APPENDIX C

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

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HENRY M. JACKSON HYDROELECTRIC PROJECT
FERC PROJECT 2157

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

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SUMMARY

The Henry M. Jackson (Sultan River) Hydroelectric Project, Snohomish County, Washington, has significantly altered the flow regime in 16 miles of river downstream from Culmback 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 construction and operation since various anadromous fish species/life stages use the 9.7-mile river reach below the Everett diversion dam. In order to evaluate pre-construction conditions, a baseline study of spawning gravel texture was initiated by the Public Utility District No. 1 of Snohomish County in the spring of 1982. In order to determine effects of project construction on sediment texture, gravel samples were collected and evaluated during February - April 1984 following termination of construction activities. In September 1987, three years following operation start up additional gravel samples were collected and analyzed. Evaluation of 1987 results in comparison to those of 1982 and 1984 is the subject of this report.

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.

Streambed sediments were removed from five salmonid spawning reaches using a tri-tube freeze-core sampler. Sampling purposely avoided spawning redds to the extent that redds were apparent to the observer. A total of 25, 12-inch deep core samples were collected. Each core was subdivided into four, three-inch strata, yielding a total of 100 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 at spawning reaches following project construction (1987) was generally similar to that evaluated for the same sites prior to and immediately following construction (1982 and 1984, respectively).

Gravels at stations located farthest upstream were significantly coarser in samples collected following construction (1984 and 1987) than prior to construction. The average proportion of fine sediment less than 0.841 mm in diameter for all stations ranged between 4.2% and 10.8% in 1987.

Sediment stratification was apparent during all three years of study. The combined mean values of the upper three inches of substrate contained a significantly lower percentage of fines and a greater geometric mean particle size than did the underlying nine 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 the substrate indices examined in this study, the need for mitigative measures for maintaining the quality of salmonid spawning gravels is not indicated.

It must be recognized that further monitoring of substrate quality in and of itself will provide only a general indication of salmonid fry survival and not a quantitative relationship.

1.0 INTRODUCTION

1.1 AUTHORIZATION

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

1.2 PROJECT BACKGROUND

Hydroelectric development on the Sultan River requires diversion of water from Culmback Dam (RM 16.5) to a powerhouse (RM 4.5) having a total installed capacity of 112 mw (Figure 1). Water is returned to the river at the powerhouse, if operating, or at the City of Everett diversion dam (RM 9.7), regardless of powerhouse operation. Water returned upstream to the diversion dam provides controlled flows downstream to the powerhouse at all times, assuring 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 factors have combined to provide streambed sediments (gravels) which are presently used by spawning anadromous fishes upstream to the Everett diversion dam (RM 9.7). Salmonid species are chinook, coho, pink and chum salmon, steelhead and sea-run cutthroat trout.

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 (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.

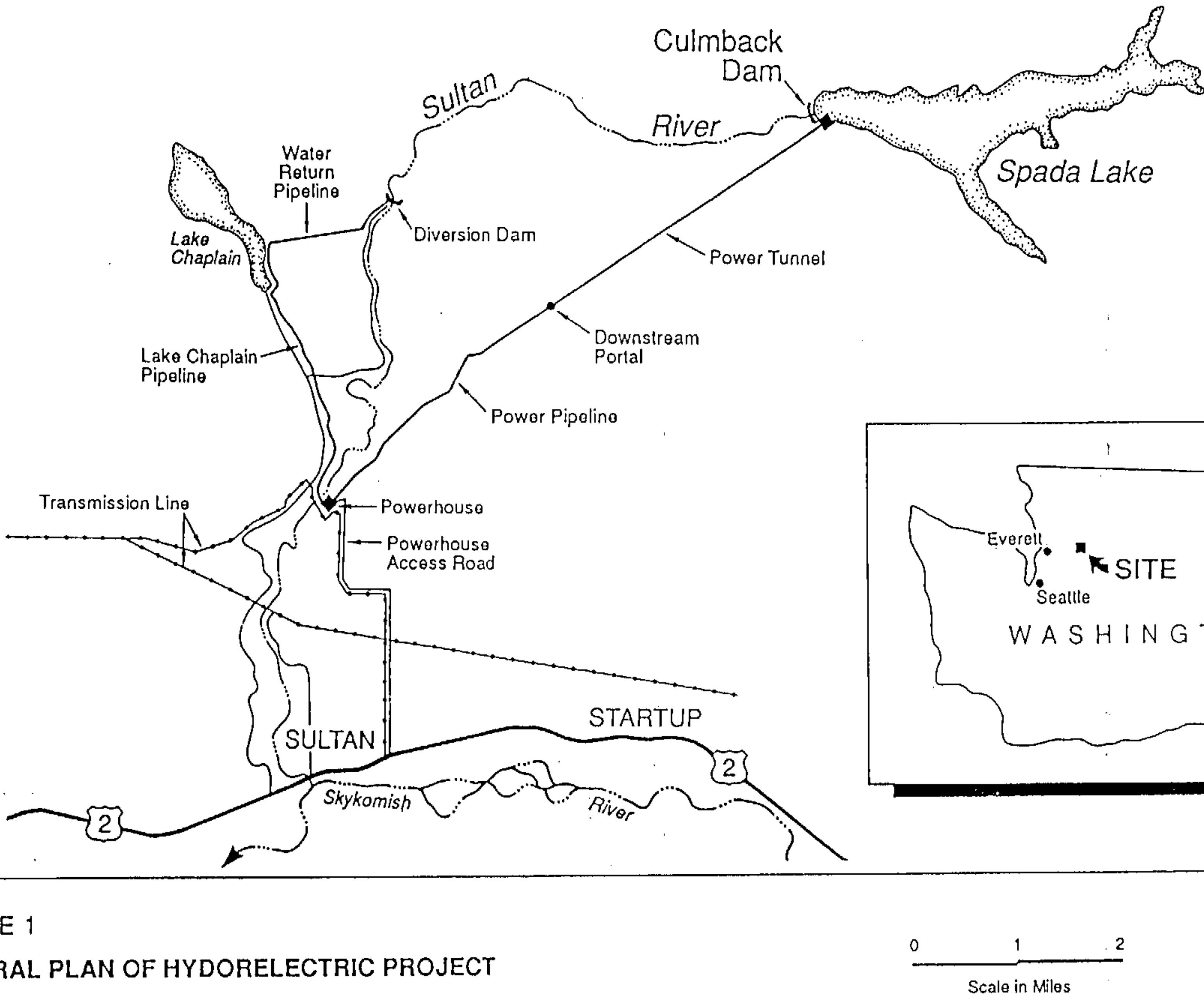


FIGURE 1

GENERAL PLAN OF HYDROELECTRIC PROJECT

SULTAN RIVER SPAWNING GRAVEL EVALUATION

SHAPIRO & ASSOCIATES

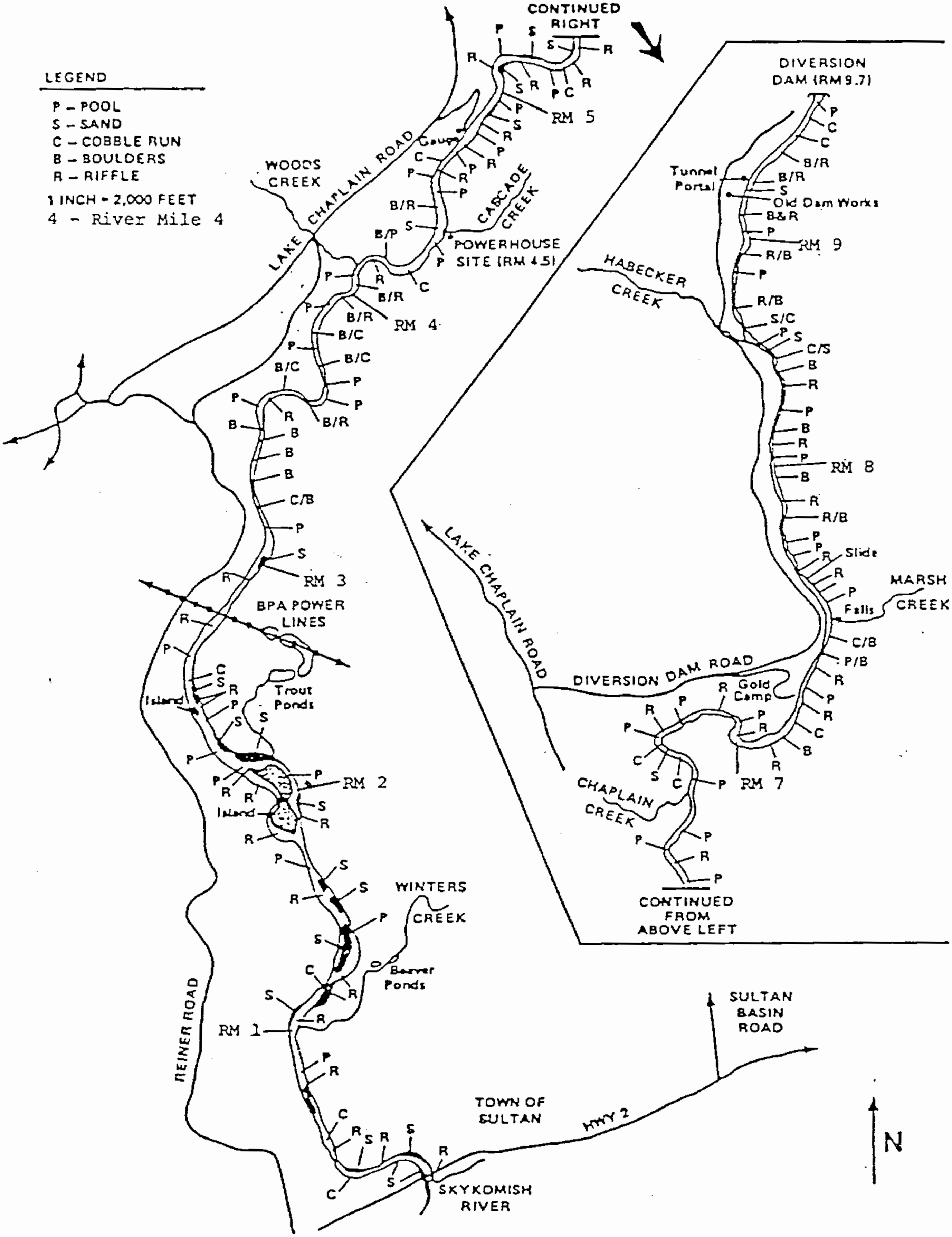
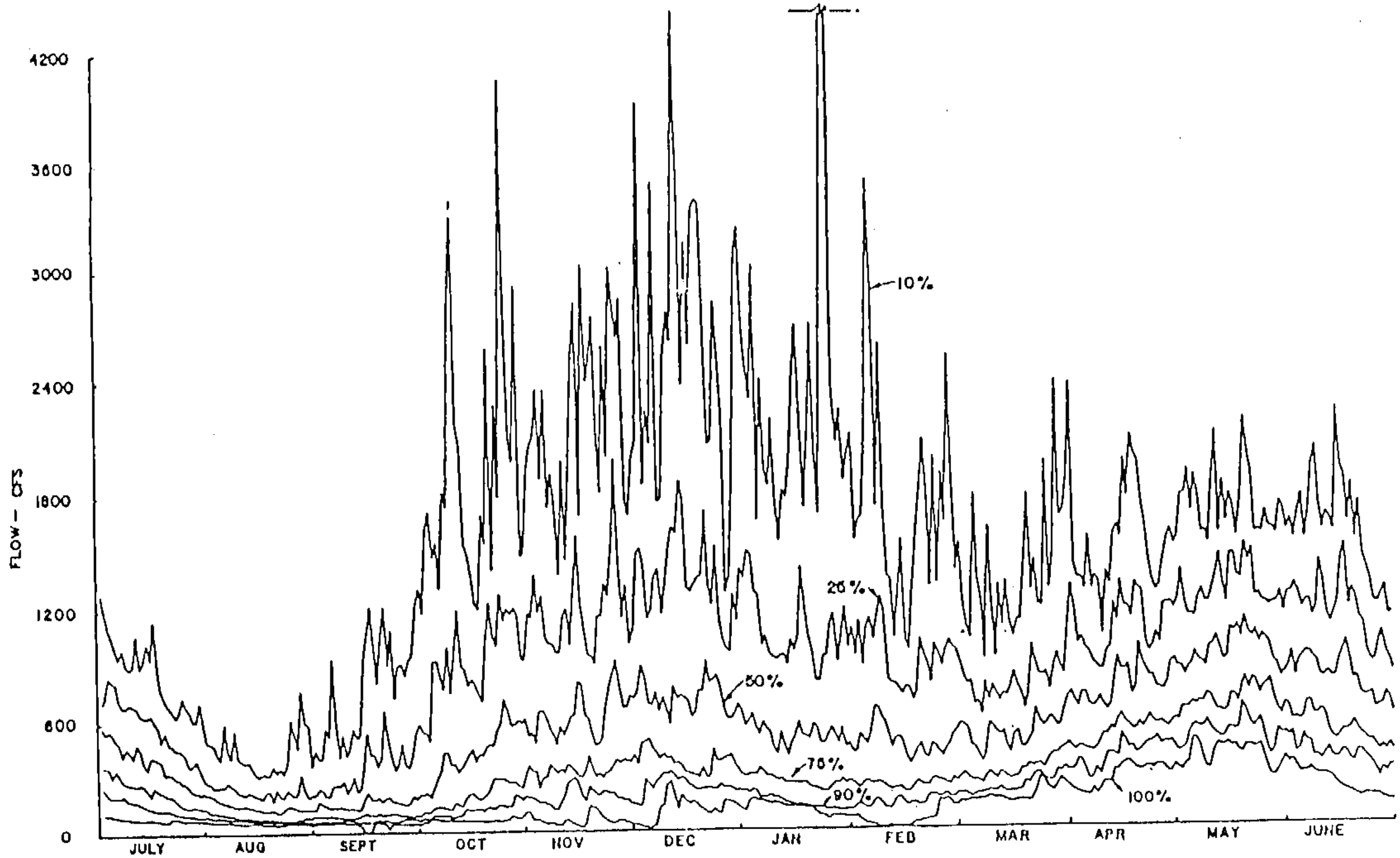


Figure 2. SULTAN RIVER HABITAT MAP. BETWEEN DIVERSION DAM AND RIVER MOUTH



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

1.4 PROJECT EFFECTS

Hydroelectric development has altered the flow regime of the Sultan River, causing increased minimum flows during low flow periods and reduced frequency and magnitude of low to moderate flood flows below Culmback Dam to the river mouth. Between the diversion dam (RM 9.7) and powerhouse (RM 4.5), flows are regulated continuously at levels determined to provide optimum or adequate conditions for salmonid life stages. Except during extreme high floods when spills occur at Culmback Dam, winter and spring freshets no longer exist in this river section (PUD, 1982). While elimination of freshets would appear to offer improved flow conditions by providing water depths and velocities more favorable to fish life, these freshets can also play an important 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 potential sediment accumulation between the diversion dam and powerhouse 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 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 licensee and the Joint Agencies: Washington Department of Fisheries (WDF), Washington Department of Wildlife (WDW), National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and the Tulalip Indian Tribes. Item 3 of that agreement requires that a determination be made of "short-term and long-term impacts of sedimentation, gravel compaction and spawning gravel reduction in the Sultan River due to construction and operation of the project." A three-phase evaluation of the textural composition of streambed sediments (1) prior to project construction, (2) following completion of construction, but prior to project operation, and (3) three years following initial project operation has been conducted to determine whether or not spawning gravel quality has changed as a result of project construction and/or operation.

The subject of this report is an evaluation of the textural composition of Sultan streambed gravels following three years of project operation. Results of this study are herein compared to gravel texture prior to and immediately following construction. 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.

2.0 METHODS

2.1 SAMPLE COLLECTION

Sampling of the stream bed was conducted in September of 1987, unlike previous sampling which occurred in winter of 1982 and 1984. This change was requested by the Washington Department of Fisheries. Sampling in 1987 took place in mid-September at the beginning of the spawning period for salmon, and following an extensive period of minimum flow (approximately 200 cfs). Thus, it should represent the time of year when the highest percentage of fine sediment is present, i.e., the "worst case" conditions. Sampling in previous years (1982 and 1984) was conducted in the winter when eggs of anadramous fish are incubating in the gravel.

As in other years, substrate samples used to evaluate the quality of spawning gravels were collected 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. Salmon or steelhead have been observed at all study sites during spawning surveys conducted by WDF and WDW since 1978.

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).
- 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).

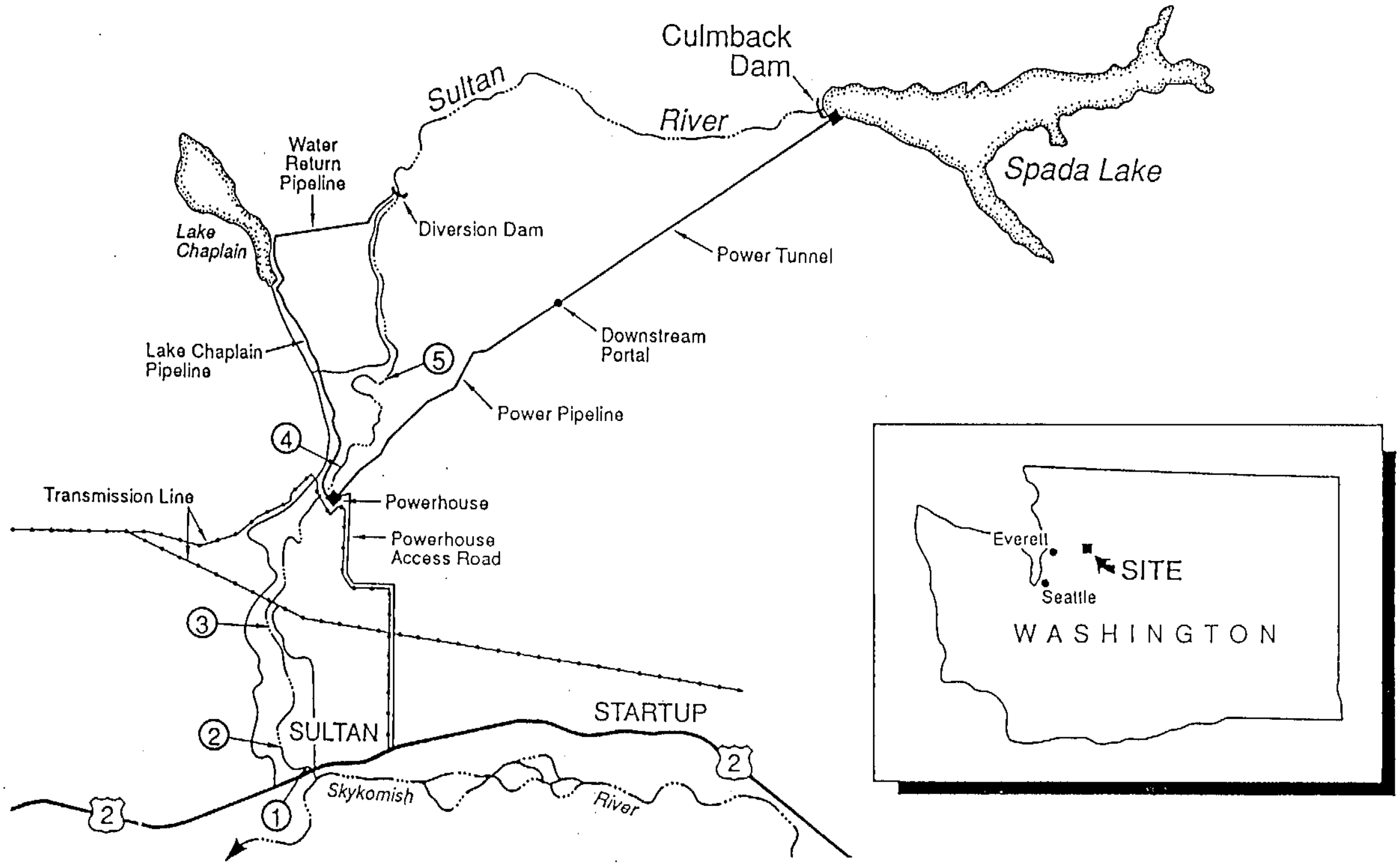


FIGURE 4

SULTAN RIVER GRAVEL SAMPLING STATIONS

LEGEND

(5) GRAVEL SAMPLING STATION

0 1 2

Scale in Miles

SULTAN RIVER SPAWNING GRAVEL EVALUATION

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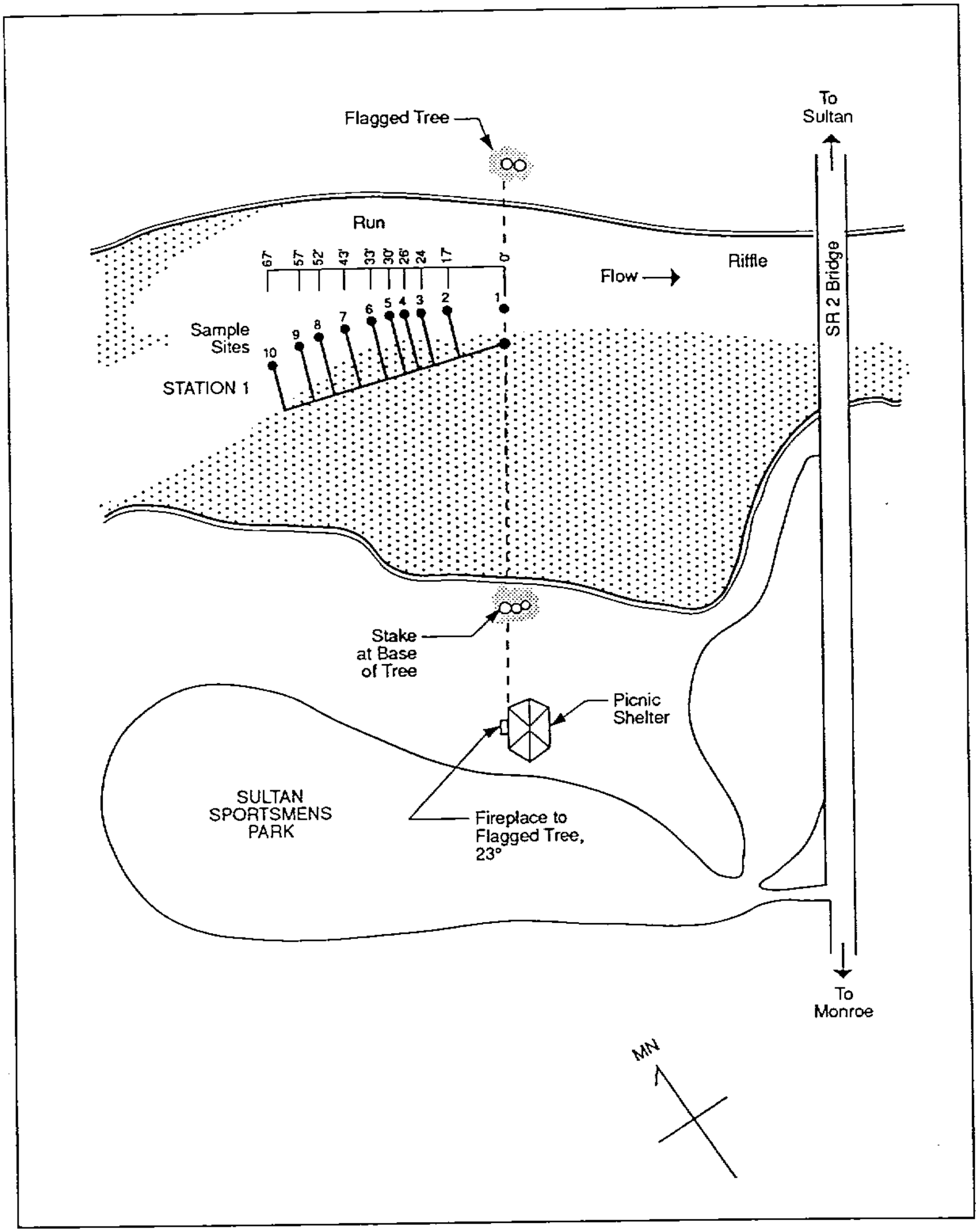

FIGURE 5

GRAVEL SAMPLING STATION S1

No Scale

SULTAN RIVER SPAWNING GRAVEL EVALUATION

SHAPIRO & ASSOCIATES INC

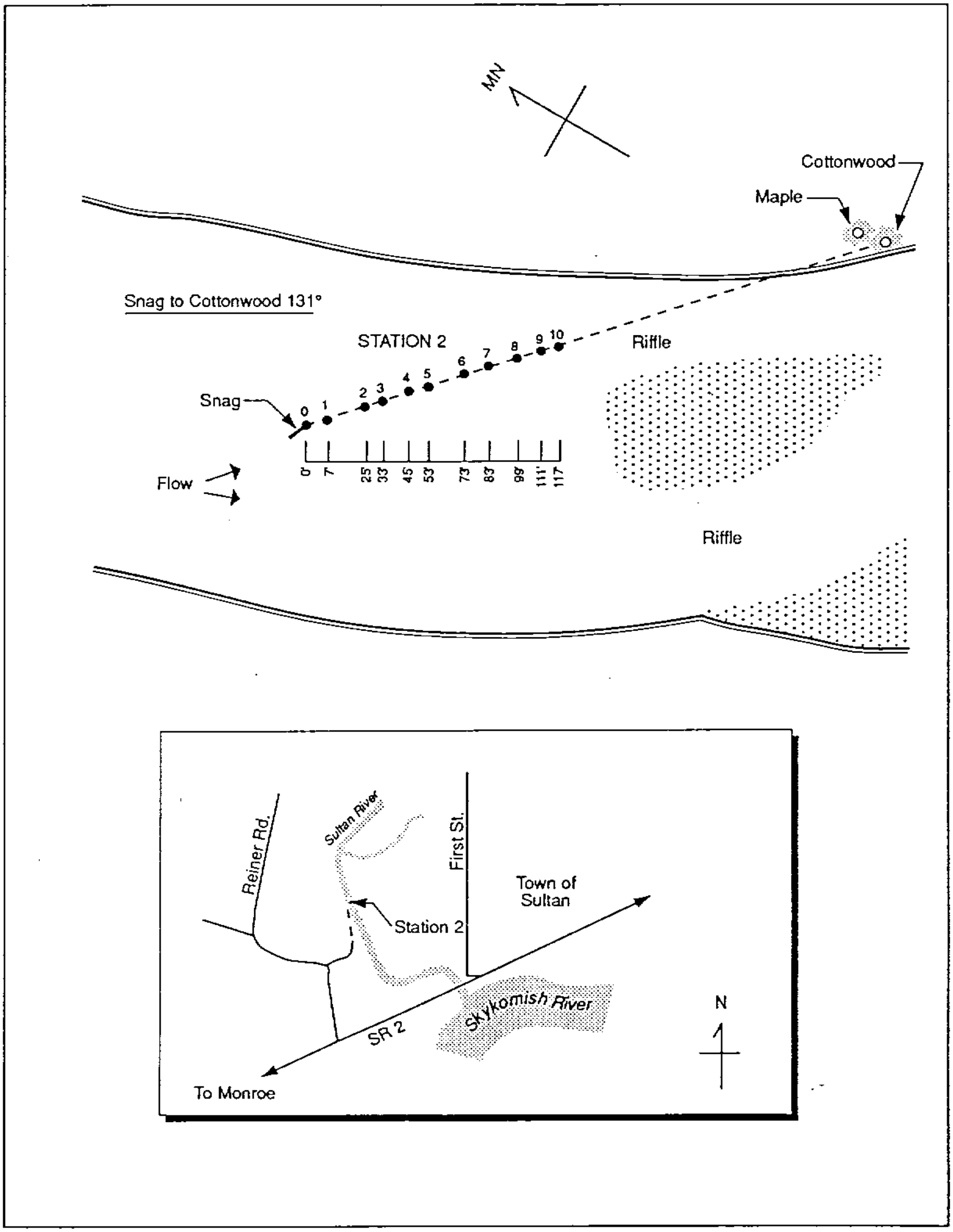

FIGURE 6

GRAVEL SAMPLING STATION S2

No Scale

SULTAN RIVER SPAWNING GRAVEL EVALUATION

SHAPIRO & ASSOCIATES INC

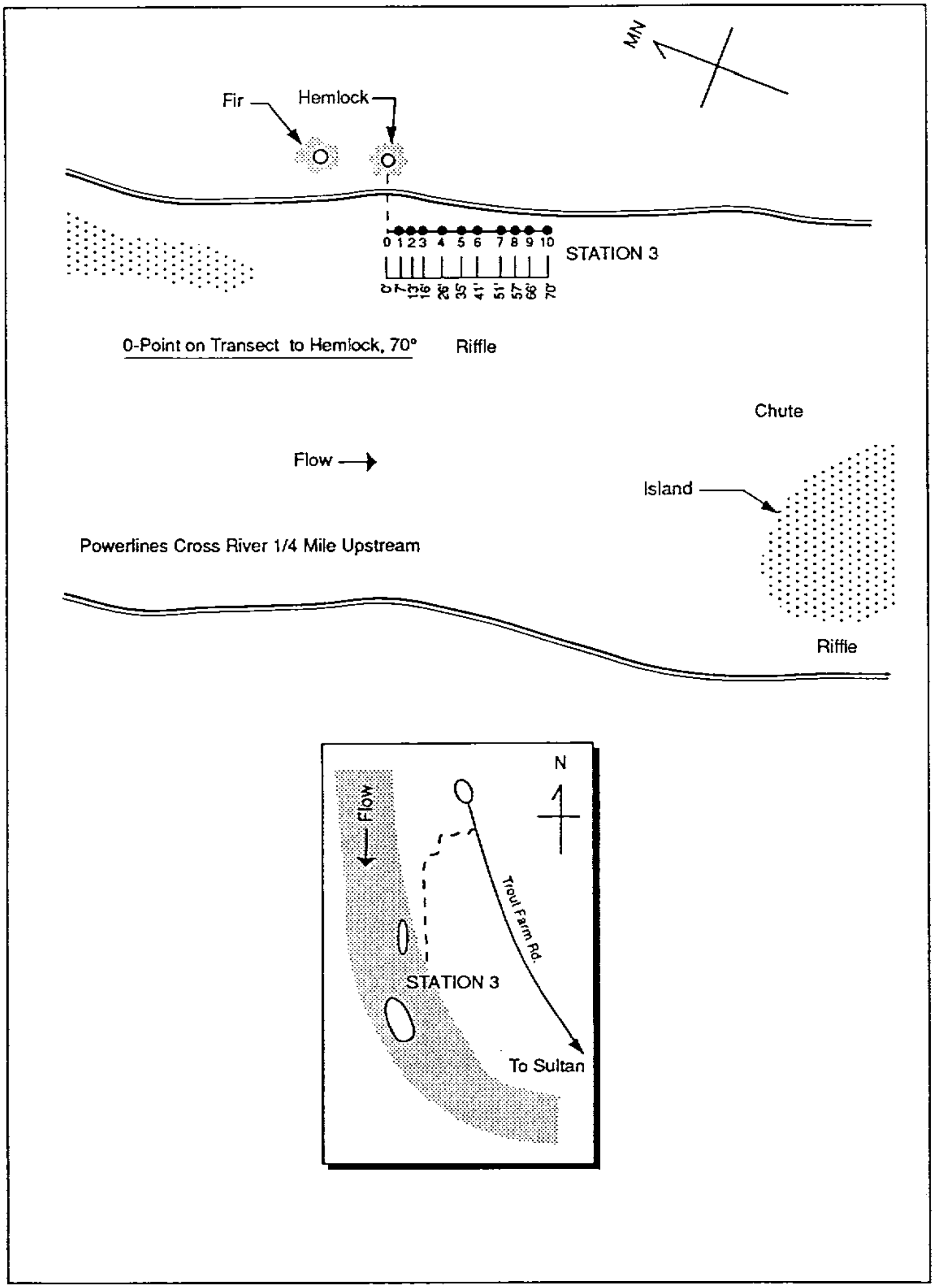

FIGURE 7

GRAVEL SAMPLING STATION S3

No Scale

SULTAN RIVER SPAWNING GRAVEL EVALUATION

SHAPIRO & ASSOCIATES INC

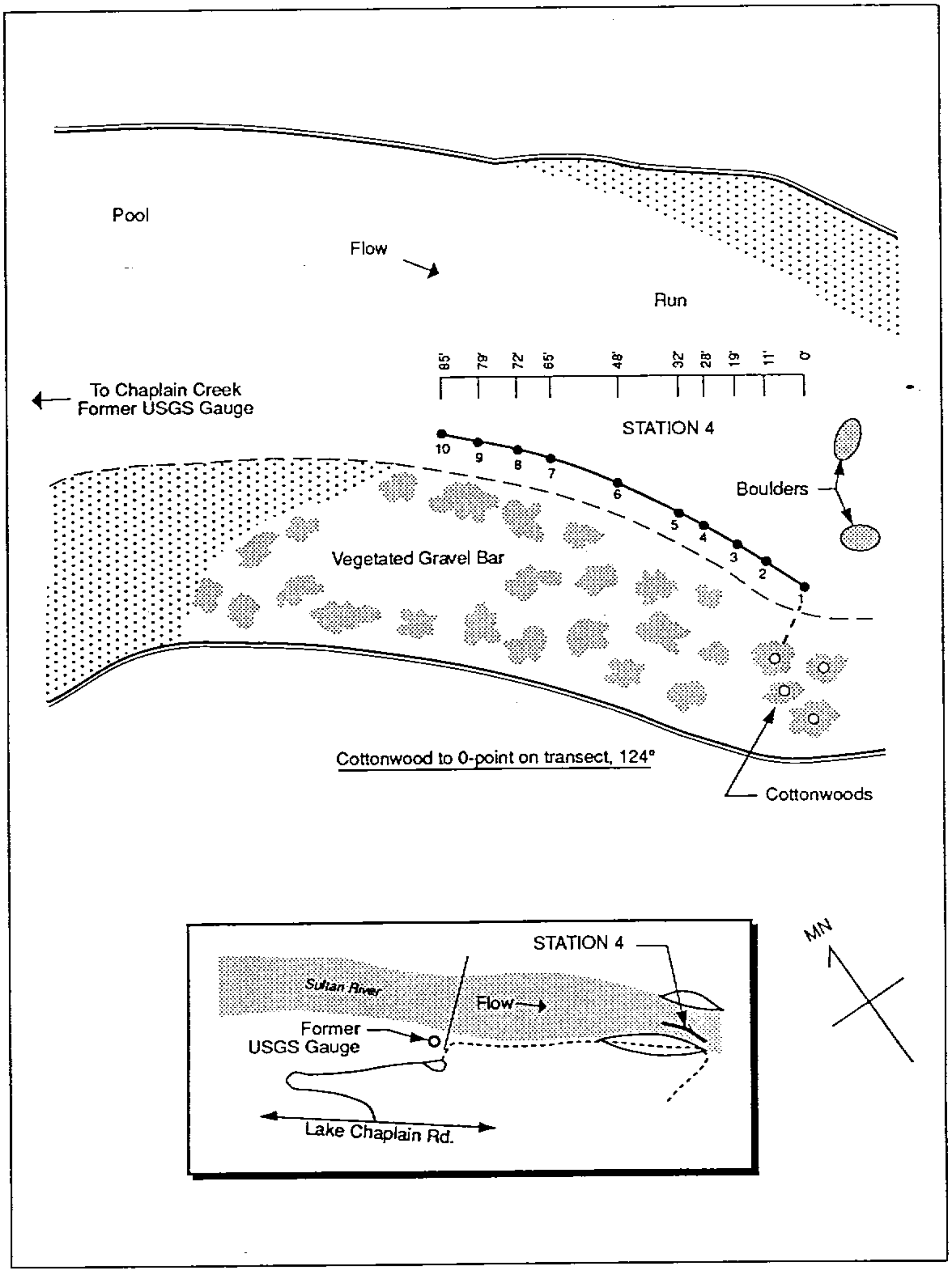

FIGURE 8

GRAVEL SAMPLING STATION S4

No Scale

SULTAN RIVER SPAWNING GRAVEL EVALUATION

SHAPIRO & ASSOCIATES INC

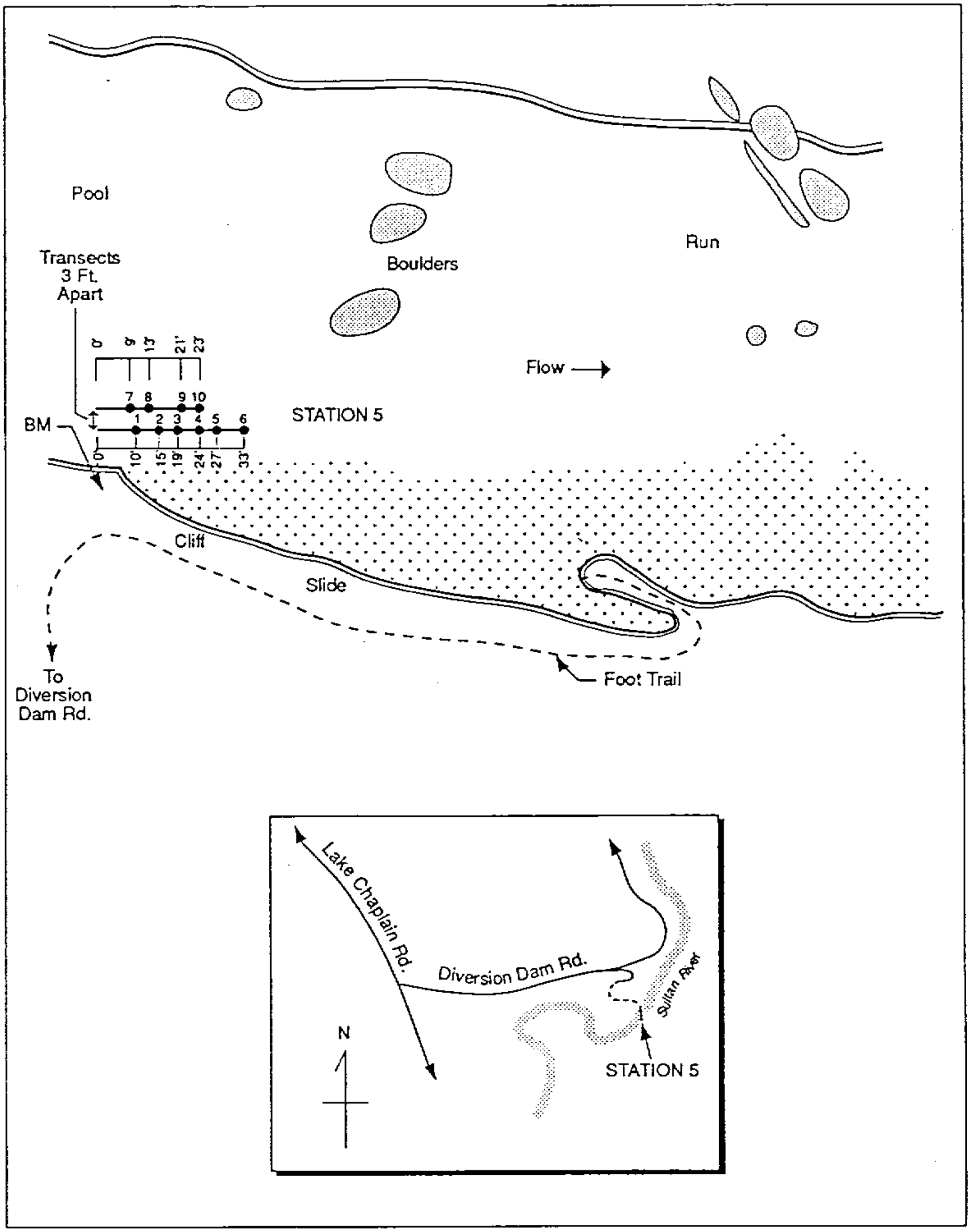

FIGURE 9

GRAVEL SAMPLING STATION S5

No Scale

SULTAN RIVER SPAWNING GRAVEL EVALUATION

SHAPIRO & ASSOCIATES INC

Table 1 shows spawning use at all sampling stations.

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

River Station	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, samples were obtained along a transect parallel to the direction of water movement within locations having spawning-size gravel less than four inches in diameter. While figures five - nine show locations for collecting ten samples at random distances along each transect, as in the previous baseline studies, only five samples were obtained this year. Analysis of within - transect variation from previous years' data substantiated the reduced sampling size. All samples from a given station were collected within an eight-hour period. Table 2 shows river flows for each sample day by location.

Table 2. Sultan River flows during each date gravel samples were collected in 1987.

Station	Date	Flow 1* (cfs)	Flow 2* (cfs)
S1	9/15/87	260	151
S2	9/16/87	260	159
S3	9/17/87	225	155
S4	9/17/87	225	155
S5	9/18/87	219	161

*Flow 1 = flow measured below powerhouse
*Flow 2 = flow measured at diversion dam

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, particularly its ability to detect stratification of sediments (Shirazi and Seim, 1979). 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 steel plates (depth gage-extractor). Liquid carbon dioxide was discharged for approximately five minutes through manifolds into the lower portion of each probe where it vaporized, inducing rapid freezing of adjacent interstitial water and sediments to the probes. One nine-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 20 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 CO2 cylinder had completely discharged. This was done in order to avoid sudden upward surges of manifolds when gases became trapped as condensation froze in the bottom of probes.

The probes and adhering sediment were extracted from the substratum using a hand winch attached to a tripod situated overhead. After extraction from the streambed, the core was then positioned horizontally over a set of six, adjacent, 7.6 cm (three-inch) wide galvanized aluminum boxes and thawed with propane torches. Material which fell into the boxes was collected and transferred to plastic bags for subsequent laboratory analysis. The weight of a single core, comprised of four subsample strata, ranged between five and ten 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 by Wert, et al. (1982). Subsamples were analyzed separately by washing the sediment through a geometric series of 10 Tyler screens ranging from 53.8 to 0.105 mm (2.12 to 0.004 inches) in mesh diameter in order to separate particle size groups. The 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 assusmed 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. 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 consensus among fisheries biologists that the textural composition of spawning substrates affects survival and emergence of salmonid embryos, a unified methodology for collecting and interpreting gravel quality has not been adopted. Chapman (1988) reviewed variables defining the effects of fine sediment on salmonid survival. The causal factors of mortality are generally believed to be the reduction of oxygenated water to incubating embryos and the trapping of alevins during the emergence period. Both of these are related to the proportion of fine sediments within gravel. Consequently, researchers have used an estimate of the percentage of fines less than a specified diameter (e.g., 0.841 mm, 1.0 mm, 3.3 mm or 6.5 mm) to interpret the suitability of streambed materials for spawning and incubation. More recently, investigators have recognized the inadequacy of using "percent fines" as a comprehensive index of substrate quality and have proposed various standardized indices to characterize the textural composition of spawning gravels.

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

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

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

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

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:

$$d_g = [d_1^{w_1} \ X \ d_2^{w_2} \ X \ . \ . \ . \ . \ d_n^{w_n}]$$

where d_1 = midpoint diameter of particles retained by a given sieve

and w_1 = decimal fraction by weight of particles retained by a given sieve

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

Parametric statistical analyses of the three geometric mean diameter (DGW, DGD, DGLS) and percent fines (PFW, PFD, PFLS) variables described above included analysis of variance (ANOVA) and Student's t-tests for differences between strata and among 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 subsequently discussed. Estimates of DGLS and PFLS values for each sample were determined by regression analysis of subsample data (n=44).

Following ANOVA oomparisons, 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 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 16.83 mm (DGW), 19.56 (DGD) and 43.96 (DGLS). The percentage of fine sediment less than 0.841 mm diameter for all stations combined averaged 7.3 (PFW), 5.0 (PFD), and 5.0 (PFLS). Substrate values determined for individual samples at each station during 1982, 1984, and 1987 studies are provided in Appendix D.

All three measures of d_g indicated that streambed composition at station S5 was by far the coarsest of the five study areas sampled. Other stations were similar to each other. ANOVA results, Table 4, rejected the hypothesis of no difference among mean d_g values for the five stations, for the variables DGW and DGD, but not for DGLS. LSD multiple-range tests indicated that the geometric mean diameter for station S5 was significantly greater than values obtained for all other study areas in the case of DGW, and all stations but S4 in the case of DGD.

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, 1987. Samples values are basedon four strata collected in individual freeze cores.

Station	No. of Samples	DGW (mm)	DGD (mm)	DGLS (mm)	PFW (%)	PFD (%)	PFLS (%)
S1	5	15.40	17.44	18.06	4.30	3.10	3.40
S2	5	15.07	18.47	29.08	10.80	7.50	6.50
S3	5	15.71	18.52	28.20	8.60	6.00	5.80
S4	5	16.07	19.33	31.58	8.30	5.50	5.50
S5	5	21.88	24.05	112.88	4.20	2.80	3.70
Total/mean	25	16.83	19.56	43.96	7.30	5.00	5.00

*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 meandiameter and percent fines for all stations are equal in 1987.

(Ho: Mean of S1 = S2 = S3 = S4 = S5)

	DGW	DGD	DGLS	PFW	PFD	PFLS
F - Ratio	3.35	2.50	1.22	13.30	13.50	7.23
F - Probability	0.03	0.08	0.33	<0.001	<0.001	<0.001

All three measures of percent fines indicated that the stream bed at station S2 contained the highest proportion of fine sediment, while S1 and S5 contained the lowest. A clearly inverse relationship between station mean d_g and percent fines values was not observed. While station S5 exhibits both the highest d_g and a low percent fines values, station S1 had a relatively low d_g and was low 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. LSD tests indicated that stations S5 and S1 had significantly fewer fines than other stations. This indicates that no consistent difference in percent fines existed between study areas upstream (S4 and S5) and downstream of the powerhouse (S1, S2, S3).

3.2 SEDIMENT STRATIFICATION

Geometric mean diameter and percent fines values calculated 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. This was especially so at station S5 which had consistently high d_g and low percent fines but was disproportionally affected by a large cobble in the surface stratum of one sample. The apparent outlier high value for DGLS at station S5 also may be explained by the greater sensitivity of this measure of d_g. 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 did not indicate a significant difference in the substrate composition of these strata however.

Since the effect of the uppermost stratum elevates mean dg 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 three 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 highest d_g and S1 and S5 had the lowest percent fines content. Significant differences among the five study sites were indicated by ANOVA due to the effect of these two stations.

3.3 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 prooes. 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 CO2 in freezing each sample. Assignment of each task in the field and laboratory to the same person minimized sampling and analytical error, respectively.

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, 1987.

Station	Stratum	DGW mm	DGD mm	DGLS mm	PFW %	PFD %	PFLS %	N
S1	1	**20.34	*22.23	*25.93	**2	**2	**2	5
	2	10.71	12.56	12.56	6	4	5	5
	3	11.46	13.22	9.38	6	4	5	5
	4	17.61	20.00	18.23	4	3	3	5
S2	1	20.27	23.37	39.65	*6	*4	4	5
	2	15.04	18.60	28.60	10	7	6	5
	3	16.68	21.09	37.56	11	7	5	5
	4	8.30	10.82	10.52	16	12	11	5
S3	1	24.78	27.11	48.09	*4	*3	3	5
	2	17.17	19.90	33.65	8	6	5	5
	3	12.45	15.63	20.04	10	7	6	5
	4	8.99	11.37	11.66	13	9	10	5
S4	1	*23.8	26.29	46.27	**3	**2	**2	5
	2	12.68	14.73	25.15	10	7	8	5
	3	14.15	18.02	24.76	9	6	6	5
	4	13.64	18.27	30.14	11	7	6	5
S5	1	*33.54	34.86	342.85	**1	**1	**1	5
	2	12.19	13.63	10.22	5	3	5	5
	3	18.74	21.79	37.56	5	3	4	5
	4	23.08	25.93	60.87	6	4	5	5
Stations Combined	1	24.55	26.77	100.56	3	2	2	25
	2	13.56	15.88	22.03	8	5	6	25
	3	14.69	17.95	25.86	8	5	5	25
	4	14.32	17.28	26.28	10	7	7	25
Overall Mean		16.83	19.56	43.96	7	5	5	

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 * at the 5% level and by **.

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, 1987.

Station	DGW (mm)	DGD (mm)	DGLS (mm)	PFW (%)	PFD (%)	PFLS (%)	n
S1	13.26	15.26	13.39*	5*	4*	4	5
S2	13.34	16.84	25.56	12	9	7	5
S3	13.99	16.84	23.86	10	7	6	5
S4	13.49	17.01	26.68	10	7	7	5
S5	18.00	20.45	36.22*	5*	4*	5	5
Total Mean	14.42	17.28	25.14	8.4	6.2	5.8	25

*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. Prior to construction (1982), gravels indicated a progressively smaller size with increased distance from the river mouth, whereas, after construction and operation (1984 and 1987, samples), the spatial variability of geometric mean particle size showed no apparent trend among stations. Stations S1 and S3 had the coarsest gravel texture before and immediately following project construction, whereas S4 and S5 had the coarsest gravel after operation. Only S5 was significantly different from other stations in 1987. In contrast, station S5 had a significantly lower geometric mean particle size in 1984 than other stations while both S4 and S5 were of significant lower value in 1982.

Comparison of gravel texture of corresponding individual stations between 1987 and other years indicated only station S5 was appreciably changed: its gravel texture was significantly coarser after operation than previously. This may be explained by gold dredging activities that occurred in the Station 5 vicinity a few weeks prior to sampling. The sediment at both stations upstream of the powerhouse site was coarser than conditions prior to construction although the difference was statistically significant only at S5 in 1987.

Relationships of geometric mean particle size for 1982, 1984, and 1987 are shown in Table 7. Significant changes include an increase in particle size at Station 4 from 1982 to 1984. At Station 5, a significant increase in particle size occurred between 1982 and 1987 and 1984 and 1987 but not 1982 and 1984. The reason for such change is uncertain. Since Station 5 is upstream of the powerhouse, discharges from the turbines can not be a factor influencing these changes.

Table 7. Geometric mean particle sizes by station, in years 1982, 1984 and 1987. Statistically significant differences (= .05), determined using t-tests (n=10 in 82 a 84, n=5 in 87 for individual stations) are indicated by superscripts.

	DGW (mm)			DGD (mm)			DGLS (mm)		
Sta	82	84	87	82	84	87	82	84	87
1	17.35	17.79	15.40	19.82	20.30	17.44	21.89	22.08	18.06
2	16.25	15.85	15.07	19.37	19.29	18.47	23.22	21.94	29.08
3	16.45$_{a}$	18.62$_{a}$	15.71	19.38$_{a}$	22.47$_{a}$	18.52	24.56	26.37	28.20
4	12.01$_{b}$	17.66$_{c}$	16.07$_{bc}$	14.70$_{b}$	18.80$_{c}$	19.33$_{bc}$	15.15	21.84	31.58
5	11.41^{b}	10.74^{c}	21.88^{bc}	13.54^{b}	13.15^{c}	24.05	10.95	7.87	112.88
Mean	15.32	16.13^{c}	16.83^{c}	17.93	18.80^{c}	19.56^{c}	19.62	20.02	43.96

a) statistically significant differences in geometric mean particle size between 1982 and 1984 samples.
b) statistically significant differences in geometric mean particle size between 1982 and 1987 samples.
c) statistically significant differences in geometric mean particle size between 1984 and 1987.

Table 8. Comparison of percentage of fines less than 0.841mm in diameter, in Sultan River streambed gravels between 1982 and 1984 and 1987 at individual stations (n=10 in 1982 and 1984; n=5 in 1987) and all stations combined (n=50 in 1982 and 1984; n=25 in 1987).

	DGW			DGD			DGLS		
Sta	82	84	87	82	84	87	82	84	87
1	4.7	4.5$_{c}$	4.3$_{c}$	3.4	3.1	3.1	3.2$_{b}$	3.3$_{c}$	3.4$_{bc}$
2	8.6	9.5^{c}	10.8^{c}	6.1	6.5	7.5	4.4^{b}	4.5$_{c}$	6.5$_{c}$
3	7.7	9.1	8.6	5.3	6.2	6.0	3.5	4.4^{c}	5.8^{c}
4	9.1$_{b}$	9.7$_{c}$	8.3$_{bc}$	6.2$_{b}$	6.3$_{c}$	5.5$_{bc}$	5.4$_{ab}$	5.4$_{ac}$	5.5$_{bc}$
5	8.6^{b}	10.4^{c}	4.2^{bc}	5.8^{b}	7.2^{c}	2.8^{bc}	5.4^{ab}	7.1^{ac}	3.7^{bc}
Mean	7.1	8.7	7.3	4.9	5.8	5.0	4.1	4.9	5.0

a) statistically significant differences in geometric mean particle size between 1982 and 1984 samples.
b) statistically significant differences in geometric mean particle size between 1982 and 1987 samples.
c) statistically significant differences in geometric mean particle size between 1984 and 1987.

The amount of fine sediment at individual study sites in 1987 was, in most cases, significantly different from previous years (Table 8). The most noteworthy change occurred at S5, which was significantly lower in fines in 1987 than in 1982 or 1984. Percent fines was greater in 1987 at S2, but the difference was not statistically significant for all methods of calculation. The regression method indicated that the amount of fine sediment at S3 was significantly greater in 1987 than in 1984, although this relationship was not reflected by the non-regression techniques.

Sediment stratification occurred in the stream bed during all years of sampling. In 1982, 1984, and 1987 the combined mean values of the upper three inches of substrate contained significantly lower percent fines and greater geometric mean particle size than the underlying nine 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.

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

5.0 CONCLUSION

The textural composition of Sultan River streambed sediments at locations of repeated sampling was similar after three years of project operation to the composition prior to and immediately following project construction. Station S5 was the most noteworthy exception, having a significantly greater average geometric mean particle size (d_g) and a lower proportion of fine sediment in 1987 than previously. This may be explained by gold dredging activities that occurred in the Station 5 vicinity a few weeks prior to gravel sampling.

There was no clear spatial trend in d_g among stations in 1987 or 1984, whereas, a trend of smaller d_g with increased distance upstream was suggested by 1982 data. Station S5 (upstream) had the coarsest gravel (largest d_g) in 1987, in contrast to 1982 and 1984, when it had the finest gravel of all stations sampled. The d_g at the three most downstream stations has been relatively stable over the three sampling periods, whereas d_g at the two upstream stations has increased significantly since project construction. In correspondence to the observations in the previous paragraph, station S5 had the lowest proportion of fines (<0.841 mm diameter) of any station in 1987, in contrast to its relatively high levels in previous years. Station S1 (river mouth) was consistently low in all years.

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

The textural composition 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. Based on these indices, the need for mitigative measures is not indicated.

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APPENDICES

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, 1984, and 1987.

E. Substrate values for each strata of individual samples collected at all study reaches during 1987.

F. Substrate values for individual samples collected from each study reach during 1987 using lowest three strata only (strata 1 omitted in sample averages.

A P P E N D I X   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~~
251-1515

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

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

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

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

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

A P P E N D I X 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. DPFT 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

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

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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 1982, 1984, and 1987 Sultan River sediment analysis. Arithmetic mean of all strata in each replicate at each station.

Year	Sta	Rep	DGW	DGD	DGLS	PFW	PFD	PFLS
1982	1	1	16.306	18.646	20.01	0.059	0.040	0.04
1982	1	2	21.166	23.648	21.50	0.039	0.027	0.03
1982	1	3	16.691	18.954	20.47	0.046	0.032	0.03
1982	1	4	25.885	28.818	43.05	0.038	0.025	0.02
1982	1	5	12.142	14.188	9.90	0.058	0.040	0.05
1982	1	6	21.330	24.484	33.27	0.039	0.026	0.02
1982	1	7	18.784	21.956	29.00	0.041	0.027	0.03
1982	1	8	14.701	17.121	11.20	0.055	0.037	0.04
1982	1	9	17.772	20.007	17.01	0.033	0.022	0.03
1982	1	10	13.102	15.129	15.38	0.049	0.033	0.04
1982	2	1	8.915	11.312	8.22	0.165	0.115	0.08
1982	2	2	14.894	17.667	14.38	0.081	0.056	0.04
1982	2	3	17.404	20.727	17.49	0.088	0.061	0.04
1982	2	4	13.982	17.089	15.21	0.093	0.064	0.05
1982	2	5	15.221	18.266	21.06	0.086	0.059	0.04
1982	2	6	18.580	22.616	31.98	0.093	0.063	0.04
1982	2	7	16.828	20.408	20.34	0.080	0.053	0.04
1982	2	8	17.492	21.611	29.89	0.083	0.056	0.04
1982	2	9	17.207	21.404	29.46	0.095	0.064	0.04
1982	2	10	17.977	21.791	31.08	0.083	0.054	0.04
1982	3	1	22.882	26.539	32.09	0.110	0.073	0.04
1982	3	2	16.492	21.382	32.38	0.125	0.085	0.05
1982	3	3	13.232	17.524	15.09	0.137	0.094	0.06
1982	3	4	17.710	21.824	30.35	0.082	0.054	0.04
1982	3	5	13.301	16.577	18.75	0.096	0.066	0.05
1982	3	6	14.079	18.175	20.51	0.112	0.075	0.06
1982	3	7	30.007	33.112	35.96	0.038	0.026	0.02
1982	3	8	18.856	22.368	14.11	0.071	0.048	0.04
1982	3	9	26.295	30.370	49.98	0.043	0.029	0.02
1982	3	10	13.343	16.860	14.46	0.098	0.065	0.06
1982	4	1	22.685	26.543	36.00	0.077	0.050	0.04
1982	4	2	12.561	16.492	13.43	0.109	0.070	0.06
1982	4	3	12.918	16.395	14.47	0.090	0.057	0.05
1982	4	4	13.097	17.053	20.80	0.115	0.073	0.06
1982	4	5	22.392	25.390	19.97	0.064	0.044	0.04
1982	4	6	9.492	12.568	7.49	0.142	0.098	0.08
1982	4	7	14.768	18.120	15.33	0.096	0.065	0.05
1982	4	8	21.387	27.287	56.23	0.095	0.060	0.04
1982	4	9	13.487	17.355	19.37	0.104	0.067	0.05
1982	4	10	33.815	10.810	15.28	0.073	0.050	0.07
1982	5	1	8.174	9.945	4.75	0.114	0.084	0.09
1982	5	2	11.346	13.877	8.35	0.094	0.064	0.07
1982	5	3	10.890	13.166	6.65	0.095	0.066	0.07
1982	5	4	9.388	12.175	7.94	0.104	0.070	0.07
1982	5	5	11.778	14.484	8.67	0.107	0.072	0.07

Appendix D. Results of 1982, 1984, and 1987 Sultan River sediment analysis. Arithmetic mean of all strata in each replicate at each station.

Year	Sta	Rep	DGW	DGD	DGLS	PFW	PFD	PFLS
1982	5	6	11.977	15.105	13.14	0.101	0.067	0.06
1982	5	7	11.015	13.405	8.53	0.088	0.060	0.06
1982	5	8	13.958	16.019	8.16	0.074	0.049	0.05
1982	5	9	7.127	9.015	4.88	0.144	0.101	0.10
1982	5	10	11.704	14.314	7.55	0.122	0.086	0.07
1984	1	1	22.600	25.450	33.63	0.030	0.030	0.02
1984	1	2	15.540	17.870	16.45	0.050	0.040	0.03
1984	1	3	18.960	21.670	28.33	0.040	0.030	0.03
1984	1	4	20.190	22.560	22.86	0.040	0.030	0.02
1984	1	5	9.390	11.240	7.23	0.060	0.040	0.05
1984	1	6	17.070	19.860	25.49	0.060	0.050	0.03
1984	1	7	16.860	19.440	23.75	0.050	0.030	0.03
1984	1	8	21.780	24.920	26.23	0.040	0.030	0.03
1984	1	9	13.840	15.810	10.69	0.060	0.040	0.05
1984	1	10	16.820	19.400	24.19	0.040	0.020	0.03
1984	2	1	24.590	28.860	58.71	0.070	0.050	0.03
1984	2	2	20.390	23.460	24.17	0.060	0.040	0.03
1984	2	3	14.090	16.900	15.45	0.090	0.060	0.05
1984	2	4	18.480	21.190	21.09	0.050	0.040	0.03
1984	2	5	12.870	15.970	18.57	0.100	0.070	0.05
1984	2	6	13.050	15.900	14.51	0.100	0.070	0.05
1984	2	7	17.630	21.220	31.56	0.090	0.070	0.04
1984	2	8	11.410	14.180	12.63	0.120	0.080	0.06
1984	2	9	19.790	23.720	25.17	0.080	0.050	0.04
1984	2	10	10.160	12.280	10.35	0.100	0.080	0.06
1984	3	1	22.120	26.090	48.37	0.080	0.050	0.03
1984	3	2	15.240	17.740	16.23	0.070	0.050	0.04
1984	3	3	13.380	16.460	20.72	0.110	0.080	0.04
1984	3	4	22.570	26.010	40.42	0.050	0.040	0.02
1984	3	5	22.550	26.110	39.83	0.060	0.040	0.02
1984	3	6	10.350	12.050	10.11	0.070	0.050	0.04
1984	3	7	13.290	16.400	16.30	0.100	0.070	0.05
1984	3	8	13.500	16.110	18.99	0.080	0.050	0.04
1984	3	9	17.650	20.560	18.99	0.080	0.050	0.03
1984	3	10	13.820	16.270	15.64	0.070	0.050	0.04
1984	4	1	16.080	19.310	18.51	0.080	0.050	0.04
1984	4	2	12.620	14.500	10.33	0.050	0.040	0.04
1984	4	3	8.470	11.170	9.72	0.130	0.090	0.08
1984	4	4	8.730	11.030	6.69	0.120	0.080	0.08
1984	4	5	15.590	20.220	35.18	0.110	0.070	0.05
1984	4	6	10.200	13.540	15.89	0.120	0.080	0.07
1984	4	7	9.560	12.560	14.08	0.130	0.090	0.07
1984	4	8	13.460	16.200	18.97	0.080	0.050	0.04
1984	4	9	11.520	13.020	10.90	0.050	0.040	0.04
1984	4	10	13.900	15.430	11.25	0.040	0.030	0.03

Appendix D. Results of 1982, 1984, and 1987 Sultan River sediment analysis. Arithmetic mean of all strata in each replicate at each station.

Year	Sta	Rep	DGW	DGD	DGLS	PFW	PFD	PFLS
1984	5	1	9.000	10.580	6.65	0.080	0.050	0.06
1984	5	2	11.680	13.820	12.34	0.080	0.060	0.05
1984	5	3	21.170	23.590	23.26	0.030	0.020	0.02
1984	5	4	11.320	14.000	12.29	0.090	0.060	0.05
1984	5	5	10.170	12.170	8.55	0.100	0.070	0.06
1984	5	6	12.810	16.300	15.91	0.110	0.070	0.05
1984	5	7	11.000	12.560	7.68	0.060	0.040	0.05
1984	5	8	10.360	12.100	7.29	0.080	0.050	0.06
1984	5	9	7.230	8.720	5.37	0.120	0.080	0.08
1984	5	10	9.380	11.580	10.11	0.110	0.080	0.06
1987	1	1	13.780	15.480	12.68	0.040	0.030	0.04
1987	1	2	16.130	18.480	22.09	0.050	0.040	0.04
1987	1	3	15.290	17.540	19.17	0.040	0.030	0.04
1987	1	4	14.900	16.520	12.16	0.040	0.030	0.03
1987	1	5	16.890	19.200	24.20	0.040	0.030	0.03
1987	2	1	13.940	16.750	25.08	0.120	0.090	0.08
1987	2	2	18.750	22.760	40.51	0.110	0.080	0.06
1987	2	3	14.130	17.320	30.14	0.120	0.080	0.07
1987	2	4	13.230	16.350	19.57	0.090	0.060	0.06
1987	2	5	15.310	19.180	30.11	0.110	0.070	0.06
1987	3	1	23.130	25.810	47.10	0.060	0.040	0.04
1987	3	2	14.170	17.530	24.30	0.110	0.070	0.06
1987	3	3	16.300	19.540	29.31	0.090	0.060	0.06
1987	3	4	10.640	12.890	13.34	0.100	0.070	0.07
1987	3	5	14.300	16.840	26.95	0.080	0.060	0.06
1987	4	1	16.650	20.290	44.54	0.090	0.060	0.06
1987	4	2	14.710	17.600	22.72	0.080	0.050	0.06
1987	4	3	12.890	16.830	27.20	0.130	0.080	0.08
1987	4	4	13.600	15.910	14.28	0.070	0.050	0.05
1987	4	5	22.480	26.000	49.16	0.050	0.030	0.03
1987	5	1	20.140	21.540	45.21	0.030	0.020	0.03
1987	5	2	19.950	21.740	20.75	0.030	0.020	0.03
1987	5	3	20.160	22.930	44.01	0.060	0.040	0.05
1987	5	4	19.670	22.170	30.46	0.040	0.030	0.04
1987	5	5	29.500	31.880	423.95	0.050	0.040	0.04

Appendix E. Results of 1987 Sultan River sediment analysis for individual strata of each sample.

Sta	Rep	Strat	DGW	DGD	DGLS	PFW	PFD	PFLS
1	1	1	16.6665	18.1151	20.24	0.014	0.010	0.02
1	1	2	11.2738	13.4840	14.86	0.060	0.042	0.05
1	1	3	8.7408	10.1481	5.58	0.080	0.059	0.06
1	1	4	18.4526	20.1609	10.05	0.018	0.012	0.02
1	2	1	26.0880	28.8897	47.62	0.027	0.018	0.02
1	2	2	11.6315	13.8664	15.22	0.065	0.047	0.04
1	2	3	13.4855	15.9468	17.98	0.052	0.036	0.04
1	2	4	13.3090	15.2143	7.54	0.055	0.040	0.04
1	3	1	18.0739	20.4415	24.17	0.034	0.024	0.03
1	3	2	12.0350	14.0099	14.82	0.053	0.038	0.04
1	3	3	10.1713	11.7057	6.34	0.050	0.037	0.05
1	3	4	20.8895	24.0176	31.36	0.036	0.026	0.02
1	4	1	20.5393	21.4765	11.69	0.016	0.012	0.01
1	4	2	7.8805	8.8945	5.33	0.048	0.036	0.05
1	4	3	13.4257	15.0861	7.63	0.047	0.033	0.04
1	4	4	17.7742	20.6154	23.97	0.053	0.038	0.03
1	5	1	12.3390	14.1431	14.68	0.040	0.029	0.04
1	5	2	14.5797	17.0623	20.04	0.052	0.037	0.04
1	5	3	25.6647	27.8335	39.62	0.021	0.015	0.01
1	5	4	14.9911	17.7787	22.44	0.046	0.032	0.04
2	1	1	17.7426	20.5632	25.44	0.058	0.040	0.03
2	1	2	24.4802	29.4361	58.66	0.065	0.045	0.03
2	1	3	10.7537	13.2732	14.17	0.109	0.079	0.05
2	1	4	2.7743	3.7164	2.05	0.243	0.183	0.21
2	2	1	35.8317	39.6096	96.33	0.031	0.021	0.01
2	2	2	19.8534	24.5190	39.97	0.085	0.058	0.04
2	2	3	10.8029	15.0931	19.89	0.151	0.102	0.07
2	2	4	8.5175	11.8201	5.85	0.175	0.120	0.10
2	3	1	13.3253	16.0429	18.22	0.089	0.061	0.05
2	3	2	9.4545	12.0722	12.95	0.115	0.079	0.07
2	3	3	28.5485	34.1616	85.38	0.064	0.043	0.03
2	3	4	5.1846	6.9892	4.00	0.199	0.143	0.12
2	4	1	11.0184	12.9778	6.39	0.088	0.060	0.06
2	4	2	16.0299	19.7384	27.31	0.080	0.055	0.04
2	4	3	19.0647	23.9443	39.85	0.093	0.063	0.04
2	4	4	6.8252	8.7234	4.72	0.106	0.069	0.10
2	5	1	23.4185	27.6564	51.86	0.057	0.036	0.03
2	5	2	5.3626	7.2359	4.09	0.160	0.109	0.12
2	5	3	14.2325	18.9944	28.49	0.112	0.073	0.06
2	5	4	18.2186	22.8298	35.99	0.096	0.066	0.04
3	1	1	33.8202	35.1006	70.58	0.006	0.004	0.01
3	1	2	33.2646	37.2062	80.47	0.029	0.020	0.01
3	1	3	19.6279	23.1331	32.97	0.053	0.037	0.03
3	1	4	5.8243	7.7812	4.37	0.155	0.109	0.11
3	2	1	26.8464	30.0484	49.38	0.035	0.024	0.02
3	2	2	11.4605	14.8719	18.79	0.119	0.084	0.06

Appendix E. Results of 1987 Sultan River sediment analysis for individual strata of each sample.

Sta	Rep	Strat	DGW	DGD	DGLS	PFW	PFD	PFLS
3	2	3	12.2476	16.8166	24.48	0.120	0.079	0.06
3	2	4	6.1245	8.3786	4.54	0.146	0.096	0.11
3	3	1	29.1081	32.7854	59.97	0.043	0.031	0.02
3	3	2	5.8132	7.5282	4.30	0.135	0.093	0.11
3	3	3	11.3536	14.8358	18.84	0.113	0.077	0.06
3	3	4	18.9071	22.9946	34.14	0.061	0.040	0.04
3	4	1	11.4251	13.4376	13.71	0.079	0.057	0.05
3	4	2	12.4190	14.9592	16.18	0.090	0.066	0.04
3	4	3	13.5850	16.8321	19.91	0.078	0.050	0.05
3	4	4	5.1137	6.3200	3.57	0.145	0.104	0.12
3	5	1	15.9493	18.7758	23.27	0.060	0.041	0.04
3	5	2	28.4944	33.2814	75.60	0.052	0.035	0.03
3	5	3	5.4333	6.5311	4.01	0.115	0.085	0.10
3	5	4	7.3400	8.7799	4.91	0.092	0.065	0.08
4	1	1	34.4916	38.9060	122.87	0.042	0.027	0.02
4	1	2	7.1435	8.8144	4.80	0.104	0.073	0.09
4	1	3	8.8497	11.1105	5.63	0.109	0.075	0.08
4	1	4	16.1340	22.3448	44.86	0.117	0.076	0.06
4	2	1	24.9240	27.5739	43.15	0.026	0.017	0.02
4	2	2	6.3224	8.0332	4.53	0.116	0.080	0.10
4	2	3	17.3438	22.2642	37.01	0.082	0.052	0.05
4	2	4	10.2532	12.5304	6.20	0.101	0.068	0.07
4	3	1	24.4791	27.4292	44.06	0.040	0.027	0.02
4	3	2	3.8508	5.1816	3.31	0.169	0.116	0.15
4	3	3	10.6185	15.3351	21.76	0.146	0.094	0.07
4	3	4	12.6148	19.3563	39.65	0.162	0.102	0.07
4	4	1	16.1118	18.0465	8.81	0.046	0.032	0.04
4	4	2	10.0326	11.6569	6.04	0.069	0.048	0.06
4	4	3	18.2429	21.3294	28.26	0.051	0.035	0.03
4	4	4	10.0163	12.6174	14.00	0.096	0.066	0.06
4	5	1	18.9937	19.4909	12.46	0.002	0.001	0.01
4	5	2	36.0499	39.9595	107.07	0.019	0.013	0.01
4	5	3	15.6935	20.0834	31.13	0.076	0.047	0.05
4	5	4	19.1830	24.4832	45.99	0.083	0.053	0.04
5	1	1	15.7076	16.6384	8.97	0.022	0.016	0.02
5	1	2	9.3296	10.3180	5.86	0.032	0.022	0.05
5	1	3	10.0081	11.0868	6.19	0.036	0.026	0.04
5	1	4	45.5244	48.1292	159.83	0.011	0.008	0.01
5	2	1	26.3760	26.8435	19.11	0.002	0.001	0.01
5	2	2	19.0015	19.8079	11.16	0.009	0.006	0.02
5	2	3	20.6429	23.3187	31.52	0.034	0.023	0.03
5	2	4	13.7845	17.0002	21.22	0.084	0.057	0.05
5	3	1	36.7678	38.9868	105.36	0.008	0.005	0.01
5	3	2	16.4491	19.2030	23.84	0.048	0.032	0.04
5	3	3	20.6236	25.0185	42.11	0.066	0.043	0.04
5	3	4	6.7895	8.5063	4.73	0.103	0.070	0.10

Appendix E. Results of 1987 Sultan River sediment analysis for individual strata of each sample.

Sta	Rep	Strat	DGW	DGD	DGLS	PFW	PFD	PFLS
5	4	1	22.9113	23.7998	13.90	0.008	0.005	0.02
5	4	2	10.6652	12.3461	6.33	0.053	0.033	0.06
5	4	3	30.3042	35.0155	93.22	0.036	0.022	0.02
5	4	4	14.8163	17.5248	8.37	0.072	0.048	0.05
5	5	1	65.9169	68.0213	1566.93	0.006	0.004	0.00
5	5	2	5.5125	6.4647	3.89	0.088	0.061	0.10
5	5	3	12.0977	14.5204	14.76	0.079	0.055	0.05
5	5	4	34.4668	38.5130	110.21	0.038	0.025	0.02

Appendix F. Results of 1987 Sultan River sediment analyses. Arithmetic means of lower three strata for each replicate at each station (the surface stratum was omitted).

STA	REP	DGW	DGD	DGLS	PFW	PFD	PFLS
1	1	12.822	14.598	10.163	.053	.038	.043
1	2	12.809	15.009	13.580	.057	.041	.040
1	3	14.365	16.578	17.507	.046	.034	.037
1	4	13.027	14.865	12.310	.049	.036	.040
1	5	18.412	20.892	27.367	.040	.028	.030
2	1	12.669	15.475	24.960	.139	.102	.097
2	2	13.058	17.144	21.903	.137	.093	.070
2	3	14.396	17.741	34.110	.126	.088	.073
2	4	13.973	17.469	23.960	.093	.062	.060
2	5	12.605	16.353	22.857	.123	.083	.073
3	1	19.572	22.707	39.270	.079	.055	.050
3	2	9.944	13.356	15.937	.128	.086	.077
3	3	12.025	15.120	19.093	.103	.070	.070
3	4	10.373	12.704	13.220	.104	.073	.070
3	5	13.756	16.197	28.173	.086	.062	.070
4	1	10.709	14.090	18.430	.110	.075	.077
4	2	11.306	14.276	15.913	.100	.067	.073
4	3	9.028	13.291	21.573	.159	.104	.097
4	4	12.764	15.201	16.100	.072	.050	.050
4	5	23.642	28.175	61.397	.059	.038	.033
5	1	21.621	23.178	57.293	.026	.019	.033
5	2	17.810	20.042	21.300	.042	.029	.033
5	3	14.621	17.576	23.560	.072	.048	.060
5	4	18.595	21.629	35.973	.054	.034	.043
5	5	17.359	19.833	42.953	.068	.047	.057