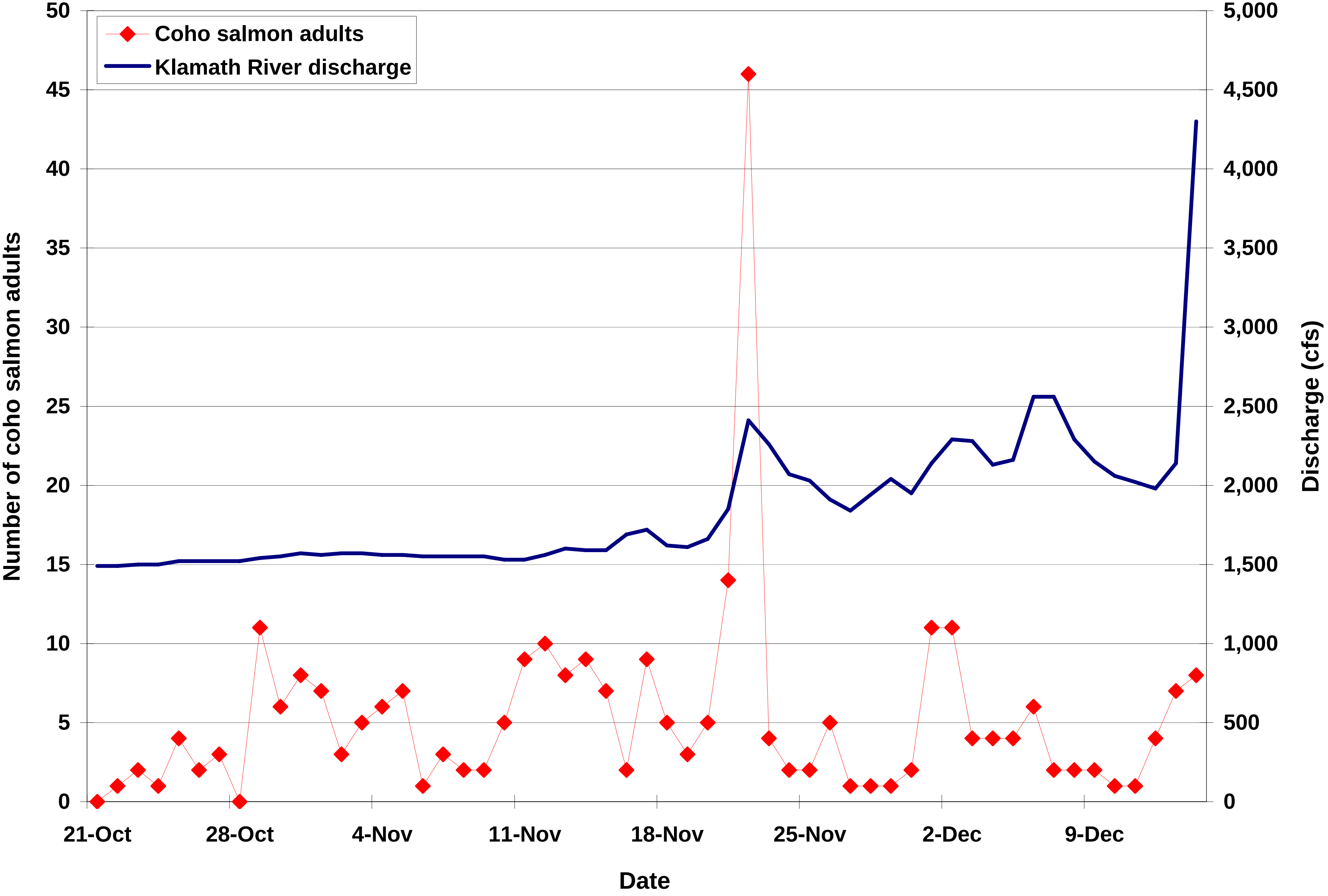

Figure 39. Number of coho salmon adults migrating upstream in the Shasta River as reported by Hampton et al. (2002, as cited in Ackerman et al. 2006) in relation to average daily discharge in the Klamath River at Seiad station for the period 21 October through 14 December 2001.

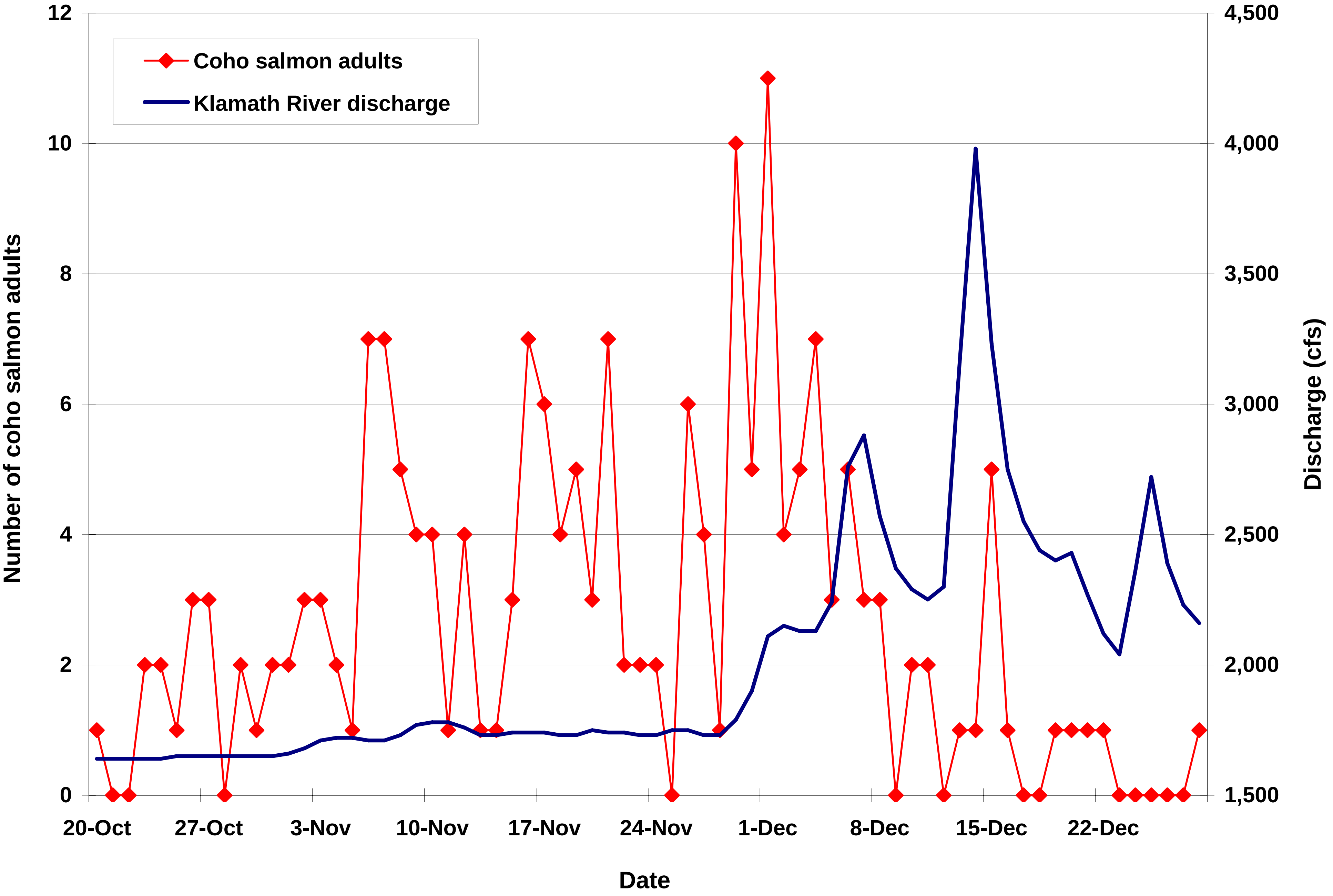

Figure 40. Number of coho salmon adults migrating upstream in the Shasta River as reported by Hampton et al. (2005, as cited in Ackerman et al. 2006) in relation to average daily discharge in the Klamath River at Seiad station for the period 20 October through 28 December 2003.

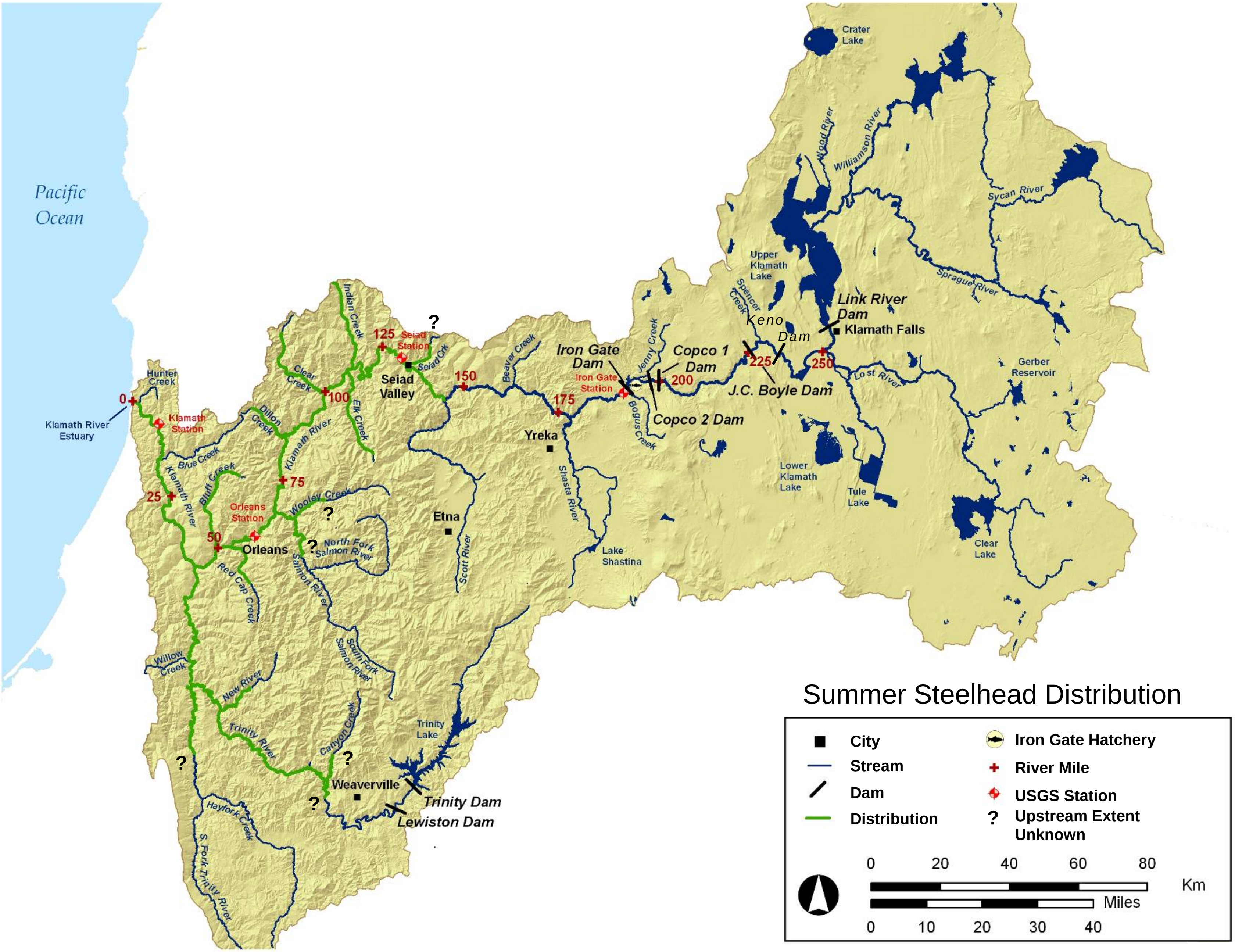

Figure 41. Summer steelhead distribution in the Klamath River basin.

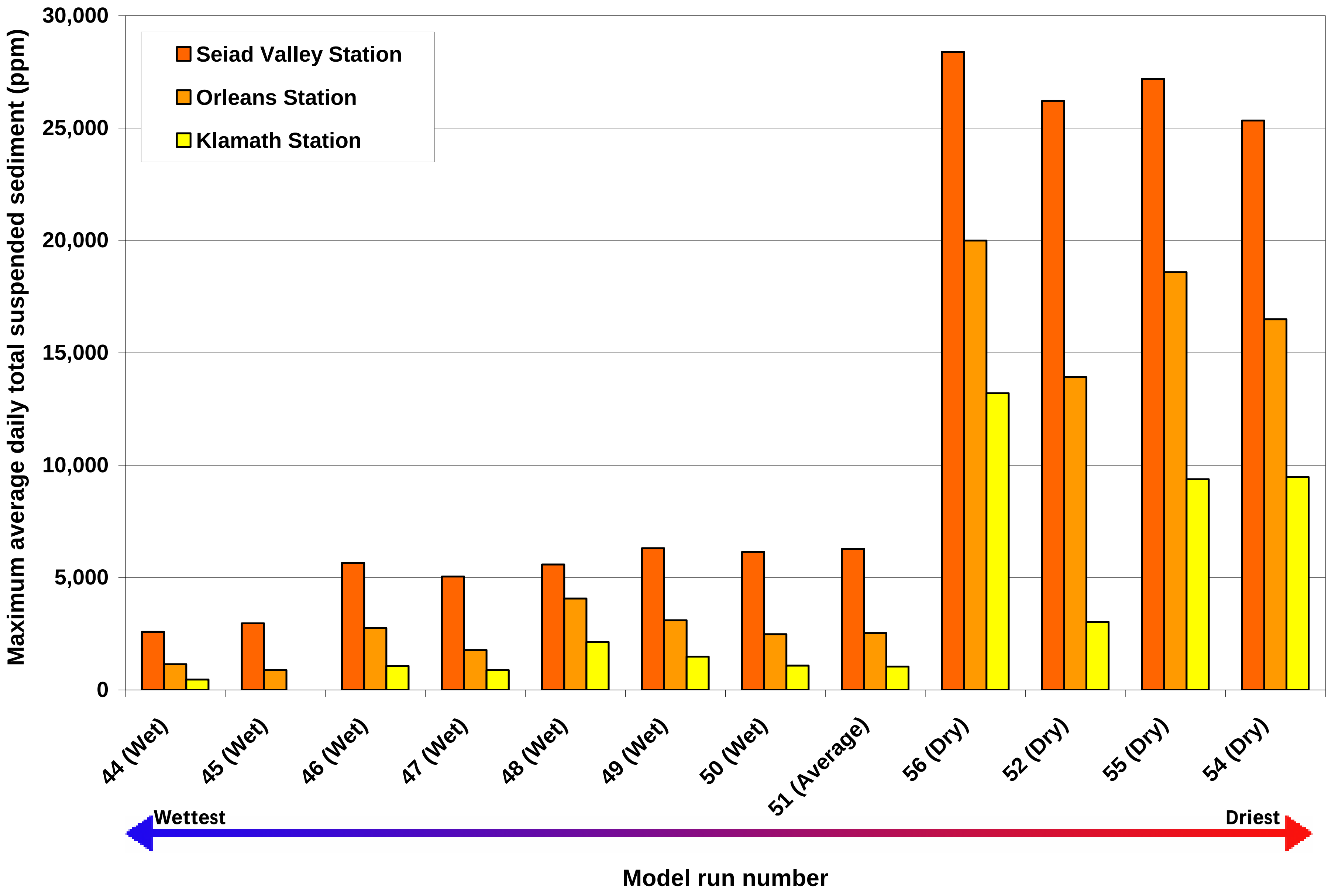

Figure 42. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 December through 28 February (the period of summer steelhead spawning).

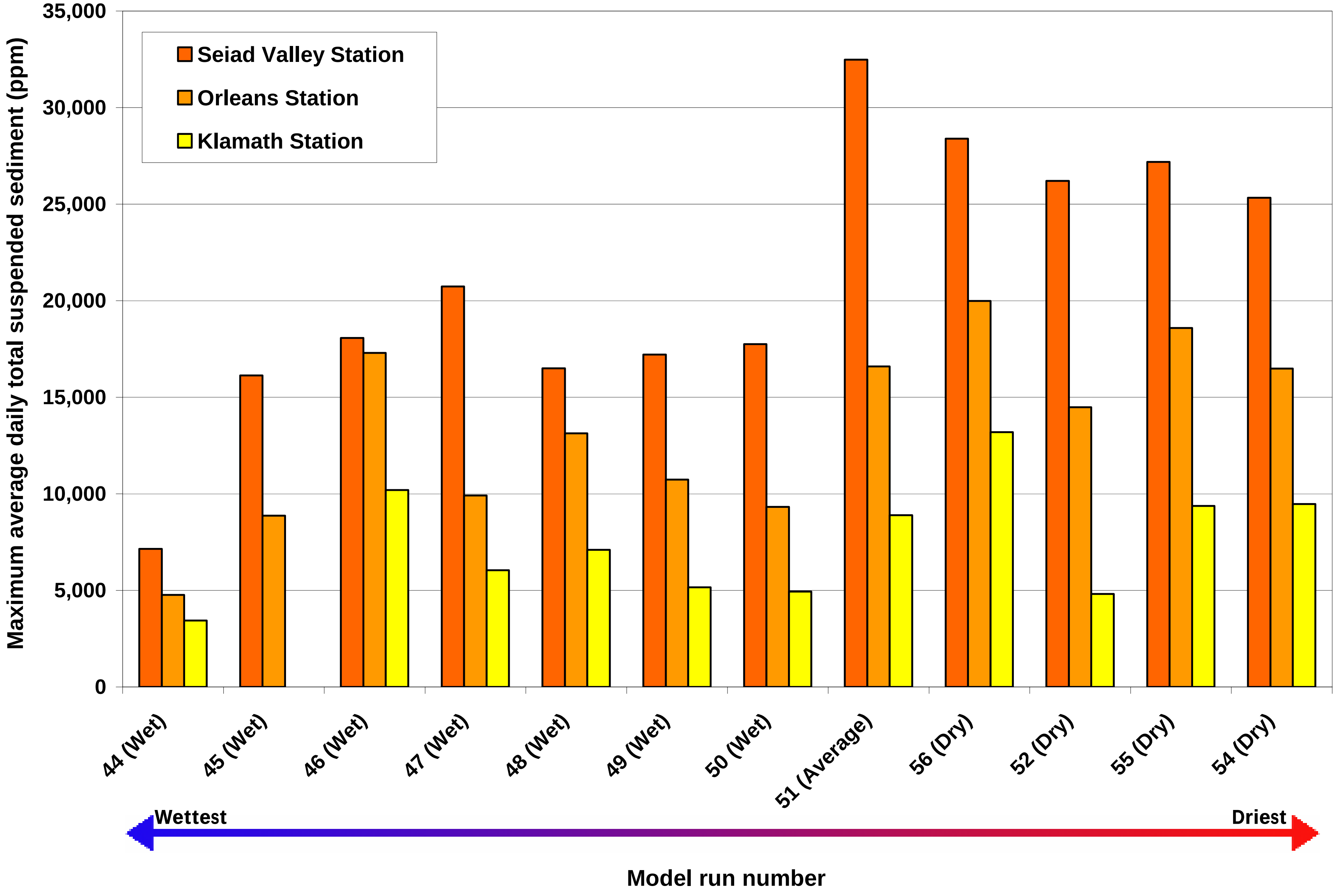

Figure 43. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 January through 31 December (the period of age-0 and 1 summer steelhead rearing.

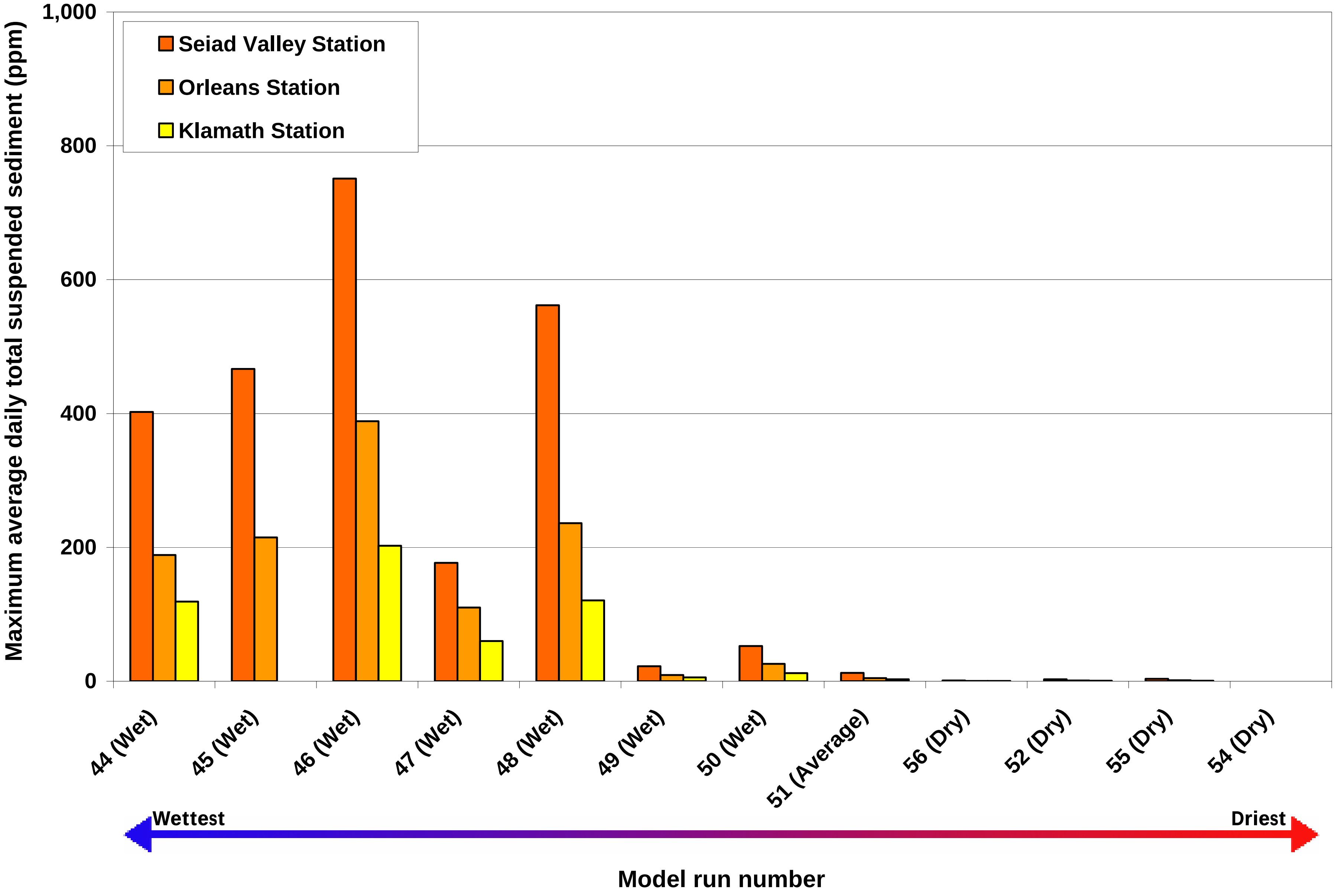

Figure 44. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 April through 30 June (the period of peak age-2 summer steelhead outmigration).

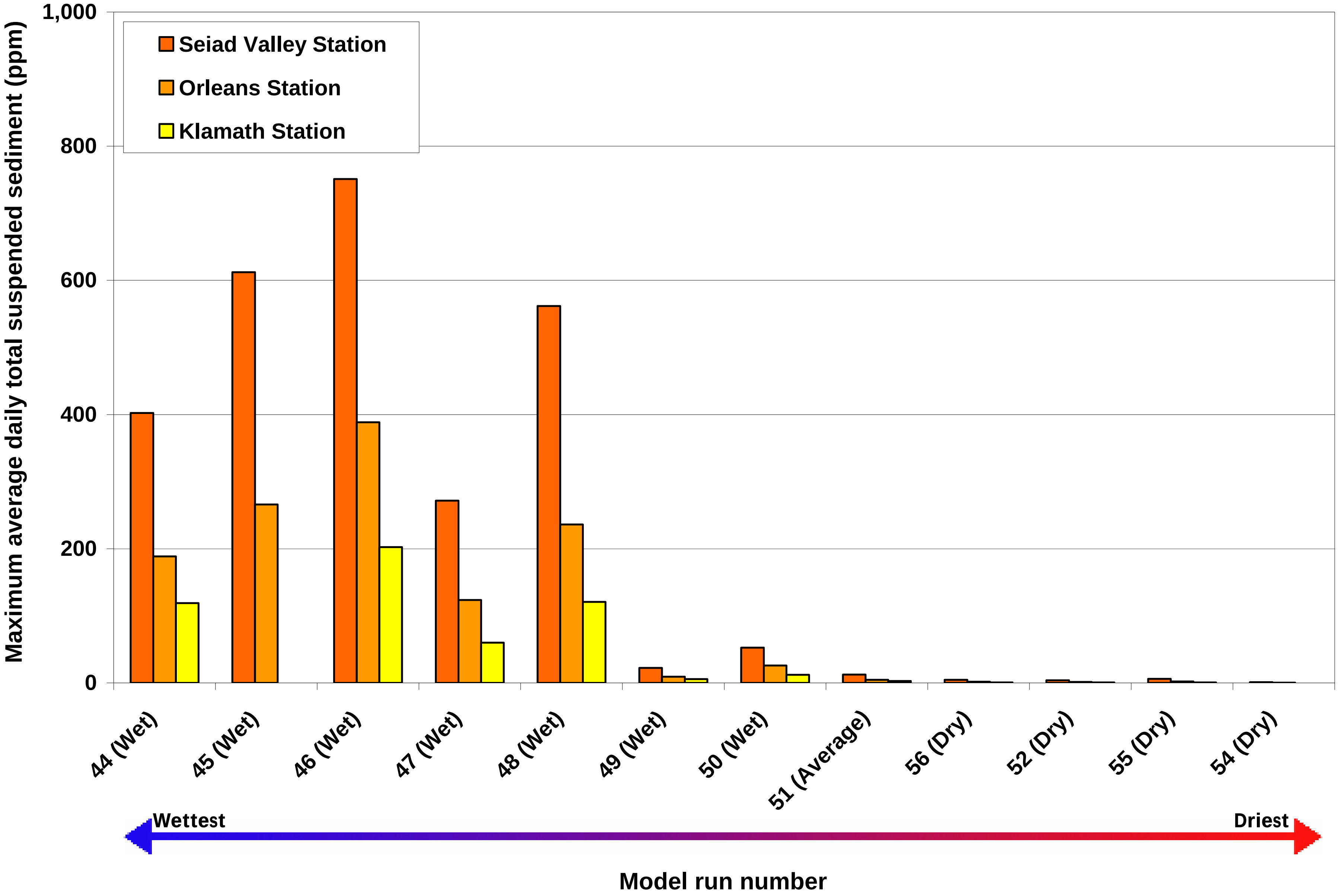

Figure 45. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 March through 30 June (the period of summer steelhead adult mainstem migration and run-backs).

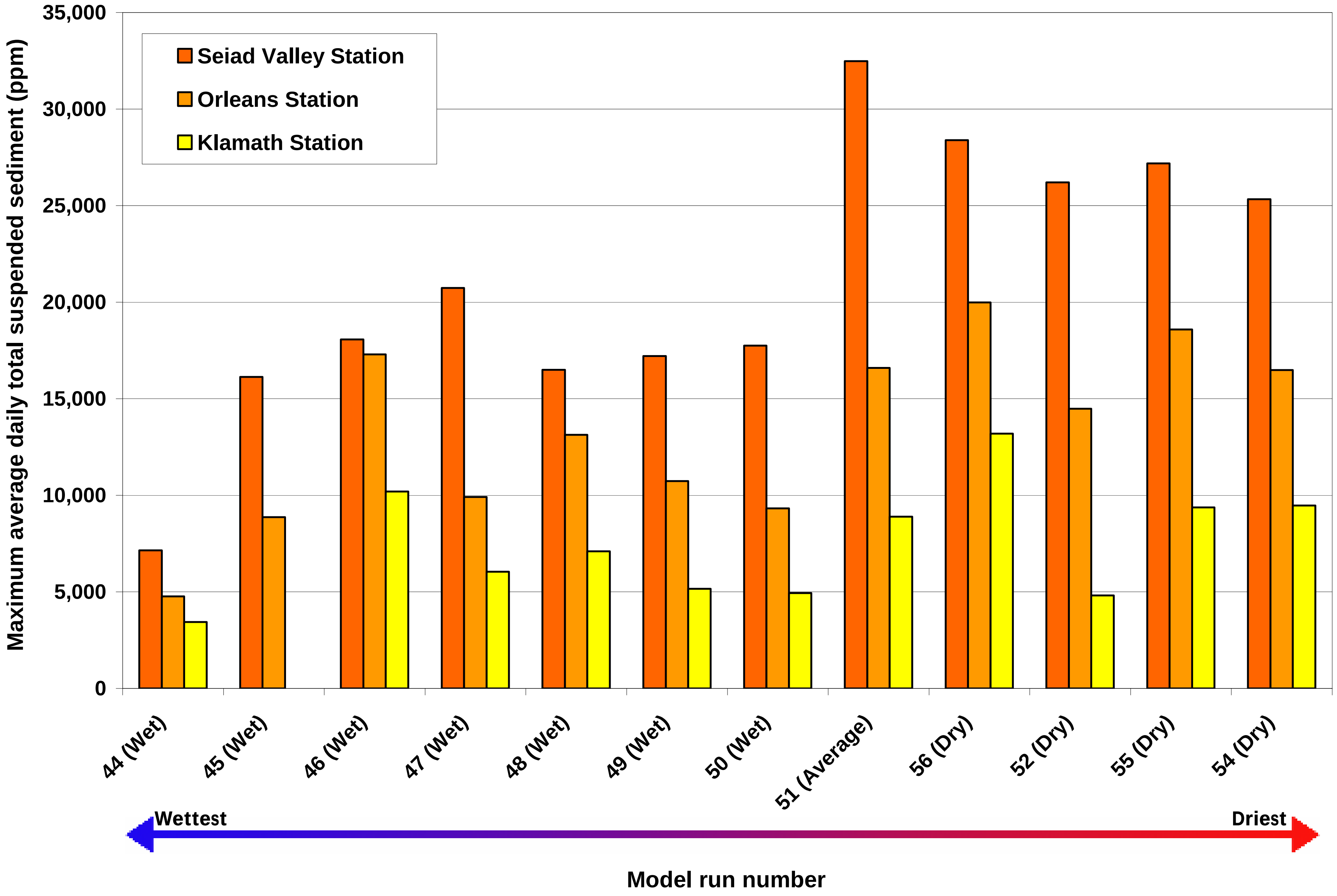

Figure 46. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 August through 31 March (the period of summer steelhead half-pounder residence.

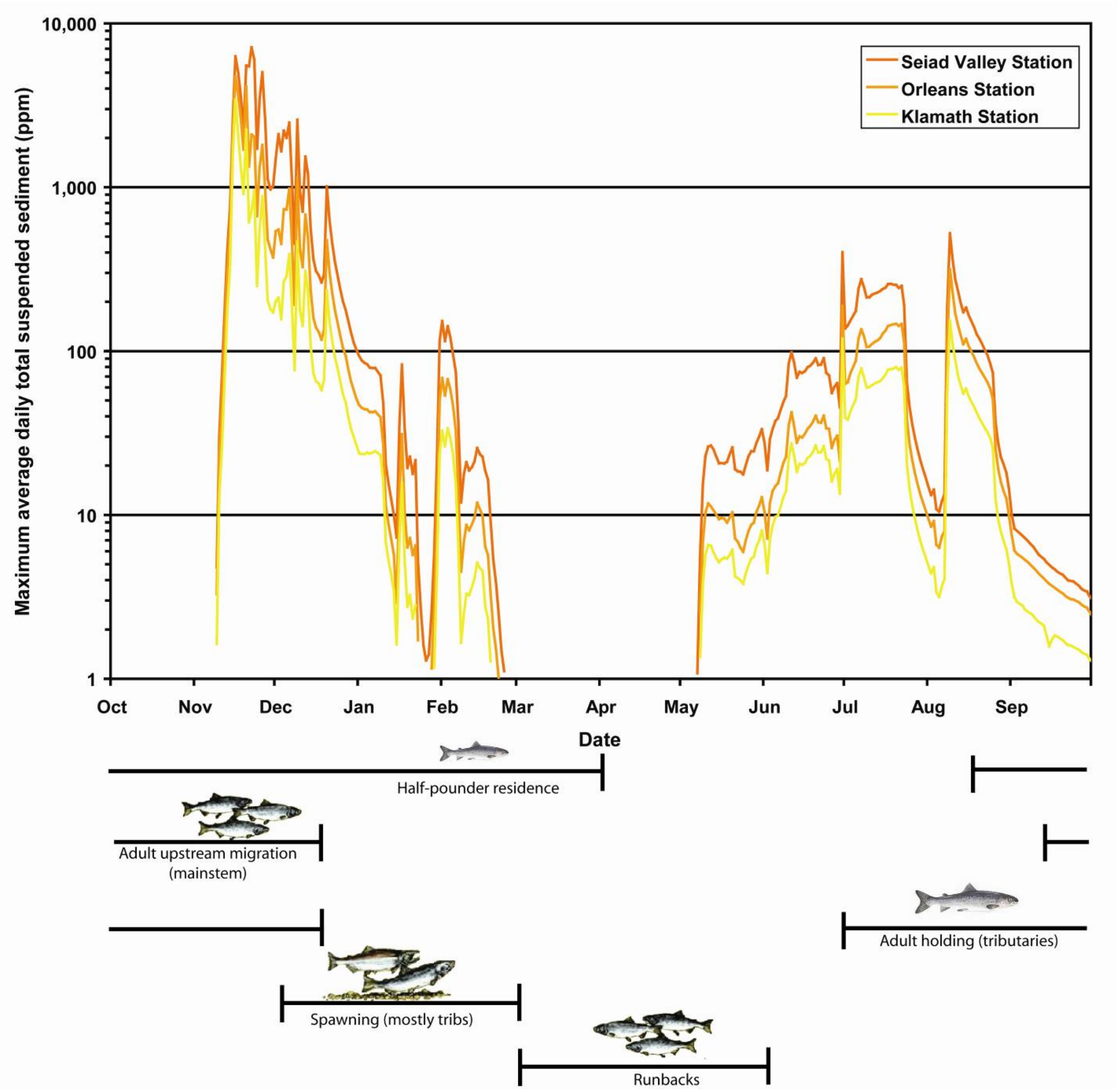

Figure 47. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with summer steelhead half-pounder residence, adult upstream migration, adult holding, spawning, and run-back life-history timing.

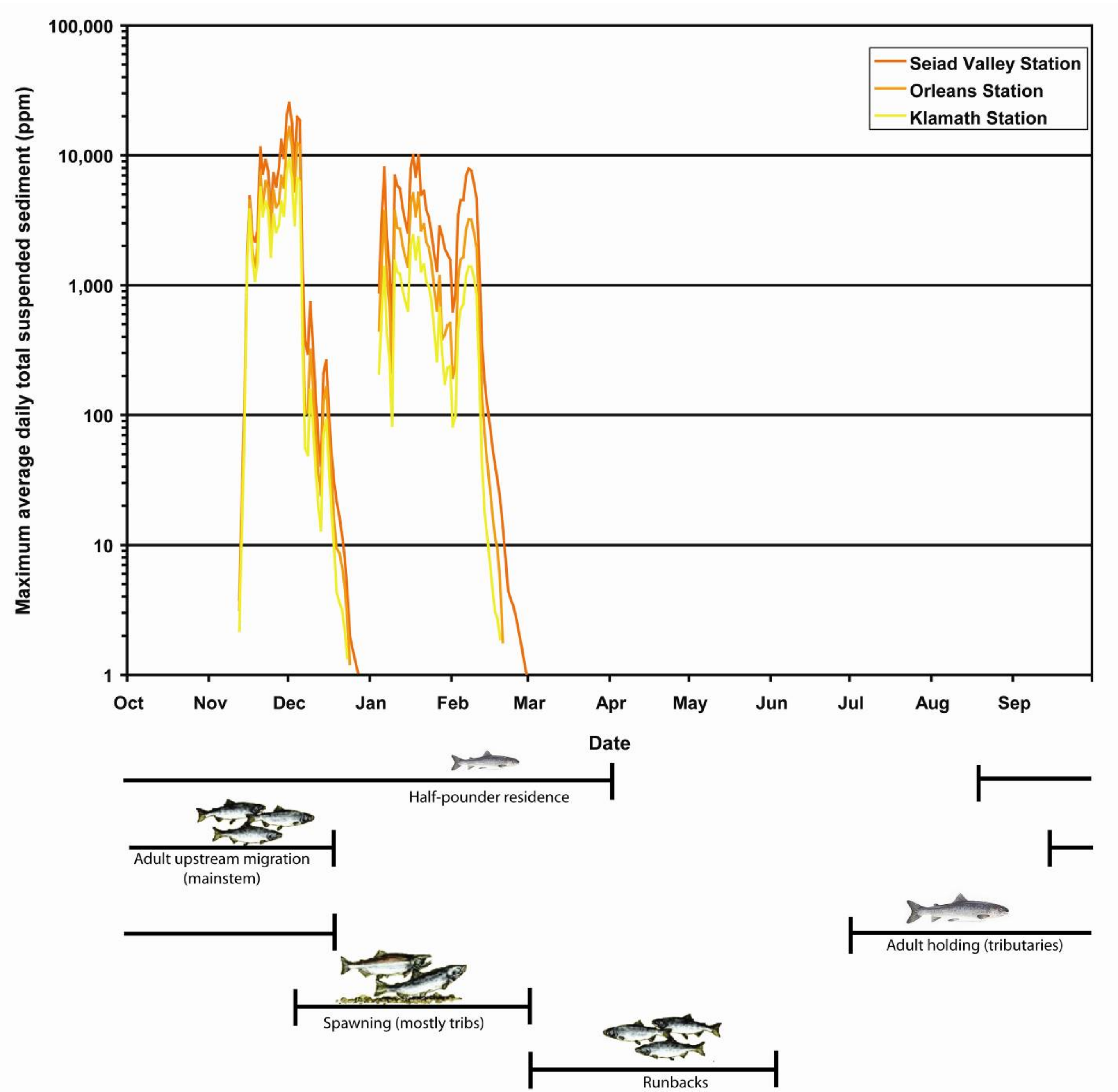

Figure 48. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with summer steelhead half-pounder residence, adult upstream migration, adult holding, spawning, and run-back life-history timing.

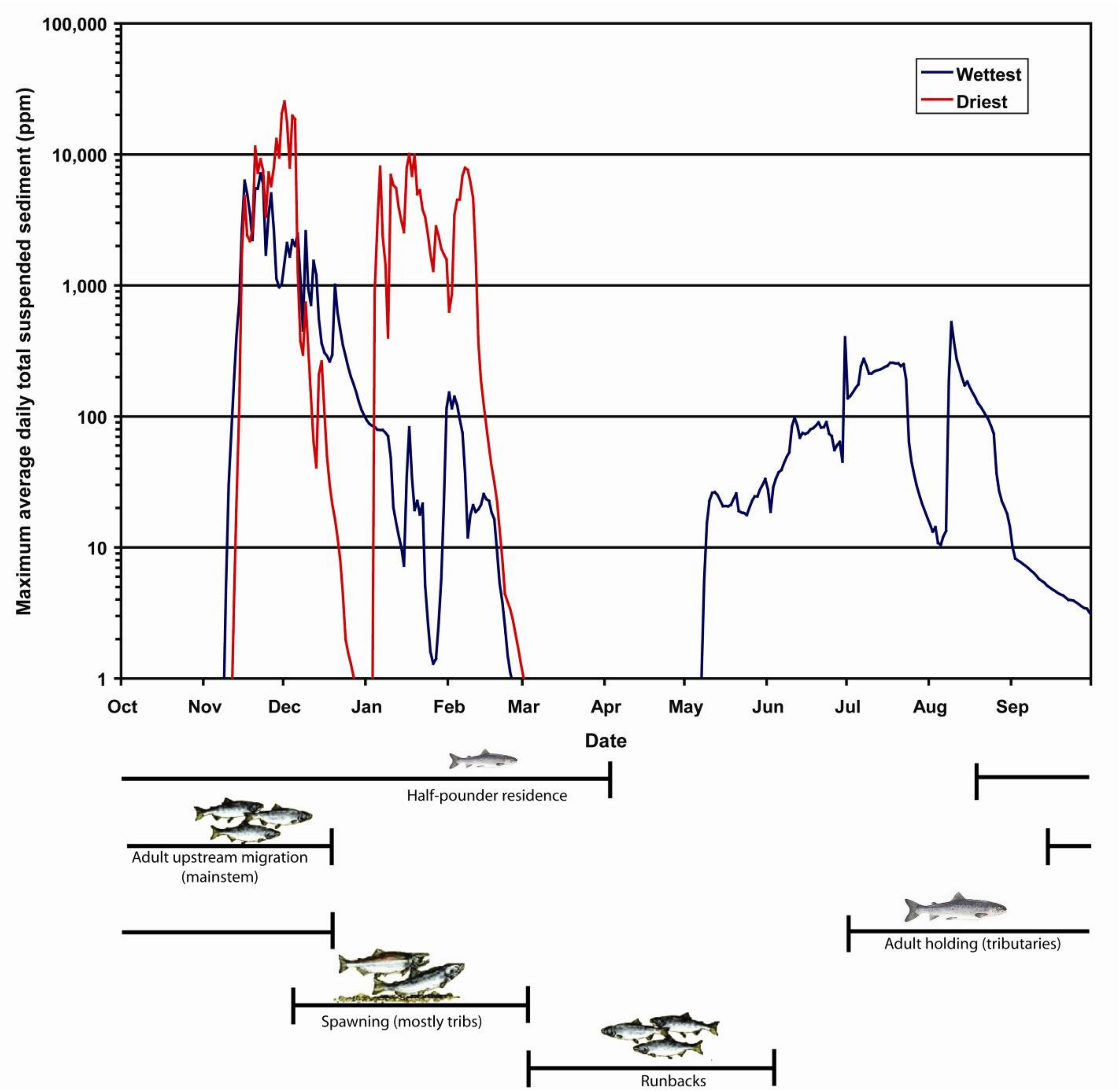

Figure 49. Average daily total suspended sediment concentrations in the Klamath River at the Seiad Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with summer steelhead half-pounder residence, adult upstream migration, adult holding, spawning, and run-back life-history timing.

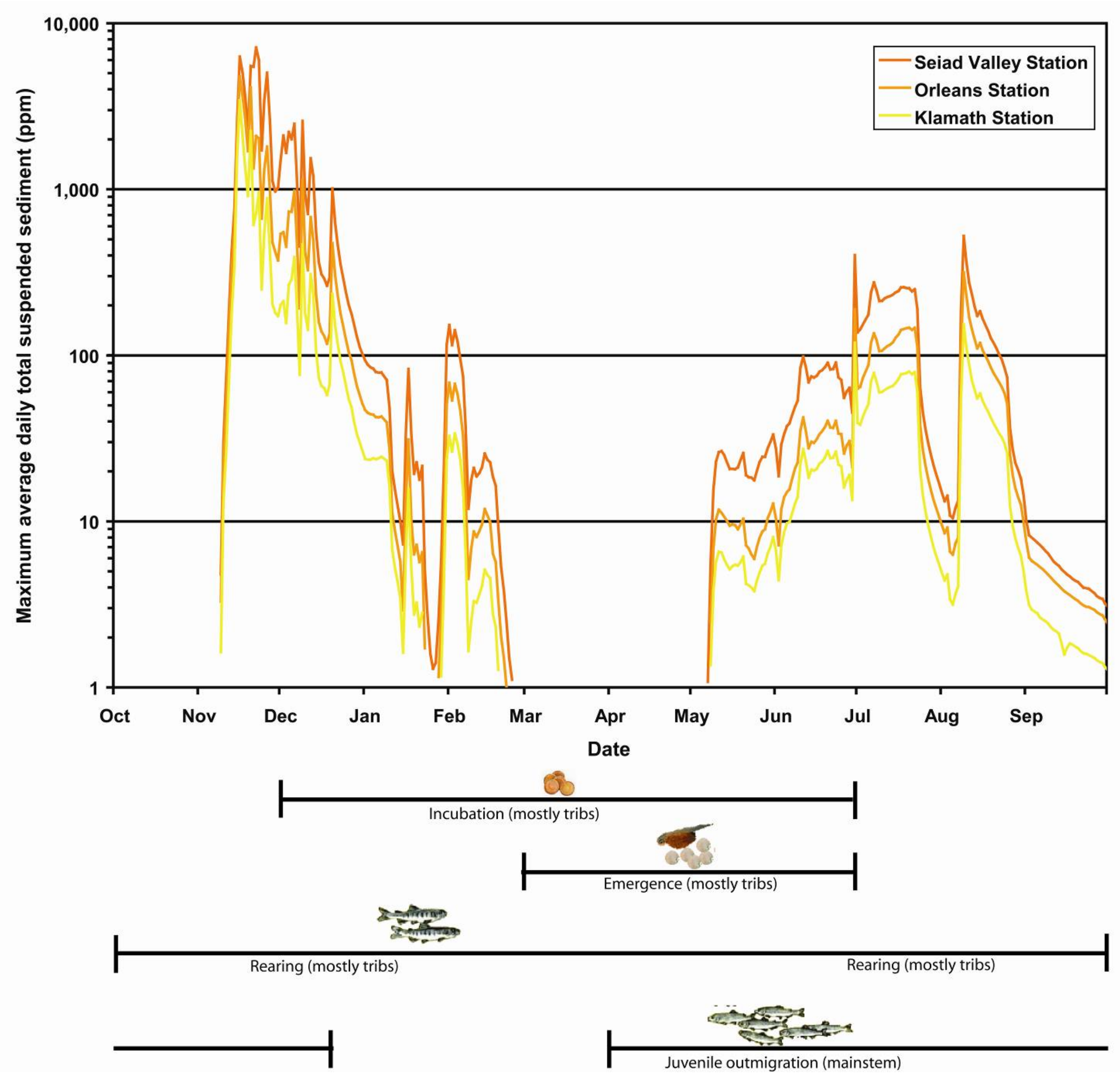

Figure 50. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with summer steelhead incubation, emergence, juvenile rearing, and outmigration life-history timing.

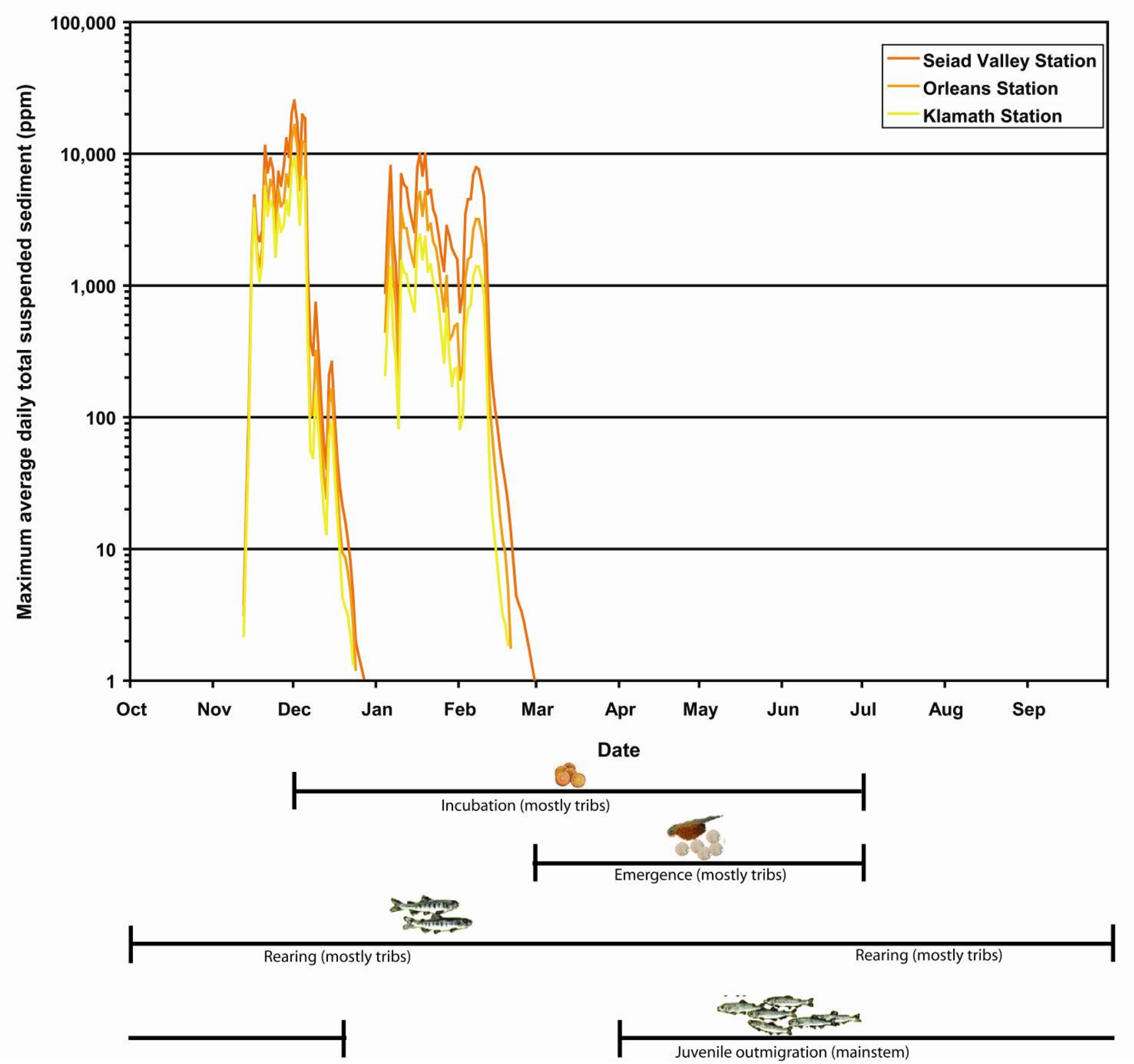

Figure 51. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with summer steelhead incubation, emergence, juvenile rearing, and outmigration life-history timing.

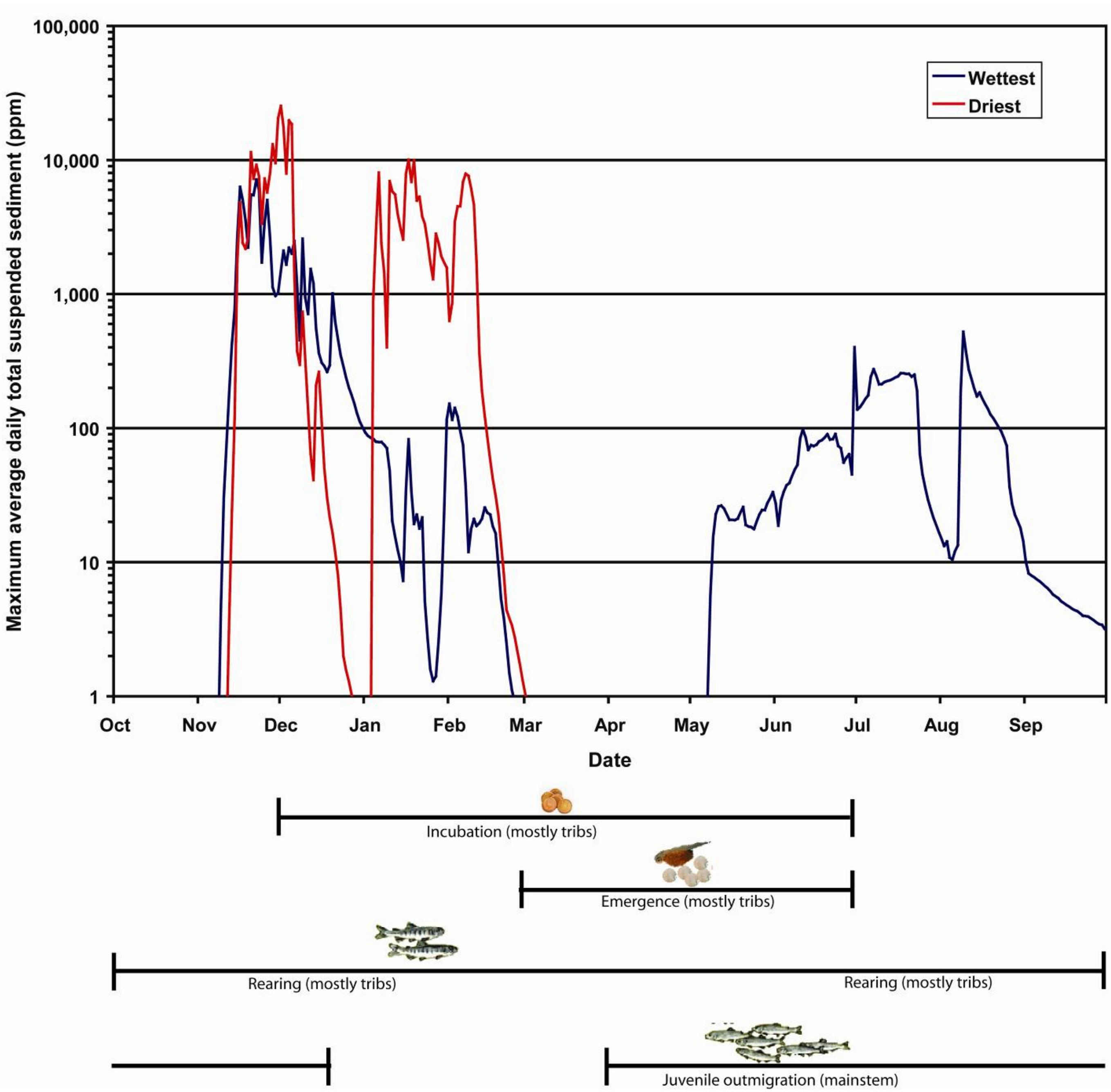

Figure 52. Average daily total suspended sediment concentrations in the Klamath River at the Seiad Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with summer steelhead incubation, emergence, juvenile rearing, and outmigration life-history timing.

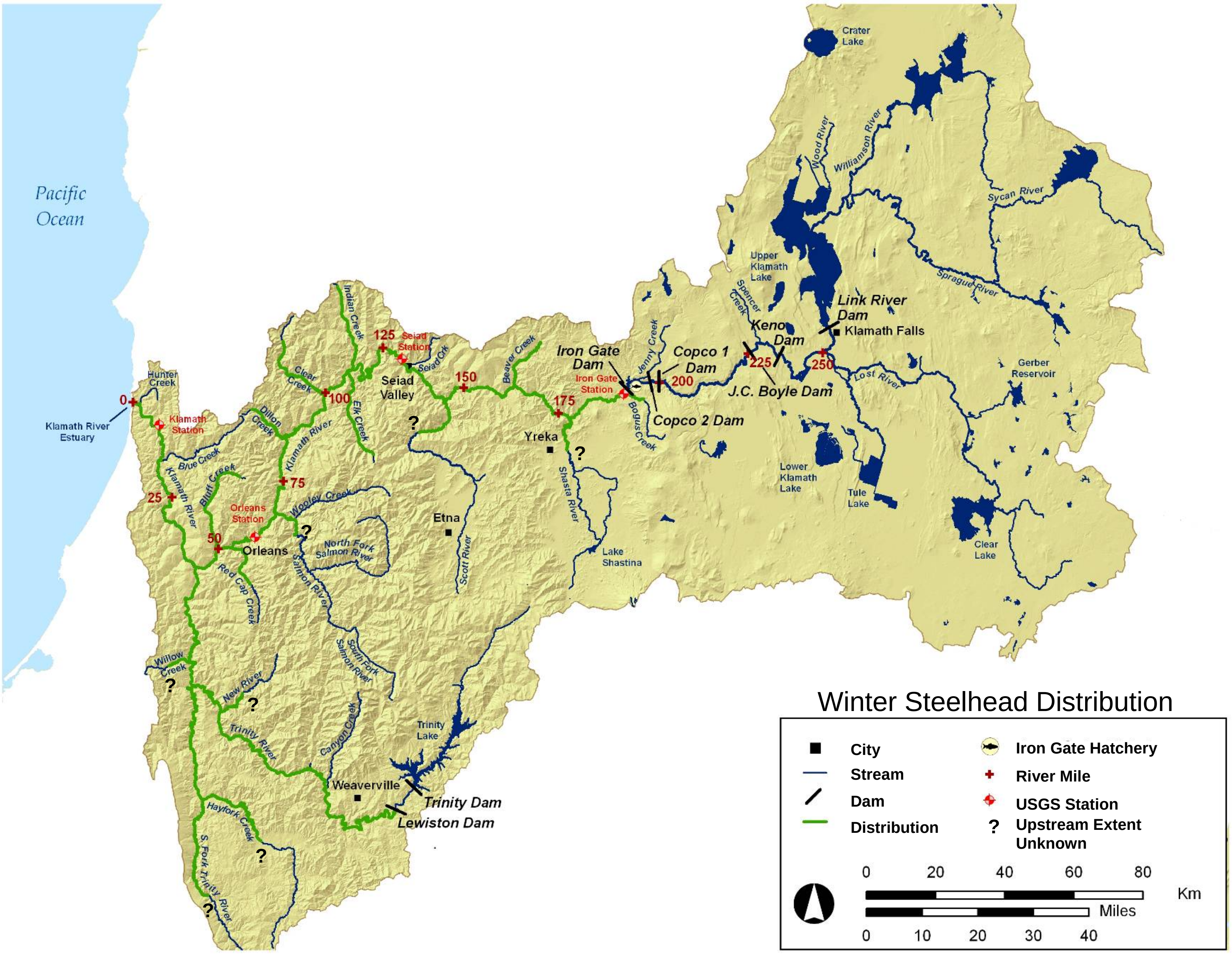

Figure 53. Winter steelhead distribution in the Klamath River basin.

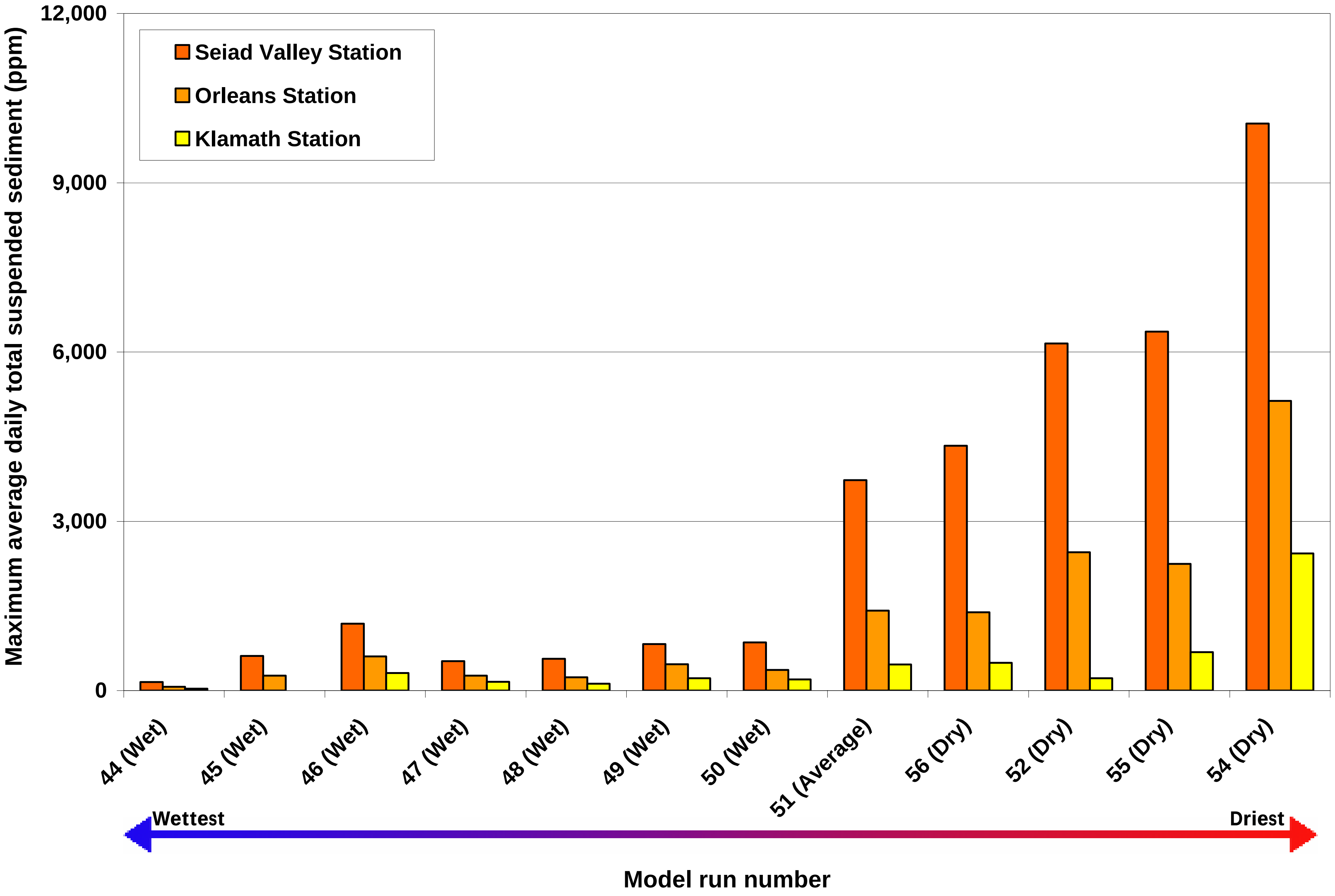

Figure 54. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 January through 15 May (the period of winter steelhead spawning).

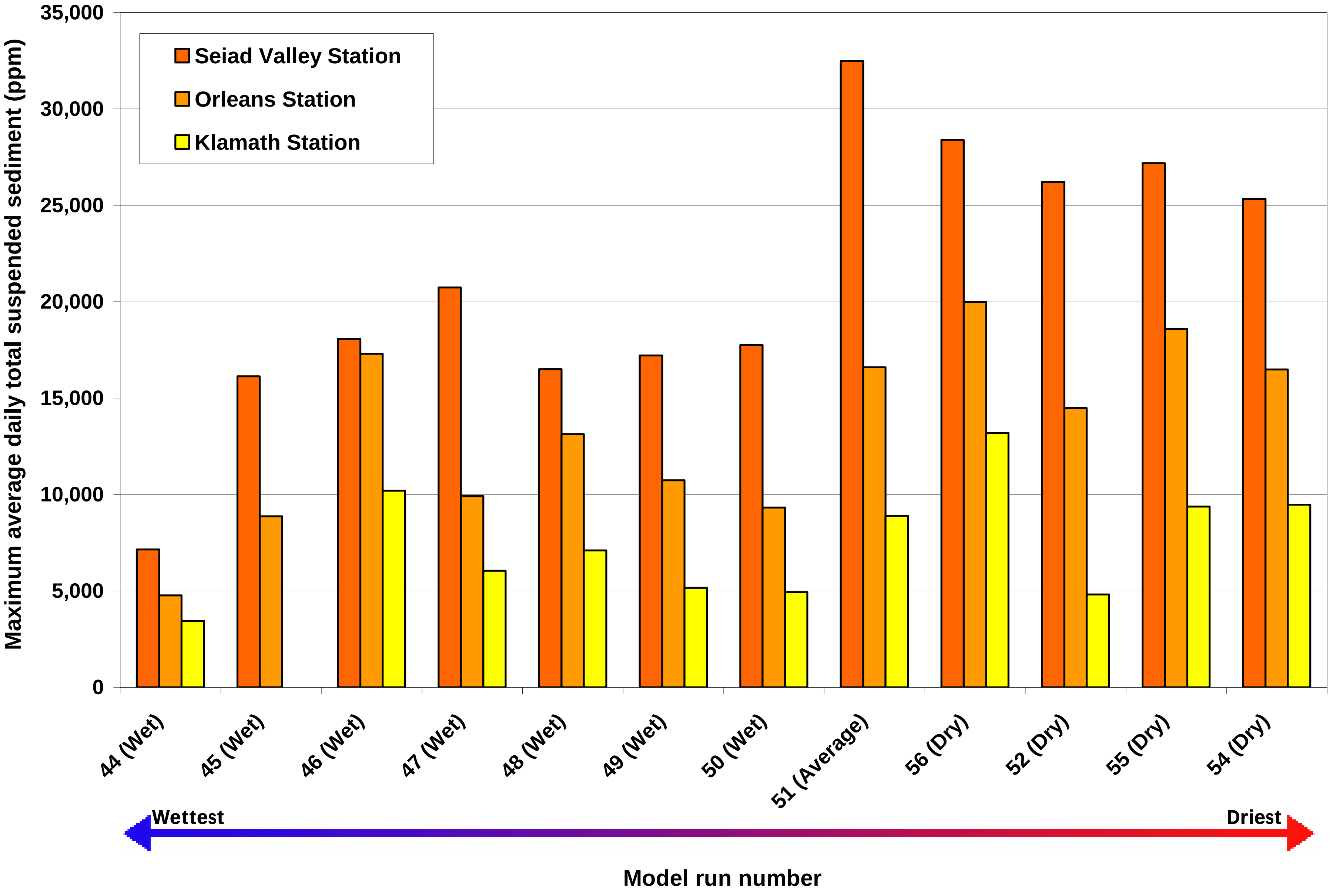

Figure 55. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 January through 31 December (the period of age-0 and 1 winter steelhead rearing).

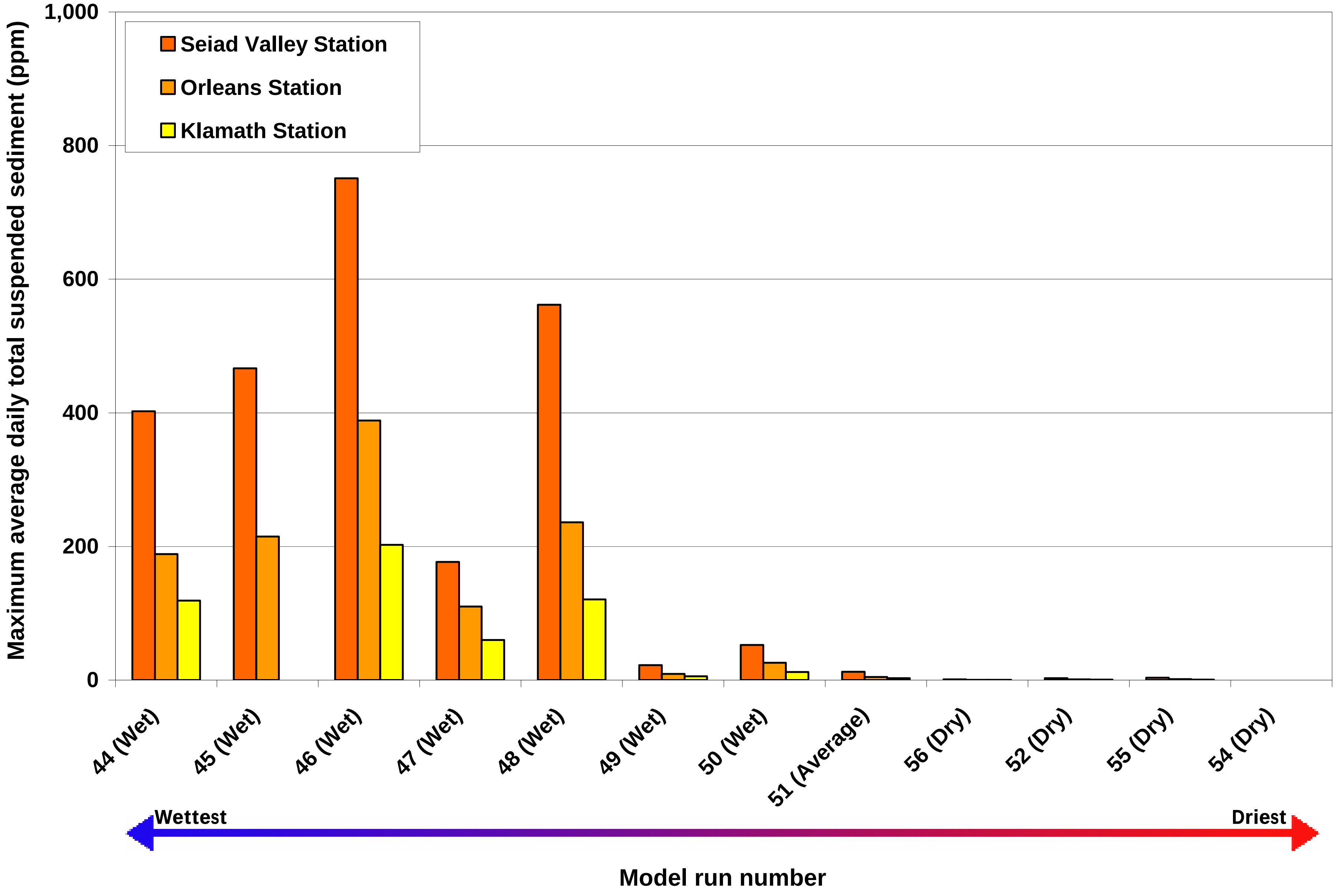

Figure 56. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 April through 30 June (the period of peak age 2 winter steelhead outmigration).

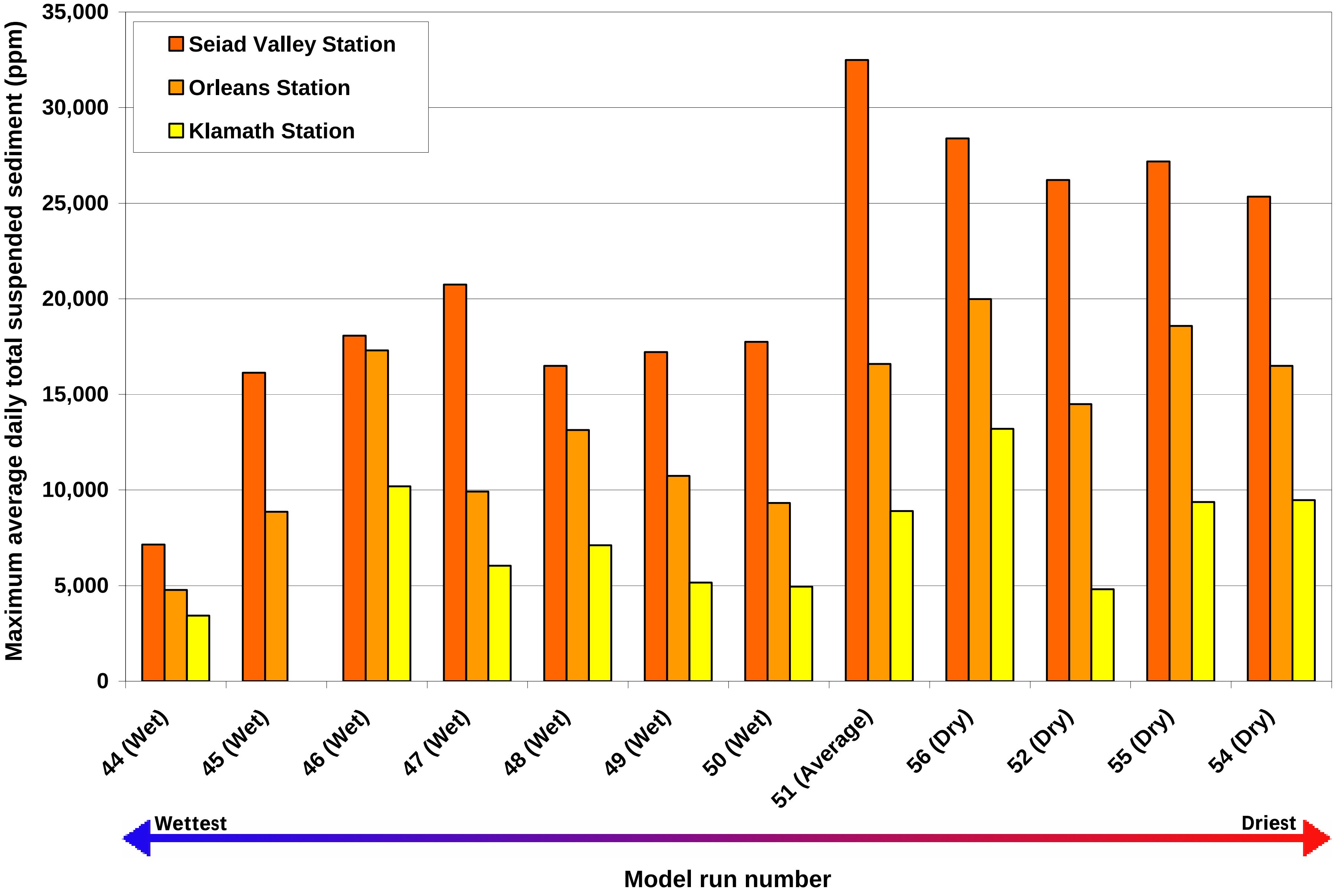

Figure 57. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 July through 31 March (the period of winter steelhead adult migration).

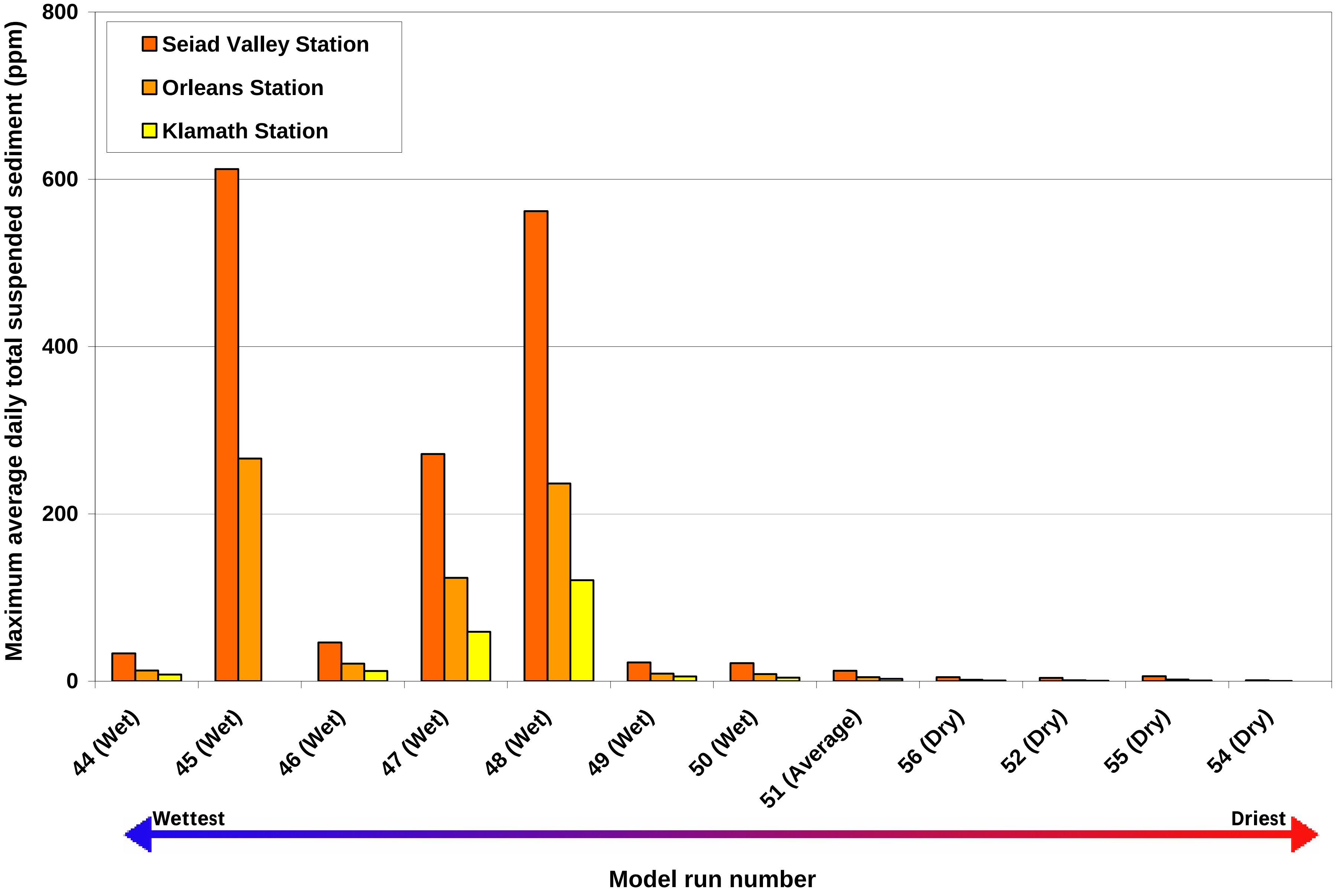

Figure 58. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 March through 31 May (the period of winter steelhead run-backs).

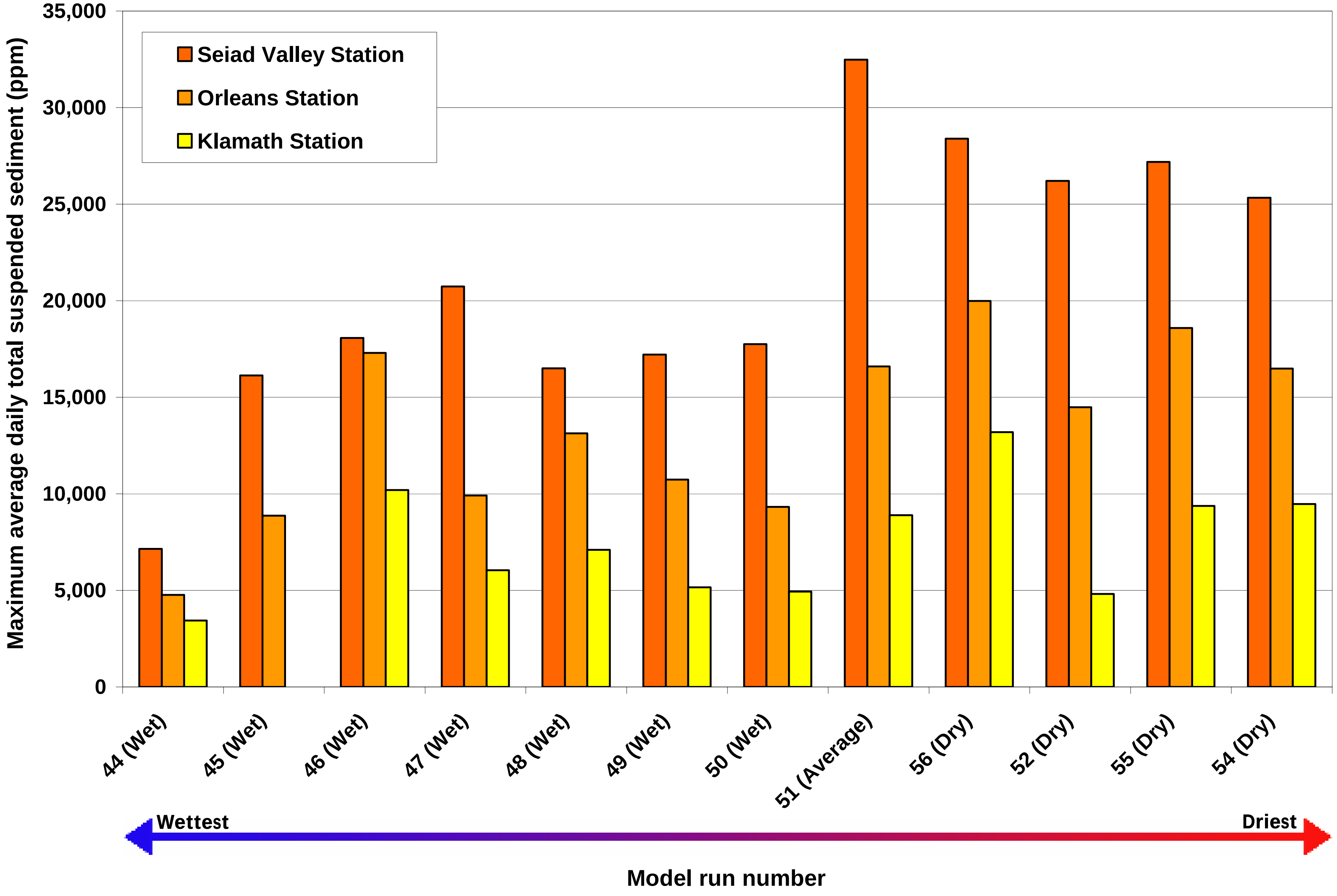

Figure 59. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Seiad Valley based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 August through 31 March (the period of winter steelhead half-pounder residence).

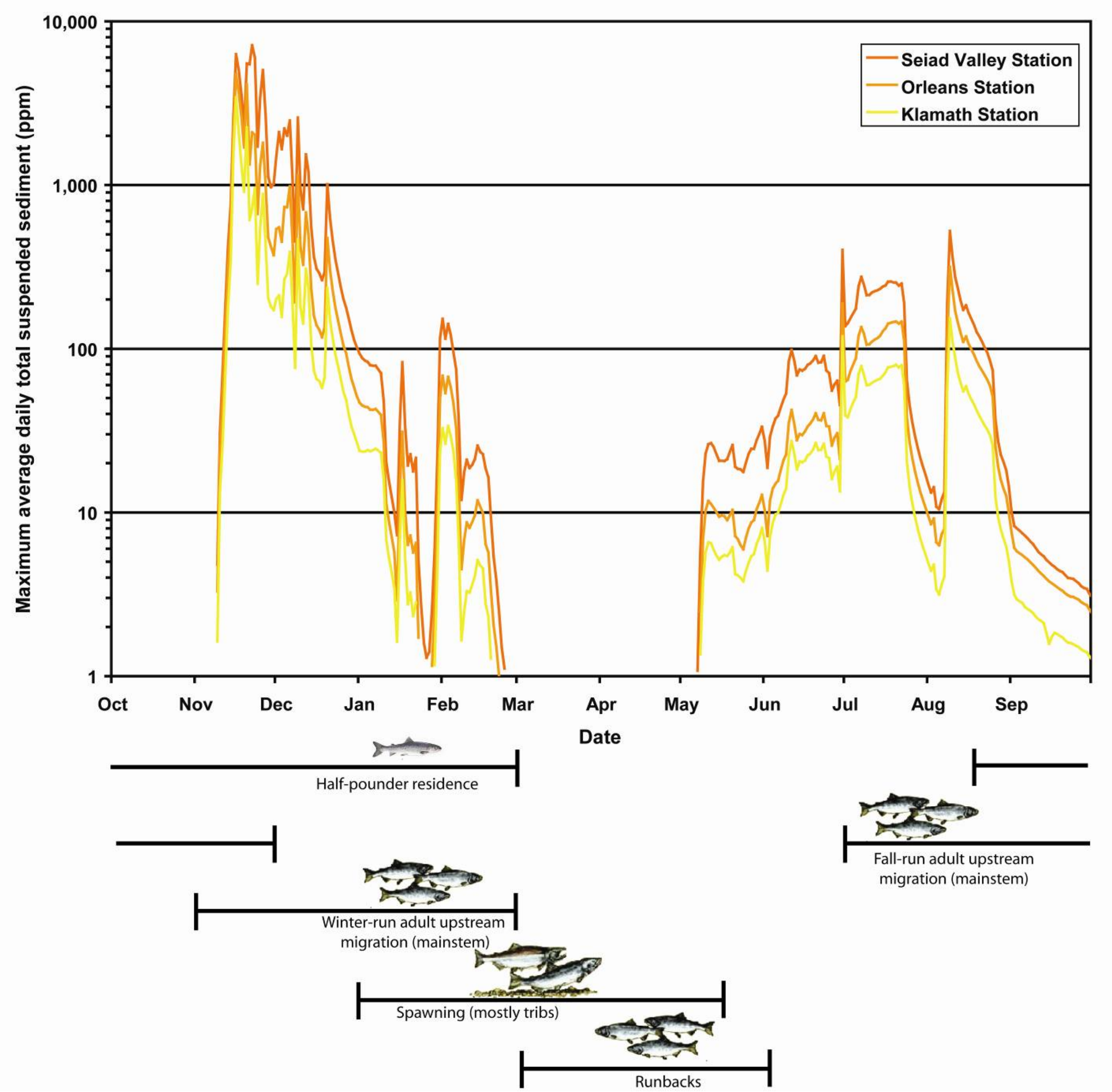

Figure 60. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with winter steelhead half-pounder residence, fall- and winter-run adult upstream migration, spawning, and run-back life-history timing.

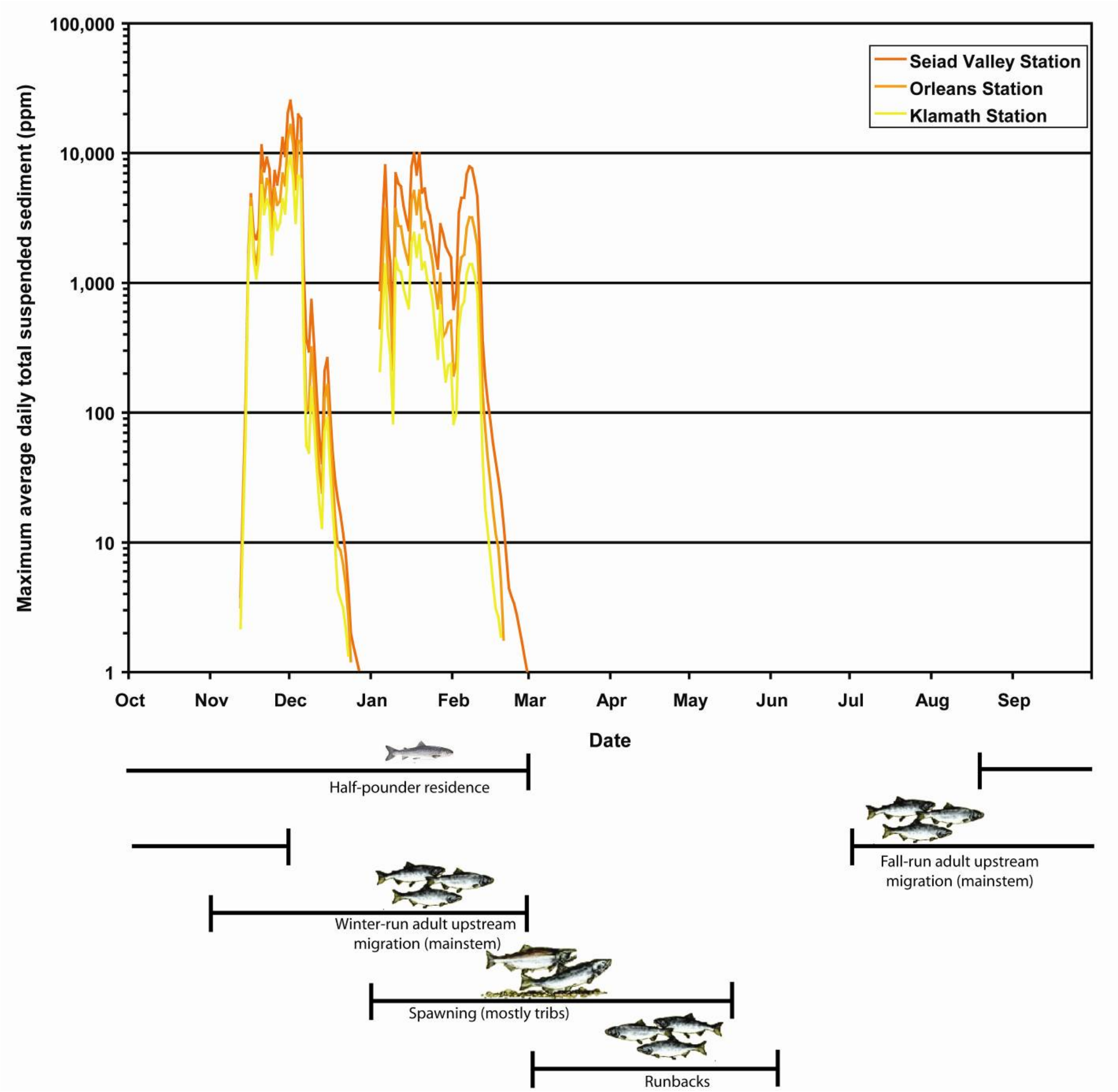

Figure 61. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with winter steelhead half-pounder residence, fall- and winter-run adult upstream migration, spawning, and run-back life-history timing.

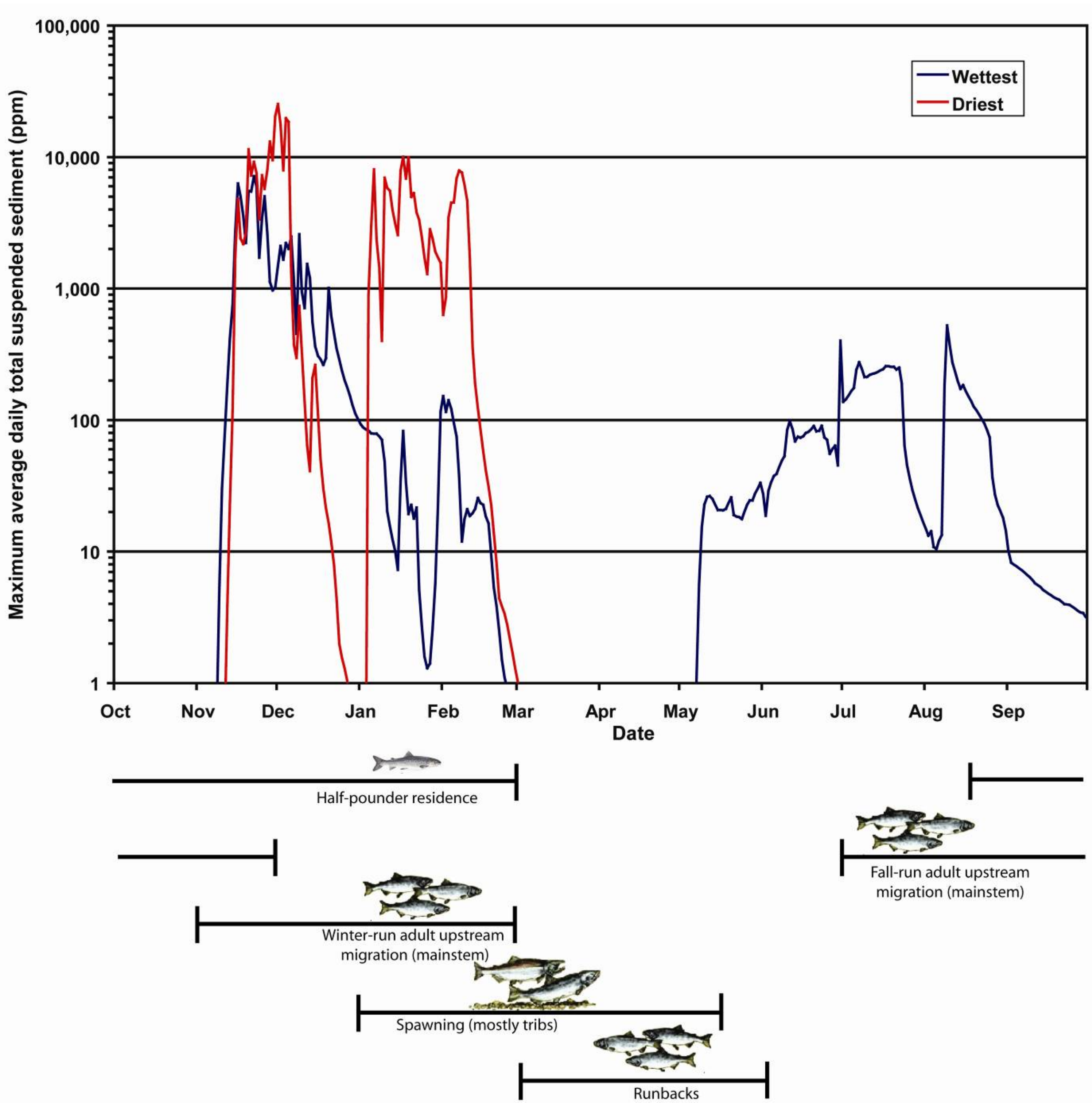

Figure 62. Average daily total suspended sediment concentrations in the Klamath River at the Seiad Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with winter steelhead half-pounder residence, fall- and winter-run adult upstream migration, spawning, and run-back life-history timing.

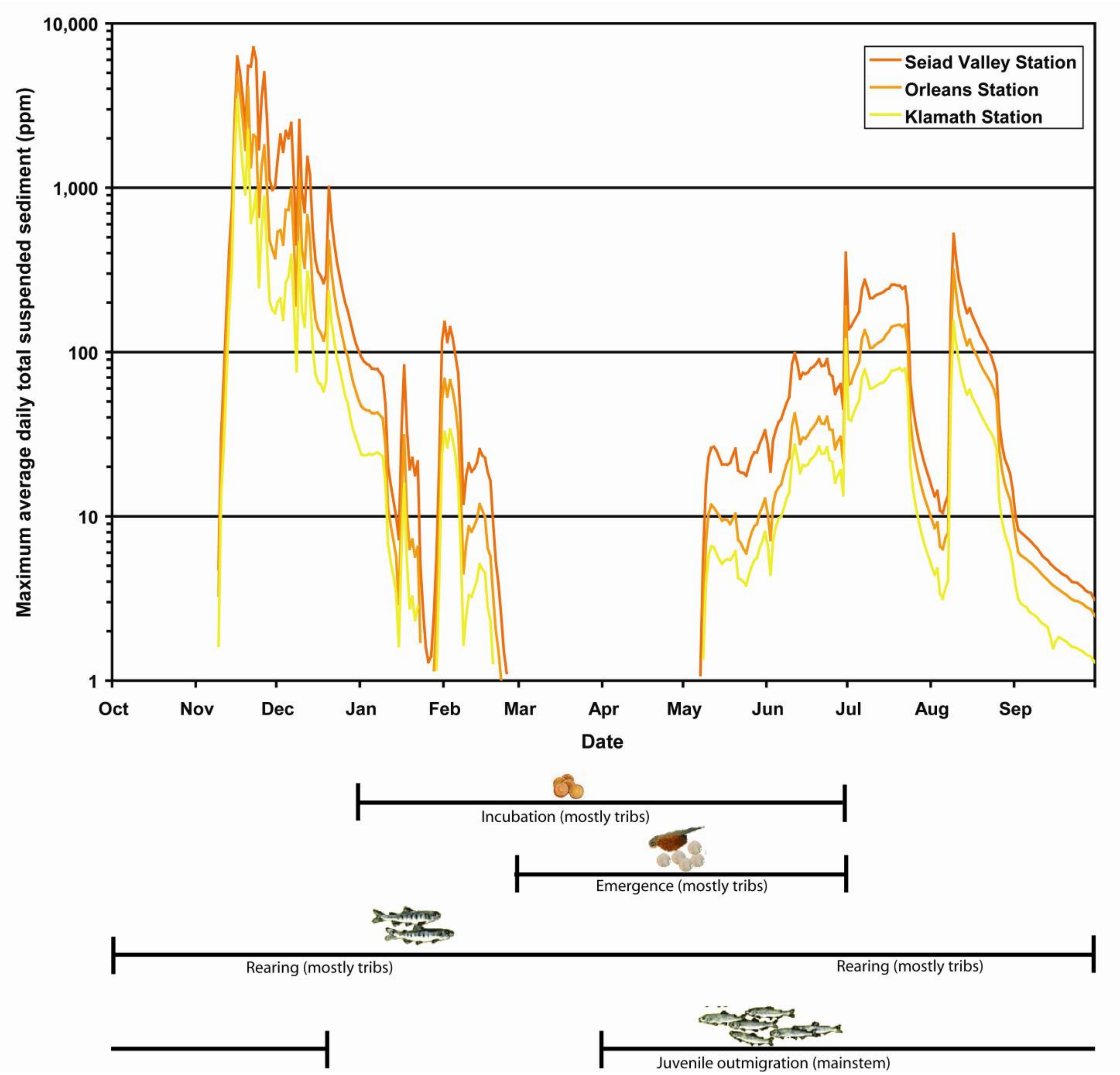

Figure 63. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with winter steelhead incubation, emergence, juvenile rearing, and outmigration life-history timing.

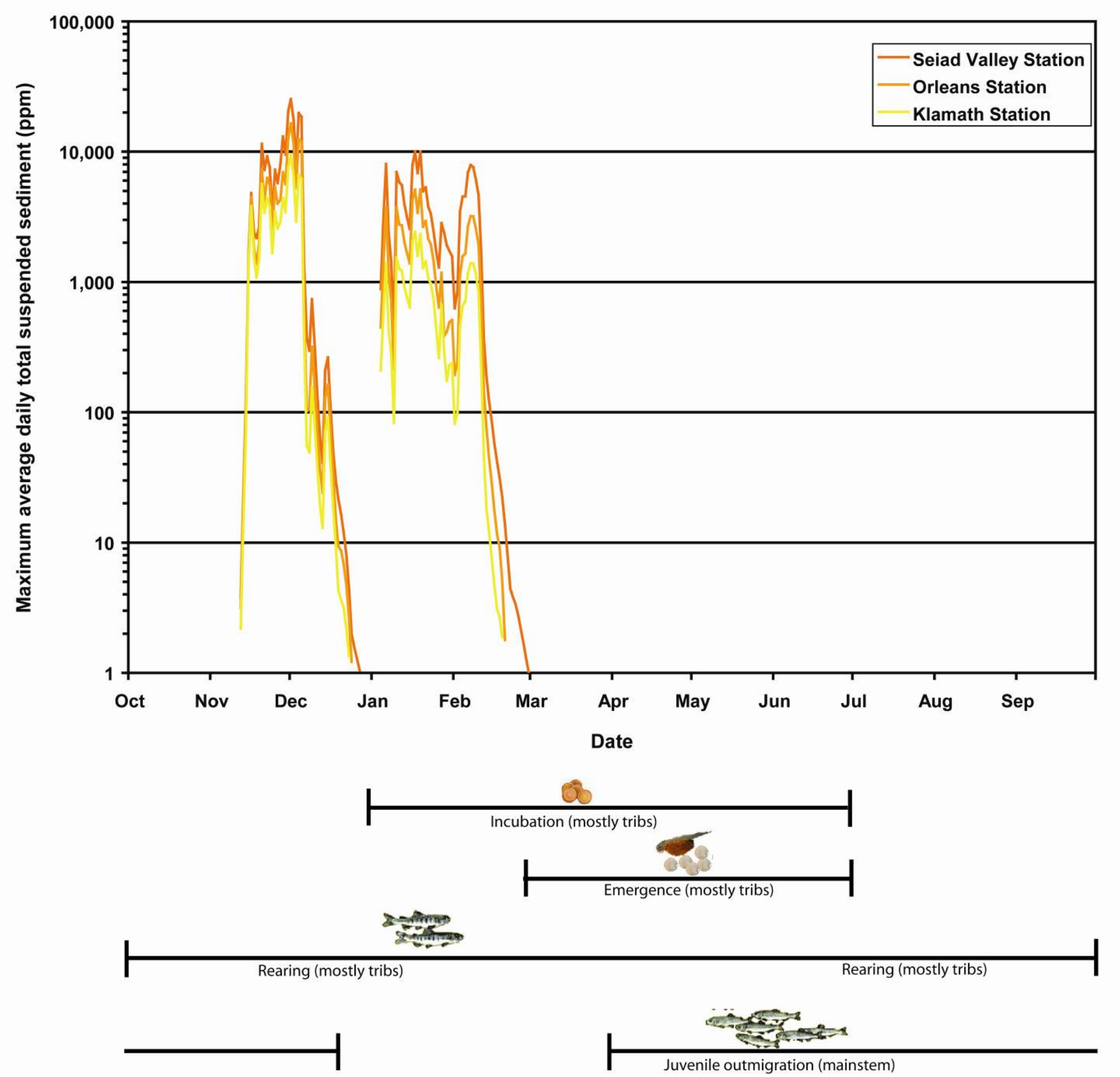

Figure 64. Average daily total suspended sediment concentrations in the Klamath River downstream of Seiad Valley based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with winter steelhead incubation, emergence, juvenile rearing, and outmigration life-history timing.

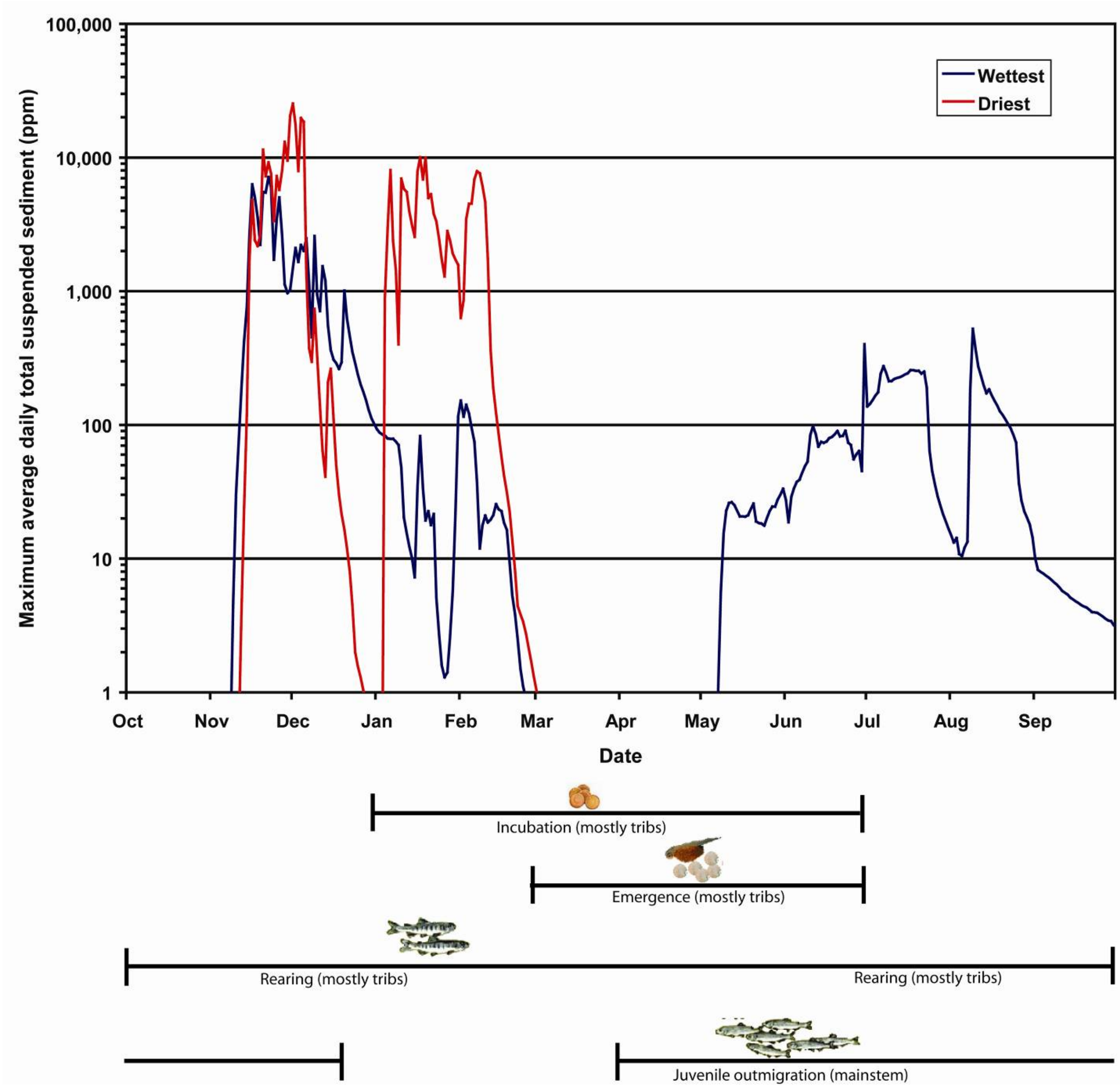

Figure 65. Average daily total suspended sediment concentrations in the Klamath River at the Seiad Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with winter steelhead incubation, emergence, juvenile rearing, and outmigration life-history timing.

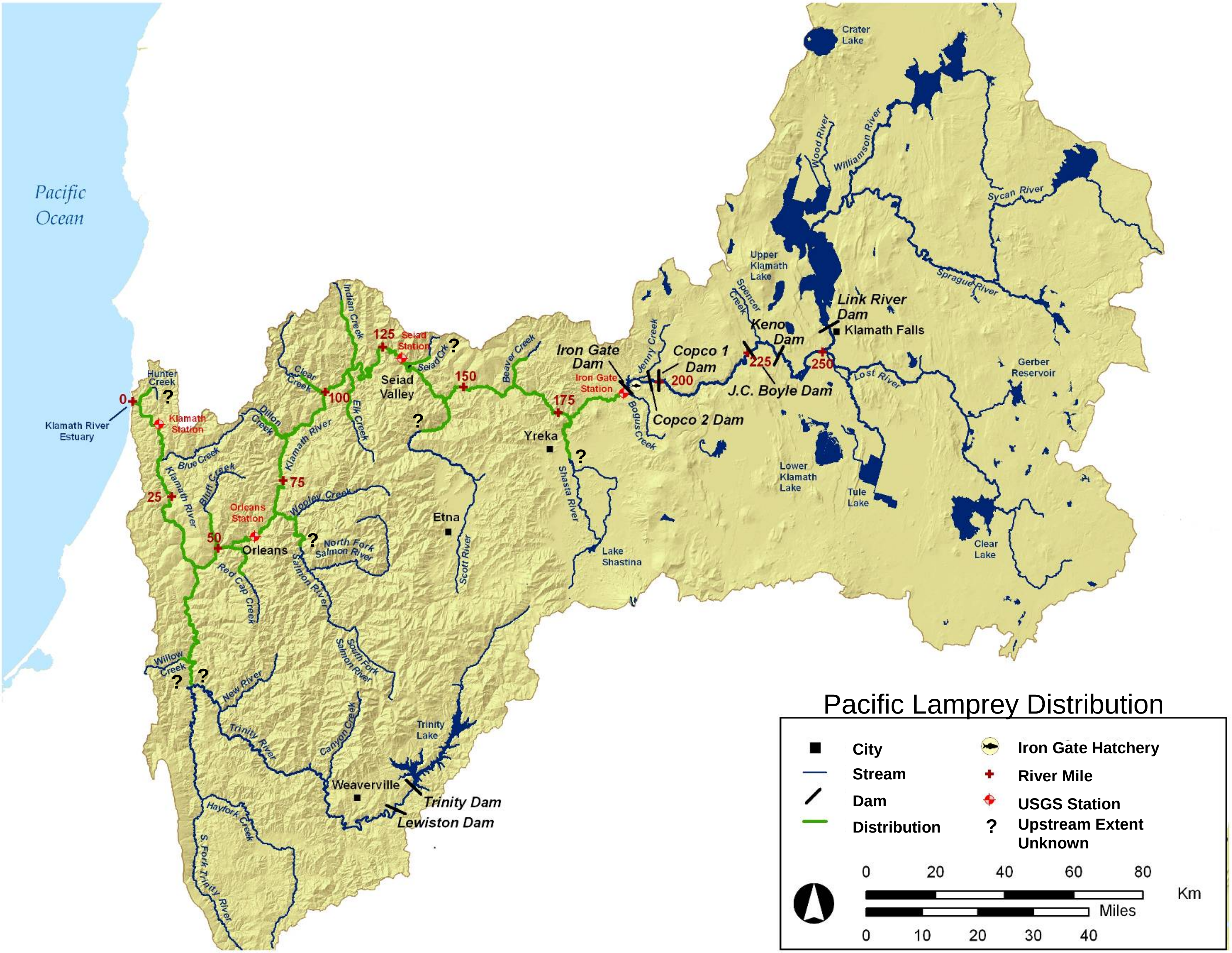

Figure 66. Pacific lamprey distribution in the Klamath River basin. Pacific lamprey are also distributed in numerous other small tributaries downstream of Iron Gate Dam.

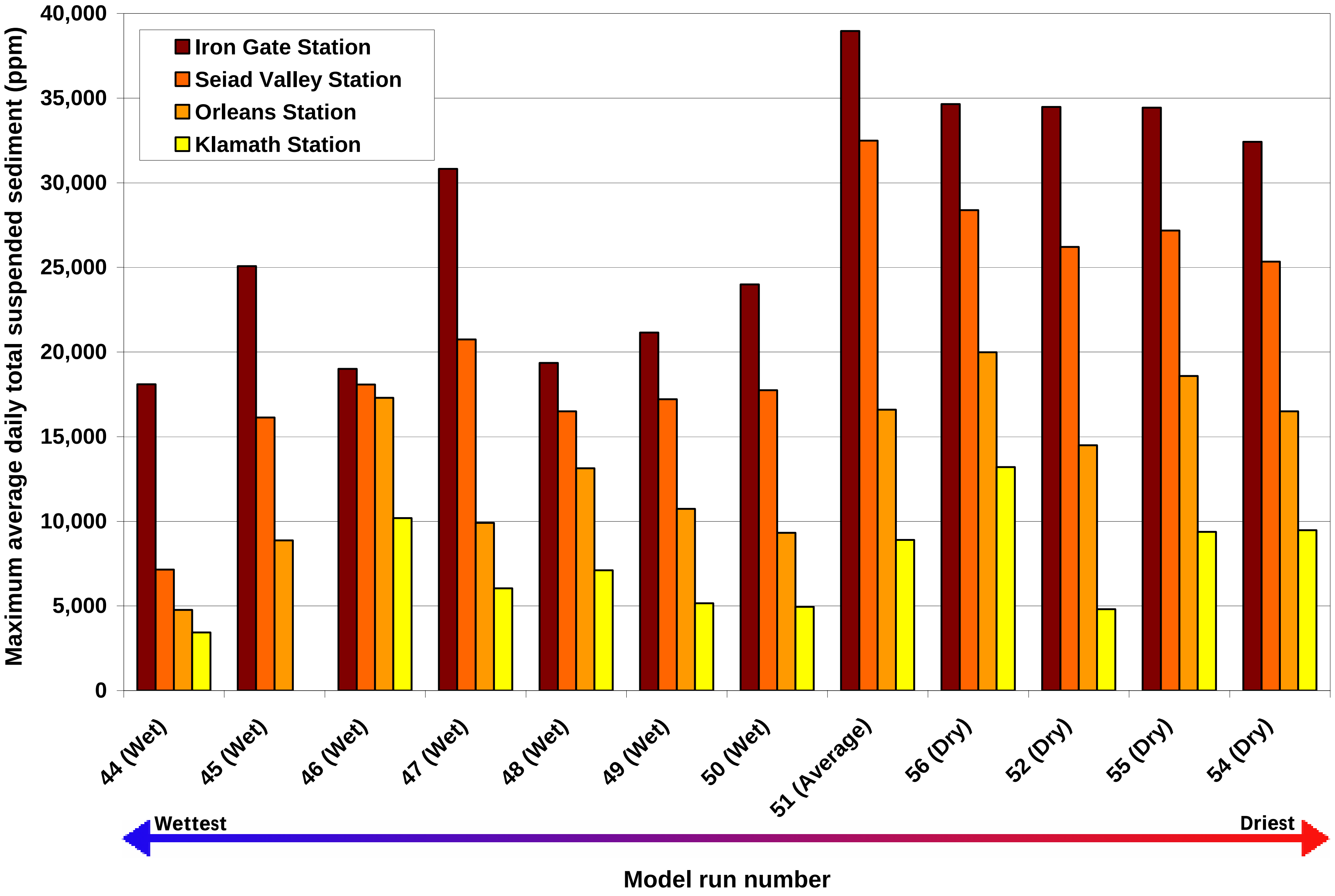

Figure 67. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 January through 31 December (the period of Pacific lamprey juvenile rearing and outmigration and adult migration).

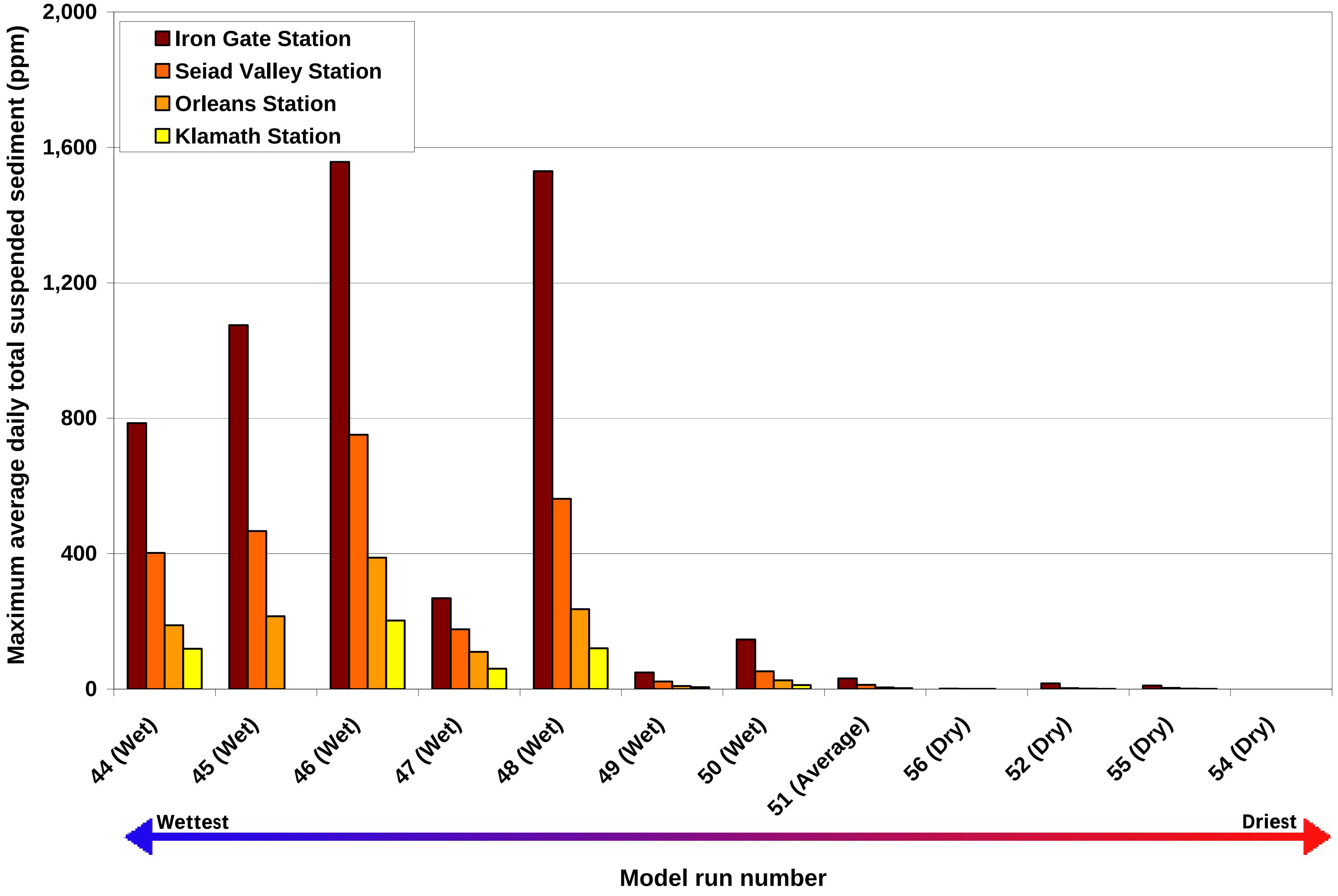

Figure 68. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Iron Gate Dam based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 April through 30 June (the period of Pacific lamprey spawning).

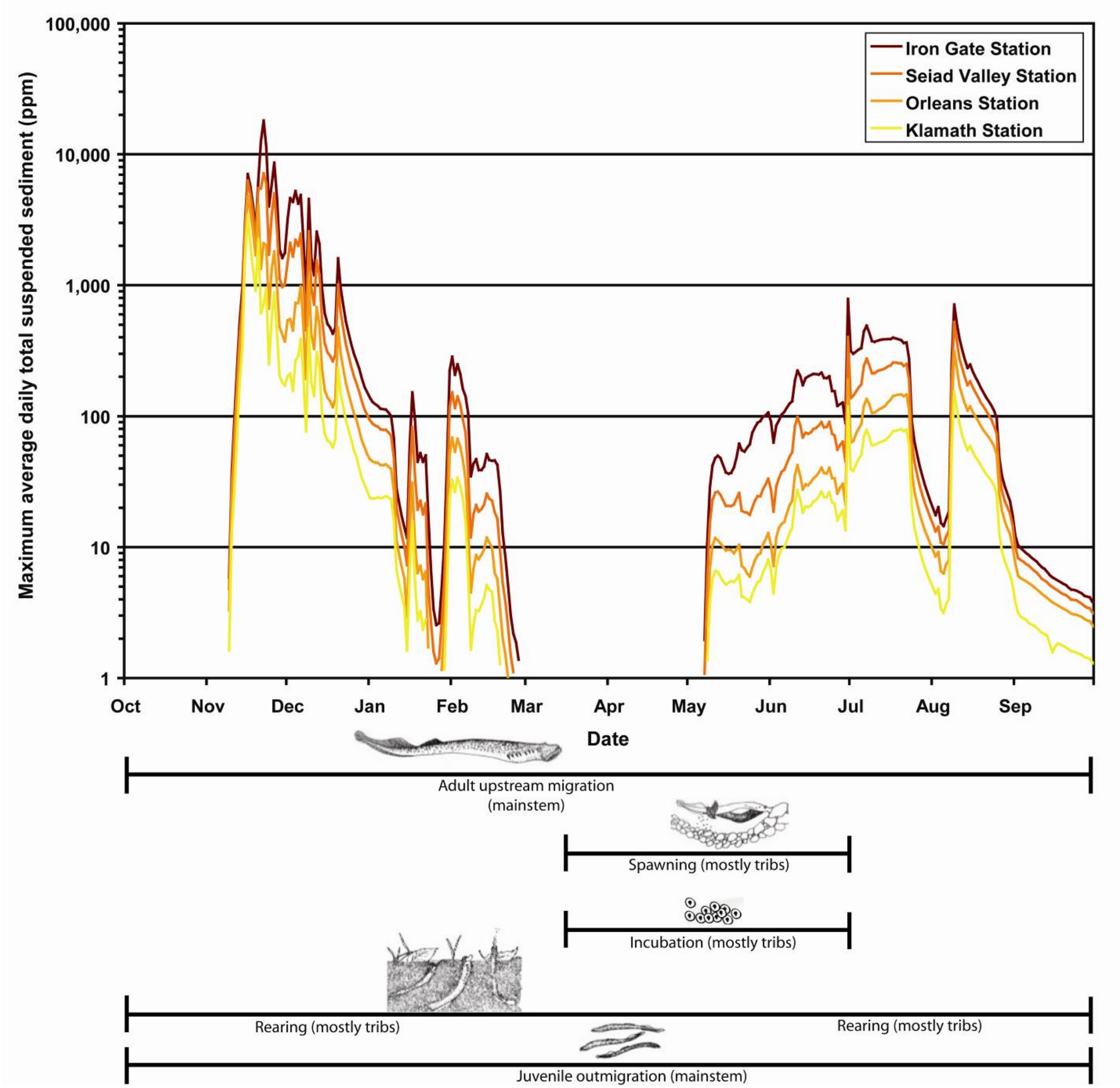

Figure 69. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with life-history timing for Pacific lamprey.

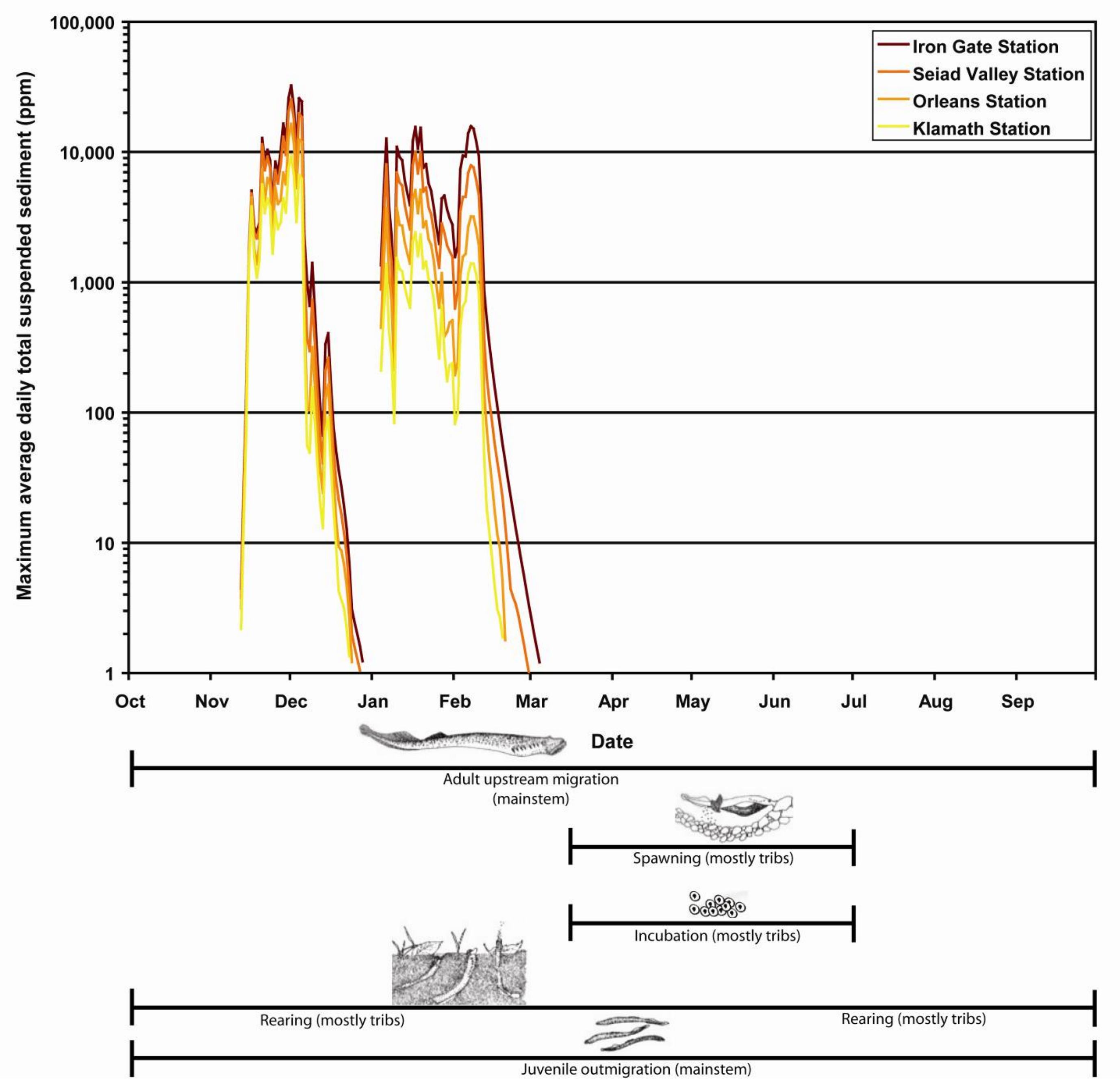

Figure 70. Average daily total suspended sediment concentrations in the Klamath River downstream of Iron Gate Dam based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with life-history timing for Pacific lamprey.

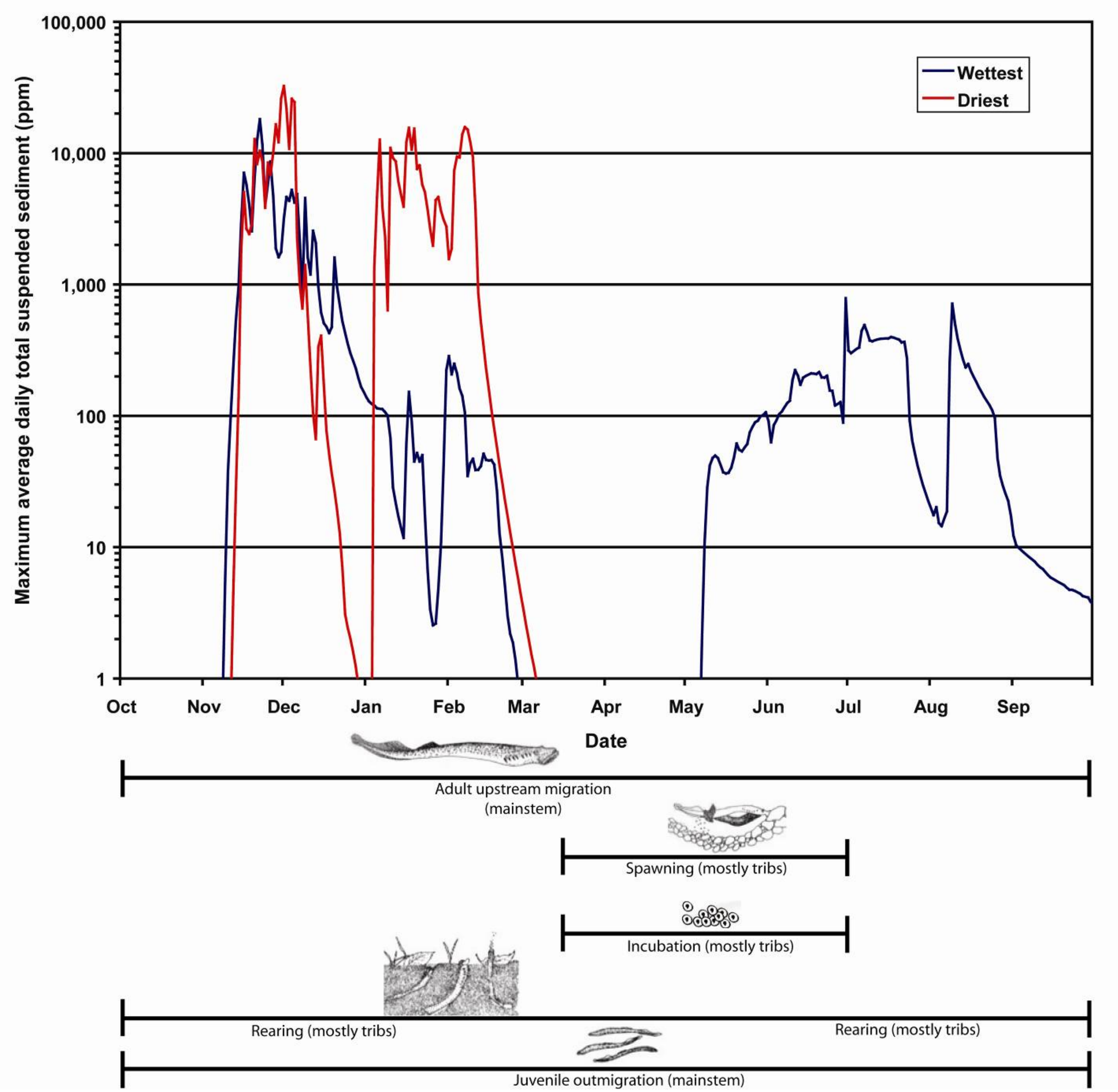

Figure 71. Average daily total suspended sediment concentrations in the Klamath River at the Iron Gate Station based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with life-history timing for Pacific lamprey.

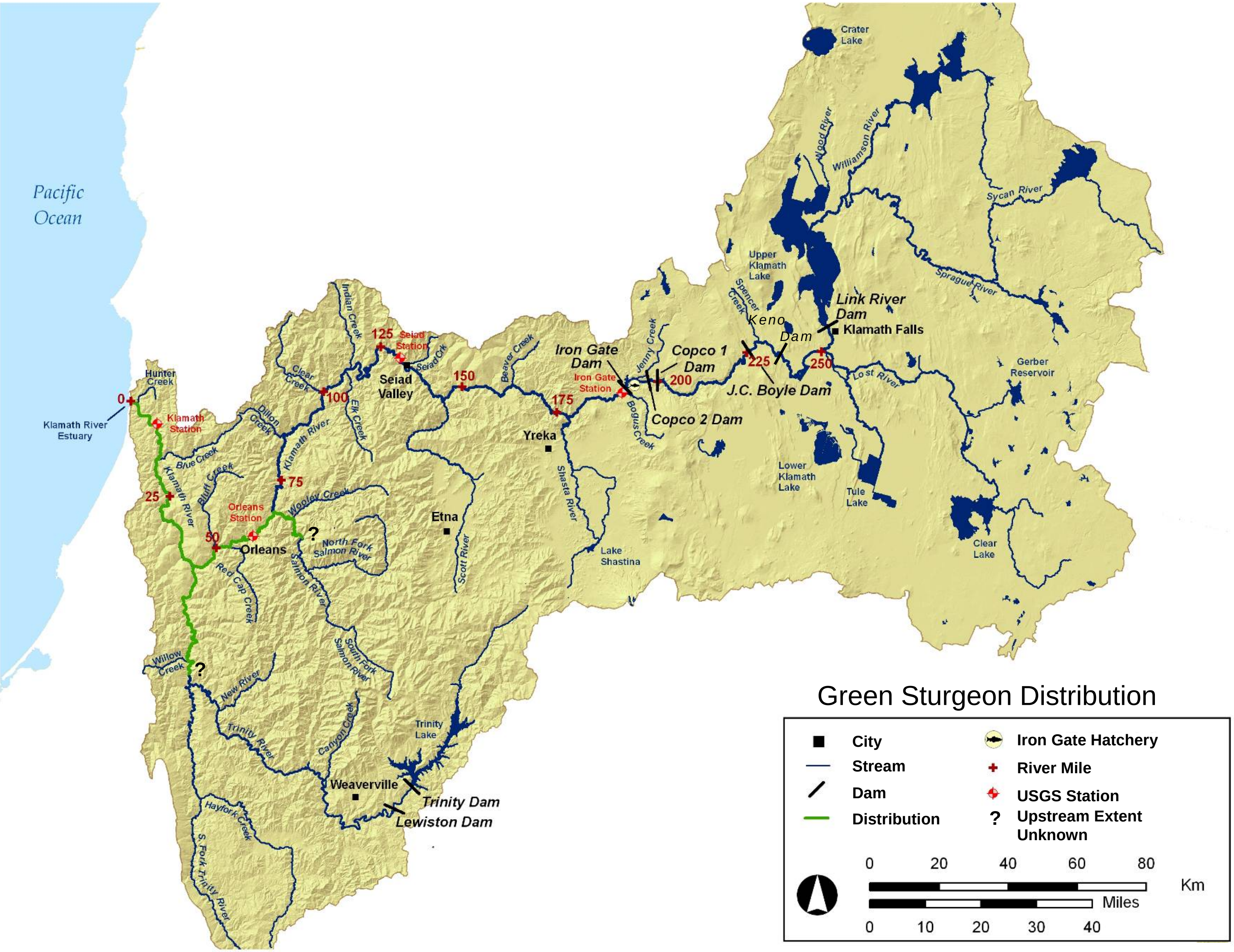

Figure 72. Green sturgeon distribution in the Klamath River basin.

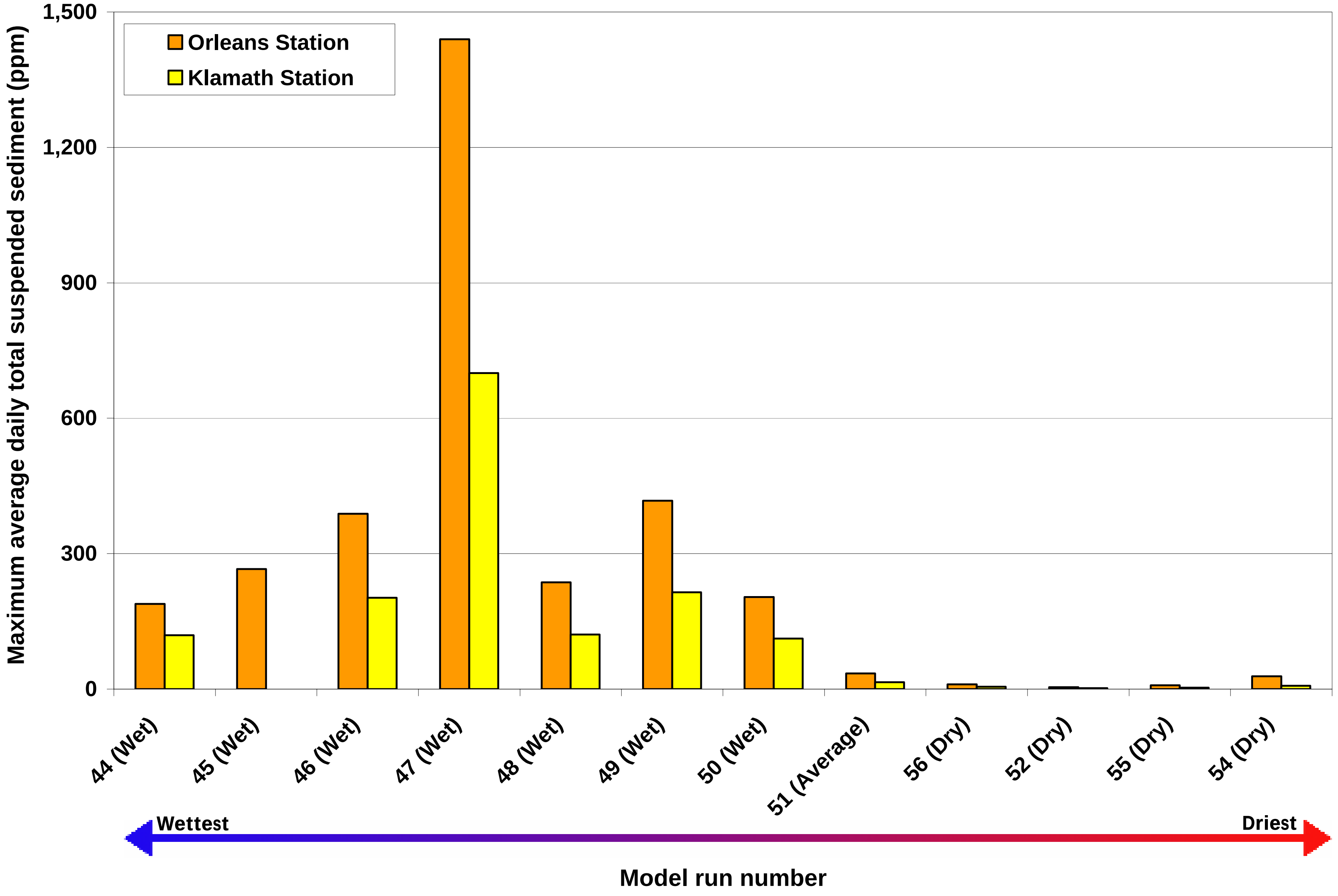

Figure 73. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 February through 31 July (the period of adult green sturgeon upstream migration and spawning).

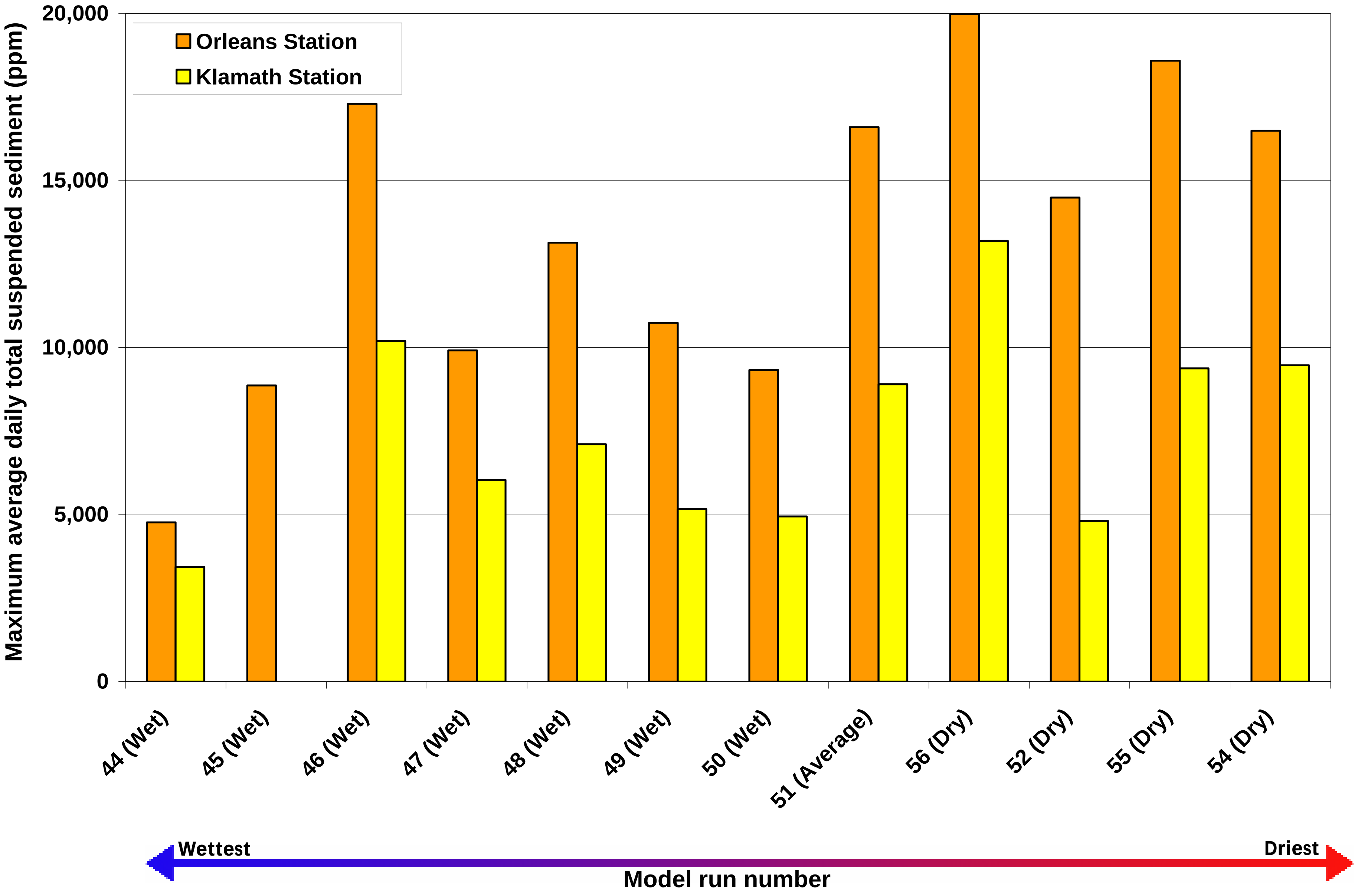

Figure 74. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 January through 31 December (the period of green sturgeon juvenile rearing).

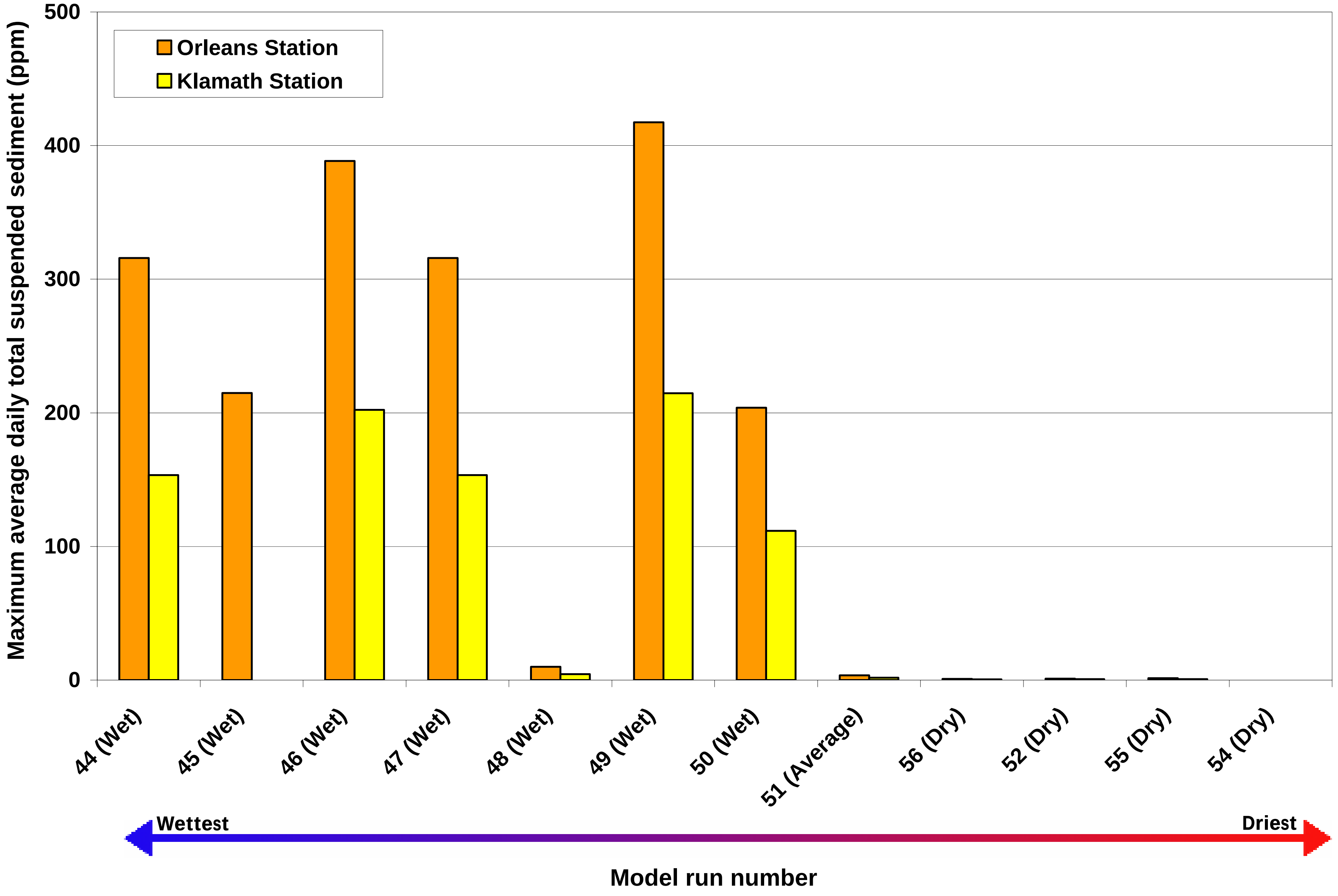

Figure 75. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 15 May through 15 October (the period of green sturgeon juvenile outmigration).

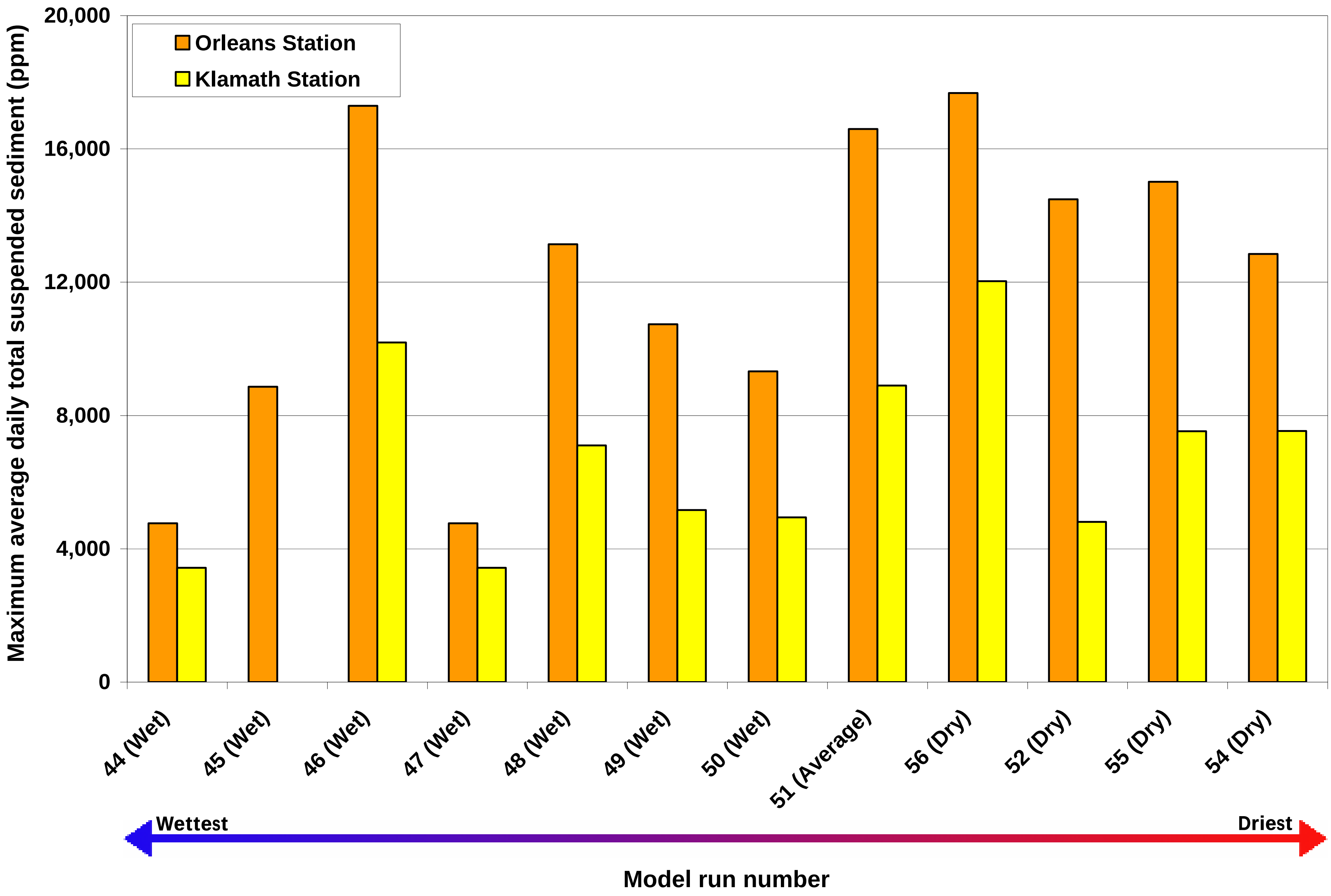

Figure 76. Maximum average daily total suspended sediment by water year type in the Klamath River downstream of Orleans based on DREAM-1 model simulations (Stillwater Sciences 2008) for the period 1 June through 30 November (the period of green sturgeon post-spawning adult holding).

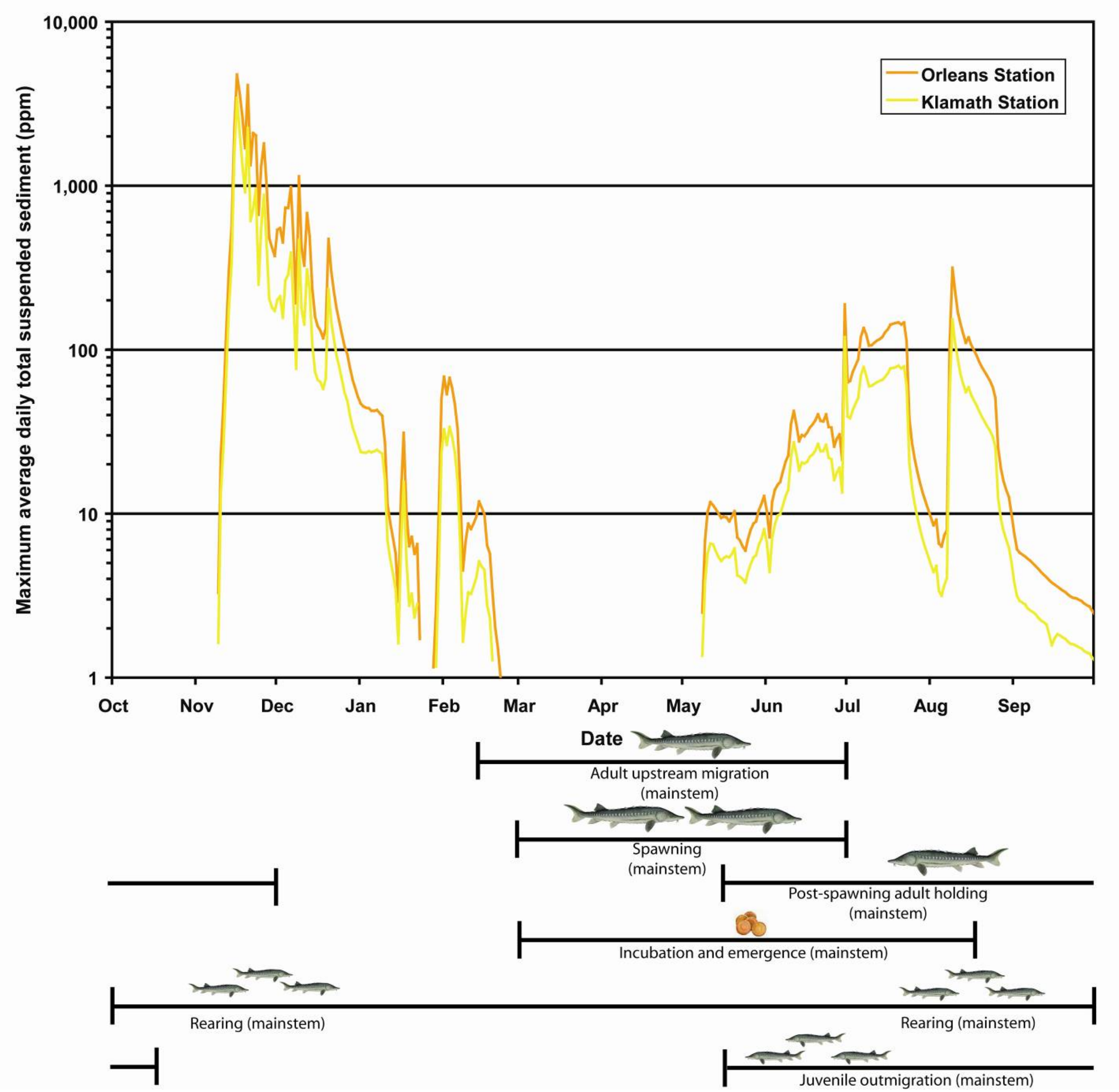

Figure 77. Average daily total suspended sediment concentrations in the Klamath River downstream of Orleans based on the DREAM-1 wettest year model simulation (Run 44, Stillwater Sciences 2008), with life-history timing for green sturgeon.

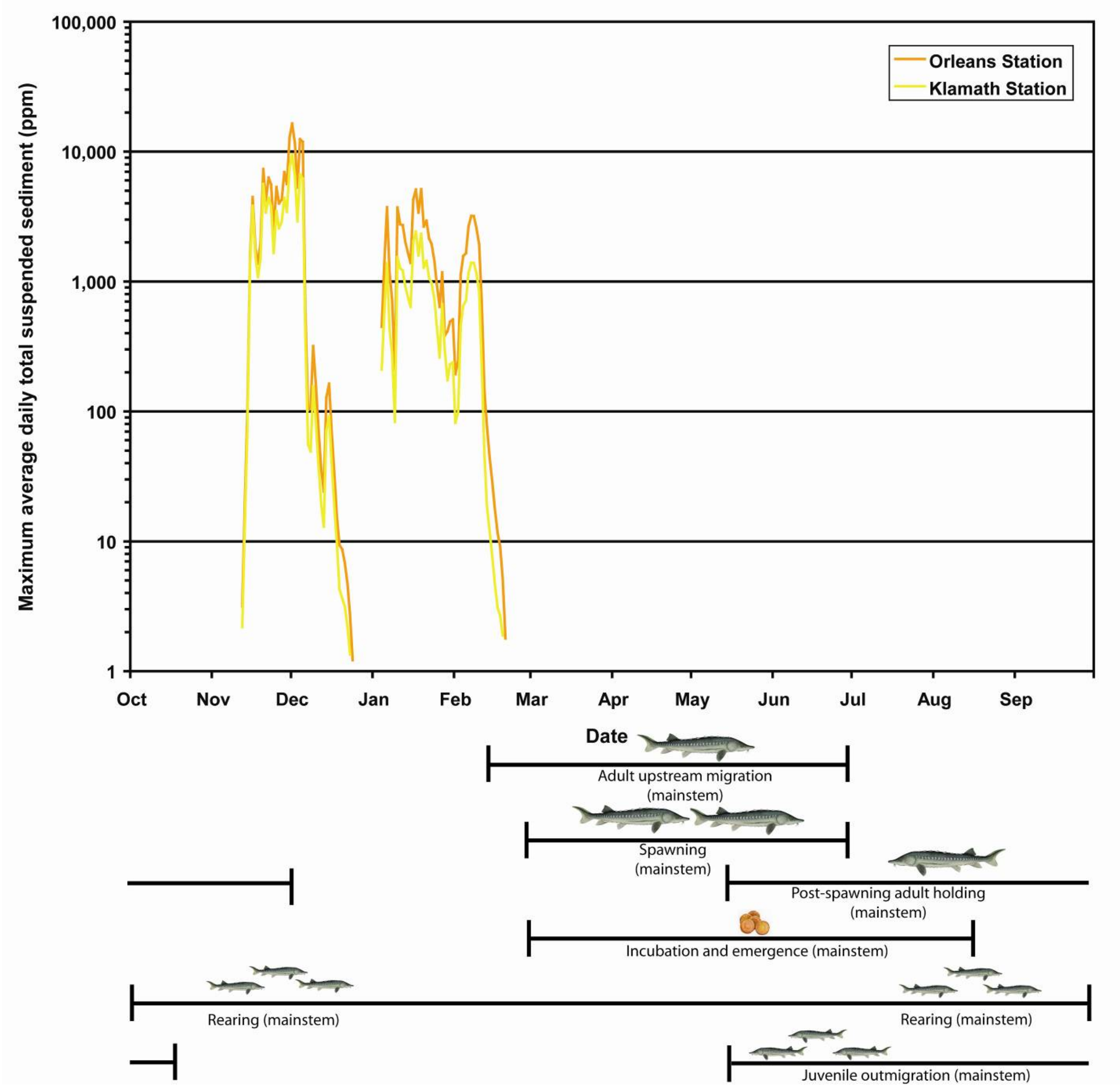

Figure 78. Average daily total suspended sediment concentrations in the Klamath River downstream of Orleans based on the DREAM-1 driest year model simulation (Run 54, Stillwater Sciences 2008), with life-history timing for green sturgeon.

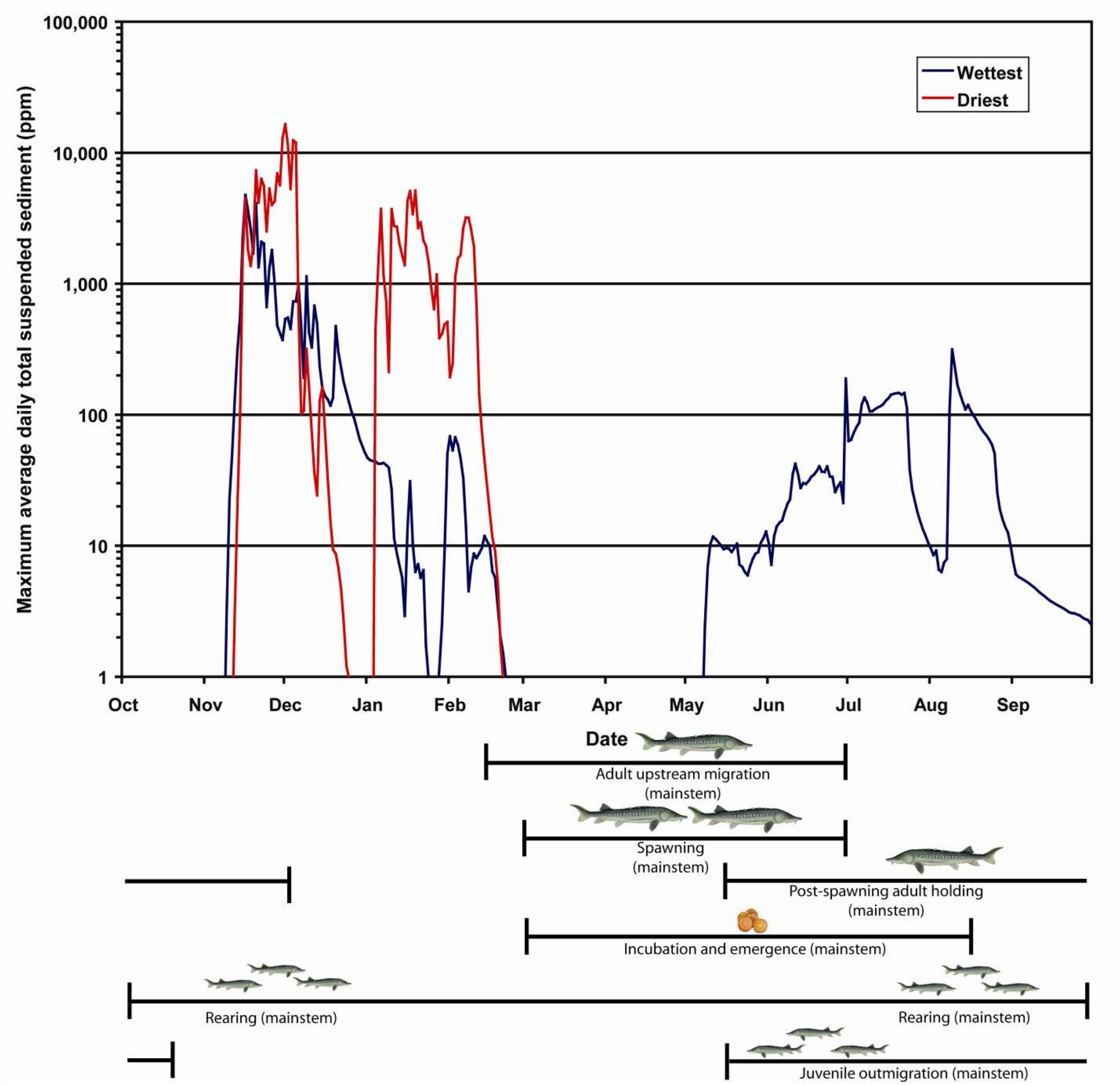

Figure 79. Average daily total suspended sediment concentrations in the Klamath River at the Orleans based on the DREAM-1 wettest and driest year model simulations (Runs 44 and 54, Stillwater Sciences 2008), with life-history timing for green sturgeon.