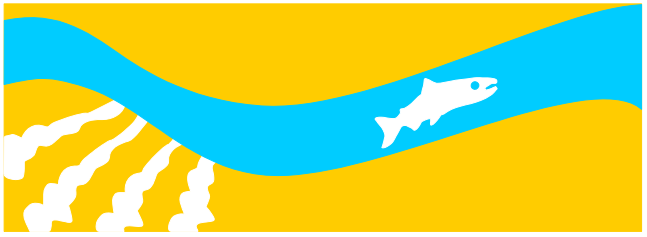
Exhibit C

Spawning Habitat Characterization

Fisheries Management Plan:
A Framework for Adaptive Management in the San Joaquin River Restoration Program

SAN JOAQUIN RIVER
RESTORATION PROGRAM



November 2010

Information on spawning habitat characteristics of Chinook salmon and other fishes are valuable for guiding restoration activities focused on spawning habitat. This exhibit provides a summary of known spawning criteria of salmon and other fishes to help guide the restoration planning process.

The abundance of Chinook salmon spawning-sized gravels below Friant Dam has been gradually reduced as a result of the upstream dams blocking sediment recruitment and gravel mining from the river terrace and the river channel. An absence of gravel recruitment tends to reduce the amount of useable spawning habitat in three ways. First, without recruitment, uncontrolled high-flow releases scour the gravel from the spawning beds so that they gradually become smaller in length and the depth of the gravel becomes shallower. Second, the smaller gravels tend to be mobilized at the highest rates, which causes the bed surface to armor with large rocks that can be too large for the salmon to move for redd construction. Both the reduction in spawning bed size and the armoring of the bed's surface has the effect of crowding the spawners into the remaining usable spawning areas. Crowding is thought to increase the rate of redd superimposition, when spawners construct new redds on top of preexisting redds, thereby killing or burying some of the eggs in the original redds. The third problem caused by reduced gravel recruitment is that uncontrolled scouring flows also erode sediment from the floodplains. For a thorough description of spawning habitat criteria for spring- and fall-run Chinook salmon, the reader is, the reader is referred to Exhibit A.

Table C-1 summarizes salmonid spawning habitat characteristics, including substrate size, water depths, and velocities, from populations in the Pacific Northwest. Tables C-2 through C-4 present information regarding ratios of sediment size composition identified in three Central Valley studies as suitable for spawning Chinook salmon. The concentration of fine sediment (e.g., sediment with D50 less than 1 millimeter (mm)) in spawning gravels is considered an important factor in egg survival and fry emergence. Raleigh et al. (1986) recommends less than 10 percent fines and other studies indicate less than 12 to 14 percent of gravels should be finer than 1 mm to produce 50 percent incubation success for salmonids (Kondolf 2000).

Table C-5 summarizes spawning habitat characteristics for other fish species, including substrate size, water depths, and velocities, and spawning habitat and egg descriptions. Some categorical data were included in the tables based on text from associated references that lack precise definitions, because they represent the best information.

Table C-1.
Salmonid Spawning Habitat Characteristics

Species (Run)	Location	Substrate size (cm)		Water depth (m)		Water velocity (m/sec)		Reference
		Range	Mean or Optimum	Range	Mean or Optimum	Range	Mean or Optimum	
California Central Valley Streams								
Chinook (Fall)	American River	.04 to 30.5	N/A	N/A	N/A	N/A	N/A	20
Chinook (Fall)	Central Valley basin	2.5 to 10.0	2.5 to 5.0	N/A	N/A	N/A	N/A	21
Chinook (Fall)	Merced River	5.0 to 30.0	N/A	N/A	N/A	0.3 to 1.3	N/A	8
Chinook (Fall)	San Joaquin River	N/A	N/A	0.1 to 2.0	N/A	0.15 to 1.0	N/A	17
Chinook (Fall)	Stanislaus River	0.6 to 12.7	N/A	N/A	N/A	N/A	N/A	12
Chinook (Fall)	Tuolumne River	0.8 to 12.8	3.5	N/A	N/A	N/A	N/A	14
Chinook (Spring)	Central Valley basin	2.5 to 10.0	2.5 to 7.5, 5.0 to 10.0	N/A	N/A	N/A	N/A	21
Chinook (Spring)	Clear Creek	2.5 to 15.0	5.0 to 10.0	N/A	N/A	N/A	N/A	19
Chinook (Spring)	San Joaquin River	N/A	N/A	0.1 to 2.0	N/A	0.15 to 1.0	N/A	17
Steelhead	Clear Creek	.25 to 15.0	2.5 to 5.0	N/A	N/A	N/A	N/A	19
Steelhead	San Joaquin River	N/A	N/A	0.2 to 1.5	N/A	0.6 to 1.15	N/A	17
Columbia River and Tributaries								
Chinook (Fall)	Hanford Reach	N/A	N/A	1.2 to 2.6	1.4	0.4 to 1.9	N/A	4
Chinook (Fall)	Hanford Reach	5 to 30	10.0 to 20.0	0.3 to 9.0	1.8 to 7.6	0.4 to 2.0	N/A	18
Chinook (Fall)	Near Wells Dam	N/A	N/A	1.6 to 9.6	5.3 to 7.2	0.4 to 1.2	0.9	9
Chinook (Fall)	Not Specified	N/A	N/A	0.2 to 2.0	N/A	0.8 to 1.1	N/A	3
Chinook (Fall)	Upper	N/A	N/A	0.6 to 4.5	N/A	N/A	N/A	5
Chinook (Fall)	Kalama River	N/A	N/A	0.4	N/A	N/A	0.6	2
Chinook (Fall)	Snake River	2.5 to 15.0	N/A	~1 to 2.0	N/A	~0.5 to 1.2	N/A	6
Chinook (Fall)	Snake River	2.5 to 15.0	N/A	0.2 to 6.5	2.8	0.4 to 2.1	1.1	10
Chinook (Fall)	Snake River	N/A	N/A	4.6 to 7.9	N/A	0.3 to 0.7	N/A	7
Chinook (Fall)	Toutle River	N/A	N/A	0.3	N/A	N/A	0.4	2

Table C-1.
Salmonid spawning habitat characteristics (contd.)

Species (Run)	Location	Substrate size (cm)		Water depth (m)		Water velocity (m/sec)		Reference
		Range	Mean or Optimum	Range	Mean or Optimum	Range	Mean or Optimum	
Other River Systems								
Chinook (Fall)	Cambell River, BC	N/A	N/A	0.3 to 0.8	0.6	0.4 to 0.8	0.6	11
Chinook (Fall)	Nechako River, BC	N/A	N/A	N/A	N/A	0.15 to 1.0	0.5	15
Chinook (Fall)	Oregon Streams	N/A	N/A	0.4	N/A	N/A	N/A	16
Chinook (Fall)	Not specific	1.3 to 10.2	N/A	N/A	N/A	N/A	N/A	1
Salmonids	Not specific	a	N/A	N/A	N/A	N/A	N/A	13

Sources:

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19 *USFWS, SFWO, Energy Planning and Instream Flow Branch Clear Creek (Whiskeytown Dam to Clear Creek Road) Spawning Final Report, August 15, 2007.*

20 *Vyverberg, K., B. Snider, and R.G. Titus. 1997. Lower American River Chinook Spawning Habitat Evaluation. DFG Environmental Sciences Division. Pg 2-7.*

21 *Exhibit A*

Key: A = Maximum to be 10% of median female salmonid length cm = centimeters m = meters m/sec = meters per second N/A = data not available

Table C-2.
Sediment Ratios for Chinook Salmon Spawning Habitat Based on Vyverberg et al. (1997) Study Results

Millimeters	Inches	Percent by volume
152 to 305	6 to 12	30% or Less
76 to 152	3 to 6	10% or More
25 to 76	1 to 3	50% or less
13 to 25	0.5 to 1	20% or less
4 to 13	0.16 to 0.5	20% or less
0.4 to 4	0.015 to 0.16	20% or less

Source: McBain and Trush. 2003. Coarse Sediment Management Plan for the Lower Tuolumne River. Final Report. Pg 77.

Table C-3.
Sediment Ratios for Chinook Salmon Spawning Habitat Based on McBain and Trush (2003) Study Results

Millimeters	Inches	Standard mix	Finer mix
64 to 128	2.5 to 5	20%	20%
32 to 64	1.25 to 2.5	35%	30%
16 to 32	5/8 to 1.25	30%	30%
8 to 16	5/16 to 5/8	15%	12%
2 to 8	1/8 to 5/16	0%	8%
	D_{84} =	74	74
	D_{50} =	35	32

Source: Vyverberg K, B. Snider, and R. G. Titus. 1997. Lower American River Chinook Spawning Habitat Evaluation. DFG Environmental Sciences Division. Pgs. 2-7.

Key: D_{84} = 84th percentile D_{50} = Median

Table C-4.
Sediment Ratios for Chinook Salmon Spawning Habitat Based on Icanberry (2006) Personal Communication

Millimeters	Inches	Mix
>127	>5	5%
51 to 127	2 to 5	15%
25 to 51	1 to 2	35%
19 to 25	0.75 to 1	15%
13 to 19	0.5 to 0.75	15%
6 to 13	0.25 to 0.5	10%
<6	<0.25	5%

Sources:

1. *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.*
2. *McBain and Trush. 2003. Coarse Sediment Management Plan for the Lower Tuolumne River. Final Report. Pg 77.*
3. *Vyverberg K, B. Snider, and R. G. Titus. 1997. Lower American River Chinook Spawning Habitat Evaluation. DFG Environmental Sciences Division. Pgs. 2-7.*

Table C-5.
Spawning Habitat Characteristics of Other Fishes

Species	Substrate size (cm)			Spawning			Egg comments	Source
	Category	Range	Mean or optimum	Depths (m)	Velocity	Habitat		
Green sturgeon	clean sand to bedrock	0.025 to unk *	12.8 to 25.6 *	>3	fast	N/A	adhesive eggs are broadcast	3, 7, 18
White sturgeon	gravel to boulders	0.2 to unk *	N/A	>3	0.6-2.4 m/sec	deep gravel riffles or in deep holes with swift currents and rock bottoms major Sacramento River spawning area are gravel	adhesive, stick to substrate	11, 16, 18, 27
Sacramento sucker	N/A	N/A	N/A	≥ 0.3	N/A	slight depression in riffle gravels	adhere to gravel or debris or bounce along the bottom until they are caught in gravel or washed to a small backwater	18, 19, 26
Sacramento perch	clay and mud to large boulders	0.0001 to unk *	N/A	0.2 to 1.0	N/A	shallow areas with heavy growth of aquatic macrophytes or filamentous algae nearby	eggs deposited into 20- to 75-cm-deep nests	1, 14 ,15, 18, 20
Prickly sculpin	large rock	N/A	N/A	N/A	moderate	build nest underneath large flat rocks	eggs adhere to ceiling of the nest	12, 18
Riffle sculpin	N/A	N/A	N/A	N/A	N/A	underside of rocks in swift riffles or inside cavities in submerged logs	eggs adhere to underside of rocks or inside cavities in submerged logs	2, 17, 18
California roach	N/A	3.0 to 5.0	N/A	shallow	flowing	shallow flowing areas	adhesive, eggs settle into crevices between rocks and adhere	8, 18
Hardhead	N/A	N/A	0.2 to 6.4 *	shallow	N/A	beds of gravel in riffles, runs, or the heads of pools	N/A	13, 18
Hitch	fine to medium gravel	0.4 to 1.6 *	N/A	N/A	N/A	riffles	eggs are not adhesive but sink into gravel interstices	10, 13, 18, 21

Table C-5.
Spawning Habitat Characteristics of Other Fishes (contd.)

Species	Substrate size (cm)			Spawning			Egg comments	Source
	Category	Range	Mean or optimum	Depths (m)	Velocity	Habitat		
Sacramento blackfish	N/A	N/A	N/A	shallow	N/A	shallow areas with heavy growth of aquatic plants	eggs extruded onto plants	6, 18, 22, 27
Sacramento pikeminnow	gravel to rocks	0.25 to unk *	N/A	N/A	N/A	eggs sink to bottom and adhere to rocks and gravel	adhesive, stick to rocks	13, 18, 23, 27
Sacramento splittail	N/A	N/A	N/A	0.5 to 2.0	N/A	flooded vegetation	adhesive, stick to vegetation and debris	18
Speckled dace	N/A	N/A	N/A	N/A	N/A	gravel edges of riffles	eggs sink into interstices and adhere to rocks	9, 18
Tule perch	N/A	N/A	N/A	N/A	N/A	none, live bearers	N/A	4, 5, 18, 24
Threespine stickleback	N/A	N/A	0.006 to 0.2 *	N/A	N/A	males excavate a shallow pit in sand in beds of aquatic plants and constructs a pile of algae and aquatic plants	eggs are extruded into nest of algae and plant material	18
Kern brook lamprey	gravel to cobble	0.2 to 25.6 *	0.2 to 6.4 *	N/A	N/A	gravel riffles	N/A	18
Pacific lamprey	gravel to cobble	0.2 to 25.6 *	0.2 to 6.4 *	0.3 to 1.5	fairly swift	build nest in gravel areas	eggs sink into interstices and adhere to rocks	18
River lamprey	gravel to cobble	0.2 to 25.6 *	0.2 to 6.4 *	N/A	N/A	they dig saucer-shaped depressions in gravelly riffles	N/A	18
Western brook lamprey	gravel to cobble	0.2 to 25.6 *	0.2 to 6.4 *	~0.15	N/A	build nest in gravel riffles	N/A	18, 25
Rainbow trout	N/A	1 to 13	1.6 to 6.4 *	0.1 to 1.5	0.2-1.5 m/sec	N/A	eggs deposited into redds	18

Table C-5.
Spawning Habitat Characteristics of Other Fishes (contd.)

Sources:

1 *Aceituno, M.E., and C.D. Vanicek. 1976. Life history studies of the Sacramento perch, Archoplites interruptus (Girard), in California. Calif. Fish Game 62:5-20.*

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3 *Brown, L.R. 2000. Fish communities and their associations with environmental variables, lower San Joaquin River drainage, California. Environmental Biology of Fishes 57:251-269.*

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Key:

unk = Unknown

N/A = Data not available

cm = centimeters

m = meters

* = Substrate categories converted to numbers based on Wentworth grain size scale

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