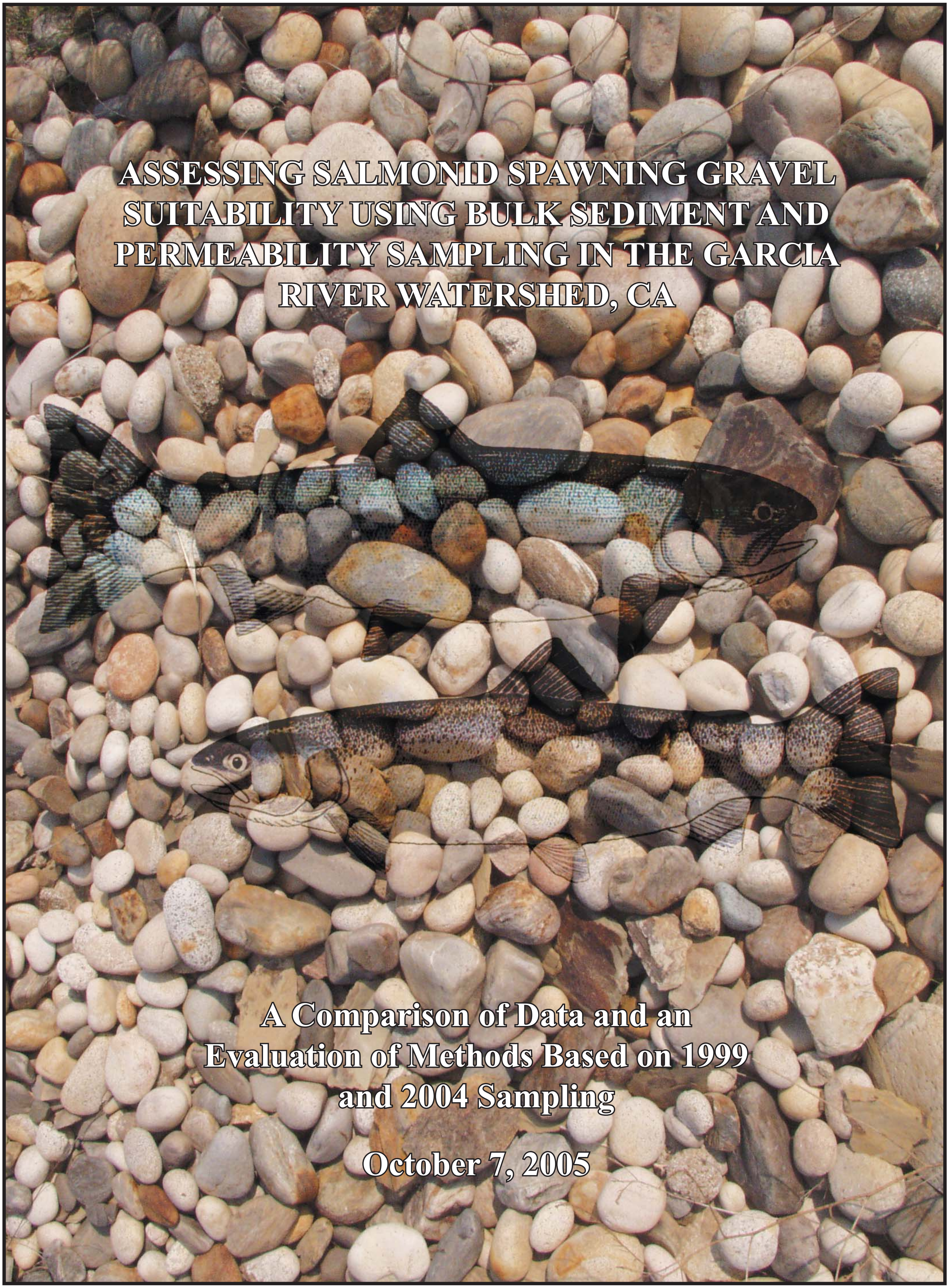

ASSESSING SALMONID SPAWNING GRAVEL SUITABILITY USING BULK SEDIMENT AND PERMEABILITY SAMPLING IN THE GARCIA RIVER WATERSHED, CA

A Comparison of Data and an Evaluation of Methods Based on 1999 and 2004 Sampling

October 7, 2005

Assessing Salmonid Spawning Gravel Suitability Using Bulk Sediment and Permeability Sampling in the Garcia River Watershed, CA

A Comparison of Data and an Evaluation of Methods Based on 1999 and 2004 Sampling

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October 7, 2005

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1 INTRODUCTION AND BACKGROUND

In 1999, ten tributaries to the Garcia River were evaluated for spawning gravel quality on the basis of substrate composition and permeability. This work was performed in response to objectives proposed in the *Watershed Assessment and Cooperative Instream Monitoring Plan for the Garcia River, Mendocino County, California* (IMP), prepared jointly by the Mendocino County Resource Conservation District (MCRCD) and the California Department of Forestry and Fire Protection (CDF). The IMP included 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 salmonid egg incubation occurs.

The 1999 analysis used two methods to relate spawning gravel quality to salmonid egg survival. The first analysis used the Tappel and Bjornn index (Tappel and Bjornn 1983), which uses data solely from bulk sediment samples. The second analysis used available data to estimate survival from permeability measured in Garcia River tributary sediments. In addition, the 1999 data provided baseline information relevant to the numeric targets presented in the Garcia River Total Maximum Daily Load (TMDL) (USEPA 1998), including indices of particle size distributions. Results of the 1999 study were presented in a summary report titled “Spawning Gravel Composition and Permeability within the Garcia River Watershed, CA” (McBain and Trush 2001; hereafter referred to as the “2001 Report”). We recommend the reader be familiar with the 2001 Report, as it provides detailed discussion of key concepts that are not restated in as much detail in this report, such as correlating sediment composition and permeability to salmonid spawning habitat condition, and relating substrate particle sizes to salmonid survival. A copy of the 2001 Report is provided as Appendix A, and is also available online at the CDF webpage: http://www.bof.fire.ca.gov/board/msg_supportedreports.html

Results from the 1999 study showed a wide and variable range of survival estimates based on the Tappel and Bjornn method, and only showed a weak correlation between sampled substrate particle size fractions and their corresponding permeabilities. The primary conclusion drawn from these results was that sample size needed to be increased, particularly increasing the number of bulk sediment samples collected within each tributary reach above n = 8 to reduce variability and improve the ability to detect differences among tributaries and between years (sampling events).

A repeat study was conducted in 2004 to document changes in substrate and permeability conditions five years later. This repeat study provided an opportunity to measure sediment composition and permeability in a selection of the same tributary reaches, compare the results, and assess the significance of any changes in permeability and particle size distributions relative to salmonid spawning gravel quality and TMDL targets. Additionally, the MCRCD hypothesized that changes in substrate composition could be attributed to recent land management activities (sediment reduction efforts since 1999), and this hypothesis is examined for a single tributary watershed.

The 2001 Report, based on statistical analyses of sample variability, recommended that the number of samples be increased in future field efforts. However, budget constraints limited the 2004 sampling effort to collecting the same number of samples per tributary as in 1999 (eight) and reduced the number of tributaries sampled in 2004 from ten to five.

1.1 Objectives

The objectives of the 1999 sampling was to: a) establish baseline substrate composition and permeability conditions for long-term trend monitoring; b) assess the relationship between substrate composition and permeability, and; c) evaluate the general utility of this relation for assessing the condition of salmonid spawning substrates. The 2004 study was designed to re-measure particle size distributions and permeability to document changes since the previous sampling in 1999.

Specific objectives of the 2004 study include:

1. Using the same sampling methods, measure permeabilities and collect bulk sediment samples at multiple sample sites within five of the ten tributary reaches sampled in 1999;
2. Compare particle size distributions and permeabilities to results from the same tributary reaches sampled in 1999, and;
3. Evaluate whether the sediment sampling and permeability measurement techniques used for this study provide adequate measures to assess changes in substrate composition (coarsening or fining), or if different methods are needed.

1.2 Study Area

The Garcia River watershed is located in southwestern Mendocino County, CA, and drains 113 square miles of rugged forest and grasslands (Figure 1). 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 40 to 60 inches per year. In addition to the mainstem, there are more than 25 named streams within the Garcia River watershed that drain individual watersheds greater than one square mile each. Land use includes timber harvesting, cattle ranching, dairy production, gravel mining, and private residency.

In the 2001 Report, tributary names were replaced with numbers for confidentiality. Tributary confidentiality is not a concern for this report; however, for the ease of comparative analyses, this report follows the same numbering scheme. Of the ten tributaries sampled in 1999, only five could be revisited in 2004 (Tributaries -1, -4, -5, -8, and -9). A list of the tributaries and their corresponding numeric codes is shown in Table 1.

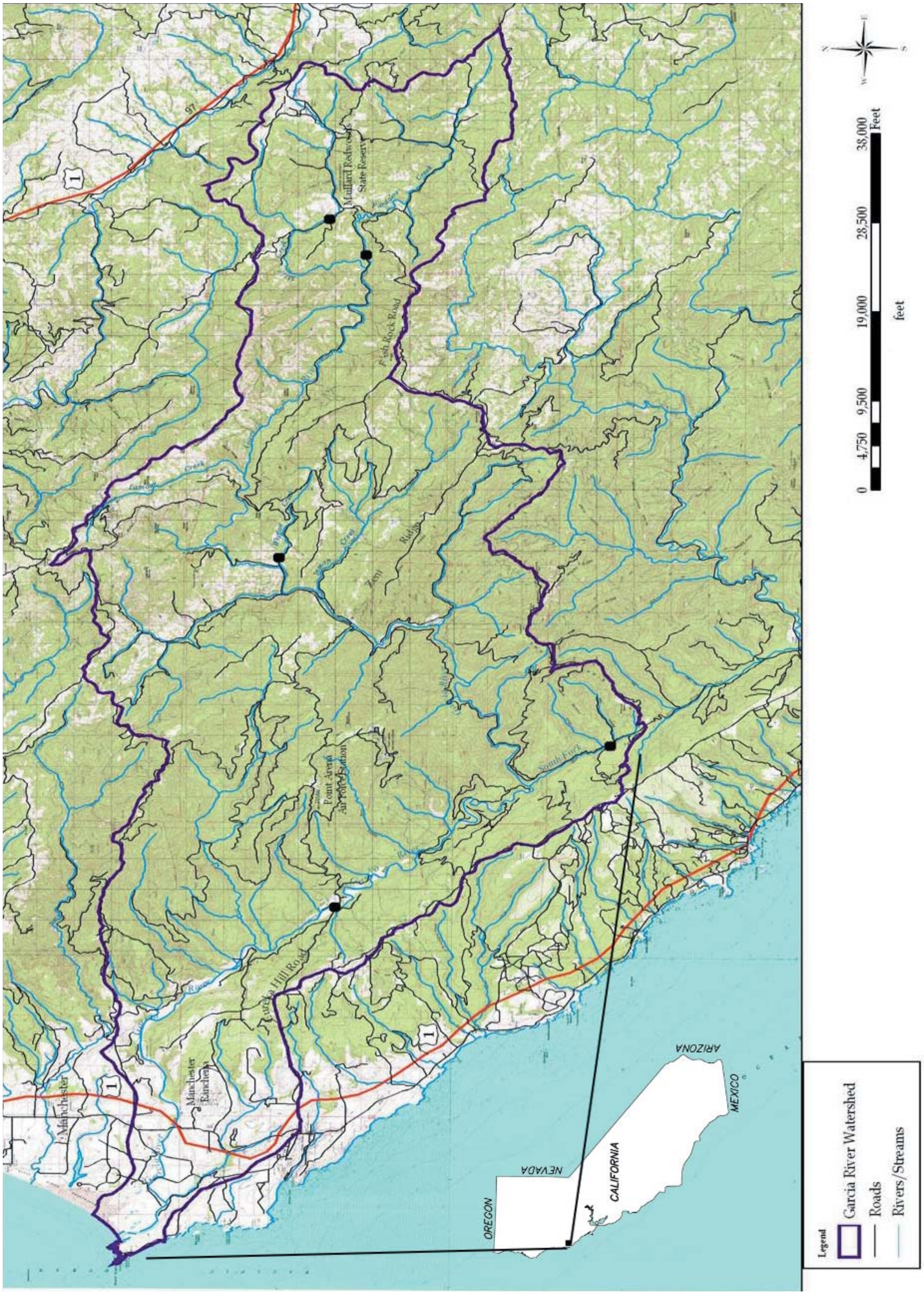


Figure 1. Map showing location of the Garcia River watershed, Mendocino County, CA.

Table 1. Tributary numeric codes and corresponding names.

Tributary code	***Tributary name***
Tributary-1	Whitlow Creek
Tributary-4	Mill Creek
Tributary-5	Pardaloe Creek
Tributary-8	Inman Creek
Tributary-9	South Fork Garcia River

2 METHODS

Variability was a key limitation identified with the 1999 data. Although the variability documented from the 1999 results was primarily attributed to sample sizes, other sources of variability exist, including:

- Field data collection / sampler bias (sampling differences between operators);
- Differences in geomorphic settings (e.g., geomorphic differences between tributaries, reaches, and/or sample sites);
- Differences in land management between tributaries.

If substrate conditions have changed since 1999, what cause(s) can this change be attributed to? The 2004 methods were developed to minimize controllable biases (data collection and geomorphic setting), increasing the likelihood that changes in substrate composition could be attributed to changes in land management.

2.1 Field data collection

In August 2004, McBain and Trush staff scientists met in the field with MCRCD representatives to review sample site selection criteria and methods, and review methods for collecting permeability and bulk sediment samples. Permeability and bulk sampling methods were reviewed on Tributary-4, and site selection criteria were reviewed on both Tributary-4 and Tributary-5. Following this meeting, MCRCD completed site selection and sampling at the remaining tributaries. A total of five tributaries were sampled for permeability and/or gravel composition (Table 2).

Table 2. Inventory of sample type collected at each tributary reach.

Location	***Bulk sediment sample***	***Permeability sample***
Tributary-1	●	
Tributary-4	●	●
Tributary-5	●	●
Tributary-8		●
Tributary-9	●	●

The 2001 Report recommended increasing the number of bulk sediment samples from 8 to between 15 and 20 per tributary and up to ten permeability samples per sample site; however, budget constraints prevented this level of sampling from being accomplished. As a result, the data collection followed the 1999 sampling scheme by collecting the same number of bulk sediment samples per tributary (n = 8) and approximately the same number of permeability samples.

Field data collection and data processing methods for this report follow the same protocols as presented in the 2001 Report and are not restated. In some cases, methods were modified slightly and a more detailed explanation is given when this occurred.

2.1.1 Site selection

Using the 1999 methods, only pool-tails were sampled to reduce variability caused by different geomorphic features. Eight pool-tails were selected within each tributary sampling reach. A pool-tail creates a hydraulic environment that promotes streamflow exchanges between the water column and the channel substrate, which has been shown to provide favorable conditions for salmonid egg incubation (Kondolf 2000).

The 2004 sampling occurred within the same tributary reaches (i.e., upstream and downstream limits of sampling were the same); however, individual sampling locations within each reach may have differed. Although it is possible that some of the pool-tails have remained stationary between 1999 and 2004, such as those with bedrock controls, other pool-tails may have changed location completely. Rather than attempt to identify and resample the exact 1999 locations, "new" pool-tails were selected within the sampling reach to provide a well-spaced distribution of sampling sites. Therefore, comparing sampling results between 1999 and 2004 reflects changes on a reach scale rather than at individual pool-tail sites.

After a pool-tail was selected, a sampling area was determined following the same method used in 1999. This was done systematically, so that the same portion of all pool-tails was sampled. First, a point was selected half-way up the slope of the pool tail. Viewed longitudinally, this point is located mid-distance from the start of the pool tail (in the deeper portion of flow, where the pool begins to slope up to the riffle crest) to the riffle crest itself. This point defines the sampling node. After the sampling node was identified, a cross section was located through the node, perpendicular to flow. The cross section served as a reference mark to delineate the lateral sampling limits, which were defined as half the distance from the node to the thalweg, and half the distance from the node to the channel centerline (Figure 2).

Bulk samples and permeability measurements were based on the sampling node location: a single bulk sample was collected at the node, and permeability samples were collected at approximately equally-spaced locations around the node, with a single permeability measurement collected at the node (Figure 2). At each pool-tail sampling site, permeability was measured first, followed by the bulk sample collection.

2.1.2 Permeability sampling

As described in the 2001 Report, permeability was measured using Terhune (1958) and Barnard and McBain (1994) standpipe methods, with the noted exceptions of an improved vacuum pump and smaller diameter standpipe. At each pool-tail site, permeability

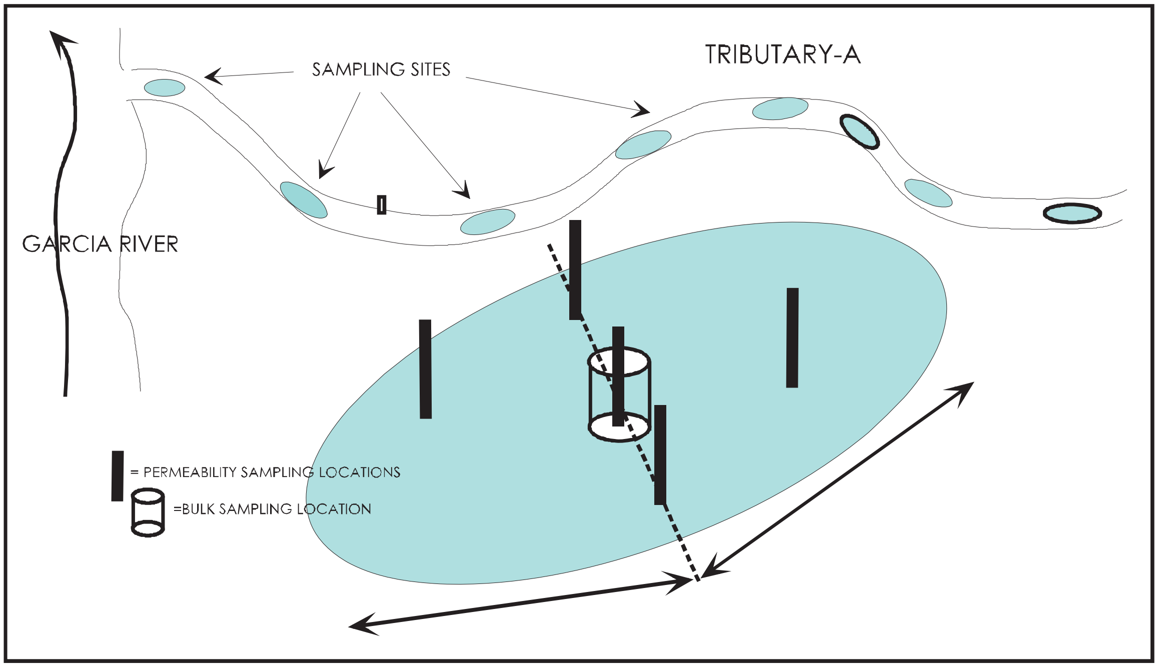


Figure 2. Conceptual diagram showing pool-tail sample sites located within the study reach of each tributary, and a single site showing the locations of the bulk sample and permeability samples. The sampling node is delineated by shared bulk sampling and permeability location symbols, the dashed line represents the cross section (extending through the node, perpendicular to flow), and the grey shaded area represents the sampling area delineated longitudinally by the upstream and downstream limits of the pool tail, and laterally by half the distance from the node to the thalweg, and half the distance from the node to the channel centerline. (from McBain and Trush 2001).

measurements were made at several locations within the pool-tail, including a single measurement at the sampling node, and from three to four additional sample locations approximately equidistant from the node to the margins of the spawning gravels (Figure 2). Each permeability *sample* consisted of three to eight *replicate* measurements of inflow rate (in ml / sec), with each replicate measurement lasting from less than two seconds to approximately 200 seconds (to summarize, at 1 pool-tail site, 4 to 5 samples were collected, where each sample consists of 3 to 8 replicate measurements). Permeability samples were collected with the center of the standpipe perforations located 25 cm below the substrate surface.

2.1.3 Bulk sediment sampling

Following permeability sampling, a single bulk sample was collected at the sampling node. This was done so that a particle size distribution could be provided for the very same location that permeability was measured. Bulk samples were collected using a 30 cm diameter by 60 cm tall stainless steel cylindrical sampler (the same sampler used in 1999). The sampler was manually worked into the bed and the substrate was carefully removed by hand and placed into plastic 5-gallon buckets.

Many gravel-bed rivers can have coarser sediments on the bed surface than the sediments immediately underlying. Because the underlying "subsurface" sediments are representative of the sediment matrix in which spawning occurs, the surface layer, if visually present during excavation, was not retained as part of the bulk sediment sample.

Bulk samples need to be sufficiently large so that individual coarse particles are not over-represented in the sample (Bunte and Abt 2001). Because large particles in small samples can account for a substantial portion of the total sample mass, Church et al. (1987) suggests the maximum particle size in the sample (D_{max}) not constitute more than 1% of the total sample mass for particles up to 128 mm (5.0 in), and not more than 5% of the total sample mass for particles greater than 128 mm. These guidelines were recommended for the 2004 sampling based on a visual estimate of the D_{max} collected in the sampler so that a representative sample volume would likely be obtained. For example, if the largest particle sampled is 64 mm (2.5 in), its corresponding weight is 0.36 kg (assuming a density of 2.65 g/cm^3). Using the 1% sampling criterion yields a representative sample mass of approximately 36 kg (79 lb). If the particle diameter is increased to 90 mm (approximately a one inch increase), the required sample mass jumps to 101 kg (223 lb). Small changes in particle size can translate into large changes in required sample mass. This method differed from the 1999 sampling where the sample volume was determined by sampler depth (minimum 30 cm) rather than by particle size). Although the 1% and 5% criteria are mathematically easy to determine based on the largest particle sampled, it can be difficult to visually determine if the amount collected is sufficient. The risk of under-sampling is unavoidable, and often the target sample mass is not reached (i.e., too little volume is collected).

2.1.4 Embeddedness measurements

Embeddedness refers to the position of a large particle relative to the plane of the streambed (Bunte and Abt 2001), and describes the relative degree to which a particle is buried in finer sediment on the streambed surface (Sylte and Fischenich 2003). Embeddedness was measured following protocols outlined in California Department of Fish and Game (CDFG) Habitat Restoration Manual (Flosi et al. 1998), and results were recorded on bulk sample field data forms. Individual embeddedness ratings were recorded as percentages and then converted to the formal CDFG codes.

2.2 Permeability and Bulk Sediment sample processing

Permeability data were managed in the same manner as in 1999. Following field measurements, data were processed in the office. For the 2004 sampling, MCRCD provided copies of the field data collection forms to McBain and Trush, where the raw data were entered into a database. Following the data entry, each individual field inflow rate measurement (ml / sec) was converted to permeability (cm / hr), and the data were summarized for subsequent analyses.

Bulk sediment samples were processed slightly differently than in 1999. In 1999, bulk sediment samples were dried and sieved in the field, and data were entered and analyzed in the office. Samples were sieved in full "phi" (ϕ) increments for coarser substrates: 128, 64, 32, 16, 8 mm, and then half phi sizes for the finer size fraction: 5.6, 4.0, 2.8, 2.0, 1.4, 1.0, 0.85, 0.5, 0.25, and 0.125 mm.

To improve field and cost efficiency, the 2004 bulk samples were shipped to Graham Matthews and Associates (GMA) in Arcata, CA where they were dried, weighed, and sieved. In total, 32 samples were collected in 46 5-gallon buckets. A complete description of GMA's laboratory analysis procedure and sample processing protocol is provided in Appendix B. Compared with the 1999 sieving, the GMA analysis used half phi increments for the complete analysis (compared to the whole phi increments used for the coarse fraction in 1999). The additional screens included 90, 45, 22.4, and 11.2 mm. In addition, a 6.5 mm screen was requested to be added to the series of sieves because of its relevance to Garcia River TMDL standards, however only a 6.3 mm screen was available, so it was used instead.

3 ANALYSIS AND RESULTS

Both bulk sediment and permeability data were analyzed for each pool-tail site, averaged for each tributary reach, and then compared with respective 1999 results. A statistical analysis was performed by Dr. Peter Baker of Stillwater Sciences in Berkeley, CA in similar fashion to his analysis of the 1999 bulk sediment and permeability data to determine changes between 1999 and 2004.

3.1 Bulk sediment sample analysis

Eight bulk sediment samples were collected on four tributaries for a total of thirty two samples. Following the sample processing by GMA, particle size-distribution curves were generated and summary size parameters were calculated. Summary tables that include cumulative frequencies and size parameters for each bulk sediment sample are presented in Appendix C.

The 2001 Report focused largely on five size parameters determined from the bulk sampling analysis: 9.5 mm, 8.0 mm, 6.5 mm, 2.0 mm, and 0.85 mm. These sizes constitute the finer fraction of the bed material sampled, and are useful metrics for: 1) describing the substrate composition relative to salmonid embryonic survival (i.e., relating to permeability) and, 2) for comparing with previous sampling as indices for substrate coarsening or fining. The 2004 analyses focused on these same size parameters to compare changes and assess the significance of change.

3.1.1 Sample size

All samples collected during 2004 sampling are assumed to be representative, but because D_{max} was visually estimated in the field and not recorded, nor was it recorded as part of the particle size analysis, we cannot precisely determine whether under-sampling occurred; however, we can evaluate sample size representativeness two ways: First, we can evaluate a "worst case scenario" by assuming D_{max} equals the *largest* possible particle size retained during the sieve analysis (that is, if 100% of sample passed a 64 mm sieve, we assumed a D_{max} = 63.9 mm). Using this assumption, 22 of the 32 samples did not meet the Church et al. 1% criteria. Conversely, if we look at the *smallest* possible size retained on the largest sieve (again if 100% of sample passed the 64 mm sieve, the next sieve that material would be caught on is 45 mm, so in this case we assumed D_{max} = 45.1 mm), the number of samples that did not meet the 1% sampling criteria is reduced to 8. The actual number of samples that did not meet the sampling criteria is likely somewhere between 8 and 22 of the 32 samples collected. However, if the sampling criteria are reduced to 5% for all D_{max} sizes, the resulting number of samples that would not meet the sampling criteria is reduced to 2 and 0 (using the largest and smallest possible size retained on the largest sieve, respectively).

It is important to note that although the Church et al. (1987) criteria are most frequently used and referenced for bulk sample collection, there is no single formally-adopted standard for bulk sediment sampling in gravel-bed rivers (Bunte and Abt 2001). Other research has shown that for the same D_{max}, less sample mass is required to constitute a representative sample (e.g., DeVries 1970), whereas others have shown that more is needed (e.g., Neumann-Mahlkau 1967). The reader should be aware that a potential bias toward coarser particles, i.e., under-sampling, may exist for some samples based on the Church et al. (1987) criteria.

3.1.2 2004 sampling results and comparison with 1999 samples

Analysis of the 1999 data focused on the 8.0 mm and 0.85 mm sizes (cumulative percent finer) as indices to characterize the variability of substrate composition within a single tributary. The intent of the 2004 analysis was to use the 1999 results as a basis to detect changes within a tributary over time, and to detect significant differences between tributaries (if they exist). The 1999 results generally showed a large variability of fine sediment percentages for both the 0.85 mm and 8.0 mm fractions within the tributary reaches sampled. The 2001 Report concluded that although certain samples showed similar results, few discernable overall patterns emerged from the data analysis (see the *Analysis of variation in particle size distribution* section in the 2001 Report).

To reduce the sampling variability, the 2001 Report recommended increasing the number of samples collected within each tributary. Sample size was estimated using a "standard" combination of statistical confidence (95%) and power (80%), which generated sample size estimates for a minimum detectable difference range of 1% to 5%. The 2001 Report subjectively selected a 3% minimum detectable difference to recommend that between 15 and 20 samples be collected from each tributary to reduce the sampling variance, but acknowledged that this increased level of sampling also increased monitoring costs.

The 2004 sampling collected 8 bulk samples per tributary, approximately the same as the number of samples analyzed in the 2001 Report. For the 2004 bulk sample statistical analysis, Dr. Baker compared the 2004 results to the 1999 results using parametric (two-tailed t-test) and nonparametric statistical testing (order-based statistics). These statistical tests compare the equality of sample means; that is, the null hypothesis is that the two sets of data were drawn from the same distribution. If test results show significance, the null hypothesis is rejected and sample means are not considered equal (the sample means between 1999 and 2004 for Tributary "X" have changed). Conversely, if significance is not determined, the null hypothesis is accepted and sample means are considered equal (the sample means between 1999 and 2004 for Tributary "X" have not changed). Both tests were performed on the cumulative fractions finer than 0.85 mm and 8.0 mm.

Results from the t-test show a statistically significant difference at Tributary-1 only; the change in the fraction finer than 0.85 mm at Tributary-1 was significant at the 90% level ($p = 0.069$), changes at the other three tributaries were not significant at any reasonable confidence level, and changes in the fraction finer than 8.0 mm were not significant for any tributary at any reasonable confidence level. The conclusion that results from the tests are "not significant at any reasonable confidence level" means that the data are strongly consistent with the null hypothesis. Formally, this has to be stated as a negative, i.e., as a failure to demonstrate that a change in sediment composition has occurred (P. Baker, personal communication), but acknowledging that an undetected change could have occurred. These results are summarized in Table 3. Results from the second test (order-based statistics) are consistent with results from the first test, but suggest that Tributary-4 may also be significant based on interpretation of the graphical results (P. Baker, personal communication).

The results of the t-test shows significance only for Tributary-1, for the fraction finer than 0.85 mm (that is, statistically, a change has occurred between means from the 2004 vs. 1999 samples), and therefore the remaining samples can be treated as if no change in their sample means has occurred. But does the lack of significance reflect a real absence of change? Considering the statistics, and acknowledging potential sample biases (e.g., size-distribution variability of individual samples within each tributary; sample mass collected based on Church et al. (1987) criteria; total number of samples collected on each tributary to reduce variability), it is still worth comparing these data to see if an overall trend of the 0.85 mm and 8.0 mm fractions is present. Table 4 presents 1999 and 2004 cumulative percentages finer than both 0.85 mm and 8.0 mm fractions, and summary statistics for each tributary. These results show that overall, some tributaries showed slight decreases in fine sediment (coarsening) where others showed slight increases in fine sediment (fining). These differences are graphically portrayed in Figures 3a and 3b.

Results from the nonparametric statistical test are summarized in a series of box-and-whisker diagrams (Figure 4). Although not derived from the data presented in Table 4, these diagrams provide an alternative view of the comparison between 1999 and 2004 distributions.

Table 3. Probability value (p) results of two-tailed t-tests for changes in selected size fractions between 1999 and 2004. The results of this test show that only Tributary -1 showed significance for the <0.85 mm fraction (i.e., the sample means have changed).

	p-value	
Site	***Percent < 0.85 mm***	***Percent < 8.0 mm***
Tributary-1	0.069	0.39
Tributary-4	0.24	0.68
Tributary-5	0.46	0.80
Tributary-9	0.37	0.34

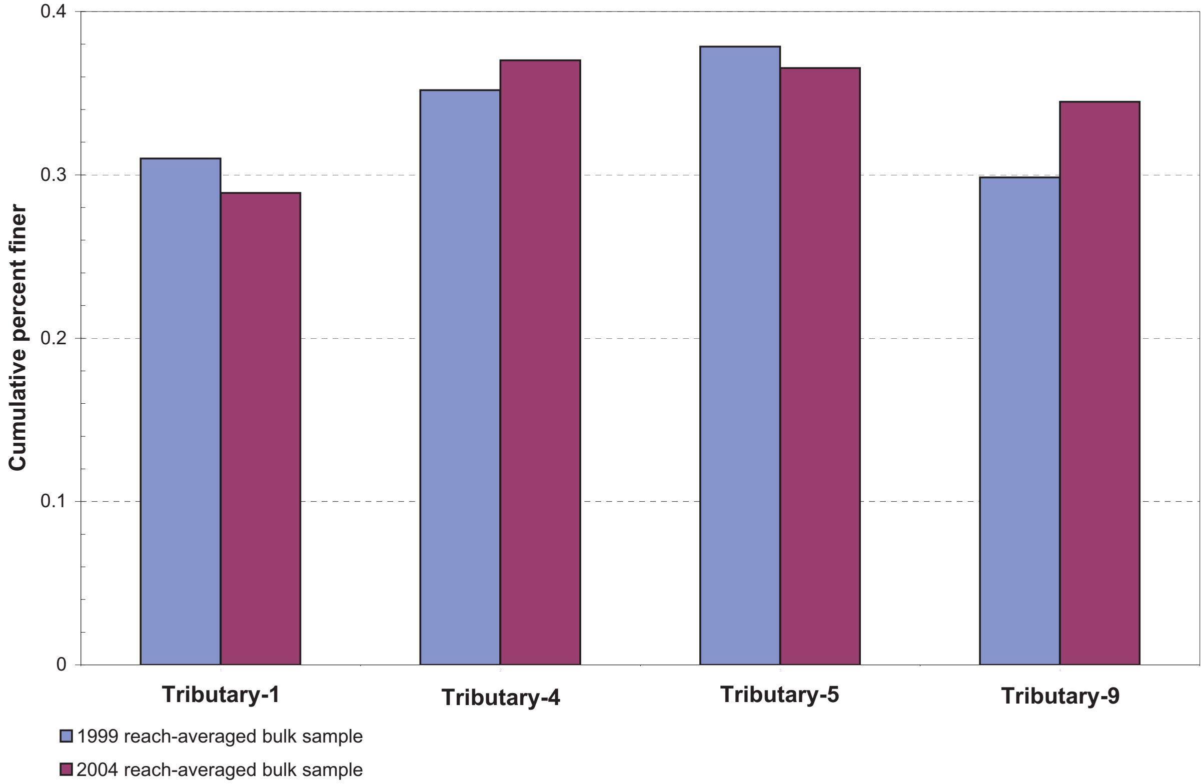


Figure 3a. Comparison of percent finer than 8.0 mm for 1999 and 2004 bulk sediment samples collected on Tributaries -1, -4, -5, and -9.

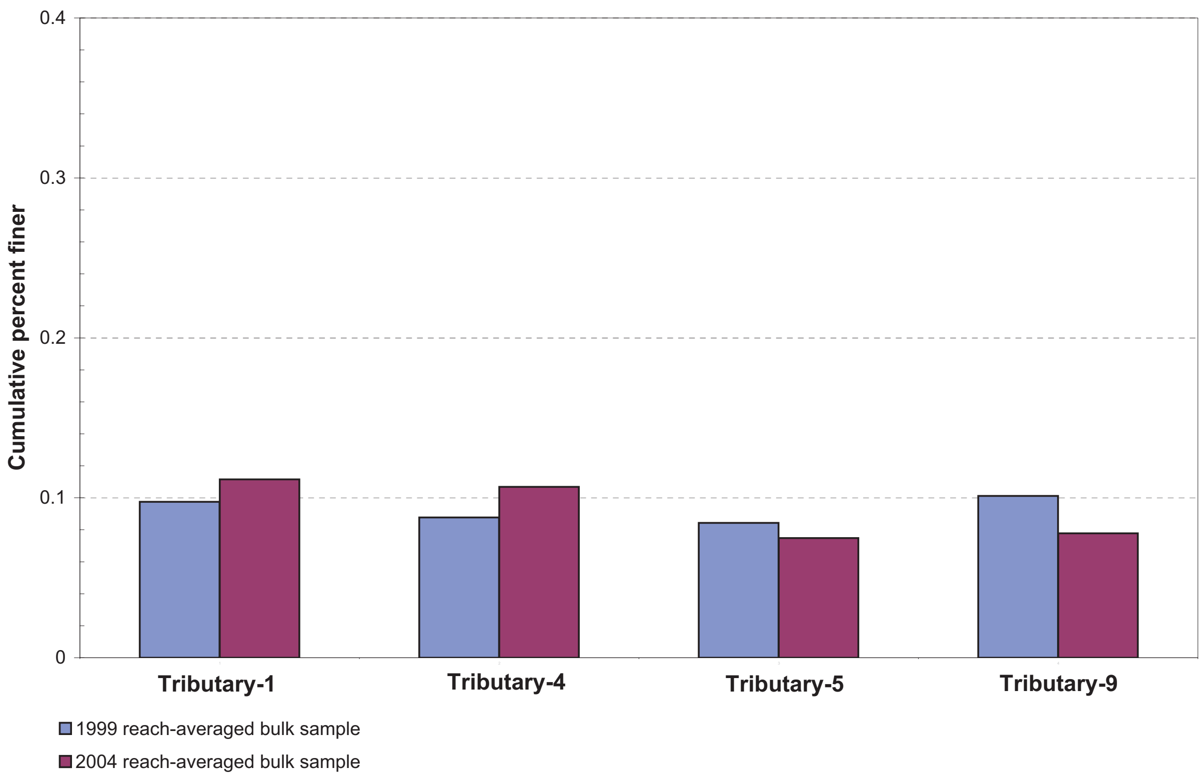


Figure 3b. Comparison of percent finer than 0.85 mm for 1999 and 2004 bulk sediment samples collected on Tributaries -1, -4, -5, and -9.

Table 4. Comparison between 1999 and 2004 bulk sediment sampling results for fractions finer than 0.85 mm and 8.0 mm.

	1999 Bulk Sample				2004 Bulk Sample			
Tributary	0.85 mm mean	0.85 mm standard deviation	8.0 mm mean	8.0 mm standard deviation	0.85 mm mean	0.85 mm standard deviation	8.0 mm mean	8.0 mm standard deviation
Tributary-1	9.7%	0.018	31.0%	0.074	11.2%	0.017	28.9%	0.049
Tributary-4	8.8%	0.021	35.2%	0.085	10.7%	0.051	37.0%	0.137
Tributary-5	8.4%	0.025	37.9%	0.068	7.5%	0.026	36.5%	0.123
Tributary-9	10.1%	0.019	29.8%	0.106	7.8%	0.020	34.5%	0.081

3.2 Permeability analysis

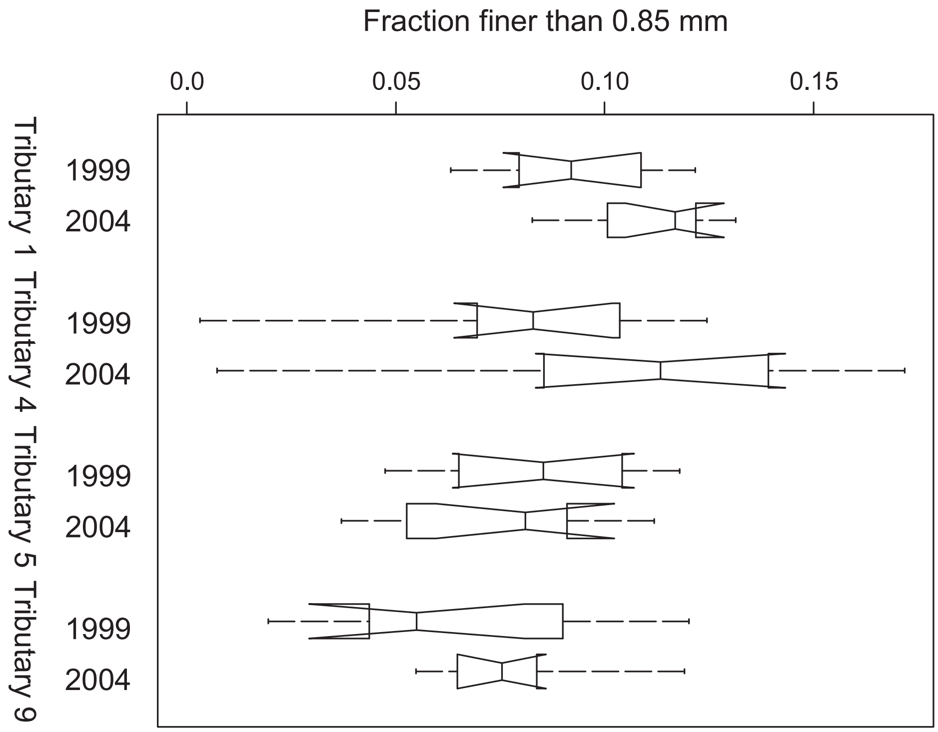
Following data collection, field data were entered into an Excel database and were summarized for comparison with the 1999 permeability results and for comparison to the bulk sediment sample results. Summarized permeability data for each tributary are presented in Appendix D. As in the 2001 Report, data from 2004 are summarized for each tributary by individual sample site and by tributary reach.

3.2.1 Sample size

Similar to the bulk sediment samples, permeability was collected at 8 sites per tributary, but with multiple samples per site and multiple replicates per sample. The 2001 Report provided sample size estimates for permeability sampling (i.e., the number of sample sites per tributary). Using the "standard" statistical confidence (95%) and power (80%), the report concluded that 2 samples per tributary were needed for a "low" level of precision (i.e., to detect a difference in sample means with a factor of 10 difference, such as from 1,000 cm/hr to 10,000 cm/hr), and that 17 samples were needed for a "high" level of precision (i.e., to detect a difference in sample means with a factor of 2 difference, such as from 1,000 cm/hr to 2,000 cm/hr).

3.2.2 2004 sampling results and comparison with 1999 samples

Permeability data for this report were analyzed somewhat differently from the permeability data presented 2001 Report. First, both the 1999 and 2004 data were log-transformed so they would be more normally-distributed (thereby allowing statistical testing which requires normal distributions). Second, rather than comparing the arithmetic means for sample site and tributary reach permeabilities, geometric means were used. Studies on relationships between permeability and salmonid embryonic survival (e.g., Tagart 1976; McCuddin 1977) suggest that survival is linearly related to log permeability, and therefore the appropriate method of aggregating permeability samples, when used as measures of suitability for salmonid incubation, is to take arithmetic means of log-transformed values (which correspond to geometric means of original values) (P. Baker, personal communication). The geometric mean was computed from the median of the replicate measures (not the average). The 2001 Report did not log-transform results and used arithmetic means rather than geometric means.



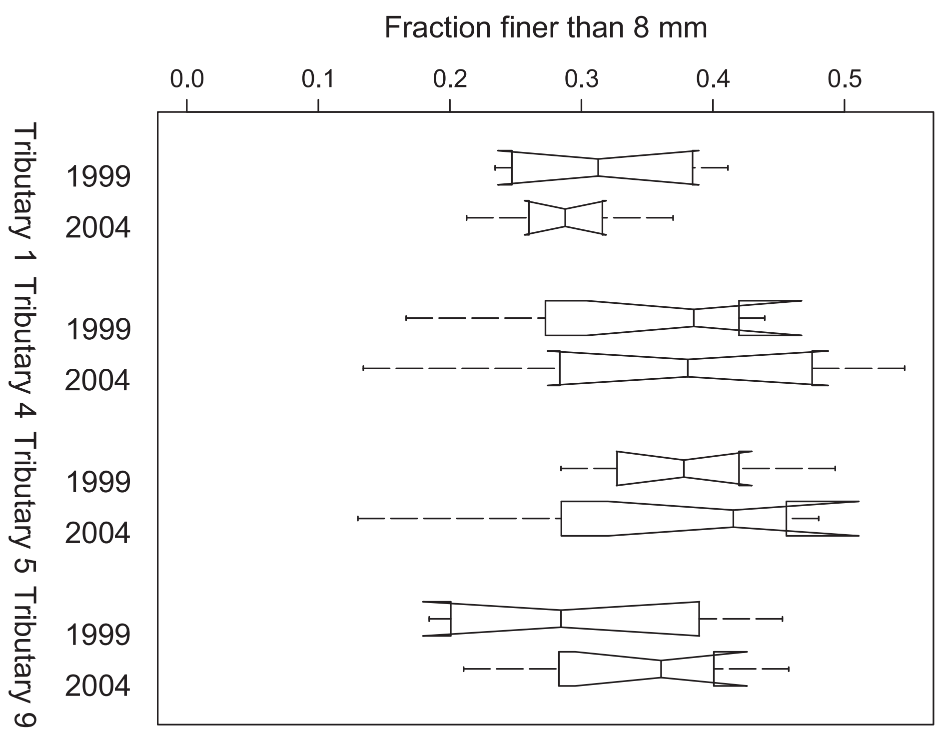


Figure 4. Box-and-whisker diagrams of the bulk sample fractions less than 0.85 mm (left) and 8.0 mm (right), comparing 1999 and 2004 data. Each box extends from the first to third quartile of the data, with whiskers extending from the minimum to the maximum value and a notch showing an approximate 95% confidence interval (derived from quartiles) for the median. These results are consistent with the results from the two-tailed t-test (shown in Table 3).

2004 permeability data are summarized in Table 5, which includes the log-transformed 1999 permeability results used for comparison. The 2004 permeability results are also presented graphically in Figure 5. Figure 5 shows the replicate permeabilities and geometric mean permeabilities for each sample site, which also illustrate the variation in permeabilities between replicate measurements and sample sites. Although the variability of replicate *mean* permeabilities appears quite large (from approximately 0 to 10,000 cm/hr), variability is even larger when considering *individual replicate* permeabilities (up to 43,000 cm/hr in 2004, and up to 96,000 cm/hr in 1999).

Table 5. 2004 and 1999 permeabilities and summary statistics from each tributary sample site.

2004 permeability

	Pool-tail site (geometric mean of replicate measurement median permeabilities) (cm/hr)								Geometric mean of all pool-tail sites
Tributary	1	2	3	4	5	6	7	8	
Tributary-4	18	1,917	5	22	3,676	3,414	4,815	77	252
Tributary-5	3,808	3,078	2,267	4,473	4,670	3,548	2,955	4,826	3,598
Tributary-8	8,250	3,863	2,455	3,016	9,952	3,647	2,111	1,398	3,551
Tributary-9	2,084	2,572	1,675	1,100	3,545	1,278	2,555	3,588	2,117

1999 permeability

	Pool-tail site (geometric mean of replicate measurement median permeabilities) (cm/hr)								Geometric mean of all pool-tail sites
Tributary	1	2	3	4	5	6	7	8	
Tributary-4	3,300	3,656	2,331	6,940	8,601		3,272	218	2,754
Tributary-5	3,771	853	963	2,237	1,403	539	289	908	1,040
Tributary-8	2,487	4,516	628	1,788		2,091		4,583	2,224
Tributary-9	1,411	95	862	1,113	4,196		3,130	4,937	1,354

Note: Tributary-6 sample 6, Tributary 8 samples 5 and 7, and Tributary-9 sample 6 were omitted from the analysis (see 2001 Report).

Similar to the bulk sediment sample analysis, the 2004 permeability data were compared with the 1999 permeability data using the same statistical tests (parametric and nonparametric) statistics. Results from the t-tests show the change at Tributary-4 was significant at the 95% confidence level ($p = 0.059$), and the change at Tributary-5 was significant at the 99% confidence level ($p = 0.0024$); changes at Tributary-8 and -9 were not significant at any reasonable confidence level (Table 6). Results from the nonparametric test yield the same qualitative results and are shown as box-and-whisker diagrams in Figure 6.

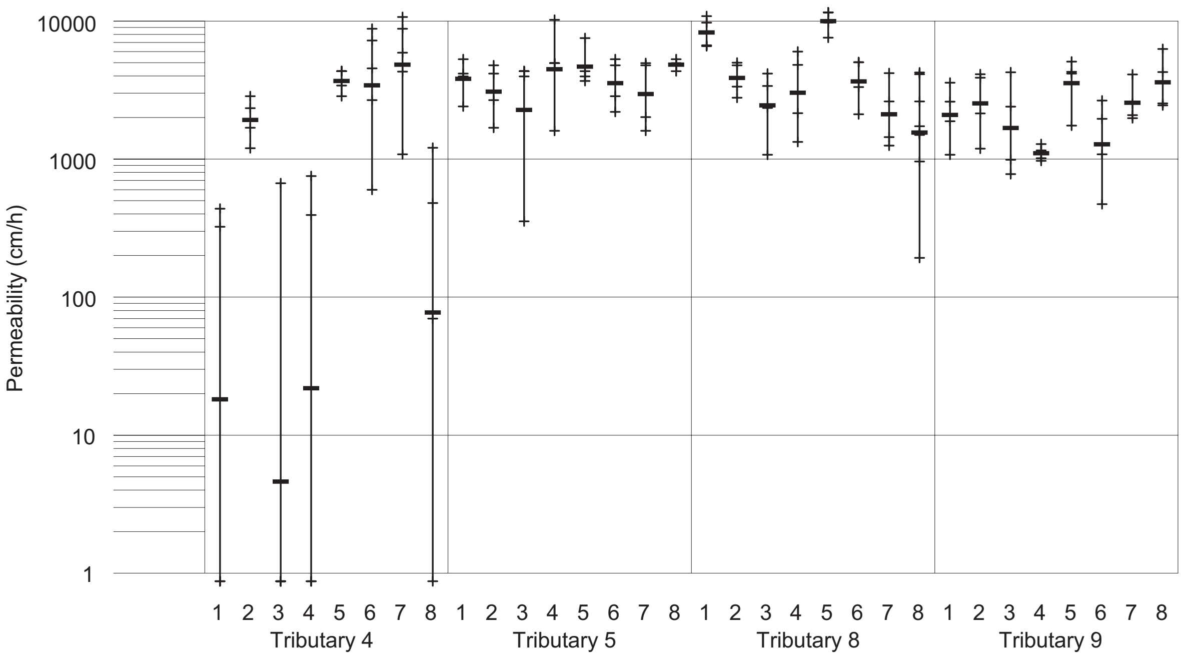


Figure 5. Variability in permeability at the standpipe, site, and tributary scales. Permeabilities at individual standpipes are marked with crosses, (geometric) site means are marked with wider horizontal bars.

Table 6. Probability value (p) results of two-tailed t-tests for changes in log permeability between 1999 and 2004. The results of this test show that Tributary-4 and Tributary-5 are significant at the 95% and 99% confidence levels, respectively (i.e., the sample means have changed).

Site	***1999 mean permeability (geometric) (cm/hr)***	***2004 mean permeability (geometric) (cm/hr)***	***Probability (p) value***	***Significant difference at 95%?***	***Significant difference at 99%?***
Tributary-4	2,754	252	0.059	Yes	No
Tributary-5	1,040	3,598	0.0024	Yes	Yes
Tributary-8	2,224	3,551	0.96	No	No
Tributary-9	1,354	2,117	0.41	No	No

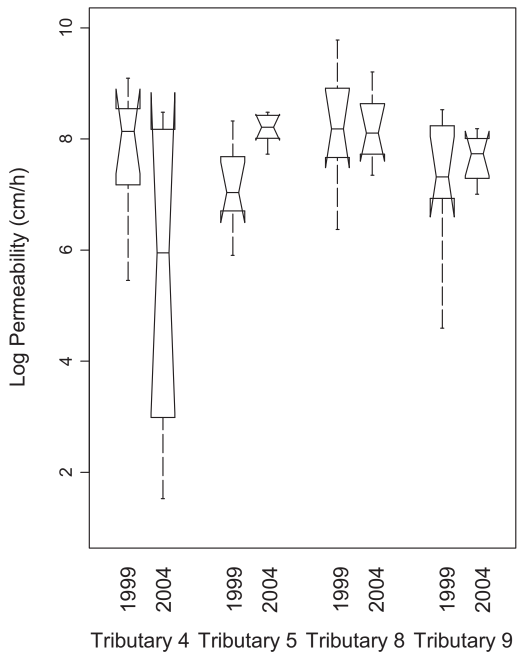


Figure 6. Box-and-whisker diagrams of the permeability estimates for sites in each tributary. Each box extends from the first to third quartile of the data, with whiskers extending from the minimum to the maximum value and a notch showing an approximate 95% confidence interval (derived from quartiles) for the median. These results are consistent with the results from the two-tailed t-test (shown in Table 6).

4 DISCUSSION

The bulk sediment and permeability data collected for this study were compared with their respective 1999 results (Objective 1) and were presented in the previous section. Because a similar sampling effort was used for both studies (i.e., eight sampling sites per tributary, approximately four permeability measurements per sampling site), the precision with which to characterize spawning gravel quality was not improved.

In addition to the data comparison, 2004 sampling study objectives include evaluating these results as indices for salmonid substrate habitat change (Objective 2), and to identify whether the sediment sampling and permeability measurement techniques used for this study provide adequate measures to assess changes in substrate composition, or if different methods are needed (Objective 3). These latter two objectives are evaluated in Sections 4.1 and 4.2. Additionally, larger questions of whether changes observed at the tributary reach scale can be related to changes at the watershed scale are addressed. This is discussed for all tributary reaches in Section 4.3 (Sediment quality relative to Garcia River TMDL standards), and more specifically for a single tributary reach (South Fork Garcia River) in Section 4.4.

4.1 Relationship between particle size and permeability to spawning gravel quality

The 2001 Report investigated the relationship between particle size distribution and permeability. The intent of this investigation was to determine whether specific particle size information could be determined from the results of permeability sampling, which in turn, could be used to relate survival of salmonid eggs to sediment composition. If a strong relationship existed, permeability alone could be used to evaluate the condition of salmonid spawning gravels and predict survival of salmonid eggs incubated in those gravels.

Results presented in the 2001 Report showed a weak correlation between selected particle size fractions (9.5 mm, 2.0 mm, 1.0 mm, and 0.85 mm) and permeability. This result was partly attributed to sample variability and to relative porosity ("degree of packing"), which was not measured. The 2001 Report concluded that until the relationship between permeability and salmonid egg survival is better understood, permeability should only be considered an index of gravel quality, and bulk sediment sampling should continue.

Since the 2001 Report, research by Graham Matthews and Associates has documented a stronger correlation using more intensive bulk sampling and permeability measurement methods (GMA 2003). GMA showed an improved relation between substrate composition and permeability; however, their results are based on simple regressions of the data and were not run through more detailed statistical tests. Although the type of data collected by GMA was the same as that used for this study, their field sampling collected more data at each at each sampling site, including an additional bulk sediment sample (n=2 per site), larger bulk sediment sample volumes, and ten permeability sites. This additional data may be the reason for their improved relationship but this has not been evaluated.

GMA reported that the best sediment composition – permeability relations were for substrate fractions < 1 mm. A similar trend was demonstrated for the 1999 and 2004 Garcia River samples. Similar to the regression analysis presented in the 2001 Report, regressions of the 2004 data show a trend of improved permeability-sediment relation as particle size criterion becomes smaller (Figure 7). The similarity of these results is expected, because data collection methods and number of samples collected are essentially the same as in 1999.

The 2001 Report also used particle size and permeability to predict salmonid egg survival. This was done by estimating salmonid egg survival based on: 1) particle size analysis methods of Tappel and Bjornn (1983), and, 2) a preliminary correlation of permeability and salmonid survival-to-emergence using a relationship developed from studies by Tagart (1976) and by McCuddin (1977). The results showed moderate egg survival using the Tappel and Bjornn analysis (mean survival estimates for chinook salmon ranged from 54% to 82% in all ten tributaries sampled); however, the 95% confidence intervals for these estimates were broad (9% to 93%), and the report noted difficulty in drawing any conclusions of spawning habitat quality based on these predictions. Focusing only on the 4 tributaries sampled in 2004, the 2001 results predicted slightly better egg survival, with mean survival estimates ranging from 66% to 82%, and 95% confidence intervals ranging from 41% to 93%. Using the 2004 data, we performed the same analysis and found similar results (Table 7a); survival predictions ranged from 60% to 76%, but 95% confidence intervals remained quite broad (6% to 89%).

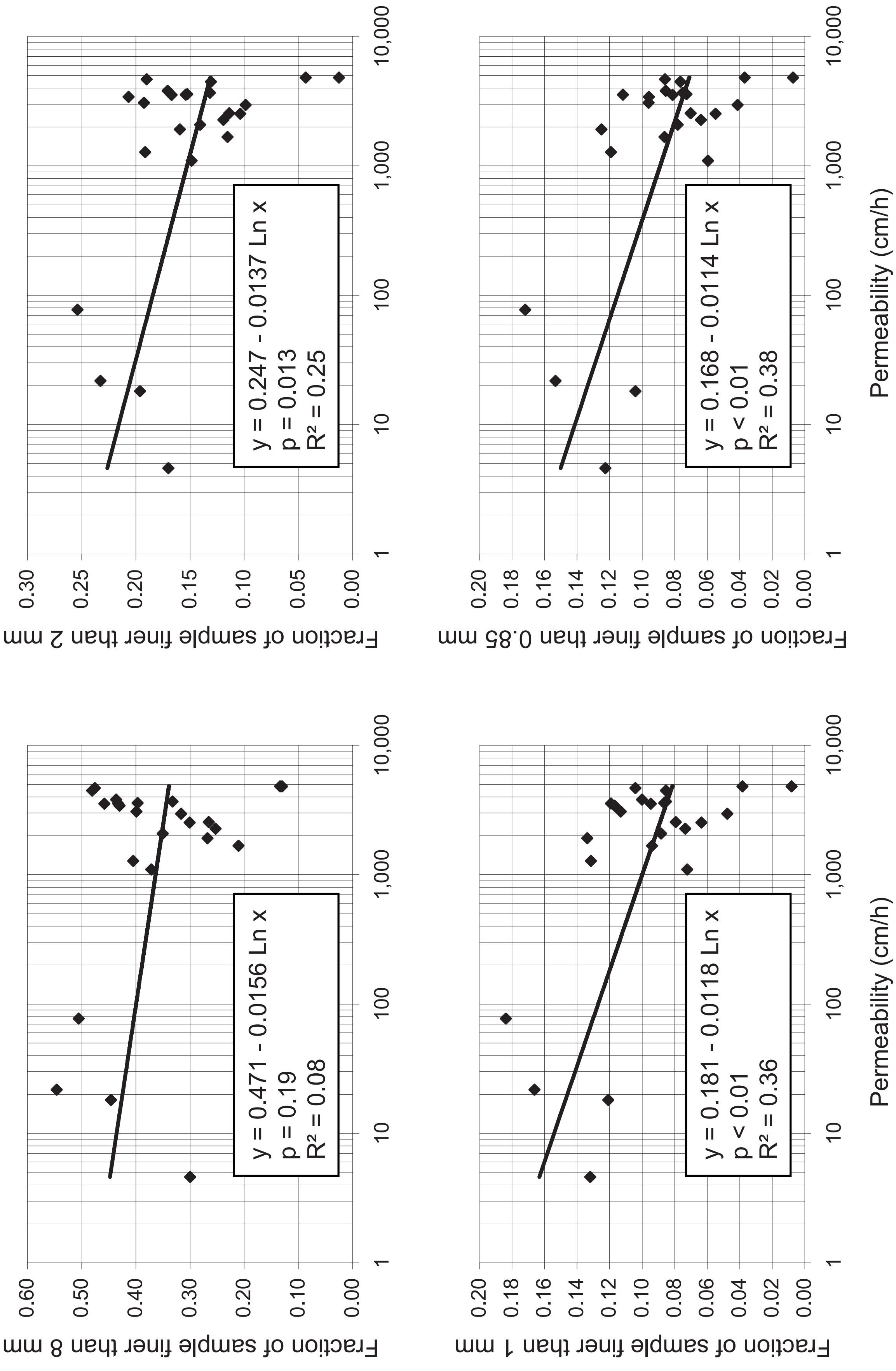


Figure 7. Linear regressions of particle size fractions (cumulative percent finer) vs. permeability. Eight bulk samples and permeability measurements were collected at three tributary reaches, providing an analysis of 24 pairs.

Survival estimates using the permeability relationship based on Tagart and McCuddin also show similar results to those presented in the 2001 Report with the exception of Tributary-4, where zero survival is predicted due to a very low mean permeability (the mean permeability for Tributary-4 falls at the bottom of the Tagart and McCuddin regression). Excluding Tributary-4, the 2004 survival estimates are very similar to the 2001 results and have similar 95% confidence intervals (Table 7b). Because the data used in the Tagart and McCuddin relationship are based on laboratory studies using two different salmonid species, survival estimates for salmonids in Garcia River tributaries should be considered an index only. Moreover, conclusions of egg survival based on these analyses must be tempered with the ability of spawning salmonids to clean fine sediment from spawning gravels during redd construction (Kondolf et al. 1993).

Table 7a. Percent survival of salmonid eggs based on Tappel and Bjornn (1983) particle size analysis methods.

	1999			**2004**		
Tributary	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval
Tributary-1	74	56	87	76	63	85
Tributary-4	70	41	87	60	6	88
Tributary-5	66	44	81	70	40	89
Tributary-9	82	57	93	73	53	86

Table 7b . Percent survival of salmonid eggs based on preliminary permeability relationship from Tagart (1976) and McCuddin (1977).

	1999			**2004**		
Tributary	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval
Tributary-4	43	31	49	0		29
Tributary-5	28	18	33	38	35	41
Tributary-8	40	25	47	38	20	46
Tributary-9	37	27	43	31	24	35

Note: Tributary-4 0% mean survival is caused by low mean permeability (see Table 5); lower 95% confidence interval could not be calculated.

4.2 Evaluation of data collection methods to characterize substrate changes

The third objective of this study was to identify, based on our assessment of the 1999 and 2004 data, whether or not the sampling methods provide adequate measures to evaluate substrate composition and detect changes in composition over time with respect to salmonid spawning gravel quality. Our evaluation focuses on the methods used to collect the data (rather than evaluate alternative metrics to assess spawning gravel quality). Both methods are described below, plus comments on the embeddedness sampling.

Bulk sediment sampling:

Section 3.1 identified two key issues related to the bulk sediment sampling: 1) the number of samples collected in each reach (as discussed in the 2001 Report), and; 2) the volume collected for individual bulk samples. As previously described, representative substrate samples are necessary to adequately characterize the particle size distribution of the streambed. For this study, samples must be representative both individually (is the single bulk sample representative of the substrate at the sample location?) and collectively (when combined, do the averaged results of all samples within the tributary reach adequately characterize the pool-tails within the tributary study reach?).

On an individual basis, some of the bulk samples did not meet the Church et al. criteria; that is, not enough sample was collected to offset the weight of the largest particle sampled. Future sampling efforts should be more rigorous when collecting the bulk sediment samples to ensure representative sample volumes (e.g., Church et al. 1987) are met. Although the number of samples gathered within each tributary reach is the same as was collected in 1999 (n = 8), collectively, the total number of samples analyzed in 1999 was slightly less (due to anomalies and biases in individual samples) (Table 8). Researchers have acknowledged that there are tradeoffs between the number of samples needed to be collected to satisfy statistical criteria versus the cost associated with collecting a sufficiently large number of samples (e.g., Bunte and Abt 2001). The 2001 Report evaluated the statistical significance of the bulk sampling methods, and concluded that in order to *strongly characterize* the sampling variance within the tributary reach (i.e., a 3% minimum detectable difference between the means of two populations), between 15 and 20 bulk samples per tributary should be collected to best balance cost and precision.

Although the number of samples collected in 2004 didn't meet the criteria recommended in 1999, the results can still be used to describe the particle size distributions of the pool-tails sampled. If we assume the same statistical validity with respect to the sample population in each of the tributaries sampled, then the data collection quality between 1999 and 2004 studies was not improved (variability was not reduced). However, if we acknowledge the variability and accept this limitation, the data collected for this study are slightly better than the data collected in 1999 based solely on the sample size analyzed.

Table 8. Comparison of the number of bulk sediment samples analyzed in 1999 versus samples analyzed for this report. Although eight samples were collected at each tributary in 1999, four were excluded from analysis based on anomalies and biases in individual samples.

Tributary	***Number of pool-tail bulk samples analyzed in 1999***	***Number of pool-tail bulk samples analyzed in 2004***
Tributary-4	6	8
Tributary-5	8	8
Tributary-8	7	8
Tributary-9	7	8

<u>Permeability sampling</u>:

Similar to the bulk sediment sampling, the permeability data must be representative of the sample site and tributary reach. For individual samples, the 2001 Report documented within-site variability ranging from 30% to over 100% (the standard deviation was greater than the mean), suggesting that the number of samples collected at a sampling site was too low to characterize variability with a high level of confidence. The report stated that variability could be reduced by increasing both the number of samples collected at each pool-tail site and increasing the total number of sample sites within a tributary reach. However, this suggestion was tempered with the broader conclusion made later in the 2001 Report: the relationship between permeability and salmonid egg survival is less well-known than that from substrate composition data, and until this relationship is better defined, permeability should only be considered an *index* of gravel quality. A brief literature search did not reveal any new studies since 2001 that relate permeability and salmonid egg survival.

<u>Embeddedness sampling</u>:

Embeddedness was not measured in 1999 but was included by MCRCD as part of the 2004 field data collection. The intent of the embeddedness sampling was to relate the embeddedness measurements to permeability or to the particle size distribution results (T. Barber, personal communication).

Although the permeability and bulk sediment sample results show large variability between individual sites, we analyzed embeddedness as a function of mean permeability and percent fine sediment finer than 8.0 mm for the embeddedness measured on Tributaries -1, -4, -5, and -9. No apparent trend exists for any of the data; a regression of the permeability data yields an R^2 value of 0.05, and a regression of the sediment data yields an R^2 value of 0.003 (Figures 8 and 9). This result is somewhat expected: embeddedness is a surface feature, whereas bulk sampling and permeability measure subsurface sediments (see Section 2.1.3). Moreover, embeddedness measurements are subjective, subject to observer bias. More research is needed to determine whether embeddedness can be linked to biological criteria or to detect changes in land management activities (Sylte and Fischenich 2003).

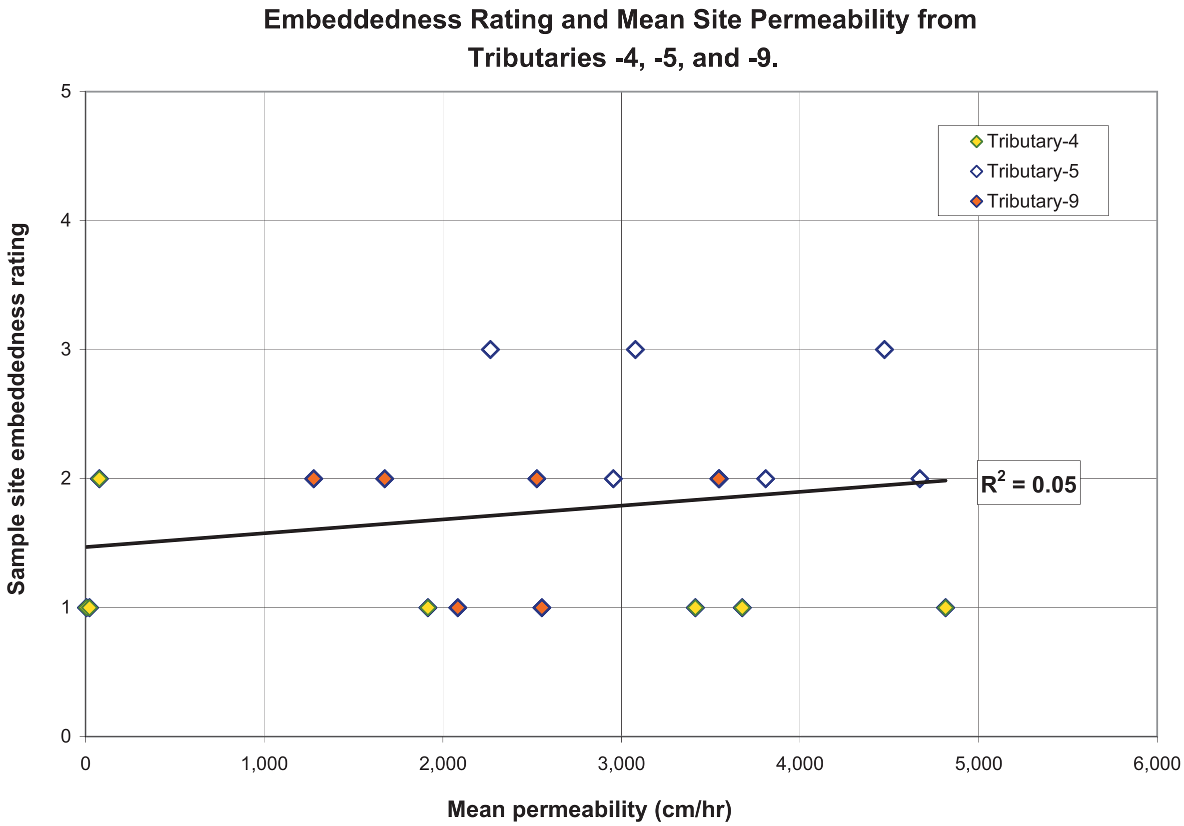


Figure 8. Embeddedness as a function of mean site permeability for Tributary-4 sample sites.

4.3 Sediment quality relative to Garcia River TMDL

TMDL numeric targets for the Garcia River watershed have been established by the USEPA (1998). More specifically, the TMDL targets the percentage of fine sediments finer than 0.85 mm and 6.5 mm, and the numeric targets are <14% and <30%, respectively. These numeric targets represent the optimal conditions for salmonid reproductive success (USEPA 1988); percentages above these targets constitute an impaired condition. Similar to the 1999 results, the 2004 results indicate that the subsurface sediments finer than 0.85 mm are below the TMDL 14% numeric target; however, three of the four tributaries sampled exceed the 30% numeric target for sediments finer than 6.5 mm (Table 9). Recall that a 6.3 mm sieve screen was used instead of a 6.5 mm screen; the results shown in Table 9 were obtained from the particle size distribution curve.

Table 9. Fraction of bulk sediment samples finer than 6.5 mm and 0.85 mm; TMDL numeric targets are <30% and <14%, respectively.

Tributary	***Percent finer than 6.5 mm (TMDL target: < 30%)***	***Percent finer than 0.85 mm (TMDL target: < 14%)***
Tributary-1	26.1%	11.2%
Tributary 4	33.4%	10.7%
Tributary-5	32.3%	7.5%
Tributary-9	30.9%	7.8%

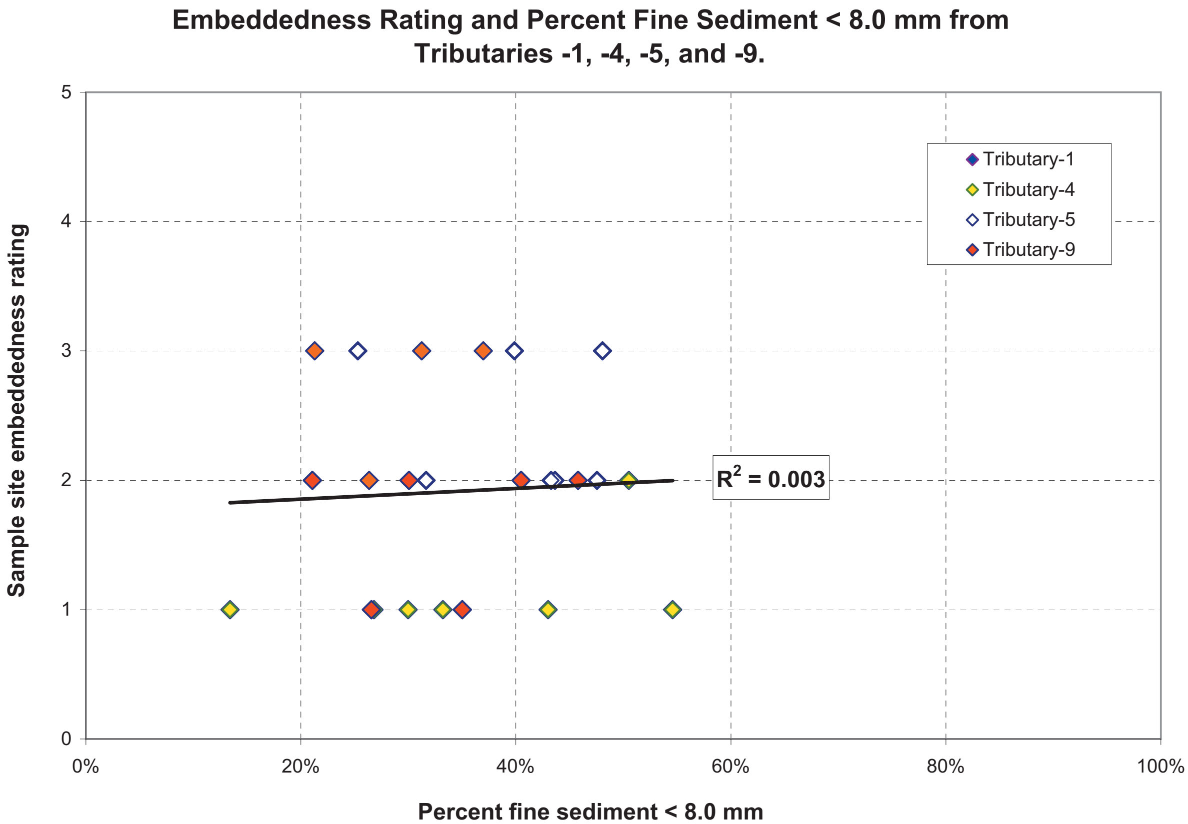


Figure 9. Embeddedness as a function of fine sediment < 8.0 mm for Tributary-4 sample sites.

4.4 Using South Fork Garcia River results as an index for watershed-scale change

Basin-wide erosion control efforts in the South Fork Garcia River watershed prompted the MCRCD to investigate whether any linkages could be established between restorative watershed efforts and improvements in permeability or spawning gravel composition. Has permeability or spawning gravel quality in the South Fork Garcia River (Tributary-9) improved? If so, can these changes be attributed to watershed-scale erosion control efforts?

To address this issue, we reviewed changes in South Fork Garcia River permeability and sediment composition from 1999 to 2004. To summarize:

- Mean permeability increased from 1,354 cm/hr to 2,117 cm/hr, but this change was not significant at any confidence level, i.e., the statistical testing could not demonstrate that a change in the means has occurred.
- The percentage of fine sediment < 8.0 mm increased from 29.8% to 34.5%, and the percentage of fine sediment < 0.85 mm decreased from 10.1% to 7.8%. Similar to the permeability results, these changes were not significant at any confidence level, i.e., the statistical testing could not demonstrate that a change in the means has occurred.

Because a change in the means for the above sampling results could not be demonstrated, using the above results to investigate a relationship between restorative watershed efforts and improvements in permeability or spawning gravel quality was not attempted.

More importantly, however, is understanding the context of the focus of such a comparison, i.e., establishing a cause-and-effect relationship between hillslope processes / land management and fluvial geomorphic processes using bulk sediment and permeability data. Bulk sediment sampling and permeability results can be useful to assess the suitability of the gravels for salmonid spawning habitat within a sampling reach. However, because the data collected for the 1999 and 2004 studies were collected within relatively short channel reaches, extrapolating these results to assess changes in sediment production rate at the watershed scale is not possible unless other factors are considered. For example, changes in sediment particle size distributions can result from a number of causes related to changes in the supply of watershed products. Monitoring efforts must therefore be broadened beyond the current sampling scheme of eight sample sites within single, approximately 1,000 ft reaches to determine how differences in substrate composition in the tributary reaches respond to changes in sediment production at the watershed scale. To do this, a larger-focus investigation would need to be performed, such as a sediment source analysis or a sediment budget. Such an investigation can help identify watershed-scale sedimentation processes (erosion, storage, transportation, deposition) responsible for delivering sediment to, and routing through, the channel. For example, a sediment budget would entail conducting sediment source inventories, calculating transport rates and delivery volumes, examining the interrelationships between transport processes and hillslope form to determine the sediment yield from locations within the basin (these can be tailored to specific monitoring reaches), and repeating the study at a later date to determine changes in the budget. This information, coupled with bulk sediment sampling and/or permeability data, would establish a much stronger linkage between changes in land management and tributary response than using bulk sediment sampling and/or permeability data alone.

In the absence of a sediment budget, sediment yield analysis, or similar watershed-scale monitoring, any changes in South Fork Garcia River substrate based on the 1999 and 2004 data collection (e.g., coarsening or fining) can only be considered as a *possible* result of watershed management efforts, such as upslope sediment reduction from erosion control measures. Presently, other factors such as the magnitude and frequency of storm events, or the number and activity of mass-wasting features in the basin cannot be ruled out as primary causes of change.

5 SUMMARY AND CONCLUSIONS

The 2001 Report established baseline substrate composition and permeability conditions for ten Garcia River tributaries for future comparisons to assess particle size and permeability changes. The 2004 data are the first to be collected and compared since the initial sampling, and were collected within the same tributary reaches following the same methodology (Objective 1). In addition to replicating study site locations and methodologies, this study compared the particle size distributions and permeabilities to results from 1999

(Objective 2), and used these results as indices for salmonid spawning gravel quality. Following the data analysis, we evaluated the measurement techniques to identify their uses and limitations for assessing change in substrate composition (Objective 3).

In assessing the relationship between substrate composition and permeability, the 2001 Report focused on sample size (the number of samples per tributary needed to characterize variability). The 2004 sampling focused on collecting samples to compare with the 1999 data, as well as using the results of the comparison to evaluate the effectiveness of the methods for detecting changes. In doing this, we identified additional sources of variability that can affect the sampling results, including: sampler bias (sampling differences between operators), and geomorphic variability (differences between tributaries, reaches, and/or sample sites). Sampler bias was minimized by McBain and Trush and MCRCD field training; however, geomorphic variability persisted, primarily in the form of sample size (the number of samples per tributary reach and collecting a representative sample volume per sample site). Both are given equal weight in terms of their importance, and future sampling efforts should try and meet the sampling criteria described in this report if the objective is to detect change from year to year. Specifically, future data collection should:

- Follow the bulk sediment sampling criteria suggested by Church et al. (1987): the maximum particle size in the sample (D_{max}) should not constitute more than 1% of the total sample mass for particles up to 128 mm (5.0 in), and not more than 5% of the total sample mass for particles greater than 128 mm.
- Follow the sample size recommendations presented in the 2001 Report: to strongly characterize the sampling variance, collect between 15 and 20 bulk sediment samples per tributary to best balance cost and precision. Alternatively, re-evaluate the minimum detectable difference to reduce the number of required samples.

The 2004 data provided a useful comparison of sample means to gauge changes in substrate composition and permeability. Most changes in sample means were not statistically significant. Independent of statistical significance, these results suggest no significant net change has occurred; overall, some of the tributary reaches showed a decrease in fine sediment, whereas others showed a slight increase in fine sediment.

Presently, research to determine a strong relationship between permeability and sediment quality (and to relate the sediment quality to salmonid spawning success) is still developmental. If future sampling is desired to investigate salmonid spawning gravel quality in the Garcia River watershed, the same data collection methods presented herein can be used; however, current literature should be reviewed before developing a study plan, to review advances in the permeability-substrate-spawning habitat relation and to determine how field data collection should be changed. This will aid in determining if permeability sampling is needed in combination with bulk sediment sampling, or if bulk sediment sampling alone will be sufficient to assess changes in spawning gravel quality. Moreover, if future monitoring objectives include a larger-scale understanding of watershed cause-and-effect relationships, monitoring should extend beyond the tributary-reach scale so that the processes responsible for generating changes in spawning gravel quality (e.g., sediment supply, magnitude and frequency of flood events) are identified.

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APPENDICES

APPENDIX A:

McBain and Trush 2001 Report: *Spawning Gravel Composition and Permeability within the Garcia River Watershed, CA; Final report with Addendum.*

AND

APPENDIX B:

Graham Matthews and Associates Garcia River Bulk Sampling laboratory analysis summary and coarse sediment laboratory quality-assurance manual.

ARE INCLUDED ON CD LOCATED IN A POCKET ATTACHED AT THE BACK OF THIS REPORT

APPENDIX C

Particle size analysis summary tables, by tributary, showing cumulative frequencies and size parameters for each sample.

Appendix C. 2004 Particle Size Analysis Summary for Tributary-1

Sample:	1	2	3	4	5	6	7	8
Total sample mass (kg):	31.94	34.59	32.11	29.91	42.08	32.11	33.87	11.15

Sieve (mm)	Finer than (mm)	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer
256	512	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
180	256	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
128	180	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
90	128	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
64	90	100.0%	100.0%	92.6%	100.0%	92.1%	95.4%	97.0%	100.0%
45	64	89.5%	89.8%	86.0%	88.3%	78.0%	84.6%	81.8%	94.3%
32	45	72.8%	79.2%	78.1%	79.3%	68.2%	77.3%	72.1%	87.6%
22.4	32	57.6%	64.0%	66.0%	70.0%	55.1%	67.0%	58.0%	68.9%
16	22.4	46.5%	53.3%	53.4%	58.1%	45.4%	59.1%	47.5%	53.1%
11.2	16	38.4%	45.0%	44.7%	48.4%	37.8%	51.4%	38.6%	41.4%
8	11.2	31.9%	37.9%	37.6%	39.3%	31.5%	43.9%	31.9%	29.4%
6.3	8	26.0%	31.2%	31.5%	31.8%	26.3%	37.0%	26.1%	21.3%
5.6	6.3	23.4%	28.5%	28.8%	27.4%	24.5%	33.4%	23.0%	17.1%
4	5.6	22.0%	27.0%	26.9%	25.9%	23.4%	31.4%	21.4%	15.6%
2.8	4	18.8%	23.1%	22.0%	21.4%	20.4%	26.1%	18.0%	12.2%
2	2.8	16.6%	20.0%	17.7%	17.7%	18.2%	20.6%	15.5%	10.7%
1	2	15.3%	18.0%	14.4%	15.2%	16.5%	16.6%	13.8%	9.9%
0.85	1	13.0%	14.5%	9.5%	12.4%	13.4%	12.6%	11.8%	9.2%
0.5	0.85	12.0%	13.1%	8.3%	11.6%	12.4%	11.8%	11.2%	8.9%
0.25	0.5	8.4%	8.5%	5.3%	8.5%	8.9%	8.5%	8.2%	7.8%
0.125	0.25	3.6%	3.2%	2.1%	3.0%	3.7%	3.0%	2.9%	3.9%
Pan	0.125	1.4%	1.1%	0.9%	0.9%	1.4%	0.9%	1.0%	1.4%

Size Parameter	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
D5	0.3	0.3	0.5	0.3	0.30	0.32	0.3	0.30
D16	2.4	1.4	2.4	2.2	1.80	1.80	3.0	5.77
D25	7.3	4.7	4.9	5.3	6.71	3.73	7.3	9.33
D35	13.3	9.7	9.7	9.3	13.65	7.00	13.2	13.22
D50	25.1	19.6	19.6	16.9	26.55	14.96	24.4	20.50
D65	37.7	32.7	31.1	27.6	41.40	29.23	37.9	29.30
D75	47.1	41.0	41.3	38.4	57.41	41.74	50.0	35.75
D84	56.9	52.8	58.6	54.1	73.95	62.14	67.3	42.11
D90	65.0	64.4	78.6	67.2	85.51	75.92	76.9	51.01
Tappel & Bjornn predicted percent survival (Chinook)	80.5	66.6	76.6	67.8	80.1	57.6	81.2	89.2

Appendix C. 2004 Particle Size Analysis Summary for Tributary-4

	Sample:	1	2	3	4	5	6	7	8
	Total sample mass (kg):	33.07	35.10	30.47	29.30	32.12	28.21	33.10	25.69
Sieve (mm)	Finer than (mm)	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer
256	512	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
180	256	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
128	180	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
90	128	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
64	90	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
45	64	95.2%	92.0%	90.7%	98.3%	100.0%	98.9%	100.0%	100.0%
32	45	88.4%	84.7%	81.5%	93.8%	92.4%	96.7%	95.6%	95.3%
22.4	32	80.9%	68.8%	73.4%	84.1%	81.7%	89.1%	78.8%	86.4%
16	22.4	69.6%	55.7%	56.3%	76.6%	68.4%	80.0%	59.7%	76.6%
11.2	16	60.9%	43.4%	43.5%	69.8%	55.8%	67.4%	40.4%	68.6%
8.0	11.2	52.1%	34.0%	35.4%	63.0%	43.4%	54.1%	24.2%	59.4%
6.3	8	44.6%	26.8%	30.0%	54.6%	33.2%	43.0%	13.4%	50.5%
5.6	6.30	39.6%	24.6%	28.5%	48.2%	28.4%	38.5%	8.9%	46.3%
4.0	5.6	36.7%	23.4%	27.4%	44.5%	26.0%	36.0%	7.0%	43.9%
2.8	4.00	29.7%	20.1%	23.5%	36.3%	20.7%	30.4%	3.6%	37.1%
2.0	2.8	24.3%	17.7%	19.9%	29.0%	16.5%	25.3%	1.9%	30.9%
1.0	2.00	19.6%	15.9%	17.0%	23.2%	13.2%	20.7%	1.3%	25.4%
0.85	1.00	12.1%	13.4%	13.2%	16.6%	8.5%	11.7%	0.8%	18.4%
0.5	0.85	10.4%	12.5%	12.3%	15.3%	7.5%	9.6%	0.7%	17.2%
0.25	0.5	6.8%	9.0%	9.1%	11.8%	4.7%	5.5%	0.5%	13.6%
0.125	0.25	2.7%	3.2%	3.8%	4.8%	1.6%	1.8%	0.3%	6.0%
Pan	0.125	0.9%	0.9%	1.1%	1.5%	0.6%	0.6%	0.2%	2.1%

Size Parameter	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
D5	0.4	0.3	0.3	0.3	0.5	0.5	4.6	0.2
D16	1.4	2.0	1.7	0.9	2.7	1.4	8.7	0.7
D25	2.9	6.6	4.5	2.2	5.3	2.7	11.4	1.9
D35	5.2	11.6	10.9	3.7	8.5	5.3	14.2	3.5
D50	10.2	19.2	19.0	6.7	13.5	9.9	18.9	7.8
D65	18.8	28.9	26.9	12.5	20.5	15.0	24.7	13.9
D75	26.6	36.6	34.3	20.7	26.8	19.6	29.8	20.9
D84	36.9	44.3	49.6	31.9	34.5	26.2	35.5	29.4
D90	48.9	58.0	62.4	39.3	41.7	33.3	40.2	36.8
Tappel & Bjornn predicted percent survival (Chinook)	47.6	76.8	72.3	-1.3	73.3	50.9	93.9	-1.5

Appendix C. 2004 Particle Size Analysis Summary for Tributary-5

	Sample:	1	2	3	4	5	6	7	8
	Total sample mass (kg):	37.19	36.21	36.81	34.11	41.09	29.56	31.40	44.57

Sieve (mm)	Finer than (mm)	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer
256	512	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
180	256	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
128	180	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
90	128	100.0%	100.0%	77.1%	100.0%	100.0%	100.0%	100.0%	100.0%
64	90	100.0%	93.2%	71.1%	94.5%	93.5%	100.0%	100.0%	95.8%
45	64	97.5%	86.1%	71.1%	89.4%	89.2%	100.0%	94.8%	85.3%
32	45	93.5%	78.5%	64.5%	83.3%	86.2%	98.9%	85.3%	75.3%
22.4	32	82.1%	71.8%	52.1%	76.7%	81.1%	92.1%	77.2%	55.1%
16	22.4	74.2%	61.8%	45.2%	70.8%	74.6%	83.7%	65.7%	37.8%
11.2	16	64.7%	53.6%	37.9%	64.5%	66.0%	71.1%	52.1%	26.9%
8	11.2	53.6%	46.2%	30.9%	57.2%	56.9%	56.9%	40.8%	18.6%
6.3	8	43.6%	39.9%	25.3%	48.1%	47.5%	43.3%	31.6%	13.0%
5.6	6.3	37.8%	36.6%	22.2%	42.3%	41.7%	35.4%	27.8%	10.1%
4	5.6	34.8%	34.8%	21.0%	38.4%	38.1%	31.7%	25.7%	8.6%
2.8	4	28.3%	29.4%	17.7%	28.7%	31.4%	24.0%	20.0%	6.2%
2	2.8	22.2%	24.3%	14.6%	18.9%	24.7%	18.6%	14.3%	4.8%
1	2	17.1%	19.2%	11.9%	13.1%	19.0%	15.4%	9.9%	4.3%
0.85	1	10.0%	11.3%	7.4%	8.5%	10.4%	11.9%	4.8%	3.8%
0.5	0.85	8.5%	9.6%	6.4%	7.7%	8.6%	11.2%	4.1%	3.7%
0.25	0.5	5.4%	5.7%	4.1%	5.3%	4.5%	8.7%	3.1%	3.2%
0.125	0.25	2.4%	2.0%	1.4%	1.9%	1.1%	3.3%	1.6%	1.5%
Pan	0.125	1.2%	0.6%	0.4%	0.5%	0.3%	0.9%	0.6%	0.5%

Size Parameter	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
D5	0.5	0.4	0.6	0.5	0.53	0.31	1.0	2.92
D16	1.8	1.5	3.3	2.4	1.57	2.13	3.1	9.58
D25	3.3	2.9	7.8	3.5	2.85	4.18	5.4	14.73
D35	5.6	5.7	13.8	5.0	4.79	6.21	9.1	20.53
D50	9.9	13.4	28.8	8.6	8.74	9.44	15.0	28.79
D65	16.2	25.1	46.2	16.4	15.41	13.72	22.0	37.79
D75	23.2	37.7	113.2	28.9	22.88	17.76	29.9	44.74
D84	33.9	58.0	141.9	46.8	38.87	22.67	42.6	61.15
D90	40.5	77.2	155.1	66.6	68.28	29.22	53.5	74.54
Tappel & Bjornn predicted percent survival (Chinook)	55.4	59.9	87.4	54.1	49.9	40.8	83.8	97.7

Appendix C. 2004 Particle Size Analysis Summary for Tributary-9

	Sample:	1	2	3	4	5	6	7	8
	Total sample mass (kg):	26.41	46.97	44.94	25.87	27.04	26.16	48.13	45.13
Sieve (mm)	Finer than (mm)	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer	Cumulative % finer
256	512	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
180	256	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
128	180	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
90	128	100.0%	92.3%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
64	90	93.2%	92.3%	100.0%	100.0%	100.0%	100.0%	94.2%	100.0%
45	64	91.6%	83.7%	94.0%	98.5%	100.0%	100.0%	84.4%	93.7%
32	45	85.8%	75.2%	80.7%	89.9%	94.7%	99.2%	76.5%	84.6%
22.4	32	74.8%	64.8%	64.4%	76.7%	80.4%	91.5%	61.8%	76.8%
16	22.4	62.6%	56.0%	47.5%	64.6%	70.0%	80.2%	50.8%	67.4%
11.2	16	52.3%	48.1%	35.6%	53.5%	62.2%	65.1%	41.4%	57.8%
8	11.2	42.9%	38.5%	27.3%	44.6%	54.6%	51.7%	33.7%	48.5%
6.3	8	35.0%	30.1%	21.1%	37.1%	45.8%	40.5%	26.6%	39.7%
5.6	6.3	30.7%	26.3%	18.4%	33.6%	40.6%	35.8%	23.1%	35.3%
4	5.6	28.4%	24.0%	17.1%	31.6%	37.5%	33.8%	21.3%	32.6%
2.8	4	23.0%	18.4%	14.4%	26.5%	30.0%	28.5%	17.2%	26.2%
2	2.8	17.9%	13.7%	12.7%	20.4%	22.5%	23.3%	13.8%	20.2%
1	2	14.1%	10.4%	11.5%	14.8%	16.7%	19.1%	11.4%	15.3%
0.85	1	8.8%	6.4%	9.4%	7.2%	9.5%	13.1%	7.9%	8.6%
0.5	0.85	7.8%	5.5%	8.6%	5.9%	8.1%	11.9%	7.0%	7.3%
0.25	0.5	5.2%	3.3%	5.9%	3.4%	5.2%	8.8%	4.6%	4.2%
0.125	0.25	1.6%	1.1%	2.2%	1.1%	1.9%	3.5%	1.8%	1.4%
Pan	0.125	0.5%	0.4%	0.7%	0.4%	0.7%	1.0%	0.5%	0.5%

Size Parameter	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
D5	0.5	0.8	0.4	0.7	0.48	0.31	0.5	0.57
D16	2.4	3.3	4.9	2.1	1.87	1.39	3.5	2.10
D25	4.5	5.9	9.9	3.7	3.15	3.15	7.2	3.72
D35	8.0	9.7	15.6	6.9	5.00	6.01	11.9	6.23
D50	14.7	17.3	23.6	13.9	9.40	10.63	21.8	11.85
D65	24.0	32.2	32.4	22.7	18.02	15.94	34.5	20.60
D75	32.2	44.7	39.9	30.4	26.56	19.95	43.4	29.89
D84	42.6	64.8	49.1	38.6	34.85	25.26	62.8	43.77
D90	58.0	82.2	57.6	45.2	40.24	30.49	77.7	55.47
Tappel & Bjornn predicted percent survival (Chinook)	71.6	82.5	91.1	74.9	55.1	45.6	84.4	66.7

APPENDIX D

Summarized permeability data by tributary.

APPENDIX D. Summarized Permeability Data for Tributary-4

	POOL-TAIL SITE:	1	2	3	4	5	6	7	8
ENTIRE POOL-TAIL	GEOMTERIC MEAN PERMEABILITY	18	1,917	5	22	3,676	3,414	4,815	77
	STANDARD DEVIATION	192	862	6,780	304	706	3,028	3,641	513
	STANDARD ERROR	45	193	1,516	68	158	606	728	115
	REPLICATE COUNT (n)	18	20	20	20	20	25	25	20
	95% CI (+/-)	95	404	3,173	142	330	1,250	1,503	240
SAMPLE 1:	FIRST PREMEABILITY	1	1,348	669	1	3,168	4,550	5,898	1
	ARITHMETIC MEAN PERMEABILITY	1	1,188	6,619	1	3,479	4,494	7,140	1
	MEDIAN PERMEABILITY	1	1,199	669	1	3,413	4,550	5,898	1
	STANDARD DEVIATION	0	168	13,322	0	347	268	2,381	0
	STANDARD ERROR	0	75	5,958	0	155	120	1,065	0
	REPLICATE COUNT (n)	3	5	5	5	5	5	5	5
	95% CI (+/-)	0	208	16,539	0	430	333	2,956	0
SAMPLE 2:	FIRST PREMEABILITY	407	3,973	1	761	2,581	3,133	3,763	1,365
	ARITHMETIC MEAN PERMEABILITY	422	3,031	1	705	3,050	2,793	4,249	1,222
	MEDIAN PERMEABILITY	438	2,853	669	753	2,853	2,678	4,296	1
	STANDARD DEVIATION	37	661	0	74	562	228	334	140
	STANDARD ERROR	17	296	0	33	251	102	149	63
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	46	821	0	92	697	283	415	174
SAMPLE 3:	FIRST PREMEABILITY	333	1,733	1	1	4,331	599	8,103	96
	ARITHMETIC MEAN PERMEABILITY	327	1,698	1	1	4,349	601	8,432	48
	MEDIAN PERMEABILITY	324	1,689	1	1	4,331	599	8,803	70
	STANDARD DEVIATION	5	107	0	0	369	45	1,563	44
	STANDARD ERROR	2	48	0	0	165	20	699	20
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	6	133	0	0	458	56	1,940	55
SAMPLE 4:	FIRST PREMEABILITY	70	3,413	149	394	4,778	6,423	11,944	451
	ARITHMETIC MEAN PERMEABILITY	15	2,637	44	378	4,403	7,425	10,612	521
	MEDIAN PERMEABILITY	1	2,336	1	394	4,331	7,219	10,693	481
	STANDARD DEVIATION	31	614	66	22	365	1,862	1,388	148
	STANDARD ERROR	14	275	29	10	163	833	621	66
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	38	762	81	27	453	2,312	1,723	183
SAMPLE 5:	FIRST PREMEABILITY						8,803	1,269	
	ARITHMETIC MEAN PERMEABILITY						8,080	1,061	
	MEDIAN PERMEABILITY						7,219	1,085	
	STANDARD DEVIATION						8,803	170	
	STANDARD ERROR						675	76	
	REPLICATE COUNT (n)						5	5	
	95% CI (+/-)						1,873	211	

APPENDIX D. Summarized Permeability Data for Tributary-5

	SAMPLE SITE:	1	2	3	4	5	6	7	8
ENTIRE POOL-TAIL	GEOMTERIC MEAN PERMEABILITY	3,808	3,078	2,267	4,473	4,670	3,548	2,955	4,826
	STANDARD DEVIATION	1,210	1,215	1,821	2,873	1,391	1,446	1,563	540
	STANDARD ERROR	270	272	407	642	311	323	350	121
	REPLICATE COUNT (n)	20	20	20	20	20	20	20	20
	95% CI (+/-)	566	568	852	1,345	651	677	732	253
SAMPLE 1:	FIRST PREMEABILITY	2,406	1,689	5,294	4,953	7,525	2,196	4,778	6,291
	ARITHMETIC MEAN PERMEABILITY	2,380	1,698	4,506	4,862	6,832	2,181	4,951	5,521
	MEDIAN PERMEABILITY	2,406	1,689	4,331	4,953	7,525	2,196	4,953	5,294
	STANDARD DEVIATION	88	37	532	351	1,012	55	211	727
	STANDARD ERROR	40	16	238	157	453	25	94	325
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	110	45	660	435	1,257	69	262	903
SAMPLE 2:	FIRST PREMEABILITY	4,331	2,678	4,331	1,855	4,778	3,168	4,156	4,331
	ARITHMETIC MEAN PERMEABILITY	4,155	2,676	4,510	1,671	4,314	2,909	4,667	4,758
	MEDIAN PERMEABILITY	4,156	2,678	4,331	1,601	4,331	2,853	4,778	5,294
	STANDARD DEVIATION	127	127	244	121	299	247	502	254
	STANDARD ERROR	57	57	109	54	134	110	225	114
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	157	157	303	150	371	307	623	316
SAMPLE 3:	FIRST PREMEABILITY	6,291	4,778	4,156	10,194	4,331	4,778	2,013	4,331
	ARITHMETIC MEAN PERMEABILITY	5,556	4,723	3,910	9,382	3,910	4,848	2,062	4,545
	MEDIAN PERMEABILITY	5,294	4,778	3,973	10,194	3,973	4,778	2,013	4,331
	STANDARD DEVIATION	5,556	232	369	1,200	369	96	97	299
	STANDARD ERROR	306	104	165	537	165	43	43	134
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	851	288	458	1,490	458	119	120	371
SAMPLE 4:	FIRST PREMEABILITY	3,973	3,413	184	4,953	3,675	6,291	1,855	5,294
	ARITHMETIC MEAN PERMEABILITY	3,969	3,880	313	5,054	3,726	5,521	1,601	4,951
	MEDIAN PERMEABILITY	3,973	4,156	354	4,953	3,675	5,294	1,601	4,953
	STANDARD DEVIATION	345	550	83	230	334	727	182	211
	STANDARD ERROR	154	246	37	103	149	325	81	94
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	428	683	103	286	414	903	226	262

APPENDIX D. Summarized Permeability Data for Tributary-8

	SAMPLE SITE:	1	2	3	4	5	6	7	8
ENTIRE POOL-TAIL	GEOMTERIC MEAN PERMEABILITY	8,250	3,863	2,455	3,016	9,952	3,647	2,111	1,398
	STANDARD DEVIATION	2,137	1,378	20,939	2,214	5,985	1,472	1,169	351
	STANDARD ERROR	456	281	4,274	472	1,276	301	244	78
	REPLICATE COUNT (n)	22	24	24	22	22	24	23	20
	95% CI (+/-)	947	582	8,843	982	2,654	622	506	164
SAMPLE 1:	FIRST PREMEABILITY	6,291	3,675	1,076	2,196	10,194	5,023	1,348	1,733
	ARITHMETIC MEAN PERMEABILITY	6,695	2,848	1,111	2,170	15,393	5,355	1,279	1,741
	MEDIAN PERMEABILITY	6,580	2,783	1,076	2,153	11,550	5,023	1,251	1,733
	STANDARD DEVIATION	1,722	459	71	24	9,736	1,121	64	100
	STANDARD ERROR	703	187	32	11	3,975	458	28	45
	REPLICATE COUNT (n)	6	6	5	5	6	6	5	5
	95% CI (+/-)	1,807	482	88	30	10,219	1,176	79	124
SAMPLE 2:	FIRST PREMEABILITY	8,803	4,270	3,019	1,330	9,730	5,023	1,750	989
	ARITHMETIC MEAN PERMEABILITY	10,165	5,301	32,086	1,335	9,461	4,881	2,574	952
	MEDIAN PERMEABILITY	10,850	4,782	1,076	1,330	9,730	5,023	2,616	1,733
	STANDARD DEVIATION	1,370	1,742	40,535	12	369	459	552	49
	STANDARD ERROR	559	711	18,128	5	165	187	247	22
	REPLICATE COUNT (n)	6	6	5	5	5	6	5	5
	95% CI (+/-)	1,438	1,828	50,323	15	458	482	685	61
SAMPLE 3:	FIRST PREMEABILITY	9,310	4,953	3,465	5,294	16,363	2,065	2,380	1,566
	ARITHMETIC MEAN PERMEABILITY	9,604	4,982	3,357	6,647	8,406	2,135	3,888	1,608
	MEDIAN PERMEABILITY	9,730	4,996	3,386	6,003	7,569	2,109	4,200	1,496
	STANDARD DEVIATION	438	304	377	1,278	4,633	66	844	338
	STANDARD ERROR	196	124	154	572	1,891	30	344	151
	REPLICATE COUNT (n)	5	6	6	5	6	5	6	5
	95% CI (+/-)	543	319	396	1,587	4,863	82	886	420
SAMPLE 4:	FIRST PREMEABILITY	4,498	3,168	2,293	4,568	11,533	3,325	1,601	1,531
	ARITHMETIC MEAN PERMEABILITY	6,284	3,313	2,407	4,976	11,109	3,776	1,544	1,531
	MEDIAN PERMEABILITY	6,668	3,351	2,349	4,813	11,533	3,325	1,444	1,531
	STANDARD DEVIATION	1,218	339	258	675	843	1,248	311	55
	STANDARD ERROR	545	138	91	255	377	472	118	25
	REPLICATE COUNT (n)	5	6	8	7	5	7	7	5
	95% CI (+/-)	1,512	356	216	625	1,047	1,154	288	69

APPENDIX D. Summarized Permeability Data for Tributary-9

	SAMPLE SITE:	1	2	3	4	5	6	7	8
ENTIRE POOL-TAIL	GEOMTERIC MEAN PERMEABILITY	2,084	2,527	1,675	1,100	3,545	1,278	2,555	3,588
	STANDARD DEVIATION	939	1,532	1,472	191	11,343	814	956	1,637
	STANDARD ERROR	200	334	321	43	2,475	182	209	366
	REPLICATE COUNT (n)	22	21	21	20	21	20	21	20
	95% CI (+/-)	416	697	670	89	5,164	381	435	766
SAMPLE 1:	FIRST PREMEABILITY	3,465	1,356	779	1,050	5,005	1,024	2,188	7,525
	ARITHMETIC MEAN PERMEABILITY	3,602	1,225	787	934	5,236	1,066	2,112	5,917
	MEDIAN PERMEABILITY	3,570	1,190	779	971	5,075	1,085	2,083	6,265
	STANDARD DEVIATION	273	88	26	100	403	48	67	1,431
	STANDARD ERROR	122	39	11	45	180	21	30	640
	REPLICATE COUNT (n)	5	5	5	5	5	5	5	5
	95% CI (+/-)	339	109	32	124	501	59	83	1,777
SAMPLE 2:	FIRST PREMEABILITY	1,050	2,013	2,555	1,155	4,550	2,695	2,135	3,868
	ARITHMETIC MEAN PERMEABILITY	1,066	2,141	2,411	1,209	4,188	2,501	2,004	4,256
	MEDIAN PERMEABILITY	1,076	2,144	779	1,155	4,156	2,651	1,978	6,265
	STANDARD DEVIATION	29	183	94	99	299	273	92	398
	STANDARD ERROR	13	75	39	44	134	122	41	178
	REPLICATE COUNT (n)	5	6	6	5	5	5	5	5
	95% CI (+/-)	36	192	99	123	371	339	114	494
SAMPLE 3:	FIRST PREMEABILITY	1,881	3,640	989	1,286	1,838	424	4,051	2,109
	ARITHMETIC MEAN PERMEABILITY	1,874	4,295	998	1,311	1,763	471	4,207	2,436
	MEDIAN PERMEABILITY	1,881	4,113	989	1,286	1,750	473	4,108	2,529
	STANDARD DEVIATION	125	504	25	79	195	32	269	214
	STANDARD ERROR	56	226	11	35	80	14	110	96
	REPLICATE COUNT (n)	5	5	5	5	6	5	6	5
	95% CI (+/-)	155	626	31	98	205	39	282	265
SAMPLE 4:	FIRST PREMEABILITY	3,115	3,325	4,261	849	43,750	2,048	2,520	2,293
	ARITHMETIC MEAN PERMEABILITY	2,625	4,295	4,452	1,031	18,501	1,951	2,639	2,490
	MEDIAN PERMEABILITY	2,608	3,885	4,261	1,015	4,279	1,960	2,520	2,450
	STANDARD DEVIATION	262	1,485	337	196	20,566	72	285	380
	STANDARD ERROR	99	664	151	88	9,197	32	127	170
	REPLICATE COUNT (n)	7	5	5	5	5	5	5	5
	95% CI (+/-)	243	1,843	418	244	25,531	89	354	471