RECLAMATION

Managing Water in the West

Technical Memorandum No. 86-68290-08-02

Klamath River Salmon Redd Scour Study, 2007–2008

Mainstem Klamath River at Willow Creek Confluence, December 11, 2007

U.S. Department of the Interior
Bureau of Reclamation

September 2008

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Summary

Within the Klamath River, the effect of flow on the potential for scouring of coho salmon redds has been identified as data gap. To address this data gap, a better understanding on the relationships between flow, bed mobility, and scour depth in mainstem reaches utilized by spawning coho salmon is needed. During the 2007-2008 winter season, Reclamation conducted a redd scour study to assess the potential impacts of scouring during high winter flows on the success of coho salmon redds within the mainstem of the Klamath River. Scour chains, cross-sectional profiles, and sediment sampling were used at three documented coho spawning locations in the mainstem Klamath River and three redd locations in Horse Creek, a reference tributary. Based on the results from this one-year study, documented bed mobility and scouring depth would suggest that scouring would have had minimum impacts on redds (egg or embryo mortality) within the mainstem of the Klamath River. Results showed the maximum daily Klamath River discharge (3,310 cfs) at Iron Gate Dam during the study occurred March 15, 2008. This discharge has been exceeded during about 78% of the years following completion of Iron Gate Dam in 1961, indicating that the 2007–2008 winter season was relatively dry. Scour chain exposed links and elevations showed little overall change between December 2007 and July 2008. Also, there was no evidence from the cross-sectional profiles that scouring had occurred at the redd locations. Sediment samples showed comparatively similar grain-sized distributions among redd locations.

Introduction

A small number of coho salmon (*Oncorhynchus kisutch*) spawn in the mainstem of the Klamath River each year, but the origin of these fish and the survival of their eggs are unknown (Cramer Fish Sciences 2008). Between 2001 and 2005, a total of 46 coho redds (ranging between 6 and 21 per year) were counted in the Klamath River mainstem (Magneson and Gough 2006). Most redds were concentrated within 20 kilometers (km) downstream from Iron Gate Dam (Magneson and Gough 2006). Cramer Fish Sciences (2007) suggested that coho redds within the mainstem Klamath River are likely scoured by relatively high flows in some years, leading to negligible production potential of the mainstem. Thus, Cramer Fish Sciences (2008) recommended that studies are needed to determine whether mainstem coho spawners are producing viable fry.

Most coho spawn between November and January (Hassler 1987; Nickelson and Lawson 1998). Peak spawning in the mainstem Klamath River occurs around mid-December, coinciding with typical rise in river flows from storm events (Magneson and Gough 2006). Coho eggs incubate for 8–12 weeks before hatching, with time inversely related to temperature (Moyle 2002). Coho egg burial mean depths range from 12–25 centimeters (cm) between the overlying

gravel and the top of the egg pocket (DeVries 1997). DeVries (1997) proposed preliminary coho egg burial depth criteria of 15- to 35-cm depth below the original stream bed level for use in scour studies. These criteria were proposed as maximum depths of scour before initial (top) and total (bottom) egg loss (DeVries 1997). Hatchlings remain in the gravel until their yolk sacs have been absorbed, 4–10 weeks after hatching (Moyle 2002). Thus, for coho spawning in January, time in the gravel could potentially extend to the end of May.

The objective of this study was to assess the potential impacts of scouring during high flows during the 2007–2008 winter season on the success of coho salmon redds within the mainstem of the Klamath River. The 2007–2008 spawning season provided a good opportunity to conduct this study due to the expected large adult coho salmon run.

Study Area

General geographic area is shown in figure 1. Three redd locations were selected that were documented in the mainstem Klamath River (Magnesen and Gough 2006) (figures 2 and 3; table 1). In addition, three reference redd locations were selected in one tributary (Horse Creek), determined after consultation with biologists from the Karuk Tribe (figure 4; table 1). Recently constructed redds were observed during the December survey at each location.

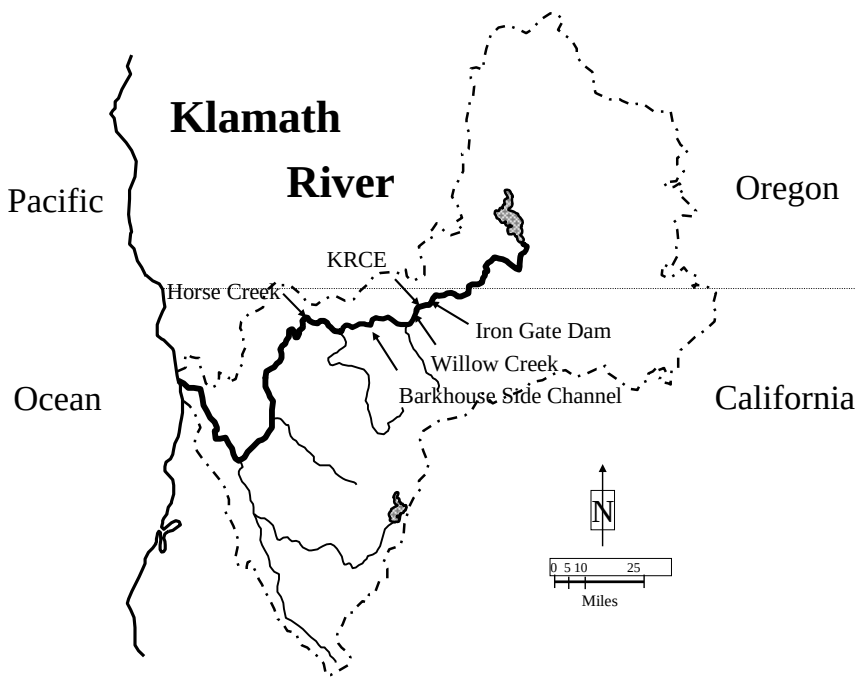

Figure 1. Study area for Klamath River redd scour study.

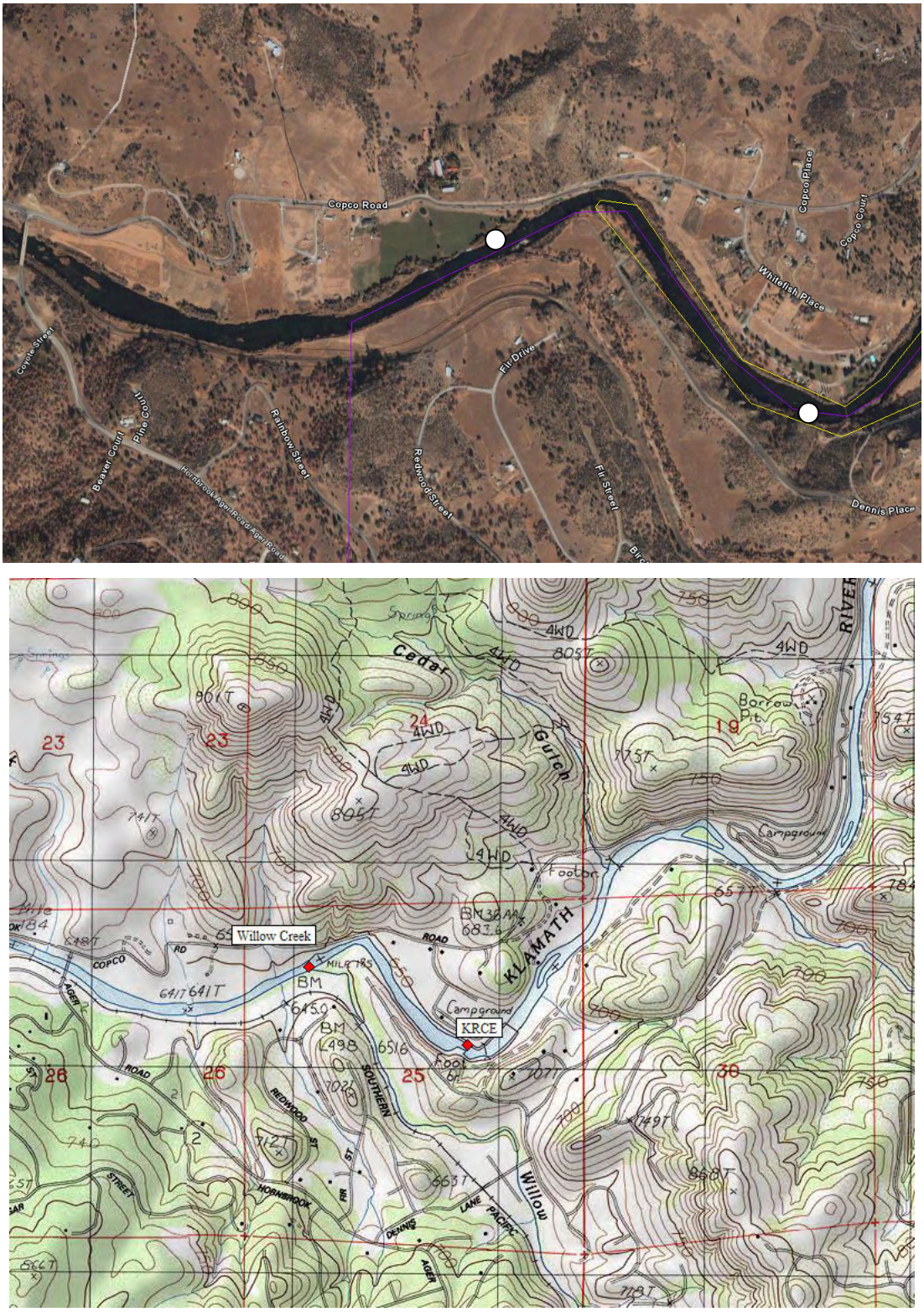

Figure 2. Locations of redds in mainstem Klamath River at Klamath River Country Estates and Willow Creek (aerial photo top; topo map bottom).

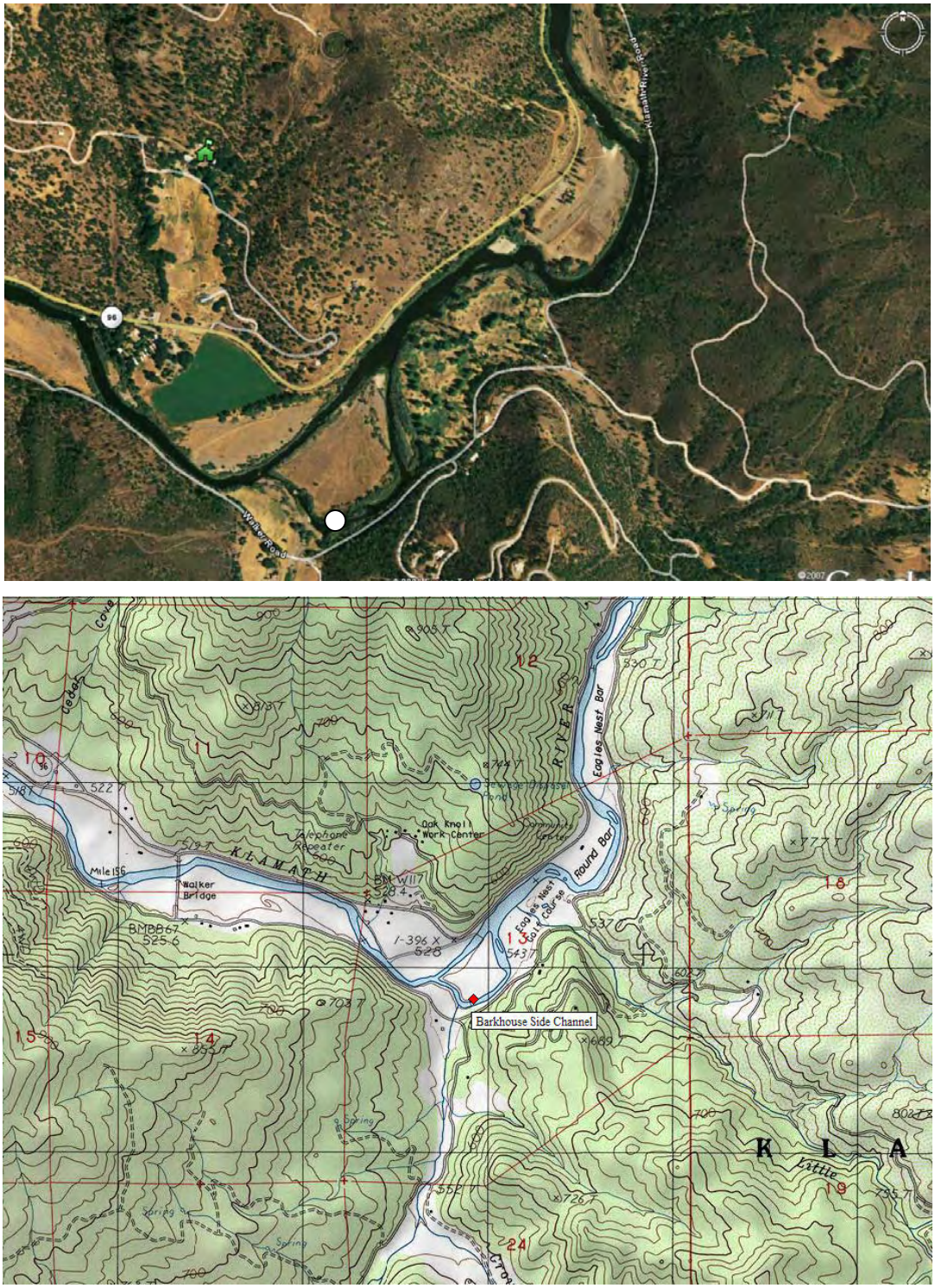

Figure 3. Location of redd in mainstem Klamath River at Barkhouse Creek side channel (aerial photo top; topo map bottom).

Table 1. Study locations for Klamath River scour study

Location Description	RKM	Mesohabitat Type	GPS Coordinates	
			Latitude	Longitude
Mainstem Near Klamath River Country Estates (KRCE)	303.1	Low slope	N41°53.734’	W122°29.074’
Mainstem at Willow Creek mouth	302.0	Low slope	N41°53.956’	W122°29.648’
Mainstem at Barkhouse Creek Side Channel	256.7	Pool	N41°49.863’	W122°50.720’
Horse Creek – Lower Site	240.0	Moderate slope	N41°50.397’	W123°01.077’
Horse Creek – Middle Site	–	Moderate slope	N41°50.434’	W123°01.292’
Horse Creek – Upper Site	–	Moderate slope	N41°50.515’	W123°01.433’

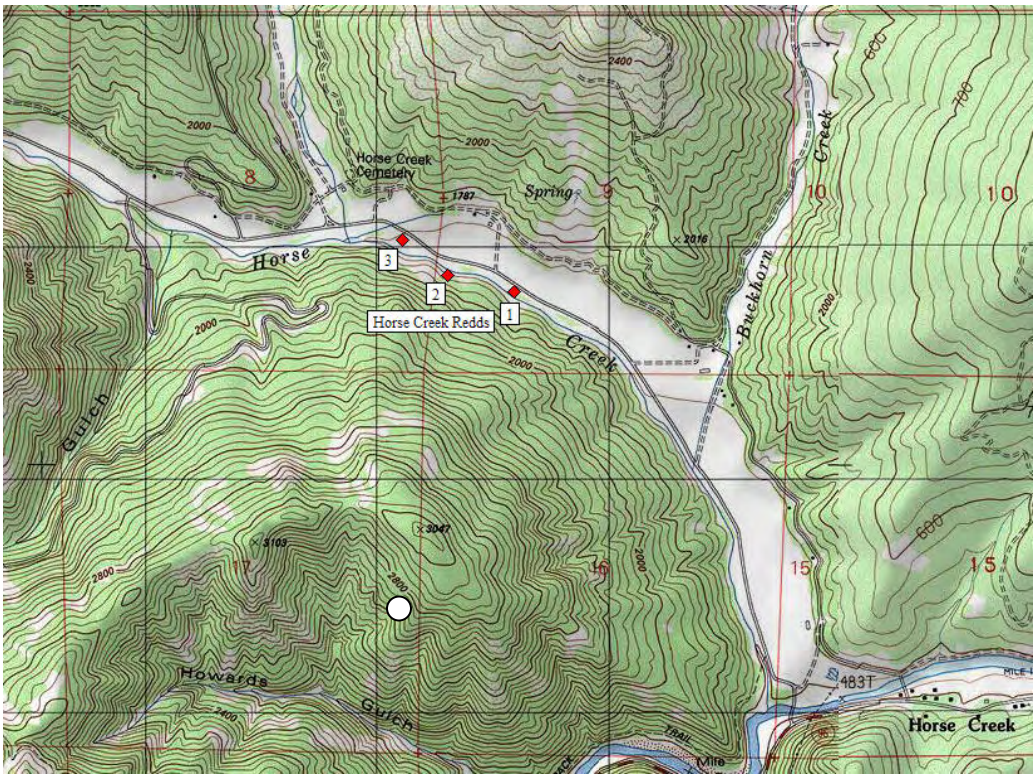

Figure 4. Locations of redds in Horse Creek (aerial photo top; topo map bottom).

Methods

Methods followed the approach described by Nawa and Frissell (1993) and Harvey and Lisle (1999). Initial transect survey and scour chain placements, timed to precede rising river flows, were conducted December 11–14, 2007, presumably after most coho salmon finished spawning to reduce confounding effects caused by scour and fill with those caused by spawning adults digging redds. Scour chains in Horse Creek were checked on April 2, 2008, prior to spring runoff. Transects were re-surveyed and scour chains checked a final time July 8–9, 2008, at a lower flow. Discharge from nearest U.S. Geological Survey (USGS) gauges was documented through the study period to compare against historical flows.

A three-person crew collected field data using the following procedures:

- Net Scour – cross sections
    - Transects were placed perpendicular to the streamflow across documented redd locations—total of six transects (three in mainstem; three in tributary).
    - Bed elevations were measured across each transect using a total station before and after high winter flows. Elevations were referenced to a local benchmark. Water surface slopes were measured at each site.
    - Discharge was measured at each transect, and the water surface elevation was measured during each of two field visits.
- Maximum scour – scour chains
    - Concept – during high flows, streambed scours and exposes a portion of scour chain, which lays parallel over depth of scour.
    - Construction – steel link chains with cord to locate later (figures 5 and 6).

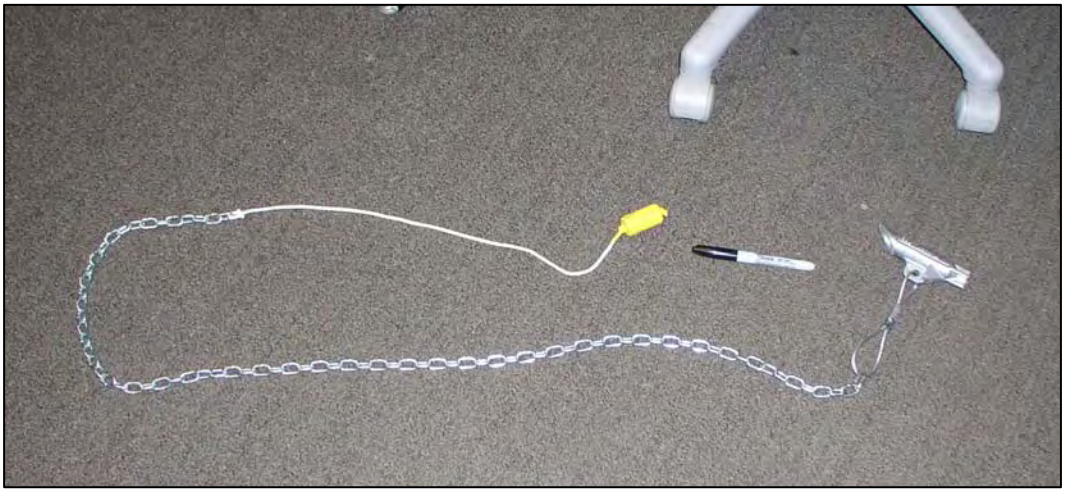

Figure 5. Example scour chain design used to measure maximum scour at salmon redd locations.

Figure 6. Scour chain and steel rod used to measure maximum scour at salmon redd locations.

Procedure for Inserting Scour Chains

The following steps were used to install scour chains, as suggested by Tom Lisle, U.S. Forest Service, personal communication, November 14, 2007, in an e-mail to Robert Milhous of the USGS:

1. Implant chains with colored cork floats.
2. Slip duck bill anchor around the bottom of the inserter.
3. Hold chain as taut as possible.
4. Hold inserter vertical at bed surface.
5. Pound the top of the inserter into the bed with a sledge hammer until the inserter handle is at the water surface, or the chain is sufficiently buried (the anchor should be buried at least 25 cm, or it won't set properly).
6. Set the anchor by pulling back and forth on the inserter and twisting.
7. Once anchor is set, pull out the inserter using a pipe wrench.
8. Pull up on the chain to get rid of any slack (usually there is a little, but not more than a few cm). If you pull up and the chain starts to come out, remove the chain and start over; the anchor was not set.
9. After chain is set, replace any gravel that may have created a hole around the chain; then attach hog ring to the first link that is exposed at the bed surface.
10. Measure the chain length from the hog ring to the end of the chain, and record it.
11. Survey the bed surface at the position of the chain using total station. Also, use hand-held global positioning system (GPS) unit to mark location.
12. Three chains were spaced about 2 meters apart along each net scour transect in the vicinity of each redd location, cautiously avoiding damaging embryos (figure 7). This resulted in 18 chains (9 in mainstem; 9 in tributary).

Figure 7. Three scour chains (red floats) surrounding salmon redd in Horse Creek.

Net scour/fill was calculated as the difference in elevations between the December 2007 and July 2008 cross-sectional profile surveys at each transect.

Maximum scour and fill were calculated as follows:

Scour:

1) Difference in elevation from the hog ring to the kink, calculated from the number of links (each link was 35 millimeters [mm] long).

2) Difference in elevation calculated from the surveys: elevation at the time of installation minus elevation of kink during measurement.

Fill:

Elevation of the surface at final measurement minus elevation of the kink.

Additionally, pebble counts were conducted at each redd location, and sediment samples were taken in December 2007 to determine particle size distribution at redd locations. Bed-material (fines) was dry-sieved and weighed in the laboratory. The sieve sizes used for bed-material analysis ranged from 0.063 to 1,143 mm. Sediment grade scales were defined as follows (Maidment 1993):

Clay – 0.00024–0.004 mm
Silt – 0.004–0.062 mm
Sand – 0.062–2 mm
Gravel – 2–64 mm
Cobble – 64–250 mm
Boulder – 250–4,000 mm

The techniques used in the sampling of the bed-material are presented in Milhous et al. (1995). There is one exception. The armour was sampled by placing a 55-gallon barrel on the stream-bed surface, sampling the particles within the barrel, and measuring the size of the particles. The barrel was moved until a total of at least 100 particles were measured. The size distribution was determined from the measurements and modified to the equivalent of a Wolman count using the techniques of Kellerhals and Bray (1971).

Results and Discussion

Streamflows

Daily streamflows measured at the gauging station just below Iron Gate Dam (USGS station 11516530) are presented in figure 8. Also shown on the figure is the egg incubation period assumed for salmon from the middle of November through March. On December 11, the scour chains were placed at the Willow Creek site and on December 13 were placed at the KRCE site. Both sites were checked for scour and deposition on July 9, 2008. This period is shown on the figure as well. The date of the maximum daily discharge (3,310 cubic feet per second [cfs]) was March 15, 2008, which was also the date with the maximum daily discharge for the water year.

The third mainstem site, Barkhouse Side Channel, is downstream from the Shasta confluence with the Klamath River. An index to the discharge was calculated by adding the daily discharge measured on the Shasta River on a given day to the discharge measured for the Klamath River just below Iron Gate Dam. As an example, the discharge measured on March 15, 2008, below Iron Gate Dam was 3,310 cfs. The daily discharge measure at the gauging station on the Shasta River near Yreka (USGS station 11517500) was 230 cfs on March 16, 2008. The index to the discharge for the Klamath River at Barkhouse on March 16, 2008, is then 3,310 cfs + 230 cfs = 3,540 cfs. This is an index to the discharge at Barkhouse and should not be considered the actual discharge. The calculated index mainstem discharge at the Barkhouse site is presented in figure 9. The maximum daily discharge in the Barkhouse Side Channel reach of the Klamath River was approximately 3,500 cfs.

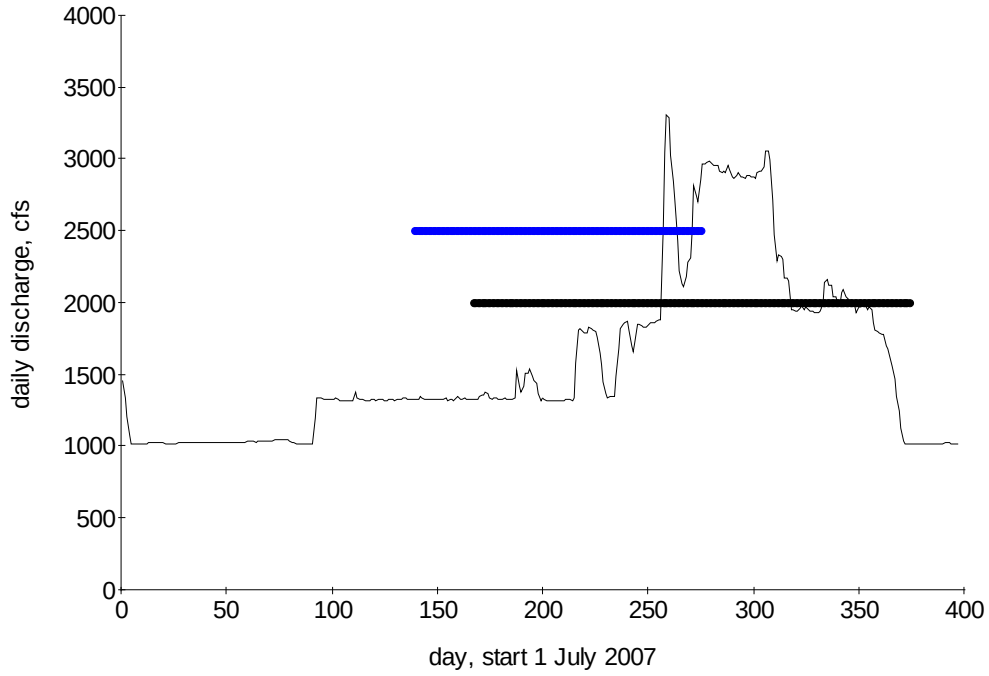

Figure 8. Streamflows of the Klamath River measured at the gauging station below Iron Gate Dam. Blue line - egg incubation period, November 16– March 31. Black line - period between chain measurements, December 11, 2007–July 9, 2008.

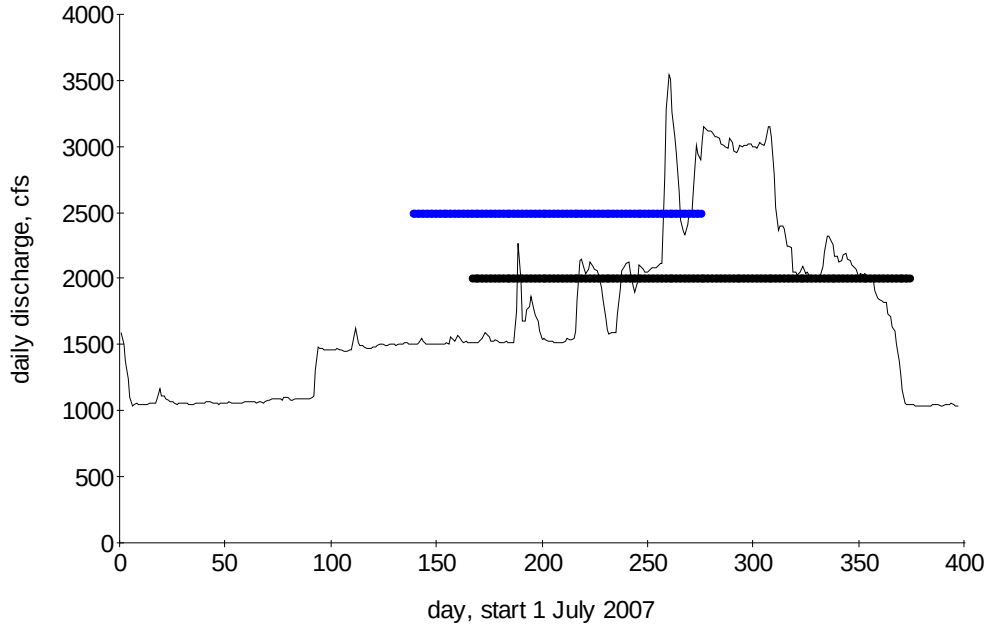

Figure 9. An index to the daily streamflows of the Klamath River at Barkhouse side channel. Blue line - egg incubation period, November 16– March 31. Black line - period between chain measurements, December 12, 2007–July 8, 2008.

Comparison of Peak Flows

The maximum daily discharge that occurred in the Klamath River during the winter and spring of 2008 has been exceeded during about 78 percent (%) of the years following completion of Iron Gate Dam in 1961. The annual maximum daily discharge for 1961–2008 is presented in figure 10. The same maximum daily discharge is shown as an exceedence diagram in figure 11. The actual exceedence for 2008 is 78.1%, but it is interesting to note that only about 10% of the 48 years of record have discharges much below the 3,310 cfs measured in 2008.

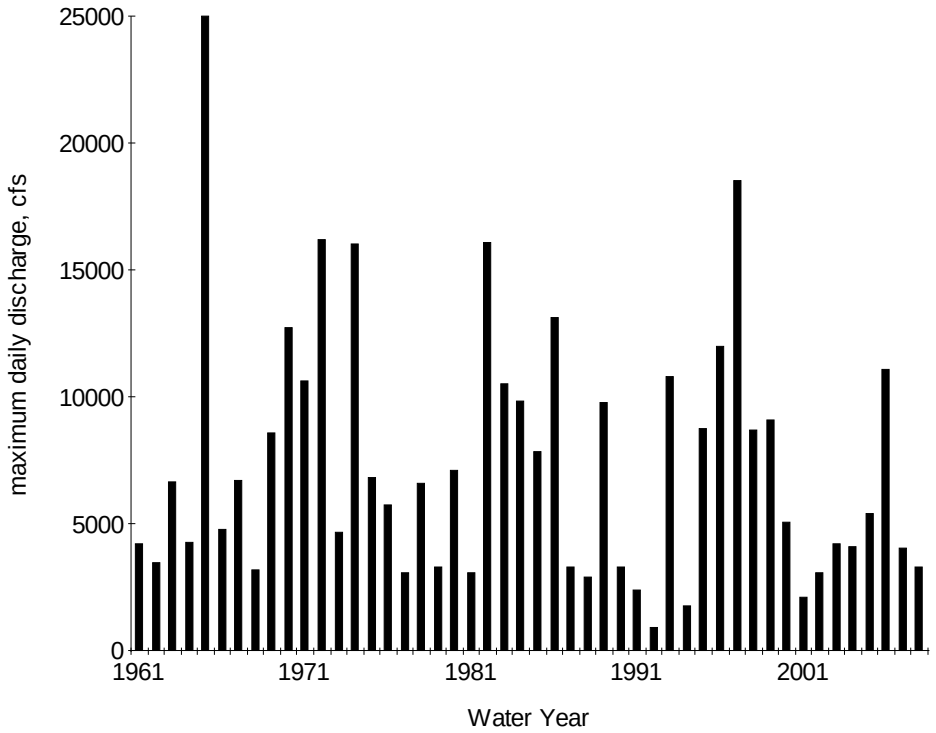

Figure 10. Annual maximum daily discharge measured at the gauge just below Iron Gate Dam for the period of record between 1961 and 2008.

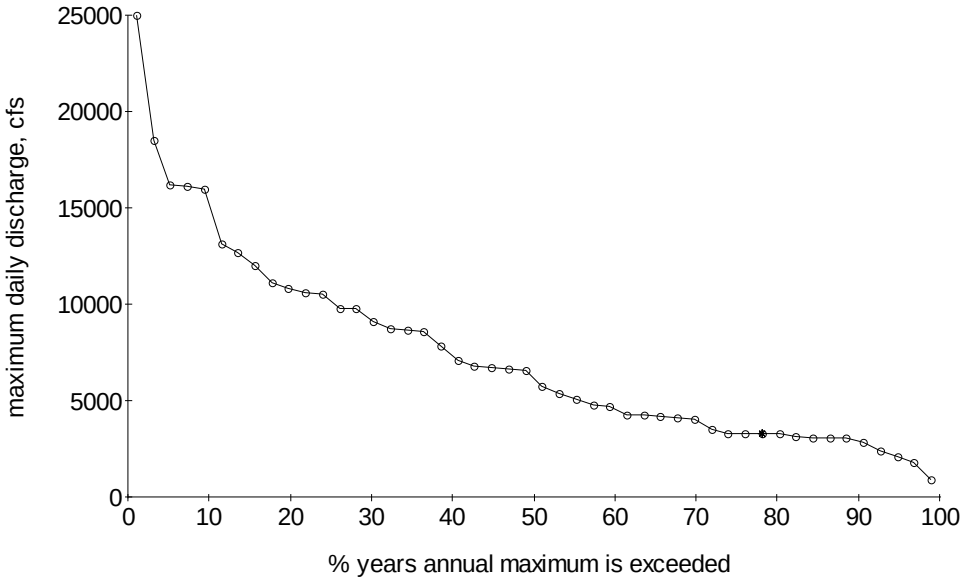

Figure 11. Exceedence diagram for the maximum daily discharge for the Klamath River below Iron Gate Dam. The maximum daily discharge for water year 2008 is shown as the solid point.

Daily mean average flows in the Klamath River at Iron Gate Dam between October 1 and May 31 are plotted in figure 12 for water years 1997–2007. The maximum daily discharge (3,310 cfs) during the scour study was March 15, 2008, which was the day with the maximum daily discharge for the water year. These plots show that flows in the Klamath River during this study were relatively low compared to many years since 1997. As a result, high flows generally associated with channel scouring were not observed. This is reflected in our results that showed little, if any, scouring at selected redd locations in the Klamath River. In fact, filling of fine sediment was observed at the redd location at the Willow Creek confluence. Since there is no stream gauge in Horse Creek, another nearby gauge from an unregulated stream (Indian Creek) was used to compare discharge during this study to previous years (figure 13). Again, the 2007–2008 winter season flows were relatively low compared to flows since 1997. Particularly noticeable was the lack of short spikes in flows from winter rains.

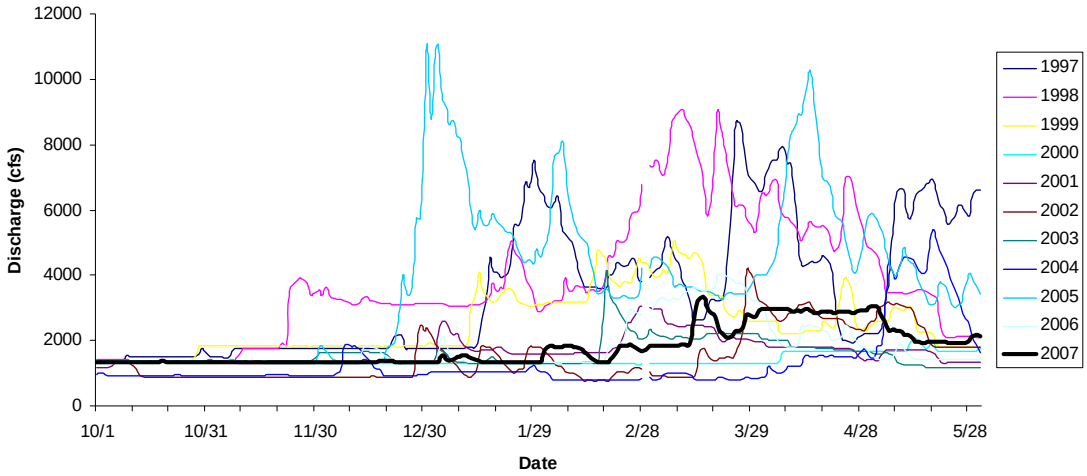

Figure 12. Discharge in Klamath River at Iron Gate Dam (October–May) for water years 1997–2007.
Source: USGS gauge at Iron Gate Dam - http://waterdata.usgs.gov/ca/nwis/uv?11516530.

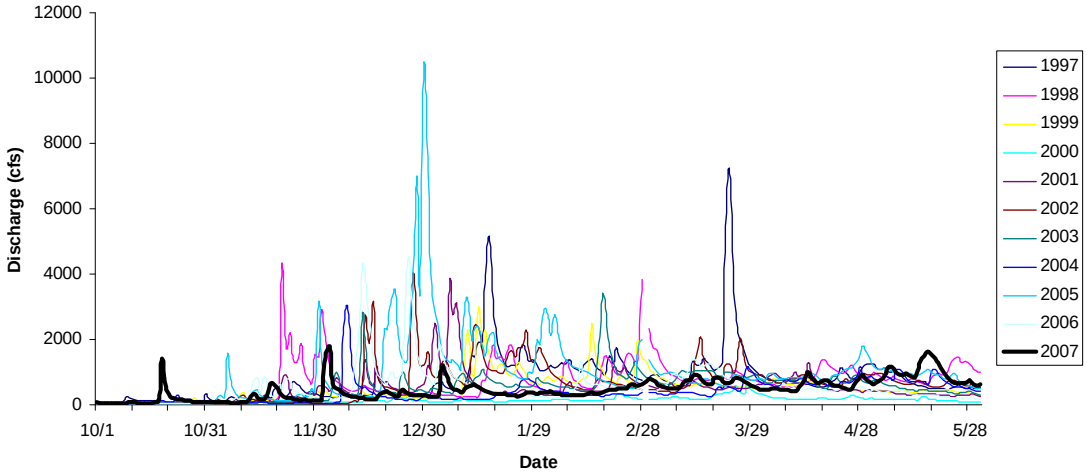

Figure 13. Discharge in Indian Creek (October–May) for water years 1997–2007.
Source: USGS gauge at Indian Creek - thttp://waterdata.usgs.gov/ca/nwis/uv/?site_no=11521500&PARAmeter_cd=00065,00060.

Survey dates and slope and discharge measurements at each study site are summarized in table 2. Slopes ranged from 0.0008 at KRCE on the mainstem Klamath River to 0.0090 at the upper Horse Creek site in December. Overall, slopes were lower in the mainstem Klamath River than Horse Creek. Horse Creek slopes increased between the lower site and upper site.

Table 2. Slope and discharge measurements for Klamath River scour study

Location Description	Date	Slope	Discharge (cfs)
Mainstem Near Klamath River Country Estates	12/13/07	0.0008	[1]1,330
	7/9/08	0.0004	[1]1,020
Mainstem at Willow Creek mouth	12/11/07	0.0044	1,224
	7/9/08	0.0036	[1]1,020
Mainstem at Barkhouse Creek Side Channel	12/12/07	[2]0.0010	93
	7/8/08	[3]0.0060	7
Horse Creek – Lower Site	12/14/07	0.0045	14
	7/8/08	0.0045	20
Horse Creek – Middle Site (split channel)	12/14/07	0.0075	11
	7/8/08	0.0077	21
Horse Creek – Upper Site	12/14/07	0.0090	14
	7/8/08	0.0075	21

[1] Iron Gate Dam release.
[2] Upstream of redd.
[3] Downstream from redd.

Redd Scour

Table 3 summarizes scour chain link results (maximum scour) at each study site. Results indicated very little overall difference in chain links exposed between December 2007 and July 2008. The greatest difference occurred at the Barkhouse side channel where nine additional links on one scour chain were exposed in July, or 31.5 cm. However, closer examination in the field suggested that this chain had been disturbed by someone, possibly trying to remove it, because a hole was created at the chain location. Of the 18 chains, 8 showed fewer links exposed in July than December, suggesting some filling of sediment occurred, particularly at the Willow Creek confluence (table 3). No change in exposed chain links was observed on three scour chains.

Scour chain elevations also showed little overall change between December 2007 and July 2008 (table 4). Aside from the scour chain at the Barkhouse site that suggested human disturbance, the largest elevation change was a 0.4-foot (12-cm) increase (fill) at one chain at Willow Creek and a 0.4-foot decrease (scour) at one chain in middle Horse Creek (table 4). These changes are less than the 15- to 35-cm depth below the original stream bed level scour criteria for coho salmon suggested by DeVries (1997). A single factor Analysis of Variance (ANOVA) test showed no significant difference (F value = 0.002836; $p = 0.95$) in scour chain elevations (pooled data) between December 2007 and July 2008 (table 5). Also, cross-sectional profiles at each redd location between December 2007 and July 2008 (figures 14 and 15) did not provide any evidence of net redd scouring. The dip in the July profile near the redd at the Barkhouse site (figure 14) was the suspicious scour chain location discussed above. Based on these data, it appeared that no redd scouring occurred during the study period.

Table 3. Scour chain link results for Klamath River scour study

Location Description	Date	Chain links exposed		
		SC1	SC2	SC3
Mainstem Near Klamath River Country Estates	12/13/07	11	13	15
	7/9/08	13	14	18
	Difference (Dec–Jul)	-2	-1	-3
Mainstem at Willow Creek mouth	12/11/07	16	13	10
	7/9/08	11	7	11
	Difference (Dec–Jul)	5	6	-1
Mainstem at Barkhouse Creek-Side Channel	12/12/07	10	16	21
	7/8/08	19	16	20
	Difference (Dec–Jul)	-9	0	1
Horse Creek – Lower Site	12/14/07	9	8	4
	4/2/08	9	4	2
	7/8/08	8	[1]7	5
	Difference (Dec–Jul)	1	1	-1
Horse Creek – Middle Site	12/14/07	12	9	9
	4/2/08	10	8	5
	7/8/08	6	10	[2]8
	Difference (Dec–Jul)	6	-1	1
Horse Creek – Upper Site	12/14/07	10	8	9
	4/2/08	6	–[3]	8
	7/8/08	6	[3]8	9
	Difference (Dec–Jul)	4	0	0

[1] Thin layer of silt covering chain.

[2] About 3-cm layer of silt covering chain.

[3] Chain covered by two small boulders (0.6 foot x 1.2 feet x 0.2 foot and 0.8 foot x 1.2 feet x 0.4 foot).

Table 4. Scour chain elevations (feet) for Klamath River redd scour study

KRCE	December 2007	July 2008	Change
SC1	97.5	97.5	0.0
SC2	97.2	97.1	-0.1
SC3	97.3	97.0	-0.2
Mean	97.4	97.2	-0.1
Willow Creek			
SC1	96.9	97.3	0.4
SC2	97.3	97.4	0.1
SC3	97.4	97.5	0.0
Mean	97.2	97.4	0.2
Barkhouse Creek			
SC1	98.4	98.0	-0.5
SC2	98.3	98.3	0.0
SC3	97.8	97.9	0.1
Mean	98.2	98.1	-0.1
Lower Horse Creek			
SC1	95.2	95.3	0.1
SC2	95.3	95.3	-0.1
SC3	95.5	95.4	-0.1
Mean	95.4	95.4	0.0
Middle Horse Creek			
SC1	96.1	96.2	0.1
SC2	96.3	95.9	-0.4
SC3	96.2	96.0	-0.2
Mean	96.2	96.1	-0.1
Upper Horse Creek			
SC1	96.7	96.9	0.2
SC2	96.6	96.6	0.1
SC3	96.6	96.7	0.1
Mean	96.6	96.8	0.1

Table 5. Analysis of variance (ANOVA) test results for scour chain elevations

Groups	Count	Sum	Average	Variance	
December 2007	18	1742.6	96.81111	0.883399	
July 2008	18	1742.3	96.79444	0.879379	
ANOVA					
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**
Between Groups	0.0025	1	0.0025	0.002836	0.957838
Within Groups	29.96722	34	0.881389		
Total	29.96972	35			

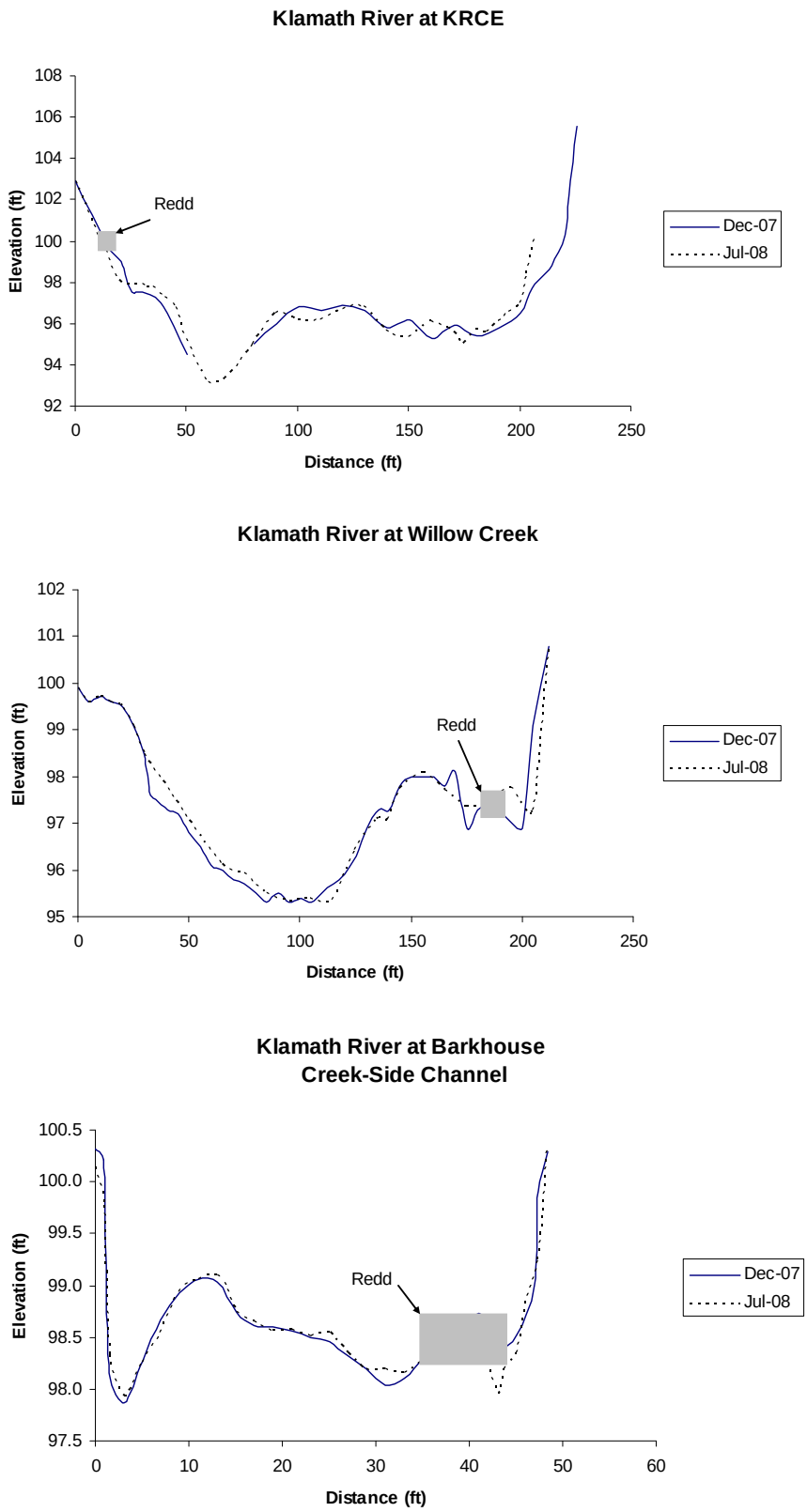

Figure 14. Cross-sectional profiles at redd locations in Klamath River.

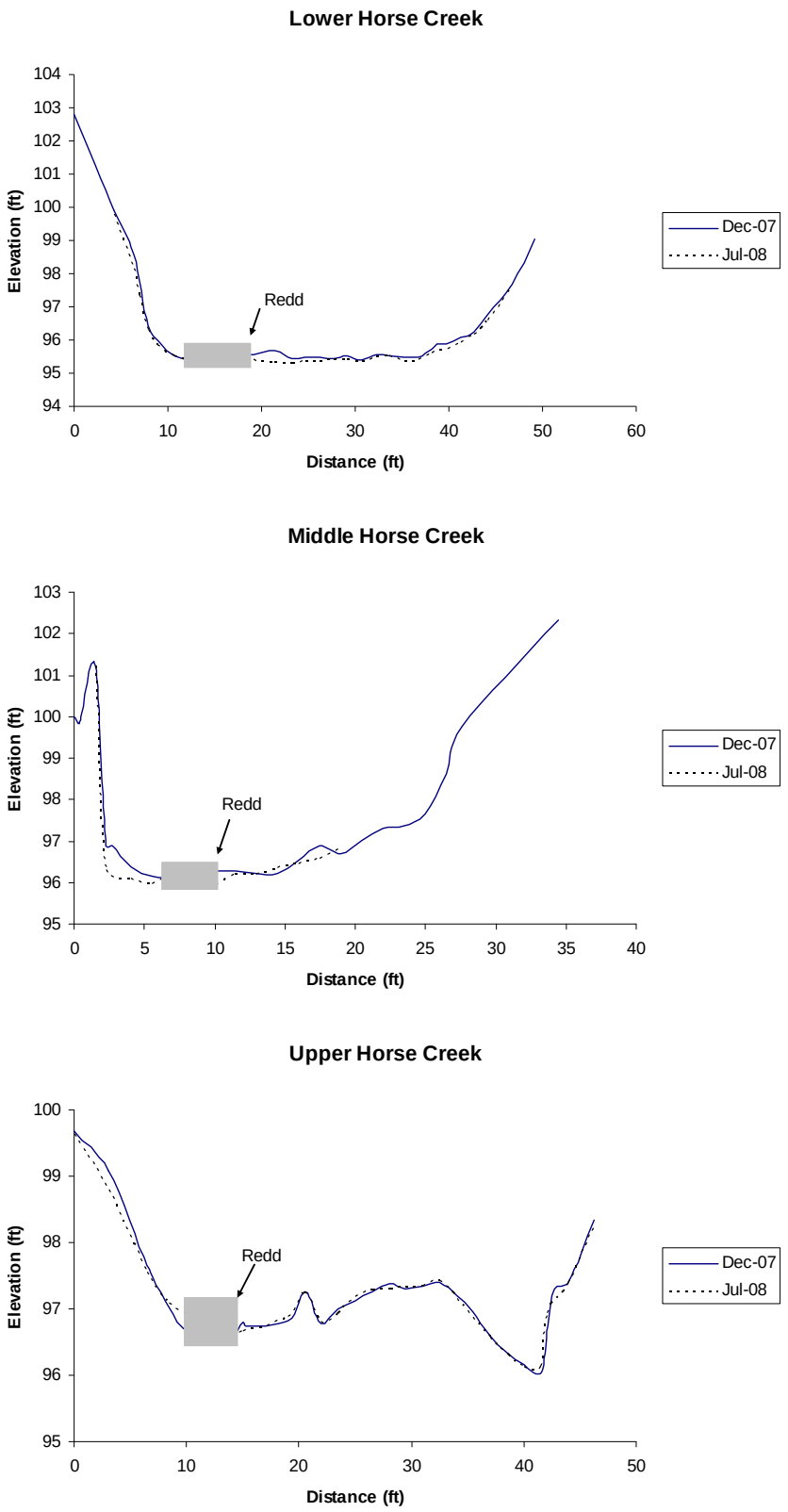

Figure 15. Cross-sectional profiles at redd locations in Horse Creek.

Sediment

The bed-material in a gravel or cobble bed river has three components that are of interest in evaluating the quality of the river bed-material for spawning, egg incubation, and fry emergence. These components (surface fines, substrate, and armour) were sampled at the three scour study sites on the Klamath River and at one of the locations on Horse Creek. The three particle size distributions of the bed-material of Horse Creek are presented in figure 16. The sample location was near the lower of the three scour study sites on Horse Creek. One of the components is the layer of sediment forming the surface of the stream bed. This sediment is the armour and must be moved by any spawning salmonids to reach the spawning gravels below. The armour must also be removed before the redd can be scoured.

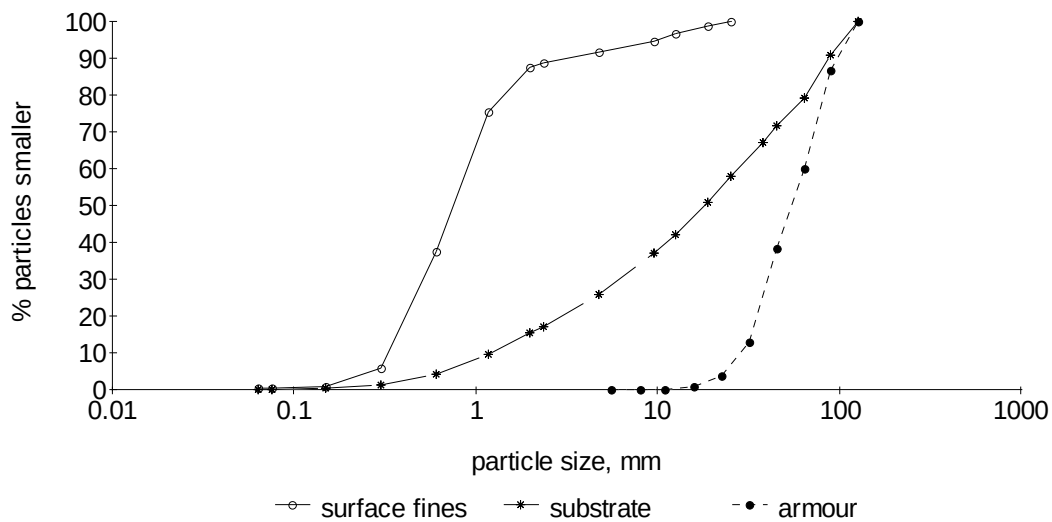

Figure 16. Particle size distributions of the bed-material of Horse Creek measured in the Klamath River scour study.

The second component is the material below the armour. This is the substrate where the spawning fish deposit the eggs, and the eggs incubate. The armour is reasonably stable, and sediment can be deposited on top of the armour. This is the ‘surface fines’ material. If there is enough fine surface material, the voids in the substrate can be filled with small sediment and/or the armour covered, preventing exit of the fry from the gravels.

There are three common uses of the term ‘fines’ when analyzing the bed-material of gravel bed streams. The first use is the sediment smaller than sand. The lower size of sand is either 0.063 mm (geologist) or 0.074 (geotechnical engineers). In this paper, a lower limit on sand will be 0.063 mm. A second usage is in the evaluation of the salmonids habitat. In this usage, fines are the sediment less than

1 mm or 0.83–0.85 mm. The size of fine material in substrate considered to be undesirable in spawning gravels used herein is 0.84 mm, but it will be used interchangeably with 0.83 and 0.85. The third usage of fines (surface fines in figure 16) is the sediment that is on the surface of the armour and is probably deposited when the armour is not being disturbed by the streamflow.

The most upstream site on the Klamath River is the KRCE bar site. The size distribution of the bed material is presented in figure 17. The next location is just below where Willow Creek enters the Klamath River. The measurements for this site are presented in figure 18. The third location on the Klamath River is downstream from the Shasta River on a side channel at Barkhouse Bar. The size distribution for that site is presented in figure 19. The armour at Barkhouse Bar was measured using the Wolman pebble count procedure.

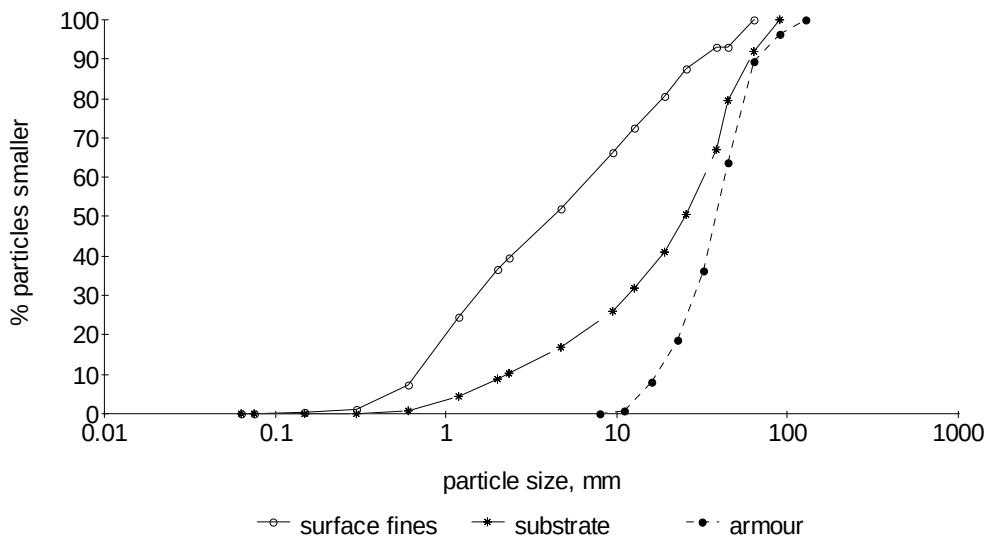

Figure 17. Particle size distributions of the bed-material in the Klamath River at the KRCE bar study site measured in the Klamath River scour study.

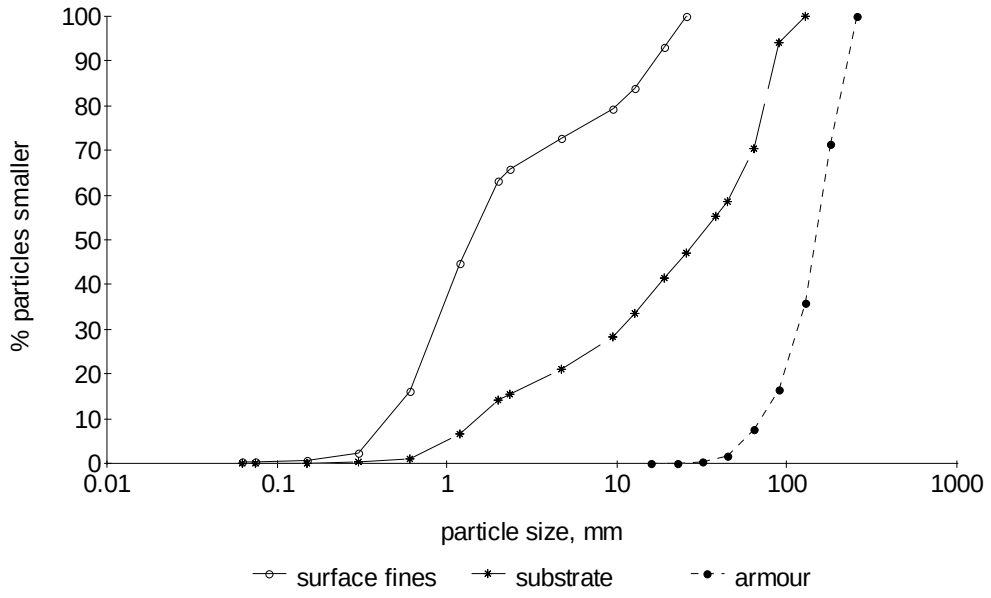

Figure 18. Particle size distributions of the bed-material in the Klamath River at the Willow Creek bar study site measured in the Klamath River scour study.

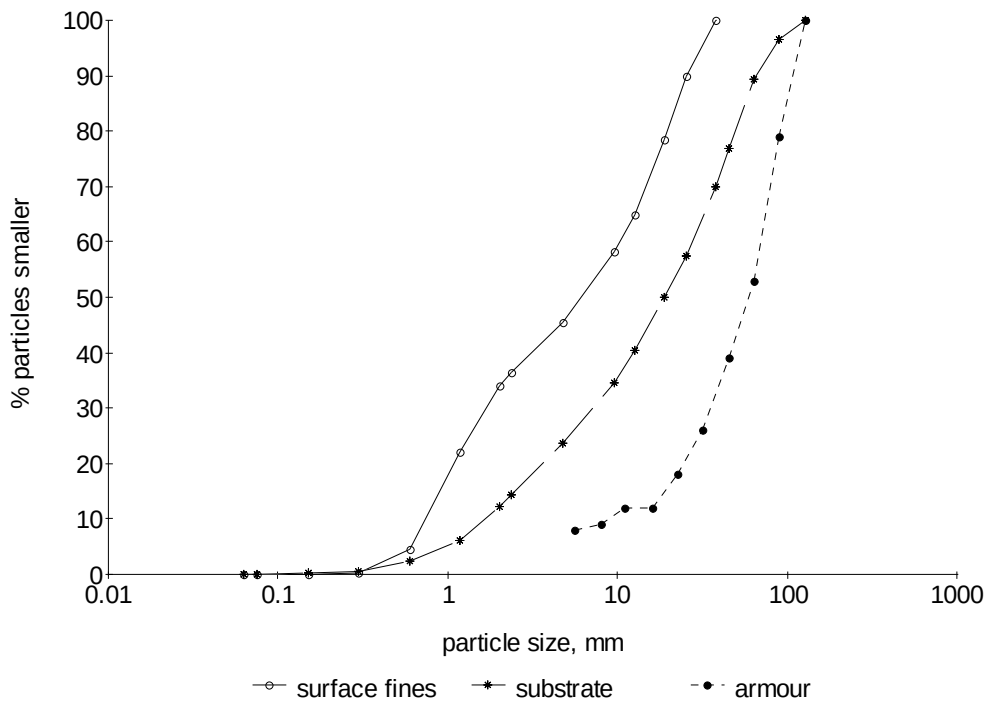

Figure 19 Particle size distributions of the bed-material in the Klamath River at the Barkhouse bar study site measured in the Klamath River scour study.

The substrate particle size distributions for the four locations sampled are presented in figure 20. The quality of the substrate for spawning is related to the overall size of the sediment and the presence of smaller material in the substrate. Substrate sample results illustrated in figure 20 show comparatively similar grain size distributions among study sites. Particle diameters (d_{50}) were: KRCE = 83 mm (cobble); Willow Creek = 62 mm (gravel); Barkhouse Side Channel = 80 mm (cobble); and Horse Creek = 74 mm (cobble). This is consistent with other studies that show coho spawn in gravel/cobble substrates with a low percentage of fines that should be less than 5% (Platts et al.1979;Reiser and Bjornn 1979).

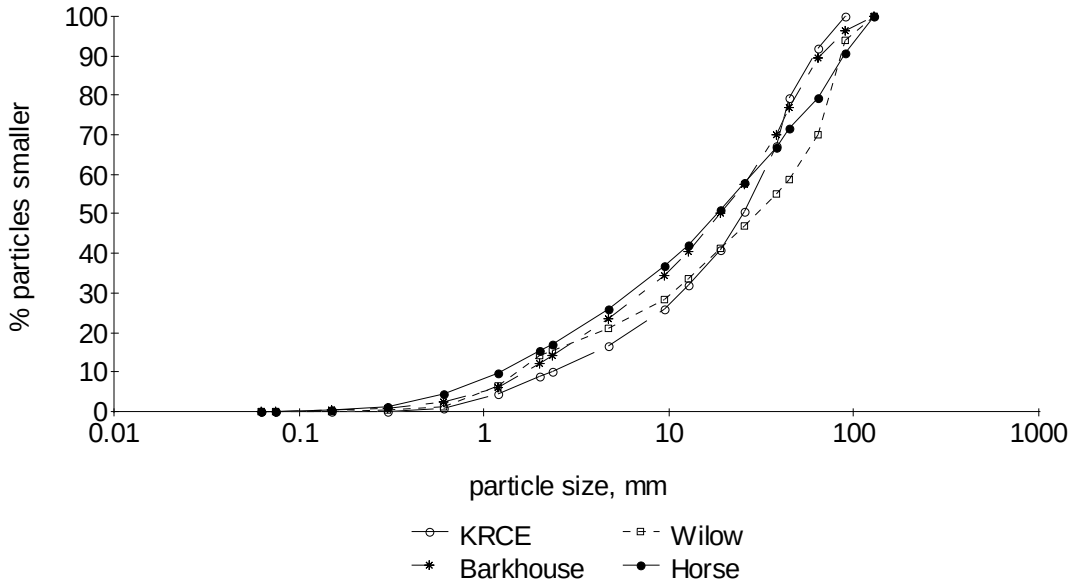

Figure 20 Particle size distributions of substrate samples taken from redd locations in the Klamath River scour study.

As indicated above, two of the important indicators of the quality of the substrate for spawning are the d_{50} size and the percent of fines in the substrate. The median size of the substrate samples from the four scour study sites are presented in table 6 along with the presented fines, based on two measures of fines.

Table 6. Grain size statistics for the scour study substrate gravels

Location	Median (d50) mm	% < 0.84 mm	% < 0.063 mm
KRCE Bar	25.0	2.3	0
Willow Creek Bar	30.0	3.3	0
Barkhouse Bar	19.0	4.0	0
Horse Creek	18.4	6.5	0.1

The first measure of fines is the particles less than 0.084 mm. Kondolf (2000) made a search of the literature and also presented work done in the Grand Canyon reach of the Colorado River in Arizona. Table 7 presents the part of the results of that study. The study also found that the spawning gravels sampled had a median of d_{50}'s of 17.7 mm with a range of 10.5 to 33.4. The Klamath River samples are within the results from previous studies.

In table 7, the range of the percent of fines less than 0.83 or 0.85 mm is from 1.5 to 20 mm with a median of 10.4%. Laboratory experiments by Tappel and Bjornn (1983) show that egg survival approaches zero when the percent of the substrate smaller than 0.85 mm is 21% for steelhead and 24% for Chinook salmon. The experiments also show that if sediment less than 0.85 mm is about 12%, then the survival is at least 70%; survival drops off quickly to zero if the percent of the sediment <0.85 mm is more than 20%. The conclusion about the Klamath River spawning substrate is that all sites are excellent for spawning salmonid fish.

Table 7. The percent of sediment less than 0.83 or 0.85 mm for salmonid redds

Source	Species	% less than 0.83 or 0.85 mm
Cederholm and Salo (1979)	Coho salmon	7.5, 17
Koski (1966)	Coho salmon	21
Tagart (1984)	Coho salmon	11
Irving and Bjornn (1984)	Cutthroat trout	20
NCASI (1984)	Rainbow trout	12
Hartman and Galbraith (1970)	Rainbow trout	6.3
Platts et al. (1979)	Salmon	7
Spoon (1985)	Brown and rainbow trout	11.1
Spoon (1985)	Brown and rainbow trout	9.8
Kondolf et al. (1989)	Colorado River tributary rainbow trout	1.5
Kondolf et al. (1989)	Colorado mainstem rainbow trout	6.8

Source: Kondolf 2000; see also for the references.

The second measure is the percent of the substrate less than 0.063 mm. The information in Kondolf (2000) suggests that this should be less than 1%, which it is at all four sites.

The particle size distribution curves for the armour at all four study sites are presented in figure 21. The objective of sampling the stream bed armour was to determine the size of the bed material needed in the calculation of the potential for scour at the study sites. Criteria for the size of the armour material that makes good habitat for spawning is not well developed. Bjornn and Reiser (1991) have given criteria that can at least be used to understand how well the armour at the study sites might be adequate for spawning. The Bjornn and Reiser paper suggests the armour should be 100 mm or less in order for the site to be good for spawning. It is not clear if the 100 mm is the median (d_{50}) or the maximum size of the armour. The percent of the armour less than 100 mm, the d_{50}, and the d_{90} size of the armour at each of the four sites is given in table 8. The d_{90} size is being used as the maximum effective size of the armour. As table 8 shows, three of the sites have very good armour. At the fourth site (Willow Creek), the armour is too large according to the 100-mm criteria. This may be a result of sampling downstream from the spawning locations at a place (more on top of the bar) that represents the stability of the spawning location, because if scour does not occur at the sampled location, it is not likely to occur where the redds are located.

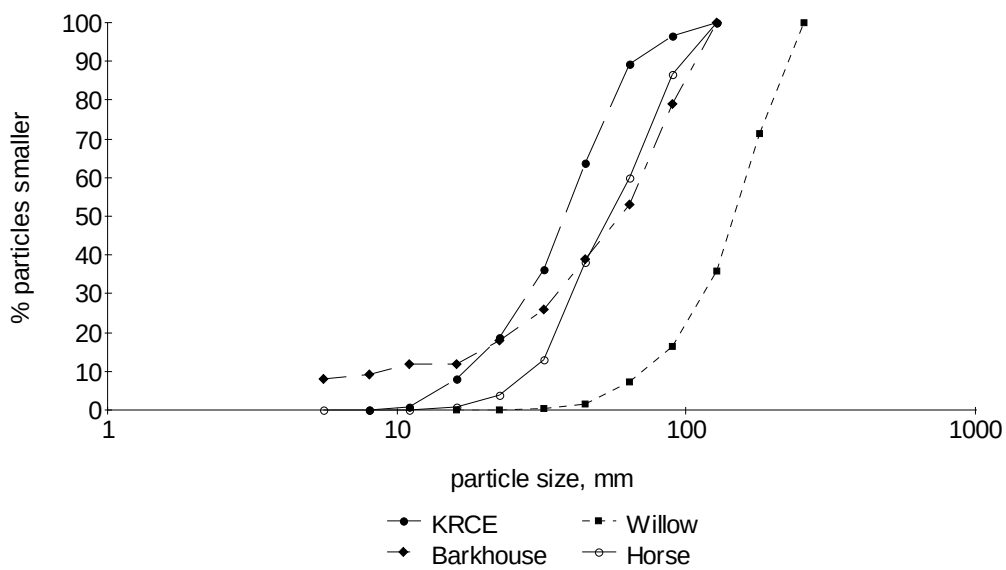

Figure 21 Particle size distributions of the bed-material armour at each of the Klamath River study sites.

Table 8. Particle size statistics for the stream bed armour at the sites used for the scour study

Location	%<100 mm	d_{90} (mm)	d_{50} (mm)
KRCE	97.4	66	39
Willow Creek	21.5	229	149
Barkhouse	84.5	110	60
Horse Creek	90.1	100	55

The third type of fines is the sediment on top of the armour. These are shown on figure 22. The Little Bogus samples are from a location upstream of all the study sites and are near the junction of Little Bogus Creek with the Klamath River. The Cottonwood Creek location is downstream from the two study locations above the Shasta River and is near the mouth of Cottonwood Creek. A summary of all the surface fines statistics is presented in table 9.

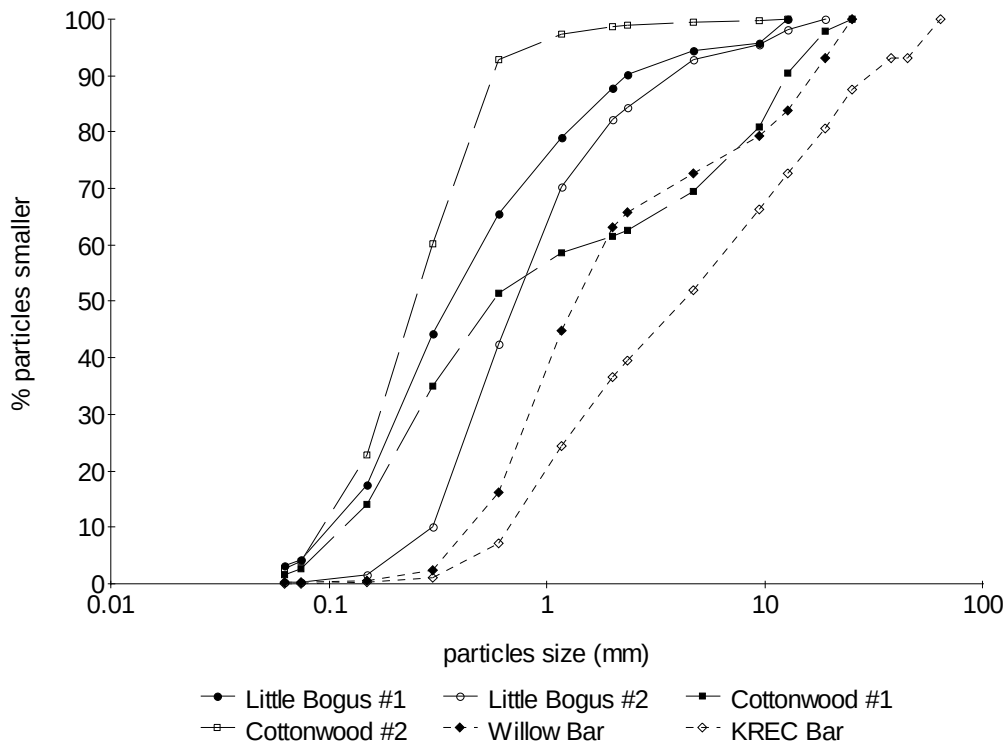

Figure 22. Particle size distribution for the study sites on the Klamath River above the Shasta River mouth and for two other sites also above the Shasta River.

Table 9. Particle size statistics for the stream bed surface fines at the sites used for the scour study and two other locations

Location	% < 0.84 mm	% < 0.063 mm	d50 (mm)	d10 (mm)
Little Bogus #1	71.2	3.25	0.38	0.11
Little Bogus #2	53.9	0.26	0.76	0.30
KREC Bar	14.3	0.11	4.38	0.69
Willow Bar	28.0	0.25	1.42	0.46
Cottonwood #1	54.4	1.64	0.57	0.12
Cottonwood #2	94.7	2.58	0.26	0.10
Barkhouse Bar	11.8	0.03	6.40	0.78
Horse Creek	53.2	0.32	0.79	0.34

The location at Little Bogus Creek has few fines, but the location at Cottonwood Creek had considerable fines on the bed surface, especially on the bars. The land use near Cottonwood Creek is more agricultural than near the other sites with significant cattle grazing near the river, which is the probable cause of more fine material near Cottonwood Creek than at the other locations.

Horse Creek had smaller fines than at the other study sites but not finer than the Little Bogus Creek location and the Cottonwood Creek locations. Spawning gravels in Horse Creek had a particle diameter (d_{84}) = 1.8 mm and a d_{50} = 0.8 mm (i.e., 84% of grains were smaller than 1.8 mm, and 50% of grains were smaller than 0.8 mm). Comparatively, at KRCE in mainstem Klamath River, d_{84} = 22.1 mm and d_{50} = 4.4 mm (figure 22). In general, interstitial sediments finer than about 1 mm reduce the permeability of the gravel and can prevent intragravel flow from providing adequate oxygen to incubating embryos and removing metabolic wastes (Kondolf 2000) if the streamflows are not adequate to keep the fine sediment moving through the system. This suggests that fines in Horse Creek may affect coho salmon spawning during years when flows are low but high enough to mobilize the fines. This is probably also the situation below Cottonwood Creek until the Shasta River joins the Klamath River. The smallest fine materials appear limited above Cottonwood Creek, indicating very little affect to coho spawning as a result of mobilized fines at this site.

Recommendations

Based on the results of this survey, the following recommendations are suggested:

- Repeat the scour study for the 2008–2009 winter period in the event that a high winter flow event occurs.
- Deploy a temporary stage recorder in Horse Creek to document discharge during the scour study.
- Do not repeat the sediment sampling.
- Conduct further coho spawning surveys to better understand where coho spawn in the Klamath River.
- Quantify available spawning habitat in documented spawning areas through mapping (i.e., locations, numbers of spawning areas, total spawning area (ft^2) relative to total river area).

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