NECHAKO RIVER SUBSTRATE QUALITY AND COMPOSITION

NECHAKO FISHERIES CONSERVATION PROGRAM
Technical Report No. M89-7

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INTRODUCTION

Substrate quality, often measured as the proportion of fine sediments in stream gravels, is associated with spawning success, incubation success, rearing habitat quality and invertebrate production. Fine sediments are particularly detrimental to successful salmonid reproduction. Numerous laboratory and field studies have described inverse relationships between the proportion of fines (above some critical level) and egg survival or fry emergence. It is generally assumed that increased mortality is caused by lower intragravel velocities, lower permeabilities, lower dissolved oxygen and entombment of eggs, alevins and fry by fine sediments.

In regulated rivers it is often assumed that substrate quality deteriorates following regulation (Reiser et al. 1985). Typically, regulation reduces peak flows, lowering sediment transport capacity for gravel and larger particles. Lack of gravel movement, or bed immobility, is associated with accumulation of fine sediments and deterioration of substrate quality.

The Nechako Fisheries Conservation Program (NFCP) Technical Committee is responsible for monitoring gravel quality along the Nechako River. This committee, through the Department of Fisheries and Oceans, has contracted with K. Rood & Associates to develop a substrate quality sampling project for the Nechako River. This was accomplished by:

1. Reviewing substrate sampling methodologies, discussing the advantages and disadvantages of each method;
2. Summarizing existing data on substrate quality and composition in the Nechako River;
3. Conducting a one-day expert workshop to review appropriate gravel quality sampling projects;
4. Summarizing results of the workshop and developing an appropriate sampling strategy for the Nechako River; and
5. Completing a pilot sampling project for gravel quality along the Nechako River, analysing the samples and presenting the results.

A background report reviewing substrate sampling techniques was circulated to workshop participants prior to the meeting on August 1, 1989. Material from the background report was incorporated into this report which critically reviews substrate sampling methodologies, summarizes the existing database on the Nechako River, summarizes workshop discussions, recommends a sampling strategy for substrate quality and presents the results of a pilot sampling on the Nechako River.

SAMPLING OF ALLUVIAL GRAVELS

Alluvial gravels are remarkably variable. At a site, particles range in size from silt and clays (less than 0.0063 mm) to large cobbles and small boulders (256 mm and larger). The distribution of grain sizes (and the statistics of the grain size distribution, such as the median size) vary from site to site. In a particular environment (such as a riffle or a bar) gravels may appear to be loosely organized into facies. The character of the gravel varies within these facies and, to a much greater extent, among the facies. Gravel character also varies from riffle to riffle down the stream.

Design of a gravel sampling project requires consideration of the following factors, in order to meet project goals:

1. The organization of alluvial gravels and standards for collection of gravel samples,
2. The bias and precision associated with different techniques for collecting gravel samples from the streambed,
3. Sampling strategies and the number of samples required to overcome variability along and across the streambed, and
4. Variability from riffle to riffle along the stream.

In spawning areas on the Nechako River additional variability is imposed by chinook salmon that modify the fluvial gravels by building dunes, rearranging the structure of the gravels and cleansing fines from redds.

Management of the Nechako River salmon stocks does not necessarily require a precise description of the alluvial gravels. For many purposes, documentation of changes in substrate over time, emphasizing those changes that are detrimental to spawning and rearing chinook, is most important. Index techniques focusing on indicating changes in the substrate, may also be suitable.

Alluvial Gravel Deposits

Most gravel deposits consist of a framework of coarse particles filled with finer materials, termed the matrix. It is convenient to divide alluvial gravels into two broad types: framework-supported gravels where the particles comprising the framework are in contact with one another and matrix gravels where the large clasts are not necessarily in contact with one another (Church et al. 1987).

Alluvial gravels on the Nechako River are framework supported. For these gravels, the maximum fines content is limited by the pore space in the gravels. Porosity in gravels exhibit a wide range, depending on the size, distribution and packing (ranging from very loose to tightly packed; Komura 1963; Carling and Reader 1982). Porosities in gravels typically range from 0.25 to 0.40; and these values represent approximate upper limits to percent fines in gravels in the Nechako River.

Alluvial framework-supported gravels may also exhibit a vertical structure. A surface layer, approximately equal in thickness to the largest clast, is typically observed. This layer is coarser than the underlying material. This surface layer is generally supposed to arise from either winnowing of fine materials from the surface to produce a stable "armour" layer or from "equilibrium transport" where less mobile larger grains are concentrated on the surface and smaller grains fall into the voids between, adjusting the mobility and relative transport rate of different size classes.

The method by which surface coarsening is produced has implications for the size distribution of the surface material relative to the underlying material. The size distributions of a winnowed surface, where grains below some selected size are removed, should be the same as a truncated subsurface size distribution. On the other hand, equilibrium transport selectively concentrates large grains and there may be no simple relationship between the size distribution of the surface and subsurface layers.

The surface layer is also identified in gravel quality investigations (Scrivener and Brownlee 1982; Scrivener 1987; Everest et al. 1982). Vertically subsampled freeze-cores often exhibit lower percent fines and larger mean sizes in the top 7.5 to 10 cm.

Other vertical structures may also develop within the alluvial gravels. Bedding may occur in depositional environments providing abrupt changes in grain size. A censored layer, void of fines, may extend down below the surface layer as a result of piping and winnowing. Alternatively, the framework gravels may be covered by a cap of sand or fine materials with clean gravels beneath. This is commonly supposed to occur by sifting of mobile fines into a static gravel layer (Einstein 1968; Beschta and Jackson 1979; Carling 1984). Development of a cap depends on the grain size of the materials carried by the stream. Fine sediments (silts and clays) penetrate the surface layers settling at depth; coarser sediments accumulate as a cap on the surface (Beschta and Jackson 1979).

Measurement Standards for the Surface Layer

Measurement of the surface layer of an alluvial gravel is commonly done using a grid-by-number technique (Kellerhals and Bray 1971). This often proceeds by stretching a tape or placing a wire-grid over the gravels and measuring the *b* (intermediate) axis of all stones falling under regularly spaced grid points; where the spacing is greater than the maximum size of the gravels. Frequency-by-number size distributions are generally thought to be equivalent to volume-by-weight sieve curves (Kellerhals and Bray 1971).

The surface is sometimes sampled by areal (all stones within a pre-determined area; Lane and Carlson 1953) or volumetric techniques, though it is difficult to specify the actual volume occupied by the surface layer.

Precision is the range in values obtained from independent estimates of a quantity, using the same measurement technique (Zrymiak and Cashman 1986). Church et al. (1987) presents standards for the precision of the mean of a surface sample, expressed as the coefficient of variation of the mean for various sample coefficient of variations and sample sizes. For typical samples of 100 stones, the precision of the mean will be near 10%. Precision estimates for other percentiles of the grain size distribution require an analysis of replicate samples.

Index Techniques

The "grid-by-number" technique will not describe the filling of interstices in the surface layer by fine sediments because only clasts larger than 8 mm are sampled. Precise determination of fines in the surface layer requires use of an adhesive gel, clay or wax to sample all grain sizes in the surface layer (Gomez 1979). These are extremely difficult to apply in the field.

More commonly, fines in the surface layer are indexed by visual methods. These techniques typically rely on rapidly collecting a large number of subjective observations to statistically assess changes in substrate and are particularly well-suited to before and after, or index studies. Platts et al. (1983) classified substrate in dominant (major size) classes at 0.3 m intervals along a number of transects to monitor sand deposition and subsequent mobilization on the South Fork Salmon River. A variety of other visual approaches are also used. Embedded-ness, a rating of the degree to which larger particles are covered by finer sediments is measured either by a rating score (Platts et al. 1983), or estimated as a percentage (Stowell et al. 1983). Substrate scores, which integrate grain size and embeddedness ratings, are also used (Crouse et al. 1981).

Measurement Standards for the Subsurface Layer

The subsurface layer is sampled in bulk (volumetric sample), size-graded by sieving and measured by weight. A meaningful subsurface sample requires sediment that is homogeneous with depth and removal of the surface layer.

Sieve analysis may be undertaken for sizes up to 256 mm (the largest stones are measured with templates) and down to 0.0625 mm. Smaller grain sizes are analysed by hydraulic settling methods.

Sample standards, that is the sample size required to provide a certain precision to percentiles of the grain size distribution, are generally based on the largest stone or one of the larger percentiles of the distribution (Church et al. 1987, de Vries 1970). The largest sizes determine sample volumes because they are fewest in number and suffer most from inadequate representation.

Church et al. (1987) examined replicate splits of a 33.5 kg sample in order to determine the standard deviation and coefficient of variation for the various sieve intervals. Their results indicate a stable coefficient of variation up to the +8 mm class (8 to 11.3 mm); the coefficient of variation increases rapidly for larger sieve classes.

The number of stones in the 8.0 to 11.3 mm class averaged 135 for the 21 splits. Grains with a diameter of 11.3 mm weigh about 2 g each or approximately 0.1% of the replicate sample weight. Church et al. (1987) proposes 0.1% of sample size for the largest clast as an informal criterion for an adequate sample. Typical precisions, for percentiles of the distribution, based on sample coefficient of variations, are near 10%.

This criterion (and de Vries' criterion) requires very large sample volumes. For the upper Nechako River spawning area, where maximum sizes are typically 125 mm, a sample volume of 2,800 kg is required to meet the above criterion; a relaxed criterion (the largest stone composing 1% of the sample volume) requires 280 kg.

One way around this practical problem is to truncate the sample and only work with a portion of the gravel sizes. In the Nechako, where grain sizes range to 125 mm, statistics could be based on the portion of the distribution sub-32 mm; adequate representation of these grain sizes only requires a 9 kg sample.

Index Techniques

The most commonly-used index technique for subsurface gravel quality is the sediment trap (Mahoney and Erman 1984). Sediment traps collect material deposited from the water column onto the channel bed and integrate deposition onto the surface layer and within the subsurface layer. Traps may be used to index accumulation of sediment over a given time period or resulting from a specific activity or to estimate cleansing or flushing resulting from high flows. General bed movement will typically erode the traps.

Traps must be carefully constructed if they are to reflect natural deposition or erosion from the bed. Sediments intrude at different rates into cleaned gravels as compared to the natural substrate. Trap design also affects the result; Carling (1984) achieved different results with porous sides on his traps.

Alluvial Gravel Samplers

Church et al. (1987) results are based on shovelled or scooped bulk samples. This technique, which easily provides large sample volumes is only appropriate in the dry or, at best, in shallow, still water. Samples from the bed of the channel, which is water-covered under all circumstances, are typically obtained from three types of instruments:

1. Bed Material Samplers: A variety of hand and cable suspended bed material samplers are available. These generally provide an inadequate and biased sample and many are not recommended for sampling gravel beds (Yuyzk 1986). However, cable-suspended instruments (BM-54, Shipek 860 or Ponar style samplers) may provide the only means of sample acquisition in deep or fast waters. Sample volumes range from 300 g (BM-54) to 10 kg (Shipek 860 and modified Ponar), including both surface and subsurface materials. Loss of fine materials is a particular problem;

2. McNeil-type Samplers: The McNeil-type samplers are stainless steel core tubes which are worked into the streambed sediments (McNeil and Ahnell 1964). Encased sediments are removed from the core tube to a catch basin. Water and suspended sediments in the core tube are also transferred to the catch basin. Alternatively, the volume of water is measured and one litre is removed to settle in an Imhoff Cone to estimate the concentration of sediment. The core tubes used in the McNeil samplers come in a variety of sizes, depending on substrate size and, as a result, sample volumes are variable. One advantage of McNeil samplers is that the surface layer can be removed from the sample and discarded prior to collecting the subsurface sample.

   McNeil samplers are restricted to shallow, slow-moving waters, generally less than one arm's length in depth. Samples slightly underestimate fines in gravels because of the loss of water and sediment in the core-tube when the tube is capped before extraction. Other limitations are:

   i) Core materials are mixed and cannot be vertically sub-sampled, and

   ii) Core tube pushes large particles out of the collecting area during insertion.

3. Freeze-core Samplers: Freeze-core samplers operate by inserting a hollow probe into the streambed and then adding a cooling medium (acetone-dry ice, liquid carbon dioxide or liquid nitrogen) to the probe to freeze the surrounding gravels. After a specified time period, the probe and attached frozen streambed are removed. Freeze coring may use a single or a tri-tube probe. Typical core sizes with the single probe liquid carbon dioxide sampler are 1.5 to 2 kg (Adams 1980); with the tri-tube samplers cores in excess of 20 kg can be taken (Everest et al. 1982). Coring with liquid nitrogen typically produces samples in excess of 10 to 15 kg (Skaugsett 1980).

   One problem with the freeze-core sampler is that the volume of substrate sampled is indeterminate. Single probe samples produce an irregular core, often with large particles adhering to the outside of the frozen sample, which produces an apparent bias to larger particles (NCASI 1986). Unless samples are properly truncated to remove this bias, the proportion of fines in the streambed will be underestimated.

   One particular advantage of freeze-core samples is the ability to vertically subsample: the surface layer or other nonrepresentative material may be discarded. As well, freeze-core samplers are not, at least in theory, restricted to shallow or slow-moving waters. Freeze-coring should be possible from a moored boat in water depths of one metre or more. Freeze-coring might also proceed through an ice cover, providing that the sample sites can be properly located.

Accuracy and Precision of McNeil and Freeze-core Samplers

The accuracy and precision of gravel samplers can be determined by:

1. Comparison to an absolute standard of a known distribution, artificially prepared in a laboratory; or

2. Comparison of the relative performance of the instruments by repetitive sampling of natural gravels.

Determination of accuracy and precision from sampling natural gravels is confounded by within and between site variability of alluvial gravels.

Several comparative studies of sampler accuracy and precision have been undertaken, however, original data are not easily available. Table 1 lists results of triplicate sampler tests against prepared laboratory standards conducted by NCASI (1986). Samples in the first two tests are based on mixtures of builders sand (primarily fine sand) and navy jack, a narrow-graded construction aggregate with sizes less than 25 mm. The artificial substrate were conditioned overnight with a simulated streamflow. In the final experiment, river sediments were mixed to produce a sample with 50% fines.

The results show a small but consistent average underestimation of percent fines for all instruments, which may result from loss of sediment from the bed during the substrate conditioning. Coefficients of variation for the replicate samples collected with each instrument range from 10 to 25% with the highest coefficients of variation associated with the lowest proportion of fines in the gravel.

Table 2 (Table 7 from NCASI 1986), compares the performance of the four samplers during repeated sampling of one riffle in Alpowan Creek. The freeze-core samples characteristically have much larger geometric mean sizes and consequently larger Fredle indices and lower percentage fines. This bias is a direct consequence of oversampling of large stones, which could be corrected by sample truncation.

Typical sample weights are quoted in Table 3 for a variety of McNeil and freeze-core samplers. These weights may be used to estimate the maximum accurately-sampled size for the different samplers, based on the criteria discussed in the subsection Alluvial Gravel Samplers. These maximum particle sizes represent truncation points that indicate the maximum size of clast which is adequately represented.

Number of Samples Required to Overcome Spatial Variability

It is commonly observed that gravels vary widely in character not only between different deposition environments (bar heads, secondary channels, channel bed, etc.) but also within specific environments. Church et al. (1987) describes variation in both surface and subsurface materials on a point bar in the Quesnel River; materials ranged from silts to 180 mm boulders and they identified distinct facies of sand, fine gravel (less than 8 mm), medium gravel (8 mm to 64 mm) and coarse gravel (larger than 64 mm).

Within a particular environment, where a number of samples have been collected, the precision, I, of a sample statistic may be defined as:

$$I = DF/F^* \qquad (1)$$

where F* is, for example, the mean percentage of fines and DF is a confidence interval constructed around that statistic. The number of samples, N, required to achieve a given precision is:

$$N = (t_{a,N} * C_v/I)^2 \qquad (2)$$

where $t_{a,N}$ is Students t at confidence level 1-a, C_v is the coefficient of variation of the sample, s/F*, and s is the standard deviation of the individual estimates of F (Church et al. 1987). The number of samples required for various precisions of the mean percent fines, at a given confidence level, may be calculated iteratively from Equation 2.

There are few substrate sampling projects reporting data for use in Equation 2. Wolcott and Church (1991) report data from bulk samples from a Quesnel River bar. (Samples meet the standards discussed in the subsection Alluvial Gravel Samplers). Using their data the number of samples required for various precisions of the mean percent fines (the proportion of the sediment with sizes less than 1 mm), at a 95% confidence level, are reported in Table 4.

Table 1
Comparison of Method, Precision and Accuracy for Percent of Fines Less Than 4 mm*

Sampler and Trial	Laboratory Flume Test 20% fines	50% fines	50% fines	Field Program
Three-Core Freeze Probe				
A	24.2	46.0	41.5	35.7
B	16.4	46.2	46.0	32.0
C	16.1	54.6	49.6	37.8
Average	18.9	48.9	45.7	35.2
Bias	-1.1	-1.1	-4.3	—
Cv (%)	24.3	10.0	8.9	8.4
One-core Freeze Probe				
A	19.9	38.0	42.0	27.8
B	14.2	53.8	31.8	34.8
C	22.9	49.2	49.3	35.9
Average	19.0	47.0	41.0	32.8
Bias	-1.0	-3.0	-9.0	—
Cv (%)	23.2	17.3	21.4	13.4
McNeil Sampler				
A	15.0	50.2	43.9	42.9
B	11.0	48.3	49.5	46.4
C	11.9	45.6	54.5	38.0
Average	12.6	48.0	49.2	42.0
Bias	-7.4	-2.0	-0.8	—
Cv (%)	16.6	4.8	10.8	9.9
Modified McNeil Sampler				
A			42.9	52.9
B			36.2	43.3
C			46.8	36.5
Average			42.0	44.2
Bias			-8.0	—
Cv (%)			12.8	18.6

*(NCASI 1986)

Detecting differences in percent fines as small as 1% between successive sets of samples requires extremely large sample numbers. However, detecting changes in percent fines in the order of 10%, requires only a moderate sample effort. Repeating these calculations for the individual grain size statistics necessary for the Fredle Index (see Equation 4) indicates that larger numbers of samples are required to achieve the same precision. This occurs because of the greater coefficient of variation for the individual grain size statistics at the extremes of the distribution.

Sample requirements calculated in Table 4 can be compared to those used in successful gravel sampling projects. At Carnation Creek (Scrivener and Brownlee 1982) 45 samples were collected three times a year at a chum spawning riffle. The coefficient of variation of all 1200 gravel cores for the percentage of sand in the total sample appears to be slightly larger than observed by Wolcott and Church. Scrivener and Brownlee were able to use their large sample numbers to statistically resolve small changes in substrate. Platts et al. (1983) collected 50 McNeil samples per spawning riffle in their study of sediment deposition and subsequent erosion resulting from the cessation of upstream logging activity.

Table 2
Comparison of Substrate for Riffles in a Small Washington Stream Collected Using Four Types of Streambed Sampling Devices*

Sampler and Trial	Sample Weight (g)	Percent Finer than 8 mm	4 mm	1 mm	.063 mm	Geometric Mean	Fredle Index
Three-Core Freeze Probe							
A	2,986	47.7	35.7	16.1	0.8	6.52	2.00
B	3,656	43.0	32	16.0	2.9	7.79	2.26
C	4,960	48.5	37.8	21.4	6.9	4.92	1.24
Average	3,777	18.9	35.2	17.8	3.5	6.41	1.83
One-core Freeze Probe							
A	1,390	42.0	27.8	11.4	3.5	7.49	2.78
B	2,079	47.9	34.8	13.5	2.8	7.36	1.95
C	2,537	43.9	35.9	21.3	2.7	8.37	1.44
Average	2,002	44.6	32.8	15.4	3.0	7.74	2.06
McNeil Sampler							
A	10,305	59.2	42.9	16.8	2.1	4.72	1.52
B	12,148	62.7	46.4	17.5	2.9	4.01	1.27
C	12,210	54.1	38	14.0	2.2	5.36	1.89
Average	11,554	58.7	42.4	16.1	2.4	4.7	1.56
Modified McNeil Sampler							
A	4,575	66.0	52.9	28.5	2.8	3.25	0.85
B	5,391	57.0	43.3	23.0	6.2	3.82	1.02
C	4,370	52.8	36.5	15.3	4.5	5.07	1.85
Average	4,779	58.6	44.2	22.3	4.5	4.05	1.24

Note: Geometric mean and Fredle Index are defined in the section Biological Measures of Sediment Quality.

*(NCASI 1986)

Table 3
Maximum Adequately Sampled Substrate Sizes for the Four Samplers Used in the NCASI (1986) Study

Sampler	Typical Sample Size (kg)	Maximum Particle Size (mm) 0.1% Criteria	1.0% Criteria
McNeil	10	21	42
Modified McNeil	5	16	33
Single Tube Freeze-core	2	11	25
Tri-tube Freeze-core	5	16	33

Table 4
Sample Numbers Required to Acheive Various Precisions for the Mean Percent Fines on a Quesnel River Bar

Precision (%)	Coefficient of Variation	Number of Samples
1	0.289	2260
5	0.289	92
10	0.289	24
20	0.289	7

Downstream Variability of Gravel Quality

Substrate sampling shows large and statistically significant variation between riffles within the same stream (Adams and Beschta 1980, Scrivener and Brownlee 1982), perhaps related to physical characteristics of the stream such as slope and grain size.

Grid samples distributed over individual riffles indicate variability both along and across the riffle. Typically the largest differences were observed on transects across the riffle (Adams and Beschta 1980). Variation within a riffle is typically much smaller than observed between riffles in the same stream.

Recommended Sampling Procedures for the Nechako River

Unbiased alluvial gravel samples require eliminating the over-sampling of large sizes that occurs with freeze-core sampling and eliminating the loss of fines that occurs with the McNeil sampler. By combining the McNeil and freeze-core instruments a sampler may be developed that has the advantages of each technique. The sampler would consist of a core-barrel inserted into the streambed to define a particular sediment volume: a probe inserted into the barrel would freeze the sediment volume prior to removal. This sampler design has the advantages of a defined sediment volume (i.e. it eliminates bias from large clasts adhering to the outside of the core), it retains all fine sediment, and it permits subsampling of the core. This is a new instrument design and some experimentation and trial and error are required to develop the technique properly.

Adequate representation of streambed gravels requires large sample volumes. Samples should exceed 10 kg in weight and should probably approach 15 kg if the cores are to sub-sampled. Liquid nitrogen is required to attain these sample volumes. In any event, the samples collected are unlikely to be representative of all the sizes in the streambed. Truncation is required prior to analysis of the samples though grain sizes up to 45 mm will be adequately represented, based on a relaxed sampling criterion.

Previous studies indicate that 30 to 50 samples are required to detect changes in the mean percent fines of approximately 10%. Samples areas should be carefully chosen to only include one "facies" and the sampling should be perpendicular to the flow in order to measure the maximum variability.

BIOLOGICAL MEASURES OF SEDIMENT QUALITY

Field and laboratory studies documenting the relationship between gravel quality and spawning success are often difficult to compare. Different sediment sizes are used to represent the upper limit of fine sediment. Gravel quality may be measured or calculated by different methods, and gravel samples, particularly in field studies, may be taken from various locations within the redd or the surrounding substrate. As Chapman (1988) points out, it is measurements within the egg pocket centrum which should be most closely related to survival-to-emergence. However, many field studies relate survival to gravel quality within the redd, but not necessarily in the centrum or even to the surrounding substrate. In laboratory studies, survival is often related to the average quality of an artificial substrate that may be structured very differently from natural redds.

For a given gravel sample, gravel quality may be calculated as either a percentage of fines or a Fredle index (Lotspeich and Everest 1981). Accurate determination of either of these quantities depend on unbiased and accurate gravel samples. If samples from the Nechako River are to be compared to either existing field or laboratory studies or to samples from previous years, then samples must be collected from the same part of the redd or channel bed to a similar standard. As is discussed in Church et al. (1987), truncation of samples may be required to ensure unbiased estimates of various parameters. While truncation successfully overcomes bias and sample volume problems, the statistics calculated from truncated samples may not easily be compared to other field or laboratory studies.

Gravel quality, expressed as percent fines, is the percentage of the total weight of the sample that is less than some maximum size. Various grain sizes are used to represent the upper limit of the fine size ranging from 0.84 mm (McNeil and Ahnell 1964) to 6.4 mm (Bjornn 1969).

Some researchers feel that percent fines is an inadequate index of survival-to-emergence because the calibre of the fines are not considered and because similar percent fines may have different effects on permeabilites, dissolved oxygen and apparent velocities in gravels of varying mean size and distribution. The Fredle-index was developed to overcome some of these weaknesses (Lotspeich and Everest 1981), where this is defined as, D_g, the geometric mean diameter, divided by S_o, the Trask sorting coefficient. The geometric mean diameter is often calculated as (Everest et al. 1982):

$$D_g = (D_{16} * D_{84})^{0.5} \qquad (3)$$

and the Trask sorting coefficient is calculated as:

$$S_o = (D_{75}/D_{25})^{0.5} \qquad (4)$$

Accurate estimation of the Fredle Index (D_g/S_o) requires accurate estimation of the proportion of the largest stones in the sample and in the substrate. These proportions are generally not well known and gravel sampling by freeze-coring often produces biased estimates of these quantities. Additionally, Fredle indices calculated from truncated samples will not reflect conditions in the sample site and cannot be compared to laboratory studies where the size distribution of the artificial spawning mix is often accurately known.

We recommend using percent fines to characterize gravel quality. Despite the interpretative weaknesses of this measure, it can be measured precisely and used to index changes in the substrate over time.

SUBSTRATE MEASUREMENTS ON THE NECHAKO RIVER

Substrate measurements along the Nechako River are of three types:

1. Surface Layer Measurements: Measurements of the size of the surface armour layer in the Nechako River for computation of gravel stability (Reid Crowther 1987). Grid-by-number samples consisting of 100 to 150 clasts were collected at three sites;
2. Bulk Samples of Surface and Subsurface Substrate Layers: Collected to assess gravel quality in redds (Russell et al. 1983, Envirocon Ltd. 1984); and
3. Index or rating observations of substrate for habitat studies (D.B. Lister and Associates Ltd 1998, *in prep.*).

As Table 5 indicates, there are few measurements of the quality or composition of the substrate along the Nechako River. The Reid Crowther measurements describe the size distribution of the coarse (>8 mm) fraction of the surface layer at several spawning sites in the uppermost Nechako River.

Measurements by Russell et al. (1983), based on small freeze-core samples, show clean spawning gravels in the Nechako River. Their measurements indicate percent fines ranging from, roughly, 3 to 5%.

SUMMARY OF WORKSHOP DISCUSSIONS

Attendees

The Substrate Quality and Composition Workshop, held on August 1, 1989 at the Department of Fisheries and Oceans, was attended by the following individuals:

- D. Hay, Chairman - Technical Committee Nechako Fisheries Conservation Program, Hay & Company Consultants Ltd.
- W. Rublee - Triton Environmental Consultants Ltd.
- S. Blachut - Department of Fisheries and Oceans
- M. Church - University of British Columbia
- R. Kellerhals - Kellerhals Engineering Services Ltd.
- W. Platts - Don Chapman Consultants Inc.
- K. Rood - K. Rood & Associates
- C. Scrivener - Department of Fisheries and Oceans

Table 5
Bed Material Measurements in the Nechako River

A. REID CROWTHER AND PARTNERS LTD. (1987)

Location	Sample Type	Sample Size	Surface Armour (mm)	
			D(50)	D(84)
km 4.9	grid-by-number	100	26	50
km 4.9	grid-by-number	100	60	115
km 7.6	grid-by-number	150	48	74
km 12.2	grid-by-number	100	48	82
km 12.2	grid-by-number	100	36	55

B. ENVIROCON LTD. (1984)

Location	Sample Type	Sample Size (kg)	D(70) Size (mm)		
			Upstream	Redd	Tailspill
Redd F21	ponar dredge	5(E)	45	42	57
Redd KK30	ponar dredge	5(E)	29	75	38

C. RUSSELL, CONLIN, JOHANNSEN AND ORR (1983)

Location	Sample Type	Sample Size (kg)	Percent Retained on Sieve (mm)			
			>0.5	0.25	.063	<0.063
natural redd	30 to 40 cm	1.87	96.8	1.8	1.3	0.1
natural redd	single probe	.77	96.8	2.2	0.8	0.2
natural redd	freeze core	.93	96.4	2.5	1.0	0.1
natural redd	samples	1.35	95.3	2.8	1.7	0.2

(Reid Crowther 1987, Russell et al. 1983, Envirocon 1984)

The purpose of the workshop was to discuss technical requirements for a gravel sampling project on the Nechako River. Instead, workshop discussions primarily focused on the applicability and relative merits of various approaches to monitoring the biological environment. Details for design of a sampling project were only discussed briefly. Discussions by the workshop participants focused on the following topics:

1. Changes in the physical environment of the Nechako River following regulation and their effect on chinook rearing and spawning,

2. Index or system-wide techniques for monitoring the physical environment of the Nechako River,

3. The relative efficacy of gravel quality and other techniques for monitoring egg to alevin survival, and

4. Technical considerations for a gravel sampling project for the Nechako River.

Discussions on topics 2 through 4 are briefly summarized in the following sections and recommendations are included in the subsection Workshop Recommendations.

Index Monitoring Measures in the Nechako River

Workshop participants suggested several measures for monitoring the general health of the Nechako

River. Most of these measures involved monitoring of the physical environment and evolved from discussions of the changes in the physical environment imposed by regulation. The following measures were suggested:

1. Quantity of Spawning Gravels: It was suggested that spawning success depends on both the quantity and quality of gravels in the Nechako River. To this end it was suggested that the quantity (or areal extent) of spawning gravels in the Nechako River be monitored. Workshop participants felt that this was a very difficult task to undertake and was partly covered by existing spawner counts by enumeration reach and by bed material mapping (see below).

2. Bed Material Mapping: The accumulation of sand on the bed surface of the Nechako River was considered to potentially affect both rearing and spawning habitat. Mapping of the extent of sand-bed areas provides a simple method of measuring gravel quality and indicating spawning or rearing sites that are likely to be affected by sediment deposition.

   C. Scrivener felt that the size distribution of the sand, particularly on riffles, should be measured because changes in the benthic community result from the build-up of sand and, to a greater extent, from scouring by remobilized sediments.

3. Vegetation Mapping: Vegetation mapping was suggested as a useful monitoring tool. Vegetation encroachment does not directly affect sediment quality in the Nechako River, however it may affect rearing habitat by providing cover.

   Maps are available for selected reaches covering the period from 1952 to 1986 (Reid Crowther 1987). Additional monitoring of vegetation encroachment should focus on the changes resulting from the long-term regime.

4. Slope Profile: During discussions it was recognized that no water surface slope profile has been surveyed along the Nechako River. While not specifically a monitoring measure, a slope profile is required to estimate the effects of accumulation of gravel at tributary fans on the upstream hydraulics of the Nechako River and would also assist in evaluating spawning areas and identifying suitable areas for habitat complexing.

Relative Efficacy of Gravel Quality and Other Monitoring Techniques

Workshop participants who have conducted gravel quality sampling projects felt that they are an impractical and ineffective technique for monitoring the incubation environment. It is difficult to collect measurements from the egg pocket and it is difficult to interpret the results as gravel quality provides only an indirect measure of the factors that actually affect incubation success. The ability of chinook salmon to clean gravels prior to spawning and the spatial heterogeneity of the gravel bed increases the difficulty of collecting representative samples.

W. Platts reported that he had monitored incubation success by inserting dissolved oxygen probes directly into the egg pocket. The probes were developed to work in low velocity environments. His project monitored twelve redds, covering a range of apparent stream velocities and gravel quality, from egg deposition to emergence.

Intragravel dissolved oxygen monitoring is preferred in the United States because there is a legal mandate to preserve dissolved oxygen. It directly affects egg survival, though intragravel velocities in the egg pocket also affect survival at low dissolved oxygen levels. However, field techniques are still in the development stage.

Monitoring of the incubation environment also requires monitoring of surface sediments which may entomb juveniles. Dissolved oxygen measurement monitors conditions in the egg pocket and reflects the deep penetration of sediments. Deposition of sediments on the bed surface may be measured visually but coring is preferred.

Permeability measurement was also discussed, but was considered expensive compared to dissolved oxygen monitoring and techniques are not readily available.

W. Platts felt that biological monitoring of the incubation environment was also preferable to gravel quality sampling. He preferred egg baskets to redd-capping. He felt that with redd-capping, the number of eggs was unknown, sediment problems were introduced by the cap and the cap altered the hydraulics of the redd.

Technical Considerations for Gravel Sampling

Some aspects of gravel sampling techniques for the Nechako River were discussed at the workshop:

1. Number of Samples: The subsection Numbers of Samples Required to Overcome Spatial Variability, provides a general guide to the number of samples that might be required to detect a significant change in gravel quality at a particular site along the Nechako River. Previous studies have used 50 to 100 cores per spawning area per year in streams that are much smaller than the Nechako River.

   Discussion ensued on whether a greater or lesser number of samples were required to define a temporal trend in substrate quality in an inactive river such as the Nechako River. M. Church felt that because only slow accumulation of fines was expected (i.e. the system was not variable from year to year), that fewer samples would be required. C. Scrivener held that because year-to-year changes are expected to be very small a much greater number of samples would be required to statistically detect deterioration in substrate quality. This issue was not resolved in the workshop.

2. Number of Sampling Sites: It was felt that in order to acquire an accurate picture of overall gravel quality in the Nechako River that several spawning areas should be monitored. Monitoring of only one spawning area may provide an unrealistic or incorrect picture of temporal gravel quality variation. A slug or pulse of sediment moving through the spawning areas over a period of decades may confound changes resulting from accumulation of fine sediments in the bed.

3. Frequency/Period of Sampling: Discussion focused on base line gravel quality measurements in the Nechako River. W. Platts felt that a minimum of two years of sampling was required to adequately describe the existing substrate. If results from the first two years are variable then additional years of sampling may be required.

   A further two or more years of sampling would be conducted after five or more years, following establishment of the ultimate flow regime. Results from the later set of measurements would be compared to the base line data set.

4. Sampling Equipment: It was generally agreed that a large sample was required to adequately measure fine contents in the substrate. Both McNeil and freeze-core samplers collect large samples. The prime advantage of the freeze-core technique is the ability to subsample the core. Subsampling allows determination of the variation of accumulation rates (and the size distribution of the accumulating sediments) with depth.

   Sample truncation was discussed as a means of correctly calculating an unbiased estimate of the proportion of fines in the gravel samples.

Workshop Recommendations

The August 1, 1989 workshop provided a new perspective on the role of gravel quality sampling in the habitat and stock monitoring conducted by the Nechako Fisheries Conservation Program. The workshop acknowledged that gravel quality measurement can be an ineffective and inefficient technique for monitoring the incubation environment. Dissolved oxygen, which directly affects egg to alevin survival, provides a more effective measure of incubation success, if intragravel measurements are technically feasible.

While gravel quality measurements are not easily linked to incubation success, they do provide a tested method of measuring temporal change in the bed of the Nechako River. Despite the limitation on biological interpretation, regular sampling may provide a useful index to overall habitat quality and help distinguish the physical causes of reduced biological performance. Finally, if dissolved oxygen monitoring is not technically feasible on the Nechako River, gravel sampling will be required to monitor the streambed.

The workshop discussions may be summarized into three recommendations for the NFCP concerning habitat and stock monitoring in the Nechako River:

1. Consider measurement of intragravel dissolved oxygen to monitor the incubation environment of the Nechako River,

2. Consider monitoring projects for sand accumulation along the Nechako River and for vegetation encroachment onto the Nechako floodplain. The Nechako River also requires a slope profile and cross section surveys, and

3. Define project objectives, sampling sites and sampling equipment before collecting base line measurements of gravel quality in the Nechako River.

Monitoring of Intragravel Dissolved Oxygen in the Nechako River

It is recommended that the Nechako Fisheries Conservation Program examine the feasibility of dissolved oxygen monitoring in redds in the Nechako River. W. Platts described a successful project of dissolved oxygen measurements. Further details of the techniques and equipment used in his project should be obtained.

Use of dissolved oxygen techniques and equipment requires careful testing in conditions similar to those in the Nechako River.

Monitoring for Sand Accumulation and Vegetation Encroachment Along the Nechako River

The following studies are suggested either as monitoring measures for sediment in the Nechako River or as studies to fill specific gaps in knowledge of the physical environment:

1. One potential physical change to the Nechako River following regulation is the gradual accumulation of sand on the bed of the channel over extended periods of time. This accumulation has the potential to affect both spawning, through burial of spawning sites, and rearing, through reduction of benthic invertebrate-producing substrate.

2. Mapping of surface sediments along the main channel and wetted secondary channels of the Nechako River provides a useful measure of the rate of development of sedimentation problems. The initial map of Nechako River substrate should carefully map existing boundaries of sand and other fine sediment accumulations. Mapping may utilize transect or other surveys, underwater observation or video cameras. Later maps would concentrate on determining changes in these boundaries.

3. Sediment boundaries should be observed at the same time of the year (either at the beginning or end of the low flow period). Initially, annual maps may be prepared: experience may indicate that only biannual or some other frequency of mapping is actually required.

   Sediment sampling would assist in the preparation and interpretation of the maps. Occasional bulk samples of accumulating sand would be collected for sieve analysis.

4. Vegetation has encroached on the Nechako River floodplain as a result of reduced flows. As discussed in Reid Crowther (1987) the shifting of peak discharges from May and June, to July and August, allows vegetation to grow to the May and June water level. In July and August, when discharges are greater, the near-bank substrate is composed of this pioneer vegetation. This vegetation also effectively filters fine sediments from the July and August flows incorporating them into the substrate.

5. Mapping of the limit of vegetation encroachment onto the floodplain indicates the ultimate size of the Nechako River under the long term flow regime. The limit of vegetation encroachment, in selected reaches, was mapped from 1986 aerial photographs (Reid Crowther 1987). Rates of encroachment are slow and repetition of mapping may only be required every five years or so. The long-

term regime, with lower discharges in May and June, should initiate further encroachment. Mapping should be repeated a few years after switching to the long-term regime.

6. The type, abundance and size of pioneer species on the floodplain are also of interest. Investigations of vegetation encroachment should also examine the type and quantity of sediments trapped in the pioneer community.

7. It was felt during workshop discussions that a slope profile of the Nechako River would assist in evaluating spawning areas along the Nechako River and also provide basic physical information on the Nechako River. As a result, it is recommended that a slope profile be surveyed.

8. One result of reduced flows in the Nechako River is re-grading of major tributaries and deposition of a fan of cobbles and gravels into the Nechako River. Deposition of sediments at tributary junctions, that are no longer moved by the Nechako River, affect water surface slopes, depths and velocities in the Nechako River upstream and immediately downstream of the fan. The altered flow character upstream of the fan also promotes deposition of fine sediments.

   Investigation of the effect of fans at tributary junctions requires measurement of the water surface profile and cross sections in the affected reaches upstream of Swanston, Targe, Greer, and Smith Creeks and the Nautley River.

9. Cross-sections surveys may also provide a useful monitoring tool in the main sand accumulation areas above Greer Creek and above the Nautley River. Within these reaches the section may change sufficiently quickly that biannual re-surveys may detect changes in the nature of the sections. The cross-section surveys would also permit estimation of the annual volume of sediment supplied to these reaches, and allow estimation of rates of sand supply and transport in the Nechako River.

   The water surface profile survey should be surveyed at a constant discharge. This may be accomplished in the spring or the fall. Monuments should be left along the Nechako River so that additional water surface profiles at higher discharges can be easily surveyed. Cross sections should be carefully monumented, described and tied to the long profile datum.

Gravel Quality Sampling on the Nechako River

An initial gravel quality sampling project for the Nechako River is discussed in the following section.

SUBSTRATE SAMPLING ON THE NECHAKO RIVER

Project Overview

Gravel sampling on the Nechako River provides an index of the quality of the spawning and incubation environment. Simple relationships between the statistics of the gravel distribution and survival-to-emergence are not expected. However, repeated measurements of gravel quality may indicate changes over time in substrate that may be assumed to reflect changes in the spawning or incubation environment.

Existing gravel quality measurements on the Nechako River are not adequate to provide a baseline for future sampling and the equipment used for sampling was untested. Consequently, the 1989/1990 gravel sampling project on the Nechako River was a pilot or reconnaissance measurement project. The substrate sampling project has two purposes:

1. Conduct a reconnaissance sampling project to test equipment and techniques to define gravel characteristics; and

2. Collect sufficient samples that the measurements may be used as a baseline data set to index changes in substrate on the Nechako River.

The sampling project began on March 23, 1989 and ended on March 30, 1990.

Measurement Apparatus

A modified freeze-core sampler was used to collect the gravel samples (see Appendix A). The sampler consists of two pieces: a core-barrel consisting of an eight inch diameter piece of hydraulic steel tube attached to a three foot length of 2.5 inch (I.D) diameter steel pipe (handles attached at the top) and a freeze-core probe, a five foot length of 2 inch (O.D.) diameter pipe with a hardened tip.

The core barrel was worked approximately 12 inches into the substrate with the attached handles. The freeze-core probe was placed inside the sampler and driven into the substrate with a sledge hammer until the tip of the probe extended below the bottom of the core-barrel. Between four and seven litres of liquid nitrogen were poured into the freeze-core probe. When the liquid nitrogen had volatilized the core barrel was lifted from the substrate and taken to shore. The frozen core was removed from the core barrel and chipped off the freeze-core probe with a small hammer. The core was split into an upper and lower half which were bagged separately.

Core volumes collected with this technique are approximately 10,000 cm^3, providing a maximum weight of 15 kg. Splits would be expected to weigh approximately 7.5 kg.

The Field Project

The field project was limited to areas that had been utilized for spawning but were not used, or only lightly used, in 1989. The first site chosen for sampling was the spawning area between km 21.1 and 21.4. However, low water levels on the river made it impractical to transport the liquid nitrogen from the road access point at Bert Irvine's Lodge to the lower spawning area. Instead, measurements were collected at km 19.3, at the downstream end of the spawning area near Bert Irvine's Lodge. This riffle is utilized for spawning but there were only a few spawners in 1989. The sampling project avoided all redds from 1989.

The site at Bert Irvine's Lodge is upstream of the majority of the tributaries to the Nechako River, except Twin Creek which enters on the right bank approximately 200 m upstream of the sampling site. Upstream sediment sources include a few bank and valley wall erosion sites along the main river, fine sediments passing through Murray and Cheslatta Lakes and the Cheslatta Falls washout in 1960.

Gravel samples were collected on a grid consisting of two closely-spaced transects. The transect approach has several advantages. The lightly spawned area was limited in extent and the transects could be placed to avoid redds. As well, the transect may be re-located and measurements repeated at similar positions in any future sampling project.

Variability of gravels is typically greatest across riffle or spawning areas (Adams and Beschta 1980) and it was important to adequately measure the variability of the spawning gravels. Finally, Twin Creek sediments are not diffused across the entire channel at the sampling site. The transects provide an opportunity to examine differences in the distribution of fine sediments across the stream.

The sampling was conducted along two transects set at approximately right angles to the flow in the Nechako River. Twenty samples were collected on the first transect, starting 10 m from the bank (14 m from the tree marking the end of the transect) at an approximate spacing of 3 m. Sampling avoided the gravels nearest the bank because of potential deposition of fine sediments in the lower velocities downstream of Bert Irvine's docks. The sampling ended 82.5 m from the tree marking the left end of the transect (15 m from the left bank waterline). Seventeen samples were collected on the second transect (set 10 m downstream of the first transect) starting from the left bank. Spacing was three or four metres along this transect.

There was obvious vertical structure in many of the cores. It was not uncommon in the coarsest sediments to have an upper unfrozen layer in the core that was generally void of fines and consisted of the largest clasts observed in the substrate. In other cores a moderately well sorted surface layer overlay a lower layer containing a few extremely coarse cobbles (Appendix A). Cores were typically split to reflect any apparent vertical structure. Not all cores were split. In some cases the core was too poorly frozen, or too small, to adequately divide into two subsamples. Of the thirty-seven samples, thirty-one were split. (Samples 3,4,15,27,28 and 31 were analysed as combined samples.)

There were also distinct variations in the character of substrate materials along the transects, apparently in response to river sorting and to spawning activity. The coarsest surface material was associated with the deepest flows and the fastest stream velocities. Sediment character also varied near the dunes. Relatively coarser (and cleaner) sediments were observed immediately upstream and downstream of dunes. These sediments were particularly difficult to sample. It was hard to insert the core-barrel and difficult to freeze the sediments.

Laboratory Analysis of Gravel Samples

Samples were dried and sieved at the Department of Geography Sediment Lab at the University of British Columbia. Weights retained on a set of sieves distributed on 1/2 *phi* intervals from a minimum size of 0.063 mm (the sand/silt break) to 128 mm were recorded for each sample. Grain size distributions and grain size statistics for each sample are available for each sample (these results are maintained on file at Triton Environmental Consultants Ltd. and are not reproduced with the report due to their volume).

Substrate Analysis

Approximately 482 kg of gravel were removed from the Nechako River. This represents approximately 0.006% of the weight of gravels in a 30 cm thick layer in the spawning area at Bert Irvine's Lodge. Table 6 describes the typical weights and the range of weights collected. Total sample weights are typically less than 15 kg suggesting that the samples were less than 30 cm deep. The lower layer generally formed the greater portion of the sample.

Table 6
Weights of Gravel Samples Collected from the Nechako River, March 24 to 29,1990

Sample Type	Number	Average Weight (kg)	Standard Deviation (kg)
Total Core	37	13.2	2.7
Upper Layer	31	7.9	2.5
Lower Layer	31	5.8	1.3

Weights of individual splits of the samples are only adequate to accurately describe the grain size distribution up to 22 mm (0.1% criterion) or 45 mm (1.0% criterion). However, the overall grain size distribution may be estimated by agglomerating or pooling the total samples. Wolcott and Church (1991) point out that pooling small samples, each smaller than required for a complete sample at any point, seems to satisfactorily replicate the results of a project of bulk sampling.

The largest sampled clast was 180 mm; however boulders up to several hundred millimetres were observed on the bed surface. Materials are variable; with the upper layer coarser and cleaner than the lower layer. The pooled percentage of sediment less than 2 mm (i.e. coarse sands and finer) is 5.2% in the upper layer and 14.7% in the lower layer samples. Corresponding Fredle Indices are 9.0 and 4.0.

The fine sediments in the bed (coarse sand and finer) are similar in both layers. Fine sediments are predominantly coarse sands (approximately three-quarters of the total), with smaller proportions of medium sands, fine sands and silt and clays. Silts and clays provide less than 0.1% of the total sample weight in both the upper and lower layers.

Statistics of the Individual Cores

The grain size distribution curves were truncated at 45 mm in order to only include those grain sizes that are adequately sampled. Truncation meant that Fredle indices (based, in part, on the distribution of the coarser fraction) could not be calculated and gravel quality was calculated as the proportion of fines in the individual layers of the cores. These percent fines are greater than discussed in the previous section because they are calculated on a portion of the total gravel sample.

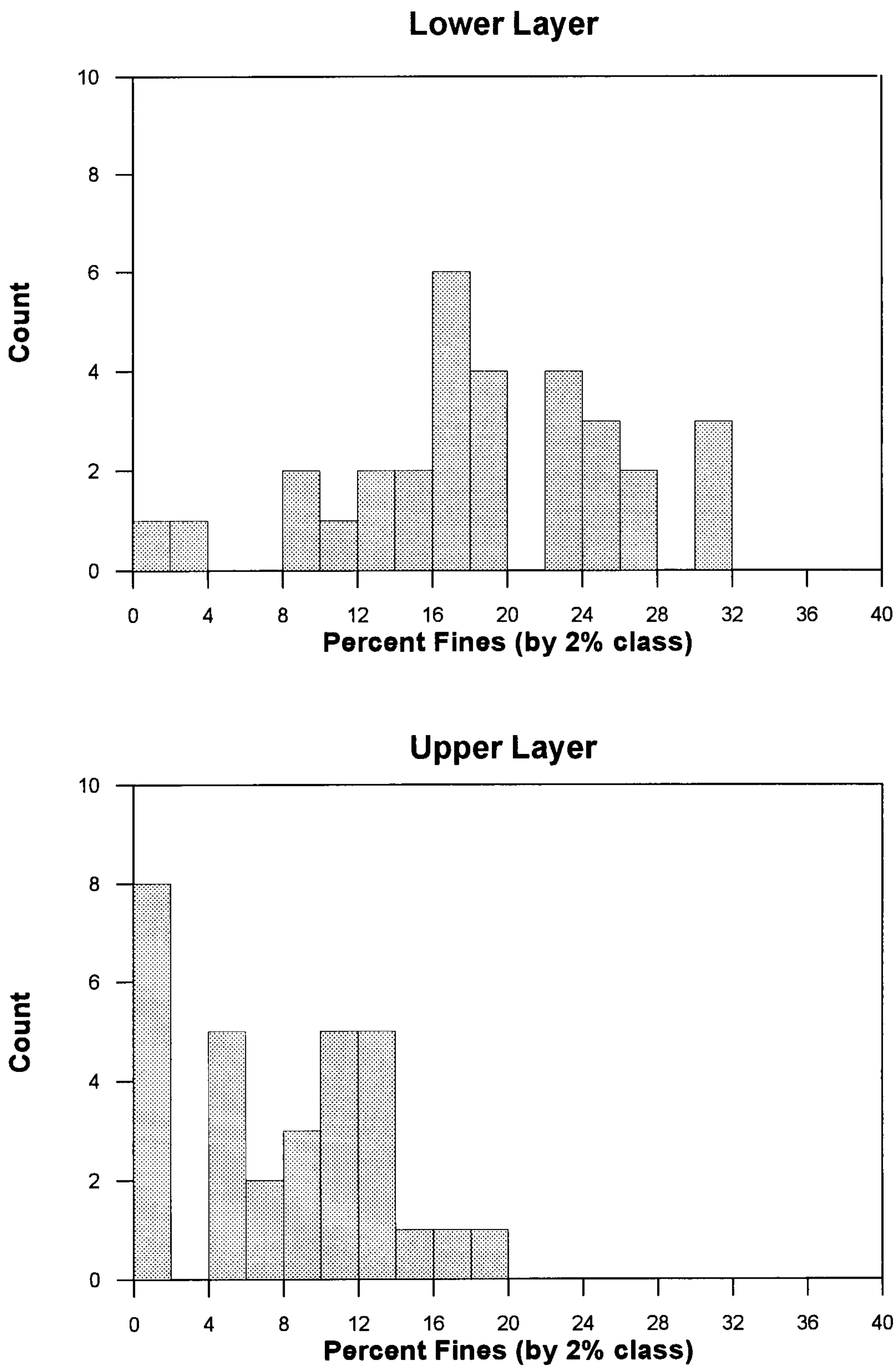
The percentage of fines in the individual cores is highly variable (Table 7). The percentage of fines in the lower layer and the total core cluster around a median or mean value (Figure 1) but the upper layer samples exhibit an unusual distribution. In this layer, an unexpectedly large number of samples are clustered between percent fines of 0 and 2%. These are mostly, but not entirely, associated with low percent fines in the lower layer of the core (Table 7). These may represent areas of the bed cleansed during redd construction in previous years though there is no

Table 7
Nechako River Gravel Samples: Percentage Fines (less than 2 mm)
in the Upper and Lower Layers and the Total Sample

Sample No.	Distance From Right Bank (m)	Percentage of Fines			Comment
		Total	Upper Layer	Lower Layer	
1A	10	26.93	19.90	31.87	
2A	13	12.01	4.70	22.15	
3A	16	3.54	—	—	upstream of dune
4A	19	10.24	—	—	upstream of dune
5A	22	12.73	10.04	18.53	
6A	25	14.53	8.03	25.72	
7A	28	11.14	5.25	22.37	
8A	31	13.41	7.97	25.38	
9A	34	17.26	12.99	24.14	
10A	37	5.94	0.42	9.32	
11A	40	18.00	12.68	26.63	
12A	43	10.64	7.14	22.52	looser material
13A	46	10.33	5.86	17.45	looser material
14A	49	11.39	5.97	16.57	looser material
15A	52	14.10			loose top layer;
16A	55	12.74	9.41	17.43	hard below
17A	58	6.15	1.29	9.77	
18A	61	12.87	11.14	16.11	
19A	64	13.83	4.15	17.67	easy penetration
20A	67	18.20	16.26	22.61	easy penetration
21B	67	19.19	14.70	26.00	easy penetration
22B	64	14.99	13.09	19.33	easy penetration
23B	61	21.68	13.80	31.04	
24B	57	15.83	11.66	19.43	
25B	53	13.53	13.8	13.07	
26B	49	10.8	1.7	31.87	
27B	45	12.92			poorly frozen
28B	41	2.13			
29B	37	11.02	8.17	14.7	
30B	33	1.4	1.3	1.54	not well frozen
31B	30	6.57			poorly frozen; small
32B	27	1.88	0.32	3.91	
33B	24	5.37	0.07	10.46	
34B	21	12.8	11.44	14.25	left edge of dune
35B	18	9.94	1.26	12.47	downstream of dune
36B	15	11.63	0.34	16.28	dune crest
37B	12	15.07	10.99	19.73	
Mean		11.97	7.45	17.59	
Std. Dev.		5.38	5.56	8.40	
Cv		45	75	48	

Note: Samples truncated at 45 mm.

Figure 1
Histogram of Percent Fines in Truncated Gravel Samples of the Upper and Lower Layers of the Nechako River



obvious surface expression associated with many of the cleaner core samples.

Preparation of a baseline set of gravel quality samples requires separating areas affected by biological cleansing from those that apparently have not been recently altered. Table 8 shows the statistics of the two sets. They are separated by the percent fines in the upper layer; less than 2% and biological activity is assumed, greater than 2% and the samples are considered undisturbed. Sample 1, closest to the right bank, was also eliminated because the upper layer has apparently been filled by deposition of fine material.

Figure 2 plots the variation of percent fines across the Nechako River for the upper and lower layer samples (i.e. the gravel quality sample set identified in Table 8). There is a statistically significant increase in percent fines across the channel in the upper layer. Though significant, this trend only explains a small portion of the total variance. There is no significant trend across the channel for percent fines in the lower layer.

SUMMARY AND CONCLUSIONS

The August 1, 1989 workshop produced several recommendations to investigate either complementary or alternate techniques to monitor substrate quality in the Nechako River. These are discussed in the subsection Workshop Recommendations. Some of these recommendations have already been implemented.

The following conclusions focus on the gravel quality and composition sampling project in the Nechako River:

1. A literature review indicates that the existing gravel quality and composition measurements on the Nechako River are too few to adequately characterize the substrate.
2. A literature review indicates that existing substrate samplers have limitations that produce biased samples. A sediment sampler was developed that attempted to combine the advantages of the McNeil and freeze-core samplers.
3. Review of the literature and workshop discussions indicate that substrate sampling provides an index to the quality of the spawning and incubation environment. Repeated measurements over time may indicate changes in substrate that may be assumed to also reflect changes in the spawning or incubation environment. The substrate sampling project may be combined with other measures such as sediment traps or fry emergence trapping to best understand the incubation environment.

Review of the literature and workshop discussions indicate that (ie. for best results):

- i) Sample volume or weight should be maximized in any substrate sampling project;
- ii) For the typical Nechako River substrate sizes and expected sample volumes on the Nechako River the samples should be truncated to eliminate those grain sizes that are not adequately sampled;
- iii) Thirty to fifty samples are required to reduce the precision of the estimate of the mean percent fines to approximately 10% (95% confidence level);
- iv) Spawning by chinook salmon will clean the gravels and produce different gravel quality in disturbed and undisturbed areas;
- v) Samples should be collected at several spawning sites to accurately assess overall gravel quality;
- vi) At least one, and possibly two years of sampling are needed for baseline data collection at the sampling sites; and,
- vii) Further sampling should proceed on three to five year intervals which may be adjusted based on project results.

4. The 1989/1990 gravel sampling project wasa reconnaissance effort that:
   - i) Determined the variability of the substrate at a site on the Nechako River; and,

Figure 2
Variability of Percent Fines in Gravel Fines With Distance From the Right Bank of the Nechako River: Upper and Lower Layers

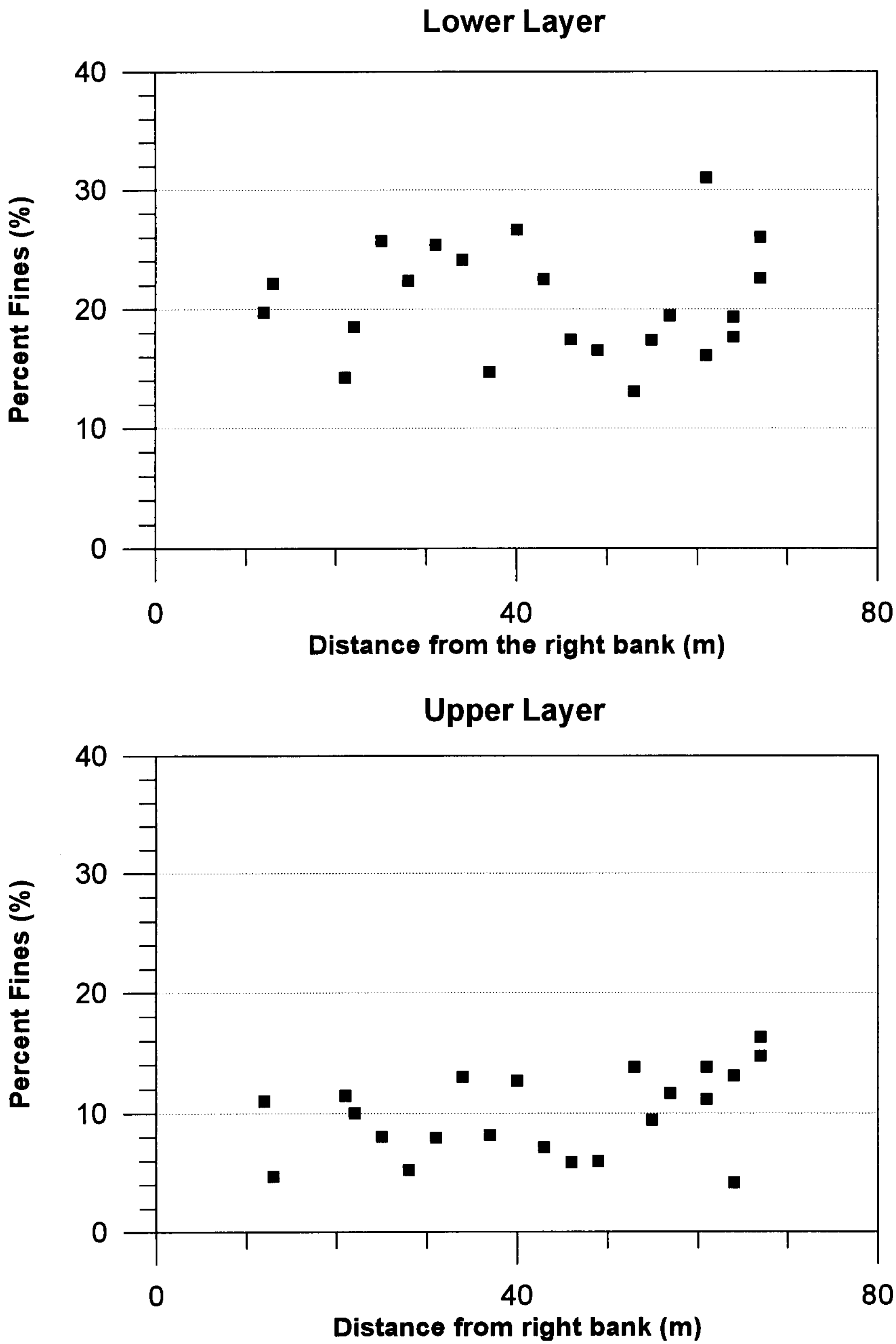


Table 8
Nechako River Gravel Samples: Baseline Gravel Quality Samples
Distinguishing Recently Cleansed Areas

Sample No.	Distance From Right Bank (m)	Percentage of Fines			Comment
		Total	Upper Layer	Lower Layer	
Undisturbed Samples (upper layer greater than 2% fines)					
2A	13	12.01	4.70	22.15	
5A	22	12.73	10.04	18.53	
6A	25	14.53	8.03	25.72	
7A	28	11.14	5.25	22.37	
8A	31	13.41	7.97	25.38	
9A	34	17.26	12.99	24.14	
11A	40	18.00	12.68	26.63	
12A	43	10.64	7.14	22.52	looser material
13A	46	10.33	5.86	17.45	looser material
14A	49	11.39	5.97	16.57	looser material
16A	55	12.74	9.41	17.43	hard below
18A	61	12.87	11.14	16.11	
19A	64	13.83	4.15	17.67	easy penetration
20A	67	18.20	16.26	22.61	easy penetration
21B	67	19.19	14.70	26.00	easy penetration
22B	64	14.99	13.09	19.33	easy penetration
23B	61	21.68	13.80	31.04	
24B	57	15.83	11.66	19.43	
25B	53	13.53	13.80	13.07	
29B	37	11.02	8.17	14.70	
34B	21	12.80	11.44	14.25	left edge of dune
37B	12	15.07	10.99	19.73	
Mean		14.24	9.97	20.58	
Std. Dev.		2.97	3.44	4.54	
Cv		21	35	22	
Cleansed Samples (upper layer less than 2% fines)					
10A	37	5.94	0.42	9.32	
17A	58	6.15	1.29	9.77	
26B	49	10.80	1.70	31.87	
30B	33	1.40	1.30	1.54	not well-frozen; v.c.
32B	27	1.88	0.32	3.91	
33B	24	5.37	0.07	10.46	
35B	18	9.94	1.23	12.47	downstrean of dune
36B	15	11.63	0.34	16.28	dune crest
Mean		6.64	0.83	11.95	
Std. Dev.		3.63	0.57	8.68	
Cv		55	68	73	

Note: Samples truncated at 45 mm.

ii) Collected sufficient samples to develop baseline gravel quality data set at one spawning site.

Thirty-seven samples were collected on two transects at km 19.3 in March 1990. The samples averaged 13.2 kg. The samples were split into an upper layer (averaging 5.8 kg) and a lower layer (averaging 7.9 kg).

5. Pooling of all samples indicates that fine sediments (primarily coarse and medium sand) compose 9.4% of the substrate. Fine content in the upper layer of the substrate was 5.2%; in the lower layer it was 14.7%. These values are higher than previous measurements (Table 5) though direct comparison is difficult because of different techniques and sample areas.

6. The percentages of fines in the individual samples were calculated after truncating the samples at 45 mm. An unusual distribution is observed for the upper layer samples. An anomalously large number of samples with very low percent fines is recorded; this is assumed to result from disturbance of the gravels by chinook salmon.

7. Removal of anomalous samples produced by spawning activity left 22 samples of reasonably undisturbed substrate. For truncated samples, the mean upper layer percent fines was 10.0% (coefficient of variation 35%) and the mean lower layer percent fines was 20.6% (coefficient of variation 22%).

8. Repetition of the 1989/1990 sampling project should allow detection of changes of approximately 10% in the mean percent fines, i.e., increases (or decreases) to approximately 11% (or 9%) in the upper layer or to approximately 22% (or 18%) in the lower layer. Approximately 200 t of sand and finer sediments would need to be added to (or removed from) the spawning area at Bert Irvine's to produce a statistically detectable increase or decrease in the mean percent fines in the undisturbed substrate.

Recommendations for a Substrate Sampling Project

Substrate sampling provides an index to the quality of the spawning and incubation environment. Repeated measurements over time may indicate changes in substrate that may be assumed to also reflect changes in the spawning or incubation environment. The following recommendations are appropriate for designing a baseline substrate sampling project:

1. The spawning area at Bert Irvine's is upstream of most of the major sediment sources and under typical conditions, only very slow changes are expected in this reach. We recommend that two or three additional baseline data collection sites be established at other spawning areas along the upper Nechako River.

2. The combined McNeil freeze-core sampler used in the 1989/1990 project collected satisfactory samples under difficult conditions; water depths ranged to 1 m, velocities to more than 1 m/s and the substrate was very coarse and clean. Further substrate sampling should utilize this instrument to prevent sampler design from biasing comparison of the baseline and future gravel quality samples.

3. We recommend a project of approximately 40 samples per spawning area in order to statistically distinguish changes in substrate quality of about 10%. The results of the first year of baseline data collection should be carefully reviewed to determine if additional sampling is required at any of the sites.

4. We recommend that the substrate sampling be carried out in conjunction with other projects or observations that help to clarify any degradation of spawning or rearing habitat and would assist in interpreting the gravel quality measurements. The gravel sampling project should be completed at sites where fry emergence trapping projects, projects to measure dissolved oxygen in redds, or sediment trapping projects are undertaken.

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APPENDIX A
Photographs of Substrate Sampling
of the Nechako River, March 23 to 30, 1990

Plate 1 Core Barrel Inserted into Substrate (Note size of substrate).

Plate 2 Adding Liquid Nitrogen to the Freeze-core Probe. (The probe projects approximately one foot above the top of the core barrel and handle).

Plate 3 Core Barrel and Frozen Core

Plate 4 Core and Freeze-core Probe