APPENDIX D

EVALUATION OF THE TEXTURAL COMPOSITION OF SULTAN RIVER SALMONID SPAWNING GRAVELS FOLLOWING HYDROELECTRIC PROJECT CONSTRUCTION

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HENRY M. JACKSON HYDROELECTRIC PROJECT
FERC PROJECT 2157

EVALUATION OF THE TEXTURAL COMPOSITION OF SULTAN RIVER SALMONID SPAWNING GRAVELS FOLLOWING HYDROELECTRIC PROJECT CONSTRUCTION

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SUMMARY

The Henry M. Jackson (Sultan River) Hydroelectric Project, in Snohomish County, Washington, has significantly altered the flow regime in 16 miles of river downstream from Culmback Dam. During project licensing, the Public Utility District No. 1 of Snohomish County (PUD) agreed with fish and wildlife agencies to determine short- and long-term effects of sedimentation and compaction of spawning gravels due to project construction and operation. This was agreed to since various anadromous fish species/life stages use the 9.7-mile river reach below the Everett diversion dam. In order to evaluate pre-construction conditions, a baseline study of spawning gravel texture was initiated by the PUD in the winter and spring of 1982. In order to determine effects of project construction and operation on Sultan River channel substrate composition, gravel samples were collected in winter and spring 1984 (February - April) following termination of construction activities. Similarly, gravel samples were collected in fall 1987 and 1994 (September) to determine the effects of 3 and 10 years of project operation on channel substrate composition. The PUD initiated the 1994 study to determine the effect (if any) of the Second Interim Operating Plan on spawning gravel quality. The plan was implemented beginning in November 1989. The study will also document gravel quality after nearly four years of river flow, which has been well below levels necessary to facilitate armor layer breakup (scouring), the mechanism for transportation of accumulated fines from the substrate. There have been no spills from Culmback Dam since 1990, and no scouring flows during that period. Therefore, the spawning gravel quality measured during this study investigates a condition in which fines have accumulated in the absence of scouring flows. This report summarizes the results of the 1994 sampling, compares these results to 1982, 1984, and 1987 data, and evaluates spatial and temporal trends in channel substrate composition following project construction and 10 years of hydroelectric project operations.

Objectives of this study were to:

1. Determine the spatial variability of Sultan River substrate samples among selected spawning reaches between the diversion dam and the river mouth;
2. Determine the vertical heterogeneity of sediments within and among spawning reaches; and
3. Compare pre-construction substrate composition with that of post-construction.

Streambed sediments were removed from five salmonid spawning reaches using a tri-tube freeze-core sampler. Sampling locations were mutually agreed upon and selected in cooperation with fisheries biologists from state and federal agencies. Sampling purposely avoided spawning redds to the extent that redds were apparent to the observer. A total of 35, 12-inch deep core samples were collected from 7 transects at the five spawning reaches. Each core was subdivided into four, three-inch strata. Because one subsample (i.e., stratum) was lost, only 34 of the 35 cores were complete and evaluated (a total of 136 subsamples).

Sediment samples were analyzed by wet sieving through a graduated series of Tyler screens. Textural composition was calculated using statistical software on a personal computer. Statistical analyses provided various substrate statistics and expressed texture in terms of geometric mean diameter and percentage of fines less than 0.841 mm in diameter.

Analysis of 1994 samples showed the textural composition of streambed sediments at spawning reaches was generally similar to that evaluated for the same sites prior to (1982) and following construction (1984 and 1987).

Geometric mean diameter of sediments at all stations were generally finer than samples collected prior to construction and during previous post-construction monitoring. Because of the high variability in particle size distribution among and within stations, there were few statistically significant differences among pre-construction, 1984 post-construction, 1987 post-operations and

1994 post-operations data. Small, but statistically significant, decreases in geometric mean diameter were observed after 10 years of project operation at two stations (S2 and S3) and for all stations combined. There were no consistently significant differences in substrate composition upstream and downstream of the project. Because the average percent fines remained unchanged or decreased at all stations, decreases in the geometric mean diameter appear to be attributable to accumulation of smaller gravels rather than fines (i.e., less than 0.841 mm).

Average amounts of fines at all five stations was comparable or decreased over the 10 year study period. The average proportion of fine sediment less than 0.841 mm in diameter for all stations ranged between 3% and 10% in 1994, comparable to previous years. Small, but statistically significant, decreases in the percentage of fines was observed at two upstream stations (S4 and S5), and no statistically significant differences from previous years were observed at the three downstream stations (S1, S2, and S3).

Sediment stratification was apparent during all four years of study. During 1994 the combined mean values of the upper 3 inches of substrate contained a lower percentage of fines and a greater geometric mean particle size than did the underlying 9 inches of sediment. In addition, most stations exhibited a greater proportion of fines and smaller geometric mean diameters between 3 and 9 inches beneath the streambed, than in the coarser, 9- to 12-inch substrate. These observations were consistent with those of past years' studies.

Although geometric mean diameter has decreased somewhat at all stations since pre-construction, the percent fines remains very similar after 10 years of operation. It appears the textural composition of Sultan River spawning gravels following project construction and operation remains quite good and appears to provide suitable conditions to yield high rates of embryonic survival, depending on other survival-limiting factors.

Based on the substrate indices examined in this study, the need for mitigative measures for maintaining the quality of salmonid spawning gravels is not indicated.

TABLE OF CONTENTS

List of Tables

TABLE OF CONTENTS

Page

List of Tables

List of Figures

LIST OF APPENDICES

1. INTRODUCTION

1.1 AUTHORIZATION

This study was authorized and funded by Public Utility District No. 1 of Snohomish County, Washington (PUD). It constitutes the fourth of a series of studies of the effects of the Sultan River Hydroelectric Project, Federal Energy Regulatory Commission (FERC) Project No. 2157, on the textural composition of salmonid spawning gravels.

1.2 PROJECT BACKGROUND

Hydroelectric development on the Sultan River requires diversion of water from Culmback Dam (RM 16.5) to a powerhouse (RM 4.5) having a total installed capacity of 112 megawatts (MW) (Figure 1). Water is returned to the river at the powerhouse, if operating, or at the City of Everett diversion dam (RM 9.7), regardless of powerhouse operation. Water returned upstream to the diversion dam provides controlled flows downstream to the powerhouse at all times, ensuring suitable flow conditions for anadromous fishes. For further details of project features, flow regimes, existing aquatic and terrestrial resources, and expected project impacts, refer to PUD (1982).

1.3 ENVIRONMENTAL SETTING

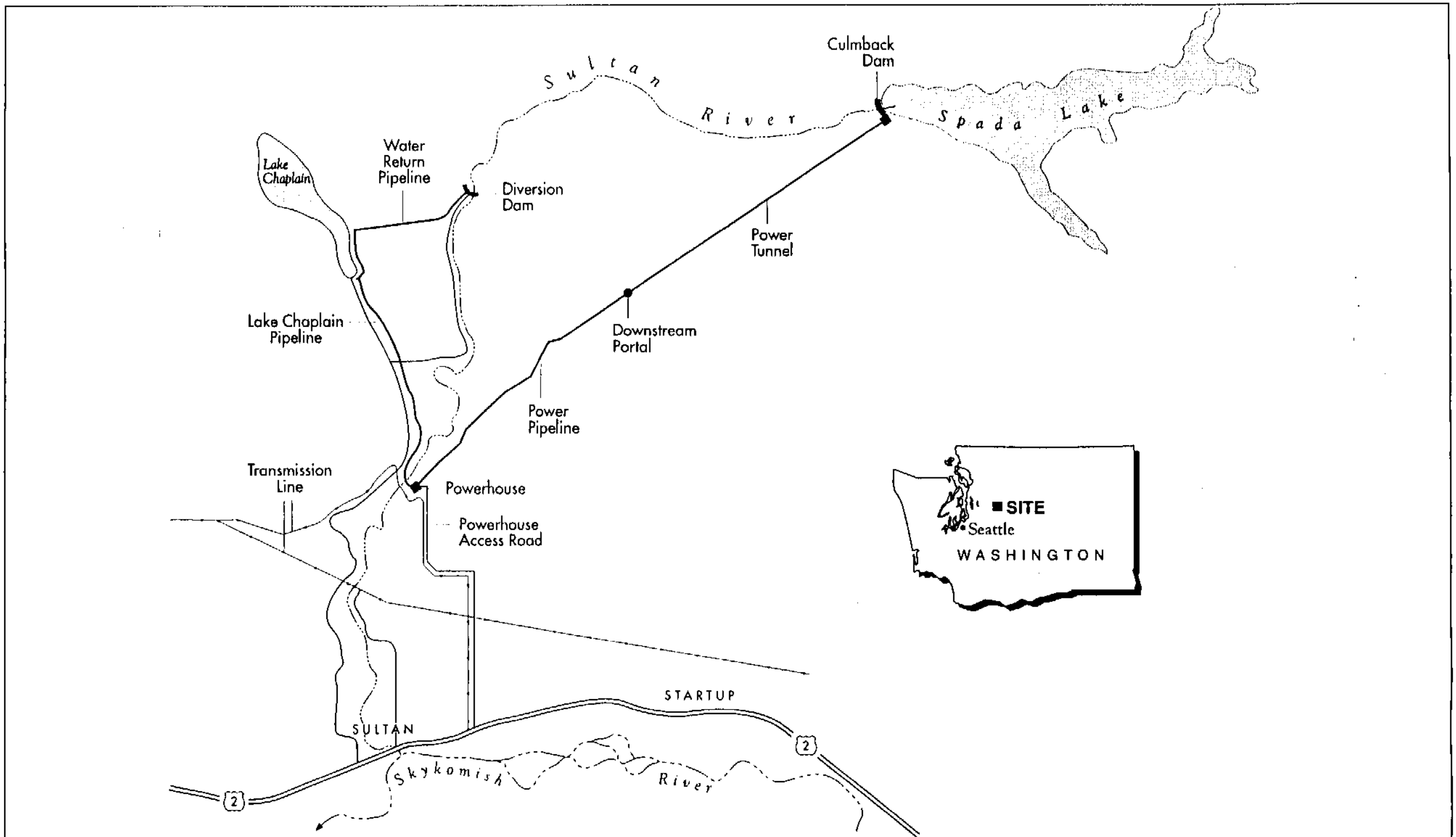
The textural composition of streambed material results primarily from a river's flow regime, local geology, the nature of soils and erosive activities in its drainage, and streambed gradient. In the Sultan River, these factors have combined to provide streambed material (gravels) that are presently used by spawning anadromous fishes upstream to the Everett diversion dam (RM 9.7). Anadromous species that use the Sultan River include chinook, coho, pink and chum salmon, steelhead, and sea-run cutthroat trout and Dolly Varden.

Between RM 9.7 and RM 3.0, the Sultan flows through a narrow canyon in a series of pools and riffles. The river bed here primarily consists of bedrock, boulders, and cobble. Gravel patches occur sparsely throughout this section and have been historically subjected to extreme flow fluctuations reaching over 10,000 cubic-feet-per-second (cfs) every 1 in 3.2 years (Eicher, 1981). Figure 2 shows Sultan River daily inflow and exceedance frequency. High flows can produce sufficient velocity to scour the streambed and cause gravel movement. This can result in dislodgment and destruction of salmonid eggs and alevins, and in extreme cases, cause actual loss of spawning gravel (Burgner, 1982).

Below the powerhouse (RM 4.5), the river flows through approximately 1.5 miles of canyon followed by 3 miles of lower-gradient glaciated soils until reaching its confluence with the Skykomish River at the town of Sultan. Below the canyon, the river widens and the channel occasionally splits, creating islands and numerous low-velocity side channels. Cobble and gravel are abundant, providing conditions suitable to anadromous fish spawning.

1.4 PROJECT EFFECTS

Hydroelectric development has altered the flow regime of the Sultan River, providing increased minimum flows during low flow periods and reduced frequency and magnitude of low to moderate flood flows below Culmback Dam to the river mouth. Between the diversion dam (RM 9.7) and powerhouse (RM 4.5), flows are regulated continuously at levels determined to provide optimum or adequate conditions for salmonid life stages. Except during extreme high floods when spills occur at Culmback Dam, winter and spring freshets no longer exist in this river section (PUD, 1982). While elimination of freshets would appear to offer improved flow conditions by providing water depths and velocities more favorable to fish life, these freshets can also play an important



0 1 2
Scale in Miles

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FIGURE 1

GENERAL PLAN OF HYDROELECTRIC PROJECT

SULTAN RIVER SPAWNING GRAVEL EVALUATION

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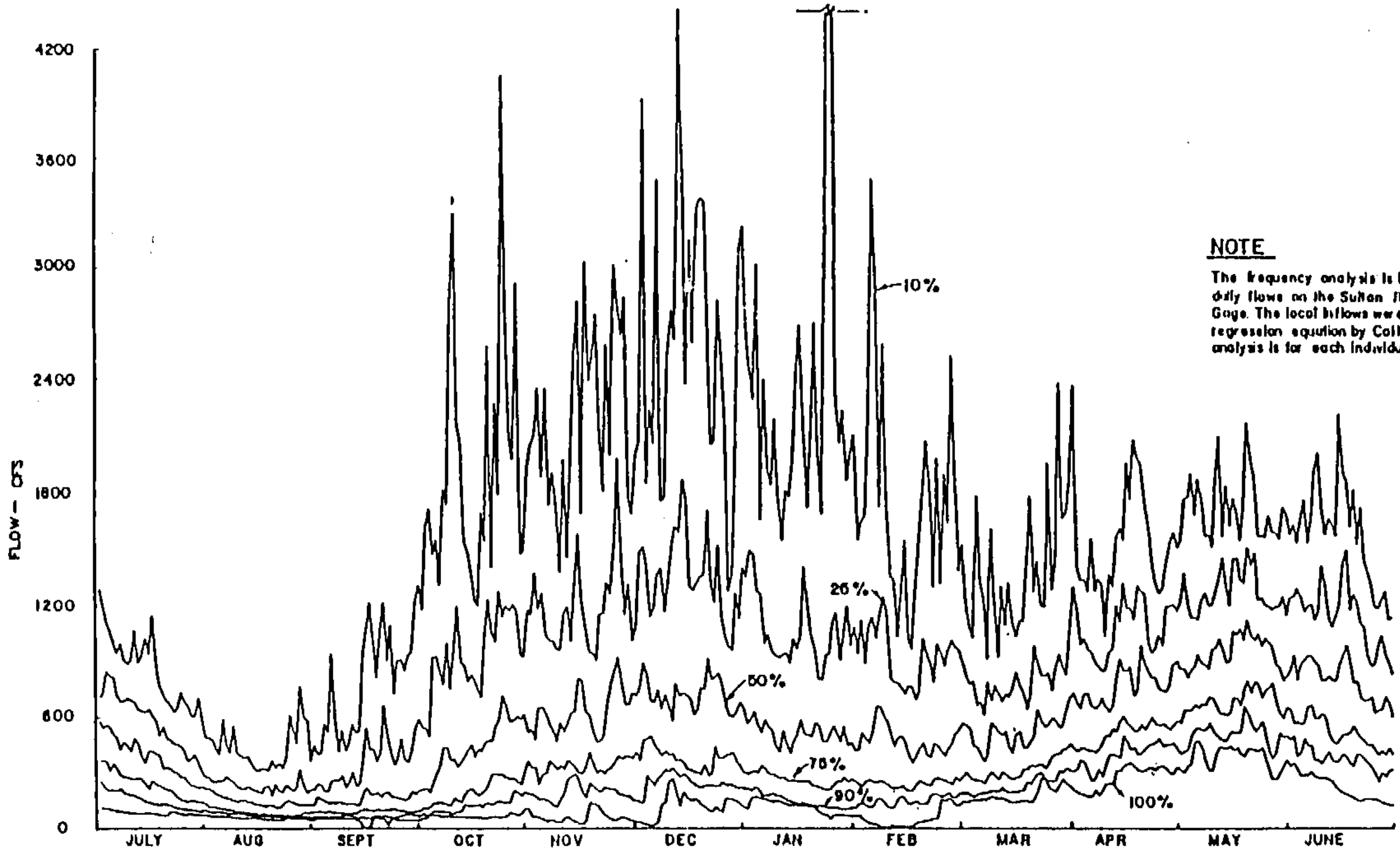

NOTE

The frequency analysis is based on 40 years of daily flows on the Sultan River at the Startup Gage. The local inflows were analyzed based on a regression equation by Collins, 1971. The frequency analysis is for each individual day of the year.

SOURCE: Public Utility District No. 1 of Snohomish County 1980.

FIGURE 2

SPADA LAKE DAILY INFLOW AND EXCEEDANCE FREQUENCY

SULTAN RIVER SPAWNING GRAVEL EVALUATION

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role in cleansing streambeds of fine sediments (Shapley and Bishop, 1965). For this reason, it becomes important to know whether or not flow constancy for extended periods of time results in a buildup of fine sediments in streambed gravels.

Downstream of the powerhouse, project flows will also be stabilized during times of high precipitation or runoff; however, flows of 1,300 cfs or greater will persist for longer durations. This series of gravel quality studies was developed to determine whether or not such a change in the flow regime will result in altered streambed texture in the lower river.

An increased proportion of fine sediments in salmonid spawning gravels may reduce gravel pore size and permeability, thus, influencing survival to emergence of incubating embryos. This occurs primarily as a result of (1) decreased intragravel water velocity, which carries oxygen to and removes metabolites from incubating embryos and (2) decreased intragravel movement and emergence of alevins (Lotspeich and Everest, 1981).

A number of different measures and definitions of fines have been established in the literature, ranging from particles less than 6.4 mm to those less than 0.841 mm diameter. Based on laboratory studies, successful emergence of alevins from redds composed of sand and gravel mixtures decreases rapidly as percent fines (2-6.4 mm) exceeds approximately 15% (Bjornn and Reiser, 1991). Others have indicated that fines less than 6.4 mm are harmful, when at least 20% are less than 0.841 mm diameter (Stowell et al., 1983).

1.5 STUDY SCOPE AND OBJECTIVES

As part of the process to obtain a FERC license to construct the project, an Uncontested Offer of Settlement was made between the licensee and the joint agencies: Washington Department of Fisheries (WDF), and Washington Department of Wildlife (WDW), National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and the Tulalip Indian Tribes. Item 3 of that agreement requires that a determination be made of "short-term and long-term impacts of sedimentation, gravel compaction and spawning gravel reduction in the Sultan River due to construction and operation of the project." A three-phase evaluation of the textural composition of streambed sediments (1) prior to project construction, (2) following completion of construction, but prior to project operation, and (3) three and ten years following project operation has been conducted to determine whether or not spawning gravel quality has changed as a result of project construction and/or operation.

The subject of this report is an evaluation of the textural composition of Sultan River streambed gravels following 10 years of project operation. The PUD initiated the 1994 study to determine the effect of the Second Interim Operating Plan on spawning gravel quality. The plan was implemented beginning in November 1989. The study will also document gravel quality after nearly four years of river flow, which has been well below levels necessary to facilitate armor layer breakup (scouring), the mechanism for transportation of accumulated fines from the substrate. There have been no spills from Culmback Dam since 1990, and no scouring flows during that period. Therefore, the spawning gravel quality measured during this study investigates a condition in which fines have accumulated in the absence of scouring flows. Results of this study are compared to gravel texture prior to construction (1982), immediately following construction (1984), and three years following project operation (1987). Objectives of this study were completed by:

1. Determining the spatial variability of streambed samples among spawning reaches between the diversion dam and the river mouth;
2. Determining the vertical heterogeneity of sediments within and among spawning reaches; and
3. Comparing pre-construction Sultan River sediment composition with that of post-construction.

2. METHODS

2.1 SAMPLE COLLECTION

Streambed sampling was conducted in September 1994. In 1987, streambed sampling also was conducted in September, unlike previous sampling, which occurred in winter and spring of 1982 and 1984. The shift in the sampling season was requested by the joint agencies. Sampling in September (at the beginning of the spawning period for salmon) follows an extensive period of low flow (approximately 200 cfs). Thus, it should represent the time of year when the highest percentage of fine sediment is present, i.e., the "worst case" conditions. Sampling in previous years (1982 and 1984) was conducted in the winter when eggs of anadromous fish were incubating in the gravel and subject to surrounding gravel composition.

Substrate samples used to evaluate the quality of spawning gravels were collected at five spawning reaches (sampling stations) shown in Figure 3. The locations of these stations were cooperatively selected during the baseline study phase by fisheries biologists from the joint agencies. Salmon or steelhead have been observed at all study sites during spawning surveys conducted by WDF and WDW (now Washington State Department of Fisheries and Wildlife) since 1978. Table 1 shows spawning use at all sampling stations.

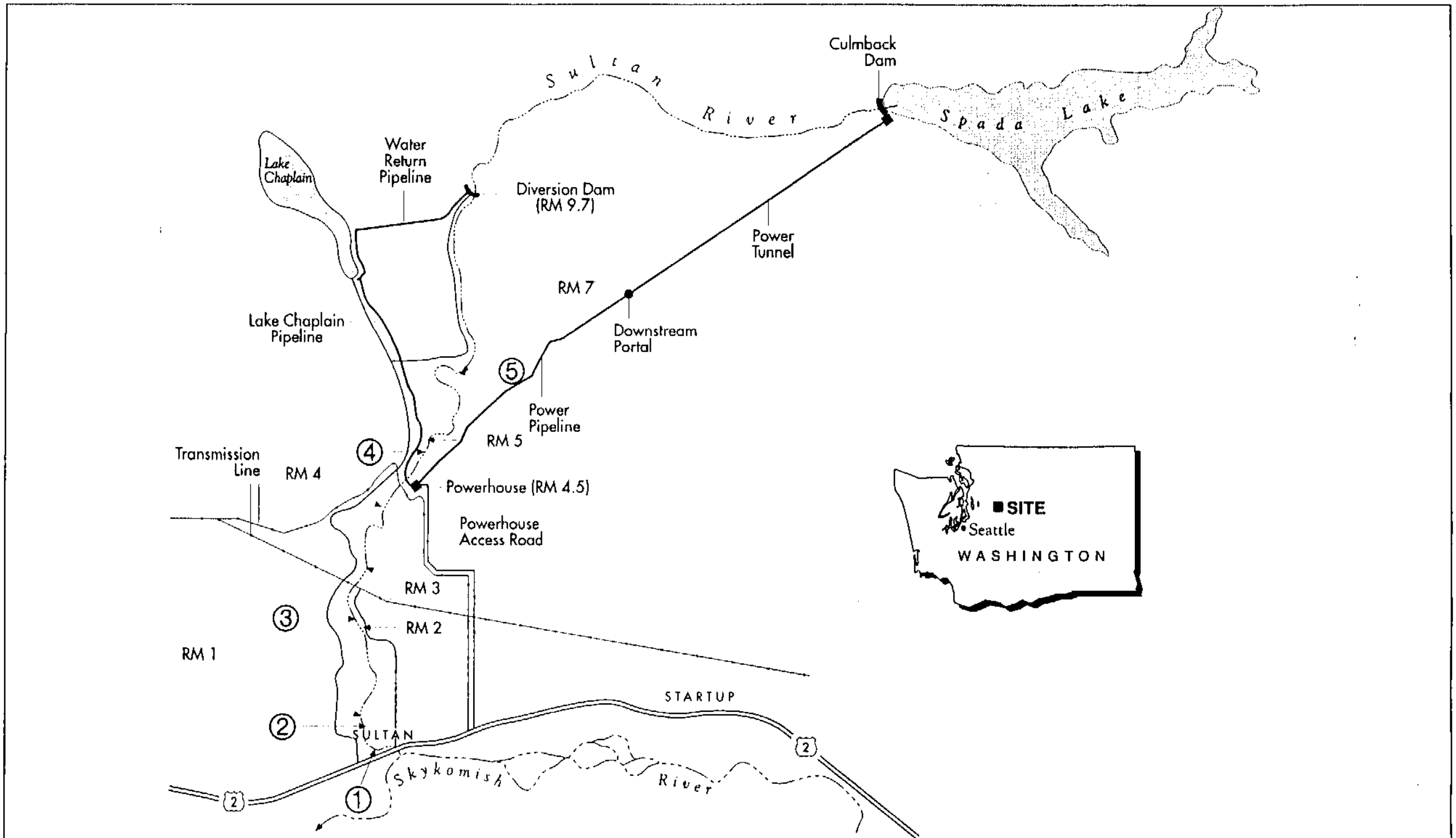
Of the five stations, three were located downstream and two upstream of the powerhouse (RM 4.5). The stations, henceforth referred to as S1, S2, S3, S4, and S5, are located as follows:

- S1 (RM 0.1) lies along the west (right bank, just north of SR 2 bridge at the City of Sultan at Sportsmans Park (Figure 4).
- S2 (RM 0.8) is mid-channel, approximately 300 yards downstream of Winters Creek confluence (Figure 5).
- S3 (RM 2.5) is along the east (left) bank, approximately 400 yards downstream from the BPA powerline crossing at the end of Trout Farm Road (Figure 6).
- S4 (RM 4.7) Transect 4A is located adjacent to the west bank, approximately 50 yards downstream from the former Chaplain Creek gaging station (Figure 7) and transect 4B is located adjacent to the east bank, approximately 300 yards upstream of transect 4A.
- S5 (RM 7.2) Transect 5A is situated along the west bank between Marsh Creek confluence and Horseshoe Bend in the area referred to as the Gold Camp approximately 50 yards downstream of the original transects (Figure 8). Transect 5B is located in a pool tailout on the bank opposite of the original transect.

Table 1: ANADROMOUS FISH SPAWNING USE AT GRAVEL SAMPLING STATIONS, SULTAN RIVER, WASHINGTON

Station	River Mile	Primary Spawning Use[1]	Occasional Spawning Use	Habitat Type
S1	0.1	SH, P	CN	Run
S2	0.8	P	CN, CO	Riffle
S3	2.5	SH, CH, CN, CO, P	--	Riffle
S4	4.7	SH,CN	P, CO	Run
S5	7.2	SH, CH	CO, P	Pool Tailout

[1]species code: SH (steelhead), CH (chum), CN (chinook), CO (coho), P (pink)
Source: Schuh, M., 1995.



N

0 1 2

Scale in Miles

LEGEND

RM River Mile
① Gravel Sampling Stations

FIGURE 3

SULTAN RIVER GRAVEL SAMPLING STATIONS

SULTAN RIVER SPAWNING GRAVEL EVALUATION

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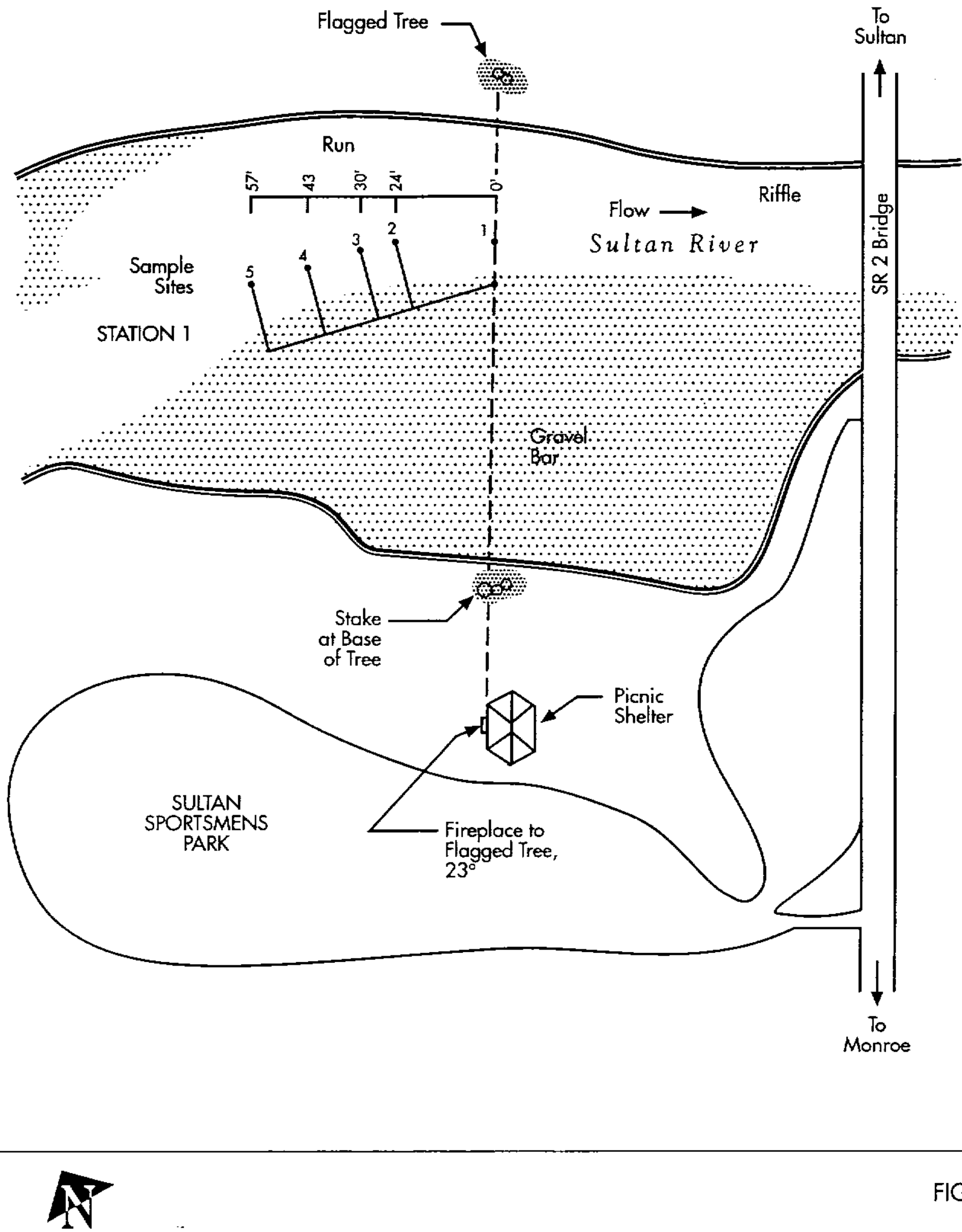

FIGURE 4

GRAVEL SAMPLING STATION S1

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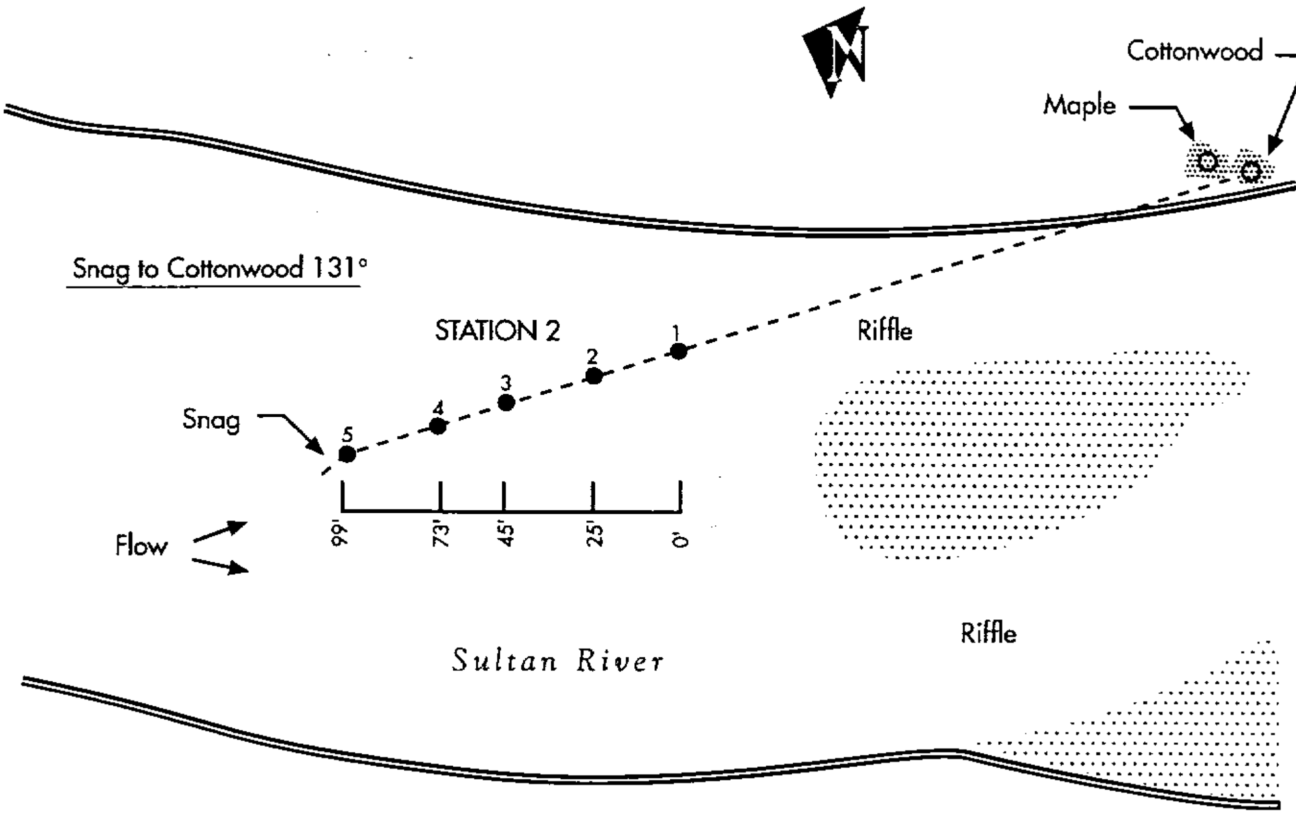

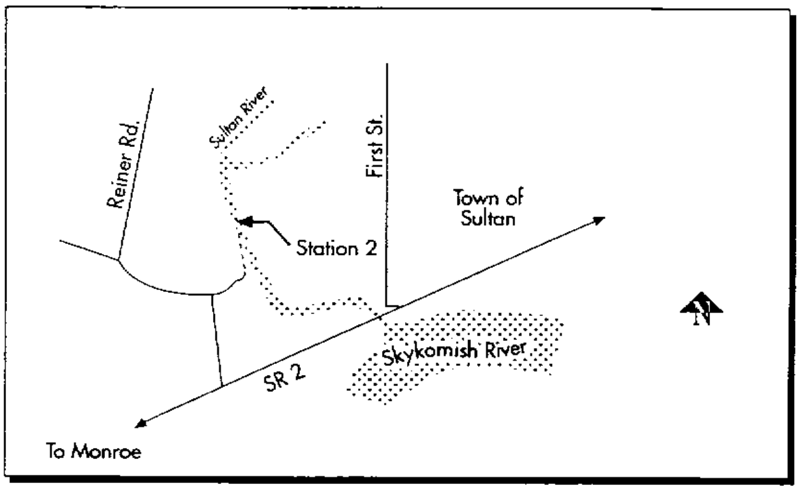

FIGURE 5

GRAVEL SAMPLING STATION S2

SULTAN RIVER SPAWNING GRAVEL EVALUATION

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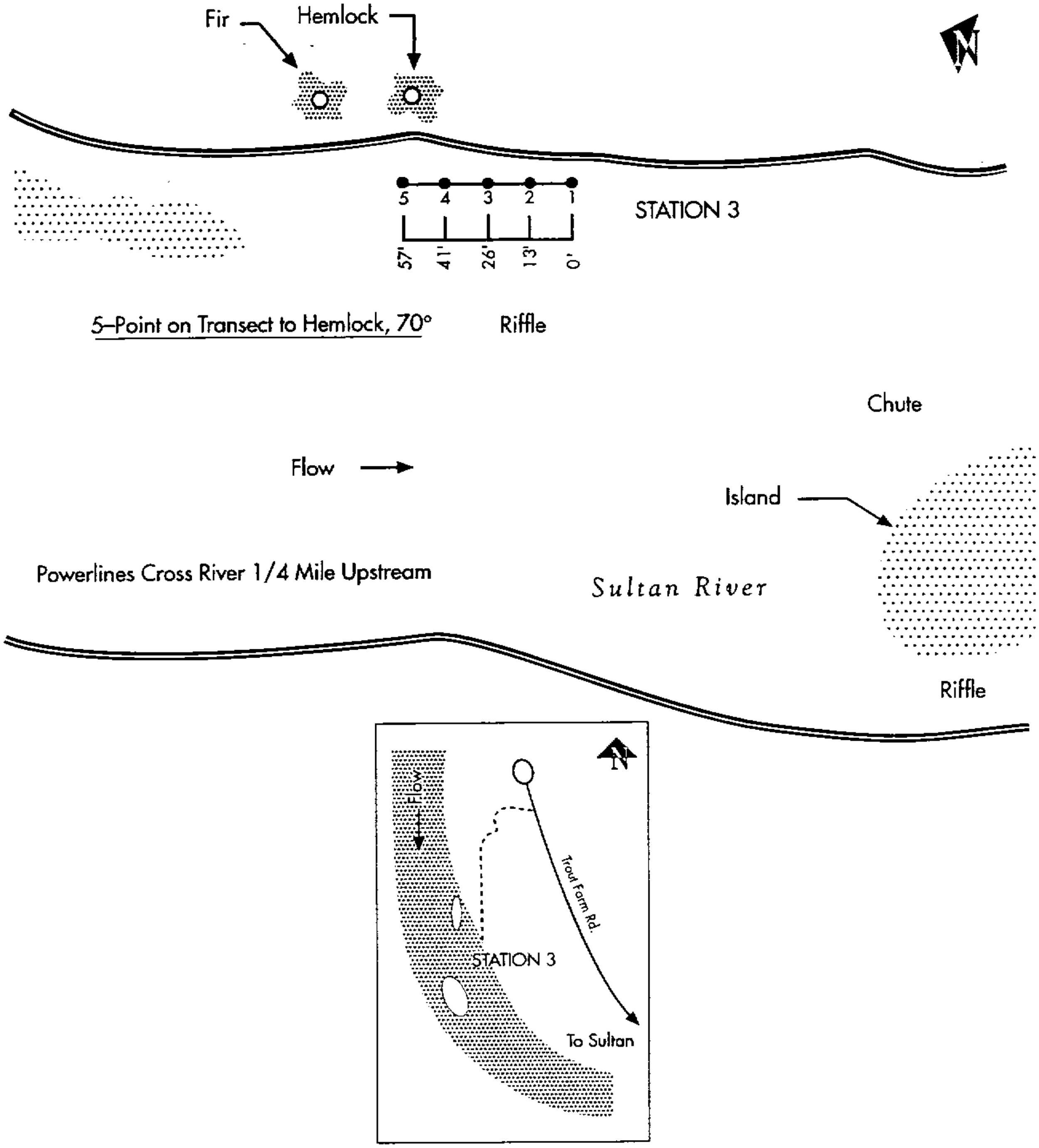

FIGURE 6

GRAVEL SAMPLING STATION S3

SULTAN RIVER SPAWNING GRAVEL EVALUATION

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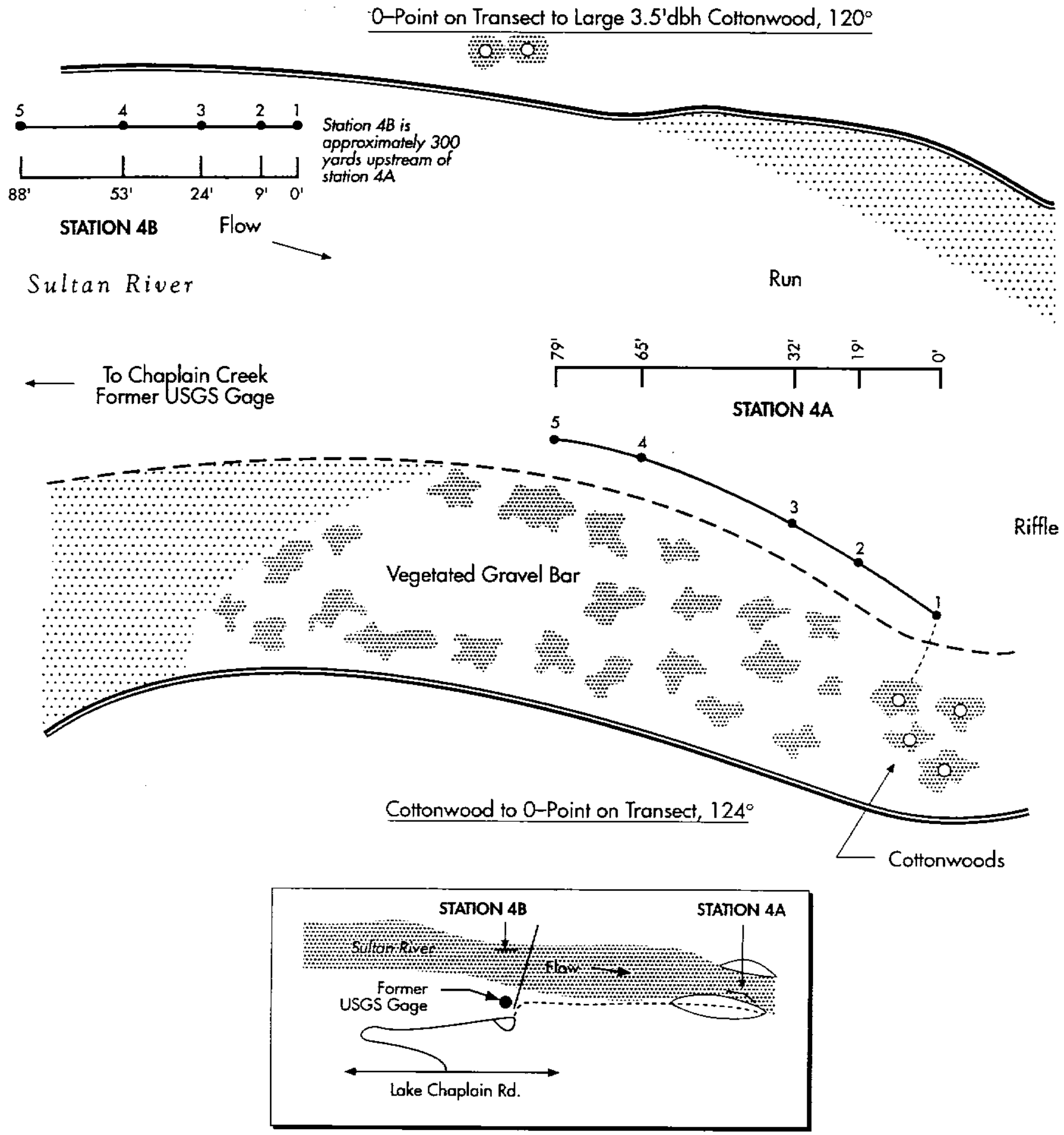

FIGURE 7

GRAVEL SAMPLING STATION S4

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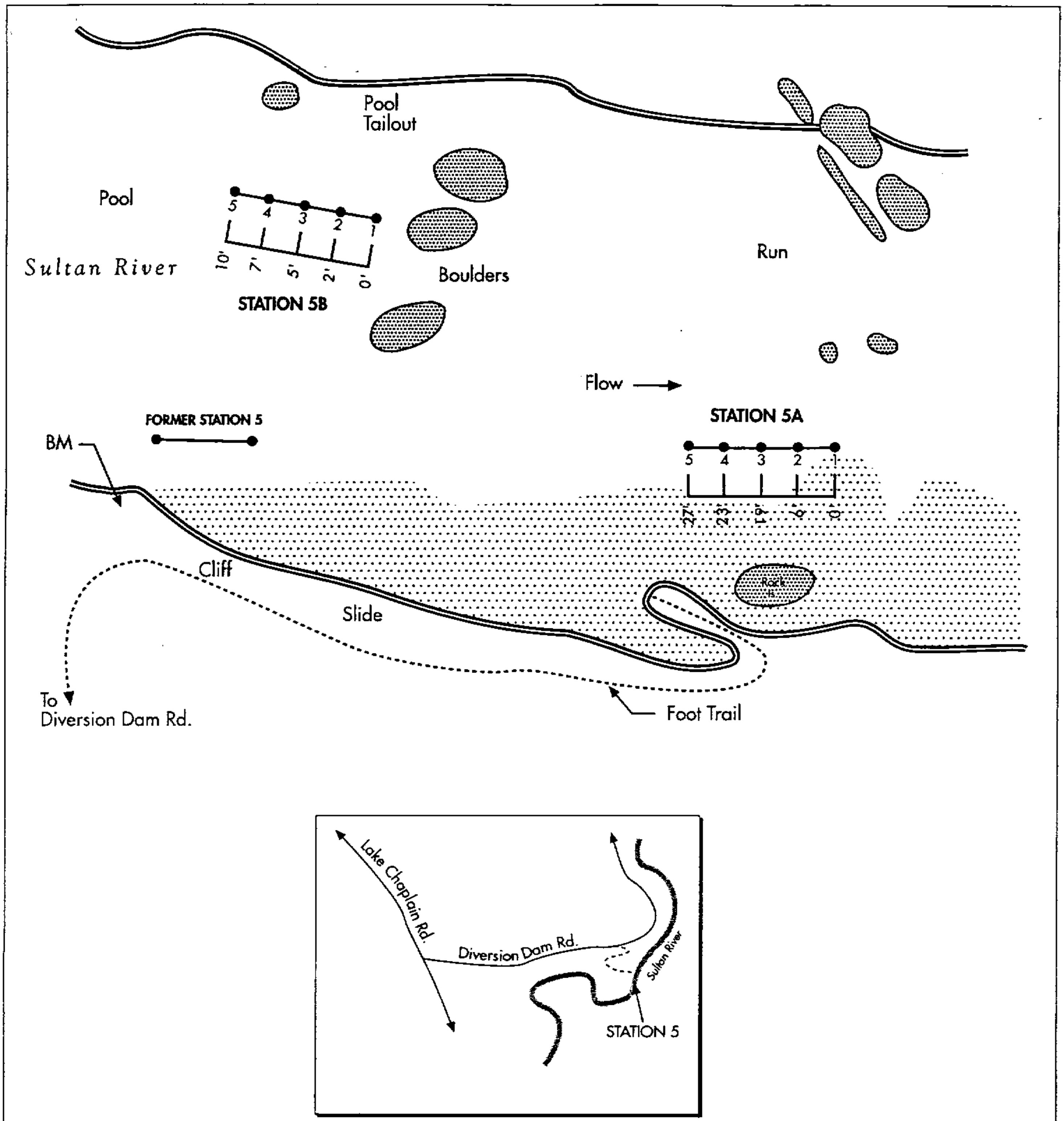

FIGURE 8

GRAVEL SAMPLING STATION S5

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In addition to the requirement that study locations are areas used by spawning salmonids, stations were selected on the basis of representativeness of associated river reach and accessibility.

Three new transects were established in 1994 in cooperation with joint agency biologists, one at station 4 and two at station 5 to evaluate the potential effects of recreational gold prospecting activities on substrate composition. At station 4, the accumulation of fine-textured sluice materials from an ongoing high level of recreational gold prospecting was observed just upstream of the sampling station. At station 5, recreational gold dredging removed all of the gravel and exposed bedrock throughout the sampling station. Considering the potential for these activities to bias the data, the PUD and joint agency biologists agreed during a site visit to sample the original transect at station 4 (4A) and to establish a new transect (4B) upstream and across the river from the gold prospecting area. At station 5, two new transects were established, one immediately downstream of the dredged area (5A) and the other just upstream and across the river (5B).

At each station, samples were obtained along a transect parallel to the direction of water movement within locations having spawning-size gravel less than 4 inches in diameter. In 1982 and 1984, 10 samples were collected along each transect. The number of samples along each transect was reduced to five beginning in 1987 following analysis of within-station variation, which supported the reduced sampling size. All samples from a given station were collected within a 24-hour period. Table 2 shows river flows for each sample day by location.

Table 2: SULTAN RIVER FLOWS DURING EACH DATE GRAVEL SAMPLES WERE COLLECTED IN 1994

Station	Date	Flow (cfs)
S1	9/7/94	192
S2	9/8/94	195
S3	9/8/94	195
S4	9/9/94	199
S5	9/12/94	192

A tri-tube freeze-core sampler, as described by Lotspeich and Reid (1980) and Everest, et. al., (1980) was used to obtain relatively undisturbed substrate samples. A list of equipment is provided in Appendix A.

The advantages of freeze-core sampling over more traditional methods have been well documented, particularly its ability to detect stratification of sediments (Shirazi et al., 1981). Vertical heterogeneity has been observed in some spawning bed materials (Peterson, 1978; Shirazi, et al., 1981; Adams, 1979) but not in others (Platts, et al., 1979).

Field sampling procedures involved driving three stainless steel probes into the streambed to a depth of 30 cm (12 inches). The alignment of the probes and the depth to which they were driven were controlled by two steel plates (depth gage-extractor). Liquid carbon dioxide was discharged for approximately five minutes through manifolds into the lower portion of each probe where it vaporized, inducing rapid freezing of adjacent interstitial water and sediments to the probes. In most cases, one 9-kg (20-lb) cylinder of carbon dioxide was used for each sample. Two tanks each were used on samples 1 and 2 at Station 3 because the first tank on each only lasted for approximately 2.5 minutes.

In order to ensure rapid sediment freezing and uniform size cores, the three/10-micron filters attached to the gas delivery manifolds were replaced or cleaned following the discharge of 20 carbon dioxide cylinders. Cleaning was accomplished by backflushing filters with clean compressed air and tapping filters to dislodge contaminants.

For safety purposes a 3.5-gallon galvanized steel bucket was inverted over the hose connection end of manifolds and held in place until the CO2 cylinder had completely discharged. This was done in order to avoid sudden upward surges of manifolds when gases became trapped as condensation froze in the bottom of probes.

The probes and adhering sediment were extracted from the substratum using a hand winch attached to a tripod situated overhead. After extraction from the streambed, the core was carried to the streambank and then positioned horizontally over a set of six, adjacent, 7.6-cm (3-inch) wide galvanized aluminum boxes and thawed with propane torches. Material which fell into the boxes was collected and transferred to plastic or Hubco soil sample bags for subsequent laboratory analysis. Photographs showing freeze-core sampling and sample processing methods are included in Appendix F. Core sizes were comparable to those obtained in previous years, which ranged from 5 to 10 kg (11 to 22 pounds).

Although Chapman (1988) reported that cobbles up to 15 cm (6 in) or larger are sometimes important components, forming the centrum of the egg pocket in redds of anadromous salmonids, including particles ≥ 15 cm diameter would skew the geometric mean diameter of the sediment core sample. To be consistent with previous Sultan River spawning gravel quality studies and to more accurately estimate the geometric mean diameter, particles ≥ 15 cm diameter in each sample were recorded in the field notes, then discarded. In the 35 samples collected, a total of 19 such cobbles were omitted from the sampled sediment cores.

2.2 LAB ANALYSIS

The procedures used to quantitatively sort gravel samples in the laboratory are identical to those described by Wert, et al., (1982). Subsamples were analyzed separately by washing the sediment through a geometric series of 10 Tyler screens ranging from 53.8 to 0.105 mm (2.12 to 0.004 inches) in mesh diameter in order to separate particle size groups. The mesh diameters of the 10 sieves used in this study from largest to smallest are as follows: 53.8 mm (2.12 in); 25.40 mm (1.0 in); 13.5 mm (0.53 in); 6.7 mm (0.27 in); 3.35 mm (0.13 in); 1.68 mm (0.07 in); 0.84 mm (0.03 in); 0.42 mm (0.02 in); 0.21 mm (0.008 in); and 0.105 mm (0.004 in). The volumetric displacement of material retained on each sieve was measured to the nearest milliliter. Fine sediment passing through the smallest sieve was concentrated in large funnel with an Imhoff cone attached and allowed to settle for approximately one-half hour. For the purposes of this study, it was assumed that the fine-grained sediment that passed through the smallest mesh sieve and was collected in the Imhoff cone averaged 0.063 mm in diameter, the size class known as "wash load" of channel sediments (American Geophysical Union, 1947).

Data collected by the volumetric method was corrected for bias resulting from increased water-holding capacity of finer sediments. Following the suggestion of (Shirazi et al., 1981), the dry contents of the 1.68 mm sieve was used to estimate the density of the sediment by dividing the dry weight of the sample in grams by the volume of water it displaced in cubic centimeters. After averaging, these estimates enabled a correction and conversion factor to be applied to volumetric data in order to derive dry weight estimates of the different particle size classes.

2.3 DATA ANALYSIS

2.3.1 Review of Substrate Indices

Although there is general consensus among fisheries biologists that the textural composition of spawning substrates affects survival and emergence of salmonid embryos, a unified methodology for collecting and interpreting gravel quality has not been adopted. Chapman (1988) reviewed variables defining the effects of fine sediment on salmonid survival. The causal factors of mortality are generally believed to be the reduction of oxygenated water to incubating embryos and the trapping of alevins during the emergence period. Both of these are related to the proportion of fine sediments within gravel. Consequently, researchers have used an estimate of the percentage of fines less than a specified diameter (e.g., 0.841 mm, 1.0 mm, 3.3 mm, or 6.5 mm) to interpret the suitability of streambed materials for spawning and incubation. More recently, investigators have recognized the inadequacy of using "percent fines" as a comprehensive index of substrate quality and have proposed various standardized indices to characterize the textural composition of spawning gravels.

Platts, et al., (1979) first advocated use of geometric mean diameter (d_g) as an appropriate index because of its relation to the permeability and porosity of channel sediments, its widespread use in sedimentary petrography and engineering, and its amenability to statistical comparison. Shirazi et al., 1981 reiterate these advantages and provide several methods, including regression analysis, to aid in the calculation of d_g. The regression technique may also be used to calculate the percentage of fines less than a specified particle diameter.

Lotspeich and Everest (1981) do not reject the regression methods of Shirazi and Seim, but do reject their use of the grain sizes of the 16th (d16) and 84th (d84) cumulative weight percentiles in calculating the sample variance, or sorting coefficient (S_o). Lotspeich and Everest suggest using the square root of the ratio of d25 and d75 as a measure of the dispersion of particles within a sample. Unfortunately, in lieu of a regression equation, the only way to calculate particle size at the 25th and 75th quartiles is by plotting a frequency curve of cumulative weight against particle diameter. In addition to the tediousness of constructing such cumulative curves, each comprised of 11 data points for multiple substrate samples, the visual estimation of the 25th and 75th percentiles is subject to considerable error. Lotspeich and Everest do provide an algorithm for calculating d_g; however, and proposed the "fredle index" (F_i), where $F_i = d_g/S_o$, as a measure of the quality of spawning substrate. Although the use of F_i appears justified from a theoretical standpoint, we believe that the methods of calculating S_o probably results in errors large enough to cast doubt on its quantitative significance. We have, therefore, chosen not to report the fredle index for Sultan River spawning gravels. The data necessary to do so; however, is readily available should a more appropriate means of calculating S_o become available.

Because of their wide acceptance and use, two general categories of substrate indices, percent fines, and geometric mean diameter were selected to evaluate the quality of Sultan River gravel samples. In this study, percent fines was designated as the fraction of sediment in a sample less than 0.841 mm in diameter. This threshold value has been used in other investigations of spawning substrate quality in western Washington streams (Cederholm and Salo, 1979; Scott, et al., 1982; Stober, et al., 1982). It has been found to represent those sizes of inorganic sediment that influence fish and insect life in the intragravel environment.

As discussed by Chapman (1988), extrapolation of sediment conditions using substrate indices to explain survival of salmonid fry should be approached with extreme caution as no accurate quantitative models currently exist.

2.3.2 Statistical Analyses

The computer program, SEDIMNT (FRG-367) was used in the past to summarize the volumetric and gravimetric data described above. This program calculated the percentage of sample collected by each sieve and the percentage of sample that is smaller than each sieve diameter. The percentage of fines that pass through the 0.841 mm mesh diameter sieve is used in statistical comparisons.

The variables PFW and PFD indicate the percent fines estimated from volumetric (wet) data and gravimetric (dry) data, respectively.

SEDIMNT also performed a least squares regression analysis for each sample following the procedure given by Shirazi et al. (1981). This regression analysis assumes the size class distribution of stream sediments follows a log normal distribution. If this assumption is true, then the regression procedure reduces the variability inherent in using untransformed data. It also facilitates an analysis of the entire textural composition of the sample and enables calculation of the geometric mean diameter and the percent fines less than 0.841 mm in diameter. The variable PFLS, used in the statistical comparisons below, is the percent fines estimated by the regression method. The geometric mean diameter calculated from the regression equation is identified as DGLS. Because the SEDIMNT program is no longer available, these same statistics were calculated using Microsoft Excel Version 4.0 on a personal computer.

The algorithm for calculating d_g suggested by Lotspeich and Everest (1981), which results in values different than those derived from the regression equation, is provided below:

$d_g = [d_1^{w_1} \times d_2^{w_2} \times \ldots d_n^{w_n}]$
where d_1 = *midpoint diameter of particles retained by a given sieve**
and w_1 = decimal fraction by weight of particles retained by a given sieve

* Although Lotspeich and Everest (1981) suggest using midpoints, sieve mesh sizes were used for this study.

The variables DGW and DGD henceforth refer to the geometric mean diameter calculated on the basis of volumetric and gravimetric data, respectively, using the above equation.

Parametric statistical analyses of the three geometric-mean-diameter (DGW, DGD, DGLS) and percent-fines (PFW, PFD, PFLS) variables (described above) included analysis of variance (ANOVA) and Student's t-tests for differences between strata and among stations. Non-regression sample statistics were computed as the average of the four subsample (strata) that comprised each sample. In some cases only the lower three strata were used to calculate the sample means used in comparisons among stations. The reason for the omission of the upper substratum is subsequently discussed. Estimates of DGLS and PFLS values for each sample were determined by regression analysis of subsample data.

3. RESULTS

3.1 GEOMETRIC MEAN DIAMETER AND PERCENT FINES

The average values for d_g and percent fines calculated for each study area are listed in Table 3. Geometric mean diameter values for all stations combined averaged 12.87 mm (DGW), 14.98 (DGD) and 27.33 (DGLS). The percentage of fine sediment less than 0.841 mm diameter for all stations combined averaged 8% (PFW), 5% (PFD), and 4% (PFLS), respectively. Substrate values determined for individual samples at each station during 1982, 1984, 1987, and 1994 studies are provided in Appendix B.

All three measures of d_g indicated that streambed composition at station S1 was by far the most coarse of the five study areas sampled. Stations 4A and 5A were composed of finer-textured materials. Other stations were similar to each other. ANOVA results (Table 4) rejected the null hypothesis of no significant difference among mean d_g values for the five stations, for the variables DGW, DGD, PFW, PFD, and PFLS when stations 4A and 5A were included.

However, without stations 4A and 5A, geometric mean diameter as estimated by DGW, DGD, and DGLS were not significantly different. PFW and PFD were significantly different among stations even without stations 4A and 5A. DGW, DGD, and DGLS for 4A were significantly smaller than values obtained for all other study areas. In addition, station 5A had significantly smaller geometric mean diameter (DGW and DGD) than all other stations. Although the geometric mean diameter appeared different among some stations, high within and between-station variability precluded statistically significant differences for all indices when stations 4A and 5A were not included in the ANOVA.

Table 3: AVERAGE GEOMETRIC MEAN DIAMETER AND AVERAGE PERCENT FINES* FOR GRAVEL SAMPLES COLLECTED IN THE SULTAN RIVER, WASHINGTON, 1994.

Station	No. of Samples	DGW (mm)	DGD (mm)	DGLS (mm)	PFW (%)	PFD (%)	PFLS (%)
S1	5	16.27	18.50	49.10	6	4	3
S2	5	11.32	13.28	19.93	10	7	4
S3	5	14.29	16.31	26.47	7	5	3
S4							
4A	4	3.99	4.59	6.81	10	8	7
4B	5	13.88	15.39	36.31	5	3	3
S5							
5A	5	9.90	11.88	25.11	10	6	6
5B	5	11.41	13.19	27.61	8	5	4
Total/mean	34	12.87	14.98	27.33	8	5	4

*Percent fines is the proportion of sediment less than 0.841 mm in diameter.

NOTE: Samples values are based on four strata collected in individual freeze cores.

DGW - volumetric average geometric mean diameter
DGD - gravimetric average geometric mean diameter
DGLS - least squares average geometric mean diameter
PFW - volumetric average percent of fines
PFD - gravimetric average percent of fines
PFLS - least squares average percent of fines

The samples collected on the transects downstream of gold prospecting activities at stations 4 and 5 (i.e., 4A and 5A) contained among the highest percent fines. Of the areas not affected by gold prospecting activities, Station S2 and S5 (i.e., 5B) contained the highest proportion of fine sediment, while S1 and S4 (i.e., 4B) contained the lowest. Although there was a general trend of lower geometric mean diameter at those stations with higher percent fines, there is not a clearly inverse relationship between station mean d_g and percent fines values. For instance, station S1 exhibits the highest d_g and a relatively low percent fines values, but station S3 had a relatively high d_g and a relatively high proportion of fine sediments.

From an inspection of the F-statistics associated with the ANOVAs performed to test for differences among station percent fines sample means (Table 4) it is evident that significant variation exists among sampling stations. Stations 2, 4A and 5A had significantly more fines than other stations. Percent fines were comparable to each other at all stations, indicating no consistent difference in percent fines between study areas upstream (S4 and S5) and downstream (S1, S2, S3) of the powerhouse.

Table 4: RESULTS OF ANALYSIS OF VARIANCE (ANOVA) FOR SULTAN RIVER GRAVELS TESTING HYPOTHESIS THAT AVERAGE GEOMETRIC MEAN DIAMETER AND PERCENT FINES FOR ALL STATIONS WERE EQUAL IN 1994.

	DGW	DGD	DGLS	PFW	PFD	PFLS
F-Ratio						
with 4A & 5A	3.84	3.82	1.73	4.62	4.92	5.14
without 4A & 5A	1.10	0.77	1.04	3.33	3.51	1.03
F-Probability						
with 4A & 5A	0.01*	0.01*	0.15	0.002*	0.002*	0.001*
without 4A & 5A	0.38	0.56	0.41	0.03*	0.03*	0.42

NOTE: (H_0: Mean of S1 = S2 = S3 = S4 = S5)
* statistically significant at indicated probability levels.
DGW - volumetric average geometric mean diameter
DGD - gravimetric average geometric mean diameter
DGLS - least squares average geometric mean diameter
PFW - volumetric average percent of fines
PFD - gravimetric average percent of fines
PFLS - least squares average percent of fines

3.2 SEDIMENT STRATIFICATION

Geometric mean diameter and percent fine values calculated for each stratum of each freeze-core sample are presented in Appendix C. Mean values at each station for strata are shown in Table 5. Except primarily for stations 4A and 5A (which were affected by recent gold prospecting activity), the d_g (DGW and DGD, but not DGLS) generally was higher in the upper and lowermost strata and somewhat lower in the two middle strata. Percent fines generally exhibited a similar pattern at undisturbed sampling locations being lower in the surface and lowermost strata and higher in the two middle strata. The lowest percent fine values occurred in the uppermost stratum. This trend was strongest at S2 and 5A (which was downstream of recent gold prospecting activity).

Interestingly, there was no common pattern in d_g or percent fines at stations 4A and 5A, which were downstream of recent gold prospecting activity. As might be expected, geometric mean diameter was significantly different between station 4A, located downstream of the gold prospecting activity, and 4B, upstream of the gold prospecting activity. Although no significant differences exist in percent fines at station 5A compared to 5B at an alpha of 0.05, 5A (downstream location) contained significantly higher percent fines (PFLS) at an alpha of 0.07. No significant differences were observed, however, between stations 5A and 5B because of high within-station variation between samples. Percent fines were generally higher at locations downstream of recent gold prospecting activity but differences were significant at an alpha of 0.05 only at station S4.

An apparent trend of increasing mean d_g and percent fines with increasing depth of substrate in the lower three strata was suggested by the combined station values listed in Table 5. Statistical tests did not indicate a significant difference in the substrate composition of these strata, however

Because the coarser nature of the uppermost stratum elevates mean d_g and lowers percent fines estimates, it was decided to test for differences among stations using averages of the lower three strata (Table 6 and Appendix D). Further justification for this is that salmonid eggs are usually deposited at depths greater than 3 inches from the gravel surface. Although the composition of the surface layers of sediment influences intragravel flow and fry emergence, salmonid egg and alevin survival is dependent for longer periods of time upon habitat occurring at greater streambed depth. Results were similar to those described earlier for sample means of all four strata. Station S1 was found to have the highest d_g and S2 the lowest. S1 and S4 (i.e., 4B) had the lowest percent fines content. Statistical analyses indicated that station S1 had significantly higher d_g, and stations 4A and 5A significantly lower d_g, compared to other stations. In addition, stations S2, 4A and 5A had significantly higher percent fines compared to other stations.

3.3 SOURCES OF ERROR

Possible sources of bias in this study include operator and analytical error. The former is influenced by the reliability of the freeze-core sampler and by the variability in sampling and sieving technique. Equipment reliability was assured by preventing contaminants or dry ice from blocking gas flow through the 10-micron inline filters and manifold nozzles. Periodic filter and nozzle cleaning precluded gas blockage, which would otherwise result in a relatively smaller and partially frozen core visually recognizable by the poor adhesion of sediment to the steel probes. This situation was avoided but would have been readily detected when the core was removed from the streambed.

Freeze-core sampling necessarily disturbs surface sediments when probes are driven into the substratum. The disturbance of the bed may cause some loss of fines in the upper strata, either by washing downstream or by settling further down into the substrate. In order to reduce the downstream transport of fine sediments, a galvanized garbage can with its bottom removed was used as a flow shunt. The shunt was pressed into the streambed before the probes were driven into the substrate. This resulted in more consistent freezing of the core at the water-substrate interface.

Variation in sampling technique was minimized by ensuring use of a uniform quantity (one cylinder) of liquid CO2 when freezing each sample. Consistent application of sample-collection and sample-processing methods minimized sampling and analytical error, respectively.

4. DISCUSSION

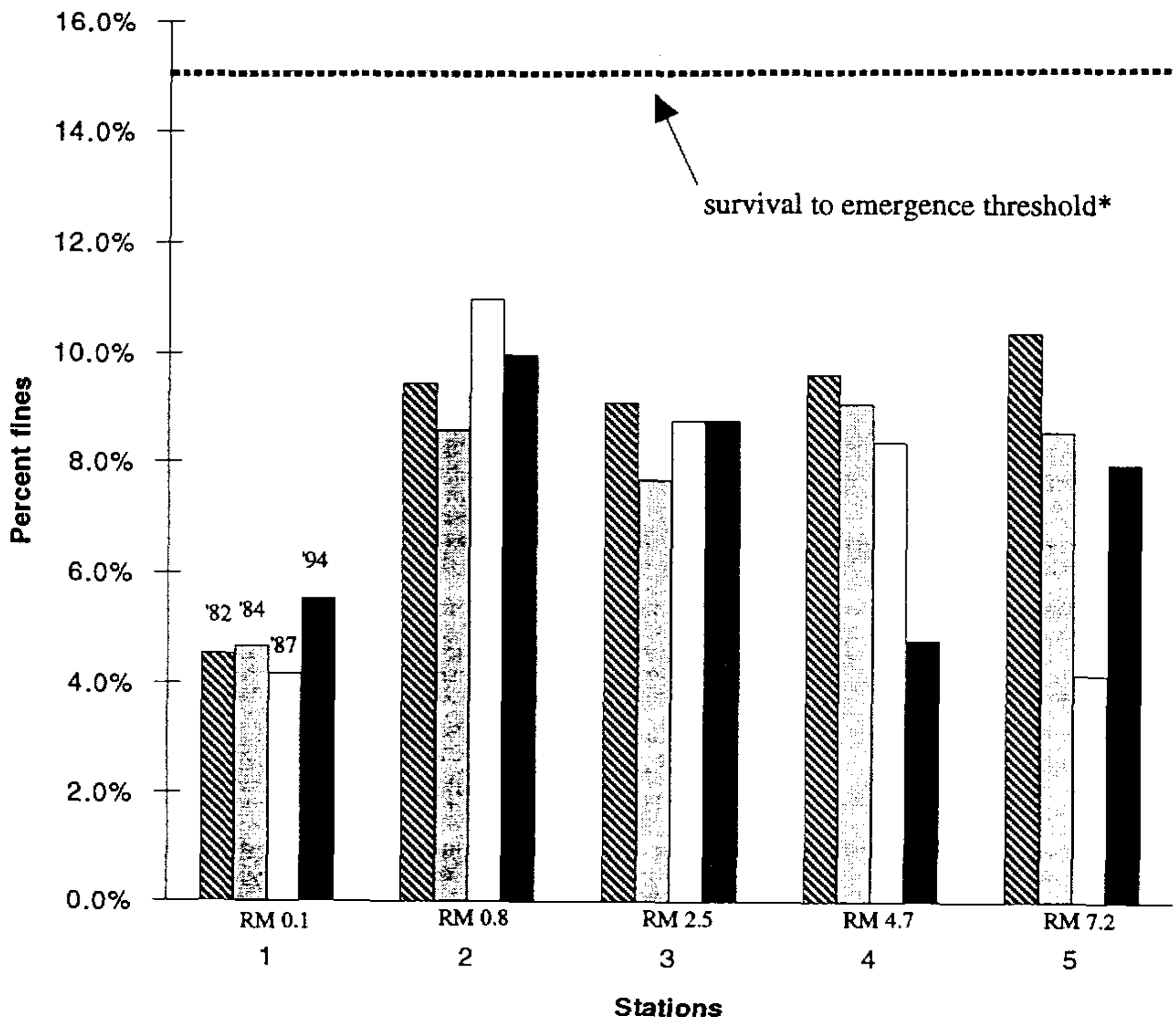
The textural composition of streambed sediments analyzed in this study was variable, but generally similar, to that reported for spawning gravels prior to construction (Wert, et al., 1982). Some significant differences and general trends were apparent, as shown in Tables 6, 7 and 8, Figure 9 and Appendix E. Prior to construction (1982), gravels occurred in a progressively smaller size with increased distance from the river mouth; whereas, after construction and 3 years of operation (1984 and 1987) (Wert et al., 1984; Wert et al., 1988), the spatial variability of geometric mean particle size showed no consistent trend among stations upstream and downstream of the powerhouse. Gravel texture at stations S1 and S3, which were the coarsest of all stations, remained comparable from 1982 through 1987. Following ten years of operation only station S1 showed no significant difference between 1994 and other years. The 1994 geometric mean for two of five stations, S2 (DGW and DGD) and S3 (DGD only) were significantly smaller compared to pre-construction. In addition, the geometric mean particle size for all stations combined also has decreased significantly over the past 10 years compared to pre-construction, which appears to be attributable to significant changes in gravel texture at S2 and S5 since 1987. Small, but significant, decreases in the geometric mean diameter for all stations combined since pre-construction appears to have resulted from accumulation of finer-textured gravels. These differences may reflect the absence of higher flushing flows over the past several years. Since 1990, there have been no spills from Culmback Dam.

Table 5: AVERAGE GEOMETRIC MEAN DIAMETER AND PERCENT FINES FOR GRAVEL STRATA WITH INDIVIDUAL STATIONS AND FOR ALL STATIONS COMBINED, SULTAN RIVER, WASHINGTON, 1994.

Station	Stratum	DGW mm	DGD mm	DGLS mm	PFW %	PFD %	PFLS %	N
S1	1	14.30	16.19	40.88	5	3	3	5
	2	14.40	16.67	23.58	7	5	3	5
	3	16.71	19.42	49.79	5	4	3	5
	4	19.67	21.71	33.43	5	4	2	5
S2	1	20.31	22.26	61.38	3	2	2	5
	2	8.00	9.78	10.45	9	6	6	5
	3	7.23	9.28	15.66	12	8	8	5
	4	9.73	11.79	16.59	12	9	6	5
S3	1	18.82	20.13	39.74	4	3	1	5
	2	13.88	15.87	31.85	6	4	3	5
	3	10.79	13.15	15.60	9	6	5	5
	4	13.66	16.08	29.20	10	7	4	5
S4*								
4A	1	2.25	2.64	3.55	16	12	15	4
4B		8.55	9.78	12.97	4	3	2	5
4A	2	3.59	4.10	5.76	11	8	8	4
4B		15.02	16.68	20.54	4	4	3	5
4A	3	5.57	6.42	8.47	7	6	5	4
4B		9.11	10.96	18.36	6	4	5	5
4A	4	8.55	9.78	12.97	7	5	4	4
4B		16.67	18.37	28.05	4	3	3	5
S5*								
5A	1	12.43	13.91	30.00	6	4	3	5
5B		13.79	15.02	38.35	4	3	2	5
5A	2	9.96	12.38	28.06	10	6	7	5
5B		8.81	15.02	18.27	8	5	5	5
5A	3	9.11	11.18	28.06	11	7	6	5
5B		11.34	13.75	27.38	10	7	5	5
5A	4	35.92	47.35	19.32	12	8	8	5
5B		11.61	13.60	25.16	8	6	5	5
Stations Combined	1	14.10	15.47	33.70	6	4	4	34
	2	10.74	12.51	19.79	8	6	5	34
	3	10.15	12.19	22.47	9	6	5	34
	4	16.78	20.11	23.53	8	6	4	34
Overall Mean		16.83	19.56	43.96	7	5	5	

DGW - volumetric average geometric mean diameter
DGD - gravimetric average geometric mean diameter
DGLS - least squares average geometric mean diameter
PFW - volumetric average percent of fines
PFD - gravimetric average percent of fines
PFLS - least squares average percent of fines
Notes:
*Two values reported for each stratum at stations S4 and S5 are for 4A and 4B, 5A and 5B, respectively.

Figure 9. Average percent fines (PFW - volumetric) < 0.841 mm for all four strata at each station on the Sultan River for all study years (1982 - 1994)



*Above 15% fines, survival to emergence in laboratory studies using mixtures of gravel and sand decreases rapidly (Bjornn and Reiser, 1991).

Table 6: AVERAGE GEOMETRIC MEAN DIAMETER AND PERCENT FINES ON THREE LOWER STRATA OF INDIVIDUAL FREEZE CORDS, 1994.

Station	DGW mm	DGD mm	DGLS mm	PFW %	PFD %	PFLS %	N
S1	16.92*	19.26*	44.80	6	4	3	5
S2	8.32	10.28	18.40	12*	9*	5	5
S3	12.76	15.03	27.62	8	6	4	5
S4[a]							
4A	5.90*	6.77*	9.07	8*	6*	6	4
4B	13.69	15.34	37.84	5	3	4	5
S5[a]							
5A	9.05*	11.21	24.42	11*	7*	7	5
5B	10.62	12.58	27.17	9	6	5	5
Total Mean[b]	11.04	12.92	27.92	8	6	5	34
	12.47	14.50	24.42	8	6	7	25

DGW - volumetric average geometric mean diameter
DGD - gravimetric average geometric mean diameter
DGLS - least squares average geometric mean diameter
PFW - volumetric average percent of fines
PFD - gravimetric average percent of fines
PFLS - least squares average percent of fines

*Indicates substrate mean values that are significantly different from those of other stations ($\alpha = 0.05$).
[a]Two mean values were recorded: 4A and 4B for S4, and 5A and 5B for station S5.
[b]The first row of mean values is including stations 4A and 5A; the second row is without 4A and 5A.

Gravel texture following approximately 10 years of hydroelectric project operations indicated only stations S1 and S4 remained appreciably unchanged compared to pre-construction (Table 7). Analyses of gravel texture at these stations (comparing 1994 data to other years) found no significant differences between any years.

By contrast, comparison of 1994 gravel texture to pre-construction monitoring data for S2, S3, S5, and all stations combined, indicated significant decreases in geometric mean diameter. Significant decreases in DGW and DGD were observed at S2 and all stations combined, and in DGD only at S3. Small but significant differences in substrate texture appear to have resulted from accumulation of finer-textured gravels rather than fines (less than 0.841 mm), which have decreased or remained comparable to pre-construction conditions.

Significant differences in geometric mean particle size also were observed among stations between post-construction and operation years (i.e., 1984, 1987, and 1994). A significant decrease in geometric mean particle size was observed at S2 and all stations combined between 1984 and 1994. Average particle size was significantly different between 1987 and 1994 for S2 and all stations combined (DGW and DGD) and at S3 and S5 (DGD only). In contrast, station S1, and S4 had no significant differences compared to samples collected in 1984 and 1987, indicating no consistent trends upstream and downstream of the powerhouse.

There also were some significant differences in DGLS between years at some stations, including stations 4B, 5B, and all stations combined. DGLS does not appear to be an accurate estimator of the true d_g, however. In some cases, the correlation coefficients (r^2) of the regression equations used to fit the data and estimate DGLS were < 0.70, representing only a moderately good fit. In all cases the d_g is consistently higher than expected compared to field observations, DGW and DGD estimates of d_g. In addition, whether d_g has significantly increased, compared to preconstruction conditions, is questionable considering that the frequency of scouring flows has been reduced by project operations and the opposite effect would have been expected.

Relationships of geometric mean particle size for 1982, 1984, 1987 and 1994 are shown in Table 7. Significant changes include an increase in particle size at Station 4 from 1982 to 1984. At Station 5, a significant increase in particle size occurred between 1982 and 1987 and 1984 and 1987, but not 1982 and 1984. In addition, a significant decrease in particle size was observed between 1987 and 1994. The reason for such change is uncertain but may be attributable to gold prospecting activities.

Spawning gravel composition measured in this study represents a condition, with respect to fine-textured sediment accumulation, where there have been no scouring flows for more than four years. Despite a general decreasing trend in dg, spawning gravel quality remains good and within the size class that is reportably suitable for all species of anadromous salmonids that use the Sultan River system. In addition, assuming the decrease in d_g has resulted from an accumulation of fine-textured gravels, absence of scouring flows and project operations appear to have increased the available quantity of suitable spawning gravels in this generally high-gradient, spawning gravel limited river system. This apparent trend is likely temporary as accumulated fine-textured gravels are likely to be re-suspended and transported downstream by future scouring flows.

The amount of fine sediment at individual study sites in 1994 was, in most cases, not significantly different from previous years (Table 8). The most noteworthy changes occurred at S4 and S5, which were significantly higher in fines in 1982 and/or 1984 than in 1994. The reason for these changes is uncertain but may be due to gold prospecting activities. Comparison of mean percent fines at station 4A (7%) and 4B (3%), which were upstream and downstream, respectively, of recent gold prospecting indicated that the area downstream contained a significantly higher percentage of fines. And although fines were higher downstream of gold prospecting activities at station 5A (6%) compared to 5B (4%), these differences were not significant at an alpha equal to 0.05. The average percent fines at 5A was significantly higher than at station 5B with an alpha equal to 0.07, however. Prospecting contributes to increased amounts of fines in depositional areas downstream of prospecting operations as fines are resuspended in the water column as a result of gravel washing. In addition, prospecting reduces the amount of fines and coarsens gravel texture in areas of prospecting dredge operations. Accumulation of fines in areas downstream of gold dredging operations reduces d_g at dredge sites and may contribute to an over coarsening of river sediments, rendering them unsuitable for some species that require smaller spawning gravels.

Based on least squares regression analysis (PFLS), percent fines were significantly lower at stations S2, S3, and all stations, combined compared to 1987. Percent fines was greater in 1994 at S1, but the difference was not statistically significant for all methods of calculation. Reduction in the percent fines at these stations may be due to a combination of gold prospecting activities and sediment retention upstream of Culmback Dam and the Everett diversion dam.

Sediment stratification occurred in the streambed during all years of sampling. In 1982, 1984, 1987, and 1994, the combined mean values of the upper three inches of substrate contained lower percent fines and greater geometric mean particle size than the underlying 9 inches. These results agree with observations of other researchers. Adams (1979) and Lotspeich and Everest (1981) reported substantial variability in substrate composition among different strata of the streambed. Milhous and Klingeman (1971) and Milhous (1973) reported the presence of relatively coarse bed material at the water-substrate interface, as is common in most gravel-bedded streams. Such

Table 7: GEOMETRIC MEAN PARTICLE SIZES BY STATION FOR 1982, 1984, 1987, AND 1994.

Station	DGW (mm)				DGD (mm)				DGLS (mm)			
	1982	1984	1987	1994	1982	1984	1987	1994	1982	1984	1987	1994
1	17.31	17.81	15.40	16.27	19.82	20.30	17.44	18.49	21.89	22.08	18.06	49.10
2	16.25[d]	15.85[c]	15.07[f]	11.32[de]	19.37[d]	19.29[e]	18.47[f]	13.28[def]	23.22	21.94	29.08	19.93
3	16.45	18.62	15.71	14.29	19.38	22.47[e]	18.52	16.31[e]	24.56	26.37	28.20	26.47
4	12.01[a]	17.66[a]	16.07	13.88	14.70[a]	18.80[a]	19.33	15.39	15.15[d]	21.84	31.58	36.31[d]
5	11.41[b]	10.74[c]	21.88[bcf]	11.41[f]	13.54[b]	13.15[c]	24.05[bc]	13.19	10.95[d]	7.87[e]	112.88	27.61[de]
Mean	14.68	16.13[cf]	16.82[cf]	13.43[f]	17.93[d]	18.80[ce]	19.56[cf]	15.33[def]	19.62[d]	20.02[e]	43.96	31.88[de]

[a]Statistically significant differences in geometric mean particle size between 1982 and 1984 samples.
[b]Statistically significant differences in geometric mean particle size between 1982 and 1987 samples.
[c]Statistically significant differences in geometric mean particle size between 1984 and 1987 samples.
[d]Statistically significant differences in geometric mean particle size between 1982 and 1994 samples.
[e]Statistically significant differences in geometric mean particle size between 1984 and 1994 samples.
[f]Statistically significant differences in geometric mean particle size between 1987 and 1994 samples.

Note: Stations 4A and 5A, which were downstream of recent gold mining, were not included in these analyses. Statistically significant differences ($\alpha = 0.05$), determined using t-tests (n = 10 in 1982 and 1984, n = 5 in 1987 and 1994 for individual stations) are indiciated by superscripts.

DGW - volumetric average geometric mean diameter
DGD - gravimetric average geometric mean diameter
DGLS - least squares average geometric mean diameter

Table 8: COMPARISON OF PERCENTAGE OF FINES LESS THAN 0.841 MM IN DIAMETER, IN SULTAN RIVER STEAMBED GRAVELS BETWEEN 1982, 1984, 1987, AND 1994 AT INDIVIDUAL STATIONS (n=10 in 1982 AND 1984; n=5 in 1987 AND 1994) AND ALL STATIONS COMBINED (n=50 in 1982 AND 1984; n=25 IN 1987 AND 1994).

	PFW				PFD				PFLS			
Station	1982	1984	1987	1994	1982	1984	1987	1994	1982	1984	1987	1994
1	4.7	4.5	4.3	5.5	3.4	3.1	3.1	3.8	3.2	3.3	3.4	2.8
2	8.6	9.5[c]	10.8[c]	9.8	6.1	6.5	7.5	6.9	4.4[b]	4.5[c]	6.5[bcf]	4.4[f]
3	7.7	9.1	8.6	6.9	5.3	6.2	6.0	6.2	3.5	4.4[c]	5.8c	3.0[f]
4	9.1[d]	9.7[e]	8.3	4.8[de]	6.2[d]	6.3[e]	5.5	3.4[de]	5.4[d]	5.4	5.5	3.0[d]
5	8.6[bd]	10.4[c]	4.2[bcf]	7.9[f]	5.8[b]	7.2[c]	2.8[bcf]	6.4[f]	5.4[abd]	7.1[ac]	3.7[bc]	4.0[d]
Mean	7.1	8.7[c]	7.3	7.0[c]	4.9	5.8	5.0	5.6	4.1	4.9	5.0[f]	3.4[f]

[a]Statistically significant differences in percent fines between 1982 and 1984 samples.
[b]Statistically significant differences in percent fines between 1982 and 1987 samples.
[c]Statistically significant differences in percent fines between 1984 and 1987 samples.
[d]Statistically significant differences in percent fines between 1982 and 1994 samples.
[e]Statistically significant differences in percent fines between 1984 and 1994 samples.
[f]Statistically significant differences in percent fines between 1987 and 1994 samples.

Note: Stations 4A and 5A, which were downstream of recent gold mining, were not included in these analyses.

PFW - volumetric average percent of fires
PFD - gravimetric average geometric mean diameter
PFLS - least squares average geometric mean diameter

variation most likely results from exposure of surficial sediment to higher water velocities than those present in intragravel flows (Garde, et al., 1977). This further indicates that evaluation of surface layers of streambed gravels does not provide a true description of underlying sediment texture.

Quantitative predictive models of salmonid fry survival based on sediment quality do not currently exist. The paucity of data from properly designed field and laboratory studies prevents the ability to satisfactorily model relationships between environmental conditions within or outside of egg pockets in the streambed and survival-to-emergence of fry (Chapman, 1988). For example, re-examination by Chapman (1988) of the relationship of salmonid survival to geometric mean particle size as reported by Shirazi, et al., (1981) indicates this model is inappropriate. For this reason, the data reported herein should only be used as a general indication of sediment quality for spawning salmonids of the Sultan River.

Compared to preconstruction and operations data, d_g and percent fines have generally decreased at all stations. The change in d_g appears to be the result of accumulations of finer-textured gravels in the absence of scouring flows over the past four years. Accumulation of finer-textured gravels resulting from project operations and a lack of scouring flows these last four years appear to have increased the quantity of spawning gravel in this generally high-gradient, spawning gravel limited river system. Despite the lack of scouring flows for the past four years, as well as hydroelectric project flow modifications to the Sultan River, spawning gravel quality remains good and does not appear to limit potential anadromous salmonid production in the Sultan River system.

5. CONCLUSION

The textural composition of Sultan River streambed substrate following 10 years of hydroelectric project operations was comparable to pre-project conditions at three stations (S1, S4, and S5) and significantly different (reduced) at two stations S2 (DGW and DGD) and S3 (DGD only). In addition, the geometric mean diameter of substrate for all stations combined is significantly lower compared to pre-construction. Because the percent fines at three stations has generally decreased, decrease in the geometric mean appears to have resulted from an accumulation of finer-textured gravels. *Significant reduction in the geometric mean diameter may have resulted from* a combination of natural spatial and temporal variation in particle size distribution and a lack of higher scouring flows over the past few years. Because significant changes in gravel texture were observed only at S5 following 3 years of hydroelectric project operation, and no significant difference in gravel texture was apparent after 10 years of operation at S5, it appears likely that significant changes in gravel texture at these stations is not due to hydroelectric project operations.

There was no clear spatial trend in d_g among stations in 1987 or 1984; whereas, a trend of smaller d_g with increased distance upstream was suggested by 1982 data. Station S5 (upstream) had the coarsest gravel (largest d_g) in 1987, in contrast to 1982 and 1984, when it had the finest gravel of all stations sampled. The d_g at three of the five stations, including the farthest downstream and the two farthest upstream stations, has fluctuated over the coarse of the study but not changed significantly compared to pre-construction. With regard to the observations in the previous paragraph, station S5 had the lowest proportion of fines (less than 0.841 mm diameter) of any station in 1987, in contrast to its relatively high levels in previous years. Station S1 (river mouth) was consistently low in all years.

Sediment stratification was noted during all years of study. The combined mean values of the upper 3 inches of substrate contained lower percentage of fines and greater geometric mean particle size than did the underlying 9 inches of sediment.

Gold prospecting activities had a significant impact on geometric mean diameter and percent fines at stations. Areas downstream of gold dredging operations (stations 4A and 5A) had significantly smaller d_g and higher percent fines compared to upstream areas (stations 4B and 5B). In addition, substrate composition at gold dredging sites may, in some cases, be over-coarsened through removal of medium and finer-textured gravels, rendering them unsuitably large for some species.

Although geometric mean diameter has decreased somewhat at all stations since pre-construction, the percent fines remains very similar after 10 years of operation. It appears the textural composition of Sultan River spawning gravels following project construction and operation remains quite good and appears to provide suitable conditions to yield high rates of embryonic survival, depending on other survival-limiting factors.

Based on the substrate indices examined in this study, the need for mitigative measures for maintaining the quality of salmonid spawning gravels is not indicated.

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Appendix A

Recommended Field Sampling Equipment and Maintenance List for Tri-tube Freeze-core Sampling

A P P E N D I X   A

RECOMMENDED FIELD SAMPLING EQUIPMENT AND MAINTENANCE LIST FOR CO_2 SAMPLER[1] (TRI-TUBE)

<u>FREEZE-CORE SAMPLER EQUIPMENT</u>

- 3 each stainless steel sample probes
- 3 each #MO297 CO_2 metering manifold assembly
- 3 each Synflex 31-50-04 pressure hose w/fittings (20 ft ea)
- 3 each Linde SG 6112 in line filters, 10 micron
- 1 each 4-way CO_2 cylinder manifold
- ~~12~~ each (or as required) 20-lb aluminun CO_2 cylinders w/siphon tubes
- 1 each depth gage/extractor

<u>OTHER SAMPLING EQUIPMENT</u>

- 1 each aluminum tripod
- 1 each galvanized garbage can w/bottom removed (flow shunt)
- 1 each set of subsampler boxes (6) in aluminum frame
- 1 each hand winch
- 2 each propane torches, extra fuel as required
- 6 boxes (or as required) food storage bags, 11-1/2 x 13 x 1.01 mil
- 1 each 1-liter plastic wash bottle
- 2 each plastic spatulas
- 10 each 5 gal plastic buckets (gravel sample transport)
- 1 each 3-1/2 gal galvanized bucket
- 1 each 3 lb sledge hammer
- 2 pair insulated rubber gloves
- 1 roll teflon tape
- 2 pair goggles
- 2 each ball peine hammers
- 1 each measuring tape, 150 ft
- 1 roll fluorescent survey tape
- 2 each adjustable wrenches, 8 inch
- 1 each adjustable wrench, 12 inch
- 1 each vise grips, large
- 1 each tool box
- 1 each watch with second hand

<u>MAINTENANCE EQUIPMENT</u>

- 24 each Modern Mfg. Co. MO298-1 modified nozzles
- 12 each Modern Mfg. Co. MO298-2 modified nozzle blanks
- 36 each Modern Mfg. Co. nozzle screens
- 3 each #97 drill for cleaning nozzles
- 1 each #29 drill bit for drilling out broken nozzles
- 1 each socket wrench, 1/4 inch drive
- 1 each 1/4 inch socket

[1]Adapted from Walkotten, 1976

1 each	7/13 inch socket
1 each	8-36 taper, plug & bottom thread tapset
1 each	#EX-1 screw extractor
1 each	ballpoint pen refill (nozzle screen inserter)
1 each	small hand drill
3 each	Linde SG 6112 in line filters, 10 micron
3 each	spare stainless steel sampling probes

Appendix B

Average Substrate Values for Individual Samples Collected from Each Study Reach During 1982, 1984, 1987 and 1994

Appendix B. Average substrate values for individual samples collected from each study reach during 1982, 1984, 1987, and 1994.

YEAR	STA	REP	DGW	DGD	DGLS	PFW	PFD	PFLS
1982	1	1	22.60	25.45	33.63	0.03	0.03	0.02
1982	1	2	15.54	17.87	16.45	0.05	0.04	0.03
1982	1	3	18.96	21.67	28.33	0.04	0.03	0.03
1982	1	4	20.19	22.56	22.86	0.04	0.03	0.02
1982	1	5	9.39	11.24	7.23	0.06	0.04	0.05
1982	1	6	17.07	19.86	25.49	0.06	0.05	0.03
1982	1	7	16.86	19.44	23.75	0.05	0.03	0.03
1982	1	8	21.78	24.92	26.23	0.04	0.03	0.03
1982	1	9	13.84	15.81	10.69	0.06	0.04	0.05
1982	1	10	16.82	19.40	24.19	0.04	0.02	0.03
1982	2	1	24.59	28.86	58.71	0.07	0.05	0.03
1982	2	2	20.39	23.46	24.17	0.06	0.04	0.03
1982	2	3	14.09	16.90	15.45	0.09	0.06	0.05
1982	2	4	18.48	21.19	21.09	0.05	0.04	0.03
1982	2	5	12.87	15.97	18.57	0.10	0.07	0.05
1982	2	6	13.05	15.90	14.51	0.10	0.07	0.05
1982	2	7	17.63	21.22	31.56	0.09	0.07	0.04
1982	2	8	11.41	14.18	12.63	0.12	0.08	0.06
1982	2	9	19.79	23.72	25.17	0.08	0.05	0.04
1982	2	10	10.16	12.28	10.35	0.10	0.08	0.06
1982	3	1	22.12	26.09	48.37	0.08	0.05	0.03
1982	3	2	15.24	17.74	16.23	0.07	0.05	0.04
1982	3	3	13.38	16.46	20.72	0.11	0.08	0.04
1982	3	4	22.57	26.01	40.42	0.05	0.04	0.02
1982	3	5	22.55	26.11	39.83	0.06	0.04	0.02
1982	3	6	10.35	12.05	10.11	0.07	0.05	0.04
1982	3	7	13.29	16.40	16.30	0.10	0.07	0.05
1982	3	8	13.50	16.11	18.99	0.08	0.05	0.04
1982	3	9	17.65	20.56	18.99	0.08	0.05	0.03
1982	3	10	13.82	16.27	15.64	0.07	0.05	0.04
1982	4	1	16.08	19.31	18.51	0.08	0.05	0.04
1982	4	2	12.62	14.50	10.33	0.05	0.04	0.04
1982	4	3	8.47	11.17	9.72	0.13	0.09	0.08
1982	4	4	8.73	11.03	6.69	0.12	0.08	0.08
1982	4	5	15.59	20.22	35.18	0.11	0.07	0.05
1982	4	6	10.20	13.54	15.89	0.12	0.08	0.07
1982	4	7	9.56	12.56	14.08	0.13	0.09	0.07
1982	4	8	13.46	16.20	18.97	0.08	0.05	0.04
1982	4	9	11.52	13.02	10.90	0.05	0.04	0.04
1982	4	10	13.90	15.43	11.25	0.04	0.03	0.03

Appendix B. Average substrate values for individual samples collected from each study reach during 1982, 1984, 1987, and 1994.

YEAR	STA	REP	DGW	DGD	DGLS	PFW	PFD	PFLS
1982	5	1	9.00	10.58	6.65	0.08	0.05	0.06
1982	5	2	11.68	13.82	12.34	0.08	0.06	0.05
1982	5	3	21.17	23.59	23.26	0.03	0.02	0.02
1982	5	4	11.32	14.00	12.29	0.09	0.06	0.05
1982	5	5	10.17	12.17	8.55	0.10	0.07	0.06
1982	5	6	12.81	16.30	15.91	0.11	0.07	0.05
1982	5	7	11.00	12.56	7.68	0.06	0.04	0.05
1982	5	8	10.36	12.10	7.29	0.08	0.05	0.06
1982	5	9	7.23	8.72	5.37	0.12	0.08	0.08
1982	5	10	9.38	11.58	10.11	0.11	0.08	0.06
1984	1	1	16.31	18.65	20.01	0.06	0.04	0.04
1984	1	2	21.17	23.65	21.50	0.04	0.03	0.03
1984	1	3	16.69	18.95	20.47	0.05	0.03	0.03
1984	1	4	25.89	28.82	43.05	0.04	0.03	0.02
1984	1	5	12.14	14.19	9.90	0.06	0.04	0.05
1984	1	6	21.33	24.48	33.27	0.04	0.03	0.02
1984	1	7	18.78	21.96	29.00	0.04	0.03	0.03
1984	1	8	14.71	17.12	11.20	0.06	0.04	0.04
1984	1	9	17.77	20.01	17.01	0.03	0.02	0.03
1984	1	10	13.10	15.13	15.38	0.05	0.03	0.04
1984	2	1	8.92	11.31	8.22	0.17	0.12	0.08
1984	2	2	14.89	17.67	14.38	0.08	0.06	0.04
1984	2	3	17.40	20.73	17.49	0.09	0.06	0.04
1984	2	4	13.98	17.09	15.21	0.09	0.06	0.05
1984	2	5	15.22	18.27	21.06	0.09	0.06	0.04
1984	2	6	18.58	22.62	31.98	0.09	0.06	0.04
1984	2	7	16.83	20.41	20.34	0.08	0.05	0.04
1984	2	8	17.49	21.61	29.89	0.08	0.06	0.04
1984	2	9	17.21	21.40	29.46	0.10	0.06	0.04
1984	2	10	17.97	21.79	31.08	0.08	0.05	0.04
1984	3	1	22.88	26.54	32.09	0.11	0.07	0.04
1984	3	2	16.49	21.38	32.38	0.13	0.09	0.05
1984	3	3	13.23	17.52	15.09	0.14	0.09	0.06
1984	3	4	17.71	21.82	30.35	0.08	0.05	0.04
1984	3	5	13.30	16.58	18.75	0.10	0.07	0.05
1984	3	6	14.08	18.18	20.51	0.11	0.08	0.06
1984	3	7	30.01	33.11	35.96	0.04	0.03	0.02
1984	3	8	18.86	22.37	14.11	0.07	0.05	0.04
1984	3	9	26.30	30.37	49.98	0.04	0.03	0.02
1984	3	10	13.34	16.86	14.46	0.10	0.07	0.06

Appendix B. Average substrate values for individual samples collected from each study reach during 1982, 1984, 1987, and 1994.

YEAR	STA	REP	DGW	DGD	DGLS	PFW	PFD	PFLS
1984	4	1	22.69	26.54	36.00	0.08	0.05	0.04
1984	4	2	12.56	16.49	13.43	0.11	0.07	0.06
1984	4	3	12.91	16.40	14.47	0.09	0.06	0.05
1984	4	4	13.10	17.05	20.80	0.12	0.07	0.06
1984	4	5	22.39	25.39	19.97	0.06	0.04	0.04
1984	4	6	9.49	12.57	7.49	0.14	0.10	0.08
1984	4	7	14.77	18.12	15.33	0.10	0.07	0.05
1984	4	8	21.39	27.29	56.23	0.10	0.06	0.04
1984	4	9	13.49	17.36	19.37	0.10	0.07	0.05
1984	4	10	33.82	10.81	15.28	0.07	0.05	0.07
1984	5	1	8.17	9.95	4.75	0.11	0.08	0.09
1984	5	2	11.35	13.88	8.35	0.09	0.06	0.07
1984	5	3	10.89	13.17	6.65	0.10	0.07	0.07
1984	5	4	9.39	12.18	7.94	0.10	0.07	0.07
1984	5	5	11.78	14.48	8.67	0.11	0.07	0.07
1984	5	6	11.98	15.11	13.14	0.10	0.07	0.06
1984	5	7	11.02	13.41	8.53	0.09	0.06	0.06
1984	5	8	13.96	16.02	8.16	0.07	0.05	0.05
1984	5	9	7.13	9.02	4.88	0.14	0.10	0.10
1984	5	10	11.70	14.31	7.55	0.12	0.09	0.07
1987	1	1	13.78	15.48	12.68	0.04	0.03	0.04
1987	1	2	16.13	18.48	22.09	0.05	0.04	0.04
1987	1	3	15.29	17.54	19.17	0.04	0.03	0.04
1987	1	4	14.90	16.52	12.16	0.04	0.03	0.03
1987	1	5	16.89	19.20	24.20	0.04	0.03	0.03
1987	2	1	13.94	16.75	25.08	0.12	0.09	0.08
1987	2	2	18.75	22.76	40.51	0.11	0.08	0.06
1987	2	3	14.13	17.32	30.14	0.12	0.08	0.07
1987	2	4	13.23	16.35	19.57	0.09	0.06	0.06
1987	2	5	15.31	19.18	30.11	0.11	0.07	0.06
1987	3	1	23.13	25.81	47.10	0.06	0.04	0.04
1987	3	2	14.17	17.53	24.30	0.11	0.07	0.06
1987	3	3	16.30	19.54	29.31	0.09	0.06	0.06
1987	3	4	10.64	12.89	13.34	0.10	0.07	0.07
1987	3	5	14.30	16.84	26.95	0.08	0.06	0.06

Appendix B. Average substrate values for individual samples collected from each study reach during 1982, 1984, 1987, and 1994.

YEAR	STA	REP	DGW	DGD	DGLS	PFW	PFD	PFLS
1987	4	1	16.65	20.29	44.54	0.09	0.06	0.06
1987	4	2	14.71	17.60	22.72	0.08	0.05	0.06
1987	4	3	12.89	16.83	27.20	0.13	0.08	0.08
1987	4	4	13.60	15.91	14.28	0.07	0.05	0.05
1987	4	5	22.48	26.00	49.16	0.05	0.03	0.03
1987	5	1	20.14	21.54	45.21	0.03	0.02	0.03
1987	5	2	19.95	21.74	20.75	0.03	0.02	0.03
1987	5	3	20.16	22.93	44.01	0.06	0.04	0.05
1987	5	4	19.67	22.17	30.46	0.04	0.03	0.04
1987	5	5	29.50	31.88	423.95	0.05	0.04	0.04
1994	1	1	14.33	16.74	39.62	0.06	0.04	0.03
1994	1	2	22.75	24.74	123.21	0.02	0.02	0.02
1994	1	3	16.65	19.46	29.47	0.08	0.05	0.04
1994	1	4	13.16	14.94	20.97	0.06	0.05	0.03
1994	1	5	14.45	16.61	32.24	0.05	0.04	0.03
1994	2	1	7.82	9.53	8.28	0.10	0.07	0.07
1994	2	2	12.27	14.24	18.51	0.11	0.08	0.04
1994	2	3	13.79	16.44	29.14	0.11	0.08	0.04
1994	2	4	13.86	16.36	30.86	0.08	0.06	0.03
1994	2	5	8.84	9.80	12.85	0.09	0.06	0.04
1994	3	1	16.78	18.65	36.23	0.05	0.04	0.02
1994	3	2	16.47	18.61	14.17	0.04	0.03	0.02
1994	3	3	11.60	13.89	33.86	0.09	0.06	0.04
1994	3	4	14.53	16.80	33.81	0.06	0.04	0.03
1994	3	5	12.06	13.59	14.29	0.10	0.08	0.04
1994	4A	2	7.33	8.37	8.19	0.11	0.11	0.06
1994	4A	3	5.38	6.34	8.12	0.12	0.12	0.07
1994	4A	4	3.93	4.49	5.98	0.09	0.09	0.07
1994	4A	5	3.31	3.73	4.94	0.09	0.09	0.09
1994	4B	1	25.58	27.37	75.99	0.02	0.01	0.01
1994	4B	2	9.66	10.71	12.30	0.04	0.04	0.00
1994	4B	3	9.44	10.63	21.04	0.10	0.02	0.04
1994	4B	4	5.82	7.10	11.72	0.03	0.08	0.07
1994	4B	5	18.91	21.16	60.49	0.05	0.02	0.03

Appendix B. Average substrate values for individual samples collected from each study reach during 1982, 1984, 1987, and 1994.

YEAR	STA	REP	DGW	DGD	DGLS	PFW	PFD	PFLS
1994	5A	1	10.88	12.82	35.07	0.08	0.08	0.05
1994	5A	2	11.34	13.73	24.25	0.10	0.10	0.05
1994	5A	3	11.15	13.19	21.95	0.09	0.09	0.05
1994	5A	4	8.99	10.80	28.43	0.09	0.09	0.06
1994	5A	5	7.13	8.86	15.87	0.12	0.12	0.08
1994	5B	1	9.74	11.04	17.24	0.08	0.05	0.04
1994	5B	2	11.36	13.22	26.60	0.08	0.07	0.04
1994	5B	3	10.54	11.68	18.66	0.05	0.06	0.02
1994	5B	4	15.09	17.35	48.08	0.06	0.06	0.03
1994	5B	5	10.34	12.65	27.48	0.11	0.08	0.06

Appendix C

Substrate Values for Each Strata of Individual Samples Collected at All Stations During 1994

Appendix C. Results of 1994 Sultan River sediment analysis for individual strata of each sample.

STA	REP	STRATUM	DGW	DGD	DGLS	PFW	PFD	PFLS
1	1	1	16.27	18.61	54.97	0.051	0.035	0.033
1	1	2	13.02	15.80	44.38	0.074	0.051	0.048
1	1	3	14.06	16.79	43.10	0.068	0.048	0.036
1	1	4	13.97	15.75	30.50	0.043	0.031	0.024
1	2	1	16.79	17.94	113.16	0.020	0.012	0.016
1	2	2	21.47	23.91	107.73	0.032	0.020	0.023
1	2	3	20.43	22.38	68.76	0.024	0.016	0.017
1	2	4	32.32	34.74	333.95	0.018	0.012	0.011
1	3	1	16.45	19.62	76.86	0.063	0.042	0.040
1	3	2	5.04	7.08	11.61	0.152	0.099	0.124
1	3	3	12.85	16.08	56.54	0.075	0.048	0.058
1	3	4	32.25	35.04	513.02	0.019	0.012	0.014
1	4	1	8.13	9.10	20.26	0.044	0.030	0.040
1	4	2	22.37	24.55	55.10	0.026	0.019	0.008
1	4	3	17.77	20.91	66.30	0.060	0.042	0.029
1	4	4	4.35	5.20	9.85	0.127	0.095	0.081
1	5	1	13.85	15.70	28.91	0.048	0.035	0.023
1	5	2	10.09	12.00	21.08	0.078	0.058	0.037
1	5	3	18.43	20.92	52.86	0.037	0.026	0.018
1	5	4	15.46	17.81	43.63	0.049	0.034	0.028
2	1	1	17.57	19.88	56.29	0.040	0.027	0.025
2	1	2	1.22	2.56	2.70	0.096	0.070	0.274
2	1	3	4.08	5.08	8.72	0.154	0.113	0.103
2	1	4	8.41	10.62	21.76	0.124	0.089	0.069
2	2	1	26.79	29.16	123.37	0.023	0.016	0.012
2	2	2	9.21	11.07	19.92	0.088	0.062	0.049
2	2	3	3.60	4.59	8.17	0.195	0.146	0.114
2	2	4	9.47	12.14	28.82	0.135	0.094	0.070
2	3	1	28.15	30.94	264.32	0.033	0.022	0.016
2	3	2	8.83	11.31	23.71	0.141	0.100	0.066
2	3	3	8.24	11.15	27.86	0.165	0.117	0.084
2	3	4	9.95	12.38	25.88	0.114	0.079	0.061

Appendix C. Results of 1994 Sultan River sediment analysis for individual strata of each sample.

STA	REP	STRATUM	DGW	DGD	DGLS	PFW	PFD	PFLS
2	4	1	12.02	13.63	25.21	0.047	0.033	0.029
2	4	2	11.77	14.24	32.24	0.095	0.067	0.046
2	4	3	14.25	18.25	62.70	0.125	0.088	0.050
2	4	4	17.42	19.34	30.20	0.050	0.034	0.018
2	5	1	17.00	17.68	120.65	0.008	0.005	0.008
2	5	2	8.94	9.72	18.54	0.021	0.012	0.025
2	5	3	6.01	7.33	17.47	0.116	0.081	0.077
2	5	4	3.40	4.48	8.34	0.201	0.145	0.136
3	1	1	32.30	33.98	252.31	0.013	0.009	0.007
3	1	2	6.88	7.79	14.95	0.064	0.047	0.044
3	1	3	19.38	22.73	123.17	0.060	0.040	0.035
3	1	4	8.56	10.10	34.93	0.081	0.056	0.054
3	2	1	17.99	18.38	112.41	0.004	0.003	0.004
3	2	2	21.03	23.12	74.01	0.035	0.024	0.017
3	2	3	1.58	3.85	11.42	0.086	0.061	0.308
3	2	4	25.29	29.06	275.53	0.052	0.035	0.025
3	3	1	8.19	9.54	22.79	0.095	0.068	0.045
3	3	2	12.75	15.26	36.57	0.087	0.062	0.041
3	3	3	13.12	15.68	37.95	0.081	0.058	0.040
3	3	4	12.33	15.10	39.86	0.094	0.066	0.049
3	4	1	11.93	13.29	21.57	0.048	0.033	0.025
3	4	2	11.63	13.52	26.11	0.066	0.047	0.034
3	4	3	15.01	17.56	43.34	0.064	0.046	0.031
3	4	4	19.53	22.85	127.86	0.057	0.037	0.035
3	5	1	23.70	25.47	92.91	0.018	0.012	0.012
3	5	2	17.10	19.67	47.76	0.058	0.041	0.023
3	5	3	4.84	5.95	11.20	0.139	0.104	0.078
3	5	4	2.59	3.29	5.29	0.203	0.155	0.146
4A	2	1	2.85	3.40	4.82	0.170	0.130	0.121
4A	2	2	2.33	2.69	3.92	0.160	0.124	0.126
4A	2	3	5.48	6.18	10.31	0.059	0.043	0.049
4A	2	4	18.65	21.20	69.81	0.038	0.026	0.026

Appendix C. Results of 1994 Sultan River sediment analysis for individual strata of each sample.

STA	REP	STRATUM	DGW	DGD	DGLS	PFW	PFD	PFLS
4A	3	1	1.74	2.09	3.04	0.214	0.166	0.185
4A	3	2	4.18	4.83	7.23	0.098	0.073	0.077
4A	3	3	9.47	11.23	19.63	0.079	0.058	0.041
4A	3	4	6.13	7.21	14.37	0.084	0.061	0.058
4A	4	1	1.89	2.16	2.82	0.139	0.106	0.162
4A	4	2	5.02	5.69	8.49	0.068	0.051	0.056
4A	4	3	3.67	4.19	6.41	0.090	0.069	0.071
4A	4	4	5.16	5.92	10.11	0.072	0.054	0.054
4A	5	1	2.51	2.89	3.80	0.108	0.076	0.130
4A	5	2	2.81	3.17	4.50	0.116	0.088	0.100
4A	5	3	3.69	4.09	5.21	0.069	0.052	0.068
4A	5	4	4.25	4.78	6.74	0.072	0.055	0.061
4B	1	1	28.44	29.17	104.89	0.004	0.003	0.003
4B	1	2	30.53	32.47	277.35	0.016	0.010	0.011
4B	1	3	13.74	15.93	39.37	0.049	0.034	0.036
4B	1	4	29.60	31.93	261.34	0.020	0.013	0.013
4B	2	1	8.59	9.72	22.42	0.058	0.043	0.036
4B	2	2	3.70	4.28	6.55	0.091	0.067	0.084
4B	2	3	4.16	4.63	7.11	0.045	0.033	0.061
4B	2	4	22.19	24.20	78.40	0.014	0.009	0.014
4B	3	1	9.24	10.05	23.26	0.018	0.011	0.028
4B	3	2	10.21	11.41	19.48	0.034	0.023	0.032
4B	3	3	8.18	9.31	24.13	0.050	0.034	0.046
4B	3	4	10.13	11.74	20.80	0.040	0.027	0.040
4B	4	1	4.39	5.24	8.99	0.120	0.090	0.078
4B	4	2	8.14	10.01	17.97	0.094	0.068	0.057
4B	4	3	7.62	9.61	18.63	0.110	0.077	0.076
4B	4	4	3.12	3.54	5.67	0.089	0.065	0.095
4B	5	1	21.54	23.63	82.94	0.017	0.011	0.017
4B	5	2	22.53	25.26	117.40	0.025	0.016	0.022
4B	5	3	13.25	15.32	34.79	0.043	0.030	0.034
4B	5	4	18.30	20.43	59.56	0.027	0.018	0.022

Appendix C. Results of 1994 Sultan River sediment analysis for individual strata of each sample.

STA	REP	STRATUM	DGW	DGD	DGLS	PFW	PFD	PFLS
5A	1	1	15.18	16.53	234.42	0.030	0.018	0.023
5A	1	2	5.88	7.10	15.98	0.095	0.063	0.080
5A	1	3	15.45	18.77	81.84	0.068	0.044	0.048
5A	1	4	7.00	8.89	38.78	0.117	0.077	0.084
5A	2	1	10.82	11.61	28.28	0.030	0.020	0.024
5A	2	2	11.83	14.93	49.33	0.093	0.061	0.064
5A	2	3	3.68	4.90	9.52	0.183	0.126	0.129
5A	2	4	19.04	23.50	231.50	0.088	0.058	0.047
5A	3	1	23.22	26.12	167.99	0.043	0.027	0.024
5A	3	2	6.31	8.19	14.98	0.139	0.096	0.094
5A	3	3	9.18	11.33	22.55	0.093	0.062	0.067
5A	3	4	5.88	7.12	16.19	0.098	0.066	0.080
5A	4	1	9.66	11.28	48.86	0.060	0.036	0.049
5A	4	2	12.78	15.62	47.53	0.074	0.049	0.052
5A	4	3	9.07	10.56	40.18	0.079	0.054	0.051
5A	4	4	4.45	5.75	13.09	0.157	0.111	0.111
5A	5	1	3.26	4.00	7.64	0.141	0.095	0.118
5A	5	2	13.02	16.05	54.62	0.078	0.051	0.055
5A	5	3	8.20	10.33	20.63	0.104	0.070	0.075
5A	5	4	4.04	5.07	9.41	0.140	0.098	0.112
5B	1	1	15.83	16.93	160.46	0.035	0.023	0.017
5B	1	2	13.41	15.18	32.57	0.049	0.033	0.033
5B	1	3	5.03	6.10	11.32	0.123	0.087	0.087
5B	1	4	4.68	5.93	11.12	0.125	0.082	0.102
5B	2	1	12.11	13.48	74.11	0.045	0.028	0.032
5B	2	2	6.89	8.50	13.89	0.109	0.075	0.078
5B	2	3	11.73	14.24	35.79	0.097	0.068	0.052
5B	2	4	14.70	16.67	36.05	0.049	0.032	0.032
5B	3	1	13.09	13.49	25.35	0.010	0.006	0.007
5B	3	2	10.10	10.64	20.25	0.014	0.008	0.017
5B	3	3	13.39	15.64	40.04	0.064	0.043	0.042
5B	3	4	5.57	6.96	16.66	0.129	0.091	0.084

Appendix C. Results of 1994 Sultan River sediment analysis for individual strata of each sample.

STA	REP	STRATUM	DGW	DGD	DGLS	PFW	PFD	PFLS
5B	4	1	18.63	20.25	51.49	0.029	0.018	0.019
5B	4	2	8.08	9.65	32.02	0.099	0.068	0.061
5B	4	3	18.21	21.74	118.39	0.070	0.046	0.040
5B	4	4	15.44	17.74	48.37	0.051	0.034	0.032
5B	5	1	9.30	10.94	35.26	0.080	0.050	0.050
5B	5	2	6.06	7.92	20.63	0.151	0.099	0.092
5B	5	3	8.35	11.04	19.77	0.154	0.104	0.078
5B	5	4	17.64	20.70	78.73	0.068	0.045	0.034

Appendix D

Arithmetic Means of Lower Three Strata for Each Replicate at Each Station (1994)

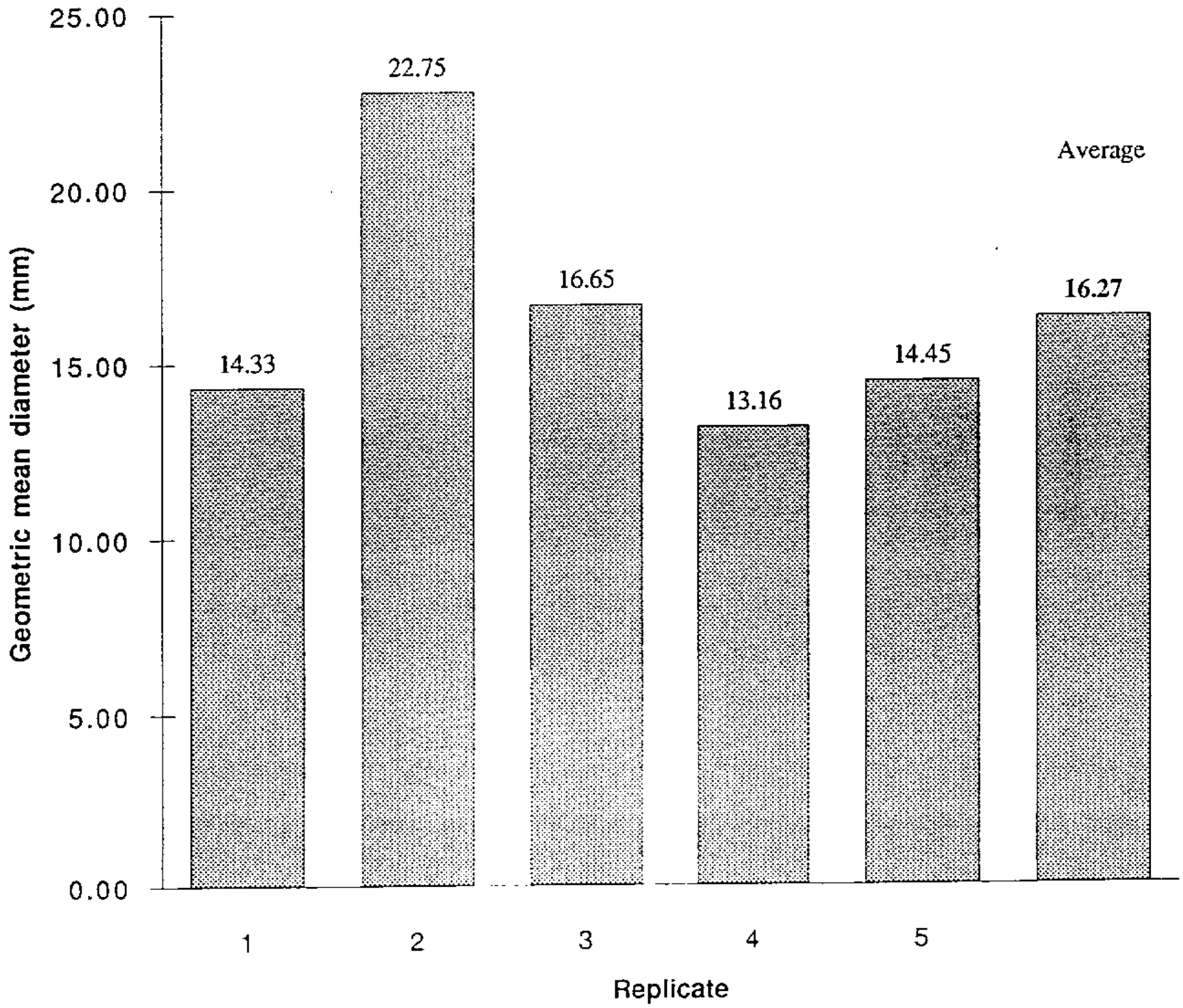
Appendix D. Results of the 1994 Sultan River sediment analyses. Arithmetic means of lower three strata for each replicate at each station (surface stratum was omitted).

STA	REP	DGW	DGD	DGLS	PFW	PFD	PFLS
1	1	13.68	16.11	36.16	0.062	0.043	0.034
1	2	24.74	27.01	109.16	0.025	0.016	0.034
1	3	16.71	19.40	23.55	0.082	0.053	0.034
1	4	14.83	16.89	21.51	0.071	0.052	0.023
1	5	14.66	16.91	33.62	0.055	0.039	0.026
2	1	4.57	6.09	6.26	0.125	0.091	0.034
2	2	7.43	9.27	15.58	0.139	0.101	0.071
2	3	9.01	11.61	25.25	0.140	0.099	0.034
2	4	14.48	17.27	34.03	0.090	0.063	0.034
2	5	6.11	7.18	10.85	0.113	0.079	0.069
3	1	11.61	13.54	31.94	0.068	0.047	0.041
3	2	15.97	18.68	13.38	0.058	0.040	0.034
3	3	12.74	15.35	37.83	0.087	0.062	0.034
3	4	8.18	9.63	43.26	0.062	0.043	0.034
3	5	8.18	9.63	11.70	0.133	0.100	0.054
4A	1	8.82	10.02	10.65	0.086	0.064	0.046
4A	2	6.59	7.76	12.21	0.087	0.064	0.055
4A	3	4.62	5.27	8.04	0.077	0.058	0.059
4A	4	3.58	4.01	5.40	0.086	0.065	0.074
4B	1	24.62	26.77	88.97	0.028	0.019	0.034
4B	2	10.02	11.04	10.91	0.050	0.037	0.035
4B	3	9.51	10.82	20.60	0.041	0.028	0.038
4B	4	6.29	7.72	12.86	0.097	0.070	0.071
4B	5	18.03	20.34	55.87	0.032	0.021	0.025
5A	1	9.44	11.59	32.13	0.093	0.061	0.066
5A	2	11.52	14.44	27.62	0.121	0.082	0.063
5A	3	7.12	8.88	17.50	0.110	0.074	0.079
5A	4	8.77	10.64	25.46	0.103	0.071	0.064
5A	5	8.42	10.48	19.40	0.107	0.073	0.075
5B	1	7.71	9.07	14.76	0.099	0.067	0.064
5B	2	11.10	13.14	23.29	0.069	0.047	0.050
5B	3	9.69	11.08	19.91	0.073	0.050	0.034
5B	4	13.91	16.38	51.77	0.124	0.083	0.042
5B	5	10.68	13.22	26.11	0.073	0.050	0.059

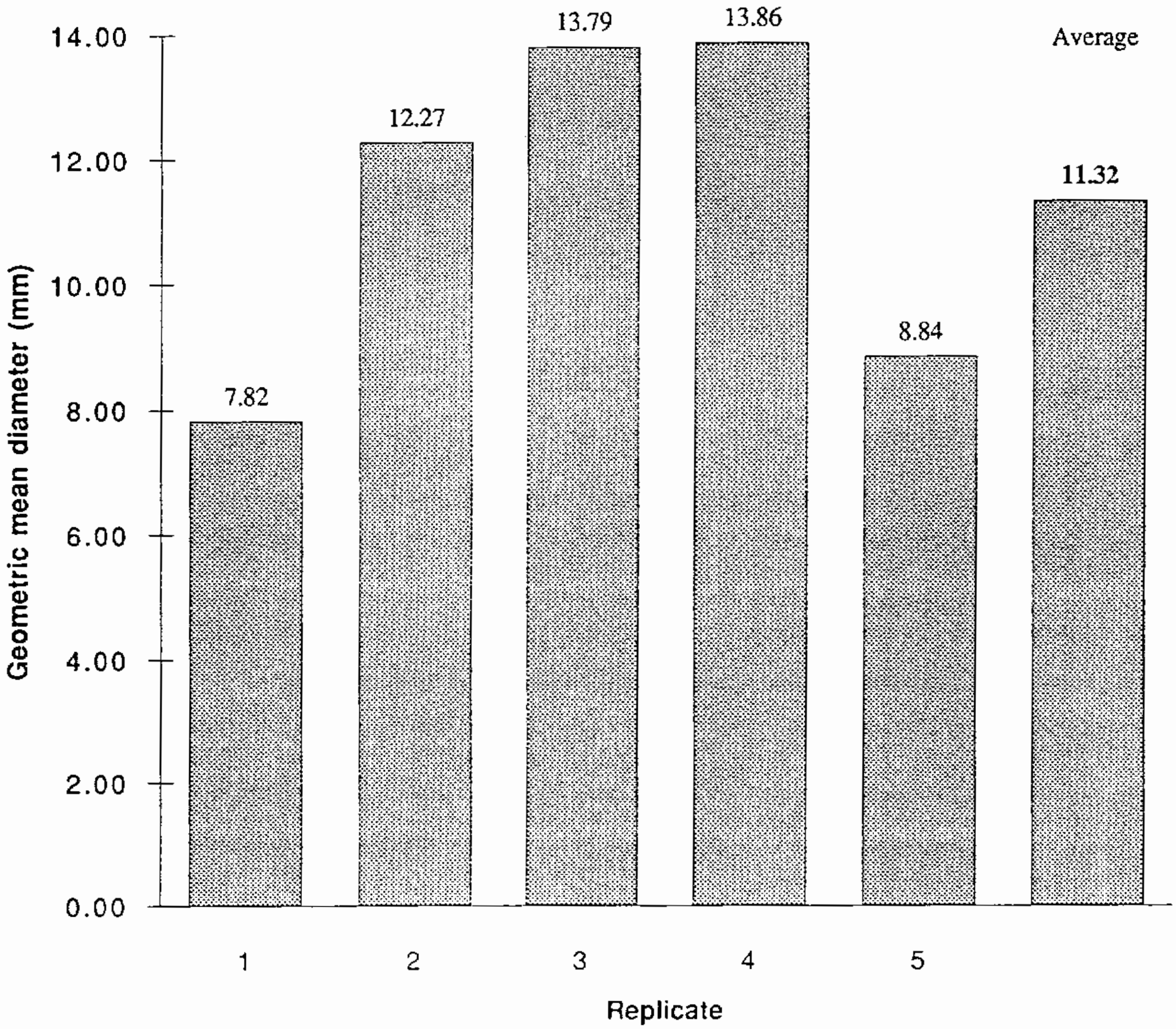
Appendix E

DGW and PFW Histograms of Sultan River Freeze-core Substrate Studies

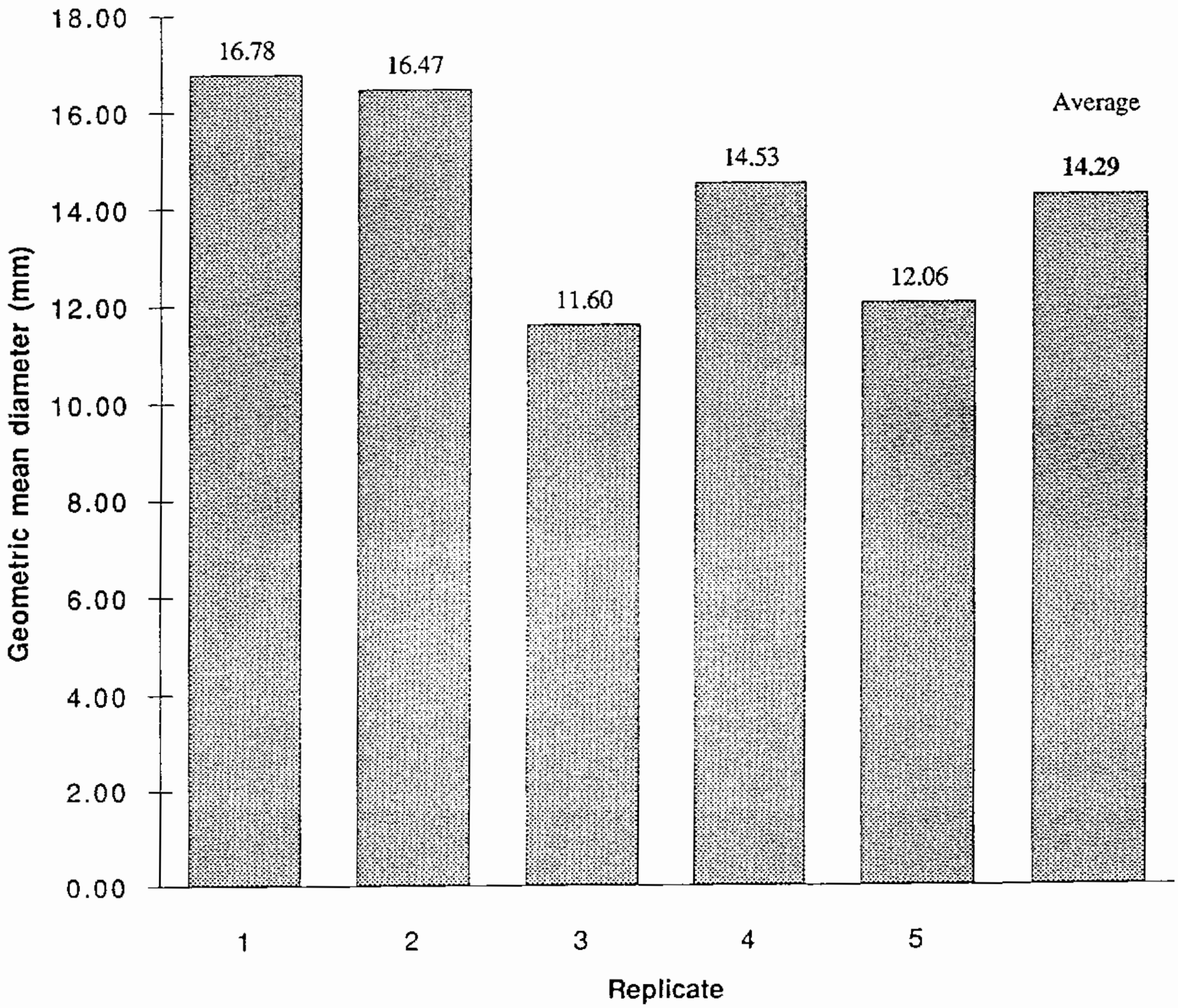
Geometric mean diameter - volumetric (DGW) using all four strata for each replicate at Station 1 on the Sultan River for 1994



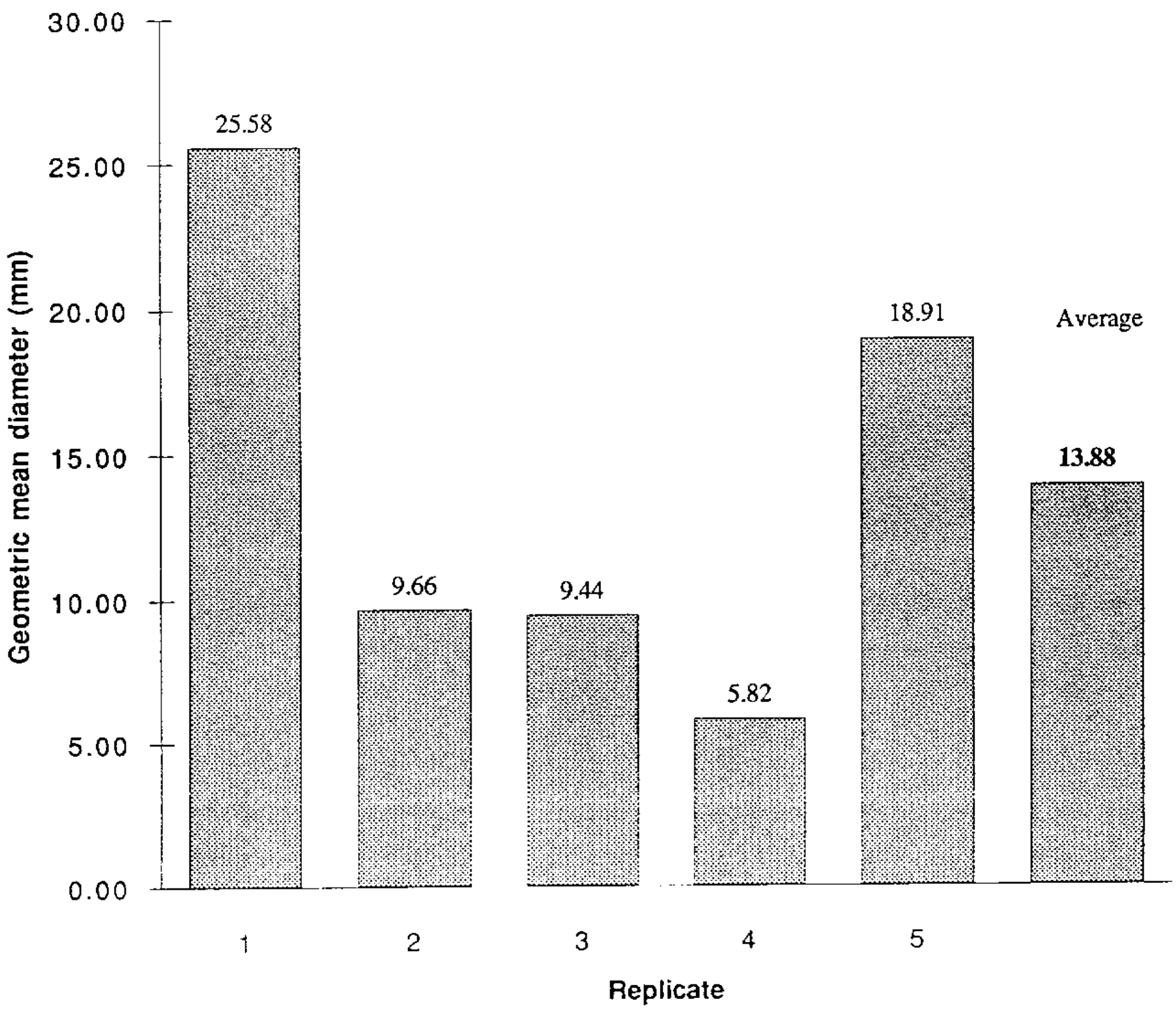
Geometric mean diameter - volumetric (DGW) using all four strata for each replicate at Station 2 on the Sultan River for 1994



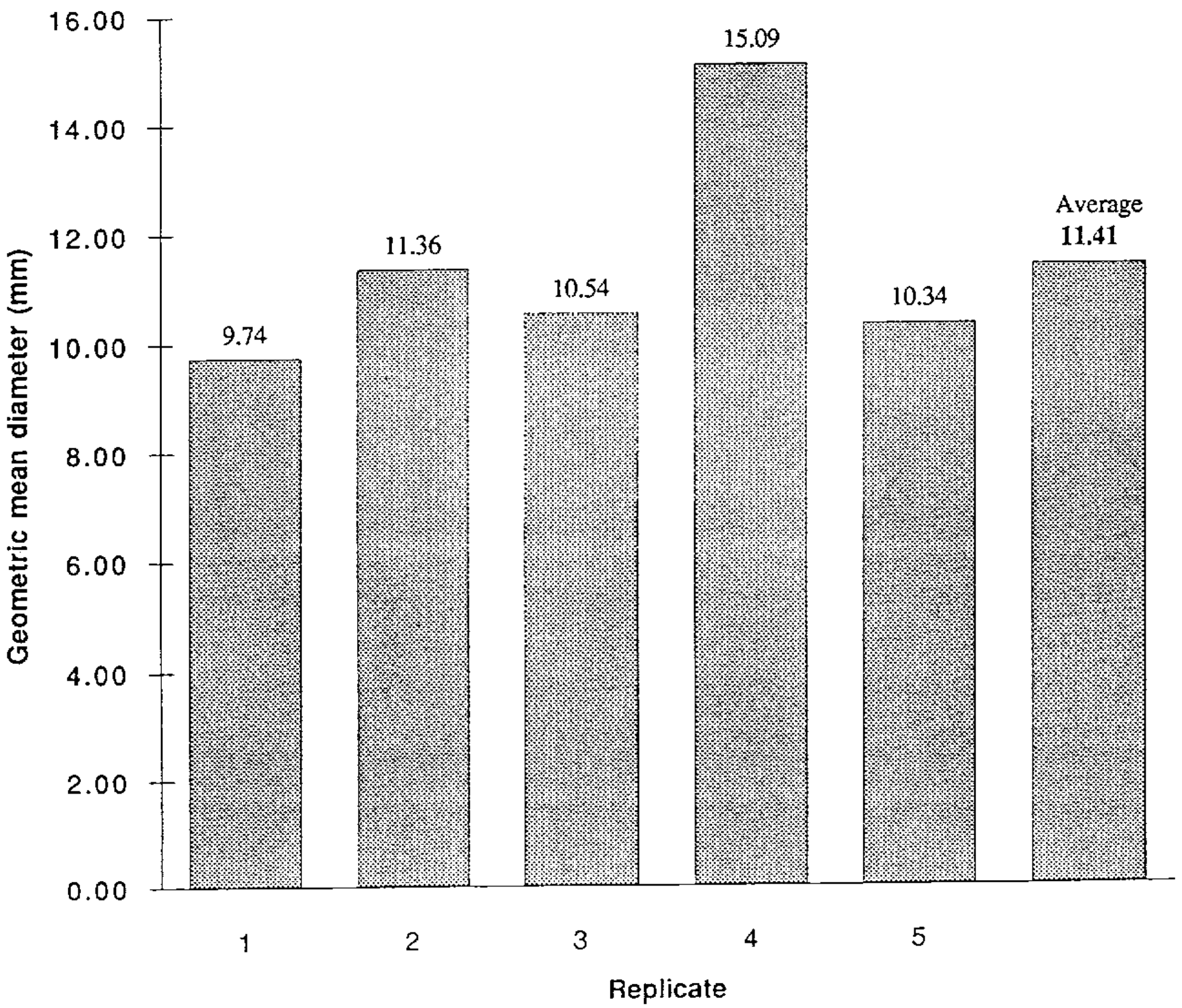
Geometric mean diameter - volumetric (DGW) using all four strata for each replicate at Station 3 on the Sultan River for 1994



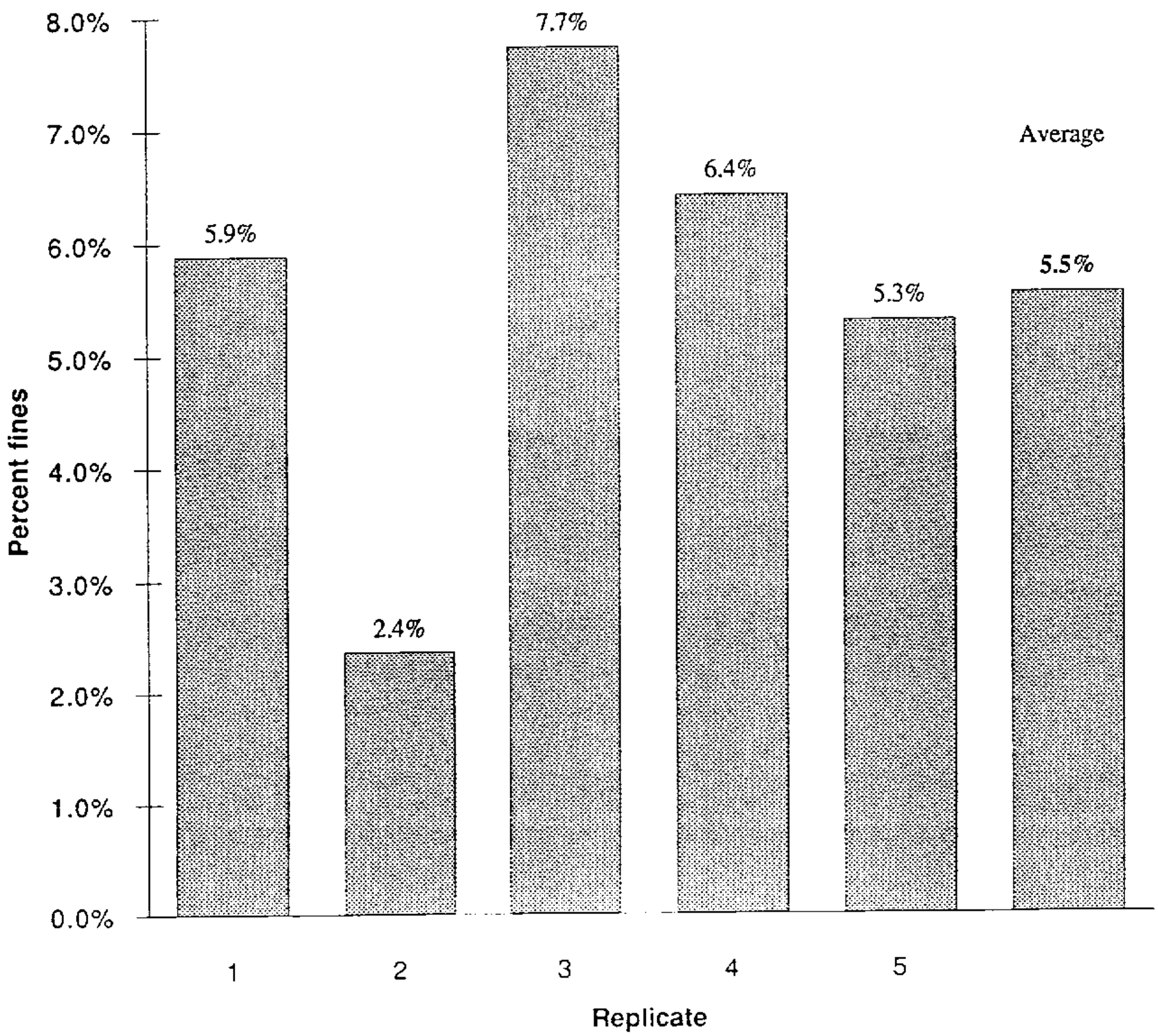
Geometric mean diameter - volumetric (DGW) using all four strata for each replicate at Station 4B on the Sultan River for 1994



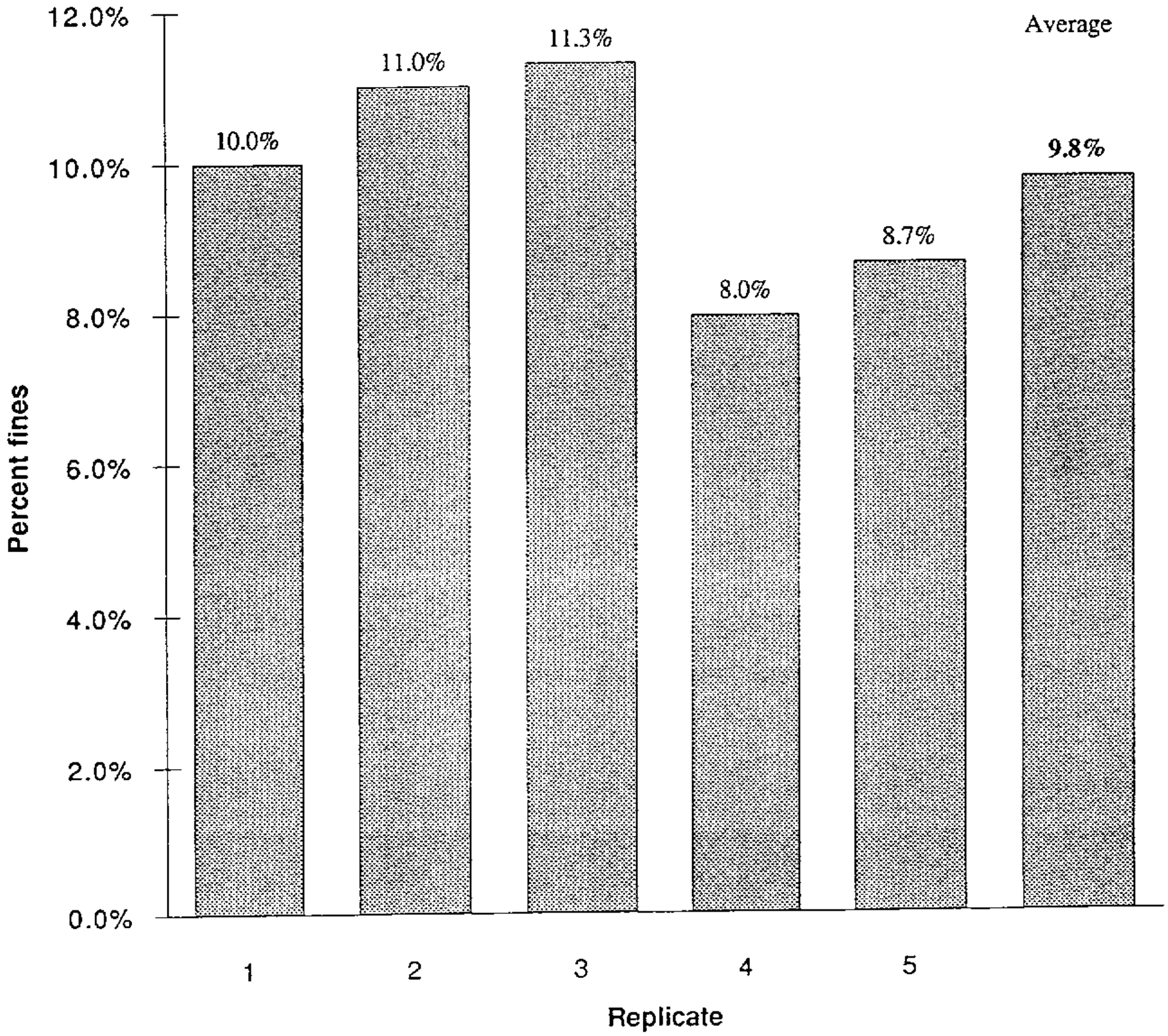
Geometric mean diameter - volumetric (DGW) using all four strata for each replicate at Station 5B on the Sultan River for 1994



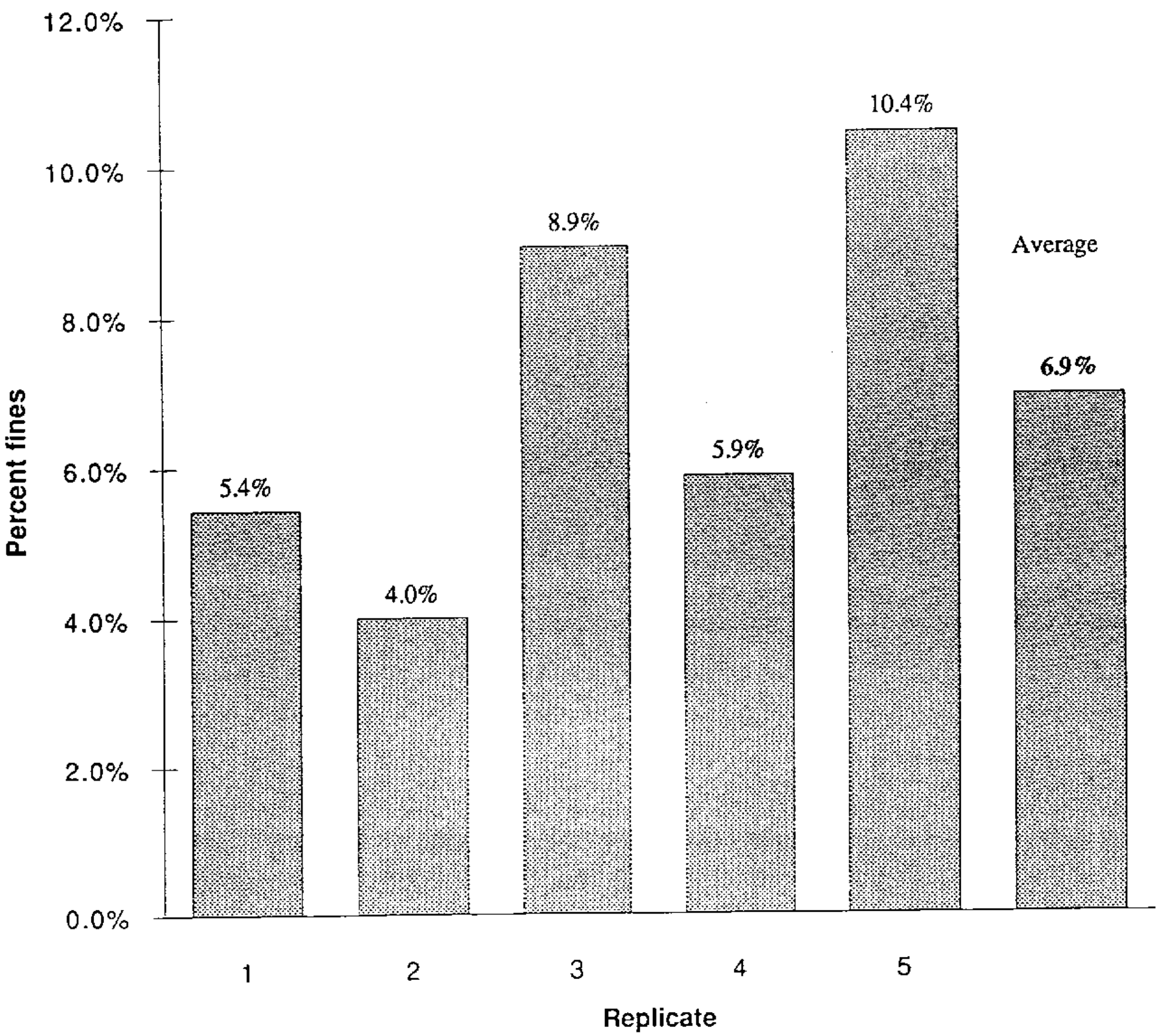
Percent fines - volumetric (PFW) using all four strata for each replicate at Station 1 on the Sultan River for 1994



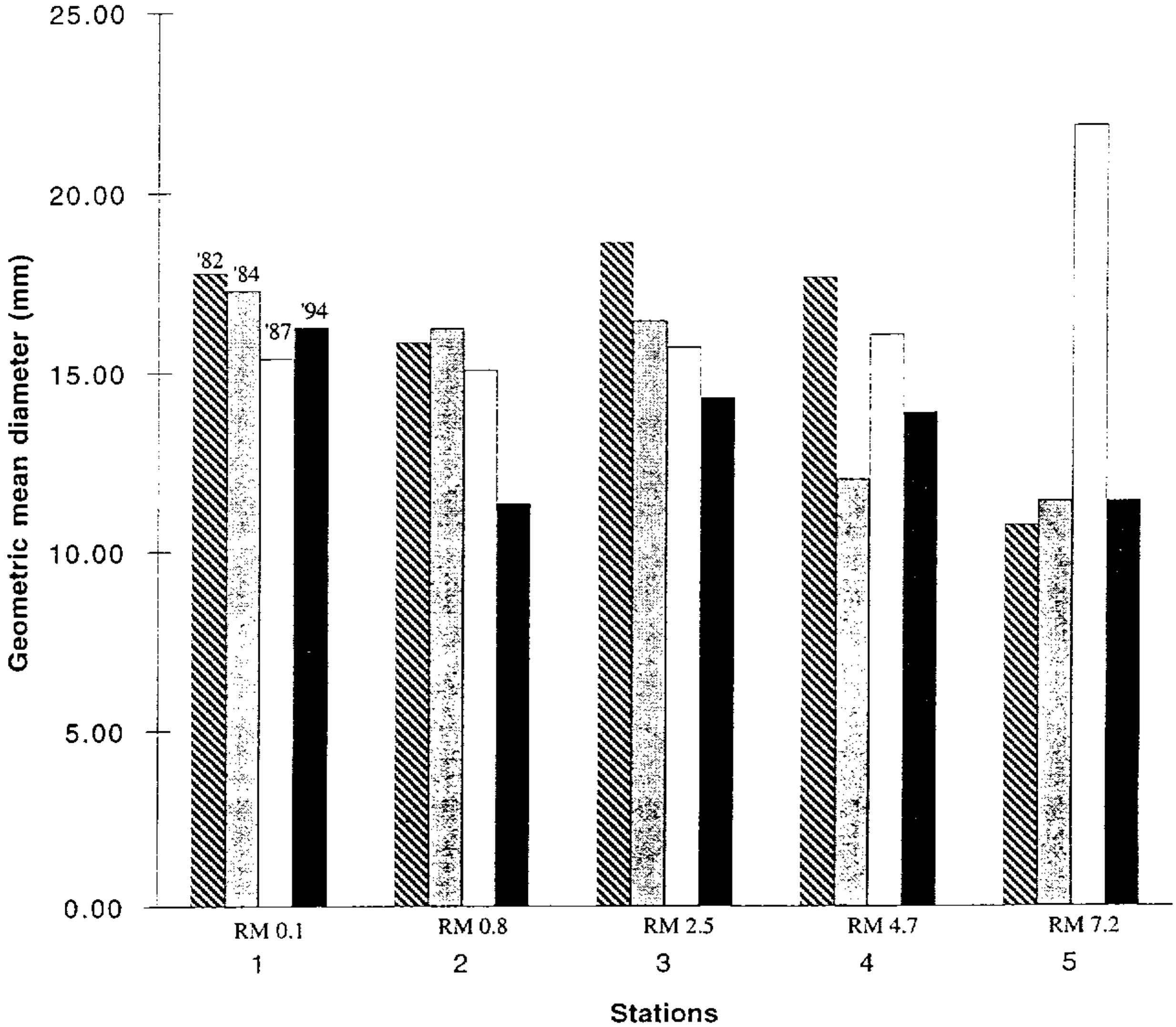
Percent fines - volumetric (PFW) using all four strata for each replicate at Station 2 on the Sultan River for 1994



Percent fines - volumetric (PFW) using all four strata for each replicate at Station 3 on the Sultan River for 1994

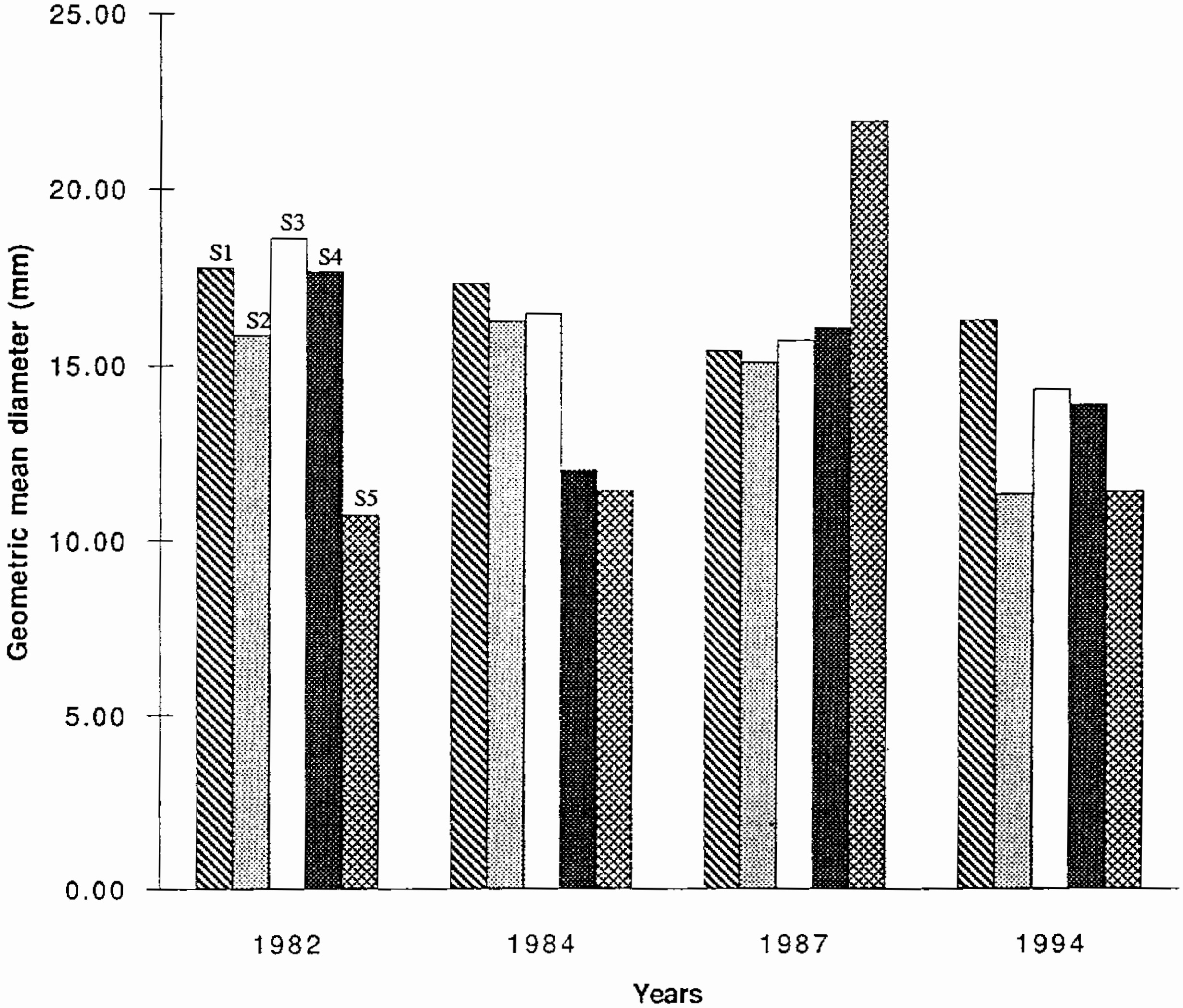


Geometric mean diameter (DGW - volumetric) for all four strata at each station on the Sultan River for all study years (1982 - 1994)

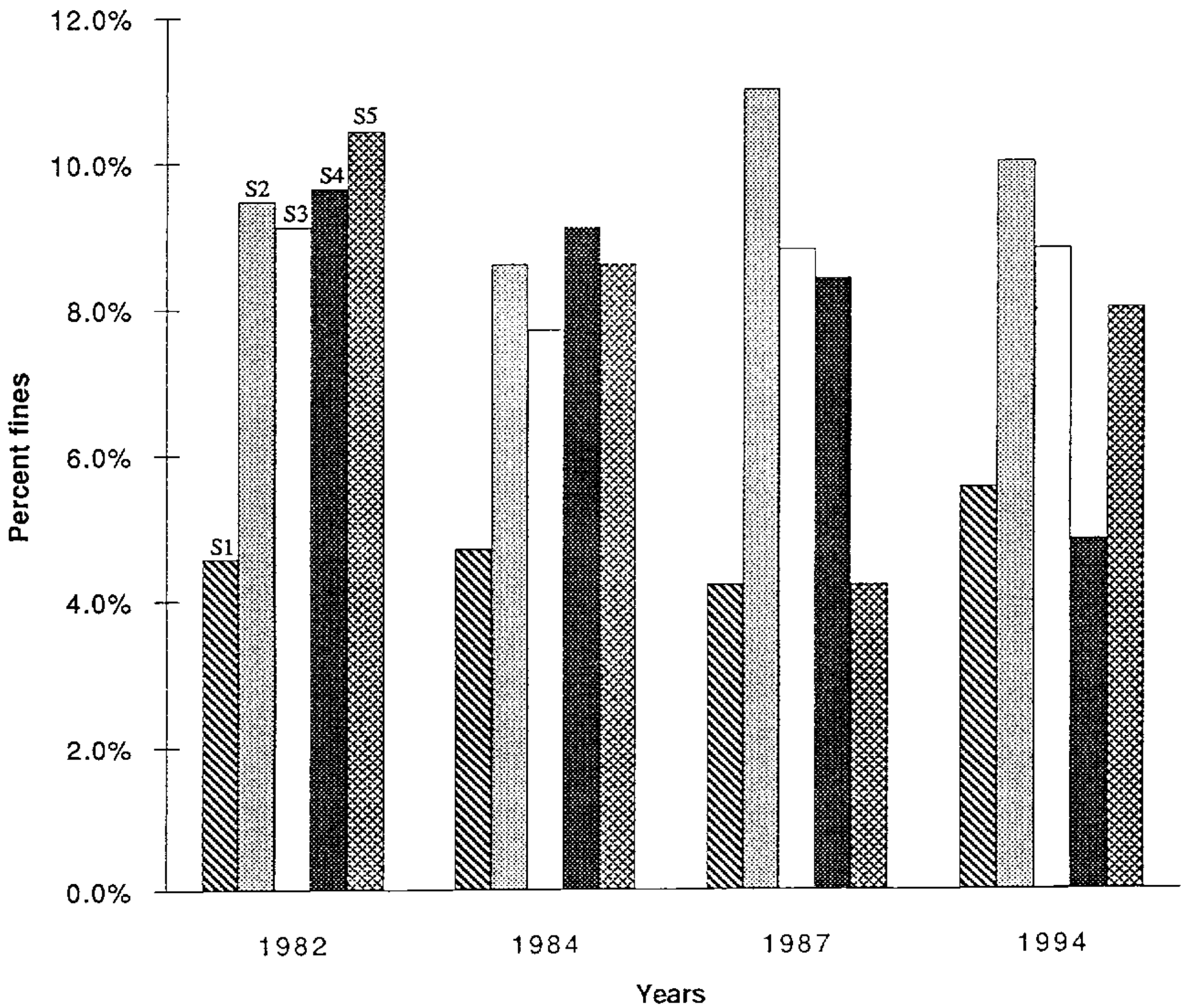


DGW Stn 1-5 ea year

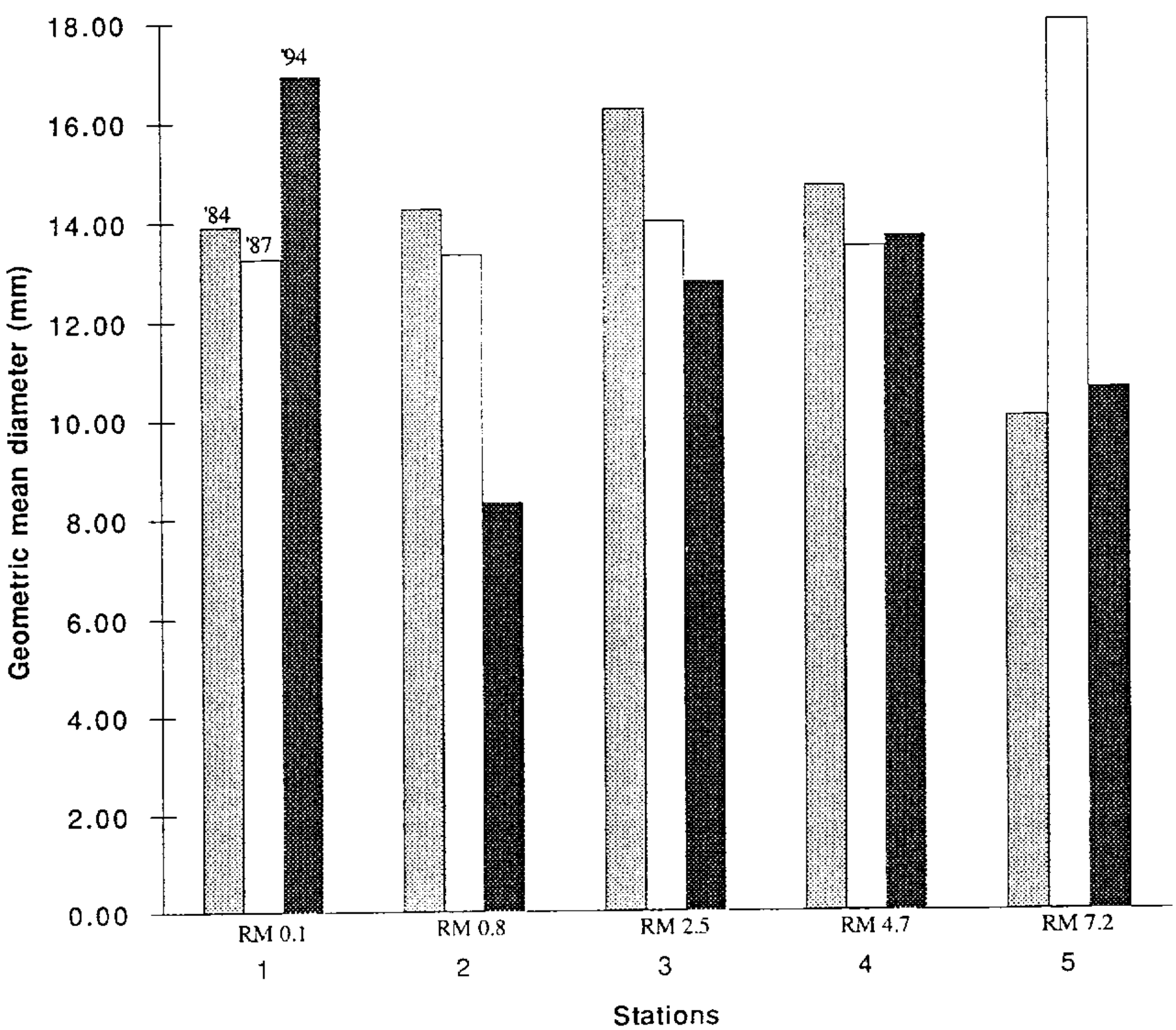
Average geometric mean diameter (DGW - volumetric) for all four strata at each station (S1-S5) on the Sultan River for each year of the study



Percent fines (PFW - volumetric) for all four strata at each station (S1-S5) on the Sultan River for each year of the study

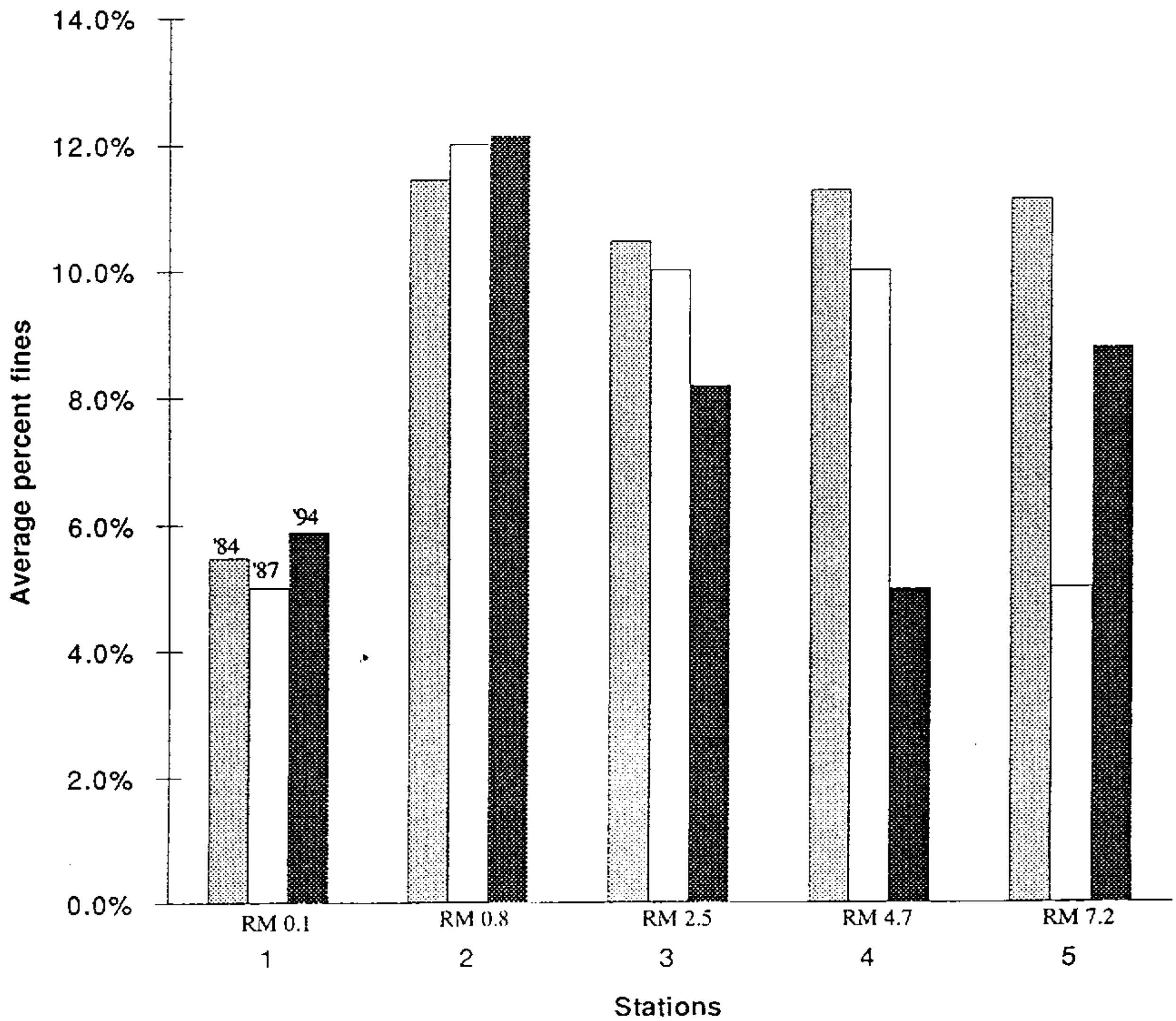


Geometric mean diameter (DGW - volumetric) using the lower three strata at each station on the Sultan River for study years 1984, 1987, and 1994



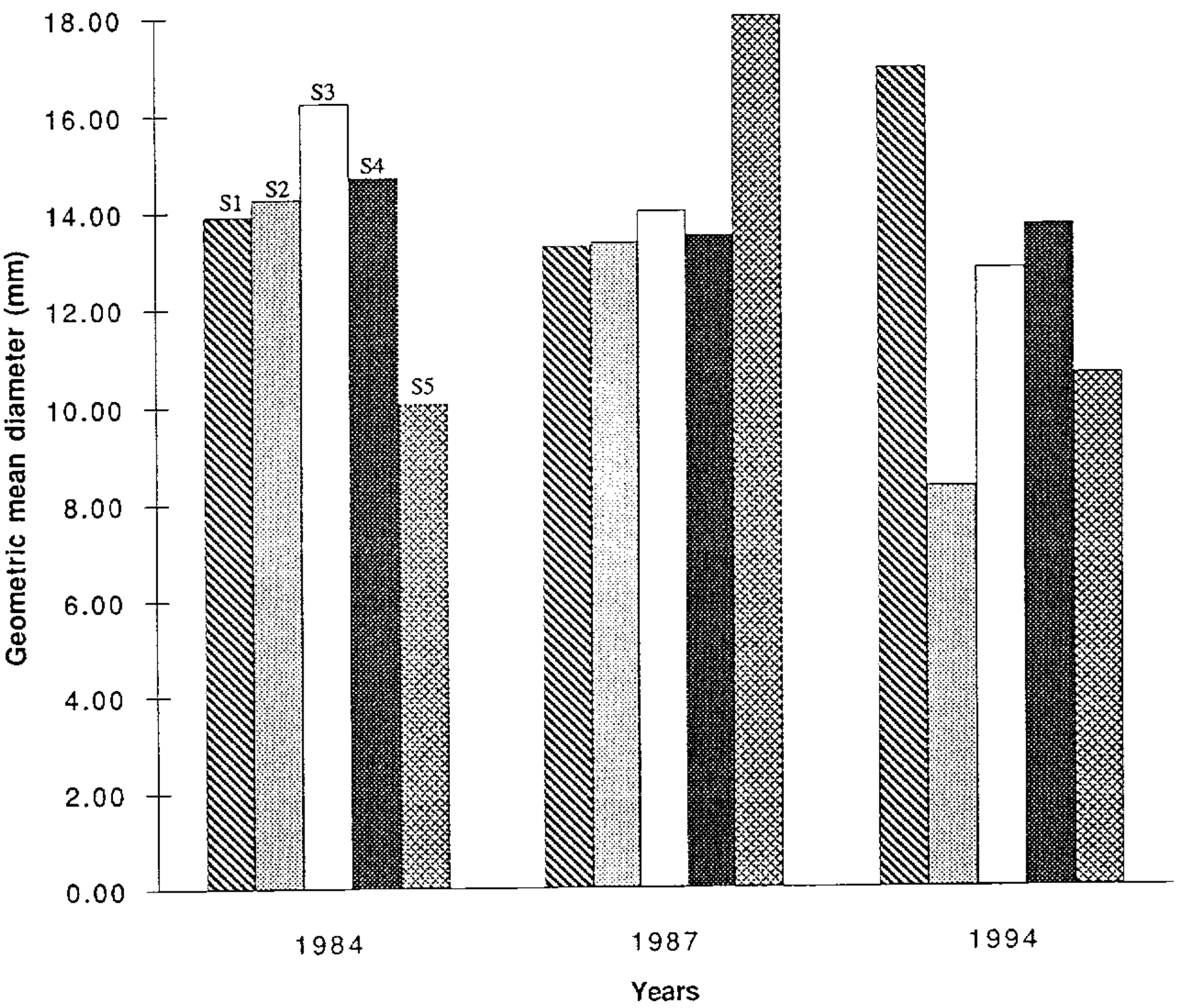
Note: 1982 data for the lower 3 strata were unavailable and are therefore not shown.

Average percent fines (PFW - volumetric) using the lower three strata at each station on the Sultan River for study years 1984, 1987, and 1994



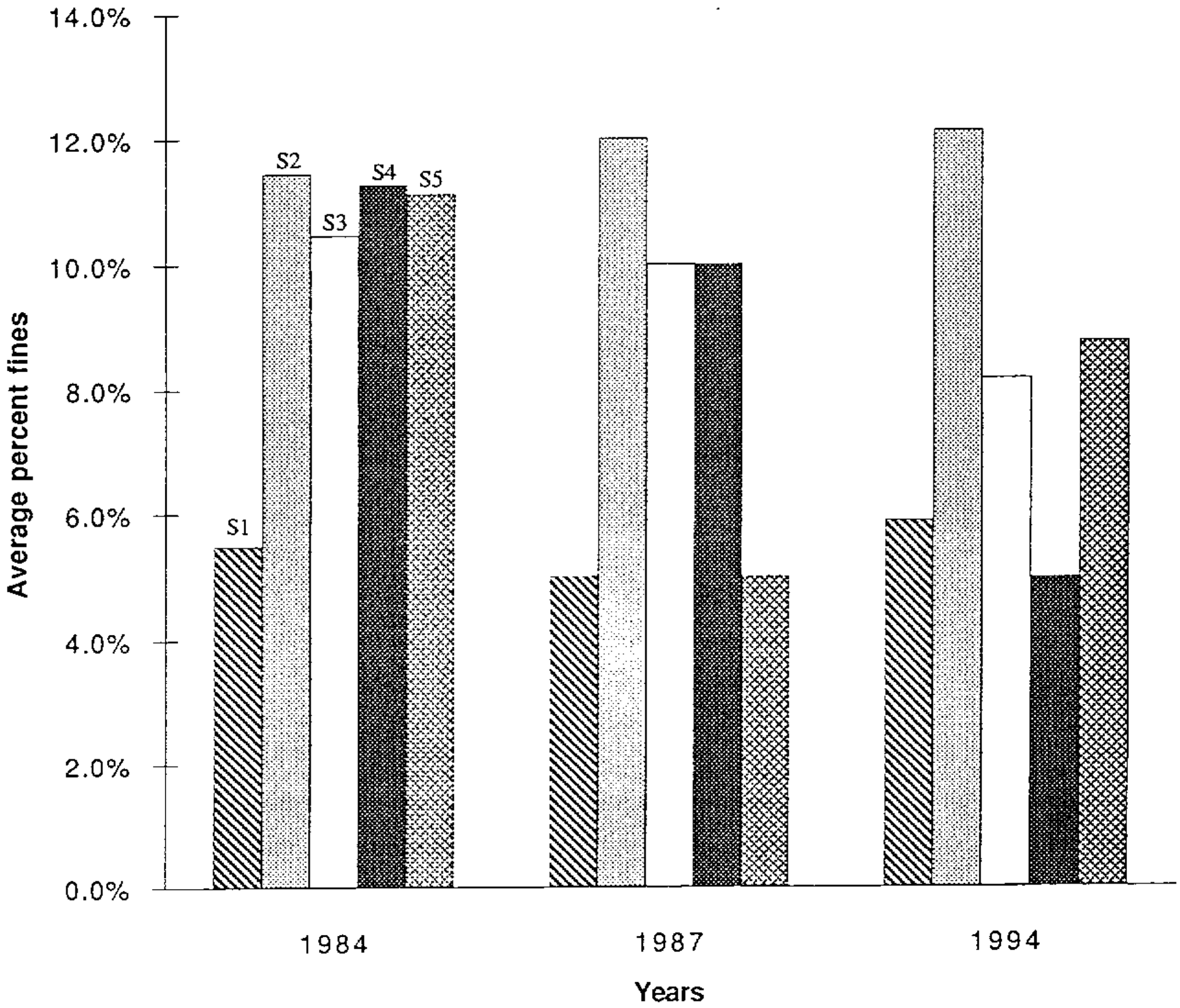
Note: 1982 data for the lower 3 strata were unavailable and are therefore not shown.

Average geometric mean diameter (DGW - volumetric) using three lower strata at each station (S1-S5) on the Sultan River for the 1984, 1987, and 1994 study years



Note: 1982 data were unavailable and are therefore not shown.

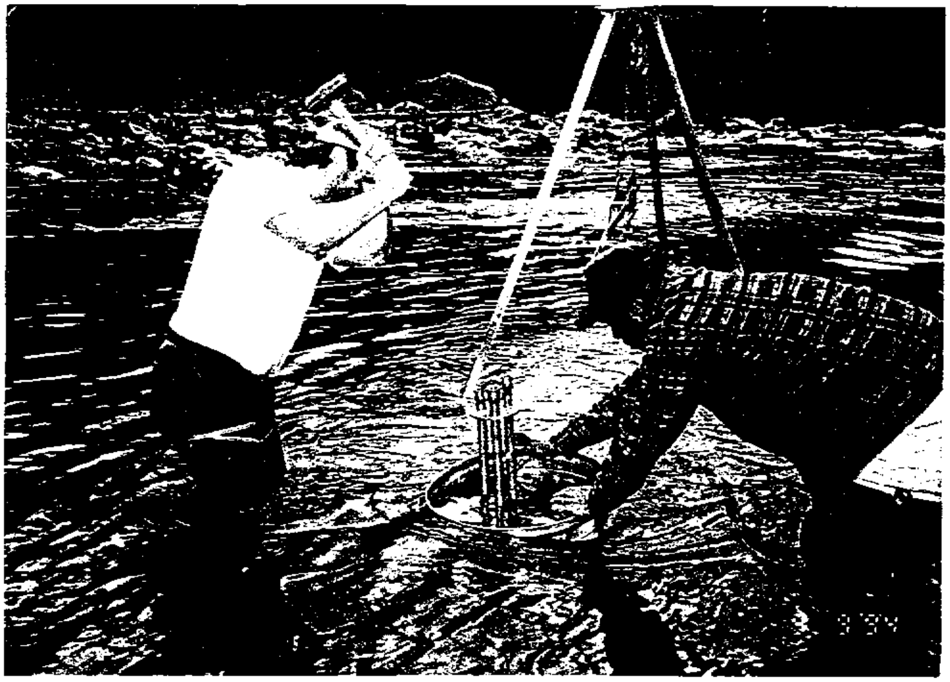
Average percent fines (PFW - volumetric) using three lower strata at each station (S1-S5) on the Sultan River for the 1984, 1987, and 1994 study years



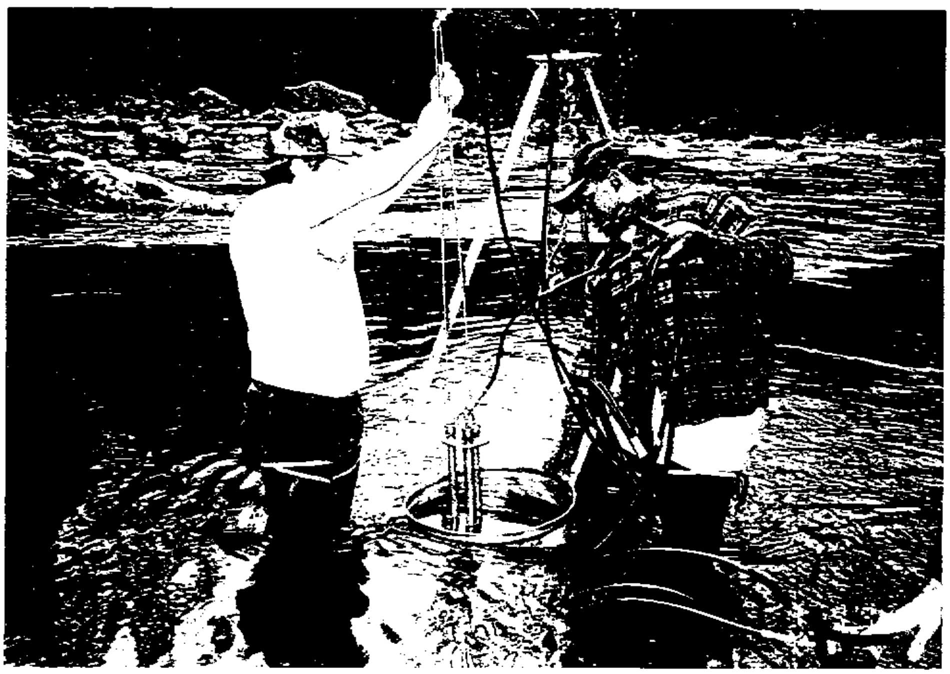
Note: 1982 data were unavailable and are therefore not shown.

Appendix F

Selected Photographs Showing Freeze-core Sampling and Processing Methods



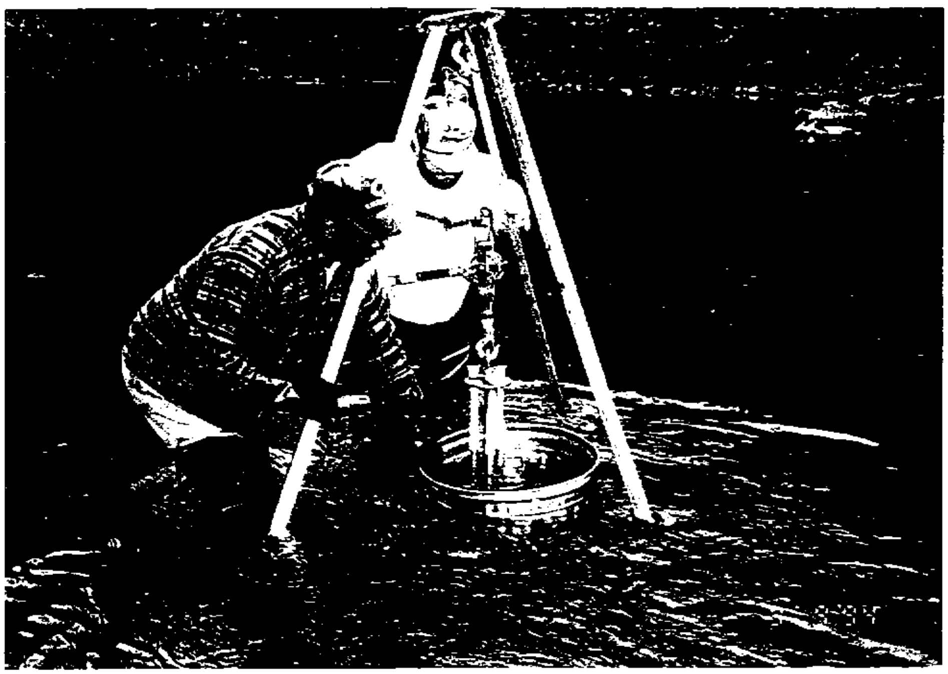
PHOTOGRAPH 1. Driving tri-tube freeze-core sampler into the streambed.



PHOTOGRAPH 2. Inserting CO2 nozzles and manifold into tri-tube freeze core sampler probes (Note Bottomless garbage can used as a flow shunt to prevent disturbance of the sediment surface).

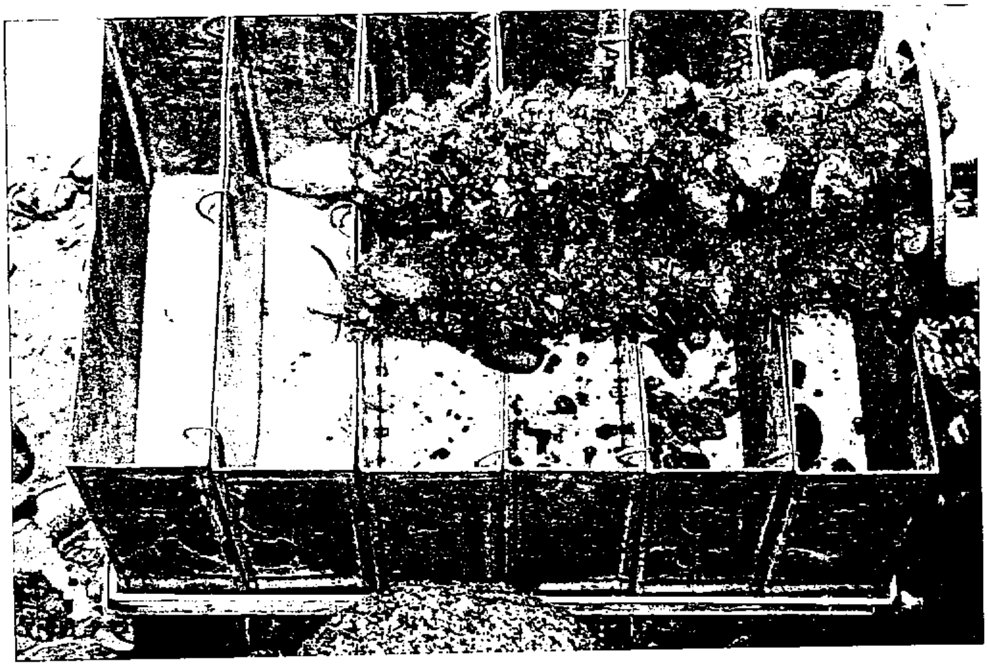
APPENDIX F1

PHOTOGRAPH 3. Freezing core by discharging the contents of one 9-kg (20-lb) cylinder of liquid CO_2 into hollow sampler probes.

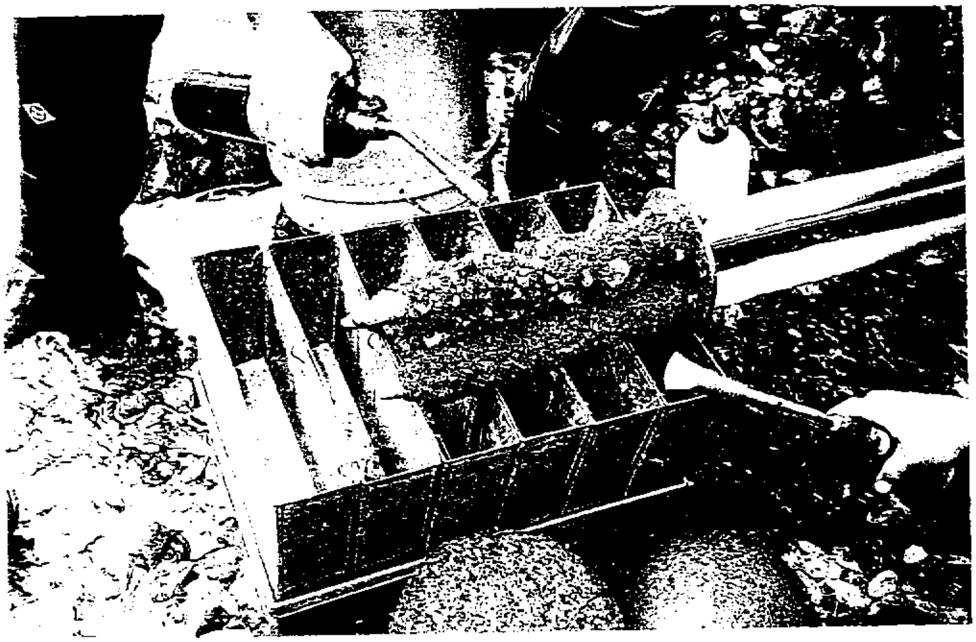


PHOTOGRAPH 4. Extracting the frozen core with a winch and tripod.

APPENDIX F2



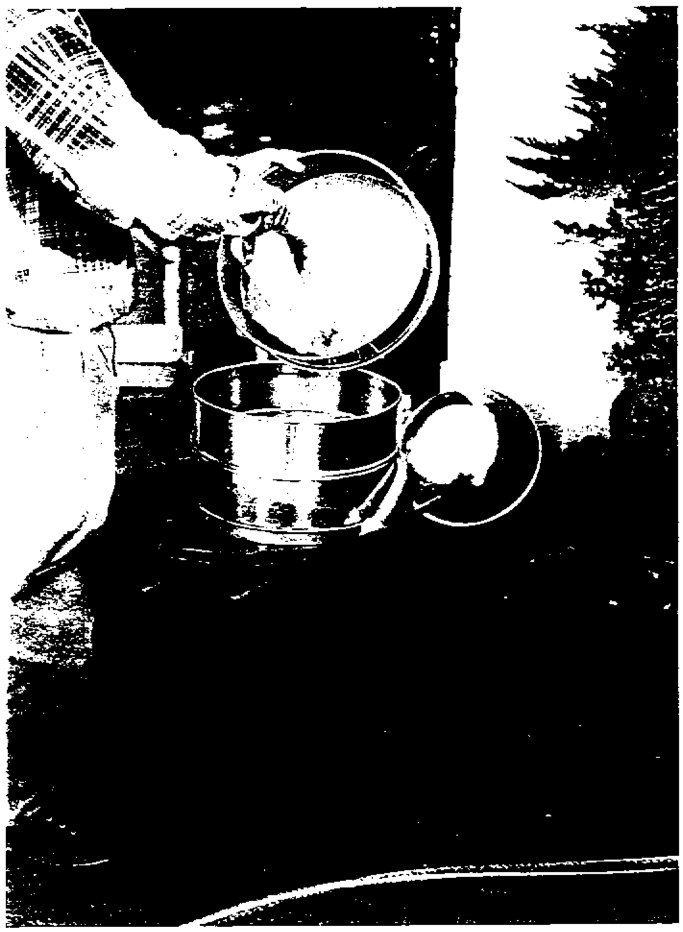
PHOTOGRAPH 5. Extracted frozen core ready for thawing over galvanized aluminum substrata collection boxes.



PHOTOGRAPH 6. Thawing an extracted core with propane torches, maintaining stratification within the 30-cm (12-inch) sample profile.

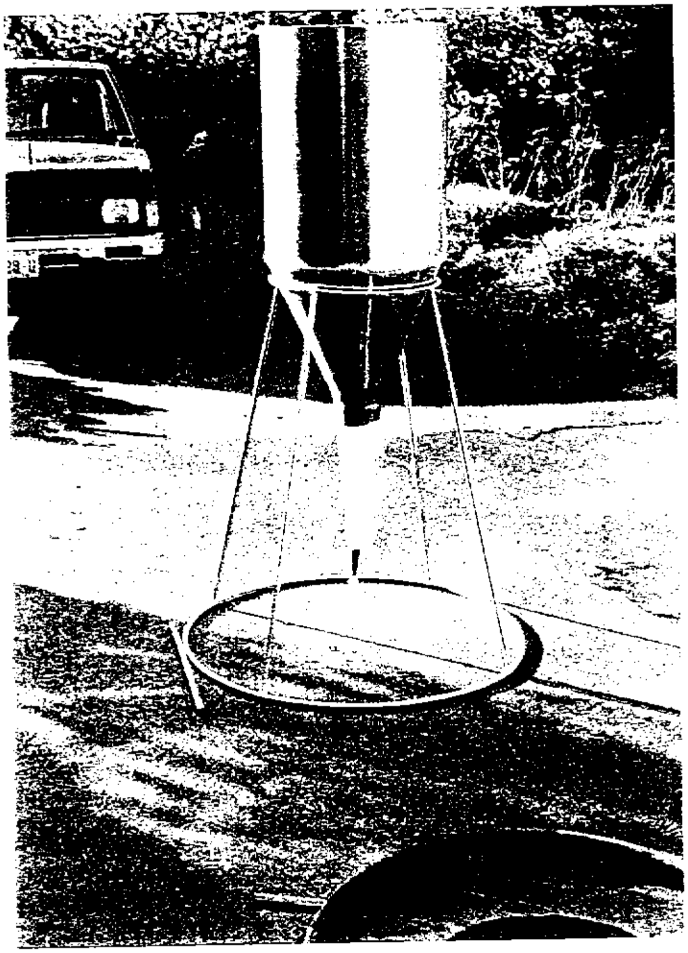
APPENDIX F3

PHOTOGRAPH 7. Wet sieving a sample through the geometric series of 10 Tyler sieves, ranging in diameter from 53.8 to 0.105 mm in mesh diameter (2.12 to 0.004 inches).



PHOTOGRAPH 8. Concentrating the sample to facilitate drainage and volumetric displacement measurements.

APPENDIX F4



PHOTOGRAPH 9. Settling fraction finer than 0.105 mm diameter (washload) in an Imhoff cone.