APPENDIX II. Rationale and Development of "SMART" Objectives and Conservation Measures for Gravel Augmentation and Rehabilitation in the Merced River for the Benefit of Anadromous Salmonids.[1]

I. **Historical Impacts and Current Conditions**

The area of suitable anadromous salmonid spawning and rearing habitats in the Merced River has been substantially reduced due to anthropogenic influences including dam construction, in-river aggregate mining, and in-river gold dredging mining. The historical impacts have led to the current conditions in the Merced River including: 1) reduction of available spawning area; 2) loss of coarse sediment recruitment into the remaining spawning reaches; 3) reduction of flow magnitude, reducing sediment movement through available habitat; 4) channel incision, disconnecting floodplain and riparian habitats from the main channel and reducing channel gradient over time; and 5) in-channel pits created by mining activity. These impacts are described further below.

As in many Central Valley rivers, a series of dams in the upper Merced River watershed has blocked access to spawning habitat in the upper river, and has blocked the transport of gravel to downstream reaches. Gravel recruitment was blocked from approximately 81% of the watershed following construction of Exchequer Dam in 1926 and New Exchequer Dam at RM 62 in 1967.[2,3] The annual sediment deficiency from New Exchequer Dam capture was estimated to be an average of 231,000 tons, with an estimated bedload yield deficiency of approximately 11,000 to 21,000 tons per annum (based on an assumption that 5-10 percent of total load is bedload). More recently, Merced ID estimated the annual sediment deficit to be 745,000 tons per annum, with estimated bedload yield deficit between 37,000 to 74,000 tons per year.[4] Based upon their earlier findings, Stillwater Sciences' restoration plan for the Merced River estimated that under current flow conditions, initial gravel infusions of 270,000-410,000 tons (Dredger Tailings Reach[5]) would be needed to restore the lower portion of the river (i.e., from below Crocker-Huffman Dam to RM 32.5 at Shaffer Bridge) to conditions approximating a normally functioning pre-development state.[6] Merced ID's recent estimates would require between 540,000 tons to 1,640,000 tons (~450,000 to1,400,00 yd^3) of aggregates of

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[1] SMART is an acronym for Specific, Measurable, Achievable, Realistic, and Time–bound. The specific objectives described in this appendix were developed by the representatives of Resource Agencies and Conservation Groups in November, 2013

[2] Dendy, F.E. and Champion, W.A. 1978. Sediment deposition in US reservoirs: summary of data reported through 1975. USDA Miscellaneous Publication 1362.

[3] Stillwater Sciences. 2001. Merced River Corridor Restoration Plan Baseline Studies Volume II: Geomorphic and riparian investigations. Prepared by Stillwater Sciences, Berkeley California for CALFED, Sacramento, California.

[4] Merced Irrigation District. 2011. Technical Memorandum 1-1. Channel Armoring. Merced Hydroelectric Project FERC Project No. 2179. Available at: http://www.eurekasw.com/MID.

[5] Dredge Tailings Reach (DTR) = RM 52.0 at Crocker Huffman Dam to RM 45.2 near G Street Bridge; Gravel Mining Reach (GM Reach 1) = RM45.2 to RM 32.5 at Shaffer Bridge.

[6] Stillwater Sciences. 2002. Merced River Corridor Plan. February 2002. Stillwater Sciences, Berkeley, 263 p.

differing size ranges (larger aggregate underlay, with spawning aggregate top cover).[7] These initial infusions would then need to be followed by annual infusions of 2,600 yds^3 - 10,400 yd^3, depending upon flows and replenishment volumes needed.[8] Spawning gravel size-class recommendations have been developed by the USFWS Anadromous Fish Restoration Program.[9]

The substrate in the channel bed downstream of the Merced Falls Dam and the Crocker-Huffman Diversion Dam was found to be armored in a FERC ordered Channel Armoring study.[10] The percentage of fine material was low in the restored reaches of the Merced River and fell in the 11th percentage rank compared with 19 other streams; however, the low percentage of fines in this study were likely due to recent additions of large coarse material during gravel augmentation projects in the Merced River.[11] Without continued input of coarse material, and given the continued input of fines from land use practices and erosional processes, spawning habitat will continue to degrade over time.[12]

Mobilization of gravel and fines below Exchequer Dam was further reduced in 1967 when expansion of the McSwain Dam reduced the frequency of high flows, and increased control of flows in the lower reaches,[13] inhibiting the flushing of fine particles (<0.85mm) from coarser bed materials.[14] McSwain Reservoir is typically operated as a re-regulating afterbay for flows released from Lake McClure. This operation allows New Exchequer Powerhouse to be used to meet peak power demands or perform load following functions while still maintaining a steady flow release to the lower Merced River. Merced River flows are modified by the four dams (New Exchequer, McSwain, Merced Falls, and Crocker-Huffman) to limit the effects of floods. Modifying the flows also eliminates the natural variability from the river reaches below the Dams. For example, the 1.5 year recurrence interval for unregulated flow went from 10,062 cfs (cubic feet per second) (below New Exchequer 1902 to 1925) to 1,338 cfs (regulated flow at Snelling 1968 to 1998), an 87 percent reduction, and the 50-year recurrence interval went from 49,177 cfs to 12,513 cfs, a 75 percent reduction. While the average annual flood is an order of magnitude greater below Merced Falls Dam than below Crocker-Huffman Diversion Dam

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[7] Channel Armoring Technical Memorandum 1-1, p. 27.

[8] To restore normal functioning.

[9] Icanberry, J. 2006. Letter to California Department of Fish and Game and California Department of Water Resources regarding AFRP recommended particle size distributions for spawning gravel enhancement projects.

[10] Channel Armoring Technical Memorandum 1-1, p. 13, p.16.

[11] Alberston, L.K., L. E. Koenig, B. L. Lewis, S. C. Zeug, L. R. Harrison and B. J. Cardinale. 2012. How does restored habitat for Chinook salmon (*Oncorhynchus tshawytscha*) in the Merced River in California compare with other Chinook streams? River Res. Applic. 29: 469–482.

[12] Sear, D.A. 1993. Fine sediment infiltration into gravel spawning beds within a regulated river experiencing floods: Ecological implications for salmonids. River Research and Applications. 8(4):373-390.

[13] Merced ID (Merced Irrigation District). 2012. Application for New License. Major Project – Existing Dam. Volume II: Exhibit E.

[14] California Department of Water Resources (CDWR). 1994. San Joaquin River tributaries, spawning gravel assessment, Stanislaus, Tuolumne, and Merced Rivers. Draft memorandum prepared by the Department of Water Resources, Northern District for CDFG. Contract number DWR 165037.

(1,336 cfs and 360 cfs respectively), the 10-year flood is only 16 percent different (7,900 cfs and 6,640 cfs, respectively). Bed shear stress does not often exceed the critical shear stress needed to mobilize the particles, which is necessary if bedload transport is to occur.

Attenuated flows, channel dredging, and the loss of sediment to reservoirs have contributed to a channel that is coarser, narrower, less complex, straighter, and probably deeper than occurred naturally. In addition, these regulated flows have incised the channel, now requiring flows over 5,000 cfs to activate potential floodplain habitat.[15] The changes in the channel described above due to years of flow regulation and lack of gravel recruitment translate into a number of specific impacts to all life stages of fall-run Chinook salmon as well as *O. mykiss* (including resident and anadromous forms). Spawning habitat is degraded due to lack of flushing flows to remove fine sediment from existing gravels, and available spawning area is reduced due to lack of recruitment of spawning gravels from upstream. Juvenile habitat is impacted by the deepening of the channel, which leaves reduced shallow water habitat for refuge from predators and reduced food production to support juvenile growth. The deeper, slower channel created by incision also provides habitat for predators and creates a situation where higher flows are needed to create and inundate floodplain habitat that would improve juvenile survival. Regulated flows create temperature impacts during critical times of the year when low discharges allow rapid heating downstream. Modifying flows may ameliorate these impacts: higher spring flows can inundate side channels and floodplains to create juvenile rearing habitat, and high fall flows in the fall attract adult fall run Chinook salmon into the system. Short-duration high peak flows to flush fine sediments will improve the spawning habitat conditions, and increasing base flows may provide relief from temperature impacts.

In addition to damming in the upper watershed, gold and aggregate mining have had a detrimental effect on spawning and rearing habitats. Approximately 40% of historic gravel beds were excavated from the 7.3 miles of the 19.5-mile reach between Crocker-Huffman Dam and Shaffer Bridge between the years 1939 and 1980 for gold and aggregate mining purposes.[16] Gravel mining reach 1 (RM 45.2 to Shaffer Bridge) contains four historic in-channel mines that occupy 4.4 miles (35 percent) of this reach.[17] The estimated volume of stored bedload removed from in-channel, captured, and breached aggregate mines of the Merced River from 1942 through 1993 was 7 to14 million tons of bedload, or 137,000 to 274,000 tons per annum.[18] This was a 350- to 1,350-fold overdraft of the natural annual bedload supply from the upper watershed.[19] Ponded sections (mid-channel pools) created by this mining have left low quality habitat that traps sediments and sustains large populations of predatory fish, but provides little shelter for salmonids of any life

[15] Merced ID (Merced Irrigation District). 2013a. Technical Memorandum 03-05. Instream Flow below Crocker Huffman. Merced Hydroelectric Project FERC Project No. 2179. Available at: http://www.eurekasw.com/MID.
[16] Stillwater Sciences, 2001, op cit, p. 11.
[17] Stillwater Sciences, 2002, op cit, p. 4-16.
[18] Vick, J. C. 1995. Habitat rehabilitation in the lower Merced River: a geomorphological perspective. Master′s thesis. University of California, Berkeley.
[19] Annual aggregate removal = amount removed ÷ years of operation (data from Vick, 1995)

stage. In addition, trapped sediments prevent replenishment of sediments in spawning habitat of downstream riffles. Input of oversized coarse materials to reduce entrenchment of mid-channel pools and habitat components (e.g. LWD), combined with restoration of spawning bed materials (riffles and tailouts), will reduce predator habitat and raise the channel bed. Reducing the incision or raising the channel bed will reconnect the active channel to the floodplain and riparian zone. The reconnection of the active channel to the floodplain will increase channel velocities to improve both spawning and rearing habitat availability and will improve floodplain inundation opportunities for juveniles.

II. <u>Impacts to Salmonids</u>

The impacts of dam construction, regulated flows, and gravel mining have contributed to the reduction of salmonid populations in the Merced River. Pre-dam, the Merced River supported fall-run Chinook salmon runs (runs) of 40,000 fish. Recent counts are extremely low. Between 2006 and 2011, runs were less than 2000 fish each year.[20] Even in years of high spawner escapement, the current limited availability of spawning habitat may result in high rates of redd superimposition, leading to reduced survival and recruitment.[21] Superimposition can also affect egg survival and overall juvenile production in the Merced River. In the Stanislaus River, superimposition rates are particularly high (82%) at the upstream sites, where redd densities ranged between 0.221 and 0.453 redds per square-yard.[22] This is also apparent in the Tuolumne River, where redd superimposition has been documented to be high due to the limited availability of optimum spawning habitat.[23,24] Habitat restoration for all life stages on the Merced River can provide more available spawning area and reduce impacts from superimposition.

Successful egg survival-to-emergence is often dependent on the physical habitat quality of the incubation environment, as determined by gravel size and the presence and accumulation of fine sediment, which directly affect gravel permeability, intra-gravel flow (i.e., apparent velocity and vertical hydraulic gradient (VHG)), and hyporheic water quality parameters (e.g. DO, temperature, etc.) at the egg pocket.[25] High volumes of fine sediment

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[20] DFG Grand Tab 2014: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84381&inline=1.
[21] Mesick, C. 2010. The high risk of extinction for the natural fall-run Chinook salmon population in the lower Merced river due to insufficient instream flow releases. Prepared by Carl Mesick Consultants for California Sportfishing Protection Alliance. *See* eLibrary no. 20110708-5013, p. 36 ff (pdf pagination).
[22]Mesick, C. F. 2003. Gravel mining and scour of salmonid spawning habitat in the lower Stanislaus River. Report produced for the Stanislaus River Group. Carl Mesick Consultants, El Dorado, CA.
[23] Turlock Irrigation District and Modesto Irrigation District. 2013. 2012 Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 58 of the License for the Don Pedro Project, No. 2299. March. (http://tuolumnerivertac.com/documents.htm).
[24] Stillwater Sciences. 2013. Chinook Salmon Population Model Study Draft Report. Prepared byby Stillwater Sciences, Berkeley, California for Turlock Irrigation District and Modesto Irrigation District, California. July. (http://www.donpedro-relicensing.com/Documents/W_AR6_Chinook_Model_Report[1].pdf).
[25] Kondolf, M. G., A. Falzone, and K.S. Schneider. 2001. Reconnaissance level Assessment of Channel Change and Spawning Habitat on the Stanislaus River below Goodwin Dam. Report to USFWS.

(<2mm) are detrimental to the survival of Chinook salmon and *O. mykiss* eggs[26,27] and have been found to reduce salmonid egg survival to emergence by as much as 95%.[28]

There is a highly significant relationship of gravel permeability rates with survival-to-emergence ratios.[29,30] Even modest reductions in survival to emergence can have serious consequences for the salmon population.[31] To develop the *Restoration Objectives for the San Joaquin River*, empirical predictions were applied to the average permeability at two potential spawning riffles in uppermost Reach 1 of the San Joaquin River (below Friant Dam) and resulted in predictions of 43% and 17% egg survival-to-emergence.[32] Salmon population modeling was used to test the sensitivity by adjusting the percentage of egg survival. Even small adjustments impacted salmon population predictions significantly. Measures that provide optimal conditions for egg-to emergence survival are therefore highly valuable in reaching population targets.

Chinook salmon egg survivorship studies conducted in Central Valley streams show that mean egg survival in the Merced River was higher than that observed in the Mokelumne River and San Joaquin River.[33,34,35] Combined average survival rate for all sites and redds in the Merced River was 47.4 percent. In wild or naturally rearing populations of Chinook salmon, egg to fry survival averaged 38 percent.[36] Merced studies were conducted using eyed eggs, so the 47.4% survival may be artificially inflated due to early development in the hatchery environment.[37] While average egg survival in Mokelumne River studies were lower, gravel augmentation sites in the Mokelumne showed a 24% improvement in average egg survival, and 11% increase in growth over

[26] Reiser, D. W. and R.G. White. 1988. Effects of two sediment size classes on survival of steelhead and Chinook salmon eggs. North American Journal of Fisheries Management. 8: 423-437
[27] Tappel, P.D., and T. C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3: 123-135.
[28] Meyer, C. B. 2003. The importance of measuring biotic and abiotic factors in the lower egg pocket to predict coho salmon egg survival. Journal of Fish Biology. 62: 534-548.
[29]Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Master's thesis. University of Washington, Seattle.
[30]McCuddin, M. E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. Master's thesis. University of Idaho, Moscow.
[31] Stillwater Sciences. 2003. Restoration Objectives for the San Joaquin River, March 2003. Prepared for Natural Resources Defense Council, San Francisco, CA., and Friant Water Users Authority, Lindsay, CA.
[32] *Ibid.*
[33] Merz, J. E., Setka, J.D., Pasternack, G.B., and Wheaton, J.M. 2004. Predicting benefits of spawning habitat rehabilitation to salmonid (*Oncorhynchus* spp.) fry production in a regulated California River. Can. J. Fish Aquat. Sci. 61: 1433-1446.
[34] San Joaquin River Restoration Program. 2012. Egg viability in the San Joaquin River Restoration Area. Annual Technical Report. San Joaquin River Restoration Program. www.restoresjr.net.
[35] Merced ID (Merced Irrigation District). 2013b. Technical Memorandum 3-6. Egg Viability. *See* eLibrary no, 20130308-5222
[36] Quinn, TP. 2005. The Behavior and Ecology of Pacific Salmon and Trout. University of Washington Press, Seattle. 378 pages.
[37] Egg Viability Technical Memorandum 3-6, p. 30.

unenhanced sites.[38] This increase in egg survival at augmentation sites validates our goal of long-term gravel replenishment. Replenishment will provide both improvements to existing habitat quality and increased habitat quantity. Combining these two elements, creating more spawning surface area and improving conditions within existing spawning area, may provide cumulative benefits to egg survival to emergence and in meeting long term population targets.

Under current flow regimes, the capacity of the juvenile habitat is so constrained that a small number of spawners can saturate the habitat with juvenile salmon, such that we see no increase in recruits with higher spawner counts from 500 to 10,500.[39] In high-flow years, however, the Merced River spawner-recruit analysis shows an increase in recruits as spawner abundance increases; however, the relationship appears to be driven primarily by increased survival observed at high flows.[40] This observation leads to the conclusion that habitat measures aimed at increasing spawning habitat must also address the issues of rearing habitat to maintain river function and to provide improved conditions for salmonids at all life stages.

The goal of this measure is to ensure that Project operation is consistent with the Final Restoration Plan for the Anadromous Fish Restoration Program (AFRP) and its goal to double the natural production of anadromous fish under the Central Valley Project Improvement Act CVPIA).[41] The goal is also to assure that the designated beneficial uses listed in the Water Quality Control Plan for the Sacramento and San Joaquin River Basins (Basin Plan) are protected. Designated beneficial uses for the Merced River include 2.1.3 Cold Freshwater Habitat, 2.1.10 Fish Migration, and 2.1.18 Fish Spawning.[42]

In 2013, the licensee submitted a draft flow proposal to the relicensing participants that included, as one element, the creation of a Merced River Ecological Resource Group, to provide real-time management of flow and non-flow measures related to the Merced River. The current measure as proposed provides the technical information to guide gravel augmentation and habitat creation in the Merced River to allow for adaptive management of gravel guided by such a group.

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[38] Merz *et al*., 2004, op cit.
[39] Mesick, 2010, op cit, p. 16.
[40] *Ibid*.
[41] USFWS. 2001. Final Restoration Plan for the Anadromous Fish Restoration Program; A Plan to Increase Natural Production of Anadromous Fish in the Central Valley of California. January 9, 2001. Prepared for the U.S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program. Stockton, CA.
[42] Central Valley Regional Water Quality Control Board. 1998 Basin Plan.

III. **Summary and Development of SMART Objectives for Chinook Salmon in the Merced**[43]

Various studies have characterized Chinook salmon spawning habitats in the Merced River using habitat preferences, such as: depth (≥ 24 cm), velocity (30-91 cm/sec), and substrate size (D_{50} 40-70 mm).[44,45,46] The weighted usable area estimated maximum in-channel spawning area for a discharge of 225-275 for three subreaches between Crocker-Huffman and Shaffer Bridge, as 47,205 ft^2 (4,385 m^2) within the 30.2 km reach for Chinook salmon and 99,454 ft^2 (9,239 m^2) for *O. mykiss* between 400-650 cfs discharge rates.[47] These values represent stream surface weighted by velocity, depth, and substrate or cover, normalized to 1,000 linear units.[48]

The AFRP doubling goal for the Merced River is 18,000 adults (this number includes providing 10% for ocean harvest). Calculations of spawners needed to support this goal (Table 1) based on survival estimates from the Tuolumne River (the closest tributary with long-term survival estimates available), empirical egg survival estimates from the Merced River[49], fecundity from the Mokelumne River[50], and redd sizes[51,52], show 4,743 females would be needed to produce 18,000 adults. The spatial extent needed to provide spawning space (7.2m^2/redd), adjusted by adding "4x redd area" defensible space surrounding individual redds, would be 68,523 m^2.[53] Given the results of the 2013 IFIM study and the calculation of area needed (Table 1), the Merced River has a deficit of over 64,000 m^2 of spawning habitat beyond what currently exists (4,385 m^2) to support doubling CV Chinook salmon and enhancing CV steelhead populations.[54] Specific annual restoration priorities and implementation plans should be determined by the Merced River Ecological Resource Group.

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[43] While Conservation Groups' recommended gravel augmentation measures also includes the Merced Falls Reach, these objectives were generated based on current extent of anadromous fish and associated data downstream of Crocker-Huffman Dam.
[44] Kondolf, G. M., and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29:2275–2285.
[45] USFWS. 1997. Identification of the instream flow requirements for fall-run chinook salmon spawning in the Merced River, California. U.S. Fish and Wildlife Service, Sacramento, Calif.
[46] Instream Flow Technical Memorandum 3-6.
[47] . *Ibid.*
[48] *Ibid*, p. 61.
[49] Egg Viability Technical Memorandum 3-6.
[50] Kaufmann, R.C., A.G. Houck, M.L. Workman, and J.J. Cech. 2009. Chinook salmon length/ fecundity: a regression model for the Mokelumne River, Ca. Cal. Fish and Game 95(2):88-105.
[51] Bjornn, T.C., and D.W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. In: W.R.Meehan, ed. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication. 19:83-138.
[52] Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313-393 in C. Groot and L. Margolis, editors. Pacific Salmon Life Histories. UBC Press, University of British Columbia, Vancouver.
[53] Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish Wildlife Service, Fish. Bull. 61:97-110
[54] Instream Flow Technical Memorandum 3-5

Table 1. Back Calculation of Number of Spawners needed to support AFRP Doubling Target

Parameter	Measure (high)	Reference
Doubling Goal	**18,000**	USFWS 2001
Smolt to Adult Survival	2.50%	Mesick 2010
Number of Smolts	**720,000**	
fry to smolt survival	12%	Sonke and Fuller 2012
Number of Fry	**6,020,067**	
egg to fry survival	47.40%	MID 2013b
Number of Eggs	**12,700,563**	
eggs per spawner	5,338	Kaufman et al 2009
Number of Females	**2,379**	
sex ratio	50%	
Total Spawners	**4,759**	
Per Redd area	7.2m^2	Bjorn and Reiser 1991; Healey 1991
Redd Buffer Area	4x the redd area	Yager et al 1997
Total Redd Area	**68523**	

Flows to encourage bedload mobility and gravel cleaning (i.e. super fine materials and vegetative growth and wildlife habitat) are an important component of the gravel rehabilitation actions. USFWS has conducted gravel mobilization/flow studies on the Merced River Ranch restoration project site (USFWS 2012 Unpublished Data).[55] Flows to mobilize restored spawning gravels (median size = 25 mm) at the Merced River Ranch were in the 1,600-2,000 cfs range; this forms the basis for the low end of sediment mobilizing flows. On the Mokelumne River, slightly higher flows than suggested here (1507-5004 cfs) would be required to mobilize significant percentages (30%-75%) of the substrate gravels.[56] Gravel augmentation and wing dam construction in the Merced River have localized effects in aggrading the channel bed and decreasing surface grain size, but may not have reach-scale effects because the river does not have the energy to transport a significant amount of bedload.[57] At the Snelling Site, the model predicted that the threshold of incipient motion (i.e., flows sufficient to mobilize the bed) is reached at approximately 4,800 cfs (approximately a 5-year flood under post-dam conditions) and that the average annual bedload transport rate (Qs) is approximately 550 tons/year.[58] Thus, restoration-based estimates of ~2,000 cfs should be considered minimum mobilization flows for the Merced River based on localized conditions only, and flows approximating 5,000 cfs will provide more reach-scale sediment transport for long term

[55] Ramon Martin, USFWS Lodi, pers. comm.
[56] Merz *et al*., 2004, op cit.
[57] Stillwater Sciences, 2004. Merced River Corridor Restoration Plan. Phase IV Dredger Tailings Reach. Technical Memorandum #3. Sediment Transport Model of the Merced River Dredger Tailings Reach. May 2004. Stillwater Sciences, Berkeley. 55 p.
[58] Stillwater Sciences, 2004, p. 27.

maintenance. The final establishment of Merced River geomorphic flows, and their timing, can be managed further in-field evaluations and decisions of the Merced River Ecological Resources Group.

Previous and continuing gravel augmentation projects between 1990 and 2011 have placed a total of 32,675 metric tons of gravel for enhancements of spawning habitat for adult Chinook salmon/ *O. mykiss* (Figure Appendix-1 below). In 2006 and 2008, the effects of gravel augmentation were no longer quantifiable in riffles within 0.3 mile of the Crocker Huffman Dam.[59,60,61] In the Merced ID Channel Armoring study, surface sediments were more coarse than subsurface sediments in the Crocker-Huffman Reach (RM 52 and downstream; P<0.01). Twelve of the 28 samples could be considered weakly or non-armored, whereas only three samples could be considered strongly armored (Figure 4.1-4 below).[62] Thirteen samples were in the range between the 1.3 and 4.0 thresholds and are considered “moderately armored.” The samples immediately downstream of gravel augmentation sites were not armored, and the samples downstream of diversions were moderately to weakly armored. Over 50% of the samples taken in the study were considered strongly to moderately armored, suggesting some limitation to anadromous salmonid spawning habitat.

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[59] Stillwater Sciences, 2001, p. 29.
[60] Stillwater Sciences, 2007. The Merced River Alliance Project, Interim Biological Monitoring and Assessment Report. April 2007. Stillwater Sciences, Berkeley, p. 105.
[61] Stillwater Sciences, 2008. The Merced River Alliance Project. Final Report, Volume II, Biological Monitoring and Assessment. September 2008. Stillwater Sciences, Berkeley, p. 8-15..
[62] Channel Armoring Technical Memorandum 1-1, Figure 4.1-4.

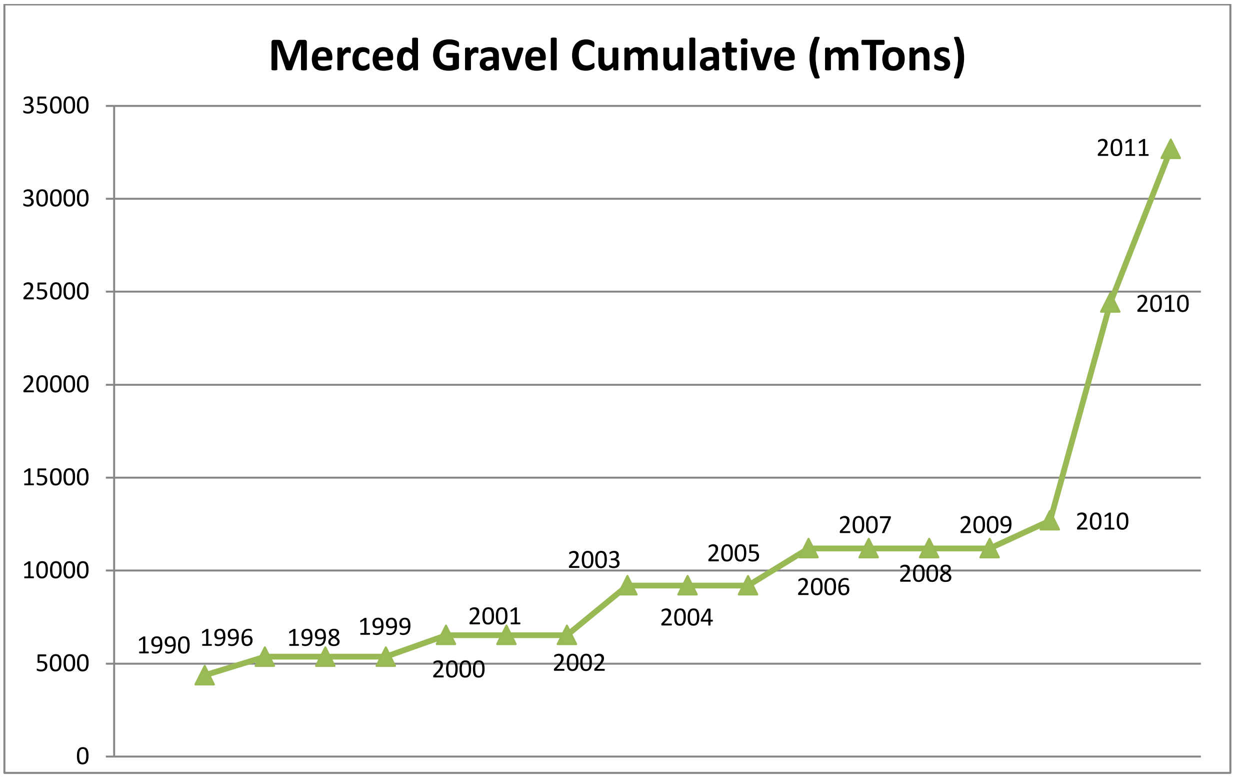

Figure Appendix-1. Cumulative tons of spawning gravel that have been added since 1990 by CDWR, CDFW, MFFC, and USFWS in the Merced River, CA.

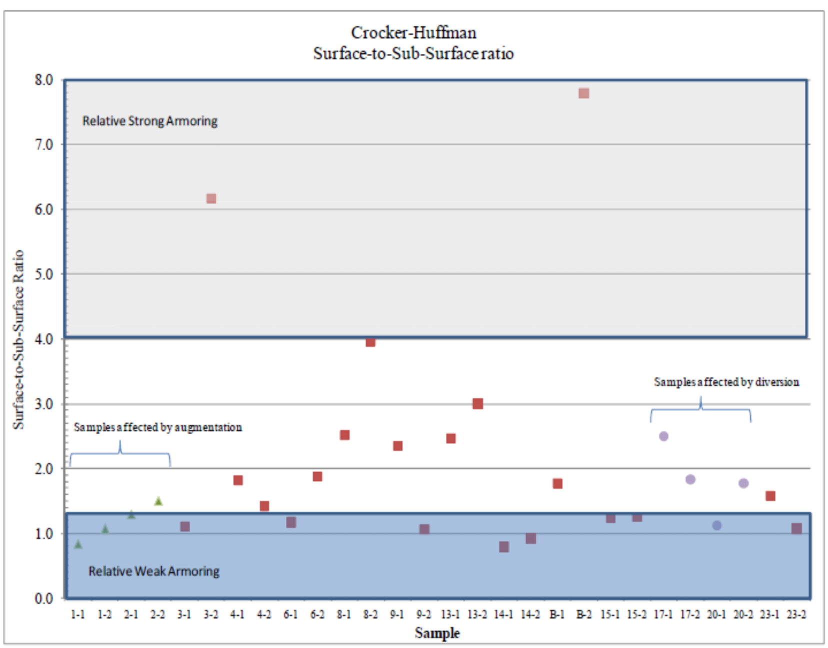

Figure 4.1-4. Crocker-Huffman Reach: surface-to-sub-surface ratio (D_{50s}:D_{50ss}; degree of armoring "armoring ratio") for each sample.

Suitable spawning habitat typically consists of sediment sizes that are movable by females during redd construction (approximately 10% of fish fork length), low levels of fine sediment accumulation, and gravel permeability sufficient to allow minimum intra-gravel dissolved oxygen and water velocity requirements of salmonid eggs.[63,64] The proposed action is within the lower Merced River between Merced Falls Dam (RM 54.9) and Shaffer Bridge (RM 32.5). The Merced River Instream Flow study delineated maximum WUA for the area encompassed by the proposed action. Maximum WUA calculations for Chinook spawning are 10,705ft^2 in sub-reach 1 at 275 cfs; 20,456 ft^2 for sub-reach 2 at 250 cfs, and 16,044 ft^2 in sub-reach 3 at 225 cfs.[65]

Each salmon redd occupies approximately 7.2 m^2 (and 4.7 m^2 for steelhead), based on the mean redd size from studies where Chinook and *O. mykiss* redds were measured in the field.[66,67] Additionally, an "average defended redd area" per redd of approximately 4 times the redd area is necessary.[68,69] Fecundity values for age 2, 3 and 4 year old fall-run Chinook salmon on the Mokelumne river were estimated as 4,185, 5,835 and 5,994, respectively, averaging 5,338, and can be used to approximate fecundity in Merced River adults.[70] Egg survival rates in the Merced averaged 47.4%.[71]

If we use fry to smolt survival estimates based on Tuolumne River data from 2008-2012[72] and smolt to adult survival of 2.5-3.6%,[73] it should result in the following outcomes:

- **Primary Outcome:** Restore spawning habitat for adult Chinook salmon / *O. mykiss* trout to increase egg to emergence survival.
    - Implicit: increase amount of suitable Chinook salmon and *O. mykiss* spawning habitat (area).

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[63]Kondolf, M. G. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society. 129: 262-281.
[64] Merz, J. E. and J. D. Setka. 2004. Evaluation of a spawning habitat enhancement site for Chinook salmon in a regulated California river. North American Journal of Fisheries Management. 24:397-407.
[65] Instream Flow Technical Memorandum 3-5, pp. 61, 68, 71, 74. While there were bimodal peaks in sub-reach 2, the slope of the WUA curve starts to re-ascend only at about 1750 cfs, and the second peak occurs at a flow of 5,603 cfs; this bimodal portion of the curve was not used in the present calculations. The Instream Flow study did not include the Merced Falls reach.
[66] Healy, 1991, op cit.
[67] Burner, 1951, op cit.
[68] Bjornn, T.C. and D.W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. In: W.R. Meehan, ed. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication. 19:83-138.
[69] Jager, H. I., H. E. Cardwell, M. J. Sale, M. S. Bevelhimer, C. C. Coutant, and W. VanWinkle. 1997. Modeling the linkages between flow management and salmon recruitment in streams. Ecological Modeling 103: 171-191.
[70] Kaufmann *et al.*, 2009, op cit.
[71] Merced ID, Technical Memorandum 3-6, p. ES-3..
[72] Sonke, C., and A. Fuller. 2012. Outmigrant Trapping of Juvenile Salmon in the Lower Tuolumne River, 2012. Fish Bio, Inc. Annual Report.
[73] Mesick, 2010, op cit.

- Alternate statement of outcome: increase the number and longitudinal distribution of Chinook salmon/ *O. mykiss* redds and decrease superimposition by 90% and female egg retention to levels less than 10% in the lower Merced River Crocker Huffman Dam (RM 52) and Shaffer Bridge (RM 32.5).
- The number of redds per square meter indicates whether salmon find the gravel appropriate for spawning (0.03 redds/square meter is a standard guideline). The level of egg retention in females indicates whether there are a sufficient number of suitable sites to spawn (less than 10% retention is a standard guideline). The percentage of salmon / *O. mykiss* using enhanced gravel indicates whether the action is providing habitat that is suitable (the action should aim for 10% on the Merced River).
- Increase annual average of egg-to-emergence survival for fall-run Chinook salmon and *O. mykiss* by 24%.[74]

Key Component	Objective
Specific - What is the specific task?	*Increase the survival of Chinook salmon and O. mykiss in the egg-to-juvenile life stages.*
Measurable - What are the standards or parameters?	*The parameters used to estimate egg-juvenile survival rates have been and can continue to be accurately measured. Egg-to-juvenile survival rates can be calculated using estimates of potential egg deposition (number of adult females * number of eggs per female) and estimates of juvenile abundance from rotary screw trap monitoring. We have 1 year of egg survival data on the Merced River, and can use fecundity estimates from Kaufman et al (2009). Regular weir counts and rotary screw trapping are needed to complete Merced specific data as standards/parameters to calculate defensible egg to juvenile survival*
Achievable - Is the task feasible?	*Because limiting factors such as redd superimposition and hyporheic water quality in the egg pocket are to be addressed via spawning habitat augmentation (i.e., increasing spawning habitat quality and quantity), it is reasonable to assume that this objective is achievable.*
Realistic - Are sufficient resources available?	*The implementation of spawning habitat augmentation projects is feasible and proven. Ongoing monitoring will allow for measurement of this objective, and the relicensing participants are supporting the measures to address key limiting factors that influence this objective. Thus, it is reasonable to assume that this objective is realistic.*
Time-Bound - What are the start and end dates?	*Measurement to assess this objective would begin once implementation of conservation measures designed to increase spawning and rearing habitat and to increase juvenile production are completed. Some of these activities (such as sediment augmentation) would be in perpetuity, and thus measurement of this objective would continue. Measurement would run for a minimum of 10 years.*

[74] Merz *et al*., 2004, op cit.

- **Secondary Outcomes:**
    - Macroinvertebrate production
    - Implicit: Increase channel habitat complexity.
    - Implicit: Increase hyporheic flow and improve intra-gravel water quality (i.e. dissolved oxygen, temperature) and permeability for egg incubation, within the gravel size distribution appropriate for redd construction.
    - Implicit: Increase life history diversity by improving spawning and egg incubation conditions (i.e. spatial and temporal).
    - Implicit: Improve riparian habitat and cottonwood recruitment by restoring fluvial geomorphic processes.
    - Implicit: Improve riparian habitat for the beneficial use of wildlife
    - Implicit: Reduce predation on juvenile Chinook salmon/ *O. mykiss* by isolating ponded sections and/or creating diverse pool/riffle/run complexes in the river and creating alluvial braided channels.
    - Increasing the area of suitable spawning habitat should decrease the area of habitat available for predatory fish.
    - Improving opportunities for overbank inundation (floodplain rearing habitat) by raising the existing bed level.

- **Action:** Increase and enhance Chinook salmon/ *O. mykiss* spawning habitat by adding 20,000 yd^3 per year of coarse sediment[75] to meet the long-term target of additional surface area of 64,139 m^2 of spawning habitat (above the available 4,385 $m^{2)}$ to support the AFRP doubling goal target for the Merced River between Crocker Huffman Dam (RM 52) and Shaffer Bridge (RM 32.5). Implement this using AFRP-recommended gravel sizes as well as larger cobbles to raise the bed elevation. Once this target is met, long-term maintenance additions to support no net loss of spawning habitat thereafter (2,600 yds^3 to 10,400 yds^3 per annum).

Particle Size (inches)	Percent Passing	Percent Retained
4" or 5"	95%-100%	0%-5%
2"	75%-85%	15%-30%
1"	40%-50%	50%-60%
3/4"	25%-35%	60%-75%
1/2"	10%-20%	85%-90%
1/4"	0%-5%	95%-100%

Table 2. AFRP Gravel Size Recommendations

- **Approach:**

[75] There is between 450,000 and 1,400,000 yd^3 of sediment deficiency. At a 20,000 yd^3 annual replenishment rate, the time would be between 22 and 70 years for the gravel rehabilitation.

- Increase and improve Chinook salmon/ *O. mykiss* spawning and rearing habitat by adding cleaned spawning sized gravels and larger materials to degraded areas within the 19.5 mile salmonid spawning reach in the lower Merced River.
- Up to 1.4 M yd^3 of cleaned spawning sized gravel and larger cobble will be harvested from the project area and inserted into the river, creating or restoring riffles, and restoring fluvial geomorphic processes, on an annual budget of 20,000 yd^3. Following the initial large-scale gravel augmentations, an annual maintenance augmentation of up to 10,400 yd^3 will be added to the river.
- Provide ~64,139m^2 additional spawning surface area to support doubling the Merced River salmon population
- Aggregate harvest will be completed in a manner that creates new floodplain areas, and in-channel placement will be completed in a manner that increases local floodplain inundation (e.g., raises the channel bed). Fine sediments harvested will be used to support riparian recruitment on created floodplain habitats.

Table 3. Summary of selected existing salmonid habitat conditions and restoration opportunities on the Merced River.

FALL-RUN CHINOOK SPAWNING

SUITABLE CONDITION (Oct-Dec; Merced Falls to Shaffer Bridge		**EXISTING CONDITION**				**RESTORATION OPPORTUNITY**		
FACTOR	***RANGE***	***LOCATION***	***TIMING***	***RANGE***	***QUALITY***	***PROBLEM(S)***	***POTENTIAL CAUSE***	***IMPACT***

Gravel Quantity	O. mykiss: 4.7m^2 average redd dimension[76] Chinook Salmon: Avg. of 24 yds^3 gravel substrate per spawning pair[77]	Merced Falls Dam to Crocker Huffman DD Crocker Huffman to Shaffer Bridge	-	9,239 m^2 of suitable spawning habitat from Merced Falls to Crocker Huffman[78] 4,385 m^2 of suitable spawning habitat from Crocker Huffman to Shaffer[79]	Unsuitable	• Total area of spawning gravel between Crocker Huffman and Shaffer Bridge is inadequate to support doubling goal targets (AFRP) • Limited gravel recruitment • Redd superimposition	• Gravel recruitment reduced due to blockage by dams, reduced transport flows; changes in streamside land use; riparian encroachment.	H

[76] Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313-393 in C. Groot and L. Margolis, editors. Pacific Salmon Life Histories. UBC Press, University of British Columbia, Vancouver.
[77] Burner, 1951.
[78] Channel Armoring Technical Memorandum 1-1.
[79] *Id*..

Gravel Quality	O. mykiss: 0.5 inches to 4 inches [80] Chinook Salmon: 0.5 inches to 4.02 inches in diameter[81]	Merced Falls to CHDD CHDD to Shaffer Bridge	-	Merced Falls Reach – 16 out of 20 riffles were at least moderately armored (3 strongly) [82] 16 out of 28 riffles were a t least moderately armored from CHDD to Shaffer Bridge (3 strongly)[83]	Unsuitable	• Armoring • Redd superimpositi on	• Infrequent bed mobilization (reduced transport flows)[84] • Loss of functional floodplain habitat[85,86,87] • Gravel recruitment reduced (see gravel quantity)	H
Escape Cover	Overhandi ng vegetation , undercut banks, submerge d	Merced Falls to CHDD CHDD to Shaffer Bridge	Oct-Dec	Not quantified from above CHDD Observations of cover types: 30 log; <20	Not quantified from above CHDD Most available cover is fine woody material	• Reduction of large wood recruitment from upstream sources • Reduction of	blockage by dams, reduced transport flows; changes in streamside land use; reduced riparian recruitment	M

[80] Orcutt, D.R., B.R. Pulliam, and A. Arp. 1968. Characteristics of Steelhead Trout Redds in Idaho Streams. Trans. Amer. Fish. Soc. 97(1):42-45.
[81] Reiser, D.W. and T.J. Bjorn. 1979. Habitat requirements of anadromous salmonids. In W.R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in the Western United States and Canada. U.S. Forest Service Gen. Tech. Rep. PNW-96, Northw. Forest Range Exp. Sta., Portland, OR.
[82] Channel Armoring Technical Memorandum 1-1.
[83] *Id.*
[84] Instream Flow Technical Memorandum 3-5.
[85] McBain and Trush. 2003. Coarse Sediment Management Plan for the Lower Tuolumne River. Final Report. Pg 77.
[86] Kondolf *et al*., 2001.
[87] McBain and Trush, 2003.

	vegetation, submerged objects (e.g., logs and rocks), floating debris, and water depth and turbulence [88]			overhanging vegetation, <10 undercut banks, >70 fine woody material [89]	and aquatic vegetation. Low representation of larger cover items	local large wood recruitment within CHDD to Shaffer Bridge		

[88] Albertson *et al*., 2012, op cit.
[89] *Id*.