TECHNICAL MEMORANDUM ◦ JULY 2021

Analyses of Fine Sediment Erosion Effects on Aquatic Species Following the Proposed Scott Dam Removal, Eel River, California

PREPARED FOR

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Cover photos: Scott Dam, Eel River, California (top left); turbid high flows over Cape Horn Dam February 14, 2019 (daily average flow 13,400 cfs, peak flow 16,500 cfs, photo courtesy of CDFW) (top right); Eel River downstream of Scott Dam (bottom)

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1 INTRODUCTION

1.1 Background

The Potter Valley Project (Project) is an inter-basin hydroelectric project located 15 miles northeast of Ukiah that annually diverts approximately 60,000 acre-feet (ac-ft) of water from the upper Eel River to the upper Russian River. Project features include Scott Dam, a 130-foot-tall concrete gravity dam that impounds Lake Pillsbury, a 2,300-acre storage reservoir; Cape Horn Dam that impounds the 106-acre Van Arsdale Reservoir; and a diversion system that diverts water from the Eel River at Van Arsdale Intake to the Project's powerhouse located in the headwaters of the Russian River watershed. The Project began diverting water in 1908 when Cape Horn Dam and the Van Arsdale Diversion were built. Scott Dam was built in 1922 approximately 12 miles upstream of Cape Horn Dam at river mile (RM) 168.5.

Pacific Gas and Electric Company's (PG&E's) Project license expires in 2022. PG&E filed a Pre-Application Document (PAD) and Notice of Intent (NOI) to formally initiate the relicensing process for the Project in April 2017. PG&E withdrew its NOI and PAD and discontinued its efforts to relicense the Project in January 2019, and in March 2019, the Federal Energy Regulatory Commission (FERC) issued a notice soliciting interested potential applicants other than PG&E to file an NOI and PAD. In May 2019, the Two-Basin Solution Partners (Partners) entered into a Planning Agreement to explore pathways to obtain a new license for the Project. In June 2019, the Partners filed a NOI with FERC stating the intent to undertake a Feasibility Study of a potential licensing proposal for the Project. The Feasibility Study examined the practicability of potential actions in meeting agreed upon common goals and to inform the Partners of cost and performance tradeoffs associated with those actions. Phase 1 of the Feasibility Study, completed and filed with FERC in May 2020, included the following key elements: (1) a Regional Entity that will apply for the new license and assume the new license if issued, (2) a Project Plan, (3) a Fisheries Restoration Plan, (4) an Application Study Plan, and (5) a Financial Plan. Phase 2 of the Feasibility Study was initiated in April 2020 with grant funding from the California Department of Fish and Wildlife to supplement technical analyses conducted during Phase 1, and to conduct new technical analyses.

This Technical Memorandum was prepared for the Partners by the Consultant Team to supplement technical analyses performed during Phase 1 of the Feasibility Study. The information provided in this document is a continuation of work along a path starting with preliminary analyses of feasibility, transitioning towards more refined analyses of a focused project plan and implementation of the best possible project that meets programmatic goals in a cost-effective manner. This Technical Memorandum is informational, is not binding of any of the Partners, and will not be filed with FERC as the basis for compliance under the Integrated License Process or other FERC regulations. While this Technical Memorandum contributes to the information available to the Partners, the Partners have not solely relied on this document for justification for any decision they have made or will make regarding FERC filings or cooperative agreements. More detailed environmental and engineering studies will be conducted during implementation of the FERC study and outside of the FERC process. Accordingly, this Technical Memorandum reflects a step that will be expanded and built upon through additional studies, analysis, synthesis, and ultimately decisions by the Partners on proceeding with a Project Plan.

Figure 1. Potter Valley Project vicinity.

1.2 Purpose

The potential removal of Scott Dam is being studied because it is considered the most effective and reliable approach to provide successful upstream and downstream fish passage and restore anadromous fish access to the 289-square-mile watershed upstream of the dam. However, removal of Scott Dam would result in the release of substantial coarse and fine sediment that has accumulated in the reservoir since its construction, potentially harming the same fish populations anticipated to benefit from restored fish passage. Elevated levels of suspended sediment have been shown to have adverse effects on anadromous salmonids, with greater negative effects associated with higher suspended sediment concentrations (SSCs). This technical memorandum describes an assessment of potential effects of fine sediment release into the Eel River downstream of Scott Dam following dam removal on steelhead (*Oncorhynchus mykiss*), Chinook Salmon (*O. tshawytscha*), and Coho Salmon *(O. kisutch)* populations. This general assessment is based on the order-of-magnitude analysis for the erosion of fine sediment and potential suspended sediment concentrations following the proposed removal of Scott Dam under rapid and phased removal alternatives (Stillwater Sciences 2021).

1.3 Sediment Storage

Scott Dam impounds Lake Pillsbury with a storage capacity of 94,400 acre-feet (acre-ft) at the top of the spillway (i.e., 1,821.12 ft elevation[1]) upon its completion in 1921 (PG&E 2017). By 2015, the storage capacity of Lake Pillsbury was reduced to 76,876 acre-ft at the same pool level (PG&E 2017) due to sedimentation. Although these storage capacities imply a minimum[2] 2015 Lake Pillsbury sediment deposition volume of 17,524 acre-ft (i.e., the difference between 94,400 and 76,876 acre-ft, or 28.3 million cubic yards [CY]), the most recent, more refined analyses that combine Digital Elevation Model (DEM) data and thalweg survey data estimate a 2015 sediment deposition volume of 13,016 acre-ft (21 million CY; Stillwater Sciences et al. 2021a).

1.4 Dam Removal

Several preliminary Scott Dam removal alternatives have been developed (e.g., McMillen Jacobs Associates 2018, McBain Associates and Princeton Hydro 2019), some of which would manage the reservoir sediment deposit in such a way that minimal erosion of fine sediment would occur (i.e., mechanically remove or stabilize most sediment prior to or during removal). This technical memorandum focuses on two of the most promising dam removal alternatives identified by Stillwater Sciences (2021) and McBain Associates and Princeton Hydro (2019) that would release fine sediment downstream through natural erosion, including: (1) a four-stage dam removal alternative ("four-stage alternative") described in McBain Associates and Princeton Hydro (2019), and (2) a rapid vertical notching dam removal alternative ("vertical notching alternative") proposed in Stillwater Sciences (2021); both of these alternatives are described in more detail in Stillwater Sciences (2021). A third rapid removal alternative would be blasting open tunnels near the base of the dam prior to a target high flow event ("tunneling alternative") with identical fine sediment transport processes compared with the vertical notching alternative (Stillwater Sciences

[1] NAVD88 datum is used throughout the report unless labeled otherwise. At Scott Dam site, add 78.78 ft to NAVD88 elevation to convert to Pacific Gas and Electric Company (PG&E) elevation. Other relevant documents may also have used NVGD29 elevations. Subtract 81.7 ft from PG&E elevations or subtract 2.92 ft from NAVD88 elevations to obtain NVGD29 elevations.

[2] Sediment accumulation calculated by differencing storage values at different times is generally less than the actual amount of sediment accumulation because sediment deposition upstream of the storage area, which is generally a small fraction of the overall sediment deposition, is not accounted for.

2021), and as such, its impact to aquatic resources would be identical to that of vertical notching alternative.

1.5 Objectives

This assessment is intended to describe the range of potential effects on focal species of releasing fine sediments considering two dam removal alternatives. The species selected for analysis include anadromous salmonids in the Eel River watershed that could be impacted from fine sediment release. These species were selected because models to assess the severity of effects of fine sediment on these species have been developed and are available. The life history timing of these species in the Eel River will be described and used to identify species and life stages that are particularly vulnerable to potential impacts of fine sediment release following dam removal. The analysis results will be used to identify critical uncertainties and opportunities to reduce potential impacts.

2 LIFE HISTORY AND DISTRIBUTION OF FOCAL SPECIES IN THE EEL RIVER

Describing the life history timing and seasonal distribution of focal fish species in the Eel River is critical for assessing the potential adverse biological effects of fine sediments related to dam removal alternatives. Life history timing, distribution, and other information relevant to assessing impacts of fine sediment on winter- and summer-run steelhead, fall-run Chinook Salmon, and Coho Salmon are provided in the sections that follow. Generalized life history timing for each species in the Eel River watershed is described, with a focus on known timing of use and seasonal distribution in the Eel River from Scott Dam downstream to the Middle Fork Eel River (Upper Eel River), where potential impacts of fine sediment release to the mainstem Eel River are expected to be greatest. The species life history timing reported here is consistent with Stillwater Sciences et al. (2021b).

2.1 Steelhead

Steelhead in the Eel River watershed can be broadly divided into two life history types or runs based on migration timing: the winter-run and summer-run (Moyle et al. 2017). Winter-run steelhead, which are more abundant and widely distributed across the Eel River watershed than summer-run, enter freshwater as sexually mature adults from late fall through spring and spawn shortly thereafter (Busby et al. 1996, VTN 1982, Kajtaniak and Gruver 2020). Summer-run steelhead enter freshwater as sexually mature adults in spring and early summer and hold until spawning the following winter or spring (Roelofs 1983, Barnhart 1991, Moyle et al. 2017). In the Eel River watershed, holding and spawning summer-run steelhead are currently restricted primarily to cooler, upper reaches of the Middle Fork Eel River and Van Duzen River (Kannry et al. 2020). However, recent genetic evidence indicates that summer-run steelhead historically occurred in reaches upstream of Lake Pillsbury (Kannry et al. 2020), where there is thermally suitable holding habitat (Cooper et al. 2020, Fitzgerald et al. 2020). Although not recently reported in the Upper Eel River, some adult summer-run steelhead were documented in 1985 during trapping at the Van Arsdale Fisheries Station (VAFS) and were also anecdotally reported upstream of Cape Horn Dam around that time (SEC 1998, NMFS 2016). Based on the current low abundance in the Upper Eel River, impacts of suspended sediment following potential dam removal are unlikely to affect summer-run steelhead; therefore, this assessment is focused on winter-run steelhead.

2.1.1 Winter-run Steelhead

The generalized life history timing for each life stage of winter-run steelhead in the Eel River watershed is presented in Table 1. Adult winter-run steelhead enter freshwater as sexually mature adults from November through April, typically moving upstream during or following increases in streamflow associated with winter rainfall (Trush 1991, Busby et al. 1996, Kajtaniak and Gruver 2020). The first adult steelhead typically arrive at VAFS at Cape Horn Dam between mid-November and mid-December, depending in part on stream flows (VTN 1982, SEC 1998, CDFW unpub. data). Larger numbers of adults do not typically arrive until early January, with peak counts occurring in February and March. In most years, the last individuals are counted at VAFS between early April and early May (SEC 1998, CDFW unpub. data).

Winter-run steelhead can spawn between November and May, with peak spawning in the Upper Eel River typically occurring from January through March (VTN 1982, Busby et al. 1996, Table 1). Limited surveys conducted by VTN (1982) documented adult steelhead and redds in several tributaries between Scott Dam and Outlet Creek, with more spawning found in larger tributaries such as Soda Creek and Tomki Creek. Winter-run steelhead presumably spawn in all streams in the Upper Eel River with access and suitable spawning habitat. VTN (1982) did not document mainstem spawning due to turbid conditions but suggested that considerable numbers of steelhead spawn in the mainstem Eel River upstream of Cape Horn Dam based on the number of adults counted at VAFS versus those observed spawning in tributaries. Relative use of tributaries versus mainstem reaches for spawning is expected to be partly dictated by streamflow conditions, where higher flows would promote greater tributary use (Moyle et al. 2017).

Unlike salmon, not all steelhead die after spawning. Some individuals emigrate back to the ocean and spawn again in subsequent years (Moyle et al. 2017). In the upper South Fork Eel River, Trush (1991) found that individual steelhead typically entered spawning tributaries, spawned, and moved back downstream within a 1–2-week period. These outmigrating adults, or “kelts”, are thought to migrate to the ocean relatively rapidly after spawning, typically no later than May (Teo et al. 2013, Moyle et al. 2017). Based on this timing, kelts may be present in the mainstem Upper Eel River from February through May.

Steelhead eggs incubate in redds for 3–14 weeks after spawning, depending on water temperatures (Shapovalov and Taft 1954, Barnhart 1991). After hatching, alevins remain in the gravel for an additional 2–5 weeks while absorbing their yolk sacs, and then emerge in spring or early summer (Barnhart 1991). After emergence, steelhead fry move to shallow-water, low-velocity habitats, such as stream margins and off-channel habitats (Hartman 1965, Fontaine 1988). As fry grow and improve their swimming abilities throughout the summer and fall, they increasingly show a preference for higher water velocity and deeper mid-channel areas with cover such as cobble and boulders (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). Juvenile steelhead in northern California typically rear in freshwater for two years before migrating to the ocean (Hopelain 1998, Moyle et al. 2017). In the Upper Eel River, individuals rearing in tributaries generally rear for two or three years before outmigrating to the ocean, whereas individuals rearing in the mainstem Eel River between Scott Dam and Cape Horn Dam often migrate after a single year due to superior growth conditions (SEC 1998). Therefore, juvenile steelhead are present in portions of the mainstem Upper Eel River and its spawning tributaries throughout the entire year where streamflow and water temperature allow (VTN 1982, SEC 1998, PG&E 2018). Relatively high densities of juvenile steelhead are typically present during summer in the reach between Scott Dam and Cape Horn Dam (SEC 1998, PG&E 2020). In general, due to high water temperatures and large numbers of predatory Sacramento Pikeminnow (*Ptychocheilus grandis*), mainstem Upper Eel River summer densities of juvenile steelhead decline substantially downstream of Cape Horn Dam, with very few or no individuals present at sites downstream of Thomas Creek (approximately 8 RM downstream of Cape Horn Dam) (PG&E 2018). Winter rearing densities of juvenile steelhead in the mainstem Upper Eel River are unknown, but juveniles are presumably present throughout the entire mainstem Upper Eel River as water temperatures become more suitable in the fall and through the winter.

Salmonid smolt outmigrant trapping data from the Upper Eel River indicate that steelhead smolt outmigration generally occurs from March through mid-June, and peaks in April and May (VTN 1982, Beak 1986, SEC 1998). Historical sampling indicates that juvenile steelhead were abundant in the Eel River estuary from mid-May through mid-July (Murphy and DeWitt 1951, as cited in SEC 1998), suggesting they spend time in the estuary prior to entering the ocean.

Table 1. Generalized life history timing of winter-run steelhead in the Eel River watershed.

Life stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult migration[1,2,3]	Peak	Peak	Peak	Span	Span						Span (partial)	Span
Spawning[1,3,4]	Peak	Peak	Peak	Span	Span							Span
Adult outmigration (kelt)[2,5,6]		Span	Span	Span	Span							
Incubation[7,8]	Span	Span	Span	Span	Span	Span						
Fry[9]			Span	Span	Span	Span	Span					
Juvenile rearing[1,2,6]	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span
Smolt outmigration[1,2,10]			Span	Peak	Peak	Span (partial)						

= Span of activity
= Peak of activity

1 VTN (1982)
2 SEC (1998)
3 CDFW (1998–2017)
4 Busby et al. (1996)
5 Teo et al. 2013
6 Moyle et al. 2017
7 Shapovalov and Taft (1954)
8 Barnhart (1991)
9 assumed based on expected time of emergence from spawning gravels
10 Beak (1986)

2.1.2 Summer-run Steelhead

As noted above (Section 1.4.1), the potential effects analysis of releasing fine sediment on Eel River steelhead is focused on winter-run steelhead. Summer-run steelhead are generally not expected to hold or spawn in the mainstem Upper Eel River, and potential effects on juvenile rearing would be similar to winter-run steelhead. However, the life history timing and seasonal distribution of summer-run steelhead in the Eel River is summarized below for reference.

The generalized life history timing for summer-run steelhead life stages in the Eel River watershed is presented in Table 2. Summer-run steelhead in Northern California enter freshwater and migrate upstream as sexually immature adults in spring and early summer, typically during the snow melt period between April and late June (Everest 1973, Busby et al. 1996, Moyle et al. 2017). Therefore, migrating adult summer-run steelhead belonging to the Middle Fork Eel River population may be present in the mainstem Eel River during the April to late June period. If adult summer-run steelhead still return to the Upper Eel River in some years as was reported in 1985 (Jones 1992, SEC 1998, NMFS 2016), they could be migrating upstream during the same April to late June period.

After migrating into cool headwater reaches, summer-run steelhead spend the summer and early fall holding in deep pools before spawning between early winter and spring (Everest 1973, Roelofs 1983, Barnhart 1991, Moyle et al. 2017). In the Upper Eel River, adult summer-run steelhead documented in summer 1985 were reported to be holding between Cape Horn Dam and Soda Creek, with the vast majority in Van Arsdale Reservoir (Jones 1992). Based on preference for cold water habitats, holding adult summer-run steelhead in the Upper Eel River would be expected to be distributed upstream of Cape Horn Dam where cool water releases from Lake Pillsbury moderate warm summer water temperatures.

Table 2. Generalized life history timing of summer-run steelhead in the Eel River watershed.

Life stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Summer-run adult migration[1,2,3]												
Summer-run holding[3,4,5]												
Fall-run & half-pounder entry & holding in lower Eel [4,6,7]												
Spawning[3,4,5]												
Adult outmigration (kelt)[3,8,9]												
Incubation[5,10]												
Fry[11]												
Juvenile rearing[3,8]												
Smolt outmigration[8,12,13]												

[1] Everest (1973)
[2] Busby et al. (1996)
[3] Moyle et al (2017)
[4] Roelofs (1983)
[5] Barnhart (1991)
[6] Kajtaniak and Gruver (2020)
[7] Hodge et al. (2014)
[8] SEC (1998)
[9] Teo et al. (2013)
[10] Shapovalov and Taft (1954)
[11] assumed based on expected time of fry emergence
[12] VTN (1982)
[13] Beak (1986)

= Span of activity
= Peak of activity

Summer-run steelhead are thought to leave mainstem holding pools and migrate into spawning streams following late fall or early winter rain events (Everest 1973). In general, summer-run steelhead are thought to spawn primarily in small headwater streams, some of which become intermittent or go dry in the summer (Everest 1973). Like winter-run steelhead, some individuals emigrate back to the ocean after spawning (Roelofs 1983, Moyle et al. 2017).

The life history timing and seasonal distribution for fry, juvenile rearing, and smolt outmigration for summer-run steelhead is presumably the same as that described for winter-run steelhead above.

The lower mainstem Eel River downstream of the South Fork Eel River also has a component of the steelhead run that enters freshwater from mid-summer through early fall (Roelofs 1983, Kajtaniak and Gruver 2020), similar to that observed in the Klamath River basin, where they enter freshwater from July through October (Hopelain 1998). These individuals, sometimes referred to as the “fall-run”, generally stage in the lower mainstem Eel River downstream of the Van Duzen River. The extent to which this component of the run migrates into the Upper Eel River is unknown, but they would not be expected to move into that part of the basin until the first fall freshets occur (typically November or December). This component of the run is often considered to be part of the summer-run population (Everest 1973, Roelofs 1983) and thus is included in this section (Table 1).

The Eel River watershed steelhead population also displays the “half-pounder” life-history variant, where some individuals return to freshwater in the summer or fall after only two to four months in the ocean, spend the fall and winter feeding in the river, then emigrate back to the ocean again the following spring (Busby et al. 1996, Hodge et al. 2014). Summer-run, fall-run, and winter-run steelhead are all thought to exhibit this life history strategy, but it appears to be most closely associated with the fall-run (Everest 1973, Hodge et al. 2014, Peterson et al. 2017).

2.2 Chinook Salmon

The generalized life history timing for each life stage of fall-run Chinook Salmon in the Eel River watershed is presented in Table 3. Adults leave the ocean and enter the estuary and lower reaches of the Eel River as early as September, but stage there until cued to migrate upstream by increasing stream flows associated with the first substantial fall rains, which typically do not occur until late October or early November (VTN 1982, Moyle et al. 2017, Kajtaniak and Gruver 2020). The first adult Chinook Salmon have been documented arriving at VAFS as early as mid-October and as late as late December, but the first individuals typically arrive between late October and late November, a timing largely controlled by timing and magnitude of fall freshets and increased stream flows (VTN 1982, SEC 1998, CDFW unpub. data). Timing of the first adults arriving at VAFS and Tomki Creek, a major spawning tributary, generally occur with a few days of each other (SEC 1998). Peak migration into the Upper Eel River typically occurs in November and December (SEC 1998, CDFW unpub. data). The last adult Chinook Salmon typically arrive at VAFS between late December and mid-January, but they have been documented as late as February (SEC 1998, CDFW unpub. data).

Fall-run Chinook Salmon generally spawn between November and January, but small numbers of live adults have been documented in early February (SEC 1998). Peak spawning in the Upper Eel River typically occurs between mid-November and late December (VTN 1982, SEC 1998).

Upstream of the Middle Fork Eel River, Chinook Salmon spawn primarily in the mainstem Eel River and its largest tributaries, Outlook Creek and Tomki Creek (SEC 1998, PG&E 2017).

Significant spawning occurs in the mainstem Upper Eel River, both upstream and downstream of Cape Horn Dam (VTN 1982).

Fall-run Chinook Salmon embryos typically hatch approximately 40–60 days after spawning and remain in gravels as alevins for another 30–40 days before emerging as fry (Moyle et al. 2017). Based on spawning timing and capture of fry in outmigrant traps, some eggs and alevins are expected to be in spawning gravels from November through early April (VTN 1982, Beak 1986).

Juvenile fall-run Chinook Salmon in the Upper Eel River display the ocean-type life history, where juveniles migrate to the estuary or ocean within weeks or a few months of emergence (VTN 1982, Beak 1986, Healey 1991, SEC 1998). Evidence from outmigrant trapping at various sites in the Upper Eel River and in Tomki Creek, as well as limited spring snorkel surveys downstream of Outlet Creek, suggest that some rearing Chinook Salmon fry may be present in the Upper Eel River and Tomki Creek between early March and early July, but most individuals emigrate in April and May as water temperatures begin to increase (VTN 1982, Beak 1986, SEC 1998). Notably, artificially cool water temperatures between Scott Dam and Cape Horn Dam may delay juvenile outmigration from that reach and create a situation where downstream temperatures exceed lethal thresholds (SEC 1998, PG&E 2017).

Table 3. Generalized life history timing of fall-run Chinook Salmon in the Eel River watershed.

Life stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult migration[1,2,3,4]	Span									Span	Peak	Peak
Spawning[1,2,3]	Span	Span									Peak	Peak
Incubation[5]	Span	Span	Span	Span							Span	Span
Fry rearing[1,2,5,6]		Span	Span	Span	Span	Span						
Juvenile outmigration[1,2,6]			Span	Peak	Peak	Span	Span					

Span = Span of activity; Peak = Peak of activity

1 VTN (1982)
2 SEC (1998)
3 PG&E (2017)
4 CDFW (1996–2017)
5 Moyle et al. 2017 and assumed based on spawning time and presence of fry reported by VTN (1982) and Beak (1986)
6 Beak (1986)

2.3 Coho Salmon

Viable Coho Salmon populations historically occurred in both the Outlook Creek and Tomki Creek watersheds, and the species utilized the mainstem Eel River primarily as a migratory corridor (Brown et al. 1994, NMFS 2014). Coho Salmon were also reportedly historically documented in Indian Creek, a mainstem tributary upstream of Outlet Creek (Brown et al. 1994). Coho Salmon have not been documented in Tomki Creek since before 1979, except for one observation in 1996 in its tributary, Cave Creek, and are presumed to be extirpated there (Garwood 2012, NMFS 2014). Coho Salmon have been documented in Outlet Creek and several of its tributaries as recently as the early 2000s, but population abundance is thought to be very low and possibly missing two year-classes (Garwood 2012, NMFS 2014). Forty-seven adult Coho Salmon were documented in the mainstem Eel River at VAFS during the 1946–1947 season but have not been documented since (Brown et al. 1994). Because of their potential future presence in the Upper Eel River watershed, the species is included herein.

The generalized life history timing for Coho Salmon life stages in the Eel River watershed is presented in Table 4, drawing largely from information in the South Fork Eel River or other northern California populations where more extensive monitoring data are available. Adults typically enter freshwater and migrate upstream to spawning tributaries from November through February (Ricker et al. 2014, Moyle et al. 2017, Guczek et al. 2019). Spawning occurs from November through February, peaking in December and January (Ricker et al. 2014, Guczek et al. 2019). Following deposition in spawning gravels, Coho Salmon eggs incubate for 6–12 weeks before hatching, with incubation time being inversely related to water temperature (Murray and McPhail 1988, Moyle et al. 2017). After hatching, alevins (or sac fry) remain in the spawning gravels while undergoing further development and absorption of the yolk sac for another 4–8 weeks before emerging as fry (Murray and McPhail 1988, Moyle et al. 2017). Based on expected spawning timing, the incubation period, and timing that newly emerged fry are captured during outmigrant trapping, developing Coho Salmon eggs or alevins may be present in spawning gravels from approximately November through May (Murray and McPhail 1988, Mendocino Redwood Company 2002, Vaughn 2005, Moyle et al. 2017). In the Upper Eel River, all Coho Salmon spawning and incubation is expected to occur in tributaries rather than the mainstem.

Following emergence from spawning gravels, juvenile Coho Salmon in larger river systems can display a variety of life history strategies including (1) rearing in natal streams for approximately 1-year before outmigrating to the ocean in the spring; (2) leaving natal streams in the spring soon after emergence and rearing in cool non-natal tributaries or the estuary prior to entering the ocean the following spring or summer; and (3) leaving natal tributaries in the fall or early winter as flows increase and water temperatures decrease and overwintering in suitable low-velocity habitats along in the mainstem corridor, low gradient non-natal tributaries, or in the estuary (Jones et al. 2014, Bennett et al. 2015, Rebenack et al. 2015, Soto et al. 2016). The extent to which these life history strategies are expressed in the Upper Eel River is uncertain. However, based on juvenile monitoring in the Klamath River (Soto et al. 2016), it is possible that Coho Salmon fry or juveniles rear in or move through the mainstem Eel River corridor anytime water temperatures are suitably cool (i.e., generally October through May). Based on rotary screw trapping data from spawning tributaries in the South Fork Eel River and other northern California streams, most individuals are expected to move downstream through the mainstem as one-year-old smolt between March and June, with peak smolt outmigration in April and May (Mendocino Redwood Company 2002, Vaughn 2005, Ricker et al. 2014).

Table 4. Generalized life history periodicity of Coho Salmon in the Eel River watershed based primarily on the South Fork Eel River and other northern California streams.

Species	Life stage	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coho Salmon	Adult migration[1,2]	Peak	Span									Span	Peak
	Spawning[1,2]	Peak	Span									Span	Peak
	Incubation[3,4]	Span	Span	Span	Span	Span						Span	Span
	Juvenile rearing[1,4]	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span
	Smolt outmigration[1,5,6]			Span	Peak	Peak	Span						

[1] Ricker et al. (2014)
[2] Guczek et al. (2019)
[3] Murray and McPhail (1988)
[4] Moyle et al. (2017)
[5] Mendocino Redwood Company (2002)
[6] Vaughn (2005)

= Span of activity
= Peak of activity

3 METHODS

This evaluation assessed the effects of increased fine sediments on winter-run steelhead, fall-run Chinook Salmon, and Coho Salmon downstream of Scott Dam following two dam removal alternatives. We analyzed the effects of elevated SSC predicted by Stillwater Sciences (2021) on each life stage of all three focal fish species and their in-river life stages, including adults, eggs/alevins, and juveniles[3].

3.1 Suspended Sediment Modeling

Stillwater Sciences (2021) provided analyses for two Scott Dam removal alternatives, using a method proposed and previously applied for Matilija Dam removal by Cui et al. (2017) that relied on three components to inform the likely magnitude and duration of high SSCs: (1) a two-phase conceptual model for reservoir sediment erosion following a sudden release of fine sediment following dam removal; (2) general principles governing geomorphic processes; and (3) comparison of results from the analyses with observations in rivers during flood events, during reservoir drawdown for sediment sluicing, and following dam removal.

[3] In this document, juvenile steelhead refers to both young-of-the-year (YOY) and age 1+/2+, unless indicated separately. YOY are age 0+ individuals less than one year old at the time of impact that hatched the previous spring or early summer and are the offspring of adults that spawned the previous winter or early spring. Age 1+/2+ refers to all pre-smolt juveniles one year old or older. YOY are likely to be between 3 and 9 months old at the time of impact, and age 1+/2+ are likely between 1.25 and 2.5 years old.

The Stillwater Sciences (2021) analyses applied conservative assumptions wherever uncertainties arose in parameters, and the results should be considered accurate to an order of magnitude[4] and very conservative (i.e., the actual duration of impact is most likely much shorter than estimated through the analyses). The results are useful for identifying the seasonality, frequency, and potential worst-case scenario for suspended sediment impacts on focal species. Although the results are only accurate to an order of magnitude when viewing each alternative independently, results from the analyses are relatively strong and informative when used to compare relative differences among alternatives. That is, results such as the SSC for alternative A is higher than alternative B, or impact duration for alternative A is shorter than alternative B should be considered as extremely reliable and not be questioned on the basis that the analyses are only accurate to an order of magnitude.

The calculated magnitude of SSC and duration were used to predict potential impacts on focal species under the two dam removal alternatives described in Section 1.3. Three flow assumptions (1,000; 2,000; and 5,000 cubic feet per second [cfs]) were considered for the vertical notching alternative, and estimated SSCs associated with these flows would reach several hundred thousand milligrams per liter that lasts for several days. A 133 cfs flow was considered for the four-stage alternative, as fine sediment release would primarily occur during the low flow construction season. The estimated SSC for the four-stage alternative is lower compared with the vertical notching alternative; however, elevated SSCs under the four-stage alternative would last much longer (four consecutive water years). More details of the estimated SSC and duration is described in Section 3.1.

3.2 Effects Analysis

Based on the scientific literature, the most commonly observed effects of suspended sediment on anadromous salmonids include: (1) avoidance of turbid waters in migrating adults resulting in delay or straying, (2) avoidance or alarm reactions by juveniles, (3) displacement of juveniles, (4) reduced feeding and growth, (5) physiological stress and respiratory impairment, (6) damage to gills, (7) reduced tolerance to disease and toxicants, (8) reduced survival, and (9) direct mortality (Newcombe and Jensen 1996).

Information on both concentration and duration of suspended sediment is important for understanding the potential severity of its effects on salmonids (Newcombe and MacDonald 1991). Herbert and Merkens (1961) stated that “there is no doubt that many species of fresh-water fish can withstand extremely high concentrations of suspended solids for short periods, but this does not mean that much lower concentrations are harmless to fish which remain in contact with them for a very long time.” Effects of suspended sediment on fish may be increased if toxics or other stressors (e.g., water temperature, disease) are present as well. 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 salmonid species have been shown to be attracted to turbid water over clear water, 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 water temperature and turbidity as potential cover qualitatively, in assessing the potential effects of a suspended sediment pulse on anadromous salmonid populations.

[4] In general, parameters relating to sediment transport rate (such as SSC) in sediment transport models are considered accurate to a factor of 2 to 3. Here “order of magnitude” accuracy means that results of the analyses may not be as accurate as what was considered for sediment transport models primarily due to the lack of basic research in the subject.

Determining the SSCs 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 milligrams per liter (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[5] (see reviews by Cordone and Kelly 1961, Sorenson et al. 1977)." For 36-hour exposures using juvenile Chinook (*O. tshawytscha*) and Sockeye Salmon (*O. nerka*), Newcombe and Flagg (1983) reported 10% mortality at concentrations of 1,400 mg/L, 50% mortality at 9,400 mg/L, and 90% mortality at 39,400 mg/L. Concentrations of 82,000 mg/L resulted in 60% mortality after 6-hours exposure. Estimated concentrations of 207,000 mg/L resulted in 100% mortality in one hour. Stober et al. (1981) reported mortality rates of 50% for juvenile Chinook and Coho Salmon exposed to 500–1,000 mg/L for 96 hours; however. From the results of these and other studies, it appears that relatively short-term exposures to increases in SSC under 500–600 mg/L would not likely result in substantial direct mortality to either juvenile or adult anadromous salmonids in the Eel River. If the duration of exposure is extended, however, some direct mortality is expected. Exposures of 19 days to SSC of 90–270 mg/L and higher have been reported as resulting in mortality to juvenile rainbow trout by Herbert and Merkens (1961). Less information is available on the effects of suspended sediment or turbidity on newly emerged salmonid fry (Sigler et al. 1984).

For comparison, daily mean suspended sediment concentration measured in the Eel River at Scotia between 1960 and 1980 (USGS gage 11477000) annually exceed 1,000 mg/L, and occasionally exceed 10,000 mg/L (Figure 2); levels high enough to result in sublethal and lethal impacts to focal species on an nearly annual basis.

[5] Parts per million (ppm) is equivalent to milligrams per liter (mg/L)

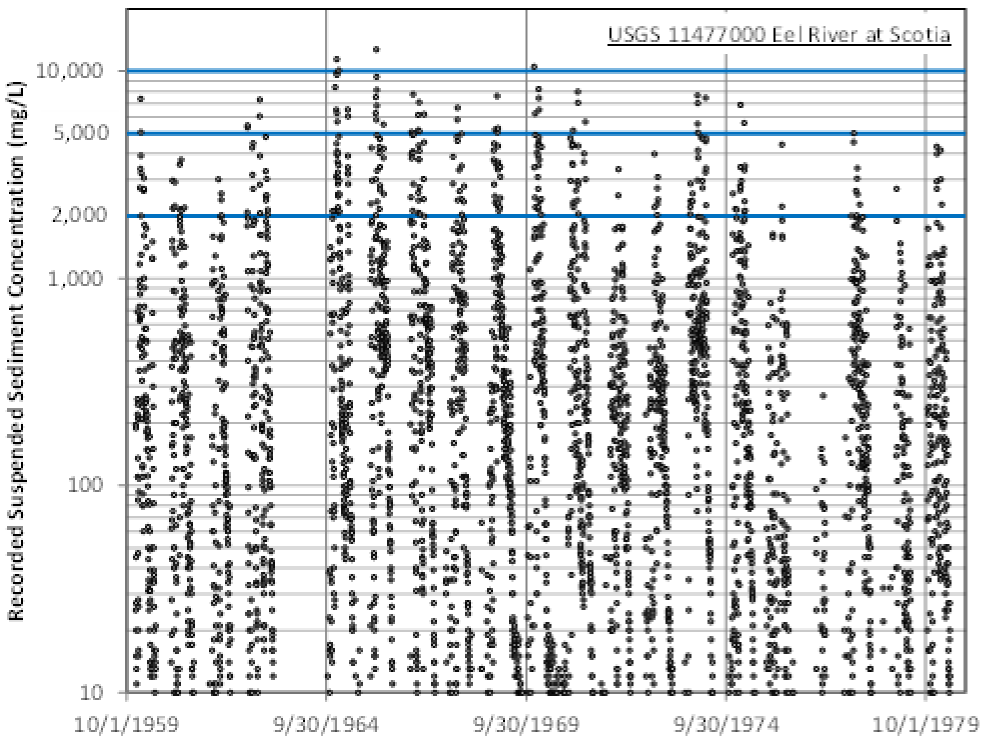

Figure 2. Recorded suspended sediment concentration at USGS gage 11477000 (Eel River at Scotia) (Horizontal blue lines highlight suspended sediment concentration thresholds of 10,000, 5,000, and 2,000 milligrams per liter [mg/L]).

Potential population-level effects of fine 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 the focal fish species and life stages. 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 (SEV)" indices (Table 5) for various species and life stages based on the duration of exposure and concentration of suspended sediment present. The SEV 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. Newcombe and Jensen (1996) collected data on fish effects (on the SEV scale), suspended sediment concentration (C, [mg/L]), and suspended sediment exposure time (D, hr), from a large number of papers dealing with many salmonid fishes at various life stages. They fit models of the form $\text{SEV} = b_0 + b_1 \log C + b_2 \log D$ 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 consider constant concentration values. Following Newcombe and MacDonald (1991), models of the form in Equation (1) are applied.

$$\text{SEV} = b_0 + b_1 \text{Ln (CD)} \qquad \text{Equation 1}$$

Based on selection of the best performing model, regression coefficients for adults are b_0=2.030; b_1=0.611, juveniles are b_0=0.978; b_1=0.681, and eggs/alevins are b_0=7.200; b_1=0.436. CD is calculated as the total mass of sediment to be eroded (M) and the discharge rate to be maintained (Q) for each alternative.

As an example calculation for SEV for adult salmonids under vertical notching alternative, M = 12,000,000 CY, which is converted to metric, and assuming a density of 943,000 mg/L resulting in a value of 8.65×10^{15} mg. Discharge rate (Q) is 1,000 cfs, which calculates as 2,446,575,546 L/d, and therefore CD = 3,536,250 mg/L×d. Using the regression coefficients for adult salmonids of b_0=2.030; b_1=0.611, $\text{SEV} = 2.03 + 0.611 \times \text{Ln}(3{,}536{,}250 \times 24) \doteq 13.25$.

The result of this approach is a life-stage-specific prediction of the severity of ill effects on the focal species in the Eel River based on the results of the general fine sediment release analysis described in Section 2.2. 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 simple application of the Newcombe and Jensen (1996) model, in that predictions are provided for only a few assumed flows, rather than evaluating modeling predictions assuming an entire hydrograph for multiple potential water years. Background turbidity also is not accounted for in the analysis. 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 review of Newcombe and Jensen (1996), the approach simplifies the effects of suspended sediment, and in doing so, assumes all effects of suspended sediment are negative, despite literature to the contrary. This exaggerates the effects of suspended sediment, particularly for lower concentrations and durations of exposure. 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 adverse in conjunction with high water temperature for some life stages (Bozek and Young 1994).

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

Category of effect	Severity	Description
No effect	0	No behavioral effects
Behavioral effects	1	Alarm reaction
	2	Abandonment of cover
	3	Avoidance response
Sublethal effects	4	Short-term reduction in feeding rates Short-term reduction in feeding success
	5	Minor physiological stress: • Increase in rate of coughing • Increased respiration rate
	6	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

Category of effect	Severity	Description
		• Poor condition
Lethal effects	9	Reduced growth rate: • Delayed hatching • Reduced fish density
	10	Increased predation of affected fish 0–20% mortality
	11	>20–40% mortality
	12	>40–60% mortality
	13	>60–80% mortality
	14	>80–100% mortality

4 RESULTS

The results of the assessment are presented in three parts. First, an overview of the predicted magnitude and duration of SSCs for the two dam removal alternatives analyzed (vertical notch and four-stage removal) is presented based on the fine sediment erosion analysis reported in Stillwater Sciences (2021). Second, a hydrologic analysis identifying the frequency and timing of potential flow thresholds for vertical notch removal is presented to inform the potential timing of sediment release as it relates to the species and life stages that could be affected. Third, the estimated effects of predicted SSCs on focal species and life stages are presented for the two dam removal alternatives analyzed.

4.1 Overview of Predicted Suspended Sediment Concentrations

The following overview draws directly from the analyses reported in Stillwater Sciences (2021). Removing Scott Dam with the proposed vertical notching alternative would result in a rapid, one-time increase in high SSC during a winter storm event on the order of 600,000 mg/L that would most likely last for approximately 4 days (3 days Phase 1 erosion, 1 day Phase 2 erosion) if streamflow following notch opening is around the targeted 2,000 cfs (Table 6). If the discharge following notch opening is only 1,000 cfs, however, the SSC would be reduced to about 450,000 mg/L, which would most likely last for approximately 9 days (8 days Phase 1 erosion, 1 day Phase 2 erosion). If the streamflow following notch opening is 5,000 cfs, the SSC would be increased to approximately 900,000 mg/L, which would most likely last for approximately 2 days (1 day Phase 1 erosion, 1 day Phase 2 erosion). A higher streamflow following notch opening would result in SSC up to slightly more than 900,000 mg/L and would shorten the duration of the high suspended sediment and turbidity. Based on available streamflow data (see Section 4.2), it is anticipated that SSC resulting from Scott Dam removal would be substantially diluted (by around 70 percent) downstream of the Middle Fork Eel River since the Middle Fork Eel River provides substantial accretion flow in all seasons.

Table 6. Calculated magnitude of suspended sediment concentration and duration for Phase 1 erosion for 12 million cubic yards fine sediment erosion (vertical notching alternative).

Concentration/ Duration	Streamflow into Lake Pillsbury		
	1,000 cfs	2,000 cfs	5,000 cfs
Suspended sediment concentration (mg/L)	457,800	612,500	900,000
Duration of Phase 1 erosion (days)	7.7	2.9	0.8

Note: 12 million cubic yards is the total volume of erosion estimated by Stillwater Sciences et al. (2021a) that included both fine and coarse sediment. The amount of fine sediment erosion is most likely less than 12 million CY.

Removing Scott Dam with the proposed four-stage alternative (one stage per year) would result in fine sediment erosion during the low flow season (May through November) up to approximately 196,000 mg/L for a combined duration of more than 100 days that spans four water years if the rate of notching is adequately fast. The most likely scenario, however, is an SSC lower than 196,000 mg/L that lasts significantly longer (Figure 3). In a likely scenario of 100,000 mg/L SSC, for example, the combined duration in the four water years could potentially exceed 250 days. A faster notching would mean higher SSC but shorter impact duration (but still longer than 100 days), and slower notching would mean a lower SSC but increased duration of impact. In the absence of mechanical sediment removal and disposal, there is no known method to reduce the magnitude of SSC and shorten the impact duration simultaneously.

Note the above discussions are entirely based on the volume of sediment erosion during different stages of dam removal estimated from GIS analysis (Stillwater Sciences et al. 2021a), and the actual volume released will certainly differ. Stage 1, for example, removes the dam to an elevation of 1,771.12 ft, which is only about 10 ft lower than the reservoir pool level during the summer of 2014 drought. As a result, the amount of fine sediment release is likely much smaller than the 1.1 million CY assumed in the analysis, and there would likely be very few to no days with elevated suspended sediment concentration during Stage 1 removal. However, the smaller amount of assumed sediment release during Stage 1 removal implies the amount of sediment erosion during the next three stages would need to be higher than assumed in the analysis, meaning more days of high suspended sediment concentration during these stages. Because of that, the combined number of days with high suspended sediment concentration during all four construction seasons should be similar if the volume of erosion amongst the four construction seasons is distributed differently.

Despite the high suspended sediment concentration during the summer months, the amount of fine sediment erosion is limited due to the low water discharge throughout the season. During the dry season of July through September, for example, a 34 cfs water discharge combined with an 83,000 mg/L suspended sediment concentration would result in only approximately 700 tons of fine sediment erosion, leaving much of fine sediment for erosion during the following winter high flow season. Because of that, it is expected that an acute peak high suspended sediment concentration event would occur during the first winter high flow event (particularly in years 2, 3, and 4), eroding a significant amount of fine sediment. The suspended sediment concentration during this initial high flow event is expected to be somewhat similar to that of the vertical notching alternative, perhaps with a slightly lower magnitude and significantly shorter duration because the amount of sediment release is much less than that for vertical notching alternative (i.e., fine sediment release in four years instead of one single event).

As described for the vertical notching alternative, it is anticipated that potential impacts from high suspended sediment concentrations would be greatest upstream of the Middle Fork Eel River, with some dilution of suspended sediment downstream of the Middle Fork confluence.

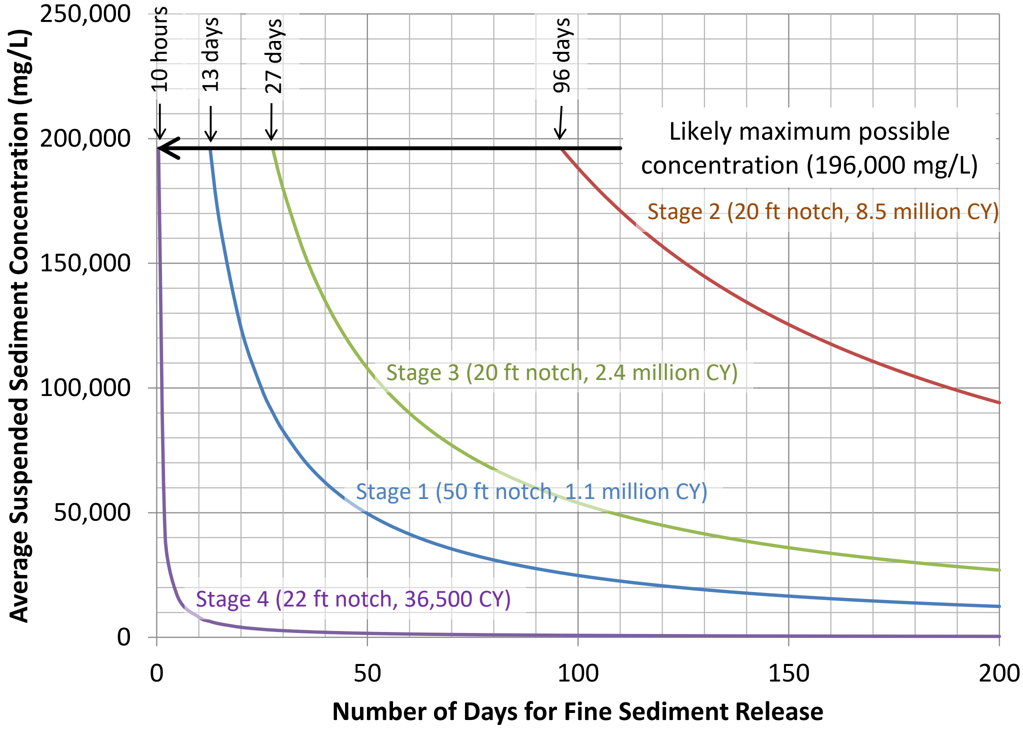

Figure 3. Suspended sediment concentration vs. duration of average suspended sediment concentration for the four-stage dam removal alternative at a flow of 133 cubic feet per second (assuming fine sediment release occurs only during lake level drawdown). Each removal stage would occur in the spring of four consecutive years with sediment erosion occurring after notching through November.

4.2 Hydrologic Analysis

To identify the frequency and timing of potential flow thresholds for the vertical notching alternative, a hydrologic analysis was conducted to inform the potential timing of sediment release as it relates to the focal species and life stages that could be affected. Based on the unimpaired hydrology for the Eel River at Scott Dam from 1911 to 2017 (Addley et al. 2019), a 2-year exceedance annual maximum daily flow is 10,240 cfs. The three flows assessed in the vertical notching alternative are 1,000 cfs, 2,000 cfs, and 5,000 cfs. A daily maximum flow of 1,000 cfs occurred in all years, 2,000 cfs is exceeded 99% of years, and 5,000 cfs is exceeded 98% of years (Table 7). A daily maximum flow of 1,000 cfs has a nearly 40% probability of occurring by the end of November, and in most years (>70%) will have occurred by the end of December (Table 7). A daily maximum flow of 2,000 cfs is more likely to occur by the end of December (59% of years), and nearly certainly by the end of January (82% of years). A daily maximum flow of 5,000 cfs has around a 40% chance of occurring by the end of December, and is more likely (>65%) to occur by the end of January (Table 7).

Table 7. Probability of maximum daily flows assessed in vertical notching alternative occurring within fall and winter months (October through March) at Scott Dam. Based on unimpaired hydrology for the Eel River at Scott Dam from 1911 to 2017 (Addley et al. 2019).

Month	1,000 cfs	2,000 cfs	5,000 cfs
October	9%	4%	2%
November	40%	24%	11%
December	71%	59%	43%
January	90%	82%	67%
February	98%	96%	90%
March	100%	99%	98%

cfs = cubic feet per second

Thirteen years of mean daily flow records (2008 through 2020) from two stream flow gages (gage E11 [Eel River downstream of Cape Horn Dam] and USGS gage 11473900 [Middle Fork Eel River Near Dos Rios]) were summarized to assess dilution of suspended sediment following removal of Scott Dam downstream to the confluence with the Middle Fork Eel River. For the period of November through January when flows are between 1,000 and 5,000 cfs, discharge at the Middle Fork Eel River was between 0.9 to 12.2 times higher than discharge downstream of Cape Horn Dam, averaging 2.5 times higher.

4.3 Predicted Effects on Focal Species

Applying the Newcombe and Jensen (1996) approach to assess effects on the SEV scale based on suspended sediment concentration (C, mg/L) and suspended sediment exposure time (D, hr) suggests that the high concentration and short duration of fine sediment release predicted under the vertical notching alternative would result in high levels of mortality for those species and life stages exposed during winter (Table 8).

Table 8. Summary of predicted Newcombe and Jensen Severity Index (SEV) and anticipated effects on focal salmonid species based on the vertical notching alternative.

Life stage	Estimated streamflow into Lake Pillsbury and estimated effect of rapid sediment release under the Vertical Notching Alternative					
	1,000 cfs (458,000 mg/L for 185 hr)		2,000 cfs (613,000 mg/L for 69 hr)		5,000 cfs (900,000 mg/L for 19 hr)	
	SEV	Effects	SEV	Effects	SEV	Effects
Adult	13	>60–80% mortality	13	>60–80% mortality	12	>40–60% mortality
Juvenile	13	>60–80% mortality	13	>60–80% mortality	12	>40–60% mortality
Eggs and alevin	14	>80–100% mortality	14	>80–100% mortality	14	>80–100% mortality

cfs = cubic feet per second

Under the four-stage alternative, the high concentration of fine sediment release would result in high levels of mortality for those species and life stages exposed during four consecutive summers (May through November) (Table 9). The implications for the focal species and life stages potentially exposed under each alternative are discussed below.

Table 9. Summary of predicted Newcombe and Jensen Severity Index (SEV) and anticipated effects on focal salmonid species based on the four-stage dam removal alternative occurring over four water years.

Life stage	Dam Removal Stage							
	Stage 1 (196,000 mg/L for 10 hours)		Stage 2 (196,000 mg/L for 13 days)		Stage 3 (196,000 mg/L for 27 days)		Stage 4 (196,000 mg/L for 96 days)	
	SEV	Effects	SEV	Effects	SEV	Effects	SEV	Effects
Adult	13	>60–80% mortality	14	>60–80% mortality	13	>40–60% mortality	11	>20–40% mortality
Juvenile	13	>60–80% mortality	14	>60–80% mortality	14	>40–60% mortality	11	>20–40% mortality
Eggs and alevin	14	>80–100% mortality	14	>80–100% mortality	14	>80–100% mortality	14	>80–100% mortality

4.3.1 Steelhead

4.3.1.1 Vertical Notching Alternative

Adult winter-run steelhead migrate through the mainstem Eel River between late November and May (Table 1) during or following high flow events. Suspended sediment released under the vertical notching alternative may occur early as November, and is nearly certain to occur by the end of January (see Section 4.2); therefore, a component of the adult migrant population would likely be exposed to lethal SSCs under the vertical notching alternative, resulting in substantial mortality for exposed adults (Table 9). However, due to a relatively prolonged migratory season and short duration of suspended sediment impacts, a substantial proportion of adults will likely have migrated through the mainstem and into tributaries prior to the suspended sediment pulse or will migrate following the pulse event. The spatial distribution of steelhead also ensures that a component of the run will migrate up the South Fork Eel River or within numerous other large and small tributaries. In addition, because the fine sediment release for this alternative would occur during winter, tributary accretion flow with relatively low SSCs is expected to provide local refuge at tributary confluences from high SSC in the mainstem, as illustrated for example in Figure 4. The Upper Eel River has substantial streamflow accretion from numerous tributaries that is estimated to dilute SSC by about 70 percent by the Middle Fork Eel River (Section 4.2). While potential impacts to adult steelhead in the mainstem will be lessened by dilution and access to tributary inflow as refuge habitat, lethal impacts are still predicted during the peak sediment release (1–8 days depending on flow, see Table 6).

Figure 4. Example of the confluence of two rivers following a storm event on April 15, 2021. The river with clear water is Qingshuijiang (Clear Water River), and the one with turbid water is Xiaojiang (Little River). The rivers are located in Jinping County, Guizhou Province, China. (Source: Jinping County Information Center, Guizhou Province, China, image downloaded from https://www.sohu.com/a/461365210_162758 on April 18, 2021).

Most steelhead spawning occurs in tributaries, and therefore most incubating eggs will avoid impacts of the peak suspended sediment in mainstem. However, considerable numbers of steelhead spawn in the mainstem Eel River above Cape Horn Dam based on the number of adults counted at VAFS versus observed spawning in tributaries, and those redds that are constructed prior to the release of sediment will likely suffer nearly complete mortality from high SSC and coarse sediment deposition.

Kelts may be present in the mainstem Upper Eel River from February through May. Depending on the timing of the fine sediment release, it is possible that relatively few kelts will be in the mainstem during the short duration of elevated sediment if it occurs during an early winter storm (i.e., before February, which is likely as described in Section 4.2), and likely few will be impacted overall.

Steelhead fry rearing in the Eel River watershed generally occurs in tributaries and based on spawning and emergence timing, occurs primarily from March through July. The first high flow event of the year of the vertical notching alternative is nearly certain to occur prior to March (see Section 4.2), and therefore steelhead fry will most likely avoid impacts. In the Upper Eel River, individuals rearing in tributaries generally rear for two or three years before migrating to the ocean, whereas individuals rearing in the mainstem between Scott Dam and Cape Horn Dam often migrate after a single year due to superior growth conditions (SEC 1998). These age 1+ juveniles rearing in the mainstem Upper Eel River would likely suffer high levels of mortality unless they are able to find refuge in tributaries or associated low-SSC inflow at tributary confluences. However, most juvenile rearing occurs in tributaries, and therefore most individuals would not be in the mainstem during the suspended sediment pulse and would be unaffected. In addition, as described for adults above, dilution and low-SSC flow entering from tributaries is expected to provide refuge from highly elevated SSC in the mainstem.

Steelhead smolt outmigration generally occurs from March through mid-June, with a peak in April and May (Table 1). Because fine sediment release from the vertical notching alternative will nearly certainly occur during an early winter flow event by the end of January (Section 4.2), smolts would likely avoid impacts of highly elevated SSC in the mainstem.

In general, the short-term impacts of suspended sediment resulting from the vertical notching alternative on steelhead are likely to result in substantial mortality for any adults migrating, eggs and alevin in constructed redds, and juveniles rearing in the mainstem. However, there are several aspects of steelhead life history in the Eel River watershed that would ameliorate these impacts. The broad spatial distribution of steelhead in the Eel River watershed and their diverse life history patterns suggests that a large proportion of adults, eggs and alevin, and juveniles that would otherwise be in the mainstem would avoid the most serious effects of high SSC resulting from the vertical notching alternative by: (1) spawning in tributaries, (2) remaining in tributaries for extended juvenile rearing, (3) rearing farther downstream where SSC will be lower due to dilution, and/or (4) moving out of the mainstem into tributaries during periods of elevated suspended sediment or finding refuge in low-SSC flow entering the mainstem at tributary confluences.

4.3.1.2 Four-stage Alternative

The four-stage alternative would have similar impacts to steelhead as the vertical notching alternative described above, since dam removal during the dry season would leave much of the fine sediment behind for erosion during subsequent winter high flow seasons (up to four years). In addition, the four-stage alternative would have a summer suspended sediment release. Based on the summer removal timing of the four-stage alternative, adult, kelt, incubating eggs, alevin, and steelhead fry (primary rearing occurs in tributaries) would avoid the impacts of the summer fine sediment release. Juveniles rearing in the mainstem during summer would suffer high levels of mortality for at least three consecutive summers (since the first stage is anticipated to have little sediment release), affecting at least three generations of production. However, most juvenile rearing occurs in tributaries, therefore, most individuals would not be in the mainstem during the suspended sediment pulse and would be unaffected.

Steelhead smolt outmigration generally occurs from March through mid-June, with a peak in April and May. Based on the summer timing of fine sediment release from the four-stage alternative, smolt outmigration could be completed prior to SSCs increasing.

In general, the short-term impacts of suspended sediment resulting from the four-stage alternative on steelhead are likely to result in substantial mortality for any adults migrating, eggs and alevin in constructed redds, and juveniles rearing in the mainstem for three consecutive years, affecting multiple generations in the mainstem Upper Eel River. However, there are several aspects of steelhead life history in the Eel River watershed that would ameliorate these impacts. The broad spatial distribution of steelhead in the Eel River watershed and their diverse life history patterns suggests that most juveniles that would otherwise be in the mainstem would avoid the most serious effects of high SSC resulting from the four-stage alternative by: (1) remaining in tributaries for extended rearing, (2) rearing farther downstream where SSC would be lower due to dilution, and/or (3) moving out of the mainstem into tributaries during periods of elevated suspended sediment.

4.3.2 Chinook Salmon

4.3.2.1 Vertical Notching Alternative

Adult Chinook Salmon typically migrate through the mainstem Eel River during fall flow events mostly in November and December and have generally completed migration by mid-January. Suspended sediment released under the vertical notching alternative may occur early as November and is nearly certain to occur by the end of January (see Section 4.2). Therefore, a component of the adult migrant population is likely to be exposed to lethal SSC under the vertical notching alternative, resulting in substantial mortality for exposed adults (Table 9). The spatial distribution of Chinook Salmon ensures that a component of the run will migrate up the South Fork Eel River or within tributaries in the mainstem, including Outlook and Tomki creeks. In addition, because the timing of fine sediment release for this alternative would occur during winter, there is expected to be low-SSC flow entering from the tributaries to provide significant local refuge from high SSC in the mainstem (e.g., Figure 4). The Upper Eel River has substantial streamflow accretion from numerous tributaries that is estimated to dilute SSC by about 70% by the Middle Fork Eel River (Section 4.2). While potential impacts in the mainstem will be lessened by dilution and access to refuge habitat, lethal impacts are still predicted for adult Chinook Salmon in the mainstem during the peak sediment release.

Most Chinook Salmon spawning occurs in the mainstem, and therefore most incubating eggs will be exposed to impacts of the elevated suspended sediment, resulting in nearly complete mortality. Although few fry would be produced from the mainstem (due to poor redd survival), substantial numbers of fry would be produced from Outlook and Tomki creeks, and would enter the mainstem to emigrate as smolts mostly in April and May after the pulse in highly elevated suspended sediment would have occurred.

In general, the impacts of suspended sediment resulting from the vertical notching alternative on Chinook Salmon are likely to result in substantial mortality for a small proportion of the adult migrants, any redds constructed in the mainstem Upper Eel River, and a low likelihood of impacts on other life stages. Overall, the Chinook Salmon population is anticipated to suffer a minor short-term impact in the mainstem Upper Eel River for one generation of production and, due to the spatial distribution of Chinook Salmon in the watershed, would be expected to recover quickly.

4.3.2.2 Four-stage Alternative

The four-stage alternative would have similar impacts to Chinook Salmon as for to the vertical notching alternative described above, since removal during the dry season would leave much of fine sediment for erosion during the winter high flow events and during next seasons (up to four years). In addition, the four-stage alternative would have a summer suspended sediment release. Based on the summer removal timing of the four-stage alternative, Chinook Salmon incubating eggs and fry would avoid the impacts of fine sediment release. Adult migration generally starts in October and based on the timing of fine sediment release from the four-stage alternative, adult migration would likely begin after primary impacts would occur. Most Chinook Salmon smolts emigrate in April and May, therefore, emigration would likely be completed prior to increased SSCs.

In general, the short-term impacts of suspended sediment resulting from the four-stage alternative on Chinook Salmon are likely to result in are likely to result in substantial mortality for a small proportion of the adult migrants, any redds constructed in the mainstem Upper Eel River, and a low likelihood of impacts on other life stages; for three consecutive years.

4.3.3 Coho Salmon

4.3.3.1 Vertical Notching Alternative

Adult Coho Salmon typically migrate through the mainstem Eel River from November through February; therefore, a component of the adult migrant population would likely be exposed to lethal SSC under the vertical notching alternative, resulting in substantial mortality for exposed adults (Table 9). However, due to a prolonged migratory season and the short duration of sediment impacts, most adults will likely have the opportunity to migrate through the mainstem into tributaries prior to the pulse in sediment or will migrate following the event. The broad spatial distribution of Coho Salmon ensures that a component of the run will migrate to tributaries within the lower mainstem Eel River, South Fork Eel River, or within tributaries to the mainstem Upper Eel River (e.g., Outlook and Tomki creeks). In addition, because the fine sediment release for this alternative would occur during winter, there would be relatively low-SSC flow entering from tributaries that is expected to provide significant refuge from high SSC in the mainstem (e.g., Figure 4). The Upper Eel River has substantial streamflow accretion from numerous tributaries that is estimated to dilute SSC by about 70% by the Middle Fork Eel River (Section 4.2). While potential impacts in the mainstem will be lessened by dilution and access to refuge habitat, lethal impacts are still predicted for adult Coho Salmon in the mainstem during the peak sediment release.

Coho Salmon spawning and fry rearing in the Upper Eel River typically occurs in tributaries and not the mainstem, and therefore incubating eggs and fry would avoid impacts of the elevated sediment. Coho Salmon juvenile rearing in the mainstem Upper Eel River can occur during winter, and those individuals exposed would likely suffer high levels of mortality. However, most juvenile rearing occurs in tributaries, and therefore most individuals would not be in the mainstem during the fine sediment pulse and would be unaffected.

Coho Salmon smolt outmigration generally occurs from March through June. Because fine sediment release from the vertical notching alternative will likely occur during an early winter flow event, smolts would likely avoid impacts of highly elevated suspended sediment in the mainstem.

In general, the short-term impacts of high suspended sediment resulting from the vertical notching alternative on Coho Salmon are likely to result in high mortality for a small portion of migrating adults and high mortality for the few juveniles rearing in the mainstem Eel River during winter. There are several aspects of Coho Salmon life history in the Eel River watershed that would ameliorate these impacts. The broad spatial distribution of steelhead in the Eel River watershed suggests that most adults, redds, fry, and juveniles would avoid the effects of highly elevated SSCs by spawning and rearing in tributaries. In addition, recent observations of Coho Salmon in the Upper Eel River are rare and these populations are presumed to be very small or potentially extirpated (NMFS 2014), and thus there are very few, if any, Coho Salmon would potentially be impacted by fine sediment released under the vertical notching alternative.

4.3.3.2 Four-stage Alternative

The four-stage alternative would have similar impacts to Coho Salmon as for to the vertical notching alternative described above, since removal during the dry season would leave much of fine sediment for erosion during the winter high flow events and during next seasons (up to four years). In addition, the four-stage alternative would have a summer suspended sediment release. Based on the summer removal timing of the four-stage alternative, migrating adult Coho Salmon would avoid the impacts of fine sediment release. Incubating eggs and fry would avoid impacts since spawning and fry rearing occurs primarily within tributaries. Juveniles typically rear in tributaries but may occur in mainstem Eel River from October through May when water temperatures are suitable. Therefore, potentially a small component of juveniles could be exposed to high SSC (and suffer high levels of mortality) for three consecutive years if the stages of removal and fine sediment release were to occur in early fall rather than summer.

Coho Salmon smolt outmigration generally occurs from March through June. Based on the summer timing of fine sediment release from the four-stage alternative, smolt outmigration could be completed prior to increased SSC.

In general, the short-term impacts of suspended sediment resulting from the four-stage alternative on Coho Salmon are likely to result in in high mortality for a small portion of any adults migrating and high mortality for the few juveniles rearing in the mainstem Eel River during winter. There are several aspects of Coho Salmon life history in the Eel River watershed that would ameliorate these impacts. The broad spatial distribution of steelhead in the Eel River watershed suggests that most adults, redds, fry, and juveniles would avoid the effects of high SSCs by spawning and rearing in tributaries. In addition, recent observations of Coho Salmon in the Upper Eel River are rare and these populations are presumed to be very small or potentially extirpated (NMFS 2014), and thus there are very few, if any, Coho Salmon would potentially be impacted by fine sediment released under the four-stage alternative.

5 SUMMARY

Both dam removal alternatives are estimated to result in the release of substantial volumes of fine sediment, causing particularly high SSCs and likely resulting in substantial mortality for some life stages of all species assessed. Steelhead are the most vulnerable to fine sediment release due to their extended freshwater rearing that would affect multiple cohorts. Their broad spatial distribution and life history flexibility, however, would allow a large proportion of the population to avoid the peak impact of fine sediment release, which could support a quick and strong recovery following impacts. Under the vertical notching alternative, an early winter (i.e., November through January) sediment release would have a relatively low likelihood of direct impacts on most species and life stages and would be consistent with the time of year when elevated SSC occurs under natural conditions (although natural winter SSC peaks are expected to be much lower than those predicted during dam removal). The four-stage alternative includes most of the impacts of the vertical notch alternative, with the additional impacts of multiple consecutive years, and potential for fine sediment release during summer. Overall, the key opportunities to reduce potential impacts to salmonids include a dam removal approach resembling the vertical notch alternative (or tunneling alternative) that results in a single fine sediment release event over a short duration of time (i.e., days), during early winter, and coincident with naturally high flows in the watershed. In addition to the three flow thresholds (i.e., 1,000, 2,000, and 5,000 cfs) considered in the analyses above, it may also be appropriate to consider a higher flow threshold (greater than 5,000 cfs) for initiating rapid dam removal and fine sediment release, with the understanding that the probability of occurrence decreases with increasing flow, and the occurrence timing may shift. Potential benefits to using a higher flow threshold include reducing the duration of exposure and lower predicted impacts to focal species. In addition, higher tributary flows could increase availability of relatively low-SSC refuge habitat at tributary confluences.

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