Proposal to add fine sediments to the restoration reach of the Trinity River, California

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Overview

Mining, logging, and road building substantially altered sediment regimes in the Trinity River and tributary watersheds beginning in 1848 with the discovery of gold. Completion of Trinity Dam in November 1960 subsequently eliminated the sediment supply from upper watershed areas before Lewiston Dam and Carr Tunnel began diverting Trinity water to the Central Valley of California in April 1963. The reduced flows enabled fine sediments from tributaries to accumulate in the channel and in berms along the riparian fringe of the river. Fine sediments are defined as grains that are ≤8 mm in diameter. The accumulations negatively impacted salmon populations and pool dredging, and other means were attempted in the 1970s to reduce fines and benefit fish habitats but with almost no lasting improvements. Work to reduce tributary supplies of sediment also began in the 1970s, most notably in Grass Valley Creek. Revegetation, road improvements, and construction and operation of Buckhorn Dam and sediment retention ponds near the confluence with the Trinity River largely eliminated the creek as a fine sediment source over time. Flushing flow studies were also undertaken in 1991–1993 to identify discharges that most efficiently removed fine sediment from subsurface areas of the river bed (see Wilcock et al., 1996). These led to policy changes that authorized environmental flow releases that effectively scoured fines from depths that salmonids lay their eggs. Watershed restoration also reduced or maintained fine sediment inputs from Deadwood, Rush, and Indian creeks in the period that sediment transport data are available for these streams (1997–2006). In 1999, the Trinity River flow study (USFWS and HVT, 1999) proposed hydrographs that were authorized for release by a Record of Decision (ROD, 2000) to restore the Trinity River fishery by promoting ecosystem processes, including bed scour, bar construction, and riparian plant establishment, to name a few. Litigation delayed implementation of ROD flows until spring 2004, and they have been implemented annually since. The combination of sediment retention by the dams, ROD flows, and restoration actions have since depleted fine sediments to the point they are now lacking in most of the restoration reach of the Trinity River (see Buxton, 2021), as demonstrated in metrics presented below.

Total Maximum Daily Load (TMDL) for the Trinity River

In 2001, the Trinity River was listed under section 303(d) of the Clean Water Act as sediment impaired (US EPA, 2001). Water quality standards of concern in the TMDL were turbidity and suspended sediment, and beneficial uses impacted by these sediments included cold-water fish habitat for spawning, rearing, and migration. Environmental indicators for these in the TMDL are spawning gravel quality and permeability, turbidity, pool depth, and geomorphic indicators of a healthy alluvial river, including attributes 1 and 3-6 in USFWS and HVT (1999; Table 1). These attributes include 1) The channel morphology is spatially complex, 3) the channel bed surfaces are frequently mobilized and 4) periodically scoured and refilled, 5) fine and coarse sediment supplies are approximately balanced, and 6) the channel location periodically migrates. Actions to address tributary contributions of fine sediment to meet these requirements included 1) reduce sediment production from roads and timber harvest in sediment-impaired watersheds; 2) continue sediment preventative measures through implementation of road maintenance, tree planting, and other beneficial actions; and 3) implement the flow schedule, restoration measures, and adaptive management program on the Trinity River that is outlined in the ROD (ROD, 2000). These actions have been implemented the past 20 years and are still being implemented to this day. Analyses have thus shown that environmental indicators of beneficial uses have been restored on the mainstem Trinity River, as shown in the following section (Buxton, 2021).

Results of Analyses

Photographic Evidence of Fine Sediment Reduction

Repeat photographs demonstrate the aforementioned actions have significantly reduced the amount of fine sediment and restored a gravel-bed channel in the Trinity River (Figures 1-4; Buxton, 2021).

Spawning Gravel Quality

Restoration of a gravel bed has improved the quality of spawning gravels in the river. To evaluate the extent of the improvements, Buxton (2021) estimated egg-to-fry survival for Chinook with an equation by Tappel and

Bjornn (1983) using measured percentages of grains smaller than 0.85 mm and 9.5 mm in subsurface areas of the bed (GMA, 2020). Results were that estimates of hatching success and emergence of Chinook fry from salmon nests in the river have averaged 84% since 2001 (range 64-96%; Table 1). This is an improvement from an average of 69% (range 0-96%) for 1991–2000 (Table 1).

Turbidity

Physiological effects of high turbidity include gill trauma at ~60 NTU (Berg and Northcote, 1985) and avoidance behavior when juvenile salmonids circumvent areas where turbidity is 60-70 NTU (Berg, 1982) and seek refuge where higher water clarity is present (Sedell et al., 1990). Decreased territoriality and collapse in social structure can also result from high turbidity (>60 NTU; Berg 1982), which can decrease fish growth and feeding rates (Bash et al., 2001). For example, Berg and Northcote (1985) noted that a dominant fish positioned in a superior feeding station is often displaced from its territory by turbidity pulses between 30 and 60 NTU. Being visual predators, reduced visibility from turbidity lessens the ability of fish to see prey, and prey consumption at 60 NTU is around 35% of that in clear water (Berg, 1982), which can lead to decreased growth and lower fish health. However, constant clear water is also not preferred, as Sigler et al. (1984) observed that juvenile salmonids sought slightly turbid water in an apparent trade between predation risk and reduced feeding success. Under these considerations, Buxton (2021) evaluated the percentage of time that turbidity was <30 NTU of the juvenile rearing period (January–July) at TRLG, TRDC, and the Trinity River above the North Fork Trinity River (RM 72.5). Results for the available data indicated the turbidity target was met 97% of the time on average (range 77% to 100%) at these stations (Table 2).

Suspended Sediments

Effects of suspended sediment on juvenile and adult Chinook salmonids in the Trinity River were evaluated by Buxton (2021) with Newcombe and Jensen's (1996) model relating durations of fish exposure and concentrations of suspended sediment to severity-of-ill (z) impacts on these freshwater life stages. The evaluations were made where sediment transport monitoring occurs on the Trinity River at Lewiston (TRAL; RM 110.2), Limekiln Gulch (TRLG, RM 98.8), and Douglas City (TRDC, RM 92.7). The target for an acceptable exposure rating in Newcombe and Jensen's (1996) model was the sub-lethal designation associated with "minor physiological stress and increased rates of coughing and respiration", which is assigned a z-value of "5". However, the model considers grain sizes ≤0.25 mm whereas suspended sediments are measured on the Trinity River as particles <0.5 mm. The actual impacts at a z-value of "5" are therefore conservatively expected to fall under the next lower z-value of "4" that is associated with a "short term reduction in feeding success". Results were the percentage of time that target z-values were met in the juvenile rearing (January–July) and adult spawning (September–January) periods for salmonids in the Trinity River were respectively >85% and ≥94% since 2006 (Table 3). Even when z-values exceeded the target numbers, juvenile and adult Chinook would have access to clear-water refuges in the Trinity River, indicating suspended sediments no longer pose a threat to these life stages of Chinook Salmon.

Pool Depths

Removal of fine sediment from pools in the Trinity River was a primary focus of restoration efforts in the mid-1960s and 1970s. This was because most large, deep pools between Grass Valley Creek (RM 104.4) and Steel Bridge (RM 99.0) were reduced to 3-6 ft in depth by sand deposition after dam closure in November 1960 (Nelson et al., 1987). Most significantly, Reo Stott pool (RM 102.5) that had a surveyed depth of 20 ft deep in 2009 (Woolpert, 2010) exhibited a depth of only less than a foot in 1966 due to filling by sand (LaFaunce, 1968; Krause, 2012). Since then, sediment control measures on Grass Valley Creek and high flow releases on the Trinity River have restored pool depths on the Trinity River. Evidence for pool restoration was measured by Gaeuman and Krause (2013) and Gaeuman (2020) by differentiating changes in pool bathymetries surveyed with sonar during summer baseflow in the Trinity River in 2009, 2011, and 2016. They found water depths remained unchanged or increased in most pools in the restoration reach between these years. Only a few pools in the restoration reach were found to have decreased slightly in depth and this was attributed to a combination of gravel injections and nearby channel rehabilitation work that lowered floodplains to promote riparian plants, which decreased stream power in the pools for scouring pool depths.

Attributes 1 and 3-6 in USFWS and HVT (1999)

Flow and sediment management and mechanical restoration work on the Trinity River have created a spatially complex channel morphology (attribute 1) on the Trinity River from what was a largely featureless channel formed by an over-abundance of fine sediment and lack of high flows (Gaeuman et al., 2016; Curtis et al., 2015). The high flows that have been available for release to the Trinity River since implementation of the ROD (2000) in 2004 now frequently mobilize the channel bed surface (attribute 3) and alternately scour and fill the channel bed (attribute 4; see Buxton (2020, 2021)). Attribute 5 in USFWS and HVT (1999) targets balanced fine and coarse sediment budgets, and Gaeuman (2013, 2020) identified that a quasi-balanced coarse sediment budget has been restored in the upper restoration reach. However, Buxton (2021) found that a deficit of fine sediments now exists between Lewiston Dam and at least Rush Creek (RM 107.9) and some indications are the deficit may extend as far downstream Junction City (RM 80.3). Finally, periodic channel migration or avulsion (attribute 6) and widening was measured in aerial photographs taken 1980–2011 by Curtis et al. (2015) and in delta areas between 1960 and 2020 (Buxton and Bradley, In Review), indicating success in meeting this goal.

Proposed Inclusion of Fines in Sediment Additions to the Trinity River

Additions of fine sediment are proposed to replenish this component of the ecosystem that is deficient in the Trinity River and its floodplains. Purposes for the additions are to increase storage of fine sediment in the subsurface environment, on the bed surface, and in patches in lee areas on the bed without violating fine sediment targets listed in Table 4. Considerations to meet these purposes include the grain-size distribution of sediment and the timing, frequency, locations, volumes of additions, and sources and storage of sediment to be added. Monitoring is also proposed to adaptively manage the size distribution and volume of additions on the river.

Grain-size Distribution

The proposed size distribution of grains for addition to the channel is based on subsurface grain-size distributions measured at RM 107.4, which is located 0.4 miles downstream of Rush Creek confluence. At this and downstream locations where bed material sampling has occurred, most biologic targets for fine sediment storage are being met but fines are below levels that promote bed mobility, channel meandering, and ammocoete rearing (Table 4; Buxton, 2021). To meet both classes of targets, the percentage of fines in the grain-size distribution is set at 28%, which was measured at RM 107.4 in 2014 and is representative of bed material samples taken recently at locations downstream of this station. The proposed grain-size distribution is meant as a guideline for composing sediment mixtures and is not explicit in percentages that are defined for addition to the channel.

Grain size, mm	256	128	64	31.5	16	8	4	2	1	0.5	0.25
Percent finer	100%	92%	82%	60%	44%	28%	18%	11%	5%	1%	0%

Timing and Frequency of Additions

Sediment mixtures with fines would be added to the channel as bars during the instream construction period (July 15–October 15) and in late winter/early spring prior to spring high flow releases from Trinity and Lewiston dams. The sediment mixtures would also be added to the channel by loaders, conveyor belt, and other suitable means during the rising or falling limb of spring flow releases from the dams.

The frequency of high flow injections would be whenever spring flow releases are ≥4,000 cfs for a duration that transports a sufficient volume of material to justify the expense sediment additions made to the channel. Discharges that equal or exceed 4,000 cfs are considered in this respect because this flow is the approximate threshold for coarse sediment entrainment on the Trinity River (Buxton, 2021). The frequency of sediment additions from bar construction would be whenever such is prescribed and permitted in channel reconstruction work or sediment management to replace material trapped by Trinity and Lewiston dams.

Locations and Volumes of Additions

The locations for sediment additions made during spring flow releases include the five sites that are currently permitted for gravel additions on the Trinity River and newly proposed sites for the additions to be made. These include Trinity River fish hatchery, Weir Hole, Old Lewiston Bridge, Lowden Meadows, and Sawmill. In addition to these, another four sites have been proposed for sediment additions and are being considered by the

State Water Board for permitting. These include China Gulch, Dark Gulch, Steel Bridge day use area, Trinity House Gulch, and Vitzhum Gulch.

The mass of additions will be computed with observed threshold discharges for coarse and fine sediment mobility and sediment transport relationships to flow measured at Douglas City for a recent hydrograph that exhibits a similar peak discharge and shape as that being considered. The transport computations will be made in daily time steps using the daily average flows at sites that additions are made and the mass transport relationship just mentioned and will consider hysteresis effects if applicable for the hydrograph shape. Daily mass transport values will be summed for the period when the bed is mobile and converted to a volume assuming 2.23 tons/cubic yard.

Sediment Sources and Storage Locations

A large pile of the coarse end of the proposed grain-size distribution is currently stored at Weir Hole. Fines for addition to this material are in large piles at Lowden Meadows. The fine material could be trucked to Weir Hole and mixed with an excavator or loader to provide the full grain-size distribution that is proposed. Additional fine and coarse sediment for placement are available for composing the grain-size distribution with native material at Sawmill. Other sediment sources may include large tailings piles at Dark Gulch and in the Junction City region.

Storage of the full distribution of grain sizes would be at their locations of placement on USFS land across from Trinity River fish hatchery, Weir Hole, adjacent to Old Lewiston Bridge, Lowden Meadows, and Sawmill. Onsite storage area is also available at Dark Gulch, Steel Bridge day use area, and Trinity House Gulch, if permitted. Areas for storage of material at China and Vitzhum gulch are unavailable so the sediment to be placed would need to be stored at one of the other sites and trucked onsite when the sediment additions are made to the river.

Monitoring Effects of the Proposed Action

Monitoring to discern effects of the proposed action were recommended by Buxton (2021) and are reproduced here. Sediment transport measurements should be undertaken on the Trinity River to enable coarse and fine sediment additions to be adapted to changing conditions on the river and lessons learned in the TRRP. Specifically, bed load transport monitoring should occur at TRAL, TRLG, and TRDC as done in the past for dry and wetter water years (see GMA, 2020). Suspended sediment and turbidity measurements should also be restarted at TRAL and TRLG in units of NTU for a minimum duration that includes the spring flow release before and continuing for all spring releases after the start of fine sediment additions, including critically dry water years. The bed load and suspended sediment transport measurements will enable sediment budgeting, provide contemporary transport rates for designing fine and coarse sediment additions, enable computations of the relative mobility of grain-size fractions to assist detection of supply-transport imbalances, and provide data to evaluate the effect of fine sediment additions near Lewiston on sediment availability and transport dynamics that govern salmonid populations in gravel bed channels (Lisle and Lewis, 1992).

Sediment storage should also be evaluated in the restoration reach to enable management actions to adapt through time to changing mainstem channel conditions from natural (e.g., landscape disturbance, tributary flow events) and imposed (e.g., restoration flow releases, channel rehabilitation, watershed restoration) conditions. Storage measurements should include bulk sampling at established, repeat sites (see Matthews, 2020) every other year for the first 6 years following implementation of this plan. Thereafter, bulk sampling at the repeat sites should be repeated every 5 years regardless of water year type. Fine sediment deposits should also be mapped in the wetted channel during summer baseflow for some distance downstream of the augmentation locations before and after implementation of the proposed action. Repeat, surface grain-size distributions and embeddedness and resisting forces (see Buxton et al. (2015)) for coarse grains should be measured on select bars to track sediment conditions for macroinvertebrates and grain mobility through time. A pilot study is also recommended to assess the feasibility of monitoring the proportion of the low flow volume of pools that is occupied by fines (e.g., V^* in Lisle and Hilton (1992)). The V^* measurements would complement bulk samples in quantifying temporal and spatial variability in fine sediment storage and for systematic assessments of fine sediment storage on bars and floodplains.

Expected outcomes of the proposed action

Both positive and negative outcomes are expected from the proposed action. An expected negative outcome is increased public concern toward the turbidity that will occur when fines are added to the channel and transported in later flow events. However, the increases in turbidity are not expected to limit feeding opportunities or growth of juvenile salmonids but help improve fish survival by providing visual cover from predators. Outreach to inform the public of the purpose and likely outcomes of fine sediment additions and their effects on turbidity in the river is an important aspect of this proposed action that will be designed and undertaken if the proposal is enacted. No additional negative effects are expected.

Positive outcomes from the proposed action are expected for the geomorphic functioning and biology of the river. Physical processes that will benefit from the addition of fines include increased channel and bar dynamics from lowered thresholds of bed mobility, enhanced substrate conditions in riparian areas for plant initiation and growth, and accelerated meandering from roughness by plants on the inside of meanders bends. Positive results for the river's biology will be increased availability of lamprey rearing habitat and enhanced nutrient storage and processing. Sediments in the proposed mixture will additionally provide substrate for bar construction, macroinvertebrates, and salmonid spawning and incubation. In consideration of grain sizes for salmon redd construction, the targeted framework particle size (i.e., D_{84}) in the proposed distribution is 77 mm and the median grain size is 22 mm. Based on data in Riebe et al. (2014) that relates salmonid length to largest particle moved in redd construction, the median Trinity River Chinook (650 mm fork length; 2018 data) can mobilize a particle that is 121 mm in diameter. This indicates that spawners will be able to incorporate on average around 90% of the added sediment into their nests.

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Supporting Evidence (adapted from Buxton (2021))

Figure 1. A large sand delta at the confluence with Hoadley Gulch (river mile (RM) 110.1) in August 1999 (a.), and the same view in August 2019 (b.). For reference, Lewiston Dam is located at RM 112.0 and the downstream end of the restoration reach of the Trinity River at the confluence with the North Fork Trinity River is RM 72.5.

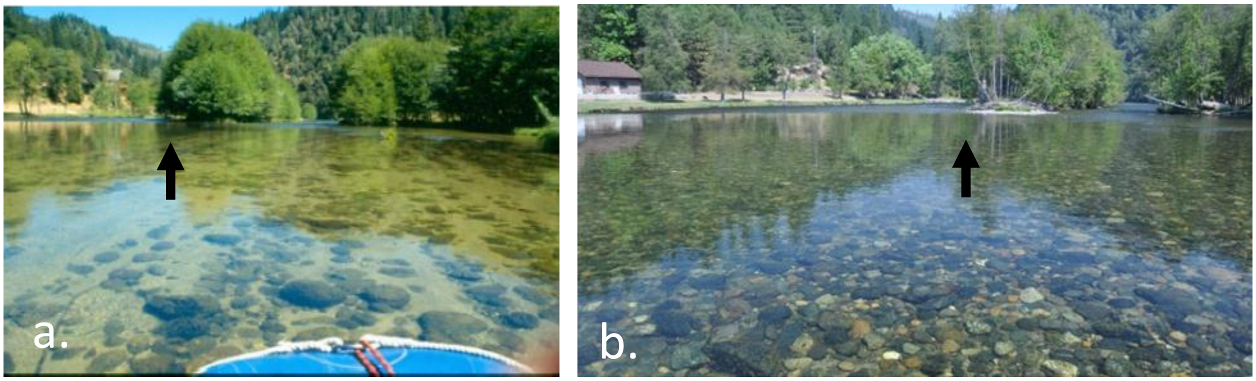

Figure 2. Sand on the channel bed surface at Society Pool tail (RM 101.7) in September 1989 (a.), and relatively few fines on the restored coarse bed surface in 2013 (b.). The arrow in each figure shows the same mid-channel island. The arrows point to the same location in both photos to orient the reader between views.

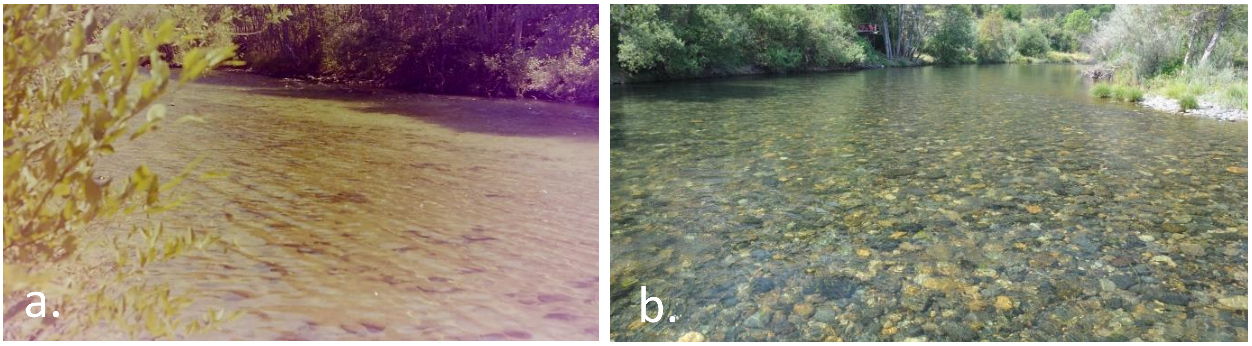

Figure 3. Sand on the bed surface in August 1975 downstream of Poker Bar Hole (RM 102.3; a.) and the same area in 2013 showing a lack of fines on the bed (b.).

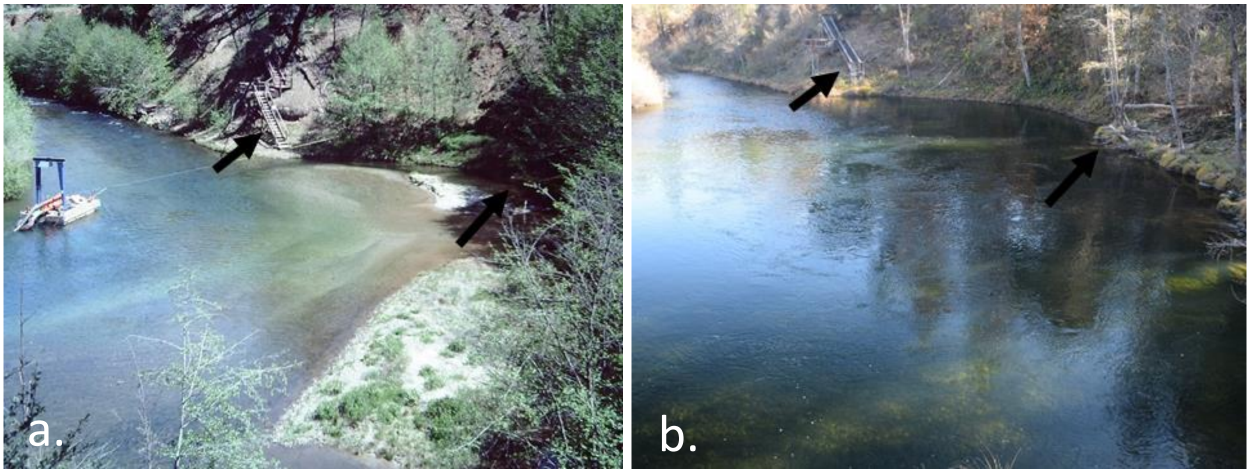

Figure 4. Reo Stott pool (RM 102.5) largely filled with fine sediments in May 1977 (a.) and the same pool with its dimensions restored by evacuation of fine sediments in November 2019 (b.). The arrows point to the same location in both photos to orient views of the pool.

Table 1. Percent egg-to-fry survival estimated for Chinook by the method of Tappel and Bjornn (1983).

Station	Water year								
	2001-2019 average	2019	2018	2014	2009	2001	2000	1997	1991
Lewiston (RM 111.5)	96%	100%	—	95%	92%	97%	94%	—	---
at Rush Creek (RM 107.4)	90%	—	84%	99%	90%	85%	—	—	76%
Poker Bar (RM 102.7)	64%	—	92%	75%	81%	7%	—	—	—
Steel Bridge (RM 99.0)	86%	—	89%	87%	88%	78%	—	—	0%
Indian Creek (RM 95.3)	83%	—	87%	75%	90%	80%	—	—	85%
Upper Steiner Flat (RM 92.0)	87%	—	89%	100%	84%	73%	—	90%	—
Evans Bar (RM 84.1)	84%	—	92%	90%	95%	59%	—	—	—
Junction City (RM 80.3)	85%	—	88%	78%	93%	82%	—	—	—

Table 2. Percent of time in the juvenile rearing period (January–July) that daily average turbidity was measured at stations on the Trinity River[1] and percent of the available data that values were <30 NTU[2].

Water year	TRLG (GMA[3])		TRLG (USBR[4])		TRDC (GMA[3])		TRNF (USBR[4])	
	% time[1]	% data[2]	% time[1]	% data[2]	% time[1]	% data[2]	% time[1]	% data[2]
2001	—	—	61%	90%	—	—	—	—
2002	—	—	100%	83%	—	—	—	—
2003	—	—	95%	85%	—	—	—	—
2004	13%	100%	100%	98%	—	—	—	—
2005	8%	100%	99%	80%	—	—	—	—
2006	30%	100%	100%	77%	89%	94%	—	—
2007	43%	100%	100%	95%	43%	100%	—	—
2008	48%	100%	99%	91%	26%	100%	—	—
2009	57%	100%	99%	95%	20%	100%	—	—
2010	27%	100%	100%	98%	45%	100%	—	—
2011	45%	100%	100%	92%	44%	94%	64%	97%
2012	40%	100%	100%	94%	33%	100%	100%	98%
2013	48%	100%	100%	100%	25%	100%	100%	100%
2014	32%	100%	100%	98%	20%	100%	100%	98%
2015	31%	100%	100%	94%	15%	100%	100%	98%
2016	53%	100%	100%	96%	42%	100%	100%	96%
2017	52%	100%	100%	89%	56%	100%	100%	95%
2018	—	—	100%	92%	—	—	100%	100%
2019	53%	99%	84%	93%	22%	96%	100%	94%

[3] Measured by Graham Mathews and Associates (GMA) in spring flow releases from Lewiston Dam.

[4] Measured year-round by the U.S. Bureau of Reclamation (USBR).

Table 3. Percentages of time that daily average values of severity-of-ill were ≤5 in the juvenile rearing (January–July) and adult spawning (September–January) periods for salmonids in the Trinity River.

Water year	Juvenile Chinook (January – July)			Adult Chinook (September – January)		
	TRAL	TRLG	TRDC	TRAL	TRLG	TRDC
2006	100%	81%	58%	100%	89%	78%
2007	100%	92%	92%	100%	94%	97%
2008	100%	93%	83%	100%	99%	90%
2009	100%	96%	91%	100%	100%	100%
2010	100%	97%	85%	100%	99%	94%
2011	100%	91%	85%	100%	99%	94%
2012	100%	95%	96%	100%	98%	100%
2013	100%	97%	90%	100%	99%	91%
2014	—	—	—	—	—	—
2015	100%	92%	93%	100%	93%	95%
2016	100%	86%	82%	100%	99%	95%
2017	—	81%	71%	—	93%	93%
2018	—	—	—	—	—	—
2019	—	91%	90%	—	100%	100%
Average	100%	91%	85%	100%	97%	94%
High value	100%	97%	96%	100%	100%	100%
Low value	100%	81%	58%	100%	89%	78%

Table 4. Fine sediment targets.

Indicator	Target
Spawning gravel quality and incubation success	Fines ≤ 2 mm $<15\%$ in subsurface bulk samples in spawning areas Chinook egg-to-fry survival $\geq 80\%$ estimated with equation (1) $\sum Q_s/\sum Q \leq 0.05$ tons/cfs in the Chinook egg incubation period (October – March)
Juvenile rearing	Turbidity <30 NTU for >80% of the juvenile rearing period (January – July) $z \leq 5$ for >80% of the rearing period (January – July)
Adult holding and spawning	V^* for pools <0.10 $z \leq 5$ for $\geq 80\%$ of the spawning period (September – January)
Benthic macroinvertebrates	Fines ≤ 2 mm $<30\%$ in subsurface bulk samples on riffles, runs, and glides Embeddedness $\leq 33\%$ outside of pools
Ammocoete rearing	Fines ≤ 2 mm $>28\%$ in composite bulk samples from slack water areas Presence of fine sediment deposits in lee areas of the winter baseflow channel
Nutrient storage	Presence of fines <0.5 mm in suspended sediment samples
Floodplains	Fines ≤ 2 mm $>15\%$ in Wolman (1954) samples Fines ≤ 2 mm $>20\%$ in subsurface bulk samples
Coarse sediment mobility	Fines ≤ 2 mm 5-12% on the bed in Wolman (1954) and bulk surface samples Fines ≤ 2 mm 16-24% in subsurface bulk samples
Channel meandering	Deposit fines ≤ 2 mm on the upper surface and in cut-off channels on bars at RM 73.1, 79.4, 82.0, 104.2, 106.1 to the depth of the local surface D_{84}