APPENDIX B

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

1984

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

PUBLIC UTILITY DISTRICT No. 1

OF SNOHOMISH COUNTY

WASHINGTON

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SULTAN RIVER PROJECT

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S U M M A R Y

The Sultan River Hydroelectric Project will significantly alter the flow regime in 16 miles of river downstream from Culmback Dam. Since various anadromous fish species/life stages use the 9.7-mile river reach below the Everett diversion dam, 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 constuction and operation. In order to evaluate pre-construction 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. In order to determine effects of project construction on sediment texture, the subject of this study, gravel samples were collected and evaluated during February - April 1984 following termination of construction activities. This report compares pre-construction (baseline) study results with those of post-construction. In 1987, three years following operation start up, sediment samples will again be collected and evaluated.

Objectives of this study were to:

1. Determine the spatial variability of sediment samples among selected spawning reaches between the diversion dam downstream to the river mouth;

2. Determine the vertical heterogeneity of sediments within and among spawning reaches;

3. Compare pre-construction sediment composition with that of post-construction;

4. Compare pre- and post-construction sediment composition with that of other west coast drainages;

5. Determine the expected survival of incubating salmonid eggs by comparing Sultan River gravel texture to reported relationships

of survival and textural compostion in the laboratory and other Pacific Northwest drainages.

Streambed sediments were removed from five salmonid spawning reaches using a tri-tube freeze-core sampler. A total of 50, 12 inch-deep core samples were collected. Each core was subdivided into four 3-inch strata yielding a total of 200 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 in diameter.

Results showed the textural composition of Sultan River streambed sediments following project construction (1984) was generally similar to that evaluated for the same sites prior to construction (1982). Some differences, however, did occur.

Gravels sampled at stations located near the river mouth and 2 miles downstream of the powerhouse had the coarsest texture, and provided the most suitable egg incubation qualities, in both 1982 and 1984. The only significant change at corresponding stations between 1982 and 1984 was at station S4, upstream of the powerhouse, where a decrease in fine sediments was noted.

The average proportion of fine sediment less than 0.841 mm in diameter for all stations ranged between 4.5 and 10.4 percent. This compares favorably to reported levels in 15 relatively undisturbed west coast salmonid spawning streams where averages ranged between 3 and 21 percent.

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

It appears the textural composition of Sultan River spawning gravels following project construction remains quite good and could provide suitable conditions to yield high rates of embryonic survival, depending on other survival-limiting factors.

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

Another study will be conducted 3 years following project operation. Comparison of results in this report to those of the future study will help determine whether or not mitigative measures are required in order to maintain river gravel of suitable quality.

1.0 INTRODUCTION

1.1 AUTHORIZATION

This study was authorized and funded by Public Utility District No. 1 of Snohomish County (PUD). It constitutes the second of a three-part study 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.

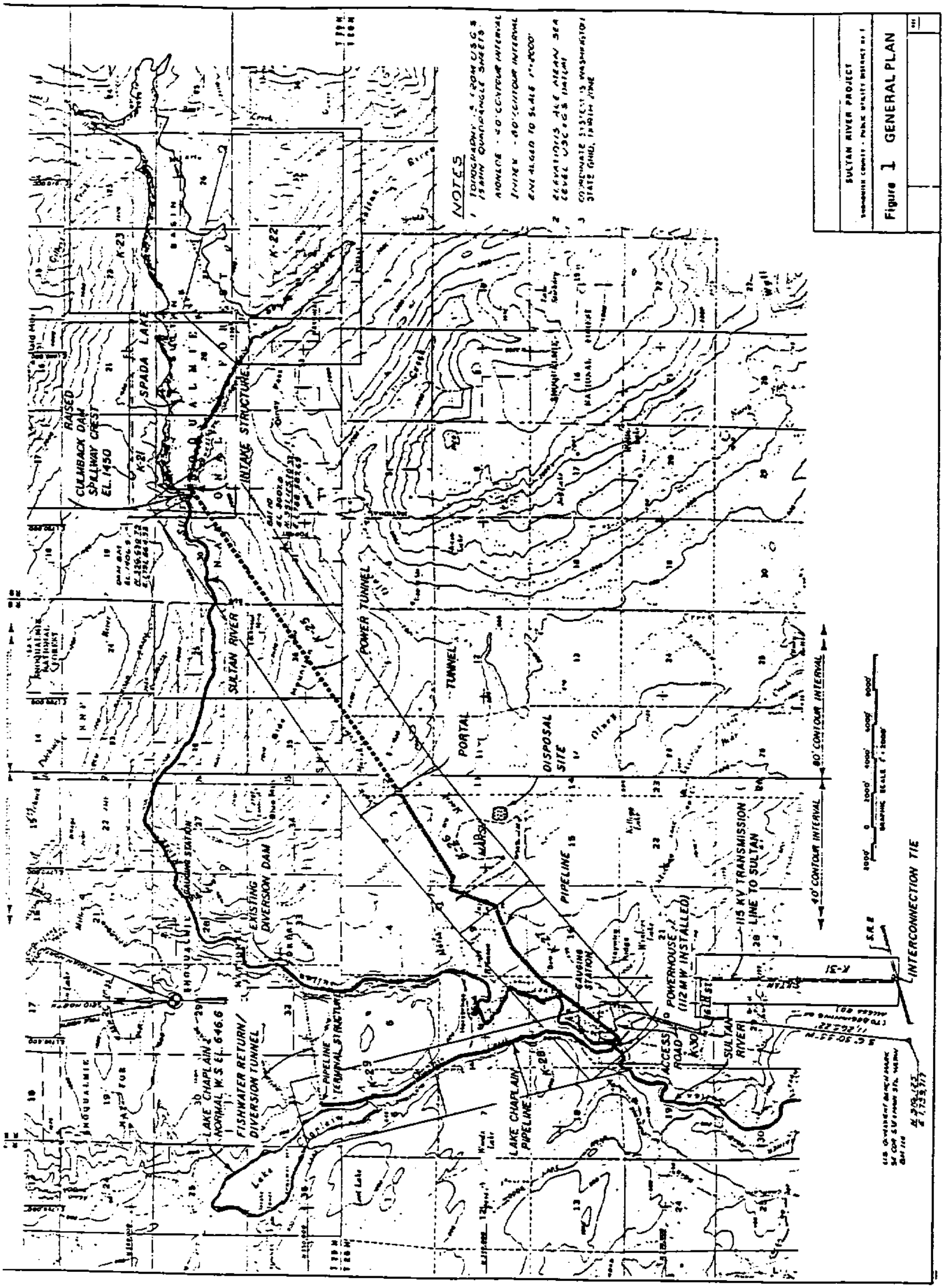
1.2 PROJECT BACKGROUND

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). 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


SULTAN RIVER PROJECT
Figure 1 GENERAL PLAN
NOTES
RAISED CULMBACK DAM SPILLWAY CREST EL. 1450
SPADA LAKE
INTAKE STRUCTURE
POWER TUNNEL
SULTAN RIVER
TUNNEL PORTAL
DISPOSAL SITE
PIPELINE
EXISTING DIVERSION DAM
GAUGING STATION
LAKE CHAPLAIN NORMAL W.S. EL. 646.6
FISHWATER RETURN/ DIVERSION TUNNEL
PIPELINE TERMINAL STRUCTURE
LAKE CHAPLAIN PIPELINE
POWERHOUSE (112 MW INSTALLED)
ACCESS ROAD
115 KV TRANSMISSION LINE TO SULTAN
INTERCONNECTION TIE
40' CONTOUR INTERVAL
80' CONTOUR INTERVAL
K-21
K-22
K-23
K-26
K-28
K-29
K-30
K-31

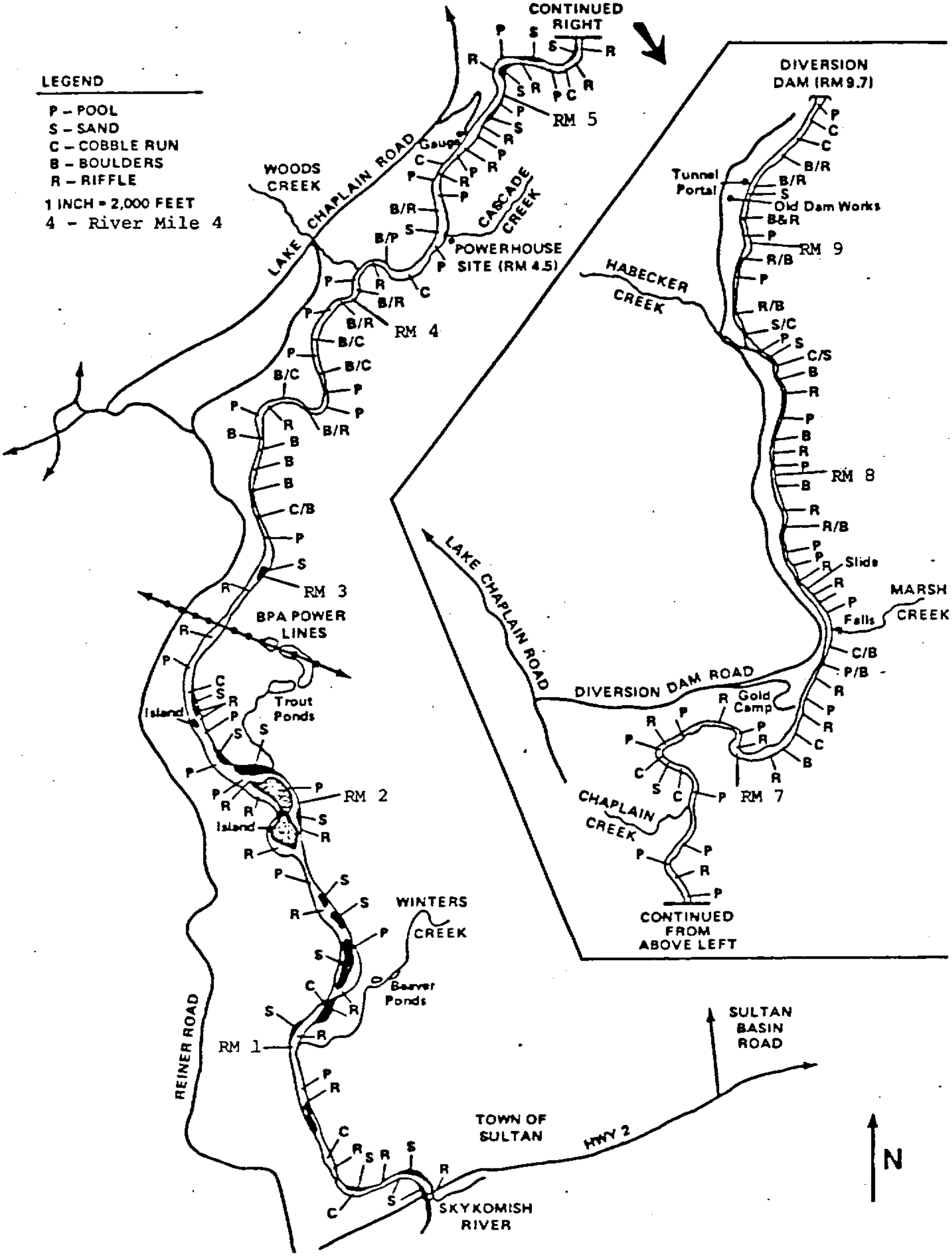


Figure 2. SULTAN RIVER HABITAT MAP. BETWEEN DIVERSION DAM AND RIVER MOUTH

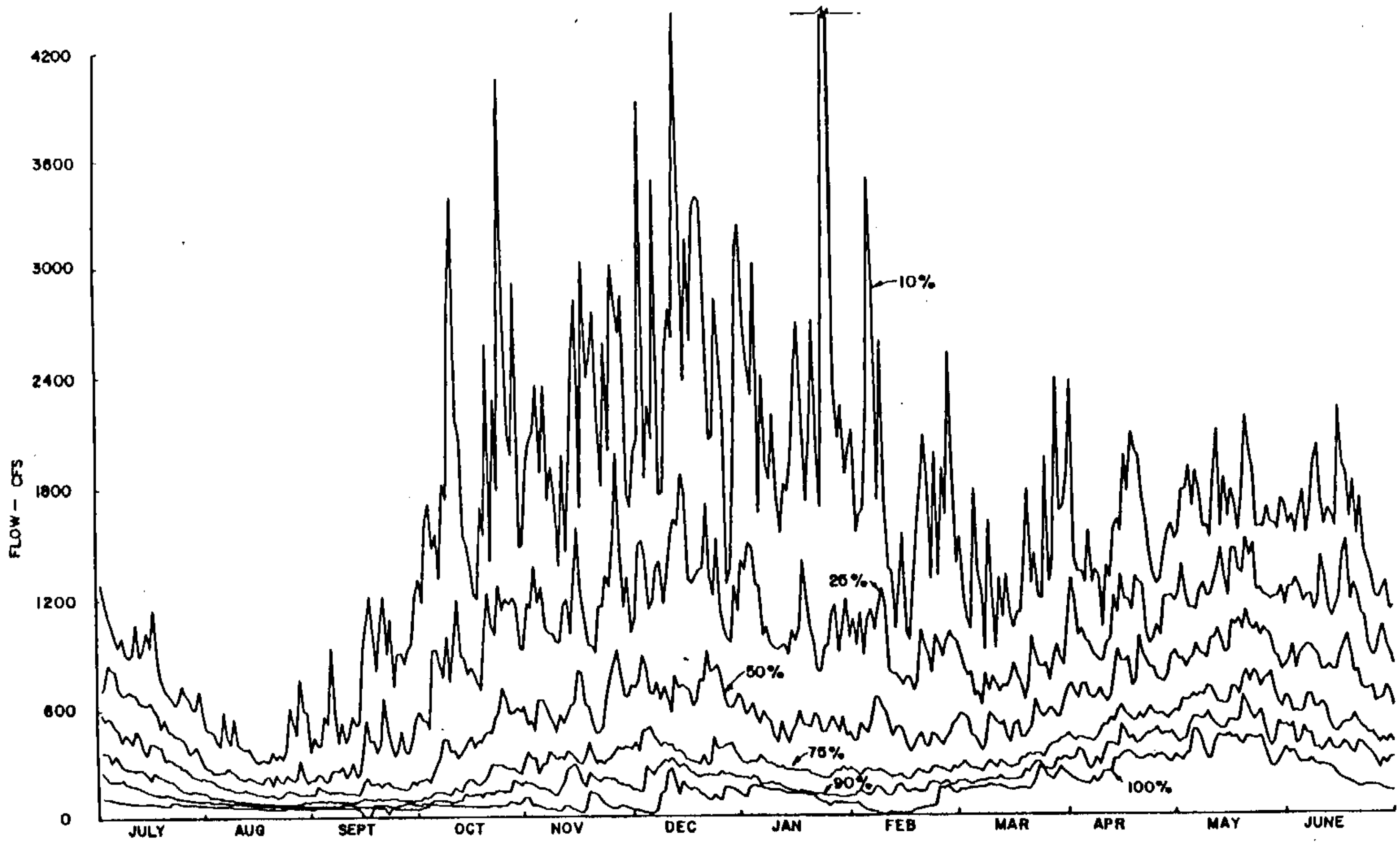
(Eicher 1981). See Figure 3 for Sultan River (Spada Lake) daily inflow and exceedance frequency. High flows can produce sufficient velocity to scour the stream bed and cause gravel movement. This can result in dislodgement and destruction of salmonid eggs and alevins, and in extreme cases, cause actual loss of spawning gravel (Burgner 1982).

Below the powerhouse, the river flows through approximately 1.5 miles of canyon followed by 3.0 miles of 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 quite conducive to anadromous fish spawning.

1.4 PROJECT EFFECTS

Hydroelectric development will alter the flow regime of the Sultan River. This will include 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 will be regulated continuously at levels determined to provide optimum or adequate conditions for salmonid life stages. Except during extreme high floods, when spills would occur at Culmback Dam, winter and spring freshets would 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 role in cleansing stream beds of fine sediments (Shapley and Bishop 1965). Entrapment of upstream sediment sources in the storage reservoir combined with intermittent spills of clear, low-sediment-bearing water may offset sediment accumulation resulting from reduced frequency of freshets. For these reasons, it becomes important to know whether or not flow constancy for extended periods of time results in a buildup of fine sediments in stream bed gravels.

An increased proportion of fine sediments in salmonid spawning gravels may reduce gravel pore size and permeability, thus influencing



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.

Figure 3

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

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

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. It is uncertain whether or not such a change in the flow regime will result in altered streambed texture in the lower river.

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 Joint Agencies (see page 8) 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, will determine whether or not spawning gravel quality has changed as a result of project construction and/or operation. Alteration of gravel quantity as a result of project operation will be evaluated in subsequent studies.

The subject of this report ia an evaluation of the textural composition of Sultan streambed gravels following project construction. Results of this study are herein compared to pre-construction gravel texture and will be later compared to gravel texture three years following operation start-up. Objectives of this study were completed by:

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) comparison of pre-construction Sultan River sediment composition with that of post-construction;

4) comparison of pre- and post-construction sediment composition with that of other west coast drainages.

5) determining the expected survival of incubating salmonid eggs by comparing Sultan River gravel texture to reported relationships of survival and textural composition from laboratory and field investigations of other Pacific Northwest drainages.

2.0 METHODS

2.1 SAMPLE COLLECTION

Following the recommendation of Adams and Beschta (1980) and because the intention of the gravel texture analyses was to index Sultan River quality as a fisheries resource, the stream bed was sampled during the winter when eggs of anadromous fish are in the gravel. Substrate samples used to evaluate the quality of spawning gravels were collected during February and March, 1984, at five spawning reaches (sampling stations) shown in Figure 4. The locations of these stations were cooperatively selected during the baseline study phase by fisheries biologists from the Joint Agencies: Washington Department of Fisheries (WDF), Washington Department of Game (WDG), National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and Tulalip Indian Tribes. Salmon or steelhead have been observed at all study sites during spawning surveys conducted by WDF, WDG and Eicher Associates between 1978 and 1982.

Three stations 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 SR2 bridge at the town of Sultan public park (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 bank approximately 50 yards downstream from Chaplain Creek gaging station (Figure 8).

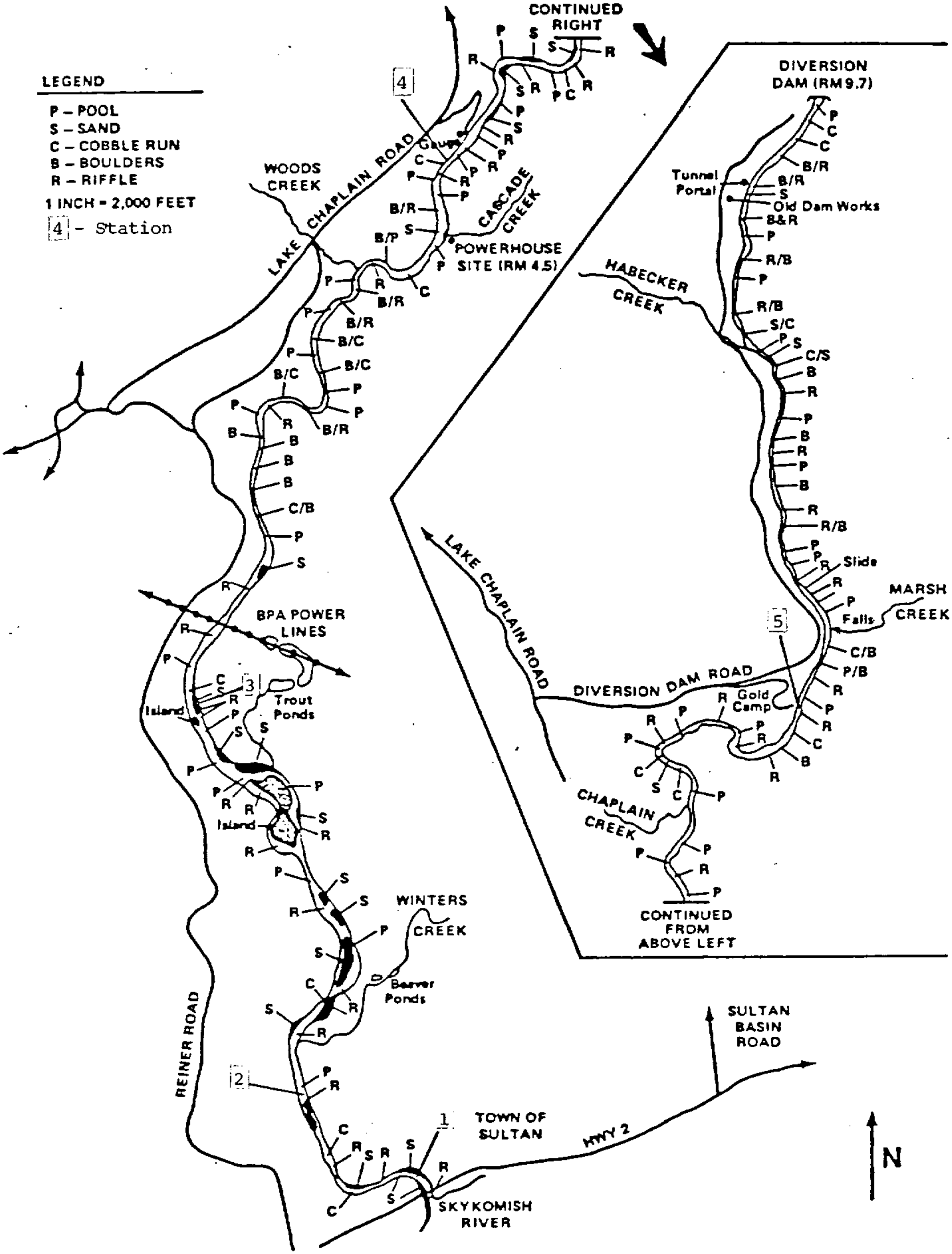


Figure 4 Map of Sultan River gravel sampling stations.

S5 (RM 7.2) is situated along the west 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.

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 locations are areas used by spawning salmonids, stations were selected on the basis of representativeness of associated river reach and accessibility. The location of the stations and the criteria used in their selection were field approved by Joint Agency fisheries biologists prior to initiation of field sampling.

At each station 10 samples were obtained along a transect parallel to the direction of water movement. These samples were collected at the same random distances along the transect as in the baseline study within locations having spawning size gravel less than 4 inches in diameter. All samples from a given station were collected within an 8-hour period. Table 2 shows river flows for each sample day by location.

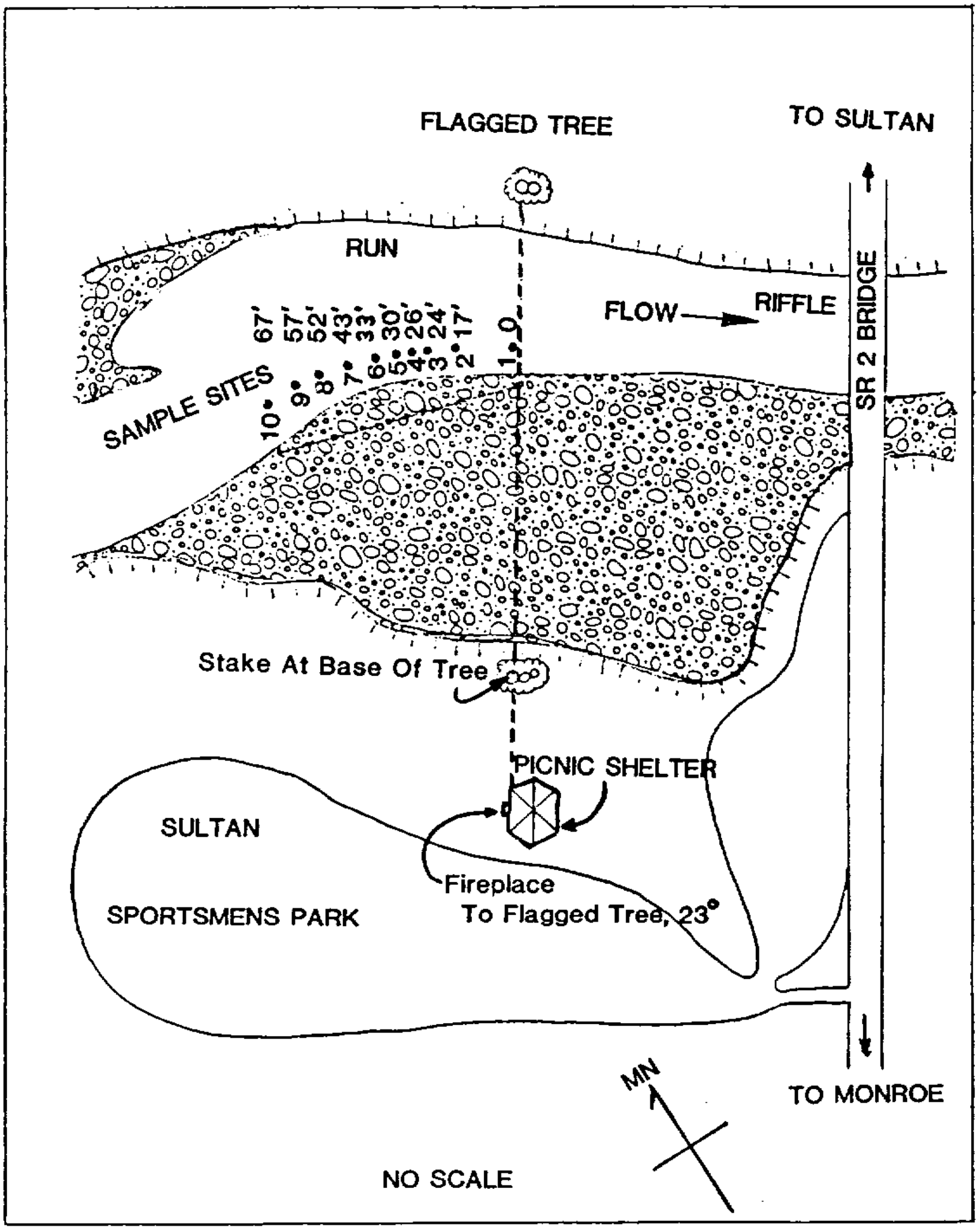


FIGURE 5 Map of gravel sampling station S1.

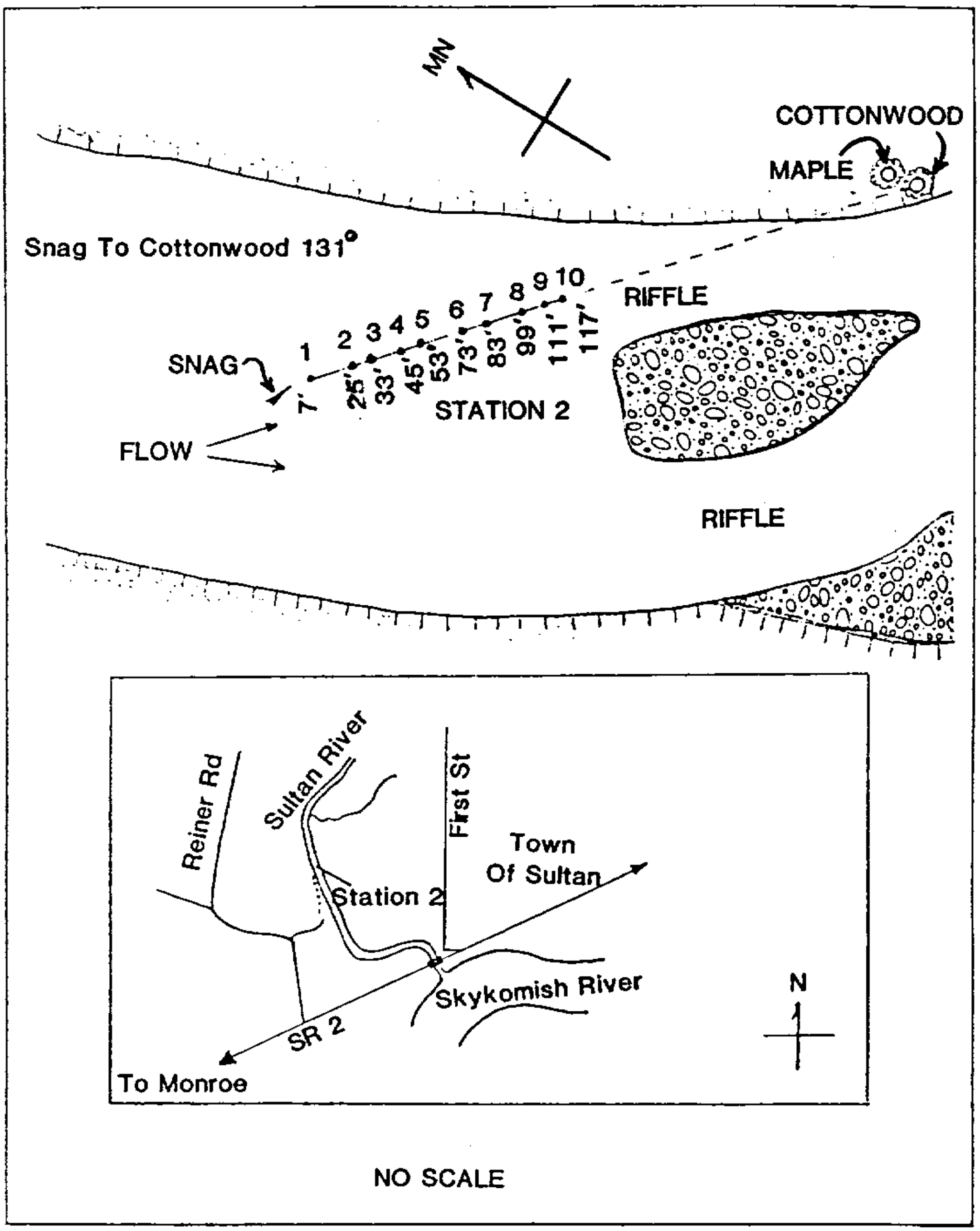


FIGURE 6 Map of gravel sampling station S2.

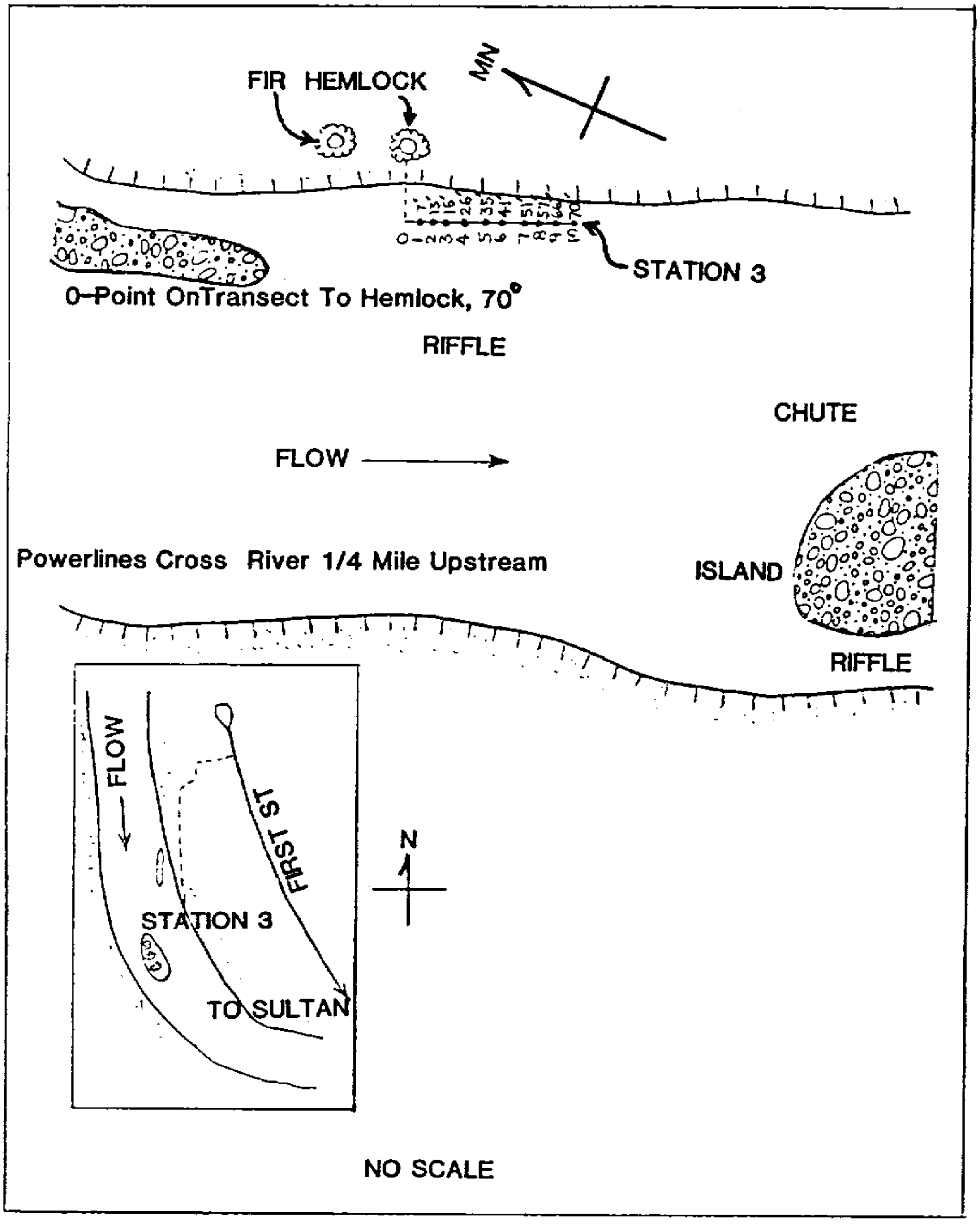


FIGURE 7 Map of gravel sampling station S3.

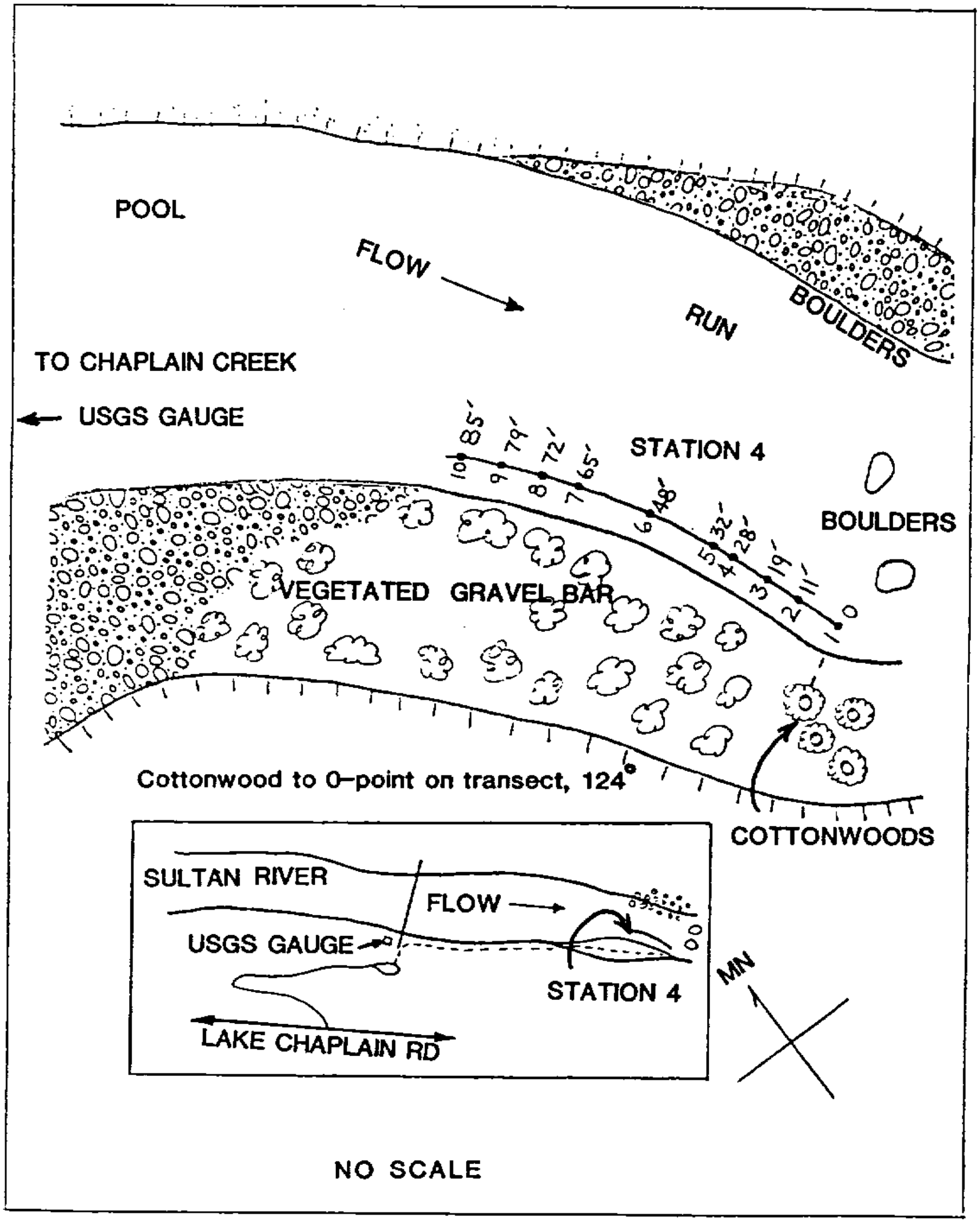


FIGURE 8 Map of gravel sampling station S4.

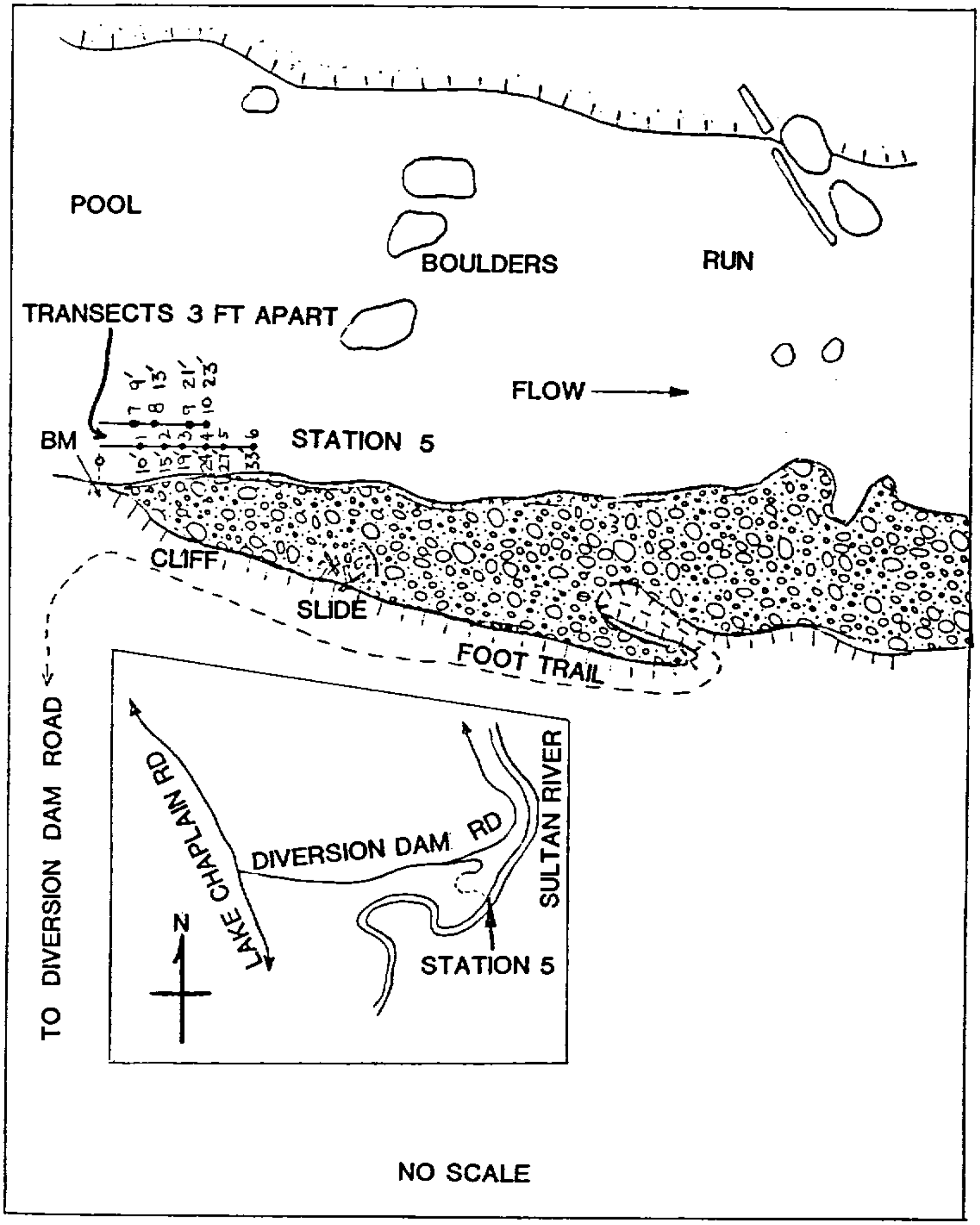


FIGURE 9 Map of gravel sampling station S5.

Table 2. Sultan River flows during each date gravel samples were collected in 1984.

Station	Date	Flow (cfs)
S1	2/20/84	315
S2	2/18/84	345
S3	2/23/84	350
S4	2/29/84	345
S5	3/ 1/84	330

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 (CO_2) 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.

In order to assure 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 twenty carbon dioxide cylinders. Cleaning was accomplished by backflushing filters with compressed air and tapping filters to dislodge contaminants.

For safety purposes a 3.5 gallon galvanized steel 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 the bottom of probes.

The probes and adhering sediment were extracted from the substratum using a hand winch attached to a tripod situated overhead. The core was 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 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

The procedures used to quantitatively sort gravel samples in the laboratory are identical to those described in Wert et al. (1982). 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, 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.

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; 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 sample collected by each sieve and the percentage of sample which is smaller than each sieve diameter (Appendix C). 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:

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

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 three geometric mean diameter (DGW, DGE, 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 study areas. Non-regression sample statistics were computed as the average of the four subsample (strata) which comprised each sample. In some cases only the lower three strata were used to calculate the sample means used in comparisons between stations. The reason for the ommission of the upper substratum is discussed later. Estimates of DGLS and PFLS values for each sample were determined by regression analysis of subsample data (n=44).

Following ANOVA comparisons, the non-parametric Scheffe's and Least Significant Difference (LSD) tests were used to detect further trends in strata and study area inter-relationships.

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 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 cleaning of filters and nozzles precluded gas blockage which would otherwise result in a relatively smaller and partially frozen core visually recognizeable 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 stream bed.

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 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.

3.2 GEOMETRIC MEAN DIAMETER AND PERCENT FINES

The average values for geometric mean diameter (d_g) and percent fines calculated for each study area are listed in Table 3. Geometric mean diameter values for all stations combined averaged 16.13 mm (DGW), 18.80 (DGD) and 20.02 (DGLS). The percentage of fine sediment less than 0.841 mm diameter for all stations combined averaged 8.7 (PFW), 5.8 (PFD) and 4.9 (PFLS). Substrate values determined for individual samples at each station during both 1982 and 1984 studies are provided in Appendix D.

All three measures of d_g indicated that streambed composition at station S3 was the coarsest of the five study areas sampled. Station S5 was characterized by a conspicuously low d_g. ANOVA results, Table 4, rejected the hypothesis of no difference among mean d_g values calculated for the five stations, regardless of the variable tested. A-priori and a-posteriori statistical tests indicated that the geometric mean diameter for station S5 was significantly different than values obtained for the other study areas. The grouping of station mean d_g values by the Least Significant Difference (LSD) a-posteriori comparison resulted in two homogeneous subsets for all variables.

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, 1984. Samples values are based on four strata collected in individual freeze cores.

Station	No. of samples	DGW mm	DGD mm	DGLS mm	PFW %	PFD %	PFLS
S1	10	17.79	20.30	22.08	4.5	3.1	3.3
S2	10	15.85	19.29	21.94	9.5	6.5	4.5
S3	10	18.62	22.47	26.37	9.1	6.2	4.4
S4	10	17.66	18.80	21.84	9.7	6.3	5.4
S5	10	10.74	13.15	7.84	10.4	7.2	7.1
Total/Mean	50	16.13	18.80	20.02	8.7	5.8	4.9

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

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 equal.
(H_o: S1 = S2 = S3 = S4 = S5)

	DGW	DGD	DGLS	PFW	PFD	PFLS
F - Ratio	4.26	5.81	4.78	10.06	9.48	11.57
F - Probability	<0.01	<0.001	<0.01	<0.001	<0.001	<0.001

All three measures of percent fines indicated that the stream bed at station S5 contained the highest proportion of fine sediment while S1 contained the lowest. An inverse relationship between station mean d_g and percent fines values was not observed. While station S5 exhibits both the lowest d_g and the highest percent fines values, station S1 had only a moderately high d_g but was lowest in fine sediments. This implies that the substrate at S1 is poorly sorted, with larger cobble and smaller sand/silt sediments forming the dominant size classes.

From an inspection of the F-statistics associated with the ANOVA's performed to test for differences among station percent fines sample means, Table 4, it is evident that significant variation exists among study areas. In contrast to the results of the d_g statistical tests, however, station S1 (rather than S5) is grouped separately from the other stations by the LSD method.

The combined mean percent fines estimates for study areas downstream of the powerhouse (S1, S2, S3) were significantly lower than the combined means for upriver stations S4 and S5. This difference was primarily due to the preponderant influence of the relatively low percent fines value at station S1. The percentage of fine sediments recorded for samples taken from the two stations upstream of the powerhouse were either higher or not significantly different from values obtained for downstream stations.

3.3 SEDIMENT STRATIFICATION

Geometric mean diameter and percent fines values obtained for the individual four strata which comprised each freeze-core sample are presented in Appendix E. Mean values at each station for strata are shown in Table 5. In all cases the highest mean d_g and the lowest percent fines values occurred in the uppermost stratum. The uniqueness of the surface layer was corroborated by statistical tests which rejected the null hypothesis that mean substrate values (either d_g or percent fines) determined for the uppermost stratum were equal to corresponding values obtained for the other strata.

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, however, did not indicate a significant difference in the substrate composition of these strata.

Since the effect of the uppermost stratum elevates mean d_g and lowers percent fines estimates, it was decided to test for differences among study areas using averages of the lower three strata (Table 6 and Appendix F). 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. Resultant statistical comparions were similar to those described earlier for sample means of all four strata. Station S5 was found to have the lowest d_g and S1 the lowest percent fines content. Significant differences among the five study sites were indicated by ANOVA due to the effect of these two stations.

Table 5. Average geometric mean diameter determined by volumetric (DGW), gravimetric (DGD), and least squares (DGLS) methods, and percent fines determined by the same methods (PFW, PFD, and PFLS), respectively, for gravel strata within individual stations and for all stations combined, Sultan River, Washington, 1984.

Station	n	Strata	DGW mm	DGD mm	DGLS mm	PFW %	PFD %	PFLS %
S1	10	1	29.39t	31.86t	83.52t	1.8t	1.2t	1.6t
	10	2	14.50	16.94	19.57	4.5	3.1	3.6
	10	3	14.99	17.77	23.41	5.6	3.8	3.9
	10	4	12.27	14.61	14.99	6.3	4.4	5.0
S2	10	1	20.64t	23.02	31.15	3.6t	2.3t	2.7t
	10	2	13.67	16.99	21.48	9.8	6.7	5.1
	10	3	13.40	17.17	23.24	12.6	8.6	6.0
	10	4	15.70	19.97	31.48	12.0	8.2	5.7
S3	10	1	25.77	28.90	96.75	5.2t	3.5t	2.8t
	10	2	15.19	18.23	31.03	9.7	6.7	5.3
	10	3	14.96	19.06	32.25	10.9	7.3	5.9
	10	4	18.55	23.71	50.62	10.8	7.1	4.9
S4	10	1	24.08t	27.29t	79.23	5.3t	3.5t	3.0t
	10	2	12.03	15.13	21.51	10.9	7.5	7.2
	10	3	14.06	18.37	31.48	11.0	7.2	6.0
	10	4	12.89	17.14	25.74	11.9	7.4	6.8
S5	10	1	12.79	15.06	18.72	8.4	5.9	6.1
	10	2	10.04	12.25	14.23	10.2	7.2	8.2
	10	3	9.61	11.96	13.90	11.4	7.9	8.4
	10	4	10.50	13.33	16.78	11.7	7.9	8.4
Stations Combined	50	1	22.53t	25.23t	61.87t	4.9t	3.3t	3.2t
	50	2	13.09	15.91	21.56	9.0	6.2	5.9
	50	3	13.40	16.87	24.86	10.3	7.0	6.0
	50	4	13.98	17.75	27.92	10.6	7.0	6.2
Overall Mean	200		16.13	18.80	20.02	8.7	5.8	4.9

Note: Statistically significant differences between stratum 1 and strata 2, 3 and 4 (composited) for each station and for all stations combined are indicated by the symbol "t".

Table 6. Average geometric mean diameter (DG) and percent fines (PF) determined by volumetric (DGW, PFW) and gravimetric (DGD, PFD) methods based on three lower strata of individual freeze cores, 1984

Station	Number of samples	DGW mm	DGD mm	PFW %	PFD %
S1	10	13.92	16.44	5.5*	3.8*
S2	10	14.25	18.04	11.4	7.8
S3	10	16.24	20.33	10.5	7.1
S4	10	12.99	16.88	11.3	7.4
S5	10	10.05*	12.51*	11.1	7.7
Total Mean	50	13.49	16.84	10.0	6.7

* Indicates substrate mean values which are significantly different from those of other stations.

4.0 DISCUSSION

The textural composition of streambed sediments analyzed in this study was generally similar to that reported for spawning gravels prior to construction (Wert et al. 1982). However, some differences were apparent. The spatial variability of geometric mean particle size showed no trend among stations whereas 1982 gravels indicated a progressively smaller size with increased distance from the river mouth. Stations S1 and S3 had the coarsest gravel texture both prior to and following project constuction. In 1984, station S5 had a significantly lower geometric mean particle size than other stations while both S4 and S5 were of significant lower value in 1982. Comparison of gravel texture of corresponding individual stations between both years indicated only station S4 was significantly changed (Figure 10). The sediment at this location, upstream of the powerhouse site, became significantly improved (coarser). A possible explanation for this change may be that in 1984, the stream bed at this site was altered by the flow regime during the winter months prior to sampling. Examination of 1984 hydrology records would show whether or not flows were of greater magnitude with more peaks than those of 1982.

Relationships between geometric mean particle size and expected percent salmonid embryo survival for 1982 and 1984 are shown in Table 7. These values were obtained from a curve (Figure 11) developed by Shirazi and Seim (1979) and based on field studies in Washington and Oregon streams and laboratory experiments using coho and sockeye salmon and cutthroat and steelhead trout.

Expected survival exceeds 80 percent in gravels at stations S1 through S4 in 1984 but only exceeds this level in stations S1 through S3 prior to construction. This corresponds to earlier discussion indicating that station S5 (1984) and S4 and S5 (1982) had significantly lower geometric mean particle size than other locations in the respective years. It is of interest to note that station S3, which is associated with the most abundant and species diverse spawning activity of the sites sampled, also provides the greatest expected percent embryo survival.

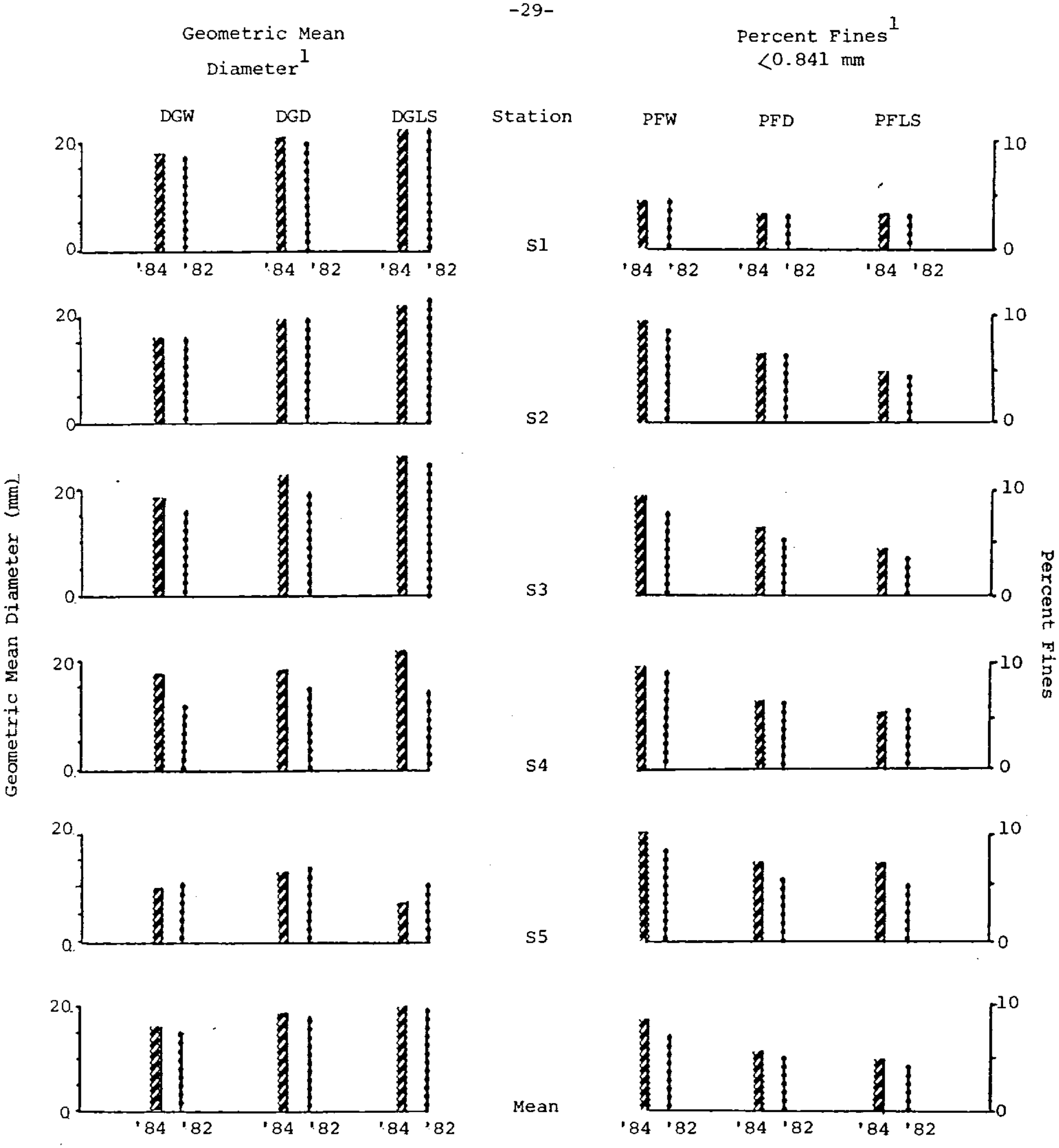


Figure 10. Comparison of Sultan River streambed gravel geometric mean diameter values and percentage of fines (<0.841 mm in diameter) between 1984 and 1982. Statistically significant differences between 1984 and 1982 mean values are indicated by an asterisk (*).

[1] Geometric mean diameter and percentage of fines by volumetric (DGW, PFW), gravimetric (DGD, PFD) and least squares regression (DGLS, PFLS) methods.

Table 7. Comparative relationships of theoretical percent salmonid embryo survival[1] and geometric mean diameter[2], in parentheses, in Sultan River stream bed gravels between 1982 and 1984 at individual stations (n = 4 strata x 10 samples = 40) and at all stations combined (n = 200).

PERCENT EMBRYO SURVIVAL

	1 9 8 4			1 9 8 2		
Station	DGW (mm)	DGD (mm)	DGLS (mm)	DGW (mm)	DGD (mm)	DGLS (mm)
1	89% (17.79)	94% (20.30)	95% (22.08)	88% (17.35)	93% (19.82)	95% (21.89)
2	82% (15.85)	92% (19.29)	95% (21.94)	83% (16.25)	92% (19.37)	95% (23.22)
3	91% (18.62)	95% (22.47)	93% (26.37)	83% (16.45)	92% (19.38)	95% (24.56)
4	89%* (17.66)	91%* (18.80)	95% (21.84)	58%* (12.01)	76%* (14.70)	78% (15.15)
5	48% (10.74)	65% (13.15)	28% (7.87)	52% (11.41)	66% (13.54)	48% (10.95)
Mean	83% (16.13)	91% (18.80)	93% (20.02)	82% (15.32)	90% (17.93)	92% (19.62)

[1] Based on relationships between percent embryo survival and substrate composition by Shirazi and Seim, 1979.

[2] Based on volumetric (DGW), gravimetric (DGD) and least squares (DGLS) indices.

* Statistically significant change in geometric mean diameter between corresponding 1982 and 1984 values.

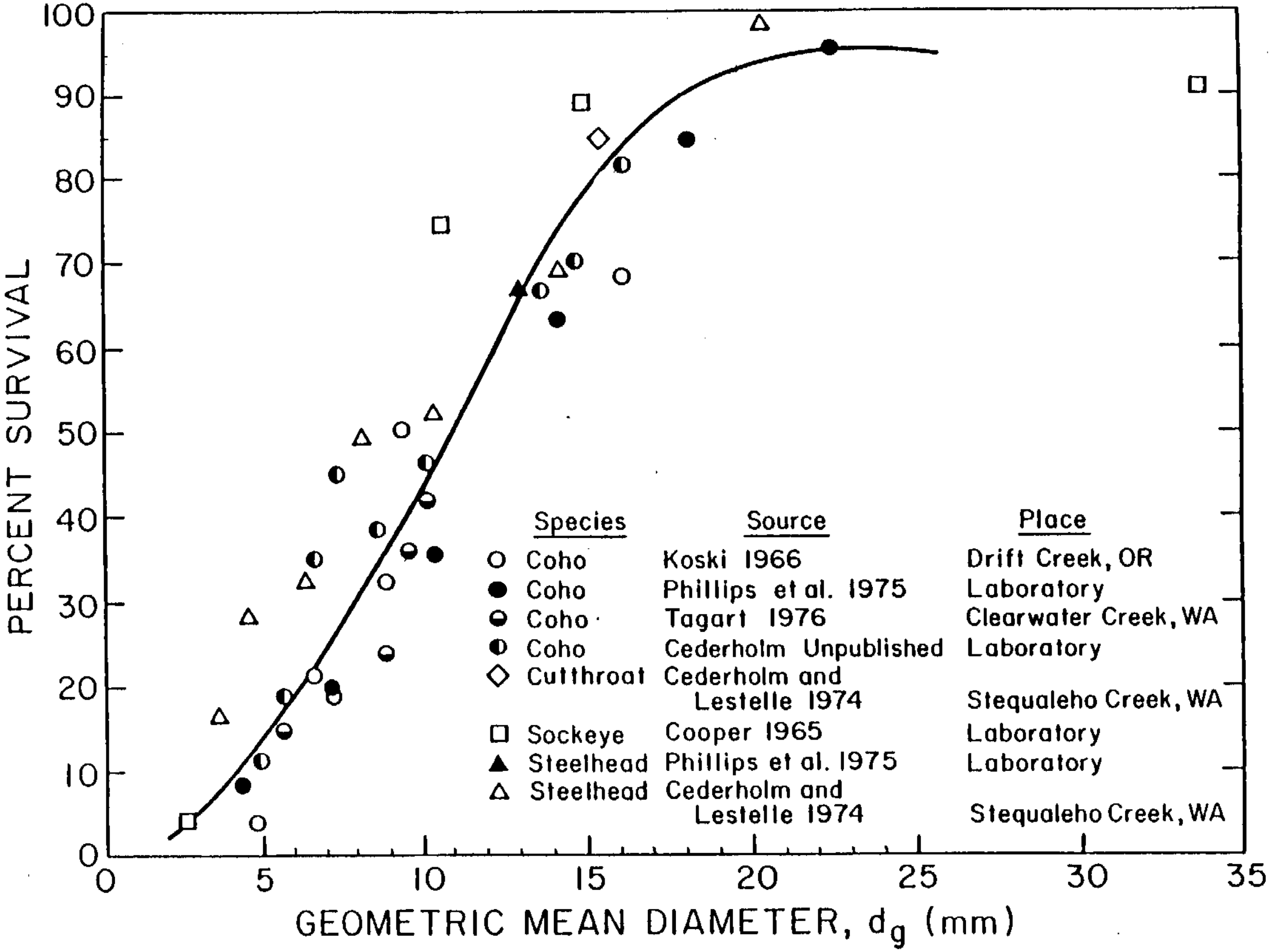


Figure 11 Relationship between percent embryo survival and substrate composition expressed in geometric mean diameter. From Shirazi and Seim, 1979.

The amount of fine sediments at the selected study sites was essentially unchanged between 1982 and 1984 (Table 8). The only notable trend among stations for both years was that gravels at station S1 continued to contain significantly lower proportions of fine sediments. Although not significantly different, mean values were in almost all cases slightly greater following costruction (Figure 10). The only significant increase was indicated by the regression value PFLS at station S5.

Comparative values for percent fines in sediments of relatively undisturbed salmond spawning streams in the Pacific Northwest have reported values (PFW) ranging from 3.1 to 20.6 percent (Table 9). Oregon coastal streams have been excluded from this table, as the geology of the coastal range is characterized by erosive marine sediments which contribute higher levels of fine materials to their drainage streams (Moring and Lantz 1974). The proportion of fine sediment in the Sultan River study sites averaged 7.1 and 8.7 percent overall prior to and following construction, respectively. Average values for individual sites ranged from 4.7 to 9.1 and 4.5 to 10.4 percent for the same respective periods. This indicates that the proportions of fine sediments within selected spawning gravels of the lower Sultan River remain comparable, following project construction, to those reported for undisturbed Pacific Northwest watersheds.

Sediment stratification continued to occur in the stream bed following project construction. In both 1982 and 1984, the combined mean values of the upper 3 inches of substrate contained significantly 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 stream bed. Milhous and Klingeman (1971) and Milhous (1973) reported the presence of relatively coarse bed material at the water-substrate interface as common in most gravel-bedded streams. Such 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.

Table 8. Comparison of percentage of fines less than 0.841 mm in diameter in Sultan River streambed gravels between 1982 and 1984 at individual stations (n = 4 strata x 10 samples = 40) and at all stations combined (n = 100).

PERCENT FINES

	1984			1982		
Station	PFW	PFD	PFLS	PFW	PFD	PFLS
1	4.5	3.1	3.3	4.7	3.4	3.2
2	9.5	6.5	4.5	8.6	6.1	4.4
3	9.1	6.2	4.4	7.7	5.3	3.5
4	9.7	6.3	5.4	9.1	6.2	5.4
5	10.4	7.2	7.1*	8.6	5.8	5.4*
Mean	8.7	5.8	4.9	7.1	4.9	4.1

* Statistically significant difference in mean percent fines between corresponding 1982 and 1984 values.

Table 9. Percentage of fine sediment (wet volume - PFW) in streambed core samples from Pacific Northwest streams not impacted by development[1].

Stream (state)	Number of Samples	Cutoff Point	Percent fines	Source
Upstream Harris River (AK)	25	<.833	13.7	McNeil & Ahnell (1960)
Anan Creek (AK)	5	<.833	5.7	"
Upper Clearwater River (WA)	27	<.850	8.3	Cederholm & Salo (1979)
South Fork Hoh River Tributary (WA)	6	<.850	3.1	"
South Fork Hoh River (WA)	19	<.850	8.3	"
Tshlecthy Creek (WA)	6	<.850	6.0	"
Bob Creek (WA)	6	<.850	4.9	"
Harlow Creek (WA)	5	<.850	9.6	"
Stequaleho Creek No. 1 (WA)	43	<.850	6.9	"
Sollecks River Nos. 1-3	91	<.850	7.9	"
Little Lost Man Creek (CA)	20	<.833	16.3	Woods (1980)
Bummer Lake Creek (CA)	21	<.800	10.2	Burns (1972)
South Fork Yager Creek (CA)	10	<.800	16.4	"
Little North Fork Noyo River (CA)	27	<.800	20.0	"
South Fork Casper Creek (CA)	20	<.800	20.6	"

[1]From Scott, et al. 1982.

5.0 CONCLUSION

The textural composition of Sultan River streambed sediments at selected spawning locations following project construction (1984) was generaly similar to that evaluated for the same sites prior to construction (1982). Some differences, however, did occur. Average values for geometric mean particle size (d_g) showed no trend in spatial variability among stations sampled in 1984 whereas a trend of smaller d_g with increased distance upstream was apparent in 1982.

Stations S1 (river mouth) and S3 (two miles downstream of powerhouse) had the coarsest texture (best sediment quality) in both 1982 and 1984.

Station S5 had a significantly lower d_g as compared to other stations in 1984, while S4 and S5 were significantly lower in 1982.

Comparison of d_g for corresponding individual stations between 1982 and 1984 showed only S4 significantly changed (became improved or coarser).

Average values for percentage of fines less than 0.841 mm was essentially unchanged between 1982 and 1984 at all stations. The only trend in variability among study sites was that station S1 continued to have significantly lower levels of fines as compared to all other stations during both years.

Proportion of fines within gravels of the selected salmonid spawning sites remained comparable, following project constuction, to those reported for undisturbed watersheds of the west coast.

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

Based on relationships from other Pacific Northwest studies, the expected percent survival of salmonid embryos incubating within gravels having sediment textural composition equal to those levels determined for all stations downstream of the powerhouse exceeds 80 percent. The average percent survival expected for all locations combined is similar for both years of study.

The textural compositon of Sultan River salmonid spawning gravel following hydroelectric construction continues to be of relatively good quality and potentially provides conditions conducive to a high rate of embryonic survival depending on other survival-limiting factors. Therefore the need for mitigative measures is not indicated.

R E F E R E N C E S

Adams, J.N. 1979. Variations in gravel bed composition of small streams in the Oregon Coast Range. M.S. Thesis, Ore. State Univ., Corvallis, OR. 160 pp.

Adams, J.N., and R.L. Beschta. 1980. Gravel bed composition in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 37:1514-1521.

American Geophysical Union. 1947. Report of the subcommittee on sediment terminology. Trans. Amer. Geophys. Union 28. 615 pp.

Burgner, R.L. 1982. Salmonid enhancement by control of stream discharge. Tech. Rept. to Public Utility District No. 1 of Snohomish County, WA. 9 pp. Unpublished.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Amer. Fish. Soc. 101:1-17.

Cederholm, C.J., W.J. Scarlett, and E.O. Salo. 1977. Salmonid spawning gravel composition data summary from the Clearwater River and its tributaries, Jefferson County, Washington, 1972-1976. Univ. of Wash., Fish. Res. Inst., Circ. 77-1. 135 pp.

Cederholm, C.J., and L.C. Lestelle. 1974. Observations on the effects of landslide siltation on salmon and trout resources of the Clearwater River, Jefferson County, Washington. 1972-1973. Univ. of Wash., Fish. Res. Inst., Final Rept,. Part I, FRI - UW - 7404. 133 pp.

Cederholm, C.J., and E.O. Salo. 1979. The effects of logging road landslide siltation on the salmon and trout spawning gravels of Stequaleho Creek and the Clearwater River Basin, Jefferson County, Washington, 1972-1978. Univ. of Wash., Fish. Res. Inst., Final Rept., Part III, FRI - UW - 7915. 99 pp.

Cooper, A.C. 1969. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevin. Int. Pac. Salmon Fish. Comm. Bull. 18. 71 pp.

Eicher, G.J. 1981. Anadromous fish enhancement from the Sultan Project, supplementary report. Public Utility Dist. No. 1 of Snohomish County, Washington. 4 pp. Unpublished.

Everest, F.H., C.E. McLemore and J.F. Ward. 1980. An improved tri-tube cryogenic gravel sampler. USDA For. Serv. Res. Note PNW-350. 8 pp. Pac. Northwest For. and Range Exp. Stn., Portland, OR.

Gales, L., and K. Swanson. 1980. SEDIMNT, a program which analyses sediment samples. Univ. of Wash., Fish. Analysis Center Document. 10 pp.

Garde, R.J., K.A. Ali and S. Siette. 1977. Armoring processes in degrading streams. ASCE Jour., Hydraulics Div. 103 (HY9):1091-1095.

Koski, K.V. 1966. The survival of coho salmon (Onchorhynchus kisutch) from egg deposition to emergence in three Oregon coastal streams. M.S. Thesis, Ore. State Univ., Corvalllis, OR. 84 pp.

Lotspeich, F.B. and B.H. Reid. 1980. Tri-tube freeze-core procedure for sampling stream gravels. Prog. Fish-Cult. 42:96-66.

Lotspeich, F.B. and F.H. Everest. 1981. A new method for reporting and interpreting textual composition of spawning gravel. USDA For. Serv. Res. Note PNW-369. 11 pp. Pac. Northwest For. and Range Exp. Sta., Portland, OR.

McNeil, W.J. and W.N. Ahnell. 1960. Measurements of gravel composition of salmon stream beds. Fish. Res. Inst., Univ. of Wash., Seattle, WA. Circ. 120 6 pp.

Milhous, R.T. 1973. Sediment transport in a gravel bottomed stream. PhD. dissertation, Ore. State Univ., Corvallis, OR. 232 pp.

Milhous, R.T. and P.C. Klingeman. 1971. Bedload transport in mountain streams. ASCE Hydraulics Div. Specialty Conf., Univ. of Iowa, Iowa City, IA. 16 pp.

Moring, J.R. and R.L. Lantz. 1974. Immediate effects of logging on the freshwater environment of salmonids. Or. Wildlife Comm., Res. Div. Proj. AFS-58, Final Report. Corvallis, OR. 101 pp.

Peterson, R.H. 1978. Physical characteristics of Atlantic salmon spawning gravel in some New Brunswick streams. Fish. and Mar. Serv. Tech. Rept. No. 785.

Platts, W.S., M.A. Shirazi and P.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning, and methods for evaluation. EPA-600/3-79-043. April 1979. USEPA, Corvallis Environ. Res. Lab., Corvallis, OR. 110 pp.

Public Utility District No. 1 of Snohomish County. 1980. Sultan River Project, FERC Project 2157, Evaluation of flood control operation. Unpublished.

Public Utility District No. 1 of Snohomish County. 1982. Sultan River Project, FERC Project 2157, Exhibit S (Revised). Fisheries and wildlife impacts of the Sultan River Project, Stage II.

Scott, J.B., C.R. Steward, and Q.J. Stober. 1982. Impacts of urban runoff on fish populations in Kelsey Creek, WA. Univ. of Wash., Fish. Res. Inst., Tech. Completion Rept. FRI-UW-8204. 377 pp.

Shapley, S.P. and D.M. Bishop. 1965. Sedimentation in a salmon stream. J. Fish. Res. Bd. of Canada. 22(4):919-927.

Shirazi, M.A. and W.K. Seim. 1979. A stream systems evaluation -- an emphasis on spawning habitat for salmonids. Ecol. Res. Series Rept. EPA-600/3-79-09. U.S. Environmental Protection Agency.

Stober, Q.J., C.R. Steward and F. Winchell. 1982. Tolt River fisheries and instream flow analysis. 1982. Univ. of Wash., Fish. Res. Inst., Annual Prog. Rept. FRI-UW-8213. 213 pp.

Tagart, J.V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. M.S. Thesis, Univ. of Wash., Seattle, WN. 101 pp.

Wert, M.A., C.R. Steward and F. Winchell. 1982. Evaluation of the textural composition of Sultan River salmonid spawning gravels. Tech. report to Public Utility District No. 1 of Snohomish County, WA. 39 pp. Unpublilshed.

Woods, P.F. 1980. Dissolved oxygen in intragravel water of three tributaries to Redwood Creek, Humboldt County, California. Water Res. Bull. 16(1):105-111.

A P P E N D I C E S

A Recommended field sampling equipment and maintenance list for CO_2 sampler.

B Freeze-core sampler supply sources and price list (1982).

C Description of SEDIMNT computer program for gravel textural composition evaluation.

D Substrate values for individual samples collected from each study reach during 1982 and 1984.

E Substrate values for each strata of individual samples collected at all study reaches during 1984.

F Substrate values for individual samples collected from each study reach during 1982 using lowest three strata only (strata 1 omitted in sample averages).

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 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

[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

[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

APPENDIX C

Identification

FRG -- 367 : SEDIMNT, a program which analyzes sediment samples

Programmed by: L. Gales and K. Swanson, Fisheries Analysis Center, University of Washington

Date : September 1980

Purpose

SEDIMNT is a program which summarizes regression statistics for sediment samples collectd at various sites. (Each sample consists of a sediment volume reading collected by a sieve of a certain diameter and is identified by stream identification, location on the stream, date, sieve diameter, and replicate number. The stream, location, and date must be properly sorted prior to input and are used to divide the data into groups which are analyzed separately.) The program generates one line of statistics, an optional scattergram, and an optional table for each group. There is also an option whereby the different locatins for a given date and stream can be combined for purposes of the regression analysis.

Operation

SEDIMNT reads in sediment volumes for each group and performs the following operations:

(1) Adjusts the sediment volume by a diameter- and density-dependent factor in order to determine the actual dry volume.

(2) Divides the replicates into separate subgroups based on the replicate value and, for each subgroup:

(a) sorts the samples in descending order by sieve diameter,

(b) computes a "percent finer than" (PFT) statistic for each sample which specifies the percentage of the total adjusted volume collected by all sieves in this subgroup which trap finer (smaller) sediments,

(c) computes the inverse probability of the PFT statistic for each sample, based on the standard (0,1) normal probability districution.

(3) Combines the samples for all the subgroups identified by (2) and computes the slope, intercept, and correlation coefficient of a regression line which passes through sets of (x,y) pairs, where x = the log10 (sieve diameter), and y = the inverse probability

corresponding to PFT. The regression line is of the form:

$$y = A*x + B$$

where A is the slope and B is the intercept.

(4) Computes a set of sieve diameters which correspond to a fixed set of PFT values, using the inverse of the regression line:

$$x = (y - B) / A$$

(5) Prints out the stream, location, date, slope, intercept, correlation coefficient, and sieve diameters corresponding to PFT values, for this group, plus the percent of fines smaller than a sieve diameter selected vy the user.

For a more complete description of the above algorithms, see pages 24 and 25 in reference 1.

Output
The main output from SEDIMNT is a table which contains one line of statistics for each group, and is formatted as follows:

Column Header	Example	Meaning
STREAM ID	BEAR CK	Stream identification
LOCATION	11	Location code
MO/DY/YR	06/76/79	Date
N	22	Number of samples in the group
SLOPE	1.19	Slope of the regression line
INTRCP	-0.08	Intercept of the regression line
CORR	0.99	Correlation coefficient
D5(MM)	0.05	Sieve diameter, in millimeters, which corresponds to a 5 "percent finer than" statistic for the regression line
D16(MM)	0.17	Sieve diameter corresp. to 16 PFT
D50(MM)	1.17	Sieve diameter corresp. to 50 PFT
D84(MM)	7.97	Sieve diameter corresp. to 84 PFT
D95(MM)	28.02	Sieve diameter corresp. to 95 PFT
SIGMA	6.84	Ratio of D84/D50
%<n.nnn	0.06	Percent of fines less than n.nnn in diameter

Optional Output
The user may obtain printer plot scattergrams and/or tables of "percent finer" statistics through the use of optional "*COMDECK" files which select those data sets to be plotted or printed.

The "*COMDECK" statements begin in column 1 and the Fortran "IF" statements that follow them begin on column 7.

The printer plots are scattergrams of inverse probability versus log10 (sieve diameter). The user may select any group of collection of groups for plotting by including a Fortran "IF" statement in a *COMDECK named SELPLT as follows:

```
*COMDECK SELPLT
     IF (<user-supplied boolean expression>) PLT = .TRUE.
```

where the <boolean expression> operates on the variables STRM (stream identification), LOC (location), and DATE (mm/dd/yy), e.g.

```
*COMDECK SELPLT
     IF (STRM.EQ."VEAR CR" .AND. DATE.EQ." 62679")OLT = .TRUE.
```

will generate printer plots for all BEAR CR stream samples collected on June 26, 1979.

The optional tables contain the following information for wet and dry sediment volumes for each selected group:

Column Header	Example	Meaning
SIZE CLASS (MM)	3.36	Sieve diameter in mm
WET VOLUME	650	Volume of wet sediment in cc
PERCENT FINER THAN	.632	Percent of trapped sediment which is finer than the above diameter in mm (decimal fraction)
PERCENT RETAINED ON	.26	Percent of sediment trapped on this sieve (decimal fraction)
DRY VOLUME	560.7	Volume of sediment after the wet-to-dry conversion factor is applied
PERCENT FINER THAN	.581	Percent of dry sediment which is finer than the above sieve diameter (decimal fraction)
PERCENT RETAINED ON	.271	Percent of dry sediment trapped on this sieve (decimal fration)
REPLICATE	1	Replicate number of experiment

The user may select tables for any group or set of groups by means of a Fortran "IF" statement contained in a "*COMDECK" named SELTBL as follows:

```
*COMDECK SELTBL
     IF (<user-supplied boolean expression>) TBL = .TRUE.
```

where the <boolean expression> operates on the same variables as in the SELPLT block above, STRM, LOC, and DATE, e.g.

```
*COMDECK SELTBL
     IF (DATE.EQ." 62679") TBL = .TRUE.
```

will print out tables for all data collected on June 26, 1979. Note that since MONTH (an alpha variable9 was coded in the data with a leading blank instead of a leading zero, then this form must be used in the boolean expression.

Input Data

The input data to program SEDIMNT is described by Fisheries Analysis Center form S320.2 and consists of one card for each sample punched as follows:

Variable	Type	Columns	Meaning
STRM	alpha	01 - 10	Stream identification, left adjusted
LOC	alpha	12 - 13	Location code, rilghr adjusted
DATE	alpha	15 - 20	Date of sample collection
MONTH	alpha	15 - 16	Month
DAY	alpha	17 - 18	Day
YEAR	alpha	19 - 20	Year
REP	integer	22 - 23	Replicate, right adjusted
DIA	real	25 - 34	Sieve diameter, right adj., mm (or in.)
VOL	real	36 - 45	Sediment volume, right adj., ml

Note: the decimal point is specifically coded for DIA and VOL. Alpha variable must be coded consistently as regards to leading blanks or zeroes, e.g. MONTH = "07" and MONTH = " 7" are not identical.

The data must be sorted in ascending order prior to input by the sort keys

```
YEAR (col. 19-20)
   MONTH (col. 15-16)
      DAY (col. 17-18)
         STRM (col. 1-10)
            LOC (col. 12-13)
               REP (col. 22-23)
```

In addition, the user must include a *COMDECK named INPAR which supplies 3 input parameters: RHO, DPFT and INCH. RHO is a density factor which is used in the calculation of wet-to-dry sediment volumes. It represents gravel density in grams/cm**3 and typically ranges from 2.2 to 2.9. If samples taken are already dry volume measurements, use RHO=0.0 and ignore the wet volume columns in the optional tables. DPET is a single diameter for which the "percent finer than" statistic is to be calculated and printed in the main output under the column head "%<n.nnn". DPFT is the number "n.nnn". The INCH parameter was included for those who record sieve diameter in inches; set INCH=.TRUE. to cause internal conversion to millimeters (tables will give diameters in millimeters, not inches, so set DPFT in mm always!).

The input parameters are specified as follows:

```
*COMDECK INPAR
     RHO  = <value>
     DPFT = <value>
     INCH = <logical value>
```

The user must also include a *COMDECK named SELRGRS which supplies two logical parameters which control the form of the regression analysis; they are called RGRS and COMBLOC. If RGRS=.TRUE. the regression analysis will be performed, otherwise it is bypassed (this is to save computer resources when only tables are wanted). When RGRS=.TRUE. and COMBLOC=.TRUE. as well, then all the locations within a stream and date will be combined for purposes of the regression analysis (the replicates are essentially re-numbered).

```
*COMDECK SELRGRS
     RGRS*   = <logical values>
     COMBLOC = <logical value>
```

File Structure/How to Obtain the Program

The SEDIMNT system consists of a set of files contained on a FILESET file structured as follows:

UPDATE/SEDIMNT	: source program for SEDIMNT in UPDATE format
COMDECK/INPAR	: an UPDATE COMDECK which specified the values for RHO, DPFT and INCH
COMDECK/SELPLT	: an UPDATE COMDECK which selects the data sets to be plotted
COMDECK/SELTBL	: an UPDATE COMDECK which selects the data sets to be printed in table format
COMDECK/SELRGRS	: an UPDATE COMDECK which controls the regression analysis
DATA/SORTED	: contains the input data after sorting by SORTMGR
XEQ/SEDIMNT	: an execution file which collects all of the above files and, after UPDATE and compilation, applies program SEDIMNT to the data

Once the above file structure has been established, it is only necessary to SUBMIT the file XEQ/SEDIMNT in order to run the program.

A basic fileset containing the element files UPDATE/SEDIMNT and XEQ/SEDIMNT is found on the usernumber BABPOOO and can be copied to your usernumber as follows:

```
DEFINE,FILESET=SDMTSET
ATTACH,SDMTSET/UN=BABPOOO
COPYEI,SDMTSET,FILESET
RETURN,SDMTSET
```

This will leave you with a direct access file on your usernumber called SDMTSET which contains the basic starter system. You must then add the sorted data file and the four COMDECKs described above, to the fileset.

Limitations

The number of points, or sieve sizes, within the replicates for a stream-location-date, is limited to 20 per replicate.

The number of replicates per stream-location-date is limited to 30.

The total number of data points per stream-location-date (all reps) is limited to 300.

Computer Resources

Hardware Resources:

- Processor : CDC 170-750
- Memory required : 760000 Octal.
- Execution time : about 50 data cards/second of processing time

Software Resources

- Operating system : NOS 1.4 (see reference 2.)
- Language : Fortran IV, as compiled under the Minnesota Fortran compiler (see reference 3.)
- Subroutine package needed:
  PRNT3D (see reference 4.)
- Software libraries needed:
  IMSLFTN (see reference 5.)
  NORFISH (see reference 6.)
  FSHLIB (see reference 7.)

R E F E R E N C E S

FILESET User's Guide. 1978. Univ. of Wash. Academic Computer Center, Publication No. W00048.

Gales, L. 1978. User's Guide for Subroutine PRNT3D. Center for Quantitative Science in Forestry, Fisheries and Wildlife. Univ. of Wash., Seattle.

Gales, L. 1980. FSHLIB Subroutine Library. Fisheries Research Institute, Univ. of Wash., Seattle.

Introduction to the IMSL Subroutine Library. 1978. Univ. of Wash. Academic Computer Cednter, Publication No. W00002.

Liddiard, I. and E. Mundstock. 1976. Minnesota Fortran Reference Manual. Univ. of Minn. Computer Center, Minneapolis, Minn.

Lindsay A. NORFISH Subroutine Library. Center for Quantitative Science in Forestry, Fishieres and Wildlife, Univ. of Wash., Seattle.

NOS Version 1 Reference Manual. Control Data Corporation, Publication No. 60435400.

Shirazi, M. and W. Seim. 1979. A stream systems evaluation -- an emphasis on spawning habitat for salmonids. Corvallis Environmental Reserch Laboratory, Office of Research and Development, U.S. E.P.A., Corvallis, Oregon.

Sample Run

For the sample run, the files needed for the SEDIMNT system were contained in a fileset called SDMTSET. The file DATA/SORTED contained data for 3 distinct stream-location-date groups.

The file XEQ/SEDIMNT looked as follows:

```
XEQSED,T30.
ID CARD.
UN CARD.
ATTACH,FILESET=SDMTSET.
GF,COMDECK/INPAR.
GF,COMDECK/SELRGRS.
GF,COMDECK/SELPLT.
GF,COMDECK/SELTBL.
REWIND,*,OUTPUT.
COPYBR,INPAR,X.
COPYBR,SELRGRS,X.
COPYBR,SELPLT,X.
COPYBR,SELTBL,X.
COPYBR,SEDIMNT,X.
PACK,X.
REWIND,X.
UPDATE,N=NEWSED,F,L=12,I=X.
MNF,I=COMPILE,J,R=0,L=0.
RETURN,*,LGO,FILESET,OUTPUT.
GF,DATA/SORTED.
RETURN,FILESET.
PUBLIC,IMSL.
ATTACH,BPR3D/UN=BAKP000,NA.
ATTACH,NORFISH/UN=GAHT000,NA.
ATTACH,FISHLIB/UN=BAKP000,NA.
LDSET,LIB=FISHLIB/NORFISH/IMSL.
LOAD,LGO.
LOAD,BPR3D.
EXECUTE,SEDIMNT,SORTED,RGRF,PLTF,TBLF.
SKIP.
EXIT.
REWIND,*,OUTPUT.
COPYEI,RGRF,OUTPUT.
COPYEI,PLTF,OUTPUT.
COPYEI,TBLF,OUTPUT.
*EOF
```

The file COMDECK/INPAR looked as follows:

```
COMDECK INPAR
     RHO  = 2.2
     DPFT = .841
     INCH = .FALSE.
```

The file COMDECK/SELPLT looked as follows, where the date "071574" was known to exist in the test data for one stream-location-date group:

```
*COMDECK SELPLT
     IF (DATE .EQ. "071574") PLT = .TRUE.
```

The file COMDECK/SELTBL looked as follows:

```
*COMDECK SELTBL
     IF (DATE .EQ. "071574") TBL = .TRUE.
```

Attached is a reduced copy of the output from the sample run.

Appendix D. Results of 1984 and 1982 Sultan River sediment analyses. All strata are combined for each sample.

Sta	#	1984 DGW	1984 DGD	1984 DGLS	1984 PFW	1984 PFD	1984 PFLS	1982 DGW	1982 DGD	1982 DGLS	1982 PFW	1982 PFD	1982 PFLS
1	1	16.306	18.646	20.010	0.059	0.040	0.040	22.60	25.45	33.63	.03	.03	.02
1	2	21.166	23.648	21.500	0.039	0.027	0.030	15.54	17.87	16.45	.05	.04	.03
1	3	16.691	18.954	20.470	0.046	0.032	0.030	18.96	21.67	28.33	.04	.03	.03
1	4	25.865	23.818	43.050	0.038	0.025	0.020	20.19	22.56	22.86	.04	.03	.02
1	5	12.142	14.188	9.900	0.058	0.040	0.050	9.39	11.24	7.23	.06	.04	.05
1	6	21.330	24.484	33.270	0.039	0.026	0.020	17.07	19.86	25.49	.06	.05	.03
1	7	18.784	21.956	29.000	0.041	0.027	0.030	16.86	19.44	23.75	.05	.03	.03
1	8	14.701	17.121	11.200	0.055	0.037	0.040	21.78	24.92	26.23	.04	.03	.03
1	9	17.772	20.007	17.010	0.033	0.022	0.030	13.84	15.81	10.69	.06	.04	.05
1	10	13.102	15.129	15.380	0.049	0.033	0.040	16.32	19.40	24.19	.04	.02	.03
2	1	8.915	11.312	8.220	0.165	0.115	0.080	24.59	28.86	58.71	.07	.05	.03
2	2	14.894	17.667	14.380	0.081	0.056	0.040	20.39	23.46	24.17	.06	.04	.03
2	3	17.404	20.727	17.490	0.088	0.061	0.040	14.09	16.90	15.45	.09	.06	.05
2	4	13.982	17.089	15.210	0.093	0.064	0.050	18.48	21.19	21.09	.05	.04	.03
2	5	15.221	18.266	21.060	0.086	0.059	0.040	12.87	15.97	18.57	.10	.07	.05
2	6	18.580	22.616	31.980	0.093	0.063	0.040	13.05	15.90	14.51	.10	.07	.05
2	7	16.828	20.408	20.340	0.080	0.053	0.040	17.63	21.22	31.56	.09	.07	.04
2	8	17.492	21.611	29.890	0.083	0.056	0.040	11.41	14.18	12.63	.12	.08	.06
2	9	17.207	21.404	29.460	0.095	0.064	0.040	19.79	23.72	25.17	.08	.05	.04
2	10	17.977	21.791	31.730	0.083	0.054	0.040	10.16	12.28	10.35	.10	.08	.06
3	1	22.832	26.539	32.090	0.110	0.073	0.040	22.12	26.09	48.37	.08	.05	.03
3	2	16.492	21.382	32.330	0.125	0.085	0.050	15.24	17.74	16.23	.07	.05	.04
3	3	13.232	17.524	15.090	0.137	0.094	0.060	13.38	16.46	20.72	.11	.08	.04
3	4	17.710	21.824	30.350	0.082	0.054	0.040	22.57	26.01	40.42	.05	.04	.02
3	5	13.301	16.577	18.750	0.096	0.066	0.050	22.55	26.11	39.83	.06	.04	.02
3	6	14.079	18.175	20.510	0.112	0.075	0.060	10.35	12.05	10.11	.07	.05	.04
3	7	30.007	33.112	35.960	0.038	0.026	0.020	13.29	16.40	16.30	.10	.07	.05
3	8	18.856	22.368	14.110	0.071	0.048	0.040	13.50	16.11	18.99	.08	.05	.04
3	9	26.295	30.370	49.980	0.043	0.029	0.020	17.65	20.56	18.99	.08	.05	.03
3	10	13.343	16.860	14.460	0.098	0.065	0.060	13.82	16.27	15.64	.07	.05	.04
4	1	22.685	26.543	36.000	0.077	0.050	0.040	16.08	19.31	18.51	.08	.05	.04
4	2	12.561	16.492	13.430	0.109	0.070	0.060	12.62	14.50	10.33	.05	.04	.04
4	3	12.918	16.395	14.470	0.090	0.057	0.050	8.47	11.17	9.72	.13	.09	.08
4	4	13.097	17.053	20.800	0.115	0.073	0.060	8.73	11.03	6.69	.12	.08	.08
4	5	22.392	25.390	19.970	0.064	0.044	0.040	15.59	20.22	35.18	.11	.07	.05
4	6	9.492	12.568	7.490	0.142	0.098	0.080	10.20	13.54	15.89	.12	.08	.07
4	7	14.768	18.120	15.330	0.096	0.065	0.050	9.56	12.56	14.08	.13	.09	.07
4	8	21.387	27.287	56.230	0.095	0.060	0.040	13.46	16.20	18.97	.08	.05	.04
4	9	13.487	17.355	19.370	0.104	0.067	0.050	11.52	13.02	10.90	.05	.04	.04
4	10	33.815	10.810	15.230	0.073	0.050	0.070	13.90	15.43	11.25	.04	.03	.03
5	1	8.174	9.945	4.750	0.114	0.084	0.090	9.00	10.58	6.65	.08	.05	.06
5	2	11.346	13.877	8.350	0.094	0.064	0.070	11.68	13.82	12.34	.08	.06	.05
5	3	10.890	13.166	6.650	0.095	0.066	0.070	21.17	23.59	23.26	.03	.02	.02
5	4	9.388	12.175	7.940	0.104	0.070	0.070	11.32	14.00	12.29	.09	.06	.05
5	5	11.778	14.484	8.570	0.107	0.072	0.070	10.17	12.17	8.55	.10	.07	.06
5	6	11.977	15.105	13.140	0.101	0.067	0.060	12.81	16.30	15.91	.11	.07	.05
5	7	11.015	13.405	8.530	0.088	0.060	0.060	11.00	12.56	7.63	.06	.04	.05
5	8	13.958	16.019	8.160	0.074	0.049	0.050	10.36	12.10	7.29	.08	.05	.06
5	9	7.127	9.015	4.330	0.144	0.101	0.100	7.23	8.72	5.37	.12	.08	.08
5	10	11.704	14.314	7.550	0.122	0.086	0.070	9.38	11.58	10.11	.11	.08	.06

Appendix E. Results of 1984 Sultan River sediment analyses for individual strata of each sample.

A[1]	B[2]	C[3]	DGW	DGD	DGLS	PFW	PFD	PFLS
1	1	1	31.991	34.586	70.910	0.017	0.011	0.010
1	1	2	12.005	14.223	14.840	0.063	0.043	0.040
1	1	3	9.642	11.621	11.910	0.078	0.053	0.050
1	1	4	11.583	14.155	15.500	0.077	0.054	0.050
1	2	1	32.415	34.010	64.480	0.007	0.005	0.010
1	2	2	17.465	19.870	24.240	0.026	0.018	0.020
1	2	3	27.444	31.839	63.020	0.036	0.023	0.020
1	2	4	7.339	8.872	4.940	0.089	0.063	0.080
1	3	1	30.131	32.624	59.570	0.016	0.011	0.010
1	3	2	15.842	18.349	21.290	0.039	0.026	0.030
1	3	3	11.178	13.547	15.190	0.073	0.051	0.050
1	3	4	9.614	11.298	10.850	0.057	0.039	0.050
1	4	1	53.692	56.297	395.030	0.007	0.004	0.010
1	4	2	17.471	20.001	24.030	0.034	0.022	0.030
1	4	3	16.757	20.092	25.890	0.052	0.036	0.030
1	4	4	15.620	18.883	24.150	0.058	0.040	0.040
1	5	1	15.484	17.181	8.710	0.027	0.017	0.040
1	5	2	9.550	11.305	11.220	0.061	0.042	0.050
1	5	3	12.615	15.310	17.730	0.074	0.052	0.040
1	5	4	10.919	12.957	6.610	0.068	0.048	0.060
1	6	1	33.113	35.844	67.680	0.016	0.011	0.010
1	6	2	15.141	17.975	21.820	0.046	0.031	0.030
1	6	3	21.269	25.504	40.000	0.047	0.031	0.030
1	6	4	15.798	18.612	22.050	0.049	0.033	0.030
1	7	1	22.443	25.355	35.440	0.028	0.019	0.020
1	7	2	19.698	23.358	33.780	0.042	0.028	0.030
1	7	3	16.507	19.552	24.630	0.045	0.030	0.030
1	7	4	16.489	19.560	24.150	0.049	0.032	0.040
1	8	1	26.086	29.267	45.430	0.028	0.019	0.020
1	8	2	16.061	19.234	24.060	0.051	0.034	0.040
1	8	3	8.440	10.105	5.390	0.075	0.051	0.070
1	8	4	8.217	9.878	5.370	0.067	0.045	0.070
1	9	1	30.071	32.842	62.960	0.015	0.009	0.010
1	9	2	9.654	10.926	5.960	0.044	0.031	0.050
1	9	3	14.204	16.414	17.370	0.039	0.026	0.030
1	9	4	17.160	19.845	24.160	0.033	0.022	0.030
1	10	1	18.522	20.603	24.990	0.020	0.012	0.020
1	10	2	12.156	14.144	14.440	0.046	0.031	0.040
1	10	3	11.819	13.735	12.990	0.045	0.029	0.040
1	10	4	9.912	12.036	12.130	0.086	0.059	0.050
2	1	1	17.271	20.106	24.080	0.055	0.034	0.040
2	1	2	8.113	10.992	10.860	0.168	0.114	0.080
2	1	3	7.016	9.872	10.270	0.185	0.125	0.090
2	1	4	3.259	4.277	2.890	0.251	0.188	0.160
2	2	1	19.808	22.140	27.300	0.036	0.023	0.030
2	2	2	7.936	9.250	5.080	0.080	0.057	0.070
2	2	3	11.029	13.926	14.770	0.121	0.085	0.060
2	2	4	20.803	25.354	40.790	0.086	0.058	0.030
2	3	1	25.457	28.541	48.330	0.027	0.017	0.020
2	3	2	13.963	16.288	16.200	0.062	0.042	0.040

[1] Station Number

[2] Sample Number

[3] Stratum Number

A[1]	B[2]	C[3]	DGW	DGD	DGLS	PFW	PFD	PFLS
2	3	3	6.442	8.358	4.570	0.173	0.124	0.100
2	3	4	23.755	29.721	65.440	0.092	0.060	0.030
2	4	1	13.553	15.118	7.630	0.041	0.027	0.040
2	4	2	15.506	19.228	24.840	0.087	0.060	0.040
2	4	3	17.507	21.671	30.470	0.100	0.070	0.040
2	4	4	9.364	12.341	13.780	0.143	0.100	0.070
2	5	1	19.016	20.734	25.470	0.027	0.017	0.020
2	5	2	19.721	23.786	35.540	0.069	0.046	0.030
2	5	3	8.485	10.789	10.590	0.136	0.097	0.070
2	5	4	13.662	17.754	22.970	0.113	0.076	0.050
2	6	1	28.677	31.954	63.300	0.031	0.019	0.020
2	6	2	10.683	13.701	15.350	0.118	0.081	0.060
2	6	3	19.296	24.486	40.400	0.105	0.071	0.040
2	6	4	15.665	20.324	29.400	0.118	0.080	0.050
2	7	1	18.358	19.569	10.490	0.021	0.014	0.020
2	7	2	15.389	19.593	27.080	0.095	0.063	0.050
2	7	3	14.692	19.163	26.340	0.120	0.081	0.050
2	7	4	18.872	23.307	34.990	0.083	0.055	0.040
2	8	1	16.843	18.991	21.550	0.044	0.029	0.030
2	8	2	18.870	23.702	37.230	0.094	0.063	0.040
2	8	3	16.115	20.612	29.560	0.102	0.068	0.050
2	8	4	18.141	23.140	36.790	0.094	0.062	0.040
2	9	1	21.527	25.164	38.370	0.052	0.034	0.030
2	9	2	10.103	13.065	14.610	0.129	0.090	0.060
2	9	3	20.063	25.159	42.590	0.093	0.062	0.040
2	9	4	17.137	22.229	35.320	0.107	0.071	0.050
2	10	1	25.860	27.929	44.970	0.025	0.016	0.020
2	10	2	16.397	20.318	28.000	0.078	0.052	0.040
2	10	3	13.324	17.655	22.810	0.120	0.077	0.060
2	10	4	16.329	21.263	32.380	0.109	0.071	0.050
3	1	1	53.685	57.325	507.850	0.016	0.010	0.010
3	1	2	23.393	28.498	54.060	0.071	0.046	0.030
3	1	3	7.690	10.922	11.640	0.185	0.126	0.090
3	1	4	6.762	9.413	8.570	0.168	0.112	0.090
3	2	1	23.599	27.248	42.250	0.058	0.039	0.030
3	2	2	10.700	14.894	19.280	0.163	0.112	0.070
3	2	3	18.826	25.376	52.160	0.123	0.082	0.050
3	2	4	12.844	18.009	27.050	0.156	0.106	0.060
3	3	1	16.016	19.617	23.920	0.090	0.061	0.040
3	3	2	5.274	6.883	4.020	0.177	0.128	0.110
3	3	3	14.861	20.391	32.940	0.142	0.095	0.060
3	3	4	16.779	23.207	44.480	0.139	0.091	0.050
3	4	1	17.730	20.694	25.320	0.058	0.037	0.030
3	4	2	14.990	18.229	22.560	0.076	0.051	0.040
3	4	3	18.295	22.753	34.210	0.087	0.059	0.040
3	4	4	19.827	25.621	48.100	0.106	0.070	0.040
3	5	1	17.684	20.999	26.290	0.068	0.046	0.030
3	5	2	9.036	11.474	11.820	0.116	0.082	0.060
3	5	3	10.545	13.423	14.970	0.108	0.074	0.060
3	5	4	15.941	20.414	29.200	0.094	0.062	0.050
3	6	1	11.988	14.444	15.020	0.079	0.055	0.050
3	6	2	7.733	10.067	10.520	0.136	0.096	0.070
3	6	3	9.409	13.494	17.170	0.148	0.095	0.080
3	6	4	27.186	34.697	119.760	0.086	0.053	0.030
3	7	1	47.345	50.255	203.080	0.014	0.009	0.010
3	7	2	40.292	44.150	136.980	0.020	0.013	0.010
3	7	3	9.366	10.863	5.880	0.065	0.047	0.060
3	7	4	23.025	27.181	44.610	0.054	0.035	0.030
3	8	1	33.872	37.921	79.870	0.026	0.018	0.010
3	8	2	9.208	11.035	5.740	0.078	0.053	0.070

A[1]	B[2]	C[3]	DGW	DGD	DGLS	PFW	PFD	PFLS
3	8	3	6.755	8.462	4.650	0.108	0.073	0.090
3	8	4	25.588	32.056	83.870	0.074	0.047	0.030
3	9	1	25.393	28.126	37.520	0.033	0.023	0.010
3	9	2	20.014	22.985	29.260	0.044	0.031	0.020
3	9	3	30.592	35.733	85.640	0.045	0.030	0.020
3	9	4	29.182	34.637	86.970	0.052	0.033	0.030
3	10	1	10.418	12.387	6.330	0.074	0.052	0.060
3	10	2	11.263	14.060	16.020	0.088	0.061	0.050
3	10	3	23.283	29.141	63.210	0.076	0.048	0.040
3	10	4	8.409	11.853	13.630	0.154	0.100	0.080
4	1	1	46.756	50.819	277.580	0.020	0.013	0.010
4	1	2	24.877	30.024	60.360	0.059	0.038	0.030
4	1	3	9.614	12.302	12.860	0.103	0.070	0.060
4	1	4	9.492	13.027	14.450	0.125	0.078	0.070
4	2	1	14.725	17.560	18.760	0.065	0.042	0.040
4	2	2	5.152	6.801	3.900	0.152	0.104	0.120
4	2	3	19.240	26.312	61.170	0.102	0.061	0.050
4	2	4	11.125	15.296	19.170	0.118	0.072	0.070
4	3	1	15.668	17.425	17.470	0.041	0.029	0.030
4	3	2	12.215	15.004	17.220	0.070	0.047	0.050
4	3	3	15.138	21.180	37.610	0.117	0.071	0.060
4	3	4	8.652	11.973	5.850	0.134	0.082	0.090
4	4	1	18.503	22.060	30.180	0.056	0.036	0.030
4	4	2	16.077	21.105	32.860	0.101	0.065	0.050
4	4	3	8.200	11.582	12.440	0.161	0.104	0.080
4	4	4	9.607	13.464	15.930	0.141	0.088	0.080
4	5	1	48.426	51.609	243.150	0.014	0.009	0.010
4	5	2	4.432	5.303	3.450	0.107	0.077	0.110
4	5	3	14.738	17.823	21.620	0.061	0.041	0.040
4	5	4	21.973	26.824	47.770	0.073	0.048	0.030
4	6	1	14.663	19.106	25.950	0.111	0.072	0.050
4	6	2	3.631	4.624	3.150	0.195	0.146	0.140
4	6	3	5.429	6.808	4.010	0.139	0.098	0.110
4	6	4	14.244	19.736	30.940	0.123	0.075	0.060
4	7	1	17.039	19.122	9.350	0.042	0.028	0.030
4	7	2	10.710	13.744	15.270	0.115	0.078	0.060
4	7	3	6.900	9.258	9.850	0.151	0.104	0.080
4	7	4	24.422	30.357	69.400	0.078	0.049	0.030
4	8	1	29.413	34.002	77.570	0.047	0.030	0.020
4	8	2	21.263	27.414	56.810	0.100	0.066	0.040
4	8	3	21.120	28.007	66.550	0.103	0.065	0.040
4	8	4	13.753	19.726	33.710	0.130	0.079	0.060
4	9	1	11.482	13.946	13.100	0.082	0.055	0.050
4	9	2	9.891	12.955	15.100	0.116	0.079	0.060
4	9	3	21.626	27.266	53.270	0.083	0.054	0.040
4	9	4	10.951	15.254	16.810	0.134	0.081	0.070
4	10	1	24.075	27.294	79.230	0.053	0.035	0.030
4	10	2	12.004	14.342	6.990	0.077	0.052	0.060
4	10	3	18.556	23.184	35.460	0.081	0.054	0.040
4	10	4	4.700	5.715	3.390	0.134	0.096	0.120
5	1	1	2.893	3.492	2.690	0.169	0.128	0.150
5	1	2	4.537	5.371	3.620	0.089	0.064	0.100
5	1	3	3.901	4.711	3.290	0.135	0.100	0.120
5	1	4	21.366	26.205	44.530	0.064	0.043	0.030
5	2	1	4.975	5.971	3.740	0.116	0.084	0.100
5	2	2	21.655	26.025	42.730	0.054	0.035	0.030
5	2	3	6.755	8.383	4.560	0.114	0.077	0.090
5	2	4	11.998	15.131	16.890	0.093	0.059	0.060
5	3	1	9.826	11.068	6.040	0.050	0.035	0.050
5	3	2	4.715	5.683	3.460	0.132	0.095	0.110

A^1	B^2	C^3	DGW	DGD	DGLS	PFW	PFD	PFLS
5	3	3	6.849	8.674	4.760	0.132	0.094	0.090
5	3	4	22.171	27.238	51.060	0.067	0.042	0.030
5	4	1	7.080	8.418	4.750	0.100	0.071	0.080
5	4	2	5.583	6.488	4.090	0.082	0.059	0.090
5	4	3	11.120	14.782	18.240	0.112	0.073	0.060
5	4	4	13.769	19.011	29.980	0.122	0.079	0.060
5	5	1	17.682	21.165	28.320	0.067	0.043	0.040
5	5	2	18.935	23.326	35.020	0.071	0.047	0.040
5	5	3	4.185	5.403	3.410	0.164	0.116	0.130
5	5	4	6.308	8.041	4.340	0.126	0.083	0.100
5	6	1	13.626	16.315	18.700	0.063	0.043	0.040
5	6	2	17.506	21.527	30.410	0.070	0.046	0.040
5	6	3	9.405	12.680	14.890	0.127	0.084	0.070
5	6	4	7.372	9.899	5.100	0.144	0.097	0.100
5	7	1	9.705	11.464	5.930	0.074	0.050	0.060
5	7	2	7.407	9.130	9.420	0.098	0.069	0.070
5	7	3	20.435	24.877	39.750	0.062	0.041	0.030
5	7	4	6.514	8.150	4.530	0.118	0.081	0.100
5	8	1	30.607	33.450	65.740	0.023	0.015	0.010
5	8	2	11.018	13.402	6.560	0.087	0.056	0.070
5	8	3	7.765	9.312	5.010	0.085	0.057	0.080
5	8	4	6.441	7.911	4.370	0.103	0.068	0.100
5	9	1	14.796	18.408	22.720	0.092	0.061	0.040
5	9	2	6.354	8.204	4.500	0.131	0.089	0.100
5	9	3	3.785	4.715	3.110	0.156	0.112	0.140
5	9	4	3.574	4.735	3.120	0.199	0.143	0.150
5	10	1	16.754	20.896	28.540	0.089	0.060	0.040
5	10	2	2.664	3.313	2.490	0.208	0.157	0.170
5	10	3	21.870	26.055	41.940	0.054	0.036	0.030
5	10	4	5.529	6.991	3.920	0.137	0.093	0.110

Appendix F. Results of 1984 Sultan River sediment analyses. Lower three strata only combined for each sample.

Sta	#	DGW	DGD	DGLS	PFW	PFD	PFLS
1	1	11.078	13.333	20.010	0.073	0.050	0.040
1	2	17.416	20.194	21.500	0.050	0.035	0.030
1	3	12.211	14.398	20.470	0.056	0.039	0.030
1	4	16.616	19.659	43.050	0.048	0.033	0.020
1	5	11.028	13.191	9.900	0.068	0.047	0.050
1	6	17.403	20.697	33.270	0.047	0.032	0.020
1	7	17.565	20.823	29.000	0.045	0.030	0.030
1	8	10.906	13.072	11.200	0.064	0.043	0.040
1	9	13.673	15.728	17.010	0.039	0.026	0.030
1	10	11.296	13.305	15.380	0.059	0.040	0.040
2	1	6.129	8.380	8.220	0.201	0.142	0.080
2	2	13.256	16.177	14.380	0.096	0.067	0.040
2	3	14.720	18.122	17.490	0.109	0.075	0.040
2	4	14.126	17.747	15.210	0.110	0.077	0.050
2	5	13.956	17.443	21.060	0.106	0.073	0.040
2	6	15.215	19.504	31.980	0.114	0.077	0.040
2	7	16.318	20.688	20.340	0.099	0.066	0.040
2	8	17.709	22.485	29.890	0.097	0.064	0.040
2	9	15.768	20.151	29.460	0.110	0.074	0.040
2	10	15.350	19.745	31.380	0.102	0.067	0.040
3	1	12.615	16.278	32.090	0.141	0.095	0.040
3	2	14.123	19.426	32.380	0.147	0.100	0.050
3	3	12.305	16.827	15.090	0 153	0.105	0.060
3	4	17.704	22.201	30.350	0.090	0.060	0.040
3	5	11.841	15.104	18.750	0.106	0.073	0.050
3	6	14.776	19.419	20.510	0.123	0.081	0.060
3	7	24.228	27.398	35.960	0.046	0.032	0.020
3	8	13.850	17.184	14.110	0.087	0.058	0.040
3	9	26.596	31.118	49.980	0.047	0.031	0.020
3	10	14.318	18.351	14.460	0.106	0.070	0.060
4	1	14.661	18.451	36.000	0.096	0.062	0.040
4	2	11.839	16.136	13.430	0.124	0.079	0.060
4	3	12.002	16.052	14.470	0.107	0.067	0.050
4	4	11.295	15.384	20.800	0.134	0.086	0.060
4	5	13.714	16.650	19.970	0.080	0.055	0.040
4	6	7.768	10.389	7.490	0.152	0.106	0.080
4	7	14.011	17.786	15.330	0.115	0.077	0.050
4	8	18.712	25.049	56.230	0.111	0.070	0.040
4	9	14.156	18.492	19.370	0.111	0.071	0.050
4	10	11.753	14.414	15.280	0.097	0.067	0.070
5	1	9.935	12.096	4.750	0.096	0.069	0.090
5	2	13.469	16.513	8.350	0.087	0.057	0.070
5	3	11.245	13.865	6.650	0.110	0.077	0.070
5	4	10.157	13.427	7.940	0.105	0.070	0.070
5	5	9.809	12.257	8.670	0.120	0.082	0.070
5	6	11.428	14.702	13.140	0.114	0.076	0.060
5	7	11.452	14.052	8.580	0.093	0.064	0.060
5	8	8.408	10.208	8.160	0.092	0.060	0.050
5	9	4.571	5.885	4.880	0.162	0.115	0.100
5	10	10.021	12.120	7.550	0.133	0.095	0.070