Henry M. Jackson Hydroelectric Project
FERC Project No. 2157

Spatial and Temporal Comparison of Spawning Gravel Quality in the Sultan River, Washington

Prepared for:

Snohomish County Public Utility District No. 1
Everett, Washington

Prepared by:

R2 Resource Consultants, Inc.
Redmond, Washington

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EXECUTIVE SUMMARY

The Henry M. Jackson Hydroelectric Project (Project) is owned and operated by the Public Utility District No. 1 of Snohomish County, Washington (referred to hereafter as the "District"). The Project alters the hydrologic and sediment transport regime of a 16.2-mile-long reach of the Sultan River, extending from the confluence with the Skykomish River to Culmback Dam. The Everett Diversion Dam at River Mile 9.7 marks the upstream extent of anadromous fish use. The Sultan River downstream from the Everett Diversion Dam provides spawning and rearing habitat for numerous anadromous fish species including: Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon; and steelhead (*O. mykiss*) and coastal cutthroat trout (*O. clarki clarki*). Bull trout (*Salvelinus malma*) have not been observed in the Sultan River, however they are known to use the river as rearing/foraging habitat.

The Hydroelectric Project was constructed in 1984, and is operated under the terms of Federal Energy Regulatory Commission (FERC) License No. 2157. Operation of the Project has reduced the capacity of the river to transport sediment. This reduction in capacity is associated with flood control on the Sultan and Skykomish rivers. Culmback Dam provides the only flood control structure on the Skykomish River system, equal to 58,500 acre-feet of incidental flood control storage per year. Under the current Project Operating Plan, approved by the Corps of Engineers, the Sultan River contributes approximately 10 percent of the flow to the Skykomish River system during peak flow events. The Project captures for regulated release, on average, 94 percent of the water flowing into Spada Lake, and any spill from Spada Lake typically occurs after high flows in the Skykomish River have peaked. One potential result of the imbalance between the sediment transport capacity and the sediment supply might be an accumulation of fine sediment in the matrix of spawning gravel deposits. As a result, the District was required as part of the existing FERC license to monitor the textural quality of spawning gravels within the study reach of the Sultan River below the Everett Diversion Dam. Gravel monitoring studies have subsequently been completed in 1982 (pre-construction), 1984 (immediately following construction), 1987 (three years after construction), and in 1994 (ten years after construction). After several consecutive years without achieving scouring flow thresholds in the Sultan River, the District was required to sample and analyze spawning gravel samples in 2005.

R2 Resource Consultants (R2) was therefore contracted by the District to collect and analyze spawning gravel samples in 2005, and to compare the results with those from 1982, 1984, 1987, and 1994. This report presents the results of both the gravel sampling conducted by R2 in 2005, and the comparisons with previous studies. Consistent with previous surveys, gravel samples were collected in 2005 from five sites including Sportsman Park (River Mile 0.1), Reese Park (River Mile 0.7), Trout Farm Road (River Mile 2.5), USGS Gage (River Mile 4.7), and Gold Camp (River Mile 7.3).

Although prior gravel samples were collected using a freeze-core tube, the samples collected in 2005 were obtained using a 12-inch diameter McNeil sampler. The primary difference between the two samplers is that the freeze-core tube permits stratification of gravel samples into three-inch thick layers to a total depth of 12 inches below the streambed surface. The larger volume of the bulk McNeil sampler, on the other hand, provides a more reliable measure of spawning gravel quality. All sampling was completed during late August to avoid disruption of redds.

The following four measures of spawning gravel quality were computed and used to assess the samples collected in 2005:

1. **Geometric mean diameter** - Shirazi and Seim (1979) collected and analyzed the results of embryo survival studies of coho salmon, cutthroat trout, sockeye salmon, and steelhead. A relationship was found between embryo survival and geometric mean diameter of the spawning gravel matrix.

2. **Percent fines less than 0.84 mm** – This metric is important for assessing survival of the egg phase during incubation. An excessive quantity of sediment finer than 0.84 mm can reduce the permeability of a gravel matrix and potentially deprive the eggs in a redd of dissolved oxygen needed for survival.

3. **Percent fines less than 6.4 mm** – The larger grain size (6.4 mm) is important for assessing survival of the alevin phase during incubation. Alevins need space within the gravel matrix to move and eventually emerge from the substrate. An excessive quantity of sediment finer than 6.4 mm can block the interstitial spaces within the gravel matrix and potentially trap the alevins within the substrate, preventing their emergence.

4. **Fredle index –** The Fredle index, Fi, was introduced by Lotspeich and Everest (1981) as a refinement of the geometric mean diameter for assessing the quality of spawning gravels. It was recognized that two different gravel samples might have identical geometric mean diameters, but one sample might be more permeable than the other because it had a more uniform grain size distribution. Thus, the geometric mean diameter was adjusted to account for the uniformity of the grain size distribution by dividing the geometric mean diameter by a sorting coefficient.

Other sources of information related to the mobility and quality of spawning gravels were reviewed including; the results of scour depth measurements in the Sultan River; Chinook spawning and escapement records; flood frequency data: and a previous investigation on sediment supply/transport conducted by GeoEngineers (1982). Information from this review in combination with the gravel quality analysis, resulted in the formulation of the following conclusions:

- The spawning gravel samples collected in 1982 and 1984, prior to initiation of power generation, were of good quality.

- Since 1984, the magnitude and frequency of floods in the Sultan River below Culmback Dam have been reduced, consistent with intended flood protection provided by the Project.

- Although the magnitude and frequency of floods in the Sultan River have been reduced, the river still has sufficient capacity to transport the sediment supplied to the river from sources downstream from Culmback Dam.

- Under the flow regime in the Sultan River since 1984, the armor layer of gravel deposits in the Sultan River is mobilized about once every 3 to 4 years on average based on sediment transport analyses. Scour depth measurements suggest that the armor layer may be mobilized even more frequently than once every 3 to 4 years.

- Except for occasional disturbances associated with gold prospecting activities and potential backwater effects caused by the Skykomish River near the mouth of the Sultan River, the quality of spawning gravels collected in 1987, 1994, and 2005 has remained "good" and on par with pre-Project conditions. Historical operations of the Project do not appear to have caused the quality of the spawning gravels to decline.

- The persistent trend of good quality spawning gravels is consistent with reported success of Chinook salmon spawning and escapement in the Sultan River downstream from the diversion dam.

1. INTRODUCTION

The Henry M. Jackson Hydroelectric Project is owned and operated by the Public Utility District No. 1 of Snohomish County, Washington (referred to herein as the "District"). The Project alters the hydrologic and sediment transport regime of a 16.2-mile-long reach of the Sultan River, extending from the confluence with the Skykomish River to Culmback Dam, as shown in Figure 1-1. The Everett Diversion Dam at River Mile 9.7 marks the upstream extent of anadromous fish use. The Sultan River downstream from the Everett Diversion Dam provides spawning and rearing habitat for numerous anadromous fish species including: Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon, steelhead (*O. mykiss*) and coastal cutthroat trout (*O. clarki clarki*). Bull trout (*Salvelinus malma*) have not been observed in the Sultan River, however they are known to use the river as rearing/foraging habitat.

The Hydroelectric Project was constructed in 1984, and is operated under the terms of Federal Energy Regulatory Commission (FERC) License No. 2157. Under the terms of this license, the District is required to monitor the textural quality of spawning gravels within the study reach of the Sultan River downstream from the Everett Diversion Dam. Previous monitoring studies were conducted in 1982 (pre-construction), 1984 (immediately following construction), 1987 (three years after construction, and in 1994 (ten years after construction). After several consecutive years without achieving scouring flow thresholds in the Sultan River, the District was required to sample and analyze spawning gravel samples in 2005.

R2 Resource Consultants (R2) was contracted by the District to collect and analyze spawning gravel samples in 2005, and to compare the results from 2005 with the results from 1982, 1984, 1987, and 1994. The locations of the spawning gravel monitoring sites are shown in Figure 1-1. The five sites studied consisted of Sportsman Park (River Mile 0.1), Reese Park (River Mile 0.7), Trout Farm Road (River Mile 2.5), USGS Gage (River Mile 4.7), and Gold Camp (River Mile 7.3). This report presents the results of this comparative assessment.

This introductory section briefly summarizes the project history and provides a simplified description of Project operations. In addition, the fishery resources of the Sultan River are reviewed, and potential impacts of the Project on the sediment supply/sediment transport balance and textural composition of salmonid spawning gravels of the Sultan River are described.

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The co-licensees will make this information available to stakeholders of the Jackson Project upon request.

Figure 1-1. Locations of spawning gravel monitoring sites on the Sultan River between the diversion dam and the confluence with the Skykomish River.

1.1 PROJECT HISTORY

In 1930, the City of Everett constructed, at RM 9.7, the Diversion Dam that exists today. This dam was used to divert water from the Sultan River, through a pipeline and tunnel, west to Lake Chaplain for municipal water supply storage.

The Snohomish County Public Utility District No. 1 and the City of Everett (referred to herein as "City") filed a joint application with the Federal Power Commission (now FERC) in 1960 to develop what was then known as the Sultan River Project. From the beginning, the Project was seen as serving two purposes: generating power for the District from the waters of the Sultan River; and increasing the City's water supply system to meet growing demands. A license authorizing construction of the Project in two phases was issued on June 6, 1961.

The Stage I development was completed in 1965 and involved the construction of Culmback Dam and the creation of a reservoir known as Spada Lake, which greatly increased the City's water supply available from the Sultan River basin. Stage I operations commenced on April 5 1965. The Stage II development, which consisted of raising Culmback Dam and the construction of hydropower generation facilities, was completed in 1984. Power generation was initiated in May 1984.

1.2 PROJECT OPERATIONS

Generally speaking, the Project has two modes of operation, as illustrated in Figures 1-2 and 1-3. These two modes of operation depend on the magnitude of the inflow to the Sultan River between Culmback Dam and the diversion dam.

Under low and normal flow conditions (shown in Figure 1-2), flow is released from Spada Lake to the Sultan River to satisfy year round instream flow requirements of 20 cfs and flow is also routed through the power pipeline to the powerhouse. Some of the water that reaches the powerhouse is delivered up to Lake Chaplain through the Lake Chaplain pipeline. Some of the water that reaches Lake Chaplain is used to supply water to the City of Everett and the remainder is routed through a tunnel to the diversion dam on the Sultan River where it is released to satisfy instream flow requirements which vary seasonally from 95 cfs to 175 cfs. The remainder of the water that reaches the powerhouse is used to generate power and to satisfy instream flow requirements below the powerhouse (165 cfs from June 16 to September 14, and 200 cfs from September 15 to June 15).

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Figure 1-2. Directions of flow movement through the Project under low or normal flow conditions.

Under high flow conditions (shown in Figure 1-3), when the total combined inflows to the Sultan River between Culmback Dam and the diversion dam exceed the City's demand for water plus the instream flow requirement below the diversion dam, then it is no longer necessary to deliver water from the powerhouse to Lake Chaplain through the Lake Chaplain pipeline. When the quality is acceptable, water is diverted from the Sultan River at the diversion dam through the tunnel to Lake Chaplain to satisfy the City's demand for water and the remainder continues down the Sultan River to satisfy instream flow requirements. All of the water that is routed through the power pipeline to the powerhouse is, at these times, returned to the river at the powerhouse.

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Figure 1-3. Directions of flow movement through the Project under high flow conditions.

1.3 FISHERY RESOURCE

The lower 9.7 miles of the Sultan River between the confluence with the Skykomish River and the diversion dam are utilized by Chinook, coho, pink, and chum salmon, and by winter steelhead for spawning. The diversion dam prevents upstream passage past River Mile 9.7.

Chinook and pink salmon typically start spawning in mid-September, followed by coho salmon at the beginning of November, and by chum salmon in mid-November (District 2005). Winter steelhead typically start spawning at the beginning of March. The timing of spawning typically varies from year-to-year for the various species, depending on factors such as flow and water temperature. Spawning gravels in the lower 9.7 miles of the Sultan River are collectively used by the various species for spawning and/or incubation from mid-September to the end of July. In 2005, spawning gravels were collected from the Sultan River during late August to avoid disruption of redds.

Over the past 27 years, an average of approximately 500 Chinook have spawned in the Sultan River annually (District 2005). Prior to Stage II of the Project, escapement to the Sultan River averaged 410 fish annually. Since then, escapement has increased to an average of 546 fish, roughly a 33 percent increase.

1.4 SEDIMENT SUPPLY/SEDIMENT TRANSPORT BALANCE

The alteration in streamflows and the interruption in sediment transport that accompany the operation of a hydroelectric project can potentially initiate changes in channel morphology affecting habitat conditions, riparian communities and the aquatic ecosystem. Project operations result in the reductions in both peak flows and base flows, alteration in seasonal runoff patterns, and trapping of sediments from upstream in the watershed. The interaction of these project effects can potentially alter the texture of the streambed downstream of the dam.

A semi-quantitative study of these potential effects was performed by GeoEngineers (1984) with Michael Wert and Thomas Dunne providing support as Biological and Sediment Transport/Hydrology consultants, respectively. USGS topographic maps from prior to the construction of Culmback Dam suggested that the area currently inundated by Spada Lake was historically a depositional zone. Although Culmback Dam currently traps all of the coarse sediment that enters Spada Lake, it was assumed that most of this sediment would have deposited in this area even if Culmback Dam were not there. However, the amount of sediment that historically would have passed through the depositional zone prior to construction of Culmback Dam was not quantified. From the assumptions made in the study performed by GeoEngineers (1984), it was concluded that the Project has had minimal impact on the supply of coarse sediment to the Sultan River below Culmback Dam.

An inventory of downstream sources of sediment to the Sultan River was performed as part of the same study. It was found that the major source of sediment was in the reach of the valley between River Mile 11.2 and Culmback Dam, as shown in Figure 1-4. Sediment was delivered to this reach of the Sultan River by tributary creeks, landslides, and debris flows from the Pilchuck-Sultan Ridge on the north side of the river, and from Blue Mountain on the south side of the river. It was estimated that the average annual quantity of sediment supplied to this reach of the Sultan River was about 3,000 yd^3 or 3,900 tons. It was reported that smaller quantities of sediment would be supplied to the River between the confluence with the Skykomish River and River Mile 11.2, but no estimates were provided for these additional quantities.

Historically, flows in the Sultan River downstream from Culmback Dam were measured at five different locations, as shown in Figure 1-5. Since the Project began generating power in 1984, flows have been measured at two locations on the Sultan River downstream from the diversion dam (USGS 12137800) and downstream from the powerhouse (USGS 12138600). Prior to Stage I of the Project, flows were measured at two other locations: upstream from the diversion dam (USGS 12137500); and between the locations of the two current gages (USGS 12138000). As a result, direct comparison of Project impacts on the hydrology of the Sultan River using raw gage records is confounded by measurements at different locations and different time periods.

Major Source of Sediment

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Figure 1-4. Longitudinal profile of the Sultan River between the confluence with the Skykomish River and Culmback Dam.

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Figure 1-5. Locations of USGS Gaging Stations on the Sultan River between the confluence with the Skykomish River and Culmback Dam.

An approximate estimate of the impacts of the Project on the flood-frequency regime of the Sultan River can be derived by comparing annual peak flows since the Project began generating power with annual peak flows prior to Stage I of the Project (with peak flows adjusted by the ratio of drainage areas).

Annual peak flows since the Project began generating power were obtained from the gage on the Sultan River below the diversion dam (USGS 12137800, 77.1 mi^2). Annual peak flows at the same location prior to Stage I of the Project were estimated by multiplying the annual peak flows from USGS 12137500 by the ratio 77.1/74.5 and by multiplying the annual peak flows from USGS 12138000 by the ratio 77.1/86.6. Results of this comparison, shown in Figure 1-6, suggest that the Project has significantly reduced the magnitudes of frequently occurring floods with a recurrence interval of 3 years or less. The results also suggest a smaller reduction in the magnitudes of less frequently occurring floods with a recurrence interval of 5 years or more.

A similar analysis was performed for Sultan River below the powerhouse (USGS 12138160, 94.2 mi^2), with results shown in Figure 1-7. Similar trends were apparent at this location. However, the reduction in flood magnitudes was smaller at this location, as a result of the return of flows from the powerhouse to the Sultan River.

The reduction in flood magnitudes in the Sultan River suggests that the Project has reduced the capacity of the river to transport sediment. However, as previously mentioned, direct comparison of Project impacts on the hydrology and sediment transport regime of the Sultan River using measured flows is confounded by measurements during different time periods and at different locations. Furthermore, annual instantaneous flood peaks are insufficient to quantify sediment transport capacity on a daily, annual, or average annual basis. To perform this assessment, it would be necessary to have a long-term record of daily flows, coupled with a sediment transport rating curve.

GeoEngineers (1984) developed bed load transport rating curves for the Sultan River. To quantify the impacts of the Project on sediment transport capacity, it would be necessary to apply these bed load transport rating curves to a long-term record of concurrent daily flows daily flows, with and without the Project.

From Water Years 1985 through 2005, there are 21 years of daily flows available to perform this assessment since Stage II of the Project was initiated, as discussed in Section 4. Thus, the sediment transport capacity can be assessed under conditions with the Project in place. Results of this calculation are reported in Section 4. However, it would be necessary to synthesize a concurrent series of daily flows without the Project in place to assess the sediment transport capacity without the Project, and thus quantify the impacts of the Project on the sediment transport regime of the Sultan River.

In the study performed by GeoEngineers (1984), it was suggested that the Project has had minimal impact on the supply of sediment to the Sultan River. One potential result of this imbalance between the sediment transport capacity and the sediment supply might be an increase in the size and number of gravel patches available for spawning. The coarse cobble-boulder streambed in the canyon reach of the Sultan River could accommodate these types of textural changes without undergoing changes in overall morphology. Another potential result of the imbalance between sediment transport capacity and sediment supply might be an accumulation of fine sediment in the matrix of spawning gravel deposits.

It should also be mentioned that Culmback Dam provides the only flood control structure on the Skykomish River system, equal to 58,500 acre-feet of incidental flood control storage per year. Under the current Project Operating Plan, approved by the Corps of Engineers, the Sultan River contributes approximately 10 percent of the flow to the Skykomish River system during peak flow events. The Project captures for regulated release, on average, 94 percent of the water flowing into Spada Lake, and any spill from Spada Lake typically occurs after high flows in the Skykomish River have peaked. Thus the reduction in capacity of the Sultan River to transport sediment, as suggested by Figures 1-6 and 1-7 is associated with flood control on the Sultan and Skykomish rivers.

As previously mentioned, upstream passage of fish in the Sultan River from the confluence with the Skykomish River is currently limited by the diversion dam to the lower 9.7 miles of the Sultan River. Thus, a spawning gravel monitoring program was initiated in this reach of the Sultan River in 1982, prior to implementation of Stage II of the Project (Wert et al. 1982). Subsequent monitoring studies were conducted in 1984 (immediately following construction, Wert et al. 1984), 1987 (three years after construction, Shapiro and Associates 1988), and in 1994 (ten years after construction, Shapiro and Associates 1995). The total number of gravel samples collected each year ranged from 25 in 1987 to 50 in 1982 and 1984, as summarized in Table 1-1. Gravel samples were collected during different seasons, as summarized in Table 1-1. The initial samples in 1982 were collected in the spring; the samples collected in 1984 were collected in winter; and the samples collected in 1987 and 1994 were collected during late summer.

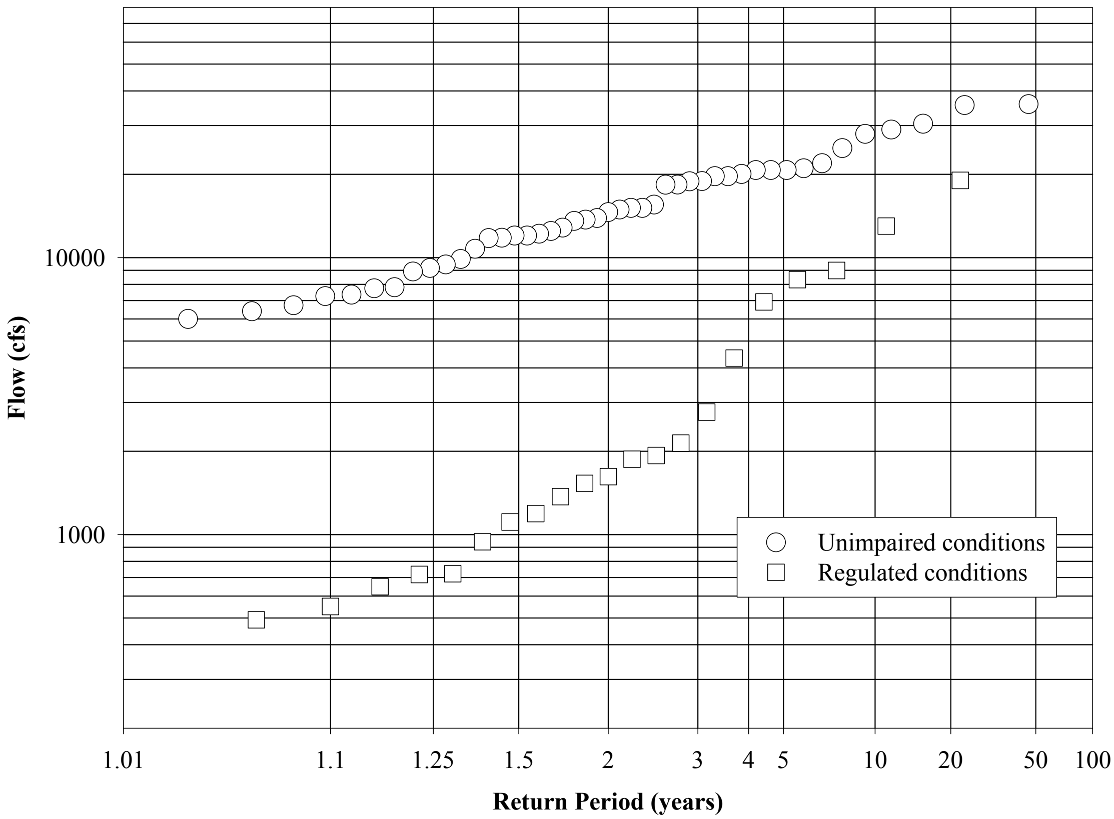

Figure 1-6. Flood-frequency regime in the Sultan River at River Mile 9.4 (below the diversion dam) prior to Stage I of the Project (unimpaired conditions) and since the Project began generating power (regulated conditions).

After several consecutive years without achieving scouring flow thresholds in the Sultan River, the District initiated sampling and analyses of spawning gravel samples in 2005 as part of its commitment to monitor spawning gravel quality following completion of gravel studies in 1994.

This report presents and compares the results of the 2005 monitoring effort with the results from the previous studies. Within the report: the **Methods** (Section 2) used to collect and analyze the spawning gravel samples are described; the **Results** (Section 3) of the spawning gravel monitoring are presented and compared with results from previous years; a **Discussion** (Section 4) of the textural quality of the spawning gravel with respect to the hydrologic/sediment transport regime is provided; and **Conclusions** (Section 5) are formulated.

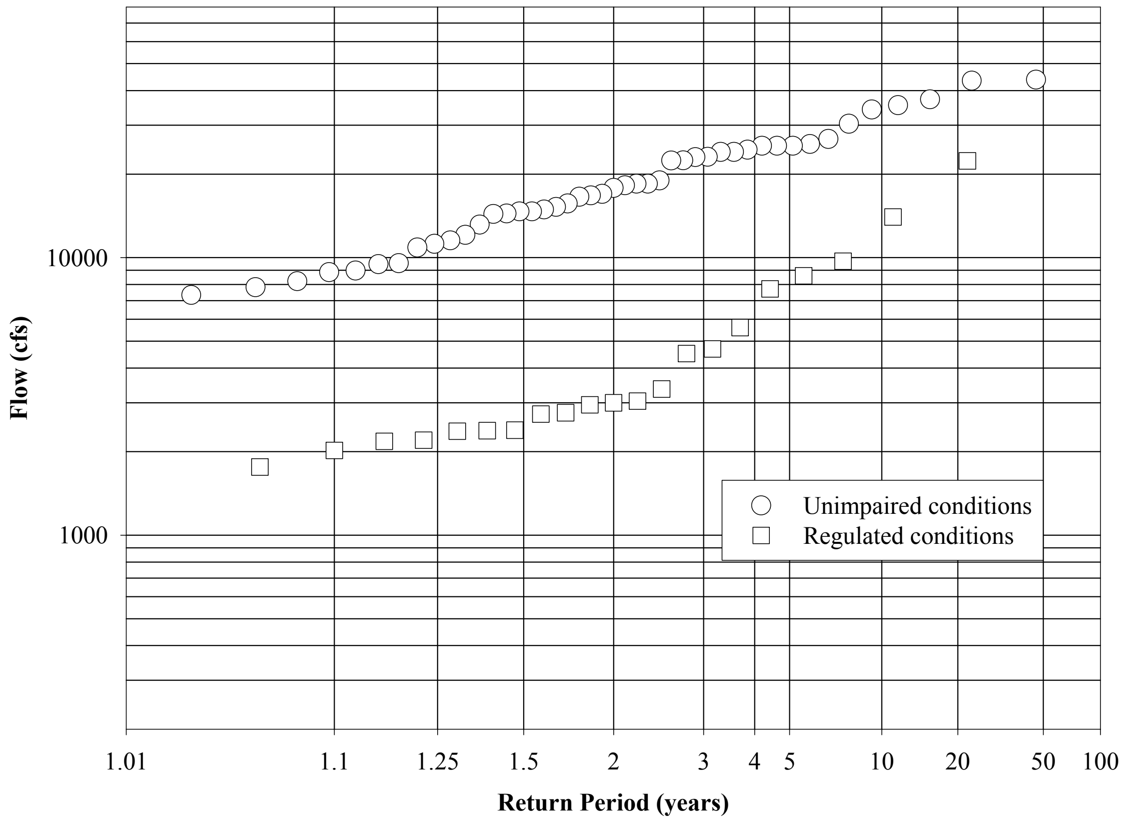

Figure 1-7. Flood-frequency regime in the Sultan River at River Mile 4.5 (below the powerhouse) prior to Stage I of the Project (unimpaired conditions) and since the Project began generating power (regulated conditions).

Table 1-1. Number of gravel samples collected from each of the five sites on the Sultan River in 1982, 1984, 1987, and 1994.

Location	1982		1984		1987		1994	
	Date	Number of Samples	Date	Number of Samples	Date	Number of Samples	Date	Number of Samples
Sportsman Park, River Mile 0.1, Site 1	May 14	10	Feb 20	10	Sep 15	5	Sep 7	5
Reese Park, River Mile 0.7, Site 2	Apr 27	10	Feb 18	10	Sep 16	5	Sep 8	5
Trout Farm Road, River Mile 2.5, Site 3	Apr 28	10	Feb 23	10	Sep 17	5	Sep 8	5
USGS Gage, River Mile 4.7, Site 4	May 12	10	Feb 29	10	Sep 17	5	Sep 9	9
Gold Camp, River Mile 7.3, Site 5	May 13	10	Mar 1	10	Sep 18	5	Sep 12	10
Total		***50***		***50***		***25***		***34***

2. METHODS

The methods utilized in the 2005 spawning gravel study were generally consistent with the methods utilized in previous years with one notable exception. Gravel samples were collected using a McNeil-type sampler (McNeil and Ahnell 1964) in 2005, whereas gravel samples collected in previous years were collected using freeze-core tubes. A comparison of these two methods is provided in Section 2.1.

In addition, two new gravel quality metrics were derived from the samples collected in 2005: percent fines less than 6.4 mm; and the Fredle Index. These two metrics, which were not derived in previous years, are useful for assessing potential survival-to-emergence of salmonid fry.

Within this section, the freeze-core tube method is compared with the McNeil method, field procedures and laboratory techniques are described, and methods for analyzing the gravel samples are discussed with regard to their biological impacts.

2.1 COMPARISON OF FREEZE-CORE TUBE METHOD WITH MCNEIL METHOD

Advantages and disadvantages of freeze-core tube samples and McNeil-type samples were discussed by Shirazi and Seim (1979) and Reiser et al. (1985). Relative advantages and disadvantages of these two techniques with respect to sampling the Sultan River are summarized below.

Primary advantages of the freeze-core tube method include the following:

- ✓ The sample can be stratified into vertical layers, thus providing some insight into where fine sediments are positioned vertically.

- ✓ The sample can be extracted from deeper water depths than would be allowed with the McNeil sampler.

Disadvantages of the freeze-core tube method include the following:

- ➢ The presence of a single large particle in the sample can bias the grain size distribution. Various criteria for minimum sample size required for sieve analyses were examined by

Church et al. (1987). The ASTM standard is illustrated in Figure 2-1. The freeze-core samples of gravel previously extracted from the Sultan River ranged in weight from 5 to 10 Kg. Thus, each sub-sampled layer ranged in weight from 1.25 to 2.50 Kg. According to Figure 2-1, gravel particles larger than 6 to 10 mm in size would be sufficient to bias the grain size distributions derived from these sub-samples.

- ➢ The field equipment required for freeze-core tube samples are heavy and cumbersome. More personnel are needed on site to collect the samples. Approximately 20 pounds of carbon dioxide are needed for each sample. The net result is that the freeze-core tube samples are more costly to obtain.
- ➢ When the steel probes are driven into the substrate, fine sediment can be shaken deeper into the gravel matrix (Lisle 1989). Thus, the method of obtaining the sample might decrease the percentage of fines in the upper strata and increase the percentage of fines in the lower strata.

Primary advantages of the McNeil sample method include the following:

- ✓ McNeil samples can accommodate larger sediment particles without biasing the grain size distribution. A sample obtained from a 12-inch-diameter by 12-inch-deep sample would weigh about 41 Kg. According to the ASTM standard shown in Figure 2-1, the largest sediment particle in the sample would need to be greater than 63 mm in size to bias the grain size distribution.
- ✓ Fewer personnel are needed in the field and no carbon dioxide is needed to collect the sample. Thus, McNeil samples are less costly to obtain.

Disadvantages of the McNeil sample method include the following:

- ➢ The sample cannot be stratified into layers, thus providing no insight into vertical distribution of fines.
- ➢ Samples are generally limited to flow depths not exceeding 1 to 1.5 feet depending on depth of the core.

Based on these comparisons, a 12-inch-McNeil-type sampler was selected for use in collecting spawning gravels during the 2005 survey.

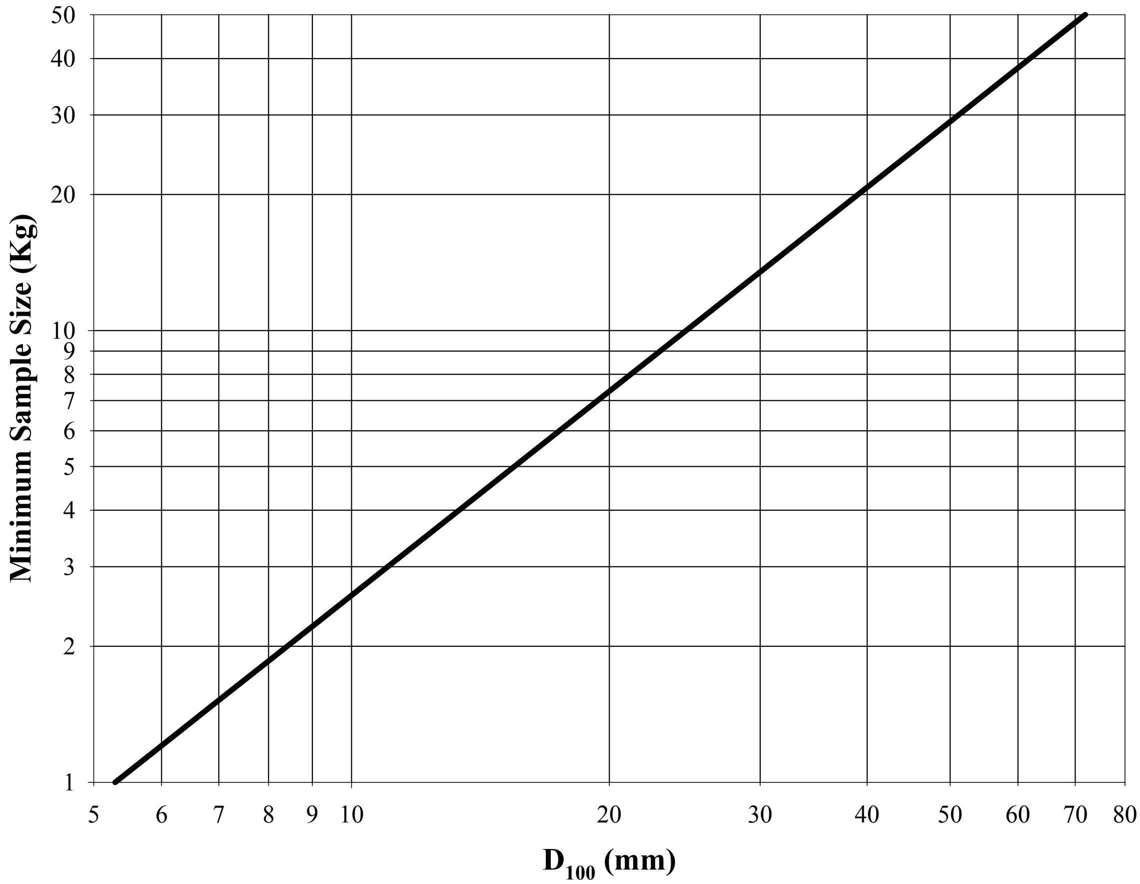

Figure 2-1. Minimum sample size required for sieve analysis, based on maximum sediment particle size in sample.

2.2 FIELD PROCEDURES

A total of 10 gravel samples were collected in 2005 from each of the 5 sites shown in Figure 1-1. Gravel monitoring from Sites 1 through 3 (below the powerhouse) was performed between August 15 and 17, when the flows in this reach of the Sultan River ranged from 171 to 174 cfs. Gravel samples from Sites 4 and 5 (between the powerhouse and the diversion dam) were collected between August 18 and 22, when the flows in this reach of the Sultan River ranged from 105 to 106 cfs.

Potential sample locations were initially selected based on a visual assessment of the gravel size composition, and then either confirmed or rejected after measuring depth and velocity. Depths were measured using a staff gage and velocities were measured using a Swoffer current meter at 6 tenths of the flow depth. Target depth and velocity ranges were selected based on spawning habitat suitability needs of the various species. The target depth range was 0.5 to 1.5 feet (limited at the higher end to prevent overtopping of the McNeil sampler). The target velocity range was 1.2 to 3.0 fps, which is within the range of velocities reportedly used by a number of salmonids (Bjornn and Reiser 1991).

The bulk composition of substrates within each sediment monitoring location was sampled using a 12-inch-diameter core sampler, shown in Figure 2-2, designed after a 6-inch version developed by McNeil and Ahnell (1964). Substrate samples were collected to a maximum depth of 12 inches below the streambed level. The samples were therefore 12 inches in diameter, 12 inches high, and weighed approximately 90 pounds (dry weight). Because the sampler can only be inserted to a depth of 8 inches, an additional 4 inches of gravel was extracted by hand below the bottom of the sampler. The extracted sediment was placed in the internal reservoir between the inner and outer cylinders, as shown in Figure 2-2. Remaining suspended fine sediments were sub-sampled by stirring the water in the sampler to resuspend the sediments and collecting a sample with a pint-sized jar.

The McNeil sample was then carried to the streambank and placed over a five-gallon bucket lined with a sample bag. The gravel sample was then transferred by hand from the internal reservoir of the McNeil sampler to the five-gallon bucket. Any remaining fine sediment in the internal reservoir was rinsed out and poured into the five-gallon bucket.

Gravel samples were separately analyzed by washing the sediment through a series of Tyler screens. Sieve sizes utilized in previous studies on the Sultan River are listed in Table 2-1. A similar but slightly different series of sieves was utilized in 2005 to provide a comparable substrate characterization of the gravel samples (Table 2-1). The volumetric displacement of material retained on each sieve was measured to the nearest 10 millimeters.

Fine sediment passing through the smallest sieve was funneled into an Imhoff cone. The sediment was allowed to settle for about half an hour. The suspended sediment samples collected with pint jars from the McNeil samples were also processed separately in the Imhoff cone. The volume of sediment collected with the pint jar was scaled-up based on the ratio of total volume of the sample to the volume of the pint jar, and the result was added to the residual fine sediment volume from the sieve analysis.

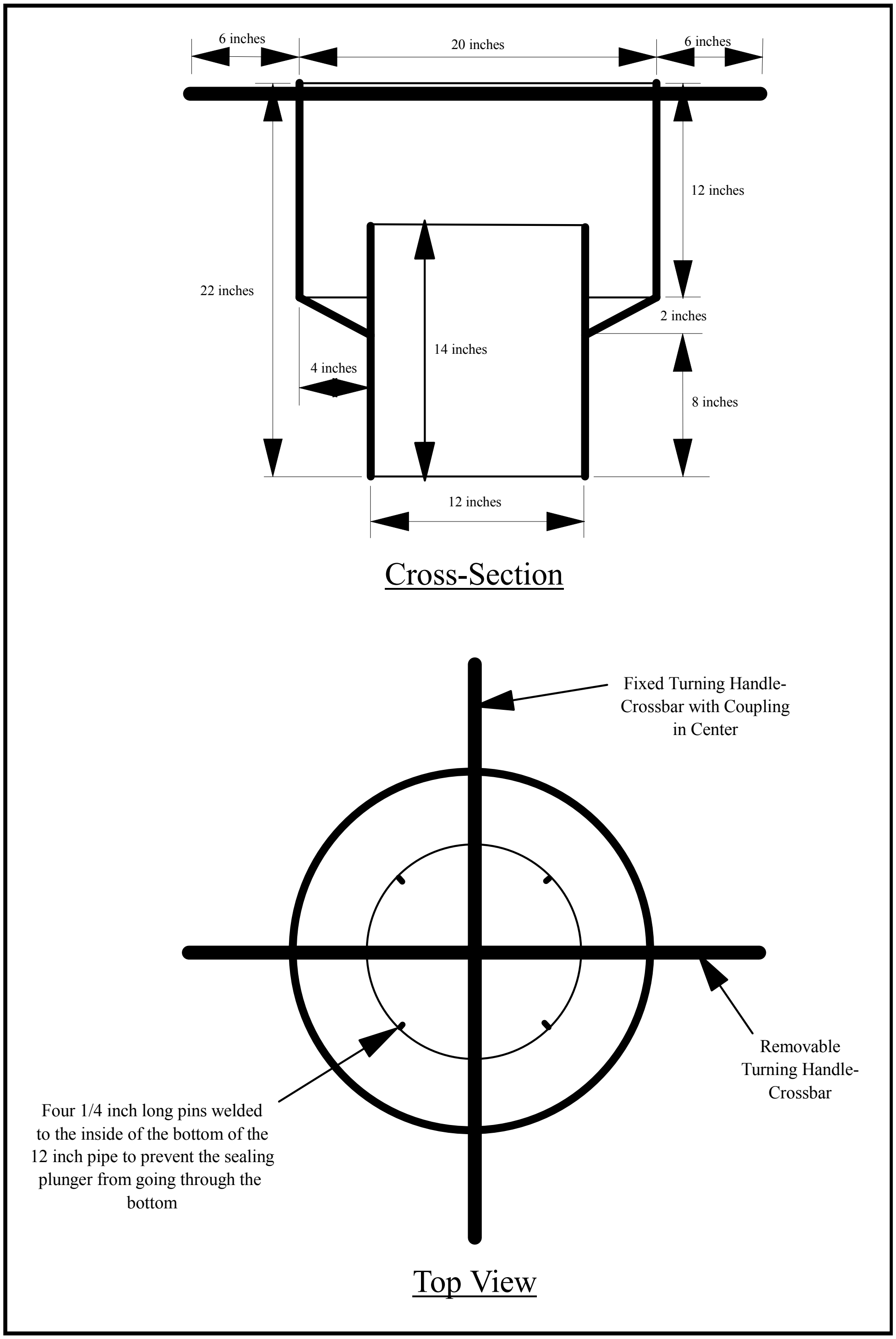

Figure 2-2. Schematic of 12-inch diameter substrate sampler, modeled after the original 6-inch diameter sampler developed by McNeil and Ahnell (1964).

Table 2-1. Sieve sizes used in previous studies on the Sultan River and sieve sizes utilized in 2005 study.

Sieve Sizes (mm)	
Used in Previous Studies on Sultan River	**Utilized in 2005 Study**
---	63
53.8	---
---	31.5
25.4	---
---	16
13.5	---
---	8
6.7	---
---	4
3.35	---
---	2
1.68	---
---	0.85
0.84	---
---	0.5
0.42	---
0.21	---
0.105	---

The portion of each sample retained on the 2 mm sieve (2 to 4 mm in size) was stored in a zip-lock plastic bag and brought back to the laboratory to determine the specific gravity of the sediment. Determination of specific gravity was needed to subsequently correct the measured wet volumes in the field to account for the portion of the wet volume comprised only of dry sediment.

2.3 LABORATORY TECHNIQUES

The portion of the gravel samples retained on the 2 mm sieve (2 to 4 mm in size) was analyzed to determine specific gravity of the sediment. The dry contents of the 2-mm sieve were used to estimate the specific gravity of the sediment by dividing the dry weight of the sample in grams by the volume of water it displaces in cubic centimeters. The sediment samples were oven-dried prior to measuring the dry weight.

The measured wet volumes in the field were then corrected to account for the portion of the total volume consisting of sediment, i.e., not including the water adhering to the sediment after allowing excess water to drain from each sample. The correction was based on the adjustment recommended by Shirazi and Seim (1979), as shown in Figure 2-3. Dry weights retained on the other sieves were estimated assuming the density was the same as the density of sediment retained on the 2-mm sieve.

2.4 ANALYSIS OF GRAVEL SAMPLES

Grain size distributions were determined for each gravel sample, based on both dry and wet volumes. These grain size distributions were then analyzed to determine various gravel indices that have been found to be significant measures of salmonid spawning quality. There are numerous metrics that have been developed and used to characterize substrate samples. The majority of the metrics have focused on defining sediment concentrations (expressed as some percentage of particles that are smaller) that may be impacting salmonid egg incubation and fry emergence. Other metrics (e.g., Fredle index, geometric mean diameter) have been developed that have attempted to link values to percentage egg survival or fry emergence. Reiser (1999) and Shirazi et al. (1981) provided an overview of these and other techniques.

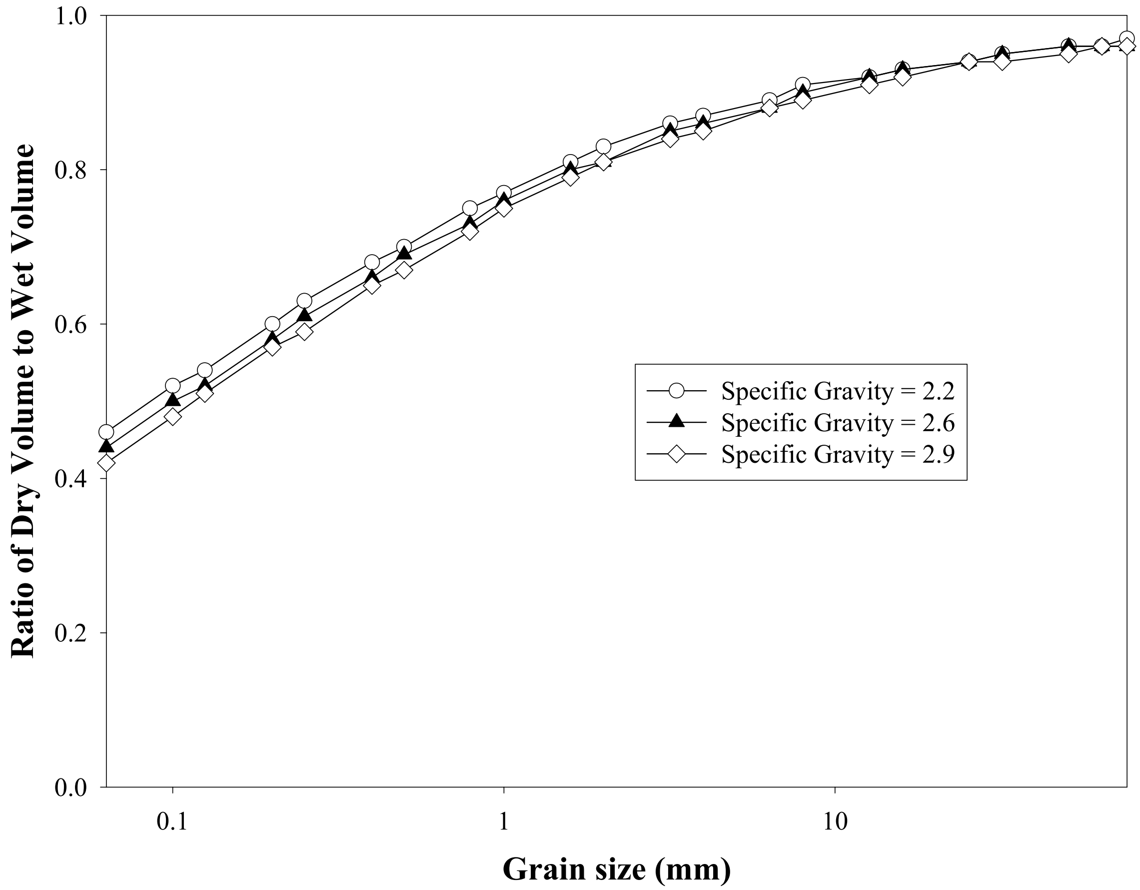

Figure 2-3. Ratio of dry volume to wet volume used to correct spawning gravel wet sieve analyses, as determined by Shirazi and Seim (1979).

The list of gravel quality metrics derived from the samples collected in 2005 are described below and include three of the six metrics determined in the previous monitoring investigations, and three new metrics:

1. ***DGD*** – the geometric mean diameter based on gravimetric data calculated using the method of Lotspeich and Everest (1981). This metric was also determined in the four previous investigations (1982, 1984, 1987, and 1994).

2. ***PFG (0.84)*** – the percent fines less than 0.84 mm based on gravimetric data. This metric was also determined in the four previous investigations (1982, 1984, 1987, and 1994).

3. ***PFG (6.4)*** – the percent fines less than 6.4 mm based on gravimetric data. This is a new metric determined only from the samples collected in 2005.

4. ***FI*** – Fredle index computed using the method described by Lotspeich and Everest (1981). This is a new metric determined only from the samples collected in 2005.

5. ***Srt*** – sorting coefficient as defined by Lotspeich and Everest (1981). This is a new metric determined only from the samples collected in 2005.

Of these gravel quality metrics, there are basically four different types that have been found to be particularly significant with regard to salmonid spawning gravel quality: geometric mean diameter; percent fines (less than 0.84 mm and percent fines less than 6.4 mm); and the Fredle index.

2.4.1 Geometric Mean Diameter

Shirazi and Seim (1979) collected and analyzed the results of embryo survival studies of coho salmon, cutthroat trout, sockeye salmon, and steelhead. A relationship was found between embryo survival and geometric mean diameter of the spawning gravel matrix, as shown in Figure 2-4. The geometric mean diameter, d_g, for a gravel sample is calculated using the following equation:

$$d_g = \left(d_1^{p_1} * d_2^{p_2} * \ldots * d_n^{p_n} \right)$$

where d is the mid-point diameter of particles retained by a given sieve and p is the fraction of particles retained by a given sieve.

From the results shown in Figure 2-4, 50% embryo survival would be associated with a geometric mean diameter of 10.8 mm. This criterion was adopted for this study to compare results from gravel samples collected in 2005 with those from previous years (1982, 1984, 1987, and 1994). Another reason for selecting the 50% threshold for geometric mean diameter is that similar thresholds can be identified for percent fines less than 0.84 mm and 6.4 mm, and for the Fredle index.

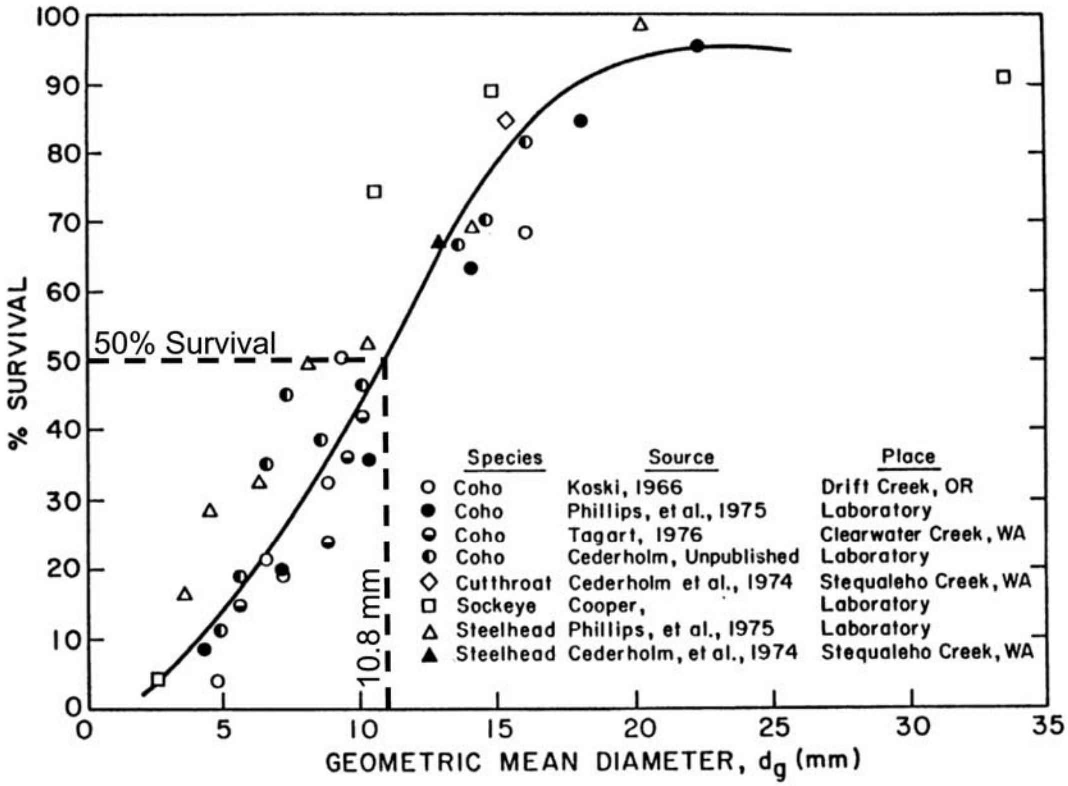

Figure 2-4. Relationship between percent embryo survival (coho salmon, cutthroat trout, sockeye salmon, and steelhead) and substrate composition expressed in terms of geometric mean diameter (Shirazi and Seim 1979).

2.4.2 Percent Fines

It has long been recognized that survival to emergence of salmonid redds can be impaired if there is an excessive portion of fine sediment in the gravel matrix. Two reference grain sizes (0.84 mm and 6.4 mm) for assessing fine sediment have become prevalent in studies of survival to emergence.

The smaller grain size (0.84 mm) is important for assessing survival of the egg phase during incubation. An excessive quantity of sediment finer than 0.84 mm can reduce the permeability of a gravel matrix and potentially deprive the eggs in a redd of dissolved oxygen needed for survival. McNeil and Ahnell (1964) performed laboratory studies of gravel permeability and found that as percent fines less than 0.833 mm in the gravel increased, the permeability of the gravel matrix decreased, as shown Figure 2-5.

Kondolf (2000) compiled the results of previous investigations of embryo survival of coho salmon and rainbow trout. The percent fines less than 0.83 mm was determined for the 50% survival level. It was found that 50% survival was associated with percent fines ranging from 7.5% to 21% with a median level of 12%, as shown in Figure 2-6. The reference grain size of 0.83 mm evaluated by Kondolf is practically the same size as the reference grain size of 0.84 mm analyzed in the previous Sultan River investigations. A criterion of 12% fines less than 0.84 mm was therefore adopted for this study to assess the results from gravel samples collected in 2005 with those from previous years (1982, 1984, 1987, and 1994).

The larger grain size (6.4 mm) is important for assessing survival of the alevin phase during incubation. Alevins need space within the gravel matrix to move and eventually emerge from the substrate. An excessive quantity of sediment finer than 6.4 mm can block the interstitial spaces within the gravel matrix and potentially trap the alevins within the substrate, preventing their emergence.

Kondolf (2000) also compiled the results of previous investigations of survival to emergence of Chinook salmon, cutthroat trout, kokanee, rainbow trout, and steelhead. The percent fines less than 6.35 mm was determined for the 50% survival level. It was found that 50% survival was associated with percent fines ranging from 15% to 40%, with a median level of 30%, as shown in Figure 2-6. A criterion of 30% fines less than 6.4 mm was adopted for this study to assess the results from gravel samples collected in 2005. Grain size distributions of gravel samples collected during the previous studies of the Sultan River were not reported, so the percent fines less than 6.4 mm could not be determined for the previous investigations.

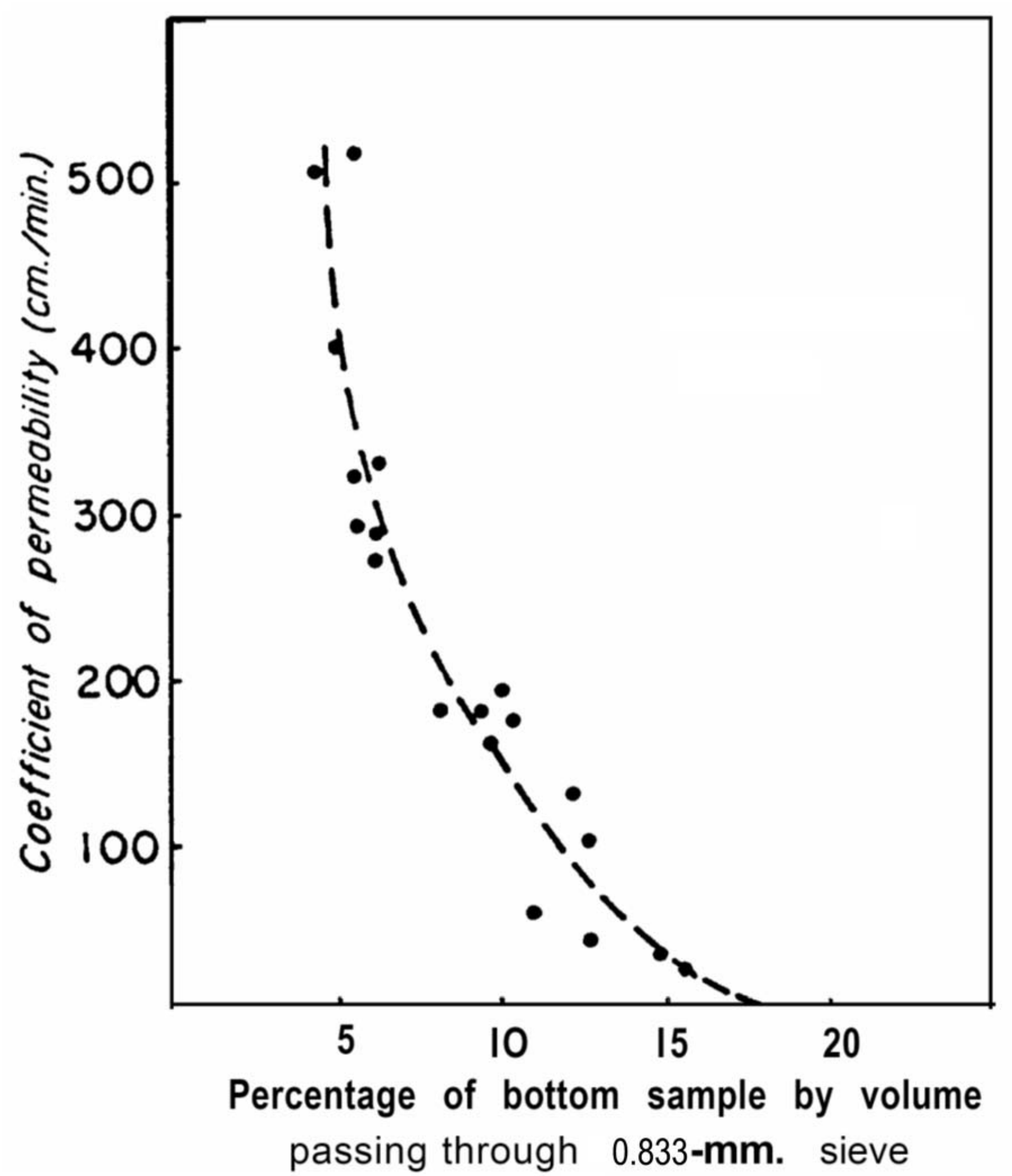

Figure 2-5. Relationship between coefficient of permeability and percent sediments finer than 0.833 mm from laboratory tests of gravel samples conducted by McNeil and Ahnell (1964).

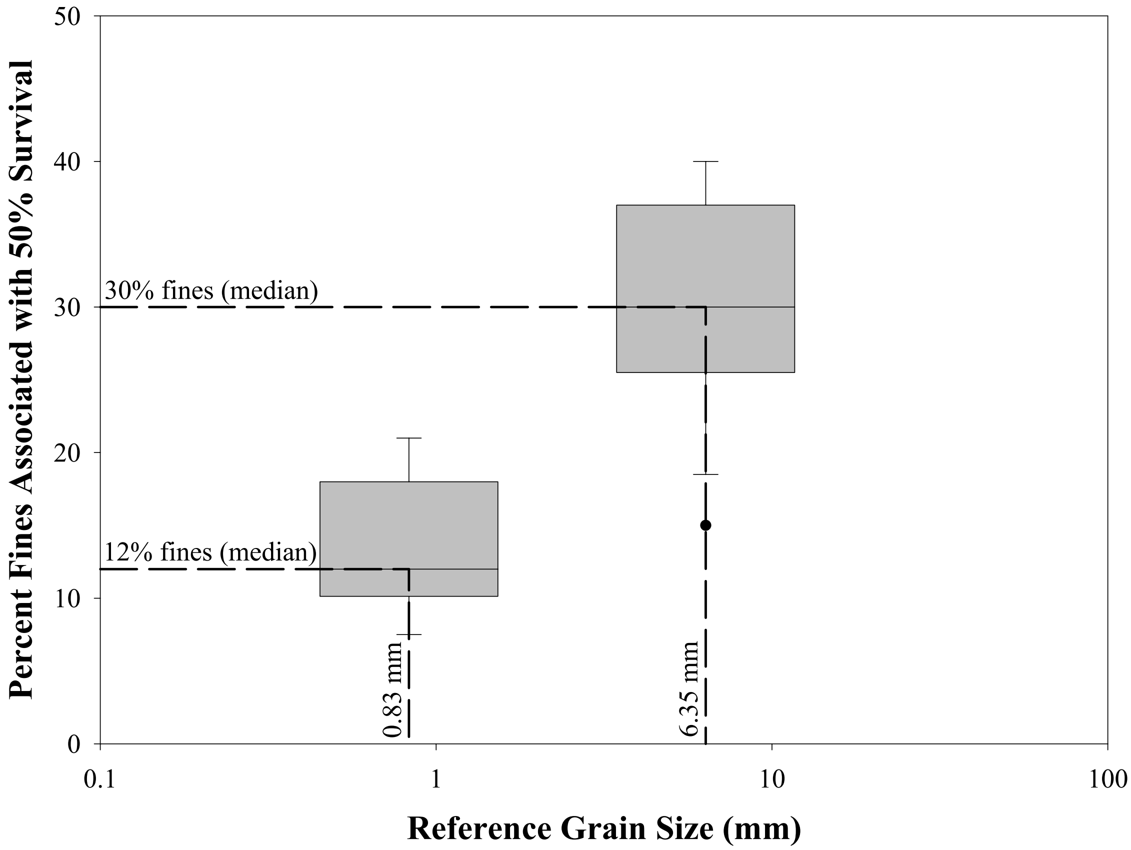

Figure 2-6. Percent fines associated with 50% survival based on reference grain sizes of 0.83 mm (coho salmon and rainbow trout) and 6.35 mm (Chinook salmon, cutthroat trout, kokanee, rainbow trout, and steelhead) as reported by Kondolf (2000).

2.4.3 Fredle Index

The Fredle index, F_i, was introduced by Lotspeich and Everest (1981) as a refinement of the geometric mean diameter for assessing the quality of spawning gravels. It was recognized that two different gravel samples might have identical geometric mean diameters, but one sample might be more permeable than the other because it had a more uniform grain size distribution. Thus, the geometric mean diameter was adjusted to account for the uniformity of the grain size distribution by dividing the geometric mean diameter by a sorting coefficient, S_o. The sorting coefficient was calculated as follows:

$$S_o = \sqrt{\frac{d_{75}}{d_{25}}}$$

Where d_{75} and d_{25} are the 75th and 25th percentiles of the grain size distribution, respectively. Thus the Fredle index is calculated as follows:

$$F_i = \frac{d_g}{S_o}$$

Lotspeich and Everest (1981) determined survival-to-emergence for coho salmon and steelhead as related to the Fredle index using data reported by Phillips et al. (1975). These results, shown in Figure 2-7, indicate that 50% survival-to-emergence is associated with a Fredle index of about 2.7 mm. This criterion was therefore adopted for this study to assess the results from gravel samples collected in 2005. Grain size distributions of gravel samples collected during the previous studies of the Sultan River were not reported, and thus the Fredle index could not be determined from those investigations.

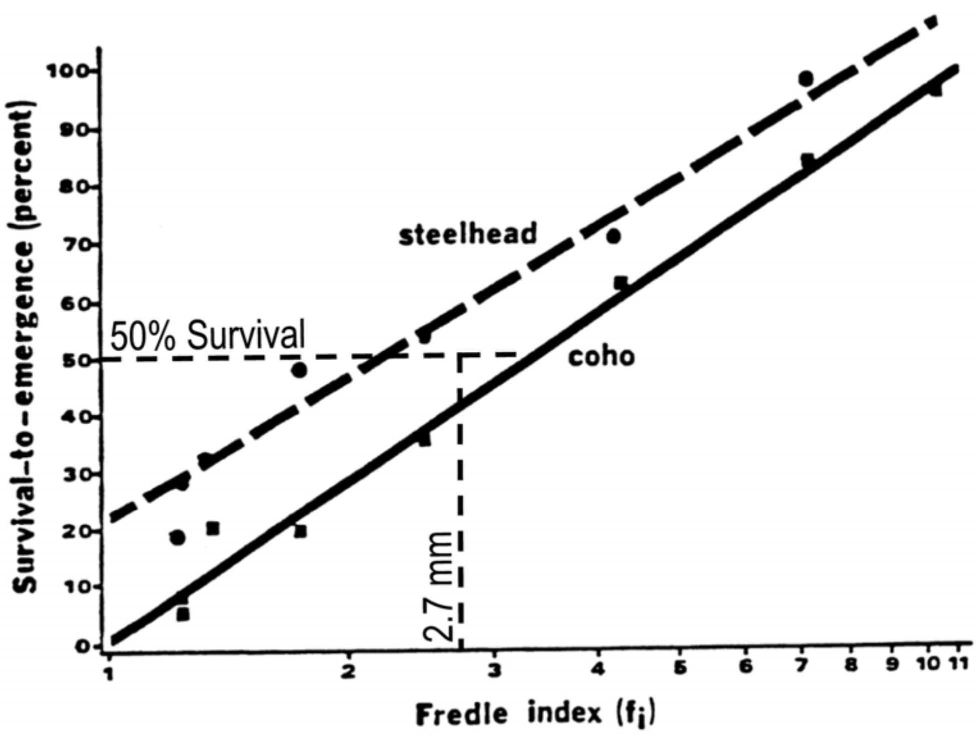

Figure 2-7. Survival-to-emergence of coho salmon and steelhead as related to the Fredle index, as reported by Lotspeich and Everest (1981).

3. RESULTS

This section presents the results of the 2005 gravel monitoring, and a comparison of results to previous surveys. The analysis focused on determining whether impacts of Stage II Project operations could be detected in the quality of spawning gravels in the Sultan River between the confluence with the Skykomish River and the diversion dam.

3.1 GRAVEL MONITORING RESULTS FROM 2005

During 2005, gravel samples were collected from the lower 9.7 miles of the Sultan River from the five locations shown in Figure 1-1: Site 1 (Sportsman Park, River Mile 0.1); Site 2 (Reese Park, River Mile 0.7); Site 3 (Trout Farm Road, River Mile 2.5): Site 4 (USGS Gage, River Mile 4.7); and Site 4 (Gold Camp, River Mile 7.3).

3.1.1 Sportsman Park, River Mile 0.1

The Sportsman Park Site is located on the Sultan River 0.1 miles upstream from the confluence with the Skykomish River (Figures 3-1 and 3-2). This site likely becomes a backwater depositional zone when there are high flows in the Skykomish River. The backwater effect of the Skykomish River could create conditions where fine sediments would deposit in the spawning gravels at this site.

Ten gravel samples were collected on August 15, 2005, at the Sportsman Park Site from the locations shown in Figure 3-1; flow in the Sultan River during this time was 172 cfs.

Grain size distributions of the 10 gravel samples from the Sportsman Park Site are listed in tabular form and shown graphically in Appendix A. Spawning gravel quality metrics, derived from these grain size distributions are shown in Table 3-1.

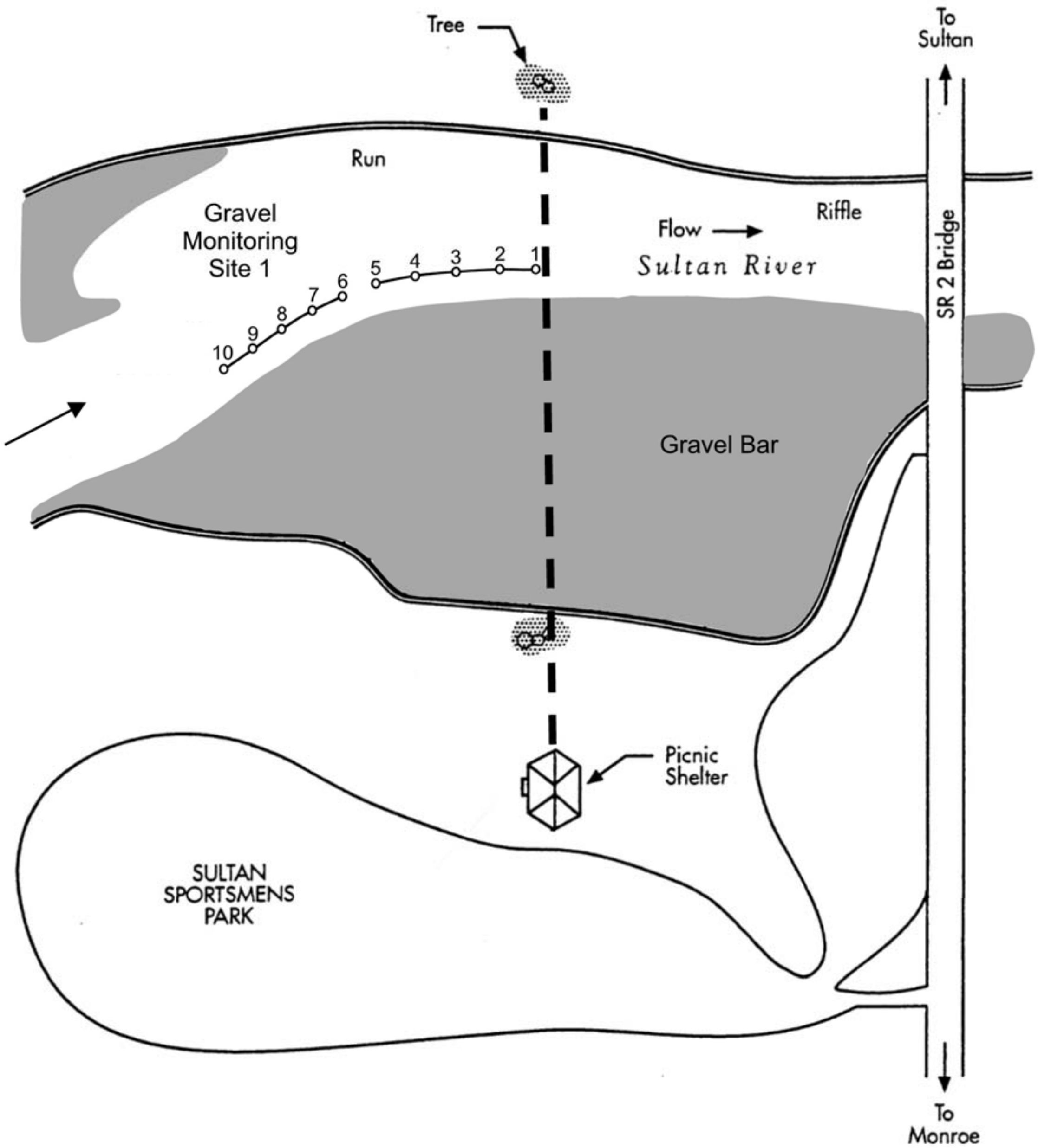

Figure 3-1. Locations of 10 gravel samples collected from Site 1 on the Sultan River (Sportsman Park, River Mile 0.1) on August 15, 2005.

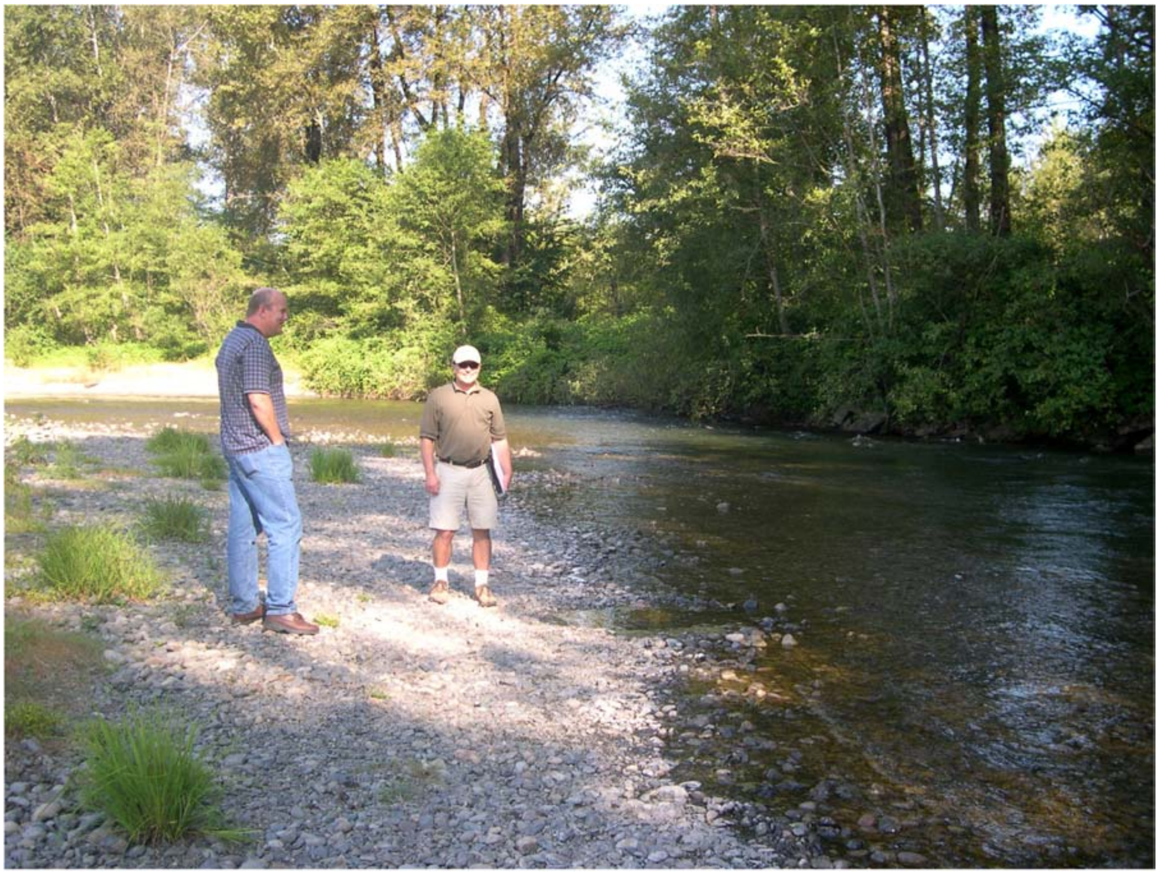

Figure 3-2. Gravel monitoring Site 1 on the Sultan River (Sportsman Park, River Mile 0.1) looking upstream, August 4, 2005, flow = 310 cfs.

The median levels of geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, and Fredle index all were associated with potential survival to emergence levels in excess of 50% for the gravel samples collected from the Sportsman Park Site. The geometric mean diameter was associated with potential survival levels in excess of 50% for all of the ten samples. One of the ten samples was associated with potential survival to emergence levels below 50% based on percent fines less than 0.84 mm; four of the ten samples were associated with potential survival levels below 50% based on percent fines less than 6.4 mm; and two of the ten samples were associated with potential survival levels below 50% based on Fredle index. The potential backwater effects from the Skykomish River might account for these elevated levels.

Table 3-1. Geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, sorting coefficient, and Fredle index of gravel samples collected from Site 1 on the Sultan River (Sportsman Park, River Mile 0.1), August 15, 2005.

Sample	**Geometric Mean Diameter (mm)**	**Percent Fines Less Than 0.84 mm**	**Percent Fines Less Than 6.4 mm**	**Sorting Coefficient**	**Fredle Index (mm)**
S1-1	11	11	37	4.5	2.5
S1-2	28	6	23	3.3	8.4
S1-3	13	13	32	4.2	3.2
S1-4	15	8	30	3.5	4.2
S1-5	11	12	36	4.0	2.7
S1-6	21	3	24	3.0	6.9
S1-7	29	1	19	2.7	10.6
S1-8	16	3	30	3.3	5.0
S1-9	16	4	31	3.5	4.6
S1-10	35	2	12	2.1	16.4
Maximum	35	13	37	4.5	16.4
Median	16	5	30	3.4	4.8
Minimum	11	1	12	2.1	2.5

3.1.2 Reese Park, River Mile 0.7

The Reese Park Site is located on the Sultan River 0.7 miles upstream from the confluence with the Skykomish River; the site is characterized by a relatively mild gradient (Figure 1-4) that creates a depositional zone for gravel transported from the upstream canyon (Figure 3-3).

Ten gravel samples were collected on August 16, 2005, at the Reese Park Site (Figure 3-4) from locations shown in Figure 3-3; flow in the Sultan River at this time was 171 cfs.

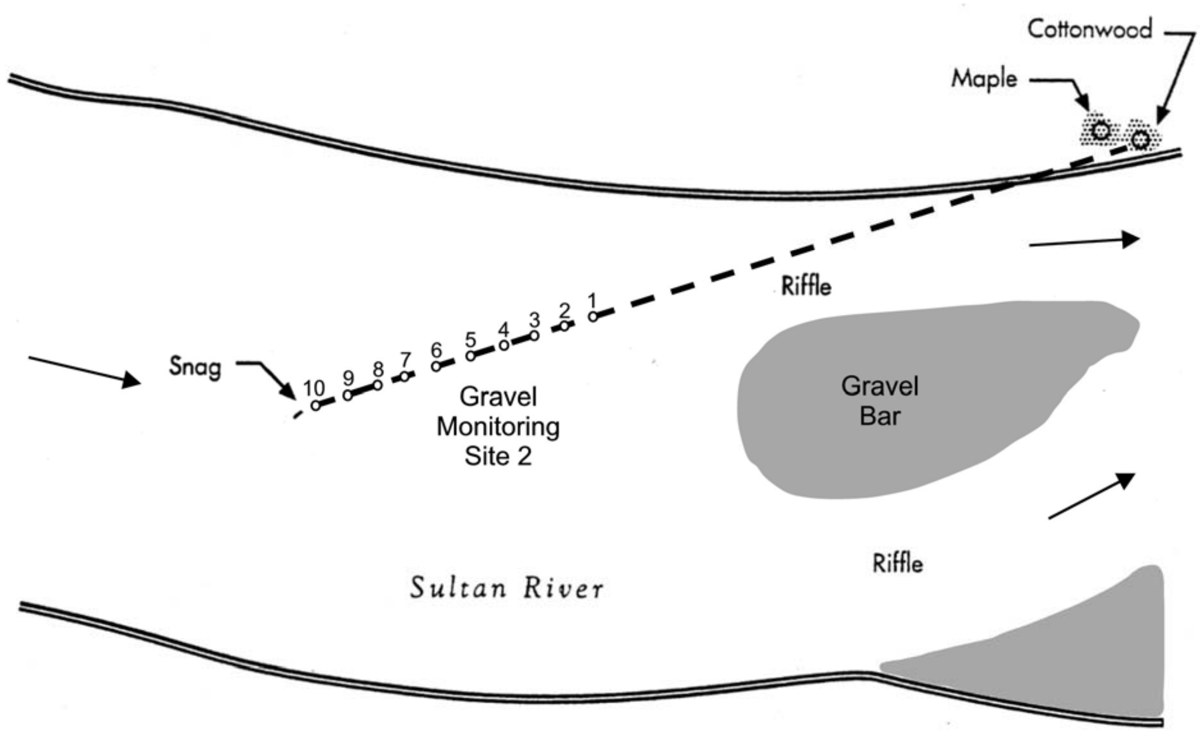

Figure 3-3. Locations of 10 gravel samples collected from Site 2 on the Sultan River (Reese Park, River Mile 0.7) on August 16, 2005.

Figure 3-4. Gravel monitoring Site 2 on the Sultan River (Reese Park, River Mile 0.7) looking upstream towards snag, August 4, 2005, flow = 310 cfs.

Grain size distributions of the 10 gravel samples from the Reese Park Site are presented in Appendix A. Spawning gravel quality metrics, derived from these grain size distributions are shown in Table 3-2.

The geometric mean diameter, percent fines less than 0.84 mm, and Fredle index all were associated with potential survival to emergence levels in excess of 50% for all ten of the gravel samples collected from the Reese Park Site. The median level of percent fines less than 6.4 mm was associated with potential survival level in excess of 50% and only two of the ten samples were associated with potential survival levels below 50% based on percent fines less than 6.4 mm.

Table 3-2. Geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, sorting coefficient, and Fredle index of gravel Table 3-2. Geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, sorting coefficient, and Fredle index of gravel samples collected from Site 2 on the Sultan River (Reese Park, River Mile 0.7), August 16, 2005.

Sample	Geometric Mean Diameter (mm)	Percent Fines Less Than 0.84 mm	Percent Fines Less Than 6.4 mm	Sorting Coefficient	Fredle Index (mm)
S2-1	18	4	28	3.9	4.6
S2-2	16	5	31	4.0	4.0
S2-3	19	4	27	3.7	5.1
S2-4	24	4	24	3.5	6.9
S2-5	19	4	25	3.2	6.0
S2-6	22	4	24	3.2	6.8
S2-7	24	3	23	3.2	7.5
S2-8	15	4	31	3.4	4.4
S2-9	29	3	18	2.7	10.5
S2-10	19	4	27	3.5	5.4
Maximum	29	5	31	4.0	10.5
Median	19	4	26	3.5	5.7
Minimum	15	3	18	2.7	4.0

3.1.3 Trout Farm Road, River Mile 2.5

The Trout Farm Road Site is located on the Sultan River 2.5 miles upstream from the confluence with the Skykomish River (Figure 1-1). This site is likewise characterized by a relatively mild gradient (Figure 1-4) that creates a depositional zone for gravel transported from the upstream canyon (Figure 3-5).

Ten gravel samples were collected on August 17, 2005, at the Trout Farm Road Site (Figure 3-6) from the locations shown in Figure 3-5; flow in this reach of the Sultan River at the time of sampling was 171 cfs.

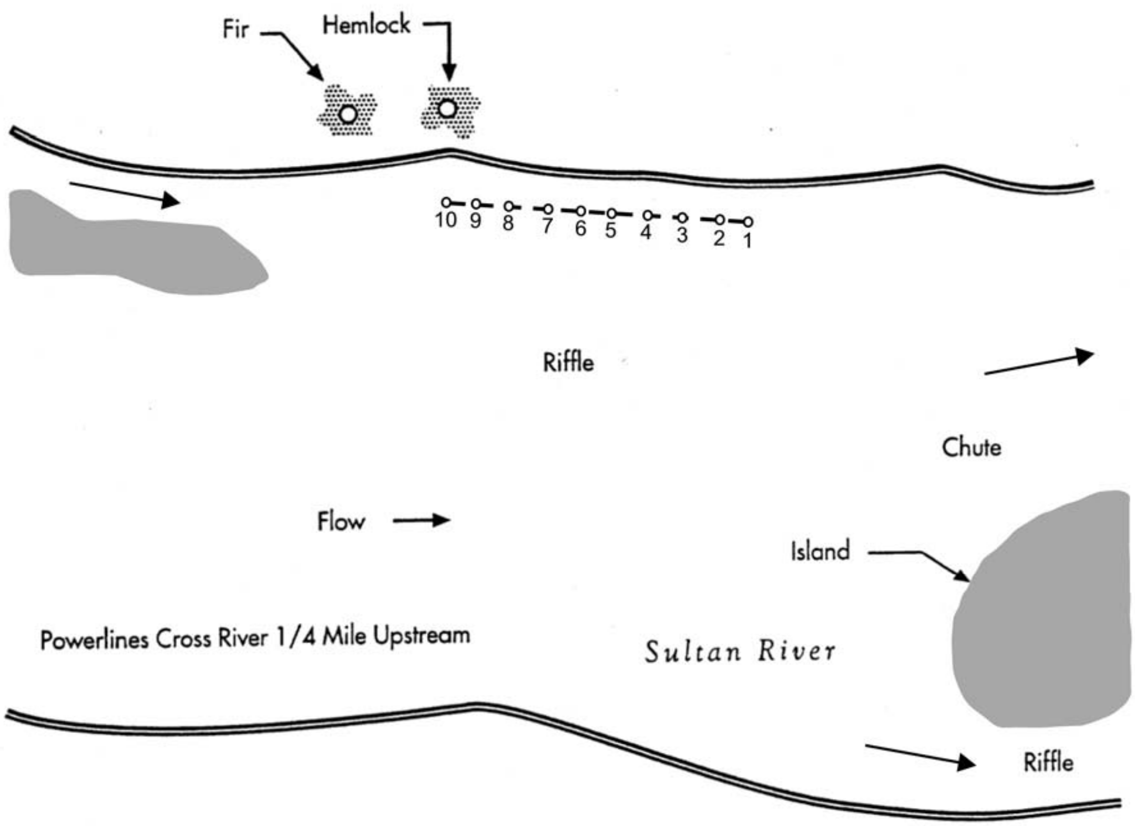

Figure 3-5. Locations of 10 gravel samples collected from Site 3 on the Sultan River (Trout Farm Road, River Mile 2.5) on August 17, 2005.

Figure 3-6. Gravel monitoring Site 3 on the Sultan River (Trout Farm Road, River Mile 2.5) looking downstream, August 4, 2005, flow = 310 cfs.

Grain size distributions of the 10 gravel samples from the Trout Farm Road Site are presented in Appendix A. Spawning gravel quality metrics, derived from these grain size distributions are shown in Table 3-3. The geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm and Fredle index all were associated with potential survival to emergence levels in excess of 50% for all ten of the gravel samples collected from the Trout Farm Road Site.

Table 3-3. Geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, sorting coefficient, and Fredle index of gravel samples collected from Site 3 on the Sultan River (Trout Farm Road, River Mile 2.5), August 17, 2005.

Sample	Geometric Mean Diameter (mm)	Percent Fines Less Than 0.84 mm	Percent Fines Less Than 6.4 mm	Sorting Coefficient	Fredle Index (mm)
S3-1	28	2	18	2.7	10.5
S3-2	27	3	22	3.1	8.6
S3-3	21	4	26	3.6	5.7
S3-4	25	2	20	2.8	9.2
S3-5	29	2	19	2.9	10.0
S3-6	20	4	29	4.3	4.8
S3-7	30	2	21	3.2	9.3
S3-8	33	2	16	2.4	13.8
S3-9	36	2	15	2.3	15.2
S3-10	33	2	20	3.2	10.4
Maximum	36	4	29	4.3	15.2
Median	28	2	20	3.0	9.7
Minimum	20	2	15	2.3	4.8

3.1.4 USGS Gage, River Mile 4.7

The USGS Gage Site is located on the Sultan River 4.7 miles upstream from the confluence with the Skykomish River (Figure 1-1). This reach of the Sultan River has a steeper gradient than the lower 3 miles with channel substrates consisting of relatively immobile boulders, with occasional patches of spawning gravel (Figure 3-7).

Ten gravel samples were collected on August 18, 2005, at the USGS Gage Site from the locations shown in Figures 3-8 and 3-9; flow during this time was 105 cfs (Figure 3-10).

Figure 3-7. Sultan River within the canyon, substrate consists of relatively immobile boulders with occasional patches of gravel.

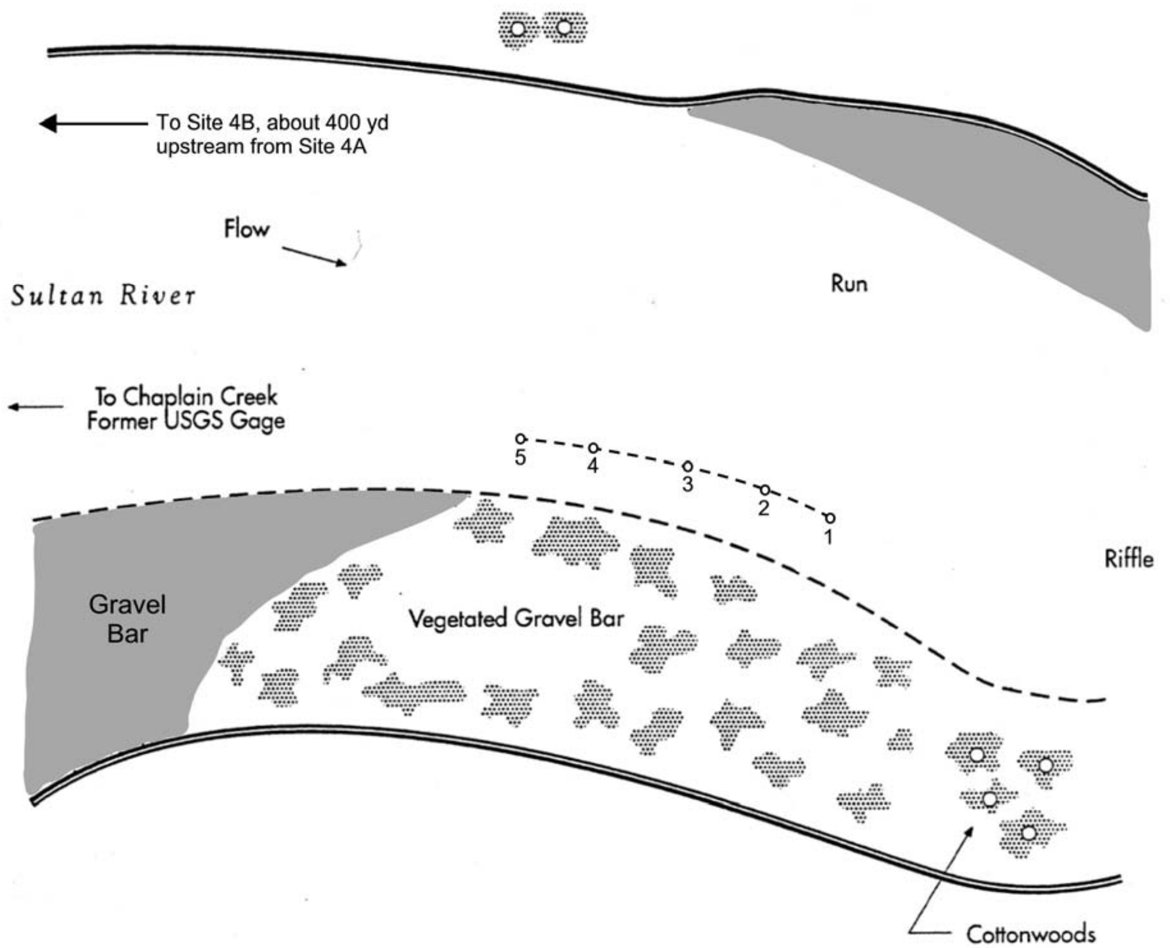

Figure 3-8. Locations of five of 10 gravel samples collected from Site 4A on the Sultan River (USGS Gage, River Mile 4.7) on August 18, 2005.

Grain size distributions of the 10 gravel samples from the USGS Gage Site are presented in Appendix A. Spawning gravel quality metrics, derived from these grain size distributions are shown in Table 3-4.

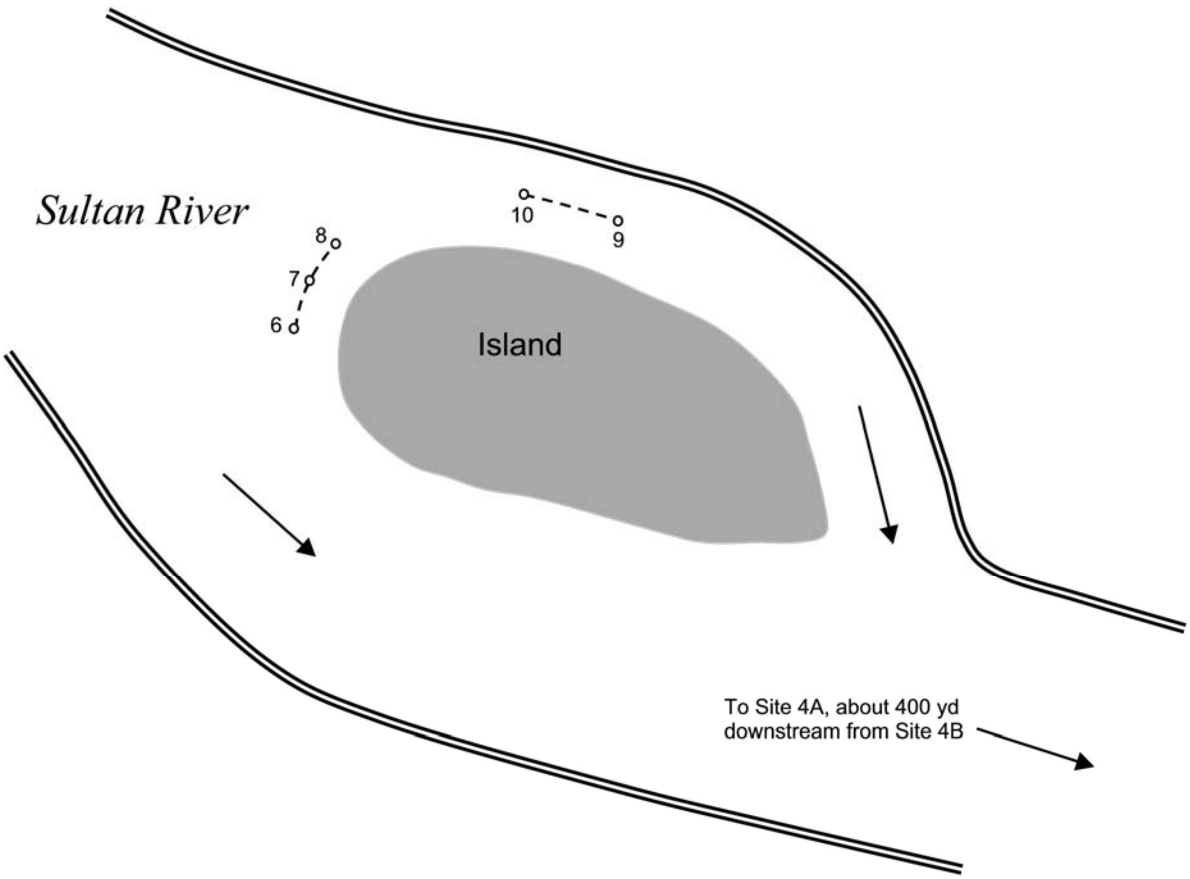

Figure 3-9. Locations of five of 10 gravel samples collected from Site 4B on the Sultan River (USGS Gage, River Mile 4.7) on August 18, 2005.

The median levels of geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, and Fredle index all were associated with potential survival to emergence levels in excess of 50% for the gravel samples collected from the USGS Gage Site. The percent fines less than 0.84 mm and Fredle index were associated with potential survival levels in excess of 50% for all of the ten samples. One of the ten samples was associated with potential survival levels below 50% based on geometric mean diameter; and one of the ten samples was associated with potential survival levels below 50% based on percent fines less than 6.4 mm.

Figure 3-10. Gravel monitoring Site 4A on the Sultan River (USGS Gage, River Mile 4.7), August 4, 2005, flow = 105 cfs.

Table 3-4. Geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, sorting coefficient, and Fredle index of gravel samples collected from Site 4 on the Sultan River (USGS Gage, River Mile 4.7), August 18, 2005.

Sample	**Geometric Mean Diameter (mm)**	**Percent Fines Less Than 0.84 mm**	**Percent Fines Less Than 6.4 mm**	**Sorting Coefficient**	**Fredle Index (mm)**
S4-1	15	4	25	2.4	6.1
S4-2	13	4	29	2.6	5.0
S4-3	20	2	19	2.2	9.3
S4-4	14	3	29	2.7	5.4
S4-5	9	4	37	2.7	3.5
S4-6	14	3	24	2.2	6.4
S4-7	13	4	27	2.3	5.8
S4-8	29	1	5	1.6	17.7
S4-9	37	1	3	1.8	20.6
S4-10	25	2	11	2.1	12.1
Maximum	37	4	37	2.7	20.6
Median	15	3	24	2.3	6.3
Minimum	9	1	3	1.6	3.5

3.1.5 Gold Camp, River Mile 7.3

The Gold Camp Site is located on the Sultan River 7.3 miles upstream from the confluence with the Skykomish River (Figure 1-1). This reach of the Sultan River has a steeper gradient than the lower 3 miles. The Gold Camp Site is located a short distance downstream from a landslide that occurred on December 11, 2004, that created a small dam on the river, estimated to be 20 to 30 feet high.

Ten gravel samples were collected on August 19 and 22, 2005, at the Gold Camp Site from locations shown in Figure 3-11; flow during this time ranged from 105 to 106 cfs.

Grain size distributions of the 10 gravel samples from the Gold Camp Site are presented in Appendix A. Spawning gravel quality metrics, derived from these grain size distributions are shown in Table 3-5.

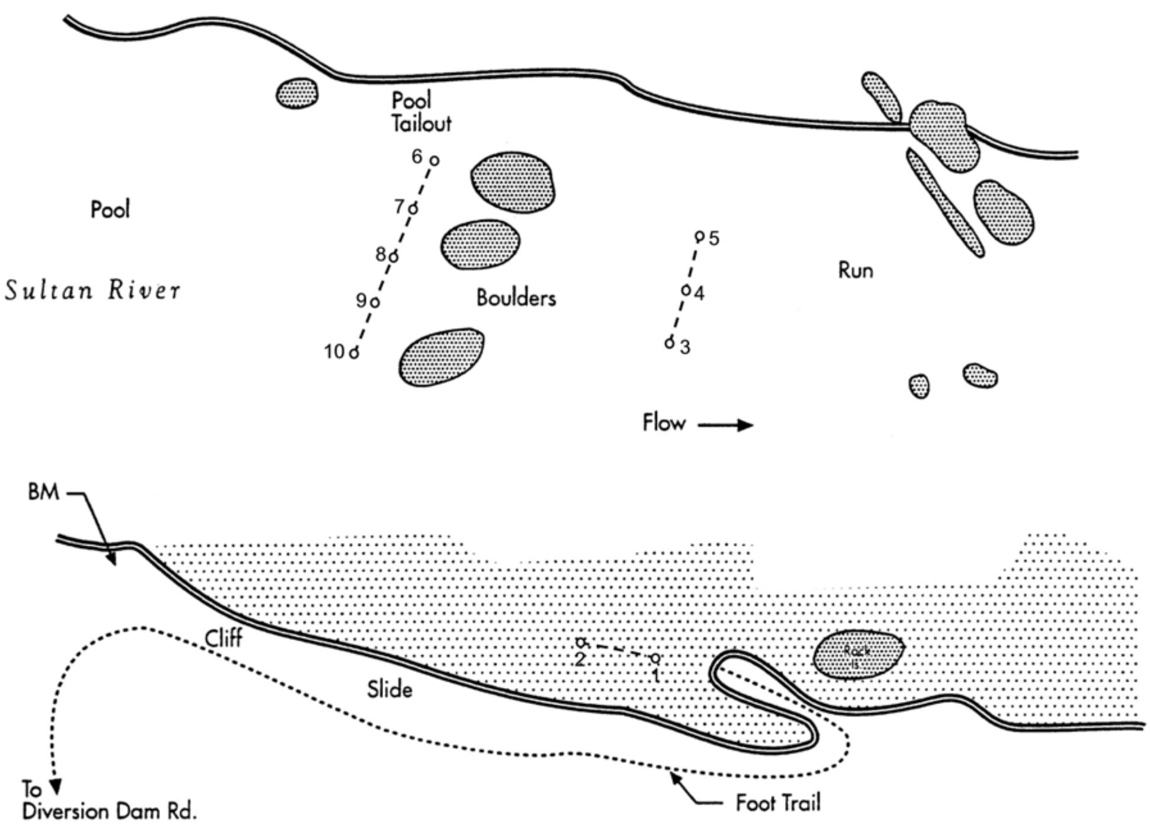

Figure 3-11. Locations of 10 gravel samples collected from Site 5 on the Sultan River (Gold Camp, River Mile 7.3) on August 19 and 22, 2005.

The median levels of geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, and Fredle index all were associated with potential survival to emergence levels in excess of 50% for the gravel samples collected from the USGS Gage Site. The percent fines less than 0.84 mm and Fredle index were associated with potential survival levels in excess of 50% for all of the ten samples. One of the ten samples was associated with potential survival levels below 50% based on geometric mean diameter; and one of the ten samples was associated with potential survival levels below 50% based on percent fines less than 6.4 mm.

Table 3-5. Geometric mean diameter, percent fines less than 0.84 mm, percent fines less than 6.4 mm, sorting coefficient, and Fredle index of gravel samples collected from Site 5 on the Sultan River (Gold Camp, River Mile 7.3), August 19 and 22, 2005.

Sample	Geometric Mean Diameter (mm)	Percent Fines Less Than 0.84 mm	Percent Fines Less Than 6.4 mm	Sorting Coefficient	Fredle Index (mm)
S5-1	22	3	18	1.9	11.4
S5-2	23	3	14	1.8	13.0
S5-3	17	3	21	2.2	7.7
S5-4	20	1	15	1.9	10.3
S5-5	16	2	23	2.3	6.7
S5-6	16	1	17	1.9	8.5
S5-7	13	3	23	1.9	6.8
S5-8	8	6	37	2.1	3.9
S5-9	13	2	23	2.0	6.7
S5-10	11	2	30	2.1	5.5
Maximum	23	6	37	2.3	13.0
Median	16	3	22	2.0	7.2
Minimum	8	1	14	1.8	3.9

3.1.6 Summary of 2005 Gravel Monitoring Results

Detailed results of the 2005 gravel monitoring are discussed for each of the five sites in the previous sections. An overall summary of results is illustrated graphically in Figure 3-12. The quality of gravels collected from the five sites in 2005 was generally “good.” Median levels of geometric mean diameter were above the threshold for 50% survival at all five sites. Median percent fines less than 0.84 mm and 6.4 mm were below the threshold for 50% survival at all five sites. The median Fredle index was above the threshold for 50% survival at all five sites.

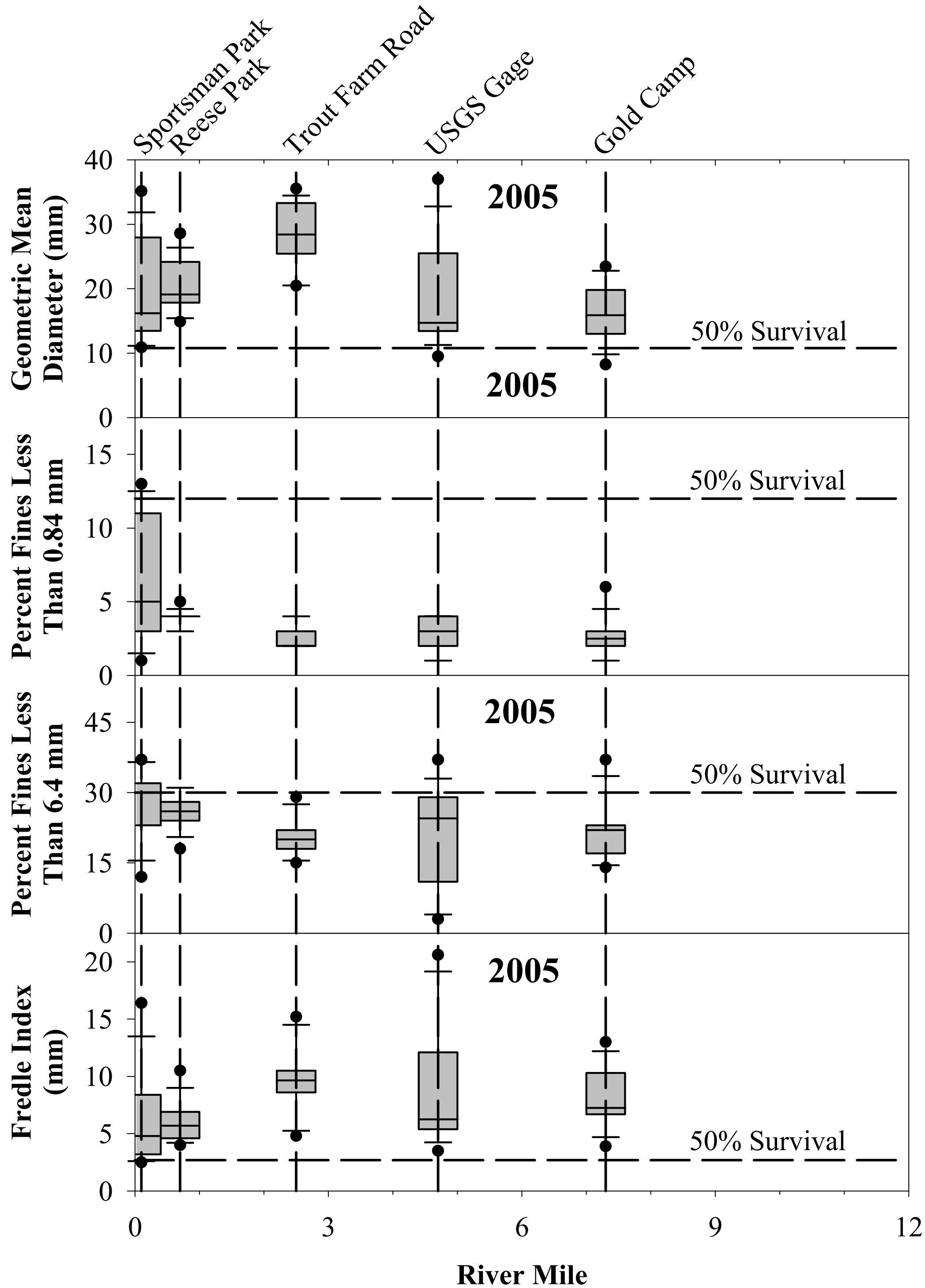

Figure 3-12. Geometric mean diameter, percent fines less than 0.84 mm and 6.4 mm, and Fredle index from gravel samples collected from five sites on the lower Sultan River in August 2005.

3.2 COMPARISON WITH RESULTS FROM PREVIOUS YEARS

In previous gravel monitoring studies on the Sultan River (1982, 1984, 1987, and 1994), the geometric mean diameter and percent fines less than 0.84 mm were determined. These results are summarized in tabular form in Appendix B, and are illustrated graphically in Figures 3-13, 3-14, 3-15, and 3-16 for 1982, 1984, 1987, and 1994, respectively.

Gravel samples collected in 1982 are useful for defining a baseline condition prior to Stage II of the Project. The geometric mean diameter and percent fines less than 0.84 mm from all five of the monitoring sites on the Sultan River are shown in Figure 3-13.

The median level of geometric mean diameter from each of the five sites was associated with potential survival levels in excess of 50% in 1982. The geometric mean diameters for all ten samples from Sites 1 through 4 (River Miles 0.1 to 4.7) were associated with potential survival levels in excess of 50%. The geometric mean diameters for two of the ten samples from Site 5 (River Mile 7.3) were associated with potential survival levels below 50%.

The median level of percent fines less than 0.84 mm from each of the five sites was associated with potential survival levels in excess of 50% in 1982. The percent fines less than 0.84 mm for all ten samples from Sites 1 through 5 (River Miles 0.1 to 7.3) were associated with potential survival levels in excess of 50%.

The 1984 gravel samples were collected in February, several months before the Project began generating power (May 1984). Thus, the gravel samples collected in 1984 can also be used to help define a baseline condition prior to Stage II of the Project. The geometric mean diameter and percent fines less than 0.84 mm from all five of the monitoring sites on the Sultan River are shown in Figure 3-14.

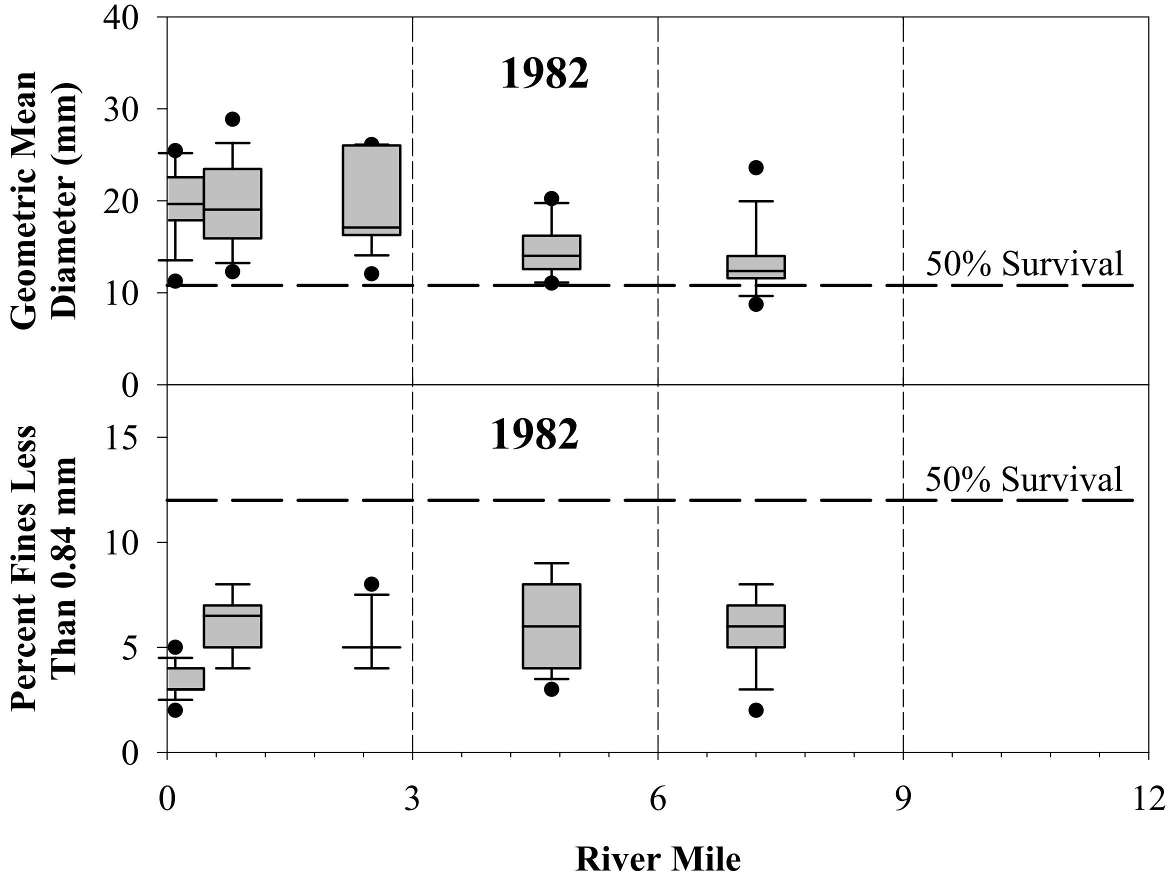

Figure 3-13. Geometric mean diameter and percent fines less than 0.84 mm from gravel samples collected from 5 sites in the Sultan River in 1982.

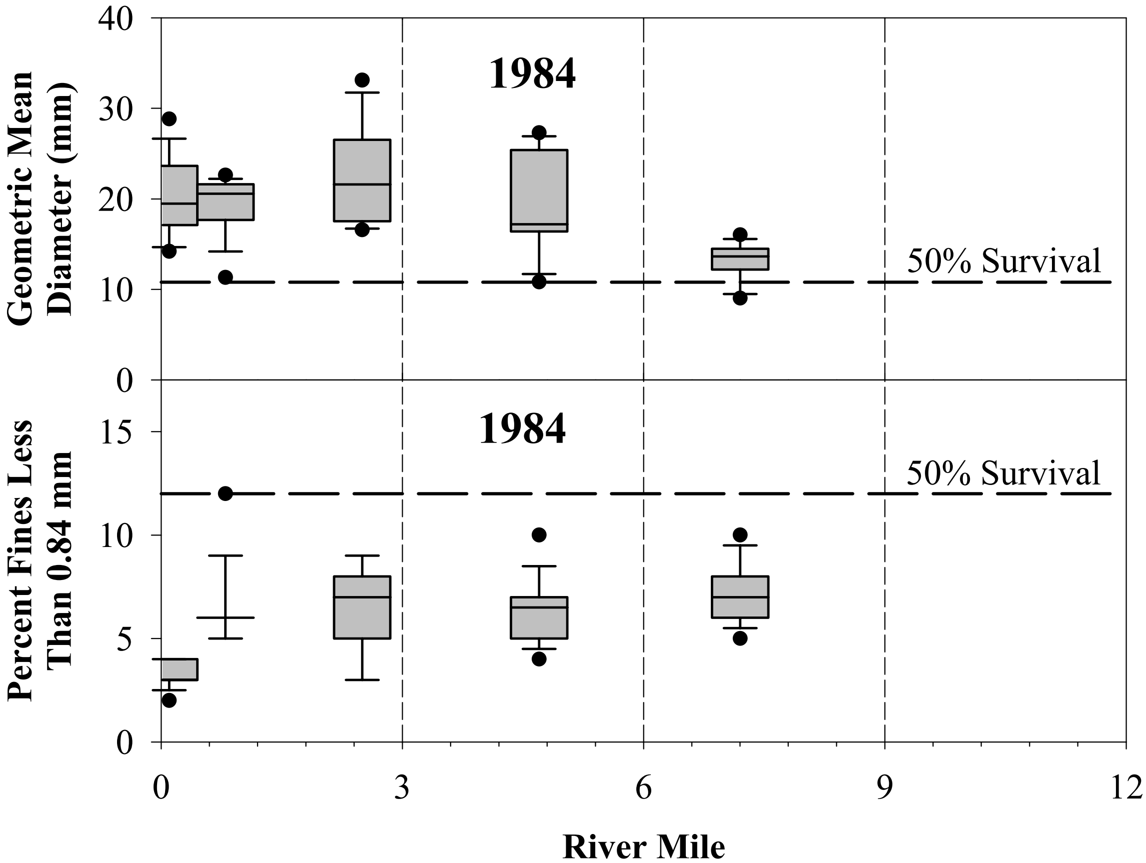

Figure 3-14. Geometric mean diameter and percent fines less than 0.84 mm from gravel samples collected from 5 sites in the Sultan River in 1984.

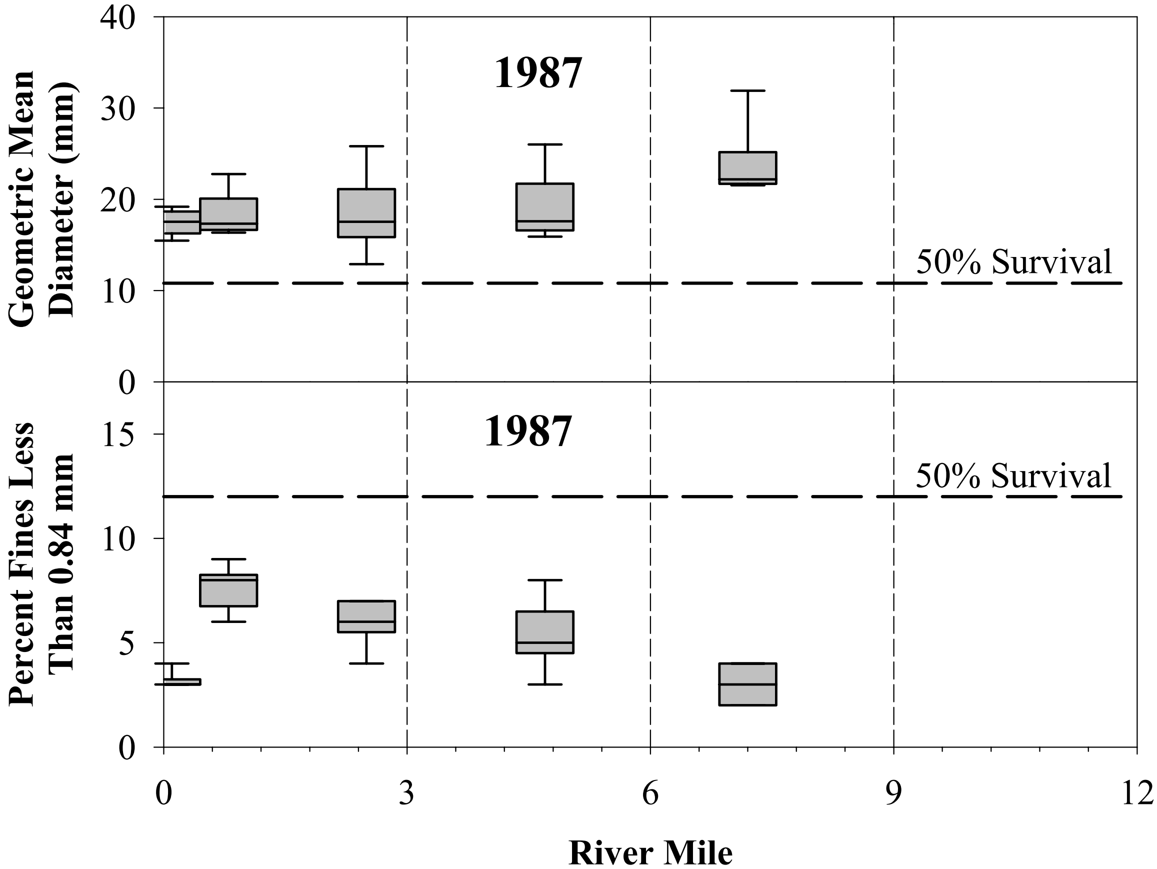

Figure 3-15. Geometric mean diameter and percent fines less than 0.84 mm from gravel samples collected from 5 sites in the Sultan River in 1987.

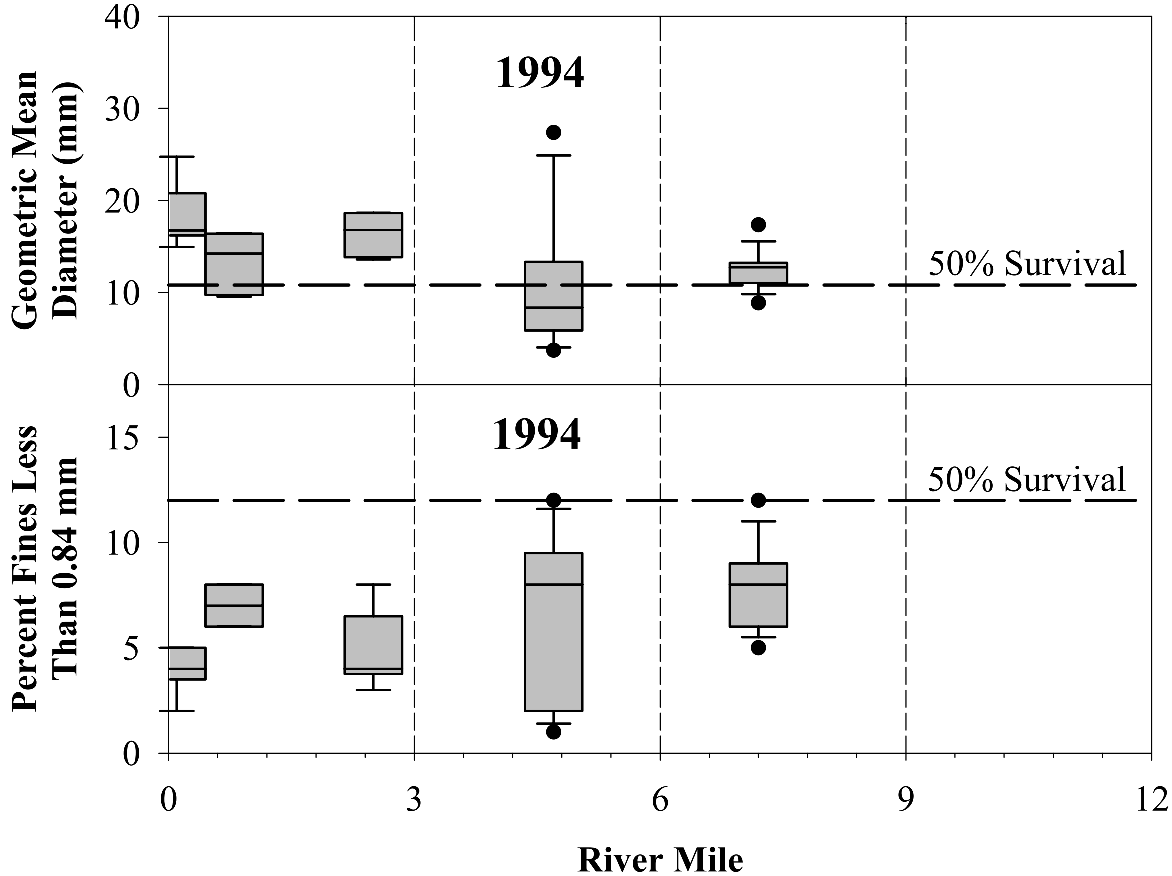

Figure 3-16. Geometric mean diameter and percent fines less than 0.84 mm from gravel samples collected from 5 sites in the Sultan River in 1994.

The median level of geometric mean diameter from each of the five sites was associated with potential survival levels in excess of 50% in 1984. The geometric mean diameter for all ten samples from Sites 1 through 4 (River Miles 0.1 to 4.7) was associated with potential survival levels in excess of 50%. The geometric mean diameter for two of the ten samples from Site 5 (River Mile 7.3) was associated with potential survival levels below 50%.

The median level of percent fines less than 0.84 mm from each of the five sites was associated with potential survival levels in excess of 50% in 1984. The percent fines less than 0.84 mm for all ten samples from Sites 1 through 5 (River Miles 0.1 to 7.3) was associated with potential survival levels in excess of 50%.

The 1987 gravel samples were collected three years after Stage II of the Project was initiated. The geometric mean diameter and percent fines less than 0.84 mm from all five of the monitoring sites on the Sultan River are shown in Figure 3-15.

The median level of geometric mean diameter from each of the five sites was associated with potential survival levels in excess of 50% in 1987. The geometric mean diameter for all five samples from Sites 1 through 5 (River Miles 0.1 to 7.3) was associated with potential survival levels in excess of 50%.

The median level of percent fines less than 0.84 mm from each of the five sites was associated with potential survival levels in excess of 50% in 1987. The percent fines less than 0.84 mm for all five samples from Sites 1 through 5 (River Miles 0.1 to 7.3) was associated with potential survival levels in excess of 50%.

The 1994 gravel samples were collected ten years after Stage II of the Project was initiated. The geometric mean diameter and percent fines less than 0.84 mm from all five of the monitoring sites on the Sultan River are shown in Figure 3-16. The initial plan for gravel monitoring in 1994 was to collect 5 samples from each of the five sites shown in Figure 1. However, during the monitoring effort, it was discovered that Sites 4 and 5 (River Miles 4.7 and 7.3) had been disturbed as a result of recent upstream gold prospecting activities. Therefore, additional gravel samples were collected from those two sites from locations that did not appear to be impacted by the gold prospecting activities.

The median level of geometric mean diameter from four of the five sites (Sites 1, 2, 3, and 5 at River Miles 0.1, 0.7, 2.5, and 7.3, respectively) were associated with potential survival levels in excess of 50% in 1994. The median level of geometric mean diameter from Site 4 (River Mile 4.7), the site most impacted by upstream gold prospecting activities, was associated with potential survival levels below 50%. The geometric mean diameter for all five samples from Sites 1 and 3 (River Miles 0.1 and 2.5) were associated with potential survival levels in excess of 50%. The geometric mean diameter from two of the five samples from Site 2 (River Mile 0.7) was associated with potential survival levels below 50%; the geometric mean diameter from five of the nine samples from Site 4 (River Mile 4.7) were associated with potential survival levels below 50%; and the geometric mean diameter from one of the ten samples from Site 5 (River Mile 7.3) was associated with potential survival levels below 50%

The median level of percent fines less than 0.84 mm from each of the five sites was associated with potential survival levels in excess of 50% in 1994. The percent fines less than 0.84 mm for all samples from Sites 1 through 5 (River Miles 0.1 to 7.3) was associated with potential survival levels in excess of 50%.

3.2.1 Sportsman Park, River Mile 0.1

The geometric mean diameter and percent fines less than 0.84 mm at Site 1 on the Sultan River (Sportsman Park, River Mile 0.1) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the powerhouse from 1984 to 2005 are shown in Figure 3-17. This site is located in a potential backwater depositional zone when flows are high in the Skykomish River.

The median level of geometric mean diameter from each of the five years was associated with potential survival levels in excess of 50% at Site 1 (Sportsman Park, River Mile 0.1). The geometric mean diameters for all samples from all five years were associated with potential survival levels in excess of 50%.

The median level of percent fines less than 0.84 mm from each of the five years was associated with potential survival levels in excess of 50% at Site 1 (Sportsman Park, River Mile 0.1). The percent fines less than 0.84 mm for all samples from four of the five years (1982, 1984, 1987, and 1994) was associated with potential survival levels in excess of 50%. The percent fines less than 0.84 mm from one of the ten samples in 2005 was associated with potential survival levels below 50%.

3.2.2 Reese Park, River Mile 0.7

The geometric mean diameter and percent fines less than 0.84 mm at Site 2 on the Sultan River (Reese Park, River Mile 0.7) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the powerhouse from 1984 to 2005 are shown in Figure 3-18.

The median level of geometric mean diameter from each of the five years was associated with potential survival levels in excess of 50% at Site 2 (Reese Park, River Mile 0.7). The geometric mean diameter for all samples from four of the five years (1982, 1984, 1987, and 2005) was associated with potential survival levels in excess of 50%. The geometric mean diameter from two of the five samples in 1994 was associated with potential survival levels below 50%.

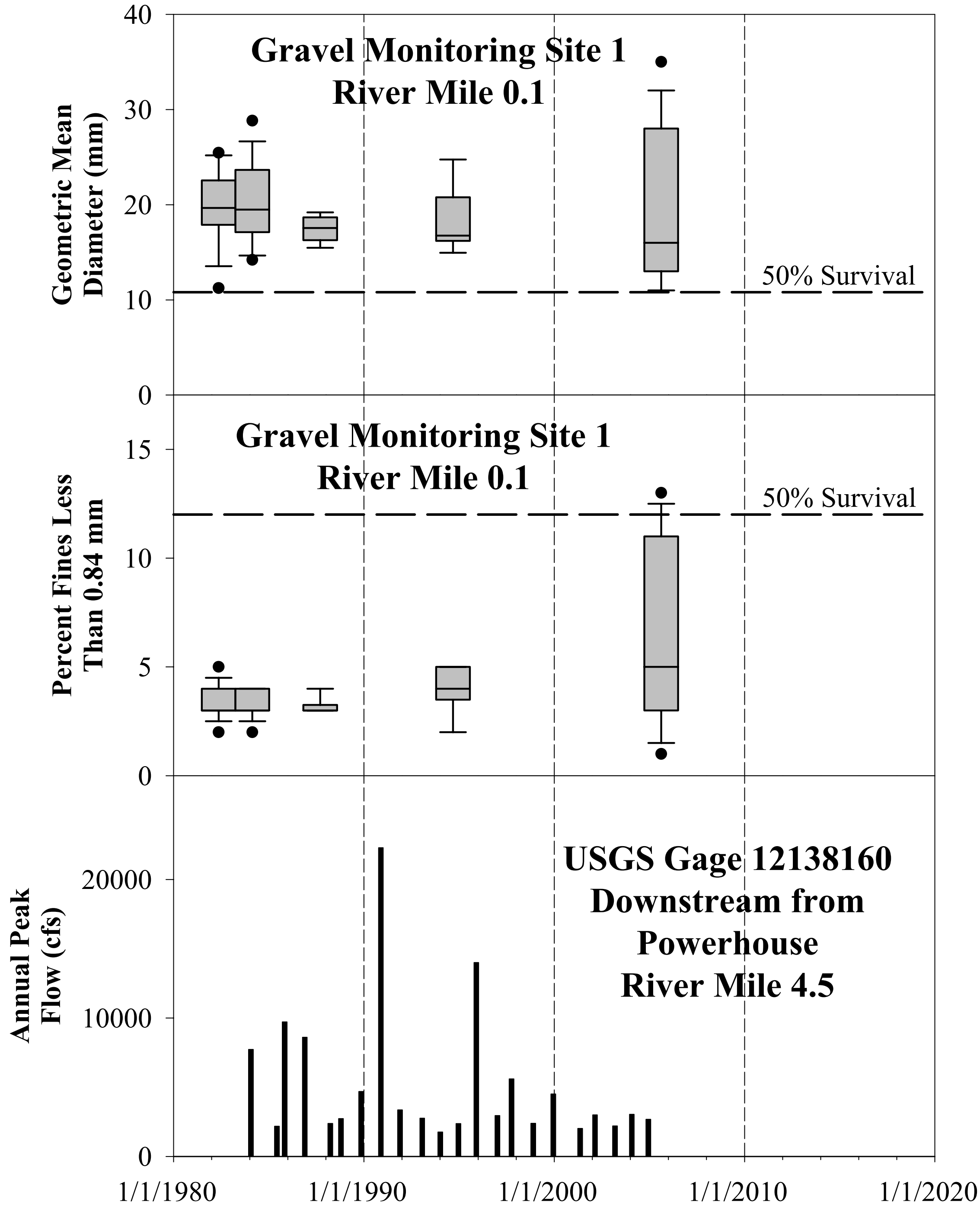

Figure 3-17. Geometric mean diameter and percent fines less than 0.84 mm at Site 1 on the Sultan River (Sportsman Park, River Mile 0.1) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the powerhouse from 1984 to 2005.

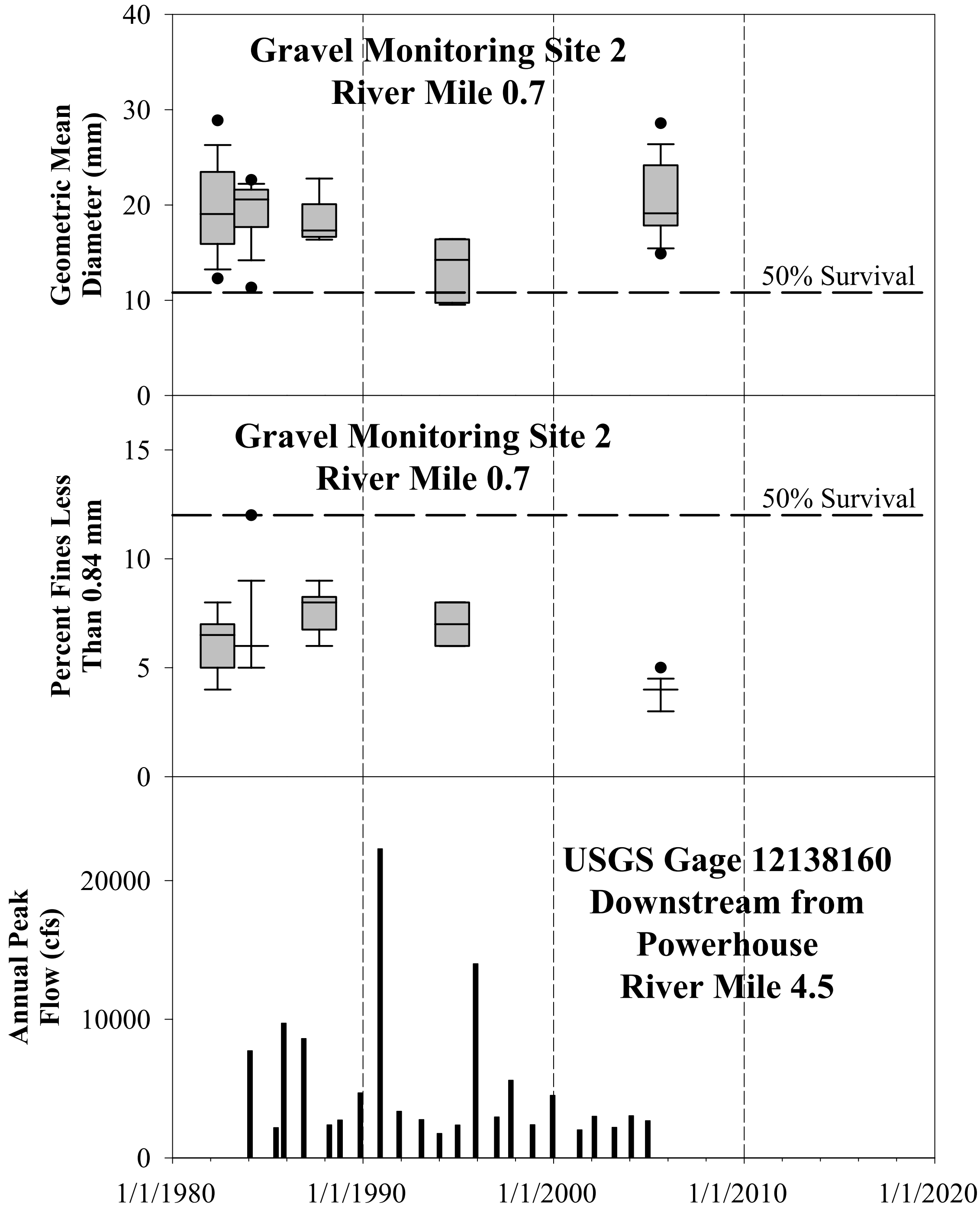

Figure 3-18. Geometric mean diameter and percent fines less than 0.84 mm at Site 2 on the Sultan River (Reese Park, River Mile 0.7) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the powerhouse from 1984 to 2005.

The median level of percent fines less than 0.84 mm from each of the five years was associated with potential survival levels in excess of 50% at Site 2 (Reese Park, River Mile 0.7). The percent fines less than 0.84 mm for all samples from all five years was associated with potential survival levels in excess of 50%.

3.2.3 Trout Farm Road, River Mile 2.5

The geometric mean diameter and percent fines less than 0.84 mm at Site 3 on the Sultan River (Trout Farm Road, River Mile 2.5) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the powerhouse from 1984 to 2005 are shown in Figure 3-19.

The median level of geometric mean diameter from each of the five years was associated with potential survival levels in excess of 50% at Site 3 (Trout Farm Road, River Mile 2.5). The geometric mean diameter for all samples from all five years was associated with potential survival levels in excess of 50%.

The median level of percent fines less than 0.84 mm from each of the five years was associated with potential survival levels in excess of 50% at Site 3 (Trout Farm Road, River Mile 2.5). The percent fines less than 0.84 mm for all samples from all five years was associated with potential survival levels in excess of 50%.

3.2.4 USGS Gage, River Mile 4.7

The geometric mean diameter and percent fines less than 0.84 mm at Site 4 on the Sultan River (USGS Gage, River Mile 4.7) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the diversion dam from 1984 to 2005 are shown in Figure 3-20.

The median level of geometric mean diameter from four of the five years (1982, 1984, 1987 and 2005) was associated with potential survival levels in excess of 50% at Site 4 (USGS Gage, River Mile 4.7). The median level of geometric diameter from 1994 was associated with potential survival levels below 50%. This site had been impacted by upstream gold prospecting activities prior to 1994.

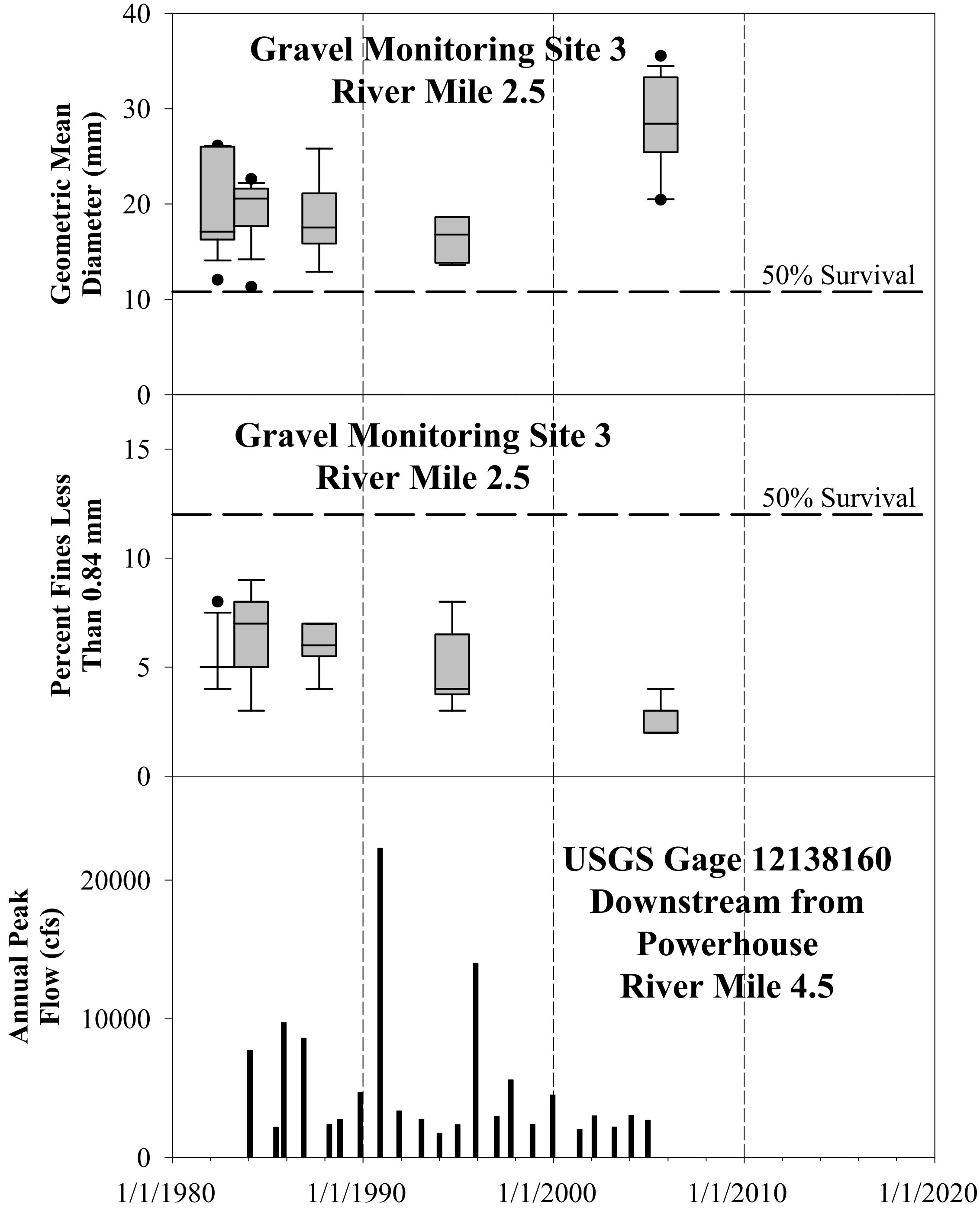

Figure 3-19. Geometric mean diameter and percent fines less than 0.84 mm at Site 3 on the Sultan River (Trout Farm Road, River Mile 2.5) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the powerhouse from 1984 to 2005.

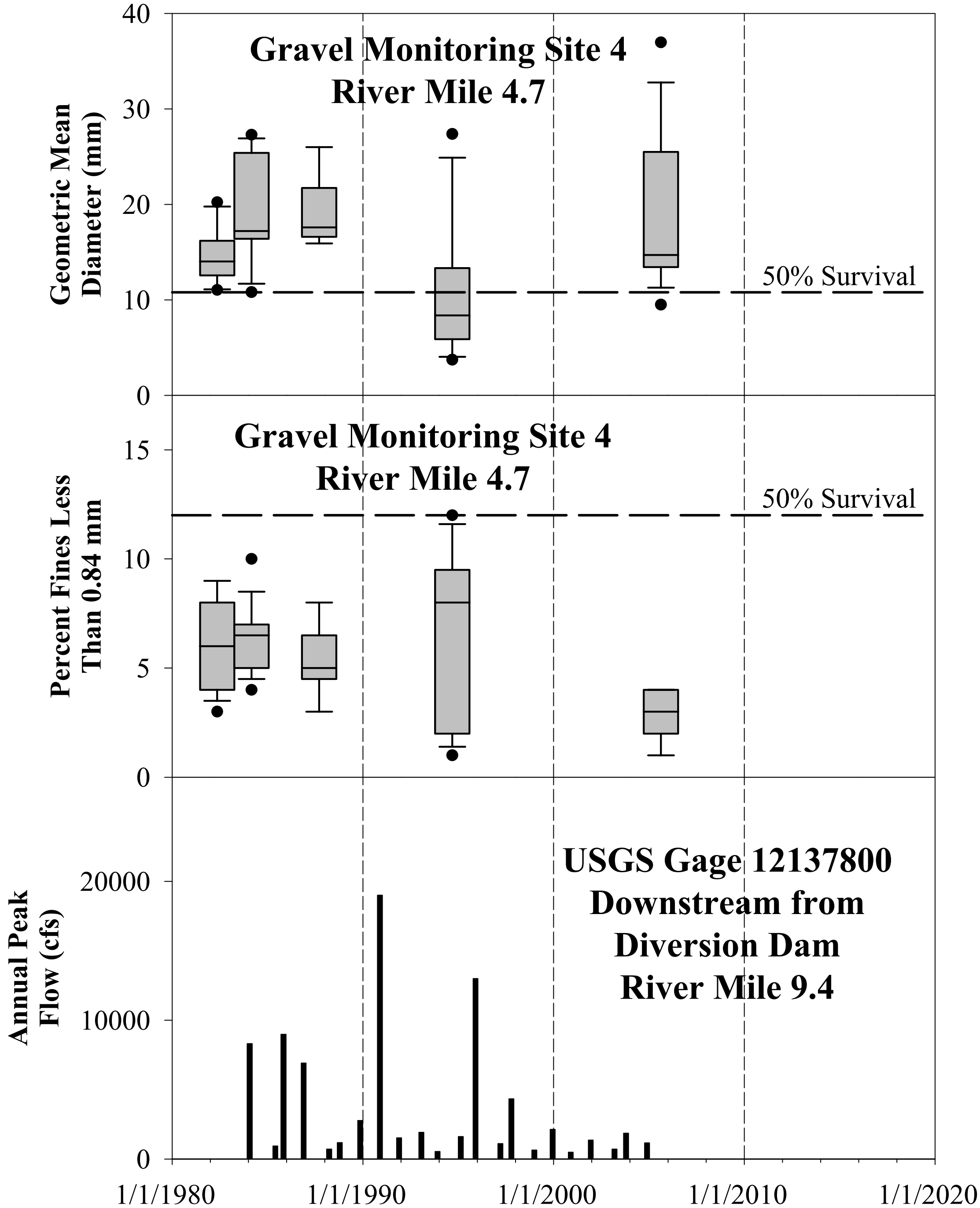

Figure 3-20. Geometric mean diameter and percent fines less than 0.84 mm at Site 4 on the Sultan River (USGS Gage, River Mile 4.7) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the diversion dam from 1984 to 2005.

The geometric mean diameter for all samples from three of the five years (1982, 1984, and 1987) was associated with potential survival levels in excess of 50%. The geometric mean diameter for five of the nine samples in 1994 was associated with potential survival levels below 50%. The geometric mean diameter for one of the ten samples in 2005 was associated with potential survival levels below 50%.

The median level of percent fines less than 0.84 mm from each of the five years was associated with potential survival levels in excess of 50% at Site 4 (USGS Gage, River Mile 4.7). The percent fines less than 0.84 mm for all samples from all five years was associated with potential survival levels in excess of 50%.

3.2.5 Gold Camp, River Mile 7.3

The geometric mean diameter and percent fines less than 0.84 mm at Site 5 on the Sultan River (Gold Camp, River Mile 7.3) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the diversion dam from 1984 to 2005 are shown in Figure 3-21.

The median level of geometric mean diameter from all of the five years was associated with potential survival levels in excess of 50% at Site 5 (Gold Camp, River Mile 7.3). The geometric mean diameter for all samples from 1987 was associated with potential survival levels in excess of 50%. The geometric mean diameter for two of the ten samples in both 1982 and 1984 was associated with potential survival levels below 50%. The geometric mean diameter for one of the ten samples in both 1994 and 2005 was associated with potential survival levels below 50%.

This site had been impacted by upstream gold prospecting activities prior to 1994. The recent landslide on December 11, 2004, just upstream from this site will likely be a significant source of sediment.

The median level of percent fines less than 0.84 mm from each of the five years was associated with potential survival levels in excess of 50% at Site 5 (Gold Camp, River Mile 7.3). The percent fines less than 0.84 mm for all samples from all five years was associated with potential survival levels in excess of 50%.

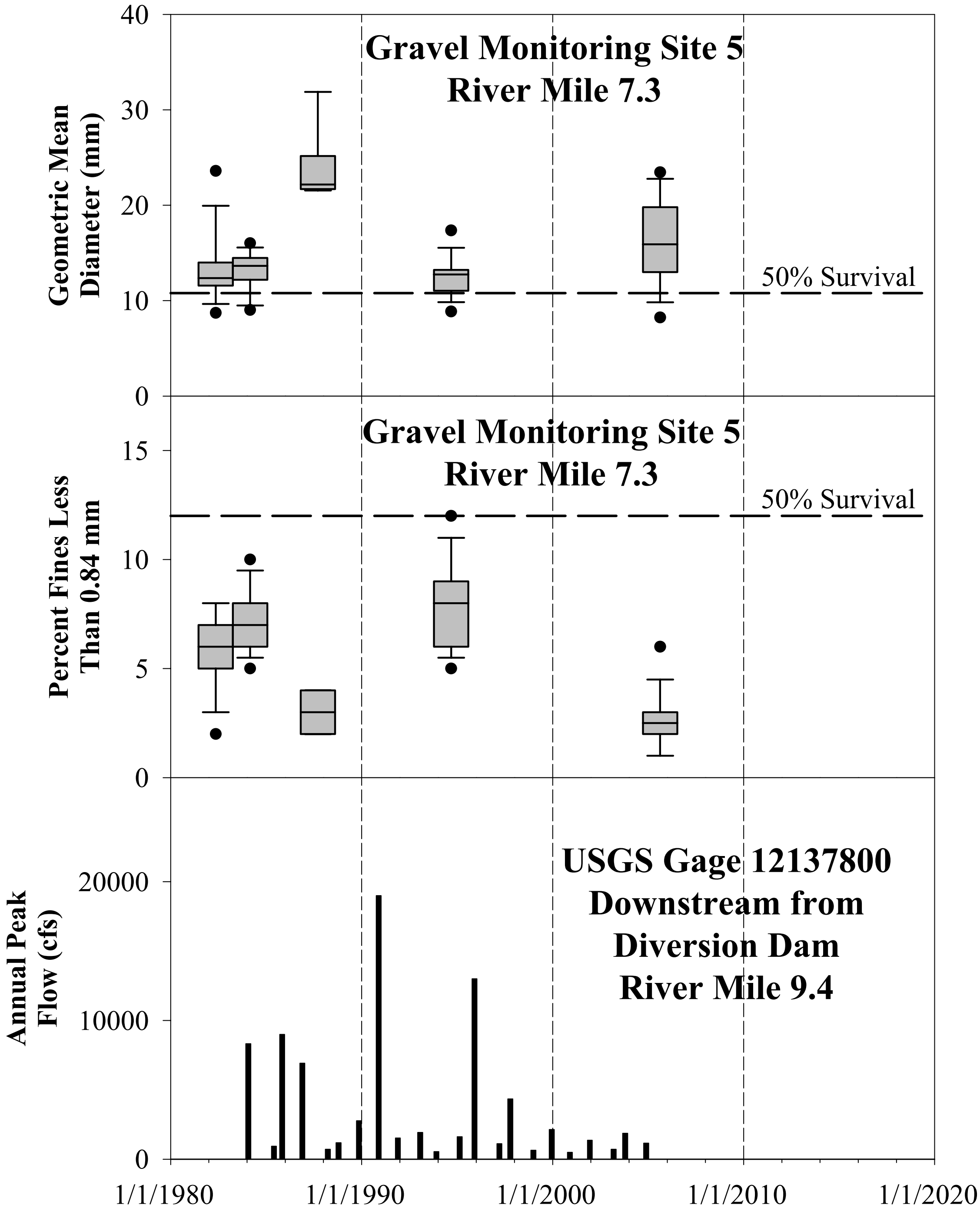

Figure 3-21. Geometric mean diameter and percent fines less than 0.84 mm at Site 5 on the Sultan River (Gold Camp, River Mile 7.3) in 1982, 1984, 1987, 1994, and 2005 and annual peak flows in Sultan River downstream from the diversion dam from 1984 to 2005.

4. DISCUSSION

Stage II of the Henry M. Jackson Project began with the initiation of power generation in May 1984. The increased storage in Spada Lake associated with Stage II created the opportunity for flood control in the Sultan and Skykomish rivers. The Project has effectively reduced the magnitude of peak flows in the Sultan River below Culmback Dam, as shown in Figures 1-6 and 1-7. The reduced frequency and magnitude of sediment-transporting flows in the Sultan River raised concerns about potential intrusion and accumulation of fine sediments in spawning gravel deposits.

To address this concern, the textural quality of spawning gravels in the Sultan River between the confluence with the Skykomish River and the diversion dam has been monitored five times since 1982. The overall quality of spawning gravels in the Sultan River below the diversion dam was generally good prior to Stage II of the Project and, except for localized disturbance associated with gold prospecting activities, has remained good since then, as shown in Table 4-1.

Table 4-1 Percentage of samples with spawning gravel quality indices associated with potential survival rates in excess of 50% in 1982, 1984, 1987, 1994, and 2005.

	Percentage of Samples With Spawning Gravel Quality Indices Associated With Potential Survival Rates in Excess of 50%				
Spawning Gravel Quality Index	**1982**	**1984**	**1987**	**1994**	**2005**
Geometric Mean Diameter	96%	96%	100%	76%	96%
Percent Fines Less Than 0.84 mm	100%	100%	100%	100%	98%
Percent Fines Less Than 6.4 mm	n/a	n/a	n/a	n/a	84%
Fredle Index	n/a	n/a	n/a	n/a	96%

In addition to monitoring of textural quality of spawning gravels, monitoring of scour depth, spawning activity, and escapement have also been performed. The results of these additional physical and biological surveys are consistent with the finding of persistent, good quality spawning gravels.

In the river gravel quantity study performed by GeoEngineers (1984), gravel transport rating curves were developed for River Miles 0.1 and 14.5 of the Sultan River. These rating curves, coupled with flow measurements in the Sultan River below the diversion dam and below the powerhouse can be used to estimate potential annual gravel transport quantities since Stage II of the Project was initiated.

Annual scour depth in gravel deposits in the Sultan River has been measured at the four sites shown in Figure 4-1: Reese Park (River Mile 0.7); Keins Bar (River Mile 1.2); Trout Farm Road (River Mile 2.5); and Chaplain Creek (River Mile 5.2). These scour depth measurements were performed each year in August or September from 1989 through 2004.

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The co-licensees will make this information available to stakeholders of the Jackson Project upon request.

Figure 4-1. Locations of scour monitoring sites in the Sultan River, 1989 through 2004.

Scour depth was measured at seven locations each year at the Reese Park Site. Results of these measurements are shown in Figure 4-2, along with annual peak flows measured in the Sultan River below the powerhouse. The median scour depth from all of the scour depths measured at the Reese Park Site is 3.7 inches.

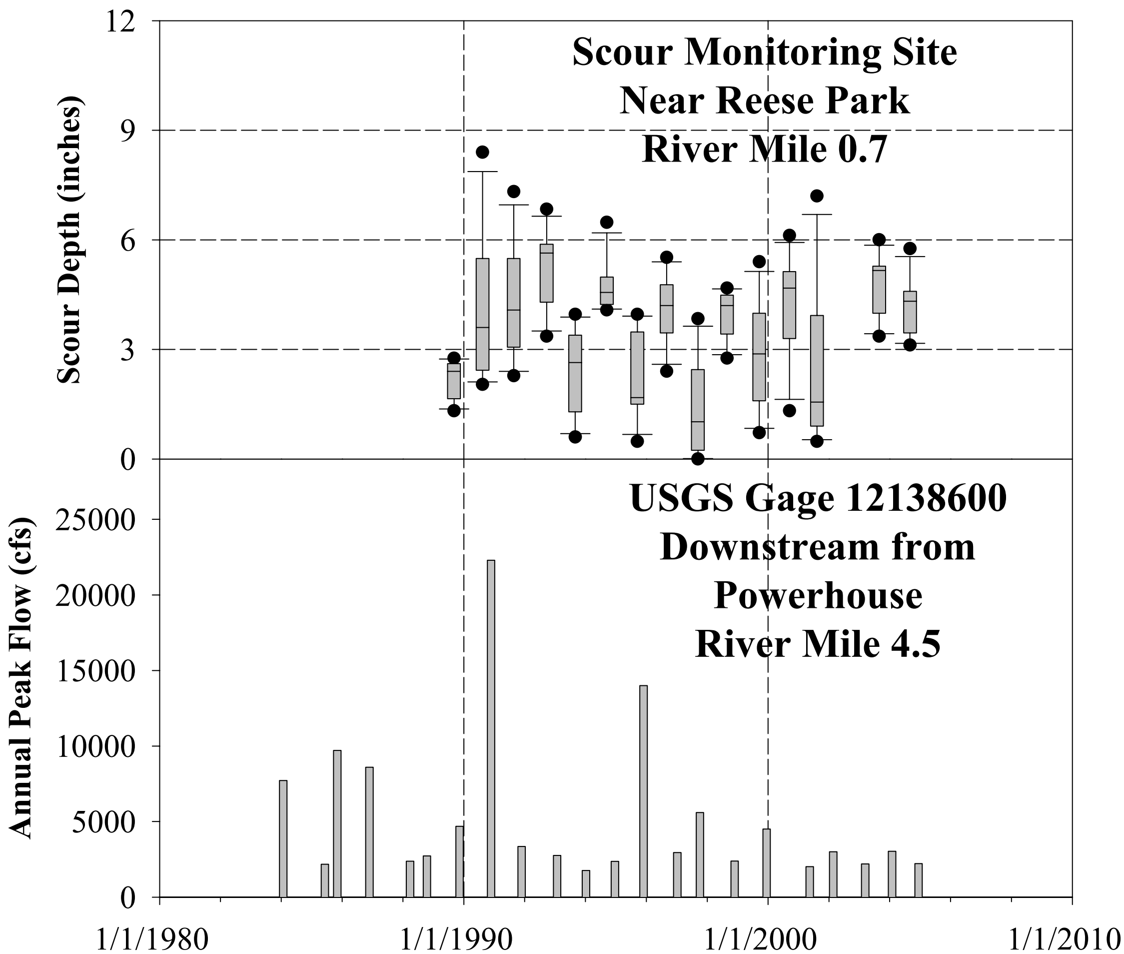

Figure 4-2. Annual scour depths measured in gravel deposits of the Sultan River at the Reese Park Site (River Mile 0.7), 1989 through 2004, and annual peak flows measured at the USGS Gage on the Sultan River below the powerhouse.

Scour depth was measured at five locations each year at the Keins Bar Site. Results of these measurements are shown in Figure 4-3, along with annual peak flows measured in the Sultan River below the powerhouse. The median scour depth from all of the scour depths measured at the Keins Bar Site is 2.3 inches.

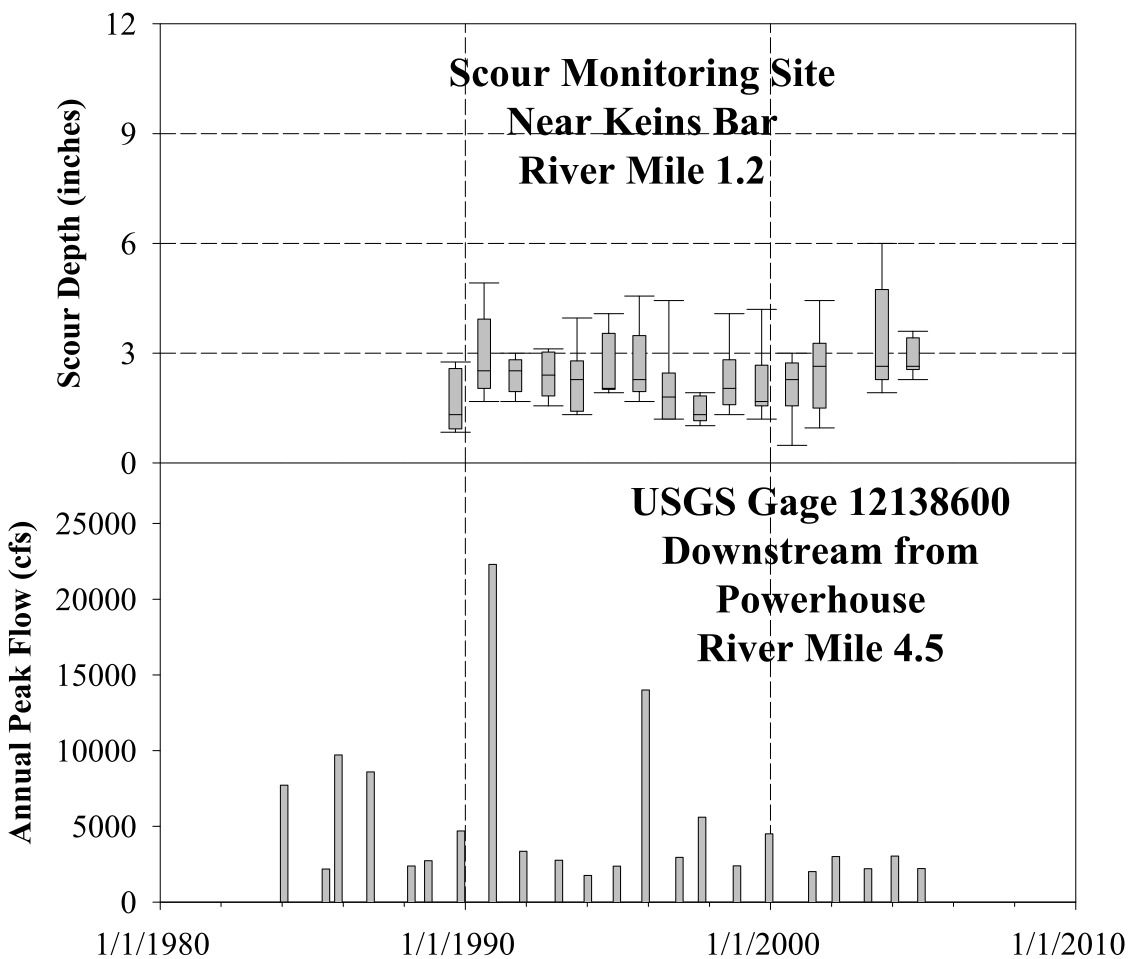

Figure 4-3. Annual scour depths measured in gravel deposits of the Sultan River at the Keins Bar Site (River Mile 1.2), 1989 through 2004, and annual peak flows measured at the USGS Gage on the Sultan River below the powerhouse.

Scour depth was measured at eleven locations each year at the Trout Farm Road Site. Results of these measurements are shown in Figure 4-4, along with annual peak flows measured in the Sultan River below the powerhouse. The median scour depth from all of the scour depths measured at the Trout Farm Road Site is 3.7 inches. However, the scour depth in recent years has been typically less than this long-term median depth.

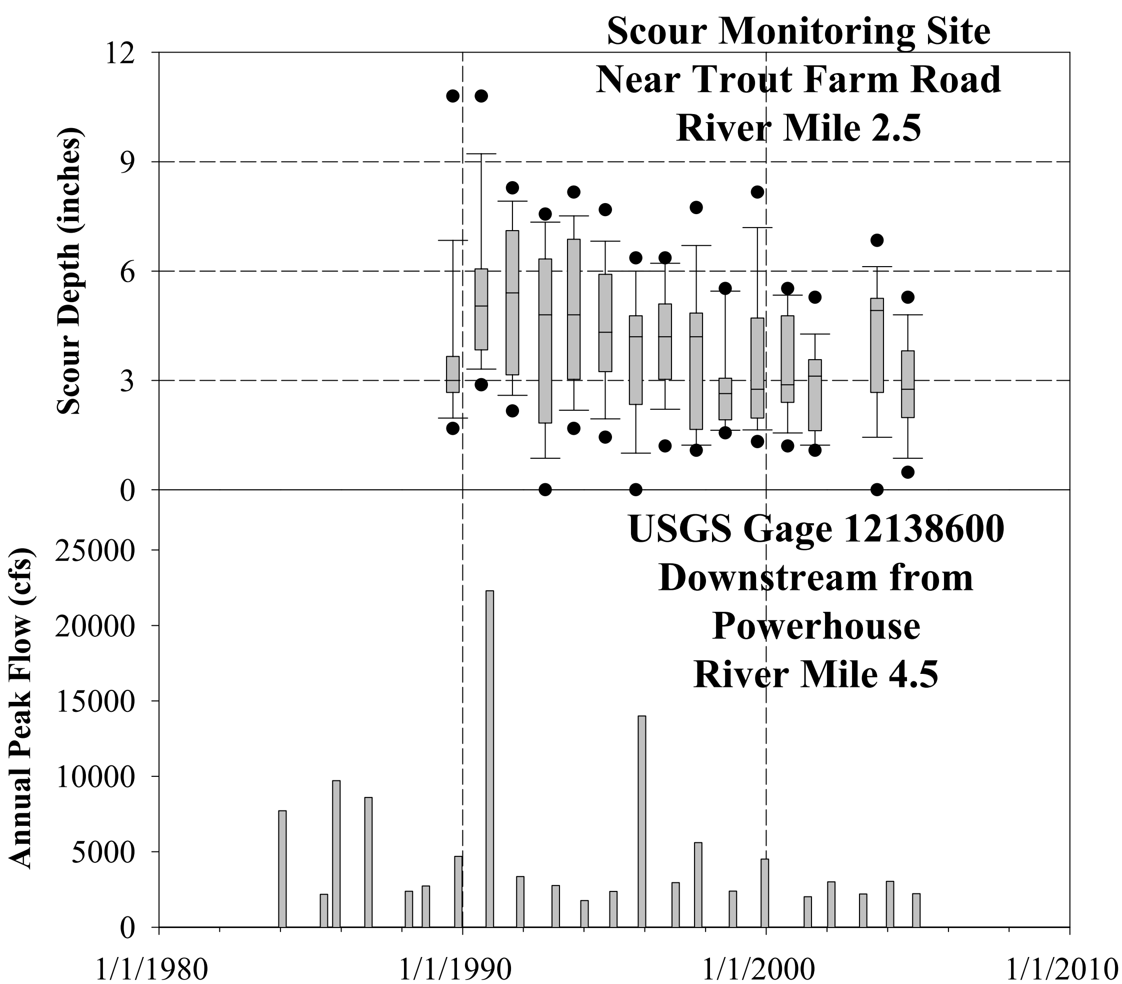

Figure 4-4. Annual scour depths measured in gravel deposits of the Sultan River at the Trout Farm Road Site (River Mile 2.5), 1989 through 2004, and annual peak flows measured at the USGS Gage on the Sultan River below the powerhouse.

Scour depth was measured at three locations each year at the Chaplain Creek Site. Results of these measurements are shown in Figure 4-5, along with annual peak flows measured in the Sultan River below the diversion dam. The median scour depth from all of the scour depths measured at the Chaplain Creek Site is 2.6 inches. However, the scour depth in recent years has been typically less than this long-term median depth.

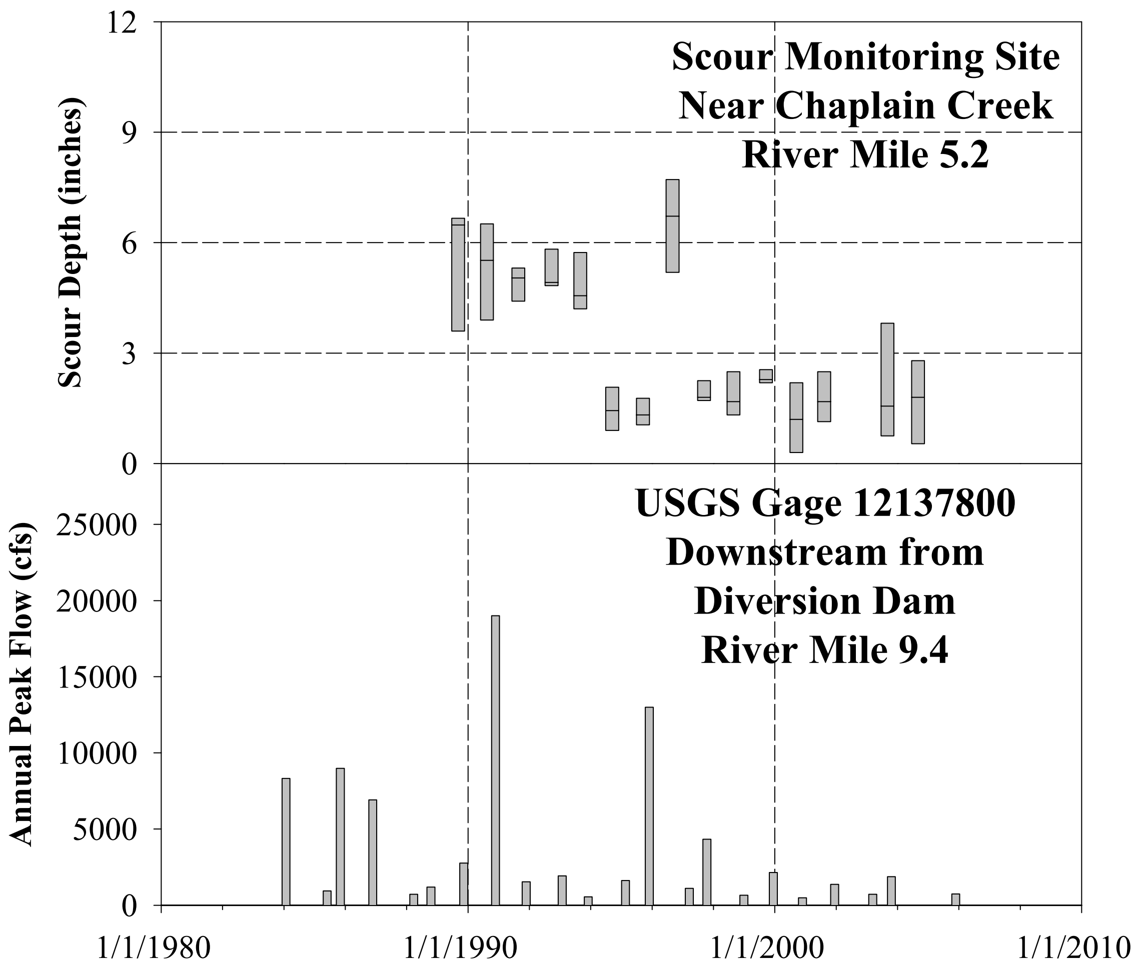

Figure 4-5. Annual scour depths measured in gravel deposits of the Sultan River at the Chaplain Creek Site (River Mile 5.2), 1989 through 2004, and annual peak flows measured at the USGS Gage on the Sultan River below the powerhouse.

Annual scour depths were measured at four different sites on the Sultan River over a 16-year period. Median scour depths ranged from 2.3 inches at Keins Bar (River Mile 1.2) to 3.7 inches at Reese Park (River Mile 0.7) and Trout Farm Road (River Mile 2.5). These scour depth measurements are consistent with vertical profiles of spawning gravel samples collected in 1982, 1984, 1987, and 1994, as shown in Appendix C.

These vertical profiles were derived from freeze-core tube samples collected to a total depth of 12 inches, and segregated into four 3-inch thick layers. Generally speaking the geometric mean diameter was larger and the percent fines less than 0.84 mm was smaller in the top 3-inch thick layer. This would be expected if the streambed were frequently exposed to flows capable of mobilizing the top layer of gravels, or surficially-flushing fine sediments from this top layer. The scour depth measurements and vertical profiles of spawning gravels suggest that the spawning gravel quality should not be declining, and are consistent with the overall results reported in Table 4-1.

Sediment supply and transport capacity in the Sultan River below Culmback Dam were studied by GeoEngineers (1984). The median grain sizes of armor layer material at River Miles 0.1 (near the confluence with the Skykomish River) and 14.5 (just below Culmback Dam) were determined to be 54 mm and 76 mm, respectively. The critical flows needed to mobilize the armor layer were estimated by GeoEngineers (1984) to be 2,900 cfs and 2,700 cfs at River Miles 0.1 and 14.5, respectively.

Sediment rating curves (potential bedload transport as a function of flow) were determined by GeoEngineers (1984) for these two locations on the Sultan River (River Miles 0.1 and 14.5). Daily flows measured at the USGS Gage below the powerhouse (Gage No. 12138160) were used to estimate the annual potential bedload transport rate at River Mile 0.1, based on the sediment rating curve developed for that location. Similarly, daily flows measured at the USGS Gage below the diversion dam (Gage No. 12137800) were used to estimate the annual potential bedload transport rate at River Mile 14.5, based on the sediment rating curve developed for that location. The sediment transport rates were assumed to be zero on days when the flow was less than the critical flow needed to mobilize the armor layer.

Results of these calculations are summarized in Table 4-2. The average annual potential bedload transport quantities were determined to be 4,000 tons and 9,400 tons at River Miles 0.1 and 14.5, respectively. These transport quantities would not be delivered at a constant rate over the 21-year period analyzed. The potential for bedload movement would occur in 7 of the 21 years at River Mile 0.1 and in 5 of the 21 years at River Mile 14.5.

Table 4-2 Potential annual bedload transport quantities at River Miles 0.1 and 14.5 of the Sultan River from Water Year 1985 through 2005 (derived by applying bed load transport rating curves developed by GeoEngineers [1984] to historical daily flows).

	Potential Annual Bedload Transport Quantity (tons)	
Water Year	**River Mile 0.1**	**River Mile 14.5**
1985	0	0
1986	18,600	43,800
1987	6,500	7,800
1988	0	0
1989	0	0
1990	2,800	0
1991	29,900	82,700
1992	0	0
1993	0	0
1994	0	0
1995	0	0
1996	22,800	58,600
1997	0	0
1998	2,100	3,600
1999	0	0
2000	1,300	0
2001	0	0
2002	0	0
2003	0	0
2004	0	0
2005	0	0
Average	***4,000***	***9,400***

In the previous study performed by GeoEngineers (1984), it was estimated that an average annual quantity of about 3,900 tons of sediment would be supplied to the Sultan River between River Mile 11 and Culmback Dam, and that this would account for the major portion of sediment delivered to the Sultan River below Culmback Dam. It would appear that the flow regime in the Sultan River between Culmback Dam and the diversion dam has been more than sufficient to transport the sediment supplied to this reach. Also, the flow regime in the Sultan River below the powerhouse should be sufficient to transport most of the sediment supplied to this reach.

It was previously mentioned that an annual average of about 500 Chinook have spawned in the Sultan River over the past 27 years. Prior to Stage II of the Project, escapement to the Sultan River averaged 410 fish annually. Since then, escapement has increased to an average of 546 fish, roughly a 33 percent increase. Prior to Stage II, returns to the Sultan River accounted for an average of 8.3 percent of the escapement to the Snohomish Basin. Since Stage II, the Sultan has accounted for an average of 11.8 percent of the basin-wide escapement.

The successful utilization of spawning gravels in the Sultan River by Chinook is consistent with the persistent pattern of good quality gravels over the years. Maintenance of the quality of spawning gravels is important to assure continued spawning success in this reach. The historical operations of the Project do not appear to have caused the quality of spawning gravels to decline.

5. CONCLUSIONS

A total of 50 gravel samples were collected from five sites on the Sultan River between the confluence with the Skykomish River and the diversion dam, in August 2005. These gravel samples were analyzed to determine four indices related to spawning gravel quality: geometric mean diameter; percent fines less than 0.84 mm; percent fines less than 6.4 mm; and the Fredle index. Results from the samples collected in 2005 were compared with results from 1982 and 1984 (prior to power generation), and results from 1987 and 1994.

Other sources of information related to the mobility and quality of spawning gravels were also reviewed. These other types of information included: the results of scour depth measurements in the Sultan River; Chinook spawning and escapement records; flood frequency data: and a previous investigation on sediment supply/transport conducted by GeoEngineers (1984). From these other sources of information, and the results of spawning gravel quality monitoring, the following conclusions were formulated:

- The spawning gravel samples collected in 1982 and 1984, prior to initiation of power generation, were of good quality.
- Since 1984, the magnitude and frequency of floods in the Sultan River below Culmback Dam have been reduced, consistent with intended flood protection provided by the Project.
- Although the magnitude and frequency of floods in the Sultan River has been reduced, the river still has sufficient capacity to transport the sediment supplied to the river from sources downstream from Culmback Dam.
- Under the flow regime in the Sultan River since 1984, the armor layer of gravel deposits in the Sultan River is mobilized about once every 3 to 4 years on average based on sediment transport analyses. Scour depth measurements suggest that the armor layer may be mobilized even more frequently than once every 3 to 4 years.
- Except for occasional disturbances associated with gold prospecting activities and potential backwater effects caused by the Skykomish River near the mouth of the Sultan River, the quality of spawning gravels collected in 1987, 1994, and 2005 has remained “good” and on a par with pre-Project conditions. Historical operations of the Project do not appear to have caused the quality of the spawning gravels to decline.
- The persistent trend of good quality spawning gravels is consistent with reported success of Chinook spawning and escapement in the Sultan River downstream from the diversion dam.

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APPENDIX A

Grain Size Distributions of Spawning Gravel Samples Collected from the Sultan River in 2005

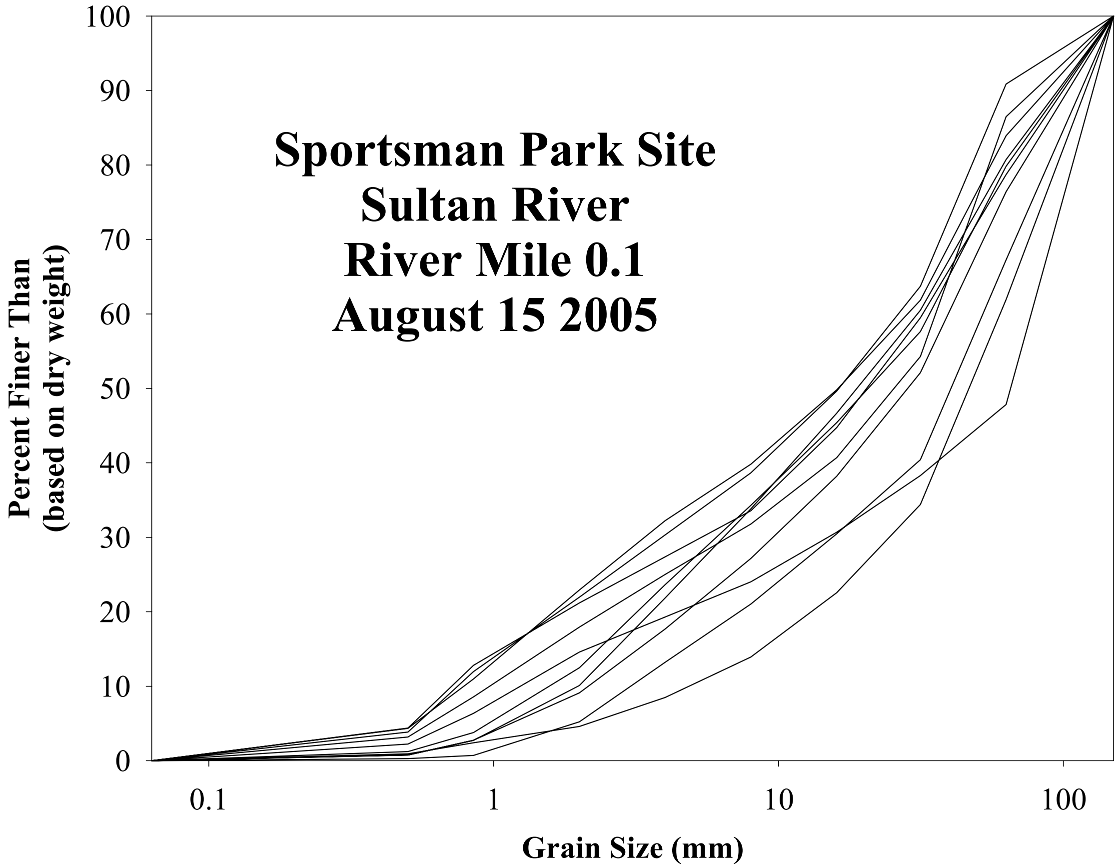

Figure A-1. Grain size distributions of spawning gravel samples collected from Site 1 on Sultan River (Sportsman Park, River Mile 0.1), August 15 2005.

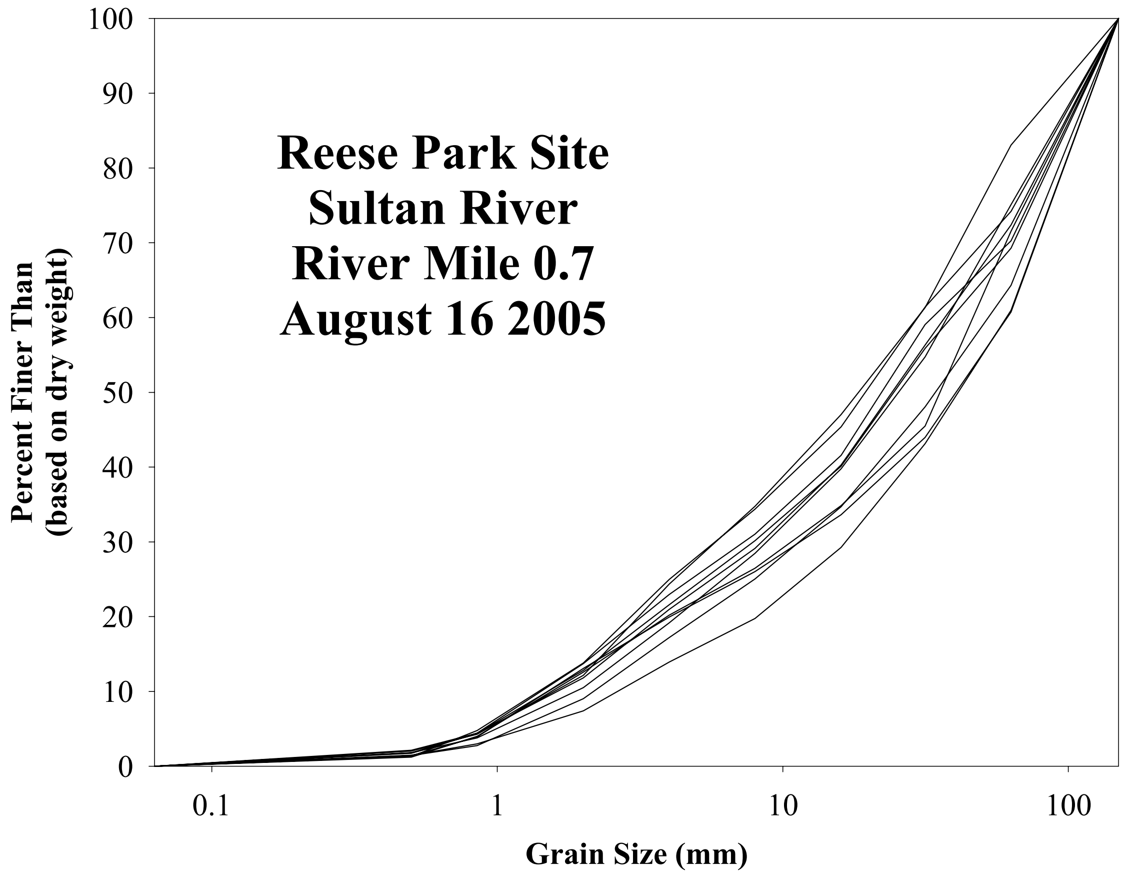

Figure A-2. Grain size distributions of spawning gravel samples collected from Site 2 on Sultan River (Reese Park, River Mile 0.7), August 16 2005.

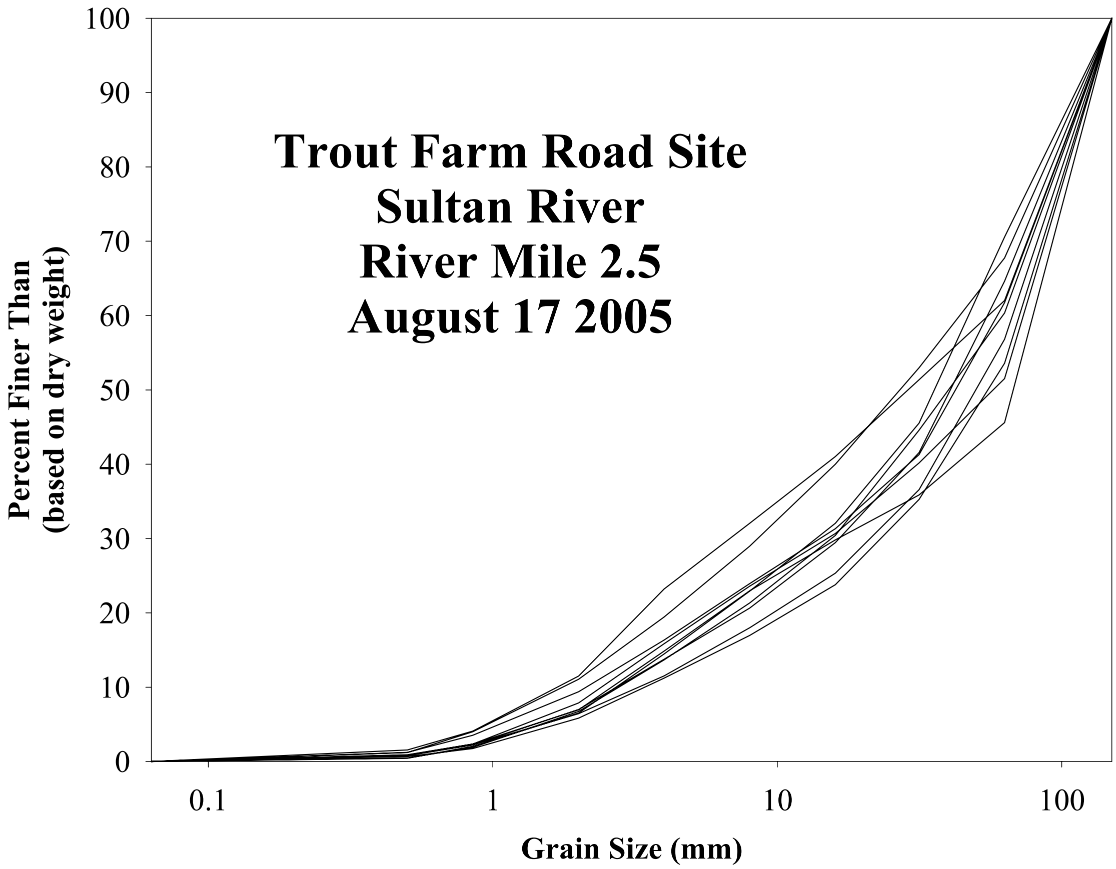

Figure A-3. Grain size distributions of spawning gravel samples collected from Site 3 on Sultan River (Trout Farm Road, River Mile 2.5), August 17 2005.

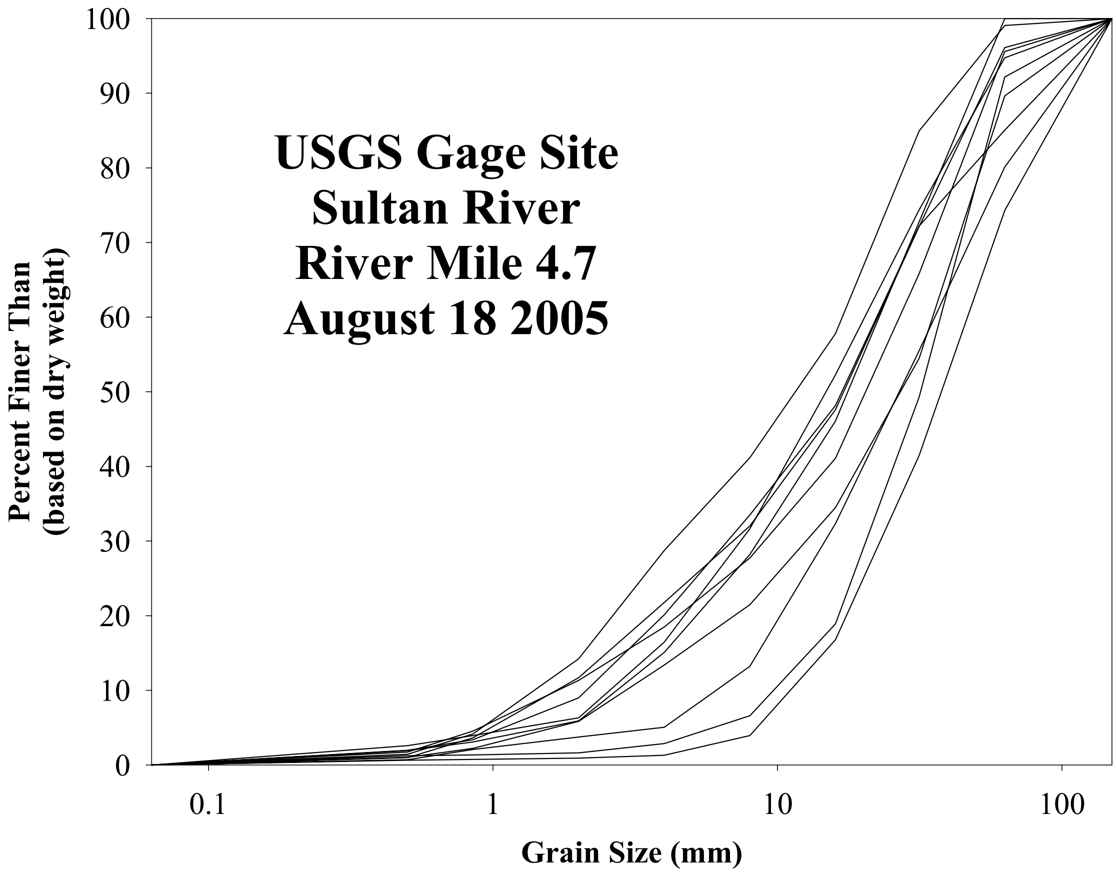

Figure A-4. Grain size distributions of spawning gravel samples collected from Site 4 on Sultan River (USGS Gage, River Mile 4.7), August 18 2005.

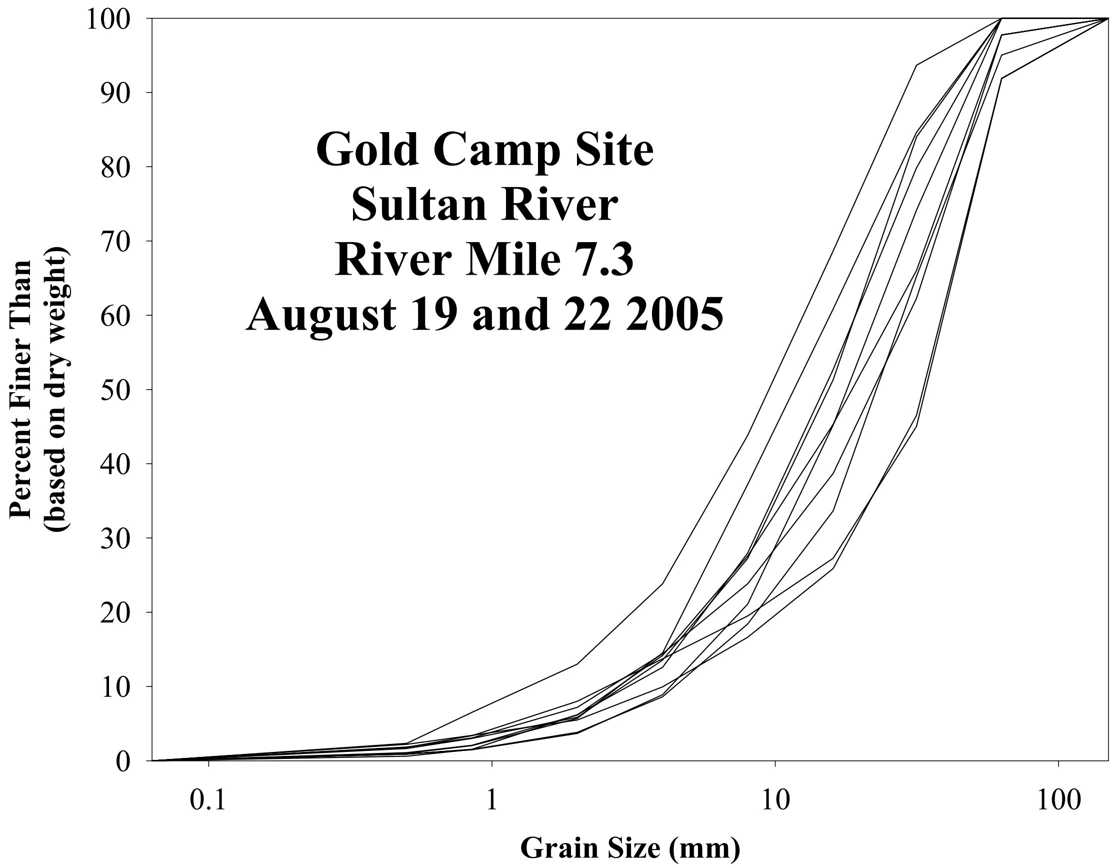

Figure A-5. Grain size distributions of spawning gravel samples collected from Site 5 on Sultan River (Gold Camp, River Mile 7.3), August 19 and 20 2005.

Table A-1. Grain size distributions (based on dry weight) of gravel samples collected from Site 1 on the Sultan River (Sportsman Park, River Mile 0.1), August 15 2005.

Grain Size (mm)	**Percent Finer Than Based on Dry Weight**									
	S1-1	**S1-2**	**S1-3**	**S1-4**	**S1-5**	**S1-6**	**S1-7**	**S1-8**	**S1-9**	**S1-10**
150	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
63	83.9	47.8	78.7	86.5	90.9	76.4	67.2	80.7	79.8	61.9
31.5	61.8	38.3	59.5	54.3	63.7	52.1	40.4	60.5	57.6	34.4
16	49.8	30.7	44.7	40.7	49.6	38.2	30.5	46.7	45.4	22.6
8	39.8	24.0	33.6	31.8	38.7	27.2	21.0	33.8	34.3	13.9
4	32.2	19.3	27.4	25.0	30.3	17.7	13.2	21.8	23.6	8.5
2	22.9	14.6	21.2	17.9	22.0	9.1	5.2	10.1	12.5	4.6
0.85	11.0	6.4	12.8	8.6	12.0	2.8	0.7	2.7	3.8	2.4
0.5	4.3	2.2	4.4	3.2	3.8	0.8	0.3	0.7	1.2	0.9
0.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-2. Grain size distributions (based on dry weight) of gravel samples collected from Site 2 on the Sultan River (Reese Park, River Mile 0.7), August 16 2005.

Grain Size (mm)	**Percent Finer Than Based on Dry Weight**									
	S2-1	**S2-2**	**S2-3**	**S2-4**	**S2-5**	**S2-6**	**S2-7**	**S2-8**	**S2-9**	**S2-10**
150	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
63	70.3	74.2	69.3	60.7	75.1	71.5	64.3	83.1	61.0	72.4
31.5	59.1	61.4	55.9	44.0	54.7	45.5	48.0	61.3	43.1	56.3
16	41.6	45.4	40.1	33.6	39.8	34.9	34.7	47.0	29.3	40.3
8	31.0	34.4	30.2	26.0	28.5	26.5	25.0	34.8	19.7	29.1
4	23.0	25.0	21.6	19.9	19.2	20.2	17.2	24.4	13.9	21.0
2	13.7	13.8	12.8	13.1	10.5	12.6	9.0	12.2	7.4	11.8
0.85	4.4	4.8	4.4	3.9	3.8	4.0	2.8	4.3	3.0	4.4
0.5	1.8	1.3	1.7	1.4	1.8	1.2	1.4	2.0	1.5	2.1
0.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-3. Grain size distributions (based on dry weight) of gravel samples collected from Site 3 on the Sultan River (Trout Farm Road, River Mile 2.5), August 17 2005.

Grain Size (mm)	Percent Finer Than Based on Dry Weight									
	S3-1	**S3-2**	**S3-3**	**S3-4**	**S3-5**	**S3-6**	**S3-7**	**S3-8**	**S3-9**	**S3-10**
150	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
63	64.6	61.7	67.7	70.6	60.3	62.0	51.5	56.8	53.6	45.6
31.5	41.6	41.3	53.0	45.5	44.6	51.4	40.2	36.6	35.3	35.9
16	29.4	31.3	40.0	32.1	30.4	41.0	30.7	25.3	23.8	29.8
8	20.6	24.0	29.0	22.9	21.3	32.1	23.6	18.0	17.0	23.0
4	13.8	16.3	19.4	14.5	13.7	23.2	15.8	11.5	11.2	14.9
2	7.0	9.4	11.1	6.5	6.7	11.5	7.9	6.4	5.8	7.0
0.85	2.2	3.5	4.0	2.0	1.9	4.1	2.4	2.2	1.7	2.4
0.5	0.8	1.2	1.2	0.4	0.5	1.6	0.9	0.8	0.7	0.9
0.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-4. Grain size distributions (based on dry weight) of gravel samples collected from Site 4 on the Sultan River (USGS Gage, River Mile 4.7), August 18 2005.

Grain Size (mm)	Percent Finer Than Based on Dry Weight									
	S4-1	**S4-2**	**S4-3**	**S4-4**	**S4-5**	**S4-6**	**S4-7**	**S4-8**	**S4-9**	**S4-10**
150	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
63	95.6	96.1	89.6	85.0	99.1	100.0	94.7	92.2	74.3	80.1
31.5	65.8	72.1	54.5	72.2	84.9	72.8	74.4	49.3	41.5	55.5
16	41.1	47.6	34.5	48.2	57.8	46.1	52.3	18.9	16.8	32.3
8	27.7	32.0	21.5	33.5	41.2	28.2	31.7	6.6	4.0	13.2
4	18.5	21.8	13.4	20.1	28.7	15.1	16.5	2.9	1.3	5.1
2	11.3	11.7	5.8	9.0	14.2	5.9	6.3	1.6	0.9	3.7
0.85	4.6	3.6	2.2	3.4	4.2	3.1	3.9	1.3	0.7	2.1
0.5	1.7	1.0	1.0	2.0	1.4	1.9	2.6	1.2	0.6	0.7
0.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-5. Grain size distributions (based on dry weight) of gravel samples collected from Site 5 on the Sultan River (Gold Camp, River Mile 7.3), August 19 and 22 2005.

Grain Size (mm)	Percent Finer Than Based on Dry Weight									
	S5-1	**S5-2**	**S5-3**	**S5-4**	**S5-5**	**S5-6**	**S5-7**	**S5-8**	**S5-9**	**S5-10**
150	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
63	91.9	91.9	97.7	95.0	97.8	100.0	100.0	100.0	100.0	100.0
31.5	45.0	46.5	62.3	65.2	66.0	74.2	84.0	93.7	79.8	84.6
16	27.3	25.9	38.7	33.6	45.3	45.2	51.3	68.7	52.7	60.8
8	19.5	16.6	23.8	18.4	27.6	21.1	27.2	43.8	28.0	37.2
4	13.7	10.0	14.4	8.6	14.2	8.9	13.5	23.8	12.6	14.5
2	8.0	5.5	7.2	3.8	6.1	3.7	5.9	13.0	6.2	5.7
0.85	3.4	3.4	3.1	1.5	2.1	1.5	3.0	6.5	1.5	2.0
0.5	1.8	2.2	1.9	0.6	1.1	0.9	1.6	2.3	0.9	1.0
0.063	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX B

Geometric Mean Diameter and Percent Fines Less Than 0.84 mm for Spawning Gravel Samples Collected from the Sultan River in 1982, 1984, 1987, and 1994

Table B-1. Gravel monitoring results from 1982.

Year	Site	Replicate	River Mile	Date Sampled	Geometric Mean Diameter (mm)			Percent Fines Less Than 0.84 mm		
					Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression	Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression
1982	1	1	0.1	5/14/1982	23	25	34	3	3	2
1982	1	2	0.1	5/14/1982	16	18	16	5	4	3
1982	1	3	0.1	5/14/1982	19	22	28	4	3	3
1982	1	4	0.1	5/14/1982	20	23	23	4	3	2
1982	1	5	0.1	5/14/1982	9	11	7	6	4	5
1982	1	6	0.1	5/14/1982	17	20	25	6	5	3
1982	1	7	0.1	5/14/1982	17	19	24	5	3	3
1982	1	8	0.1	5/14/1982	22	25	26	4	3	3
1982	1	9	0.1	5/14/1982	14	16	11	6	4	5
1982	1	10	0.1	5/14/1982	17	19	24	4	2	3
1982	2	1	0.8	4/27/1982	25	29	59	7	5	3
1982	2	2	0.8	4/27/1982	20	23	24	6	4	3
1982	2	3	0.8	4/27/1982	14	17	15	9	6	5
1982	2	4	0.8	4/27/1982	18	21	21	5	4	3
1982	2	5	0.8	4/27/1982	13	16	19	10	7	5
1982	2	6	0.8	4/27/1982	13	16	15	10	7	5
1982	2	7	0.8	4/27/1982	18	21	32	9	7	4
1982	2	8	0.8	4/27/1982	11	14	13	12	8	6
1982	2	9	0.8	4/27/1982	20	24	25	8	5	4
1982	2	10	0.8	4/27/1982	10	12	10	10	8	6
1982	3	1	2.5	4/28/1982	22	26	48	8	5	3
1982	3	2	2.5	4/28/1982	15	18	16	7	5	4
1982	3	3	2.5	4/28/1982	13	16	21	11	8	4
1982	3	4	2.5	4/28/1982	23	26	40	5	4	2
1982	3	5	2.5	4/28/1982	23	26	40	6	4	2
1982	3	6	2.5	4/28/1982	10	12	10	7	5	4
1982	3	7	2.5	4/28/1982	13	16	16	10	7	5
1982	3	8	2.5	4/28/1982	14	16	19	8	5	4
1982	3	9	2.5	4/28/1982	18	21	19	8	5	3
1982	3	10	2.5	4/28/1982	14	16	16	7	5	4
1982	4	1	4.7	5/12/1982	16	19	19	8	5	4
1982	4	2	4.7	5/12/1982	13	15	10	5	4	4
1982	4	3	4.7	5/12/1982	8	11	10	13	9	8
1982	4	4	4.7	5/12/1982	9	11	7	12	8	8
1982	4	5	4.7	5/12/1982	16	20	35	11	7	5
1982	4	6	4.7	5/12/1982	10	14	16	12	8	7
1982	4	7	4.7	5/12/1982	10	13	14	13	9	7
1982	4	8	4.7	5/12/1982	13	16	19	8	5	4
1982	4	9	4.7	5/12/1982	12	13	11	5	4	4
1982	4	10	4.7	5/12/1982	14	15	11	4	3	3
1982	5	1	7.2	5/13/2982	9	11	7	8	5	6
1982	5	2	7.2	5/13/2982	12	14	12	8	6	5
1982	5	3	7.2	5/13/2982	21	24	23	3	2	2
1982	5	4	7.2	5/13/2982	11	14	12	9	6	5
1982	5	5	7.2	5/13/2982	10	12	9	10	7	6
1982	5	6	7.2	5/13/2982	13	16	16	11	7	5
1982	5	7	7.2	5/13/2982	11	13	8	6	4	5
1982	5	8	7.2	5/13/2982	10	12	7	8	5	6
1982	5	9	7.2	5/13/2982	7	9	5	12	8	8
1982	5	10	7.2	5/13/2982	9	12	10	11	8	6

Table B-2. Gravel monitoring results from 1984.

Year	Site	Replicate	River Mile	Date Sampled	Geometric Mean Diameter (mm)			Percent Fines Less Than 0.84 mm		
					Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression	Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression
1984	1	1	0.1	2/20/1984	16	19	20	6	4	4
1984	1	2	0.1	2/20/1984	21	24	22	4	3	3
1984	1	3	0.1	2/20/1984	17	19	20	5	3	3
1984	1	4	0.1	2/20/1984	26	29	43	4	3	2
1984	1	5	0.1	2/20/1984	12	14	10	6	4	5
1984	1	6	0.1	2/20/1984	21	24	33	4	3	2
1984	1	7	0.1	2/20/1984	19	22	29	4	3	3
1984	1	8	0.1	2/20/1984	15	17	11	6	4	4
1984	1	9	0.1	2/20/1984	18	20	17	3	2	3
1984	1	10	0.1	2/20/1984	13	15	15	5	3	4
1984	2	1	0.8	2/18/1984	9	11	8	17	12	8
1984	2	2	0.8	2/18/1984	15	18	14	8	6	4
1984	2	3	0.8	2/18/1984	17	21	17	9	6	4
1984	2	4	0.8	2/18/1984	14	17	15	9	6	5
1984	2	5	0.8	2/18/1984	15	18	21	9	6	4
1984	2	6	0.8	2/18/1984	19	23	32	9	6	4
1994	2	7	0.8	2/18/1984	17	20	20	8	5	4
1984	2	8	0.8	2/18/1984	17	22	30	8	6	4
1984	2	9	0.8	2/18/1984	17	21	29	10	6	4
1984	2	10	0.8	2/18/1984	18	22	31	8	5	4
1984	3	1	2.5	2/23/1984	23	27	32	11	7	4
1984	3	2	2.5	2/23/1984	16	21	32	13	9	5
1984	3	3	2.5	2/23/1984	13	18	15	14	9	6
1984	3	4	2.5	2/23/1984	18	22	30	8	5	4
1984	3	5	2.5	2/23/1984	13	17	19	10	7	5
1984	3	6	2.5	2/23/1984	14	18	21	11	8	6
1984	3	7	2.5	2/23/1984	30	33	36	4	3	2
1984	3	8	2.5	2/23/1984	19	22	14	7	5	4
1984	3	9	2.5	2/23/1984	26	30	50	4	3	2
1984	3	10	2.5	2/23/1984	13	17	14	10	7	6
1984	4	1	4.7	2/29/1984	23	27	36	8	5	4
1984	4	2	4.7	2/29/1984	13	16	13	11	7	6
1984	4	3	4.7	2/29/1984	13	16	14	9	6	5
1984	4	4	4.7	2/29/1984	13	17	21	12	7	6
1984	4	5	4.7	2/29/1984	22	25	20	6	4	4
1984	4	6	4.7	2/29/1984	9	13	7	14	10	8
1984	4	7	4.7	2/29/1984	15	18	15	10	7	5
1984	4	8	4.7	2/29/1984	21	27	56	10	6	4
1984	4	9	4.7	2/29/1984	13	17	19	10	7	5
1984	4	10	4.7	2/29/1984	34	11	15	7	5	7
1984	5	1	7.2	3/1/1984	8	10	5	11	8	9
1984	5	2	7.2	3/1/1984	11	14	8	9	6	7
1984	5	3	7.2	3/1/1984	11	13	7	10	7	7
1984	5	4	7.2	3/1/1984	9	12	8	10	7	7
1984	5	5	7.2	3/1/1984	12	14	9	11	7	7
1984	5	6	7.2	3/1/1984	12	15	13	10	7	6
1984	5	7	7.2	3/1/1984	11	13	9	9	6	6
1984	5	8	7.2	3/1/1984	14	16	8	7	5	5
1984	5	9	7.2	3/1/1984	7	9	5	14	10	10
1984	5	10	7.2	3/1/1984	12	14	8	12	9	7

Table B-3. Gravel monitoring results from 1987.

Year	Site	Replicate	River Mile	Date Sampled	Geometric Mean Diameter (mm)			Percent Fines Less Than 0.84 mm		
					Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression	Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression
1987	1	1	0.1	9/15/1987	14	15	13	4	3	4
1987	1	2	0.1	9/15/1987	16	18	22	5	4	4
1987	1	3	0.1	9/15/1987	15	18	19	4	3	4
1987	1	4	0.1	9/15/1987	15	17	12	4	3	3
1987	1	5	0.1	9/15/1987	17	19	24	4	3	3
1987	2	1	0.8	9/16/1987	14	17	25	12	9	8
1987	2	2	0.8	9/16/1987	19	23	41	11	8	6
1987	2	3	0.8	9/16/1987	14	17	30	12	8	7
1987	2	4	0.8	9/16/1987	13	16	20	9	6	6
1987	2	5	0.8	9/16/1987	15	19	30	11	7	6
1987	3	1	2.5	9/17/1987	23	26	47	6	4	4
1987	3	2	2.5	9/17/1987	14	18	24	11	7	6
1987	3	3	2.5	9/17/1987	16	20	29	9	6	6
1987	3	4	2.5	9/17/1987	11	13	13	10	7	7
1987	3	5	2.5	9/17/1987	14	17	27	8	6	6
1987	4	1	4.7	9/17/1987	17	20	45	9	6	6
1987	4	2	4.7	9/17/1987	15	18	23	8	5	6
1987	4	3	4.7	9/17/1987	13	17	27	13	8	8
1987	4	4	4.7	9/17/1987	14	16	14	7	5	5
1987	4	5	4.7	9/17/1987	22	26	49	5	3	3
1987	5	1	7.2	9/18/1987	20	22	45	3	2	3
1987	5	2	7.2	9/18/1987	20	22	21	3	2	3
1987	5	3	7.2	9/18/1987	20	23	44	6	4	5
1987	5	4	7.2	9/18/1987	20	22	30	4	3	4
1987	5	5	7.2	9/18/1987	30	32	424	5	4	4

Table B-4. Gravel monitoring results from 1994.

Year	Site	Replicate	River Mile	Date Sampled	Geometric Mean Diameter (mm)			Percent Fines Less Than 0.84 mm		
					Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression	Based on Wet Volume	Based on Dry Weight	Based on Log Normal Regression
1994	1	1	0.1	9/7/1994	14	17	40	6	4	3
1994	1	2	0.1	9/7/1994	23	25	123	2	2	2
1994	1	3	0.1	9/7/1994	17	19	29	8	5	4
1994	1	4	0.1	9/7/1994	13	15	21	6	5	3
1994	1	5	0.1	9/7/1994	14	17	32	5	4	3
1994	2	1	0.8	9/8/1994	8	10	8	10	7	7
1994	2	2	0.8	9/8/1994	12	14	19	11	8	4
1994	2	3	0.8	9/8/1994	14	16	29	11	8	4
1994	2	4	0.8	9/8/1994	14	16	31	8	6	3
1994	2	5	0.8	9/8/1994	9	10	13	9	6	4
1994	3	1	2.5	9/8/1994	17	19	36	5	4	2
1994	3	2	2.5	9/8/1994	16	19	14	4	3	2
1994	3	3	2.5	9/8/1994	12	14	34	9	6	4
1994	3	4	2.5	9/8/1994	15	17	34	6	4	3
1994	3	5	2.5	9/8/1994	12	14	14	10	8	4
1994	4A	2	4.7	9/9/1994	7	8	8	11	11	6
1994	4A	3	4.7	9/9/1994	5	6	8	12	12	7
1994	4A	4	4.7	9/9/1994	4	4	6	9	9	7
1994	4A	5	4.7	9/9/1994	3	4	5	9	9	9
1994	4B	1	4.9	9/9/1994	26	27	76	2	1	1
1994	4B	2	4.9	9/9/1994	10	11	12	4	4	0
1994	4B	3	4.9	9/9/1994	9	11	21	10	2	4
1994	4B	4	4.9	9/9/1994	6	7	12	3	8	7
1994	4B	5	4.9	9/9/1994	19	21	60	5	2	3
1994	5A	1	7.2	9/12/1994	11	13	35	8	8	5
1994	5A	2	7.2	9/12/1994	11	14	24	10	10	5
1994	5A	3	7.2	9/12/1994	11	13	22	9	9	5
1994	5A	4	7.2	9/12/1994	9	11	28	9	9	6
1994	5A	5	7.2	9/12/1994	7	9	16	12	12	8
1994	5B	1	7.2	9/12/1994	10	11	17	8	5	4
1994	5B	2	7.2	9/12/1994	11	13	27	8	7	4
1994	5B	3	7.2	9/12/1994	11	12	19	5	6	2
1994	5B	4	7.2	9/12/1994	15	17	48	6	6	3
1994	5B	5	7.2	9/12/1994	10	13	27	11	8	6

APPENDIX C

Vertical Profiles of Geometric Mean Diameter and Percent Fines Less Than 0.84 mm for Spawning Gravel Samples Collected from the Sultan River in 1982, 1984, 1987, and 1994

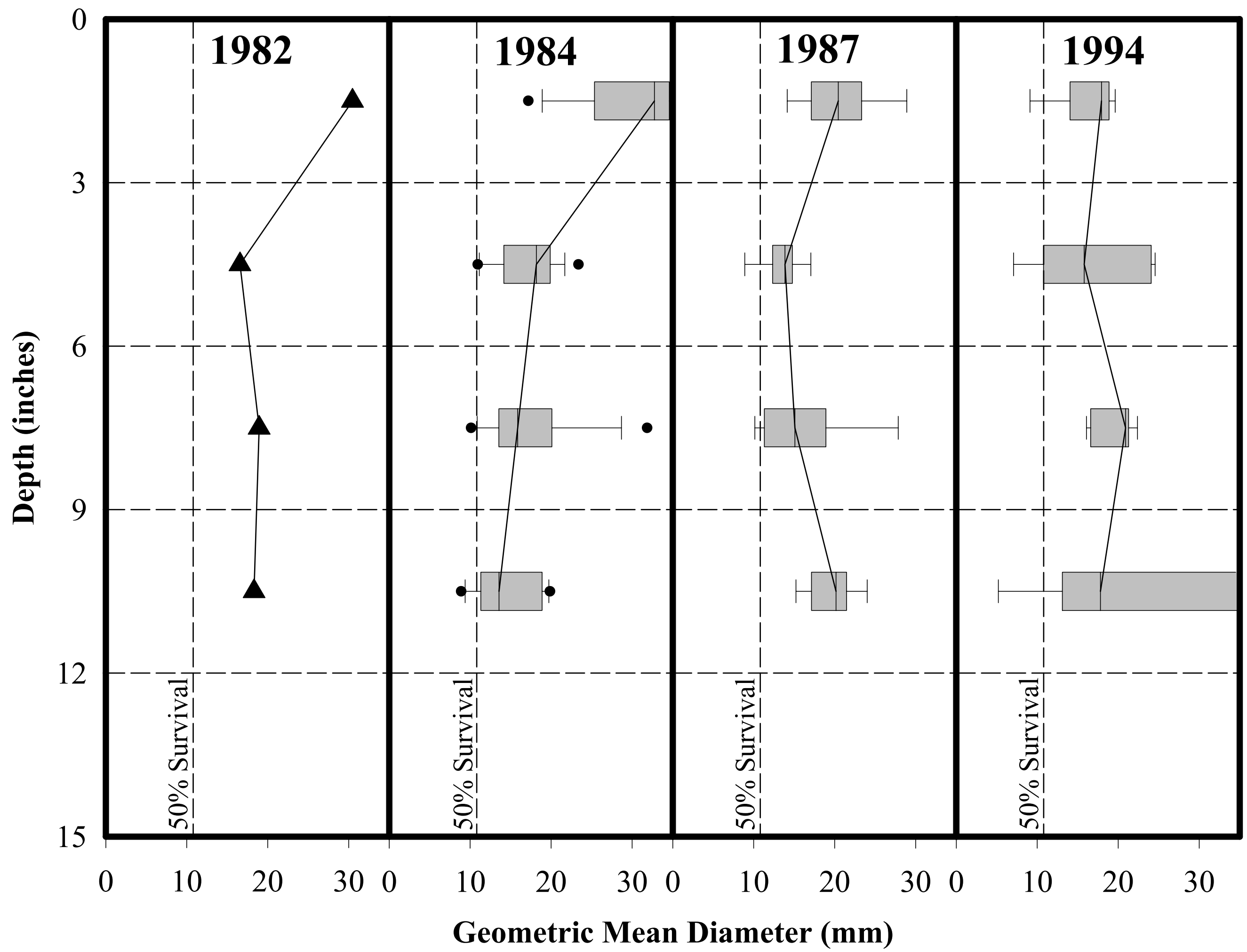

Figure C-1. Vertical profile of geometric mean diameter from gravel samples collected from Site 1 (Sportsman Park, River Mile 0.1) in 1982, 1984, 1987, and 1994.

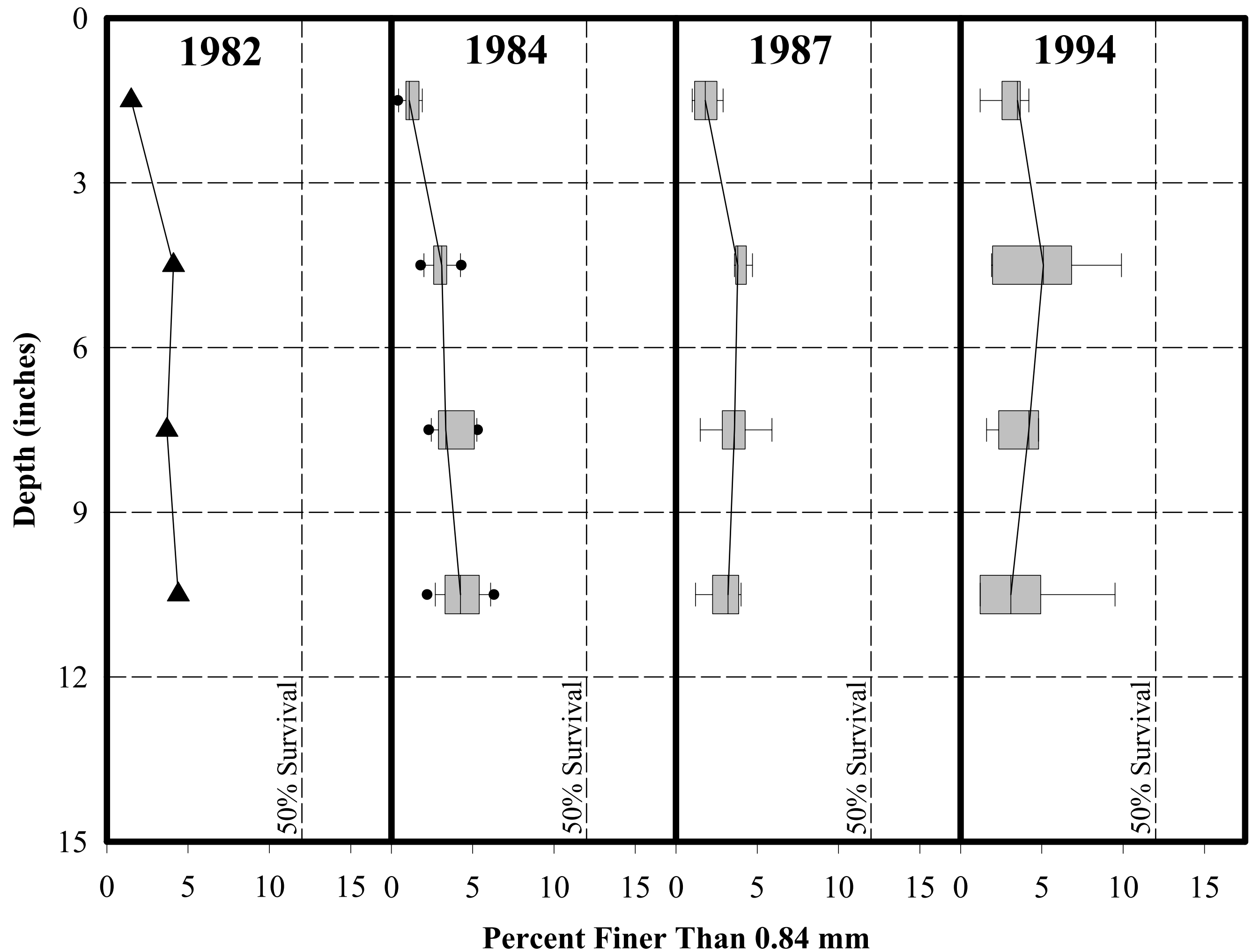

Figure C-2. Vertical profile of percent fines less than 0.84 mm from gravel samples collected from Site 1 (Sportsman Park, River Mile 0.1) in 1982, 1984, 1987, and 1994.

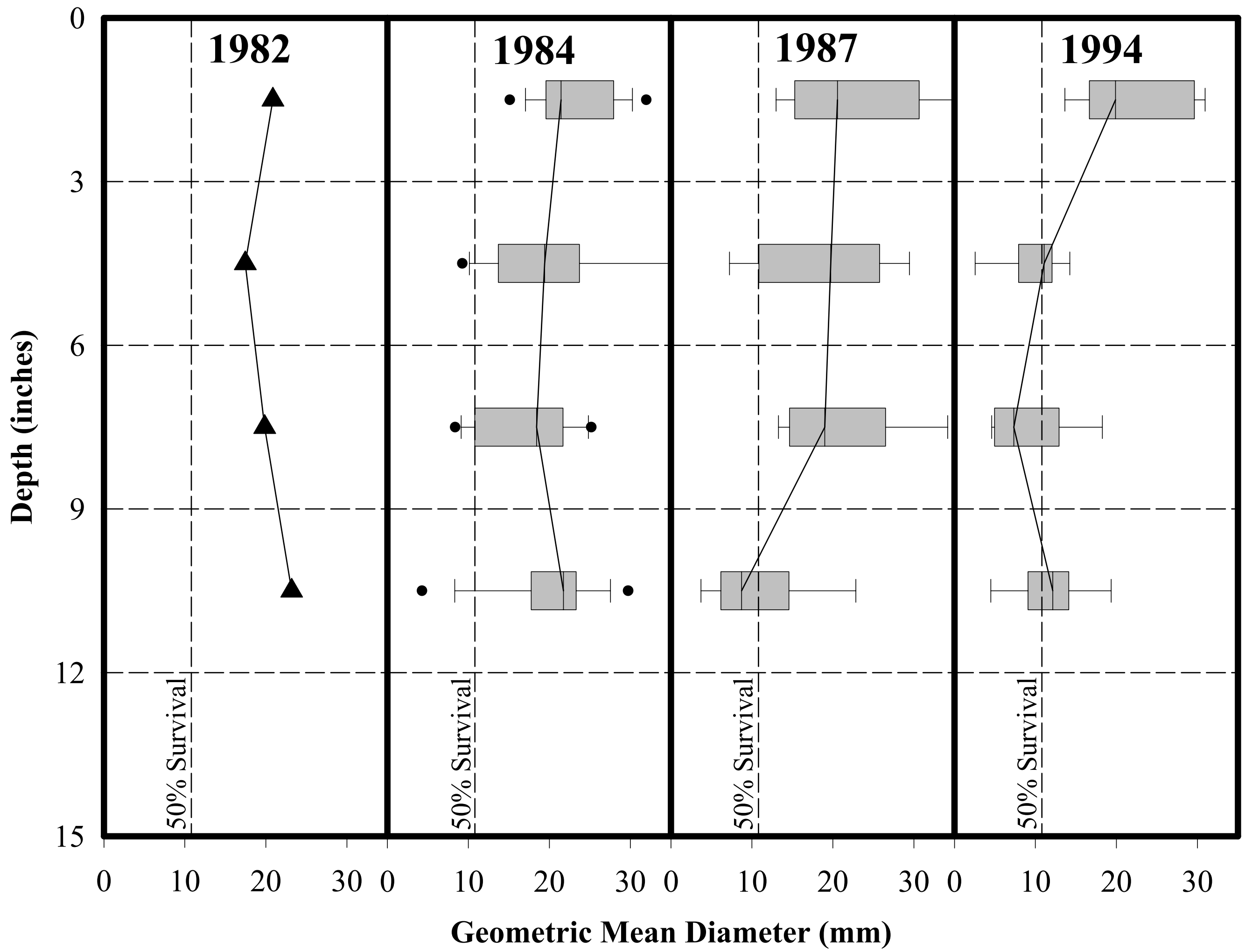

Figure C-3. Vertical profile of geometric mean diameter from gravel samples collected from Site 2 (Reese Park, River Mile 0.7) in 1982, 1984, 1987, and 1994.

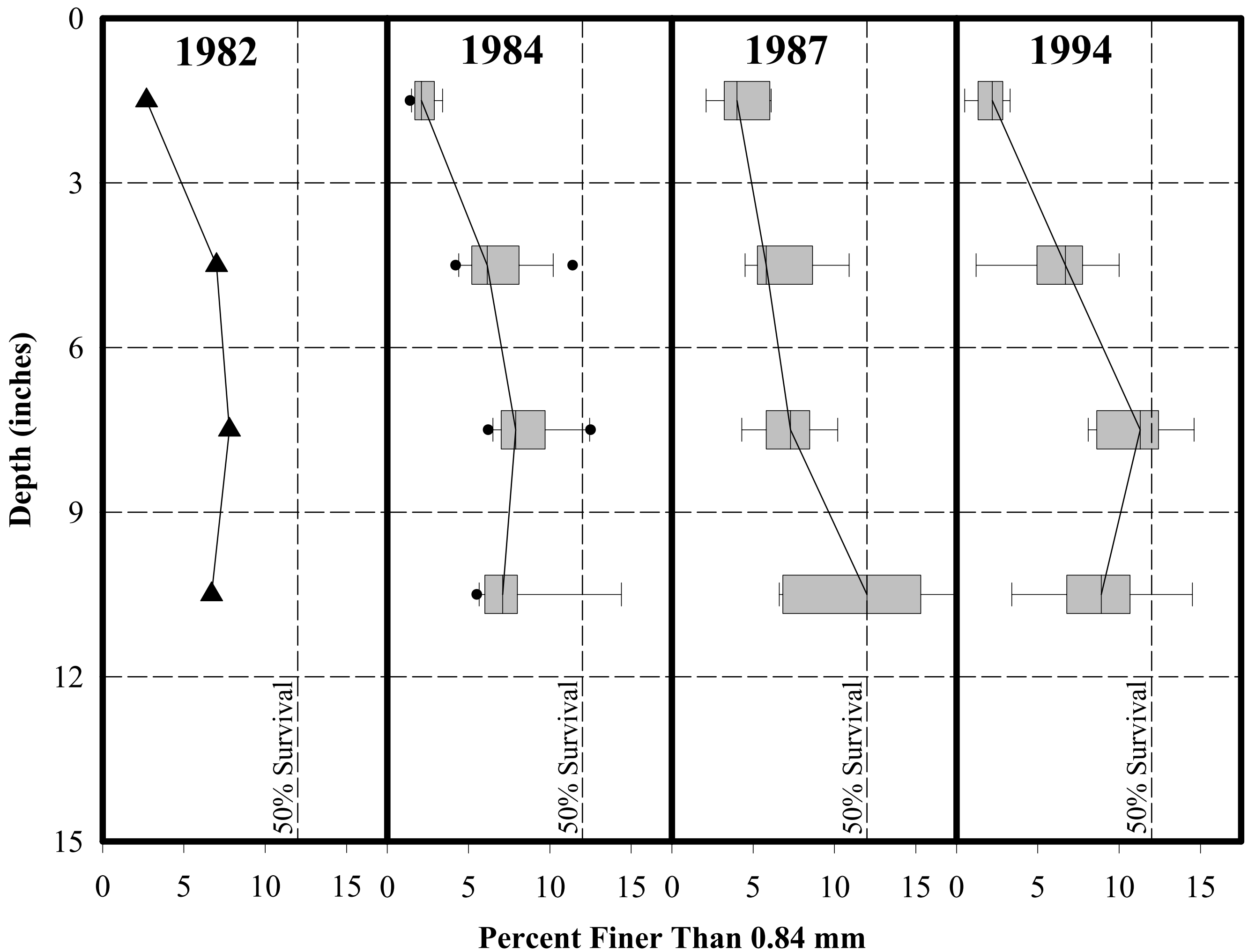

Figure C-4. Vertical profile of percent fines less than 0.84 mm from gravel samples collected from Site 2 (Reese Park, River Mile 0.7) in 1982, 1984, 1987, and 1994.

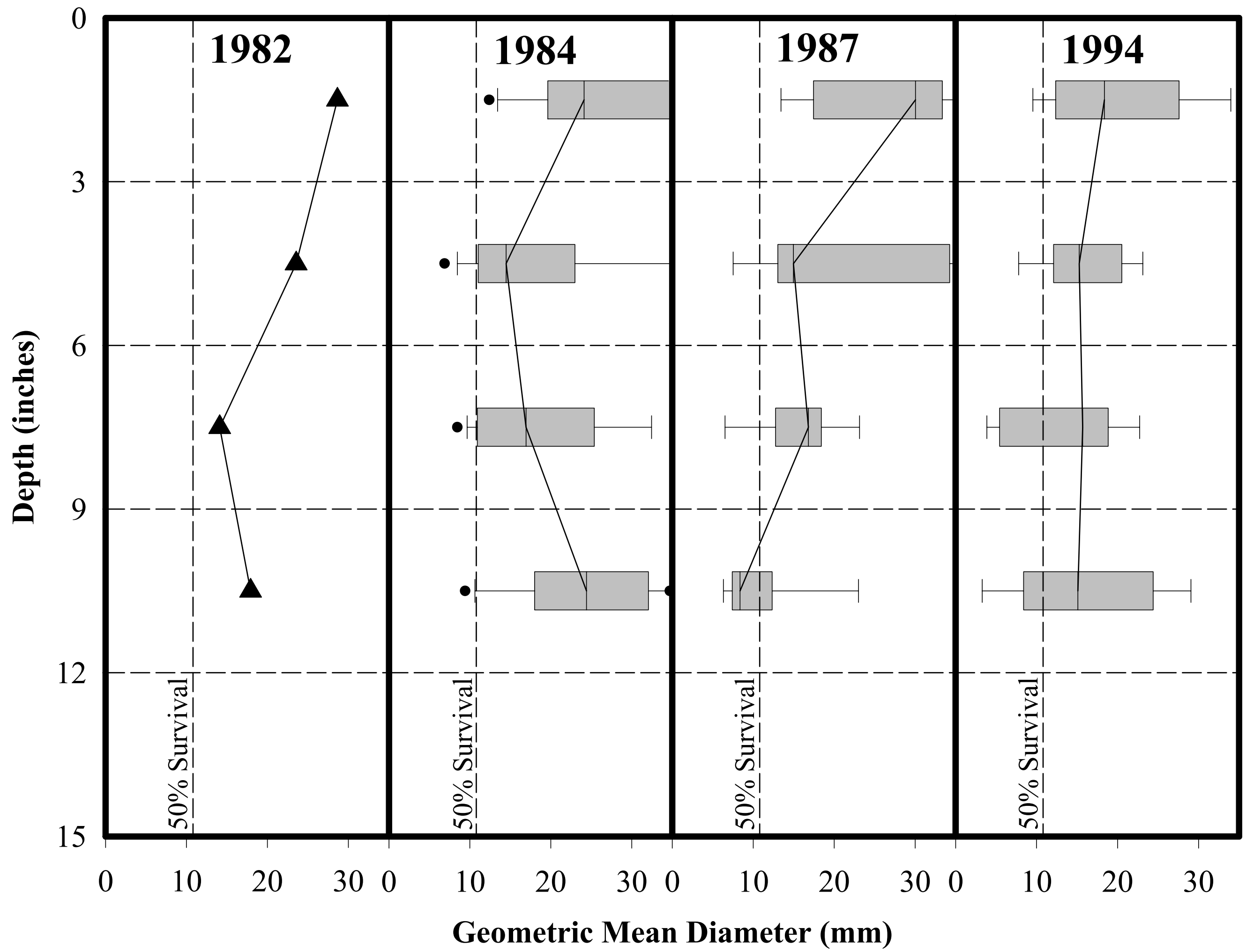

Figure C-5. Vertical profile of geometric mean diameter from gravel samples collected from Site 3 (Trout Farm Road, River Mile 2.5) in 1982, 1984, 1987, and 1994.

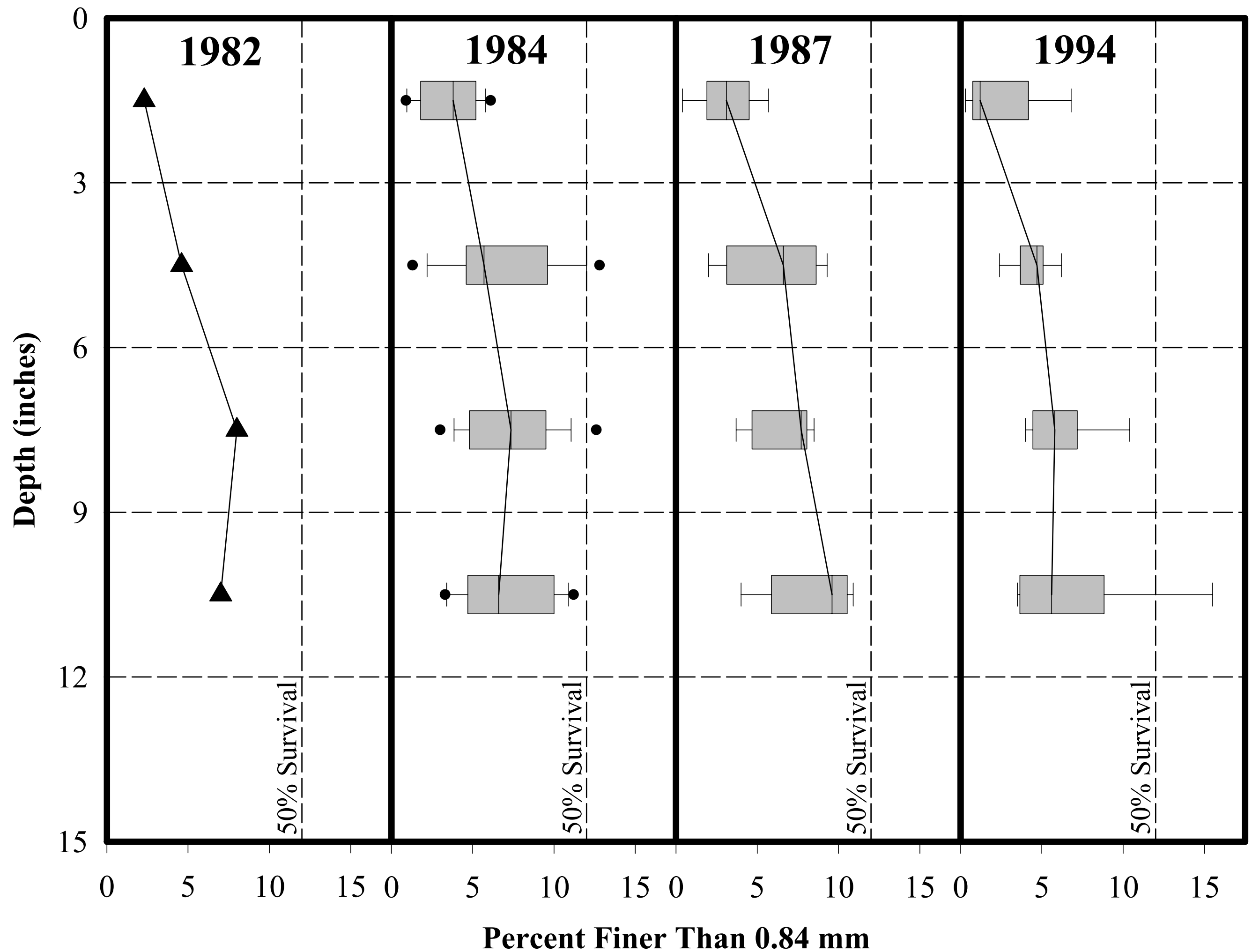

Figure C-6. Vertical profile of percent fines less than 0.84 mm from gravel samples collected from Site 3 (Trout Farm Road, River Mile 2.5) in 1982, 1984, 1987, and 1994.

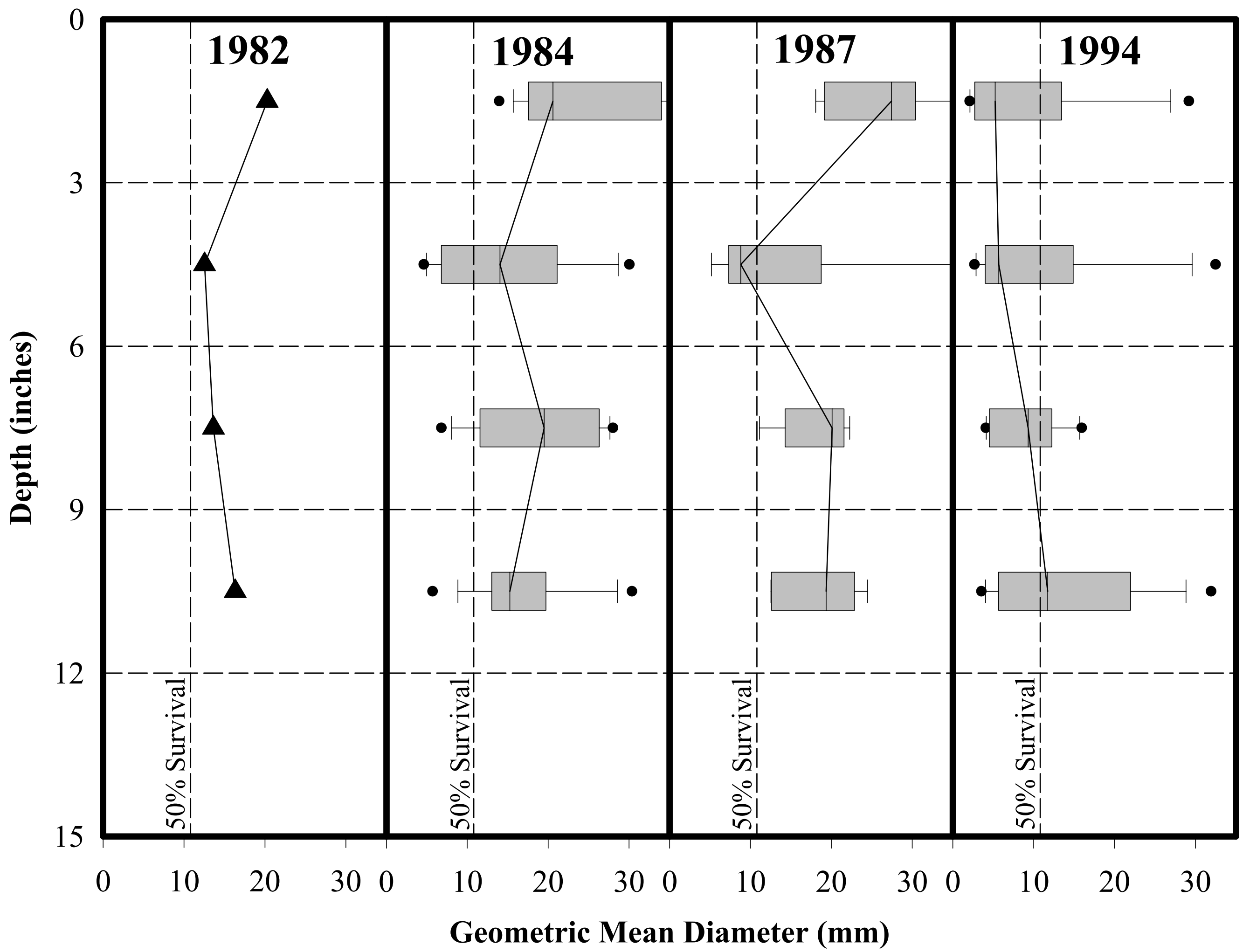

Figure C-7. Vertical profile of geometric mean diameter from gravel samples collected from Site 4 (USGS Gage, River Mile 4.7) in 1982, 1984, 1987, and 1994.

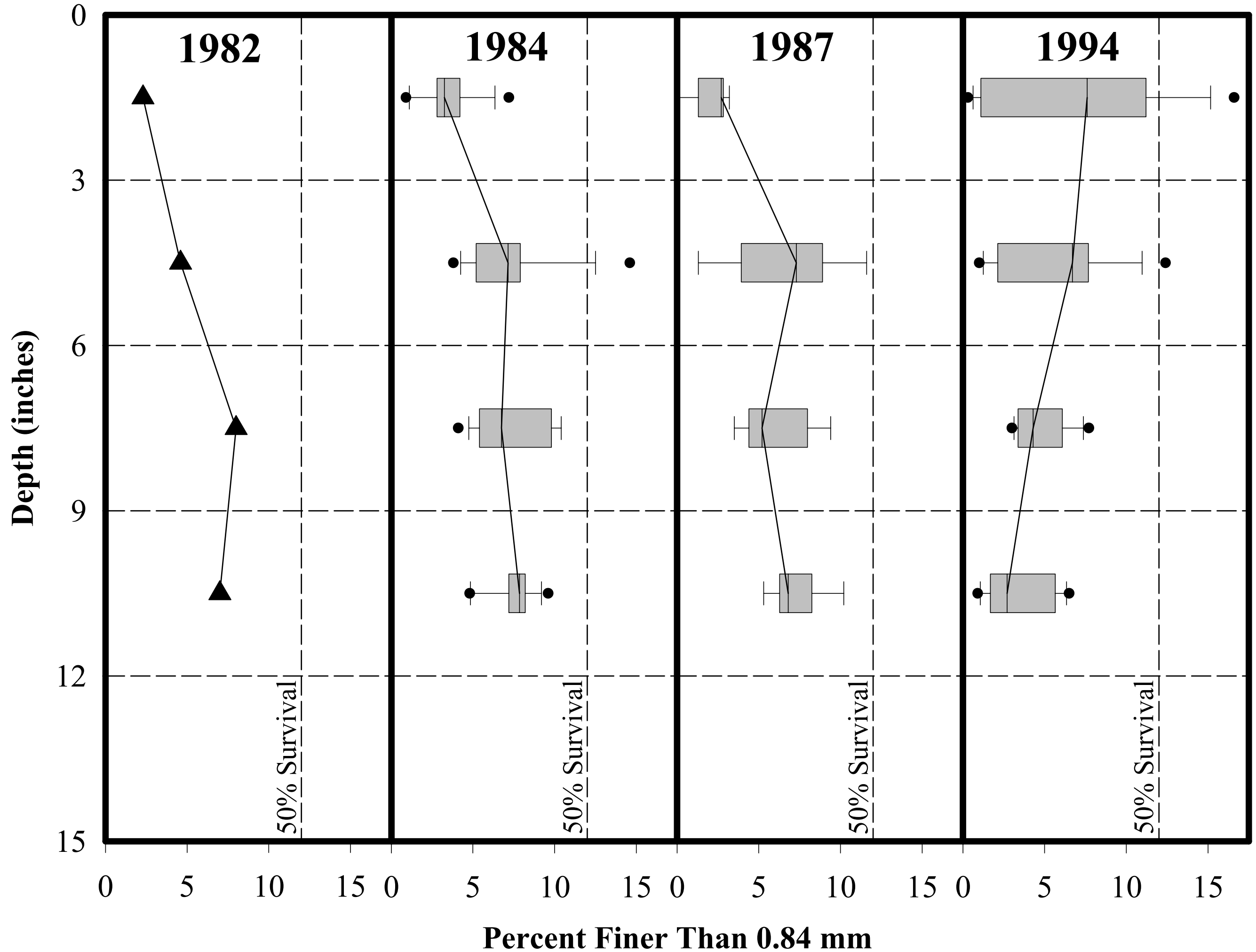

Figure C-8. Vertical profile of percent finer than 0.84 mm from gravel samples collected from Site 4 (USGS Gage, River Mile 4.7) in 1982, 1984, 1987, and 1994.

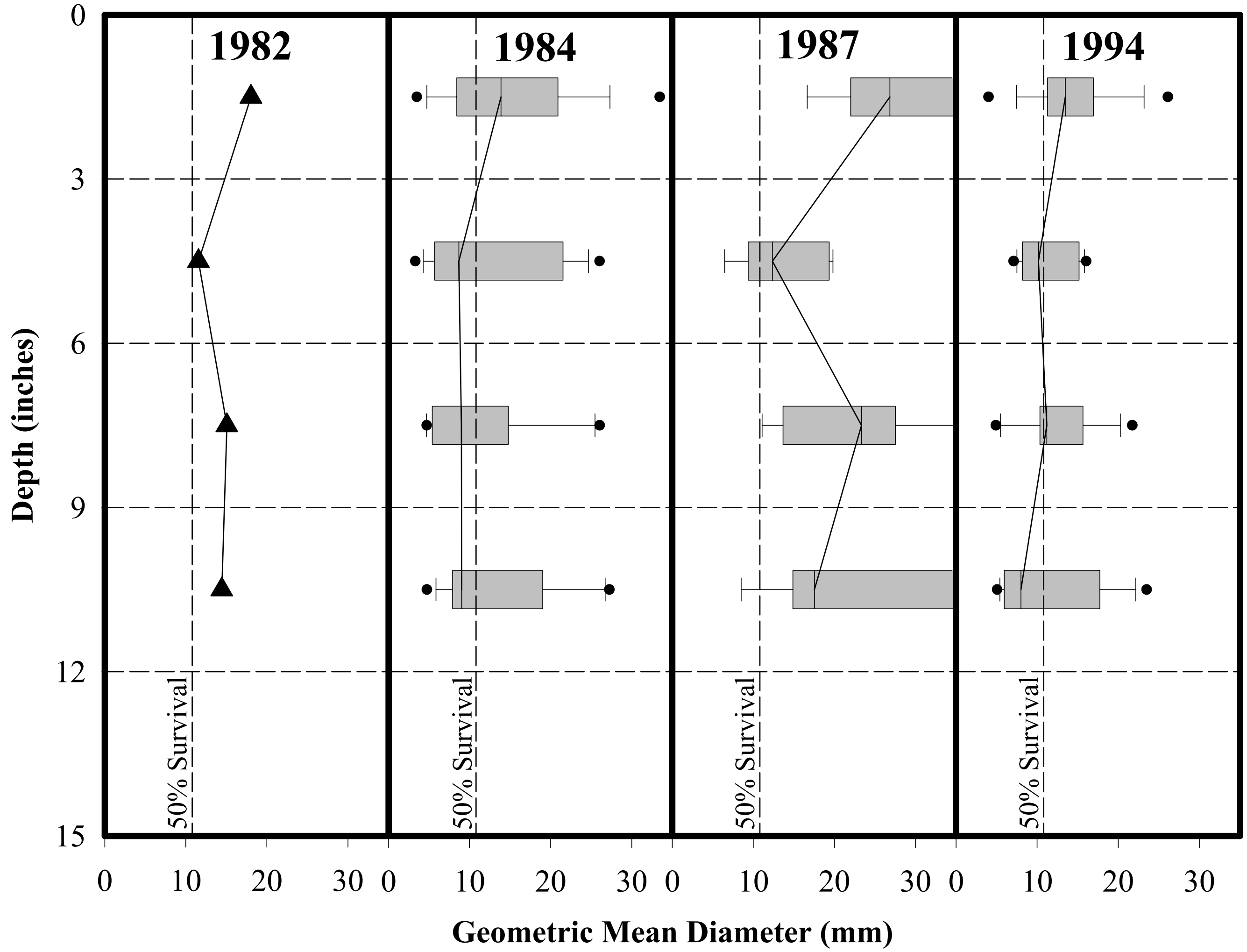

Figure C-9. Vertical profile of geometric mean diameter from gravel samples collected from Site 5 (Gold Camp, River Mile 7.3) in 1982, 1984, 1987, and 1994.

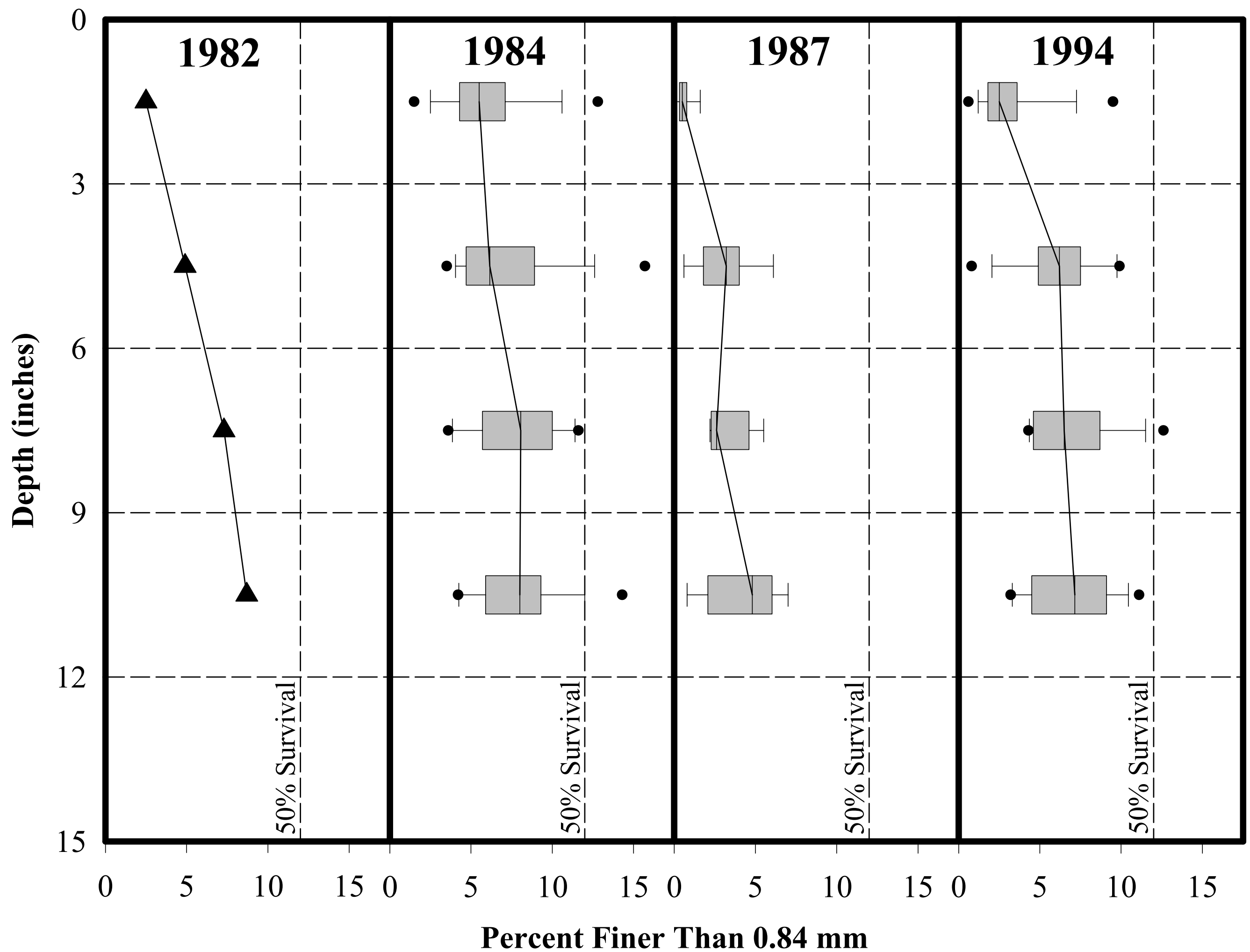

Figure C-10. Vertical profile of percent fines less than 0.84 mm from gravel samples collected from Site 5 (Gold Camp, River Mile 7.3) in 1982, 1984, 1987, and 1994.