SPAWNING GRAVEL COMPOSITION AND PERMEABILITY WITHIN THE GARCIA RIVER WATERSHED, CA

FINAL REPORT

prepared for

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I. Introduction

The purpose of this study is to fulfill objectives proposed in the *Watershed Assessment and Cooperative Instream Monitoring Plan for The Garcia River, Mendocino County, California (IMP)*, prepared by the Mendocino County Resource Conservation District (MCRCD) and the California Department of Forestry and Fire Protection (CDF). The objectives of the IMP are: (1) test the capability and effectiveness of the California Forest Practice Rules to protect determined beneficial uses, in this case the salmonid fishery of the Garcia River, (2) create a long-term monitoring data set whereby the Garcia River can be compared to other neighboring rivers in the development of a regional standard [to assess long-term trends in watershed conditions], and (3) understand the Garcia River watershed and reduce its overall sediment load through adaptive management.

The IMP includes several protocols for assessing the quality of spawning gravels used by anadromous salmonids, including analyzing substrate composition to determine the particle size distribution and the volume of fine sediment stored in stream beds, and measuring the permeability of gravel in locations where incubation of salmonid eggs and alevin occurs. The National Marine Fisheries Service (NMFS) has listed coho salmon (*Oncorhynchus kisutch*) as *threatened* under the Federal Endangered Species Act, and is expected to extend the listing of *threatened* to steelhead trout (*Oncorhynchus mykiss*) in the near future. The objectives of this study are:

(1) establish baseline substrate composition and permeability conditions for long-term trend monitoring in the Garcia River watershed;
(2) assess the relationship (correlation) between substrate composition and permeability, and the general utility of these methods for assessing the condition of salmonid spawning substrates (in terms of the statistical precision of the results they generate, sample size needed to detect significant differences among different streams and over time, and their ability to predict salmonid survival to emergence).

Background

Substrate composition is a common measure of salmonid spawning habitat condition. Chapman (1988) provides a thorough review of the extensive field and laboratory data spanning several decades on the detrimental effects of fine sediment on survival to emergence of salmonid embryos and alevins, and will not be reiterated here. However, researchers have not provided reliable field-based methods to assess the condition of salmonid spawning habitat that allows prediction of survival to emergence *quantitatively* and with *known accuracy*.

Perhaps the best methods available are those based on Tappel and Bjornn (1983), who relate substrate particle sizes to salmonid survival. Their methods rely on determination of the percentage of substrate smaller than 0.85 mm and 9.5 mm, with the cumulative distribution truncated at 25.4 mm. They equated these two particle size classes with survival of chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) eggs. This method can be useful if sediment samples collected for a particular site have a narrow range of particle size distributions (i.e., low variance). If variance is high, the survival equations predict a broad range of survival, compromising the utility of this method. The Tappel and Bjornn methods can determine the relative survival of salmonid eggs incubated in a particular sediment distribution, but may not adequately assess entire tributaries. Considering the potentially enormous effort required to collect a sufficient number of sediment samples to allow accurate predictions and detect changes over time, other methods are needed. Permeability may offer better quantitative results and less costly application.

Salmonid egg survival depends on the supply of oxygen delivered to incubating eggs, and removal of waste from the egg pocket. According to Terhune (1958), to estimate the probability of survival of salmonid eggs, two quantities must be known: (a) the concentration of dissolved oxygen in the water, and (b) the apparent velocity of water through gravel.

Pollard (1955) showed that apparent velocity depends on the ***hydraulic head*** and ***gravel permeability***. Hydraulic head in a spawning riffle is determined by the hydraulic gradient, which is the slope of the water surface ($S=\Delta h/L$). Because hydraulic head will change with discharge (via change in slope), apparent velocity also changes with discharge. Additionally, apparent velocity (V) is more difficult to measure. Pollard also shows that, for laminar flows occurring at the velocities usually encountered in spawning gravels, D'Arcy's coefficient of permeability, K, defined by $K=V/S$, is independent of apparent velocity, V. *Permeability depends only on the composition and degree of packing of the gravel, and viscosity of the water* (viscosity is related to water temperature). In the equation $K=V/S$, slope is dimensionless, so permeability will have the same dimensions as apparent velocity (usually cm/hr). Therefore "permeability of the gravel, the ease with which water can pass through it, may be used as a figure of merit for the gravel – the higher the permeability the greater the supply of oxygenated water that can reach the salmon eggs for a given river gradient" (Terhune 1958).

The intrusion of fine sediment into gravel reduces intragravel flow of water by reducing permeability, which results in reduced rates of oxygen delivery to incubating embryos and removal of metabolic waste from the egg pocket. The volume of fine sediment in spawning substrates is thus an indirect measure of gravel conditions that affect survival to emergence, whereas permeability directly measures conditions affecting embryonic survival.

Chapman's (1988) review of Koski (1966) and McCuddin (1977) demonstrates survival to emergence of salmonid embryos is positively and significantly correlated to permeability ($r^2=0.85$). Despite this finding, few researchers or resource managers have employed permeability techniques to assess salmonid spawning gravel quality. The reason for this is unknown.

Until recently, permeability measurement has relied on Terhune's (1958) methods, which employed a hand pump (a bicycle or bilge pump) to extract water from a 4.5 cm stainless steel standpipe into a 2.0 L graduated cylinder. The quantity of water withdrawn into the cylinder and the corresponding time interval were used to calculate the "inflow rate" of water into the standpipe from the surrounding substrate. A correction factor was necessary to account for the 2.54 cm pressure head at the top of the standpipe-well, and the operator was required to pump vigorously and consistently for up to several minutes in low permeability conditions. Young (1988) shows significant imprecision in this technique. He found significant differences in permeability samples withdrawn by different individuals (sampling bias), resulting in substantial variability in permeability estimates. Young also points out that previous research relied on only one replicate per sample to estimate permeability, when variation in permeability would be expected at a particular sample location.

To improve permeability measurements, several researchers have begun using a homemade pumping device that employs a 12 volt DC battery and a diaphragm pump to draw water into a cylindrical vacuum chamber (7.0 cm diameter, 50 cm long). The device is mounted on a backpack frame. An 8 mm plastic hose connects from the vacuum chamber to a rigid tube (copper or stainless steel) fed down the standpipe. The standpipe is also smaller diameter (2.54 cm), to reduce disturbance when inserted into the gravel. When the pump is switched on, water is drawn up the tube into the vacuum chamber. Inflow rate (ml/s) is quantified by measuring the change in water volume in the chamber for a measured time interval, then converted to permeability (K, in cm/hr) using the Terhune (1958) and Barnard and McBain (1994) calibration curve. The device allows consistent, replicate sample collection in a short time, from which a mean permeability and variance can be computed for a single sample location. A single replicate measurement requires approximately 20-60 seconds, with 5-10 replicates suggested for each sample. Application of the device in several independent studies (MRC 1998, Klatte 1998 in progress, Lower Tuolumne River Spawning Gravel Assessment, in progress) has shown consistent permeability sample estimates.

Supplied with this monitoring tool, watershed managers can use permeability to evaluate the condition of salmonid spawning gravels, define the precision of the estimates, and eventually predict survival of salmonid eggs incubated in those gravels.

II. Methods

Geographical setting

The Garcia River watershed is located in southwestern Mendocino County, CA, (Figure 1) and drains 113 square miles of rugged forest and grasslands. The watershed is part of the Coast Range, and includes the San Andreas fault zone, which the South Fork and lower mainstem Garcia River follow. More than 150 miles of perennial streams, including 40 miles of the Garcia River mainstem, drain directly into the Pacific Ocean. Average annual precipitation ranges from 100 to 150 cm per year. In addition to the mainstem, there are more than 25 named streams within the Garcia watershed that drain individual watersheds greater than one square mile each. The land is used for timber harvesting, cattle ranching, dairy production, gravel mining, and private residency. Landowners include timber companies, independent ranchers, an Air Force Base, a Rancheria, and residential and non-industrial holdings.

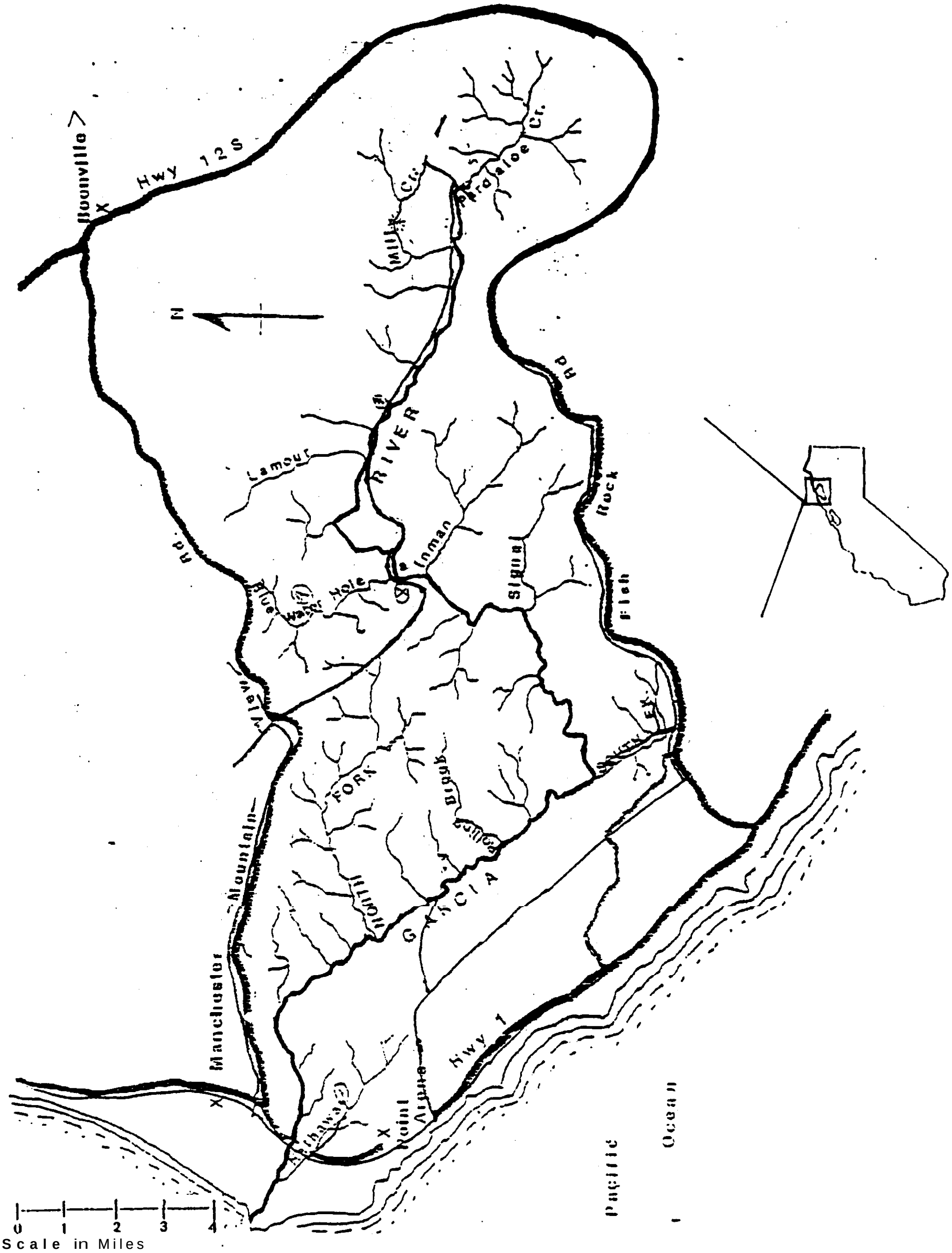

Figure 1. Map showing location of the Garcia River watershed, Mendocino County, CA.

Ten tributaries to the Garcia River were selected for monitoring, based on recommendations in the IMP. For confidentiality, these tributaries were numbered Tributary 1-11 (excluding Tributary-2). Tributaries were selected from the eastern portion of the watershed (at approximately 500 ft elevation), the middle portion of the watershed (at approximately 300 ft elevation), and the lower portion of the watershed (at approximately 100 to 200 ft elevation). Study reaches were located by the MCRCD along the lower approximately 2,500 ft of each tributary's confluence with the Garcia River.

Field Methods

Substrate composition (bulk sampling) and permeability were sampled from eight pool-tails within the study reach of each tributary (Figure 2). To avoid the potential variability introduced by sampling from both within and outside of redds, and the variability of sampling different geomorphic surfaces, we sampled only sites without obvious redds or redd markers left from the previous spawning season. We randomly located the bulk sample within a selected pool-tail by establishing a cross section half-way between the riffle crest and the pool/pool-tail boundary, then placing the bulk sample on this cross section half-way between the thalweg (deepest portion of channel) and mid-channel (half-way between wetted edges).

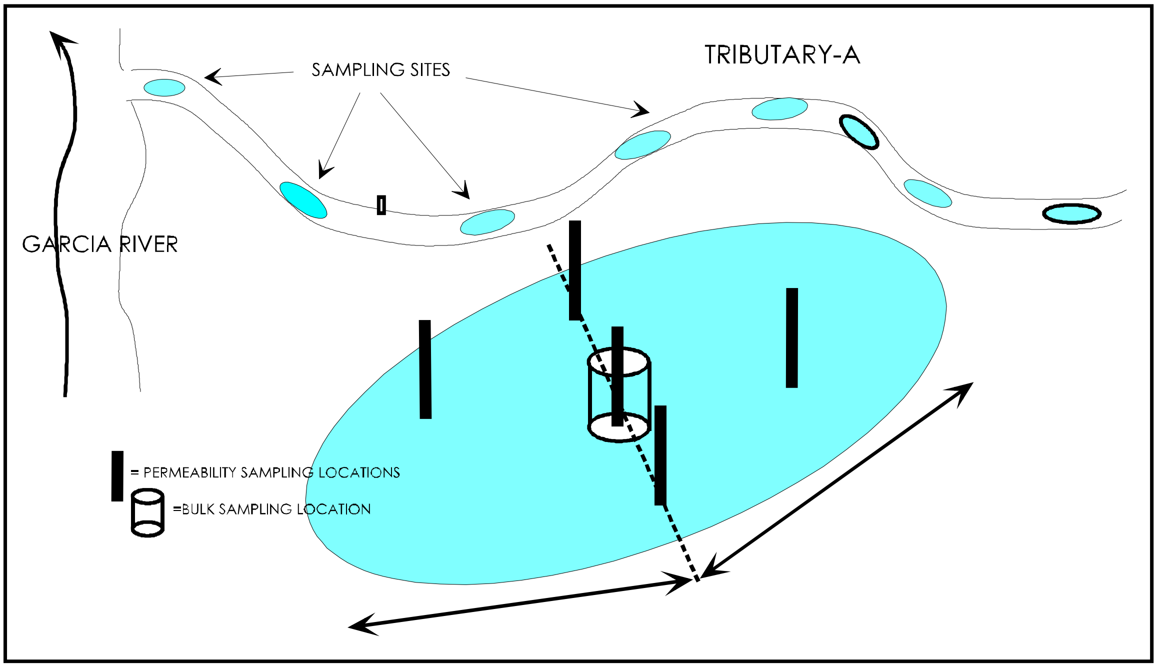

Figure 2. Diagram of pool-tail sample sites located within the study reach of each tributary, and a single site showing the locations of the bulk sample and permeability samples.

Before excavating the bulk sample, we measured permeability at several locations within the pool-tail, including the eventual bulk sample site and 3-8 additional samples located equidistant from the bulk site to the margins of the spawning gravels (Figure 2). Permeability was measured using Terhune (1958) and Barnard and McBain (1994) standpipe methods, with the noted exceptions of a modified vacuum source, and smaller diameter standpipe. Each permeability *sample* consisted of approximately five to ten *replicate* measurements of inflow rate, each replicate requiring approximately 20 to 60 seconds. Permeability samples were collected with the middle of the standpipe perforations located 25 cm below the substrate surface.

Once permeability samples were collected, a bulk sample was collected. The bulk sampler was a 30 cm diameter by 60 cm long stainless steel cylinder, with large handles on each side. The sampler was worked into the substrate to a depth of at least 30 cm (1 foot), and the material excavated generated a sample ranging from approximately 30 to 80 kg of sediment. The cylinder center was placed at the permeability standpipe location. The substrate surface usually consisted of a coarse layer of gravel and cobble, which was removed and analyzed separately from the subsurface layer. All sediment samples were dried and sieved to 8 mm with rocker box sieves (hand shaking), then sieved from 5.6 mm to 0.125 mm with a mechanical shaker. Samples with large fractions finer than 8 mm (= most samples) were split with a funnel splitter, and the subsample then sieved with the mechanical shaker. A combination of field methods was used for sieving, including air drying/sieving at the tributary site, transporting the samples to a central location within the watershed for air drying/sieving, or transporting the samples home for later air drying/sieving. Air drying samples in the sun usually required four to eight hours. We used full “phi” (ϕ) sieve sizes for coarser substrates: 128, 64, 32, 16, 8, then half phi sizes for fine particle sizes: 5.6, 4, 2.8, 2.0, 1.4, 1.0, 0.85, 0.5, 0.25, and 0.125 mm. This selection of sieves gives high resolution to the distribution of fine particles in each bulk sample.

Substrate composition analysis

All gravel sampling techniques have biases, and past researchers have expressed contrasting opinions as to which methods provide the most accurate data. For example, Everest et al. (1982) reported freeze core sampling to be more accurate in estimating the percentages of fine sediment, whereas Ringler (1970) found McNeil samples to be more accurate. Barnard and McBain (1994) originally employed freeze core sampling, but eventually abandoned this technique in favor of bulk sampling with a 12 inch diameter core. They found a selective bias with the freeze core techniques toward larger framework particle sizes that would attach to the frozen standpipe core, whereas finer matrix particles escaped collection (Scott McBain, personal communication). The bulk sampling method also provides a larger sediment sample.

Researchers have also debated the relative merits of volumetric analysis, in which the particle fraction is measured by the *volume* displaced in a graduated cylinder, and gravimetric analysis, in which the sample *weight* is measured and reported relative to the entire sample weight. The primary problems with volumetric analysis are: (1) it requires reading the meniscus in a graduated cylinder before and after the sediment fraction is added, a much less accurate form of measurement compared to a digital balance reading in tenths of grams, and (2) converting volume displacement to the “actual” volume or weight by conversion factors that relate wet weights to dry weights, if wet weights are recorded (Shirazi and Siem 1979). Barnard (1990, unpublished manuscript) showed high variability in the conversion from wet to dry weights. Volumetric analysis is preferred simply because it allows on-site processing of wet sediment samples, whereas gravimetric (weight) analysis usually requires drying samples before sieving.

The Redwood National Park (1991) study compared freeze core/dry sieve/gravimetric analysis with McNeil core/wet sieve/volumetric analysis in a discreet comparison of methods. They reported that the amount of fine sediment measured by volumetric analysis (wet sieve) was generally greater that gravimetric analysis (dry sieve). Their McNeil samples (with volumetric analysis) gave percent fines smaller than 1.0 mm that were on average three times the value of freeze core samples (with gravimetric analysis). They stated that the volumetric analysis (McNeil technique) is more sensitive to fine sediment than gravimetric analysis (freeze core), but conclude that it is unclear which method represents the most accurate picture of gravel size composition (RNP 1991, p45). If their freeze core sampling was subjected to a similar selective bias toward larger particles as encountered by Barnard and McBain, this would also explain the lower percentages of fine sediments in their freeze core samples. Their methods did not evaluate McNeil core sampling with dry sieve/gravimetric analysis. Platts et al. (1983) recommend gravimetric techniques, stating that "laboratory analysis of dry weights is the most accurate because all water in the sample can be evaporated, thus eliminating the need for conversion factors associated with the wet method." Similarly, Valentine (1995) recommends using a McNeil sampler and dry sieving for particle size analysis when "the highest control on measurement error is required; e.g., research situations."

Methods used in this study were based on (1) the specific study objectives, which were to assess current spawning gravel conditions and establish baseline data for future monitoring, (2) to assess the correlation between substrate composition and permeability, which requires the most accurate data collection methods available, (3) the sediment sampling protocols recommended in Valentine (1995) for the northcoast region, and (4) experience from application and refinement of methods by Barnard and McBain (1994), and others. These methods may result in less reliable comparisons to past data or regional standards (e.g., Garcia River Total Maximum Daily Load 1998) if those data/standards are based on data obtained by volumetric analysis.

To summarize methods for field data collection:

- bulk substrate samples were collected from 10 tributaries, at approximately eight different sites within the study reach, for a targeted goal of 80 bulk samples.
- permeability samples were made at several locations within each site, including where the bulk sample was removed. Each permeability sample included numerous replicate measurements of inflow rate (ml/s), which were later converted to permeability (cm/hr) and averaged for each sample, site, and tributary.

The following exceptions to the above sampling program are noted:

- Tributary-3 had only six sample sites, instead of eight.
- Tributary-7 had nine sample sites, instead of eight.
- Tributary-6 had only three bulk sample sites (6, 7, and 8) with associated permeability data, and an additional 5 sites (1-5) from which only permeability data were collected. Sites 1-5 were too coarse for bulk sampling.

- Tributary-10 bulk samples from sites 2 and 5 were mixed together accidentally during the sieving process, and thus cannot be compared to the associated permeability samples.

The following samples were excluded from analyses:

- Tributary-1 bulk sample 2 had only 12 kg of sediment because a large boulder prohibited excavation beyond 6 inches. This small sample is thus biased by the larger particle sizes;
- Tributary-8 sample 5 and Tributary-4 sample 4 had extremely loose, unconsolidated gravels that were atypical sites in terms of spawning substrates;
- Tributary-7 sample 6 and Tributary-9 sample 2 had unconsolidated bedrock patches (Franciscan melange) within the bulk samples, which reduced permeability to zero;
- Tributary-4 sample 6 had high percent error (5.36%) comparing pre-sieve dry weight to total processed weight.

The total data set used for analyses therefore included 66 sediment samples with associated permeability measurements (for regression analysis), and 71 sites with permeability measurements.

III. Results

Sediment particle size distribution

Each sieved bulk sample was entered into a standardized template (MS Excel 97) to compute the relative weight of each particle size fraction (i.e., the proportion of material passed through one sieve and caught on the next smaller sieve), and then “cumulative percent finer”, the percent (by weight) of substrate smaller than a given particle size. Surface and subsurface sediment samples were collected, sieved, and analyzed separately, then combined for additional analyses. We also computed the cumulative percent finer with the data truncated at 32 mm to examine the correlation with permeability, and also truncated at 25.4 mm for use in the Tappel and Bjornn (1983) methods described above. To check the accuracy of field sieving, we compared the initial “pre-sieve dry weight” to the “total processed weight”, and reported this as “net gain or loss” and “percent of total sample”.

Data were compiled into summary tables for each tributary (Appendix A), and a single summary table containing all particle size data. The tributary summaries present descriptive statistics, and were used to analyze trends in the data, while the single summary table was used in combination with the permeability data to examine relationships between particle size and permeability. Each tributary summary contains particle size distribution for (1) the proportion of each size fraction, (2) the cumulative percent finer, (3) the cumulative percent finer with data truncated at 32 mm, and (4) the cumulative percent finer with surface and subsurface samples combined. The mean, standard deviation, variance, standard error, and the 95% confidence interval are provided. Also reported was the average weight of bulk samples for each tributary, the total fraction <8 mm, and the weight and percentage of each <8 mm subsample.

The "cumulative percent finer" for subsurface bulk samples is the primary independent variable for this study, and henceforth all reference to the particle size distribution will be to cumulative percent finer, unless otherwise specified.

Analysis of variation in particle size distribution

The second objective of this study was to determine if bulk sampling and sediment particle size analysis could adequately characterize the variability of substrate composition within a single tributary. To be useful to resource managers, the method should detect significant differences between tributaries (if they exist), and detect changes within a tributary over time. Two sediment sizes (percent finer than 8.0 mm and 0.85 mm) were selected as indices, and used to analyze the variation within each tributary. The data are summarized in Table 1, which presents the cumulative percent finer for each sediment size for each bulk sample, along with the mean (ý), standard deviation (s), standard error (SE), 95% confidence intervals, and the coefficient of variation (s/ý).

Single-factor ANOVA tests (NCSS 6.0 Statistical Software) were performed to determine if there were significant differences in these two particle size fractions among tributaries. For the two size classes tested, <0.85 mm and 8.0 mm, ANOVA found significant differences among sites (p=0.045 and p=0.015, respectively) (Figure 3 and 4).

For the percentage of fine sediment smaller than 0.85 mm, variability expressed by the 95% confidence interval (Table 1) was relatively low within some tributaries, especially considering the heterogeneity of sampling sites and the small sample size (n=8 for most tributaries). For example, Tributary-1 fines smaller than 0.85 mm ranged from 8.1% to 11.4%, a 3.3% difference; Tributary-8 had very low percent fines <0.85 mm and a narrow confidence interval, ranging from 5.1% to 6.8%. Most tributaries, however, had much higher ranges of confidence intervals: fines smaller than 0.85 mm in Tributary-7 (n=9) ranged from 8.0% to 15.5%, a 7.5% difference; Tributary-10 ranged from 3.8% to 10.5%, nearly a 7% difference in the 95% confidence interval. For individual tributaries the 95% confidence interval ranged from 2.1% to 13.5% fines smaller than 0.85 mm. We will see in later sections that broad confidence intervals such as these translates to equally broad prediction of salmonid survival based on Tappel and Bjornn (1985).

The condition of spawning gravels at individual sites showed equally high variability: percent fines <0.85 mm from individual bulk samples ranged as low as 2.0% (Tributary-9) to as high as 19.0% (Tributary-7), but in general most samples were closer to the mean (8.2% finer than 0.85 mm). Tributary-7 and Tributary-11 had the highest mean percent fines <0.85 mm, 10.8% and 10.1%, respectively. Tributary-9 and Tributary-6 had the lowest mean percent fines <0.85 mm, with 5.7% and 4.9% respectively. Few discernible patterns emerged from analysis of the data, and while ANOVA detected significant differences in the means of fractions smaller than 0.85 mm and 8.0 mm, the variability (evident in Figure 3) was generally very high.

Sample size

An important objective from the analysis of variation in the particle size data is determining how many bulk samples are needed within a single tributary to reduce the variability to some statistically acceptable standard, and what is that standard? The problem is to determine the *minimum sample size* (*n*) needed to detect a difference of size "δ" between the means of two populations (assuming both populations are normally distributed and have the same standard deviation) with known confidence ($1-\alpha$) and power ($1-\beta$). An approximate formula for this is:

$$n = 2\sigma^2\left(\frac{z_{\alpha/2} + z_\beta}{\delta}\right)^2$$

(equation 1)

for each sample (Peter Stillwater Sciences, Berkeley CA, personal communication), where α is confidence level, β is power, σ is standard deviation, and δ is the minimum detectable difference. Sample size estimates based on this equation should be rounded up to the next highest integer. A popular or "standard" combination of confidence and power is 95% confidence and 80% power, which are used for our estimates of sample size.

To compute the minimum sample size, some value of σ must be assumed. From our ANOVA test, the gravel fractions <0.85 mm yielded a $\sigma = 0.031$ (this value could be obtained from a pilot study to determine an initial variance expected in the planned study).

A note about δ: the "minimum detectable difference" is a decision made depending on the study objectives (i.e., a subjective decision). The δ can be interpreted, for example, as the percent difference in percent fines <0.85 mm that the research expects to detect, with the sample size then determined by the above formula. If two tributaries are sampled with the objective of determining a significant difference of at least 3% (with 95% confidence and 80% power) between the means of percent fines less than 0.85 mm, then $\delta=0.03$. With these initial objectives, the proposed study may not then detect a 2% or less difference in the means of fines <0.85 mm.

Cumulative percent finer than 0.85 mm for each tributary bulk sample

	BULK SAMPLE												95% Confidence Interval		
Tributary Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**ý**	**s**	**S.E.**	**Lower**	**Upper**	**CV (s/ý)**
Tributary-1	8.8%		8.5%	9.6%	9.8%	11.9%	12.2%	7.4%		9.7%	1.8%	0.7%	8.1%	11.4%	18.1%
Tributary-3	9.4%	11.1%	6.9%	13.7%	8.2%	9.7%				9.8%	2.4%	1.0%	7.4%	12.3%	24.1%
Tributary-4	12.4%	8.6%	9.7%	6.3%			7.7%	8.0%		8.8%	2.1%	0.9%	6.5%	11.0%	24.2%
Tributary-5	5.3%	8.3%	10.6%	10.2%	11.8%	7.7%	4.8%	8.7%		8.4%	2.5%	0.9%	6.4%	10.5%	29.4%
Tributary-6						3.7%	5.9%	5.0%		4.9%	1.1%	0.7%	2.1%	7.7%	23.2%
Tributary-7	12.1%	8.3%	19.0%	9.2%	12.0%	8.4%	12.0%	7.5%	8.7%	10.8%	3.6%	1.2%	8.0%	13.5%	33.2%
Tributary-8	5.5%	6.6%	7.6%	5.8%		5.2%	5.3%	5.7%		6.0%	0.9%	0.3%	5.1%	6.8%	14.7%
Tributary-9	9.4%	9.9%	9.6%	9.1%	8.0%	14.0%	11.8%	9.0%		10.1%	1.9%	0.7%	8.5%	11.7%	19.0%
Tributary-10			4.6%	5.3%		6.0%	11.1%	8.5%		7.1%	2.7%	1.2%	3.8%	10.5%	38.0%
Tributary-11	11.3%		5.3%	6.7%	5.5%	5.5%	3.5%	2.0%		5.7%	2.9%	1.1%	3.0%	8.4%	51.7%

Cumulative percent finer than 8.0 mm for each tributary bulk sample

	BULK SAMPLE												95% Confidence Interval		
Tributary Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**ý**	**s**	**S.E.**	**Lower**	**Upper**	**CV (s/ý)**
Tributary-1	40.4%		30.4%	25.0%	41.1%	24.5%	23.4%	32.2.%		30.8%	8.1%	3.3%	22.7%	38.9%	26.2%
Tributary-3	34.9%	44.9%	29.4%	25.0%	35.0%	25.9%				32.5%	7.4%	3.0%	24.7%	40.3%	22.8%
Tributary-4	42.7%	29.3%	41.3%	43.9%	20.9%	26.3%	38.2%	38.9%		35.2%	8.5%	3.0%	27.4%	42.9%	24.3%
Tributary-5	42.7%	36.4%	41.2%	49.3%	35.3%	39.2%	28.5%	30.2%		37.9%	6.8%	2.4%	32.2%	43.5%	17.9%
Tributary-6						39.9%	44.3%	31.2%		38.5%	6.7%	3.8%	21.9%	55.0%	17.3%
Tributary-7	41.0%	36.5%	50.9%	41.9%	31.3%	34.2%	44.9%	39.6%	36.5%	39.6%	5.9%	2.0%	35.1%	44.2%	14.9%
Tributary-8	36.0%	55.8%	53.8%	38.6%	86.2%	33.8%	67.3%	29.6%		50.1%	19.5%	6.9%	33.3%	67.0%	38.9%
Tributary-9	45.3%	42.3%	18.4%	32.3%	35.6%	24.6%	21.4%	18.8%		29.8%	10.6%	3.7%	21.0%	38.7%	35.5%
Tributary-10			31.9%	25.6%		34.3%	45.7%	41.6%		35.8%	8.0%	3.6%	25.9%	45.7%	22.2%
Tributary-11	38.3%		33.5%	39.3%	31.1%	19.1%	42.0%	43.6%		35.3%	8.4%	3.2%	27.5%	43.0%	23.8%

Table 1. Summary of particle size distribution data for all ten tributaries sampled in the Garcia River watershed. The cumulative percent finer than 0.85 mm and 8.0 mm is reported for each bulk sample, with summary statistics. N=66 samples.

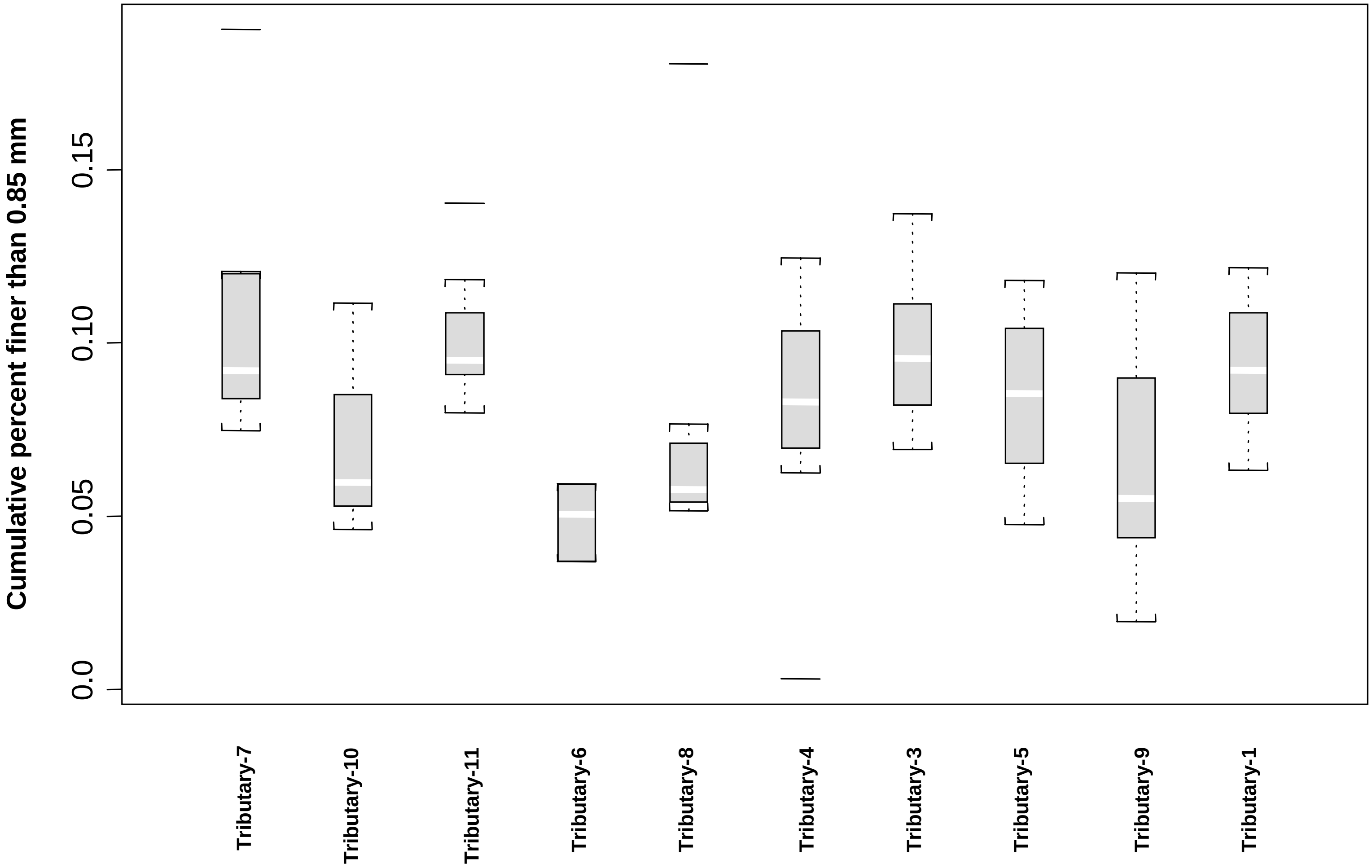

Figure 3. Box-whisker diagram of the bulk sample fraction less than 0.85 mm. ANOVA showed significant differences among sites (p=0.045). [Reading the box and whisker plot: the rectangular box represents the interquartile range, and the white band represents the median value. The whiskers represent the range of data within 1.5 times the width of the interquartile range from the median value. Dashes represent outlying data points.]

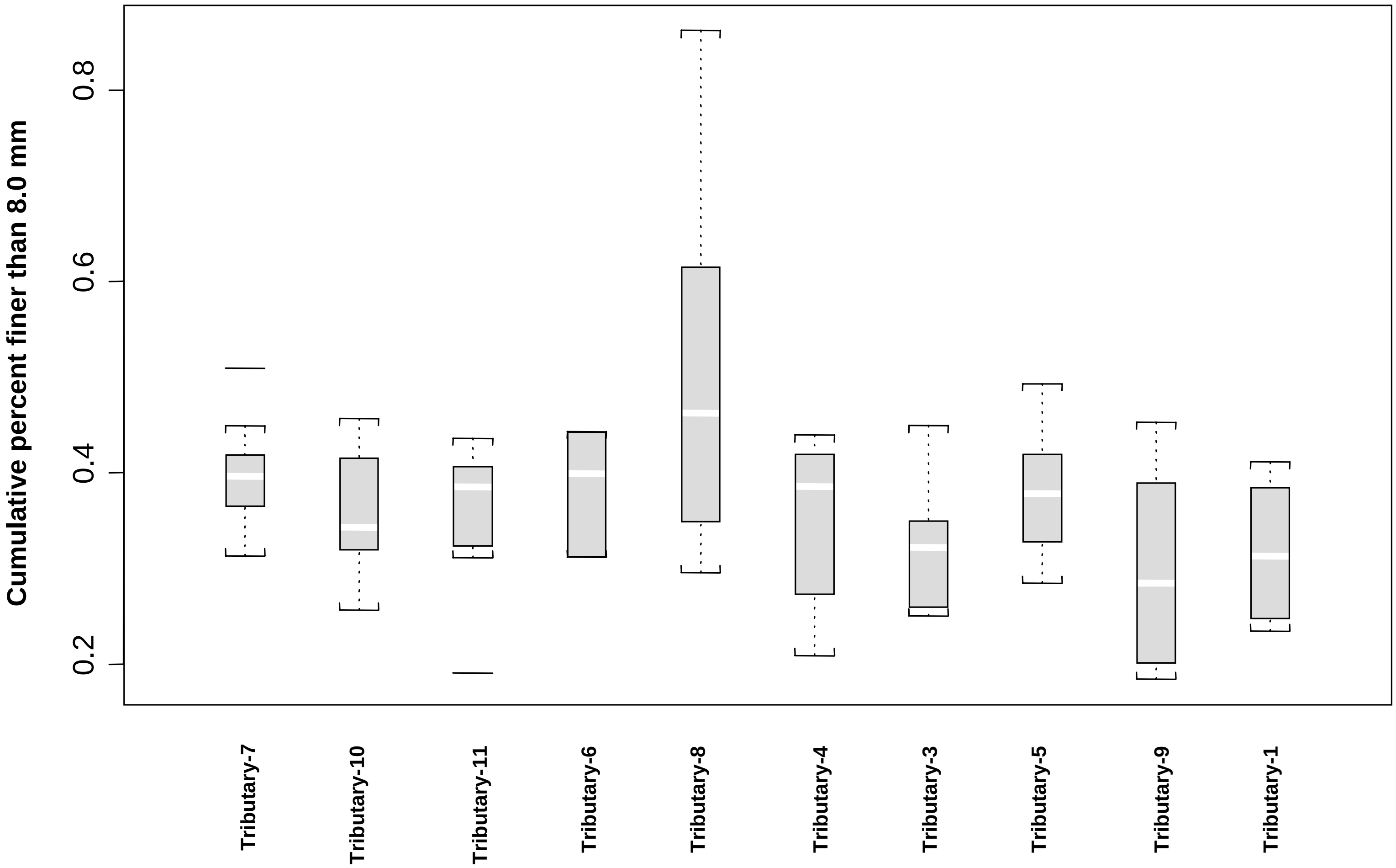

Figure 4. Box-whisker diagram of the bulk sample fraction less than 8.0 mm. ANOVA showed significant differences among sites (p=0.015). [Reading the box and whisker plot: the rectangular box represents the interquartile range, and the white band represents the median value. The whiskers represent the range of data within 1.5 times the width of the interquartile range from the median value. Dashes represent outlying data points.]

This formula is an approximation, whereas the exact formula replaces the critical values of the normal distributions with the appropriate critical values for t-distributions. Since the t-distribution depends on the sample size, this leads to an iterative solution for sample size. However, *since we know the distributions won't necessarily be normal, and since our σ is just an estimate, the predicted sample size should be assumed to be an estimate*. Table 2 presents a range of potential sample sizes using the approximated formula above and iterations using the exact formula, based on 95% confidence, 80% power, and the mean standard deviation for all tributaries combined. Estimates of sample sizes for individual tributaries may vary if the standard deviation for each tributary is used.

Table 2. Number of bulk samples required per tributary to detect a significant difference in the population means, at α=0.05 and β=0.80, based on the mean and variance of particle sizes less than 0.85 mm..

Minimum detectable difference	Sample size (n) based on z values	Sample size (n) based on iteration with t-values
1%	148	150
2%	37	39
3%	17	19
4%	10	12
5%	6	8

Analysis of variation in permeability data

The permeability data were entered into a standardized template (MS Excel 97) designed to compute the inflow rate (ml/s), convert this rate to permeability (K, in cm/hr), then adjust for temperature differences using a viscosity correction factor (Terhune 1958). The adjusted permeability for each replicate measurement (approximately 5 to 10 replicates per sample) was then averaged to determine a mean *sample* permeability. Mean sample permeabilities were in turn averaged to determine the mean permeability for each *site* and *tributary*. Permeability data were also compiled into summary sheets for each tributary (Appendix B) and into a single summary table containing all permeability data. The tributary summary sheets report the mean permeability, standard deviation, coefficient of variation (mean/standard deviation), standard error, replicate count number, and 95% confidence intervals summarized for: (1) the entire tributary, (2) each pool-tail site, and (3) each sample taken within the pool-tail site.

Recall that each permeability sample consisted of several replicate measurements at each standpipe location, and that numerous samples were collected at each pool-tail site. The first replicate measurement at each sample location was generally the lowest permeability measurement, and frequently had the highest suspended sediment concentration, (visually estimated from water inflow into the pump vacuum chamber) indicating that the permeability sampler was extracting silt particles from the gravel interstices. Sample replicates were repeated until the inflow rate reached an asymptote (Figure 5). One ancillary issue is whether the first permeability, the mean permeability, or the permeability at the asymptote is the measurement to characterize a sample. We assumed mean permeability was best.

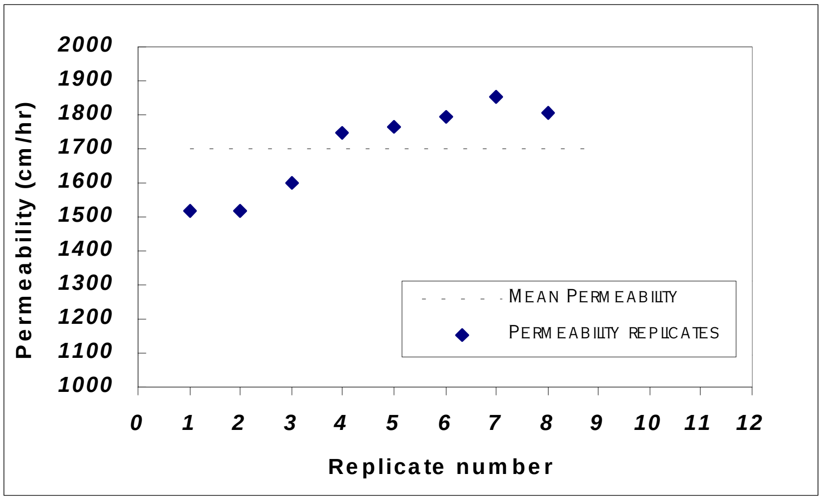

Figure 5. Variation in within-sample permeability during a typical progression of replicate measurements. The first measurement taken was generally the lowest permeability, and as a rule measurements were continued until the final measurement was not the highest, indicating an asymptote had been reached.

The number of replicate measurements taken for each sample was adequate to characterize the permeability of each sample, i.e., within-sample variation was low (Appendix B). The coefficient of variation (ratio of standard deviation to the mean) for each sample was small, generally ranging between 5% and 20 %. Samples with more than 5 replicates usually had much lower variability. The Tributary-3 site-1, sample #1, had 10 replicate measurements, and a CV of 2%. However, the variation in mean permeability within a pool-tail (n=3 to 9 samples) was generally higher (within-site variation), and much higher in many sample locations. Permeabilities often ranged from several hundred to several thousand cm/hr at a single pool-tail site. For example, sample permeabilities at Tributary-1 site 1 ranged from 257 cm/hr to 3,914 cm/hr. When considering this range of variability within context of the entire range of permeabilities observed in Figure 6 (ranging up to 100,000 cm/hr), this is a relatively broad range.

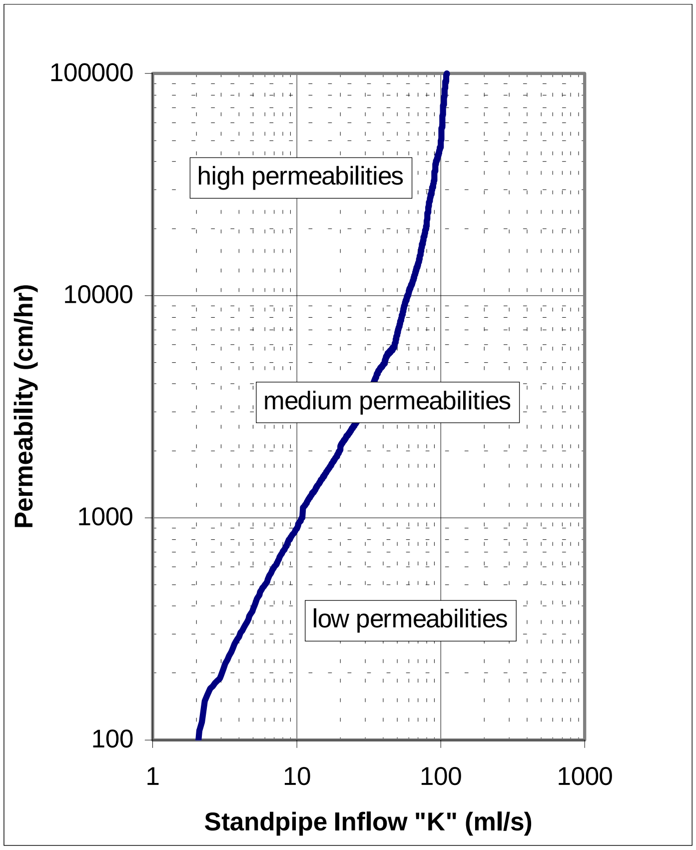

Figure 6. Relationship between inflow rate (ml/s) and permeability (cm/hr) used to convert field inflow measurements into permeability. Note that permeability ranges across three orders of magnitude, from 0 cm/hr to 100,000 cm/hr.

Coefficient of variation values for within-site variability generally ranged from 30% to over 100% (i.e., the standard deviation was higher than the mean), indicating that the number of samples collected at a pool-tail site was insufficient to characterize variability in permeability at a site with a high level of confidence. Variance could be reduced by eliminating samples with exceptionally low permeability (e.g. 0.0 cm/hr) that significantly biased the mean and variance. These “zero permeability” sites were often atypical sites, for example containing unconsolidated bedrock patches (Franciscan melange) or patches of sand that clogged the standpipe perforations and resulted in low permeabilities. Additionally, this within-site variation could be reduced by applying stricter criteria for selecting sample sites, such as avoiding sample sites near the channel margin or that were marginally within the depositional feature (pool-tail). Finally, additional measurements at each pool-tail site (for example, up to 10 to 12 samples) would require little additional effort.

Permeabilities for each bulk sample site (within-site variability) and for the entire pool-tail site (within-tributary variability) are summarized with the mean and several measures of variability (Table 3). Tributary-10 had the highest mean permeability, of 5,002 cm/hr. The poorest permeabilities were measured in Tributary-5, with a mean of 1,708 cm/hr. Again, the variation was high (but consistent), with coefficient of variation values ranging from 31% to 65%. But the range within which the variation generally occurred was often relatively narrow compared to the entire range of permeabilities (Figure 6). Tributary-4, for example, had the highest upper 95% confidence limit (α=0.05), which was only 7,586 cm/hr.

A single-factor ANOVA test (NCSS 6.0 Statistical Software) was performed to determine if there were significant differences in the permeability among tributaries. For the log permeabilities, the simple analysis of variance shows that there are highly significant differences between sites (p=0.0011) (Figure 7).

A central consideration for our analysis of variance was determining sample size (*i.e., the number of spawning sites within a single tributary*) necessary to: (1) establish the mean and measures of variance at some level of precision, and (2) detect differences among different tributaries, or temporal changes within a single tributary. Equation (1) calculates a range of sample sizes for permeability monitoring, (95% confidence and 80% power) with different "minimum detectable differences." For a low-range estimate of sample size, figure 6 shows permeabilities ranging across three orders of magnitude, classified as "low", "medium", and "high" permeabilities. The sample size needed to detect a significant difference between these three classes (δ = a factor of 10 difference) was approximately 2 samples per tributary (Table 4). A high-range estimate, to detect a difference in means with a factor of 2 (e.g., from 1,000 cm/hr to 2,000 cm/hr), would require a sample size of 17 spawning sites per tributary. This is a relatively modest increase in sampling effort compared to monitoring conducted in 1999, in which approximately eight sites were sampled.

Table 4. The range of sample sizes necessary for low and high levels of precision in permeability sampling.

Minimum detectable difference	Sample size (n) based on z values
factor of 10	2
factor of 2	17

Mean Permeability for each pool-tail site (cm/hr)

	POOL-TAIL SITE												95% Conf Int		
Tributary Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**ý (trib)**	**s**	**S.E.**	**Lower**	**Upper**	**CV (s/ý)**
Tributary-1	2,185	2,941	1,669	2,214	513	455	1,090	4,001		1,883	1,219	431	864	2,902	0.65
Tributary-3	2,855	3,113	2,414	1,021	2,632	3,057				2,515	778	317	1,699	3,332	0.31
Tributary-4	3,835	3,883	3,785	8,952	8,748		4,050	879		4,876	2,930	1,108	2,166	7,586	0.60
Tributary-5	3,876	1,304	1,231	2,349	1,922	767	1,183	1,031		1,708	1,012	358	862	2,554	0.59
Tributary-6			2,381	761	1,782	2,011	1,974	2,575		1,914	635	259	1,248	2,580	0.33
Tributary-7	1,872	3,743	1,240	598	1,638		1,800	3,014	983	1,861	1,047	370	986	2,737	0.56
Tributary-8	2,826	4,884	2,859	2,006		2,710		8,496		3,964	2,421	988	1,422	6,505	0.61
Tributary-9	734	2,660	2,676	1,034	4,325		2,239	1,438		2,158	1,227	464	1,023	3,293	0.57
Tributary-10	7,268	4,756	7,955	6,157	982	4,300	4,784	3,817		5,002	2,183	772	3,177	6,828	0.44
Tributary-11	1,608		1,313	1,651	4,754	3,238	5,006	5,614		3,312	1,822	688	1,627	4,997	0.55

Mean Permeability for each bulk sample site (cm/hr)

	POOL-TAIL SITE												95% Conf Int		
Tributary Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**ý (trib)**	**s**	**S.E.**	**Lower**	**Upper**	**CV (s/ý)**
Tributary-1	1,830	359	3,642	2,849	734	303	732	5,152		1,950	1,778	629	463	3,437	0.91
Tributary-3	4,500		1,699	265	1,832	2,954				2,250	1,579	706	434	4,066	0.70
Tributary-4	4,253	1,622	2,208	12,575	9,023		1,383	812		4,554	4,520	1,708	374	8,734	0.99
Tributary-5	4,967	1,396	559	1,246	571	866	1,714	761		1,510	1,456	515	293	2,727	0.96
Tributary-6			3,027	671	873	2,500	2,246	2,501		1,970	964	394	958	2,981	0.49
Tributary-7	552	4,179	337	792	1,092		2,018	3,637	963	1,696	1,460	516	476	2,917	0.86
Tributary-8	2,043	2,376	1,672	1,161		5,611		2,229		2,515	1,578	644	859	4,171	0.63
Tributary-9	1,503	2,551	1,830	1,797	2,448		1,468	2,048		1,949	426	161	1,555	2,343	0.22
Tributary-10	5,616	7,917	11,075	2,050	779	2,497	2,161	1,922		4,252	3,618	1,279	1,227	7,277	0.85
Tributary-11	1,224		2,781	3,652	4,213	8,122	5,388	8,722		4,872	2,747	1,038	2,331	7,412	0.56

Table 3. Summary of permeability data for all ten tributaries sampled in the Garcia River watershed. The mean permeability at each pool-tail site reports includes all samples. Permeabilities were generally quite low for most tributaries.

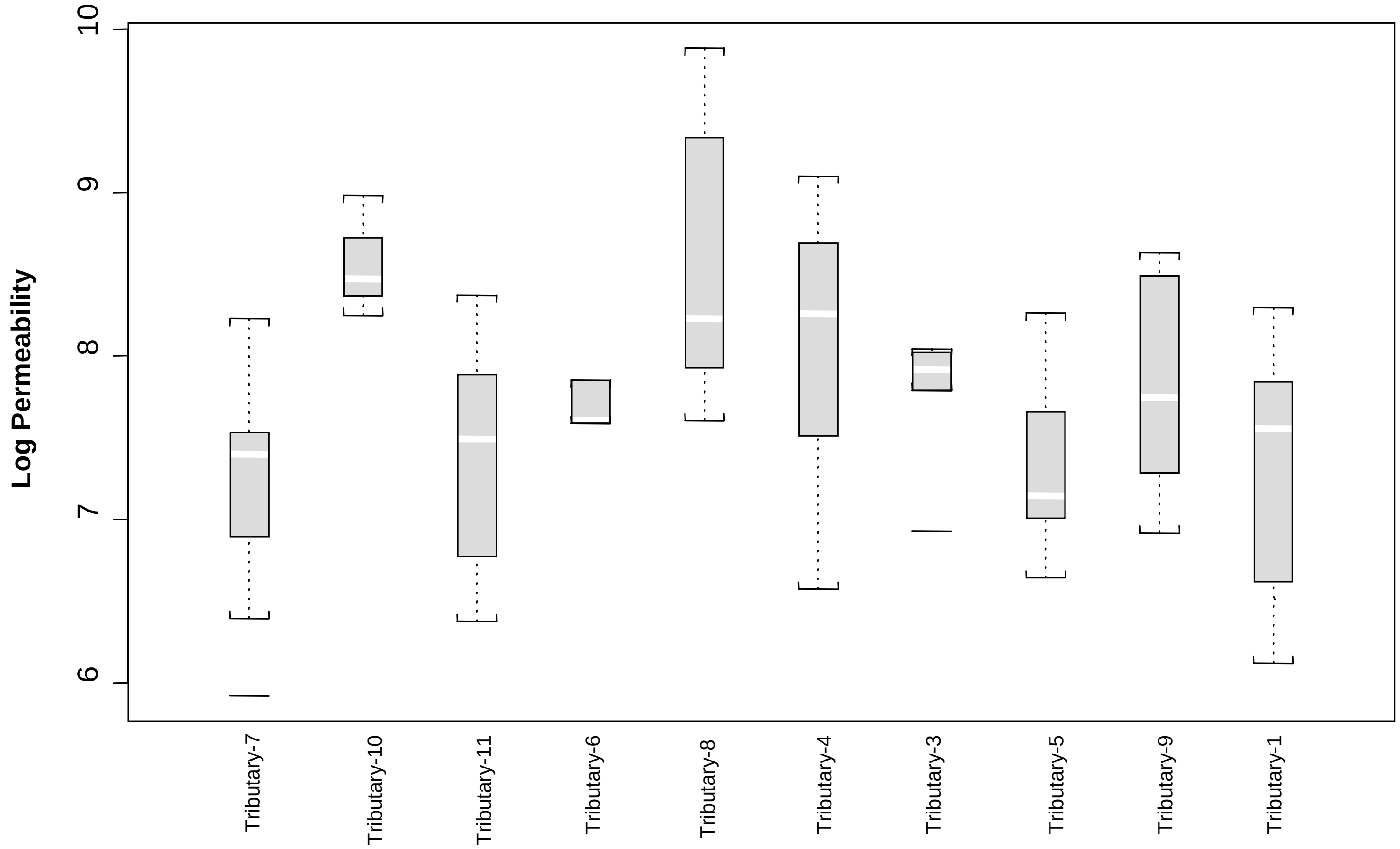

Figure 7. Box-whisker diagram of the permeability data. ANOVA showed highly significant differences among sites (p=0.0011). [Reading the box and whisker plot: the rectangular box represents the interquartile range, and the white band represents the median value. The whiskers represent the range of data within 1.5 times the width of the interquartile range from the median value. Dashes represent outlying data points.]

IV. Discussion

Correlation of particle size distribution and permeability
Each fraction of particle size (from the cumulative distribution) was compared independently with the mean permeability from the bulk sample location to determine how well permeability and sediment composition are correlated. The smaller particle size fractions showed better correlation, but overall the correlation was not strong. Four tests from a range of particle size fractions are presented: 9.5 mm, 2 mm, 1 mm, and 0.85 mm fractions (Figure 8). The correlation coefficient for the cumulative percent finer than 0.85 mm versus permeability was the highest (r^2=0.25).

The weak correlation between each particle size fraction and permeability was not surprising, i.e., one would not necessarily expect a single particle fraction to determine permeability. However, the relationship (or ratio) between framework (larger particle sizes) and matrix particles (smaller fractions) may contribute to determining permeability (Kondolf 2000). When larger framework particles are deposited, they generally come to rest against each other, creating interstitial spaces that contribute to high permeability. These spaces may fill with finer matrix particles that are either deposited within the framework, or infiltrate into interstitial spaces. If the ratio of fine sediment (matrix) to coarse sediment (framework) is high (i.e., high percent fines in bulk samples), the interstitial spaces fill completely, reducing permeability to very low ranges. Thus intuitively, a combination of two or more particle sizes (one framework and one matrix) may strongly correlate with permeability. We tested this hypothesis with a multiple regression test, which showed that 32 mm and 0.5 mm size fractions combined had the strongest, but still weak, correlation to permeability (r^2=0.45).

As mentioned before, permeability depends only on composition and degree of packing of the gravel, and water viscosity. By showing only a weak correlation between gravel composition and permeability, and adjusting for water viscosity, we can hypothesize the degree of packing of substrate particles explains the remaining variability in permeability.

Estimates of salmonid survival to emergence
The relationship between particle size distribution and salmonid survival described by Tappel and Bjornn (1983) was used to estimate survival for chinook salmon eggs. The percentage of particles finer than 9.5 mm and 0.85 mm was used (with samples truncated at 25.4 mm). The results indicated a wide range of survival percentage for most tributaries (Table 5), with mean survival ranging from 0% to 34%, and the 95% confidence intervals ranging from 0% in all tributaries to as high as 63% survival. Conclusions about the condition of salmonid spawning habitat are difficult based on predictions of egg survival from Tappel and Bjornn (1983).

Survival based on permeabilities was computed using a relationship developed independently by Tagart (1976) and McCuddin (1977). Data from these studies are based on survival tests with different salmonid species (chinook and coho salmon), and interpretations in this report based on these studies should therefore be considered preliminary. Their results show that permeability is strongly correlated to salmonid egg survival (Figure 9), and that permeability is a better indicator of spawning gravel conditions than estimates based on Tappel and Bjornn (1983). The range of predicted survivals was much smaller in all tributary samples (Table 5). The mean survival ranged from 29% to 43% and the 95% confidence intervals ranged from 18% to 49%. The broadest confidence interval, predicted for Tributary-8, ranged from 25% to 47% survival. The primary variable that controlled the low predictions of survival was not the percent of fines <0.85 mm, but instead the high percentage of particles <9.5 mm.

Comparison of results with other data and regional standards

The Garcia River Total Maximum Daily Load (1998) was developed by the US Environmental Protection Agency (EPA) and incorporated by the State of California's North Coast Regional Water Quality Control Board (Regional Board) in order to "identify the necessary reductions of human-related delivery of sediment to the river system" and to establish water quality standards for the protection of beneficial uses of the Garcia River watershed. The Garcia River TMDL established numeric targets for two parameters that are relevant to data collected in this study: percent fine sediments <0.85 mm (numeric target = 14%) and percent fine sediments <6.5 mm (numeric target = 30%. Results from our study indicate that the substrate composition of subsurface samples (excluding the armor layer from analysis) for the Garcia River tributaries sampled are below the TMDL numeric targets for fine sediments <0.85 mm. Our sieving analysis did not include a sieve size of 6.5 mm, so this numeric target could not be directly assessed. However, the percent substrate finer than 5.6 mm (our next lower sieve size) exceeded the TMDL numeric target of 30% for six of the ten tributaries, and therefore the percent finer than 6.3 mm would also exceed the TMDL standard for these tributaries.

These results vary from other data collected within the Garcia River watershed. For example, Monschke (1993) reported "more than 25% of the sediment measuring 2.5 mm and smaller in the North Fork Garcia." From our data, the average percent finer than 2.8 mm was 19.4% for six samples, but ranged as high as 26.5%. The following data are summarized from Manglesdorf (1997) and include data reported from other cited studies: Manglesdorf (1997), Garcia River watershed data, volume III: upper Redwood Creek <0.85 mm, 32.2% (average for 1994) truncated to 32mm; lower Redwood Creek, 19.4%; Redwood Creek, 25.8%. Morrison (1996), cited in Manglesdorf (1997) reported for Mill D Bridge on Mainstem Garcia, 18.2% <0.85mm in 1995 (truncated at 32 mm). CFL, cited in Manglesdorf (1997) reported for Inman Creek 15.2% <0.85mm (1994) and 12.8% (1995) (truncated at 32 mm). GP, 1994 data for North Fork Garcia River, cited in Manglesdorf (1997), 14.6% <0.85 mm (truncated to 32mm) (average for NF).

The Garcia River TMDL (1998) also provides the following data for Garcia River tributaries: Upper Redwood Creek: 32.2%; Lower Redwood Creek: 19.4%; mainstem at Bluewater Hole: 18.2%; mainstem at Inman: 15.8%; Inman: 12.8%; lower North Fork: 17.3%, 20.9%, 14.1%; mid-lower North Fork: 13.3%; 15.4%, 15.1%, mid North Fork: 25.3%, 17.7%, 20.6%; mid-upper North Fork: 25.9%, 25.7%, 27%; upper North Fork: 26.3%, 27.1%, 31.3%. They list the average for the drainage as 20.6%. The average percent <0.85 mm for all tributary samples in our study combined was 8.1% (SE=0.7), with 95% confidence interval ranging from 5.9% to 10.4%. The Garcia River TMDL does not provide information on data collection method accompanying this information.

Recent work by Louisiana-Pacific Corporation (LP 1997) reported data for Garcia River mainstem and tributary bulk sediment samples that are much more similar to the findings in this report. Their bulk sampling methods were also similar to our methods, including use of a 30 cm diameter bulk sampler, field drying of samples, and gravimetric analysis. They report percent fines <0.85 mm (outside of identified salmonid redds) for the Garcia River mainstem: 9.5% with a maximum of 22%; Mill Creek: 6.7%; South Fork: 10.0%; Rolling Brook: 5.6%.

We offer the following interpretations of the above data. First, the Garcia River TMDL determined water quality standards based on data collected from the Garcia River watershed and other surrounding watersheds, but did not evaluate these standards (or numeric targets) in terms of their effects on salmonid spawning success. Our study shows that despite meeting the numeric targets for percent fine sediment <0.85 mm, and in some cases for percent fines <6.3 mm, tributary spawning gravels nevertheless provide low egg to emergence survival for chinook salmon, based on the relationship established by Tappel and Bjornn (1983). The same is probably true for steelhead survival to emergence, although we did not evaluate steelhead survival. In a recently published review, Kondolf (2000) noted that fines <0.85 mm of more than 14% provide egg to emergence survival of only approximately 50% or less, which is generally in accordance with our data. Our data predicted mean survival to emergence ranging between 0% and 34%. Second, recent sediment composition data from the mainstem Garcia River, collected with methods similar to ours, show that the mainstem has percent fine sediments <0.85 only slightly higher than the tributaries we sampled. This difference is expected because tributaries generally have higher channel gradients than the mainstem, and therefore retain lower percentages of fine sediments. Third, our results show that tributary gravels contain an average of 51.6% of the substrate finer than 16 mm. Bjornn and Reiser (1991) report 13 mm as the lower limit of the suitable range of spawning gravels for chinook salmon and coho salmon, and 6 mm for steelhead. Spawning gravels from Garcia River tributaries have roughly half of their sediment composition smaller than the lower limit of suitability, indicating that, despite meeting the TMDL target for fines <0.85 mm, tributary spawning gravels are highly impacted. Finally, if data from which numeric targets were established were generated using volumetric analytical methods and inaccurate conversions from wet to dry weights, then these data (and the targets) may be artificially inflated. This last point cannot be verified with available information.

Unit Cost Evaluation

The final issue is the relative costs of conducting monitoring with one of the two techniques. Our evaluation of cost is based on the amount of work a crew of two could accomplish in a 10-hr day (excluding travel), which can then be extrapolated to determine costs of implementing future monitoring. These estimates are based on the effort expended in this study. For bulk sediment sampling, a 2-person crew, 10-hr day can:

- excavate, transport, and dry approximately 6 bulk samples (one per pool-tail site) per day (weighing up to 80 kg per sample).

- sieve the subsurface and surface portions of 6 samples per day, including data entry.

This totals 40 person-hours per six samples, or approximately 7 person-hours per sample (rounding up), multiplied by approximately 15 to 20 samples per tributary needed to adequately characterize the sampling variance, equates to **105 to 140 person-hours per tributary**.

For permeability sampling, a 2-person crew, 10-hr day can:

- sample a single pool-tail site in approximately 1.5 hours, with up to 10 samples per site, equating to approximately 6 sites per day, including data entry.

This totals 20 person-hours per six sites, or approximately 3.5 hours per site (rounding up), multiplied by approximately 17 sites per tributary needed to strongly characterize the sampling variance, equates to **60 person-hours per tributary**, *with significantly better sampling resolution provided by permeability methods*.

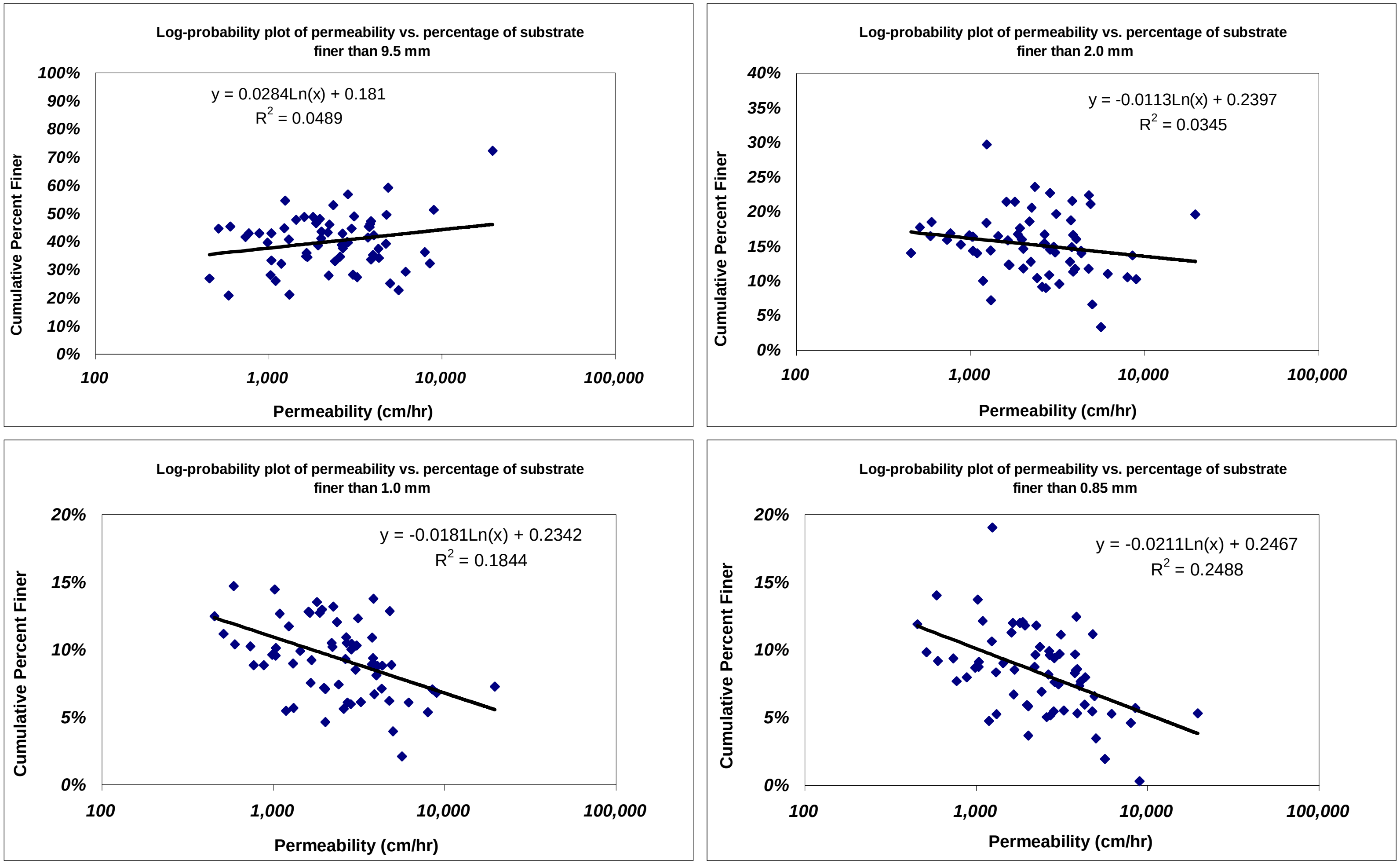

Figure 8. Linear regression plots of particle size fractions (cumulative percent finer) verses permeability (cm/hr).

Table 5. Percent survival of salmonid eggs, based on particle size analysis methods of Tappel and Bjornn (1983) and preliminary data relating egg survival to permeability from Tagart (1976) and McCuddin (1977).

	PERCENT FINE SEDIMENT			***PERMEABILITY***		
	estimated chinook survival (%)			***estimated chinook survival (%)***		
	mean	***lower 95% CI***	***Upper 95% CI***	***mean***	***lower 95% CI***	***Upper 95% CI***
Tributary-1	0	0	35	29	18	35
Tributary-3	0	0	41	33	27	37
Tributary-4	13	0	72	43	31	49
Tributary-5	0	0	39	28	18	33
Tributary-6	34	0	64	29	23	33
Tributary-7	0	0	21	29	20	34
Tributary-8	4	0	53	40	25	47
Tributary-9	20	0	63	37	27	43
Tributary-10	15	0	58	43	36	47
Tributary-11	0	0	41	31	20	37

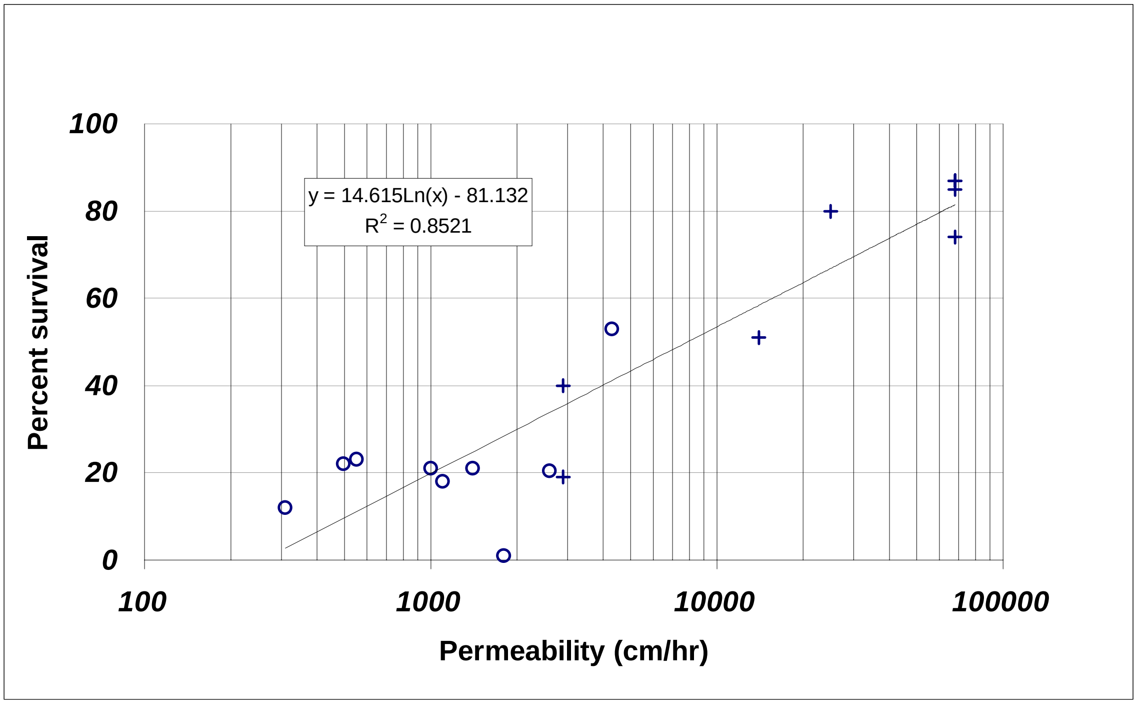

Figure 9. Data from Tagart (1976) and McCuddin (1977) showing a highly significant relationship between survival of chinook (McCuddin data, +) and coho salmon (Tagart data, o), and permeability of the incubation substrate.

V. Conclusions

To assess the quality of salmonid spawning gravels, resource managers need monitoring techniques that quantify some aspect of the spawning habitat environment that affects the success of spawning and incubation, and allow description of the variability in the spawning habitat conditions with some specified level of precision. Substrate composition has been shown to affect the survival of salmonid eggs (Tappel and Bjornn 1983), and survival can be predicted if certain fractions of the particle size distribution are known. However, to gather this data with sufficient precision to characterize spawning gravel quality of an entire stream reach requires an enormous sampling effort, perhaps beyond the capabilities and budgets of resource agencies, organizations, and private companies. For example, to collect substrate composition data on ten tributaries to the Garcia River at the level of sampling suggested in the unit cost evaluation (20 samples per tributary) would require expenditure of at least $10,000 per tributary. Clearly, better methods are needed.

The permeability methods evaluated as part of this study show the potential to define the variability in spawning gravel quality with better resolution and at lower cost than substrate composition analysis, but the relationship between permeability and salmonid egg survival is less well known. Until this relationship is better defined, permeability should only be considered an *index* of gravel quality, and predictions of salmonid reproductive success are tentative.

This study has:

(1) established baseline monitoring data for spawning gravel quality of ten tributaries to the Garcia River, Mendocino County, that support listed salmonid species.
(2) shown a weak correlation between particle size fractions of substrate samples collected within the Garcia River watershed, and permeability measurements taken within the substrate sample. The remaining variation in the data is probably best explained in terms of the degree of packing of the substrate.
(3) provided evidence that permeability methods may better describe the condition of salmonid spawning gravels than substrate composition analysis, but continued application is dependent on establishing a stronger relationship between permeability and salmonid egg survival.
(4) provided methods for estimating the sample size needed to achieve specified levels of precision in the data, for either substrate composition analysis or permeability.

Literature Cited

Barnard, K. 1990. Report on gravel quality monitoring of MJ Ruddy Ruddy, Inc. 1989 salmon spawning restoration projects on the Tuolumne River. Trinity Fisheries Consulting, unpublished manuscript.

Barnard, K. and S. McBain. 1994. Standpipe to determine permeability, dissolved oxygen, and vertical particle size distribution in salmonid spawning gravels. Fish Habitat Relationships Technical Bulletin No. 15. U. S. Forest Service.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society, 117(1)1-21.

Chapman, D.W. and K.P. McLoud. 1987. Development of criteria for fine sediment in the Northern Rockies ecoregion. Final Report EPA 919/587-162. U.S. Environment Protection Agency, Water Division.

Koski, K. V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams. Master's thesis. Oregon State University, Corvallis.

Manglesdorf, A.T. 1997. Assessment of aquatic conditions in the Garcia River watershed, prepared for the North Coast Regional Water Quality Control Board (Vol 1-4).

McCuddin, M. E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. Master's thesis. University of Idaho, Moscow.

Monschke, J. 1996. Overview of stream channel conditions, North Fork Garcia River. No other information given.

Louisiana-Pacific Corporation. 1997. Preliminary results of spawning gravel permeability and composition, for the Garcia River watershed.

Mendocino County Resource Conservation District and California Department of Forestry. 1998. Watershed Assessment and Cooperative Instream Monitoring Plan for the Garcia River Mendocino County, CA. Report prepared by: Forest, Soil and Water, Inc., O’Connor Environmental, Inc., and East-West Forestry.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. Gen Tech Rep. INT – 138. Ogden UPSTREAM: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Pollard, R. A. 1955. Measuring seepage through salmon spawning gravel. J Fish. Res. Bd. Canada, 12(5): 706-741.

Redwood National Park (RNP). 1991. Monitoring the impacts and persistence of fine sediment in the Prairie Creek watershed 1989 – 1990.

Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Master's thesis. University of Washington, Seattle.

Tappel, P. D. and T. C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3: 123-135.

Terhune, L. D. B. 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. Journal of the Fisheries Research Board of Canada 15: 1027-1063.

US EPA. 1998. Garcia River sediment total maximum daily load. US EPA, Region IX, dated March 16, 1998.

Valentine, B. E. 1995. Stream substrate quality for salmonids: guidelines for sampling, processing, and analysis. Appendix B of *Aquatic Field Protocols Adopted by the Fish, Farm, and Forest Communities (FFFC) Technical Committee,* Version 1.1 compiled by R. N. Taylor, October 1996.

Young, M. K., W. A. Hubert, and T. A. Wesche. 1989. Evaluation of variation in permeability measurements when using the MARK VI standpipe. Canadian Journal of Fisheries and Aquatic Sciences 46: 1-4.

<u>Addendum to:</u>

SPAWNING GRAVEL COMPOSITION AND PERMEABILITY WITHIN THE GARCIA RIVER WATERSHED, CA

FINAL REPORT

APRIL 20, 2000

Recent studies of substrate composition and permeability of spawning substrates conducted in the Trinity River revealed a significant error in our interpretation of the Tappel and Bjornn (1983) methods described in this report. These methods were used to in this report to estimate the percent survival-to-emergence of chinook salmon eggs based on the cumulative percentage of sediment finer than 9.5mm and 0.85mm. Our original interpretation of the methods included truncating the entire bulk sample data at 25.4mm, recalculating the cumulative percentages, then using these data in the regression equations provided by Tappel and Bjornn (1983) to estimate the percent survival-to-emergence. The correct interpretation, confirmed independently with both authors (Paul Tappel and Dr. T.C. Bjornn), is to estimate the percent survival-to-emergence using the cumulative percents finer than 9.5mm and 0.85mm from the **entire sediment sample, not truncated at 25.4mm**. We have updated our results, using the entire sediment **subsample**, with the surface layer of coarser particles removed, which is fairly standard practice.

We therefore offer this addendum to our final report, which required the following changes:

1. <u>Page 1 of Introduction, Background section, paragraph-2, 2nd sentence should read</u>:

> "Their methods rely on determination of the percentage of substrate smaller than 0.85 mm and 9.5 mm." ~~**, with the cumulative distribution truncated at 25.4 mm.**~~

2. <u>Page 8 of the Results, paragraph-1, 3rd sentence should read</u>:

"We also computed the cumulative percent finer with the data truncated at 32 mm to examine the correlation with permeability." ~~**, and also truncated at 25.4 mm for use in the Tappel and Bjornn (1983) methods described above.**~~

3. <u>Page 18 of the Discussion, paragraph-4 under the subsection "Estimates of salmonid survival-to-emergence", should read</u>:

"The relationship between particle size distribution and salmonid survival described by Tappel and Bjornn (1983) was used to estimate survival for chinook salmon eggs. The percentage of particles finer than 9.5 mm and 0.85 mm was used. ~~**(with samples truncated at 25.4 mm)**~~. The results indicated a wide range of survival percentage for most tributaries (Table 5), with mean survival ranging from 54% to 82%, and the 95% confidence intervals ranging from 9% in all tributaries to as high as 93% survival." ~~**with mean survival ranging from 0% to 34%, and the 95% confidence intervals ranging from 0% in all tributaries to as high as 63% survival.**~~ Conclusions about the condition of salmonid spawning habitat are difficult based on predictions of egg survival from Tappel and Bjornn (1983).

<u>Interpretation</u>: R*ecalculations* of our estimates of percent survival-to-emergence using the Tappel and Bjornn methods indicate that our original estimates were somewhat low based on the gravel composition encountered in the Garcia River tributaries. Included here is a revised Table 5, which

shows that the range of survival estimates is higher than originally reported, and slightly higher than estimates based on our permeability measurements (approximately 26-48% higher). Nevertheless, the range covered by the 95% confidence interval remained quite broad; for example, the 95% CI for Tributary-8 ranged from 9 to 93%, meaning that our "confidence" in the survival estimate derived from sediment composition is essentially zero. Other tributary sediment samples provided better survival estimates. These revised survival estimates likely appear more realistic in light of the low percentage of fines in the Garcia River tributaries.

Table 5. Percent survival of salmonid eggs, based on particle size analysis methods of Tappel and Bjornn (1983) and preliminary data relating egg survival to permeability from Tagart (1976) and McCuddin (1977).

	PERCENT FINE SEDIMENT			**PERMEABILITY**		
	estimated chinook survival (%)			***estimated chinook survival (%)***		
	mean	***lower 95% CI***	***Upper 95% CI***	***mean***	***lower 95% CI***	***Upper 95% CI***
Tributary-1	74	56	87	29	18	35
Tributary-3	71	45	87	33	27	37
Tributary-4	70	41	87	43	31	49
Tributary-5	66	44	81	28	18	33
Tributary-6	77	58	89	29	23	33
Tributary-7	54	27	75	29	20	34
Tributary-8	68	9	93	40	25	47
Tributary-9	82	57	93	37	27	43
Tributary-10	73	44	89	43	36	47
Tributary-11	65	42	81	31	20	37

4. Page 20 of the Discussion, last paragraph, should read:

"We offer the following interpretations of the above data. First, the Garcia River TMDL determined water quality standards based on data collected from the Garcia River watershed and other surrounding watersheds, but did not evaluate these standards (or numeric targets) in terms of their effects on salmonid spawning success. Our study shows that despite meeting the numeric targets for percent fine sediment <0.85 mm, and in some cases for percent fines <6.3 mm, tributary spawning gravels nevertheless provide **moderate to** low egg to emergence survival for chinook salmon, based on the relationship established by Tappel and Bjornn (1983). The same is probably true for steelhead survival to emergence, although we did not evaluate steelhead survival. In a recently published review, Kondolf (2000) noted that fines <0.85 mm of more than 14% provide egg to emergence survival of only approximately 50% or less, which is generally in accordance with our data. Our data predicted mean survival-to-emergence ranging between **54% and 82%, with 95% CI ranging broadly from 9% to 93% survival**. Second, recent sediment composition data from the mainstem Garcia River, collected with methods similar to ours, show that the mainstem has percent fine sediments <0.85 only slightly higher than the tributaries we sampled. This difference is expected because tributaries generally have higher channel gradients than the mainstem, and therefore retain lower percentages of fine sediments. Third, our results show that tributary gravels contain an average of 51.6% of the substrate finer than 16 mm. Bjornn and Reiser (1991) report 13 mm as the lower limit of the suitable range of spawning gravels for chinook salmon and coho salmon, and 6 mm for steelhead. Spawning gravels from Garcia River tributaries have roughly half of their sediment composition smaller than the lower limit of suitability, indicating that, despite meeting the TMDL target for fines <0.85 mm, tributary spawning gravels are highly impacted. Finally, if data from which numeric targets were established were generated using volumetric analytical methods and inaccurate conversions from wet to dry weights, then these data (and the targets) may be artificially inflated. This last point cannot be verified with available information.

5. Finally, we include an additional table that shows the cumulative percentages of particles smaller that 9.5 mm and 0.85 mm together with the survival-to-emergence estimates, to better facilitate comparison of the sediment composition to our survival estimates.

		BULK SAMPLE										95% Conf Int		estimated chinook survival (%)		
Tributary	***% Finer***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***mean***	***lower***	***upper***	***mean***	***lower CI***	***Upper CI***
Tributary-1	9.5 mm	43%	40%	34%	28%	45%	27%	26%	35%		34.8%	28.4%	41.2%	74	56	87
	0.85 mm	9%	6%	9%	10%	10%	12%	12%	7%		9.3%	6.8%	11.8%			
Tributary-3	9.5 mm	40%	49%	33%	28%	39%	28%				36.2%	28.1%	44.2%	71	45	87
	0.85 mm	9%	11%	7%	14%	8%	10%				9.8%	6.5%	13.2%			
Tributary-4	9.5 mm	46%	34%	45%	51%	29%	29%	42%	43%		40.0%	32.9%	47.2%	70	41	87
	0.85 mm	12%	9%	10%	6%	0%	11%	8%	8%		8.0%	3.5%	12.5%			
Tributary-5	9.5 mm	47%	41%	45%	53%	39%	43%	32%	33%		41.6%	35.6%	47.7%	66	44	81
	0.85 mm	5%	8%	11%	10%	12%	8%	5%	9%		8.4%	5.4%	11.5%			
Tributary-6	9.5 mm	44%	48%	35%							42.2%	32.5%	51.8%	77	58	89
	0.85 mm	4%	6%	5%							4.9%	2.6%	7.1%			
Tributary-7	9.5 mm	47%	41%	55%	45%	35%	38%	49%	45%	40%	43.7%	38.8%	48.7%	54	27	75
	0.85 mm	12%	8%	19%	9%	12%	8%	12%	7%	9%	10.8%	6.7%	14.9%			
Tributary-8	9.5 mm	40%	59%	57%	41%	0%	38%	72%	32%		42.5%	23.7%	61.4%	68	9	93
	0.85 mm	5%	7%	8%	6%	18%	5%	5%	6%		7.5%	2.2%	12.8%			
Tributary-9	9.5 mm	49%	46%	21%	36%	39%	27%	25%	23%		33.3%	24.0%	42.6%	82	57	93
	0.85 mm	11%	12%	5%	7%	5%	6%	3%	2%		6.5%	2.2%	10.8%			
Tributary-10	9.5 mm	36%	29%	37%	50%	45%					39.6%	30.9%	48.3%	73	44	89
	0.85 mm	5%	5%	6%	11%	9%					7.1%	2.9%	11.3%			
Tributary-11	9.5 mm	42%	43%	38%	43%	34%	21%	46%	48%		39.3%	31.8%	46.7%	65	42	81
	0.85 mm	9%	10%	10%	9%	8%	14%	12%	9%		10.1%	7.8%	12.4%			

Appendix A

Appendix B