APPENDIX A

BASELINE EVALUATION OF THE TEXTURAL COMPOSITION OF SULTAN RIVER SALMONID SPAWNING GRAVELS

1982

SULTAN RIVER PROJECT

FERC PROJECT NO. 2157

BASELINE EVALUATION OF THE TEXTURAL COMPOSITION OF SULTAN RIVER SALMONID SPAWNING GRAVELS

PUBLIC UTILITY DISTRICT NO. 1
OF
SNOHOMISH COUNTY
WASHINGTON

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SULTAN RIVER PROJECT

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SUMMARY

The Sultan River Hydroelectric Project will significantly alter the flow regime in all 9.7 miles of river downstream of the Everett diversion dam. Since various anadromous fish species/life stages use this river section, the licensee agreed with fish and wildlife agencies to determine short and long term impacts of sedimentation and compaction of spawning gravels due to project construction and operation. In order to evaluate existing conditions a baseline study of spawning gravel texture was initiated by the Public Utility District No. 1 of Snohomish County in the spring of 1982.

Objectives of this study were to:

1. Determine the spatial variability of sediment samples among selected spawning reaches between the diversion dam and river mouth;
2. Determine the vertical heterogeneity of sediments within and among spawning reaches;
3. Determine the short-term temporal variability of sediment samples at a specific location before and after a two week period of controlled increased flow.

Streambed sediments were removed from five salmonid spawning reaches using a tri-tube freeze-core sampler. A total of 60, 12 inch-deep core samples were collected. Each core was subdivided vertically into 3-inch strata yielding a total of 240 subsamples.

Gravel samples were analyzed by wet sieving through a graduated series of Tyler screens. Textural composition was calculated using the computer program SEDIMNT at the Fisheries Research Institute (FRI), University of Washington. This program provided various substrate statistics and expressed texture in terms of geometric mean diameter and percentage of fines less than 0.841 mm.

Results showed a significant variation among stations with respect to geometric mean diameter. Stations averaged between 11.41 and 18.42 mm with a combined average of 15.32 mm. Values were progressively smaller with increased distance upstream from the river mouth.

The proportion of Sultan River fine sediments less than 0.841 mm averaged 7.1 percent for all stations combined and ranged between 3.7 and 9.1 percent for individual stations.

Subsequent studies will be conducted following project construction and 3 years following project operation. Comparison of results in this report to those of future studies will provide a basis for determining whether or not mitigative measures are required to maintain the quality of Sultan River spawning gravels.

1.0 INTRODUCTION

1.1 AUTHORIZATION

This study was authorized and funded by the Public Utility District No. 1 of Snohomish County. It constitutes the first of a three-part study to determine the effects of the Sultan River Hydroelectric Project, FERC Project no. 2157, on the textural composition of salmonid spawning gravels.

1.2 PROJECT BACKGROUND

Plans for hydroelectric development on the Sultan River call for diversion of water from Culmback Dam (RM 16.5) to a powerhouse (RM 4.5) having a total installed capacity of 112 mw (Figure 1). Water will be 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 will provide controlled flows downstream to the powerhouse at all times. This will assure 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 sediments results primarily from a river's flow regime, the nature of soils and erosive activities in its drainage and streambed gradient. In the Sultan River, these parameters have combined to provide streambed sediments (gravels) which are presently used by spawning anadromous fishes upstream to the Everett diversion dam (RM 9.7). Predominant species are chinook, coho, pink and chum salmon, steelhead and sea-run cutthroat.

Between RM 9.7 and RM 3.0, the Sultan flows through a narrow canyon in a series of pools and riffles (Figure 2). The river bed here consists primarily 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 cfs every 1 in 3.2 years

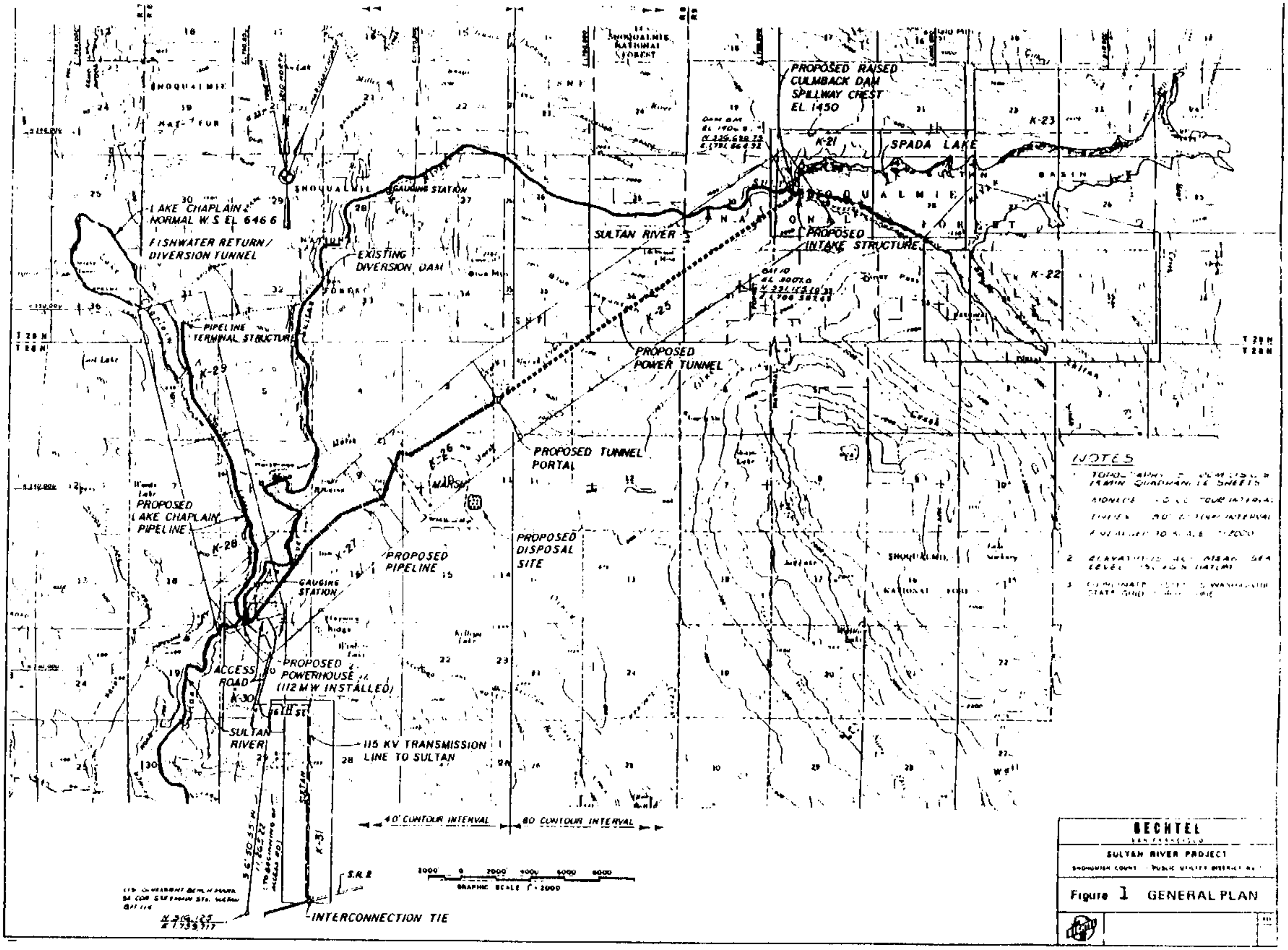


Figure 1 GENERAL PLAN

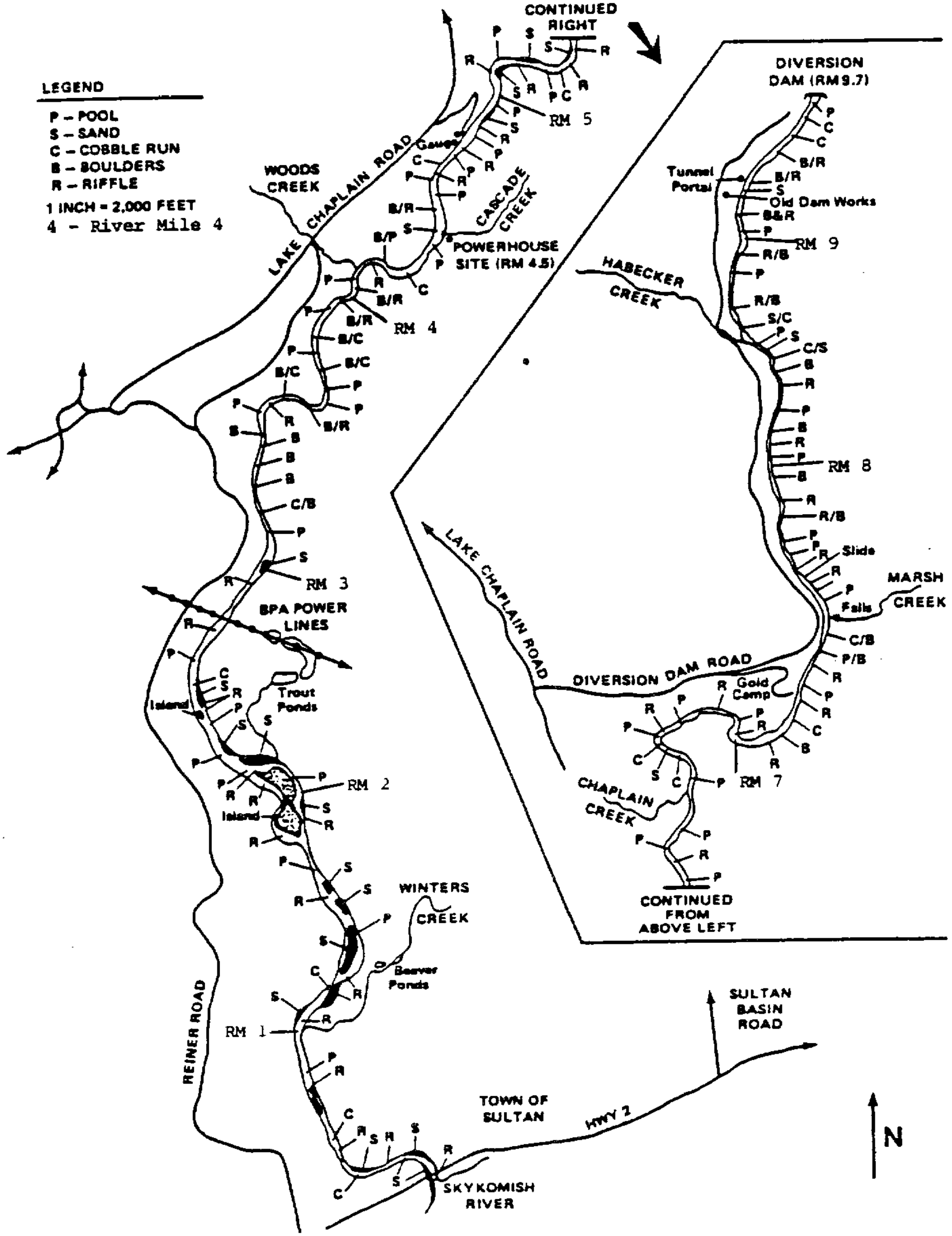


Figure 2 SULTAN RIVER HABITAT MAP. BETWEEN DIVERSION DAM AND RIVER MOUTH

(Eicher 1981). See Figure 3 for Sultan River (Spada Lake) daily inflow and exceedance frequency. High flows can produce sufficient velocity to scour the streambed and cause gravel movement. This can result in dislodgement and destruction of salmonid eggs and alevins, and in extreme cases, cause actual loss of spawning gravel (Burgner 1981).

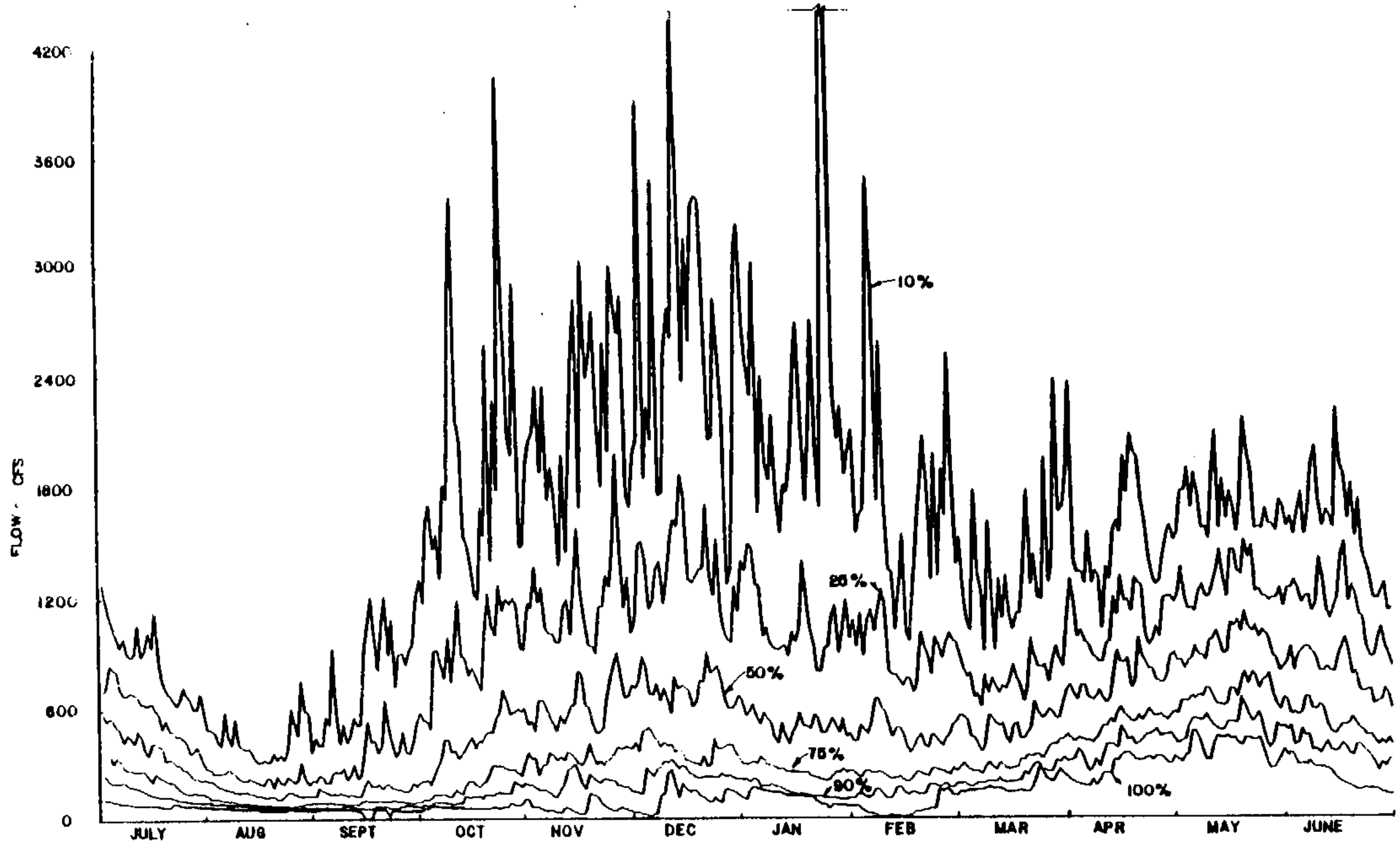
Below the powerhouse, the river flows through approximately 1.5 miles of canyon followed by 3.0 miles of flood plain until reaching its confluence with the Skykomish River at the town of Sultan. Below the canyon, the river widens and the channel occasionally splits, creating islands and numerous low-velocity side channels. Cobble and gravel are abundant, providing conditions quite conducive to anadromous fish spawning.

1.4 STUDY SCOPE AND OBJECTIVES

As part of the License Agreement for FERC Project 2157, an Uncontested Offer of Settlement was made between the Joint Agencies (see page 7) and the licensee. 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) 3 years following initial project operation, are intended to determine whether or not spawning gravel quality has changed as a result of project construction and/or operation. Alteration of gravel quantity, if any, as a result of the project will be evaluated in subsequent studies.

The subject of this report focuses on evaluating the size or textural composition of Sultan streambed gravels prior to project construction. Results of this study will provide a baseline to which future measurements of streambed sediments can be compared.

The objectives of this study involved evaluation of the textural composition of Sultan River spawning gravels by:



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

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PUBLIC UTILITY DISTRICT NO 1
OF SNOHOMISH COUNTY
SULTAN RIVER PROJECT
SPADA LAKE DAILY INFLOW
AND EXCEEDANCE FREQUENCY

DATE	DRAWN	APPROVED	NO
JULY 1980	JPR		3

From: Public Utility District No. 1 of Snohomish County, 1980

1) Determining the spatial variability of sediment samples among spawning reaches between the diversion dam and river mouth.

2) determining the vertical heterogeneity of sediments within and among spawning reaches;

3) determining the short-term temporal variability of sediment samples at a specific location before and after a two week period of controlled increased flow.

2.0 METHODS

2.1 SAMPLE COLLECTION

Substrate samples used to evaluate the quality of spawning gravels within the Sultan River were collected during April and May, 1982, at five spawning reaches shown in Figure 4. These study locations were cooperatively selected by fisheries biologists from Washington Department of Fisheries (WDF), Washington Department of Game (WDG), National Marine Fisheries Service (NMFS) and Tulalip Indian Tribes (Tulalips). Salmon or steelhead have been observed at all sites during spawning surveys conducted by WDF, WDG and Eicher Associates between 1978 and 1982.

Three study sites were located downstream and two upstream of the powerhouse (RM 4.5). The study areas, 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 SR2 bridge at the town of Sultan public fishing access area (Figure 5).

S2 (RM 0.8) is mid-channel approximately 300 yards downstream of Winters Creek confluence (Figure 6).

S3 (RM 2.5) is along the east (left) bank approximately 400 yards downstream from the BPA powerline crossing at the end of First Street (Figure 7).

S4 (RM 4.7) is located adjacent to the west (right) bank approximately 50 yards downstream from Chaplain Creek gaging station (Figure 8).

S5 (RM 7.2) is situated along the west (right) bank between Marsh Creek confluence and Horseshoe Bend in the area referred to as the Gold Camp (Figure 9).

Table 1 shows spawning use at all sampling stations.

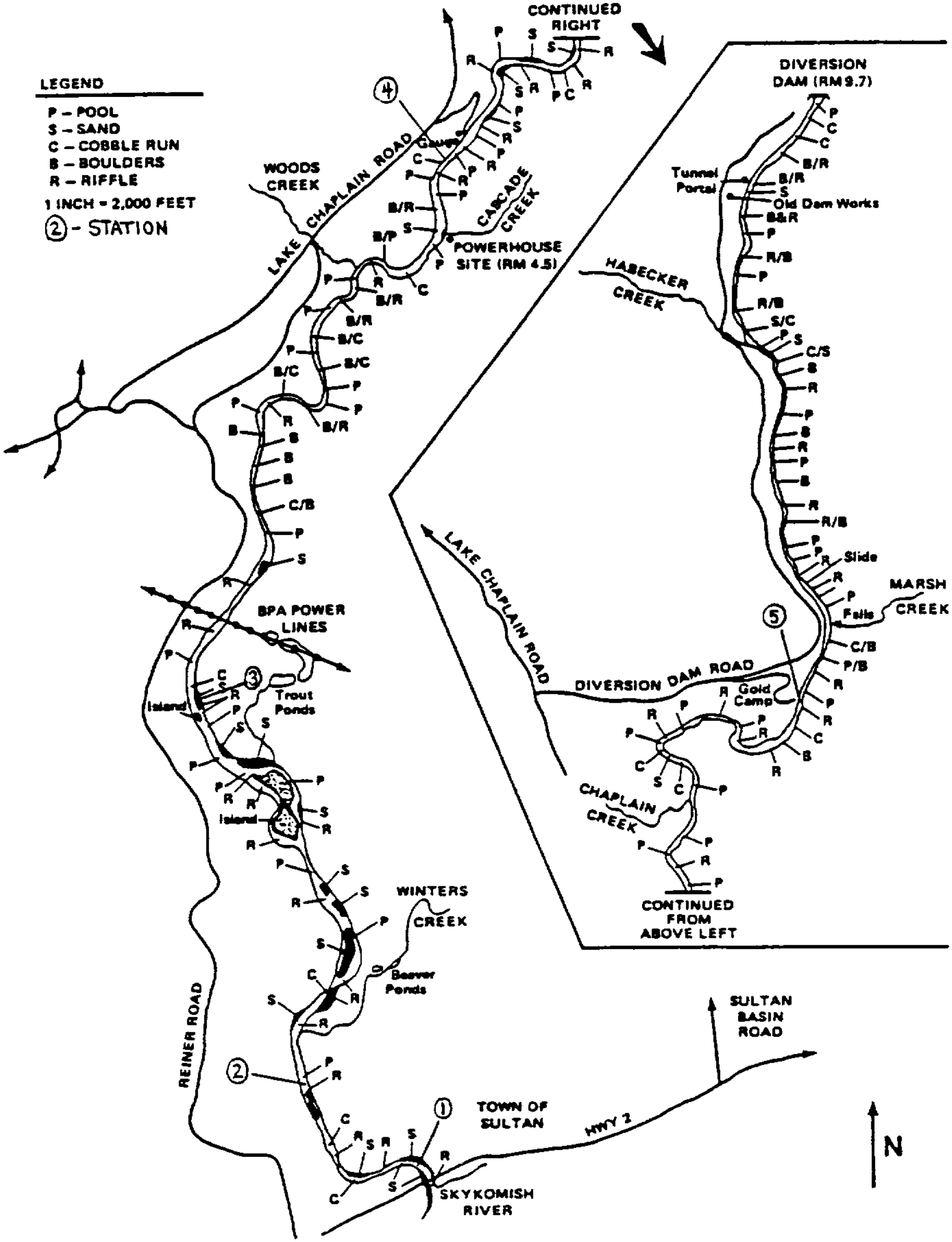

Figure 4 Map of Sultan River gravel sampling stations.

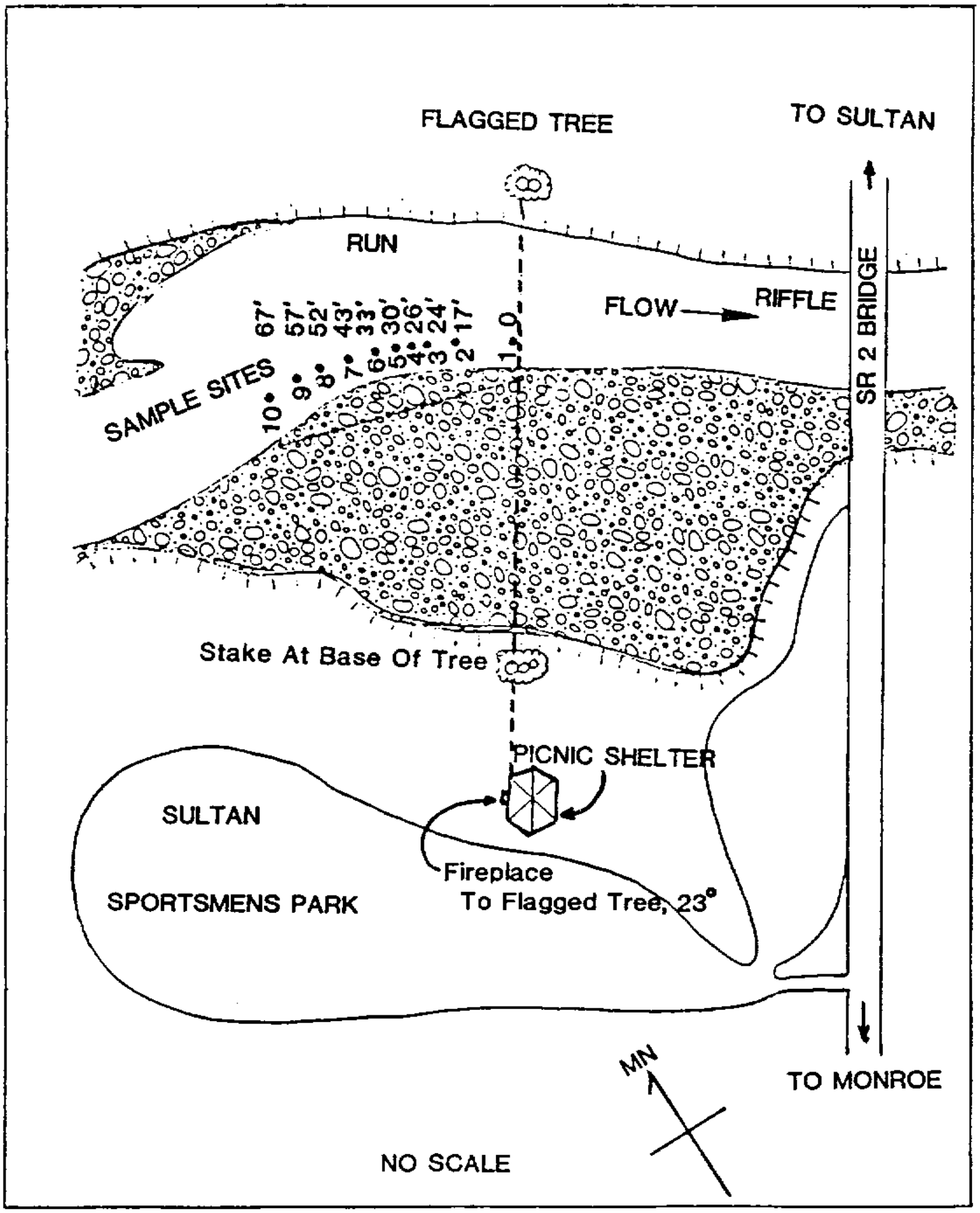

FIGURE 5 Map of gravel sampling station S1.

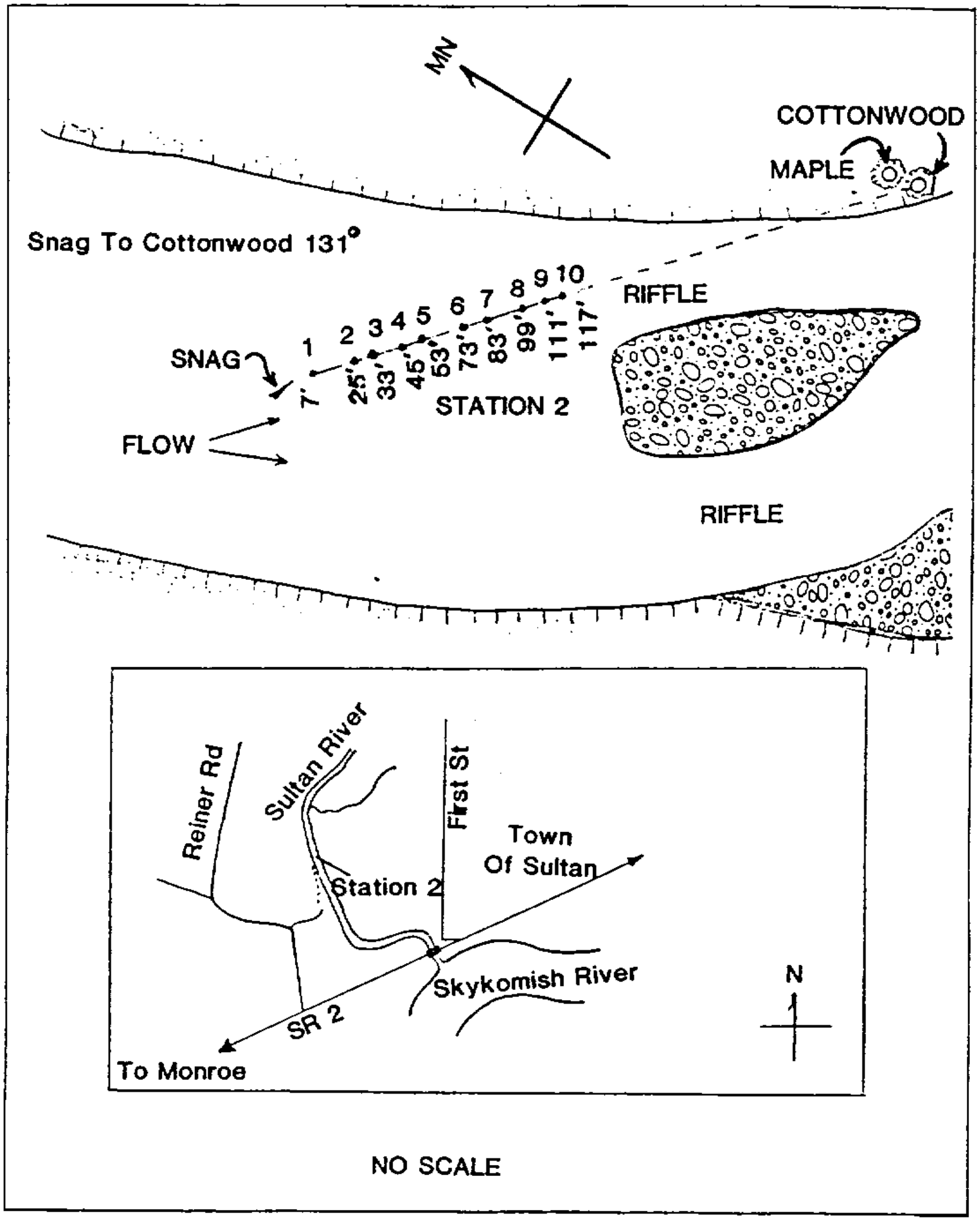

FIGURE 6 Map of gravel sampling station S2.

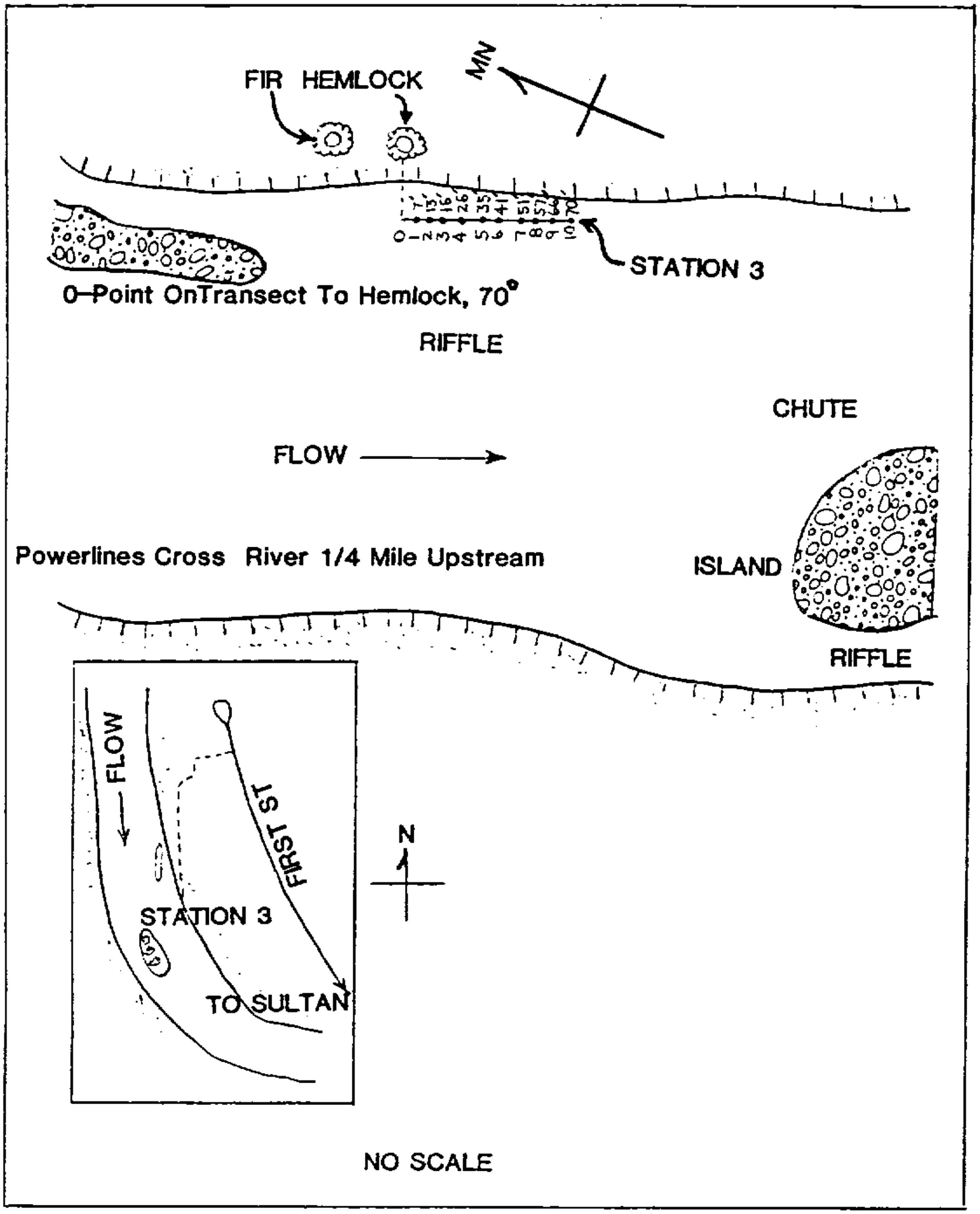

FIGURE 7 Map of gravel sampling station S3.

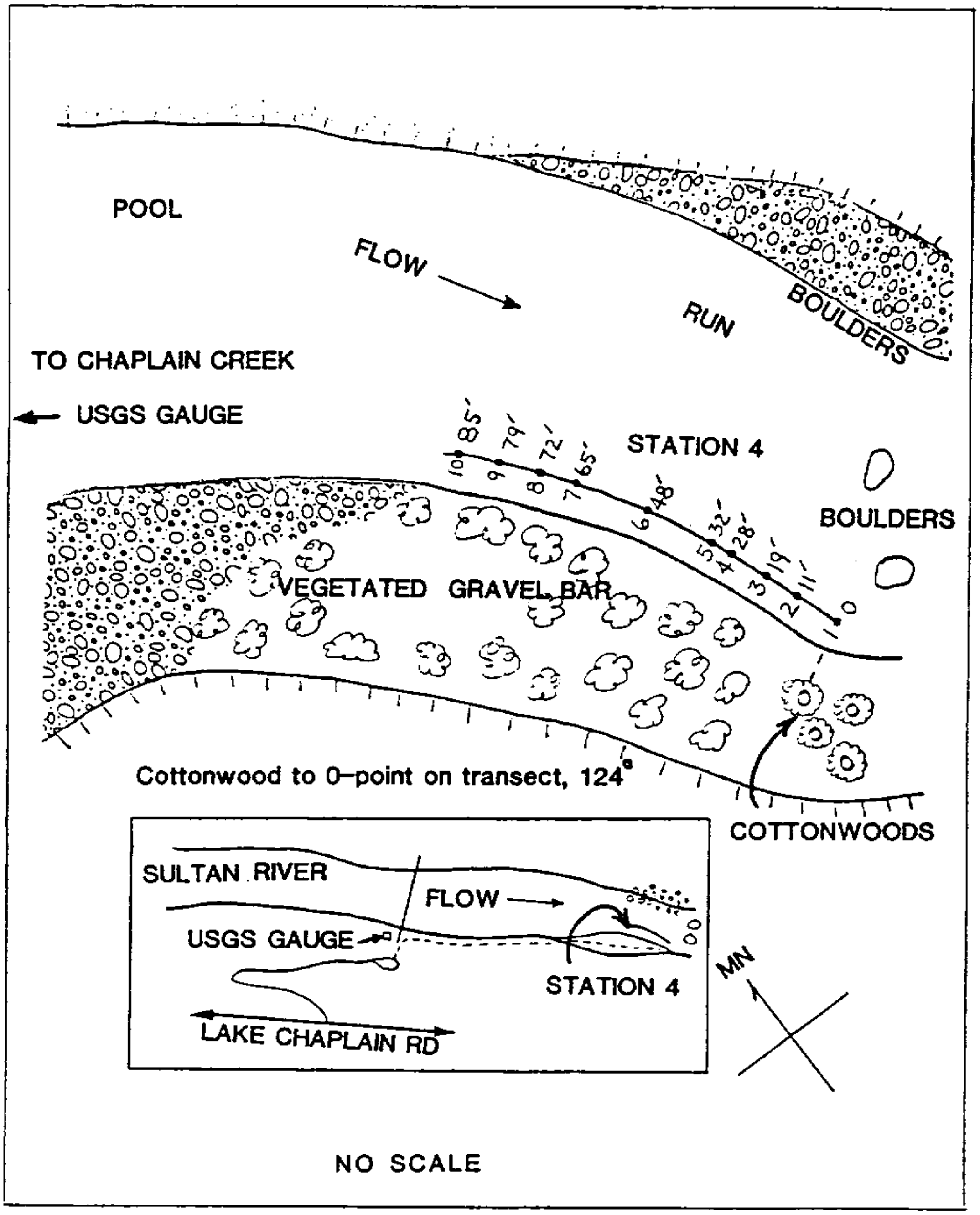

FIGURE 8 Map of gravel sampling station S4.

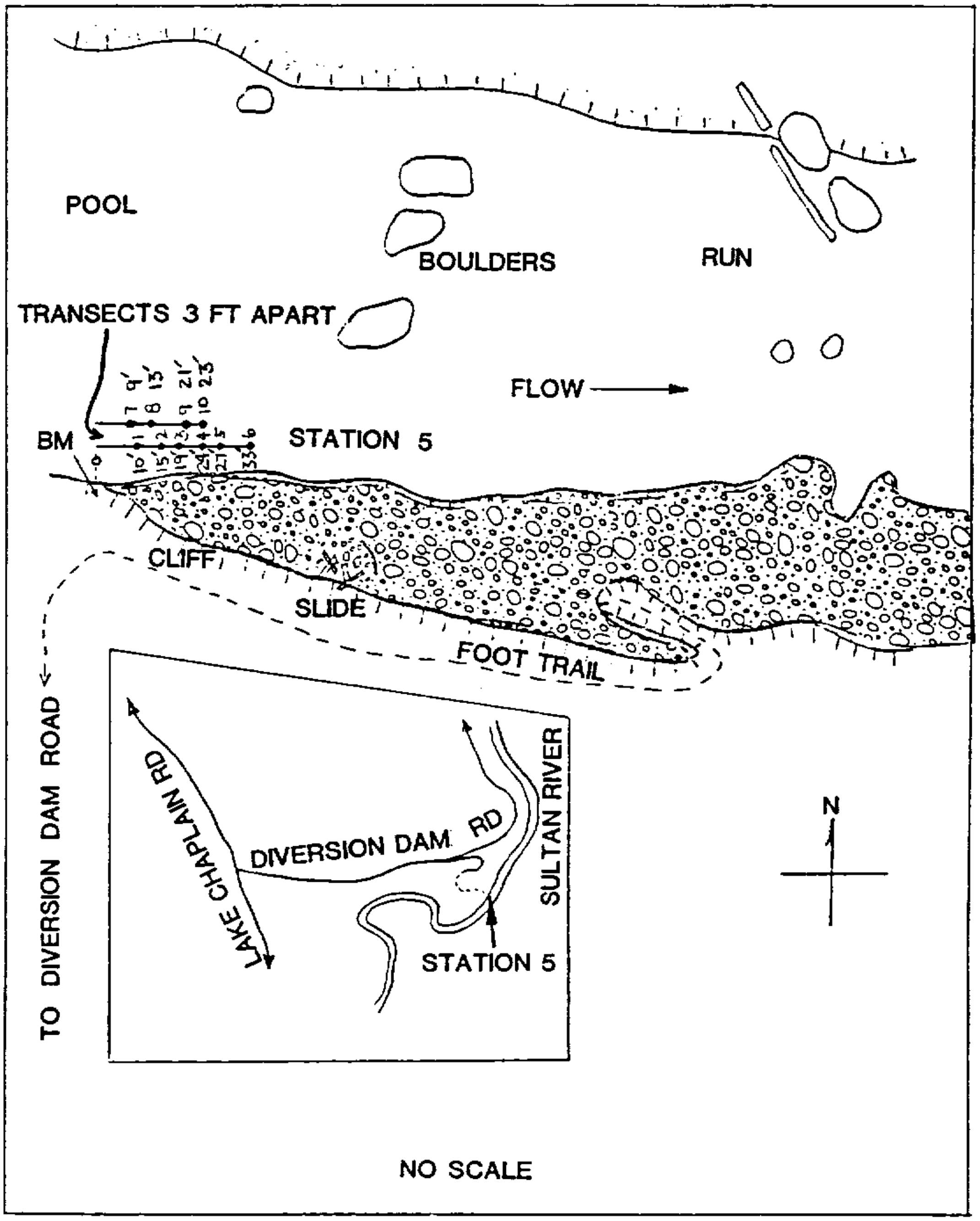

FIGURE 9 Map of gravel sampling station S5.

Table 1. Anadromous fish spawning use at gravel sampling stations, Sultan River, Washington.

Station	River Mile	Primary Spawning Use[1]	Occasional Spawning Use
S1	0.1	SH	CH
S2	0.8	P	CH, CO
S3	2.5	SH, CH, CO, P	--
S4	4.7	SH, CH	--
S5	7.2	SH, CH	CO

[1] Species code: SH(steelhead), CH (chinook), CO (coho), P (pink)

In addition to the requirement that study areas are those used by spawning salmonids, sites were selected on the basis of representativeness of associated river reach and accessibility. The location of the study areas and the criteria used in their selection were formally approved by WDF, WDG, NMFS and Tulalips fisheries biologists prior to initiation of field sampling.

At each study area, 10 samples were obtained along a transect parallel to the direction of water movement. These samples were selected at random distances along the transect within locations having spawning size gravel less than 4 inches in diameter. Water velocities were measured directly above each sampling location for comparative purposes. All samples within a given study area were collected within an 8-hour period, with the exception of S3. Sampling at this study area on April 28 was interrupted by a rapid and unexpected increase in river flow (670 to 1100 cfs). The remaining samples, 4 through 10, were collected on May 12 after the river had stabilized at its former level. Station S1 was sampled twice during the study, once before (S1A - 4/26/82) and once after (S1B - 5/14/82), the other stations had been sampled in order to document changes in streambed composition which may have occurred during the sampling period as a result of flow variation. Table 2 shows flows for each sample day-location.

Table 2. Sultan River flows during each date gravel samples were collected.

Station	Date	Flow (cfs)
S1A	4/26/82	476
S2	4/27/82	481
S3	4/28/82	670-1100
S3	5/12/82	325
S4	5/11/82	325
S5	5/13/82	325
S1B	5/14/82	325

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 used, sources and costs are provided in Appendices A and B. Total cost for major equipment items, excluding carbon dioxide and cylinders, was approximately $1,700.

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

Field sampling procedures involved driving three stainless steel probes into the stream bed 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 templates (depth gage-extractor). Liquid carbon dioxide was discharged for approximately 5 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. One 9-kg (20-lb) cylinder of carbon dioxide was used for each sample. For safety purposes a 3-1/2 gallon plastic bucket was inverted over manifolds and held in place until the CO_2 cylinder had completely discharged. This was done in order to avoid sudden upward surges of manifolds when gases became trapped as condensation froze in bottom of probes. The probes and adhering sediment were extracted from the substratum using a hand winch attached to a tripod situated over the sample site. The core was then positioned horizontally over a set of six, adjacent, 7.6 cm (3 inch) wide galvanized aluminum boxes and thawed with a propane torch. Material which fell into the boxes was collected and transferred to thick-gage plastic bags and taken to the laboratory for analysis. The weight of a single core, comprised of four subsample strata, ranged between 5 and 10 kilograms (11 and 22 pounds).

2.2 LAB ANALYSIS

Subsamples were analyzed separately by washing the sediment through a 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 volumetric displacement of material retained on each sieve was measured to the nearest milliliter. Fine sediment passing through the smallest sieve was concentrated in a large funnel and allowed to settle for approximately one-half hour. For the purposes of this study, it was assumed that the fine-grained sediment collected in a graduated cylinder at the base of the funnel 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 and Seim (1979), 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. The density was estimated for at least one sample from each study area. After averaging, these estimates enabled a correction 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 concensus 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. 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 and Seim (1979) reiterate these advantages and provide several methods, including regression anaysis, 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 per se, but do reject their use of the grain sizes at the 16th (d_{16}) and 84th (d_{84}) 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 d_{25} and d_{75} 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 alogrithm for calculating d_g, however, and propose 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 calulating 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.

Two general categories of substrate indices, percent fines and geometric mean diameter, were used 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 statistic has been used in other investigations of spawning substrate quality in western Washington streams (Cederholm, et al. 1981; Scott, et al. 1982; and Stober, et al. 1982). It has been found to represent those sizes of inorganic sediment which influence fish and insect life in the intragravel environment.

2.3.2 COMPUTER PROGRAM "SEDIMNT"

The computer program SEDIMNT (FRG-367), written by Gales and Swanson (1980), was used to summarize the volumetric and gravimetric data described above. The program calculates the percentage of the sample collected by each sieve and the percentage of the sample which is smaller than each sieve diameter. The percentage of fines which 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 performs a least squares regression analysis for each sample following the procedure given by Shirazi and Seim (1979). 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.

The alogrithm for calculating d_g suggested by Everest, et al (1980), which results in values different than those derived from the regression equation, is provided below:

$$d_g = [d_1^{w_1} \times d_2^{w_2} \times \ldots \ldots d_n^{w_n}]$$

where d = midpoint diameter of particles retained by a given sieve

and w = decimal fraction by weight of particles retained by a given sieve.

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 above named variables were conducted and involved analysis of variance (ANOVA) for differences between strata and among stations, various tests of normality and homoseedocity, and regression analysis using water velocity as the independent variable. In making a-posteriori comparisons following analysis of variance, the non-parametric Scheffe's and Least Significant Difference (LSD) tests were applied.

3.0 RESULTS

3.1 SOURCES OF ERROR

Possible sources of substrate sampling 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 technique. Equipment reliability was primarily affected by the blockage of gas flow through the inline filters and from manifold nozzles clogging with dry ice, both resulting in a partially frozen core. This situation occurred infrequently and was readily detected when the core was removed from the stream bed. In such cases, faulty nozzles and/or inline filters were replaced and a new sample was taken.

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 bottom removed, was used as a flow shunt. The shunt was pressed into the stream bed around the probes and resulted in more consistent freezing of the core at the water-substrate interface.

Variation in sampling technique was minimized by assuring use of a uniform quantity (one cylinder) of liquid CO_2 in freezing each sample. Assignment of each task in the field and laboratory to the same person minimized sampling and analytical error, respectively.

In order to determine whether or not water velocity affected sediment texture variation among samples, velocity measurements were taken at each freeze core sample. None of the percent fines and geometric mean diameter variables were significantly correlated with water column velocities measured directly above the stream bed from which samples were obtained. Water velocity explained less than 2% of the variation recorded in DGD, DGW, DGLS, PFD, PFW and PFLS. Bed composition is undoubtedly influenced by a combination of hydraulic and geomorphologic factors which were not investigated in this study.

3.2 PERCENT FINES AND GEOMETRIC MEAN DIAMETER

The average percent fines and geometric mean diameter values calculated for each study area are listed in Table 3. The proportion of fine sediment averaged 7.1 percent for all stations combined and ranged from 3.7 to 9.1 percent for individual stations. Geometric mean diameter values averagfed 15.32 mm (DGW), 17.93 mm (DGD) and 19.62 (DGLS).

Table 4 shows F statistics calculated in analyses of variance which tested for differences among study areas. The mean percent fines and geometric mean diameter values calculated from station S1 samples collected on April 24 and May 14 are not statistically different. A t-test comparing these two sets of samples (S1A and S1B) revealed that all six mean values are statistically indistinguishable due to the influence of within-station variability among samples. Since these two sampling dates bracket the sampling period, it appears that substrate composition within the study areas remained constant throughout the duration of sampling and comparison among stations are valid.

From an inspection of Table 3 it is apparent that trends indicated by DGW and DGD are similar, although the geometric mean diameter calculated from gravimetric data is always larger than that based on volumetric data. The reverse is true of PFW and PFD, although differences tend to remain constant.

We have included estimates of geometric mean and percent fines based on both volumetric and gravimetric data for comparison with results of other studies. In the following statistical comparisons, virtually all results are identical when DGW and DGW or PFW and PFD are used. The DGLS and PFLS values, although calculated from gravimetric data, were typicaly higher and lower, respectively, than other geometric mean (DGW, DGW) and percent fines (PFW, PFD) values.

Analysis of variance rejected the hypothesis that all study areas had equal mean values for any of the variables tested at the 95 percent confidence level (Table 4). A-posteriori contrasts using the Least

Table 3. Average geometric mean diameter by volumetric (DGW), gravimetric (DGD), and least squares (DGLS) methods and average percent fines by volumetric (PFW), gravimetric (PFD) and least squares (PFLS) methods for gravel samples collected in the Sultan River, Washington 1982.

Study Area	Number of samples	DGW (mm)	DGD (mm)	DGLS (mm)	PFW %	PFD %	PFLS %
S1A	10	18.42	20.78	21.96	3.7	2.6	2.5
S1B	10	17.35	19.82	21.89	4.7	3.4	3.2
S2	10	16.25	19.37	23.22	8.6	6.1	4.4
S3	10	16.45	19.38	24.56	7.7	5.3	3.5
S4	10	12.01	14.70	15.15	9.1	6.2	5.4
S5	10	11.41	13.54	10.95	8.6	5.8	5.4
Total/Mean	60	15.32	17.93	19.62	7.1	4.9	4.1

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 are all equal.

$(H_o : \mu S1A = \mu S1B = \mu S2 = \mu S3 = \mu S4 = \mu S5)$

	DGW	DGD	DGLS	PFW	PFD	PFLS
F - Ratio	5.73	5.02	2.89	10.79	10.39	8.85
F Probability	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01

Signifigant Difference (LSD) Method (α=0.05) resulted in a minimum of two homogeneous subsets for each comparison, as shown in Figures 10 and 11. Of special interest is that study areas were generally grouped differently using geometric mean and percent fines variables, suggesting that the two measures were not completely inversely related. Using DGW and DGD resulted in stations S4 and S5, those areas located farthest upstream, being ranked separately from stations S1, S2 and S3 by virtue of their lower geometric mean values. Comparing all stations based on DGLS values indicated S5 was different from all other stations except S4. The average geometric mean diameter for S4, however, was not significantly different from S1A, S1B or S2, but was from S3. The conclusion is that, when comparing all stations regardless of which geometric mean value was used (DGW, DGD or DGLS), the average particle size in the upstream spawning reaches of the Sultan River was smaller than that found downstream. A decrease in substrate geometric mean diameter occurred for the most part with increasing distance from the river mouth (S1>S3>S2> S4>S5).

Using percent fines as the dependent variable, ANOVA also rejected the hypothesis that mean values of all stations were identical. Figure 11 shows that Station S1, which had fewer fine sediments on both sampling dates (S1A, S1B) than any other station, may effectively be considered distinct from stations S2, S3, S4 and S5. The latter stations could not be separated on the basis of their mean percentage of fine sediments. Additionally, no general gradient of percent fines was apparent along the river length, as was observed for geometric mean diameter values.

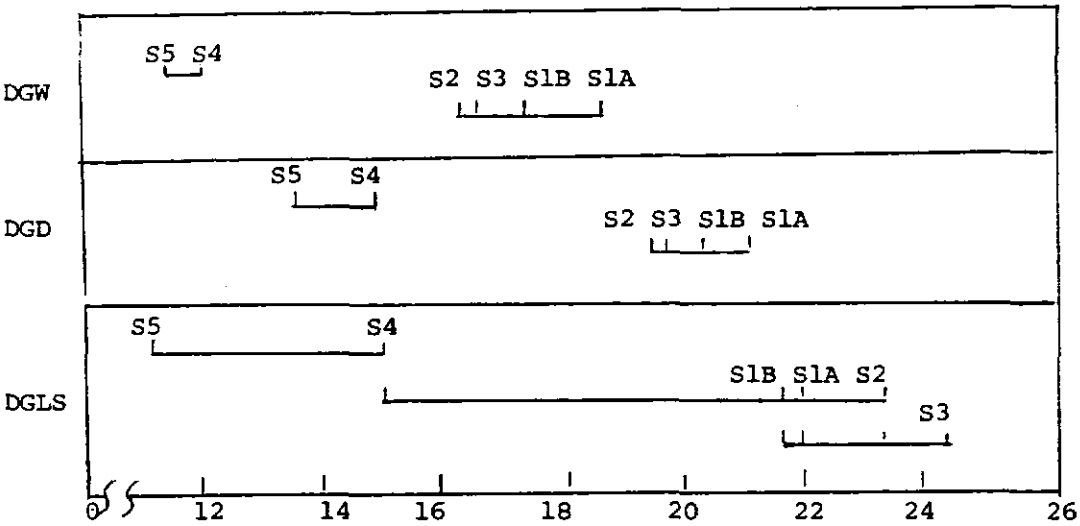

Figure 10. Schematic representation of geometric mean diameter (d_g) by volumetric (DGW), gravimetric (DGD) and least squares (DGLS) methods for gravels collected from Sultan River stations S1-S5 grouped into homogeneous subsets by the LSD (a-posteriori) method. Ranges are for the $\alpha = 0.05$ level.

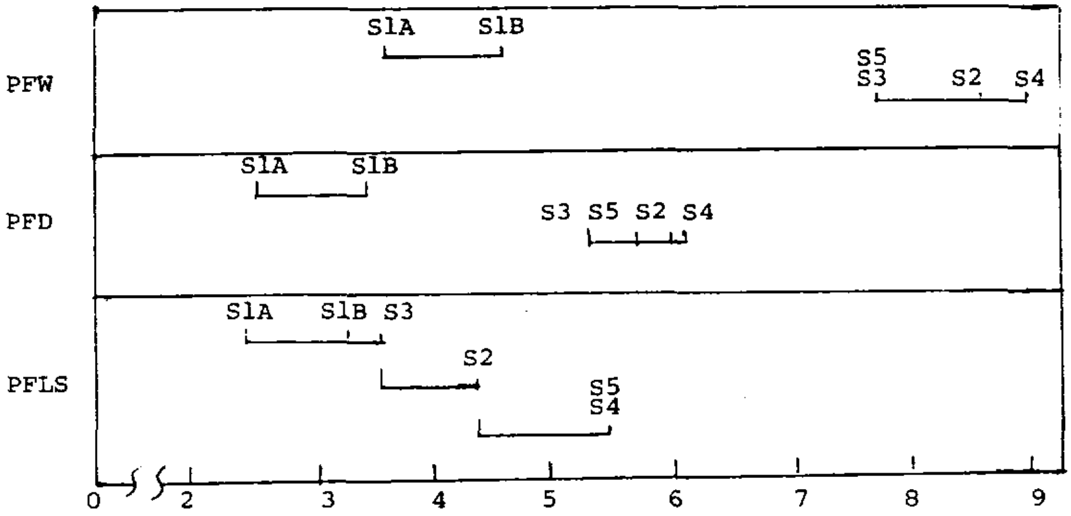

Figure 11. Schematic representation of percent fines less than 0.841 mm by volumetric (PFW), gravimetric (PFD), and least squares (PFLS) methods for gravels collected from Sultan River stations S1-S5 grouped into homogeneous subsets by the Least Significant Difference, LSD (a-posteriori) method. Ranges are for the $\alpha = 0.05$ level.

3.3 SEDIMENT STRATIFICATION

In order to detect stratification within streambed sediments, four subsamples, or strata, from each core were analyzed separately. Strata 1 extended from the bed surface to a depth of 3 inches. Stratas 2, 3 and 4 represented bed depths ranging from 3 to 6, 6 to 9 and 9 to 12 inches, respectively. The texture of these deeper strata, particularly the second and third, is more influential in the survival of salmonid embryos than is that of surface substrate.

Strata sediments were compared for differences in average geometric mean diameter (DGW and DGD) and percent fines (PFW and PFD). For simplification, the variables DGLS and PFLS were not used in comparing different strata. Unless otherwise noted, results and conclusions pertaining to geometric mean diameter and percent fines were equally valid for both DGW or DGD and PFW or PFD, respectively.

The geometric mean diameter and percent fines values for individual stations (4 strata X 10 samples, N = 40) and for all six stations combined (N = 240) are presented in Table 5. All strata within samples from a given station have sediments with equal average geometric mean diameters at locations S1A, S2 and S3. The average geometric mean diameter in strata 1 is significantly greater than it is in composited stratas 2, 3 and 4 at all stations except S3. This suggests that surface sediments are generally coarser than those found at deeper levels. The difference among average geometric mean diameter of all strata 1 subsamples and that of all other strata combined was statistically tested using a t-test. Significant differences are indicated in Table 5 by the symbol "t". Similar comparisons were made to test differences in percent fines. When the mean percent fines value for strata 1 ($\bar{y}_1$) was significantly different from the combined mean values for stratas 2, 3 and 4, then the hypothesis H_o: $\bar{y}1 = \bar{y}2 = \bar{y}3 = \bar{y}4$ was rejected as indicated also in Table 5 by the symbol "t". Strata 1 percent fines were significantly lower at all stations when stations were examined individually or combined.

Table 5. Average geometric mean diameter by volumetric (DGW) and gravimetric (DGD) and percent fines (less than 0.841 mm) by volumetric (PFW) and gravimetric (PFD) methods for gravel strata within individual stations and for stations combined, Sultan River, Washington, 1982.

Station	Strata	DGW (mm)	DGD (mm)	PFW (%)	PFD (%)
S1A	1	21.52	23.34	2.4t	1.7t
	2	19.29	21.90	3.6	2.6
	3	19.56	22.35	4.1	2.9
	4	16.74	19.25	4.6	3.3
S1B	1	27.81t	30.47t	2.2t	1.5t
	2	14.45	16.57	5.6	4.1
	3	16.58	18.94	5.1	3.7
	4	15.61	18.32	6.2	4.4
S2	1	18.69	20.86	4.2t	2.7t
	2	14.41	17.46	10.0	7.0
	3	16.14	19.86	11.1	7.8
	4	19.20	23.18	9.7	6.7
S3	1	26.25	28.64	3.2t	2.3t
	2	20.39	23.54	6.4	4.6
	3	11.58	14.10	10.9	8.0
	4	14.48	17.92	10.1	7.0
S4	1	18.10t	20.27t	4.4t	3.1t
	2	10.17	12.53	10.7	7.5
	3	10.80	13.63	11.4	7.6
	4	12.93	16.33	10.0	6.5
S5	1	16.59t	18.03t	3.4t	2.5t
	2	10.00	11.57	6.9	4.9
	3	12.35	15.07	10.6	7.3
	4	11.47	14.44	12.8	8.7
Stations Combined	1	21.49t	23.60t	3.3t	2.3t
	2	14.79	17.26	7.2	5.1
	3	14.50	17.32	8.8	6.2
	4	15.07	18.24	8.9	6.1

Note: Statistically significant differences between stratum 1 and strata 2-4 (composited) for each station and for all stations combined are indicated by the symbol "t".

Statistical comparisons revealed that stratas 2 and 3 were less likely to be different in composition than were 2 and 4 or 3 and 4. Sediments from strata 1 showed greatest variability in geometric mean diameter, while percent fines variation was greatest in strata 3. Changes in geometric mean diameter and percent fines followed no apparent trend in relation to depth.

3.4 STEELHEAD EGGS AND SEDIMENT TEXTURE

Although an effort was made to avoid sampling locations where evidence of egg deposition was apparent, freeze-core samples occasionally contained steelhead eggs in one or more strata. The geometric mean diameter and percent fines calculated for strata containing eggs are listed in Table 6. Steelhead embryos primarily occurred in sample strata 2 and 3 (3 to 9 inches deep). Eggs occurred infrequently below 9 inches but were never present in stratum 1 (0 to 3 inches).

The DGD for samples containing eggs averaged 16.65 mm and ranged from 9.76 to 26.68 mm. For comparison purposes, strata 2, 3 and 4 (combined) of all samples not containing eggs had an average DGD of 17.64 mm, with a range of 5.08 to 41.42 mm. No significant difference was found in average geometric mean diameter and percent fines values between strata in which eggs occurred and strata 2, 3 and 4 of samples without eggs. In spite of the small sample size, it was tentatively concluded that most of the samples collected in the various study areas were of a texture suitable for salmonid egg incubation.

Table 6. Geometric mean diameter and percent fines (less than 0.841 mm) of sample strata combined and for individual strata containing steelhead eggs.

SUBSTRATE STATISTICS[1]

AVERAGE FOR SAMPLE STRATA COMBINED

Station	Sample	Strata	DGW (mm)	DGD (mm)	DGLS (mm)	PFW (%)	PFD (%)	PFLS (%)
S3	5	1-4	22.55	26.11	39.83	6.0	4.0	2.0
S3	7	1-4	13.29	16.40	16.30	10.0	7.0	5.0
S4	8	1-4	8.73	11.03	6.69	12.0	8.0	8.0
S5	2	1-4	11.68	13.82	12.34	8.0	6.0	5.0
S5	3	1-4	21.17	23.59	23.26	3.0	2.0	2.0
S5	6	1-4	12.81	16.30	15.91	11.0	7.0	5.0
S5	8	1-4	10.36	12.10	7.29	8.0	5.0	6.0

AVERAGE FOR INDIVIDUAL STRATA

Station	Sample	Strata	DGW (mm)	DGD (mm)	DGLS (mm)	PFW (%)	PFD (%)	PFLS (%)
S3	5	3	17.25	20.85		8.3	6.1	
S3	7	2	14.33	17.52		8.9	6.4	
S4	8	2	10.45	12.25		7.8	5.1	
S5	2	3	18.95	22.71		6.2	4.3	
S5	3	3	26.68	30.13		3.6	2.6	
S5	3	4	22.59	27.06		6.3	4.2	
S5	6	2	9.76	11.57		7.5	5.1	
S5	8	2	13.07	15.06		4.6	3.0	

[1] SUBSTRATE STATISTIC CODE

DGW = Geometric mean diameter by volumetric method (wet)
DGD = Geometric mean diameter by gravimetric method (dry)
DGLS = Geometric mean diameter by least squares method
PFW = Percent fines by volumetric method (wet)
PFD = Percent fines by gravimetric method (dry)
PFLS = Percent fines by least squares method

4.0 DISCUSSION

Composition of streambed sediments used by spawning salmon and trout is highly variable in both time and space. Although this study did not investigate changes in streambed characteristics over time, seasonal variations in runoff patterns and sediment loading are known to influence local substrate conditions. As these factors also vary spatially considerable differences in bed composition may be found among different areas of the stream bed, even within a single spawning riffle (Adams and Beschta 1980). Because of such potential spatial variation, several samples must be taken within each station in order to effectively compare two or more areas with statistical validity. The sample variances of the mean values of geometric mean diameter and percent fines calculated for all areas indicated a sample size of ten per station was sufficient to allow valid statistical comparisons, with 90 percent certainty, between two or more stations (Sokal and Rohlf 1969). Differences of 5 mm in geometric mean diameter (DGW, DGD) and 5 percent fines (PFW, PFD) were detectable between stations at the 5 percent level of significance.

Analysis of variance demonstrated that average geometric mean diameter and percent fines were not equal when compared among all stations. A-posteriori tests indicate use of geometric mean diameter variables (DGW, DGD, DGLS) result in a different grouping or ranking of study areas than that from use of percent fines variables (PFW, PFD, PFLS).

Mean geometric particle size was progressively smaller with increasing distance from the river mouth. Stations most upstream (S4, S5) were grouped separately from other stations on the basis of DGW and DGD values. This longitudinal gradient might reflect qualitative differences between spawning areas in upstream reaches and those downstream. Spawning gravels in upstream reaches occurred as localized patches interspersed with boulder and cobble substrates. These gravel patches were typically found near the stream margins or at the tail end of pools where water velocity and bed transport conditions result in smaller bed materials. In contrast to this were the more open channel conditions further downstream. There the stream bed was more homogeneous, yet coarser, in texture. The substrate at station S1, for example, was dominated by gravel and small cobble size particles distributed uniformly across the channel. In the lower river variations in bed morphology, particularly in the form of gravel bars, were more apparent to the observer than were changes in substrate composition. A possible explanation for differences in substrate texture in these two areas may be the source of gravel recruitment. Although substrates are continuously transported downstream, new materials are introduced along the river's course. In the canyon, slides and steep-gradient tributary streams are an important source of recruitment. These materials may not have experienced the same hydraulic conditions as those of the lower river where stream banks containing glacially deposited outwash sediments are a major source.

When measures of percent fines were used to compare different study areas, slightly different results were obtained than those observed using geometric mean diameter. This suggests that the relationship between percent fines and geometric mean diameter is not simply an inverse one. Although the fine sediment content at station S1 averaged less than that at any other stations, there was no obvious longitudinal gradient as was observed for geometric mean diameter.

Analysis of variance results indicated that a significant difference occurred among the 4 strata in at least one of the mean values of percent fines and geometric mean diameter when all samples were combined. Subsequent t-tests revealed that the uppermost strata was coarser and contained fewer fine sediments than deeper strata. Field observations verified that cores were completely frozen from top to bottom, ruling out the possibility that the method failed to adequately sample the top of the bed. As mentioned earlier, the insertion of probes into the substratum may have altered the composition of upper layers. While fines were never observed to wash away when probes were driven into the bed, some may have filtered down into lower strata thus affecting the sediment content of uppermost strata. There is substantial evidence, however, that the presence of relatively coarse bed material at the water-substrate interface is common in most gravel-bedded streams (Milhous and Klingeman 1971; Milhous

1973). It has been shown that during storms, surface layers of a gravel bed become progressively coarser during the falling limb of the hydrograph (Garde, et al. 1977), a process referred to as armoring. Any of the above mentioned factors, acting independently or in combination, may have caused the stratification observed in this study. These results agree with the observations of other researchers. Garvin (1974), Adams (1980) and Lotspeich and Everest (1981) report substantial variability in substrate composition among different strata of the stream bed.

5.0 CONCLUSIONS

Substrate textural composition varied among the stations examined. Analysis of variance demonstrated that average geometric mean diameter and percent fines (less than 0.841 mm) were statistically unequal when compared among all stations. The average geometric mean diameter (DGW) for all stations ranged from 11.41 to 18.42 mm with a grand average of 15.32 mm. The average percent fines (PFW) for all stations ranged from 3.7 to 9.1, with a grand average of 7.1 percent. Mean geometric particle size was progressively smaller with increasing distance from the river mouth. No apparent trend was observed between percent fines values and stations.

Substrate textural composition varied among core sample strata. Analysis of variance indicated that at least one of the mean values of percent fines and geometric mean diameter was significantly different among the four strata when all samples were combined. The uppermost strata (0 to 3 inches) was significantly coarser and contained fewer fine sediments than deeper strata. This may be explained by, but not limited to, streambed armoring or disturbance of surface sediments by sampling techniques.

Substrate textural composition did not change throughout the duration of sampling, although flows during this period increased to 1,100 cfs for several days.

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APPENDIX A

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

FREEZE-CORE SAMPLER EQUIPMENT

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

OTHER SAMPLING EQUIPMENT

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 steel 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

MAINTENANCE EQUIPMENT

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

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[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

FREEZE-CORE SAMPLER SOURCES[1] AND PRICE LIST (1982)

Modern Manufacturing, Inc.
815 Houser Way North
Renton, WA 98053
(206) 228-4500 Frank Leedle

Quantity	Item	Unit Price	Total Price
3 each	#MO297 CO_2 manifold (probe)	$95.00	$285.00
24 each	#MO298-1 modified nozzles	2.15	51.60
12 each	#MO298-2 modified nozzle blanks	2.15	25.80
36 each	Nozzle screens	.85	30.60
			$393.00

Eagle Metals
4755 First Avenue South
Seattle, WA 98134
(206) 762-0600 Rick Johnson

6 each	T316 stainless steel pipe 3/4 in Sch. 40 x 41 ft)		133.00
6 each	T316 stainless steel pipe 1 in Sch. 40 x 2 in)		
2 each	T304 stainless steel plate 1/4 in x 6 in diameter		50.00
			$183.00

Kolstrand Supply Company
4714 Ballard Avenue, Northwest
Seattle, WA 98107
(206) 789-1500 Nick Zardis

1 each	5/8 in x 4 ft threaded stainless steel rod) weld collars and tips on 6 s.s. probes)		$130.00

Cryogenics Northwest, Inc.
4020 Airport Way South
Seattle, WA 98108
(206) 464-1950 Don Ostrander

6 each	Linde SG 6112 in line filters	62.50	375.00
3 each	Synflex 31-50-04 hose w/fittings	40.00	120.00
1 each	Custom manifold - 4 way	40.00	40.00
			$535.00

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[1] Trade names mentioned are for reader's convenience and do not imply author's endorsement.

Compressed Gas Western
4535 West Marginal Way Southwest
Seattle, WA 98108
(206) 935-5093 Russ Ivers

Quantity	Item	Unit Price	Total Price
As required	20 lb aluminum CO_2 cylinders with siphon tubes (lease)	$10.50/refill	As required

OTHER EQUIPMENT SOURCES

Ballard Sheet Metal Works, Inc.
4763 Ballard Avenue Northwest
Seattle, WA 98107
(206) 784-0545 Don Simpson

1	Aluminum tripod (7 ft legs)	
1	set of 6 subsampler boxes in alum. frame (both fabricated according to Everest, et al 1980)	$346.45