Appendix E

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

E.1 Introduction

Under the Proposed Project removing the four Lower Klamath Project dams could release up to 5.3 to 8.6 million yd^3 of sediment (sand, silt, and finer) downstream (USBR 2012), resulting in high suspended sediment loads and local, short-term sediment deposition. Over 80 percent of the reservoir sediments are fine sediment (organics, silts, and clays), which are expected to remain suspended in the Klamath River flow as it moves downstream and out into the Pacific Ocean. Coarse sediment (i.e., sand and larger) transport would occur more slowly depending on the hydrologic conditions with deposition of coarser sediment from dam removal expected to primarily occur between the reservoirs and the confluence of the Klamath River and the Shasta River. The downstream transport of this sediment, currently stored in reservoir deposits, can affect downstream habitats as both suspended sediment and bedload deposition. Elevated suspended sediment concentrations (SSC) may clog or abrade the gills of fish or prevent fish from foraging efficiently. As the transported sand and fine sediment 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.

Sediment release associated with the Proposed Project are also anticipated to cause short-term increases in oxygen demand and corresponding reductions in dissolved oxygen. As described in Section 3.2.5.4 *Dissolved Oxygen*, predicted short-term increases in oxygen demand under the Proposed Project generally result in dissolved oxygen concentrations remaining greater than 5 mg/L. Exceptions to this would occur four to eight weeks following reservoir drawdown (approximately in February of dam removal year 2) for median and dry year hydrologic conditions, when dissolved oxygen would drop to levels below 5 mg/L from Iron Gate Dam to near the confluence with the Shasta River (RM 179.5). The impacts on aquatic resources from reduced dissolved oxygen are considered synergistic with the impacts of SSC within this reach of primary impact. As such, the impacts of SSC are anticipated to dominate and mask any impacts that would occur otherwise as a result of reduced dissolved oxygen.

This appendix to the Lower Klamath Project EIR describes a modeling analysis of the potential effects of suspended sediment on anadromous fish populations in the Klamath Basin under: 1) existing conditions; 2) the No Project Alternative; and 3) the Proposed Project (described in Section 2 *Proposed Project*). Available data on SSCs under existing conditions in the Klamath River upstream and downstream from 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 USBR used suspended sediment data collected by United States Geological Survey (USGS) stream gages at (1) Shasta River near the City of Yreka, (2) Klamath River near Orleans, and (3) Klamath River at Klamath, CA to estimate daily SSCs (milligrams per liter [mg/l]) as a function of flow (cubic feet per second [cfs]) using the SRH-1D 2.4 sediment transport model (Sedimentation and River Hydraulics–One Dimension Version 2.4) (Huang and Greimann 2010, USBR 2012), hereafter referred to as "the model." Daily SSCs were modeled for water years 1961 through 2008 to represent existing conditions and the No Project Alternative, as well as for the year following removal of the dams under multiple drawdown scenarios (USBR 2012).

E.2 Methods

Daily durations of SSC concentrations were modeled assuming the Proposed Project occurred within each of the 48 years in the available hydrology from 1961 through 2009. As described in Chapter 6 of USBR (2012), the 2010 NMFS BiOp (NMFS 2010) flows were used for modeling suspended sediment, but flow requirements in the Klamath River have changed since the modeling was performed. The NMFS and USFWS 2013 Joint BiOp (NMFS and USFWS 2013) along with court-ordered flushing and emergency dilution flows are the current key flow requirements to which the Lower Klamath Project must operate. The 2013 Joint BiOp altered flow conditions by shifting the monthly timing and water year type distribution of flows but retained the overall magnitude of 2010 BiOp flows. As described in Section 3.1.6 *Summary of Available Hydrology Information for the Proposed Project*, the 2013 Joint BiOp (NMFS and USFWS 2013) flows, that replaced the 2010 BiOp flows, are sufficiently similar to the 2010 BiOp flow releases used in the modeling that the model results are still representative of the key hydrological factors including timing, frequency, and magnitude of flows released during winter and spring.

Flows under the Proposed Project were modeled assuming Klamath River hydrology defined by Klamath Basin Restoration Agreement (KBRA) operations of the Klamath Irrigation Project (USBR 2012). As described in Section 3.1.6 *Summary of Available Hydrology Information for the Proposed Project*, the KBRA has expired, and hydrology under the Proposed Project will be pursuant to the 2013 BiOp (NMFS and USFWS 2013). As detailed in Section 3.1.6, the 2013 Joint BiOp flows are sufficiently similar to KBRA flows used in the modeling that the model results are still representative of the key hydrological factors including timing, frequency, and magnitude of flows released during winter and spring.

The rate of reservoir drawdown would also affect the amount of erosion of the sediment deposit. A faster drawdown rate would reduce the time of interaction between the flow and reservoir sediment deposits, thus reducing the overall amount of sediment erosion, whereas a slower drawdown rate would increase the time of interaction between the flow and reservoir sediment deposits, thus increasing the overall amount of sediment erosion. The analysis presented here is based on USBR (2012) modeled maximum drawdown rate of 2.25 to 3 feet per day. However, under Proposed Project, a maximum drawdown rate of 5 feet per day would occur (Appendix B: *Definite Plan – Appendix P*). As described in detail in Section 2.7.3 *Reservoir Sediment Deposits and Erosion During Drawdown*, this increased drawdown rate would slightly decrease the total amount of sediment erosion that occurs during drawdown. The modeled maximum drawdown rate would result in 36 to 57 percent of erosion of the sediment deposit from the reservoirs and increasing the drawdown rate to 5 feet per day would most likely result in an amount of erosion toward the lower end of the estimated range or slightly lower. The implication for this analysis is that predictions of impacts discussed here based on a lower drawdown rate may be slightly higher than would occur with the faster drawdown rate under the Proposed Project.

In addition, under the Proposed Project, as describe in Section 2.7.3 *Reservoir Sediment Deposits and Erosion During Drawdown,* during drawdown, erosion and transport of sediments deposited within the Copco No. 1 and Iron Gate reservoir footprints would be supported by using barge-mounted pressure sprayers to jet water onto newly exposed reservoir-deposited sediments as the water level decreases, a process called sediment jetting. Sediment jetting was not considered with the USBR (2012) model used for this analysis. Sediment jetting would maximize the erosion of reservoir-deposited sediments on the historical floodplain areas during drawdown and minimize the potential for reservoir sediment erosion outside of the reservoir drawdown period. The majority of the sediment erosion would occur during the reservoir drawdown process and would be a combination of direct erosion of the sediment by moving water, slumping of the fine sediment along the reservoir sides toward the river, and sediment jetting of some areas of reservoir-deposited sediments during drawdown. Considering the relatively small amount of water coming from the hose(s) (estimated to be approximately 18 cfs) used for jetting compared to the river flow anticipated during drawdown, the additional sediment erosion from the jetting practice will only marginally (500 to 1,000 mg/l) increase the predicted sediment concentration and may decrease the duration of increased suspended sediment in comparison with the model results of USBR (2012) used in this analysis. However, the range in estimated erosion volume in each reservoir will be primarily dependent upon whether the prevailing hydrology during reservoir drawdown corresponds to a dry hydrologic year or a wet hydrologic year, and the relative influence of the sediment jetting would have an unsubstantial effect on SSC magnitude and duration. The peak increase in SSCs due to sediment jetting using conservative assumptions would be within the general uncertainty of the modeled SSCs (factor of 2). The increase in SSCs due to sediment jetting likely would be less than the peak increase in SSCs due to the relatively low magnitude of flow from the hose(s), and relatively high magnitude of SSC predicted from upstream sources. As a result, the SSCs associated with drawdown and sediment jetting would usually be within the range of modeled SSCs with only occasional potential increases above the modeled peak SSCs (still within the factor of 2 uncertainty). Therefore, the model results of USBR (2012) are assumed to be sufficient for the prediction of impacts to aquatic resources, without quantitative consideration of sediment jetting.

The analysis of the potential effects of SSC on aquatic species in the Klamath River followed a four-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 a) existing conditions/No Project Alternative, and b) the Proposed Project;
3. Describe the potential effects of predicted SSCs on the various life stages of each focal species using available information; and
4. Evaluate the potential consequences of SSC for focal species' populations under existing conditions and the Proposed Project.

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 from 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;
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 SSCs.

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 SSCs used in this analysis were based on the sediment transport model, which:

1. Predicts daily SSC as a continuous time series following facility removal; and
2. 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 SSCs 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, but can simultaneously affect different life history stages of different species such as adult migrants of one species and smolts of another. For predicting potential SSC impacts to species identified above, the model evaluated each species and its life history stages separately.

E.2.2.1 Range of Conditions Assessed

Modeling results are very sensitive to hydrology. Effects on individual species (discussed below) during winter are predicted to be more severe during a dry year when sediment releases will be less diluted by surface flows. Effects during spring are more severe during a wet year, when it is predicted that under the Proposed Project the reservoirs could re-fill during winter, delaying the release of SSC until they drop during spring (USBR 2012). Daily durations of SSC concentrations were modeled assuming the Proposed Project occurred within each of the 49 years in the available hydrology record (1961 through 2009). During this 49 years of record all hydrological conditions are represented, including extremely wet years, and multiple extreme drought years of equal magnitude to that which occurred more recently (e.g., 2014). The results of modeling all potential years were summarized for each life-stage of each species assessed.

Because the SSC varies with hydrology, and in order to account for (and compare) the range of results and impacts that might occur under each alternative, three scenarios were analyzed for existing conditions/No Project Alternative, and for the Proposed Project, with the goal of predicting the potential impacts to fish that has either a 90 percent (least impacts on fish), 50 percent (likely to occur) or 10 percent (worst impacts on fish) probability of occurring, defined as follows:

For Existing Conditions/No Project Alternative:

- **Median conditions for fish:** This scenario represents the conditions that most often occur for each species and life stage—that is to say, SSCs and durations with a 50 percent exceedance probability for the mainstem Klamath River downstream from Iron Gate Dam. This means that under existing conditions there is an equal chance that the SSCs will be higher or lower than described. Exceedance probabilities were based on modeling SSCs for all water years from 1961 to 2009 with facilities in place.
- **Mild conditions for fish:** This scenario represents mild conditions of the potential sediment-related impacts to a species and life stage. It uses suspended sediment concentrations and durations with a 90 percent exceedance probability. This means that under this rare mild conditions for fish scenario the probability of these concentrations and durations being equal to or less than this level for each assessed species and life-stage in any one year is 10 percent, and the probability of them being exceeded is 90 percent.
- **Extreme conditions for fish:** This scenario represents extreme conditions for fish from potential sediment-related impacts. It uses SSCs and durations with a 10 percent exceedance probability. This means that under this rare extreme conditions for fish scenario the probability of these concentrations and durations being equal to or greater than this level for each assessed species and life-stage in any one year is 10 percent, and the probability of them being less than this level is 90 percent.

For the Proposed Project:

- **Most-likely impacts on fish:** This scenario represents the conditions that are most likely to occur for each species and life stage—that is to say, SSCs and durations with a 50 percent exceedance probability for the mainstem Klamath River downstream from Iron Gate Dam. This means that there is an equal chance that the SSCs will be higher or lower than described. Exceedance probabilities were based on modeling SSCs for all water years from 1961 to 2009 under the Proposed Project.
- **Least impacts on fish:** This scenario represents the least impacts on fish from potential sediment-related impacts to a species and life stage. It uses suspended sediment concentrations and durations with a 90 percent exceedance probability. This means that under this rare least impacts on fish scenario the probability of these concentrations and durations being equal to or less than this level for each assessed species and life-stage in any one year is 10 percent, and the probability of them being exceeded is 90 percent.
- **Worst impacts on fish:** This scenario represents the worst impacts on fish of potential sediment-related impacts to the species. It uses SSCs and durations with a 10 percent exceedance probability. This means that under this rare worst impacts on fish scenario the probability of these concentrations and durations

being equal to or greater than this level for each assessed species and life-stage in any one year is 10 percent, and the probability of them being less than this level is 90 percent.

By definition, the "median conditions for fish" and "most-likely impacts on fish" scenarios described above use a median (50 percent) threshold of analysis, which means that for any given fish species and life-stage there are numerous (approximately half) corresponding water years in the modeled hydrologic record during which the predicted median SSCs and associated exposure durations would occur. However, there may be few instances in the modeled 49-year hydrologic record in which the median condition would occur in the same water year for multiple life-stages of a given species (e.g., three years [6 percent] for spring-run Chinook salmon smolts and adults), and even fewer instances in which the median condition would occur in the same water year for multiple species and life-stages (e.g., one year [2 percent] for fall-run Chinook salmon smolts and coho salmon smolts).

The "mild conditions for fish" and "least impacts on fish" scenarios described above use a 90 percent threshold of analysis, which means that for any given species and life-stage the predicted low SSC and duration is infrequent, and SSCs would be higher would be higher nearly all (90 percent) of the water years in the modeled hydrologic record. There are even fewer instances in which the low SSCs condition would occur in the same water year for multiple life-stages of a given species (e.g., four years [8 percent] for spring-run Chinook salmon smolts and adults), and few instances (< 0.5 percent) in which the low SSCs condition would occur in the same water year for multiple species and life-stages.

Similarly, by definition, the "extreme conditions for fish" and "worst impacts on fish" described above use a 10 percent threshold of analysis, which means that for any given species and life-stage there are only a few corresponding water years in the modeled hydrologic record during which the predicted high SSCs and associated exposure durations would occur. There are few instances in which the high SSCs condition would occur in the same water year for multiple life-stages of a given species (e.g., two years [4 percent] for coho salmon smolts and adults), and few instances (< 0.5 percent) in which the high SSCs condition would occur in the same water year for multiple species and life-stages.

Overall, this analysis framework was chosen to allow for a more meaningful assessment of the potential impacts of predicted SSCs and exposure durations specific to the species and life-history stage that would experience them, rather than applying a set of predicted SSCs and exposure durations associated with a particular water year and potentially exaggerating or understating the range of possible conditions experienced by any one species and/or life-stage under the Proposed Project and the alternatives.

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). 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 [i.e., 20,000 mg/L] (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 (48 hours one study), 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 (days rather than weeks) 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 the 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 (SEV) table (Table E-1) was used to rate the severity of exposure to suspended sediment. Newcombe and Jensen (1996) collected data on fish effects (on the SEV scale), suspended-sediment concentration (C in mg/L), and suspended-sediment exposure time (D in hr), from a large number of papers dealing with many salmonid fishes at various life stages. Newcombe and Jensen (1996) fit models of the form SEV $= b_0 + b_1 \log C + b_2 \log D$ to these data for adults, juveniles, and eggs/alevins life stages, where "*b*" are terms for regression coefficients based on selection of the best performing model. These data all appear to consider constant concentration values. However, for this application the effects of concentration levels, which change over the exposure period, are evaluated. Following Newcombe and MacDonald (1991), models of the form SEV $= b_0 + b_1 \log(CD)$ are applied to varying concentrations by replacing the term CD with the integral of concentration over time to accurately predict SEV when concentrations fluctuate over the period being assessed.

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	Behavioral effects	Alarm reaction
2		Abandonment of cover
3		Avoidance response
4	Sublethal effects	Short-term reduction in feeding rates Short-term reduction in feeding success
5		Minor physiological stress: Increase in rate of coughing Increased respiration rate
6		Moderate physiological stress
7		Moderate habitat degradation Impaired homing
8		Indications of major physiological stress: Long-term reduction in feeding rate Long-term reduction in feeding success Poor condition
9	Lethal effects	Reduced growth rate: Delayed hatching Reduced fish density
10		0–20 percent mortality Increased predation of effected fish
11		>20–40 percent mortality
12		>40–60 percent mortality
13		>60–80 percent mortality
14		>80–100 percent mortality

The result of this approach is a location, species, and life-stage specific prediction of the SEV for each year in the hydrologic record using the SSC predictions of USBR (2012). For example, Figure E-1 shows the SEV results for all years for dam removal years 1 and 2 for adult salmon with a rolling 30-day exposure (typical migration duration) at Iron Gate Dam.

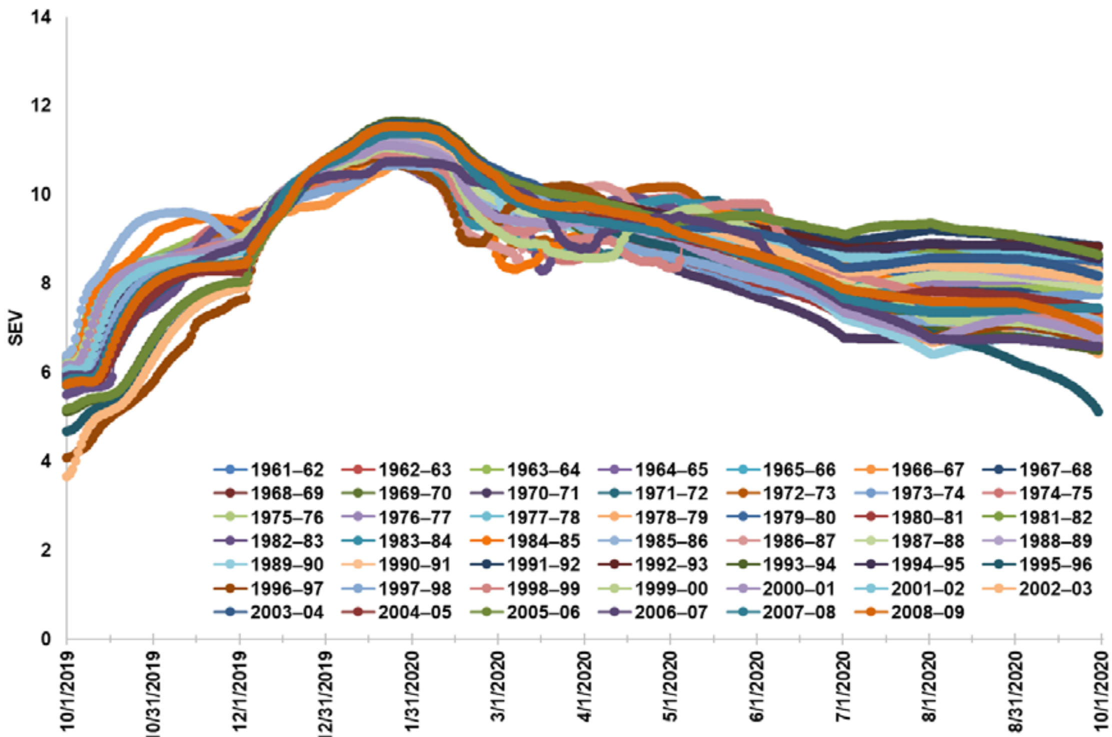

Figure E-1. Example SEV Values Assuming a 30-day Exposure at Iron Gate Dam, based on the SSC Predictions using the SRH-1D Model.

To assess the least impacts on fish, most-likely impacts on fish, or worst impacts on fish scenario, SSCs and durations were predicted for all years in the record. In addition, for the time-period each life stage was assessed, it was assumed that species would encounter either the lowest, highest, or median SSC concentration during that period. For example (and as described in detail for each species), smolts of some species outmigrating from tributaries have been observed to alter behavior (e.g., delay and avoidance) in response to poor water quality conditions are assumed to delay migration in response to high SSC concentration until SSC decrease, and thus will be exposed to the lowest SSCs during the period of their typical peak in outmigration, whereas fish spawning in the mainstem will be unable to avoid the highest concentrations during the period. As an example, Figure E-2 shows the median results for adult coho salmon migrating to tributaries downstream of Iron Gate Dam (SSC predications at Seiad Valley), based on their life history timing and assuming that based on behavioral response adults would be able to avoid the highest peaks in SSC. The best (90 percent), most-likely (50 percent), and worst impacts on fish scenarios (10 percent) can be interpreted based on the exceedance values.

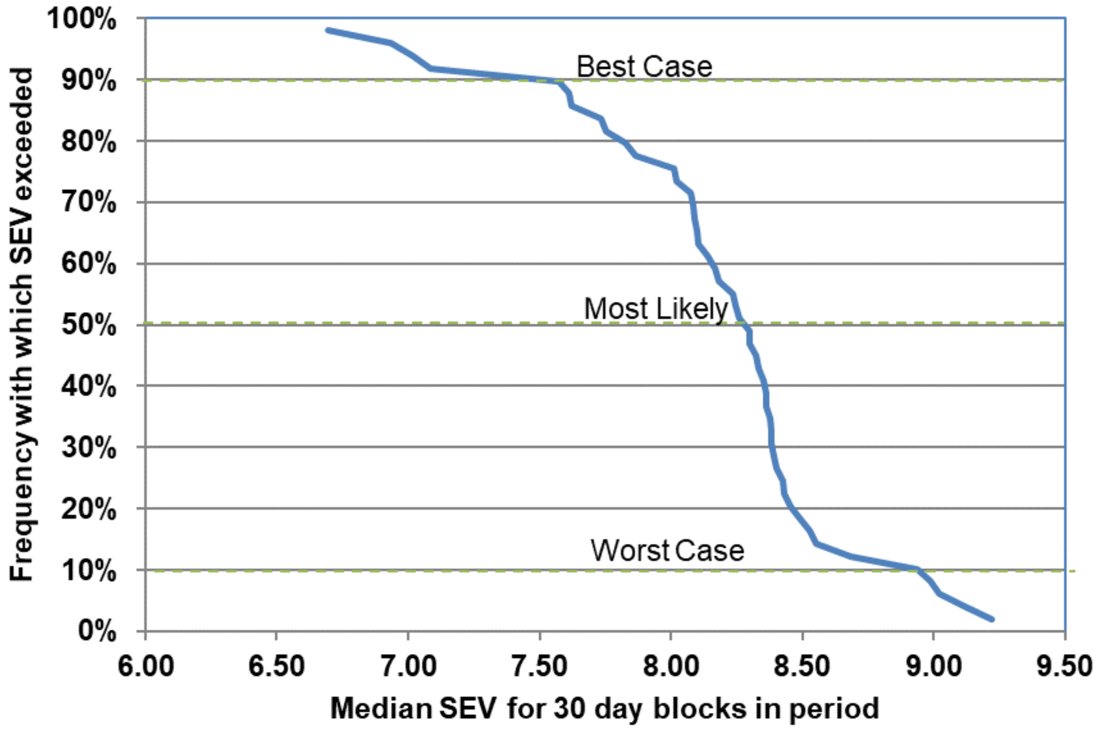

Figure E-2. Example SEV exceedance for a 30-day Coho Salmon Adult Migration.

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

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 to suspended sediment. This means that three occurrences of exposure to extreme sediment each lasting for two days can be, for example, equivalent to a SEV 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 the SEV stress model (first presented by Newcombe and MacDonald 1991), 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. Assuming only negative effects of elevated SSCs 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 sublethal impacts of suspended sediment could be lethal 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 non-salmonids were used in this analysis to assess effects on Pacific lamprey and green sturgeon, in conjunction with discussions with experts (documented in Section E.3.1.6) regarding the potential effects.

E.3 Results

E.3.1 Existing Conditions

Information on sediment transport within the Klamath Basin is available from Stillwater Sciences (2010) and USBR (2012). 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 from 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.

Appendix C.2 *Suspended Sediments* summarizes suspended sediment concentrations under existing conditions in the Klamath River upstream and downstream from Iron Gate Dam. Historical (1950 to 1979) SSC for the Klamath River at Orleans (RM 58.9) (USGS gage no.11523000) range from less than 5 mg/L during summer (low-flow) periods to greater than 5,000 mg/L during winter (high-flow) periods, although some high (>1,000 mg/L) suspended sediment events have occurred during summer months (e.g., 1974, see Figure C-15 in Appendix C). To assess existing conditions daily SSC were modeled for water years 1961–2009 (USBR 2012).

E.3.1.1 Fall-run Chinook Salmon

Fall-run Chinook salmon range throughout the Klamath River and its tributaries downstream from Iron Gate Dam. The Upper Klamath and Trinity Rivers ESU is listed as a CDFW Species of Special Concern and a USDA Forest Service Sensitive Species. 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 2007). They also spawn in the mainstem Klamath River (approximately 8 percent on average), with the highest densities of redds found between Iron Gate Dam (River Mile [RM] 193.1) and the confluence with the Shasta River (RM 179.5) (Magneson 2006). Incubation for Chinook salmon, with typical water temperature in the mainstem Klamath River, requires approximately 90 days (Velsen 1987).

Fall-run Chinook salmon in the Klamath Basin exhibit three juvenile life-history types: Type I (ocean entry at age 0[10] 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 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 (Jetter and Chesney 2016), 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-run Chinook salmon typically migrate upstream in late summer and early fall when SSCs are usually very low in the Klamath River, resulting in minor behavioral effects to avoidance under most conditions. Spawning typically peaks in late October and substantially declines by the end of November (Shaw et al. 1997). Based on the propensity of fall-run Chinook salmon to spawn upstream of the Shasta River confluence and downstream of Iron Gate Dam, the analysis is based on modeling results from Iron Gate Dam Station. 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. However, it is well documented that fine sediment can infiltrate spawning gravel and reduce survival of salmonid eggs (Newcomb and MacDonald 1991). Under mild and median conditions for fish, exposure to suspended sediment in the mainstem is predicted to result in delayed growth and possibly low levels of mortality for eggs, alevins, and fry (Table E-2), but may cause 20 to 40 percent mortality under extreme conditions for fish (Table E-2) as well as downstream from the Shasta River confluence, where SSCs 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. Juveniles that are progeny of mainstem spawning rear in the mainstem during late winter prior to outmigration and are anticipated to have behavioral effects to minor physiological stress depending on conditions (Table E-2). Jetter and Chesney (2016) report that between 2001 and 2016 Type I outmigration from the Shasta and Scott rivers occurred primarily between February and June. Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (greater than 150 mg/l) SSC, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982,

[10] 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.

Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, it was assumed that Chinook salmon outmigration during dam removal year 2 will occur within the period of typical outmigration with the lowest predicted SSC. Based on the location of the majority of outmigration from Shasta River and tributaries downstream, the analysis is based on modeling results from Seiad Valley station. 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 at Seiad Valley. Under existing conditions, suspended sediment in the mainstem is predicted to be at concentrations resulting in minor to major physiological stress for Type I fry during their 30-day migration depending on conditions. 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 Klamath River would likely result in the mortality of some portion of these fish. The parr-smolt transformation can also be compromised in stressed juveniles (Bash et al. 2001), which could increase mortality.

Table E-2. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Fall-run Chinook Salmon in the Klamath River at Iron Gate Dam[1] and Seiad Valley[2].

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Adult upstream migrants (July 15–Oct 31) Exposure to median SSC for the period	2.5	3.3	3.8	Behavioral effects such as alarm reaction or avoidance under most conditions
Spawning, incubation, and fry emergence (Oct 15–Feb 28) 90 days of exposure to highest SSC for the period	9.8	10.6	11.5	Effects of suspended sediment on egg survival were not modeled; however, long duration of exposure could result in delayed growth to greater than 20 to 40 percent mortality depending on conditions. ~8 percent of adults spawn in the mainstem downstream from Iron Gate Dam.
Juvenile rearing (Jan 1–Mar 28) 30 days of exposure to highest SSC for the period	5.9	6.9	7.6	Minor to major stress depending on conditions
Type I outmigration (Feb 1–August 1) 30 days of exposure to lowest SSC for the period	5.2	6.2	7.3	Minor to moderate physiological stress and reduced growth depending on conditions. Applies to ~60 percent of total production.

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Type II outmigration (Sept 1–Nov 30) 30 days of exposure to lowest SSC for the period	3.8	5.0	5.7	Behavioral effects such as avoidance to minor physiological stress depending on conditions. Applies to ~40 percent of total production.
Type III outmigration (Feb 1–April 15) 30 days of exposure to lowest SSC for the period	7.2	7.9	8.6	Moderate stress to reduced growth depending on conditions for Type III (yearling) outmigrants (<1 percent of production)

[1] Adult migration, spawning, incubation, and fry emergence life stages
[2] Juvenile rearing and outmigration life stages
[3] Mild conditions for fish = 90 percent exceedance probability
[4] Median conditions for fish = 50 percent exceedance probability
[5] Extreme conditions for fish = 10 percent exceedance probability

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 Klamath River on their outmigration to the ocean in the fall, when SSCs are lowest. Under existing conditions, avoidance behavior (under mild or median conditions for fish) to minor physiological stress (under extreme conditions for fish) are predicted for Type II life-history fish. Additional factors such as disease or elevated temperatures in the lower Klamath River are less likely to increase the impacts of suspended sediment on Type II life-history 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 less than one percent of all production) in the Klamath River fall-run Chinook population (USFWS 2001), although based on Sullivan (1989) these larger smolts can contribute approximately 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. The model predicts that suspended sediment would cause moderate (under mild conditions for fish) to major physiological stress (under median conditions for fish), and growth could be affected in extreme conditions for fish.

Overall, fall-run Chinook salmon use the mainstem Klamath River for spawning, rearing, and as a migratory corridor. SSCs under existing conditions can be high (>500 mg/L) in the mainstem Klamath River, resulting in reduced growth of alevins, and low levels of mortality in some years with poor water quality conditions. SSCs and durations during upstream and downstream migration, even under extreme conditions for fish, 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 Klamath River for spawning and rearing, and the fact that smolt outmigration primarily occurs when SSCs are naturally low (< 200 mg/l).

E.3.1.2 Spring-run Chinook Salmon

Spring-run Chinook salmon spawn primarily in the Salmon and Trinity rivers, with the vast majority (approximately 95 percent) spawning in the Trinity River; therefore, the review of existing conditions focuses on potential exposure to suspended sediment in the mainstem Klamath River downstream from the Salmon River. The Upper Klamath and Trinity Rivers ESU is listed as a CDFW Species of Special Concern and a USDA Forest Service Sensitive Species.

Sediment-transport model predictions for suspended sediment and associated effects on spring-run Chinook salmon under varying conditions are summarized in Table E-3. Adult spring-run migrants returning to the Salmon River may be exposed to SSCs that cause impaired homing (under mild to median conditions for fish) to major stress (under extreme conditions for fish). Adult spring-run Chinook migrating to the Trinity River may only be exposed to suspended sediment in the mainstem Klamath River for about a week, and about two weeks for those migrating to the Salmon River (Strange 2007a, 2007b, 2008).

Table E-3. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Spring-run Chinook Salmon under for Klamath River at Orleans (RM 60).

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Adult spring migration (Apr 1–June 30) 14 days of exposure to median SSC for the period	7.2	7.8	8.3	Impaired homing to major physiological stress for adults returning to Salmon River. Majority (~95 percent on average) of adults enter Trinity River and would be exposed to higher concentrations for shorter durations. However, up to 35 percent of “natural” escapement returns to Salmon River.
Adult summer migration (Jul 1–Aug 31) 2 days of exposure to median SSC for the period	4.3	4.8	5.4	Behavioral to minor physiological stress to the ~50 percent of the summer migration returning exclusively to the Trinity River.
Spawning, incubation, and fry emergence (Sept 1–Feb 28)	No effect	No effect	No effect	Spring-run do not generally spawn in the mainstem; no effect to this life stage is anticipated.
Juvenile rearing (variable)	No effect	No effect	No effect	Juveniles primarily rear in tributaries; no effect is anticipated.
Type I outmigration (Apr 1–May 31) 30 days of exposure to lowest SSC for the period	7.3	7.9	8.4	Moderate to major stress for Type I fry (~80 percent of production) in smolt outmigration from Salmon River. Majority (~95 percent) of juveniles outmigrate from Trinity River and are exposed to higher concentrations.

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Type II outmigration (Oct 1–Nov 15) 30 days of exposure to lowest SSC for the period	5.2	6.0	6.5	Minor to moderate stress for Type II smolts from the Salmon River (~20 percent) during downstream migration. Majority (~95 percent) of juveniles outmigrate from Trinity River and are exposed to higher concentrations.
Type III outmigration (Jan 15–May 31) 30 days of exposure to lowest SSC for the period	7.1	7.6	8.3	Moderate to major stress for Type III fry from Salmon River (<1 percent) during downstream migration. Majority (~95 percent) 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.

[1] Mild conditions for fish = 90 percent exceedance probability
[2] Median conditions for fish= 50 percent exceedance probability
[3] Extreme conditions for fish = 10 percent exceedance probability

In some years, later-arriving adults have been observed to delay migration upon encountering high water temperatures in the mainstem Klamath River (greater than 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 SSCs for longer durations, particularly in years with extreme conditions for fish. 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 fall-run Chinook and coho salmon (*Oncorhynchus kisutch*) adults during the September 2002 fish kill in the lower Klamath River (M. Belchik, Senior Biologist, Yurok Tribe, pers. comm., 2008). Among radio-tagged adult spring-run Chinook, these later-returning migrants have been observed to have the highest mortality rates (Strange 2007a, 2007b, 2008). In contrast, approximately half of the observed spring-run Chinook salmon adults make a relatively rapid summer migration (approximately 2 days in the Klamath River) to the Trinity River, at a time of year in which suspended sediment is naturally low.

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

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), approximately 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 tributaries to the 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.

Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (> 150 mg/l) SSC, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982, Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, it was assumed that Chinook salmon outmigration during dam removal year 2 will occur within the period of typical outmigration with the lowest predicted SSC. 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 Klamath River. 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 (Wallace 2004), a maximum of 30 days is assumed for exposure of outmigrating smolts. Exposure to suspended sediment during Type I smolt outmigration is anticipated to result in moderate (under mild or median conditions for fish) to major physiological stress (under extreme conditions for fish). This exposure, in association with other environmental factors in the basin (e.g., water temperatures, exposure to disease), could lead to sublethal or lethal effects, although data is not available to estimate potential mortality. The Type II outmigration pattern is common (~20 percent), with juveniles departing from the Salmon River in the fall when suspended sediment downstream from the Salmon River is predicted to cause minor (under mild conditions for fish) to major physiological stress (under median or extreme conditions for fish). Age-1 juveniles of the Type III life history outmigrating during winter and early spring may be exposed to SSCs causing moderate (under mild or median conditions for fish) to major physiological stress (under extreme conditions for fish).

E.3.1.3 Coho Salmon

In order to evaluate the effects 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 3.3.2.1 *Aquatic Species [Coho Salmon]*. 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). Southern Oregon Northern California Coast coho are listed as threatened under the ESA. Effects of SSC on distinct population units are differentiated where appropriate.

Coho salmon are distributed throughout the Klamath River downstream from Iron Gate Dam, and spawn primarily in tributaries (Trihey and Associates 1996, NRC 2004). Rearing has also been observed in tributary confluence pools in the mainstem Klamath River (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 193.1) and were formerly known to occupy mainstem Klamath River and tributary habitat at least as far upstream as Spencer Creek at RM 232.6 (NRC 2004, as cited in NMFS 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. Based on radio telemetry data for five coho salmon adults tagged in the Klamath River Estuary and tracked to upstream tributaries (Strange 2004), upstream migration is highly variable and averages approximately 33 days. Exposure to SSC in the mainstem Klamath River during migration was assumed to occur for 30 days.

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. Exposure is predicted to result in moderate stress (under mild conditions for fish), to impaired homing (under median conditions for fish), or major physiological stress (under extreme conditions for fish) (Table E-4). 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 farther upstream.

Table E-4. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Coho Salmon for Klamath River at Seiad Valley (RM 132.7).

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Adult upstream migrants (Sept 1–Jan 1) 30 days of exposure to median SSC for the period	6.6	7.2	8.5	Moderate to major stress and impaired homing for adults migrating upstream (~4 percent of all populations exposed).
Spawning, incubation, and fry emergence (Nov 1–Mar 14) 60 days of exposure to highest SSC for the period	11.6	12.2	12.9	No modeling of suspended sediment infiltration into gravel was conducted. Available information suggests 20 to 60 percent mortality 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.
Age-1 juveniles during winter (Nov 15–Feb 14) Exposure to highest SSC for the period	7.4	8.7	9.9	Moderate to major stress and reduced growth rates depending on conditions for age 1 juveniles rearing the mainstem. An unknown but assumed small number of all juveniles (<1 percent) rear in mainstem during winter.

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Age-0 juveniles during summer (Mar 15–Nov 14) Exposure to highest SSC for the period	8.8	9.5	10.2	Major stress to some mortality depending on conditions for age 0 juveniles rearing in mainstem.
Age 1 juvenile outmigration (Feb 15–May 31) 20 days of exposure to median SSC for the period	8.3	8.7	8.9	Moderate to major stress and reduced growth rates depending on conditions for smolts.

1 Mild conditions for fish = 90 percent exceedance probability
2 Median conditions for fish = 50 percent exceedance probability
3 Extreme conditions for Fish (10 percent exceedance probability

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 Klamath River were evaluated based on SSC predictions for the period of November 1 to March 15 in the vicinity of Seiad Valley. Based on typical water temperatures in the mainstem Klamath River, incubation likely occurs within 60 days or less (Velsen 1987). 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 Klamath River under both normal and extreme conditions, with possibly up to 100 percent mortality under extreme conditions in the vicinity of Seiad Valley (Table E-4) and farther downstream. However, coho salmon are typically tributary spawners (NMFS 2010) and based on Magneson and Gough (2006) spawning surveys from 2001 to 2005, only from 6 to 13 redds are typically observed in the mainstem. In 2015 no redds were observed in the mainstem Klamath River between Portuguese Creek (RM 128) and Bogus Creek (RM 192.6) (Hentz and Wickman 2016), and seven were observed in 2017 in the same reach (Dennis et al. 2017). Due to the low number of redds observed in the mainstem Klamath River, it can be assumed that elevated suspended sediment during winter flows 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 Klamath River.

There may be wide variation in terms of how long juvenile coho salmon rear in natal tributaries versus the mainstem Klamath River, making it difficult to determine their exposure to elevated SSC in the mainstem. Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (> 150 mg/l) SSC, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982, Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, it was assumed that coho salmon outmigration during dam removal year 2 will occur within the period of typical outmigration with the lowest predicted SSC. Some fry and age 0 juveniles enter the mainstem Klamath River in the spring and summer following emergence. These fish may spend their remaining rearing period in the mainstem Klamath River, but by early fall, only low densities of juvenile coho salmon are found in the mainstem. The latter indicates that over-summer 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 Klamath River during winter would also be exposed to SSCs high enough to cause major physiological stress even under mild or median conditions for fish (Table E-4). Although some juveniles may rear in the mainstem Klamath River, most production from all population units probably results from fish that 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. 2008, 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. 2008, 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 Klamath River 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 Klamath River, 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 an average of 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 approximately 30 days, a maximum of 20 days exposure to mainstem suspended sediment at Seiad Valley during migration was assumed for the analysis. Under normal or extreme conditions, SSC in the mainstem Klamath River during outmigration for all populations would remain in the sublethal range but could result in moderate or major physiological stress and inhibit feeding.

During experimental releases of wild and hatchery radio-tagged coho salmon smolts in the Klamath River near Iron Gate Dam, the fish sustained mortality rates of approximately 35 to 70 percent (Beeman et al. 2007, 2008). Variability in survival rates may be associated with: (1) the length of residency in tributaries prior to migrating (i.e., fish that enter the mainstem Klamath River later have higher survival), (2) mainstem discharge (migrants sometimes showed higher survival when flows in the mainstem

Klamath River were higher), or (3) spawning location (i.e., survival is much lower for smolts originating upstream of the Scott River). The relative contribution from SSC under existing conditions to these mortality rates is not known.

Overall, under existing conditions, SSC in the mainstem Klamath River 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 from the Trinity River confluence (RM 43.3) to the estuary mouth (RM 0.0) is listed as sediment impaired under Section 303(d) of the Clean Water Act (State Water Board 2006, North Coast Regional Board 2010). 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 Steelhead

The following analysis and discussion apply 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 steelhead would be similar to those found for juvenile steelhead.

Both summer and winter steelhead are distributed throughout the Klamath River and its tributaries downstream from 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 43.3) and Seiad Creek (RM 132), 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 mild and median conditions for fish, 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 during extreme 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 SSCs are uncommon during summer. Under median conditions for fish, SSC are high enough to cause major stress and possibly impaired homing. The 80 percent of steelhead spawning upstream of the Trinity River would be exposed to elevated SSCs for a longer period due to the additional time spent migrating in the mainstem Klamath River. Under extreme conditions, SSC would cause major stress and impaired homing. Concentrations remain in the sublethal range; however, adult steelhead stressed by elevated suspended sediment could be more vulnerable to disease-related mortality. The amount of time that adult steelhead could be exposed would 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 adult steelhead, or “runbacks,” migrate downstream in the spring to return to the sea, typically from April through May 30. Under most conditions, SSCs are high enough to cause major stress. There are little data on downstream-migrating steelhead in the Klamath River with which to understand potential consequences of exposure to suspended sediment during this life history phase.

Half-pounders (i.e., 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 the adult half-pounder life history, approximately 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, SSCs in the mainstem Klamath River during the period when half-pounders are present would be in a range that may cause major physiological stress, and possibly mortality (0–20 percent), depending on conditions (i.e., moderate, normal, and extreme) (Table E-5).

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 Klamath River.

Juvenile summer-run 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 Klamath River 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 Klamath River, it is difficult to track how much exposure each cohort might receive to suspended sediment in the mainstem. Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (> 150 mg/l) SSC, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982, Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, the analysis assumes that steelhead outmigration during dam removal year 2 will occur within the period of typical outmigration, with the lowest predicted SSC. Juveniles found in the mainstem Klamath River cannot generally be identified to a specific run, so for this analysis the model assumes summer-, fall-, and winter-run fish share a similar life history with those that have been observed. There is evidence in the literature that juvenile salmonids 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-5. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Steelhead for Klamath River at Seiad Valley (RM 132.7).

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Adult summer upstream migrants and runbacks (Mar 1–June 30) 30 days of exposure to median SSC for the period	7.8	8.5	9.1	Major stress, avoidance of turbidity, and possibly impaired homing.
Adult winter upstream migrants (Aug 1–Mar 31) 30 days of exposure to median SSC for the period	7.2	8.0	9.0	Major stress and potential for impaired homing.
Adult runbacks (Apr 1–May 30) 30 days of exposure to median SSC for the period	7.9	8.5	9.0	Major stress to downstream-migrating adults; effect dependent on time it takes runbacks to return downstream to the sea.
Half-pounder residence (Aug 15–Mar 31) 90 days of exposure to median SSC for the period	7.8	8.9	10.0	Major stress, and possibly reduce growth or some mortality (0–20 percent) depending on conditions. Proportion of run that returns as half-pounders is unknown. Fish may escape exposure to high suspended sediment in the mainstem by entering tributaries.
Spawning though emergence (Dec 1–June 1) Exposure to highest SSC for the period	No effect	No effect	No effect	No mainstem spawning.
Age 0 juvenile rearing (Mar 15–Nov 14) Exposure to highest SSC for the period	8.3	9.0	9.8	Major stress to reduced growth rates for portion of age 0 juveniles rearing in mainstem (~60 percent of run upstream of Trinity River)
Age 1 juvenile rearing (year-round) Exposure to highest SSC for the period	8.8	9.5	10.0	Major stress, reduced growth rates, to mortality (0–20 percent) depending on conditions for portion of age 1 juveniles rearing in mainstem (~60 percent of run upstream of Trinity River)

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Age 2 juvenile rearing (Nov 15–Mar 31) Exposure to highest SSC for the period	8.3	9.0	9.8	Age 2 in the mainstem (~40 percent of run upstream of Trinity River) expected to experience major stress to reduced growth rates depending on conditions.
Juvenile/smolt outmigrants (Mar 1–May 1) 20 days of exposure to lowest SSC for the period	8.8	9.5	10.0	Major stress, reduced growth rates, to mortality (0–20 percent) depending on conditions.

[1] Mild conditions for fish = 90 percent exceedance probability
[2] Median conditions for fish = 50 percent exceedance probability
[3] Extreme conditions for Fish = 10 percent exceedance probability

Under normal existing conditions, age-0 steelhead may experience major physiological stress (mild conditions for fish) and or reduced growth (median conditions or extreme conditions for fish) (Table E-5). If steelhead remain to rear in the mainstem Klamath River for another year, SSCs would result in major physiological stress and reduced growth rates for this cohort. However, it appears that many of these juveniles are avoiding conditions in the mainstem Klamath River by using tributary and other off-channel habitat during winter (Soto et al. 2008, Hillemeier et al. 2009), lowering their exposure to SSCs. The approximately 55 percent of the total summer-run steelhead population that spawn and rear in the Trinity River and downstream the mainstem Klamath River 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 Klamath River, it appears that approximately 40 percent of the steelhead population rears in tributaries until age-2. Approximately 60 percent of juvenile steelhead in the mainstem Klamath River upstream of the Trinity River confluence are age 1, approximately 37 percent are age 2, and approximately 3 percent are age 3 (Scheiff et al. 2001). Age 1 steelhead rearing year-round in the mainstem Klamath River could experience major physiological stress (under mild conditions for fish), reduced growth rates (under median conditions for fish), or mortality rates up to 20 percent (under extreme conditions for fish). For juvenile steelhead age 2- or 3- rearing in the mainstem during fall, suspended sediment may cause major stress (under mild conditions for fish) or reduced growth rates (under median or extreme conditions for fish).

Smolts are captured in the mainstem Klamath River 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). Jetter and Chesney (2016) report that between 2001 and 2016 steelhead age-2 outmigration from the Shasta and Scott rivers occurred primarily between March and May. Temperatures in the mainstem Klamath River 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 Klamath River would 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 the ocean. Approximately half of the juvenile steelhead population outmigrates from the Trinity River and tributaries downstream; the shorter distance to the ocean should also shorten the time they are exposed to suspended sediment in the mainstem Klamath River during outmigration. Under mild or median conditions for fish, SSCs can cause major physiological stress during the outmigration period. Under extreme conditions for fish, SSCs and durations could be high enough to cause up to 20 percent mortality. Smolts originating from tributaries farther inland (i.e., not produced from the Trinity River or lower-elevation streams) would likely be exposed to high SSCs because there is a greater chance that their outmigration may coincide with a sediment pulse. The duration of their exposure to high SSCs would depend both on timing and rates of travel downstream (i.e., the amount of time spent in the mainstem Klamath River; assumed to be 20 days for this analysis, based migration monitoring data [Goldsmith 1994]). 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 2007, PacifiCorp 2006), of which only resident Klamath River lamprey and anadromous Pacific lamprey are present downstream from Iron Gate Dam (PacifiCorp 2004, FERC 2007). Pacific lamprey was chosen as the focal species, since most information on life-history, distribution, and habitat requirements is from this species. Pacific lamprey have no Federal or State special status. If basic patterns in distribution differ between the species (e.g., if Klamath River lamprey are found in more abundance directly downstream from 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 (lamprey larva) 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 (Goodman and Hetrick 2017). Therefore, the review of existing conditions focuses on exposure of Pacific lamprey life stages to suspended sediment in the mainstem Klamath River downstream from 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. Radio telemetry studies of adult migrating Pacific lamprey observe adults often hold in suitable habitat in lower river areas, and then migrate relatively rapidly to spawning areas during early winter when temperatures decrease and flows increase (Clemens et al. 2011, McCovey 2011, Starcevich et al. 2014). Based on typical migration rates of approximately five miles/day or slightly faster (Starcevich et al. 2014), this analysis assumed 30 days of exposure to SSC during adult Pacific lamprey winter migration to reach spawning habitat between Seiad Valley (RM 132.2) or farther upstream (adults migrating to downstream locations would have a shorter exposure). Under existing conditions, SSC during adult Pacific lamprey migration could cause major physiological stress and impaired homing (Table E-6). Pacific lamprey are observed to spawn in the mainstem Klamath River, exposing ammocoetes to suspended sediment within the mainstem year-round. Under mild conditions for fish there could be major stress, and under extreme conditions for fish mortality of 0 to 20 percent is anticipated (Table E-6). Most ammocoete rearing occurs within tributaries.

Juvenile Pacific lamprey (ages 2 to 10) outmigrate to the ocean from the mainstem Klamath River and tributaries year-round, with peaks in migration during late spring and fall. Based on effects on salmonids, juvenile Pacific lamprey migrating during spring are anticipated to be exposed to SSCs high enough to cause moderate (under mild or median conditions for fish), to major physiological stress (under extreme conditions for fish) (Table E-6). Juvenile Pacific lamprey migrating during fall are exposed to relatively low concentrations of suspended sediment. Based on data collected on salmonids, concentrations would cause minor (under mild conditions for fish) to moderate physiological stress (under median or extreme conditions for fish) (Table E-6).

As there are multiple year-classes of Pacific 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 SSCs are high.

Table E-6. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Pacific lamprey for Klamath River at Seiad Valley (RM 132.7).

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Adult upstream migration and spawning (year-round) 30 days of exposure to median SSC for the period	7.8	8.5	9.0	Major stress and impaired homing for adult migrants. Adults migrating during late spring and summer are exposed to lower concentrations of SSC.
Ammocoete rearing (year-round) Exposure to highest SSC for the period	8.7	9.5	10.3	Major stress of ammocoetes rearing in the mainstem, reduced growth, and potentially 0–20 percent mortality depending on conditions. A majority of ammocoetes rear in tributaries.
Spring outmigration (May 1–June 30) 30 days of exposure to lowest SSC for the period	6.7	7.8	8.7	Moderate to major stress for juveniles during spring outmigration.

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Fall/winter outmigration (Sept 1–Dec 31) 30 days of exposure to lowest SSC for the period	5.0	5.9	6.4	Minor to moderate stress for juveniles during fall outmigration.

1 Mild conditions for fish = 90 percent exceedance probability
2 Median conditions for fish = 50 percent exceedance probability
3 Extreme conditions for fish = 10 percent exceedance probability

E.3.1.6 Green Sturgeon

The Klamath Basin is the principal spawning watershed for green sturgeon in California (Moyle 2002). Green sturgeon in the Klamath River are part of the Northern DPS and are not a special status species. Green sturgeon spawn primarily in the lower 67 miles of the mainstem Klamath River (downstream from Ishi Pishi Falls), in the Trinity River 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 Klamath River downstream from Orleans.

There is not extensive literature on the effects of suspended sediment on green 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 green 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, adult green sturgeon have been observed to remain alive for days out of water, and no adult or juvenile green 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 when SSCs reach levels expected to cause moderate (under mild conditions for fish) to major physiological stress (under median or extreme conditions for fish). However, adult green sturgeon are likely to be relatively tolerant compared to salmonids. Feeding is not likely to be a problem even when SSCs are high, because green sturgeon 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 DWR 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 DWR 2003). Under median conditions for fish, eggs and larvae are expected to be exposed to SSCs 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 (Table E-7). However, green sturgeon do successfully spawn in the mainstem Klamath River under existing conditions (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, approximately 25 percent of green sturgeon migrate directly back to the ocean (Benson et al. 2007), and the remainder hold in mainstem Klamath River pools from RM 13 to RM 67 through November. During this holding period, SSCs are relatively low, and only minor to moderate effects are anticipated.

Juvenile green sturgeon may rear for one to three years in the Klamath River system before they migrate to the estuary and the ocean (NRC 2004, FERC 2007, CALFED 2007), usually during summer and fall (Emmett et al. 1991, as cited in CALFED 2007). Juvenile green sturgeon 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, pers. comm., 2008), but juvenile green sturgeon may be rearing for additional months or years in the lower Klamath River or estuary before migrating to the ocean. During the rearing period, juvenile green sturgeon are anticipated to be exposed to SSCs that cause moderate to major stress and reduced growth in salmonids (Table E-7). 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, 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 green sturgeon to migrate to the estuary or the 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, 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, green sturgeon in the Klamath River mainstem are regularly exposed to SSCs 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, this approach likely overestimates effects on green sturgeon.

Table E-7. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Green Sturgeon for Klamath River at Orleans (RM 59).

Life-history Stage (period)	SEV at Conditions			Effects on Production
	Mild[1]	Median[2]	Extreme[3]	
Adult migration and spawning (Mar 15–July 15) Exposure to median SSC for the period	7.7	8.3	8.8	Moderate to major stress for adult migrants and spawners.
Eggs and larvae (Apr 1–Aug 15) Exposure to highest SSC for the period	11.5	11.8	12.2	20 to 60 percent mortality for eggs and larvae depending on conditions (based on salmonid literature, effects likely overestimated).
Adult post-spawning holding (July 15–Nov 15) Exposure to median SSC for the period	5.6	6.1	6.6	Minor to moderate physiological stress (based on salmonid literature, effects likely overestimated).
Juvenile rearing (year-round) and outmigration (May 15–Oct 15) Exposure to median SSC for the period	7.1	7.7	8.4	Moderate to major stress (based on salmonid literature, effects likely overestimated).

[1] Mild conditions for fish = 90 percent exceedance probability
[2] Median conditions for fish = 50 percent exceedance probability
[3] Extreme conditions for fish = 10 percent exceedance probability

E.3.2 Proposed Project

Under the Proposed Project, full facility removal would result in the release of 5.3 and 8.6 million yd^3 of fine sediment stored in the reservoirs into the Klamath River downstream from Iron Gate Dam over a two-year period (USBR 2012), resulting in higher SSCs than would normally occur under existing conditions, and local, short-term sediment deposition. SSCs 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 the Klamath River. Reservoir drawdown is expected to commence in January dam removal year 2. Based on the suspended sediment modeling conducted to analyze each alternative (including facility removal) (USBR 2012), SSCs 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 Project on anadromous fish populations in the Klamath River.

Model results (USBR 2012) indicate that the impact of increased SSC is limited to one year following the initiation of dam removal. As a result, the hydrologic conditions beyond the first year following dam removal will have minimal effect toward the impact of increased SSC. After the first year following dam removal, the flow will be confined within the historical main channel and no longer be able to access the remaining fine sediment left on the floodplain, unless an extremely high flood event is to occur. As a result, the suspended sediment condition in the Klamath River after the first year will be similar to existing conditions with minimal impact from dam removal under most hydrological conditions. The riverine flows will have the potential to access the reservoir deposits left on the floodplain only during high flood events, during which the additional suspended sediment from erosion of the reservoir deposits is expected to be minor (high flow events carry high concentrations of suspended solids and any increase in SSCs from reservoir sediments would be insignificant). In the following sections, SSCs predicted for the most-likely and worst impacts on fish scenarios are used to evaluate the potential effects of the Proposed Project 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 from 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 from downstream from Iron Gate Dam, and downstream from 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 Project, SSCs during fall migration could be high enough to cause moderate physiological stress and impaired homing (under least or most-likely impacts on fish), to major physiological stress (under worst impacts on fish) in the fall following removal of the dams (dam removal year 2).

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 to calculate this component; however, suspended sediment resulting from the Proposed Project is predicted to result in up to 100 percent mortality of eggs and fry from all mainstem Klamath River spawning in dam removal year 1 (Table E-8). The sediments released during dam removal would likely be primarily conveyed as wash load and would not fall out of suspension; however, the fraction deposited on spawning gravels would carry high concentrations of very fine sediment. These sediments may smother the eggs by adhering to the chorion (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 sediment. Sediment transport analysis conducted by Stillwater Sciences (2008) concluded that fine sediment deposition is expected to be limited to the upper portion of the bed surface after dam removal, which can be readily flushed during a high-flow event after the fine sediment supply in the former reservoir area is exhausted, or to be removed by 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 Project on spawning success is unlikely to persist beyond the summer of dam removal year 2.

Much of the overall effect of the Proposed Project on fall-run Chinook salmon would depend on the relative proportion of mainstem Klamath River spawners during the fall of dam removal year 1, prior to the January dam removal year 2 initiation of facility removal. Based on redd surveys using a mark and re-sight methodology from 1999 through 2009 (Magneson and Wright 2010), an average of approximately 2,100 redds from hatchery and naturally returning adults are constructed in the mainstem Klamath River, which based on escapement estimates in the Klamath River Basin from 2001 through 2009 (CDFG 2010, unpublished data) is consistently approximately eight 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 (Magneson and Wright 2010) indicate that approximately half of the fall-run 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 2007) and thus would be most vulnerable to sediment released in association with the Proposed Project. With a predicted 100 percent mortality, approximately 2,100 redds on average could be lost under the Proposed Project assuming either the mostly-likely or worst impacts on fish scenario. Assuming constructed redds are related to escapement, this equates to approximately 8 percent of all anticipated redds in the basin in dam removal year 1. Based on the proximity to the Iron Gate Hatchery, it is expected that much of the redds affected would 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. Jetter and Chesney (2016) report that, between 2001 and 2016, Type I outmigration from the Shasta and Scott rivers occurred primarily between February and June. Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (> 150 mg/l) SSCs, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982, Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, it was assumed that Chinook salmon outmigration during dam removal year 2 will occur within the period of typical outmigration with the lowest predicted SSC. As discussed in Section E.3.1.1, a maximum duration of exposure to SSCs at Seiad Valley during migration of 30 days was assumed for the analysis (Wallace 2004). Under the Proposed Project, SSC in the mainstem would likely result in moderate (under least impacts on fish) to major physiological stress (under most-likely or worst impacts on fish), which is a slightly higher impact than predicted under existing conditions (Table E-8). Prolonged exposure to higher SSCs 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 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 fall-run Chinook. Parr-smolt transformation can also be compromised in stressed juveniles (Bash et al. 2001) and be a potential source of mortality.

The Type II life history is also common for fall-run Chinook salmon (~40 percent of cohort) (Sullivan 1989). These juveniles remain to rear in the tributaries in which they were spawned and would only be exposed to suspended sediment in the mainstem Klamath River during their outmigration to the ocean in the fall. Under the Proposed Project, SSCs would be slightly higher than existing conditions, unless there are worst impacts on fish conditions in the fall after dam removal (dam removal year 2), in which case SSCs would be high enough to cause major physiological stress.

Type III life-history fish are relatively rare (<1 percent of production) in the Klamath River fall-run Chinook 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 Project, SSC could cause major stress or reduced growth in a worst impacts on fish scenario (Table E-8); slightly more of an impact than predicted under existing conditions (Table E-8). Based on outmigrant trapping in the mainstem Klamath River at Big Bar, approximately 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 approximately 0.1 percent of trap captures. Based on abundance estimates, annual average Type III life-history Chinook outmigration is approximately 943 smolts each year. Based on Sullivan (1989) the typically larger Type III fall-run Chinook 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).

Table E-8. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on fall-run Chinook Salmon for Proposed Project for the Klamath River at Iron Gate Dam[1] and Seiad Valley[2].

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[3]	Most Likely[4]	Worst[5]	
Adult upstream migrants (July 15–Oct 31) Exposure to median SSC for the period	6.9	7.6	8.8	Moderate to major physiological stress and impaired homing depending on scenario.
Spawning, incubation, and fry emergence (Oct 15–Feb 28) 90 days of exposure to highest SSC for the period	13.6	13.8	14.0	Effects of suspended sediment on spawning gravel quality were not modeled; however, suspended sediment may result in nearly 100 percent mortality of all progeny from mainstem spawning under all scenarios (approximately 2,100 redds, or approximately 8 percent of production).
Juvenile rearing (Jan 1–Mar 28) 30 days of exposure to the highest SSC for the period	10.5	10.8	11.1	No juvenile progeny anticipated from mainstem due to impacts during incubation. All other juveniles rear in tributaries.
Type I outmigration (Feb 1–August 1) 30 days of exposure to lowest SSC for the period	6.9	7.2	7.8	Moderate to major physiological stress and reduced growth depending on scenario. Applies to ~60 percent of total production.
Type II outmigration (Sept 1–Nov 30) 30 days of exposure to lowest SSC for the period	6.2	6.5	7.4	Moderate to major physiological stress depending on scenario. Applies to ~40 percent of total production.

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[3]	Most Likely[4]	Worst[5]	
Type III outmigration (Feb 1–April 15) 30 days of exposure to lowest SSC for the period	8.5	9.0	9.4	Major stress to reduced growth depending on scenario. (0 to 189 smolts, or less than 1 percent of production).

[1] Adult migration, spawning, incubation, and fry emergence life stages
[2] Juvenile rearing and outmigration life stages
[3] Least impacts on fish= 90 percent exceedance probability
[4] Most likely impacts on fish = 50 percent exceedance probability
[5] Worst impacts on fish = 10 percent exceedance probability

E.3.2.2 Spring-run Chinook Salmon

Based on spring-run Chinook salmon distribution, the Proposed Project would 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 Klamath River downstream from the Salmon River, including those that migrate to and from the Trinity River.

Under existing conditions and the Proposed Project, SSC during upstream migration would cause impaired homing to major stress to spring-run Chinook salmon. Adult Chinook migrating later in the season (July through August) would experience minor (under least or most-likely impacts on fish) to moderate physiological stress (under worst impacts on fish) under the Proposed Project.

Spring-run Chinook upstream migration is separated into two time periods—spring and summer. Under the Proposed Project, adult spring migrants are expected to be exposed to higher SSCs than under existing conditions, leading to increased stress and impaired homing (Table E-9). However, the duration of exposure is relatively short (<14 days), and effects are expected to be sub-lethal. Behavioral responses of adult Chinook 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.

Approximately half of the observed spring-run Chinook salmon adults migrate relatively rapidly to the Trinity River in the summer (approximately two days within the mainstem Klamath River). Even under a worst impacts on fish scenario, effects would only be slightly higher than under existing conditions—only 1–2 days of exposure to SSCs causing moderate stress (Table E-9).

Since no spring-run Chinook salmon spawning occurs in the mainstem Klamath River under existing conditions, the egg through fry life stages are not anticipated to be affected by suspended sediment resulting from the Proposed Project (Table E-9).

Table E-9. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Spring-run Chinook Salmon for Proposed Project for Klamath River at Orleans (RM 59).

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Adult spring migration (Apr 1–June 30) 14 days of exposure to median SSC for the period	7.8	8.0	8.5	Impaired homing to major stress for adults returning to Salmon River for all scenarios. Majority (~95 percent on average) of adults enter Trinity River, and would be exposed to lower concentrations. Up to 35 percent of "natural" escapement returns to Salmon River.
Adult summer migration (Jul 1–Aug 31) 2 days of exposure to median SSC for the period	5.3	5.7	6.4	Minor to moderate physiological stress depending on scenario to the ~50 percent of the summer migrants returning to Trinity River.
Spawning, incubation, and fry emergence (Sept 1–Feb 28)	No effect	No effect	No effect	Spring-run do not generally spawn in the mainstem; no effect to this life stage is anticipated.
Juvenile rearing (variable)	No effect	No effect	No effect	Juveniles rear in tributaries; no effect to this life stage is anticipated.
Type I outmigration (Apr 1–May 31) 30 days of exposure to lowest SSC for the period	7.9	8.2	8.6	Major stress and possibly reduced growth rates under a worst impacts on fish scenario for Type I fry (~80 percent) in smolt outmigration from Salmon River. Majority (~95 percent) of juveniles outmigrate from the Trinity River, and would be exposed to lower concentrations.
Type II outmigration (Oct 1–Nov 15) 30 days of exposure to lowest SSC for the period	6.2	6.6	7.2	Moderate physiological stress for Type II smolts from the Salmon River (~20 percent) during downstream migration. Majority (~95 percent) of juveniles outmigrate from Trinity River and are also exposed to no SSC from Proposed Project.
Type III outmigration (Jan 15–May 31) 30 days of exposure to lowest SSC for the period	7.9	8.2	8.6	Major stress to reduced growth rates for Type III smolts from Salmon River. (approximately 16 smolts less than 1 percent of the total smolt population from the Salmon River).

[1] Least impacts on fish = 90 percent exceedance probability
[2] Most likely impacts on fish = 50 percent exceedance probability
[3] Worst impacts on fish = 10 percent exceedance probability

Based on outmigrant trapping in the Salmon River from 2001 to 2006 (Karuk Tribe, unpubl. data), approximately 80 percent of spring-run Chinook salmon 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 adult Chinook returning to the Salmon River (~70 percent) exhibited the Type II life history and outmigrate during fall, and approximately 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 mainly rear in tributaries (West 1991, Dean 1994, 1995), reducing likelihood of exposure to suspended sediment in the mainstem Klamath River. Type I juveniles move from tributaries into the mainstem Klamath River and continue downstream to the ocean in April and May. Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (> 150 mg/l) SSCs, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982, Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, it was assumed that Type I spring-run Chinook salmon outmigration during dam removal year 2 will occur within the period of typical outmigration with the lowest predicted SSC. SSCs would cause major stress (under least impacts on fish) to reduced growth rates (under most-likely or worst impacts on fish), slightly higher than under existing conditions.

Under the Proposed Project, SSCs during the Type II outmigration would cause moderate stress, slightly higher than under existing conditions.

Type III Chinook outmigrants that overwinter in the mainstem Klamath River when SSCs are highest, or those migrating from the Salmon River (<1 percent of outmigrants within Klamath River watershed), would have the greatest exposure to suspended sediment. Suspended sediment conditions would cause major physiological stress to reduced growth rates during the Type III Chinook outmigration under all scenarios of the Proposed Project, but would remain in the sub-lethal range. Type III age 1 spring-run Chinook outmigrants are very rare (only 30 were observed in the Salmon River in five years of trapping). Based on Olson (1996) the typically larger Type III Chinook 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). Most spring-run Chinook outmigrants (95 percent) originate from the Trinity River; they have a shorter distance to travel to the ocean and SSCs resulting from the Proposed Project should be lower due to dilution (USBR 2012), so they may experience major stress, but suffer little or no mortality.

E.3.2.3 Coho Salmon

The effects of suspended sediment on coho salmon in the Klamath River described here follow the Williams et al. (2006) designation of nine population units (see Section E.3.1.3). 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 from the Shasta River. Therefore, the analysis focuses on exposure to suspended sediment within, and downstream from, Seiad Valley. Coho salmon within the Upper Klamath River Population Unit upstream of Seiad Valley are expected to be exposed to slightly higher SSCs, and fish rearing in all other population units further downstream to lower SSCs.

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 coho salmon migration observations in the Scott River (2007–2009), Shasta River (2007–2009), and Bogus Creek (2003–2009), on average only approximately 4 percent of adults remain in the mainstem Klamath River after December 15 (initiation of reservoir drawdown under the Proposed Project) (California Department of Fish and Game, unpubl. data). In most years, all adult coho salmon have entered tributaries prior to December 15, although in some years (e.g., Scott River in 2009) most fish were delayed until between December 15 and January 1. Therefore, most adult coho should already be in tributaries when reservoir drawdown begins in January of dam removal year 2 (Table E-10). In addition, adult migrant coho salmon are anticipated to avoid high SSCs by seeking refuge in tributaries, as was observed for Chinook salmon during removal of the Elwha Dam (McHenry et al. 2017). Therefore, it is assumed that all adult coho salmon will be within tributary habitat by December 15 of dam removal year 1, and the impacts analysis is based on the assumption that adult coho salmon are exposed to the median SSC conditions for 30 days of migration (Strange 2004). Under the most-likely impacts on fish and worst impacts on fish scenarios, effects of the Proposed Project on migrating adult coho salmon from all population units are anticipated to be slightly higher than those experienced under existing conditions but would remain in the sub-lethal range (Table E-10).

Coho salmon from the Upper Klamath River Population Unit that spawn in the mainstem Klamath River, as well as their progeny, would suffer 60 to 80 percent mortality depending on scenarios of the Proposed Project (Table E-10); however, even under existing conditions, very high mortality (20 to 60 percent) is expected due to the effects of suspended sediment on these life stages (in addition to other sources of mortality). Based on spawning surveys conducted from 2001 through 2017 (Magneson and Gough 2006, Hentz and Wickman 2016, Dennis et al. 2017), 0 to 13 redds could be affected in dam removal year 1 during the Proposed Project. Many of these redds are thought to be from returning hatchery fish (NMFS 2010a), and thus may be only selecting this habitat after failing to locate the hatchery collection site. Based on the range of escapement estimates of Ackerman et al. (2006), 13 redds (the highest number observed) would be much less than one percent of the natural and hatchery returns combined.

Table E-10. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Coho Salmon for Proposed Project for Klamath River at Seiad Valley (RM 132.7).

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Adult upstream migrants (Sept 1–Dec 15) 30 days of exposure to median SSC for the period	6.8	8.0	8.6	Moderate to major stress and impaired homing for adults migrating upstream (~4 percent of all populations exposed).
Spawning, incubation, and fry emergence (Nov 1–Mar 14) 60 days of exposure to highest SSC for the period	13.5	13.7	13.9	60 to 80 percent mortality of progeny from mainstem spawning. (<13 redds, or 0.7–26 percent of Upper Klamath River Population unit natural escapement).

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Age-1 juveniles during winter (Nov 15–Feb 14) Exposure to highest SSC for the period	10.8	11.0	11.3	20 to 40 percent mortality for age 1 juveniles from the dam removal year 1 cohort rearing in the mainstem depending on scenario. An unknown but assumed small number (<1 percent) of juveniles rear in mainstem during winter.
Age-0 juveniles during summer (Mar 15–Nov 14) Exposure to highest SSC for the period	10.8	11.0	11.4	20 to 40 percent mortality for age 1 juveniles from dam removal year 1 cohort rearing in mainstem during late spring and early summer. Avoidance behavior anticipated to result in small number (<1 percent) of juveniles rearing in mainstem during dam removal year 2.
Age 1 juvenile outmigration (Feb 15–May 31) 20 days of exposure to lowest SSC for the period	7.2	7.7	8.3	Moderate to major stress and possibly reduced feeding depending on scenario for smolts outmigrating from Upper Klamath, Mid-Klamath, Shasta River, and Scott River populations during early spring. (impacts vary by population)

[1] Least impacts on fish = 90 percent exceedance probability
[2] Most likely impacts on fish = 50 percent exceedance probability
[3] Worst impacts on fish = 10 percent exceedance probability

Although most (assumed >50 percent) coho salmon 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 Klamath River during the spring and summer following dam removal (dam removal year 2) would be exposed to concentrations of suspended sediment that would result in 20 to 40 percent mortality under the Proposed Project (Table E-10), slightly higher than predictions for existing conditions under the worst impacts on fish scenario. 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 Klamath River. There could also be indirect effects on marine survival for coho salmon that survive the summer, but smolt at a smaller size (Bilton et al. 1982, Hemmingsen et al. 1986).

Under existing conditions, SSCs are typically high during the winter in the mainstem Klamath River and predicted to cause major stress under all scenarios (least impacts on fish, most-likely impacts on fish, or worst impacts on fish). Under the Proposed Project, age-1 juveniles (progeny of the dam removal year 1 cohort) that have either successfully over-summered or moved from tributaries into the mainstem Klamath River during the fall, could be exposed to much higher SSCs in the mainstem during the winter of dam removal than under existing conditions, and may suffer mortality rates of up to 40 percent under a worst impacts on fish scenario (Table E-10). However, many juvenile coho salmon in the mainstem Klamath River appear to migrate downstream to rear and may avoid adverse conditions in the mainstem by using tributary or off-channel habitats during winter, thus reducing high SSC exposure and potential mortality (Soto et al. 2008, Hillemeier et al. 2009). This assumption is 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 higher SSCs expected under the Proposed Project. Overall, it is not known how many juvenile coho salmon rear in the mainstem Klamath River 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 dam removal year 1 cohort are expected to outmigrate to the ocean beginning in late February, although most natural origin smolts outmigrate to the mainstem Klamath River 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). Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (> 150 mg/l) SSCs, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982, Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, it was assumed that coho salmon outmigration during dam removal year 2 will occur within the period of typical outmigration with the lowest predicted SSC. Once in the mainstem Klamath River, coho salmon smolts move downstream fairly quickly (Stutzer et al. 2006). As discussed in detail in Section E.3.1.3, this analysis assumes a maximum exposure of 20 days of exposure at Seiad Valley for downstream migration. Under the Proposed Project, SSCs would be slightly higher during spring than under existing conditions, and coho salmon smolts are likely to suffer moderate to major stress and reduced feeding depending on scenario (Table E-10); assuming delayed outmigration to avoid high SSCs as discussed above.

Based on the results of coho salmon outmigrant trapping by the USFWS (2001) on the mainstem Klamath River compared with trapping in the Trinity River from 1997 to 2000 (USFWS 2011), most (>80 percent) coho smolts originate from the Trinity River and Lower Klamath River populations. For the majority of coho salmon smolts, produced from tributaries downstream from Orleans, effects of the Proposed Project would be similar to existing conditions by late April.

Under existing conditions, coho salmon smolts outmigrating from the Upper Klamath River, Scott River, and Shasta River populations currently have high 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 Project, could result in even higher mortality in the spring of dam removal year 2.

E.3.2.4 Steelhead

Although steelhead do migrate as far upstream as Iron Gate Dam, nearly all spawning occurs in tributaries downstream from Seiad Valley (NRC 2004); therefore, this analysis focuses on exposure to suspended sediment in the mainstem Klamath River downstream from Seiad Valley.

Adult summer-run steelhead typically enter and migrate up the Klamath River from March through June (Hopelain 1998). Under the Proposed Project, SSCs would be higher than under existing conditions, most likely resulting in major physiological stress and impaired homing. Based on summer-run 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 approximately 657 adult summer-run 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). The summer-run steelhead that spawn in the Trinity River (~55 percent of the run based on escapement data) and other downstream tributaries would likely be exposed to only slightly higher impacts from suspended sediment than under existing conditions.

The Proposed Project is anticipated to have a direct effect on returning adult winter-run steelhead. Adult winter-run steelhead enter the Klamath River in late summer and fall and migrate and hold in the mainstem Klamath River through fall and winter. These adult steelhead would likely be exposed to higher SSCs than under existing conditions (Table E-11). Information on the abundance of winter-run 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 winter-run 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 approximately 3,500 to the Klamath River upstream of the Trinity River (Busby et al. 1994). However, in more recent years (2000 through 2016), the highest return was 631 adult steelhead to the Iron Gate Hatchery (Pomeroy 2016). Based on USFWS (1998), on average approximately 80 percent of winter-run steelhead migrate upstream after December 15 and could be exposed to high SSCs from the Proposed Project, although in some years many more steelhead migrate in the fall before that time. Stressed adult steelhead 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., 2008).

Since no winter-run steelhead spawning occurs in the mainstem Klamath River under existing conditions, the egg, alevin, and fry life stages are not anticipated to be affected by suspended sediment resulting from the Proposed Project (Table E-11).

Post-spawning adult steelhead ("runbacks") migrate downstream in the spring to return to the sea, typically from April through May. Under the Proposed Project, SSCs would be higher than under existing conditions, and sub-lethal but major stress is likely under all scenarios (Table E-11). There are little data on downstream-migrating steelhead in the Klamath River to understand the potential consequences of exposure to suspended sediment during this life-history phase.

Table E-11. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Steelhead for Proposed Project Seiad Valley (RM 132.7).

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Adult summer upstream migrants (Mar 1–June 30) 30 days of exposure to median SSC for the period	8.7	9.0	9.3	Major stress and impaired homing for adult migrants. The ~55 percent that migrate to the Trinity River or tributaries further downstream would not be as affected.
Adult winter upstream migrants (Aug 1–Mar 31) 30 days of exposure to median SSC for the period	9.3	9.4	9.9	Major stress, impaired homing, and possibly some mortality (0–20 percent for adult migrants.
Adult run-backs (Apr 1–May 30) 30 days of exposure to median SSC for the period	8.7	9.0	9.5	Moderate to major stress to downstream-migrating adults; effect would depend on timing of outmigration in relation to suspended sediment pulse.
Half-pounder adults (Aug 15–Mar 31) 90 days of exposure to median SSC for the period	10.7	10.7	11.1	Mortality ranging from 0 to 40 percent depending on scenario. Majority remain in tributaries and would not be affected.
Spawning through emergence (Dec 1–June 1)	No effect	No effect	No effect	Spawning occurs in tributaries; no effect.
Age 0 juvenile rearing (Mar 15–Nov 14) Exposure to highest SSC for the period	9.3	9.7	10.0	Major stress, reduced growth to 20 percent mortality depending on scenario (up to 843 juveniles or approximately 3 percent of population basin-wide age 0 production in a worst impact on fish scenario). Approximately 40 percent rear in tributaries and would not be affected.
Age 1 juvenile rearing (year-round) Exposure to highest SSC for the period	10.9	11.1	11.5	0 to 40 percent mortality depending on scenario (up to 6,314 juveniles or approximately 11 percent of population basin-wide age 1 production in a most-likely or worst impact on fish scenario).
Age 2 juvenile rearing (Nov 15–Mar 31) Exposure to highest SSC for the period	10.9	11.1	11.4	0 to 40 percent mortality depending on scenario (up to 5,303 juveniles or approximately 10 percent of population basin-wide age 2 production in a most-likely or worst impact on fish scenario).
Juvenile/smolt outmigrants (Mar 1–May 1) 20 days of exposure to lowest SSC for the period	8.0	8.4	8.7	Major stress and reduced growth. Approximately 57 percent outmigrate from Trinity River and would have less exposure.

1 Least impacts on fish = 90 percent exceedance probability
2 Most likely scenario = 50 percent exceedance probability
3 Worst-case impacts on fish scenario = 10 percent exceedance probability

Adult summer-run steelhead half-pounders typically enter the mainstem Klamath River and hold from mid-August through March, and thus would be affected by the Proposed Project during the winter of dam removal year 2. Steelhead half-pounders in the mainstem Klamath River upstream of the Trinity River could be exposed to higher SSC than under existing conditions, with potential mortality ranging from 0 to 40 percent depending on scenario (Table E-11). However, an unknown proportion of steelhead half-pounders are observed to hold in the Trinity River or other tributaries, and these fish would not be affected.

Juvenile steelhead rear in the mainstem Klamath River, tributaries to the Klamath, and the estuary. Since most (>90 percent) juvenile steelhead smolt at age-2, those juveniles leaving tributaries to rear in the mainstem Klamath River would be exposed to elevated SSCs resulting from the Proposed Project through both winter and spring. Based on captures in tributaries and the mainstem Klamath River, it appears that approximately 40 percent of the juvenile steelhead population rears in tributaries until age-2 (Scheiff et al. 2001) and would 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 Klamath River upstream of Trinity River would likely be exposed to much higher SSCs than under existing conditions, with mortality rates up to 40 percent in a worst impacts on fish scenario (Table E-11). Table E-12 summarizes the total number of rearing juvenile 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-12 were based on 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 approximately 40 percent of steelhead juveniles rear in tributaries and would not be exposed. These mortality estimates do not consider juvenile steelhead produced from tributaries downstream from the Trinity River, and thus the actual rate of mortality could be lower. Numerous field and laboratory studies have shown that juvenile salmonids actively avoid exposure to high (> 150 mg/l) SSCs, including altering migratory patterns to seek lower turbidity (Bisson and Bilby 1982, Berg and Northcote 1985, Redding et al. 1987, Servizi and Martens 1992, Bash et al. 2001, Carlson et al. 2001, Kemp et al. 2011, Kjelland et al. 2015). Therefore, it was assumed that steelhead outmigration during dam removal year 2 will occur within the period of typical outmigration with the lowest predicted SSC. It does appear that many of these juveniles avoid conditions in the mainstem Klamath River by using tributary and off-channel habitats during winter, which would reduce their exposure to high SSCs (Soto et al. 2008, Hillemeier et al. 2009). This assumption is consistent with the observation that juvenile salmonids avoid turbid conditions. Most steelhead 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 Klamath River later in the winter after concentrations decrease.

Table E-12. Summary of Steelhead Juvenile Rearing Abundance and Estimated Mortality Resulting from the Proposed Project.

	Klamath River			Trinity River		
	Age 0	**Age 1**	**Age 2+**	**Age 0**	**Age 1**	**Age 2+**
Average juvenile abundance	4,217	15,784	13,256	13,384	20,445	17,401
Least Impacts on Fish						
Estimated mortality rate	0%	20%	20%	0%	0%	0%
Mortality estimate	0	3,157	2,651	0	0	0
Percentage of total production	0%	5.2%	5.2%	0%	0%	0%
Most-Likely Impacts on Fish						
Estimated mortality rate	0%	40%	40%	0%	0%	0%
Mortality estimate	0	6,314	5,303	0	0	0
Percentage of total production	0%	10.5%	10.4%	0%	0%	0%
Worst Impacts on Fish						
Estimated mortality rate	20%	40%	40%	0%	0%	0%
Mortality estimate	843	6,314	5,303	0	0	0
Percentage of total production	2.9%	10.5%	10.4%	0%	0%	0%

Under the Proposed Project, steelhead outmigrating in spring as age-2 smolts from tributaries higher in the basin would likely be exposed to suspended sediment for longer than under existing conditions, with major physiological stress predicted for all scenarios (Table E-11). 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 would be exposed to SSCs similar to those under existing conditions.

E.3.2.5 Pacific Lamprey

Based on Pacific lamprey distribution, the impacts of the Proposed Project would 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 from 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 analysis 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 (December through February), and thus a large proportion of adults could be directly affected by suspended sediment resulting from the Proposed

Project in winter and early spring, with major stress and likely impaired homing (Table E-13). Goodman and Hetrick (2017) report that in a 2008 ammocoete survey within the Klamath River Basin no Pacific lamprey were detected in the reach from Iron Gate Dam downstream to the confluence with the Shasta River (RM 179.5), and the densities did not approach levels observed elsewhere in the watershed until the confluence with the Scott River (RM 145.1). Therefore, the proportion of the Pacific lamprey population potentially exposed to high SSCs during dam removal is low. Approximately 44 percent of Pacific lamprey are believed to spawn in the Trinity River basin (Scheiff et al. 2001). These individuals would be exposed to lower SSCs, while those adults returning in fall, summer, or late spring would avoid exposure to the highest SSCs likely to result from the Proposed Project.

Pacific lamprey ammocoetes rear for a variable number of years before outmigrating to the ocean; therefore, suspended sediment resulting from the Proposed Project has the potential to affect multiple year-classes of the population (Table E-13). 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 20–40 percent depending on scenario (Table E-13), but because Pacific lamprey ammocoetes rear in burrows in fine sediment, they may tolerate spikes in suspended sediment resulting from the Proposed Project, although excessive sedimentation from the settling out of suspended fines could possibly smother ammocoetes in some areas. Ammocoetes are filter-feeders, so reduced growth rates might be expected from elevated suspended sediment, and it is assumed that mortality would be higher than under existing conditions. However, the broad spatial distribution of Pacific 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 would not be impacted by the Proposed Project.

Juvenile Pacific lamprey (ages 2 to 10) outmigrate to the ocean from the mainstem Klamath River and tributaries rear-round, with peaks in late spring (late May to mid-June) and fall (October and November). Exposure to suspended sediment from the Proposed Project is only slightly higher during the spring and fall migration than under existing conditions (Table E-13).

Table E-13. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Pacific lamprey for Proposed Project for Klamath River at Seiad Valley (RM 132.7).

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Adult upstream migration and spawning (all of dam removal year 2) 30 days of exposure to median SSC for the period	8.8	9.1	9.4	Major stress and impaired homing. Adults migrating in late spring and summer exposed to lower SSC, as are lamprey returning to lower river tributaries such as the Trinity River.

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Ammocoete rearing (all of dam removal year 2) Exposure to highest SSC for the period	11.0	11.1	11.5	20–40 percent mortality depending on scenario for multiple year classes. Majority rear in tributaries and would not suffer mortality.
Spring outmigration (May 1–June 30) 30 days of exposure to lowest SSC for the period	7.7	8.1	8.9	Moderate to major stress and reduced growth rate depending on scenario for all juveniles during spring outmigration.
Fall/winter outmigration (Sept 1–Dec 31) 30 days of exposure to lowest SSC for the period	5.6	6.1	6.5	Minor to moderate stress for all juveniles during spring outmigration.

[1] Least impacts on fish = 90 percent exceedance probability
[2] Most likely scenario = 50 percent exceedance probability
[3] Worst-case impacts on fish scenario = 10 percent exceedance probability

E.3.2.6 Green Sturgeon

Based on green sturgeon distribution, the Proposed Project would have the highest potential effect on green sturgeon within the Klamath River downstream from Ishi Pishi Falls; therefore, this analysis focuses on exposure of green sturgeon to suspended sediment downstream from Ishi Pishi Falls (at the confluence with the Salmon River).

Very little information is available on the effects of suspended sediment on green sturgeon. This assessment is based on available information of the effects of suspended sediment on salmonids, with the assumption that effects on green sturgeon are equivalent or less severe than on salmonids. Most life stages of green 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 Project, are likely to be to exposed to long durations of high SSCs that would result in major physiological stress in salmonids under all scenarios (Table E-14). 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 sediments on the species in terms of feeding ability (EPIC et al. 2001, as cited in DWR 2003). Green sturgeon in the Klamath River spawn approximately 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 green sturgeon population (as well as 100 percent of sub-adults) can be assumed to be in the ocean during dam removal year 2 and avoid effects associated with the Proposed Project.

Another behavior that may influence the effects of the Proposed Project 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 adult green sturgeon that entered the Rogue River returned downstream without spawning. Similar behavior has also been observed in white sturegon (J. Van Eenennaam, pers. comm., 2008). Some adults may turn back upon encountering high SSCs resulting from the Proposed Project and not complete their spawning migration or may enter later in the spring when concentrations are expected to be lower. However, this behavior has not been documented in the Klamath River (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 Project 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 prevent eggs from adhering to one another, reducing egg viability (EPIC et al. 2001, as cited in DWR 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 SSCs for longer periods than under existing conditions. Although 40–60 percent mortality is predicted based on effects on salmonids under the Proposed Project (Table E-14), this is only slightly higher existing conditions and does not occur every year. Fine sediment deposition resulting from the Proposed Project could reduce production from the mainstem Klamath River to an unknown degree (J. Van Eenennaam, pers. comm., 2008). Spawning of green sturgeon is common downstream from the confluence with the Trinity River, where SSCs resulting from the Proposed Project should be similar to existing conditions. Green sturgeon production from the Trinity River, which is estimated to be approximately 30 percent of total production from the Klamath Basin (Scheiff et al. 2001), would be unaffected by the Proposed Project in dam removal year 2. In addition, production from the Salmon River in dam removal year 2, which is occasionally high, would be unaffected by the Proposed Project.

Table E-14. Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Green Sturgeon for Proposed Project for Klamath River at Orleans (RM 59).

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Adult migrants (Mar 15–July 15) Exposure to median SSC for the period	8.3	8.6	9.0	Major stress for adult migrants and spawners. Approximately 75 percent of mature adult population not expected to migrate in dam removal year 2.
Incubation and emergence (April 1–Aug 15) Exposure to highest SSC for the period	12.2	12.4	12.6	40 to 60 percent mortality depending on scenario for all mainstem production. Approximately 30 percent of production is from Trinity River and would be unaffected. Assessment based on salmonid literature, effects likely exaggerated.

Life-history Stage (period)	SEV at Impacts			Effects on Production
	Least[1]	Most Likely[2]	Worst[3]	
Adult post-spawning holding (Jul 15–Nov 15) Exposure to median SSC for the period	6.7	7.0	7.9	Moderate to major physiological stress.
Juvenile rearing (year-round) and outmigration (May 15–Oct 15) Exposure to median SSC for the period	7.6	8.0	8.6	Moderate to major stress. Approximately 30 percent of juveniles rear in the Trinity River and would not be affected.

[1] Least likely impacts on fish = 90 percent exceedance probability),
[2] Most likely scenario = 50 percent exceedance probability)
[3] Worst-case impacts on fish scenario = 10 percent exceedance probability

After spawning, approximately 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 66.3 through November. Benson et al. (2007) found that after spawning, most green sturgeon held in deep pools (15–30 feet) in the mainstem Klamath and Trinity rivers from June through November for 116 to 199 days. Benson et al. (2007) reported that during three years of study (2002–2004) the majority of post-spawning adult green sturgeon outmigrated in the fall and winter after summer holding and appeared to be triggered by increasing flows. SSCs related to the Proposed Project prior to adult green sturgeon downstream migration is predicted to be similar to existing conditions, with major stress anticipated under a worst impacts on fish 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 2007, 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., 2008), but some juvenile green sturgeon may rear for additional months or years in the lower Klamath River and the estuary before migrating to the ocean. Under the Proposed Project, juvenile green sturgeon, of the dam removal year 1 cohort rearing downstream from Orleans in dam removal year 2, are anticipated to be exposed to higher SSCs for longer periods than under existing conditions. These exposures are expected to result in moderate to major stress to juvenile green sturgeon depending on scenario (Table 14). 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 green sturgeon rearing is common downstream from the Trinity River, where SSCs would be similar to existing conditions. Juvenile green sturgeon rearing in the Trinity River, which may represent ~30 percent of the total production in the Klamath Basin (Scheiff et al. 2001), would not be impacted by the Proposed Project in dam removal year 2. In addition, any juvenile green sturgeon rearing in the Salmon River in dam removal year 2, which occasionally has abundant production, would not be impacted by the Proposed Project.

E.4 Klamath River Estuary

Estuary fish species regularly documented to occur in the Klamath River Estuary (Moyle 2002) include:

- Pacific herring (*Clupea pallasii*); no special status
- Longfin smelt (*Spirinchus thaleichthys*); Federal candidate species
- Eulachon (*Thaleichthys pacificus*); Federally listed as Threatened
- Topsmelt (*Atherinops affinis*); no special status
- Shiner perch (*Cymatogaster aggregata*); no special status
- Arrow goby (*Clevelandia ios*); no special status
- Starry flounder (*Platichthys stellatus*); no special status

Under existing conditions, SSCs within the Klamath River Estuary is relatively high (often 100 to 800 mg/l for several days) , the lower Klamath River downstream from the Trinity River confluence (RM 43.3) 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 (State Water Board 2006, North Coast Regional Board 2010) (EIR Section 3.2.3.3). Under the Proposed Project, sediment would be released from Iron Gate Dam and would 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 Project relative to existing conditions is at its lowest level in the Klamath River Estuary (Figure E-3). SSCs in the estuary would be less than 40 percent of the peak concentrations that are anticipated to occur immediately downstream from Iron Gate Dam. These peaks would still be substantial and would be higher than the extreme conditions for fish values estimated by the sediment transport model for existing conditions. However, aquatic species that occur in the Klamath River Estuary are highly adapted to estuary conditions, including periods of elevated suspended sediment. The habitat conditions that currently exist within the Klamath River Estuary also provide some refuge from poor water quality conditions. In addition, many of these species are known to migrate out of the estuary environment to avoid poor water quality conditions (NMFS 2010b). Overall, predicted increases in SSCs under the most-likely impacts on fish scenario are within the range of existing extreme conditions for fish that estuarine species have adapted to survive, and only sublethal physiological stress is anticipated under the Proposed Project. Under a worst impacts on fish scenario SSCs could be higher than typically occur within the estuary (>1,000 mg/l) for a period of weeks, which could result in mortality of some individuals.

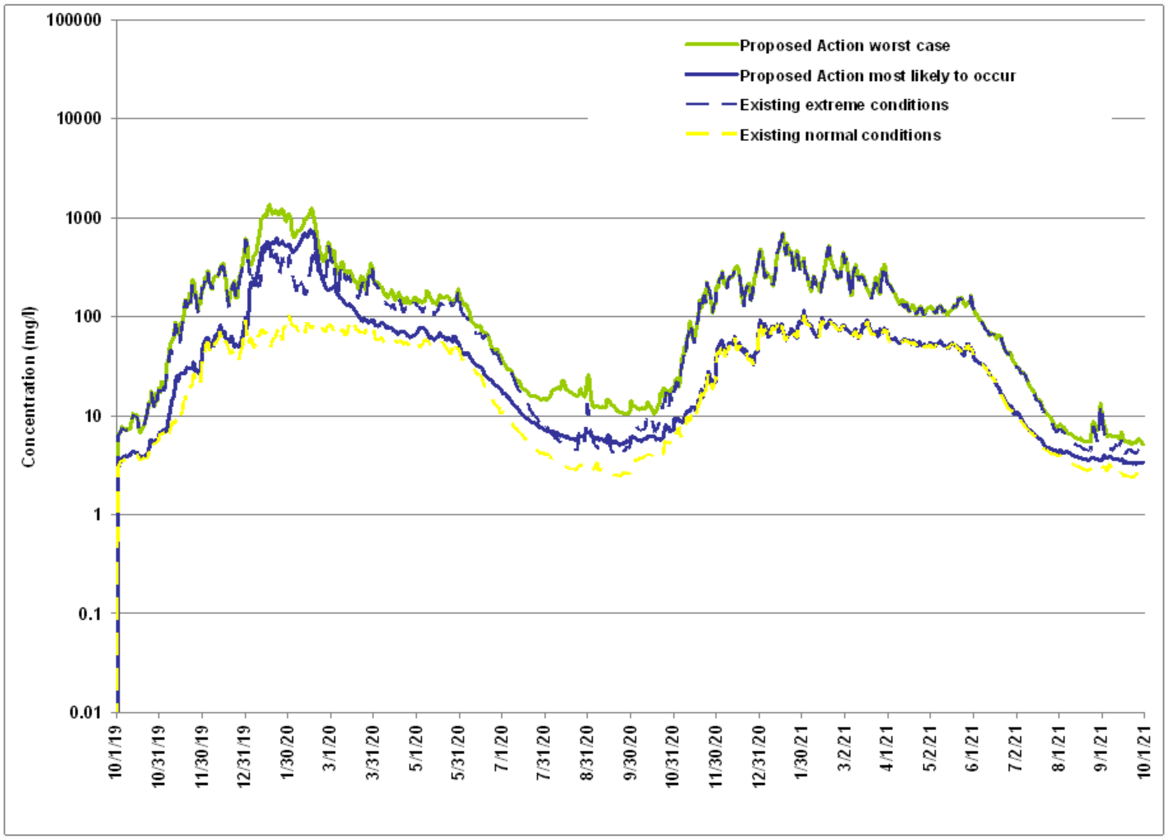

Figure E-3. Comparison of SSC at Klamath Station (RM 5) under Existing Conditions and the Proposed Project, as Predicted Using SRH-1D Model.

E.5 Pacific Ocean Nearshore 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-4). 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 a relationship 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 SSCs 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 Klamath River suspended sediment concentrations is expected to occur in the nearshore under the Proposed Project; based on data from 110 coastal watersheds in California, where nearshore SSCs were measured at >100 mg/L during the El Niño winter of 1998 (Mertes and Warrick 2001), peak SSCs 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 Project is likely to be greater than under existing conditions. This would potentially increase the rate of sediment deposition to nearshore benthic sediments. Overall, any spikes in SSCs associated with the Proposed Project are not anticipated to have effects on species distinguishable from existing conditions.

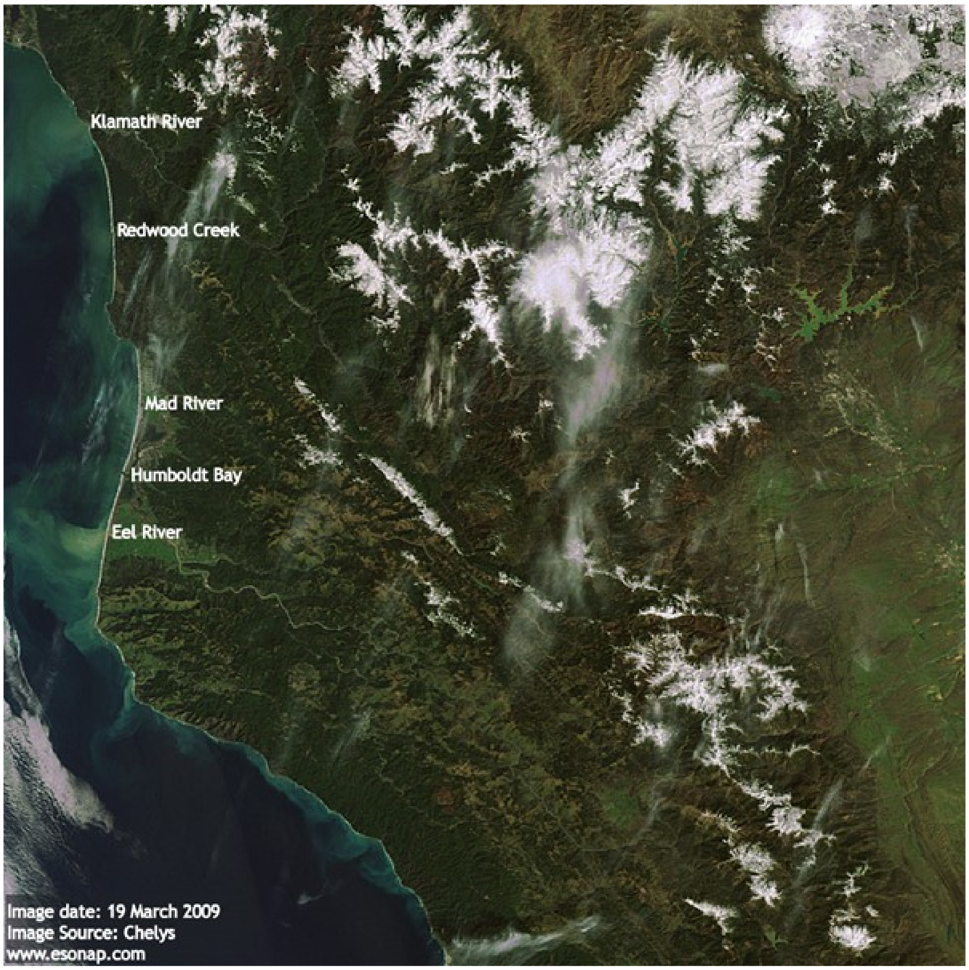

Figure E-4. River Plumes for Rivers in the Vicinity of the Klamath River during Typical Winter Conditions.

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