SPAWNING GRAVEL SUITABILITY ASSESSMENT
SONOMA CREEK WATERSHED

Sonoma Ecology Center
Technical Advisory Committee

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1.0 EXECUTIVE SUMMARY

Spawning gravels in the Sonoma Creek watershed were evaluated to determine their suitability to support the successful reproduction of steelhead trout. The extent to which framework gravel sizes and fine sediment content may be adversely affecting spawning habitat and thereby limiting steelhead (and possibly Chinook salmon) populations in the Sonoma Creek watershed were investigated. Four locations on Sonoma Creek and four tributaries; Graham, Calabazas, Carriger, and Bear Creeks were evaluated. Results strongly indicate that the quality of spawning gravels are not a factor limiting the steelhead fishery. All 26 gravel samples evaluated met the criteria for fine sediment content. Results suggest that erosion and sediment production to stream channels in those portions of the Sonoma Creek watershed investigated are not likely to be a significant factor affecting fish habitat, particularly spawning conditions. This study provides a basis for future comparative studies and monitoring programs that may be important as agricultural, residential development, and other land-uses expand in the watershed.

2.0 INTRODUCTION AND OBJECTIVES

Sonoma Creek historically supported a population of steelhead (*Oncorhynchus mykiss gairdneri*), which has reportedly been in great decline in recent decades. Few studies have been undertaken in the watershed to determine the causes of this decline. Steelhead are listed by the National Marine Fisheries Service (NMFS) as a federally threatened species within the Central California Coast Evolutionary Significant Unit (ESU) which includes the Sonoma Creek watershed. Chinook salmon (*Oncorhynchus tshawytscha*), although not known to be prevalent in the watershed, were observed during the course of this study (November 1998) spawning in the lower reaches of Sonoma Creek. Chinook salmon are not currently listed by NMFS, however they are a federal candidate[1] species which could be listed in the near future. Coho salmon (*Oncorhynchus kisutch*), is occasionally mentioned as a species present in the watershed (Southern Sonoma County Resource Conservation District [SSCRCD], 1997) but have never been observed by past Department of Fish and Game (CDFG) field surveys, recent electrofishing surveys conducted jointly by the Sonoma Ecology Center (SEC) and CDFG, or studies of fish distribution in the San Francisco Bay drainage (Leidy, 1984). Possibly present as an occasional stray, it is highly unlikely that Coho salmon were either historically or are currently found in Sonoma Creek since this species is typically associated with streams draining forested Pacific coastal watersheds.

Sonoma Creek and its tributaries (Figure 1) are designated by the San Francisco Bay Regional Water Quality Control Board 303(d) list as an Impaired Waterbody for sediment. Aquatic habitat inventories conducted for the Sonoma Creek Watershed Enhancement Plan (SSCRCD, 1997) classified portions of mainstem Sonoma Creek upstream of Madrone Road as having high levels of embeddedness, a potential indicator of accelerated fine sediment production and deposition.

Although the Regional Water Quality Control Board (RWQCB) designation and the SSCRCD Watershed Enhancement Plan indicate that sedimentation may impair beneficial uses[2], including fish habitat, there have been no quantitative studies performed to assess the causes, extent, or probable locations where sediment may be affecting streams or limiting steelhead populations. The SSCRCD (1997) did develop a Pacific Southwest Inter-Agency Committee (PSIAC) model which calculates the relative sediment yield for 10 sub-basins in the Sonoma Creek watershed. However, the methods used to assign a rating to the physical parameters that serve as inputs to the model (surface geology, soils, climate, runoff, topography, ground cover, land type, upland erosion, and channel erosion/sediment transport) are not described, and calibration of the model, if it was performed, is not discussed. The model results did not indicate if the sediment yield values for the 10 sub-basins are indicative of a sediment supply which is accelerated beyond natural, background rates. Also, the model results did not indicate or imply how sediment yield might affect channel geomorphic or fish habitat conditions. .

[1] sufficient information exists to potentially warrant a proposal for listing spring-run Chiook salmon as endangered or threatened

[2] beneficial uses are designated by the Regional Water Quality Control Board, and include in the Sonoma Creek watershed: cold and warm-water aquatic habitat, fish migration and spawning, wildlife, agriculture, contact and non-contact recreation

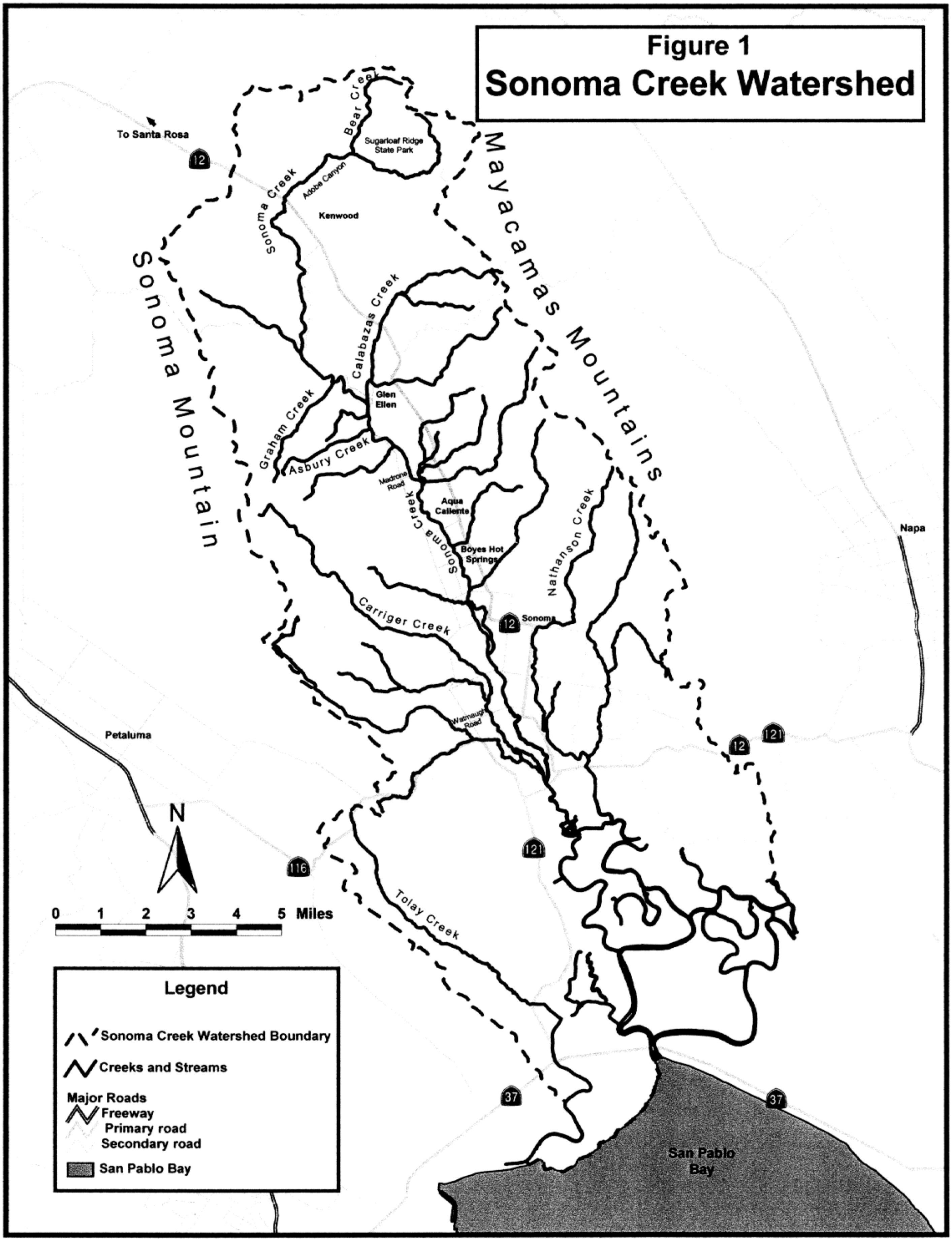
Figure 1
Sonoma Creek Watershed
To Santa Rosa
Sugarloaf Ridge State Park
Bear Creek
Adobe Canyon
Sonoma Creek
Kenwood
Sonoma Mountain
Mayacamas Mountains
Calabazas Creek
Graham Creek
Glen Ellen
Asbury Creek
Madrone Road
Aqua Caliente
Boyes Hot Springs
Nathanson Creek
Carriger Creek
Sonoma
Napa
Petaluma
Watmaugh Road
Tolay Creek
San Pablo Bay
0 1 2 3 4 5 Miles
N
Legend
Sonoma Creek Watershed Boundary
Creeks and Streams
Major Roads
Freeway
Primary road
Secondary road
San Pablo Bay

This spawning gravel suitability assessment was conducted to assess the extent and identify locations where sediment may be adversely affecting spawning habitat and thereby limiting steelhead (and possibly Chinook salmon) populations in the Sonoma Creek watershed. The amount and distribution of spawning habitat available in the watershed was not investigated, although prior studies have evaluated the extent of various habitat types on mainstem Sonoma Creek (SSCRCD, 1997). The specific objectives for this study include:

(1) identify potential spawning gravel locations on mainstem Sonoma Creek and selected tributaries for sampling and assessment
(2) evaluate the suitability of spawning gravels to support steelhead populations by assessing fine sediment content and framework of gravel size

This study did not attempt to identify the site-specific locations of sediment source contribution to streams, or to quantify the amounts of sediment contributed by those sources in the watershed. It also did not quantify the effects of sediment contributions to other aquatic habitat or channel geomorphic conditions (i.e., pools). However, the results do provide information useful for interpreting the potential effects of erosion and sediment production in the watershed on channel and aquatic habitat conditions other than spawning gravels.

3.0 EFFECT OF SEDIMENT ON SPAWNING GRAVEL QUALITY AND SUCCESSFUL REPRODUCTION

During spawning, salmonids select locations in channels to dig a pit in streambed gravels (known as a redd) and deposit eggs for incubation. Spawning locations are selected by the female based on the presence of suitable depths and water velocities, as well as the presence of suitably sized gravels. Preferred water depths for steelhead are greater than 24cm and preferred velocities range from 40-91cm/sec (Bjornn and Reiser, 1991). The suitability of gravel substrate for spawning is related to fish size and species. Larger fish can typically use larger gravels. The preferred range of gravel sizes used by steelhead is 6-100mm (Bjornn and Reiser, 1991). Kondolf (1993) compiled numerous studies of gravel sizes in redds for various species and found that the median diameter of steelhead gravels ranged between 10-45mm.

In alluvial stream channels with a pool-riffle morphology, spawning sites selected by many trout and salmon species are often located at the tail-out of pools immediately above a riffle (Bjornn and Reiser, 1991). The convexity of the bedform at the pool-riffle transition induces down-welling of water through the gravels. This down-welling creates a hydraulic gradient through the redd, bringing oxygenated water to the eggs and removing metabolic waste. Some species such as chum salmon, brown trout, and brook trout prefer to select spawning areas with upwelling groundwater (Bjornn and Reiser, 1991).

In stream channels that do not have a pool-riffle morphology, for example steeper channels with a step-pool configuration, other sites of gravel deposition such as in the lee of boulders, may be selected by the female for spawning. The female digs a redd by turning on her side and using her tail fin to fan the surface of the streambed gravels. Her tail fanning action creates a suction which lifts the gravels up into the current. The larger gravel particles are carried a short distance downstream (up to 3 feet) to form a tailspill. The finer gravel particles may be captured by the current and carried further downstream, away from the redd. After a suitable redd has been excavated, the female will release her eggs and the male will fertilize them. After spawning, the female will resume digging the redd immediately upstream, which buries the fertilized eggs.

Successful spawning, incubation, and emergence of salmonids requires that streambed substrates be of an appropriate size class composition, particularly with respect to the amount of fine sediment. It is also important that the streambed gravels are small and loose enough to be movable by the spawning female to create a redd. It is well known that the size of sediment particles influences the permeability of spawning gravels. Spawning gravels must be sufficiently free of interstitial fine sediment to permit adequate circulation of oxygenated water to the embryos. Spawning gravels also need to be sufficiently permeable to remove metabolic wastes from the redd. The detrimental effects of excess fine sediment on salmonid embryo survival has been intensively studied (McNeil and Ahnell, 1964, Koski, 1966; Bjornn, 1969, Hall and Lantz, 1969, Koski, 1975, Tagart, 1976, Cederholm et al, 1981). Reduced permeability restricts the flow of water around the incubating salmonid embryos, resulting in a decreased supply of oxygen and the accumulation of toxic metabolic wastes. Entombment of embryos and alevins may also occur when fine material blocks gravel interstices, preventing emergence from the redd.

4.0 SPAWNING HABITAT IN THE SONOMA CREEK WATERSHED

Few studies have been conducted to identify the amount and distribution of spawning habitat available in the Sonoma Creek Watershed. Historically, most of what is known is qualitative information based on stream surveys conducted by CDFG (1957, 1959, 1960, 1961, 1965, 1968, 1974, 1975, 1976, 1981). A CDFG field survey (Elwell, R.F., 1957) indicates that spawning areas were "very good throughout the Adobe Canyon and main branches down to Boyes Hot Springs and below". The best spawning locations are cited in the Kenwood area, as are "several good spawning tributaries" in the Kenwood reach, although the specific tributaries are not mentioned and apparently were not directly observed for this report. Downstream from the Boyes Hot Springs area, the 1957 survey indicates that spawning areas are fair to poor. The CDFG 1957 survey report is provided in Appendix A.

Habitat conditions on mainstem Sonoma Creek, upstream from Madrone Road, were recently quantified using standard CDFG habitat typing methods (SSCRCD, 1997). The study found that 67% of the low gradient riffles (approximately 70,000 sq.ft.) measured on mainstem Sonoma Creek had either gravel or small cobble as the dominant substrate. Presumably some of these low-gradient riffles would provide spawning habitat. The study did not conclude that quantity of spawning habitat is a limiting factor for either steelhead or Chinook salmon on the mainstem, but did identify lack of rearing habitat as a limiting factor. Of the pool-tailouts measured, 51% had high embeddedness ratings. Embeddedness is a semi-quantitative index of the extent to which larger gravels or cobbles are buried by fine sediment (sands, silts, and clays) and is measured by visual observation. The higher the embeddedness rating, the greater the presence of fine sediment burying or surrounding larger streambed particles. Only 9% of the observed pool-tailouts had a very low rating for embeddedness in the SSCRCD study. The study concludes that "spawning gravel exists, but there is a high rate of fine sediment deposition…"

Embeddedness ratings however, are not quantitative measures. The ratings tend to be subjective, varying between individual observers, and can only account for the amount of fine sediment visually observed on the bed surface. Embeddedness is therefore not necessarily an appropriate measure of fine sediment present in spawning gravels, particularly as it effects the egg pocket of a redd, and may not be a good predictor of spawning success.

In general, most steelhead habitat available in the watershed today, including spawning areas, is found upstream of Glen Ellen (Moyle, 1976), which confirms observations made during the 1957 CDFG stream survey. However, large gravel bars have been observed on mainstem Sonoma Creek downstream of Glen Ellen to Sonoma which may also provide spawning habitat. This area of the lower watershed was not investigated as part of the habitat typing performed for the 1997 Watershed Enhancement Plan (SSCRCD, 1997). Chinook salmon were observed by the Sonoma Ecology Center (SEC) and local residents during the course of this study spawning downstream of the Watmaugh Bridge in October 1998. It is possible that Chinook salmon in the watershed are strays that only occasionally enter Sonoma Creek to spawn. Long-term residents in the area report that this reach of Sonoma Creek is also sometimes used by spawning steelhead, particularly in drier years when streamflow conditions are very low further upstream (pers. comm., Mr. Bob Kiser).

There are no known habitat typing studies or other assessments of spawning areas on tributaries to Sonoma Creek. Successful spawning is likely occurring in many of the tributaries since steelhead were historically known, and continue to be present in many of the tributaries today. Calbazas and lower Bear Creek are two tributaries where juvenile steelhead were recently identified based on electrofishing surveys jointly conducted by CDFG and SEC in 1995. Recent visual observations have also confirmed the presence of steelhead on Nathanson Creek[3] and Carriger Creek. Historically, Graham Creek, Stuart Creek, and Asbury Creek reportedly supported steelhead populations, although there have not been recent observations or other reports of steelhead on these streams. Graham Creek was the site of a successful steelhead hatchery for several decades, from about the mid-1880's until the about 1909 (pers. comm., Mr. Arthur Dawson). Other tributary streams likely support steelhead today.

[3] Nathanson Creek is not technically a tributary to Sonoma Creek since it never joins the mainstem, but rather flows directly into San Pablo Bay. However, it is included here because it is very close to the Sonoma Creek drainage.

5.0 METHODS

5.1 Site Selection

For this assessment we sampled potential spawning sites at 8 locations in the Sonoma Creek watershed (Figure 2). Sampling sites were selected during the 1998 summer and fall low-flow period. Relatively recent observations of spawning activity were used to guide selection of sampling locations. Presence/absence electrofishing surveys jointly conducted by CDFG and SEC confirming the presence of steelhead at various mainstem and tributary locations were also considered in site selection. Priority for selecting sampling sites was given to stream reaches where there had been recent spawning observations or where juvenile steelhead are known to rear. We assumed that some adult spawning would likely have occurred within the vicinity of known juvenile rearing locations, although juveniles may swim some distance from their spawning and incubation areas to rear. There are no available historical records of spawning surveys or redd counts to identify site-specific locations utilized by adult spawners.

Sample sites were selected to include a range of representative stream channel types and to encompass a wide geographic distribution in the watershed. Additional considerations for selecting sampling locations included obtaining permission from private landowners and the relative ease of access to the site. Selected sampling locations were drawn from both mainstem Sonoma Creek and from tributaries arising on the east and west sides of Sonoma Valley. Table 1 lists the sampling locations and describes the basis for selecting each sampling site.

Four locations on mainstem Sonoma Creek and four tributaries were sampled (see Table 1). The mainstem locations included sites distributed from near the headwaters of the watershed (Site A in Adobe Canyon) to the most downstream location below Watmaugh bridge (Site H), near the upstream range of tidal influence from San Pablo Bay. During the process of site selection, Chinook salmon were observed actively spawning downstream of Watmaugh bridge in October 1998. Two tributaries on the east side of Sonoma Valley, Bear Creek and Calabazas Creek, and two tributaries on the west side of the valley, Carriger Creek and Graham Creek, were sampled.

All of the sampling sites are in perennial stream reaches, although some samples were taken from dry gravels which were not in the active channel during the low-flow sampling period. During the spawning and incubation season, December to May for winter-run steelhead and October to January for fall-run Chinook salmon, all sampling sites would be within the wetted, active channel.

Sampling locations fell into one of two bedform morphological types, pool-riffle and step-pool. Sampling locations with a pool-riffle configuration exhibit a sequence of steeps (riffles) and flats (pools). The pool tail-outs, which typically define the upstream head of a riffle, are often a preferred site for spawning steelhead. In channel reaches with a pool-riffle configuration, the pool tailouts were frequently selected, (although not exclusively), as the “micro-habitat” for sampling of spawning gravels. Figure 3 shows a typical pool-riffle sampling location at Site C, on mainstem Sonoma Creek in Kenwood.

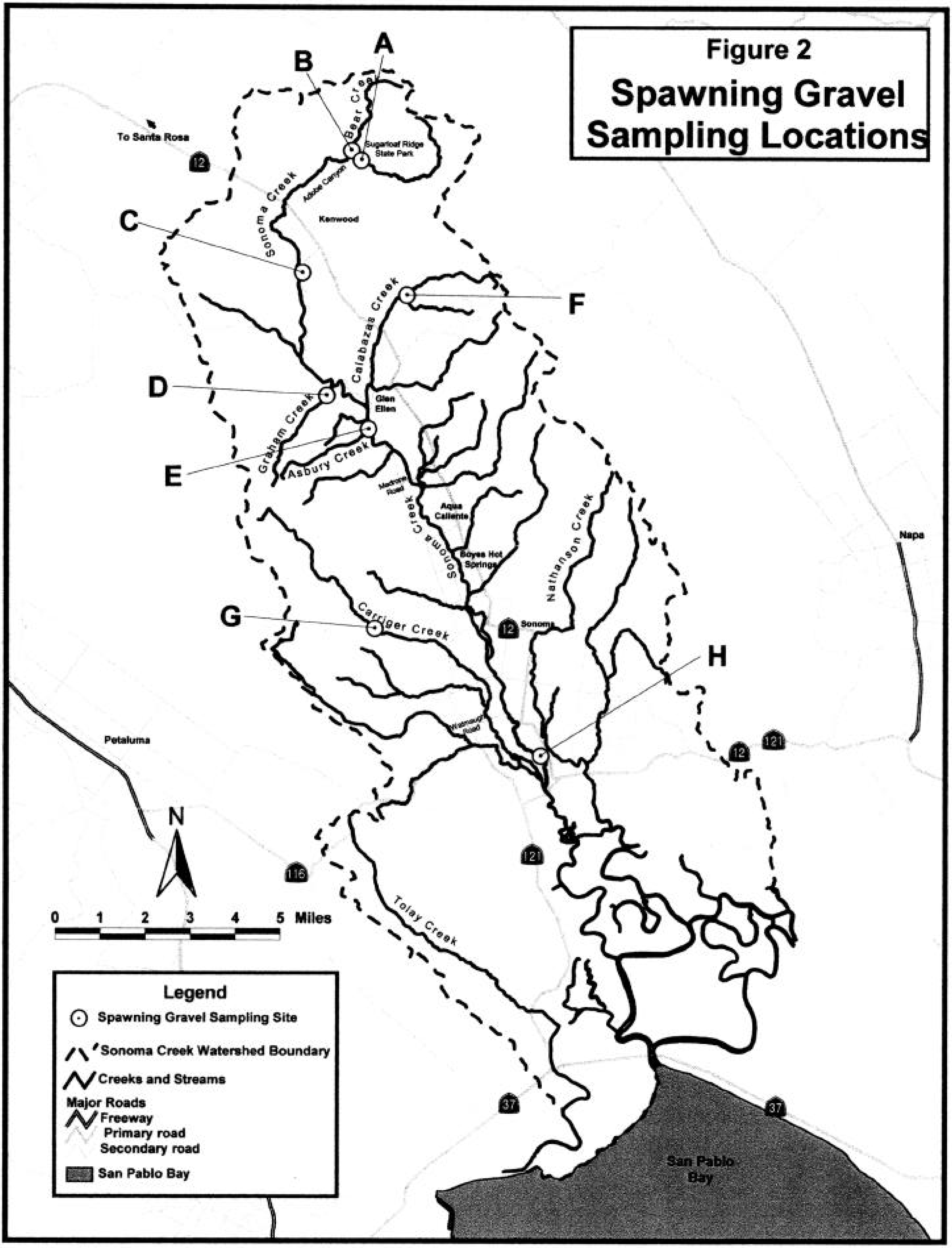

Figure 2
Spawning Gravel Sampling Locations

A step-pool configuration is the other type of dominant bedform found in the selected sampling locations. The step-pool channel is characterized by water flowing from one small boulder cluster to another with closely spaced intervening small pools between. During low flow the bedform gives the appearance of a series of steps. The step-pool channel segments are formed in locations with a higher channel gradient than the pool-riffle segments and were typically dominated by larger bed materials such as cobbles and small boulders compared to the pool-riffle stream reaches. Spawning sized gravels are generally deposited in the lee or fore of larger bed elements where velocity-shadows slow streamflow. These “pocket” gravels appeared to be the only source of spawning habitat available to steelhead in the step-pool streams. Figure 4 shows a typical step-pool sampling location at Site D on Graham Creek.

All of the mainstem reaches sampled, except for Sonoma Creek in Adobe Canyon (Site A), were characterized by a pool-riffle bedform. The tributaries sampled were predominantly step-pool channel types, although pool-riffle sequences were represented near a few of the sampling sites where the channel bedform begins to transition. Table 1 lists the type of bedform morphology at each of the sampling sites.

5.2 Sampling Method and Protocol

At each selected sampling site, 3 to 4 bulk gravel samples were collected using a modified McNeil sampler with a 12-inch diameter core. The sampler is constructed of stainless steel, and is driven into the streambed by hand to a depth approximating that of the typical egg-pocket in a steelhead redd. Based on observations by CDFG staff, steelhead deposit eggs in the redd to a depth of approximately 6-8 inches (pers. comm. Bill Cox, Region 9, Yountville). Chinook salmon cover eggs with 8 inches to 14 inches of gravel (Groot, 1996). Streambed materials were sampled to a minimum depth of 5.5 inches, and up to a maximum depth of about 8 inches below the ground surface. Some of the samples collected from pocket gravels in the tributary step-pool channels could only be taken to a maximum depth of about 5.5 inches. Bedrock or buried small boulders and cobble sized material occasionally prevented coring with the McNeil sampler to depths greater than 5.5 inches in tributary reaches. Samples which could not be collected to a depth of at least 5.5 inches were discarded. Bed material collected from sampling sites in the pool-riffle dominated reaches were generally cored to a greater depth. Typically, a volume of at least 3 gallons of bed material was extracted from the McNeil sampler.

Bed materials were removed by hand from within the sampler and placed in a plastic bucket, sealed with a lid, and labeled for transport and later processing. Field notes were recorded at each sampling location, including a sketch of the channel configuration and sampling sites, and depth of each sample. Photographs were also taken to document channel conditions.

TABLE 1. SAMPLE LOCATIONS, BASIS FOR SELECTION, AND CHANNEL BEDFORM MORPHOLOGY

ID	Sample Location	Description	Basis for Selection	Bedform Morphology
Site A	**Mainstem Sonoma Creek in Adobe Canyon** (east side of Sonoma Valley)	At entrance to Sugar Loaf Ridge State Park, downstream of the Goodspeed trail bridge crossing, at the confluence with Bear Creek (Site B)	Near most upstream location accessible to spawners on mainstem. Natural passage barriers above Adobe Canyon. Juvenille steelhead were identified during 1995-96 CDFG survey	Step-pool
Site B	**Bear Creek** (east side of Sonoma Valley)	In Sugar Loaf Ridge State Park, immediately upstream from confluence with Sonoma Creek	Juvenile SH found in 1995 electrofishing survey with CDFG	Step-pool
Site C	**Mainstem Sonoma Creek in Kenwood**	Between Lawndale bridge and Mound Ave bridge crossings	Juvenile SH found in 1995 electrofishing survey with CDFG and observed spawning in 1997	Pool-riffle
Site D	**Graham Creek** (west side of Sonoma Valley)	0.2 mi. up Sonoma Mountain Rd., upstream from confluence with Sonoma Creek in Glen Ellen	Historically used as hatchery (no longer in operation) for steelhead in Sonoma Valley.	Step-pool
Site E	**Mainstem Sonoma Creek at Jack London Village**	Adjacent to Jack London Village in Glen Ellen	Near expected downstream limit of steelhead spawning. Steelhead found a few hundred yards upstream during 1995-96 CDFG electrofishing surveys.	Pool-riffle
Site F	**Calbazas Creek** (east side of Sonoma Valley)	Near Beltane Ranch, up Nunn's Canyon Rd.	Sampling by electrofishing identified SH in 1995 and CDFG identification as spawning area	Step Pool and Pool-riffle
Site G	**Carriger Creek** (west side of Sonoma Valley)	Downstream of road crossing and pedestrian bridge at Goode property	Reports of steelhead spawning in 1998-1999	Step-pool
Site H	**Mainstem Sonoma Creek in Sonoma**	Approximately 200 yds. downstream of Watmaugh bridge	Active Chinook salmon spawning on riffles immediately upstream of sampling site in Oct. 1998	Pool-riffle

Figure 3. Site C on mainstem Sonoma Creek in Kenwood with a pool-riffle bedform

Figure 4. Site D sampling location on Graham Creek with a step-pool bedform

At each of the 8 sampling locations, 3 to 4 samples were collected. Two samples were collected as "side-by-side" paired samples whenever possible. At some of the step-pool sites, gravel deposits were not sufficiently large enough to permit paired sampling. A total of 26 samples were collected, with 12 samples collected as side-by-side pairs. At each location, samples were collected beginning with the most downstream site, working in the upstream direction. All samples were collected during the low-flow period between October and early December, 1998 prior to the beginning of high-flow.

In the SEC laboratory samples were removed from their buckets, spread on individual plastic tarps, and allowed to completely air dry for several weeks. After drying, the samples were sorted into 17 size classes from <.062mm to 180mm, as shown in Table 2. Standard ASTM sieves were used to sort the smaller particle sizes (.062mm to 16mm and 32mm) and clear plastic rulers were used to size larger particles (22mm, and 45mm to 180mm). The particle size categories used are based on the Wentworth Scale which is often used by sedimentologists to categorize the type of sediment (see Table 2). Sieving was processed by hand. For larger sediment sizes rulers were used to measure the b-axis diameter of each particle. All particles collected in the McNeil sampler were used in the sieving processes. No particles larger than 180mm were encountered in any sample.

TABLE 2. PARTICLE SIZE CLASSES (BASED ON WENTWORTH GRADING SCALE)

SIZE CLASS (mm)	WENTWORTH PARTICLE SIZE GRADING SCALE
> 256	**BOULDER**
180	**COBBLE**
128	
90	
64	**GRAVEL**
45	
32	
24	
16	
8	
4	**SAND**
2	
1	
0.5	
0.25	
0.12	**SILT**
.062	
<.0039	**CLAY***

* smallest particle size sieved in this study was .062mm

Each size class was weighed using either a spring scale for larger particle sizes or an electronic scale for smaller particle sizes. The scales were calibrated using a known weight prior to measuring each sample. Weights associated with each size class were recorded on data sheets and later entered into a computer spreadsheet program for statistical analysis.

6.0 RESULTS

6.1 Gravel Size Distributions

Cumulative size distribution curves are typically used to present the wide range of sediment sizes that are often associated with spawning gravels. Weights retained on each sieve (or determined by measuring the b-axis diameter) were converted to percentages of the total sample weight, and summed to develop the cumulative size distribution curves. The cumulative size distribution curves for each of the eight sample locations A through H is provided in Appendix B. For each of the eight sampling locations, the individual samples collected at that site are plotted together. Paired samples, when they were collected, are identified.

Statistics were developed from the distribution curves to facilitate comparison between each of the samples. Table 3 indicates the D50, D16, and D84 for each sample. The D50 is the median particle diameter, and is often used as a measure of central tendency of the distribution. The D16 and D84 are the sizes at which 16% and 84% of the sample are finer. Also presented is another measure of central tendency, the geometric mean, computed as $dg = (D84*D16)^{0.5}$ (Vanoni, 1975). The geometric mean diameter is usually less than the median diameter because the gravel size distributions from stream channels tend to be negatively skewed, characterized by distribution curves extending into the fine sediment sizes.

From Table 3, the range of median particle sizes (D50) is 9mm to 48mm (samples A1 and D3, respectively), and the range of geometric mean diameters is 7mm to 30mm (samples A1 and G1, respectively). Individual samples collected from within the same stream reach were generally defined by a more narrow range of median particle sizes than individual samples compared between different stream reaches. The greatest variability in D50 at a location was at Site A (Sonoma Creek in Adobe Canyon), where there was a 31 mm difference between sample A1 (9mm) and sample A2 (40mm). Excluding location A, all other samples had no more than a 17mm difference (site E), and typically there was less than a 10mm difference between D50 values at a sampling site. The geometric mean diameter is similarly characterized by a smaller particle size range when considering only the samples taken from within a designated sampling reach. The largest difference is at site G, with a 15mm difference between samples G1 and G2. At most sites, the difference in geometric mean diameter was also less than 10mm. These data indicate that the variability of particle sizes is greater when comparing samples taken from different stream reaches than from within the same stream reach. The D16 encompasses a very narrow range of particle sizes when comparing all sites, from 2mm to 8mm. The D84 encompasses a much broader range of particle sizes, from 17mm to 154mm. Figure 5 is a box-and-whisker plot of all 26 samples. The box-and-whisker plot indicates the D10, D25, D50, D75, and D90 for each sample.

Table 3. PARTICLE SIZE STATISTICS

		D16	D84	D50	dg
A1	Sonoma Creek in Adobe Canyon	3	17	9	7
A2*		2	150	40	17
A3*		2	64	15	11
B1	Bear Creek	2	32	12	8
B2		2	44	15	9
B3*		3	45	16	12
B4*		4	30	15	11
C1*	Sonoma Creek in Kenwood	6	62	23	19
C2*		4	51	21	14
C3		2	70	21	12
D1	Graham Creek	4	107	40	21
D2		3	109	40	18
D3		3	154	48	21
E1	Sonoma Creek at Jack London Village	6	80	32	22
E2*		3	58	15	13
E3*		4	75	25	17
E4		8	80	32	25
F1*	Calabzas Creek	2	45	12	9
F2*		4	44	22	13
F3		6	76	28	21
G1	Carriger Creek	7	127	35	30
G2		3	75	25	15
G3		7	90	29	25
H1	Sonoma Creek in Sonoma	4	40	18	13
H2*		5	50	25	16
H3*		5	53	22	16

* indicates paired samples at each site (designated by letter code)

There are no strong trends related to the particle size statistics (Table 3 and Figure 5) that are associated with either stream location in the watershed or distance downstream from the headwaters. Often, there is a fining of particle sizes with distance downstream from the headwaters due to deposition as stream gradients decrease and to attrition of larger particles that breakdown during transport downstream. Comparison of the D50 values between the four Sonoma Creek samples do not indicate a pattern of either fining or coarsening of spawning gravels. Similarly, tributaries do not show any clear trend when compared with the mainstem samples. Samples from the two west side tributaries, Graham Creek (Site D) and Carriger Creek (Site F) have slightly larger median particle sizes than either of the east side tributaries or mainstem Sonoma Creek. Samples collected from Bear Creek (east-side tributary) have the smallest median particle sizes.

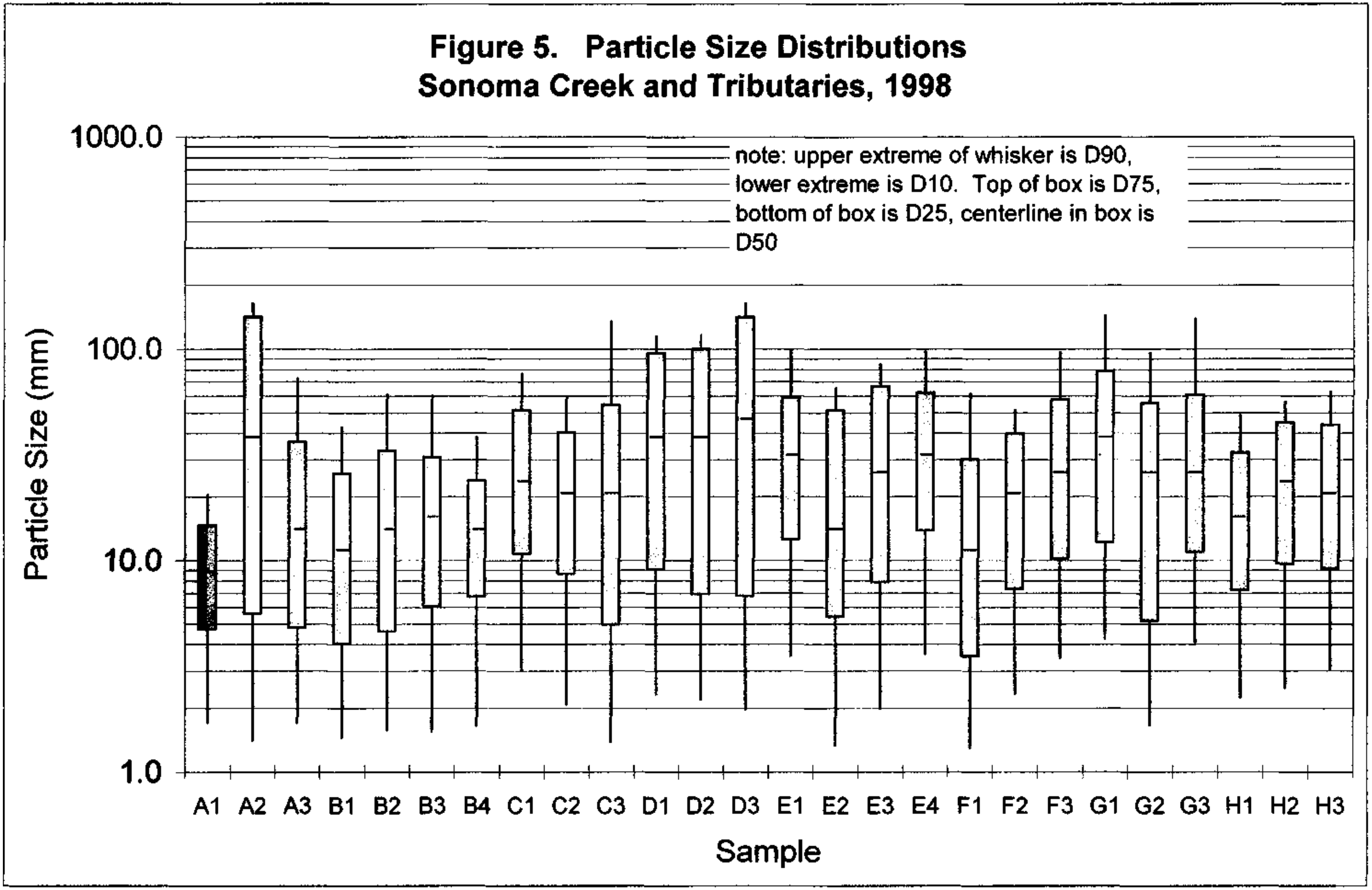
Figure 5. Particle Size Distributions
Sonoma Creek and Tributaries, 1998
note: upper extreme of whisker is D90, lower extreme is D10. Top of box is D75, bottom of box is D25, centerline in box is D50
Particle Size (mm)
1000.0
100.0
10.0
1.0
A1 A2 A3 B1 B2 B3 B4 C1 C2 C3 D1 D2 D3 E1 E2 E3 E4 F1 F2 F3 G1 G2 G3 H1 H2 H3
Sample

6.2 Fine Sediment Content

The fine sediment content of the samples for the percentage (by weight) of material less than 1% and less than 3% is shown in Table 4.

Table 4. Percentage, By Weight, of Fine Sediments Less Than 1mm and 3mm

		%<1mm	%<3mm
A1	Sonoma Creek in Adobe Canyon	7	16
A2*		7	18
A3*		5	18
B1	Bear Creek	7	21
B2		6	19
B3*		7	16
B4*		7	15
C1*	Sonoma Creek in Kenwood	4	10
C2*		5	13
C3		7	19
D1	Graham Creek	3	13
D2		3	16
D3		3	16
E1	Sonoma Ck at Jack London Village	3	9
E2*		9	16
E3*		6	15
E4		5	9
F1*	Calabzas Creek	7	23
F2*		3	14
F3		1	9
G1	Carriger Creek	1	7
G2		5	16
G3		1	7
H1	Sonoma Creek in Sonoma	5	14
H2		3	13
H3		1	11

* indicates paired samples within each sample location (designated by letter code)

For the less than 1mm size class, the largest percentage of sediment present by weight is 9% (E2) and the smallest percentage sediment is 1% (H3, F3, G1, G3). For the less than 3mm size class the largest percentage of sediment present is 23% (F1) and the smallest percentage of sediment in the less than 3mm size class is 7% (G1 and G3).

7.0 ANALYSIS AND CONCLUSIONS

For successful incubation of embryos, the amount of fine sediment present in spawning gravels must not reduce gravel permeability so as to lower levels of dissolved oxygen in the redd or cause suffocation of embryos. Sediments also must not block fry emergence through interstitial spaces in the gravel matrix. Although excessive levels of fine sediments are commonly acknowledged to limit spawning success, there is no single particle size statistic that adequately relates fine sediment composition to survival. Kondolf (2000), based on a review of laboratory and field studies suggests that sediments finer than 1mm can reduce gravel permeability affecting dissolved oxygen content and removal of metabolic wastes from the redd. Larger sediments in the 1 to 10mm size range are generally considered to be responsible for inhibiting fry emergence through interstitial gravel spaces. Criteria for allowable fine sediment content of sampled gravels used in this analysis is based on Kondolf's (2000) compilation of laboratory and field studies, as follows:

- Percentage finer than 1 mm < 14%
- Percentage finer than 3 mm < 30%

No samples exceed the percent fines criteria for particle sizes finer than 1mm (Table 4). The greatest percent fines measured was 9%, with most samples 7% or less for particles sizes smaller than 1mm. Similarly, no samples exceeded the criteria for percentage finer than 3mm. The greatest percent fines measured in the less than 3mm particle size class was 23%, with most samples 19% or less.

These data demonstrate that fine sediments are not excessively present in spawning gravels, and are not a factor limiting spawning success. The percentage of fine sediment measured in potential spawning gravels should be adjusted downward to account for the cleansing effect salmonids have on gravels when constructing a redd (Kondolf, 2000). Thus, actually spawned gravels would have a lower fine sediment content than those reported here for un-spawned gravels. It should be noted that fine sediments may infiltrate into the redd during winter flows when eggs are incubating. If deposition occurs during the incubation period this could counteract the influence of fine sediment cleansing during redd construction. Sampling for this study occurred during the late summer and fall prior to the onset of 1999 winter flows and therefore do not reflect conditions during embryo incubation in the redd. Sampling would be required during the steelhead incubation period and at sites where redds were identified in order to more accurately evaluate gravel composition as experienced by eggs and embryos. However, such sampling can be extremely difficult since streamflows are typically much higher during that time of the year.

A companion measurement to percent fines, the geometric mean diameter was also calculated. Geometric mean diameter (Dg) is often used to describe the composition of substrate sizes. Tappel and Bjornn (1983) found that steelhead and Chinook salmon embryos had high survival rates, approximately 90%, when the geometric mean of the gravel mixture exceeded 10mm. As Dg decreased below 10mm, percent survival decreased. Shirazi and Seim (1979) found that embryo survival was less than 90% unless the Dg exceeded 15mm. Three samples fall below the 10mm geometric mean threshold (B1, A1, and F1). An additional 9 samples fall at or below the 15mm threshold (C2, C3, B2, B3, B4, A3, F2, G2, and E2). A 90% survival rate is quite high. Most fisheries biologists would likely consider a 50% emergence success to be very productive. It should be recognized that the usefulness of the geometric mean as a predictor of spawning success is limited because gravel mixtures may have the same geometric mean but have very different size compositions with respect to fine sediment content.

There are no identifiable trends associated with fine sediment content for either mainstem reaches or tributaries. The data indicate that the west side tributaries, Graham creek and Carriger Creek have slightly lower fine sediment content for most samples compared with the east side tributaries Calabazas and Bear Creek (Table 4). However the differences are not great and are probably not statistically significant.

The relatively low fine sediment content found in almost all spawning gravel samples may well be an indicator of low overall sediment production rates in the watershed. Accelerated sediment production would likely adversely impact spawning gravels if the sediment transport capacity of the mainstem or tributaries were greatly exceeded. However, this is apparently not the case. It is possible that accelerated erosion and sediment production occurs in the watershed, but either eroded sediments do not reach most stream channels (sediment may be deposited into long-term storage on the floodplain along the valley flat adjacent to Sonoma Creek), or sediment production has not accelerated beyond the transport capacity of streams in the watershed.

A sediment budget, which is an accounting of the disposition of sediment sources, deposition sites, and transport rates would be a valuable study to quantify sediment production. Nevertheless, the results of this study indicate that if there is accelerated sediment production in the watershed, fine sediment deposition has not adversely impacted spawning habitat. Other types of impacts to spawning habitat, for example a reduction in overhead and instream cover in spawning areas due to removal of vegetation in the riparian corridor, could be adversely effecting spawning conditions, but these types of impacts were not investigated for the present study.

Vineyard development, grazing, and residential development may all be contributors of sediment to the streams draining the Sonoma Valley. Vineyard development has been particularly extensive in recent decades. As of 1994 there was approximately 13,300 acres (21 mi^2) of vineyards in the 170-square mile watershed (pers. comm., Chris Finlay, Growers & Vintners Alliance). Although there is no data for present-day acreage in the Sonoma Valley, there has been a 1,500 acre average annual increase in vineyard acreage (86% of which is conversion from other agricultural activities) in Sonoma County during the past decade. In light of this extensive vineyard and also residential development in the Sonoma Creek watershed in recent decades, this study can provide a good basis for comparison with future investigations and monitoring programs.

Although this study evaluated the suitability of spawning gravels, it did not consider how fine sediments may be influencing other fish habitat conditions, particularly the frequency and depth of pools. Excess fine sediments can reduce the volume of pools, thereby impacting rearing and nursery habitat. Studies which consider the presence of fine sediment in pools would be required in order to determine if there are adverse impacts from excess fine sediments. One valuable technique for quantifying and monitoring the presence of fine sediment in pools over time is the V* method developed by Hilton and Lisle (1993). Such a study could provide additional information related to erosion, sedimentation, and effects on fish habitat conditions.

8.0 ACKNOWLEDGEMENTS

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Several residents of the watershed and others participated in this study, volunteering to assist with the collection and processing of gravel samples. The study could not have been executed without their assistance. The SEC would like to thank the following individuals for their efforts:

Richard Dale	Royce Spear	Terry Wright, Sonoma State Univ.
Jorge Garibay	Steve Kapner	Jim Zanzot
Joan MacDonald	Page Leonard	
Julie Shoffner-McGee	Nancy Swick	

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APPENDIX A

CALIFORNIA DEPARTMENT OF FISH and GAME 1957 SURVEY REPORT

CALIFORNIA DEPARTMENT OF FISH AND GAME

STREAM SURVEY

File form No. ________

NAME: SONOMA CREEK **COUNTY:** Sonoma

STREAM SECTION: ________ **FROM:** mouth **TO:** Headwaters **LENGTH:** ________

TRIBUTARY TO: San Pablo Bay **TWP:** 4 N **R:** 5 W **SEC:** 29

OTHER NAMES: none. **RIVER SYSTEM:** ________

SOURCES OF DATA: Personal observation and local residents

EXTENT OF OBSERVATION –

Stream was checked by auto via Sears Point road, Highway 12, Warm Springs road, and various county roads, from the mouth upstream to the headwaters area north of Kenwood on 2-4-57 by R. F. Elwell. Stops were made at frequent intervals for closer inspection on foot.

LOCATION –

Enters San Pablo Bay from the north, approximately 9 miles south of Sonoma.

RELATION TO OTHER WATERS –

Stream is utilized by steelhead as a spawning and nursery grounds.

GENERAL DESCRIPTION –

Watershed – General area is characterized by wide, heavily populated and extensively cultivated valley, bounded by well wooded hills.

Immediate Drainage Basin – The main stream is situated almost entirely in the broad, flat Valley of the Moon in Sonoma County. The entire section is rather heavily populated and is either agricultural or irrigated pasture land. Most of the mid- and upper section runs through dense shade. The lower half lacks shade and is devoted primarily to agricultural land and pasture.

Altitude – 0' - 2000'

Gradient – Moderate to shallow throughout. [lwr section.]

Width – Average 10 ft. (3-25 ft.).

Depth – Average 8 in. (6 in. - 3 ft.).

Flow – Estimated 1 c.f.s. in upper section; 2 c.f.s. in mid-section; 3 c.f.s. in lower section.

Velocity – Generally rapid to cascading throughout entire [upper] stream section, [sluggish in lwr section.]

Bottom – Gravel, rubble and boulder.

Spawning Areas – Very good throughout the adobe canyon and main branches down to Boyes Hot Springs and below.

Pools – Very good pool development in upper section, fair mid-section and poor in lower.

Shelter – Good in mid- and upper sections, poor in lower section.

Barriers – Many open center flashboard dams are scattered along the entire stream and tributaries. Ho permanent barriers were observed.

Diversions – There are large number of diversions along the main stream and tributaries [both] for individual home use and large-scale irrigation. One of the larger diversions is [that] of the Saunders Sonoma County Golf course, located in Boyes Springs, across from the Valley of the Moon Recreation District catchable trout pond. Heavy pumping for the watering of the lawns in this golf course draws the water down very low in this area during the summer.

Temperatures – Maximum water temperatures probably range well above 70° in the open, unshaded lower section during the summer. Temperatures are probably considerably cooler in the mid- and upper sections along the densely shaded areas.

Food – Native insects and larvae.

Aquatic Plants – Few.

Winter Conditions – This stream is subject to heavy winter runoffs.

Pollution – Heavily populated areas occur along entire stream section including wineries and dairies.

Springs – None noted.

FISHES PRESENT AND SUCCESS –
Steelhead fingerling averaging 2-3 in. in length are quite common along the entire stream section. Success is evidently good in those nursery areas above Boyes Springs.

OTHER VERTEBRATES –
None observed.

FISHING INTENSITY –
Heavy in some sections of stream.

OTHER RECREATIONAL USE –
There are considerable number of summer dams along the entire stream which are utilized for swimming during the summer months.

ACCESSIBILITY –
Stream is accessible from Highway 12 for almost the entire length.

OWNERSHIP –
Most of the land bordering the stream is privately owned.

POSTED OR OPEN –
Although some sections of the stream are heavily posted against trespass, most of the stream is open.

IMPROVEMENTS –
The construction of several earth-fill check dams below Boyes Hot Springs is proposed by the Valley of the Moon Recreation District.

PAST STOCKING –
The 7-acre impoundment area behind the Valley of the Moon Recreation District flashboard dam is stocked with catchable trout.

GENERAL ESTIMATE –
This appears to be a very good steelhead producing stream. The best spawning areas occur from the Highway 37 - 12 bridge upstream to the headwaters area above Kenwood. The best nursery areas occur from Glen Ellen upstream.

RECOMMENDED MANAGEMENT –
It is recommended that this stream be managed as a steelhead spawning and nursery ground. The number of water diversions should be held to a minimum above the tidewater section, particularly the main stream section between Boyes Hot Springs and Kenwood.

The continuation of catchable trout planting in the Valley of the Moon Recreation District Park pool at Boyes Hot Springs is recommended.

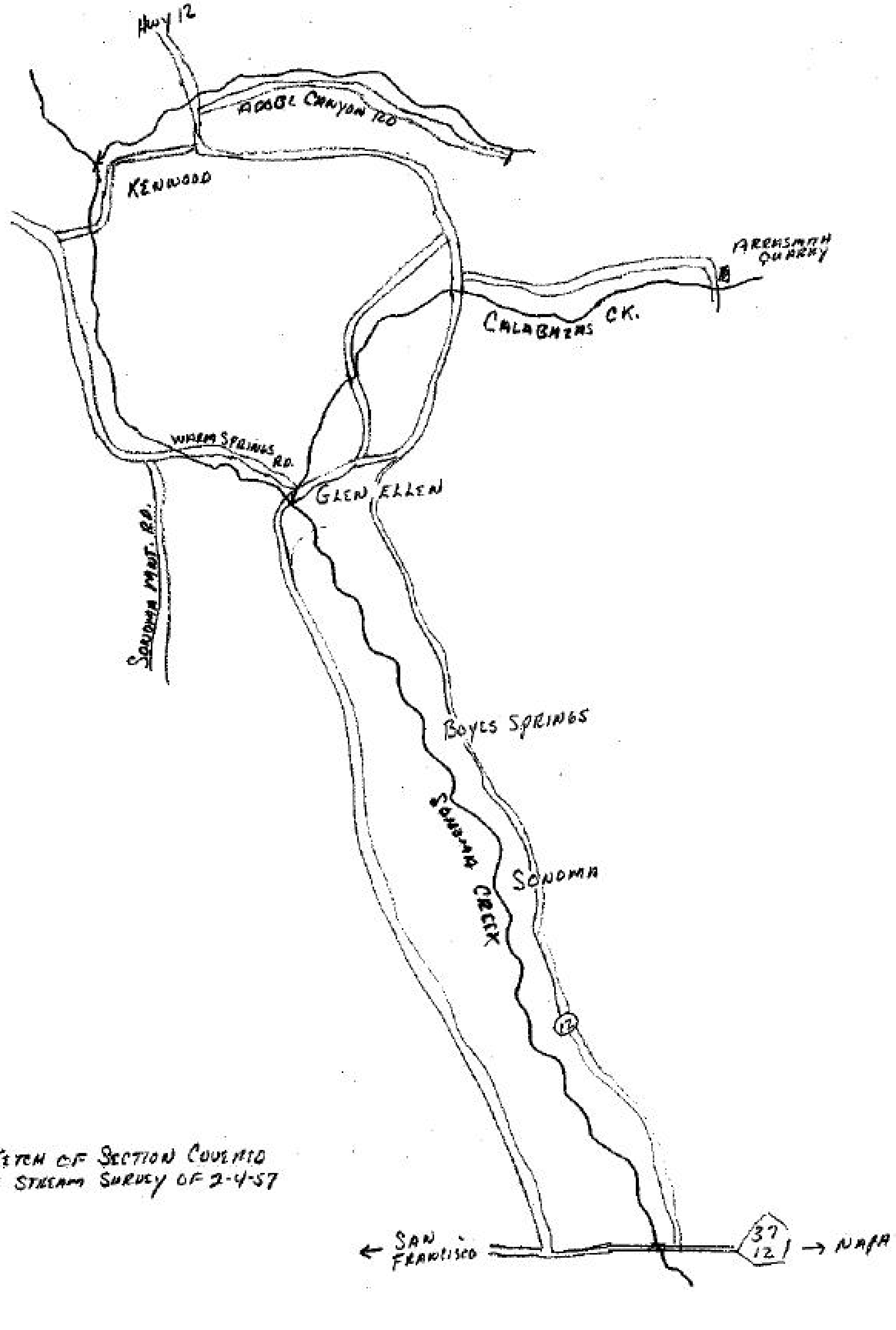
SKETCH MAP –
See attached.

REFERENCES AND MAPS –
Sonoma County (Division of Forestry 1956)[*; U.S.G.S. Quads: Sonoma, 1942; Mare Island,' Santa Rosa, 1944; Rutherford, 1951.*]

R.F. Elwell

RFE:cd

SONOMA CREEK
SONOMA CO.
2-4-57 R.F.E.



NOTE: ROUGH SKETCH OF SECTION COVERED ON BRIEF STREAM SURVEY OF 2-4-57

SONOMA CREEK
Sonoma County

FIELD NOTES

2-4-57

From mouth upstream to Highway 37 bridge

Stream in this tidewater section courses through open, cultivated and pasture land and marshland. Water just below the Highway 37 bridge was very murky on this date and choked with tules and debris. Width varies from 20 ft. at Highway 37 bridge to 20© ft. at mouth.

From Highway 37 bridge upstream to Boyes Hot Springs

Creek courses through agricultural land in steep bank channel. Shade is generally fair. Bottom composed mostly of rubble, gravel and silt. Spawning areas fair to poor with poor nursery grounds. Average width 20 ft. (10-25 ft.), average depth 6 in. (3-8 in.) Pool development is fair, shelter generally poor.

From Boyes Hot Springs upstream to Glen Ellen

Creek courses at a moderate gradient over a rubble, gravel bottom with some bedrock and silted sections. Spawning areas are generally good, pool development also good. Willow-oak shade fair to poor in the vicinity of Boyes Hot Springs. Average stream width 15 ft. (12-20 ft.), average depth 6 in. (4-8 in.). The stream section below Boyes goes dry in July.

From Glen Ellen upstream to Kenwood

Creek courses at a moderate gradient through a well shaded (oak-bay) small valley that is extensively cultivated and populated. The flow was an estimated 2 c.f.s. Spawning areas very good, pool development also very good. Bottom generally gravel rubble with some bedrock. Average width 8 ft. (3-15 ft.), average depth 1 ft. (6 in. - 2 ft.). Several good spawning tributaries run into stream in this section. This also appears to be a very good nursery area. Several open center flashboard dams and many water diversions noted in this section.

Adobe Canyon road tributary

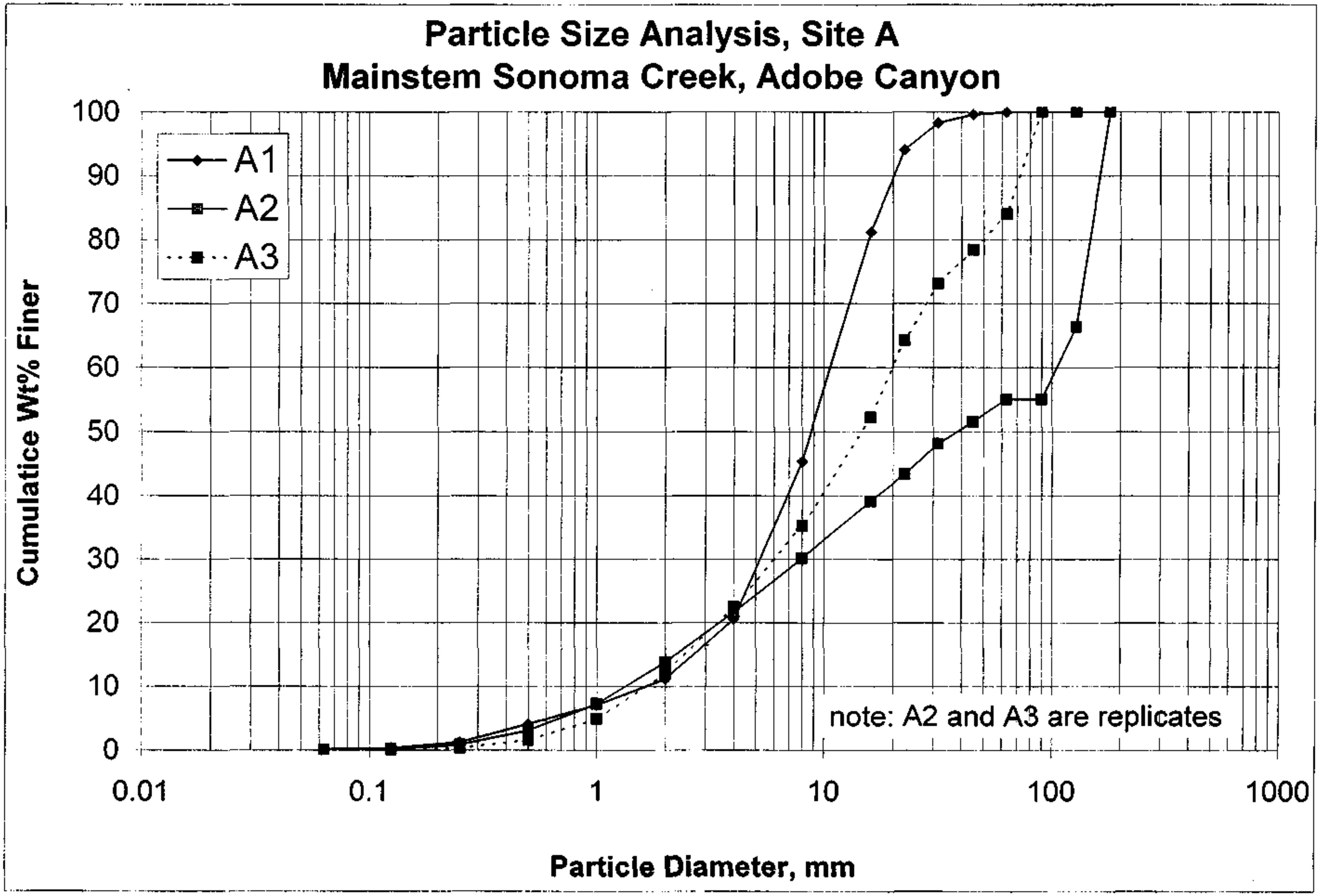
Tributary runs through steep well-wooded and populated canyon. Oak-alder-bay-conifer shade is very good. Spawning areas generally fair to good, pools good. Bottom generally boulder rubble. Velocity rapid to cascading with an estimated flow 1.5 c.f.s. Average width 8 ft. (6-12 ft.), average depth 6 in. (5 in. - 1 ft.). Stream posted against trespass by the BC Gun Club and Ongard Ranch at a locked gate 2 miles above Highway 12. Tributary opens into an open cultivated valley approximately 2 miles below this gate.

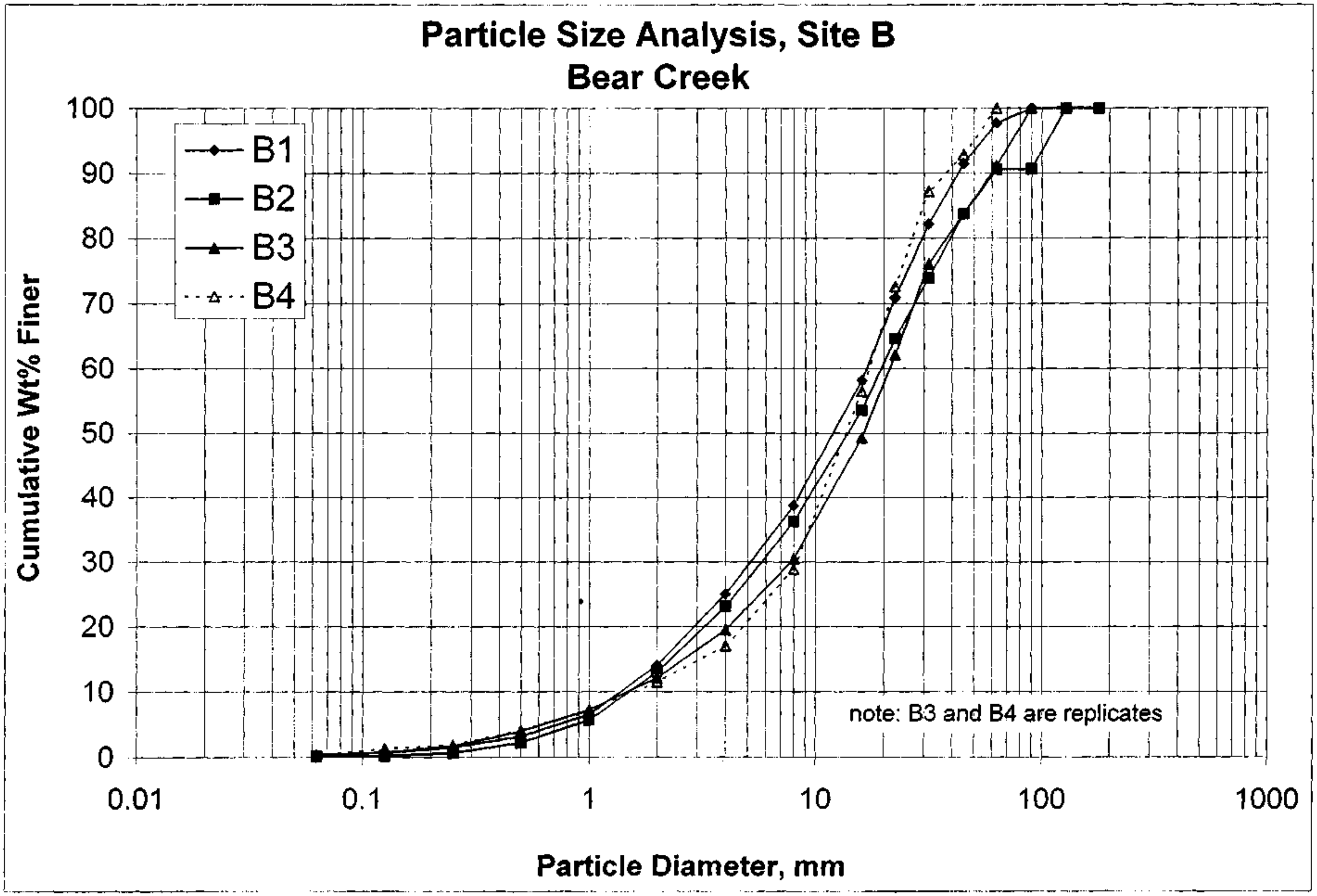
RFE
R.F.Elwell

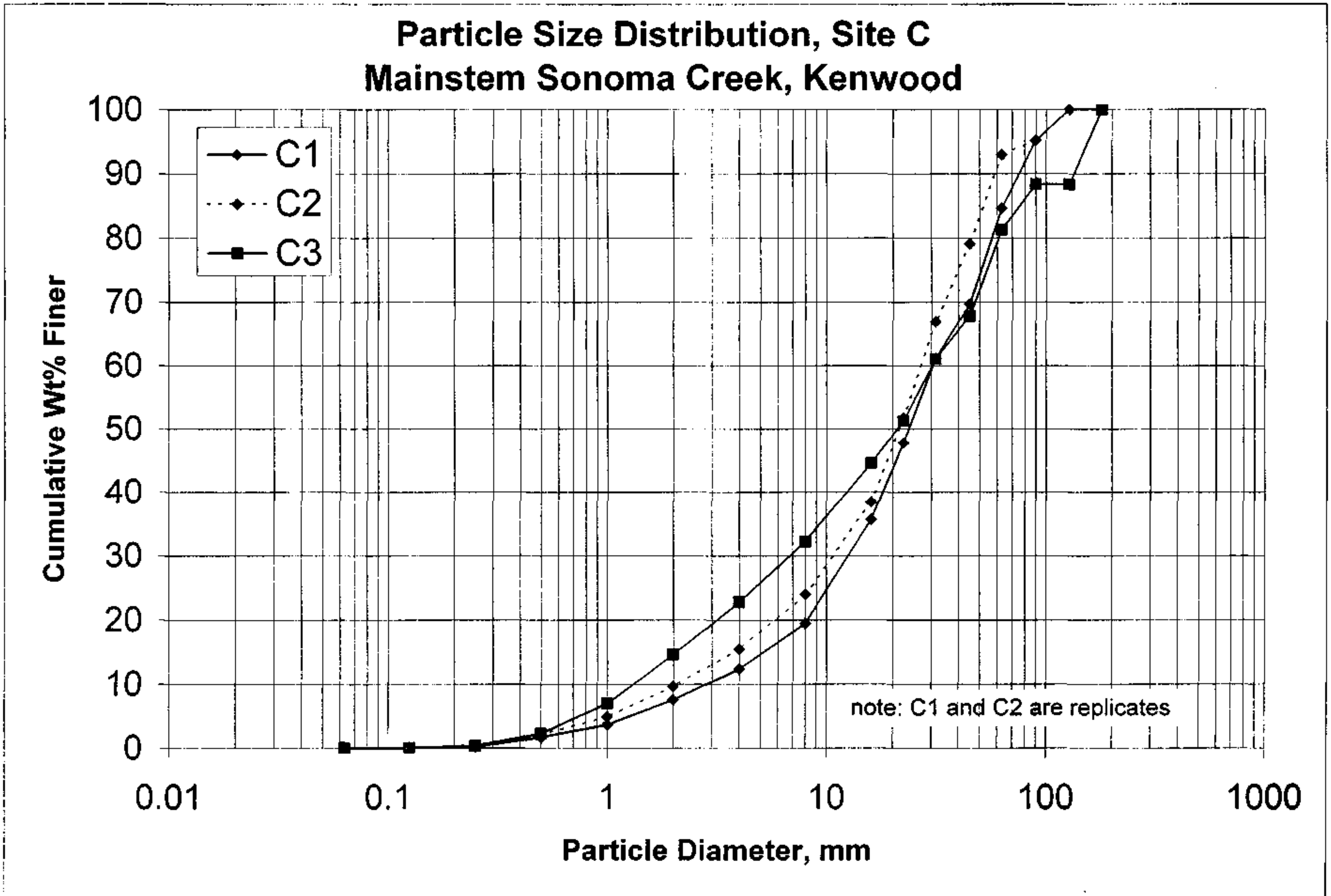
RFE:cd

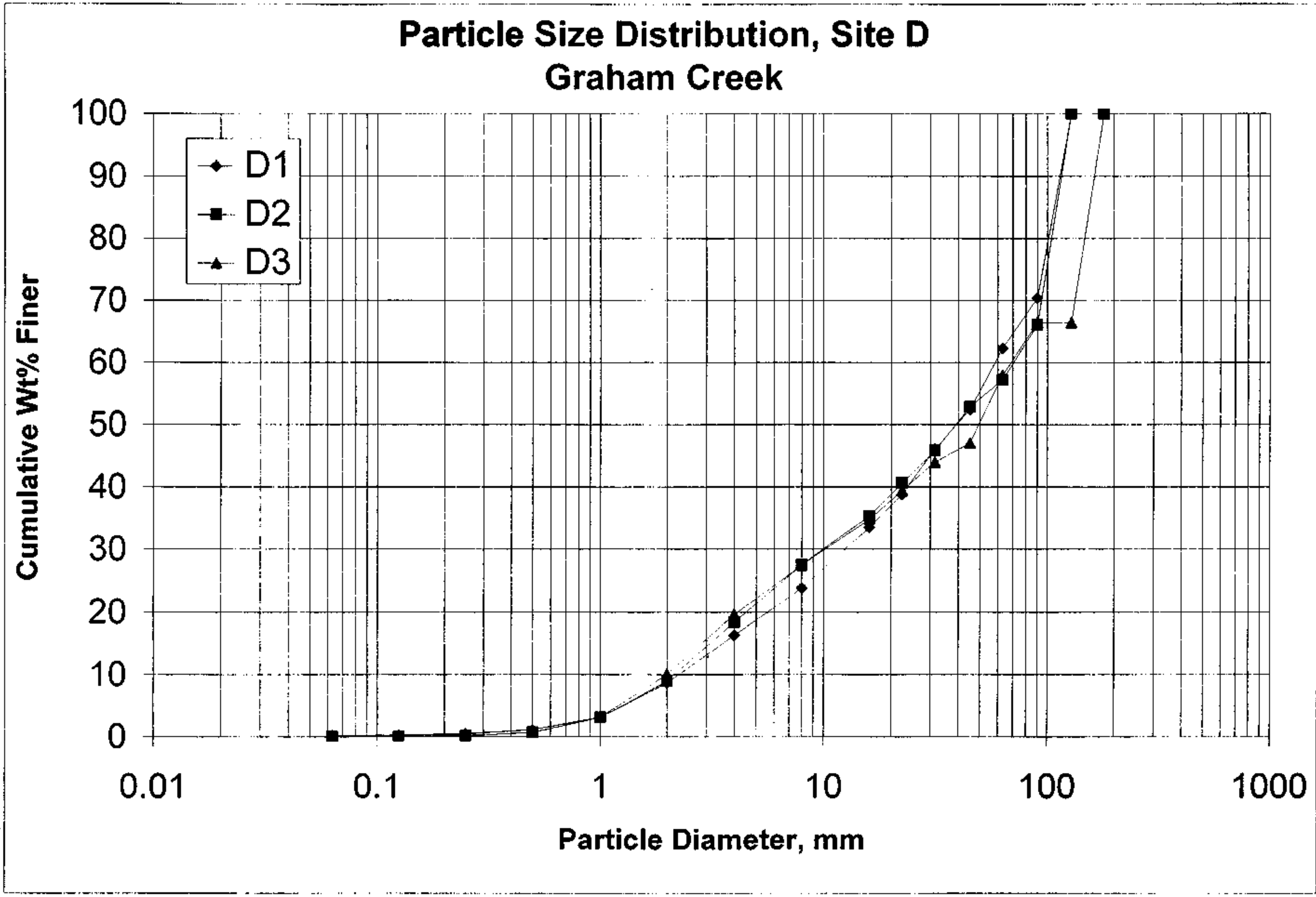
APPENDIX B

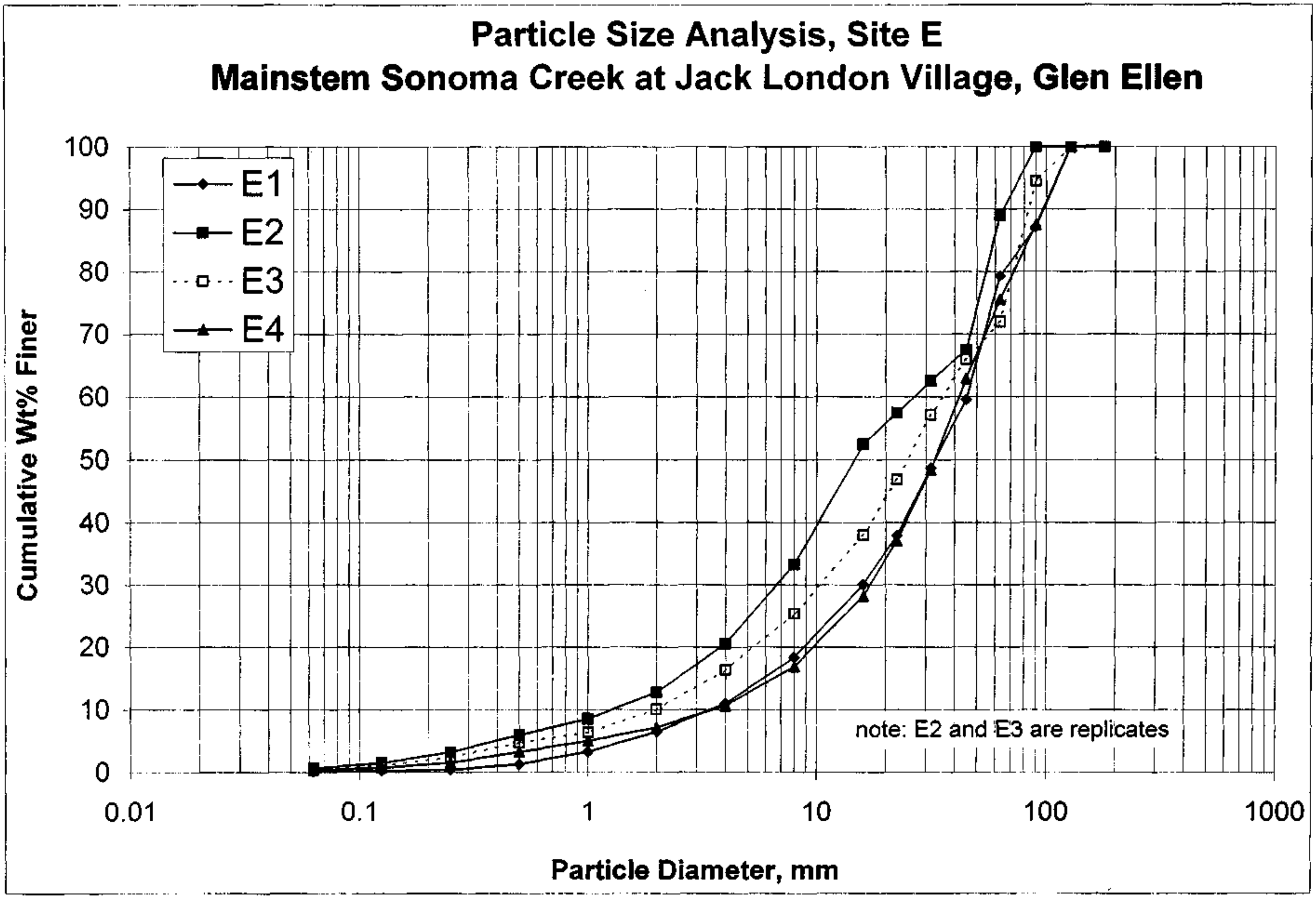
PARTICLE SIZE DISTRIBUTION CURVES

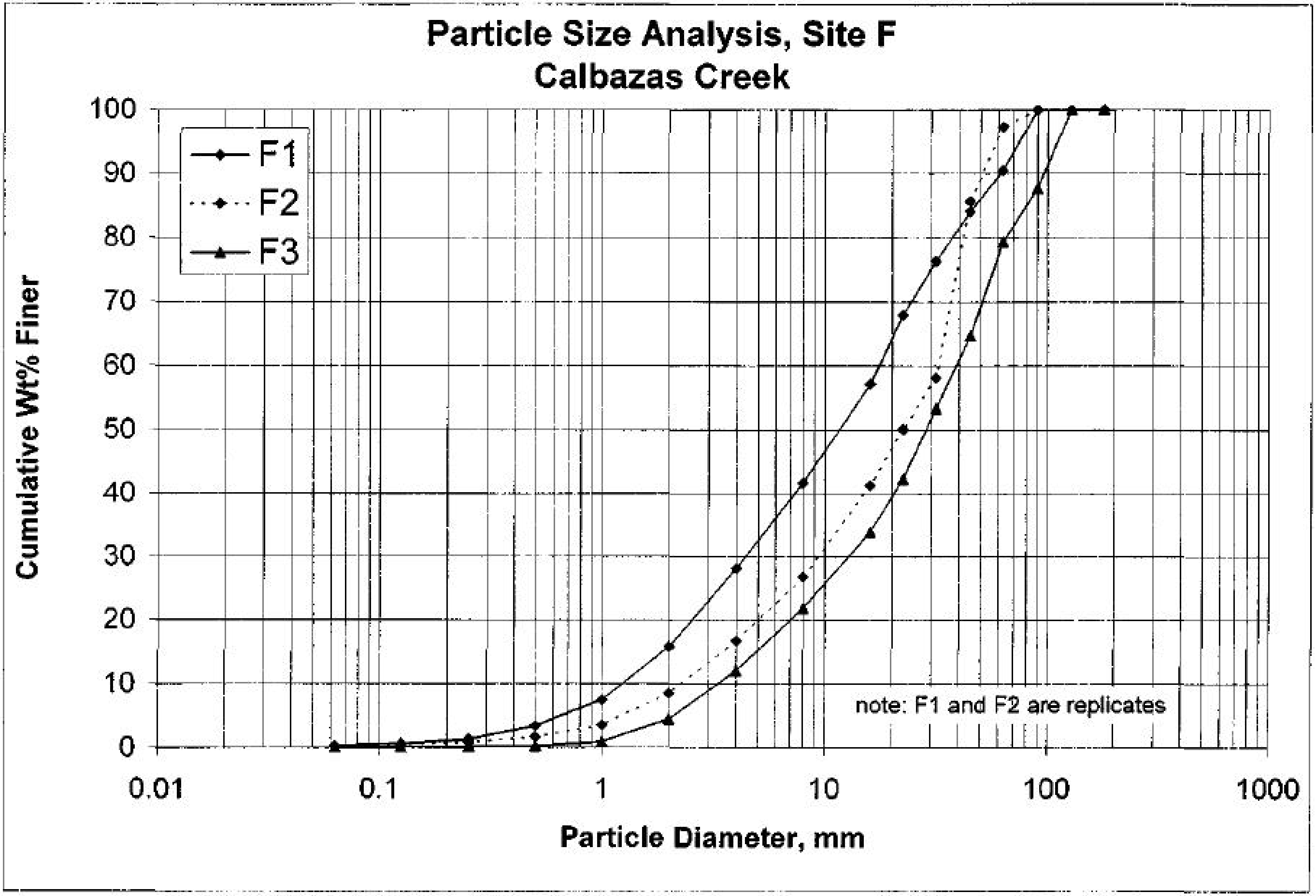

Particle Size Analysis, Site A
Mainstem Sonoma Creek, Adobe Canyon
A1
A2
A3
Cumulatice Wt% Finer
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
1000
note: A2 and A3 are replicates
Particle Diameter, mm

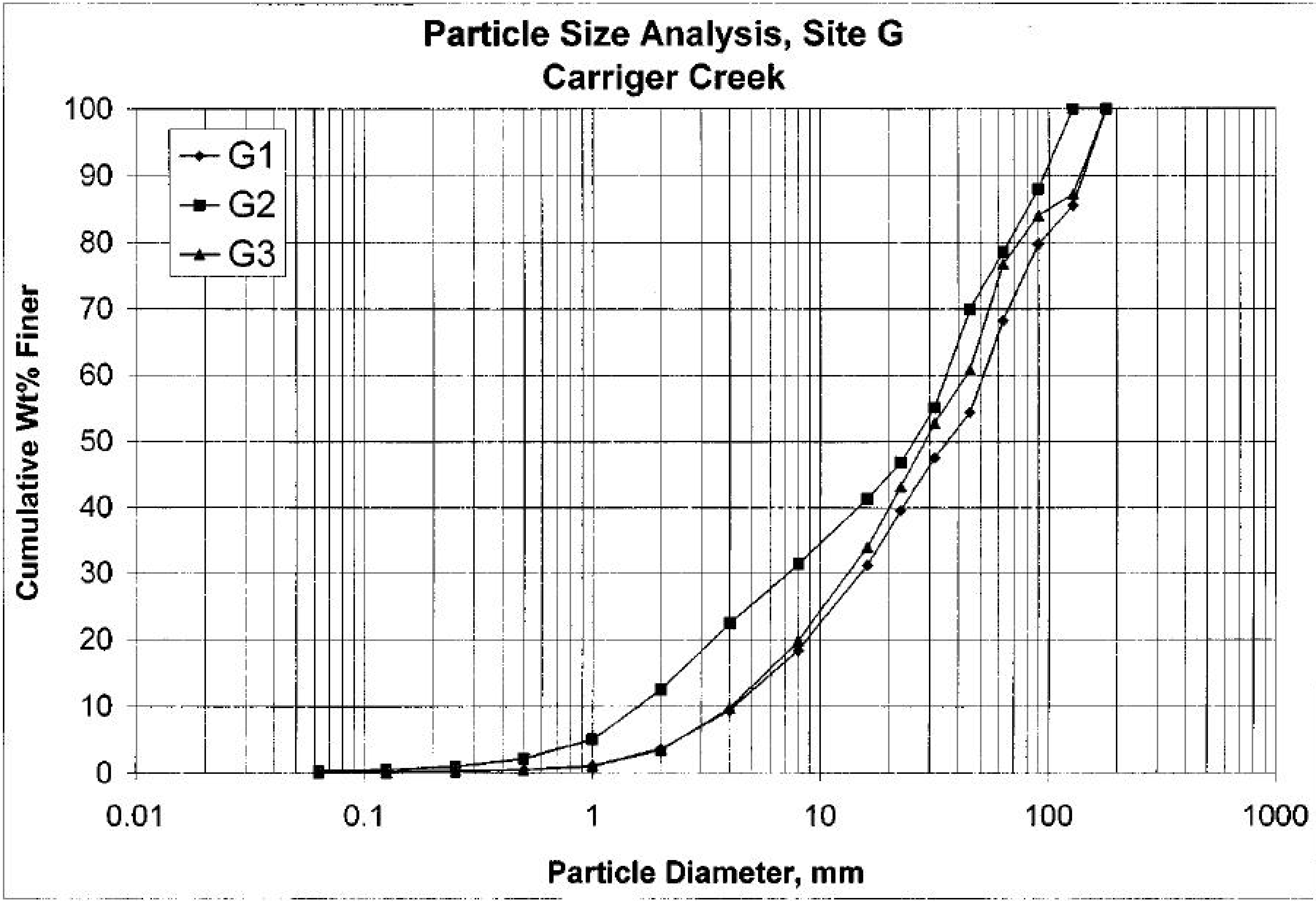

Particle Size Analysis, Site B
Bear Creek
Cumulative Wt% Finer
Particle Diameter, mm
B1
B2
B3
B4
note: B3 and B4 are replicates
0
10
20
30
40
50
60
70
80
90
100
0.01
0.1
1
10
100
1000


Particle Size Distribution, Site C
Mainstem Sonoma Creek, Kenwood
Cumulative Wt% Finer
Particle Diameter, mm
C1
C2
C3
note: C1 and C2 are replicates
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
1000

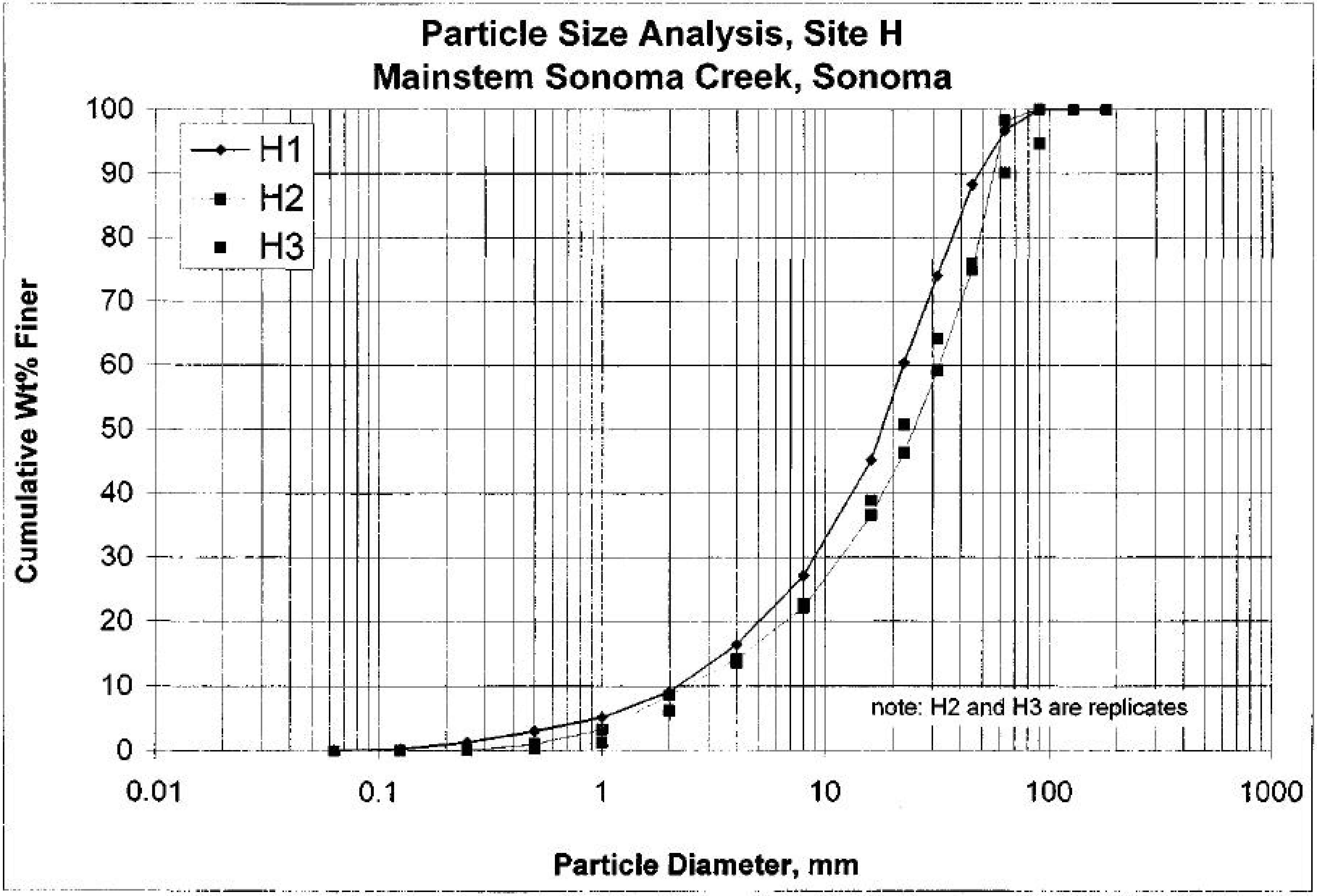

Particle Size Distribution, Site D
Graham Creek
Cumulative Wt% Finer
Particle Diameter, mm
D1
D2
D3
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
1000


Particle Size Analysis, Site E
Mainstem Sonoma Creek at Jack London Village, Glen Ellen
Cumulative Wt% Finer
100
90
80
70
60
50
40
30
20
10
0
E1
E2
E3
E4
note: E2 and E3 are replicates
0.01
0.1
1
10
100
1000
Particle Diameter, mm


Particle Size Analysis, Site F
Calbazas Creek
Cumulative Wt% Finer
100
90
80
70
60
50
40
30
20
10
0
F1
F2
F3
note: F1 and F2 are replicates
0.01
0.1
1
10
100
1000
Particle Diameter, mm



Particle Size Analysis, Site G
Carriger Creek
G1
G2
G3
Cumulative Wt% Finer
0
10
20
30
40
50
60
70
80
90
100
0.01
0.1
1
10
100
1000
Particle Diameter, mm



Particle Size Analysis, Site H
Mainstem Sonoma Creek, Sonoma
Cumulative Wt% Finer
Particle Diameter, mm
H1
H2
H3
note: H2 and H3 are replicates
0
10
20
30
40
50
60
70
80
90
100
0.01
0.1
1
10
100
1000