Appendix E
An Analysis of Potential Suspended Sediment Effects on Anadromous Fish in the Klamath Basin

E.1 Introduction

Removing the four dams in the mid-Klamath River (the "Proposed Action") could release up to 1.2-2.9 million metric tons of fine sediment (sand, silt, and finer) downstream (Bureau of Reclamation [Reclamation] 2011), resulting in high suspended sediment loads and local, short-term sediment deposition. The downstream transport of this sediment, currently stored in reservoir deposits, can affect downstream habitats as both suspended sediment and bedload. Among other impacts, elevated suspended sediment concentrations (SSC) may clog or abrade the gills of fish or prevent them from foraging efficiently, and as the material settles on the streambed, it can reduce the survival of incubating eggs and developing alevins in salmonid redds by impeding intergravel flow as well as the emergence of fry.

This report describes a modeling analysis of the potential effects of suspended sediment on anadromous fish populations in the Klamath Basin under existing conditions and the No Action/No Project Alternative, as well as under the Proposed Action. Available data on suspended sediment under existing conditions in the Klamath River upstream and downstream of Iron Gate Dam (summarized in Section 3.2.3, Water Quality – Existing Conditions/Affected Environment) were determined to be insufficient for conducting this type of analysis. To compensate for this shortfall, the Reclamation used suspended sediment data collected by the United States Geological Survey at the (1) Shasta River near Yreka, (2) Klamath River near Orleans, and (3) Klamath River at Klamath gauges to estimate daily suspended sediment concentrations (milligrams per liter [mg/l]) as a function of flow (cfs) using the SRH-1D 2.4 sediment transport model (Sedimentation and River Hydraulics–One Dimension Version 2.4) (Huang and Greimann 2010, USBR 2011), hereafter referred to as "the model." Daily SSC were modeled for water years 1961 through 2008 to represent existing conditions and the No Action/No Project Alternative, as well as for the year following removal of the dams (Water Year 2020-2021) under multiple drawdown scenarios (Reclamation 2011).

E.2 Methods

The analysis of the potential effects of suspended sediment on aquatic species in the Klamath River followed a five-step process similar to that used in prior modeling of these effects conducted by Stillwater Sciences (2008, 2009a, 2009b):

1. Select appropriate focal species for the analysis;

2. Use the model to predict SSC regimes for existing conditions and the No Action/No Project Alternative, and alternatives;

3. Describe the potential effects of the predicted concentrations on the various life stages of each focal species using available information; and

4. Evaluate the potential consequences of suspended sediment for focal species' populations under existing conditions and the No Action/No Project Alternative, and alternatives.

E.2.1 Focal Species Selection

Focal species selected for the analysis were expected to meet the following criteria:

1. Species historically native to, and still found within the Klamath Basin downstream of Iron Gate Dam, and within the area of primary effect (i.e., upstream of the confluence with Trinity River);

2. Species that are listed or proposed for listing under the Federal or State Endangered Species Acts, or

3. Species without special regulatory status that meet other criteria, such as: species having high economic or public interest value, species believed to be important interactors within the affected ecosystem ("key species"), species believed to be strong indicators of the overall health of aquatic communities ("indicator species"), or those whose presence is believed to reflect habitat conditions for a large suite of species ("umbrella species"); and

4. Species for which sufficient information is available to allow at least a qualitative assessment of their response to increases in suspended sediment.

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

- Chinook salmon (fall- and spring-runs)
- coho salmon
- steelhead (summer and fall/winter runs)
- Pacific lamprey
- green sturgeon

E.2.2 Using the Model to Predict Suspended Sediment Concentrations

Predictions of suspended sediment concentrations used in this analysis were based on the sediment transport model, which:

1. Predicts SSC as a continuous time series following facility removal;

2. Predicts the exceedance duration (number of consecutive days) for specific SSC ranges within time periods corresponding to specific life-history stages of the focal species (such as upstream migration); and,

3. Predicts the downstream dilution of SSC at important locations within the distributions of the focal species where gauging data are available, including Iron Gate Dam, Seiad Valley, Orleans, and Klamath Station.

The model was used to predict the magnitude and duration of suspended sediment concentrations for discrete calendar-year periods corresponding to each species' life history stages. These periods could not overlap in order to avoid erroneously accounting for an event's impact on two separate life stages of a cohort at the same time, which is impossible; e.g., a pulse of suspended sediment in March cannot simultaneously affect rearing juveniles and outmigrating smolts of the same cohort.

E.2.2.1 Range of Conditions Assessed

Modeling results are very sensitive to hydrology. Effects during winter are predicted to be more severe during a dry year when low reservoir levels expose more sediment in January. Effects during spring (when smolt outmigration generally occurs) are more severe during a wet year, when it is predicted that the reservoirs could re-fill during winter delaying the release of SSC until they drop during spring (Reclamation 2011). Daily durations of SSC concentrations were modeled assuming the Proposed Action occurred within each of the 48 years in the available hydrology record since 1961. The results of modeling all potential years were summarized for each life-stage of each species assessed. Because the suspended sediment varies with hydrology, and in order to account for (and compare) the range of results and impacts that might occur under each alternative, two scenarios were analyzed for existing conditions and the No Action/No Project Alternative, and for action alternatives, with the goal of predicting the potential impacts to fish that has either a 50 percent (likely to occur) or 10 percent (unlikely, or worst case) probability of occurring, defined as follows:

For Existing Conditions and the No Action/No Project Alternative:

- **Normal conditions:** suspended sediment concentrations and durations with a 50 percent exceedance probability for the mainstem Klamath River downstream of Iron Gate Dam (i.e., the probability of these concentrations and durations being equaled or exceeded for each assessed species and life-stage in any one year is 50 percent). Exceedance probabilities were based on modeling SSC for all water years subsequent to 1961 with facilities in place. To assess "normal conditions" the median (50 percent) suspended sediment concentration and duration from these results was estimated.

- **Extreme conditions:** suspended sediment concentrations and durations with a 10 percent exceedance probability; i.e., the probability of these concentrations and durations being equaled or exceeded for each assessed species and life-stage in any 1 year is 10 percent).

For the Proposed Action– Full Facilities Removal of Four Dams:

- **Most likely scenario:** suspended sediment concentrations and durations with a 50 percent exceedance probability for the mainstem Klamath River downstream of Iron Gate Dam (i.e., the probability of these concentrations and durations being equaled or exceeded for each assessed species and life-stage in any one year is 50 percent). Exceedance probabilities were based on the results of modeling suspended sediment in the Klamath River downstream of Iron Gate Dam using hydrologic data for all water years observed since 1961 with facility removal. To assess the "most likely scenario" the median (50 percent exposure concentration) was estimated.

- **Worst-case scenario:** suspended sediment concentrations and durations with a 10 percent exceedance probability; i.e., the probability of these concentrations and durations being equaled or exceeded for each assessed species and life-stage in any 1 year is 10 percent).

E.2.3 Effects Analysis

Based on a review of the scientific literature, the most commonly observed effects of suspended sediment on salmonids include: (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 necessary for understanding the potential severity of its effects on salmonids (Newcombe and MacDonald 1991); e.g., 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 exacerbated if pollutants or other stressors (e.g., water temperature, disease) are present as well. Turbidity can function as cover to reduce predation at some life stages, not only in riverine, but also in estuary and nearshore marine environments (Gregory and Levings 1998, Wilber and Clarke 2001, Gadomski and Parsley 2005). Some species have been shown to be attracted to turbid water over clear, which may reflect its use as cover (Gradall and Swenson 1982, Cyrus and Blaber 1992, both as cited in Wilber and Clarke 2001). This analysis will consider these other factors qualitatively, but not quantitatively, in assessing the effects 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 mg/l 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 e.g., review by Cordone and Kelly 1961).” At very high concentrations (e.g., 20,000 to 30,000 mg/l), juvenile salmon may survive short-term exposures, but their survival may be subsequently affected by slower response times for seeking cover and avoiding predators (Korstrom and Birtwell 2006). Based on the results of laboratory studies, it appears that relatively short-term exposures to increases in suspended sediment concentrations under 500–600 mg/l 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 for weeks or months, however, direct mortality (10–20 percent of individuals exposed) is expected (Newcombe and Jensen 1996).

Potential population-level effects 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. In this analysis the results of Newcombe and Jensen (1996) were used to assess impacts of SSC on aquatic species. 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 (Table E-1) for various species and life stages based on the duration of exposure and concentration of suspended sediment present. The severity of ill effects provides a ranking of the effects of SSC on salmonid species, as calculated by any of six equations that address various taxonomic groups of fishes, life stages of species within those groups, and particle sizes of suspended sediments.

Assessing the potential effects of suspended sediment on anadromous fish species required identifying the spatial and temporal distribution of each life stage in the Klamath Basin relative to expected areas of elevated suspended sediment. For each focal species and life stage, potential effects were determined by evaluating the magnitude and duration of SSC predicted by the model for the mainstem Klamath River at times and locations where the life stage of any focal species is likely to be present. For salmonids, Newcombe and Jensen’s (1996) Severity of Ill Effects table (Table E-1) was used to rate the severity of exposure to suspended sediment. The values for suspended sediment concentrations were divided into ranges (33–90 mg/l, 90–245 mg/l, 245–685 mg/l, and so on) based on those used in Newcombe and Jensen (1996). Wherever possible, effects were quantified based on the percentage of the cohort predicted be in the mainstem during suspended sediment events, considering both spatial distribution (proportion of the life stage expected to be in the mainstem compared to tributaries; proximity to Iron Gate

Dam) and life-history timing (proportion of the population expected to be present during period of effect).

Table E-1. Scale of the Severity of Ill Effects Associated with Elevated Suspended Sediment (based on Newcombe and Jensen 1996).

Severity	Category of Effect	Description of Effect
0	Nil effect	No behavioral effects
1		Alarm reaction
2	Behavioral effects	Abandonment of cover
3		Avoidance response
4		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	Sublethal effects	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		Reduced growth rate: Delayed hatching Reduced fish density
10	Lethal effects	0–20% mortality Increased predation of effected fish
11		>20–40% mortality
12		>40–60% mortality
13		>60–80% mortality
14		>80–100% mortality

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), and their report remains the best available source for determining effects of SSC on salmonids (Berry et al. 2003). However, there are inherent sources of uncertainty in this application of the model. Newcombe and Jensen (1996) base much of their analysis on laboratory studies that were conducted in controlled environments over short-durations, mostly examining acute lethal impacts of non-fluctuating concentrations of suspended sediment. This analysis is a relatively complex application of the Newcombe and Jensen (1996) model, in that temporal variation in SSC within periods is captured by summing continuous days of exposure in various concentration categories of suspended sediment. This means that three occurrences of exposure to extreme sediment each lasting for two days can be, for example, equivalent to a severity of ill effect predicted for 6 continuous days. How the actual outcome will vary from predictions is uncertain. In addition, Newcombe and Jensen (1996) do not explicitly address the translation of sublethal severity levels into population-level effects. As Gregory et al. (1993) note in their criticism of Newcombe and Jensen, the approach simplifies the effects of suspended sediment and in doing so assumes all effects of suspended sediment are negative, despite literature to the contrary. This exaggerates the effects of suspended sediment, particularly for lower concentrations and durations of exposure. Although the predictions of mortality at high concentrations and durations of exposure are considered more certain than the predictions of sublethal effects, in this application sublethal effects resulting from exposure to lower concentrations are included because of the concern that following sublethal impacts of suspended sediment could be adverse when occurring in conjunction with the already stressed condition of some species and life-stages from water temperature (Bozek and Young 1994) and disease.

Because of their relative importance within the watershed, potential impacts of SSC on Pacific lamprey (*Lampetra tridentata*) and green sturgeon (*Acipenser medirostris*) were assessed. However, little scientific literature exists regarding the effects of SSC on these species. The models developed by Newcombe and Jensen (1996) for assessing impacts to nonsalmonids were used in this analysis to assess effects on Pacific lamprey and green sturgeon, in conjunction with discussions with experts regarding the potential effects.

E.3 Results

E.3.1 Existing Conditions and No Action/No Project Alternative

Information on sediment transport within the Klamath Basin is available from Stillwater Sciences 2010 and USBR 2011. The current supply of coarse and fine sediment can be summarized, as follows:

- Upstream of Keno Dam, sediment supply to the Klamath River is minimal due to deposition in Upper Klamath Lake, which captures nearly all sediment entering from its tributaries.
- Between Keno Dam and Iron Gate Dam, total average annual sediment delivery is an estimated 200,000 tons/year.
- Downstream of Iron Gate Dam, the Scott, Salmon, and Trinity Rivers supply approximately 607,000 tons/year; 320,000 tons/year; and 3.3 million tons/year, respectively.

Section 3.2.3 (Water Quality – Existing Conditions/Affected Environment) summarized suspended sediment concentrations under existing conditions in the Klamath River upstream and downstream of Iron Gate Dam. In general, the data indicate that suspended sediment downstream of Iron Gate Dam ranges from less than 5 mg/l during summer low flows to greater than 5,000 mg/l during winter high flows (Section 3.2.3.3). Daily SSC were modeled for water years 1961–2008 (Reclamation 2011) (Figures E-1 and E-2).

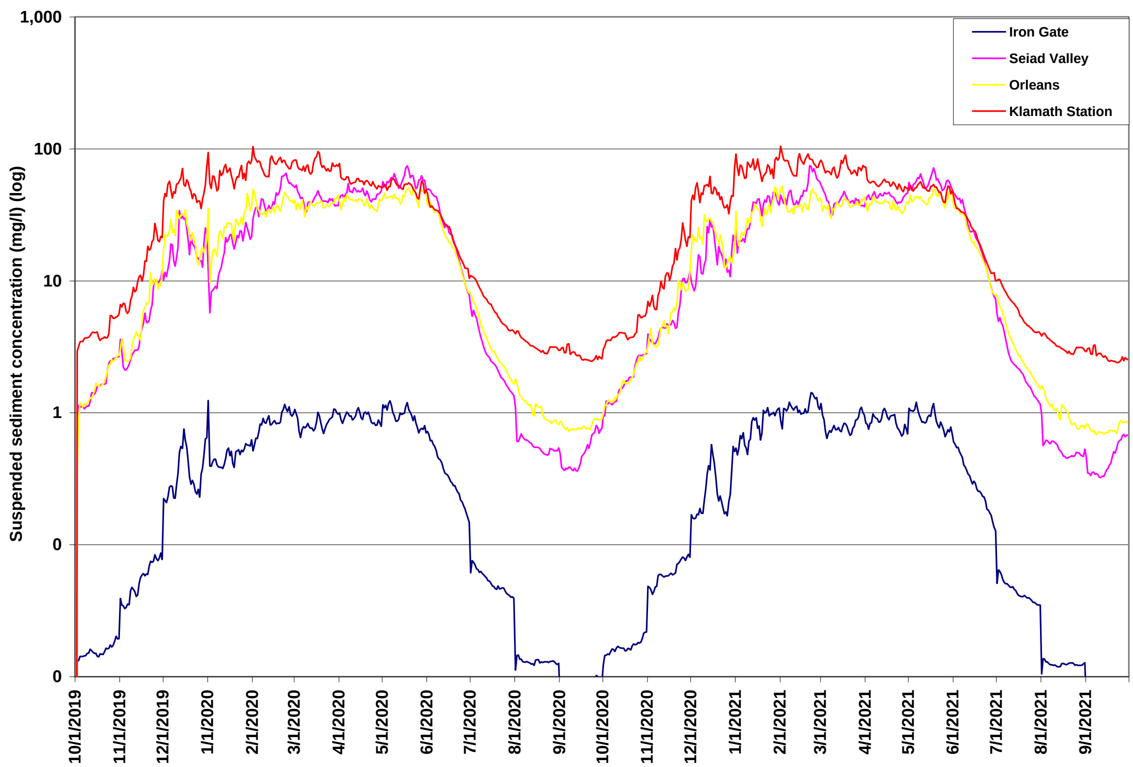

Figure E-1. Normal Conditions (50% exceedance probability) Suspended Sediment Concentrations at Three Locations Downstream of Iron Gate Dam under Existing Conditions, as predicted using the SRH-1D model.

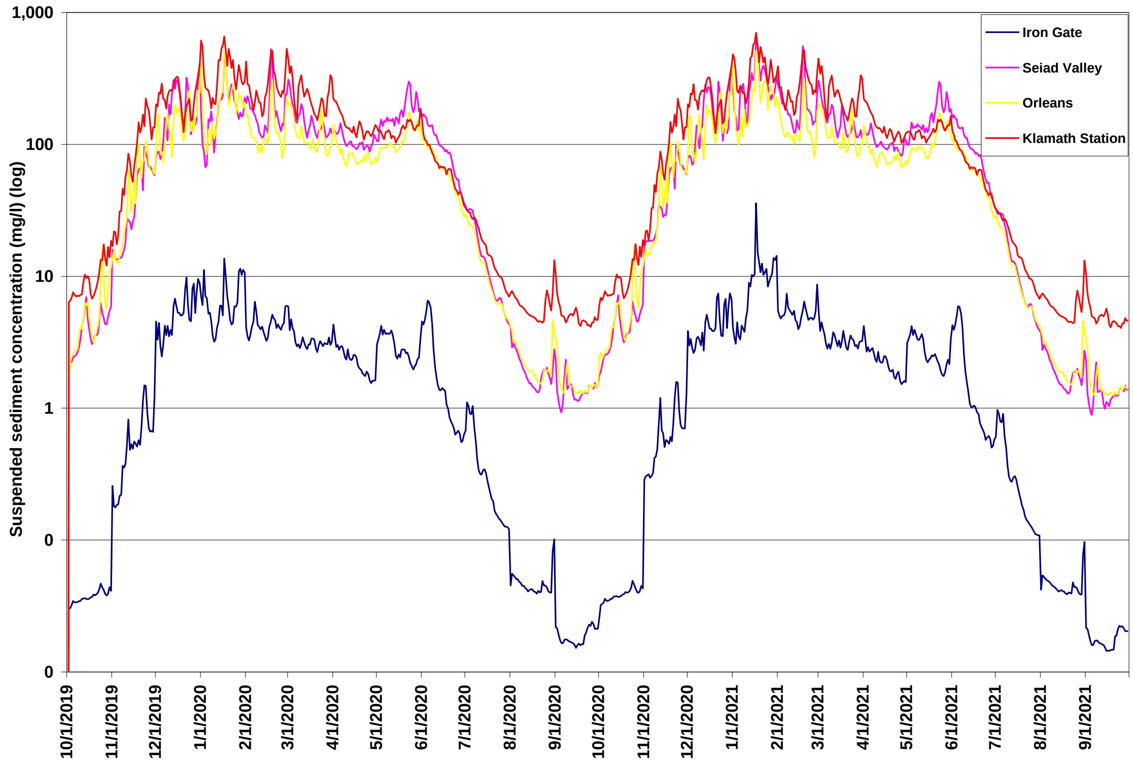

Figure E-2. Extreme Conditions (10% exceedance probability) Suspended Sediment Concentrations at Three Locations Downstream of Iron Gate Dam under Existing Conditions, as Predicted using the SRH-1D Model.

E.3.1.1 Fall-run Chinook Salmon

Fall-run Chinook salmon range throughout the Klamath River and its tributaries downstream of Iron Gate Dam. The largest number of spawners are found in the Trinity River (36 percent), Bogus Creek (11 percent), Shasta River (7 percent), Scott River (7 percent), and the Salmon River (3 percent), based on escapement data collected from 1978 to 2002 (FERC 2006). They also spawn in the mainstem, with the highest densities of redds found between Iron Gate Dam (River Mile [RM] 310.3) and the Shasta River (RM 288) (Magneson 2006).

Fall-run Chinook salmon in the Klamath Basin exhibit three juvenile life-history types: Type I (ocean entry at age 0[1] in early spring within a few months of emergence), Type II (ocean entry at age 0 in fall or early winter), and Type III (ocean entry at age 1 in spring) (Sullivan 1989). Based on outmigrant trapping at Big Bar on the Klamath River from 1997 to 2000, 63 percent of natural Chinook salmon outmigrants are Type I, 37 percent are Type II, and less than 1 percent are Type III (Scheiff et al. 2001). Although, trapping efforts are not equal among seasons, the results are consistent with scale analysis of adult

[1] A fish emerging in spring is designated as age 0 until January 1st of the following year, when it is designated as age 1 until January 1st of the next year, when it is designated age 2.

returns by Sullivan (1989). Large numbers of fry from the Shasta River, Scott River, and Hunter and Blue creeks move into the mainstem Klamath River in spring, where they may continue to rear before outmigrating to the ocean (Chesney 2000, Chesney and Yokel 2003). Few age-0 juveniles are observed in the mainstem Klamath River or Trinity River in the fall; most have probably already outmigrated in early fall as Type II smolts.

Fall Chinook salmon typically migrate upstream in late summer and early fall when suspended sediment concentrations are usually very low in the Klamath River. Spawning typically peaks in late October and substantially declines by the end of November (Shaw et al. 1997). The SRH-1D SSC modeling analysis does not account for stress or mortality that might result from infiltration of fine sediment into the channel bed because no suitable measurements or models were available with which to calculate this component. Under normal conditions, suspended sediment is predicted to result in minimal stress on spawning adults, eggs, alevins, and fry in the mainstem because of sediment capture by the dams and time of year (Table E-2), but may cause reduced size at emergence under extreme conditions (Table E-3) as well as further downstream where concentrations would be expected to be higher due to accretion from tributary streams.

Most fry produced by fall-run Chinook salmon in the Klamath River exhibit the Type I life history, in which they enter the ocean within a few months of emergence in early spring. Age 0 fry rearing in the mainstem during late winter for a period of a month prior to outmigration are anticipated to have moderate to major physiological stress under normal and extreme conditions respectively. Using radio-tag data, Foott et al. (2009) reported that it took hatchery Chinook smolts a median of 10.2 days to travel the 184 miles from Iron Gate Dam to Blake’s Riffle (RM 8). Wallace (2004) reported that it took radio-tagged hatchery Chinook smolts a median of 30–34 days (range 13–109 days) to travel from the hatchery to the estuary. Based on these studies, the analysis assumed a maximum duration of exposure to suspended sediment during migration of 30 days. In a normal year under existing conditions and the No Action/No Project Alternative, suspended sediment in the mainstem is predicted to be at concentrations resulting in major physiological stress for Type I fry during their 30-day migration. In either scenario, this exposure, although not predicted to result in direct mortality, could indirectly affect survival by reducing growth and thus the size at which the smolts enter the ocean (Bilton 1984). Exposure to disease or elevated temperatures in the mainstem would likely result in the mortality of some portion of these fish. The parr-smolt transformation can also be compromised in stressed juveniles (Wedemeyer and McLeay 1981, as cited in Bash et al. 2001), which could increase mortality.

Table E-2. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Fall-Run Chinook Salmon under Normal Conditions (50% exceedance probability), for Klamath River at Iron Gate Dam (adult migration, spawning, incubation, and fry emergence life stages) and Seiad Valley (juvenile rearing and outmigration life stages).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migrants (Jul 15–Oct 31)	0	0	0	No effect
Spawning, incubation, and fry emergence (Oct 15–Feb 28)	0	0	0	~8 % of adults spawn in the mainstem downstream of Iron Gate Dam where suspended sediment is low due to capture of sediment by Iron Gate Dam
Juvenile rearing (year-round)	245 to 665	2	8	Major stress
	90 to 245	9	8	
	33 to 90	22	8	
Type I outmigration (Apr 1–Aug 31)	90 to 245	5	8	Major stress for Type I fry (~60% of all production)
	33 to 90	17	8	
Type II outmigration (Sept 1–Nov 30)	0	0	0	No effect
Type III outmigration (Feb 1–Apr 15)	245 to 665	<1	7	Moderate to major stress for Type III (yearling) outmigrants (<1% of production)
	90 to 245	4	8	
	33 to 90	11	8	

Table E-3. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Fall-Run Chinook Salmon under Extreme Conditions (10% exceedance probability), for Klamath River at Iron Gate Dam (adult migration, spawning, incubation, and fry emergence life stages) and Seiad Valley (juvenile rearing and outmigration life stages).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migrants (Jul 15–Oct 31)	0	0	0	No effect
Spawning, incubation, and fry emergence (Oct 15–Feb 28)	33 to 90	2	9	~8 % of adults spawn in the mainstem downstream of Iron Gate Dam where suspended sediment is low due to capture of sediment by Iron Gate Dam
Juvenile rearing (year-round)	1,808 to 4,915	1	9	Major stress, reduced growth, and up to 20% mortality for age 1 rearing in the mainstem.
	665 to 1,808	2	8	
	245 to 665	7	9	
	90 to 245	25	9	
	33 to 90	39	9	
Type I outmigration (Apr 1–Aug 31)	245 to 665	5	8	Major stress and reduced growth for Type I fry (~60% of all production).
	90 to 245	20	9	
	33 to 90	30	8	
Type II outmigration (Sept 1–Nov 30)	245 to 665	1	7	Short-term (1 wk) moderate stress.
	90 to 245	1	7	
	33 to 90	5	7	
Type III outmigration (Feb 1–Apr 15)	665 to 1,808	2	8	Major stress for Type III (yearling) outmigrants (<1% of production).
	245 to 665	4	8	
	90 to 245	14	8	
	33 to 90	27	8	

The Type II life history is also common among Klamath River fall-run Chinook. These juveniles remain to rear in the tributaries in which they were spawned (Section 3.3.3.1) and are only exposed to suspended sediment in the mainstem on their outmigration to the ocean in the fall, when SSC are lowest. In a normal year under existing conditions and the No Action/No Project Alternative, no adverse effects of suspended sediment are predicted for these fish, while in a year of extreme conditions, concentrations may cause avoidance, reduced feeding, and moderate physiological stress for approximately one week. Additional factors such as disease or elevated temperatures in the lower Klamath River are less likely to increase the impacts of suspended sediment on these fish than for other life-history types, because neither disease or water temperature are problems in the Klamath River mainstem during the fall when Type II smolts outmigrate.

Type III life-history fish are relatively rare (<1 percent of all production) in the Klamath River fall-run population (USFWS 2001), although based on Sullivan (1989) these larger smolts can contribute around 4 percent of the escapement. These fish typically remain to rear in the spawning tributaries until outmigrating in late winter and early spring as yearlings. In a normal year, the model predicts that suspended sediment will cause moderate to major physiological stress for about two weeks, but under extreme conditions, exposure to suspended sediment is predicted to remain at levels producing major stress for the approximately one month it takes for them to reach the sea, but growth may not be substantially affected.

Overall, fall-run Chinook salmon use the mainstem Klamath River for spawning, rearing, and as a migratory corridor. Although SSCs under existing conditions and the No Action/No Project Alternative are relatively high in the mainstem downstream of Orleans, and even more so downstream of the Trinity River (State Water Resource Control Board [SWRCB] 2006, North Coast Regional Water Quality Control Board [NCRWQCB] 2010) (Section 3.2.3), they are relatively low in the reach downstream of Iron Gate Dam where most mainstem spawning occurs. Suspended sediment concentrations and durations during upstream and downstream migration, even under extreme conditions, are low enough that effects are limited to physiological stress and possibly reduced growth rates. In general, fall-run Chinook salmon appear relatively resilient to current suspended sediment conditions because of their limited use of the mainstem for spawning and rearing, and the fact that smolt outmigration primarily occurs when SSC are naturally low.

E.3.1.2 Spring-run Chinook Salmon

Spring-run Chinook salmon spawn primarily in the Salmon and Trinity rivers, with the vast majority (~95 percent) spawning in the Trinity River; therefore, the review of existing conditions and the No Action/No Project Alternative focuses on potential exposure to suspended sediment in the mainstem Klamath River downstream of the Salmon River.

Sediment-transport model predictions for suspended sediment and associated effects on spring-run Chinook salmon under normal and extreme conditions are summarized in Table E-4 and E-5, respectively. Under normal conditions, adult spring-run migrants returning to the Salmon River may be exposed to suspended sediment concentrations that cause moderate stress and impaired homing, but because the span of elevated concentrations is only around two weeks, some migrants may avoid exposure altogether. Under extreme conditions, concentrations may increase slightly, but the duration of exposure may double. Adults migrating to the Trinity River may only be exposed to suspended sediment in the mainstem for about a week, and those migrating to the Salmon River about two weeks (Strange 2007a, 2007b, 2008).

Table E-4. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Spring-Run Chinook Salmon under Normal Conditions (50% exceedance probability), for Klamath River at Orleans (RM 58).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult spring migration (Apr 1–June 30)[a]	90 to 245	2	7	Impaired homing for adults returning to Salmon River. Majority (~95% on average) of adults enter Trinity River, and will be exposed to higher concentrations for shorter durations. However, up to 35% of “natural” escapement returns to Salmon River.
	33 to 90	14	7	
Adult summer migration (Jul 1–Aug 31)[b]	0	0	0	No effect to the ~50% of the summer migration returning exclusively to the Trinity River.
Spawning, incubation, and fry emergence (Sept 1–Feb 28)	n/a	n/a	n/a	Spring-run do not generally spawn in the mainstem.
Juvenile rearing (variable)	n/a	n/a	n/a	Juveniles primarily rear in tributaries; no effect is anticipated.
Type I outmigration (Apr 1–May 31)[c]	90 to 245	2	7	Major stress for Type I fry (~80% of production) in smolt outmigration from Salmon River. Majority (~95%) of juveniles outmigrate from Trinity River, and are exposed to higher concentrations
	33 to 90	18	8	
Type II outmigration (Oct 1–Nov 15)[c]	0	0	0	No effect for Type II smolts from the Salmon River (~20 percent) during downstream migration. Majority (~95%) of juveniles outmigrate from Trinity River and are exposed to higher concentrations.
Type III outmigration (Jan 15–May 31)[c]	245 to 665	<1	7	Major stress for Type III fry from Salmon River (<1%) during downstream migration. Majority (~95 %) of juveniles outmigrate from Trinity River and are exposed to higher concentrations for shorter durations. Outmigrate from Trinity River and are exposed to higher concentrations for shorter durations.
	90 to 245	5	8	
	33 to 90	20	8	

a Maximum duration of exposure during migration = 14 days
b Maximum duration of exposure during migration = 2 days
c Maximum duration of exposure during migration = 30 days

Table E-5. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Spring-Run Chinook Salmon under Extreme Conditions (10% exceedance probability), for Klamath River at Orleans (RM 58).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult spring migration (Apr 1–June 30)[a]	245 to 665	<1	7	Impaired homing and major stress for adults returning to Salmon River. Majority (~95% on average) of adults enter Trinity River, and will be exposed to higher concentrations for shorter durations. However, up to 35% of “natural” escapement returns to Salmon River.
	90 to 245	14	8	
	33 to 90	14	7	
Adult summer migration (Jul 1–Aug 31)[b]	33 to 90	<1	6	Moderate stress for the ~50% of the summer migration returning exclusively to the Trinity River.
Spawning, incubation, fry emergence (Sept 1–Feb 28)	n/a	n/a	n/a	Spring-run do not generally spawn in the mainstem.
Juvenile rearing (variable)	n/a	n/a	n/a	Juveniles primarily rear in tributaries; no effect to this life stage is anticipated.
Type I outmigration (Apr 1–May 31)	90 to 245	12	8	Major stress for Type I fry (~80%) in smolt outmigration from Salmon River. Majority (~95 %) of juveniles outmigrate from Trinity River, and are exposed to higher concentrations.
	33 to 90	30	8	
Type II outmigration (Oct 1–Nov 15)[c]	90 to 245	1	7	Moderate stress for Type II smolts from the Salmon River (~20%) during downstream migration. Majority (~95 %) of juveniles outmigrate from Trinity River and are exposed to higher concentrations.
	33 to 90	2	6	
Type III outmigration (Jan 15–May 31)[c]	665 to 1,808	1	8	Major stress for Type III fry from Salmon River (<1%) during downstream migration. Majority (~95%) of juveniles outmigrate from Trinity River and are exposed to higher concentrations.
	245 to 665	5	8	
	90 to 245	13	8	
	33 to 90	30	8	

a Maximum duration of exposure during migration = 14 days
b Maximum duration of exposure during migration = 2 days
c Duration of exposure during migration = 30 days

In some years, later-arriving adults have been observed to delay migration upon encountering high water temperatures in the mainstem (>22°C) and hold in the river for up to 30 days before continuing on to their spawning streams (Strange 2007a, 2007b, 2008). These fish could be exposed to elevated suspended sediment for longer durations, particularly in extreme years. 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 and coho salmon (*Oncorhynchus kisutch*) adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., 2008). Among radio-tagged adult spring Chinook, these later-returning migrants have been observed to have the highest mortality rates (Strange 2007a, 2007b, 2008). In contrast, around half of the observed spring Chinook salmon adults make a relatively rapid summer migration (~2 days in the Klamath River) to the Trinity River, at which time of year suspended sediment is naturally low under both normal and extreme conditions.

Since no spring-run Chinook salmon spawning occurs in the mainstem Klamath River under existing conditions and the No Action/No Project Alternative, incubating eggs, developing alevins, and emergent fry are not anticipated to be affected by suspended sediment in the mainstem).

There appear to be three juvenile life-history types for spring-run Chinook salmon in the Klamath Basin: Type I (ocean entry at age 0 in early spring within a few months of emergence), Type II (ocean entry at age 0 in fall or early winter [Olson 1996]), and Type III (ocean entry at age 1 in spring) (Sullivan 1989). Based on outmigrant trapping in the Salmon River from 2001 to 2006 (Karuk Tribe, unpubl. data), around 80 percent of outmigrants are Type I, 20 percent are Type II, and less than 1 percent are Type III. Rearing of age-0 juveniles likely occurs to some extent in the mainstem Klamath River, although it appears that the majority remain to rear in their natal streams (i.e., Salmon and Trinity rivers). It is unclear to what extent juvenile spring-run Chinook rear in the mainstem Trinity and Klamath Rivers as trapping studies do not differentiate between the spring and fall runs.

Most late-winter rearing of Type I and II juveniles is thought to occur in tributaries (West 1991; Dean 1994, 1995), reducing the likelihood of exposure to suspended sediment in the mainstem. Type I juveniles migrate downstream to the mainstem and ocean in April and May. Based on radio-tagging studies of Chinook salmon smolt travel times, a maximum of 30 days is assumed for exposure of outmigrating smolts. Under both normal and extreme conditions, exposure to suspended sediment during Type I smolt outmigration is anticipated to result in major physiological stress. This exposure, in association with other environmental factors in the basin (e.g., water temperatures, exposure to disease), could lead to mortality or reduced fitness. The Type II outmigration pattern is common (~20 percent),with juveniles departing from the Salmon River in the fall when suspended sediment downstream of the Salmon River is too low to have an effect under normal conditions, and only slightly higher under extreme conditions when concentrations may cause moderate physiological stress for a few days. Age-1 juveniles of the Type III life history outmigrating during winter and early spring may be exposed to suspended sediment concentrations causing major physiological stress under both normal and extreme conditions.

E.3.1.3 Coho Salmon

In order to evaluate the affects of suspended sediment on coho salmon in the Klamath River, the historical population structure of Southern Oregon Northern California Coast coho salmon presented in Williams et al. (2006) was used, as described in Section 3.3.3.1. Williams et al. (2006) identifies nine populations within the Klamath River, including the Upper Klamath River, Shasta River, Scott River, Salmon River, Mid-Klamath River, Lower Klamath River, and three population units within the Trinity River watershed (Upper Trinity River, Lower Trinity River, and South Fork Trinity River population units). Affects of SSC on distinct population units are differentiated where appropriate.

Coho salmon are distributed throughout the Klamath River downstream of Iron Gate Dam, and spawn primarily in tributaries (Trihey and Associates 1996, National Research Council [NRC] 2004). Rearing has also been observed in tributary confluence pools in the mainstem Klamath River (T. Shaw, USFWS, unpubl. data, 2002; as cited in NRC 2004). During their upstream migration, adult coho salmon from the Upper Klamath River Population Unit may travel upstream as far as Iron Gate Dam (RM 190.1) and were formerly known to occupy mainstem and tributary habitat at least as far upstream as Spencer Creek at RM 228 (NRC 2004, as cited in National Marine Fisheries Service [NOAAFisheries] 2007). Thus, the mainstem Klamath River functions primarily as a migration corridor for coho salmon, but also likely provides rearing habitat and allows for movement of juvenile fish between tributaries.

The vast majority of coho salmon that spawn in the Klamath Basin are believed to be of hatchery origin. Indirect estimates indicate 90 percent of adult coho salmon in the system return directly to hatcheries or spawning grounds in the immediate vicinity of hatcheries (Brown et al. 1994). This analysis of SSC effects pertains to the adults and progeny of both hatchery-returning adults and those that spawn in the river, differentiating between the two where possible.

Upstream migration of adult coho salmon in the Klamath River spans the period from September to January, with peak movement occurring between late-October and mid-November. As this is the only period when adults are present in the mainstem Klamath River, it is also the only period when they would be exposed to elevated suspended sediment in the mainstem. Under both normal and extreme conditions concentrations would be stressful (Tables E-6, E-7); however, the duration of time over which the exposure occurs is relatively short (<2 wk). Adults from the Trinity River population units and the Lower Klamath River Population Unit likely receive less exposure to suspended sediment due to shorter migration times than for populations further upstream.

Table E-6. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Coho Salmon under Normal Conditions (50% exceedance probability), for Klamath River at Seiad Valley (RM 129.4).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migrants (Sept 1–Jan 1)	90 to 245	2	7	SSC only predicted to be in stressful range for 5 days. Adverse effects on adults assumed unlikely due to short period of exposure (5 days) that may only coincide with a portion of the run.
	33 to 90	3	7	
Spawning, incubation, and fry emergence (Nov 1–Mar 14)	245 to 665	2	10	No modeling of suspended sediment infiltration into gravel was conducted. Available information suggests low survival (<2%) of spawning adults, incubating eggs, and emergent fry in the mainstem; typically a small percentage of the percent of the Upper Klamath River Population spawns in the mainstem as opposed to tributaries.
	90 to 245	4	10	
	33 to 90	9	11	
Age-1 juveniles during winter (Nov 15–Feb 14)	245 to 665	2	8	Short-term (10 d) moderate stress for age 1 juveniles rearing the mainstem. An unknown but assumed small number of all juveniles (<1 %) rear in mainstem during winter.
	90 to 245	3	7	
	33 to 90	5	7	
Age-0 juveniles during summer (Mar 15–Nov 14)	90 to 245	6	8	Major stress for age 0 juveniles rearing in mainstem.
	33 to 90	19	8	
Age 1 juvenile outmigration (Feb 15–May 31)	245 to 665	1	7	Major stress for smolts outmigrating during early spring (~44 % of run).
	90 to 245	7	8	
	33 to 90	20	8	
Age 1 juvenile outmigration (Apr 1– June 30)	90 to 245	5	8	Major stress for smolts outmigrating during late spring (~56 % of run).
	33 to 90	16	8	

Table E-7. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Coho Salmon under Extreme Conditions (10% exceedance probability), for Klamath River at Seiad Valley (RM 129.4).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migrants (Sept 1–Jan 1)	665 to 1,808	1	8	Moderate to major stress for adults migrating upstream.
	245 to 665	3	8	
	90 to 245	6	8	
	33 to 90	8	7	
Spawning, incubation, and fry emergence (Nov 1–Mar 14)	1,808 to 4,915	1	10	No modeling of suspended sediment infiltration into gravel was conducted. Available information suggests low survival (0%) of spawning adults, incubating eggs, and emergent fry in the mainstem; typically a small percentage of the percent of the Upper Klamath River Population spawns in the mainstem as opposed to tributaries
	665 to 1,808	2	10	
	245 to 665	5	11	
	90 to 245	14	12	
	33 to 90	14	11	
Age-1 juveniles during winter (Nov 15–Feb 14)	1,808 to 4,915	1	9	Major stress and reduced growth for age 1 juveniles rearing the mainstem. An unknown but assumed small number of all juveniles (<1 %) rear in mainstem during winter.
	665 to 1,808	2	8	
	245 to 665	5	8	
	90 to 245	10	8	
	33 to 90	11	8	
Age-0 juveniles during summer (Mar 15–14 Nov)	245 to 665	5	8	Major stress and reduced or no growth for age 0 juveniles rearing in mainstem.
	90 to 245	20	9	
	33 to 90	39	8	
Age 1 juvenile outmigration (Feb 15–May 31)	665 to 1,808	2	8	Major stress and reduced growth for smolts during early spring (~44 % of run).
	245 to 665	5	8	
	90 to 245	21	9	
	33 to 90	37	8	
Age 1 juvenile outmigration (Apr 1– June 30)	245 to 665	5	8	Major stress for smolts outmigrating during late spring (~56 % of run).
	90 to 245	16	8	
	33 to 90	20	8	

Spawning begins within a few weeks of fish arriving at their spawning grounds. Potential effects on the Upper Klamath River Population Unit spawning coho salmon in the mainstem were evaluated based on SSC predictions for the period November 1 to March 15 in the vicinity of Seiad Valley. The modeling analysis does not account for effects that might result from infiltration of fine sediment into the channel bed because no suitable measurements or models were available with which to calculate this component. However, cumulative effects of suspended sediment on spawning adults, incubating eggs, developing alevins, and emergent fry would result in low survival for any coho salmon spawning in the mainstem under both normal and extreme conditions, with possibly up to 100 percent mortality under extreme conditions in the vicinity of Seiad Valley

(Table E-7) and further downstream. However, coho salmon are typically tributary spawners (NOAAFisheries 2010), and based on Magneson and Gough (2006) spawning surveys from 2001 to 2005, only from 6 to 13 are observed in the mainstem, so elevated suspended sediment during winter flows can be assumed to have only minimal effects on the Upper Klamath River Population Unit. In addition, it is believed by experts in the watershed that progeny of mainstem spawning coho salmon experience reduced survival compared to fish produced from tributary spawners (Simondet 2006), since rearing and growth conditions within tributaries are more favorable than in the mainstem.

Varity of behavioral responses of coho salmon to exposure to SSC increases uncertainty in the analysis. There may be wide variation in terms of how long juvenile coho salmon rear in natal tributaries versus the mainstem, making it difficult to determine their exposure to elevated SSC in the mainstem. Some fry and age 0 juveniles enter the mainstem in the spring and summer following emergence. These fish may spend their remaining rearing period in the mainstem, but by the early fall, only low densities of juvenile coho salmon are found in the mainstem. The latter indicates that oversummer survival may be low due to high temperatures and exposure to disease in the mainstem Klamath River (NRC 2004). Even those that survive may experience reduced growth due to high summer temperatures, resulting in ocean entry at a smaller size and lower marine survival (Bilton et al. 1982, Hemmingsen et al. 1986). SSC modeling predicts that age 0 fish rearing in the mainstem during winter would also be exposed to suspended sediment concentrations high enough to cause major physiological stress even under normal conditions (Table E-6). Although some juveniles may rear in the mainstem, most production from all population units probably results from fish that remain to rear in tributaries.

Additional age 0 juveniles depart from tributaries in the Mid-Klamath and Salmon River population units (and possibly others) during fall (Soto et al. 2009, Hillemeier et al. 2009). Some of these have been observed to overwinter in tributaries and off-channel habitats in the lower mainstem Klamath River near or within the estuary (Soto et al. 2009, Hillemeier et al. 2009), which may reduce the amount of time they are exposed to suspended sediment in the mainstem.

Most juveniles from all population units appear to rear in tributaries or off-channel habitats during winter, and are not affected by mainstem pulses of suspended sediment until they migrate to the ocean as smolts, with the exception of potential migrations among tributaries (e.g., Ebersole et al. 2006). This seems to be the case for most naturally produced coho salmon, which depart tributaries from February through mid-June as age-1 smolts (Wallace 2004). During outmigrant trapping efforts from 1997 to 2006 in tributaries in the Upper-Klamath River, Shasta River, and Scott River populations, 44 percent of coho salmon smolts were captured from February 1 to March 31, and 56 percent from April 1 through the end of June (Courter et al. 2008). Once in the mainstem, smolts move downstream fairly quickly. Stutzer et al. (2006) report a median migration rate for wild coho smolts of 13.5 miles/day (range -0.09–114 miles/day) and a median migration rate for hatchery smolts of 14.6 miles/day (range -2.3–27.8 miles/day). This equates to 14.3 days for wild smolts to travel the 193 miles from Iron Gate Dam to the estuary, and 13.2 days for hatchery smolts. Beeman et al. (2007) report even higher rates of travel: a median migration rate for wild smolts of 22.5 miles/day (range 2.9–113.9 miles/day) and 15.7 miles/day (range 1.9–122.0 miles/day) for hatchery smolts. At these rates, it would take only 7.6 days (range 1.5-59.8 days) for wild smolts to travel from Iron Gate Dam to the estuary and 10.9 days (range 1.4–91.8 days) for hatchery smolts. Based on these data, and the observed outmigration rates for Chinook salmon of around 30 days, a maximum of 20 days exposure to mainstem suspended sediment during migration was assumed for the analysis. Under normal conditions, SSC in the mainstem Klamath River during outmigration for all populations would remain in the sublethal range but could result in major physiological stress and inhibit feeding. Suspended sediment concentrations under extreme conditions would be somewhat higher, and would result in major stress and reduced growth, but would remain in the sublethal range during the rearing and outmigration periods.

During experimental releases of wild and hatchery radio-tagged coho salmon smolts in the Klamath River near Iron Gate Dam sustained mortality rates of around 35 to 70 percent (Beeman et al. 2007, 2008). Although these numbers are based on only a few years of data, it appears that survival is higher for wild fish than for hatchery fish. This disparity in survival rates may be associated with (1) the length of residency in tributaries prior to migrating (i.e., fish that enter the mainstem later have higher survival), (2) mainstem discharge (migrants sometimes showed higher survival when flows in the mainstem were higher), or (3) spawning location (survival is much lower for smolts originating upstream of the Scott River). The relative contribution from SSC to these mortality rates is not known.

Overall, under existing conditions and the No Action/No Project Alternative, suspended sediment concentrations in the mainstem are sufficiently high and of long enough duration that major physiological stress and reduced growth of coho salmon are anticipated in most years. Consistent with these findings, the lower Klamath River downstream of the Trinity River confluence (RM 40.0) to the estuary mouth (RM 0.0) is listed as sediment impaired under Section 303(d) of the Clean Water Act (SWRCB 2006, NCRWQCB 2010) (Section 3.2.3.3). Relatively high SSC, in association with elevated water temperatures and disease may be contributing to the high smolt mortality that has been observed in the mainstem Klamath River (Beeman et al. 2007, 2008).

E.3.1.4 Summer- and Winter-run Steelhead

The following analysis and discussion applies to summer-, fall-, and winter-run steelhead (*Oncorhynchus mykiss*) (steelhead returning in the fall are sometimes lumped with the winter run) except where indicated. Because juvenile steelhead from various runs are indistinguishable from each other, the model assumes that steelhead from both the summer and winter runs share similar juvenile life-history patterns. The vast majority of existing information addresses steelhead rather than resident rainbow trout. This section primarily addresses steelhead, but it is reasonable to assume that effects of suspended sediment on resident *O. mykiss* will be similar to those found for juvenile steelhead.

Both summer and winter steelhead are distributed throughout the Klamath River and its tributaries downstream of Iron Gate Dam. Based on available escapement data, approximately 55 percent of summer steelhead spawn in the Trinity River and other lower-elevation tributaries. Most remaining summer steelhead are believed to spawn in tributaries between the Trinity River (RM 43) and Seiad Creek (RM 129), with high water temperatures limiting their use of tributaries farther upstream (NRC 2004). Winter steelhead spawn primarily in the Trinity, Scott, Shasta, and Salmon rivers.

Adult summer steelhead typically enter and migrate up the Klamath River from March through June (Hopelain 1998) and then hold in cooler tributary habitat until spawning begins in December (USFWS 1998). Summer steelhead in the Klamath River were reported by Hopelain (1998) to have a greater incidence of repeat spawning (40-64 percent) than the fall and winter runs, and a large proportion of adults are observed to migrate downstream to the ocean after spawning (also known as "runbacks"). Under normal conditions, SSC would remain in the sublethal range during adult migration; however, concentrations may be high enough to cause avoidance, physiological stress, and possibly impaired homing. Concentrations should still remain in the sublethal range under extreme conditions, but would be slightly higher and durations longer than under normal conditions.

In contrast to summer-run steelhead, winter-run are sexually mature upon freshwater entry (Papa et al. 2007). Upstream migration for adult fall-run steelhead in the Klamath River typically lasts from July to October and for adult winter-run steelhead from November through March (Hopelain 1998, USFWS 1998). Fall steelhead may be migrating as early as July, but elevated suspended sediment concentrations are uncommon during summer. Under normal conditions, SSC are high enough to cause major stress and possibly impaired homing for about three weeks. The 80 percent of steelhead spawning upstream of the Trinity River would be exposed for a longer period due to the additional time spent migrating in the mainstem. Under extreme conditions, SSC would cause major stress and impaired homing for around six weeks, twice the duration seen under normal conditions. Concentrations remain in the sublethal range; however, adults stressed by elevated suspended sediment could be more vulnerable to disease-related mortality. The amount of time that adults could be exposed will vary, depending on run timing relative to precipitation events that cause high SSC and how quickly an adult moves upstream and enters a spawning tributary.

Post-spawning adults, or "runbacks," migrate downstream in the spring to return to the sea, typically from April through May 30. Under normal conditions, suspended sediment concentrations are high enough to cause major stress for a little over two weeks, but under extreme conditions the elevated concentrations occur for six weeks or more. If runbacks spend a limited amount of time in the mainstem while traveling from their spawning tributaries to the ocean, this may overestimate the duration of their exposure to sediment in the mainstem. There are little data on downstream-migrating steelhead in the Klamath with which to understand potential consequences of exposure to suspended sediment during this life history phase.

Half-pounders—sexually immature fish that return after one year in the ocean—migrate upstream in the late summer and remain in the Klamath River through March. On average, 32 percent of summer steelhead adults returning to the North Fork Trinity River are half-pounders (Hopelain 1998); the proportion of the summer run that employs this life-history pattern in the area upstream of the Trinity River is unknown. A large portion (~94 percent) of the fall steelhead run that spawns in tributaries upstream of Weitchpec return as half-pounders, as well as a large portion of adults returning to the Trinity River (~80 percent) (Hopelain 1998). The winter run has a much lower incidence of fish using the half-pounder life history, ~18 percent. Half-pounders tend to be found in the lower mainstem Klamath River, but they can be found all the way upstream to Beaver Creek from December through February. In a normal year under existing conditions and the No Action/No Project Alternative, suspended sediment concentrations in the mainstem during the period when half-pounders are present would be in a range that may cause major physiological stress, but would not be expected to be lethal or reduce growth (Table E-8). In an extreme year, suspended sediment concentrations would be somewhat higher, persist longer, and may reduce growth, but should also remain in the sublethal range (Table E-9).

No steelhead spawning occurs in the mainstem Klamath River; therefore, spawning adults, incubating eggs and developing alevins, and emergent fry should be unaffected by suspended sediment in the mainstem.

Juvenile summer steelhead in the Klamath Basin may rear in fresh water for up to three years before outmigrating. Although the majority of steelhead outmigrate at age 1 (Scheiff et al. 2001), those that outmigrate at age 2 appear to have the highest survival. (Hopelain 1998). Juveniles outmigrating from tributaries at age-0 and age-1 may rear in the mainstem for one or more years before reaching an appropriate size for smolting. Because juvenile steelhead may spend varying amounts of time between tributaries and the mainstem, it is difficult to track how much exposure each cohort might receive to suspended sediment in the mainstem. Juveniles found in the mainstem cannot generally be identified to run, so for the sake of the analysis the model assumes summer-, fall-, and winter-run fish share a similar life history with those that have been observed. In addition, there is some evidence in the literature that juvenile salmonids may actively avoid turbid waters by moving into tributaries, so behavior in years of relatively clear conditions may be different from that in years with elevated suspended sediment.

Table E-8. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Steelhead under Normal Conditions (50% exceedance probability), for Klamath River at Seiad Valley (RM 129.4).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult summer upstream migrants and runbacks (Mar 1–June 30)	245 to 665	<1	7	Major stress, avoidance of turbidity, and possibly impaired homing.
	90 to 245	6	8	
	33 to 90	19	8	
Adult winter upstream migrants (Aug 1–Mar 31)	245 to 665	2	8	Major stress and potential for impaired homing.
	90 to 245	6	8	
	33 to 90	10	7	
Adult runbacks (Apr 1–May 30)	90 to 245	5	8	Moderate to major stress to downstream-migrating adults; effect dependent on time it takes runbacks to return downstream to the sea.
	33 to 90	14	7	
Half-pounder residence (Aug 15–Mar 31)	245 to 665	2	8	Major stress, and possibly reduce growth or cause mortality. Proportion of run that returns as half-pounders is unknown. Fish may escape exposure to high suspended sediment in the mainstem by entering tributaries.
	90 to 245	5	8	
	33 to 90	10	7	
Spawning though emergence	N/A	—	—	No mainstem spawning.
Age 0 juvenile rearing (Mar 15–Nov 14)	90 to 245	6	8	Major stress for portion of age 0 juveniles rearing in mainstem (~60% of run upstream of Trinity River)
	33 to 90	19	8	
Age 1 juvenile rearing (year-round)	245 to 665	2	8	Major stress for portion of age 1 juveniles rearing in mainstem (~60% of run upstream of Trinity River)
	90 to 245	9	8	
	33 to 90	22	8	
Age 2 juvenile rearing (Nov 15–Mar 31)	245 to 665	2	8	Age 2 in the mainstem (~40 percent of run upstream of Trinity River) expected to experience moderate to major stress. Effects on growth may only last 2-3 weeks, perhaps not enough to substantially reduce size and ocean survival.
	90 to 245	6	8	
	33 to 90	10	7	
Juvenile/smolt outmigrants (Apr 1–Nov 14)	90 to 245	5	8	Major stress.
	33 to 90	17	8	

Table E-9. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Steelhead under Extreme Conditions (10% exceedance probability), for Klamath River at Seiad Valley (RM 129.4).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult summer migrants and runbacks (Mar 1–June 30)	665 to 1,808	1	9	Major stress, avoidance of turbidity, and impaired homing.
	245 to 665	5	8	
	90 to 245	21	8	
	33 to 90	37	8	
Adult winter migrants (Aug 1–Mar 31)	1,808 to 4,915	1	9	Major stress and impaired homing for about four months.
	665 to 1,808	2	9	
	245 to 665	5	9	
	90 to 245	15	8	
	33 to 90	20	8	
Adult runbacks (Apr 1–May 30)	245 to 665	4	8	Major stress; exposure duration dependant on time it takes runbacks to return to sea.
	90 to 245	11	8	
	33 to 90	28	8	
Half-pounder residence (Aug 15–Mar 31)	1,808 to 4,915	1	9	Major stress and reduced growth. Proportion of run returning as half-pounders is unknown. Some half-pounders use large tributaries. Fish may enter tributaries to escape high suspended sediment in the mainstem.
	665 to 1,808	2	9	
	245 to 665	10	9	
	90 to 245	15	8	
	33 to 90	24	8	
Spawning through emergence	—	—	—	No mainstem spawning.
Age 0 juvenile rearing (Mar 15–Nov 14)	245 to 665	5	8	Major stress and reduced growth for several months for age 0 rearing in mainstem (~60% of run upstream of Trinity River)
	90 to 245	20	9	
	33 to 90	39	8	
Age 1 juvenile rearing (year-round)	1,808 to 4,915	1	9	Major stress, reduced growth, and up to 20% mortality for age 1 rearing in mainstem (~60% of run upstream of Trinity River)
	665 to 1,808	2	8	
	245 to 665	7	9	
	90 to 245	25	9	
	33 to 90	39	9	
Age 2 juvenile rearing (Nov 15–Mar 31)	1,808 to 4,915	1	9	Major stress and reduced growth for >1 month for age 2 in mainstem (~40% of run upstream of Trinity River)
	665 to 1,808	2	8	
	245 to 665	5	8	
	90 to 245	15	8	
	33 to 90	20	8	
Juvenile/smolt outmigrants (Apr 1–Nov 14)	245 to 665	5	8	Major stress and reduced growth depending on duration of exposure.
	90 to 245	20	9	
	33 to 90	32	8	

Under normal existing conditions and the No Action/No Project Alternative, age 0 steelhead may experience major physiological stress for about three to four weeks (Table E-8). If they remain to rear in the mainstem for another year, suspended sediment concentrations would result in major stress for another month for this cohort. Under extreme existing conditions and the No Action/No Project Alternative, concentrations modeled for the age 0 period would cause major stress and reduced growth for about two months, and if they remain in the mainstem until smolting, the same cohort could be exposed to conditions causing reduced growth for an additional two months. However, it appears that many of these juveniles are avoiding conditions in the mainstem by using tributary and other off-channel habitat during winter (Soto et al. 2009, Hillemeier et al. 2009), lowering their exposure and potential mortality. The approximately 55 percent of the total summer steelhead population that spawn and rear in the Trinity River and downstream may be exposed to higher concentrations due to tributary accretion, but for shorter durations because of the shorter distance (and shorter travel time) from the sea to the mouths of their spawning tributaries.

Based on captures in tributaries and the mainstem, it appears that around 40 percent of the population rears in tributaries until age-2; upstream of the Trinity River confluence, around 37 percent of rearing steelhead in the mainstem (run unknown) are age 2, and 3 percent are age 3 (Scheiff et al. 2001). For these fish, suspended sediment in a normal year under existing conditions and the No Action/No Project Alternative may cause major stress for about two to three weeks. Under extreme conditions, the model predicts suspended sediment concentrations that may cause stress for about six weeks.

Smolts are captured in the mainstem and estuary throughout the fall and winter (Wallace 2004), but peak smolt outmigration normally occurs from April through June, based on estuary captures (Wallace 2004). Temperatures in the mainstem are generally suitable for juvenile steelhead, except for reaches upstream of Seiad Valley where summer water temperatures are considered stressful. Exposure of outmigrating juvenile and smolt steelhead to suspended sediment in the mainstem will depend on the timing of their outmigration relative to conditions contributing to elevated suspended sediment, as well as the length of time it takes them to outmigrate to sea. Approximately half of the population outmigrates from the Trinity River and tributaries downstream; the shorter distance to the sea should also shorten the time they are exposed to suspended sediment in the mainstem during outmigration. Under normal conditions, suspended sediment concentrations can cause major stress extend for about three weeks during the outmigration period (April 1 to November 14). Under extreme conditions, concentrations would be high enough to cause major stress and reduce growth for almost eight weeks, much longer than under normal conditions. Because of this, more smolts originating from tributaries farther inland (i.e., not produced from the Trinity River or lower-elevation streams) would likely be exposed to high suspended sediment concentrations (because there is a greater chance that their outmigration may coincide with a sediment pulse). The duration of their exposure will depend both on timing and rates of travel downstream (i.e., the amount of time spent in the mainstem). For smolts that are outmigrating in an active fashion, feeding may be less important, thus the effect of suspended sediment on growth may be relatively minimal in terms of overall survival.

E.3.1.5 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), of which only resident Klamath River lamprey and anadromous Pacific lamprey are present downstream of Iron Gate Dam (PacifiCorp 2004, FERC 2006). Pacific lamprey was chosen as the focal species, since most information on life-history, distribution, and habitat requirements is from this 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 effects could vary from those discussed here.

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 (Hardy and Addley 2001, NRC 2004). 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 spawning and rearing habitat, and Pacific lamprey are not regularly observed there. Therefore, the review of existing conditions and the No Action/No Project Alternative focuses on exposure of Pacific lamprey life stages to suspended sediment in the mainstem Klamath River downstream of Seiad Valley.

There is not extensive literature on the effects of suspended sediment on lamprey. This analysis was based on the effects of SSC on salmonids, with the assumption that impacts on lamprey are likely less than or equal to those on salmonids. It is generally observed that most life stages of Pacific lamprey are more resilient to poor water quality than salmonids (Zaroban et al. 1999), so these assumptions are likely conservative.

Anadromous Pacific lamprey enter the Klamath Basin throughout the year, although numbers peak in early winter. Under existing conditions and the No Action/No Project Alternative, SSC during adult migration could cause major physiological stress under both normal (Table E-10) and extreme conditions (Table E-11), although the duration of exposure under extreme conditions might be about double that under normal conditions. Pacific lamprey are observed to spawn in the mainstem Klamath River, exposing ammocoetes to suspended sediment within the mainstem year-round. Under normal conditions, concentrations are anticipated to be high enough and last long enough (~5 weeks) to cause major physiological stress under normal conditions, and major stress and reduced growth for a longer period (~10 weeks) under extreme conditions (Table E-11).

Juvenile lamprey (ages 2 to 10) outmigrate to the ocean from the mainstem Klamath River and tributaries rear-round, with peaks in migration during late spring and fall. Based on effects on salmonids, juvenile lamprey migrating during spring are anticipated to be exposed to suspended sediment concentrations high enough to cause major stress under both normal and extreme conditions, with duration of exposure in extreme conditions (~6 weeks) being much longer than the duration under normal conditions (~two weeks). Juveniles migrating during fall are exposed to relatively low increases in suspended sediment for less than a week under normal conditions, and only about two weeks under extreme conditions (Table E-11). Based on data collected on salmonids, concentrations would cause physiological stress, but would remain in the sublethal range in most years.

Table E-10. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Pacific lamprey under Normal Conditions (50% exceedance probability), for Klamath River at Seiad Valley (RM 129.4).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migration and spawning (year-round)	245 to 665	2	8	Major stress and potentially impaired homing for adult migrants. Adults migrating during late spring and summer are exposed to lower concentrations of SSC.
	90 to 245	9	8	
	33 to 90	22	8	
Ammocoete rearing (year-round)	245 to 665	2	8	Major stress of ammocoetes rearing in the mainstem. Majority of ammocoetes rear in tributaries.
	90 to 245	9	8	
	33 to 90	22	8	
Spring outmigration (May 1–June 30)	90 to 245	5	8	Major stress for all juveniles during spring outmigration.
	33 to 90	12	8	
Fall/winter outmigration (Sept 1–Dec 31)	90 to 245	2	7	Short-term (5 d) moderate stress and reduced feeding for all juveniles during fall outmigration.
	33 to 90	3	6	

Table E-11. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Pacific lamprey under Extreme Conditions (10% exceedance probability), for Klamath River at Seiad Valley (RM 129.4).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migration (year-round)	1,808 to 4,915	1	9	Major stress and impaired homing for adult migrants. Adult migrating during late spring and summer are exposed to lower concentrations of SSC.
	665 to 1,808	2	9	
	245 to 665	7	9	
	90 to 245	25	9	
	33 to 90	39	8	
Ammocoete rearing (year-round)	1,808 to 4,915	1	9	Major stress and reduced growth of ammocoetes rearing in the mainstem. Majority of ammocoetes rear in tributaries.
	665 to 1,808	2	8	
	245 to 665	7	9	
	90 to 245	25	9	
	33 to 90	39	8	
Spring outmigration (May 1–June 30)	245 to 665	5	8	Major stress for all juveniles during spring outmigration.
	90 to 245	14	8	
	33 to 90	21	8	
Fall/winter outmigration (Sept 1–Dec 31)	665 to 1,808	1	8	Major stress for all juveniles during spring outmigration.
	245 to 665	3	8	
	90 to 245	5	8	
	33 to 90	7	7	

To summarize, under both normal and extreme conditions, Pacific lamprey are anticipated to suffer from stressful levels of suspended sediment while rearing and migrating through the mainstem Klamath River, with exposure durations generally much longer under extreme conditions. Because there are multiple year-classes of lamprey in the mainstem Klamath River at any given time, and since adults may migrate upstream throughout the year, Pacific lamprey populations may be well-adapted to persisting through years when suspended sediment concentrations are high, especially since they remain within the sublethal range based on salmonid data.

E.3.1.6 Green Sturgeon

The Klamath Basin is the principal spawning watershed for green sturgeon in California (Moyle 2002). 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 (KRBFTF 1991, Adams et al. 2002, Benson et al. 2007). Based on this distribution, this analysis focuses on exposure of green sturgeon life stages to suspended sediment in the mainstem downstream of Orleans.

There is not extensive literature on the effects of suspended sediment on sturgeon. This analysis is based on available information of the effects of SSC on salmonids, with the assumption that effects of suspended sediment on sturgeon are likely less than or equal to those on salmonids. It is generally believed that most life stages of sturgeon are more resilient to turbidity than salmonids, so these assumptions are likely conservative. For example, juvenile green sturgeon exposed to high suspended sediment in the Connecticut River showed no apparent physiological stress, even though several other sturgeon species suffered gill infections (B. Kynard, Fisheries Biologist, BK-Riverfish, pers. comm., 2008). During extensive radio telemetry studies of green sturgeon, McCovey (2010) found that adults did not respond to periods of poor water quality, including high water temperature, algal blooms, disease outbreaks, and pulses of suspended sediment. In addition, adults have been observed to remain alive for days out of water, and no adult or juvenile sturgeon mortalities were observed during the September 2002 fish kill in the lower Klamath River.

Adult green sturgeon enter the Klamath River beginning in mid-March, and under both normal and extreme conditions suspended sediment concentrations reach levels expected to cause physiological stress in salmonids. Adult sturgeon are likely to be relatively tolerant compared to salmonids, however. Feeding is not likely to be a problem even when suspended sediment concentrations are high, because they do not generally rely on eyesight to feed, but instead feed primarily on invertebrates in mud and silt using sensitive barbels to detect prey, and they may suspend feeding for long periods during their spawning migration (EPIC et al. 2001, as cited in California Department of Water Resources [CDWR] 2003).

Green sturgeon females are broadcast spawners that lay thousands of adhesive eggs that settle into the spaces between cobble substrates (Moyle 2002; Emmett et al. 1991, as cited in CALFED 2007). It is generally believed that silt can cause mortality by preventing eggs from adhering to one another and attaching to the substrate (EPIC et al. 2001, as cited in CDWR 2003). Under normal conditions, eggs and larvae are expected to be exposed to suspended sediment concentrations over 50 mg/l for a period of about three weeks, which based on the Newcombe and Jensen (1996) approach would be expected to cause high rates of mortality of salmonid eggs and emergent fry, yet green sturgeon do successfully spawn in the mainstem Klamath River under existing conditions and the No Action/No Project Alternative (Benson et al. 2007), and while some mortality is likely occurring, it is likely that effects are not as severe as suggested for salmonids.

After spawning, around 25 percent of green sturgeon migrate directly back to the ocean (Benson et al. 2007), and the remainder hold in mainstem pools in the Klamath River from RM 13 to RM 65 through November. During this holding period, SSC are relatively low, and no effects are anticipated under normal conditions; under extreme conditions, SSC would be elevated to levels moderately stressful to salmonids, but only for a few days.

Juvenile green sturgeon may rear for one to three years in the Klamath River system before they migrate to the estuary and ocean (NRC 2004, FERC 2006, CALFED 2007), usually during summer and fall (Emmett et al. 1991, as cited in CALFED 2007). Juveniles are reported to grow rapidly, 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., 2008), but juveniles may be rearing for additional months or years in the lower river or estuary before migrating to the ocean. During the rearing period, juveniles are anticipated to be exposed to SSC that cause major stress and reduced growth in salmonids for about a month under normal conditions and double that under extreme conditions (Tables E-12, E-13). However, juvenile green sturgeon exposed to high suspended sediment in the Connecticut River showed no apparent physiological stress, even though several other sturgeon species suffered gill infections (B. Kynard, Fisheries Biologist, BK-Riverfish, pers. comm., 2008). Green sturgeon eggs sampled in the Klamath River by Van Eenennaam et al. (2006) were the largest recorded for a North American sturgeon, and likely produce large, fast-growing juveniles. These traits may allow them to migrate to the estuary or ocean after only one year of residence (Van Eenennaam et al. 2006). This is consistent with observations of high growth rates in the mid-Klamath River (M. Belchik, Fisheries Biologist, Yurok Tribe, pers. comm., 2008), and may be related to the fact that the lower Klamath River and estuary offer very little foraging habitat compared with large systems such as the Sacramento-San Joaquin Bay-Delta, or Columbia River estuaries (J. Van Eenennaam, Research Associate, University of California Department of Animal Science, pers. comm., 2008).

Overall, under existing conditions and the No Action/No Project Alternative, green sturgeon in the Klamath River mainstem are regularly exposed to suspended sediment concentrations documented to cause major physiological stress, reduced growth, and mortality in salmonids, especially during their egg and larval stages, and the year-round juvenile rearing period. However, these metrics likely overestimate effects on sturgeon.

Table E-12. Predicted Suspended Sediment Concentration, Exposure Duration, and Anticipated Effects on Green Sturgeon under Normal Conditions (50% exceedance probability), for Klamath River at Orleans (RM 58).

Life-History Stage (Timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult migration and spawning (Mar 15–July 15)	90 to 245	3	7	Moderate to major stress for adult migrants and spawners.
	33 to 90	24	8	
Eggs and larvae (Apr 1–Aug 15)	90 to 245	2	10	Up to 68% mortality for eggs and larvae (based on salmonid literature, effects likely overestimated).
	33 to 90	22	12	
Adult post-spawning holding (July 15–Nov 15)	0	—	—	No effects anticipated.
Juvenile rearing (year-round) and outmigration (May 15–Oct 15)	245 to 665	1	7	Major stress (based on salmonid literature, effects likely overestimated).
	90 to 245	5	8	
	33 to 90	24	8	

Table E-13. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Green Sturgeon under Extreme Conditions (10% exceedance probability), for Klamath River at Orleans (RM 58).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migrants (Mar 15–July 15)	245 to 665	2	8	Major stress for adult migrants and spawners.
	90 to 245	14	8	
	33 to 90	34	8	
Eggs and larvae (Apr 1–Aug 15)	245 to 665	<1	8	Up to 84% mortality for eggs and larvae (based on salmonid literature, effects likely overestimated).
	90 to 245	14	12	
	33 to 90	31	12	
Adult post-spawning holding (July 15–Nov 15)	90 to 245	1	7	Short duration and relatively low concentrations not expected to result in adverse effects on adults. About 75% of adults remain holding in the mainstem after spawning; remainder migrates to ocean.
	33 to 90	2	7	
Juvenile rearing (year-round) and outmigration (May 15–Oct 15)	665 to 1,808	2	8	Major stress and reduced or no growth (based on salmonid literature, effects likely overestimated).
	245 to 665	6	9	
	90 to 245	18	9	
	33 to 90	37	8	

E.3.2 Proposed Action– Full Facilities Removal of Four Dams

Under the Proposed Action, full facility removal would result in the release of 1.2-2.9 million metric tons of fine sediment stored in the reservoirs into the Klamath River downstream of Iron Gate Dam over a two-year period (Reclamation 2011), resulting in higher suspended sediment concentrations than would normally occur under existing conditions and the No Action/No Project Alternative (Figure E-3), and local, short-term sediment deposition. SSC would begin to increase during reservoir drawdown, prior to the deconstruction of the dams and continue to rise through the spring runoff period as material behind the dams is mobilized downstream. Reservoir drawdown is expected to commence in January 2020. Based on the suspended sediment modeling conducted to analyze each alternative (including facility removal) (Reclamation 2011), suspended sediment concentrations are expected to exceed 1,000 mg/l for weeks, with the potential for peak concentrations exceeding 5,000 mg/l for hours or days, depending on hydrologic conditions during facility removal. The transport of this suspended sediment load is expected to affect anadromous fish species in various ways; in the following sections, the predicted effects of SSC on each focal fish species and cohort (referenced by the year of birth) are analyzed to evaluate the likely effects of the Proposed Action on anadromous fish populations in the Klamath River.

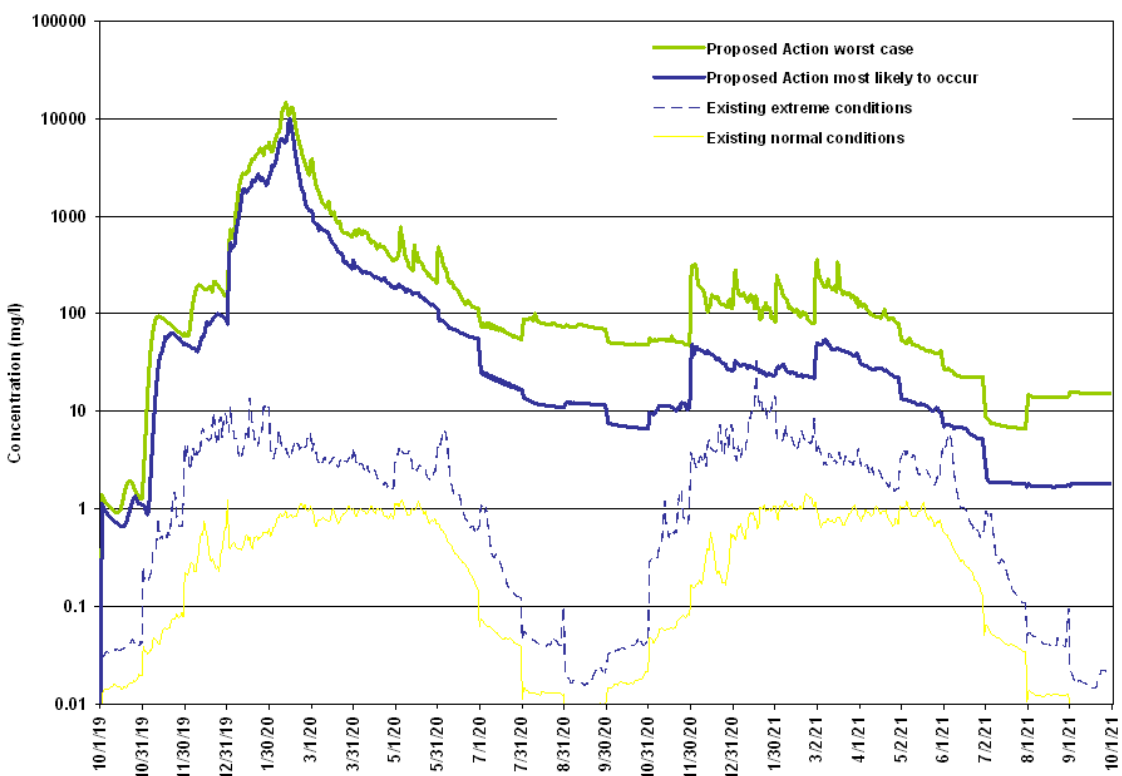

Figure E-3. Comparison of SSC under Proposed Action and Existing Conditions and the No Action/No Project Alternative at Iron Gate Dam for the Two-Year Period following Reservoir Drawdown beginning January 1st 2020, as Predicted using SRH-1D Model.

In the sections below, SSC predicted for the most likely and worst-case scenarios are used to evaluate the potential effects of the Proposed Action on anadromous fish species.

E.3.2.1 Fall-run Chinook Salmon

Although fall-run Chinook salmon migrate as far upstream as Iron Gate Dam to spawn, they are primarily distributed downstream of Seiad Valley. Therefore the assessment of effects focuses on exposure of fall-run Chinook salmon adult migrants and spawning to suspended sediment in the mainstem downstream of downstream of Iron Gate Dam, and downstream of Seiad Valley for all other life stages.

Adult fall-run Chinook salmon in the Klamath River migrate upstream from August through October, when suspended sediment levels are generally low, and typically take two to four weeks to reach their spawning grounds. Under the Proposed Action, SSC in the mainstem Klamath River during this migratory period is predicted to be nearly the same as under existing conditions and the No Action/No Project Alternative, with the exception that suspended sediment concentrations would be high enough to cause major physiological stress and impaired homing in the fall immediately following removal of the dams (2020).

Fall-run Chinook salmon spawning typically peaks in late October and substantially declines by the end of November (Shaw et al. 1997). The SSC modeling analysis does not account for potential effects that might result from infiltration of fine sediment into the channel bed because no suitable measurements or models were available with which to calculate this component; however, suspended sediment resulting from the Proposed Action is predicted to result in 100 percent mortality of eggs and fry from all mainstem Klamath River spawning in 2019 (Table E-14). The sediments released during dam removal will likely be primarily conveyed as wash load and will not fall out of suspension; however, the fraction deposited on spawning gravels will carry high concentrations of very fine sediment. These sediments may smother the eggs by adhering to the chorion [1] (Greig et al. 2005, Levasseur et al. 2006). The degree to which sediments will adhere to the egg is affected by the properties (e.g., angularity) of the minerals within the sediment. Sediment transport analysis conducted by Stillwater Sciences (2008) concluded that fine sediment infiltration is expected to be limited to the upper portion of 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 be removed by the redd construction activities of spawning fish in subsequent years. Therefore, since the majority of sediment is predicted to be released within the first year following reservoir drawdown, the effect of fine sediment from the Proposed Action on spawning success is unlikely to persist beyond the summer of 2020.

Much of the overall effect of the Proposed Action on fall-run Chinook salmon will depend on the relative proportion of mainstem spawners during the fall of 2019, prior to the January 2020 initiation of facility removal. Based on redd surveys using a mark and re-sight methodology from 2001 through 2009 (California Department of Fish and Game, unpubl. data), an average of around 9,300 hatchery and naturally returning adults spawn in mainstem Klamath River, which is consistently around ~8 percent (range from 5.3 to 13.5 percent) of the total escapement in the Klamath Basin (not including grilses). Spawner surveys conducted by USFWS indicate that approximately half of the fall Chinook that spawn within the 82-mile survey reach construct their redds in the 13.5-mile section between Iron Gate dam and the Shasta River (FERC 2006) and thus would be most vulnerable to sediment released in association with the Proposed Action. Based on the long-term average of 8 percent, 9,300 adults could spawn in the mainstem downstream of Iron Gate Dam in the fall of 2019. Assuming two fish per redd, and with a predicted 100 percent mortality, around 4,600 redds could be lost under the Proposed Action assuming either the mostly-likely or worst-case scenario. Assuming constructed redds are related to escapement, this equates to around 8 percent of all anticipated redds in the basin in 2019. Based on the proximity to the Iron Gate Hatchery, it is expected that much of the redds affected will be of hatchery origin.

Approximately 60 percent of the fry produced by fall-run Chinook salmon in the Klamath River exhibit the Type I life history, in which they enter the ocean within a few months of emergence in early spring. Type I fry enter the mainstem in April and May. As discussed in Section E.3.1.1, a maximum duration of exposure to SSC during migration of 30 days was assumed for the analysis. Under the Proposed Action, SSC in the mainstem will likely result in major physiological stress and reduced growth under either the mostly-likely or worst-case scenario, which is also predicted under both normal and extreme existing conditions and the No Action/No Project Alternative (Tables E-14 and E-15). Prolonged exposure could affect early marine survival by reducing growth and thus the size at which the smolts enter the ocean (Bilton 1984). This would also be expected to be the case under existing conditions and the No Action/No Project Alternative even in normal years, but to a lesser degree. Exposure to disease or elevated temperatures during this phase would likely result in the mortality of some portion of these fish. Parr-smolt transformation can also be compromised in stressed juveniles (Wedemeyer and McLeay 1981, as cited in Bash et al. 2001), and act as a potential source of mortality.

The Type II life history is also common (~40 percent of cohort) (Sullivan 1989). These juveniles remain to rear in the tributaries in which they were spawned and will only be exposed to suspended sediment in the mainstem during their outmigration to the ocean in the fall. Under the Proposed Action, SSC would be very low, similar to existing conditions and the No Action/No Project Alternative, unless there are worst-case conditions in the fall after dam removal (2020), in which case SSC would be high enough to cause moderate to major physiological stress for a period of one to two weeks.

Type III life-history fish are relatively rare (<1 percent of production) in the Klamath River fall-run population (USFWS 2001). These fish typically remain to rear in the spawning tributaries and outmigrate in late winter and early spring as yearlings. Under the Proposed Action, SSC could cause up to 20 percent mortality, and up to 100 percent mortality in a worst-case scenario (Tables E-14 and E-15). Under existing conditions and the No Action/No Project Alternative, suspended sediment concentrations remain in the sublethal range (Table E-15). Based on outmigrant trapping in the mainstem Klamath

River at Big Bar, around 942,829 Chinook salmon smolts outmigrate each spring, including both hatchery and naturally produced fish (USFWS 2001). Type III age 1 spring outmigrants are very rare, and only 31 were observed at Big Bar in four years of trapping, or around 0.1 percent of trap captures. Based on abundance estimates annual average Type III outmigration is around 943 smolts each year. Based on model predictions of 0 to 20 percent mortality, around 0 to 189 smolts could perish, or around 0.02 percent of the total fall-run Chinook salmon smolt production. This does not take into account Type II outmigrants during fall which are not sampled in the Klamath River, so the actual percentage could be lower. Under a worst case scenario mortality rates of up 71 percent are predicted for the Proposed Action, equating to up to 669 smolts, or around 0.07 percent of the total fall-run Chinook salmon smolt production. Based on Sullivan (1989) the typically larger Type III smolts can contribute up to 4 percent of the escapement despite their low proportion of smolt production, perhaps due to their larger size at ocean entry (Bilton 1984). Therefore the effect on the population of mortality to the Type III smolts may be proportionally higher than the effect of mortality of other life-histories.

Table E-14. Suspended Sediment Predictions for Fall-Run Chinook Salmon for most likely Scenario (50% exceedance probability), Klamath River at Iron Gate Dam (adult migration, spawning, incubation, and fry emergence life stages) and Seiad Valley (juvenile rearing and outmigration life stages).

<table>
<tr><th>Life-History Stage (timing)</th><th>Suspended Sediment Concentration (mg/l)</th><th>Exposure Duration (days)</th><th>Newcombe and Jensen Severity Index</th><th>Effects on Production</th></tr>
<tr><td>Adult upstream migrants (July 15–Oct 31 2020)</td><td>0</td><td>0</td><td>0</td><td>No effect anticipated.</td></tr>
<tr><td rowspan="6">Spawning, incubation, and fry emergence (Oct 15 2019–Feb 28 2020)</td><td>4,915 to 13,360</td><td>10</td><td>12</td><td rowspan="6">Effects of suspended sediment on spawning gravel quality were not modeled; however, suspended sediment may result in nearly 100% mortality of all progeny from mainstem spawning (approximately 4,600 redds, or around 8% of production).</td></tr>
<tr><td>1,808 to 4,915</td><td>14</td><td>13</td></tr>
<tr><td>665 to 1,808</td><td>8</td><td>12</td></tr>
<tr><td>245 to 665</td><td>5</td><td>11</td></tr>
<tr><td>90 to 245</td><td>10</td><td>11</td></tr>
<tr><td>33 to 90</td><td>27</td><td>10</td></tr>
<tr><td>Juvenile rearing (Fall 2019 through 2020)</td><td>n/a</td><td>n/a</td><td>n/a</td><td>No juvenile progeny anticipated from mainstem due to impacts during incubation. All other juveniles rear in tributaries.</td></tr>
<tr><td rowspan="3">Type I outmigration (April 1–August 31 2020)</td><td>245 to 665</td><td>4</td><td>8</td><td rowspan="3">Major stress and reduced growth. Applies to ~60% of total production.</td></tr>
<tr><td>90 to 245</td><td>19</td><td>9</td></tr>
<tr><td>33 to 90</td><td>21</td><td>8</td></tr>
<tr><td>Type II outmigration (Sept 1–Nov 30 2020)</td><td>0</td><td>0</td><td>0</td><td>No effect anticipated.</td></tr>
<tr><td rowspan="4">Type III outmigration (Feb 1–April 15 2020)</td><td>1,808 to 4,915</td><td>11</td><td>10</td><td rowspan="4">Major stress, reduced growth and up to 20% mortality. (0 to 189 smolts, or less than 1% of production).</td></tr>
<tr><td>665 to 1,808</td><td>8</td><td>9</td></tr>
<tr><td>245 to 665</td><td>11</td><td>9</td></tr>
<tr><td>90 to 245</td><td>11</td><td>8</td></tr>
</table>

Table E-15. Suspended Sediment Predictions for Fall-Run Chinook Salmon for Worst-Case Scenario (10% exceedance probability), Klamath River at Iron Gate Dam (adult migration, spawning, incubation, and fry emergence life stages) and Seiad Valley (juvenile rearing and outmigration life stages).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult migration (July 15–Oct 31 2020)	90 to 245	5	8	Major stress and impaired homing for migrating adults.
	33 to 90	58	8	
Spawning, incubation, and fry emergence (Oct 15 2019–Feb 28 2020)	13,360 to 36,316	1	11	Effects of suspended sediment on spawning gravel quality were not modeled; however, suspended sediment may result in nearly 100% mortality of all progeny from mainstem spawning (approximately 4,600 redds, or around 8% of production).
	4,915 to 13,360	18	13	
	1,808 to 4,915	28	13	
	665 to 1,808	17	12	
	245 to 665	8	11	
	90 to 245	20	12	
	33 to 90	43	13	
Juvenile rearing (year round)	n/a	n/a	n/a	No juvenile progeny anticipated from mainstem due to impacts during incubation. All other juveniles rear in tributaries.
Type I outmigration (Apr 1–Aug 31 2020)	665 to 1,808	1	8	Major stress and reduced growth. Applies to ~60% of total run progeny.
	245 to 665	12	9	
	90 to 245	30	9	
	33 to 90	30	8	
Type II outmigration (Sept 1–Nov 30 2020)	245 to 665	<1	6	Moderate to major stress. Applies to ~40% of total run progeny.
	90 to 245	4	8	
	33 to 90	6	7	
Type III outmigration (Feb 1–Apr 15 2020)	4,915 to 13,360	5	11	Major stress, reduced growth, and up to 71% mortality. (Up to 669 smolts, or less than 1% of production).
	1,808 to 4,915	17	11	
	665 to 1,808	13	10	
	245 to 665	18	9	
	90 to 245	25	9	
	33 to 90	8	7	

E.3.2.2 Spring-run Chinook Salmon

Based on spring-run Chinook salmon distribution, the Proposed Action will have the largest effect on spring-run Chinook salmon returning to or emigrating from the Salmon River. Therefore, this assessment focuses on life stages most likely to be found in the mainstem downstream of the Salmon River, including those that migrate to and from the Trinity River.

Under existing conditions and the No Action/No Project Alternative, and the Proposed Action, SSC during upstream migration would cause moderate-to-major stress and impaired homing, with duration of exposure expected to be slightly longer (2–7 days) under the Proposed Action than under existing conditions and the No Action/No Project Alternative. Adults migrating later in the season (July through August) are exposed to elevated suspended sediment for less than two days under any scenario, existing or proposed.

Spring-run Chinook upstream migration is separated into two time periods—spring and summer. Under the Proposed Action (most-likely and worst-case scenarios), spring migrants are expected to be exposed to higher concentrations of SSC than under existing conditions and the No Action/No Project Alternative, leading to increased stress and impaired homing (Table E-16). However, the duration of exposure is relatively short (<14 days), and effects are expected to be sublethal. Behavioral responses of adult salmon to high suspended sediment can include straying into nearby tributaries with lower levels of suspended sediment and ceasing or delaying upstream movements when there are no clearer waters to take refuge in (Cordone and Kelley 1961). Whitman et al. (1982) found that adult male Chinook showed an avoidance response to their home water when exposed to an ash suspension of 650 mg/l, but no indication that homing was affected. The increased energy expenditure that may result from a delay in migration can potentially reduce spawning success (Berman and Quinn 1991), particularly if factors such as elevated temperatures or disease are a problem.

Around half of the observed spring Chinook salmon adults migrate relatively rapidly to the Trinity River in the summer (~ 2 days within mainstem Klamath River). Under a worst-case scenario, effects would be nearly identical to existing conditions and the No Action/No Project Alternative —only one to two days of exposure to concentrations causing moderate stress (Table E-17).

Since no spring-run Chinook salmon spawning occurs in the mainstem Klamath River under existing conditions and the No Action/No Project Alternative, the egg through fry life stages are not anticipated to be affected by suspended sediment resulting from the Proposed Action (Tables E-16 and E-17).

Based on outmigrant trapping in the Salmon River from 2001 to 2006 (Karuk Tribe, unpubl. data), around 80 percent of outmigrants are Type I, 20 percent are Type II, and less than 1 percent are Type III. Based on otolith analysis conducted by Olson (1996), most adults returning to the Salmon River (~70 percent) exhibited the Type II life history and outmigrated during fall, and around 7 percent exhibited the Type III life history despite being infrequently observed outmigrating. Juvenile spring-run Chinook of both Types I and II are believed to rear in tributaries for the most part (West 1991; Dean 1994, 1995), reducing likelihood of exposure to suspended sediment in the mainstem. Type I juveniles move from tributaries into the mainstem and continue downstream to the ocean in April and May. Suspended sediment concentrations would cause moderate-to-major stress during the Type I outmigration under all scenarios, both existing and proposed, with duration of exposure 20 days under normal existing conditions and the No

Action/No Project Alternative and 28 days under the most-likely scenario of the Proposed Action. Since a maximum exposure of 30 days was assumed for outmigration, the worst-case scenario of the Proposed Action would be almost equivalent to extreme existing conditions and the No Action/No Project Alternative —30 days with major physiological stress.

Table E-16. Predicted Suspended Sediment Concentration, Exposure Duration, and Anticipated Effects on Spring-run Chinook Salmon for most likely Scenario (50% exceedance probability), for Klamath River at Orleans (RM 58).

<table>
<tr><th>Life-History Stage (timing)</th><th>Suspended Sediment Concentration (mg/l)</th><th>Exposure Duration (days)</th><th>Newcombe and Jensen Severity Index</th><th>Effects on Production</th></tr>
<tr><td rowspan="2">Adult spring migration (Apr 1–Jun 30, 2020)[a]</td><td>90 to 245</td><td>9</td><td>8</td><td rowspan="2">Major stress and impaired homing for adults returning to Salmon River. Majority (~95% on average) of adults enter Trinity River, and will be exposed to lower concentrations. However, up to 35% of “natural” escapement returns to Salmon River.</td></tr>
<tr><td>33 to 90</td><td>14</td><td>7</td></tr>
<tr><td>Adult summer migration (Jul 1–Aug 31, 2020)[b]</td><td>0</td><td>0</td><td>0</td><td>No effect to the ~50% of the summer migrants returning to Trinity River.</td></tr>
<tr><td>Spawning, incubation, and fry emergence (Sept 1 2019–Feb 28, 2020)</td><td>n/a</td><td>n/a</td><td>n/a</td><td>Spring-run do not generally spawn in the mainstem.</td></tr>
<tr><td>Juvenile rearing (variable)</td><td>n/a</td><td>n/a</td><td>n/a</td><td>Juveniles rear in tributaries; no effect to this life stage is anticipated.</td></tr>
<tr><td rowspan="2">Type I outmigration (Apr 1–May 31, 2020) [c]</td><td>90 to 245</td><td>7</td><td>8</td><td rowspan="2">Major stress for Type I fry (~80%) in smolt outmigration from Salmon River. Majority (~95%) of juveniles outmigrate from the Trinity River, and will be exposed to lower concentrations.</td></tr>
<tr><td>33 to 90</td><td>21</td><td>8</td></tr>
<tr><td>Type II outmigration (Oct 1–Nov 15, 2020)[c]</td><td>0</td><td>0</td><td>0</td><td>No SSC exposure, no effect for Type II smolts from the Salmon River (~20%) during downstream migration. Majority (~95%) of juveniles outmigrate from Trinity River and are also exposed to no SSC from Proposed Action.</td></tr>
<tr><td rowspan="5">Type III outmigration Jan 15–May 31, 2020)[c]</td><td>1,808 to 4,915</td><td>2</td><td>9</td><td rowspan="5">Stressful conditions resulting in reduced growth and up to 20% mortality for Type III smolts from Salmon River. (around 16 smolts, less than 1% of the total smolt population from the Salmon River).</td></tr>
<tr><td>665 to 1,808</td><td>17</td><td>10</td></tr>
<tr><td>245 to 665</td><td>8</td><td>9</td></tr>
<tr><td>90 to 245</td><td>16</td><td>8</td></tr>
<tr><td>33 to 90</td><td>23</td><td>8</td></tr>
</table>

a Maximum duration of exposure during migration =14 days.
b Maximum duration of exposure during migration = 2 days.
c Maximum duration of exposure during migration = 30 days

Table E-17. Predicted Suspended Sediment Concentration, Exposure Duration, and Anticipated Effects on Spring-Run Chinook Salmon for Worst-Case Scenario (10% exceedance probability), for Klamath River at Orleans (RM 58).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult spring migration (Apr 1–Jun 30, 2020)[a]	245 to 665	6	9	Major stress and impaired homing for adults returning to Salmon River. Majority (~95% on average) of adults enter Trinity River, and will be exposed to lower concentrations. However, up to 35% of "natural" escapement returns to Salmon River.
	90 to 245	14	8	
	33 to 90	14	7	
Adult summer migration (Jul 1–Aug 31, 2020)[b]	33 to 90	2	7	Impaired homing for the approximately 50% of the summer migration returning exclusively to the Trinity River.
Spawning, incubation, and fry emergence (Sept 1 2019–Feb 28, 2020)	n/a	n/a	n/a	Spring-run do not generally spawn in the mainstem.
Juvenile rearing (variable)	n/a	n/a	n/a	Juveniles rear in tributaries; no effect to this life stage is anticipated.
Type I outmigration (Apr 1–May 31, 2020) [c]	245 to 665	3	8	Major stress for Type I fry (~80%) in smolt outmigration from Salmon River. Majority (~95%) of juveniles outmigrate from the Trinity River, and will be exposed to lower concentrations.
	90 to 245	16	8	
	33 to 90	34	8	
Type II outmigration (Oct 1–Nov 15, 2020) [c]	90 to 245	1	7	Moderate stress for Type II smolts from the Salmon River (~20%) during downstream migration. Same effects as under existing conditions.
	33 to 90	2	6	
Type III outmigration Jan 15–May 31, 2020) [c]	1,808 to 4,915	6	10	Stressful conditions resulting in reduced or no growth and up to 36% mortality for Type III smolts from Salmon River. (up to 28 smolts, less than 1% of the total smolt population from the Salmon River).
	665 to 1,808	30	10	
	245 to 665	16	9	
	90 to 245	25	9	
	33 to 90	30	8	

a Maximum duration of exposure during migration =14 days.
b Maximum duration of exposure during migration = 2 days.
c Maximum duration of exposure during migration = 30 days

Under existing conditions and the No Action/No Project Alternative, and the Proposed Action, SSC during the Type II outmigration would cause moderate-to-major stress for one to three days, and only under extreme existing conditions and the No Action/No Project Alternative or the worst-case scenario of the Proposed Action.

Type III outmigrants that overwinter in the mainstem Klamath River when SSC are highest, or those migrating from the Salmon River (<1 percent of outmigrants within Klamath River watershed), will have the greatest exposure to suspended sediment. Suspended sediment conditions would cause major physiological stress during the Type III outmigration under both normal and extreme existing conditions and the No Action/No Project Alternative, but remain in the sublethal range. Type III age 1 spring outmigrants are very rare (only 30 were observed in the Salmon River in five years of trapping). Based on model predictions of 0 to 20 percent mortality under a most likely to occur scenario, around 16 smolts would perish at worst, or less than 1 percent of the total smolt population from the Salmon River, and an even smaller percentage of the total production from the Klamath Basin. Under a worst case scenario mortality rates of 20 to 36 percent are predicted, or around 28 smolts at worst (<1 percent of production). However, based on Olson (1996) the typically larger Type III smolts can contribute up to 7 percent of the escapement despite their low proportion of smolt production, perhaps due to their larger size at ocean entry (Bilton 1984). Therefore the effect on the population of mortality to the Type III smolts may be proportionally higher than the effect of mortality of other life-histories. Most spring-run outmigrants (95 percent) originate from the Trinity River; they have a shorter distance to travel to the ocean and suspended sediment concentrations resulting from the Proposed Action should be lower due to dilution (Reclamation 2011), so they may experience major stress, but suffer little or no mortality.

E.3.2.3 Coho Salmon

As described in Section E.3.1.3, the affects of suspended sediment on coho salmon in the Klamath River described here follow the Williams et al. (2006) designation of nine population units. Although coho salmon within the Upper Klamath River Population Unit do migrate as far upstream as Iron Gate Dam, in general coho salmon are primarily distributed within tributaries downstream of the Shasta River. Therefore, the analysis focuses on exposure to suspended sediment within, and downstream of, Seiad Valley. Fish within the Upper Klamath River Population Unit upstream of Seiad Valley could be expected to be exposed to slightly higher SSC concentrations, and fish rearing in all other population units further downstream to lower concentrations.

Adult coho salmon enter the Klamath River between late September and mid-December, with peak upstream migration occurring between late October and mid-November. Based on adult migration observations in Scott River (2007–2009), Shasta River (2007-2009), and Bogus Creek (2003–2009), on average only around 4 percent of adult remain in the mainstem after December 15th (initiation of reservoir drawdown under the Proposed Action) (California Department of Fish and Game, unpubl. data). In most years all adults are observed prior to December 15th, although in some years (e.g., Scott River in 2009) most fish are observed between December 15th and January 1st. Therefore, most adult coho should already be in tributaries when reservoir drawdown begins in January 2020 (Table E-18 and E-19), especially those returning the shorter migration distances to the Trinity River and Lower Klamath River populations. Under the most likely and worst case scenarios, effects of the Proposed Action on migrating adults from all population units are anticipated to be slightly higher than those experienced under existing conditions and the No Action/No Project Alternative, but will remain sublethal (Table E-18 and E-19). The worst-case scenario under the Proposed Action would differ from extreme existing conditions only in extending the duration of exposure to elevated suspended sediment by a week.

Table E-18. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Coho Salmon for Proposed Action most likely Scenario (50% exceedance probability), Klamath River at Seiad Valley (RM 129).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migrants (Sept 1, 2019–Jan 1, 2020)	245 to 665	<1	7	Major stress and impaired homing for adults migrating upstream (~4% of all populations exposed).
	90 to 245	5	8	
	33 to 90	20	8	
Spawning, incubation, and fry emergence (Nov 1, 2019–Mar 14, 2020)	1,808 to 4,915	14	13	Effects of suspended sediment on spawning gravel quality were not modeled; however, suspended sediment may result in nearly 100% mortality of progeny from mainstem spawning. (~13 redds, or 0.7–26% of Upper Klamath River Population unit natural escapement).
	665 to 1,808	11	12	
	245 to 665	10	12	
	90 to 245	6	11	
	33 to 90	20	12	
Age-1 juveniles during winter (Nov 15, 2019–Feb 14, 2020)	1,808 to 4,915	4	10	Reduced growth and up to 20% mortality for age 1 juveniles from the 2019 cohort rearing in the mainstem. An unknown but assumed small number (<1%) of juveniles rear in mainstem during winter.
	665 to 1,808	8	9	
	245 to 665	7	9	
	90 to 245	5	8	
	33 to 90	17	8	
Age-0 juveniles during summer (Mar 15– Nov 14, 2020)	245 to 665	7	9	Reduced growth for age 0 juveniles from 2019 cohort rearing in mainstem during late spring and early summer. Majority (>50%) of juveniles believed to rear in tributaries during summer and will have no exposure.
	90 to 245	23	9	
	33 to 90	23	8	
Age 1 juvenile outmigration (Feb 15–March 31, 2020)[a]	1,808 to 4,915	4	10	Major stress, reduced growth, and up to 20% mortality for smolts outmigrating from Upper Klamath, Mid-Klamath, Shasta River, and Scott River populations during early spring (~44% of run). (total of 2,668 smolts, 3% of all populations; impacts vary by population)
	665 to 1,808	6	9	
	245 to 665	12	9	
	90 to 245	20	9	
	33 to 90	18	8	
Age 1 juvenile outmigration (April 1– June 30, 2020)	245 to 665	4	8	Major stress and reduced growth for smolts outmigrating from Upper Klamath, Mid-Klamath, Shasta River, and Scott River populations during late spring (~56% of run).
	90 to 245	19	9	
	33 to 90	17	8	

a maximum migration duration = 20 days

Table E-19. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Coho Salmon for Proposed Action Worst-Case Scenario (10% exceedance probability), for Klamath River at Seiad Valley (RM 129).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migrants (Sept 1, 2019–Jan 1, 2020)	665 to 1,808	1	8	Major stress and impaired homing for all adults migrating upstream (~4% of all populations exposed).
	245 to 665	7	9	
	90 to 245	13	8	
	33 to 90	34	8	
Spawning, incubation, and fry emergence (Nov 1, 2019–Mar 14, 2020)	4,915 to 13,360	5	12	Effects of suspended sediment on spawning gravel quality were not modeled; however, suspended sediment is predicted to result in nearly 100% mortality of all progeny from mainstem spawning. (~13 redds, or 0.7–26% of Upper Klamath River Population unit natural escapement).
	1,808 to 4,915	26	13	
	665 to 1,808	26	13	
	245 to 665	16	12	
	90 to 245	14	12	
	33 to 90	34	12	
Age-1 juveniles during winter (Nov 15, 2019–Feb 14, 2020)	1,808 to 4,915	24	11	Reduced growth and up to 52% mortality for age 1 juveniles from the 2019 cohort rearing in the mainstem. An unknown but assumed small number of all juveniles (<1%) rear in mainstem during winter.
	665 to 1,808	24	10	
	245 to 665	12	9	
	90 to 245	14	8	
	33 to 90	28	8	
Age-0 juveniles during summer (Mar 15–Nov 14, 2020)	665 to 1,808	4	9	Reduced or no growth for age 0 juveniles from 2019 cohort rearing in mainstem. Majority (>50%) of juveniles believed to rear in tributaries during summer and will have no exposure.
	245 to 665	13	9	
	90 to 245	41	9	
	33 to 90	52	9	
Age 1 juvenile outmigration (Feb 15–March 31, 2020)[a]	4,915 to 13,360	3	10	Major stress, reduced growth, and up to 49% mortality for smolts outmigrating from Upper Klamath, Mid-Klamath, Shasta River, and Scott River populations during early spring (~44% of run). (up to 6,536 smolts, 8% of all populations; impacts vary by population)
	1,808 to 4,915	6	10	
	665 to 1,808	11	10	
	245 to 665	18	9	
	90 to 245	20	9	
	33 to 90	20	8	
Age 1 juvenile outmigration (April 1– June 30, 2020)[a]	665 to 1,808	1	8	Major stress and reduced growth for smolts outmigrating from Upper Klamath, Mid-Klamath, Shasta River, and Scott River populations during late spring (~56% of run).
	245 to 665	12	9	
	90 to 245	20	9	
	33 to 90	20	8	

[a] maximum migration duration = 20 days

Because coho salmon spawning in the mainstem is uncommon (Magneson and Gough 2006), it is unlikely that dam removal will directly affect egg or alevin development, with the exception of any redds in the mainstem. Coho salmon from the Upper Klamath River Population Unit that spawn in the mainstem, as well as their progeny, would suffer up to

100 percent mortality under either scenario of the Proposed Action (Table E-18); however, even under existing conditions and the No Action/No Project Alternative, very high mortality (98 to 100 percent) is expected (Table E-6 and E-7) due to the effects of suspended sediment on these life stages (in addition to other sources of mortality); therefore, the effects of suspended sediment resulting from the Proposed Action are within the range of those predicted for existing conditions and the No Action/No Project Alternative. Based on spawning surveys conducted from 2001 to 2005 (Magneson and Gough 2006), from 6 to 13 redds could be affected, many of which are thought to be hatchery returning fish (NOAAFisheries 2010). Based on the range of escapement estimates of Ackerman et al. (2006), 13 redds could represent anywhere from 0.7 to 26 percent of the naturally returning spawning in the Upper Klamath River Population Unit, and much less than 1 percent of the natural and hatchery returns combined.

Although most (assumed >50 percent) fry rearing is believed to occur in tributaries, age-0 fry are observed outmigrating from tributaries in late spring and early summer. Juvenile coho in the mainstem during the spring and summer following facility removal (2020) would be exposed to concentrations of suspended sediment that will result in major physiological stress and reduced growth (possibly no growth at all) under the Proposed Action (Tables E-18 and E-19), similar to predictions for extreme existing conditions and the No Action/No Project Alternative (Table E-7). These effects, in addition to possible exposure to diseases and the elevated temperatures often recorded in the mainstem Klamath River during summer, could result in high mortality of this cohort for all populations that have some rearing in the mainstem. There could also be indirect effects on marine survival for those fish that survive the summer, but smolt at a smaller size (Bilton et al. 1982, Hemmingsen et al. 1986).

Under existing conditions and the No Action/No Project Alternative, suspended sediment concentrations are typically high during the winter in the mainstem Klamath River, and predicted to cause major stress for a month under both normal and extreme conditions (Table E-7). Under the Proposed Action, age-1 juveniles (progeny of the 2019 cohort) that have either successfully oversummered or moved from tributaries into the mainstem in fall, could be exposed to much higher SSC in the mainstem during the winter of facility removal than under existing conditions and the No Action/No Project Alternative (Table E-7), and may suffer mortality rates of up to 52 percent under a worst-case scenario (Table E-19). However, many juveniles in the mainstem Klamath River appear to migrate to the lower river to rear and may avoid adverse conditions in the mainstem by using tributary or off-channel habitats during winter, thus reducing their exposure and potential mortality (Soto et al. 2009, Hillemeier et al. 2009), consistent with the observation that juvenile salmonids avoid turbid conditions (Sigler et al. 1984, Servizi and Martens 1992). This strategy may be even more pronounced under the even higher SSC expected under the Proposed Action. Overall, it is not known how many juveniles rear in the mainstem during winter, but it is assumed to be a small (<1 percent) proportion of any of the coho salmon populations.

Coho salmon smolts from the 2019 cohort are expected to outmigrate to the ocean beginning in late February, although most natural origin smolts outmigrate to the mainstem Klamath during April and May (Wallace 2004). During migrant trapping studies from 1997–2006 in tributaries upstream of and including Seiad Creek (Horse Creek, Seiad Creek, Shasta River, and Scott River), 44 percent of coho smolts were captured from February 15 to March 31, and 56 percent from April 1 through the end of June (Courter et al. 2008). Once in the mainstem, smolts move downstream fairly quickly (Stutzer et al. 2006). As discussed in detail in Section A.2, this analysis assumes a maximum exposure of 20 days for downstream migration. Under the Proposed Action, concentrations would be higher during spring than under existing conditions and the No Action/No Project Alternative, and smolts outmigrating in early spring (prior to April 1) are likely to suffer up to 60 percent mortality in a worst-case scenario (Table E-19). Smolts outmigrating in late spring (after April 1) will be exposed to lower concentrations, and may experience only slightly worse physiological stress and reduced growth rates compared with existing conditions and the No Action/No Project Alternative, even under a worst-case scenario.

Based on the results of outmigrant trapping by the USFWS (2001) on the mainstem Klamath River compared with trapping in the Trinity River from 1997 to 2000 (USFWS 2010), most (>80 percent) coho smolts originate from the Trinity River and Lower Klamath River populations. For the majority of smolts produced from tributaries downstream of Orleans, effects of the Proposed Action will be similar to existing conditions and the No Action/No Project Alternative by late April (Figure E-4). The overall mortality rates predicted to occur as a result of the Proposed Action vary for each population, and are summarized in Table E-20, based on the average smolt abundance predicted for the 2018 brood year (age 1 smolts in spring 2020). Smolt abundance data are available for the Shasta River, Scott River, and Trinity River populations. Smolt abundance data from all tributaries within the Upper Klamath, Mid-Klamath, Salmon and Lower Klamath River populations is not available, and so smolt production estimates modeled by Courter et al. (2008) were used. Courter et al. (2008) modeled all mainstem and tributary reaches within the Klamath Basin based on available smolt production data and habitat conditions within tributaries, and thus comprise the most complete assessment of potential smolt production available.

Under existing conditions and the No Action/No Project Alternative, coho salmon smolts outmigrating from the Upper Klamath River, Scott River, and Shasta River populations currently have mortality rates (35 to 70 percent) presumably as a result of poor water quality and disease (Beeman et al. 2007, 2008), which, in conjunction with physiological stress and reduced growth resulting from the Proposed Action, could result in even higher mortality in the spring of 2020.

Table E-20. Summary of Predicted Age 1 Coho Salmon Smolt Mortality during Early Spring Outmigration (44% of total smolt abundance) Resulting from the Proposed Action within Coho Salmon Population Units of the Klamath River Watershed.

Population Unit	Estimated Total Smolt Abundance	Estimated mortality					
		Most Likely to Occur Scenario			Worst Case Scenario		
		Mortality (%)	Number of Smolts	Proportion of Population (%)	Mortality (%)	Number of Smolts	Proportion of Population (%)
Upper Klamath River	7,675[a]	20	676	9	49	1,655	22
Shasta River	1,131[b]	20	100	9	49	244	22
Scott River	1,300[b]	20	114	9	49	280	22
Mid-Klamath River	20,211[a]	20	1,779	9	49	4,357	22
Salmon River	4,611[a]	0	0	0	0	0	0
Upper Trinity River; Lower Trinity River; South Fork Trinity River	3,122[c]	0	0	0	0	0	0
Lower Klamath River	45,861[a]	0	0	0	0	0	0
Total	83,911		2,668	3		6,536	8

[a] Based on Courter et al. (2008) for an average water year under existing conditions.

[b] California Department of Fish and Game, unpublished data 2011. Predictions for 2018 brood year based on average of brood year 2003, and 2006 smolt production (spring 2005 and 2008).

[c] Based on Scheiff et al. (2001) abundance estimates for natural production.

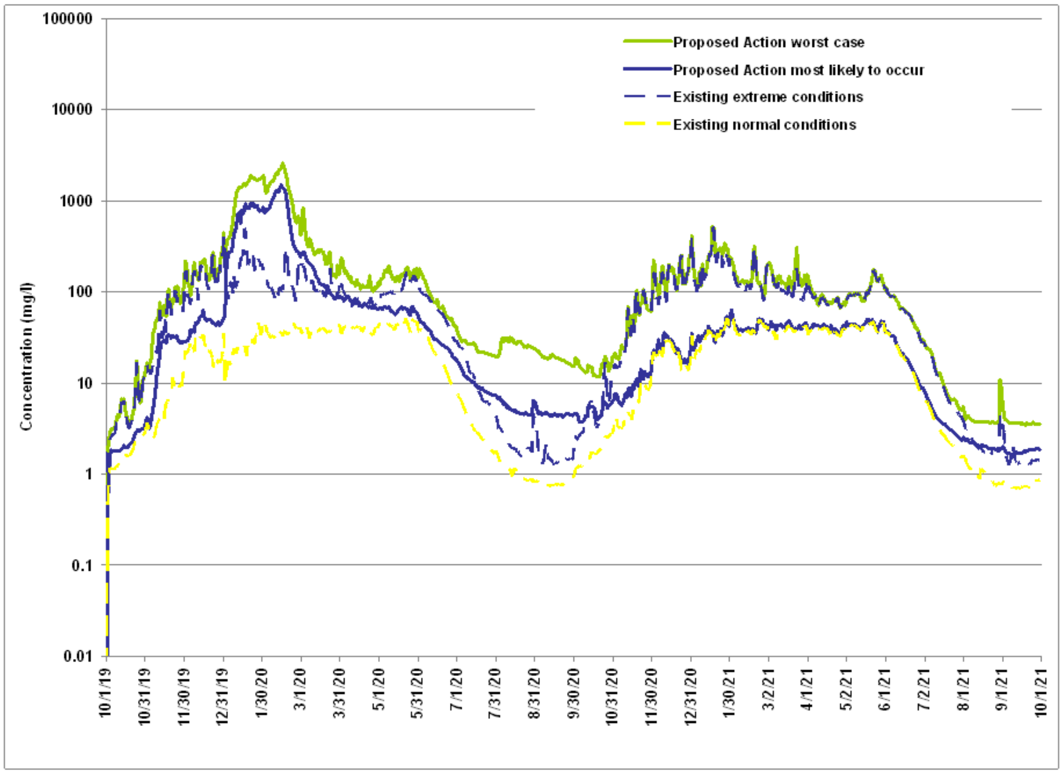

Figure E-4. Proposed Action Compared to Existing Conditions and the No Action/No Project Alternative at Orleans, as Predicted using SRH-1D Model.

E.3.2.4 Summer- and Winter-run Steelhead

Although steelhead do migrate as far upstream as Iron Gate Dam, they are primarily distributed downstream of Seiad Valley; therefore, this analysis focuses on exposure to suspended sediment in the mainstem Klamath River downstream of Seiad Valley.

Adult summer steelhead typically enter and migrate up the Klamath River from March through June (Hopelain 1998). Under the Proposed Action, SSC would be higher than under existing conditions and the No Action/No Project Alternative, most likely resulting in major physiological stress and impaired homing, or up to 20 percent adult mortality under a worst-case scenario. Based on summer steelhead surveys conducted in the Salmon River and other tributaries to the Klamath River by the USDA Forest Service and others from 1985 to 2009, on average around 657 adult summer steelhead migrate up the Klamath River to tributaries upstream of the Trinity River (USDA Forest Service, unpubl. data; Salmon River Restoration Council, unpubl. data), with an additional 800 on average migrating up the Trinity River (Busby et al. 1994). Under the worst case scenario 0 to 20 percent mortality could result from the Proposed Action, resulting in mortality of from 0 to 130 adults, or from 0 to 9 percent of the basin-wide escapement. Those summer steelhead that spawn in the Trinity River (~55 percent of the run based on escapement data) and other downstream tributaries will likely be exposed to only slightly higher impacts from suspended sediment than under existing conditions and the No Action/No Project Alternative.

The Proposed Action 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 will likely be exposed to much higher SSC than under existing conditions and the No Action/No Project Alternative (Tables E-21 and E-22). Information on the abundance of winter steelhead, which is considered to be the most abundant form, is very limited due to logistical difficulties in sampling adults during the winter season. The only decent long-term data on adult returns is from hatchery returns to the Iron Gate Hatchery and Trinity River Hatchery (Busby et al. 1994). In a good year around 7,000 adults return to both hatcheries, including around 3,500 to the Klamath River upstream of the Trinity River (Busby et al. 1994). Based on USFWS (1998) periodicities assessment, on average around 80 percent (2,800 fish) of winter steelhead migrate upstream after December 15th, and could be exposed to SSC released from the Proposed Action, although in some years many more fish migrate in the fall before that time. Based on predictions of up to 40 percent mortality of the adult winter run under the most-likely scenario, up to 1,008 adults, or up to 14 percent of the total run could be affected by the Proposed Action. Under the worst-case scenario up to 71 percent mortality is predicted to occur as a result of the Proposed Action, resulting in up to 1,988 adults, or up to 28 percent of the basin-wide escapement. Stressed adults are also assumed to be more susceptible to disease, possibly increasing pre-spawn mortality, unless they respond to the high turbidity by entering tributaries earlier than usual, as was observed for upstream-migrating Chinook and coho salmon during the September 2002 fish kill event in the lower Klamath River (M. Belchik, pers. comm., August 2008). In addition, steelhead are a highly migratory species that regularly occur in environments with high SSCs, and therefore the predictions described here are likely more dire than would occur.

Since no steelhead spawning occurs in the mainstem Klamath River under existing conditions and the No Action/No Project Alternative, the egg, alevin, and fry life stages are not anticipated to be affected by suspended sediment resulting from the Proposed Action (Tables E-21 and E-22).

Post-spawning adults (“runbacks”) migrate downstream in the spring to return to the sea, typically from April through May. Under the Proposed Action, SSC will be higher than under existing conditions and the No Action/No Project Alternative, and sublethal but major stress is likely under either scenario (Tables E-21 and E-22). If runbacks migrate relatively quickly from their spawning tributaries to the ocean, this may overestimate the duration of their exposure to sediment in the mainstem. There are little data on downstream-migrating steelhead in the Klamath with which to understand potential consequences of exposure to suspended sediment during this life-history phase.

Table E-21. Predicted Suspended Sediment Concentrations, Durations, and Anticipated Effects on Steelhead for Proposed Action Most Likely Scenario (50% exceedance probability), Seiad Valley (RM 129).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult summer upstream migrants (Mar 1–June 30, 2020)	665 to 1,808	3	9	Major stress and impaired homing for adult migrants. The ~55% that migrate to the Trinity River or tributaries further downstream will not be as affected.
	245 to 665	10	9	
	90 to 245	25	9	
	33 to 90	18	8	
Adult winter upstream migrants (Aug 1 2019–Mar 31, 2020)	1,808 to 4,915	14	10	Major stress, impaired homing, and up to 36% mortality for adult migrants. (Up to 1,008 adults, or up to 14% of the total escapement).
	665 to 1,808	11	10	
	245 to 665	11	9	
	90 to 245	7	8	
	33 to 90	20	8	
Adult run-backs (Apr 1–May 30, 2020)	245 to 665	1	8	Moderate to major stress to downstream-migrating adults during a two-week period; effect will depend on timing of outmigration in relation to suspended sediment pulse.
	90 to 245	17	8	
	33 to 90	8	7	
Half-pounder residence (Aug 15, 2019–Mar 31, 2020)	245 to 665	2	8	Major stress and potentially impaired homing. Majority remain in tributaries and will not be affected.
	90 to 245	7	8	
	33 to 90	13	7	
Spawning through emergence (Dec 1, 2019–June 1, 2020)	n/a	n/a	n/a	Spawning occurs in tributaries; no effect.
Age 0 juvenile rearing (Mar 15–Nov 14, 2020)	245 to 665	7	9	Major stress and reduced growth. Around 40% rear in tributaries and will not be affected.
	90 to 245	23	9	
	33 to 90	23	8	
Age 1 juvenile rearing (year-round)	1,808 to 4,915	14	11	Major stress resulting in reduced growth and up to 52% mortality. (Up to 8,200 juveniles or around 14% of total age 1 production).
	665 to 1,808	11	10	
	245 to 665	13	9	
	90 to 245	25	9	
	33 to 90	25	8	
Age 2 juvenile rearing (Nov 15, 2019–Mar 31, 2020)	1,808 to 4,915	14	11	Major stress resulting in reduced growth and up to 52% mortality. (Up to 6,893 juveniles or around 13% of total age 2 production).
	665 to 1,808	11	10	
	245 to 665	11	9	
	90 to 245	7	8	
	33 to 90	17	8	
Juvenile/smolt outmigrants (Apr 1–Nov 14, 2020)	245 to 665	4	8	Major stress and reduced growth. Around 57% outmigrate from Trinity River and will have less exposure.
	90 to 245	19	9	
	33 to 90	22	8	

Table E-22. Predicted Suspended Sediment Concentrations, Durations, and Anticipated Effects on Steelhead for Proposed Action Worst-Case Scenario (10% exceedance probability), Seiad Valley (RM 129).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult summer upstream migrants (Mar 1–June 30, 2020)	1,808 to 4,915	<1	9	Major stress, impaired homing, and up to 20% mortality for adult migrants. (From 0 to 130 adults, or from 0 to 9% of the basin-wide escapement).
	665 to 1,808	8	10	
	245 to 665	18	9	
	90 to 245	41	9	
	33 to 90	32	8	
Adult winter upstream migrants (Aug 1 2019–Mar 31, 2020)	4,915 to 13,360	5	11	Major stress, impaired homing, and up to 71% mortality for adult migrants. (Up to 1,988 adults, or up to 28% of the basin-wide escapement).
	1,808 to 4,915	26	11	
	665 to 1,808	26	10	
	245 to 665	17	9	
	90 to 245	20	8	
	33 to 90	34	8	
Adult run-backs (Apr 1–May 30, 2020)	665 to 1,808	1	8	Major stress to downstream-migrating adults.
	245 to 665	10	9	
	90 to 245	32	9	
	33 to 90	25	8	
Half-pounder residence (Aug 15 2019–Mar 31, 2020)	1,808 to 4,915	1	9	Major stress and reduced growth. Majority remain in tributaries and will not be affected.
	665 to 1,808	2	9	
	245 to 665	11	9	
	90 to 245	18	8	
	33 to 90	30	8	
Spawning–fry emergence (Dec 1–Jun 1, 2020)	n/a	n/a	n/a	Spawning occurs in tributaries; no effect.
Age 0 juvenile rearing (Mar 15–Nov 14, 2020)	665 to 1,808	4	9	Major stress and reduced growth. Around 40% rear in tributaries and will not be affected.
	245 to 665	13	9	
	90 to 245	41	9	
	33 to 90	52	9	
Age 1 juvenile rearing (year-round)	4,915 to 13,360	5	11	Major stress resulting in reduced growth and up to 71% mortality. (Up to 11,207 juveniles or around 19% of total age 1 production).
	1,808 to 4,915	26	11	
	665 to 1,808	26	10	
	245 to 665	18	9	
	90 to 245	41	9	
	33 to 90	52	9	

Table E-22. Predicted Suspended Sediment Concentrations, Durations, and Anticipated Effects on Steelhead for Proposed Action Worst-Case Scenario (10% exceedance probability), Seiad Valley (RM 129).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Age 2 juvenile rearing (Nov 15 2019–Mar 31, 2020)	4,915 to 13,360	5	11	Major stress resulting in reduced growth and up to 71% mortality. (Up to 9,412 juveniles or around 18% of total age 2 production).
	1,808 to 4,915	26	11	
	665 to 1,808	26	10	
	245 to 665	17	9	
	90 to 245	20	9	
	33 to 90	28	8	
Juvenile/smolt outmigrants (Apr 1–Nov 14, 2020)	665 to 1,808	1	8	Major stress and reduced growth. Around 57% outmigrate from Trinity River and will have less exposure and no mortality.
	245 to 665	12	9	
	90 to 245	39	9	
	33 to 90	52	9	

Adult summer-run half-pounders typically enter the mainstem and hold from around mid-August through March, and thus would be affected by the Proposed Action during the winter of 2020. Half-pounders in the mainstem upstream of the Trinity River could be exposed to higher SSC than under existing conditions and the No Action/No Project Alternative, with major physiological stress predicted under either scenario (Tables E-21 and E-22). However, an unknown proportion of half-pounders are observed to hold in the Trinity River or other tributaries, and these fish will not be affected.

Juvenile steelhead rear in the mainstem Klamath River, tributaries to the Klamath, or the estuary. Since most (>90 percent) juvenile steelhead smolt at age-2, those juveniles leaving tributaries to rear in the mainstem will be exposed to elevated suspended sediment concentrations resulting from the Proposed Action through both winter and spring. Based on captures in tributaries and the mainstem, it appears than around 40 percent of the population rears in tributaries until age-2 (Scheiff et al. 2001), and will only be susceptible while outmigrating. The approximately 60 percent of the rearing population that outmigrates from tributaries as age-0 or age-1 and rears for extended periods in the mainstem upstream of Trinity River would likely be exposed to much higher SSC than under existing conditions and the No Action/No Project Alternative, with mortality rates up to 100 percent in a worst-case scenario (Tables E-21 and E-22). Table E-23 summarizes the total number of rearing steelhead of each class within the Klamath River estimated based on migrant trapping data from the Trinity River at Willow Creek and the Klamath River at Big Bar from 1997 to 2000 (Scheiff et al. 2001). Mortality estimates in Table E-23 were based on the extrapolated estimates of abundance for each class within the Klamath River, as compared to the average total production estimated in both the Klamath and Trinity river trap locations, and assuming around 40 percent of juveniles rear within tributaries and will not be exposed. This estimate does not consider juveniles produced from tributaries downstream of the Trinity River, and thus the actual rate of mortality would be lower than estimated here. It does appear that many of these juveniles avoid conditions in the mainstem by using tributary and off-channel habitats during winter, which would reduce their exposure (Soto et al. 2009, Hillemeier et al. 2009), consistent with the observation that juvenile salmonids avoid turbid conditions (Sigler et al. 1984, Servizi and Martens 1992). Most smolts outmigrate in the fall, so many juveniles should already be in the estuary or ocean when initial pulses in sediment occur, or they may migrate out of the mainstem later in the winter after concentrations decrease.

Table E-23. Summary of Steelhead Juvenile Rearing Abundance and Estimated Mortality Resulting from the Proposed Action.

	Age 0		Age 1		Age 2 and older	
	Klamath River	**Trinity River**	**Klamath River**	**Trinity River**	**Klamath River**	**Trinity River**
Average juvenile abundance	4,217	13,384	15,784	20,445	13,256	17,401
Most-likely to occur scenario						
Estimated mortality rate	0%	0%	52%	0%	52%	0%
Mortality estimate	0	0	8,208	0	6,893	0
Percentage of total production	0%	0%	14%	0%	13%	0%
Worst-case scenario						
Estimated mortality rate	0%	0%	71%	0%	71%	0%
Mortality estimate	0	0	11,207	0	9,412	0
Percentage of total production	0%	0%	19%	0%	18%	0%

Under the Proposed Action, steelhead outmigrating in spring as age-2 smolts from tributaries higher in the basin will likely be exposed to suspended sediment for longer than under existing conditions and the No Action/No Project Alternative, with major physiological stress predicted for both scenarios (Tables E-21 and E-22). Based on migrant trapping data from the Trinity River at Willow Creek and the Klamath River at Big Bar from 1997 to 2000 (Scheiff et al. 2001) approximately 57 percent of smolts outmigrate from the Trinity River, and will be exposed to SSC similar to those under existing conditions and the No Action/No Project Alternative.

E.3.2.5 Pacific lamprey

Based on Pacific lamprey distribution, the impacts of the Proposed Action will be highest on those lamprey returning to or emigrating from mid-Klamath River tributaries such as the Scott River; therefore, this analysis focuses on exposure to suspended sediment in the reach downstream of Seiad Valley.

There is little to no literature on the effects of suspended sediment on lamprey. This analysis used the effects of suspended sediment on salmonids to predict effects on lamprey, with the assumption that effects on lamprey are equivalent or less severe than on salmonids. In general, most life stages of Pacific lamprey appear more resilient to poor water quality conditions than salmonids (Zaroban et al. 1999), so this is likely a conservative assessment of potential effects.

Anadromous Pacific lamprey enter the Klamath Basin throughout the year, although their numbers peak in early winter, and thus a large proportion of adults could be directly effected by suspended sediment resulting from the Proposed Action in winter and early spring, with possibly up to 40 percent mortality under a most-likely scenario, and up to 100 percent under a worst-case scenario (Tables E-24 and E-25). Approximately 44 percent of Pacific lamprey are believed to spawn in the Trinity River basin (Scheiff et al. 2001). These individuals will be exposed to lower SSC, while those adults returning in fall, summer, or late spring will avoid exposure to the highest suspended sediment concentrations likely to result from the Proposed Action.

Pacific lamprey ammocoetes rear for a variable number of years before outmigrating to sea; therefore, suspended sediment resulting from the Proposed Action has the potential to affect multiple year-classes of the population (Tables E-24 and E-25). Lamprey are reported to have an intermediate level of tolerance to increased sedimentation and turbidity (Zaroban et al. 1999), but it is not known how changes in suspended sediment affect ammocoete survival. Juvenile salmonids would have mortality rates of 60-100 percent under a worst-case scenario (Tables E-24 and E-25), but because Pacific lamprey ammocoetes rear in burrows in fine sediment, they may tolerate spikes in suspended sediment resulting from the Proposed Action, although excessive sedimentation from the settling out of suspended fines could possibly smother ammocoetes in some areas. Ammocoetes are filter-feeders, so at a minimum reduced growth rates might be expected from elevated suspended sediment, and it is assumed that mortality will be higher than under existing conditions and the No Action/No Project Alternative. However, the broad spatial distribution of lamprey in the Klamath Basin, including mid-Klamath River tributaries such as the Scott River, and the fact that ~44 percent of adults return to the Trinity River, should mean that a large portion of the rearing ammocoete population will escape impacts from the Proposed Action.

Juvenile lamprey (ages 2 to 10) outmigrate to the ocean from the mainstem Klamath River and tributaries rear-round, with peaks in late spring and fall. Exposure to suspended sediment from the Proposed Action is only slightly higher during the spring migration than under existing conditions and the No Action/No Project Alternative and the same as existing conditions and the No Action/No Project Alternative during fall (Tables E-24 and E-25).

Table E-24. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Pacific lamprey for Proposed Action Most Likely Scenario (50% exceedance probability), for Klamath River at Seiad Valley (RM 12).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migration and spawning (all of 2020)	1,808 to 4,915	14	10	Major stress, reduced growth, and up to 36% mortality for adult migrants. Adults migrating in late spring and summer exposed to lower SSC, as are lamprey returning to lower river tributaries such as the Trinity River.
	665 to 1,808	11	10	
	245 to 665	13	9	
	90 to 245	25	9	
	33 to 90	25	8	
Ammocoete rearing (all of 2020)	1,808 to 4,915	14	11	Major stress, reduced growth, and up to 52% mortality for multiple year classes. Majority rear in tributaries and will not suffer mortality.
	665 to 1,808	11	10	
	245 to 665	13	9	
	90 to 245	25	9	
	33 to 90	25	8	
Spring outmigration (May 1–June 30, 2020)	90 to 245	10	8	Major stress for all juveniles during spring outmigration.
	33 to 90	16	8	
Fall/winter outmigration (Sept 1–Dec 31, 2020)	90 to 245	2	7	Moderate stress for all juveniles during spring outmigration.
	33 to 90	4	7	

Table E-25. Predicted Suspended Sediment Concentration, Exposure Duration, and Anticipated Effects on Pacific Lamprey for Proposed Action Worst-Case Scenario (10% exceedance probability), for Klamath River at Seiad Valley (RM 129).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult upstream migration and spawning (all of 2020)	4,915 to 13,360	5	11	Major stress, reduced growth, and up to 71% for adult migrants. Adult migrating during late spring and summer are exposed to lower concentrations of SSC, as are lamprey returning to lower river tributaries such as the Trinity River, and thus should avoid mortality
	1,808 to 4,915	26	11	
	665 to 1,808	26	10	
	245 to 665	18	9	
	90 to 245	41	9	
	33 to 90	52	8	
Ammocoete rearing (all of 2020)	4,915 to 13,360	5	11	Major stress, reduced growth, and up to 71% mortality for multiple year classes. Majority rear in tributaries and will not suffer mortality.
	1,808 to 4,915	26	11	
	665 to 1,808	26	10	
	245 to 665	18	9	
	90 to 245	41	9	
	33 to 90	52	9	
Juvenile spring outmigration (May 1–June 30, 2020)	665 to 1,808	<1	7	Moderate to major stress and reduced growth for all juveniles during spring outmigration
	245 to 665	9	9	
	90 to 245	26	9	
	33 to 90	30	8	
Juvenile fall/winter outmigration (Sept 1 2020–Dec 31, 2020)	665 to 1,808	1	8	Major stress for all juveniles during spring outmigration
	245 to 665	3	8	
	90 to 245	6	8	
	33 to 90	18	8	

E.3.2.6 Green Sturgeon

Based on green sturgeon distribution, the Proposed Action will have the highest potential effect on green sturgeon within the Klamath River downstream of Ishi Pishi Falls (i.e., downstream of the Salmon River and Orleans; RM 66); therefore, this analysis focuses on exposure of green sturgeon to suspended sediment in this reach.

Very little information is available on the effects of suspended sediment on sturgeon. This assessment is based on available information of the effects of suspended sediment on salmonids, with the assumption that effects on sturgeon are equivalent or less severe than on salmonids. Most life stages of sturgeon are more resilient to poor water quality conditions than salmonids, so this is likely a conservative assessment.

Adult green sturgeon enter the Klamath River beginning in mid-March, and under the Proposed Action are likely to be to exposed to long durations of high SSC, that would result in reduced growth and major physiological stress in salmonids under a worst-case scenario for the Proposed Action (Tables E-26 and E-27). Green sturgeon typically go for long periods without feeding during their spawning migration, and generally feed on benthic organisms detected in fine sediments by their sensitive barbels, both of which traits would likely reduce the impacts of suspended sedimentation on the species in terms of feeding ability (EPIC et al. 2001, as cited in CDWR 2003). Green sturgeon in the Klamath River spawn an average of every four years (occasionally males spawn every two years) (McCovey 2010), which is consistent with spawning return intervals observed in the Rogue River (Erickson and Webb 2007; D. Erickson, Fisheries Biologist, Pew Institute for Ocean Science, pers. comm., August 2008). The result of this life history pattern is that up to 75 percent of the mature adult population (as well as 100 percent of sub-adults) can be assumed to be in the ocean during 2020 and avoid effects associated with the Proposed Action.

Another behavior that may influence the effects of the Proposed Action is that green sturgeon appear to forego spawning migrations if environmental conditions are less than optimal (CALFED 2007). Webb and Erickson (2007) observed that some of the mature adults that entered the Rogue River returned downstream without spawning, and this behavior has also been observed in white sturgeon (J. Van Eenennaam, pers. comm., August 2008). Some adults may turn back upon encountering high suspended sediment concentrations resulting from the Proposed Action and not complete their spawning migration, or may enter later in the spring when concentrations are expected to be lower. Such behavior has not been documented in the Klamath River, however (J. Israel, Research Associate, University of California Department of Animal Science, pers. comm., 2008).

Green sturgeon are broadcast spawners that lay thousands of adhesive eggs that settle into the spaces between cobbles (Moyle 2002). The Proposed Action may affect the spawning, egg, and larval stages in a variety of ways, based on the limited information available. It is generally believed that silt can prevents eggs from adhering to one another, reducing egg viability (EPIC et al. 2001, as cited in CDWR 2003). Fine sediment deposition on the channel bed may reduce availability of exposed cobble surfaces for eggs to adhere to, and incubating eggs could be exposed to higher SSC for longer periods than under existing conditions and the No Action/No Project Alternative. Although 100 percent mortality is predicted for salmonids under the Proposed Action (Tables E-26 and E-27), it is also predicted under existing conditions and the No Action/No Project Alternative, and clearly does not occur every year. Fine sediment deposition resulting from the Proposed Action could reduce production from the mainstem to an unknown degree (J. Van Eenennaam, pers. comm., August 2008). Spawning of green sturgeon is common downstream of the confluence with the Trinity River, where SSC should be similar to existing conditions and the No Action/No Project Alternative. Production from the Trinity River, which is estimated to be around 30 percent of total production from the Klamath Basin (Scheiff et al. 2001), will be unaffected by the Proposed Action in 2020. In addition, production from the Salmon

River in 2020, which is occasionally quite high, will be unaffected by the Proposed Action.

Table E-26. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Green Sturgeon for Proposed Action Most Likely Scenario (50% exceedance probability), for Klamath River at Orleans (RM 58).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult migrants (Mar 15–July 15, 2020)	90 to 245	14	8	Major stress for adult migrants and spawners. Around 75% of mature adult population not expected to migrate in 2020.
	33 to 90	28	8	
Incubation and emergence (April 1–Aug15, 2020)	90 to 245	9	11	Up to 76% mortality for all mainstem production. Around 30% of production is from Trinity River, and will be unaffected. Assessment based on salmonid literature, effects likely exaggerated.
	33 to 90	27	12	
Adult post-spawning holding (Jul 15–Nov 15, 2020)	0	0	0	No effects anticipated.
Juvenile rearing (year-round) and outmigration (May 15–Oct 15, 2020)	1,808 to 4,4915	2	9	Reduced growth and up to 20% mortality. Around 30% of juveniles rear in the Trinity River and will not be affected.
	665 to 1,808	17	10	
	245 to 665	9	9	
	90 to 245	18	9	
	33 to 90	28	8	

Table E-27. Predicted Suspended Sediment Concentrations, Exposure Durations, and Anticipated Effects on Green Sturgeon for Proposed Action Worst-Case Scenario (10% exceedance probability), for Klamath River at Orleans (RM 58).

Life-History Stage (timing)	Suspended Sediment Concentration (mg/l)	Exposure Duration (days)	Newcombe and Jensen Severity Index	Effects on Production
Adult migrants (Mar 15–July 15, 2020)	245 to 665	8	9	Major stress (adults don't feed) for adult migrants and spawners. ~ 75% of adult population not expected to migrate in 2020.
	90 to 245	29	9	
	33 to 90	62	8	
Incubation and emergence (April 1–Aug15, 2020)	245 to 665	6	11	95% mortality for all mainstem production. Around 30% of production is from Trinity River, and will be unaffected. Assessment based on salmonid literature, effects likely exaggerated.
	90 to 245	29	12	
	33 to 90	58	13	
Adult post-spawning holding (July 15–Nov 15, 2020)	90 to 245	2	7	Short duration and relatively low concentrations not expected to result in adverse effects on adults. About 75% of adults remain holding in the mainstem after spawning; remainder migrate to ocean.
	33 to 90	4	7	
Juvenile rearing (year-round) and outmigration (May 15–Oct 15, 2020)	1,808 to 4,915	6	10	Reduced growth and up to 36% mortality. Around 30% of juveniles rear in the Trinity River and will not be affected.
	665 to 1,808	32	10	
	245 to 665	17	9	
	90 to 245	29	9	
	33 to 90	62	9	

After spawning, around 25 percent of green sturgeon return directly back to the ocean (Moyle 2002), and the remainder hold in mainstem pools in the Klamath River from RM 13 to RM 65 through November. 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 = 116–199 days). 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. SSC related to the Proposed Action prior to adult downstream migration is predicted to be similar to existing conditions and the No Action/No Project Alternative, with no associated effects anticipated, even under a worst-case scenario.

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 2007), usually during summer and fall (Emmett et al. 1991, as cited in CALFED 2007). 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, pers. comm., August 2008), but at least some juveniles may rear for additional months or years in the lower river and the estuary before migrating to the ocean. Under the Proposed

Action, juveniles of the 2019 cohort rearing downstream of Orleans in 2020 are anticipated to be exposed to higher SSC for longer periods than under existing conditions and the No Action/No Project Alternative (Table E-12). These exposures would be expected to result in no growth and up to 40 percent mortality for juvenile salmonids under a worst-case scenario (Tables E-26 and E-27). However, juvenile green sturgeon exposed to high suspended sediment in the Connecticut River showed no apparent physiological stress, despite the fact that several other sturgeon species suffered gill infections during these same events (B. Kynard, pers. comm., 2008). Juvenile rearing is common downstream of the Trinity River, where SSC will be similar to existing conditions and the No Action/No Project Alternative. Juveniles rearing in the Trinity River, which may represent ~30 percent of the total production in the Klamath Basin (Scheiff et al. 2001), will be unaffected by the Proposed Action in 2020. In addition, any juveniles rearing in the Salmon River in 2020, which also occasionally has abundant production, will be unaffected by the Proposed Action.

E.4 Klamath River Estuary

Estuary fish species regularly documented to occur in the Klamath River estuary (Moyle 2002) 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*)

Under existing conditions and the No Action/No Project Alternative, SSC within the Klamath River Estuary is relatively high, the lower Klamath River downstream of the Trinity River confluence (RM 40.0) to the estuary mouth (RM 0.0) is currently listed as sediment impaired under Section 303(d) of the Clean Water Act, as related to protection of the cold freshwater habitat (COLD) beneficial use associated with salmonids (SWRCB 2006, NCRWQCB 2010) (Section 3.2.3.3). Under the Proposed Action sediment will be released from Iron Gate Dam, and will decline in concentration in the downstream direction as a result of accretion from downstream tributaries. As a result, the magnitude of SSC from the Proposed Action relative to existing conditions and the No Action/No Project Alternative is at its lowest level in the Klamath River Estuary (Figure E-5). Therefore effects on aquatic species from SSC within the estuary are not anticipated to be distinguishable from existing conditions and the No Action/No Project Alternative.

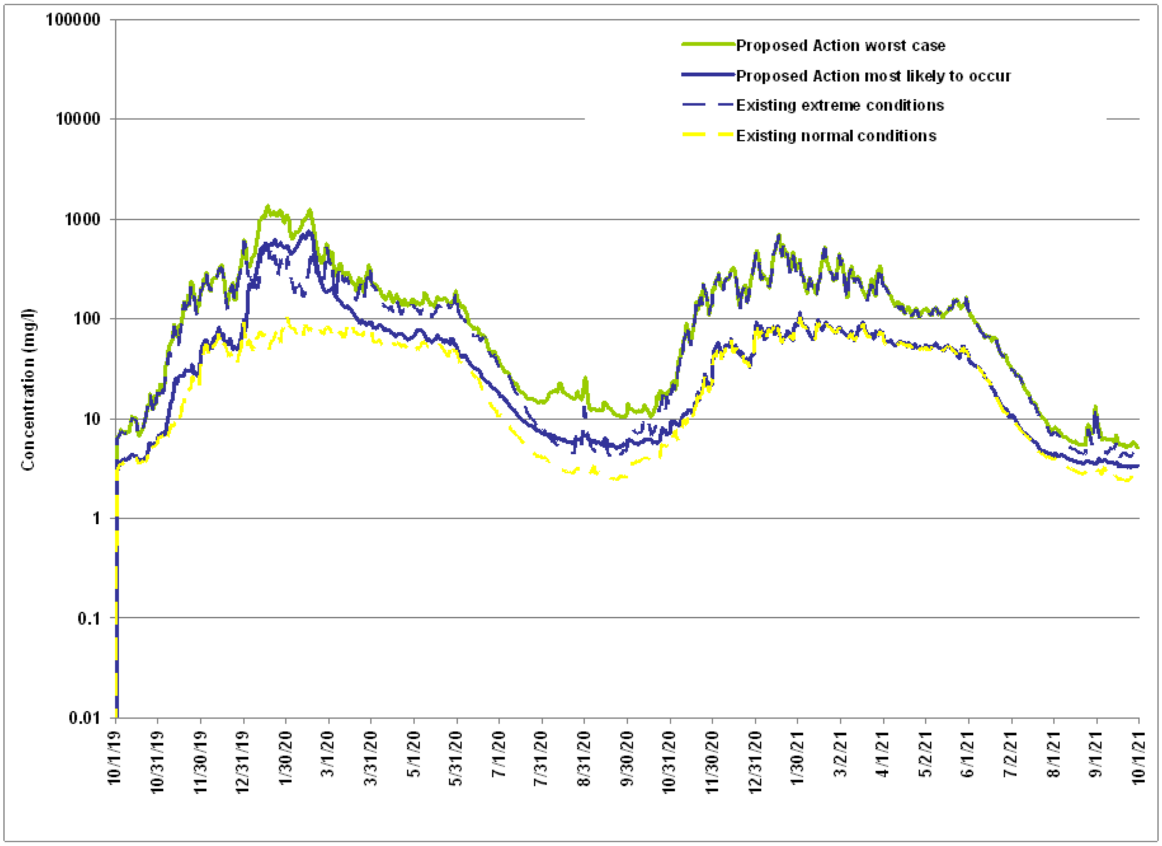

Figure E-5. Comparison of SSC at Klamath Station (RM 5) under Existing Conditions and the Proposed Action, as Predicted Using SRH-1D Model.

E.5 Pacific Ocean near Shore Environment

Many aquatic species occur within the nearshore environment in the vicinity of the Klamath River. Under existing conditions there exists a "plume" within the nearshore environment in the vicinity of the Klamath River that is subject to strong land runoff effects following winter rainfall events. This includes low-salinity, high levels of suspended particles, high sedimentation, and low light (and potential exposure to land-derived contaminants). The extent and shape of plume is variable, and influenced by wind patterns, upwelling effects, shoreline topography (especially Point Saint George), and alongshore currents. High SSC events contribute to the plume, especially during floods (Figure E-6). In a study of the Eel River nearshore sediment plume, located approximately 80 miles to the south of the Klamath River, *in situ* measurements of plume characteristics indicated no relationship with suspended sediment concentration, turbulent-kinetic-energy, time from river mouth, wind speed, wave height, or discharge (Curran et al. 2002). A relationship apparently did exist between effective settling velocity (bulk mean settling velocity) of plume sediments and wind speed/direction, as well as with tides (Curran et al. 2002). In contrast to the lower Klamath River, modeled short-term suspended sediment concentrations following dam removal are not available for the nearshore marine environment adjacent to the Klamath River. Substantial dilution of the high (>1,000 mg/L) mainstem river suspended sediment concentrations is expected to occur in the nearshore under the Proposed Action; based on data from 110 coastal watersheds in California [1], where nearshore SSC were measured at >100 mg/L during the El Nino winter of 1998 (Mertes and Warrick 2001), peak SSC leaving the Klamath River estuary may be diluted by 1-2 orders of magnitude from >1,000 mg/L to >10-100 mg/L. However, considering that dilution of high wintertime SSC loads occurs under existing conditions as well, the magnitude and extent of the sediment plume under the Proposed Action is likely to be greater than that of the No Action/No Project Alternative. This would potentially increase the rate of sediment deposition to nearshore benthic sediments. Overall, any elevations in SSC associated with the Proposed Action are not anticipated to have effects on species distinguishable from existing conditions.

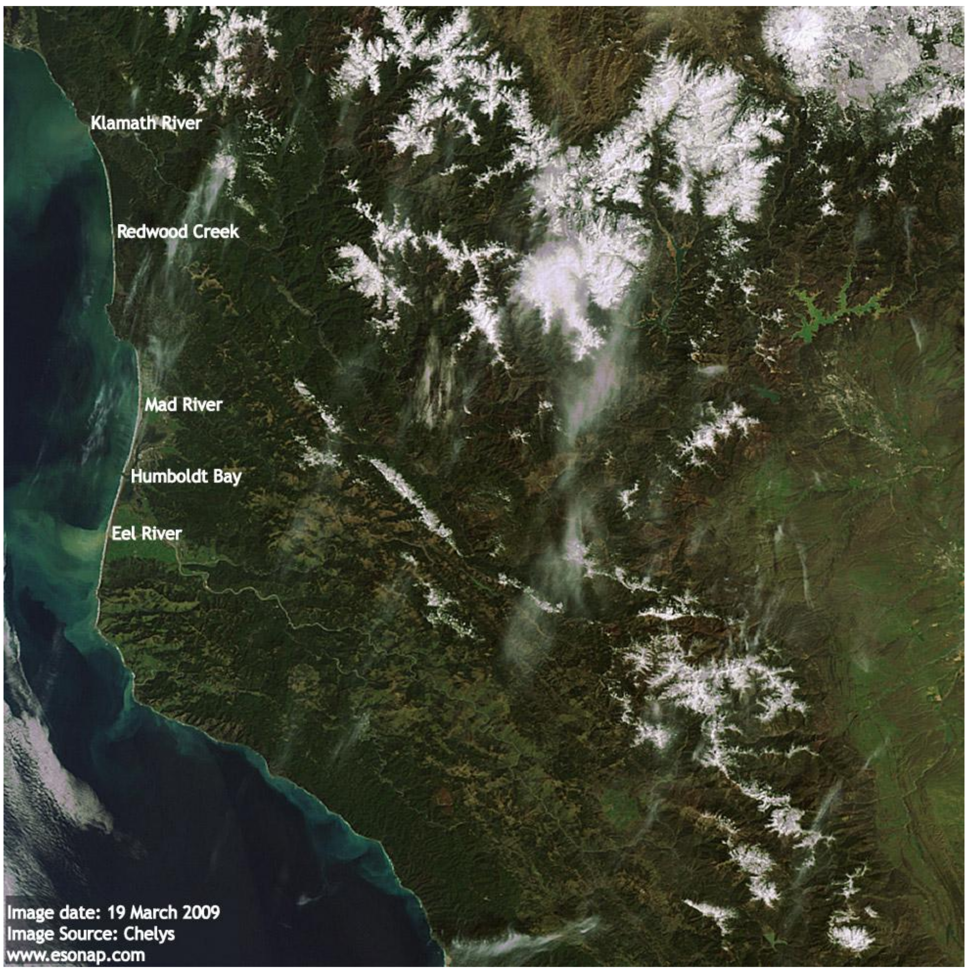

Figure E-6. River Plumes for Rivers in the Vicinity of the Klamath River during Typical Winter Conditions.

E.6 Literature Cited

Ackerman, N. K., B. Pyper, I. Courter, and S. Cramer. 2006. Estimation of returns of naturally produced coho to the Klamath River. Review Draft. Klamath coho integrated modeling framework technical memorandum series. Technical Memorandum #1 of 8. Prepared by Cramer Fish Sciences, Gresham, Oregon submitted to the 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. 2007. Age/size effects on juvenile green sturgeon, *Acipenser medirostris*, oxygen consumption in saline environment. Environmental Biology of Fishes 79: 211–229.

Bash, J., C. Berman, and S. Bolton. 2001. Effects of turbidity and suspended solids on salmonids. Center for Streamside Studies, University of Washington, Seattle.

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.

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.

Berman, C. H., and T. P. Quinn. 1991. Behavioral thermoregulation and homing by spring Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Yakima River. Journal of Fish Biology 39: 301–312.

Berry, W., N. Rubinstein, B. Melzian, and B. Hill. 2003. The biological effects of suspended and bedded sediment (SABS) in aquatic systems: a review. U. S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Laboratory, Narragansett, Rhode Island, and Duluth, Minnesota.

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.

Bozek, M. A., and M. K. Young. 1994. Fish mortality resulting from delayed effects of fire in the Greater Yellowstone Ecosystem. Great Basin Naturalist 54:91-95.

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.

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. 2007. Green sturgeon (*Acipenser medirostris*). *In* Delta regional ecosystem restoration implementation plan. Draft Report. CALFED Ecosystem Restoration Program, Sacramento, California.
http://www.delta.dfg.ca.gov/erpdeltaplan/docs/cm_Risk percent20Model_Green percent20Sturgeon_Edited_10_31_06.pdf

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

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., 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.

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.

Courter, I., S. P. Cramer, R. Ericksen, C. Justice, and B. Pyper. 2008. Klamath coho life-cycle model version 1.3. Prepared by Cramer Fish Sciences for USDI Bureau of Reclamation, Klamath Basin Area Office.
http://www.fishsciences.net/projects/klamathcoho/model.php

Curran, K. J., P. S. Hill, and T. G. Milligan. 2002. Fine-grained suspended sediment dynamics in the Eel River flood plume. Continental Shelf Research 22: 2,537–2,550.

Cyrus, D. P., and S. J. M. Blaber. 1992. Turbidity and salinity in a tropical northern Australian estuary and their influence on fish distribution. Estuarine, Coastal, and Shelf Science 35: 545–563.

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.

Ebersole, J. L., P. J. Wigington, Jr., J. P. Baker, M. A. Cairns, M. R. Church, B. P. Hansen, B. A. Miller, H. R. LaVigne, J. E. Compton, and S. G. Leibowitz. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. Transactions of the American Fisheries Society 135:1681-1697.

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 et al. (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.

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.

Foott, J. S., G. Stutzer, R. Fogerty, H. C. Hansel, S. D. Juhnke, and J. W. Beeman. 2009. Pilot study to assess the role of *Ceratomyxa shasta* infection in mortality of fall-run Chinook smolts migrating through the lower Klamath River in 2008. Technical report. Prepared by the U. S. Fish and Wildlife Service and U. S. Geological Survey. U. S. Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, California. http://www.fws.gov/canvfhc/reports

Gadomski, D. M., and M. J. Parsley. 2005. Effects of turbidity, light level, and cover on predation of white sturgeon larvae by prickly sculpins. Transactions of the North American Fisheries Society 134: 369–374.

Gradall, K. S., and W. A. Swenson. 1982. Responses of brook trout and creek chubs to turbidity. Transactions of the American Fisheries Society 111: 392–395.

Gregory, R S., and C. D. Levings. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127: 275–285.

Gregory, R. S., J. A. Servizi, and D. W. Martens. 1993. Comment: utility of the stress index for predicting suspended sediment effects. North American Journal of Fisheries Management 13:868-873.

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: 1,681–1,691.

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.

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.

Hillemeier, D., T. Soto, S. Silloway, A. Corum, M. Kleeman, and L. Lestelle. 2009. The role of the Klamath River mainstem corridor in the life history and performance of juvenile coho salmon (*Oncorhynchus kisutch*): May 2007–May 2008. Prepared by Yurok Fisheries Program, Klamath, California; Karuk Tribe Department of Natural Resources, Orleans, California; and Biostream Environmental, Poulsbo, Washington for U. S. Bureau of Reclamation, Klamath Falls, 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.

Huang, J., and B. Greimann. 2010. Sedimentation and river hydraulics—one dimension. Version 2.6 (SRH-1D 2.6). U. S. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

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.

Korstrom, J. S., and I. K. Birtwell. 2006. Effects of suspended sediment on the escape behavior and cover-seeking response of juvenile Chinook salmon in freshwater. Transactions of the American Fisheries Society 135: 1,006–1,016.

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.

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: 1,450–1,459.

Magneson, M. 2006. Mainstem Klamath River fall Chinook salmon spawning survey 2005. Arcata Fisheries Data Series Report DS 2006-05. U. S. Fish and Wildlife Service, 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.

McCovey, B. W. 2010. Klamath River green sturgeon acoustic tagging and biotelemetry monitoring, 2009. Final Technical Report. Yurok Tribal Fisheries Program, Hoopa, California.

Mertes, L. A. K., and J. A. Warrick. 2001. Measuring flood output from 110 coastal watersheds in California with field measurements and SeaWiFS. Geology 29: 659-662.

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

NMFS (National Marine Fisheries Service). 2007. Magnuson-Stevens Reauthorization Act Klamath River coho salmon recovery. Prepared by F. R. Rogers, I. V. Lagomarsino, and J. A. Simondet for NMFS, Southwest Region, Long Beach, California.

NMFS. 2010. Biological opinion on the operation of the Klamath Project between 2010 and 2018. NMFS, Southwest Region, http://www.usbr.gov/mp/kbao/operations/FINAL%20-Klamath%20Ops_3-15-10.pdf.

NCRWQCB (North Coast Regional Water Quality Control Board). 2010. Final staff report for the Klamath River Total Maximum Daily Loads (TMDLs) addressing temperature, dissolved oxygen, nutrient, and Microcystin impairments in California, the proposed site-specific dissolved oxygen objectives for the Klamath River in California, and the Klamath River and Lost River implementation plans. State of California North Coast Regional Water Quality Control Board, Santa Rosa, California. http://www.swrcb.ca.gov/northcoast/water_issues/programs/tmdls/klamath_river/

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. http://www.nap.edu/catalog.php?record_id=10838

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., 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.

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.

PacifiCorp. 2006. Klamath hydro relicensing lamprey workshop notes. 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.

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.

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: 1,389–1,395.

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.

Simondet, J. A. 2006. Expert testimony provided for trial-type hearing. Matter of the Klamath Hydroelectric Project (License Applicant PacifiCorp), Docket Number 2006-NMFS-0001, FERC Project Number 2082. Final Ruling dated 27 September 2006.

Soto, T., A. Corum, H. Voight, D. Hillemeier, and L. Lestelle. 2009. The role of the Klamath River mainstem corridor in the life history and performance of juvenile coho salmon (*Oncorhynchus kisutch*). Phase 1 Report: 2006-07 winter. Prepared for U. S. Bureau of Reclamation, Mid-Pacific Region, Klamath Area Office, Klamath Falls, Oregon.

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. 2009a. Dam removal and Klamath River water quality: a synthesis of the current conceptual understanding and an assessment of data gaps. Prepared by Stillwater Sciences, Berkeley, California for California Coastal Conservancy, Oakland.

Stillwater Sciences. 2009b. Effects of sediment release following dam removal on the aquatic biota of the Klamath River. Technical Report. Prepared by Stillwater Sciences, Arcata, California for California Coastal Conservancy, Oakland.

Stillwater Sciences. 2010. Anticipated sediment release from Klamath River dam removal within the context of basin sediment delivery. Prepared by Stillwater Sciences, Arcata, California for California Coastal Conservancy, Oakland.

Strange, J. 2007a. 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.

Strange, J. 2007b. Adult Chinook salmon migration in the Klamath River Basin. 2006 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.

Strange, J. 2008. Adult Chinook salmon migration in the Klamath River Basin. 2007. Biotelemetry Monitoring 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.

Stutzer, G. M., J. Ogawa, N. J. Hetrick, and T. Shaw. 2006. An initial assessment of radio telemetry for estimating juvenile coho salmon survival, migration behavior, and habitat use in response to Iron Gate Dam discharge on the Klamath River, California. Arcata Fisheries Technical Report Number TR2006-05. U. S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, 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.

SWRCB (State Water Resources Control Board). 2006. 2006 CWA Section 303(d) CWA SECTION 303(d) list of water quality limited segments.

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

USBR (U. S. Bureau of Reclamation). 2011. Hydrology, hydraulics and sediment transport studies for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration, Klamath River, Oregon and California. Technical Report No. SRH-2011-02. Prepared for USBR, Mid-Pacific Region, Technical Service Center, Denver, Colorado.

USFWS (US Fish and Wildlife Service). 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. 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. Arcata Fish and Wildlife Office, Arcata, California.

USFWS. 2010. Mark-recapture trapping efficiency summary for coho captured in the McGarvey Creek frame net/pipe trap from 1999–2008. Unpublished data acquired from D. Gale, Fish and Wildlife Biologist, U. S. Fish and Wildlife Service. 3 January 2011.

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.

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.

Walters, D. M., M. C. Freeman, D. S. Leigh, B. J. Freeman, M. J. Paul, and C. M. Pringle. 2001. Bed texture and turbidity as indicators of fish biotic integrity in the Etowah River system. Pages 233–236 *in* K. J. Hatcher, editor. Proceedings of the 2001 Georgia Water Resources Conference, Athens, Georgia.

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.

Wedemeyer, G. A., and D. J. McLeay. 1981. Methods for determining the tolerance of fishes to environmental stressors. Pages 247–268 *in* A. D. Pickering, editor. Stress and fish. Academic Press, Toronto, Ontario.

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

Wilber, D. H., and D. G. Clarke. 2001. Biological effects of suspended sediments: a review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. North American Journal of Fisheries Management 21: 855–875.

Williams, T. H., E. P. Bjorkstedt, W. G. Duffy, D. Hillemeier, G. Kautsky, T. E. Lisle, M. McCain, M. Rode, R. G. Szerlong, R. S. Schick, M. N. Goslin, and A. Agrawal. 2006. Historical population structure of coho salmon in the southern Oregon/northern California coasts evolutionarily significant unit. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-390. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.

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.