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AN EVALUATION OF THE INCUBATION LIFE PHASE OF CHUM SALMON IN THE MIDDLE SUSITNA RIVER

SUSITNA HYDRO AQUATIC STUDIES
WINTER AQUATIC INVESTIGATIONS:
SEPTEMBER, 1983 - MAY, 1984
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VOLUME 1

-by-

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PREFACE

This report is one of a series of reports prepared for the Alaska Power Authority (APA) by the Alaska Department of Fish and Game (ADF&G) to provide information to be used in evaluating the feasibility of the proposed Susitna Hydroelectric Project. The ADF&G Susitna Hydro Aquatic Studies program was initiated in November 1980. The five year study program was divided into three study sections: Adult Anadromous Fish Studies (AA), Resident and Juvenile Anadromous Studies (RJ), and Aquatic Habitat and Instream Flow Studies (AH). Reports prepared by the ADF&G prior to 1983 on this subject are available from the APA.

Beginning with the 1983 reports, all reports were sequentially numbered as part of the Alaska Department of Fish and Game Susitna Hydro Aquatic Studies Report Series.

TITLES IN THE ADF&G REPORT SERIES

Report Number	Title	Publication Date
1	Adult Anadromous Fish Investigations: May - October 1983	April 1984
2	Resident and Juvenile Anadromous Fish Investigations: May - October 1983	July 1984
3	Aquatic Habitat and Instream Flow Investigations: May - October 1983	Sept. 1984
4	Access and Transmission Corridor Aquatic Investigations: May - October 1983	Sept. 1984
5	Winter Aquatic Investigations: September, 1983 - May, 1984	March 1985

This report provides results of the 1983-1984 winter studies conducted by the ADF&G to evaluate and compare existing chum salmon incubation conditions in selected slough, side channel, tributary, and mainstem habitats of the Susitna River between Talkeetna and Devil Canyon (River Miles 98-152). The types of data presented in this report include development and survival data for chum salmon embryos, surface and intragravel water quality data (pH, conductivity, temperature and dissolved oxygen), and substrate composition data.

AN EVALUATION OF THE INCUBATION LIFE-PHASE OF CHUM SALMON IN THE MIDDLE SUSITNA RIVER

REPORT NUMBER 5: VOLUME 1

WINTER AQUATIC INVESTIGATIONS: SEPTEMBER, 1983 - MAY, 1984

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1985

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ABSTRACT

An evaluation of the survival and pattern of development of chum salmon embryos (to 50% hatch) was made between embryos incubated in artificial redds in slough, side channel, tributary and mainstem habitats. Eggs were obtained on site and artificially fertilized. After allowing them to water-harden, fifty embryos were placed in each Whitlock-Vibert Box (WVB) and installed in the streambed. Intragravel temperature, dissolved oxygen, pH, conductivity and substrate composition were measured within each type and compared to the percent survival of embryos. A quantitative analysis of the effect of each variable on survival was hampered by the overwhelming mortality due to dewatering and subsequent freezing of the substrate (and embryos). This effect was greatest in side channels and least in sloughs, and was observed to be directly related to the location and strength of upwelling. Mouth areas in slough, side channel, and tributary habitats also undergo freezing

because the stage in the mainstem decreases significantly after fish spawn, resulting in dewatering of mouth areas. Although there were no definable relationships between percent survival and any other variables, the lower limit of survival was apparent for percent of fine substrate (<0.08 in) and for dissolved oxygen. The percent survival of embryos decreased to zero when the percent of fines (< 0.08 in) was greater than 18%. Similarly, percent survival of embryos was zero at dissolved oxygen levels below 3.0 mg/l.

Intragravel water temperature directly controls the pattern of development of embryos. There was a high degree of variability in the intragravel water temperatures within and between habitat types. In general, sloughs exhibit relatively warmer (approximately 2.0-4.0°C) and stable intragravel temperatures because of the stabilizing influence of. In contrast, intragravel water temperatures in tributary and mainstem habitats reflect the large seasonal variations in surface water temperatures. Temperature conditions in side channels do not conform to a "typical" pattern. It is hypothesized that the earlier arrival of chum salmon spawning in tributaries, compared to sloughs, is related to the differences in their thermal regimes.

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1.0 INTRODUCTION

1.1 Background

The primary purpose of this report is to compare development and survival of incubating chum salmon (Oncorhynchus keta) embryos within selected slough, side channel, tributary, and mainstem habitats of the middle reach of the Susitna River between Talkeetna and Devil Canyon (RM 98-152; Figure 1). The report is based on the results of field studies conducted during the 1983-1984 ice-covered season (October - May).

The middle reach of the Susitna River was selected for study because the most obvious changes in existing physical characteristics of fish habitats are expected to occur within this reach (Acres 1982). Within this reach of river, slough and side channel habitats were selected as the primary focus of study because they (primarily sloughs) are extensively used by chum salmon for spawning and are likely to be directly influenced by project construction and operation. Chum salmon were selected as the target species for study for two reasons. First, they are the numerically dominant species of salmon which utilize slough and side channel habitats for spawning and incubation in this reach of the Susitna River. Secondly, they are considered a good indicator species of expected changes which may affect sockeye salmon, the other salmon species of significance which also utilize these habitats for spawning and incubation.

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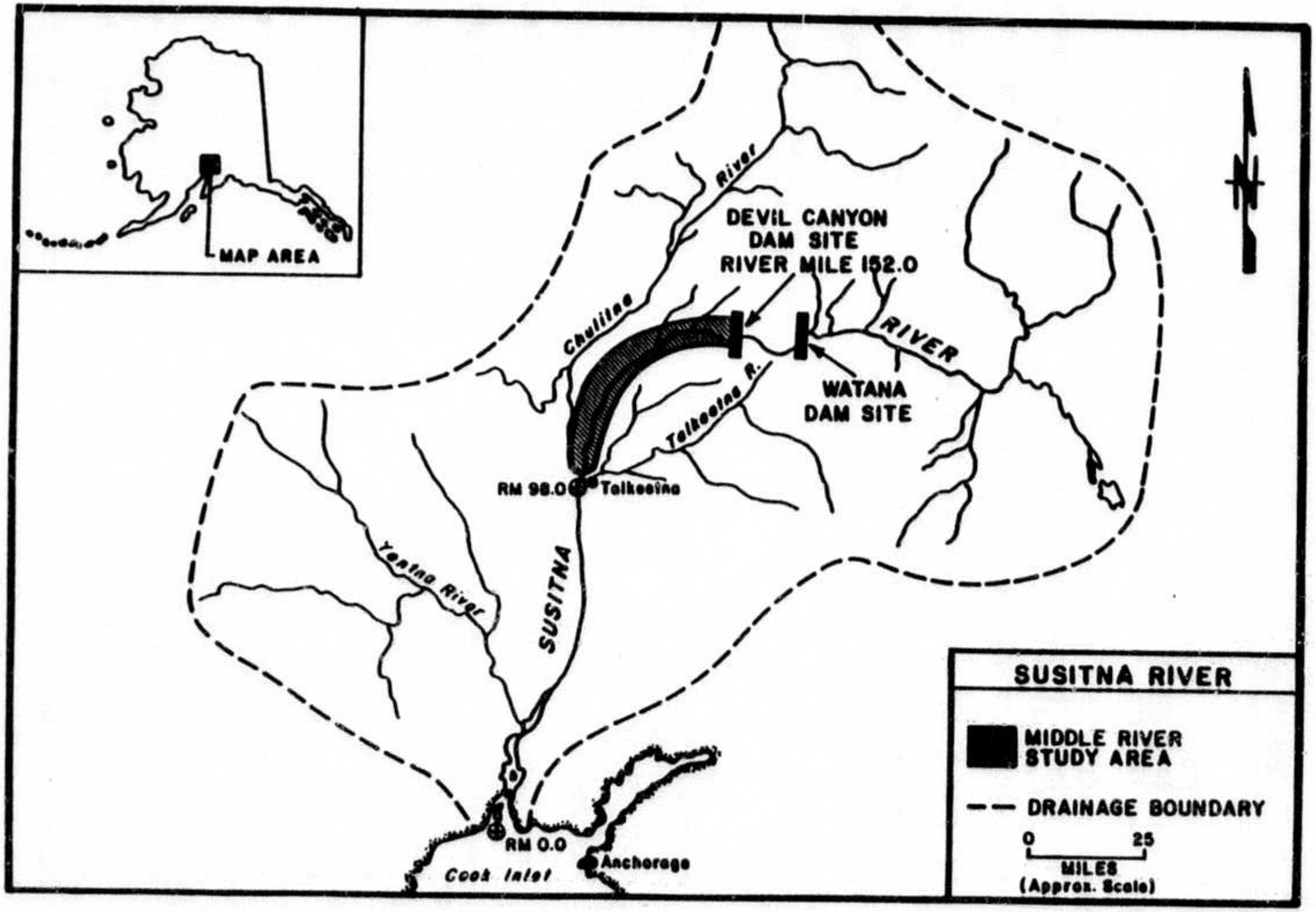

Figure 1. Map of the Susitna River Basin, with delineations of the basin drainage area and the middle reach of river.

There are four basic life-phases in the life cycle of chum salmon: passage, spawning, incubation, and rearing. The freshwater period of the life cycle includes all four life-phases, whereas the saltwater period includes only portions of the rearing and passage life phases. In general, chum salmon spend approximately 20% of their total life in freshwater and approximately 80% in saltwater (Figure 2).

In the middle reach of the Susitna River system, upstream passage of adult chum salmon generally peaks during the last two weeks of August and the first two weeks of September (ADF&G 1983b: Appendix B; Sautner et al. 1984). During this time, adult chum salmon migrate into a variety of aquatic habitat types (mainstem, slough, side channel, tributary, and tributary mouth) within this reach of the river to spawn, with major concentrations occurring in slough and tributary habitats.

Once on the spawning grounds, female chum salmon select a suitable spawning site, often in areas of upwelling (ADF&G 1983b: Appendix B; Vincent-Lang et al. 1984). The female normally excavates a depression in the streambed (i.e., redd) by turning on its side and rapidly flexing her body, creating strong water currents with the caudal fin. Once a depression is completed, the female and one or more attending males simultaneously release eggs and milt, respectively, into the depression. The eggs are then fertilized thus beginning a new generation of chum salmon. After fertilization, the female swims immediately upstream of the redd to begin excavation of another depression. In this way, the fertilized eggs deposited in the previously attended depression are

CHUM SALMON LIFE CYCLE

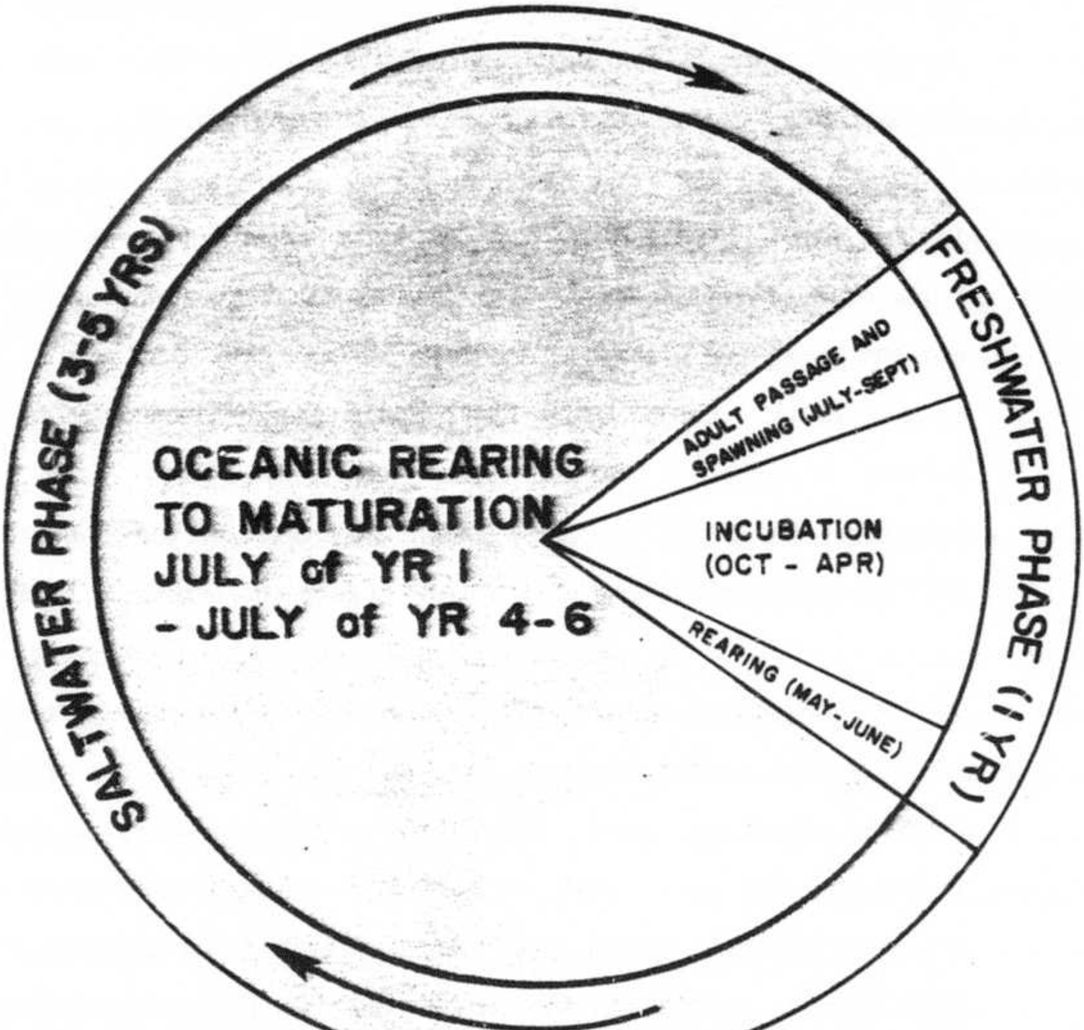

Figure 2. Generalized life cycle of a chum salmon indigenous to the middle Susitna River, Alaska.

covered with substrate materials that are excavated from the new depression. This process is successively repeated until the female has released all her eggs. After spawning, both sexes usually die within a few days (Morrow 1980).

The fertilized eggs (embryos) remain in the substrate and incubate for several months. The length of this period is highly variable depending upon environmental conditions, particularly water temperature. Generally, this period of time from fertilization of the egg until active feeding by fry, is referred to as the incubation period or life-phase (McNeil and Bailey 1975).

While in the gravel, the embryos undergo a developmental process which can be divided into three phases: cleavage, gastrulation, and organogenesis (Velsen 1980). During cleavage, the embryo undergoes a period of prolific cell division and ends as a flattened multicellular disc called a blastodisc. During gastrulation, the cells formed during cleavage develop into recognizable tissues which form the basic structure of the embryo. This phase ends when the yolk becomes completely enveloped by a thin sheet of cells, resulting in the closure of the blastopore (external opening in the main cavity of an embryo during gastrulation phase). During the organogenesis phase, fins and internal organs are formed and the circulatory system becomes developed. It is during this phase that embryos become "eyed". The organogenesis phase ends when the embryo hatches out of the protective egg shell. At this point, embryos are called alevins or pre-emergent fry (or sac-fry).

Newly hatched alevins (post hatching) remain in the gravel until spring. During this time they are sustained by absorbing their large yolk sac. When yolk sac absorbtion is nearly complete, the alevins emerge from the gravel and begin to actively feed (their rearing life-phase). Upon emergence from the gravels, they are referred to as fry. After spending only 1-2 months rearing in freshwater the seaward migration and smoltification process begins (Figure 2). Once at sea, they grow rapidly, generally reaching adult size in three to five years. Upon reaching this stage, they return to freshwater, cease feeding, and migrate upstream to their place of origin to spawn and die, thus completing their life cycle.

During much of the incubation period, chum salmon embryos remain within the streambed and are unable to move actively to other areas. This immobility results in a close dependence of the incubating salmon embryos to the multitude of environmental (i.e., physical, chemical, and biological) conditions in the immediate area. The close dependence of the incubating salmon embryos on local environmental conditions causes this life-phase to be particularly vulnerable to changes in physical, chemical, and biological conditions which may result from the construction and operation of the Susitna Hydroelectric Project.

Environmental changes which are expected to impact incubating chum salmon in slough and side channels of the middle reach of the Susitna River as a result of the operation and construction of the proposed hydroelectric facility include decreased and stabilized flows during the open water periods, increased flows in the winter (Acres 1982), and a marked change in seasonal water temperatures and ice processes (AEIDC 1984). In addition, seasonal reductions in upwelling and increases in the frequency of overtopping, which are anticipated in sloughs and side channels, could impact incubating salmon embryos (Woodward-Clyde 1984). Changes such as lower or higher intragravel water temperatures and changes in the concentration of dissolved gases during the incubation life-phase could have secondary effects on the development and/or survival rates of pre-emergent fry (Combs 1965; Baxter and Glaude 1980; Velsen 1980; Heming 1982), as well as affecting the emergence timing of fry (e.g., Koski 1966).

1.2 Objectives

Due to the importance of the incubation life-phase, a study was initiated during the fall of 1983 to address two objectives:

1) Compare selected physical and chemical conditions used for chum salmon incubation in selected slough, side channel, tributary, and mainstem habitats of the middle Susitna River; and,

2) Evaluate the influence of selected physical, chemical, and biological variables on the survival of chum salmon embryos placed in artificial redds in slough, side channel, tributary, and mainstem habitats of the middle Susitna River.

2.0 METHODS

2.1 Selection of Study Sites

A total of 16 sites were selected for study in slough, side channel, tributary, and mainstem habitats within the middle reach of the Susitna River (Figure 3, Table 1, Appendix Figures B-1 to B-12). Based on the type and quantity of data collected, each study site was classified as either primary or secondary. In general, greater effort was expended for data collection purposes at primary study sites.

Primary Sites

Primary study sites were selected to provide a comparison of the rate of development and percent survival of chum salmon embryos between slough and side channels. Information collected at primary study sites included water quality, substrate, continuous water temperature, and embryo survival and development data. Of the eight primary study sites selected seven were used to evaluate embryo survival (Sloughs 10, 11, and 21, Side Channels 10 and 21, Mainstem (RM 136.1), and Fourth of July Creek) and five were used to evaluate embryo development [Slough 11, Mainstem (RM 136.1), Fourth of July Creek, Side Channel 21, and Upper Side Channel 11].

The process used to select primary sites was influenced by a variety of interrelated factors. In general, these sites were selected according to the following prioritized criteria:

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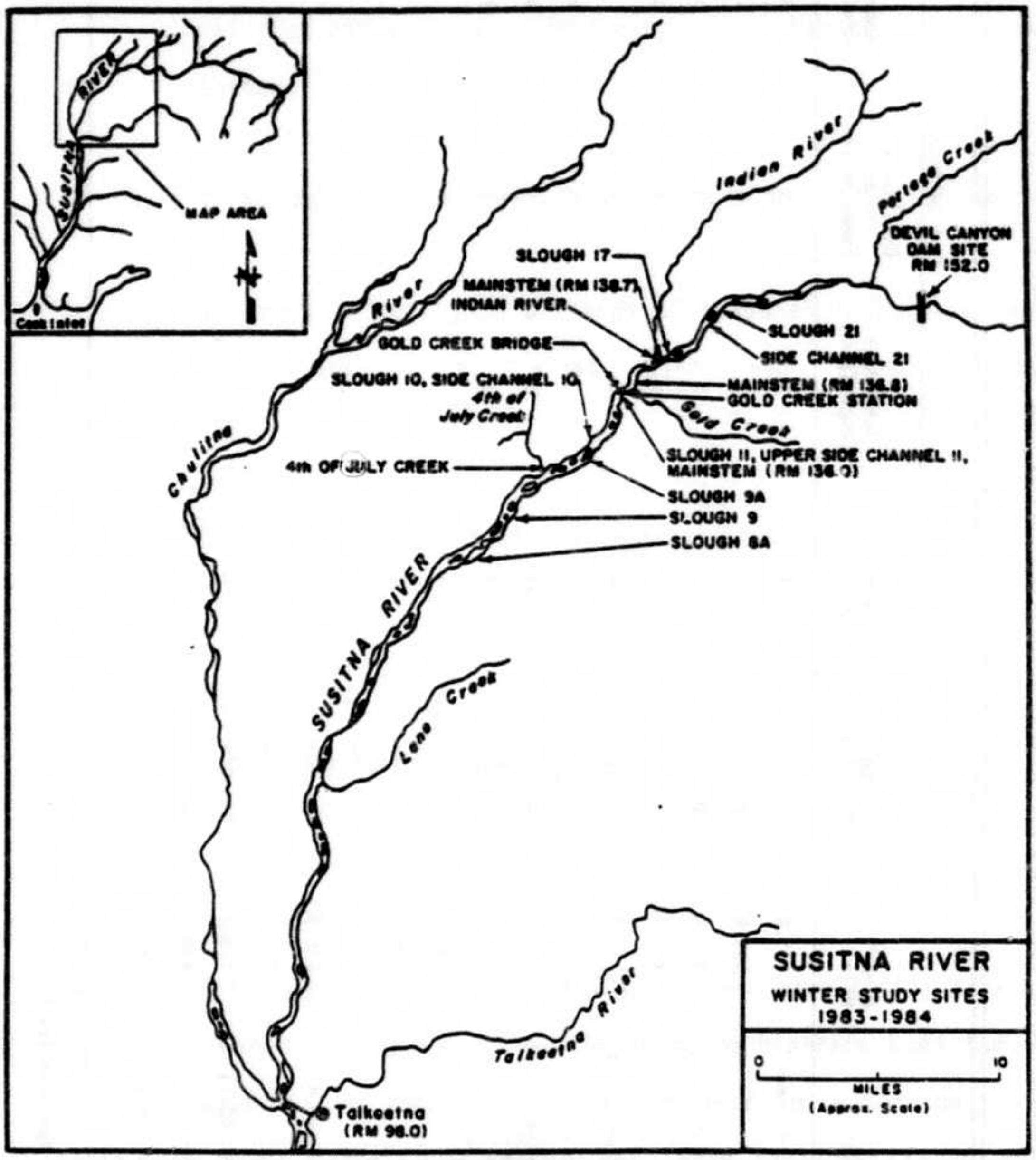

Figure 3. Locations of study sites within the middle reach of the Susitna River (RM 98-152).

Table 1. Reference list of study sites providing relative site priority, river mile location and type of data collected at each site.

Site Location	River Mile[a]	Site Priority	TYPE OF DATA: Water Quality[b]	Substrate Composition	Continuous Water Temperature	Embryo Survival	Embryo Development
Fourth of July Creek	131.1	Primary	X	X	X	X	X
Slough 10	133.8	Primary	X	X	X	X	
Side Channel 10	133.8	Primary	X	X	X	X	
Slough 11	135.3	Primary	X	X	X	X	X
Upper Side Channel 11	136.1	Primary	X	X	X		X
Mainstem (RM 136.1)	136.1	Primary	X		X	X	X
Side Channel 21	141.0	Primary	X	X	X	X	X
Slough 21	141.8	Primary	X	X	X	X	
Slough 8A	125.9	Secondary	X		X		
Slough 9	128.3	Secondary	X		X		
Slough 9A	133.6	Secondary	X				
Mainstem (RM 136.8)	136.8	Secondary	X				
Indian River	138.6	Secondary	X		X		
Mainstem (RM 138.7)	138.7	Secondary	X				
Slough 17	138.9	Secondary	X				
Mainstem (RM 138.9)	138.9	Secondary		X			

[a] Source: R&M Consultants (1982)

[b] Water quality variables include pH, conductivity, dissolved oxygen and temperature.

1) to be representative of a wide range of chum salmon spawning density (i.e., in high and low density areas);

2) to ensure that side slough, upland slough, side channel, mainstem and tributary (including mouth) habitats were represented;

3) to be representative of a wide range in the amount of upwelling;

4) in areas differing in patterns of seasonal intragravel water temperatures (i.e. areas with and without upwelling);

5) to be representative of a wide range in the relative amount of fine substrate in the spawning gravels; and,

6) in locations that were previously used for the Instream Flow Group 4 Hydraulic Model (IFG-4) (Vincent-Lang et al. 1984).

Secondary Sites

Secondary sites were selected to provide a more comprehensive data base for winter water quality conditions in selected habitats used for chum salmon incubation. As such, only a limited amount of water quality and continuous water temperature measurements were collected at secondary study sites. In the selection of these secondary sites, priority was given to sites which were known to be used as spawning sites and/or sites used as water quality stations during the previous winter (as reported in ADF&G 1983c). Secondary sites include Sloughs 8A, 9, 9A, and 17, three mainstem sites (RM 136.8, RM 138.7 and RM 138.9), and Indian River.

2.2 Procedures for Evaluating Physical and Chemical Variables

Methods presented in the following section are a summary of those presented in the FY84 ADF&G Procedures Manual (ADF&G 1984). As such, they are only intended to provide sufficient detail to allow for a critical review of the analyses presented. Specific details are only provided in areas where methods used in the field differed slightly from those presented in ADF&G (1984).

2.2.1 Intragravel Standpipes

The measurement of water quality variables (other than continuous intragravel water temperature data) in the intragravel environment required the use of polyvinyl chloride (PVC) standpipes installed into the streambed. Standpipes designed for this study contained 40 perforations 0.3 mm (one eighth inch) in diameter, located within a 7.6 cm (3.0 inch) band at one end of the standpipe. When the standpipe was installed into the streambed, the perforations allowed intragravel water to pass through the standpipe allowing water quality measurements to be obtained. The adopted designs for constructing the driving rod and standpipe were modified from Gangmark and Bakkala (1958) and McNeil

(1962) and had the advantages of being relatively inexpensive and easy to install (Figure 4).

Standpipes were driven in the substrate using a driving rod and sledge hammer (Plate 1). Each standpipe was pounded into the substrate to a depth of approximately 37 cm (14.5 inches) centering the perforations at a depth of approximately 25 cm (10 inches) into the substrate. This depth was selected because it is the average depth at which chum salmon place their eggs in some Alaskan and British Columbian stream systems (Kogl 1965; Merritt and Raymond 1982).

After a standpipe was properly installed, a cork/weight assembly was placed inside each standpipe to aid in removal of ice plugs formed during freezing weather conditions. This assembly was suspended inside each standpipe from a nylon cord attached to the standpipe cap (Figure 4). Ice plugs were removed by gently heating a small metal heat shield attached to the exterior of the standpipe at the water surface. The metal shield was heated with a propane torch while exerting upward pressure on the pipe cap. After a few minutes of heating, the ice plug partially melted and allowed the cork/weight assembly with attached ice plug to be withdrawn (Plate 2), thereby allowing for intragravel water quality measurements to be obtained.

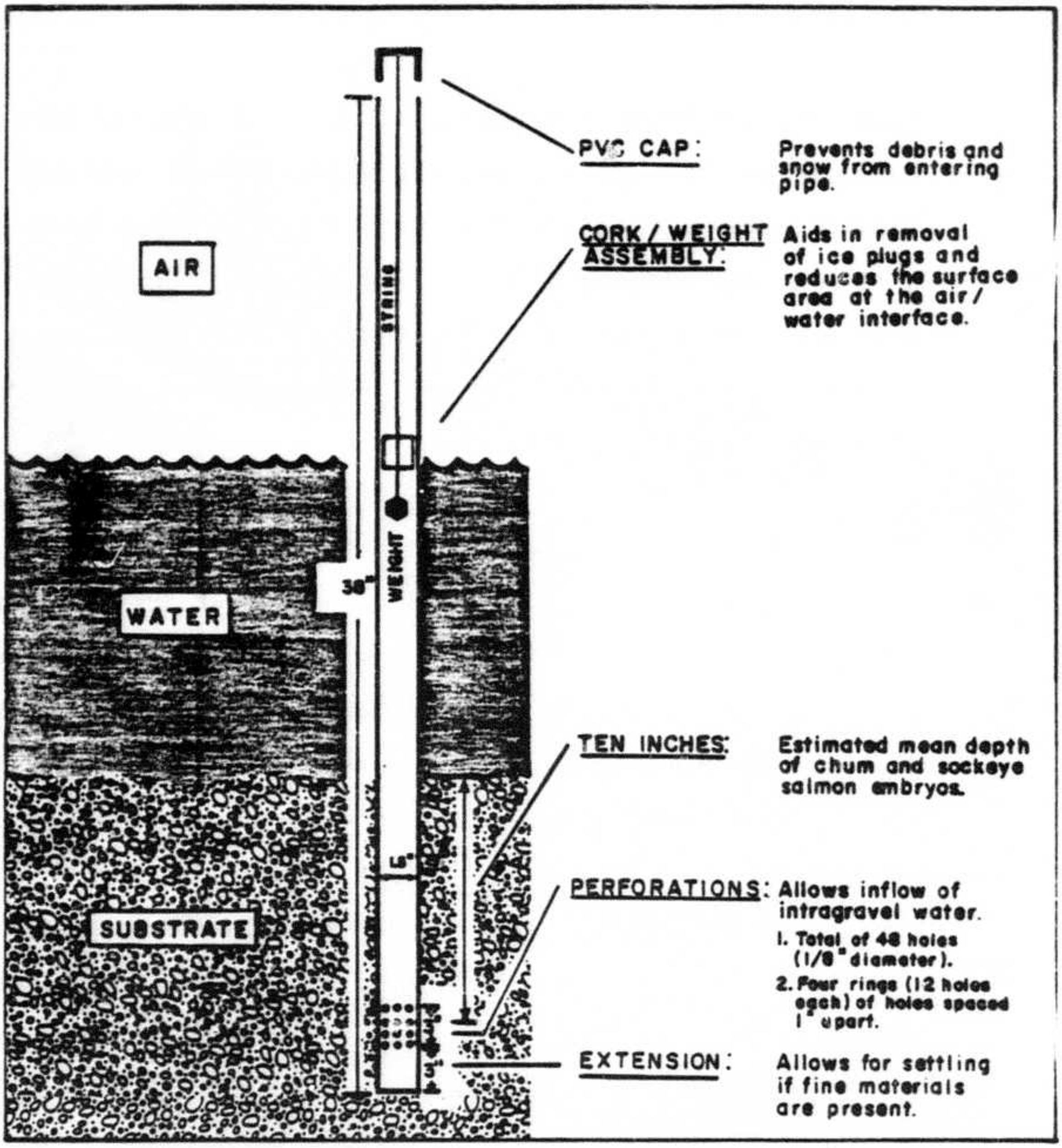

Figure 4. Diagram of a polyvinyl chloride (PVC) standpipe used to evaluate intragravel water conditions in streambeds of salmon spawning habitats in the middle Susitna River, Alaska.

Plate 1. Method for installing polyvinyl chloride standpipes in the streambed using a sledgehammer and driving rod.

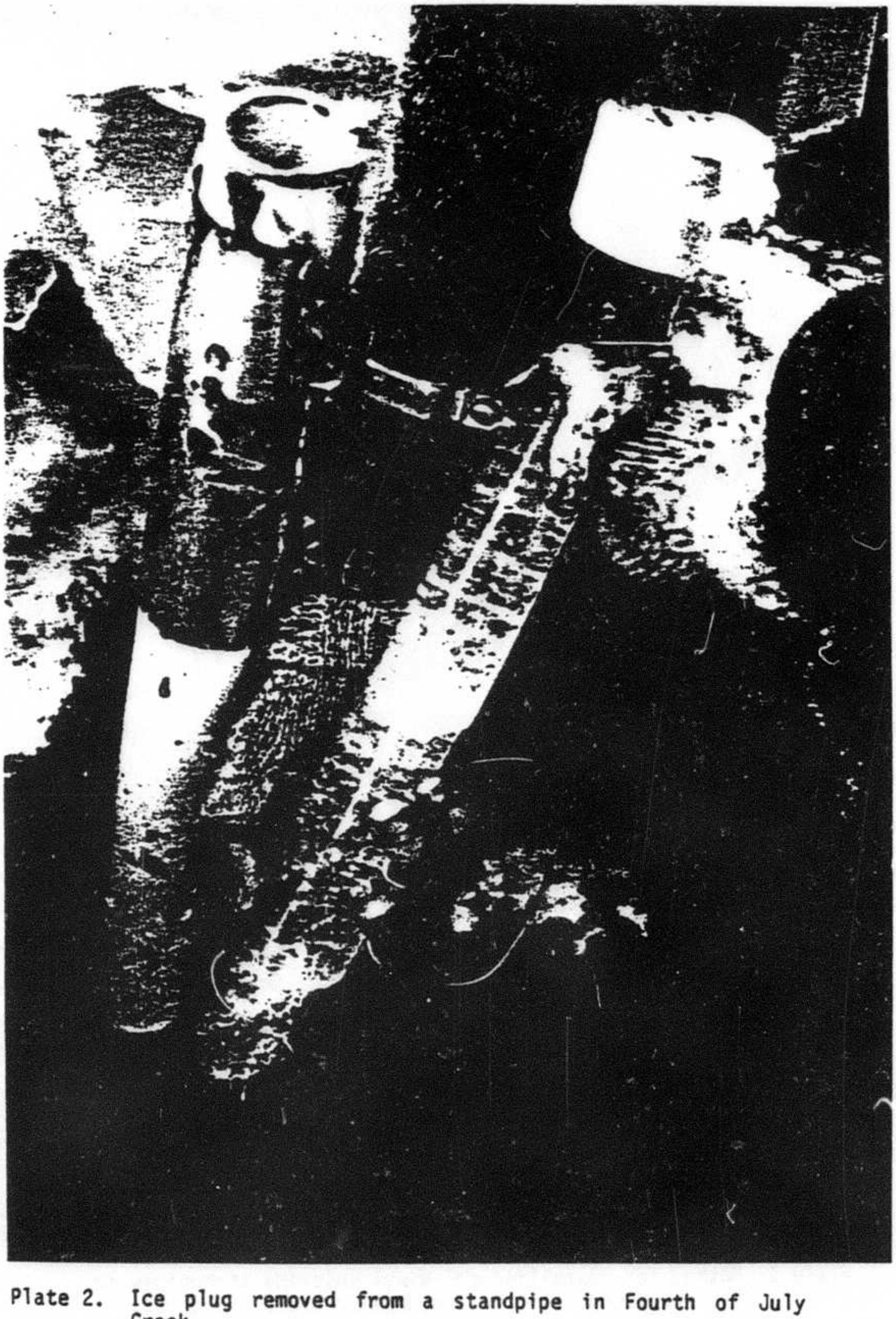

Plate 2. Ice plug removed from a standpipe in Fourth of July Creek.

2.2.2 Physical Variables

2.2.2.1 Water Temperature

Instantaneous surface and intragravel water temperatures were measured at all primary and secondary study sites. A Yellow Springs Instrument (YSI) dissolved oxygen/temperature meter (Model 57) and a YSI conductivity/temperature meter were the primary instruments used to obtain instantaneous water temperatures inside and outside the PVC standpipes at all water quality study sites. On each sampling day, each YSI meter was calibrated using a Hydrolab Model 4041 water quality meter as a standard. The Hydrolab meter was calibrated before and after field sampling trips following the procedures outlined in ADF&G (1984).

Continuous water temperature data were collected at selected primary study sites using either Omnidata datapod recorders and associated thermister probes (Model No. 2321) or Ryan (Model J90) thermographs. Specific methods pertaining to these instruments and their use are presented in Appendix A of this report.

2.2.2.2 Substrate Composition

Two primary methods were used to assess substrate composition in this study: the McNeil sampler method and the Whitlock-Vibert Box sampler method.

2.2.2.2.1 McNeil Sampler

Substrate samples were collected at selected study sites using a modified McNeil substrate sampler (Figure 5). At each selected study site, the McNeil substrate sampler was pushed down into the substrate to an approximate depth of 20-25 cm (8-10 inches). Substrate materials were then removed with a small shovel and placed into plastic five gallon buckets. After the non-suspended portion of the substrate materials was removed from the sampler, the remaining water inside the sampler (containing the suspended sediments) was agitated to bring fines into suspension by swirling a hand inside the sampler (care was taken to avoid formation of a vortex). After thoroughly agitating the water column, a one liter aliquot of water was removed and stored for further processing. The non-suspended and suspended portions of each substrate sample were transported to a laboratory facility for size class determinations.

At the laboratory, the non-suspended portion of the substrate samples were placed in an oven at a uniform temperature (110°C) until dry (approximately 24 hrs). Once dried, samples were sifted (while being continuously shaken) through a series of sieves which included the following mesh sizes: 12.5, 7.6, 2.5, 0.2, 0.05, and 0.0062 cm (5.0, 3.0, 1.0, 0.08, 0.02, and 0.0025 in. respectively). Sieve size selection was based upon recommendations of Platts et al. (1983) and those previously used by ADF&G personnel for visual assessment of substrate materials in spawning areas (Vincent-Lang et al. 1984). After

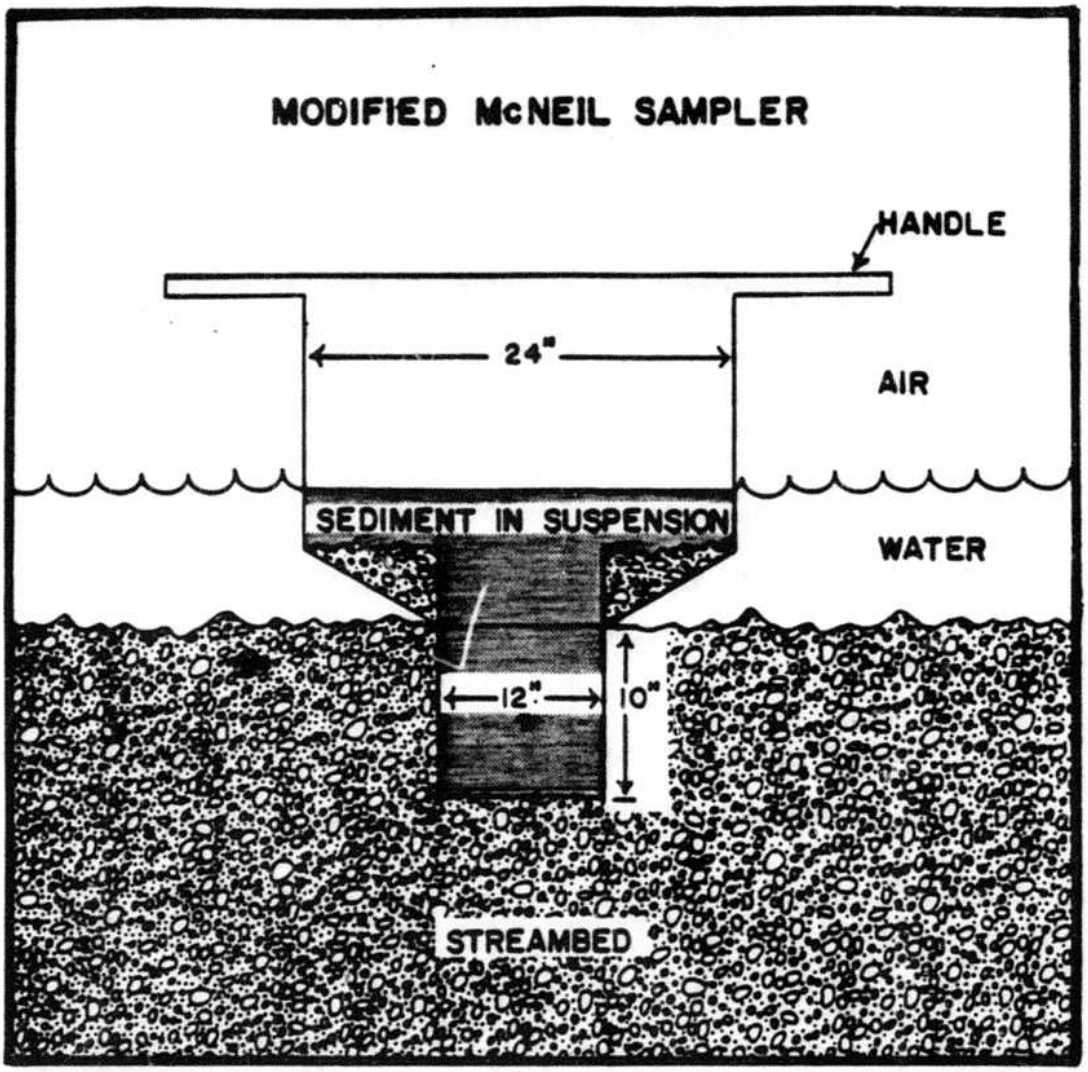

Figure 5. A modified McNeil substrate sampler used to evaluate substrate conditions of salmon spawning habitats in the middle Susitna River, Alaska. Sampler not drawn to scale.

sifting through sieves, the dry weight of each size class of non-suspended sediment was measured to the nearest gram and percent of total sample was calculated.

The smallest sieve size (0.0062 cm; 0.0025 in) corresponds to the size at which particles no longer readily settle out of suspension in water. For this reason, the amount of suspended particles in each sample was determined by estimating the amount of suspended sediment in the one liter aliquot of water taken at the time of sampling. This amount was then used to extrapolate for the total amount of suspended sediment in the entire volume of water inside the McNeil sampler. This quantity was then added to the quantity of substrate which passed through the smallest sieve size to determine total weight for this sieve size.

The procedure for determining the amount of non-suspended and suspended material in each substrate sample is summarized in Figure 6.

2.2.2.2.2 Whitlock-Vibert Box Sampler

In previous studies Whitlock-Vibert Boxes (WVBs) have been used as incubation chambers to evaluate the effects of environmental variables on salmon embryo survival (e.g., Reiser and Wesche 1977; Reiser 1981; Reiser and White 1981a). In each of these studies, fine sediments from the surrounding streambed were found to have accumulated in the WVBs when they were removed from the substrate. Based on this, and telephone conversations with D. Reiser (pers. comm.), it was determined that in

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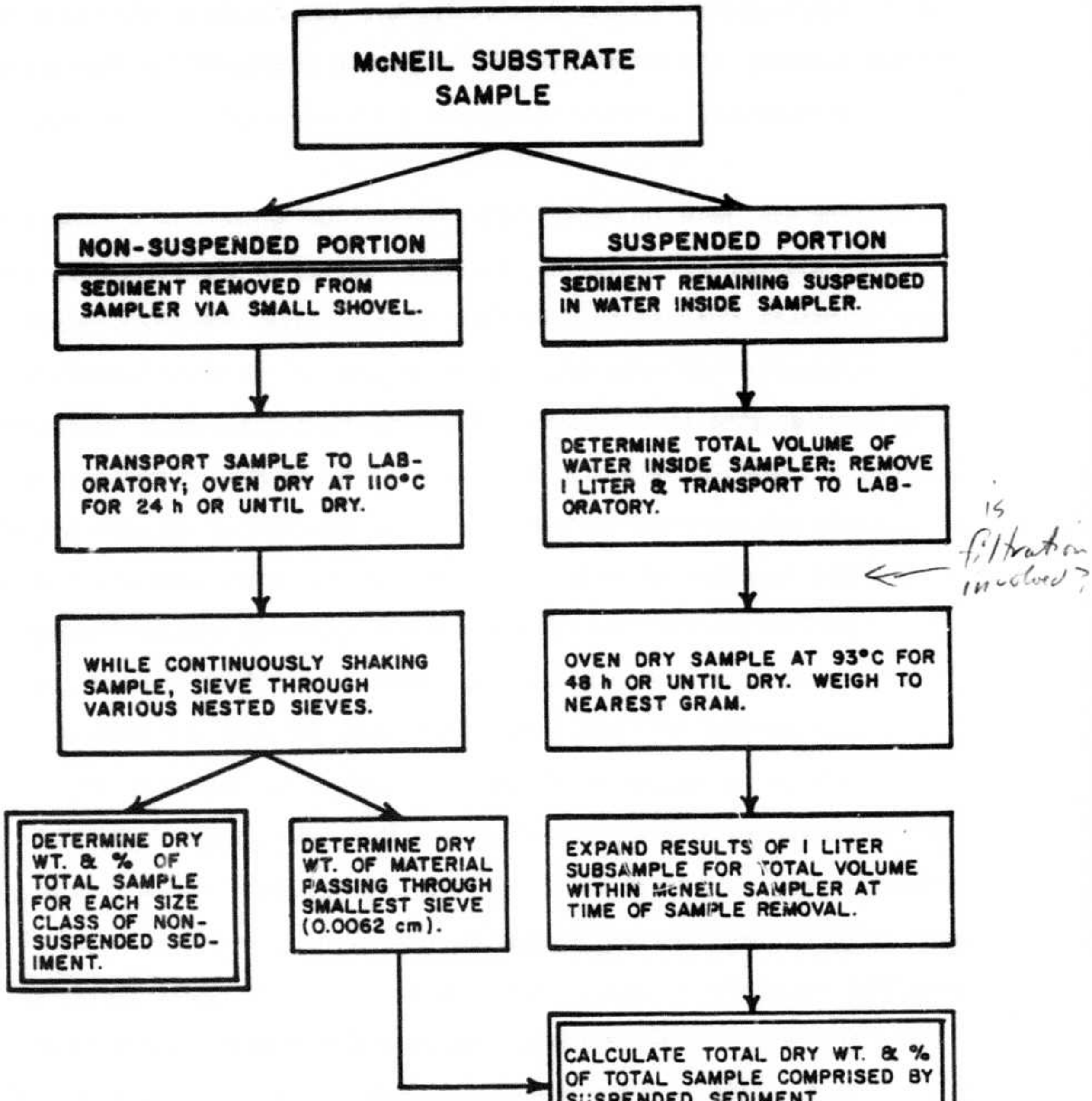

Figure 6. Summary of methods used to evaluate substrate conditions obtained with a modified McNeil substrate sampler.

addition to using WVBs as experimental incubation chambers to evaluate embryo survival (Sec. 2.2.4.1.1), they could also be used as a means to evaluate the amount of fine materials present in the surrounding substrate.

The WVBs were initially filled with sifted gravels of a known size (1.3 - 2.5 cm; 0.5 - 1.0 in. diameter), buried in the streambed, and later removed after a three to five month period. Substrate materials were removed from each WVB, double bagged in plastic freezer bags, and transported to a laboratory facility where the sample was frozen until it could be analyzed. Each sample was analyzed in the same manner as the non-suspended sediment portion of the McNeil substrate samples with the suspended portion of substrate sample being taken as the sediment portion passing through the smallest substrate sieve. The dry weights of fine substrate particles less than 0.2 cm (0.08 in.) were compared to dry weights of this size class obtained with the McNeil substrate sampler to determine if the two sampling methods were providing comparable data on the accumulation of fines.

Additional Substrate Evaluation Methods

Two secondary methods were used to evaluate substrate conditions during this study. These additional methods were employed to allow a comparison of substrate data collected at IFG-4 modeling sites with substrate data collected for the incubation study. One method consisted of a visual classification method previously used to assess substrate conditions in chum and sockeye salmon spawning habitat (Vincent-Lang et al. 1984; Appendix Table E-1). The other method was a simple visual method which classified the relative degree of embeddedness[1] of the surface substrate with fine particles (Platts et al. 1983). Specific categories of embeddedness are defined in Appendix Table E-2.

2.2.2.3 Water Depth and Velocity

Water depth and velocity were periodically measured to provide additional information on the physical characteristics influencing incubation conditions at each study site. Water depths were obtained using a top-setting wading rod while collecting water velocities in selected locations at each study site. Water velocities were obtained with a Marsh-McBirney (Model 201) flow meter using procedures described in ADF&G (1984).

2.2.2.4 Turbidity

Turbidity samples were collected in clean 250 ml Nalgene bottles. Bottles were filled approximately two-thirds full and stored in a cool, uniform environment until analysis could be completed. Samples were analyzed using an HF Instruments (Model 2100A) turbidimeter following the procedures provided in the manufacturer's operations manual.

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[1] Embeddedness is defined as the percent of surface area of the larger sized substrate particles in a streambed which is covered by fine sediment (Platts et al. 1983).

2.2.3 Chemical Variables

2.2.3.1 Dissolved Oxygen

Intragravel dissolved oxygen (DO) measurements were obtained inside PVC standpipes using a YSI (Model 57) dissolved oxygen/temperature meter. This meter has a probe that is the proper diameter to fit inside the PVC standpipe used in this study. The meter was calibrated at each sampling site by adjusting the observed reading to match that of a calibrated Hydrolab (Model 4140) water quality meter. A Hydrolab was used to collect baseline DO measurements of surface water at each site.

After the YSI meter was calibrated, measurements were collected by lowering the probe to a depth of 85 cm (33.5 inches) inside the standpipe, which placed the probe in near proximity of the perforations in the standpipe (refer to Figure 4). After lowering to the proper depth, the probe was gently agitated to circulate water over the DO membrane and measurements were recorded when the reading stabilized.

2.2.3.2 pH

Measurements of pH were obtained with a Hydrolab (Model 4041) water quality meter following procedures described in ADF&G (1984). Intragravel samples were obtained by withdrawing a water sample from inside a PVC standpipe with a Geofilter peristaltic pump (Geotech Environmental Equipment) and then measuring pH with the Hydrolab.

2.2.3.3 Conductivity

Conductivity measurements were obtained using a YSI specific conductance/temperature (Model 33) meter according to procedures presented in ADF&G (1984). A calibration curve was developed by comparing conductivity values obtained with the YSI meter to those obtained with a calibrated Hydrolab meter over the range of temperatures encountered in the field. All values measured in the field were then adjusted on the basis of the calibration curve.

2.3 Biological Variables

2.3.1 Salmon Incubation

2.3.1.1 Procedures to Install and Remove Whitlock-Vibert Boxes

In addition to being used as experimental substrate samplers, WVB's were also used as experimental embryo incubation chambers to assess development and survival of chum salmon embryos at the eight primary study sites. As originally designed, each WVB was constructed from molded polypropylene which is 145 x 90 x 60 mm in size and contains two chambers. The upper incubation chamber is separated by a grid-like partition from the lower nursery chamber. This two-chambered design, however, has been found to result in an excess accumulation of fine substrate particles inside the boxes (D. Reiser and R. White, personal communication). For this reason, the two-chambered design was structurally modified to form a single incubation/nursery chamber to help alleviate this problem during this study.

The modified WVBs were filled with spawning size gravel to simulate natural conditions which were favorable for embryo incubation. To achieve this, gravels were obtained by sifting substrates through wire screens to provide a mixture of gravels which ranged from 1.3 to 2.5 cm (0.5 - 1.0 in.) in diameter. This size range was selected to provide interstitial spaces large enough to separate eggs and allow free movement of intragravel flow, yet small enough to pack conveniently into the WVB's. A total of 50 fertilized eggs were placed between alternating layers of gravel within each WVB.

2.3.1.2 Artificial Fertilization Procedure

Methods used to obtain and fertilize chum salmon eggs for implantation in the WVBs followed those presented in Smoker and Kerns (1977) and are generally consistent with those presented in McNeil and Bailey (1975) and Leitritz and Lewis (1976). A flow chart depicting the general procedure for obtaining and artificially fertilizing eggs is presented in Figure 7. Details of these methods are presented in ADF&G (1984).

Care was taken to protect the fertilized eggs from exposure to light and mechanical shock prior to, during, and after the time they were placed into WVBs. After embryos were allowed to water-harden for two hours, they were gently transferred from a large container to the WVBs. The entire process of placing embryos and sifted gravel within the WVBs was

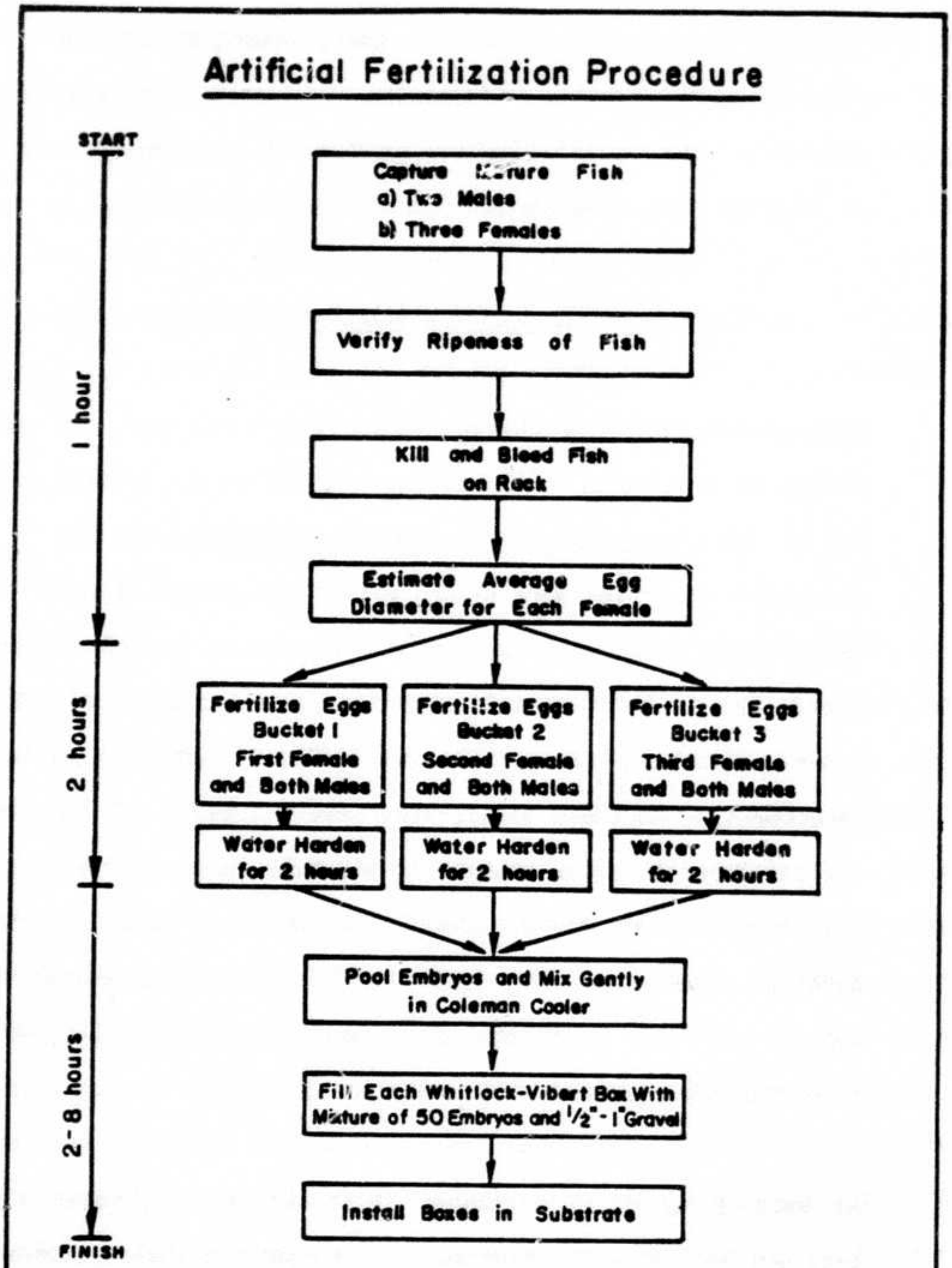

Figure 7. Flow diagram depicting the sequence of events which occurred during the artificial fertilization of salmon eggs and the subsequent installation of artificial incubation chambers (Whitlock - Vibert Boxes) in the streambed.

conducted inside a dome tent to reduce potential adverse effects from exposure to the outside environment. Embryos were kept in a water bath maintained at the local water temperature and shielded from harmful ultraviolet rays from the sun (Smoker and Kerns 1977).

2.3.1.3 Installation of Whitlock-Vibert Boxes

Whitlock-Vibert Boxes charged with fertilized eggs and gravel were placed in artificial redds at each of the eight primary study sites. Six of the primary study sites were used to evaluate embryo survival. In these sites, WVBs were placed within the streambed based on a random selection of grid coordinates on a site map, in an attempt to represent the range of environmental conditions present at each site. At the other two primary sites, WVBs were primarily used to evaluate embryo development. At these sites, WVBs were placed at a single location in the streambed to allow embryos in all WVBs to be influenced by similar environmental conditions. One additional site used to assess embryo development was physically located within the same site used to evaluate embryo survival in Slough 11. For specific details on the site selection procedures, refer to Section 2.1.

At each study site, streambed materials were loosened with a high pressure jet of water generated by a Homelite gas-powered water pump. After thoroughly loosening the substrate, a plastic bottomless bucket (19 liter; 5 gallon capacity) was forced into the loosened substrate while the contents were extracted by hand to a depth of 20 to 25 cm (8 to 10 in.). The bucket prevented substrate from collapsing into the excavated hole and allowed holes to be excavated for several locations on the day prior to installing Whitlock-Vibert Boxes. Two WVBs and one PVC standpipe were placed in each excavated hole after the hole was refilled with the surrounding gravel. A nylon cord served to attach each WVB to a large steel spike (30 cm; 12 in.) which was marked with orange surveyors flagging for future identification. The location of each WVB was also determined using standard survey gear.

2.3.1.4 Removal of Whitlock-Vibert Boxes

Whitlock-Vibert boxes were later removed by locating each metal spike and nylon cord and tracing the nylon cord to the point where the cord entered the substrate (Plates 3 and 4). Gentle upward pressure on the cord and simultaneous removal of surface substrate materials allowed the box to be withdrawn from the substrate. Upon withdrawal, each box was placed inside a plastic container to retain fine materials and placed inside a large cooler with water which kept boxes and embryos from freezing. After all boxes were removed at a site, the cooler was transported to a heated work space, at which time the embryos present in each box were removed and preserved. Substrate and fine materials from the boxes were bagged, frozen, and stored for later analysis. All unhatched embryos were preserved in Stockard's Solution[1]. An unbuffered solution of 10% formalin was used to preserve alevins.

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[1] One liter of solution is comprised of 50 ml formaldehyde, 40 ml glacial acetic acid, 60 ml glycerin and 850 ml distilled water.

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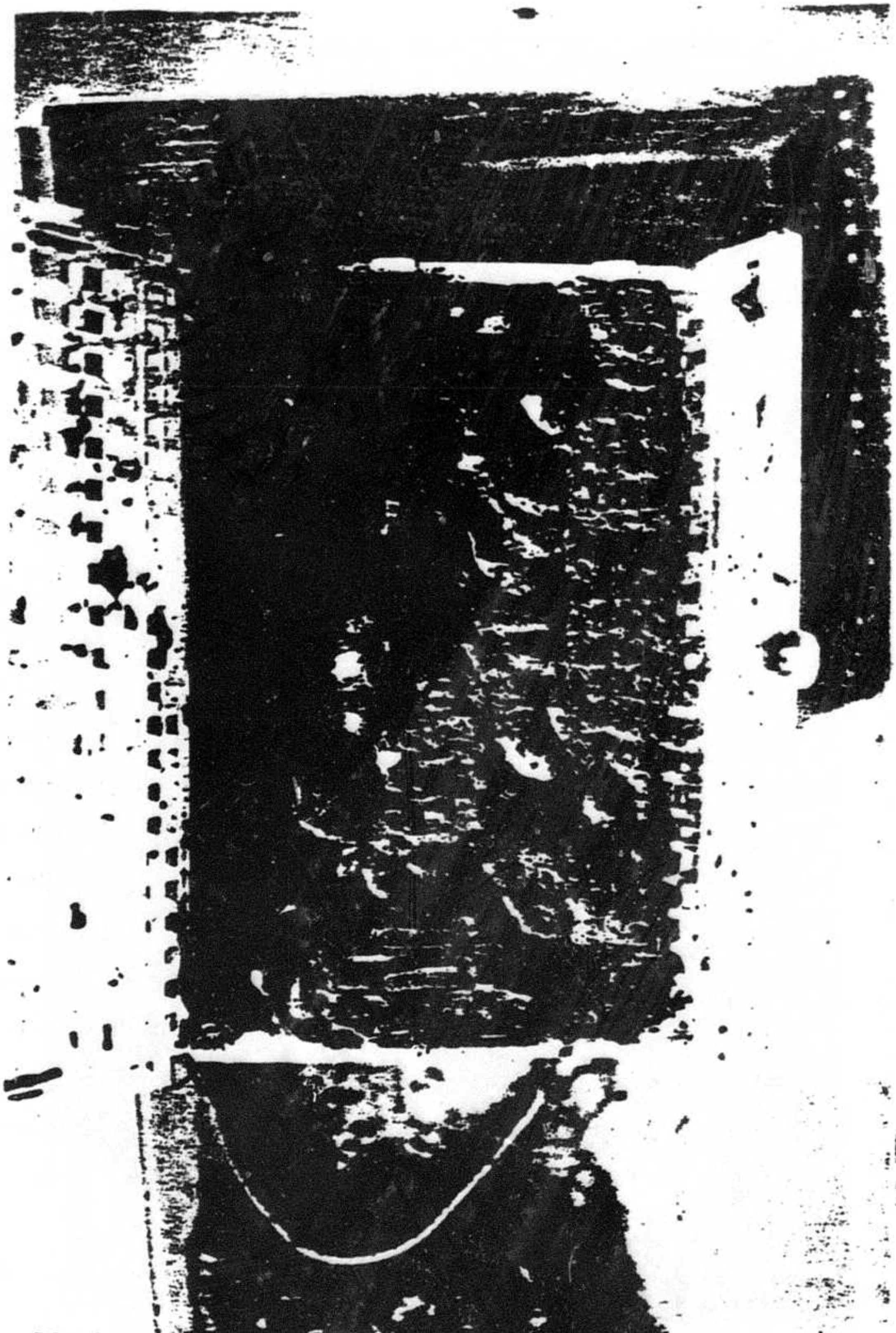


Plate 3. Whitlock-Vibert Box compacted with accumulated silt and sand.

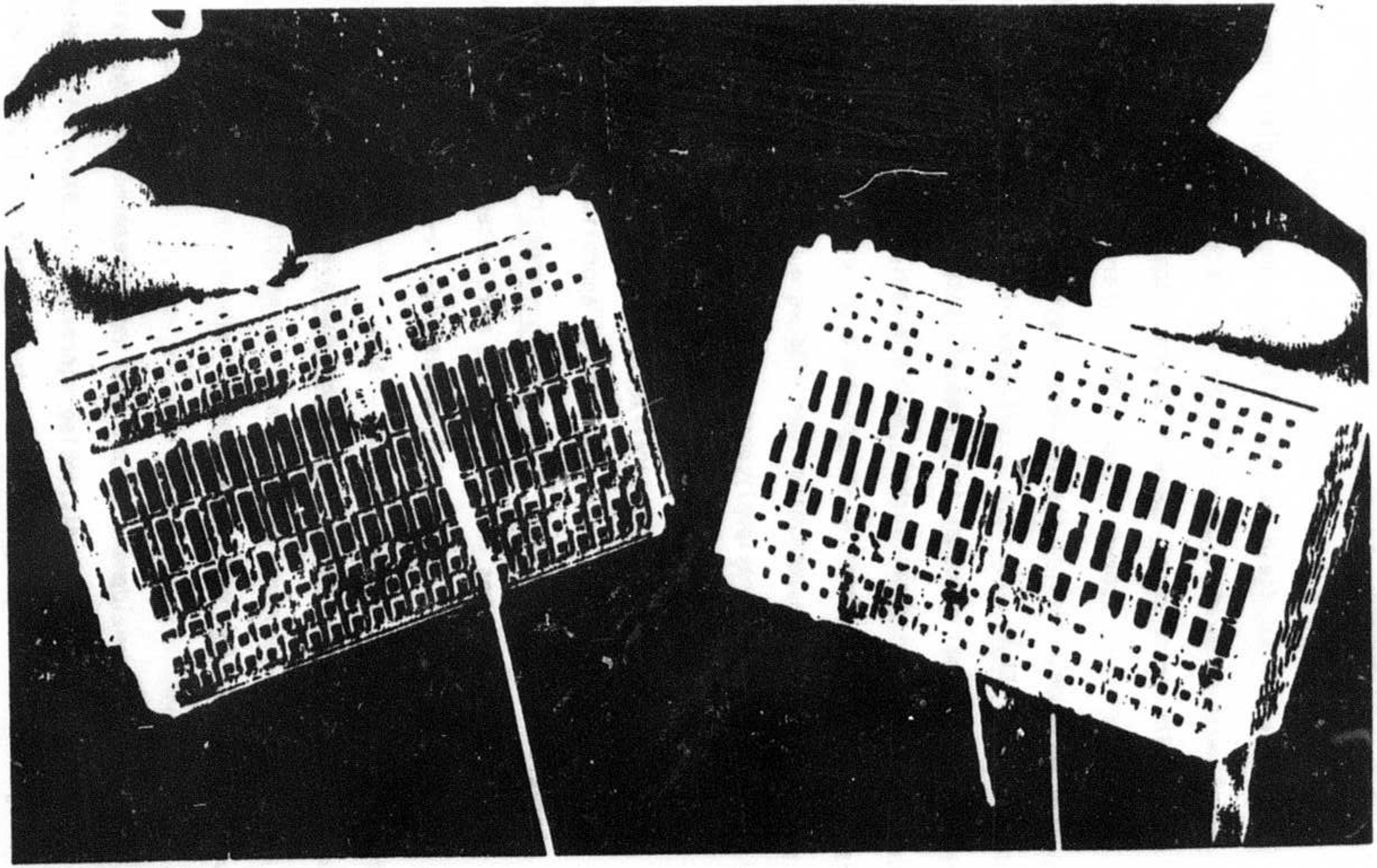


Plate 4. Whitlock-Vibert Boxes each containing sorted gravels and 50 chum salmon embryos, wrapped with a nylon cord. The nylon cords were later used to remove boxes from the substrate.

2.3.2 Flatworms

During the winter field program, large numbers of flatworms (Turbellaria) were observed to be present in WVBs retrieved at several sampling sites. The presence of these flatworms appeared to coincide with the absence of some embryos from WVBs. Therefore, an experiment was designed to determine if the flatworms were related to the disappearance of embryos. Eight WVBs were each filled with gravel and 10 dead embryos (free from fungal colonization) free of flatworms, and buried to a depth of approximately eight inches in two areas. Four of these WVBs we buried in areas where flatworms were observed in greatest numbers (Slough 11) and the remaining four WVBs were buried in an area where no flatworms had been previously observed (Side Channel 10).

The WVBs remained in the gravels for a period of three weeks. At that time, one WVB at each site was removed approximately every two weeks thereafter until all WVBs were removed. Upon removal of a WVB, the number of dead embryos remaining inside were determined and the relative density of flatworms was visually assessed.

2.3.3 Analysis of Development and Survival of Embryos

2.3.3.1 Embryonic Development

The stage of development of embryos was determined by observing preserved embryos under a dissecting microscope at 3X magnification. All embryos were initially preserved in Stockard's solution, which was selected because of its reported excellent clearing properties of the outer egg membrane (Velsen 1980). In this study, however, the solution did not adequately clear the outer egg membrane. Therefore, it was necessary to remove the outer membrane of the majority of preserved embryos to determine the stage of development.

For the purposes of this study, the four basic periods of embryonic development (cleavage, gastrulation, organogenesis, and post-hatching) were further subdivided into twelve distinct stages as identified by laboratory examination of preserved chum salmon embryos (Table 2). These particular stages were selected to establish a foundation for comparisons between sites. The first eleven stages correspond to the period prior to hatching. Stage 12 is a general category which includes all post-hatching alevins. Plates 5 through 8 show chum salmon embryos at selected stages of development.

2.3.3.2 Embryonic Survival

The percent survival of chum salmon embryos was determined at all primary sites except upper Side Channel 11. Whitlock-Vibert Boxes containing embryos were removed, placed in a cooler, and transported to a heated field station where embryos were removed from the boxes. Live and dead embryos were distinguished by visual inspection and enumerated. In most cases, live embryos were easily distinguished from dead ones by appearance. Live embryos were rather translucent and free from fungus. Most dead embryos were opaque and were often colonized by fungus.

Table 2. Stages of embryonic development for chum salmon identified for use in this study. Stages correspond to information reported for sockeye salmon by Velsen (1980).

Developmental Period	Stage Number	Brief Description	Characteristics of Stage	
			Start	End
Cleavage	1	all of cleavage	fertilized egg	blastula
Gastrulation	2	embryo formation	terminal caudal bud present	embryo clearly visible
	3	blastopore formation	1/2 epiboly	3/4 epiboly
	4	blastopore closed	blastopore closed	blastopore closed
Organogenesis (early)	5	caudal bud free	caudal bud free from yolk surface	parts of brain visible
	6	initial yolk vascularization	initial vascular-ization	2/3 yolk vascular-ization
	7	eyed	eye pigment visible through egg membrane	3/4 yolk vascular-ization
(late)	8	anal fin formation	anal fin faintly visible	anal fin distinct
	9	dorsal fin formation	dorsal fin faintly visible	dorsal fin distinct
	10	pelvic bud formation	pelvic buds faintly visible	pelvic buds distinct
	11	body pigmented	pigment present on dorsum of head	pigment present on dorsum of head and body
Alevin	12	alevin	just hatched	yolk sac completely absorbed; ventral suture remaining

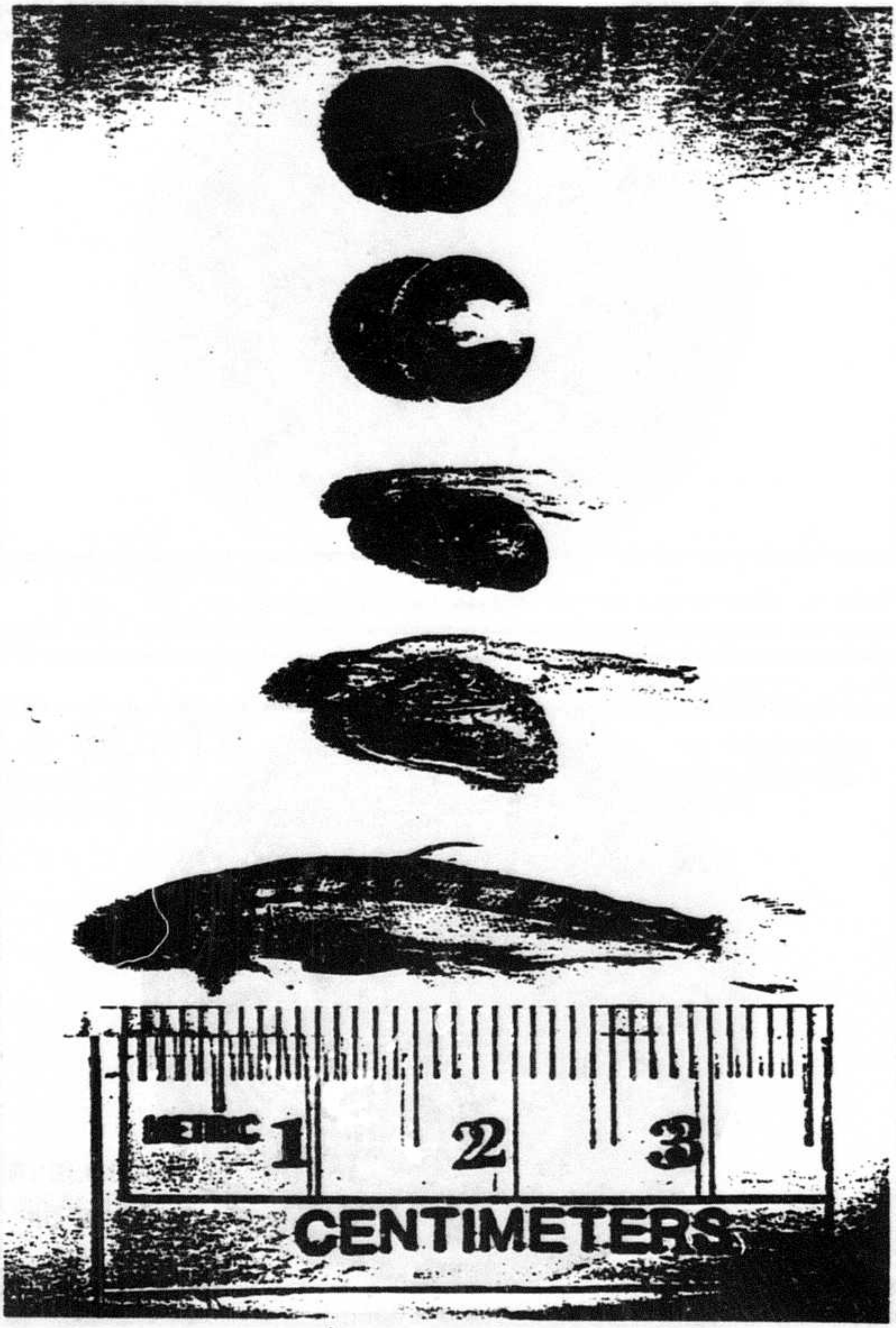


Plate 5. Various stages of embryonic development of chum salmon from fertilization to complete yolk-sac absorption.

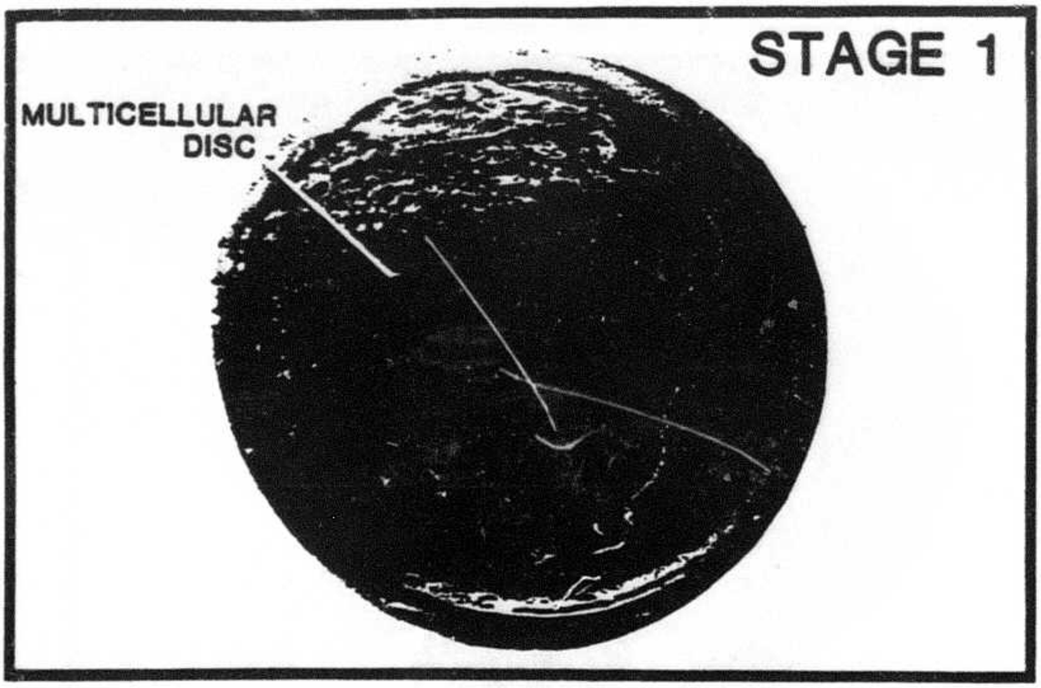


Plate 6. Chum salmon embryo late in the cleavage stage.

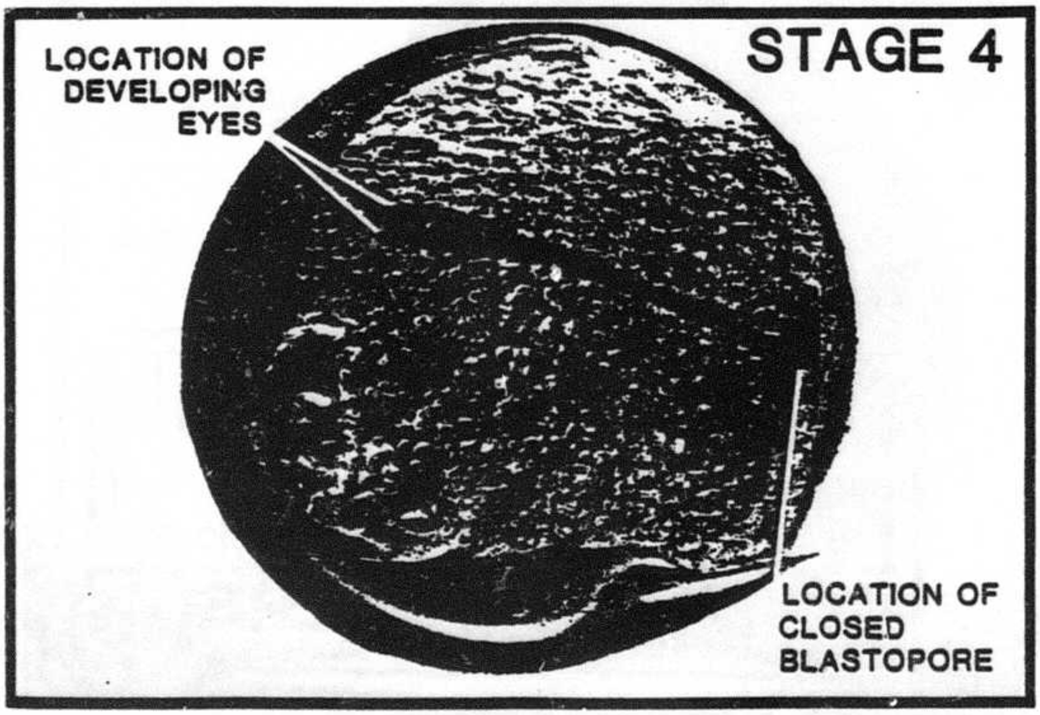


Plate 7. Chum salmon embryo at late gastrulation.

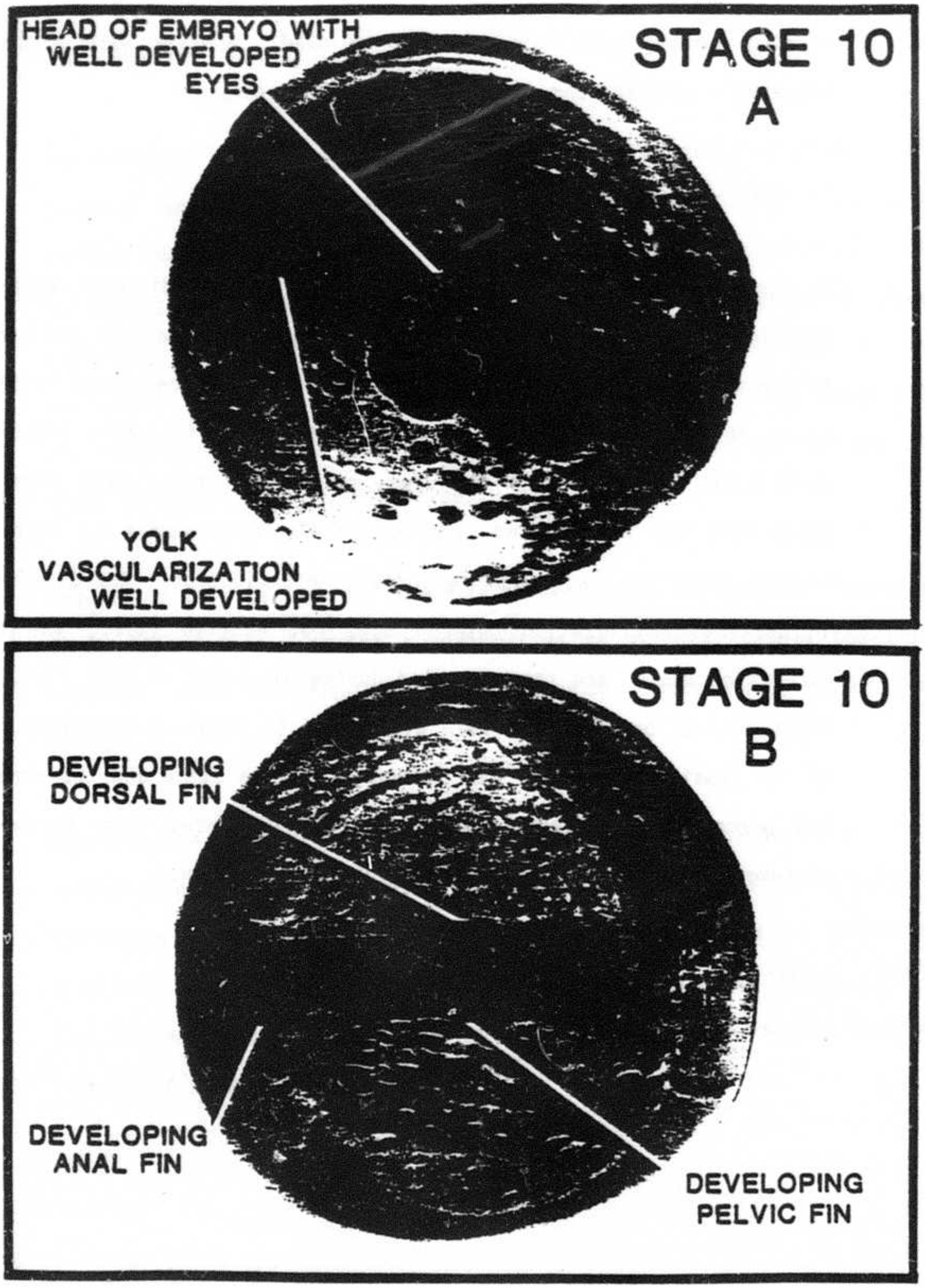


Plate 8. Head (A) and body (B) of a chum salmon embryo at late organogenesis.

Missing embryos were considered to be dead. Embryos were placed in Stockard's solution and returned to the laboratory.

2.3.3.3 Embryo Survival Control

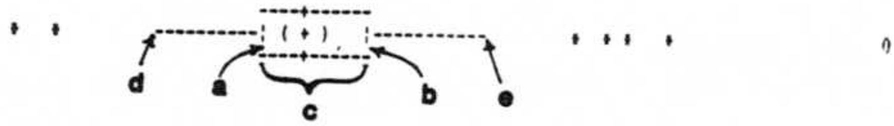
To assess embryo mortality due to handling, three additional WVBs from each incubation study site were charged with fertilized eggs and handled in the same manner at each study site. These WVBs were placed in Slough 11 in an area that appeared to represent highly favorable incubation conditions. After two to ten days, one of the three WVBs from each study site was removed and assessed in the same manner as that previously presented for assessing percent fertilization. Any differences in percent fertilization between eggs not handled (i.e., in stream incubation trays) and those handled during placement of WVBs (i.e., the first control box removed) were attributed to handling mortality. One of the remaining two WVBs was removed at eye-up stage and the other at 100 percent hatch stage. These survival estimates were assumed to represent survival under optimal incubation conditions.

3.0 RESULTS

This section is divided into three parts: 1) a description of selected physical and chemical characteristics of individual study sites and various habitat types (i.e., slough, side channel, tributary and mainstem); 2) a summary of embryo survival and development data collected at individual study sites and habitat types; and 3) an evaluation of the influence of selected physical and chemical characteristics of habitats on the survival of chum salmon embryos at study sites and among habitat types.

Results in this section are shown in several types of figures. Three of these figure types warrant a designation of symbols, namely box-and-whiskers plots (or boxplots), scatter number plots, and scatter box plots.

Boxplots are used in this report to summarize water temperature, dissolved oxygen, pH, and conductivity data. The format basically follows that used by Velleman and Hoaglin (1981). The boxplots as presented here were computer generated by the microcomputer program SYSTAT (1984). The following example displays all the symbols used in the boxplot figures of this report.



Measured values (i.e., dissolved oxygen, water temperature, etc.) from each study site comprise a data batch, which is ordered from lowest value to highest. Specific symbols used in the boxplot figures of this report are defined below.

Symbol	Representative Term
a, b	lower and upper hinges (about 25 percent of the way in from each end of an ordered batch)
c	H-spread (the difference between the hinges; middle half of the data batch)
d	minimum adjacent value [lower hinge - (1.5 x H-spread)]
e	maximum adjacent value [upper hinge + (1.5 x H-spread)]
+	median (middle value of the batch)
*	outside value (outside of the adjacent values)
0	far outside value [outside of the following range: lower hinge - (3 x H-spread) upper hinge + (3 x H-spread)]
( )	notches (represent approximately a 95% confidence limit about the median) defined as median $\pm$ 1.58 x (H-spread)/$\sqrt{n}$

Scatter number plots are used in a number of figures in this report to summarize water temperature, dissolved oxygen, pH, and conductivity data. Each number represents the number of occurrences in single integers (1-9) at that point. Letters are used to denote 10 or more occurrences, beginning with "A" (A=10, B=11, F=15, etc.).

Scatter box plots are used in several figures in this report to summarize survival data. Each box represents one occurrence at that point.

3.1 Comparison of Physical and Chemical Characteristics of Study Sites and Habitat Types

3.1.1 Physical Characteristics

3.1.1.1 Water Temperature

Water temperature data presented in the following sections include instantaneous surface and intragravel water temperatures measured at both primary and secondary sites, and continuous intragravel water temperatures measured only at primary sites.

3.1.1.1.1 Instantaneous Intragravel Water Temperatures

Comparisons of instantaneous intragravel water temperatures (°C) measured within standpipes, grouped by habitat type and study site, are presented in Figures 8 and 9, respectively. Because temperatures undergo marked variations over time, median values presented for study sites and habitat types are strongly influenced by the time of year at which individual temperature measurements were recorded (refer to Appendix C). For this reason, comparisons between median values have not been made. The figures can be used, however, to show differences in the range of intragravel water temperature variations associated with individual study sites and habitat types.

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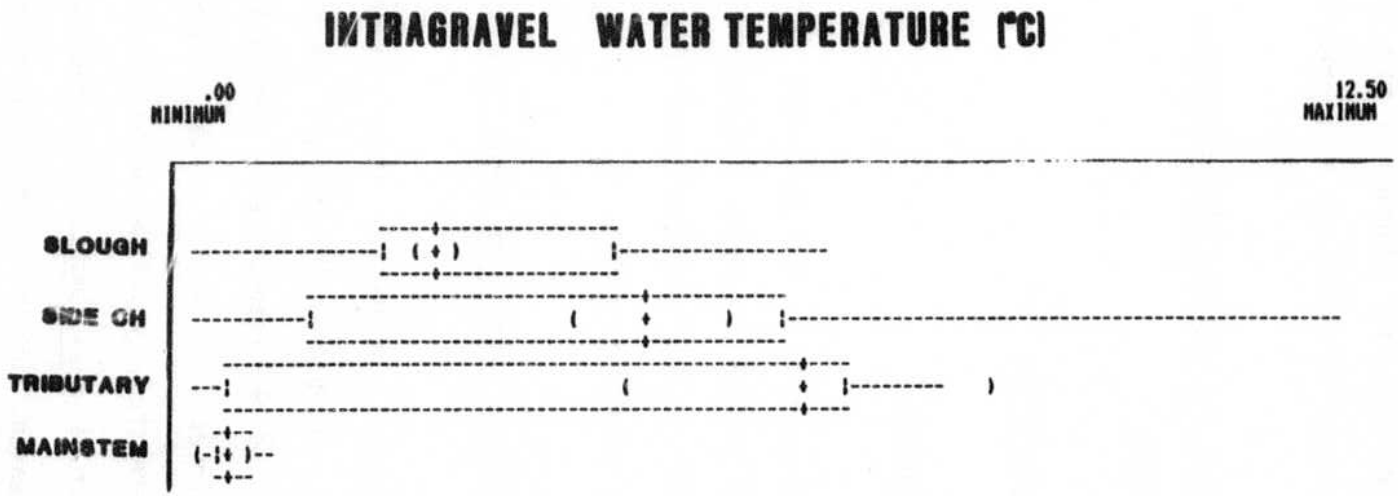

Figure 8. Summary, by habitat type, of the intragravel water temperature data (°C) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

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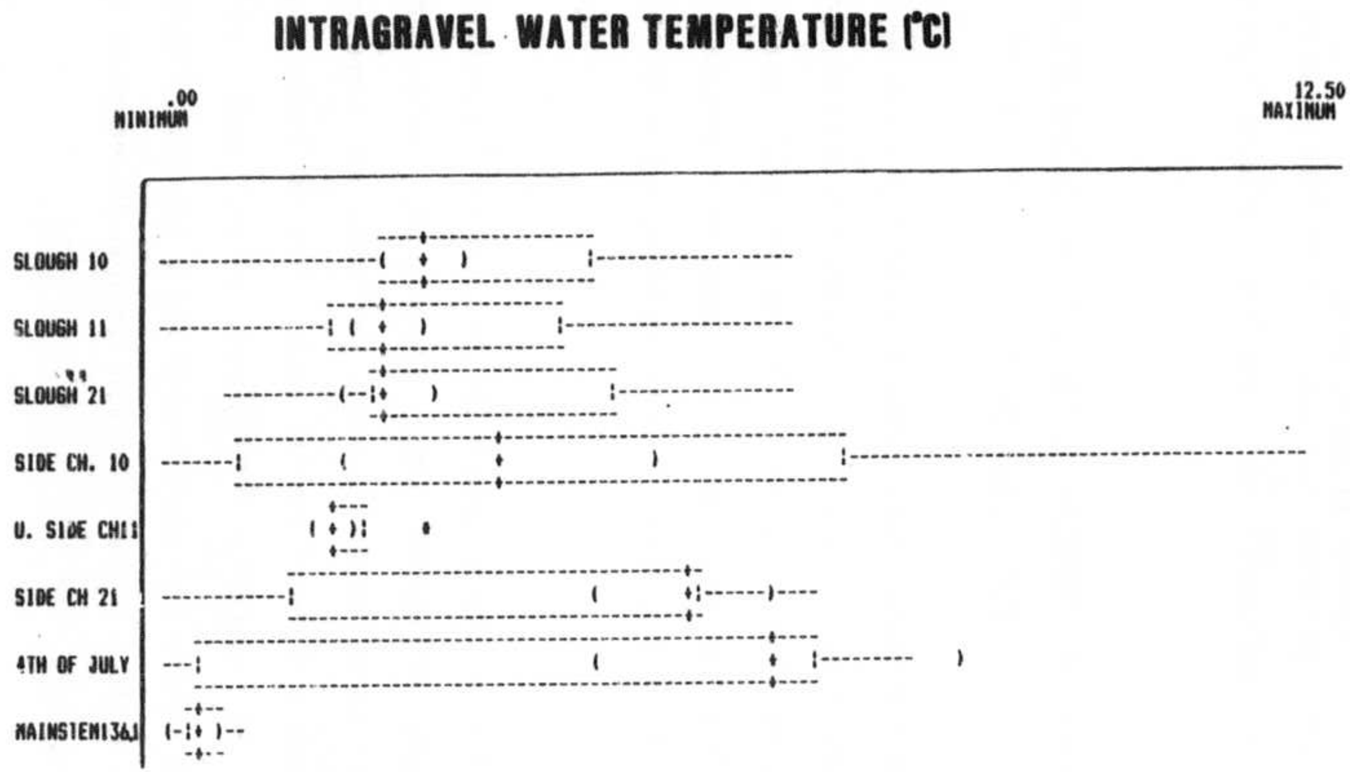

Figure 9. Summary, by study site, of the intragravel water temperature data (°C) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

Generally, data show that instantaneous intragravel water temperatures were least variable in mainstem and slough habitats and most variable in tributary and side channel habitats. This is likely due to the varying degree of influence of upwelling between these habitat types.

3.1.1.1.2 Comparison of Instantaneous Surface and Intragravel Water Temperatures

A comparison of instantaneous surface and intragravel water temperatures measured at standpipe locations in slough, side channel, and tributary habitat study sites are presented in Figures 10-12, respectively. The combined data from the three habitat types are presented in Figure 13. Data used to develop these figures are presented in Appendix C (Table C-2).

In each figure, there appears to be a direct relationship between surface and intragravel water temperatures. This indicates that intragravel water sources strongly influence the temperature of the surface waters of each habitat type. This is likely caused by the presence of upwelling intragravel within each habitat type. The effect appears most pronounced in slough habitats (Figure 10), which is likely related to the relatively greater influence of upwelling in this habitat type.

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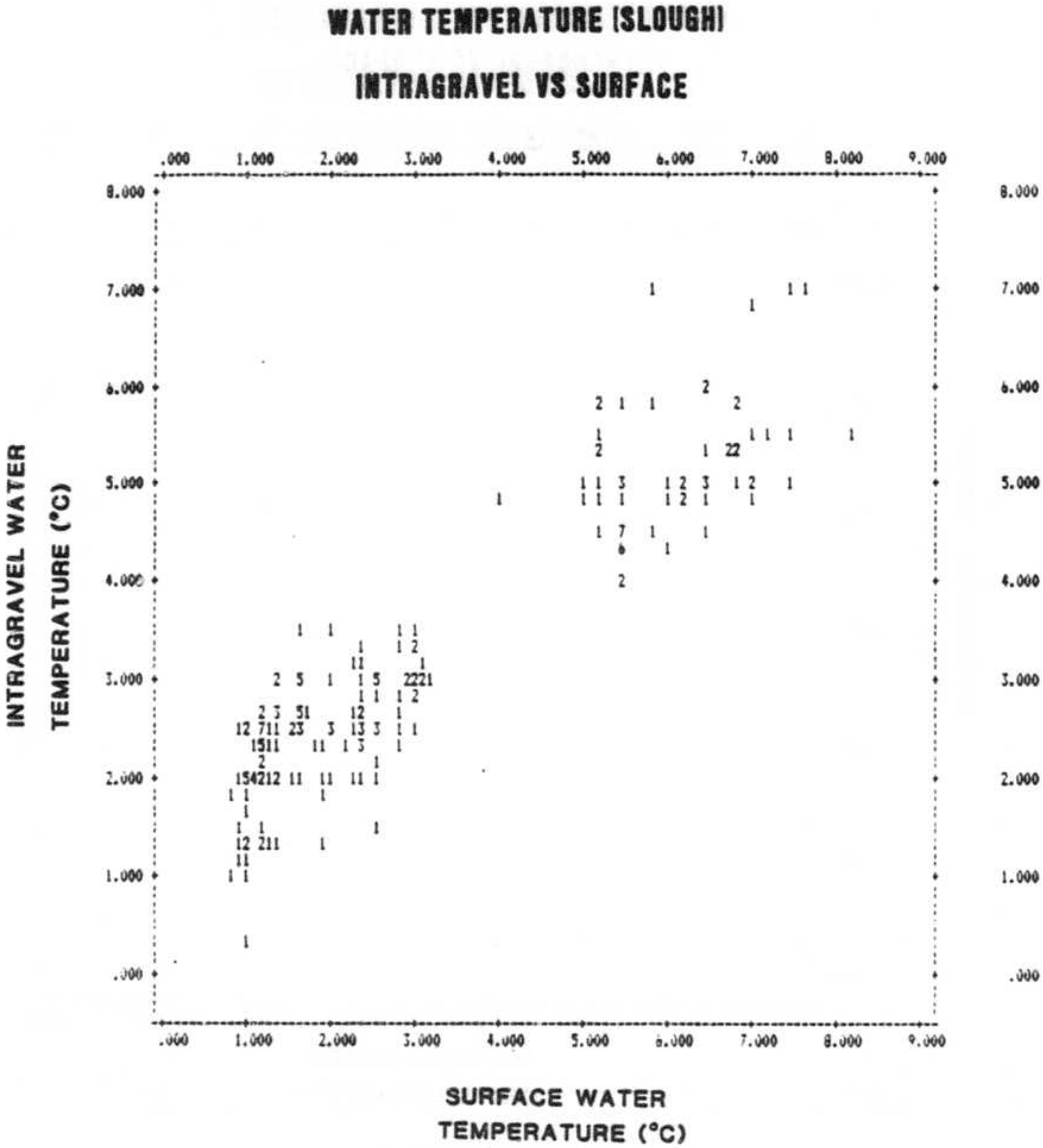

Figure 10. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within slough habitat of the middle Susitna River, Alaska.

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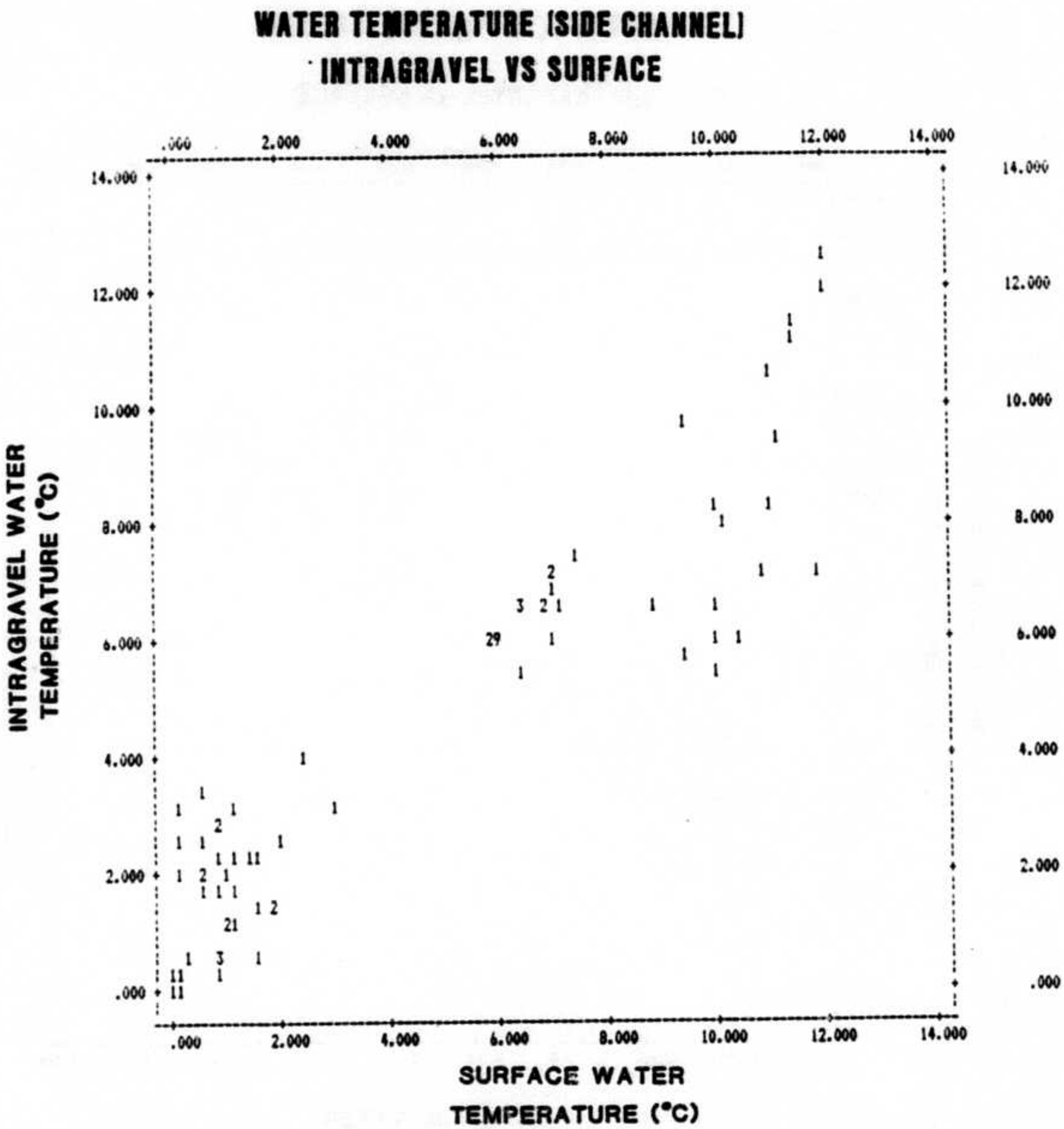

Figure 11. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within side channel habitat of the middle Susitna River, Alaska.

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WATER TEMPERATURE (TRIBUTARY)
INTRAGRAVEL VS SURFACE

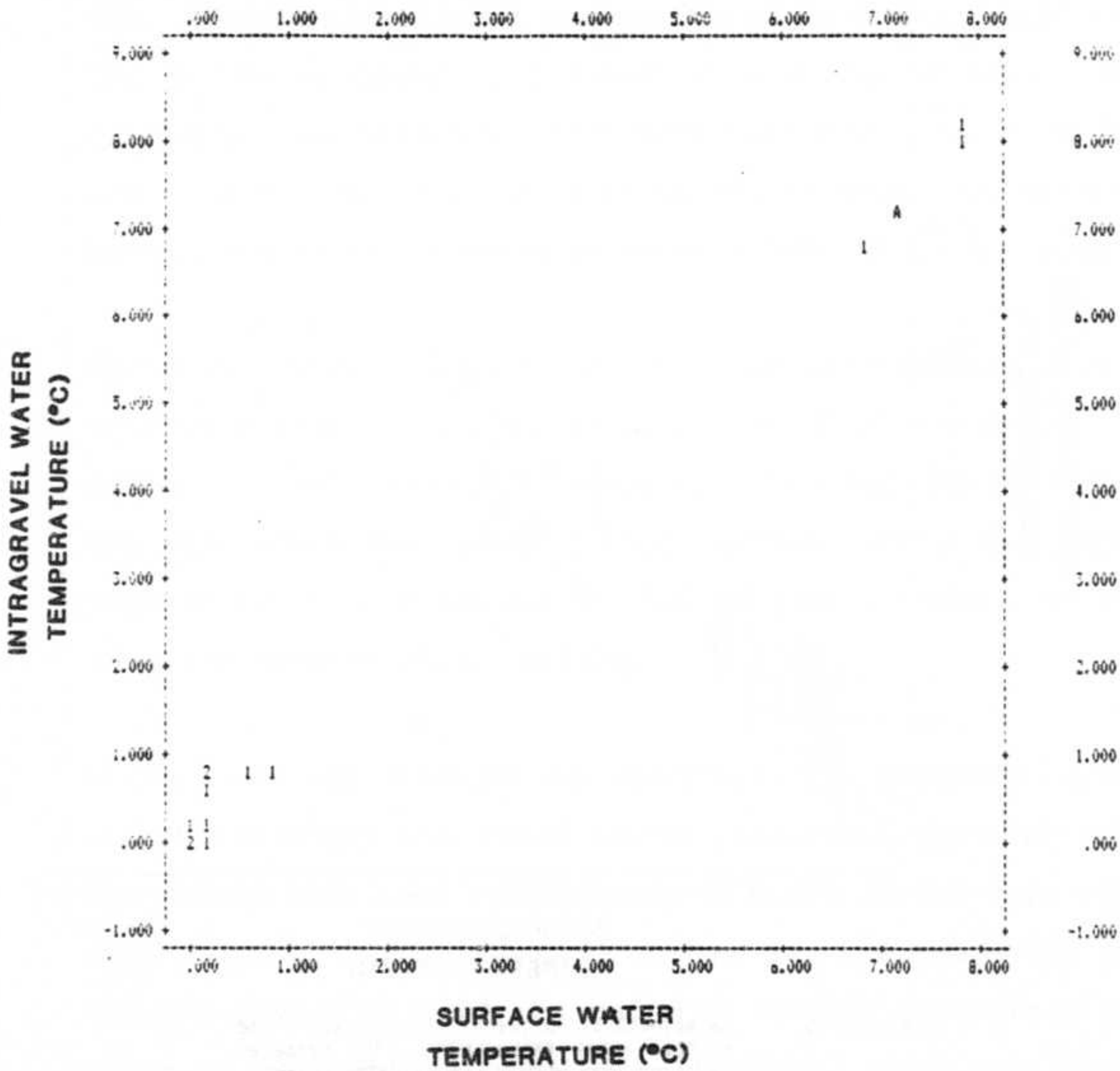

Figure 12. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within tributary habitat of the middle Susitna River, Alaska.

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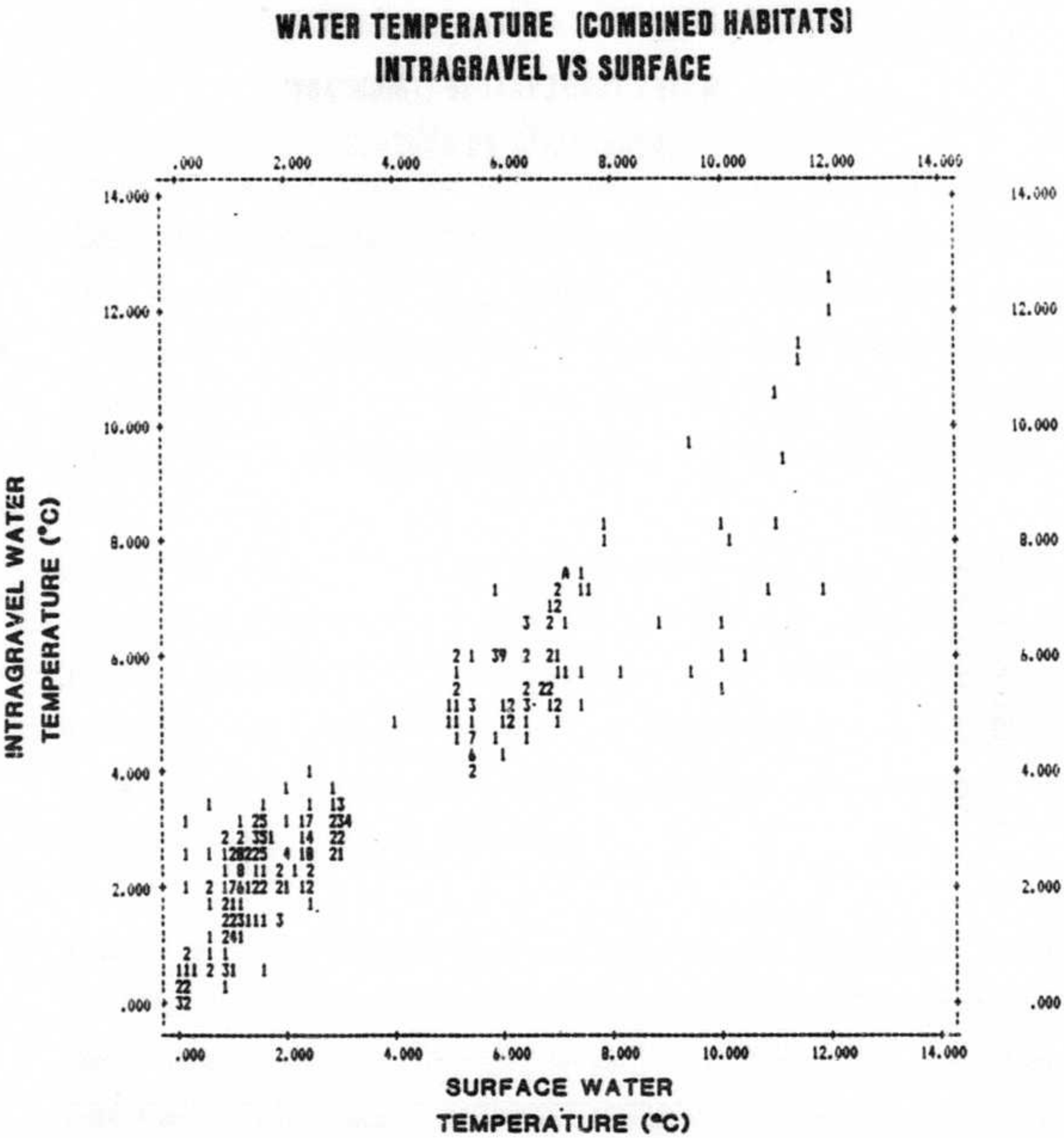

Figure 13. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within slough, side channel, and tributary habitats of the middle Susitna River, Alaska.

3.1.1.1.3 Continuous Intragravel Water Temperatures

Continuous intragravel water temperatures were measured at 18 sites in the middle Susitna River during the period from September 1983 to June 1984. A complete presentation of these data are included in Appendix A. This section is limited to a summary of a portion of these data, focusing only on intragravel water temperature data collected at the primary study sites in slough, side channel, tributary, and mainstem habitats used to evluate chum salmon emb.,: survival and/or development.

Figures 14 through 16 present the intragravel water temperature data collected at primary slough habitat study sites. From these data, it is apparent that intragravel water temperatures in slough habitats remain relatively stable from October to May, typically ranging from 3-4°C. These relatively warm temperatures indicate that the source of the intragravel water is likely upwelling.

Figures 17 through 19 present the intragravel water temperature record collected at primary side channel habitat study sites. These data show that although intragravel water temperatures in side channel study sites remain relatively stable from October to May, they show more variability over time compared to slough habitats. This indicates that although the source of the intragravel waters in side channel habitats is likely upwelling, other water sources, such as surface water downwelling, may influence the intragravel water component.

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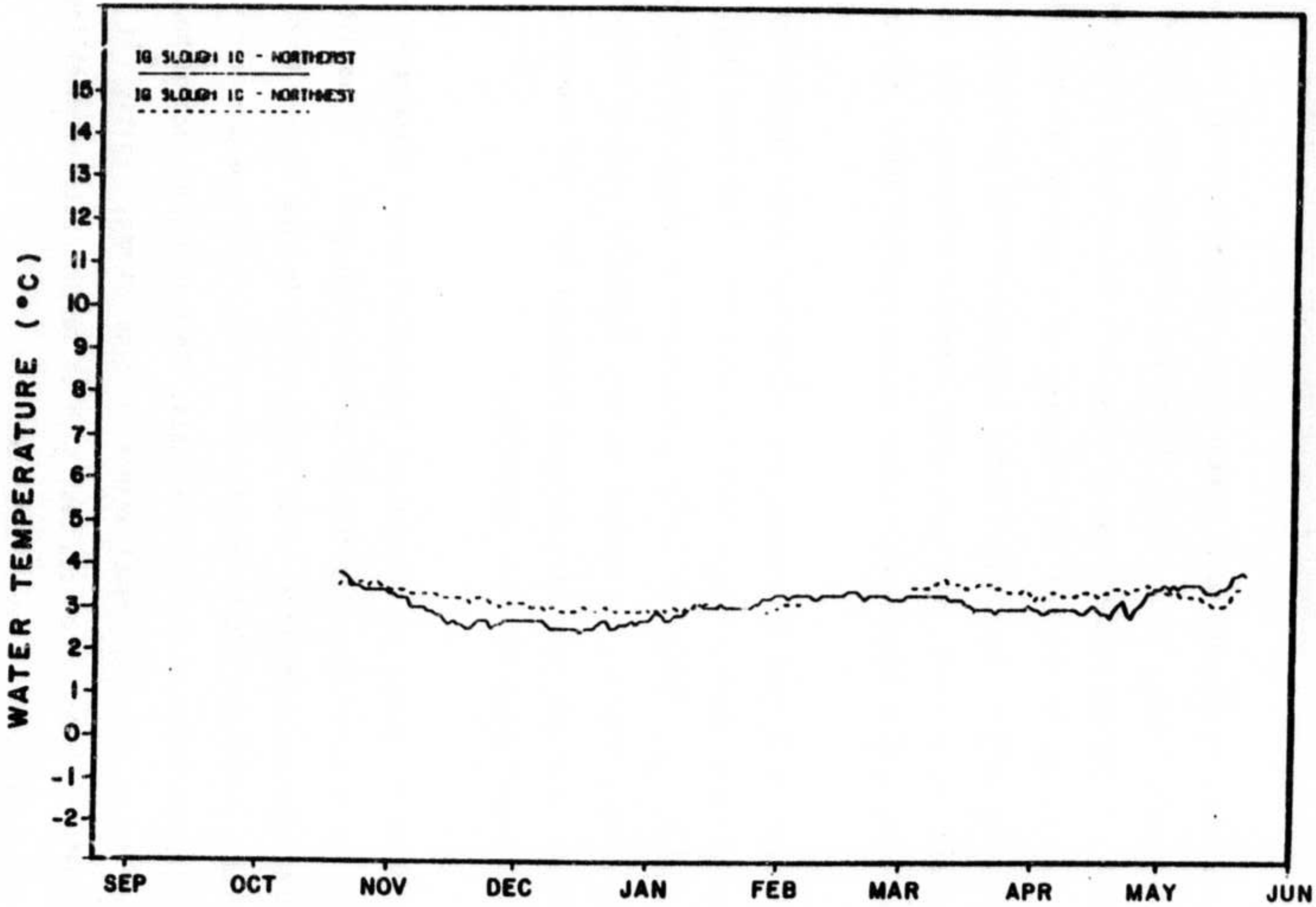

Figure 14. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Slough 10 (RM 133.8), middle Susitna River, Alaska.

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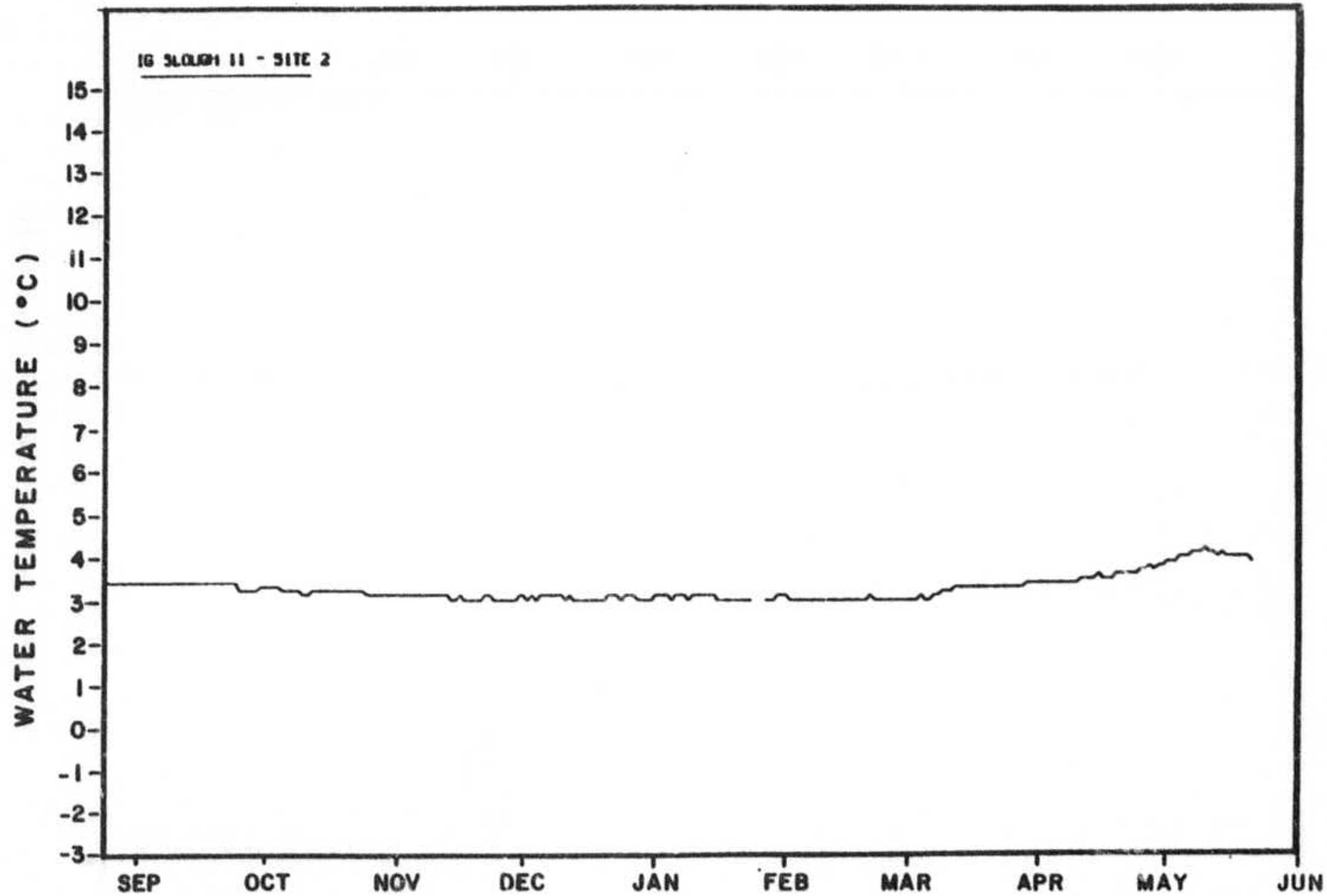

Figure 15. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Slough 11 (RM 135.3), middle Susitna River, Alaska.

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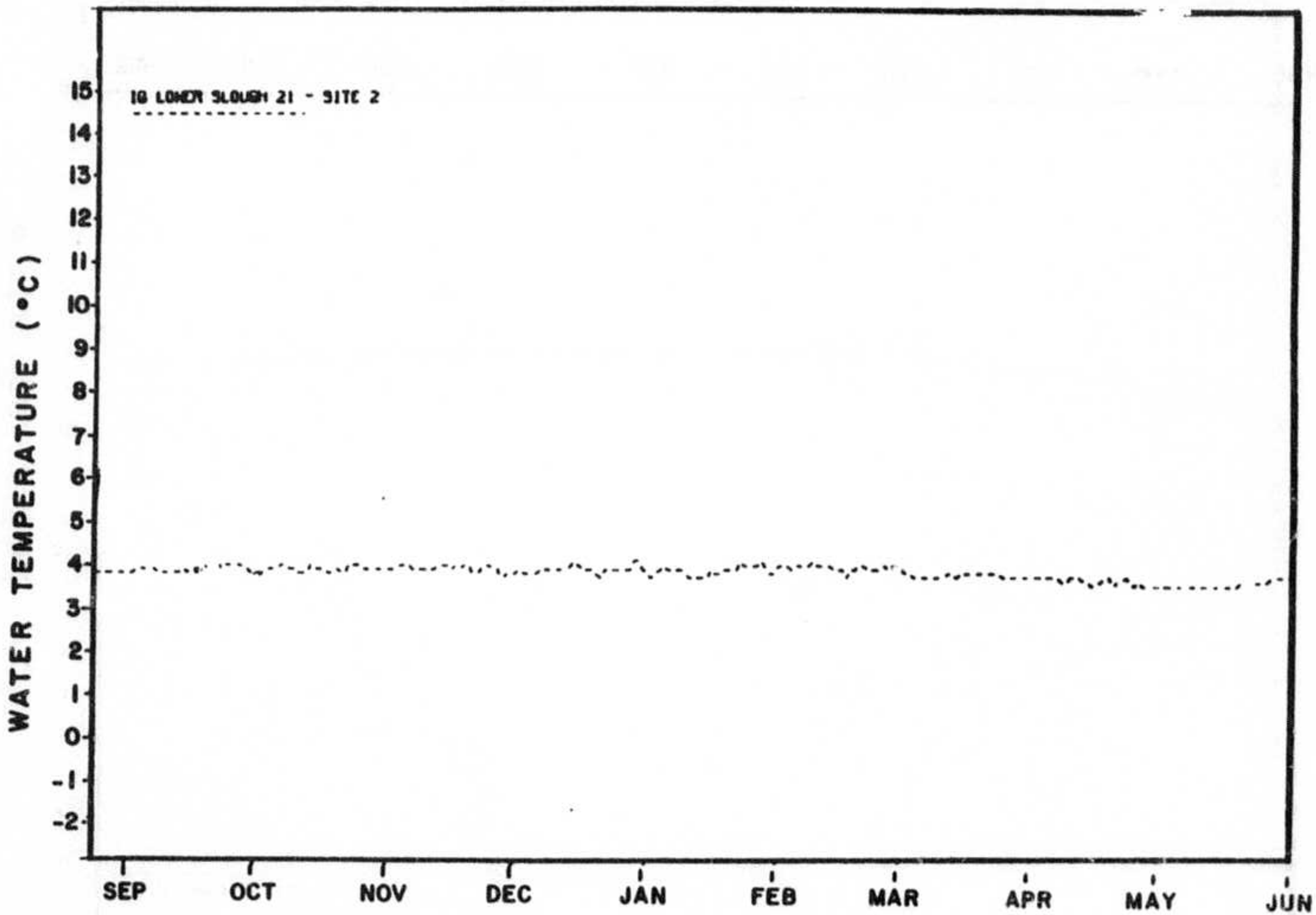

Figure 16. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Slough 21 (141.8), middle Susitna River, Alaska.

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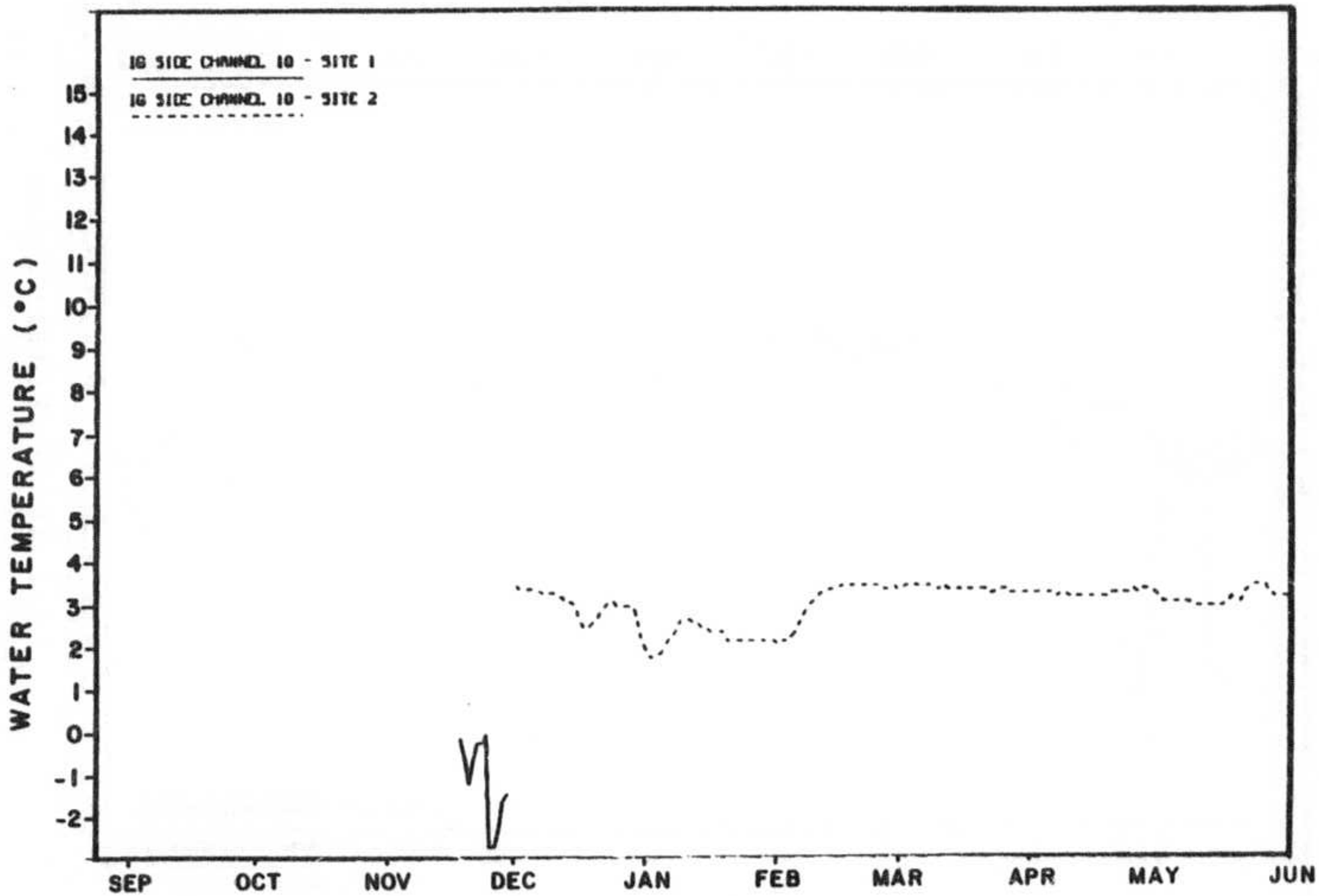

Figure 17. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Side Channel 10 (RM 133.8), middle Susitna River, Alaska.

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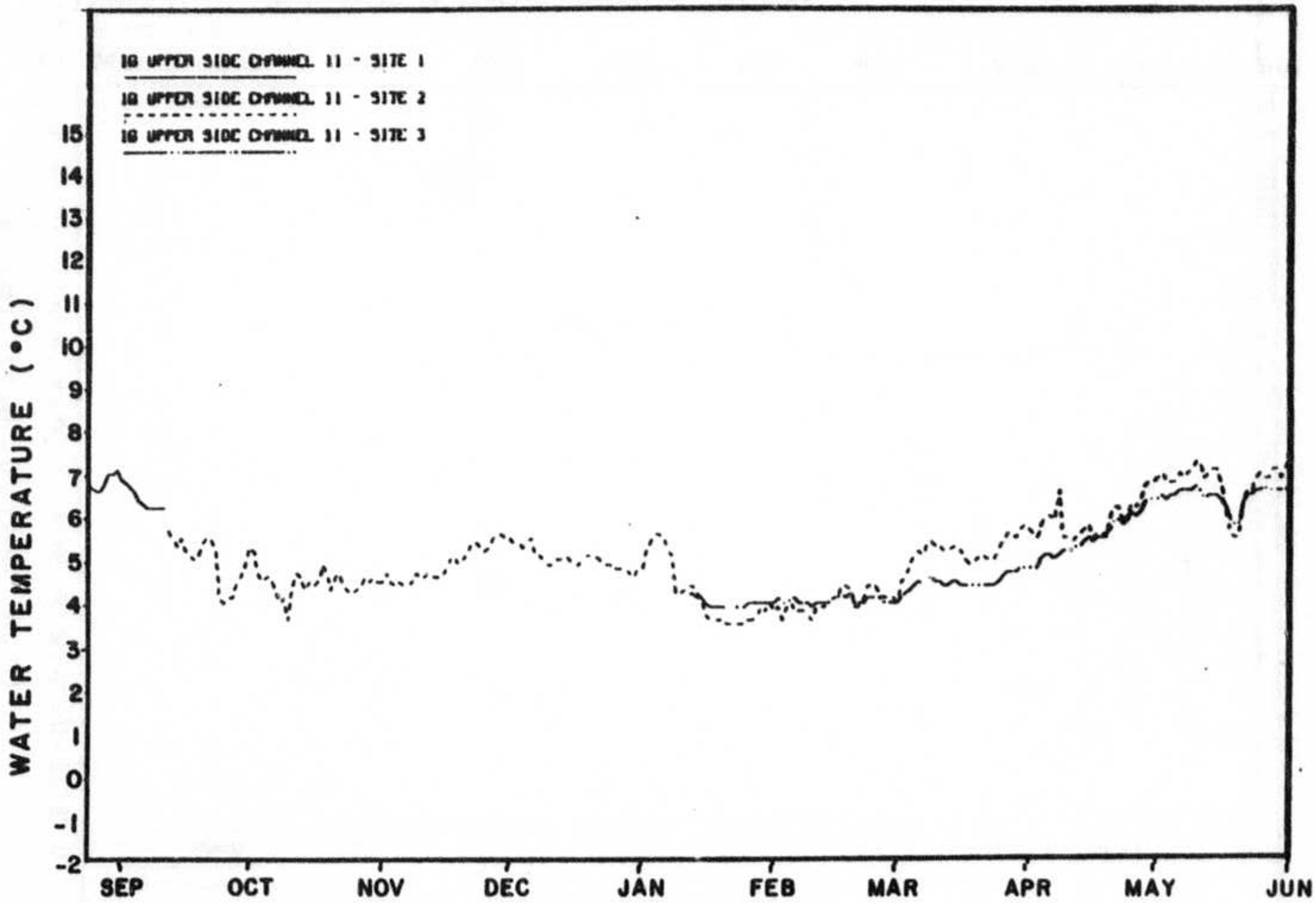

Figure 18. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Upper Side Channel 11 (RM 136.1), middle Susitna River, Alaska.

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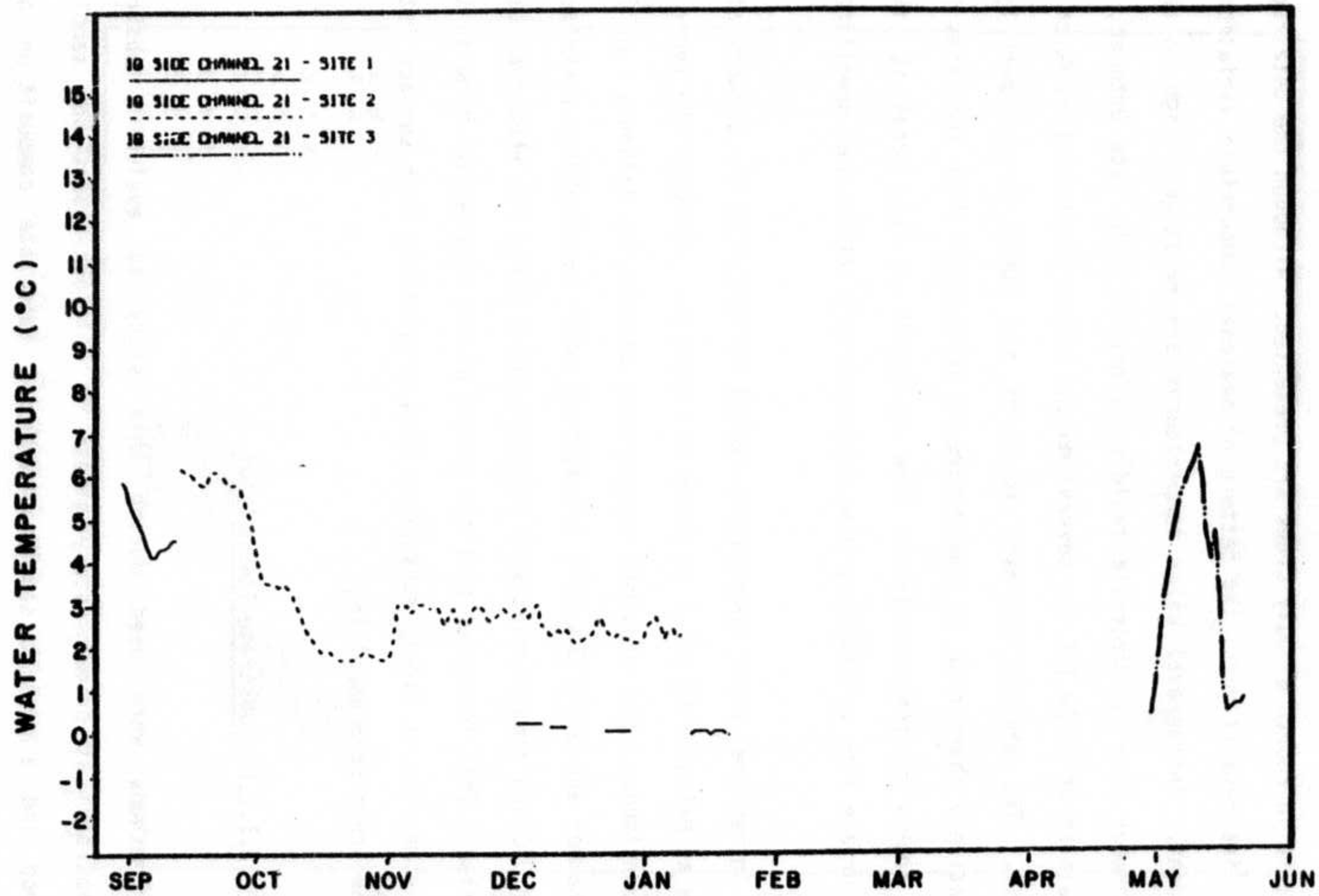

Figure 19. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Side Channel 21 (RM 141.0), middle Susitna River, Alaska.

In Figure 20, intragravel water temperatures measured at three sites located in Fourth of July Creek are presented. Although the data record contains several gaps, the pattern of seasonal temperature variation is evident. Intragravel water temperatures are relatively high in early September (6-8°C), decrease rapidly to near 0°C in late October, and remain at or below 1°C for several months before increasing in March and April. The gradual increase in March and April is followed by a relatively sharp rise in temperature in early May. This indicates that the source of the intragravel flow at Fourth of July Creek is likely subsurface flow originating from surface waters rather than upwelling.

The intragravel water temperature record collected at the primary study site at Mainstem RM 136.1 is shown in Figure 21. Although the record is discontinuous, the seasonal temperature pattern is evident. In late September and early October, intragravel water temperatures decrease to near 0°C and remain relatively constant until early May when they begin to rise. This indicates that the source of the intragravel flow at this mainstem site is likely subsurface flow originating from surface waters rather than from upwelling.

3.1.1.2 Substrate Composition

Two methods were used during this study to evaluate substrate composition at primary study sites: a Whitlock-Vibert Box sampling method and a McNeil sampling method. Substrate composition data obtained using each of these sampling devices at primary study sites are presented in Appendix D (Tables D-1 and D-2).

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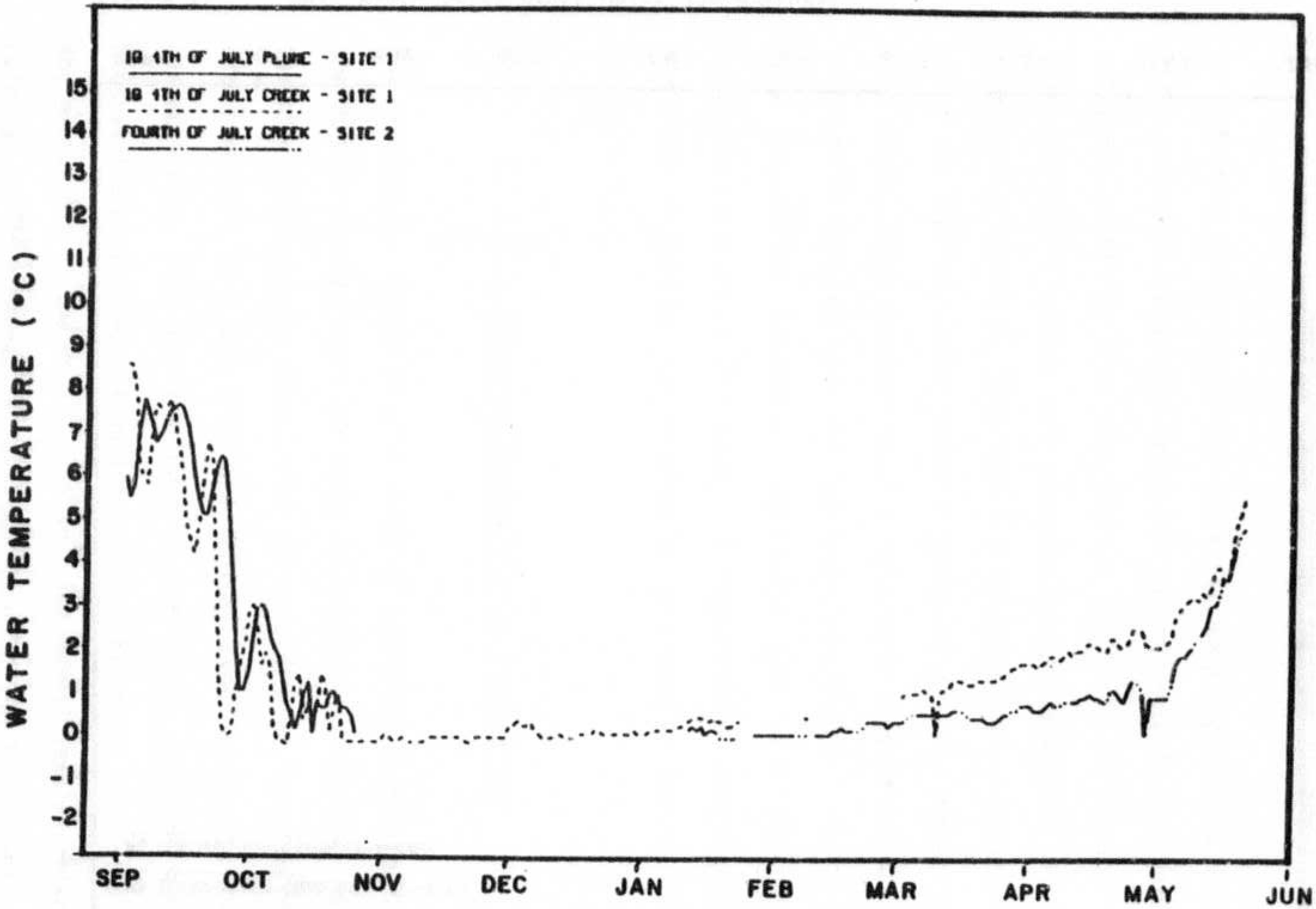

Figure 20. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Fourth of July Creek (RM 131.1), middle Susitna River, Alaska.

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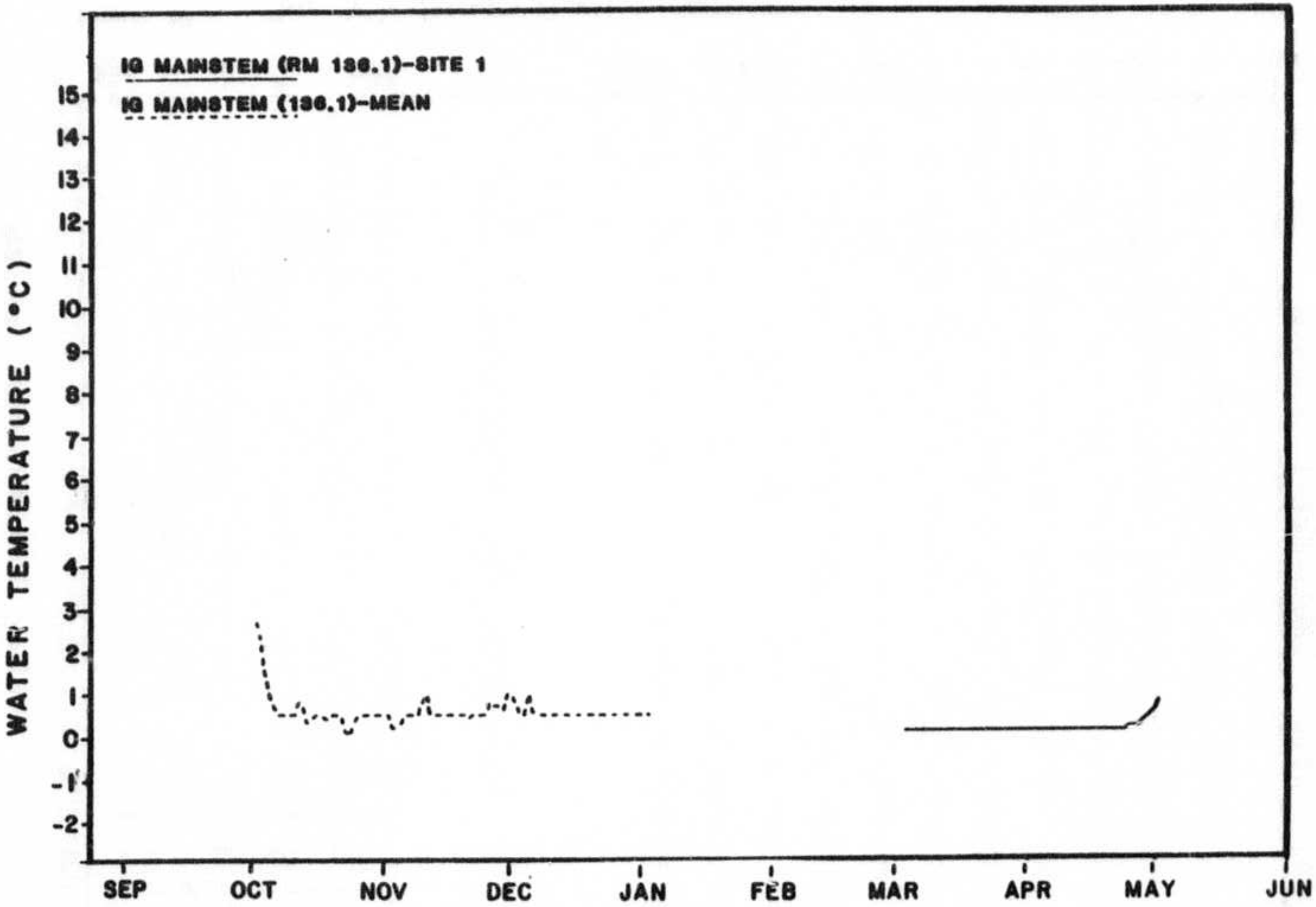

Figure 21. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Mainstem (RM 136.1) middle Susitna River, Alaska.

3.1.1.2.1 Comparison of McNeil and Whitlock-Vibert Box Samplers

To determine whether the two substrate sampling methods used in this study provided comparable results, the dry weights and percentage of substrate particles less than 0.2 cm (0.08 in) in diameter collected using the McNeil sampler were compared to the dry weights and percentage of substrate particles less than 0.2 cm (0.08 in) in diameter collected using the Whitlock-Vibert boxes (Figures 22 and 23, respectively). In both cases, there appears to be a relatively good relationship between the results obtained with the two types of samplers. For this reason, only the McNeil substrate composition data were used in further substrate analyses in this study. A comparison of sampling devices for individual substrate size classes is presented in Appendix D (Figures D-1 to D-7).

3.1.1.2.2 Substrate Composition at Study Sites

The percent dry weight by size class of substrate samples obtained with the McNeil sampler over the range of substrate conditions observed at the nine primary study sites, with the exception of Mainstem (RM 136.1), are presented by study site and habitat type in Figures 24 and 25, respectively. Data for the Mainstem (RM 136.1) site are not included because the excessively large substrate particles at this site prevented the proper use of the McNeil sampler. Two McNeil samples, however, were obtained at an alternative mainstem location (RM 138.9) which appeared to have substrate similar to that typically selected by chum salmon for spawning. These two samples have been included in the Figure 24 presen-

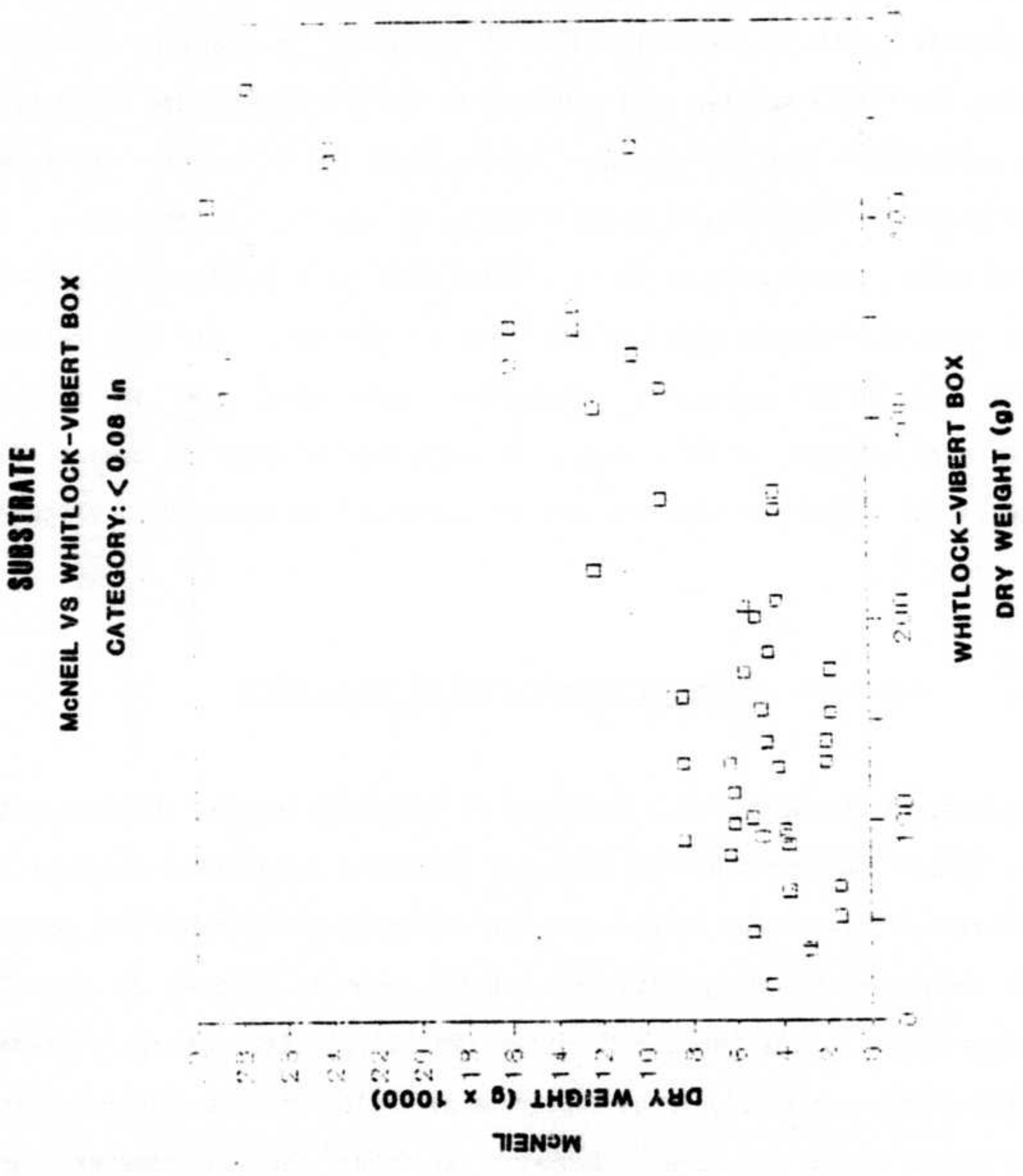

Figure 22. Comparison of the dry weights (g) of fine substrate (< 0.08 in. diameter) obtained from paired samples collected with McNeil and Whitlock-Vibert Box samplers.

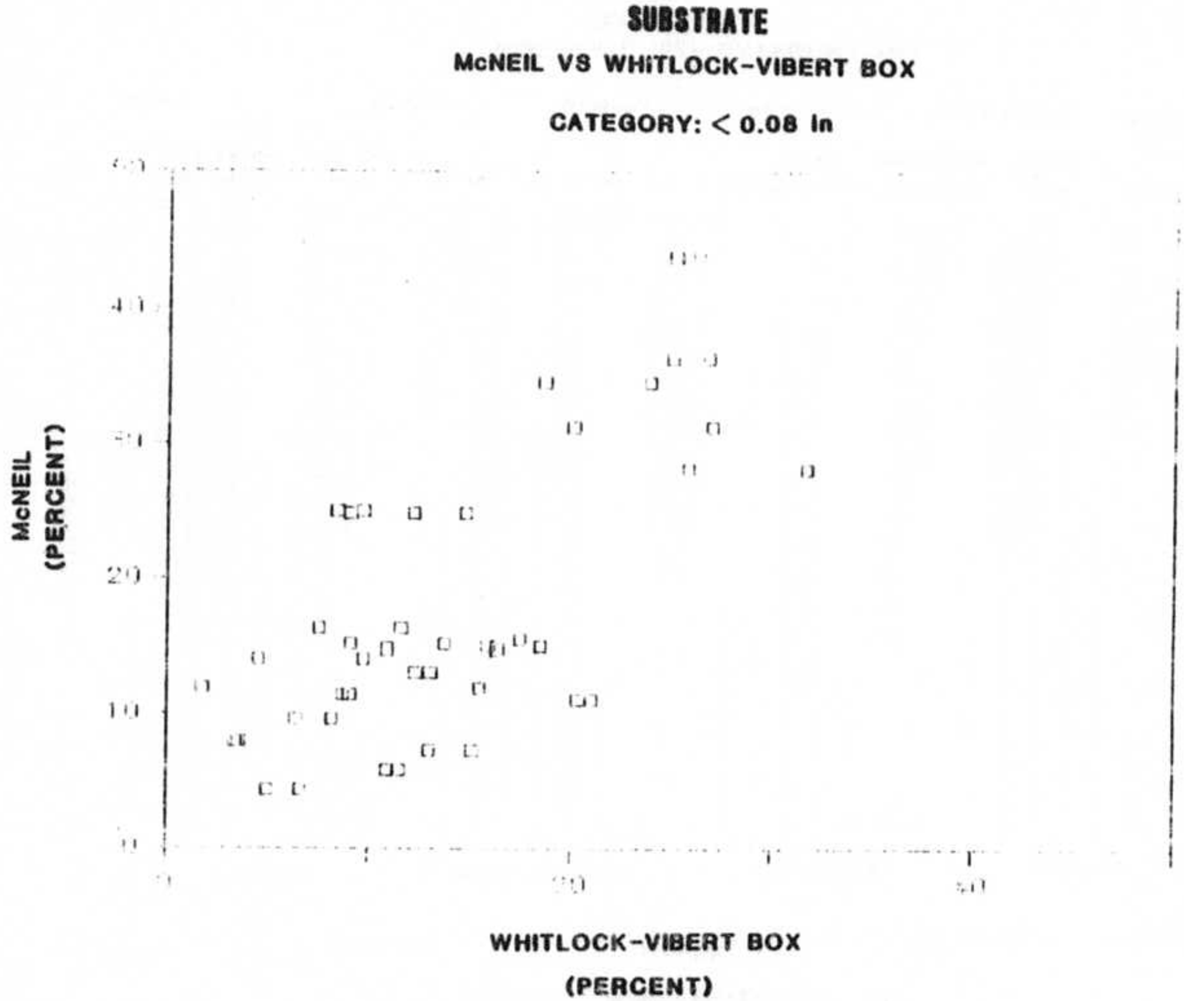

Figure 23. Comparison of dry weights (%) of fine substrate (< 0.08 in. diameter) obtained from paired samples collected with McNeil and Whitlock-Vibert Box samplers.

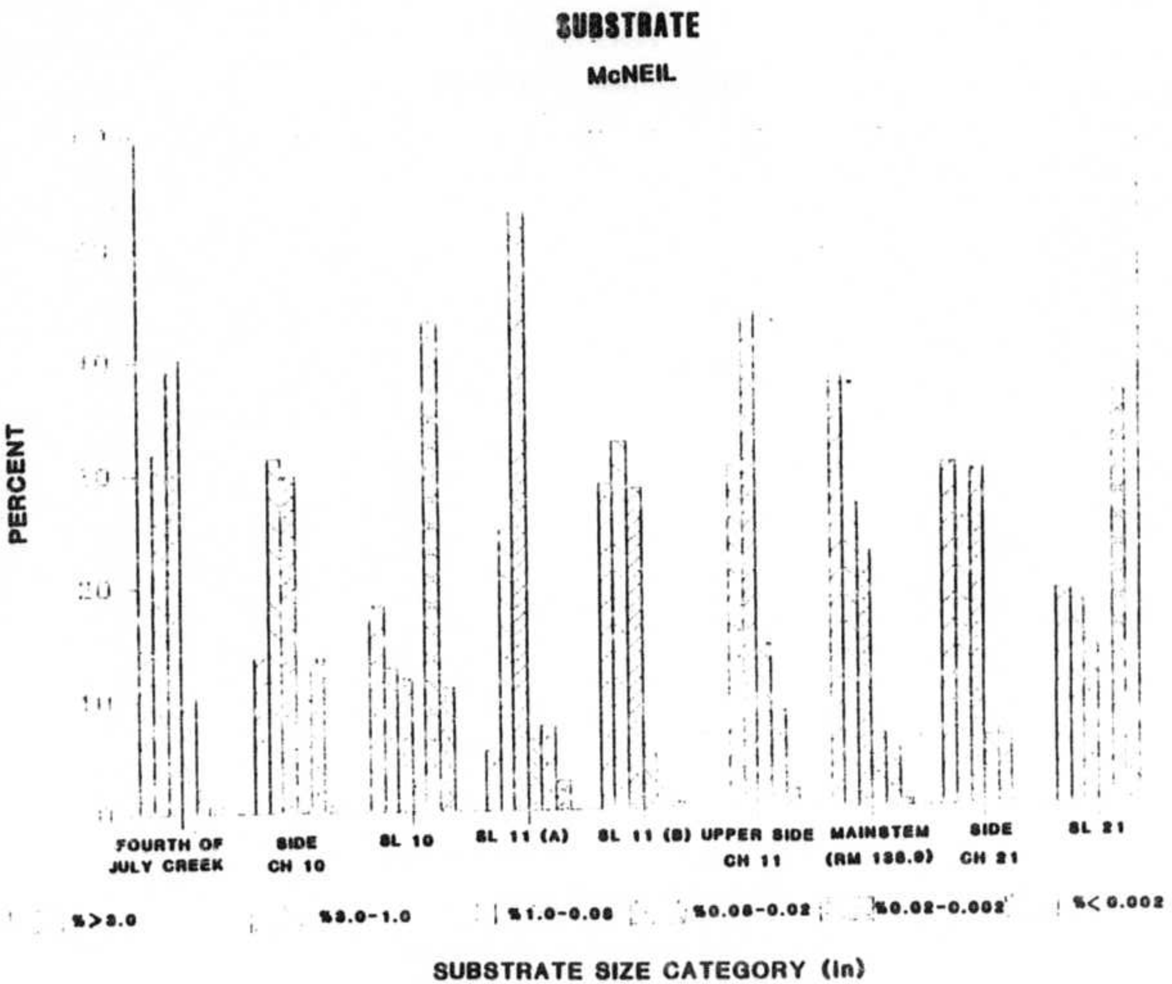

Figure 24. Percent size composition of McNeil substrate samples collected at study sites in the middle Susitna River, Alaska.

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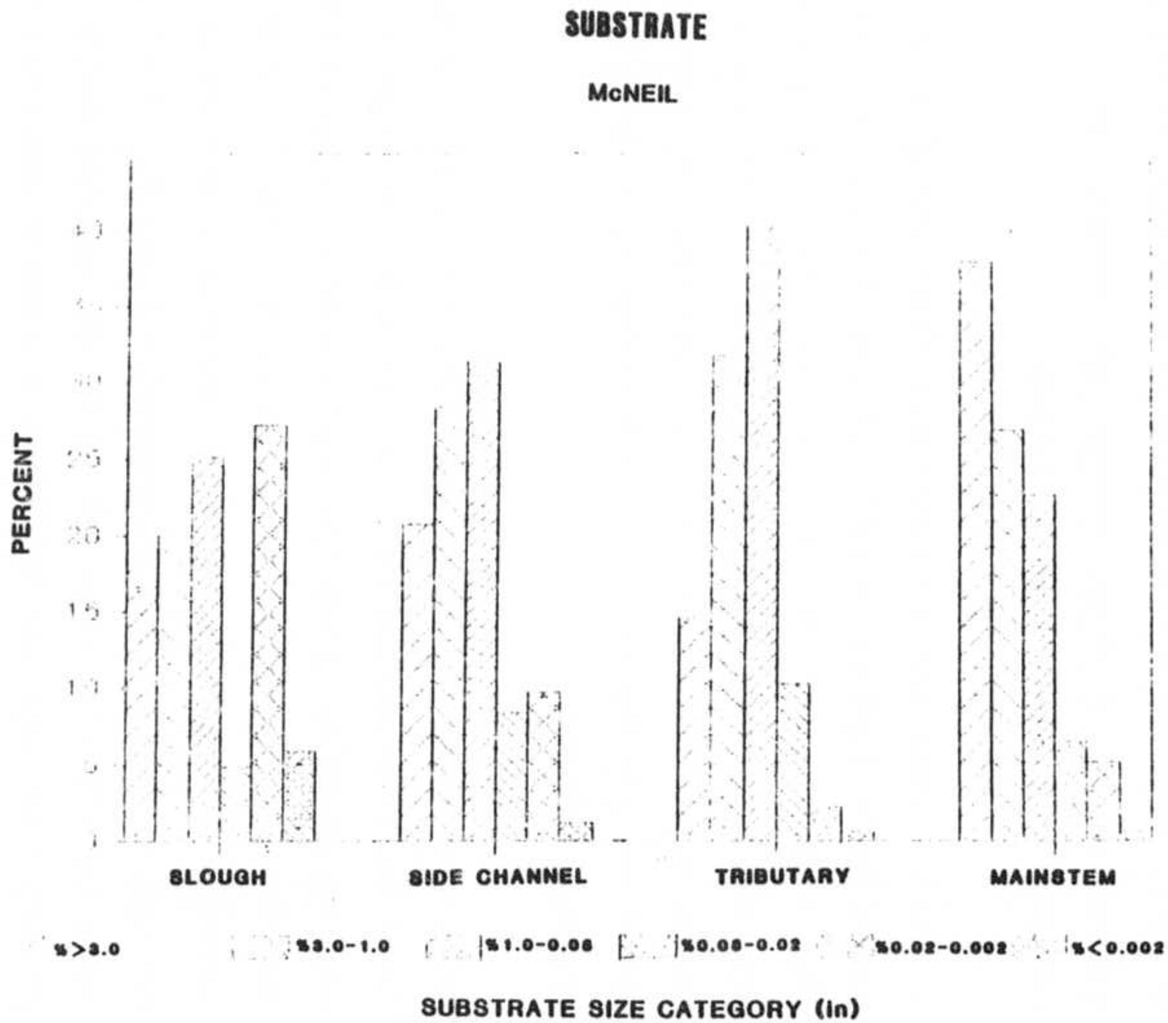

Figure 25. Percent size composition of McNeil samples collected in various habitat types in the middle Susitna River, Alaska.

tation for comparative purposes. In addition, the percentage of substrate materials in each of the three smallest substrate size classes (henceforward termed "fines") for each of the above nine primary study sites, grouped by study site and habitat type, are presented in Figures 26 and 27, respectively. The total height of each bar represents the combined percent of fines, whereas, the internal bar divisions correspond to individual fines size classes.

In general, these data illustrate that slough habitat study sites contain smaller substrate materials and greater amounts of fines than other habitat types. This is likely the result of lower water velocities within these habitat types. The mainstem habitat study site had the largest substrate materials and least amount of fines present whereas the side channel and tributary habitat study sites contained intermediate amounts.

The percent composition of substrate materials collected using the McNeil sampler in areas utilized for spawning by chum salmon at study sites and grouped by habitat type, are presented in Figures 28 and 29, respectively. In addition, the percent substrate composition of fine substrates collected using the McNeil sampler at study sites utilized for spawning by chum salmon are presented in Figure 30. In all cases except the site at Mainstem (RM 138.9), the substrate samples were collected within approximately 5.0 feet of a natural chum salmon redd. The data for Mainstem (RM 138.9) were not collected at a chum salmon redd, but rather, at a site that appeared to have a similar substrate

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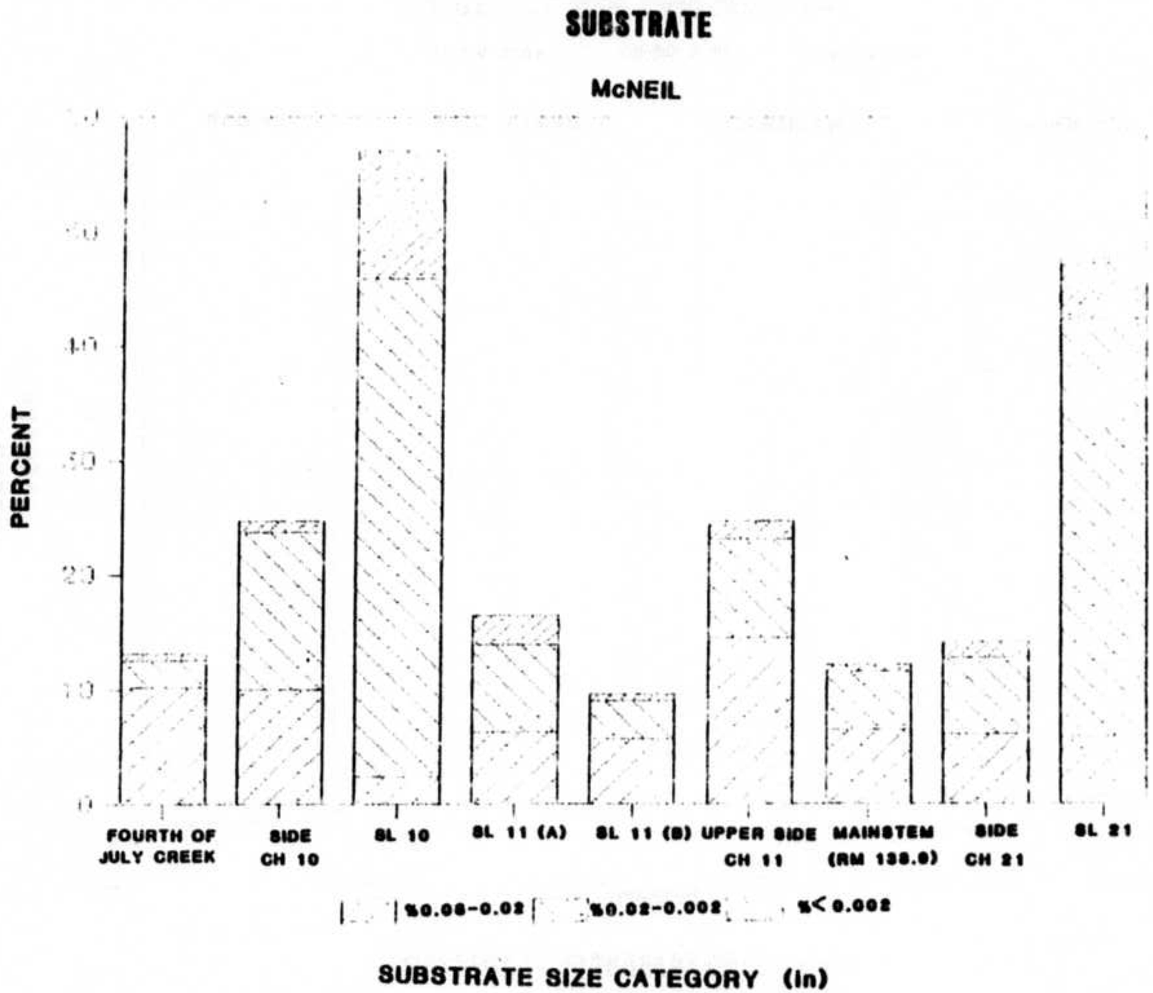

Figure 26. Percent size composition of fine substrate (< 0.08 in. diameter) in McNeil samples collected at study sites in the middle Susitna River, Alaska.

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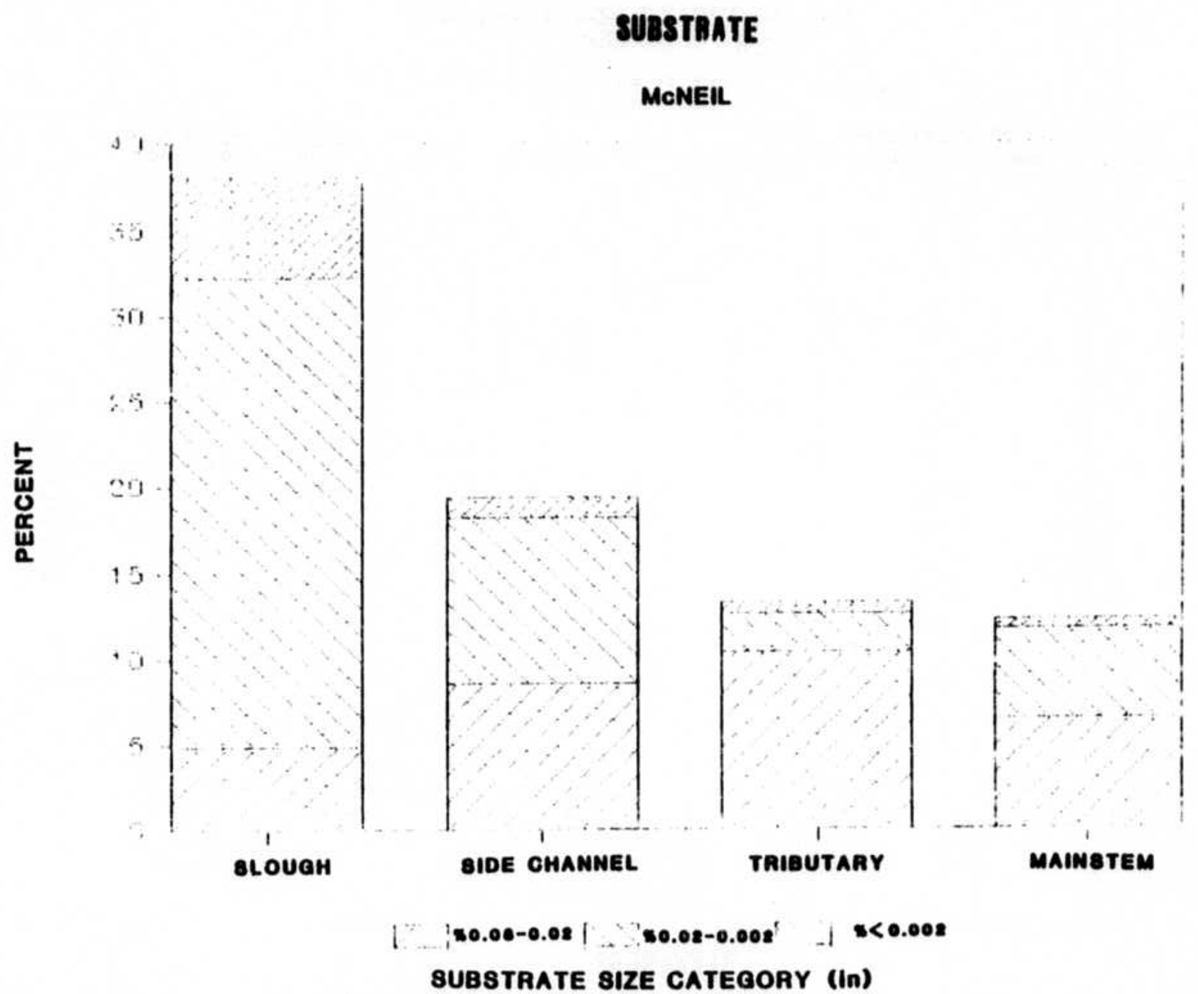

Figure 27. Percent size composition of fine substrate (<0.08 in. diameter) of McNeil samples collected in various habitat types in the middle Susitna River, Alaska.

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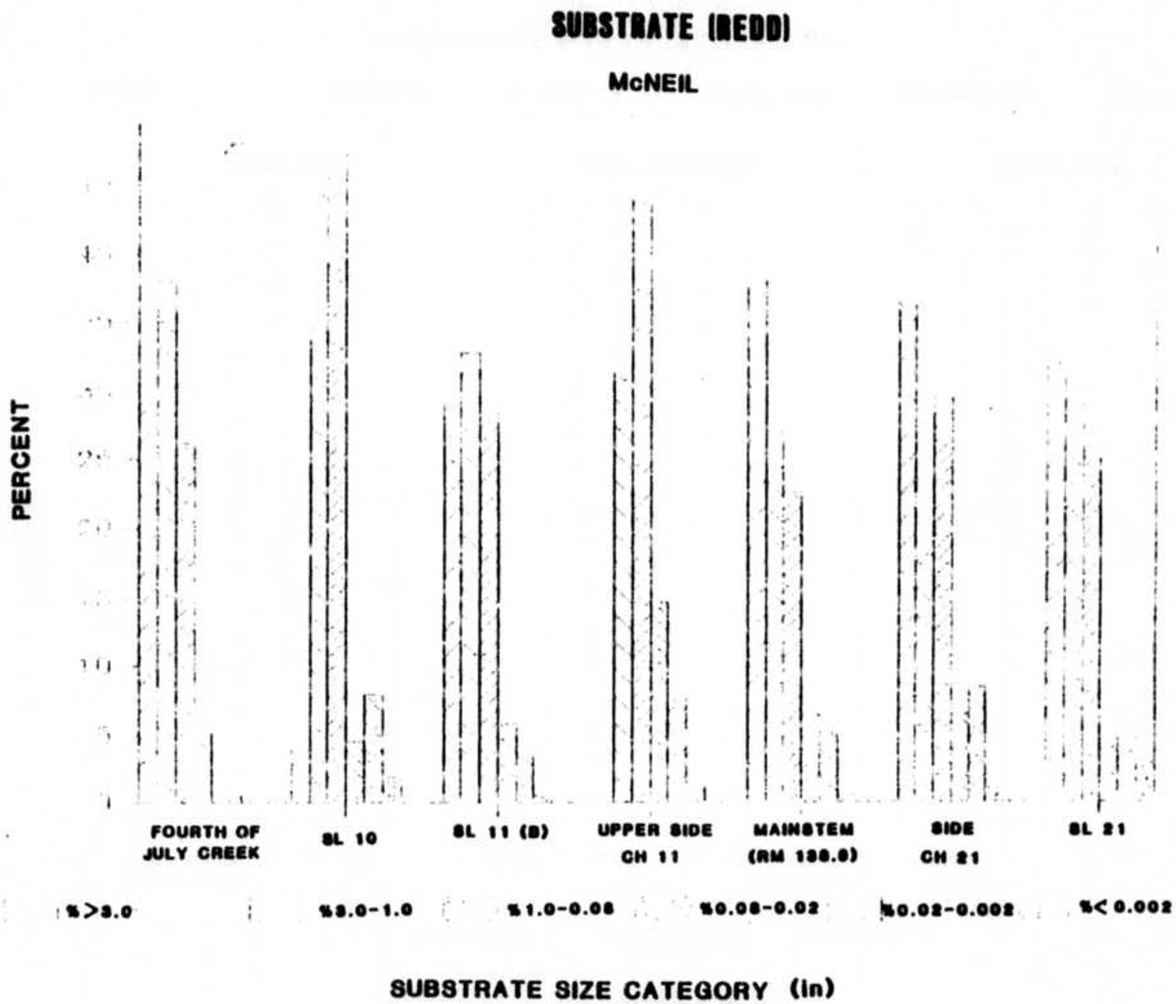

Figure 28. Percent size composition of McNeil substrate samples collected at chum salmon redds during May 1984, in the middle Susitna River, Alaska.

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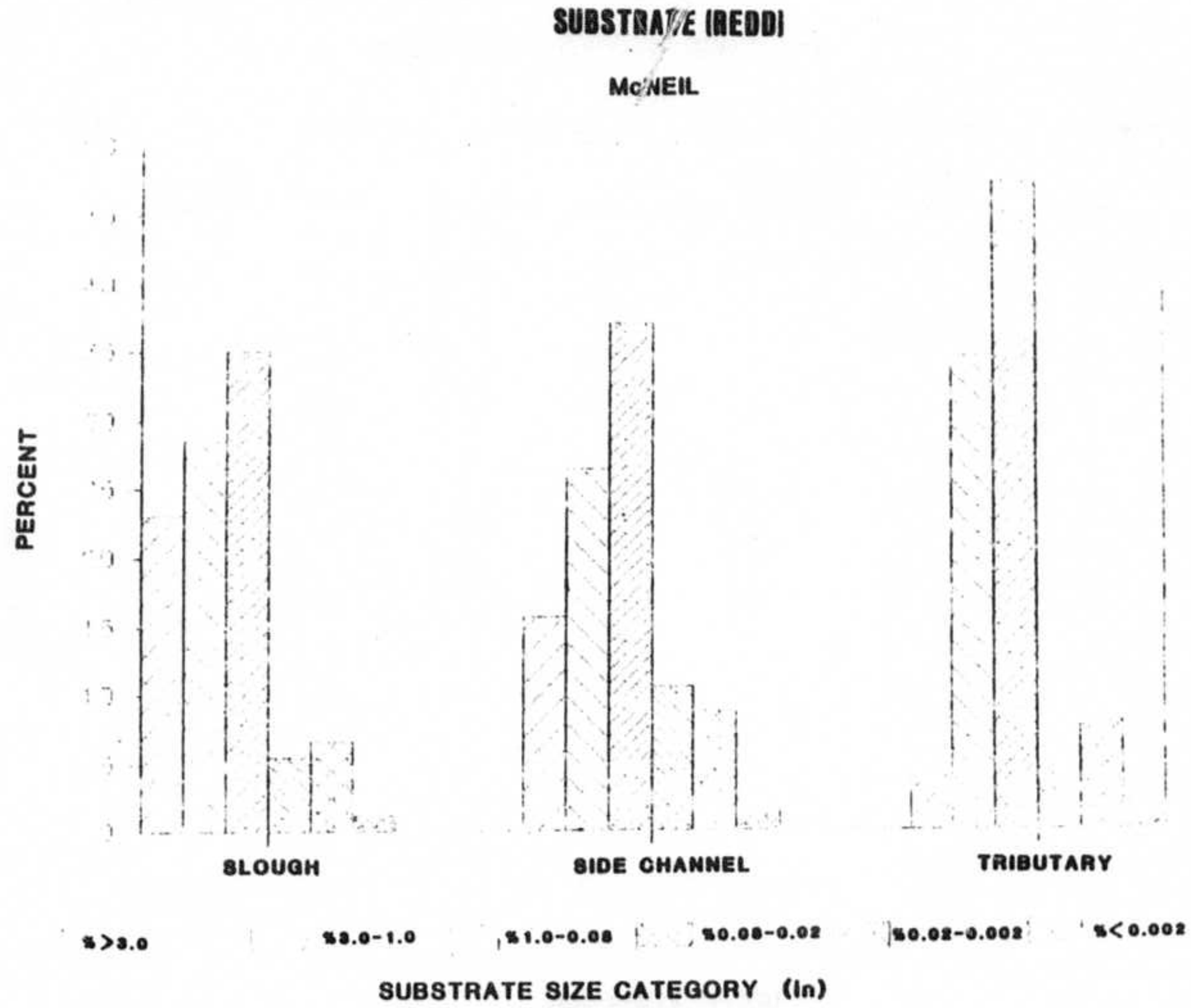

Figure 23. Percent size composition of McNeil substrate samples collected at chum salmon redds during May 1984, in various habitats of the middle Susitna River, Alaska.

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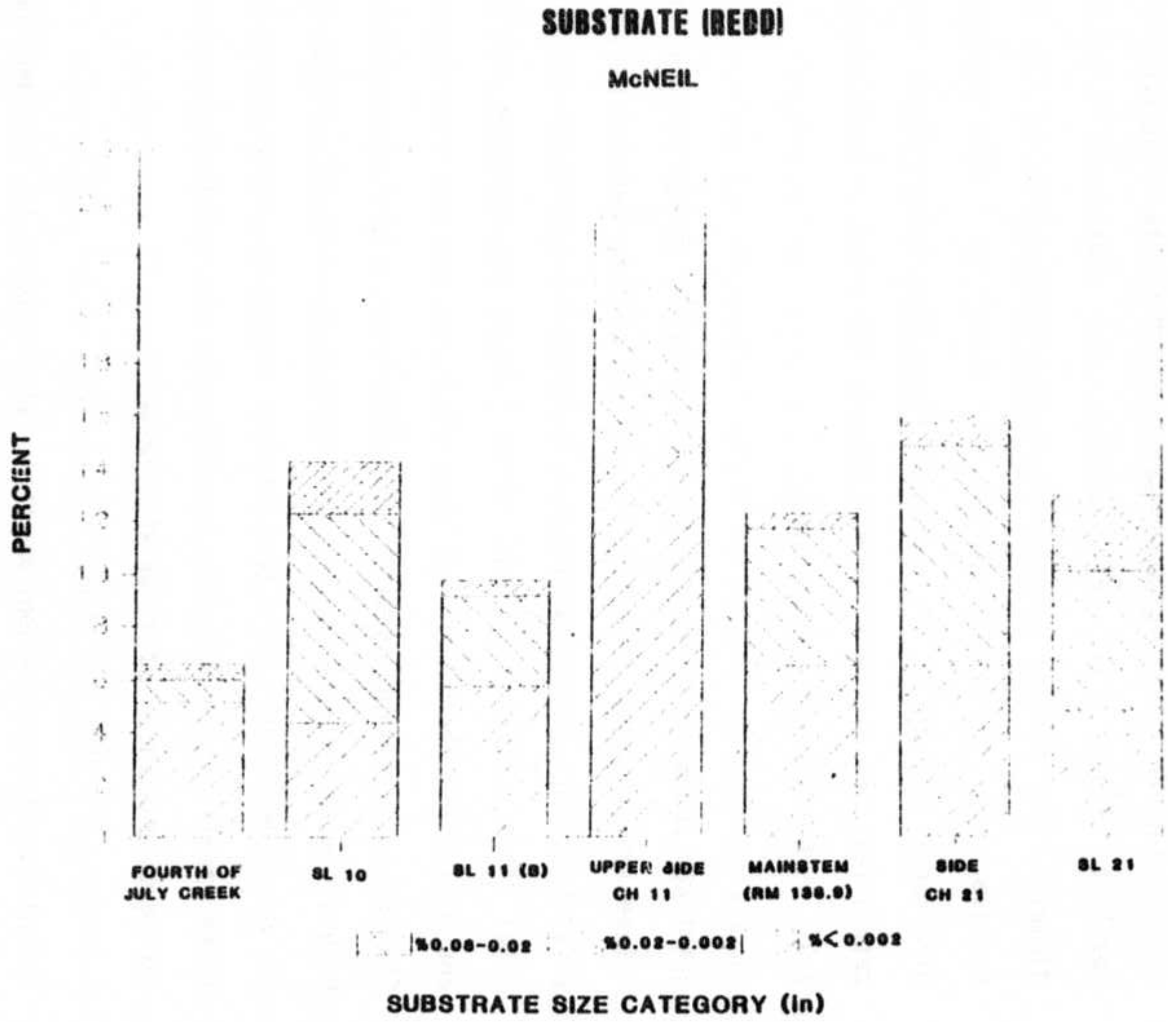

Figure 30. Percent size composition of fine substrate (< 0.08 in. diameter) in McNeil samples collected at chum salmon redds during May 1984 in study sites of middle Susitna River, Alaska.

composition to that in areas utilized for spawning by chum salmon. It is included for comparative purposes.

The variation in substrate composition of salmon redds is relatively greater for the three largest substrate categories than for the three smallest (Figure 28). For example, for substrates 1.0-0.08 in. diameter, the percent composition varies from a low of 23% for the mainstem site to a high of 47% for Slough 10. This represents a difference of 24%. In contrast, for the three finer substrate categories, the greatest variety between the sites in each category is 3.0%, 6.0% and 15.0%, respectively.

Substrate composition for the finest three size categories are compared between study sites in Figure 30. Of all sites evaluated, two sites [Fourth of July Creek and Slough 11(Subsite B)] contained less than 10% total fines. Three additional sites [Slough 10, Mainstem (RM 138.9), and Slough 21] contained less than 15% fines, and one site (Upper Side Channel 11) contained greater than 20% fines. It is noteworthy that both of the sites with the greatest amounts of fines (Upper Side Channel 11 and Side Channel 21) also contain extensive areas of upwelling. These upwellings undoubtedly act to reduce the deleterious effects of increased amounts of fines in the streambed.

The substrate composition of chum salmon redds is compared between samples collected in different habitat types in Figure 29. In general, slough and side channel habitat study sites contain relatively greater amounts of fine substrate materials and relatively lesser amounts of larger substrate materials compared to tributary habitat study sites. However, areas where salmon established redds in each habitat type (Figure 29) contained fewer fines than the range of substrate materials available in each habitat type (Figure 25).

3.1.2 Chemical Variables

3.1.2.1 Dissolved Oxygen

Comparisons of dissolved oxygen concentrations (mg/l) measured in surface and intragravel waters in slough, side channel, and tributary habitat study sites are presented in Figures 31-33, respectively. These data, grouped for all study sites, are presented in Figure 34. Similar plots for dissolved oxygen, expressed as percent saturation, are included in Appendix C.

In each figure, there appears to be a general relationship between surface and intragravel dissolved oxygen levels indicating a relationship between upwelling water and surface waters within each habitat type. The relationship appears strongest for tributary habitat study sites (Figure 33) and weakest for slough habitat study sites (Figure 31). It is interesting to note that the relationship for slough habitat study sites does not appear uniform over the entire range of concentrations, being much weaker (i.e., wider scatter of points) at low and intermediate values than at higher values.

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DISSOLVED OXYGEN (SLOUGH)
INTRAGRAVEL VS SURFACE

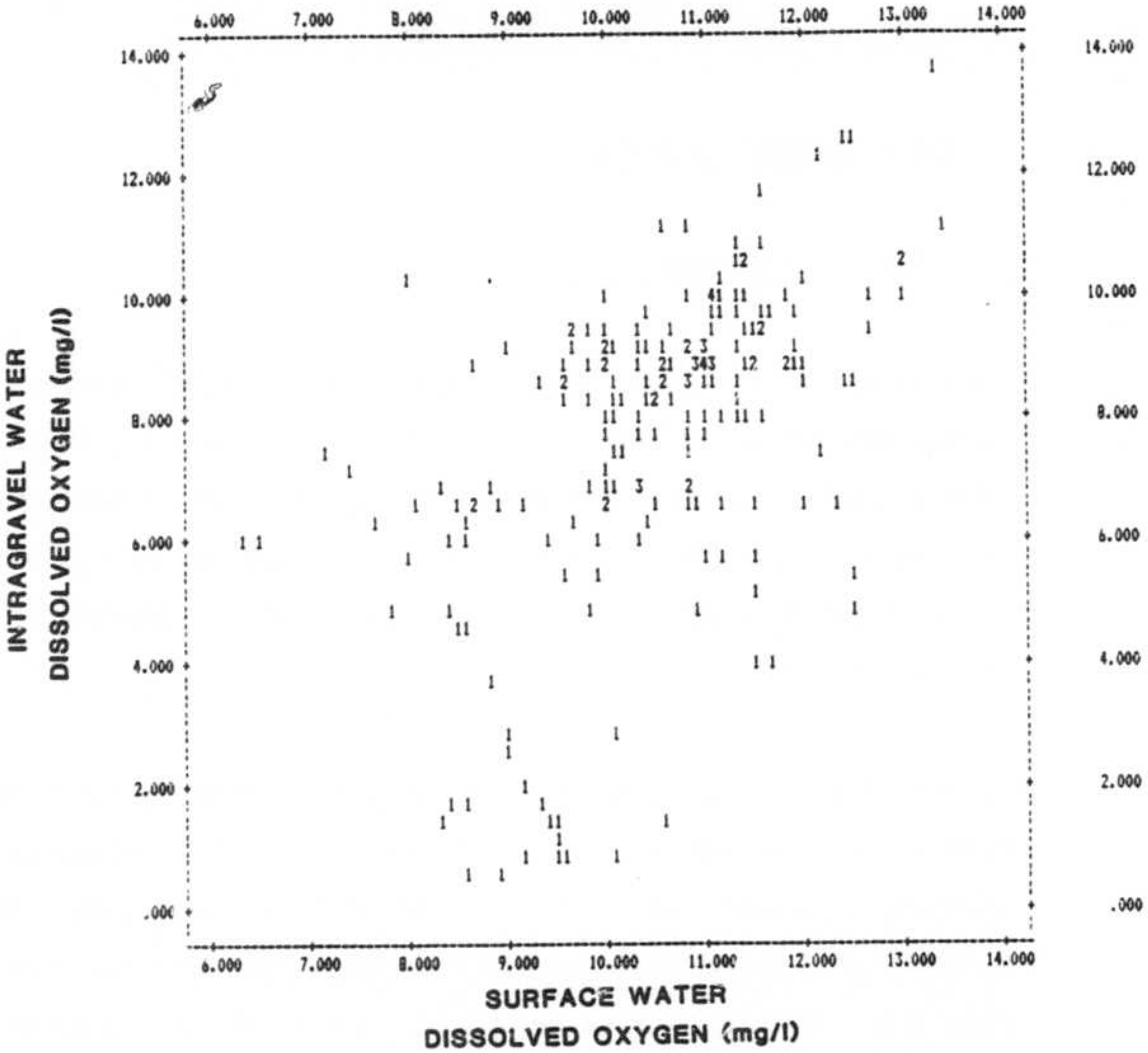

Figure 31. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/l) measured at standpipes within slough habitat of the middle Susitna River, Alaska.

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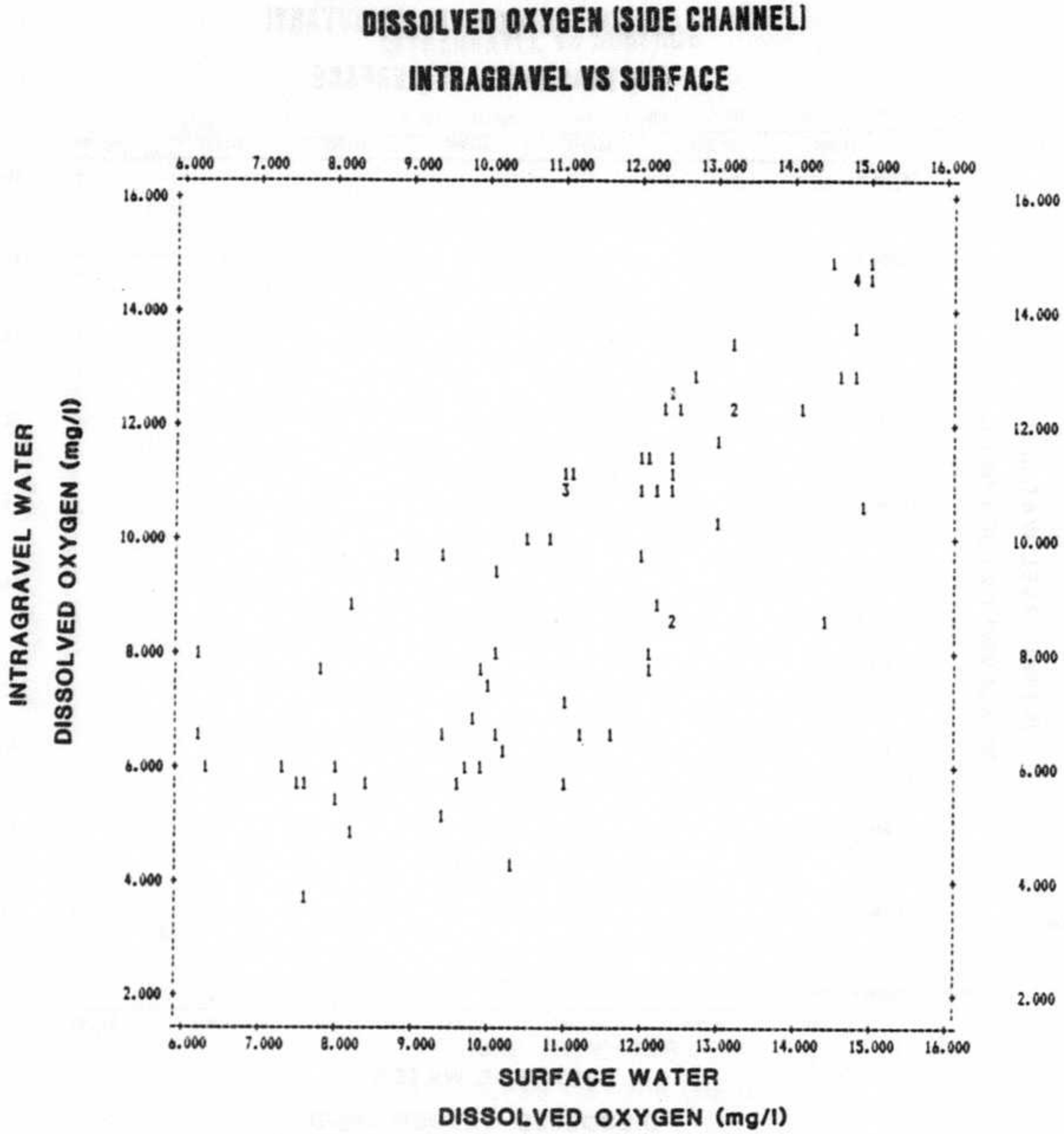

Figure 32. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/l) measured at standpipes within side channel habitat of the middle Susitna River, Alaska.

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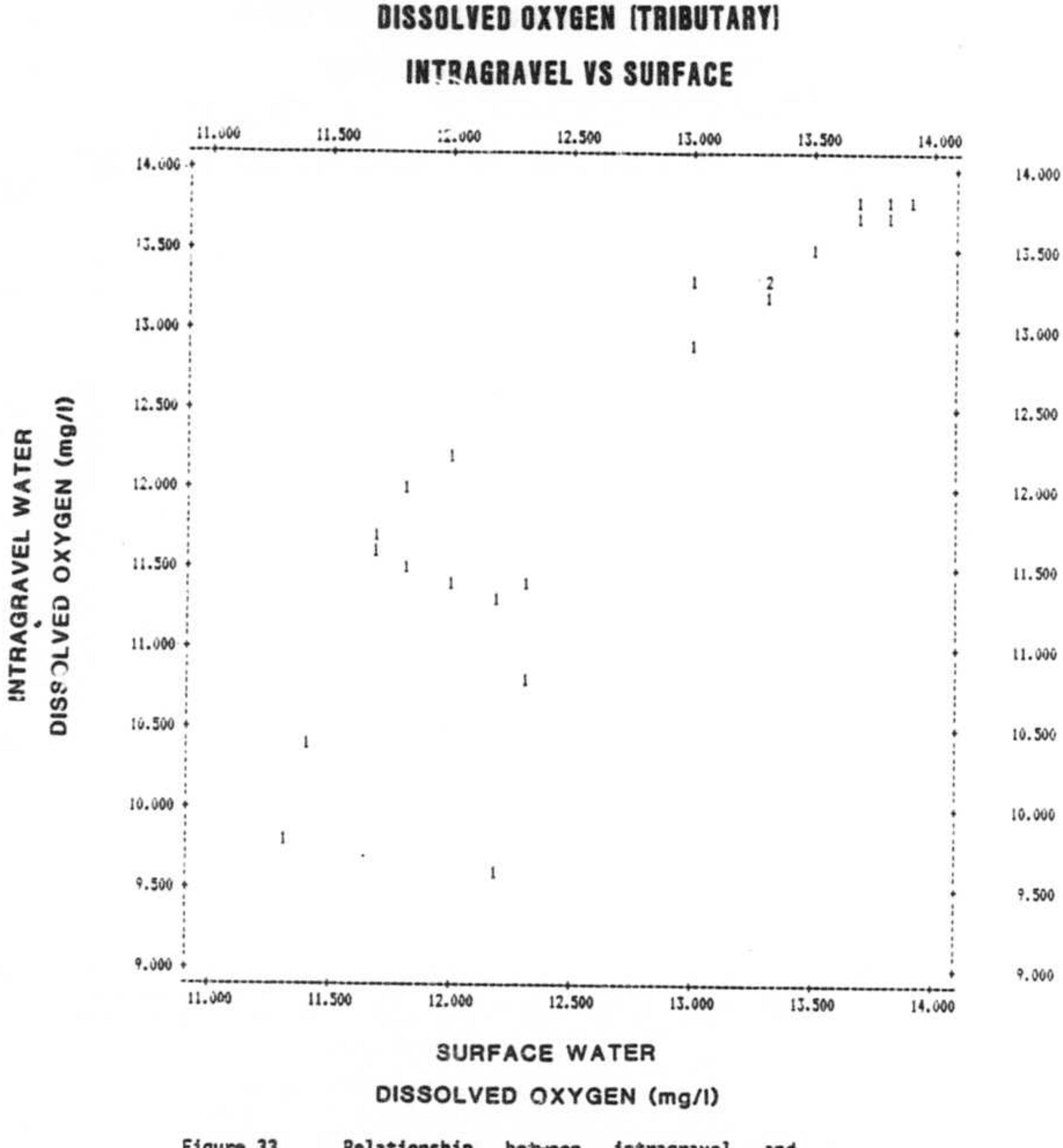

Figure 33. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/l) measured at standpipes within tributary habitat of the middle Susitna River, Alaska.

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DISSOLVED OXYGEN (COMBINED HABITATS)

INTRAGRAVEL VS SURFACE

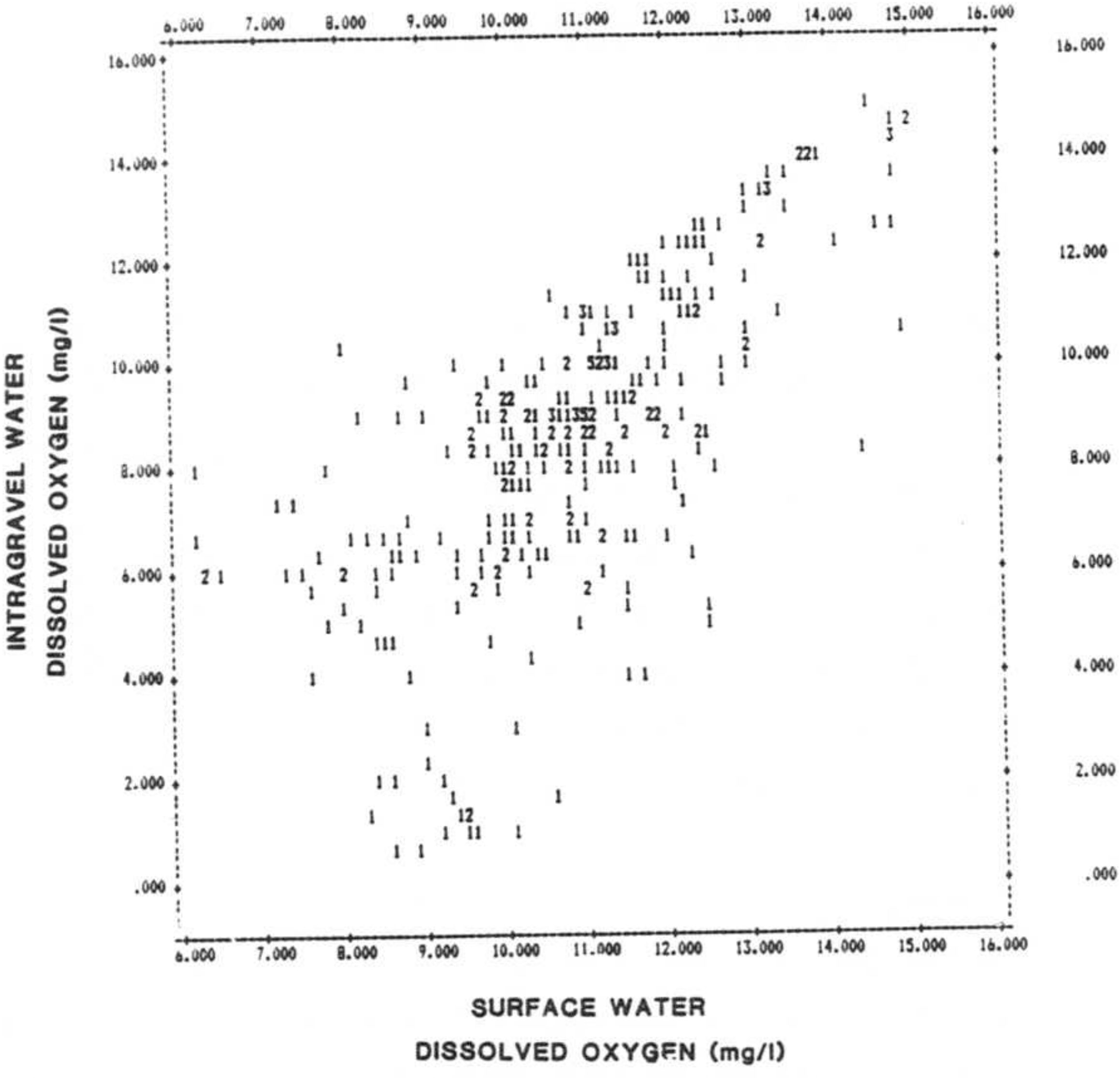

Figure 34. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/l) measured at standpipes within slough, side channel, and tributary habitats of the middle Susitna River, Alaska.

A summary of intragravel dissolved oxygen (DO) concentration (mg/l) data is presented by study site and habitat type in Figures 35 and 36, respectively. These data show that median DO levels are generally lowest for slough habitat study sites, intermediate for side channel and mainstem habitat study sites, and greatest for tributary habitat study sites.

3.1.2.2 pH

Comparisons of pH levels measured in surface and intragravel waters in slough and side channel habitat study sites are presented in Figures 37 and 38, respectively. These data grouped for all study sites are presented in Figure 39. Because this variable was not measured at all standpipe locations, there were insufficient data for comparable plots for tributary and mainstem habitat study sites. In general, these data show that there is a relationship between pH values measured in surface and intragravel waters in each of these habitat types, with the relationship being weakest for side channel habitats (Figure 38).

A summary of intragravel pH levels is presented by study site and habitat type in Figures 40 and 41, respectively. These data show that, with the exception of Side Channel 21, slough and side channel habitat study sites exhibit the same median pH values and are intermediate between the lower tributary habitat study site levels and the higher mainstem habitat study site levels.

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INTRAGRAVEL DISSOLVED OXYGEN (mg/l)

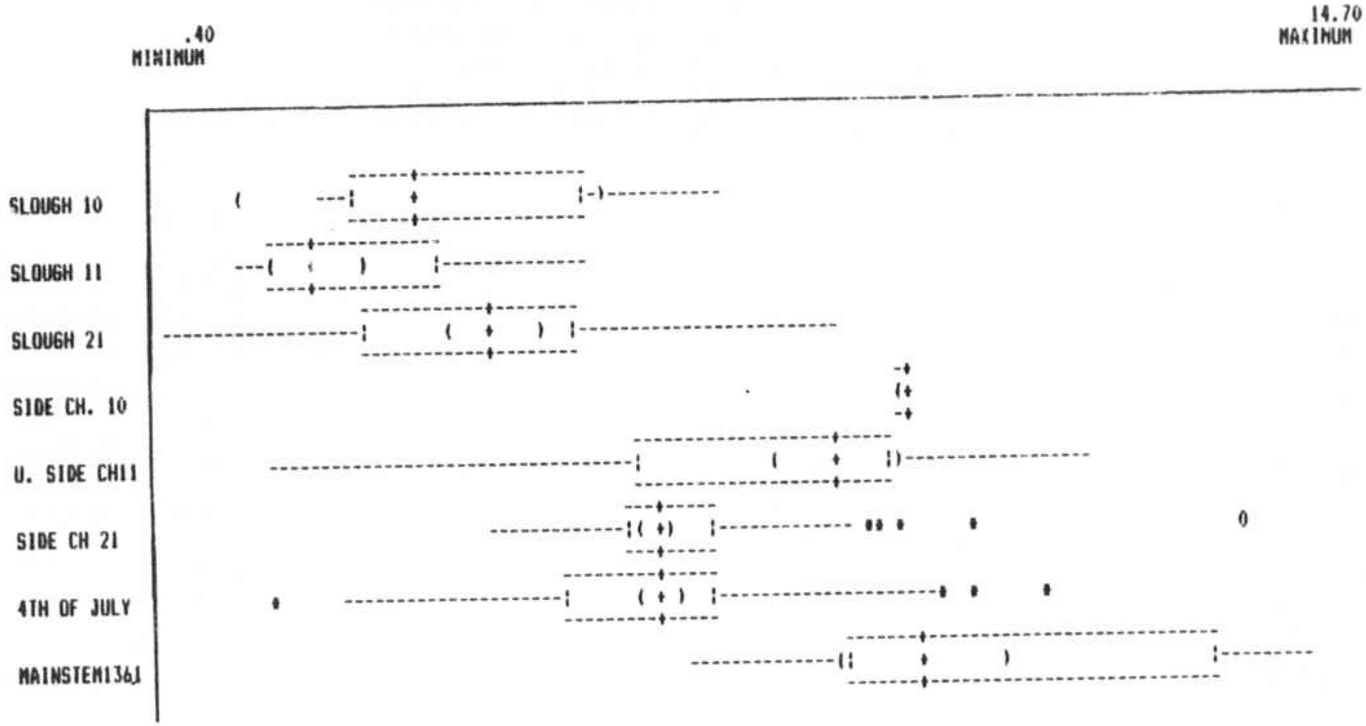

Figure 35. Summary, by study site, of the intragravel dissolved oxygen data (mg/l) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

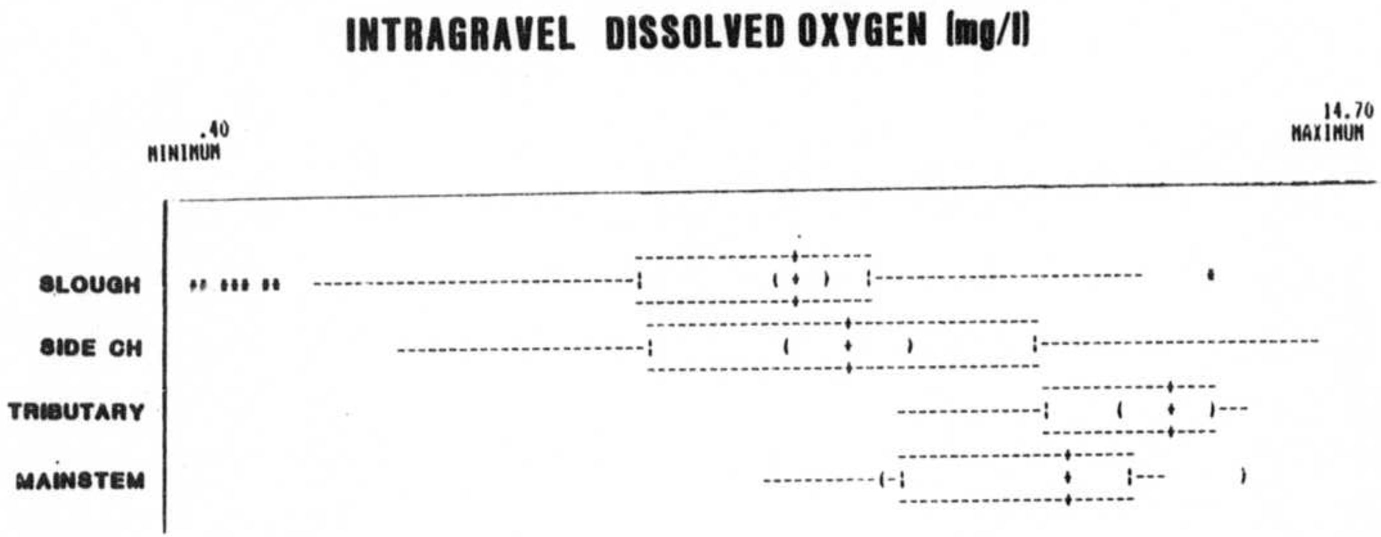

Figure 36. Summary, by habitat type, of the intragravel dissolved oxygen data (mg/l) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

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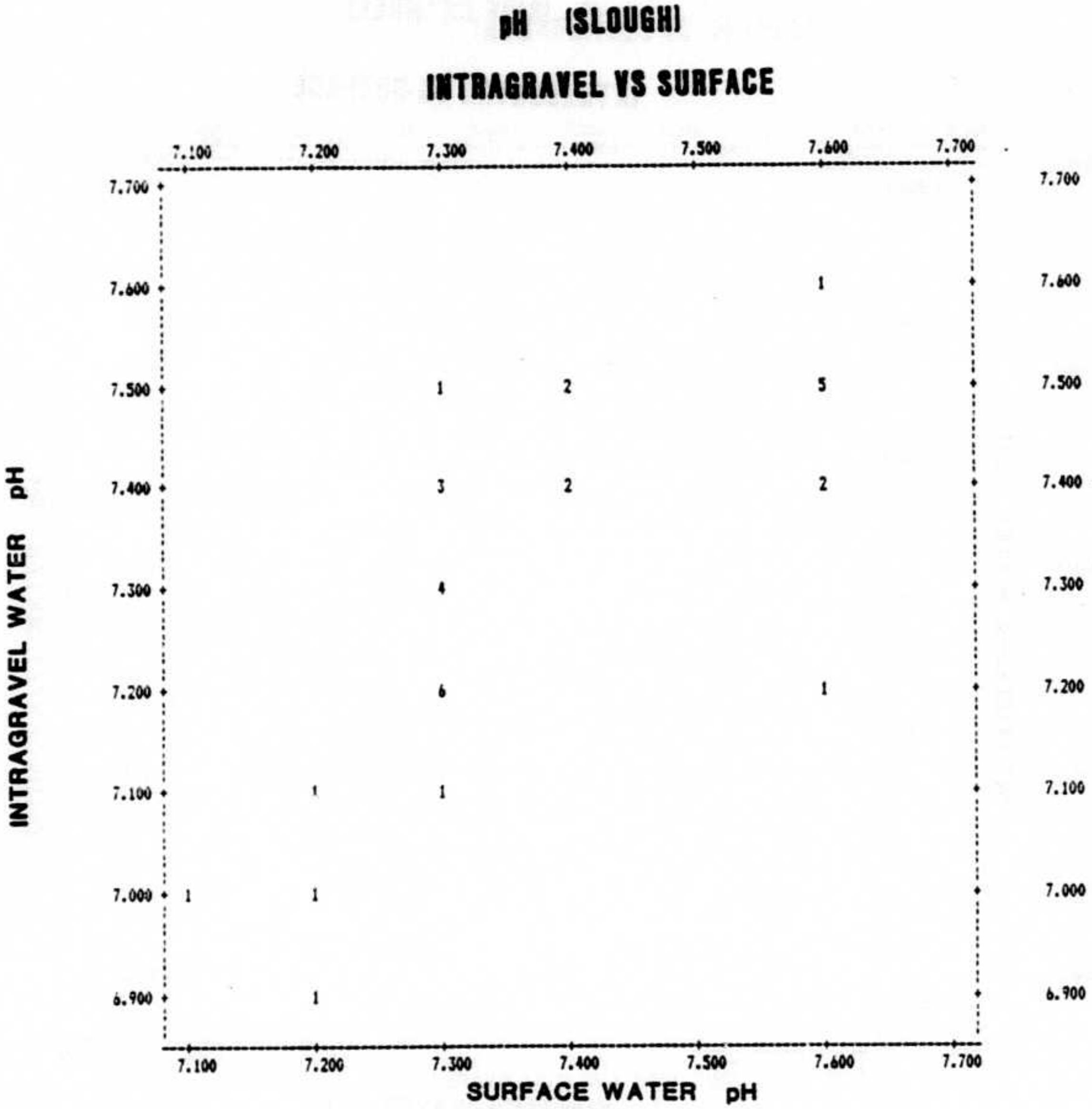

Figure 37. Relationship between intragravel and surface water pH levels measured within slough habitat of the middle Susitna River, Alaska.

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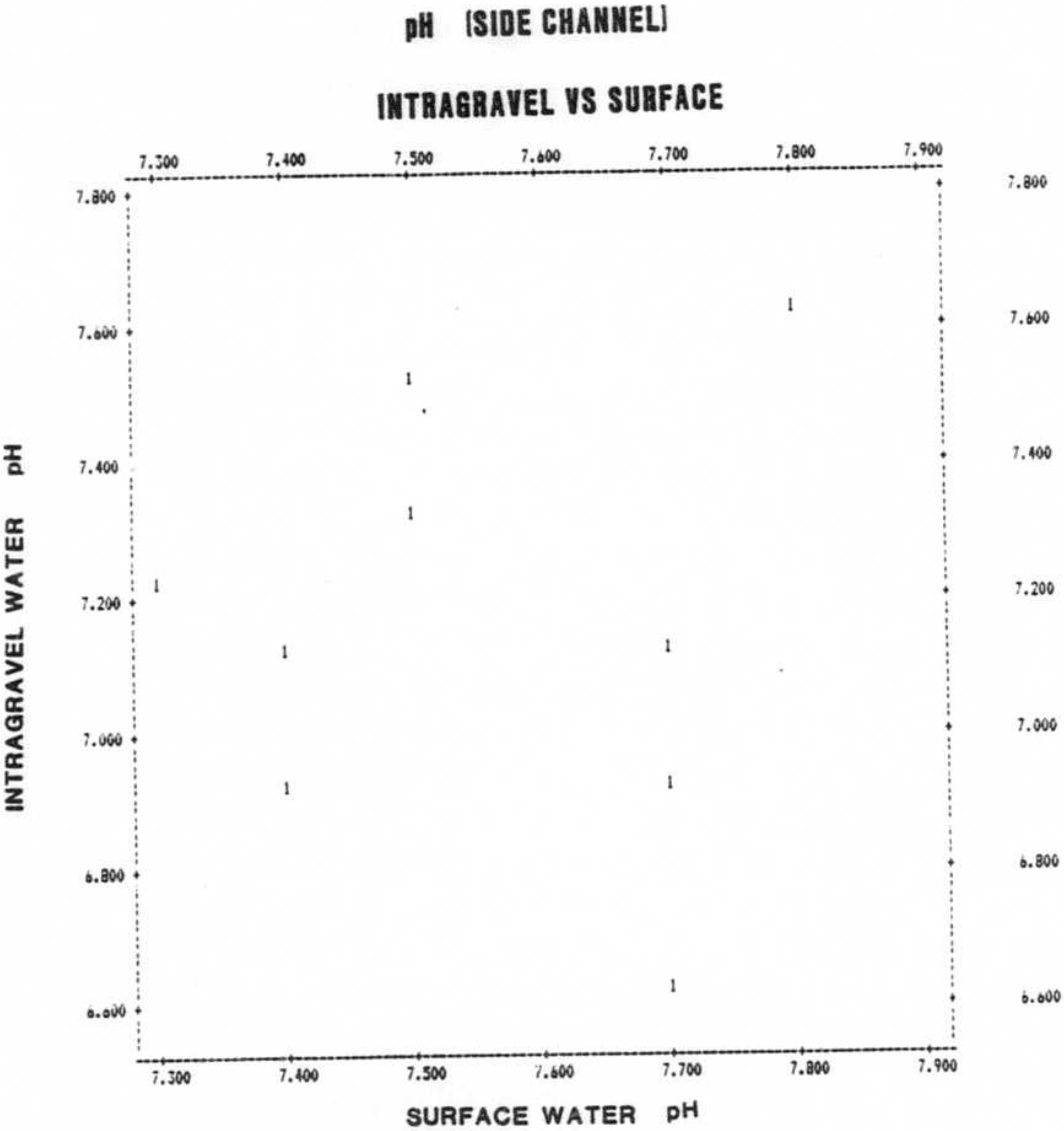

Figure 38. Relationship between intragravel and surface water pH levels measured within side channel habitat of the middle Susitna River, Alaska.

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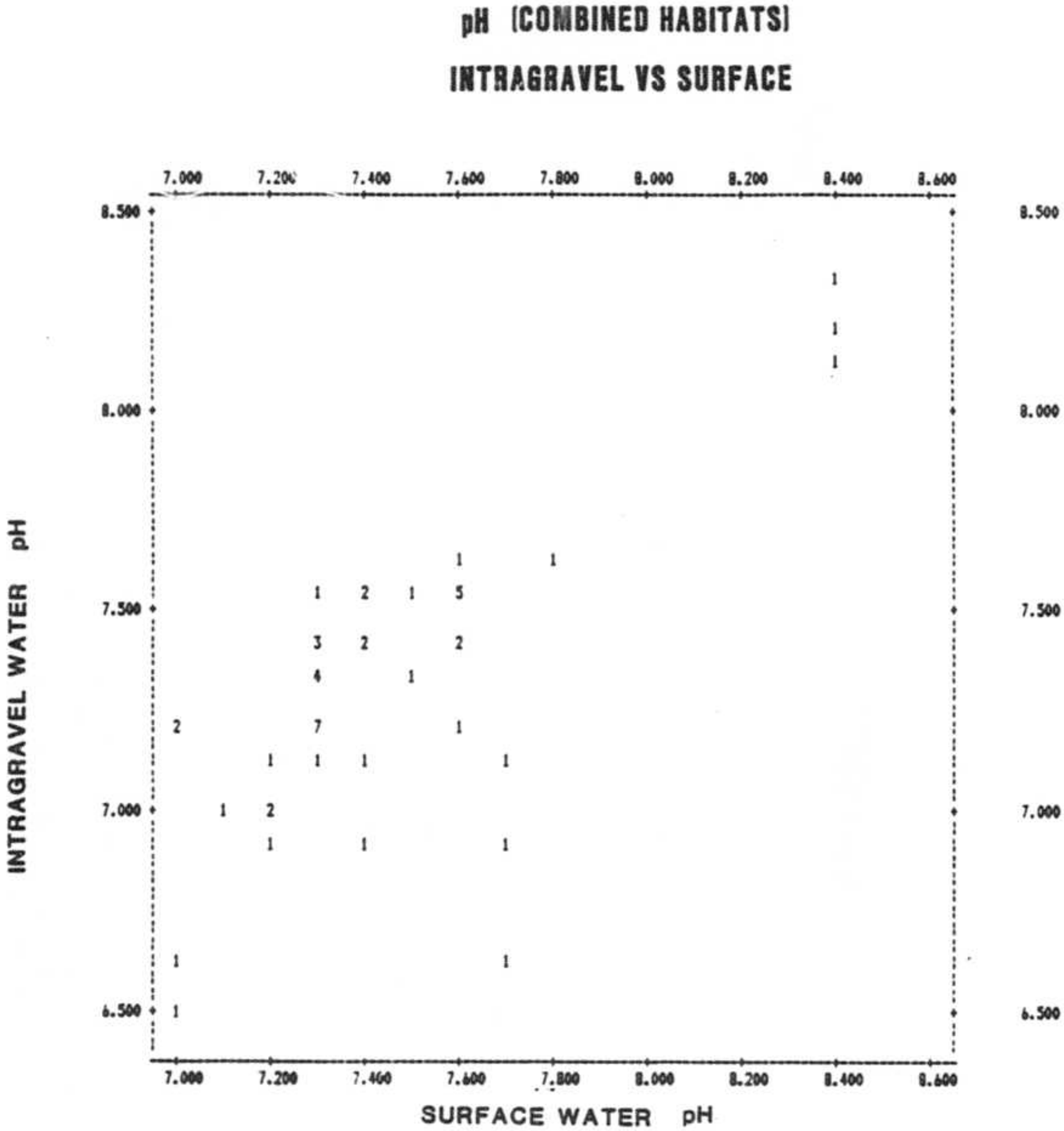

Figure 39. Relationship between intragravel and surface water pH levels measured within slough and side channel habitats of the middle Susitna River, Alaska.

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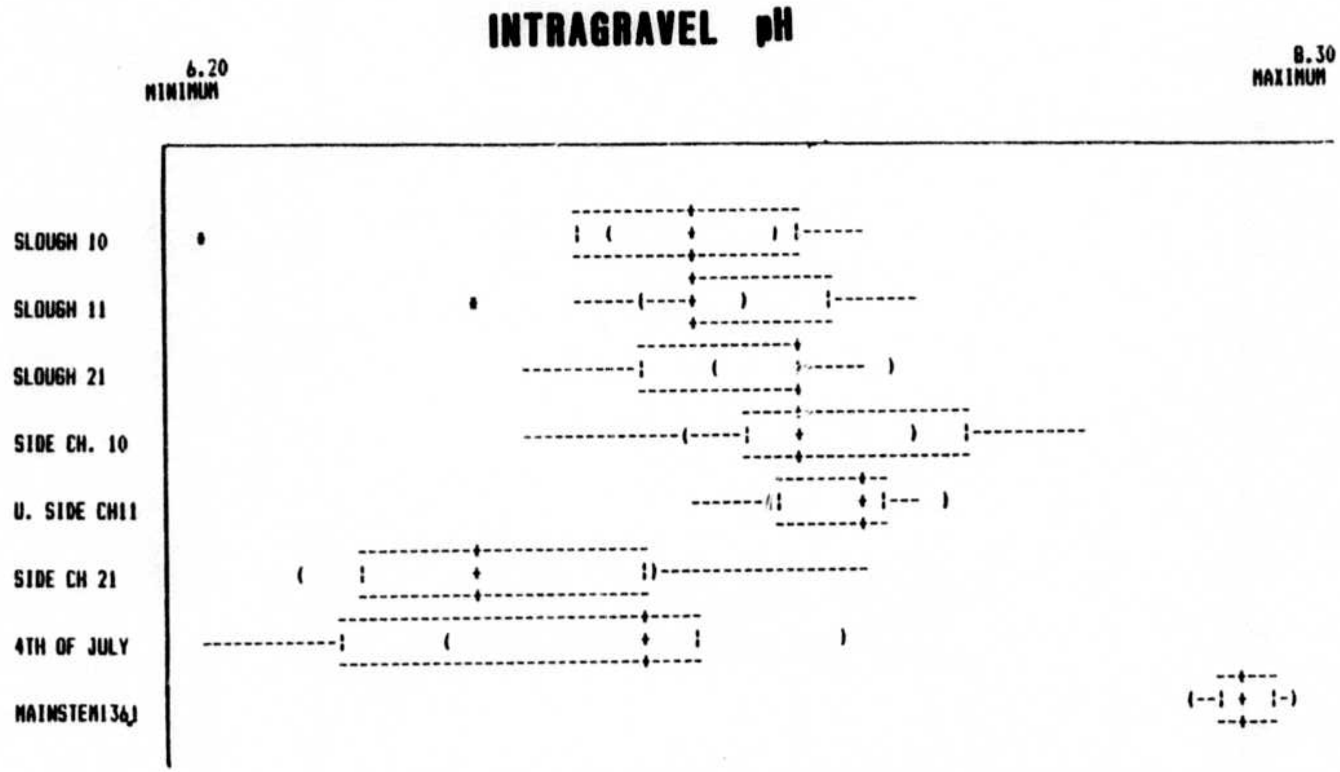

Figure 40. Summary, by study site, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

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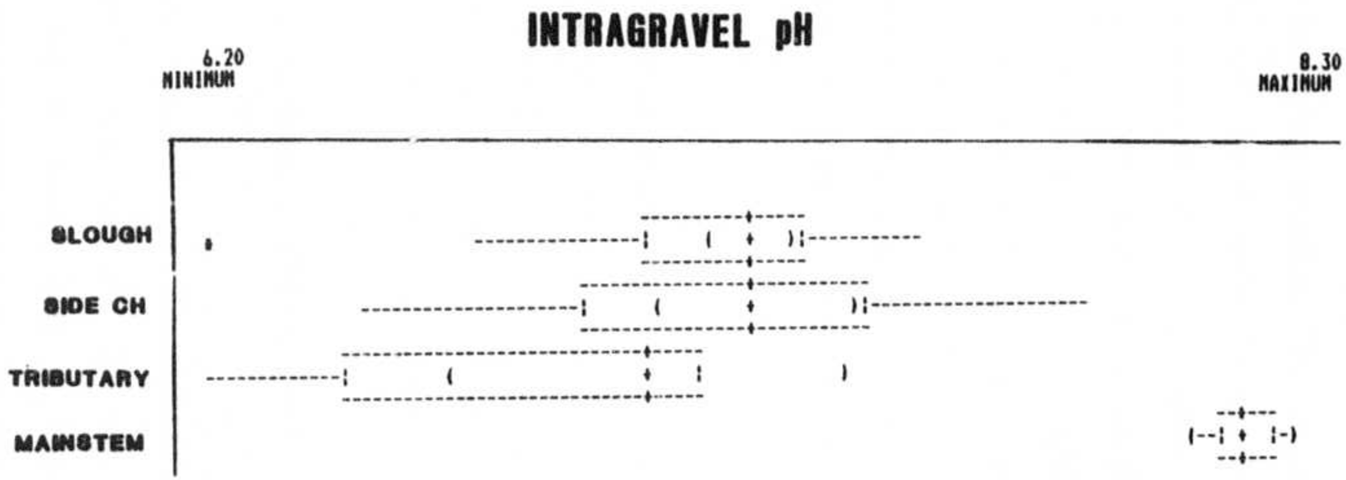

Figure 41. Summary, by habitat type, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

3.1.2.3 Conductivity

The relationships between conductivity levels (umhos/cm) measured in surface and intragravel water in slough, side channel, and tributary habitat study sites are presented in Figures 42-44, respectively. In addition, these data, grouped for all study sites, are presented in Figure 45. In general, the relationship between conductivity levels measured in surface and intragravel water appears to be well defined for all habitat types except sloughs. In sloughs, the relationship appears to be well defined for surface water conductivity values greater than approximately 200 umhos/cm, but is less defined for values below this point (Figure 42), indicating that surface water conductivities in these habitat types are influenced by intragravel conductivities to a higher degree in areas of upwelling.

A summary of intragravel conductivity data (umhos/cm) is presented by study site and habitat type in Figures 46 and 47, respectively. In general, slough, side channel, and mainstem habitat study sites have relatively equal conductivity ranges in contrast to the tributary habitat study site, which exhibits distinctly lower conductivity values.

3.2 Comparison of Embryo Survival at Study Sites and Habitat Types

The percent survival of chum salmon embryos and alevins is presented for individual study sites in Figure 48. Two estimates of survival are provided for subsites A and B in Side Channel 21 and Slough 11. Subsites A and B in Side Channel 21 are distinguished from each other

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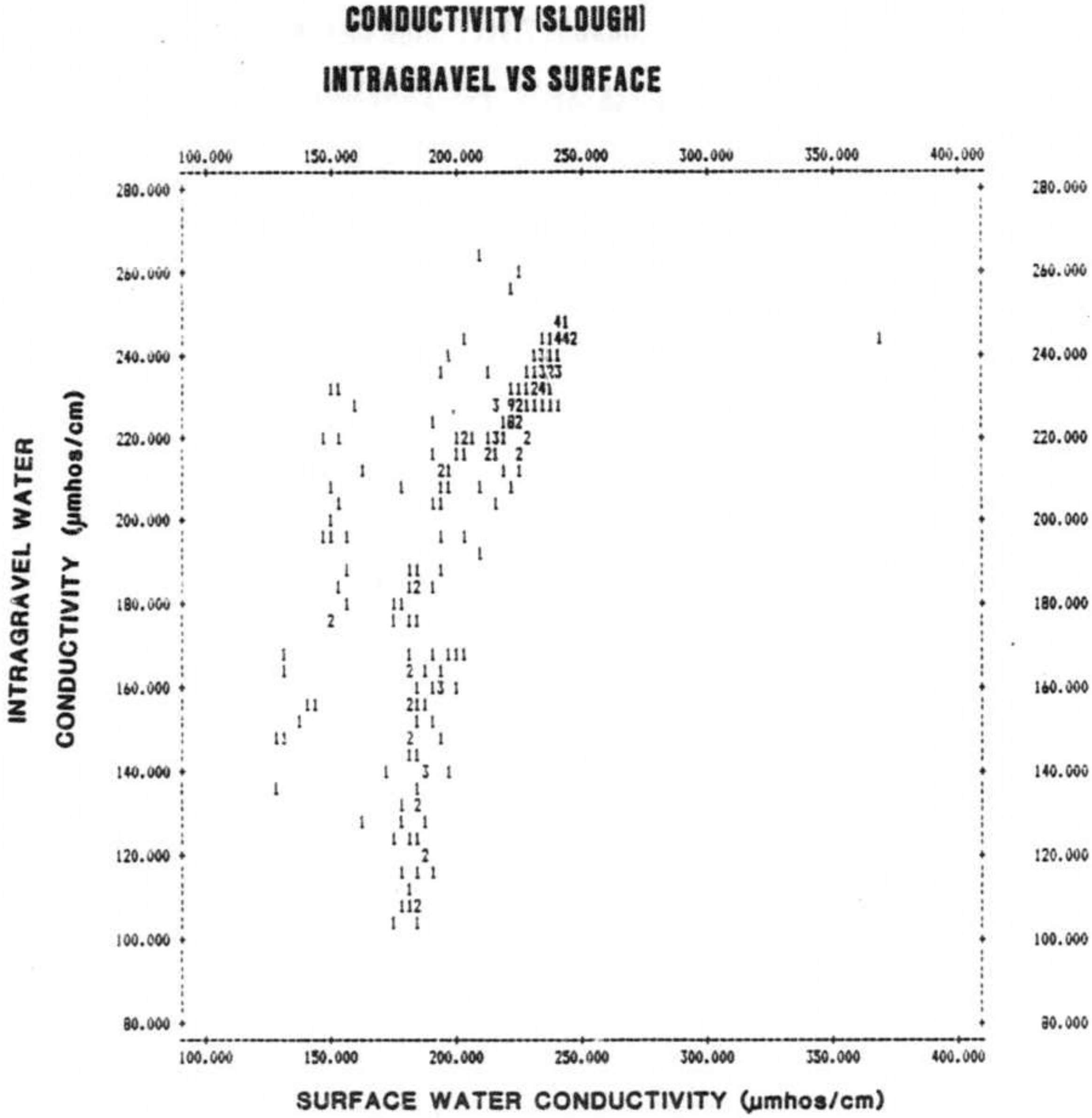

Figure 42. Relationship between intragravel and surface water conductivity levels (µmhos/cm) measured within slough habitat of the middle Susitna River, Alaska.

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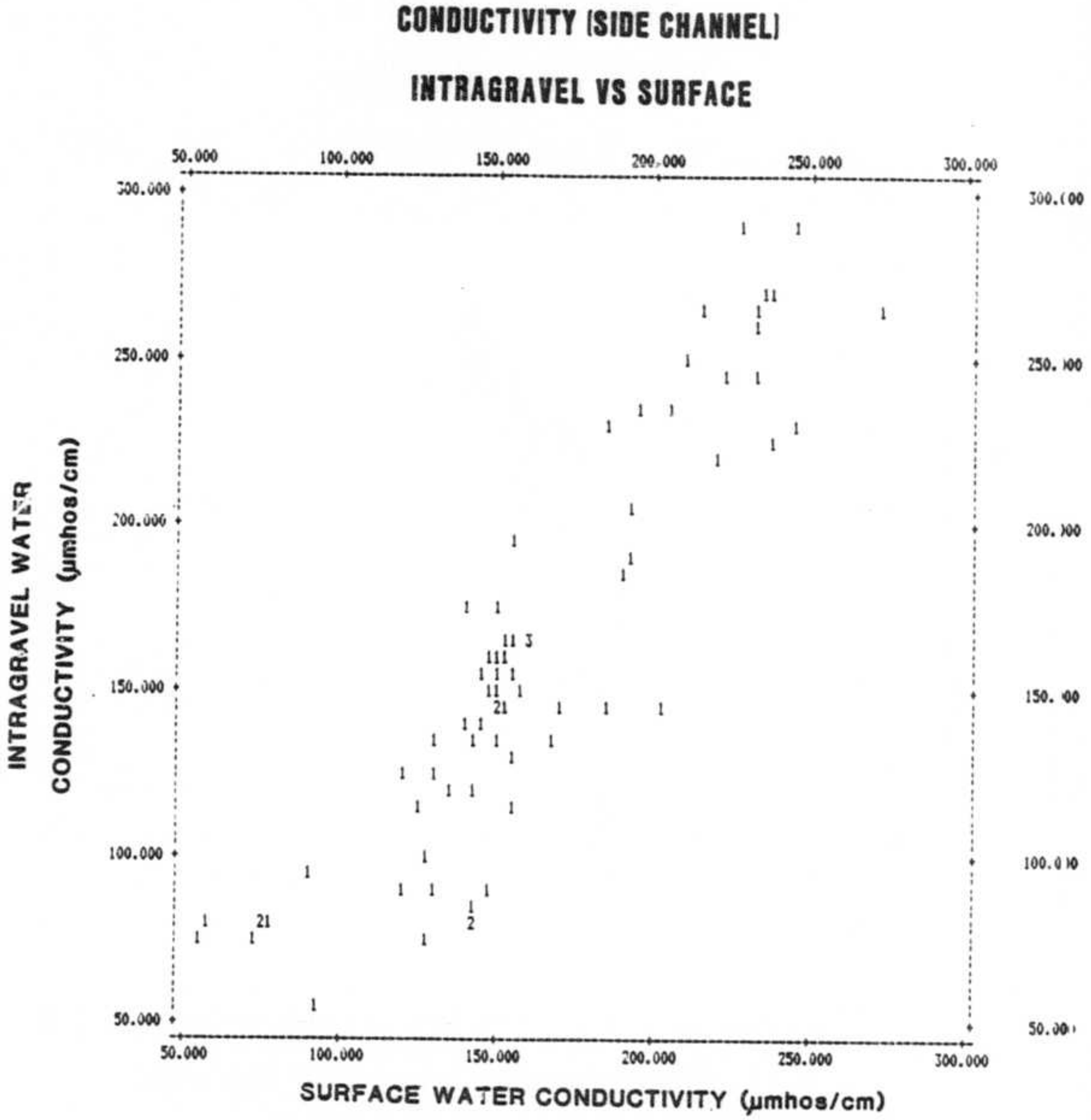

Figure 43. Relationship between intragravel and surface water conductivity levels (µmhos/cm) measured within side channel habitat of the middle Susitna River, Alaska.

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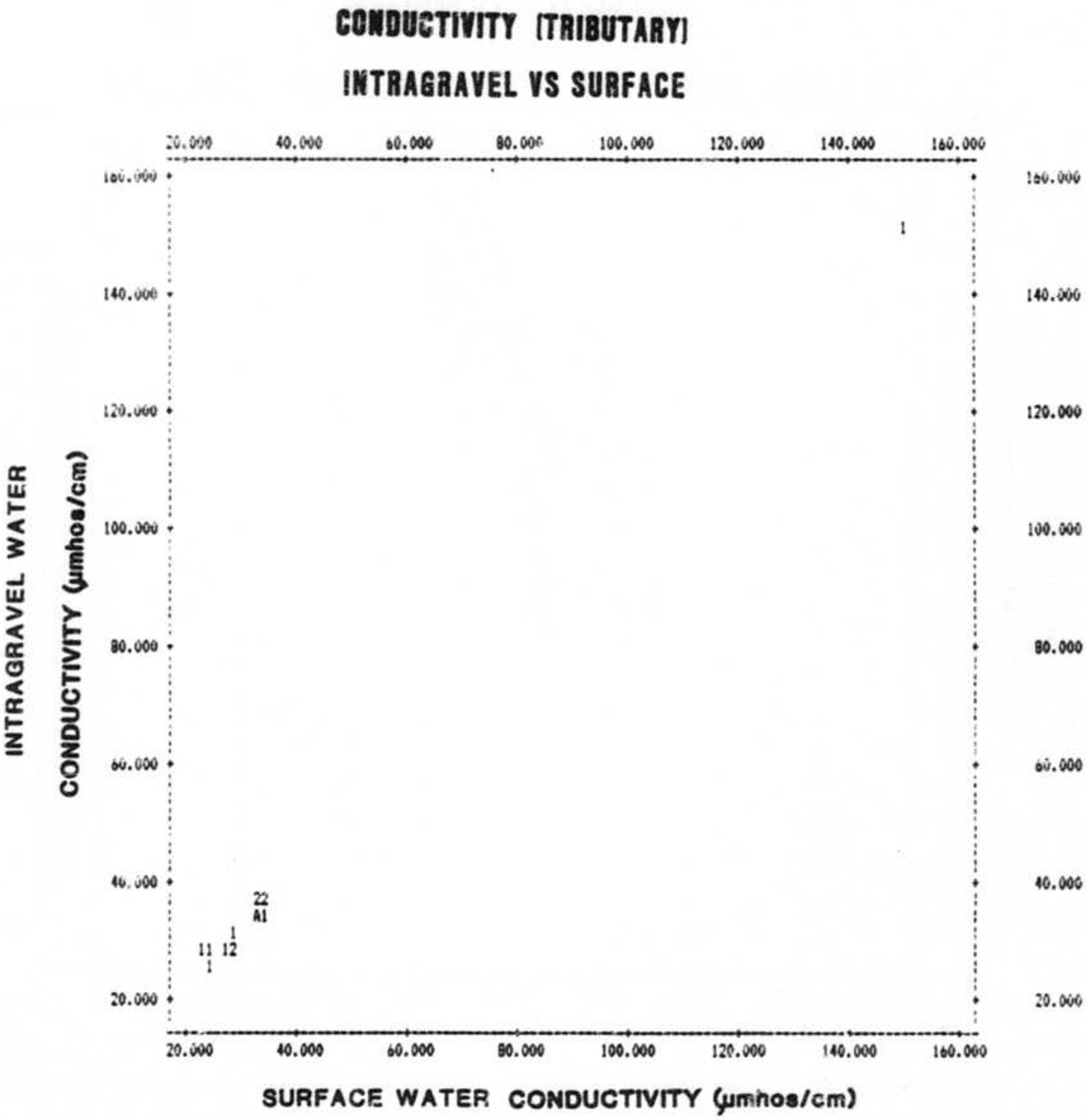

Figure 44. Relationship between intragravel and surface water conductivity levels (µmhos/cm) measured within tributary habitat of the middle Susitna River, Alaska.

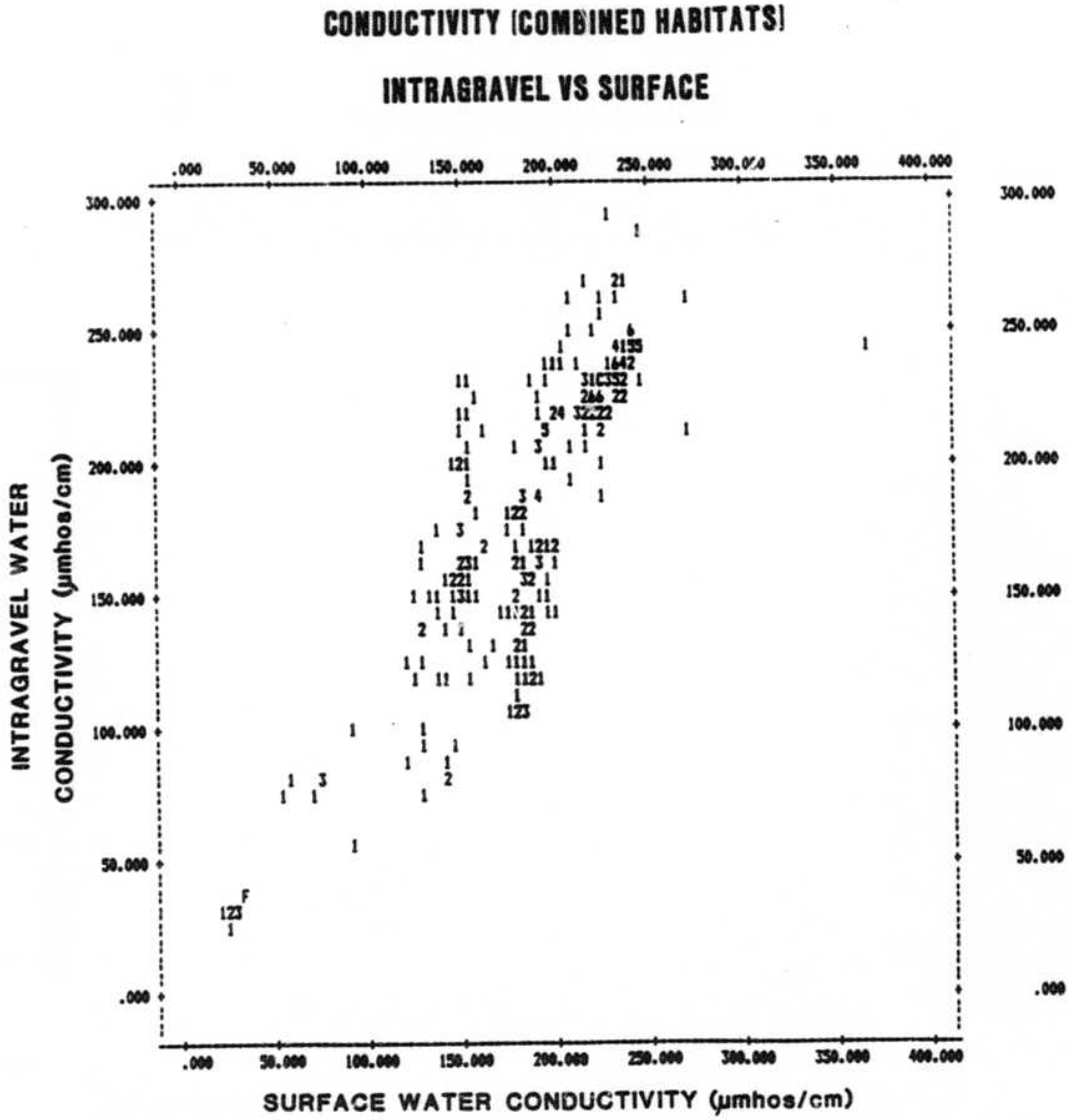

Figure 45. Relationship between intragravel and surface water conductivity levels (µmhos/cm) measured within slough, side channel, and tributary habitats of the middle Susitna River, Alaska.

INTRAGRAVEL CONDUCTIVITY (μmhos/cm)

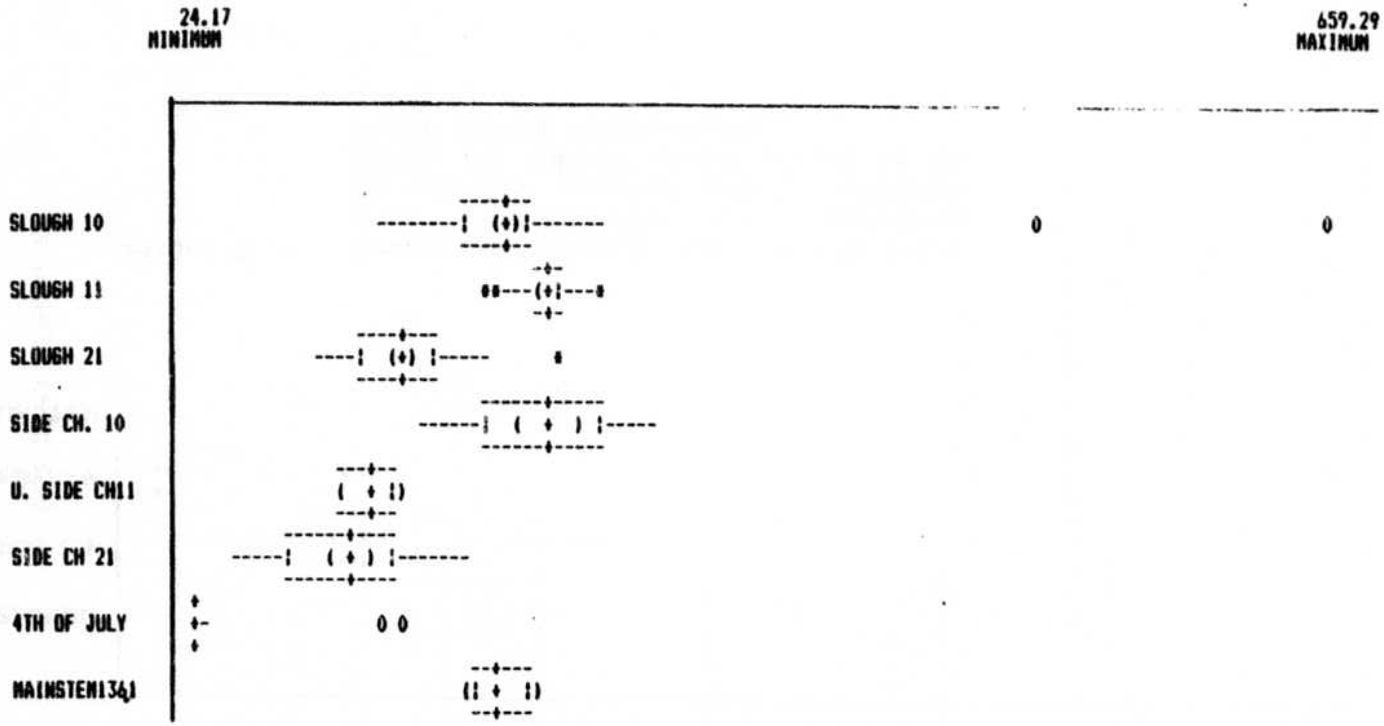

Figure 46. Summary, by study site, of the intragravel conductivity data (μmhos/cm) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

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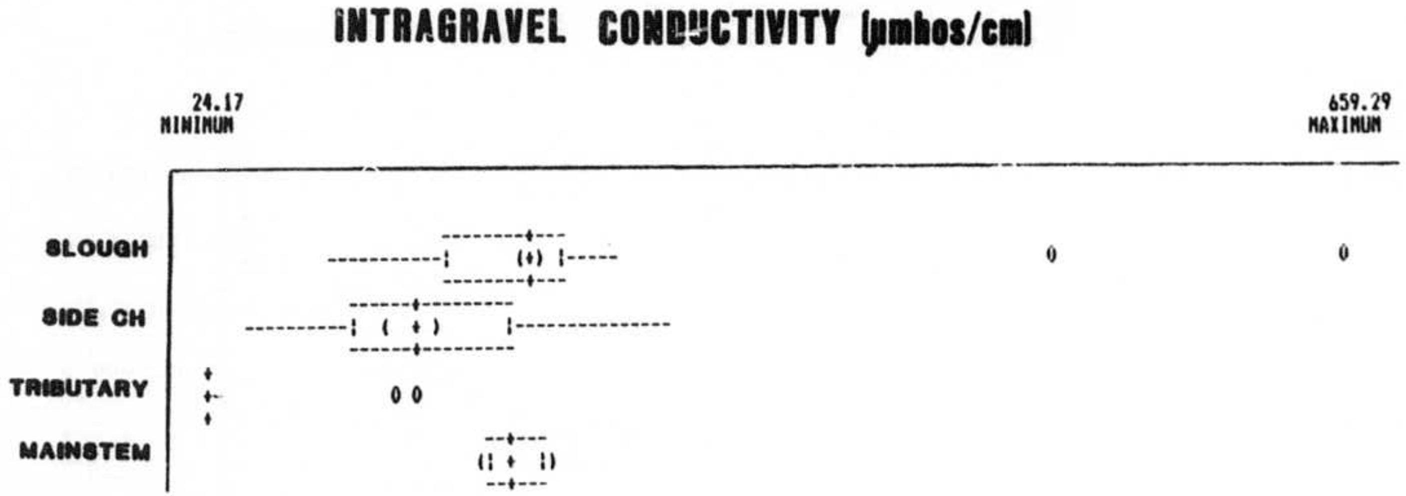

Figure 47. Summary, by habitat type, of the intragravel conductivity data (µmhos/cm) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska.

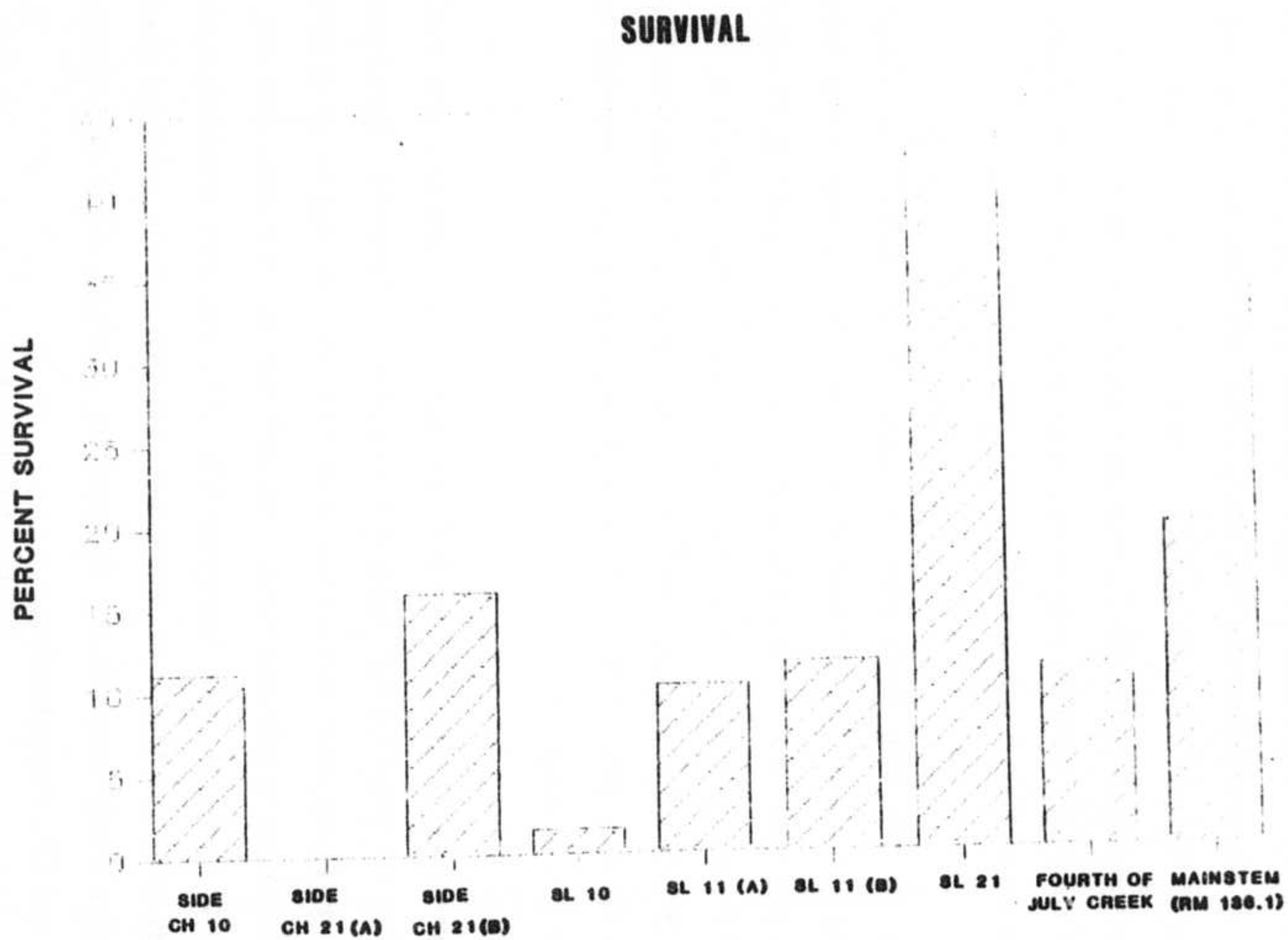

Figure 48. Comparison of survival (%) of salmon embryos removed from artificial redds in study sites in the middle Susitna River, Alaska.

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because Whitlock-Vibert Boxes containing fertilized eggs were installed at two different times (approximately two weeks apart). Subsites A and B in Slough 11 are distinguished from each other because they represent two distinct areas within this slough, and contained embryos originating from different parental sources. Subsite A contained embryos from salmon captured in Slough 11, whereas subsite B served as a control site and contained embryos originating from salmon captured at Slough 21, Side Channel 21, Fourth of July Creek, and Slough 11.

Four of the nine study sites evaluated [Side Channel 10, Slough 11 (Subsites A and B), and Fourth of July Creek] had survival rates between 10% and 15%. Of the remaining sites, two [Side Channel 21 (Subsite A) and Slough 10] had survival rates lower than 10% and three [Side Channel 21 (Subsite B), Mainstem (RM 136.1), and Slough 21] had survival rates greater than 15%. Survival of embryos in Slough 21 was more than twice that in any other site.

Differences in percent survival of chum salmon embryos and alevins within different habitat types are presented in Figure 49. Equal weight was given to each study site, regardless of the number of Whitlock-Vibert Boxes within each site. The mainstem habitat study site had the highest survival rate (approximately 19%) and the tributary habitat study site the lowest (approximately 9%) with slough and side channel habitat study sites having intermediate survival rates (approximately 17% and 11%, respectively).

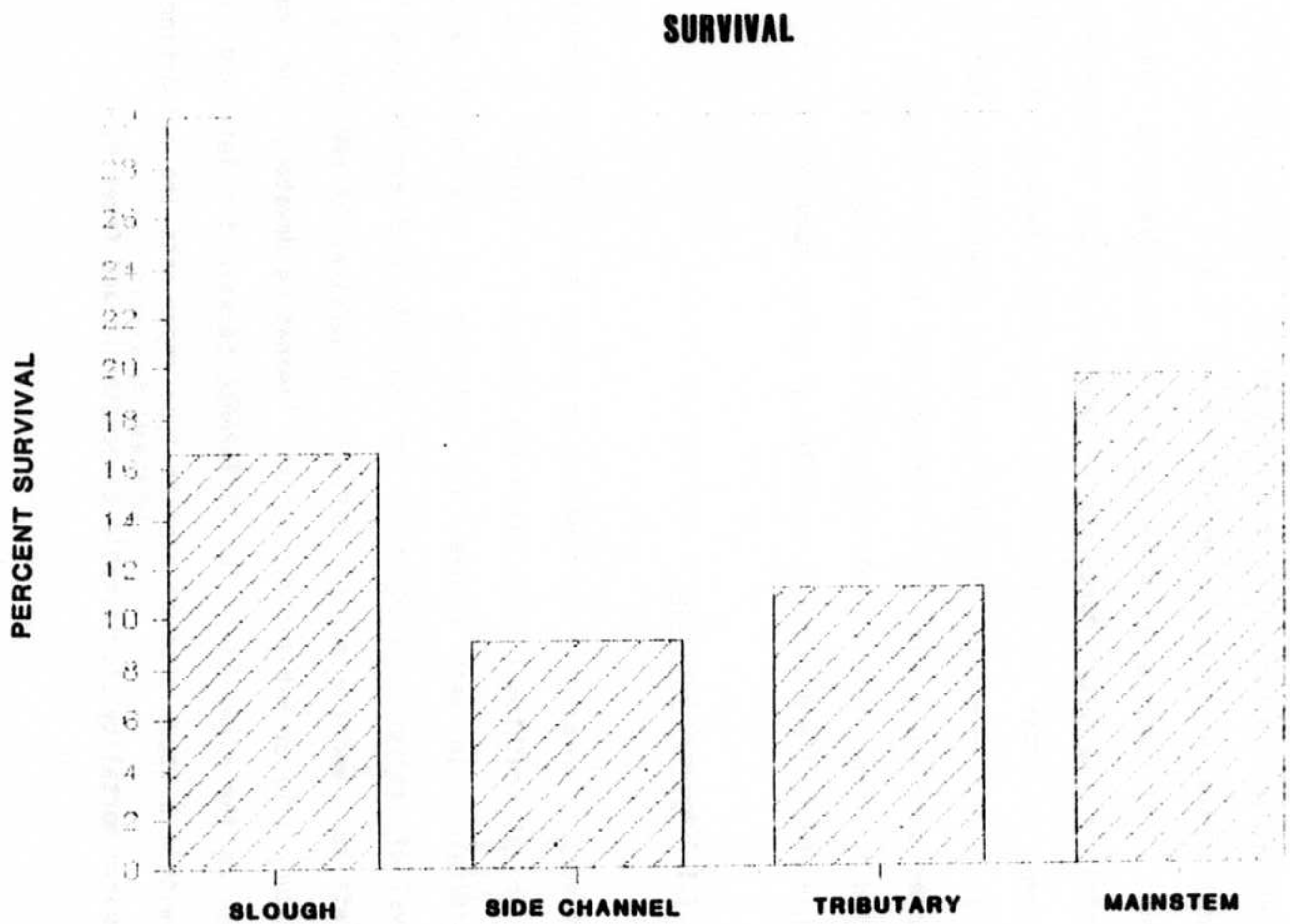

Figure 49. Comparison of survival (%) of salmon embryos removed from artificial redds in various habitat types in the middle Susitna River, Alaska.

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3.3 Effects of Physical, Chemical and Biological Habitat Variables on Embryo Survival at Study Sites and Habitat Types

A quantitative evaluation of the effects of selected physical and chemical habitat variables on embryo survival in this study was limited in that large numbers of WVBs at study sites dewatered and froze resulting in the total mortality of embryos in the affected WVB's. Therefore, in order to discern the differences between effects on survival due to dewatering and freezing versus other habitat variables, dewatered and frozen WVBs were removed from further analyses. This resulted in vastly reduced embryo survival data to analyze the effects of other physical and chemical variables on embryo survival.

3.3.1 Physical Variables

The effects of dewatering and freezing on embryo survival within habitat types and at individual study sites are depicted in Figures 50 and 51, respectively. In each figure, the estimate of the total percent survival of embryos in study sites and habitat types are presented as the left bar, and the percent estimate of survival of embryos at the same study site or habitat type after eliminating dewatered and frozen samples as the right bar. The difference between the left and right bars within a study site or habitat type represents the proportion of the embryo mortality attributable to dewatering and freezing.

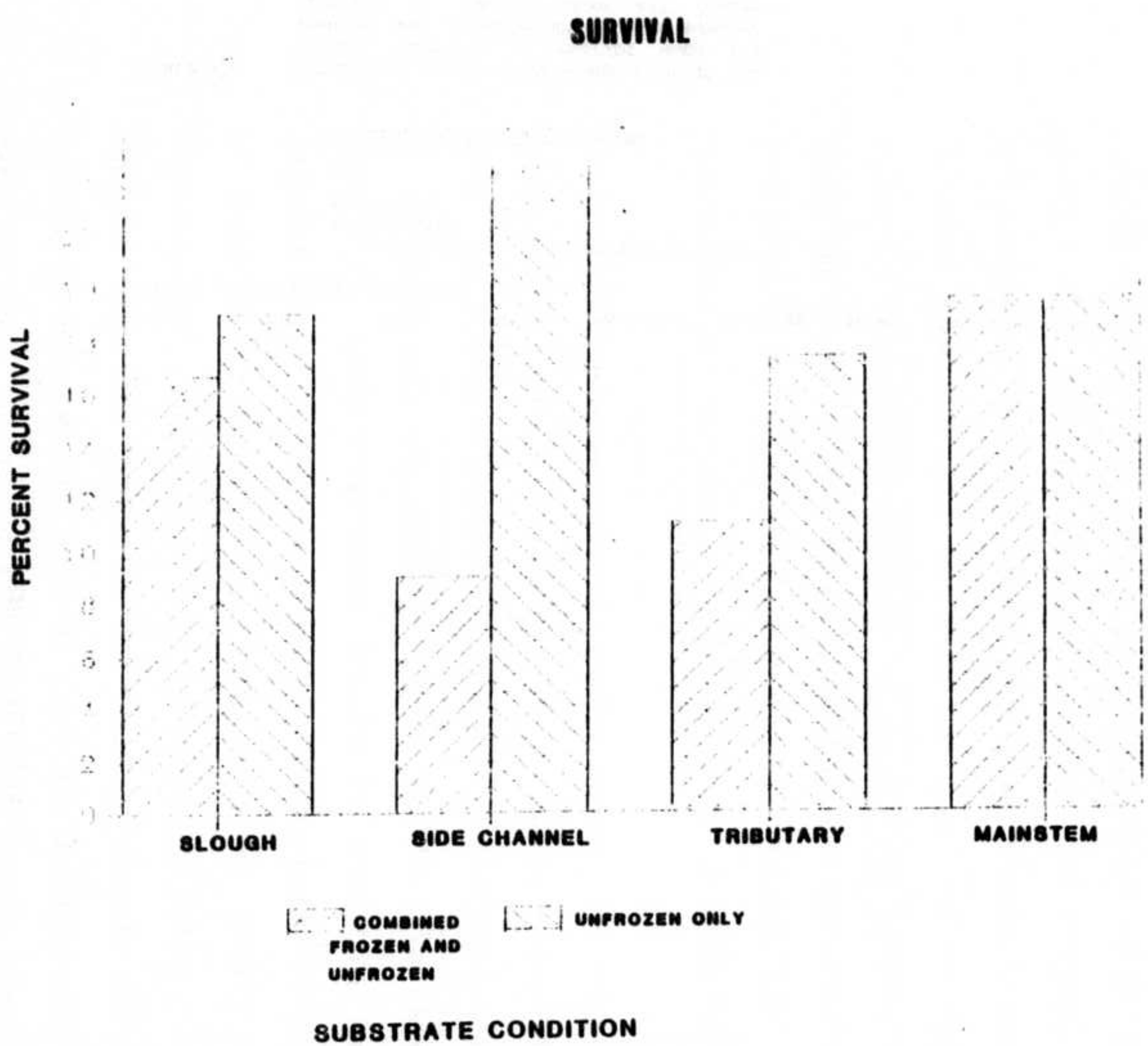

Figure 50. Comparison within each habitat type of the percent survival of embryos when all samples are considered to the percent survival of embryos when all frozen samples are removed from consideration: middle Susitna River, Alaska.

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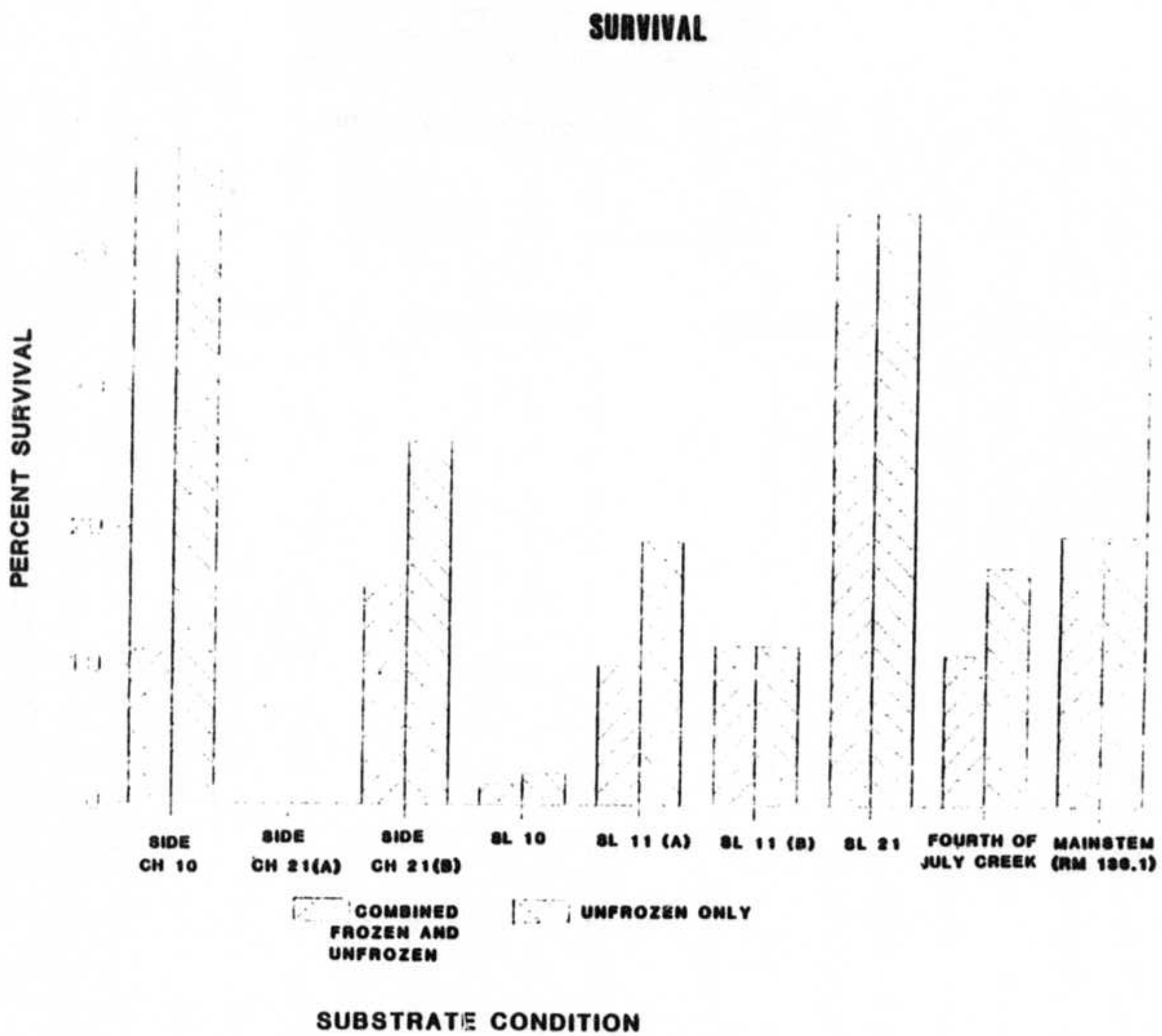

Figure 51. Comparison within each study site of the percent survival of embryos when all samples are considered to the percent survival of embryos when all frozen samples are removed from consideration: middle Susitna River, Alaska.

The data in Figure 50 show that when dewatered and frozen samples are taken into account, survival is highest in mainstem and slough habitat study sites and lowest in tributary and side channel study sites. However, when dewatered and frozen samples are excluded from the survival estimates, side channel habitat study sites exhibit the highest survival rates followed by mainstem, slough, and tributary habitats. Such differences are likely attributable to differences in the degree of influence upwelling has in each of these habitat types. The relatively high survival indicated for the mainstem habitat, however, is likely due to the consideration that was taken to specifically select a site which would not dewater and freeze (see section 3.2). For this reason, care must be taken in the interpretation of these numbers.

The data also show the variable nature dewatering and freezing effects had on embryo survival at individual study sites of a particular habitat type. The absence of any bars associated with Side Channel 21 (Subsite A) indicates that all implanted embryos at this site dewatered and froze. The study sites least affected by dewatering and freezing included Sloughs 11 (Subsite B) and 21, and Mainstem (RM 136.1). Lack of freezing in the two slough study sites was largely due to the influence of upwelling which served to keep the sites buffered from both dewatering and freezing, whereas the absence of freezing at Mainstem (RM 136.1) is likely due to the consideration that care was taken to specifically avoid this problem during the site selection process. Of the remaining study sites, Side Channels 10 and 21 (Subsite B) were influenced most by dewatering and freezing, followed in decreasing order by Slough 11 (Subsite A), Fourth of July Creek, and Slough 10.

The relationship between survival of embryos and the percent of fine substrates (< 0.08 in. diameter) within WVBs removed from artificial redds within study sites is presented in Figure 52. In general, embryo survival decreases with increasing amounts of fines in the substrate. The four points in the upper right hand portion of this figure which appear to contradict this trend were located in areas of major concentration of upwelling. It is likely that the relatively high survival at these sites, which have high concentrations of fines, is related to the relatively higher rate of intragravel flow at these sites.

The relationship between survival of embryos and intragravel water temperature at study sites is presented in Figure 53. Based on the data presented in this figure, there does not appear to be a relationship between these variables.

3.3.2 Chemical Variables

The relationships between selected water quality variables (dissolved oxygen, pH, and conductivity) and embryo survival at all study sites are depicted in Figures 54-56. Plots in each figure are derived from data presented in Appendices C, D, and F. In cases where multiple measurements of water quality variables were present, the lowest measured value was used in the plot.

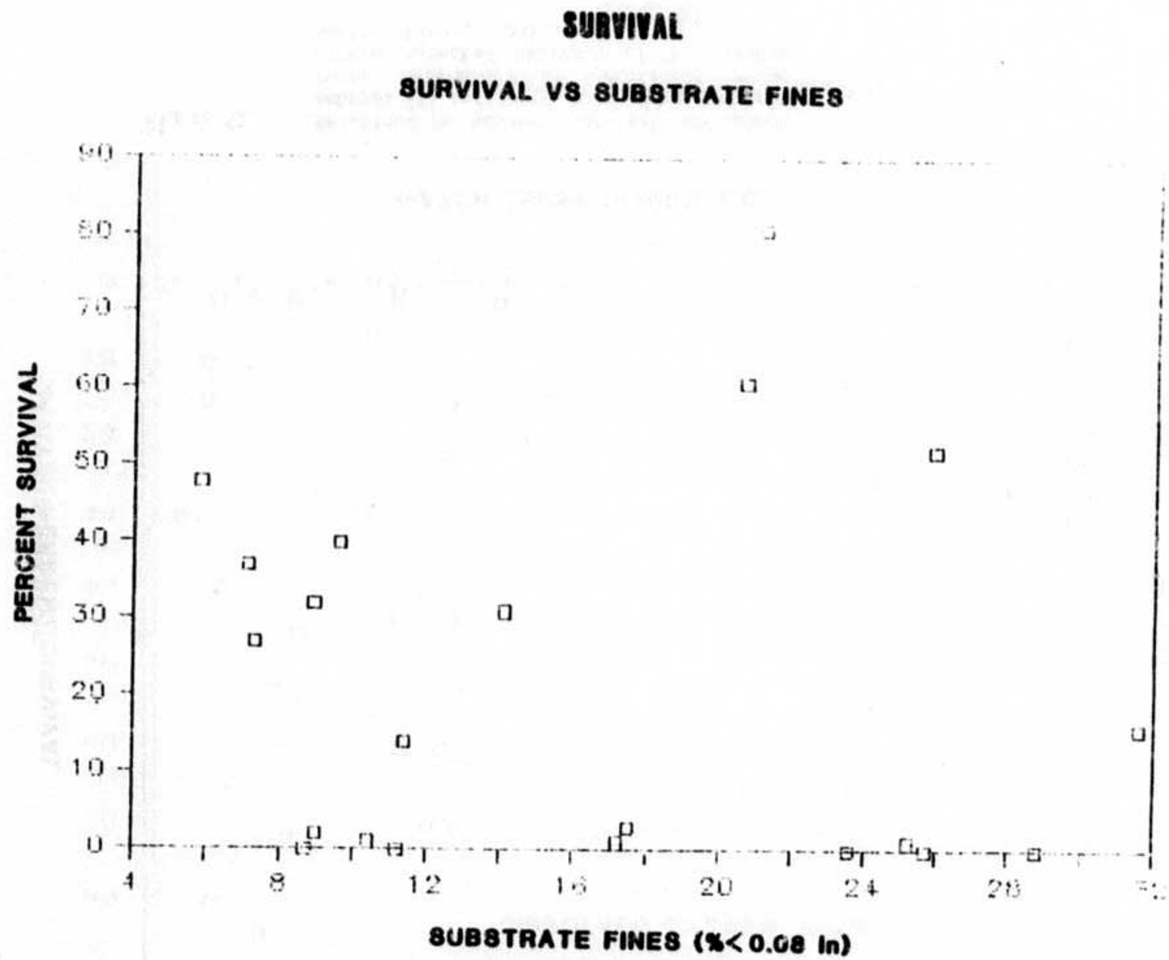

Figure 52. Relationship between survival of salmon embryos (%) and the percent of fine substrate (< 0.08 in. diameter) within Whitlock-Vibert Boxes removed from artificial redds within selected habitats of the middle Susitna River, Alaska.

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SURVIVAL

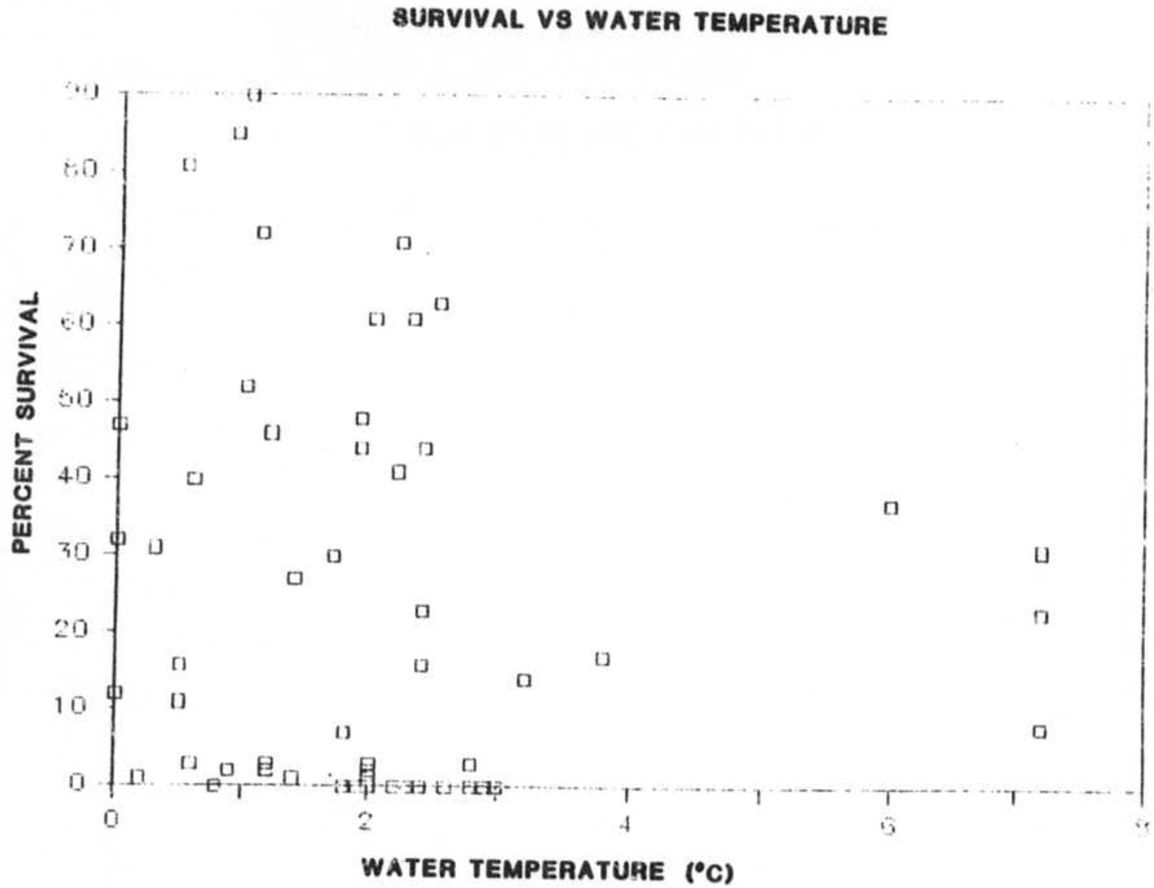

Figure 53. Relationship between survival of salmon embryos (%) and intragravel water temperatures determined at artificial redds within selected habitats of the middle Susitna River, Alaska.

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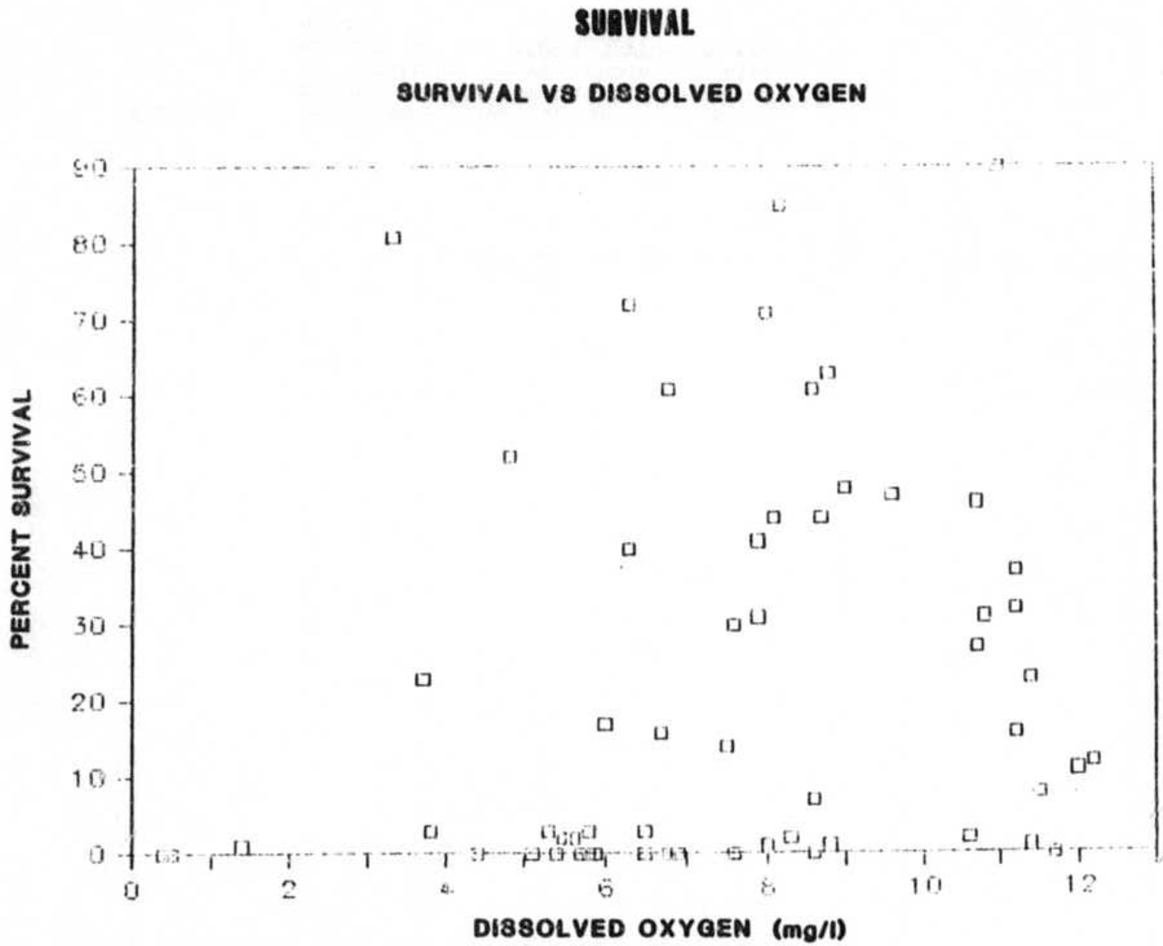

Figure 54. Relationship between survival of salmon embryos and concentration of intragravel dissolved oxygen (mg/l) measured at artificial redds within selected habitats of the middle Susitna River, Alaska.

SURVIVAL

SURVIVAL VS pH

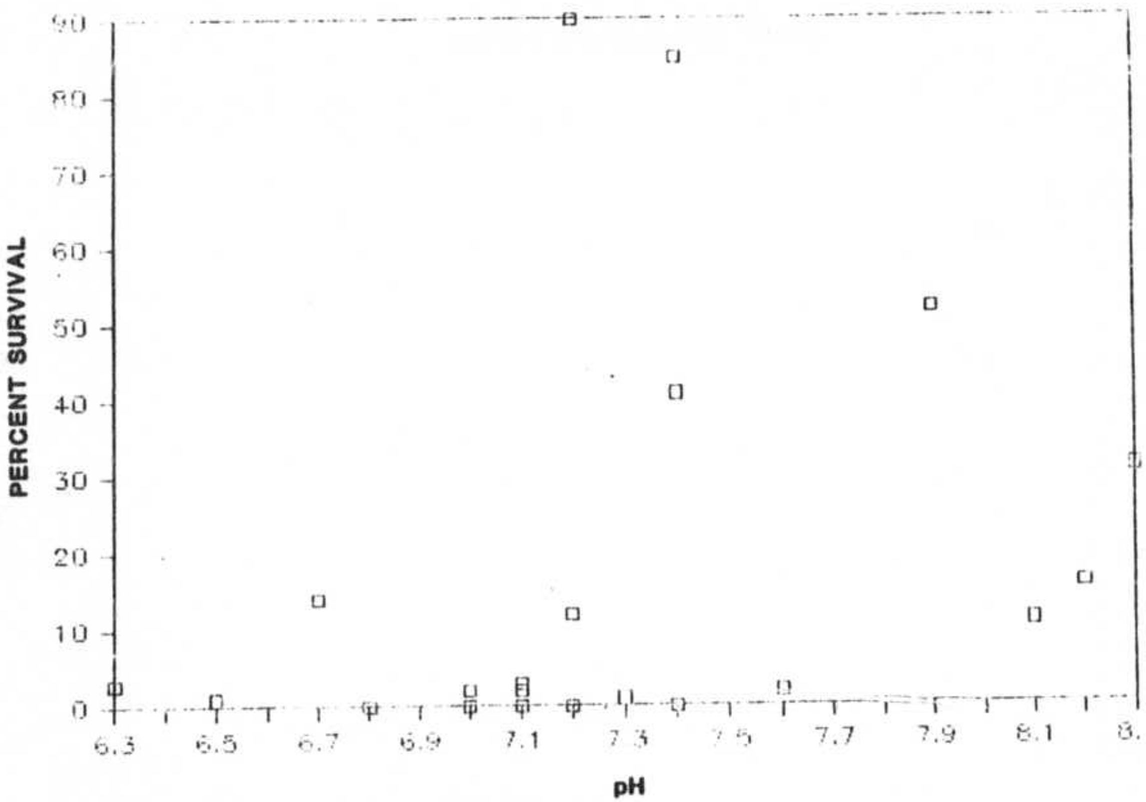

Figure 55. Relationship between survival of salmon embryos and intragravel pH level measured at artificial redds within selected habitats of the middle Susitna River, Alaska.

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SURVIVAL

SURVIVAL VS CONDUCTIVITY

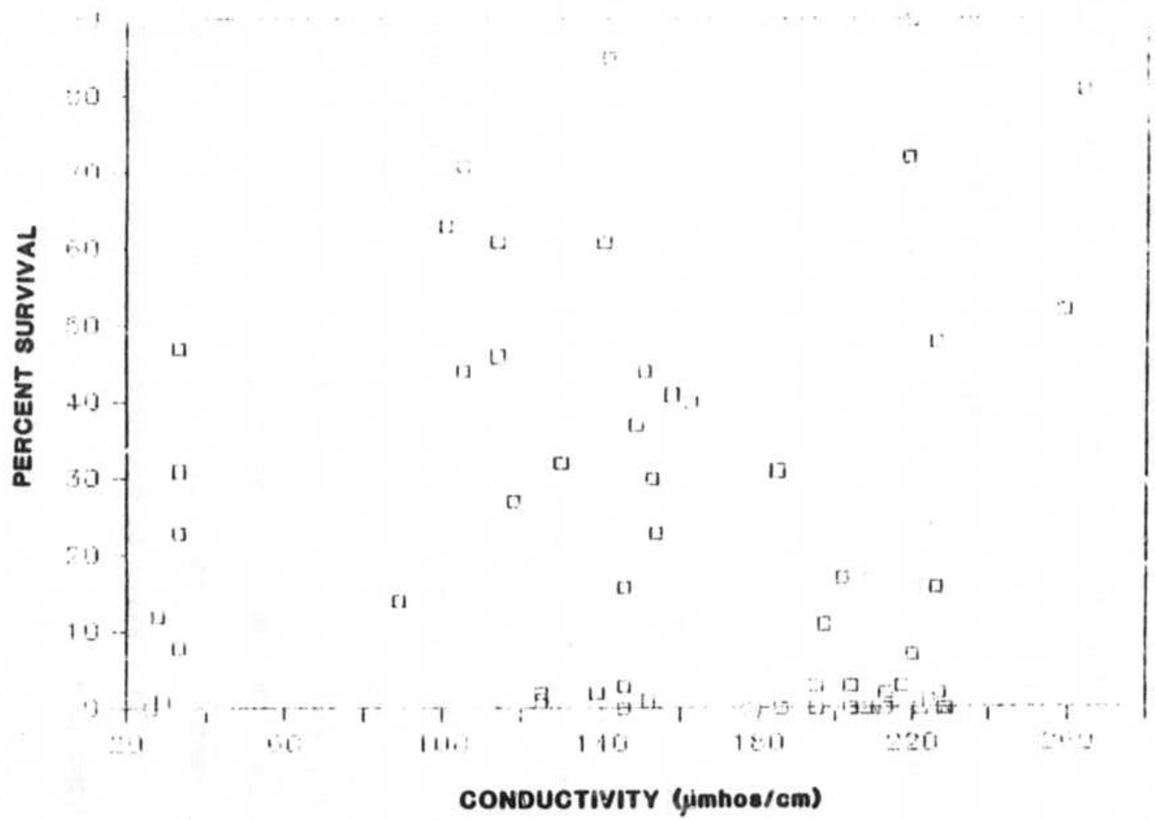

Figure 56. Relationship between survival of salmon embryos and intragravel conductivity level (umhos/cm) measured at artificial redds within selected habitats of the middle Susitna River, Alaska.

There was no strong relationship identified between any of the water quality variables evaluated and the percent survival of embryos. For this reason, plots grouping study sites by habitat types were not constructed. In the plot for conductivity, a relationship was not evident. The plot for pH contained too few data points to enable any firm conclusions to be made. However, the absence of high survival values at low pH indicates the pH may affect embryo survival at low pH values. A similar pattern is evident with dissolved oxygen. No strong relationship is evident between embryo survival and dissolved oxygen (DO) at DO concentrations greater than 2.5 mg/l, whereas at DO concentrations less than 2.5 mg/l survival rates are near zero.

3.3.3 Biological Variables

3.3.3.1 Development of Chum Salmon Embryos

Data on development of chum salmon embryos are presented in Appendix F. Data is reported for eight study sites: Fourth of July Creek, Sloughs 10, 11, and 21, Side Channels 10, 21 and Upper Side Channel 11, and Mainstem (RM 136.1). The majority of these data were taken from experimental development sites established by ADF&G. However, a limited amount of data was also obtained from natrual redds and these data are included here.

3.3.3.2 Flatworms

In this study, a relatively large proportion of embryos were missing at the time when Whitlock-Vibert Boxes (WVBs) were removed from the substrate. The number of embryos missing from each WVB is reported in Table F-2 of Appendix F. The mean number of embryos missing at each site is expressed as a percent of the total for each site as follows: Fourth of July Creek (22%); Side Channel 10 (1.2%); Slough 10 (35%); Mainstem (RM 136.1) (9%); Upper Side Channel 11 (80%); Slough 11, Subsite A (32%); Slough 11, Subsite B (73%); Side Channel 21, Subsite A (1%); Side Channel 21, Subsite B (8%), and Slough 21 (9%).

At the time when embryos were removed from WVBs, it was observed that a large number of flatworms were usually present in boxes where large numbers of embryos were missing. Therefore, the relative number of flatworms present in each WVB was ranked at the time of removal and an experiment was initiated to attempt to determine the rate that embryos disappeared from WVBs once they were dead (Table 3).

Table 3. Condition of dead embryos at time of removal from substrate.

Location	Sample Number	Date	No. Embryos Recovered	Fungal Condition	Flatworm Abundance Rank
Slough 11	1	28 March 1984	10 of 10	low	3
Side Channel 10	1	30 March 1984	10 of 10	none	4
Slough 11	2	10 April 1984	8 of 10	medium	3
Side Channel 10	2	13 April 1984	10 of 10	low	4
Slough 11	3	17 April 1984	10 of 10	high	2
Side Channel 10	3	17 April 1984	10 of 10	low	4
Slough 11	4	2 May 1984	10 of 10	high	3
Side Channel 10	4	2 May 1984	10 of 10	low	4

* All Whitlock-Vibert Boxes containing embryos were installed in the streambed on 2 March 1984.

4.0 DISCUSSION

A discussion of the physical and chemical water quality of incubation habitat conditions for chum salmon and their relationships to mainstem discharge is presented in this chapter.

Incubating embryos require a supply of water which is of suitable temperature, contains an ample concentration of dissolved oxygen, and is free of toxic substances. In addition, the supply of water which reaches the embryo must be replenished at a rate sufficient to remove metabolic waste products. Therefore, the successful development of embryos is directly related to both the physical and chemical characteristics of the source of water surrounding the developing embryos.

4.1 Physical, Chemical, and Biological Variables Associated with Chum Salmon Incubation Habitats

4.1.1 Upwelling

In the middle Susitna River, adult chum salmon have been observed to favor areas containing upwelling as sites for spawning (ADF&G 1983b: Appendix C, D; Vincent-Lang et al. 1984). This characteristic of chum salmon has also been reported in other areas (e.g., Kogl 1965; Lister et al. 1980) indicating that upwelling is a favorable environmental factor affecting the survival and development of embryos. The importance of upwelling to incubating embryos is due to several reasons:

1) it reduces the likelihood of dewatering and freezing;

2) it provides a relatively stable incubation environment (especially temperature) for developing embryos less affected by variations in local climatic conditions; and

3) it increases the rate of exchange of water over the developing embryos which would enhance replenishment of dissolved oxygen and removal of metabolic wastes.

Upwelling and surface water are the two primary sources which contribute water to the intragravel environment (McNeil 1966). The extent to which each source contributes to the intragravel water at the location of a particular redd depends upon a variety of other factors, which in the Susitna River are poorly understood.

Interchange between the surface and intragravel water is highly variable, depending on the turbulence of water in the stream and physical characteristics of the streambed (Vaux 1968). Factors which enhance high levels of dissolved oxygen in intragravel environments include high streamflow, high streambed gradient, uneven streambed surface and coarse bed material (McNeil 1969). In addition to these factors, the composition of the substrate also affects the rate of exchange of water to incubating embryos based on the permeability of the substrate (Pollard 1955).

In general, slough habitats in the middle Susitna River are affected by upwelling to a greater extent than are other habitat types. Upwelling areas are also evident in side channel, tributary, and mainstem habitats, but to a lesser and more variable extent. As a result, the beneficial effects of reduced dewatering and freezing of substrate, relatively stable intragravel temperatures and increased intragravel flow is afforded to slough habitats over other habitat types.

4.1.2 Dewatering and Freezing

Freezing of artificial redds associated with surface dewatering was determined to be the most important factor contributing to the high mortality of chum salmon embryos in this study. Because it was observed that the substrate in the streambed of almost all dewatered surface areas of sloughs could soon freeze in sloughs lacking an upwelling water source, the effects of surface dewatering in areas lacking upwelling were considered synonymous with the freezing of substrate in this study. The potential effects of surface dewatering and associated freezing conditions of substrate are included here because it is likely that the influence of dewatering and freezing of habitat without an upwelling water source may be of greater significance under post-project conditions if mainstem river stage fluctuates appreciably in response to power demands.

Surface water fluctuations which affect the presence or absence and rate of upwelling will also be of significance. Dewatering of the intragravel water environment of a salmon redd results in significant changes in the incubation environment within which embryos develop (Reiser and White 1981a, b; Neitzel and Becker 1983; Neitzel et al. 1984). Two primary effects of these changes are the direct exposure of the embryos to desiccation of respiratory structures and to increased temperature fluctuations, especially freezing (Neitzel and Becker 1983).

The effects of desiccation on embryo survival varies with the stage of embryonic development (Becker et al. 1982). Experimental studies indicate that incubating embryos are more tolerant of dewatering than alevins primarily because of the differences in their respective means of respiration (Neitzel and Becker 1983). Alevin respiration involves delicate gill structures that cannot function without a water medium; whereas, respiration of pre-hatched embryos involves a transfer of oxygen across the egg membrane, requiring only that the membrane remain moist.

The deleterious effects of temperature fluctuations, especially freezing, to embryos resulting from dewatered salmon redds in the middle Susitna River involve cold and/or freezing temperatures during the ice covered season. Cold, but nonfreezing temperature conditions can contribute to embryo mortality in dewatered redds if the conditions occur prior to the embryonic stage when the blastopore closes (this is further discussed in Section 4.1.3). In comparison, freezing temperatures cause embryo mortality regardless of the stage of embryonic development prior to hatching. The ability of alevins to transport themselves through gravels to favorable environments reduces the effects of localized freezing on them relative to unhatched embryos.

Although the length of time from initial dewatering of an area which is lacking upwelling to the time when the substrate was frozen to a depth of 8-10 in. (depth at which WVBs were placed) is unknown, it undoubtedly depends upon site specific features such as ambient air temperatures, proximity to thermal influences of upwelling, and the depth of the snow cover.

The areas which were observed as being the most susceptible to high embryo mortality due to surface dewatering and freezing in this study were those most directly influenced by mainstem stage at the time when fish were actively spawning (mid August - mid September) and lacking an upwelling water source. These areas include the mouths of both sloughs and tributaries, major portions of side channels, and peripheral areas in the mainstem river. In each of these areas, water levels were significantly higher during the spawning period when fertilized eggs were deposited. However, as the mainstem discharge decreased to winter flows, these areas progressively became dewatered and exposed to freezing ambient temperatures. This ultimately resulted in a frozen substrate environment and the salmon embryos deposited within the dewatered redds. Areas which are thermally influenced by strong upwelling sources (e.g., mouth area of Slough 11) or dewatered areas adjacent to areas of flowing water (e.g., Side Channel 21) were protected from the winter surface dewatering and associated freezing conditions.

The effects of dewatering and freezing of embryos was clearly evident in the progression of seasonal events which occurred in Side Channel 21. Forty Whitlock-Vibert Boxes containing chum salmon embryos were initially placed in this side channel at the end of the spawning season in late August. These WVBs were buried approximately 8-10 inches in the substrate and did not include the deeper section (thalweg) of the site. At this time, the mainstem discharge was 27,000 cfs at Gold Creek and this side channel area was breached. Approximately two weeks later, the discharge in the mainstem dropped to 11,100 cfs. As a result, the side channel was no longer breached, and the local flow in this side channel was significantly reduced. The majority of the locations lacking an upwelling source where WVBs had been implanted two weeks earlier had dewatered. Therefore, twenty additional WVBs were installed in the remaining wetted area of the channel in the same manner as during the high flows. The flow continued to decrease throughout the winter but the majority of locations at which additional WVBs had been installed during the lower flows remained wetted. All the embryos in the forty WVBs which were initially installed during the earlier period (August 27) died due to dewatering and freezing whereas, in the latter set of 20 WVBs installed after the water level dropped, 11 WVBs contained living embryos at the time of sampling. This example clearly indicates that the water level at the time when fish are spawning is important in determining the amount of wetted habitat available for spawning, but that the effective area in which embryos survive depends upon either water levels which occur after the spawning period or the presence and persistence of upwelling.

4.1.3 Substrate

The composition of substrate is of critical importance in determining the survival of embryos to emergence. The substrate provides the physical structure within which embryos are placed and thus is the medium through which the intragravel water must flow in order to supply embryos with necessary oxygen and to transport waste metabolites away from the embryos. These two processes occur simultaneously and are both dependent upon a variety of physical factors such as the composition of the substrate, gradient of the streambed, rate of exchange between surface and intragravel water, relative importance of upwelling, depth and permeability of the gravel, and the configuration of the surface of the streambed (Vaux 1962). Although each of these factors may influence the rate of intragravel flow to various degrees, the composition of the substrate has received the most attention by researchers. In general, researchers agree that the amount of fine substrate particles in the spawning gravels is a primary factor affecting mortality of embryos and alevins. High levels of fines reduce the intragravel flow which may result in oxygen deprivation and toxic build-up of waste metabolites. However, despite the general consensus that "large" amounts of "fine sediments" are detrimental to survival of salmon embryos, there is much variation in the literature in defining what constitutes "large" amounts and what particle sizes should be regarded as "fines". Table 4 presents a summary of these literature on this topic.

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Table 4. Documented effects of sediment and substrate size on salmonids, based on a review of selected literature.

Species	Method of Substrate Collection/Evaluation	Substrate/Sediment Size Classes	Results	Reference
Chum	Vibert Boxes	large gravel (5.1-10.2 cm) small gravel (1.0-3.8 cm)	Survival to emergence was less in small gravel (31%) than large gravel (100%); lower survival due to entrapment of alevins, siltation-not reduced DO levels	Dill and Northcote (1970a)
	not specified	sand	Survival to emergence significantly decreased with increasing proportions of fine sands	Koski (1975)[a]
	acetone/dry ice frozen core technique; 5 sieves, percent of total weight	5 classes: <0.074- 9.55 mm	Survival to fry stage was negatively affected by fines accumulated from logging	Scrivener and Brownlee (1980)
Autumn Chum, Pink	grab samples, scoop/screens	11 size classes: 0.05 mm - >100 mm	Survival of embryos decreased with increasing proportions of sand	Rukhlov (1969)
Pink	McNeil cores/coefficient of permeability	<0.833 mm	Potential fry production of a spawning bed was directly related to its permeability (high permeability when substrate contains < 5% materials < 0.833 mm) fry emergence was inversely related to percent substrate 0.833 mm	McNeil and Ahnell (1964)
	hydraulic sampler for embryo and alevin collection	not specified - upper to lower creek (3 stream segments)	Highest survival to hatching, largest embryos and alevins were produced in coarsest gravels studied (with high intregravel water DO)	Wells and McNeil (1970
Sockeye	sieves	<3.36 mm	Survival of embryos was negatively affected by silt deposition on spawning gravels and fine substrate (< 10% survival when particles < 3.36 mm comprised ≥ 35% of substrate) gravel uniformity reduced embryo survival, except possibly coarse gravels	Cooper (1965)
	sieves/percent of total sample (weight)	15 size classes: < 0.0074 - < 10.16 cm	Survival of eyed embryos was negatively correlated with percentage of particles finer than 0.336 cm	Pyper[b]
Chinook	low (test) vs. high (control) flows	< 0.84 mm	Survival from "green" embryo to hatching was most negatively affected during low flows at the sediment level 7% < 0.84 mm	Reiser and White (1981)
	particle size distribution plotted on log - probability paper (linear)	0.42 - 9.5 mm	Survival of eyed embryos to emergence was negatively correlated with percentage of particles 0.85 to 9.50 mm in diameter, predicted embryo survival approached "0" when > 20% of substrate was < 0.85 mm	Tappel and Bjornn (1983)
Chinook, Steelhead	not specified	<6.4 mm	Recommended limit < 25% fines for successful incubation of salmonid embryos.	Reiser and Bjornn (1979)

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Table 4 (Continued).

Species	Method of Substrate Collection/Evaluation	Substrate/Sediment Size Classes	Results	Reference
Coho	not specified	< 0.85 mm	Survival of embryos to emergence rapidly decreased when % fine substrate (< 0.85 mm) exceeded natural levels of 10%.	Cederholm et al. (1981)
	concentric ring traps/ Vibert Boxes	large gravel (3.2-6.3 cm) small gravel (1.9-3.2 cm)	Emergence was significantly delayed by small gravel; downward movement was more marked in large than small gravel	Dill and Northcote (1970b)
	McNeil cores/sieves/nylon netting fry traps	< 0.83 mm, 1-3 mm	Success of fry emergence was inversely proportional to concentrations of sediment 1-3 mm; survival to emergence approached "0" when > 30% of substrate was < 0.83 mm	Hall and Lantz (1969)
	sieves/percent of total sample (volume)	< 3.327 mm	Survival to emergence decreased with increasing proportions of fines in gravel, particularly fines < 3.327 mm	Koski (1966)
	not specified	4 size classes: 0.64 - 3.18 cm	Emergence was restricted at gravel sizes smaller than 1.91 - 2.54 cm	Phillips (1964)[a]
	experimental troughs simulating hatching conditions	8 sand and gravel mixtures	Survival to emergence was inversely related to quantity of sand and fines (< 3.3 mm); premature fry emergence was related to higher concentrations of fines	Phillips et al. (1975)
	not specified	< 0.85 mm	Survival from embryo deposition to emergence decreased in natural redds when > 20% of substrate was < 0.85 mm	Tagart (1976)[a]
Steelhead	not specified	4 size classes: 0.64 - 3.18 cm	Emergence was restricted at gravel sizes < 1.27 - 1.91 cm; only smaller steelhead emerged from 0.64 - 1.27 cm gravel	Phillips (1964)[a]
	particle size distributions plotted on log-probability paper (linear)	0.42 - 9.50 mm	Survival of embryos to emergence was negatively correlated with percent substrate < 0.85 mm	Tappel and Bjornn (1983)

[a] cited in literature review paper by Iwamoto et al. (1978)

[b] cited in paper by Cooper (1965)

In addition to restricting intragravel flow of water, large amounts of fines also restrict fry from emerging from the substrate (e.g., Dill and Northcote 1970a). Fine substrate reduces the interstitial spaces between larger substrate particles. This results in entrapment of emerging fry, especially large fry (Wells and McNeil 1970).

The composition of substrate varies extensively between habitat types in the middle Susitna River. This characteristic is evident in the preparation of fines reported for McNeil samples collected in each habitat type (refer to Figure 27). Based on the small number of samples collected, slough habitats contained more than twice the percent of fines as tributary and mainstem habitats (Figure 27). Side channel habitat contained intermediate amounts of fines. However, spawning salmon within each habitat type apparently succeed in selecting redd locations with substantially less fines. For example, even though slough habitats contained more than 35% fines for combined slough samples (Figure 27), the percent of fines present in chum salmon redds obtained at various sites did not exceed 16% (refer to Figure 30) in five of the six sites evaluated. (Samples from the mainstem site were not obtained at redds).

Substrate data obtained with Whitlock-Vibert Boxes revealed similar results. With the exception of four outlier points, the data represented in Figure 52 indicate that embryo survival approaches zero when fines exceed 16%. Thus, based on data obtained in this study, it appears that chum salmon typically select redd locations in areas containing less than 14% fines (< 0.08 in. diameter).

Of the four habitats evaluated, the greatest risk for adverse effects involving substrate/dissolved oxygen interactions exist for slough habitats. Slough habitats are used extensively by chum and pink salmon for spawning; yet, they contain the highest levels of fine substrates and lowest levels of intragravel dissolved oxygen. This apparent contradiction is best explained in terms of the ameliorating effects of the upwelling systems which apparently maintain an adequate flow of water through the gravels even though the DO levels are relatively low. In addition, as stated previously, the upwelling water prevents the substrate materials from dewatering and freezing. Thus, it appears that the single most important feature which maintains the integrity of the incubation habitat in sloughs (and localized areas in side channel and mainstem habitats) is upwelling. If there is an alteration in the quality or quantity of water supplied to sloughs via the upwelling system, it will undoubtedly result in alterations in the quality of the habitat for incubation of chum salmon embryos. In particular, if the quantity of water is reduced, the rate of exchange of intragravel DO may also be reduced.

4.1.4 Water Temperature

Two primary effects of water temperature on the development and/or survival of salmon embryos involve the effect of temperature on the rate of embryo metabolism and the effect of temperature as a stress factor. The water temperature of the intragravel environment in which embryos are incubated is a primary determinant of the rate of basic embryonic metabolism within the tolerance limits of a given species of fish. A rise in temperature will result in a corresponding rise in metabolic rate. This development is more rapid at higher temperatures. However, the ecological effects of an altered rate of development is varied. For example, if the average daily intragravel water temperature is increased in mainstem-affected habitats as a result of construction or operation of the proposed Susitna dams, it would undoubtedly result in a corresponding increase in the rate of development of incubating embryos in these habitats.

Another direct effect of water temperature is its role as a stress factor. Thermal stress resulting from excessively high or low temperatures may result in increased mortality of embryos. These effects are most pronounced in salmon during the period of development before the closing of the blastopore (Combs 1965; Bams 1967; Velsen 1980). For chum and sockeye salmon from the middle Susitna River, 3.4°C was reported as the temperature below which mortalities were observed to increase (Wangaard and Burger 1983). [In chum salmon, blastopore closure is complete when embryos have accumulated approximately 140 thermal units (TUs) (Combs 1965)]. For pink salmon, Bailey and Evans (1971) defined a lower threshold temperature of 4.5°C (Table 5). Below this temperature, mortality of embryos is increased.

In addition to dewatering and freezing of salmon embryos, thermal stress in incubating habitats in the middle Susitna River is likely to result from the occurrence of "overtopping" or "breaching" of the upstream end

Table 5. Observed temperature ranges for embryo/alevin life stages of Pacific salmon [(table derived from AEIDC (1984)].

Species	Reference	Location	Incubation Temperatures (°C)[a]
Chum	McNeil (1966)	Southeast Alaska	0-15.0
	Merritt & Raymond (1982)	Noatak River, Alaska	0.2-9.0
	Sano (1966)	Japan	4
	McNeil & Bailey (1975)	Southeast Alaska	4.4
	Kogl (1965)	Chena River, Alaska	0.5-4.5
	Francisco (1977)	Delta River, Alaska	0.4-6.7
	Raymond (1981)	Clear, Alaska	2.0-4.5
	ADF&G (1983c)	Susitna River, Alaska	0-7.4
	Wangaard & Burger (1983)	Laboratory	0.5-8.0
Pink	Bell (1973)		4.4-13.3
	Bailey & Evans (1971)	Southeast Alaska	4.5
	Combs & Burrows (1957)	Laboratory	0.5-5.5
	McNeil et al. (1964)	Southeast Alaska	1.0-8.0
	Godin (1980)	Laboratory	3.4-15.0
Sockeye	Bell (1973)		4.4-13.3
	Combs (1965)	Laboratory	4.5-14.3, 1.5[b]
	ADF&G (1983c)	Susitna River, Alaska	2.9-7.4
	Waangard & Burger (1983)	Laboratory	2.0-6.5
Chinook	Bell (1973)		5.0-14.4
	Combs (1965)	Laboratory	1.5[b]
	Alderdice & Velsen (1978)		2.5-16.0
Coho	Bell (1973)		4.4-13.3
	McMahon (1983)		4-14, 4-10[c]

[a] Single temperature values are lower observed thresholds.

[b] After eggs had developed to the 128-cell or early blastula stage at 5.5°C.

[c] Optimum range.

of slough and side channel habitats with cold water from the mainstem. The inundation of these habitats with water from the mainstem Susitna River will undoubtedly result in a rapid and significant reduction in the intragravel water temperature. Such an event would alter the timing of developmental processes and could be lethal to embryos if overtopping occurred before embryos have developed past the point of blastopore closure. Thus, the deleterious effects of overtopping will be greater during the early weeks of the incubation period. For example, if chum salmon eggs were fertilized on September 1, and are incubated at 4°C, closure of the blastopore would occur during the first week of October (approximately 35 days later). If overtopping occurred after the first week of October, and affected the temperature of intragravel water of a redd site, the likelihood of mortality due to thermal stress would be greatly reduced.

Temperature may also affect embryos indirectly through its influence on other variables such as dissolved oxygen. In addition to increasing the metabolic demand for oxygen by embryos, an increase in temperature reduces the saturation level of oxygen in water. Thus, there is less oxygen available and the demand is greater. Since oxygen concentrations can also affect a large variety of developmental factors (see Section 4.1.5) this relationship to water temperature could be critical, particularly in areas where dissolved oxygen values are near threshold levels. If incubation temperatures are higher, the increased metabolic demand for dissolved oxygen may result in higher embryonic mortality in suboptimal habitat where the intragravel flow of water is restricted. This effect would be expected to be greatest in incubation habitats containing relatively large amounts of fine particles and also in areas lacking upwelling. Such areas include the mouth areas of slough, side channel and tributary habitats.

The seasonal pattern of variation of intragravel water temperature varies distinctly between habitat types in the middle Susitna River. Differences appear to be linked to the relative importance and source of the upwelling water system supply in each habitat type. Areas heavily influenced by upwelling water which exhibit a high degree of thermal stability are buffered from the hazards of surface dewatering and freezing (previously discussed). Sloughs such as 10, 11, and 21 fit this pattern. Salmon embryos incubating in these areas accumulate TUs at a relatively uniform rate.

In contrast, the intragravel thermal regime of tributary habitats and probably most of the mainstem habitats is influenced primarily by surface water. In these habitats, the seasonal variation in intragravel temperatures is much greater. Tributaries typically have relatively high intragravel water temperatures during the fall when spawning occurs. These intragravel temperatures seem to be nearly identical to the surface water temperatures which decline sharply in late October to near freezing levels. Temperatures remain near freezing levels until warming spring waters cause a sharp rise in temperature. The pattern of accumulation of TUs for developing embryos is thus very much dependent upon the time when spawning occurs and the ambient temperatures which control the surface and intragravel water temperatures.

In early September, during the chum salmon spawning season, temperatures in Fourth of July Creek were nearly 8°C (refer to Figure 20). However, by early October, intragravel water temperatures dropped to less than 2°C. Temperatures in this range may result in mortality of embryos if blastopore closure is not completed. This pattern of rapid decrease in water temperature during September may account for the observed differences in the timing of the arrival of chum salmon which spawn in slough and tributary habitats. Although the difference in time of arrival is not large, it appears that fish which spawn in tributaries arrive earlier than fish which spawn in sloughs.

The thermal regime in the mainstem is similar in pattern to that of a tributary. However, the water temperatures in fall and spring are not as high. As a result, this habitat type is not used extensively by spawning chum, presumably because they cannot acquire an adequate number of TUs to complete their development.

Areas in the mainstem which are presently used by chum salmon for spawning appear to be restricted to areas where upwelling occurs. Presumably these areas afford a more favorable thermal regime and enable development to be completed. An increase in the water temperature in this habitat type may be beneficial to the incubation of chum salmon in that a greater amount of habitat may be thermally suitable for completing development. This increase in area is likely to be closely linked to areas of upwelling.

Side channel habitats are characterized by a high degree of thermal variability. They typically undergo extensive dewatering, which is generally followed by the freezing of the substrate. The primary areas which provide suitable habitat for spawning chum salmon are relatively small, localized areas of upwelling (e.g., areas in Side Channel 10), and the relatively narrow, unfrozen channel which flows throughout the winter (e.g., Side Channel 21). In general, this habitat type provides poor incubation conditions.

4.1.5 Dissolved Oxygen

Although researchers generally agree that low concentrations of dissolved oxygen (DO) result in deleterious effects in the development and the survival of salmon embryos, there is considerable question as to the precise level of DO which may be considered harmful. A summary of documented effects of low dissolved oxygen on incubating salmon embryos is presented in Table 5. Numerous studies have shown that low, but non-lethal concentrations of DO may result in a decrease in the rate of embryonic development (Garside 1959), an abnormal progression of tissue differentiation (Hayes 1949), a reduction in size of alevins at hatching (Silver et al. 1963; Shumway et al. 1964), premature hatching (Alderdice et al. 1958), and increased mortality (Wickett 1954, 1958; Alderdice et al. 1958; Coble 1961; Phillips and Campbell 1961; McNeil 1962; Koski 1975).

Consumption of dissolved oxygen by salmon embryos progressively increases from the time of fertilization to hatching, with lower threshold levels ranging from 1.0 - 7.0 mg/l, respectively (Alderdice et al. 1958). There are two stages of embryonic development which are particularly sensitive to DO levels. These include the period just prior to the development of a functional circulatory system [approximately 200 Thermal Units (TUs) for chum salmon] and the period just prior to hatching (Alderdice et al. 1958). Of these two periods, the latter appears to be most sensitive to low dissolved oxygen levels. The reasons for increased sensitivity to low DO levels during these two periods is related to the physiology and the timing of development of the circulatory system in relation to changes in the biological demand for oxygen in developing tissues.

During the first of the two sensitive periods, DO consumption for basal metabolism is lower and embryos possess a physiological plasticity which enables them to compensate for hypoxial conditions by delaying development. This compensatory ability, however, is apparently lost after embryos have acquired 200 TUs and developed a functional circulatory system (Alderdice et al. 1958). Thus, the increased sensitivity of the second sensitive period (just before hatching) results primarily from its relatively higher DO requirement for basal metabolism compounded by the loss of ability to compensate for increased DO consumption by delaying embryonic development (Alderdice et al. 1958).

The respiratory exchange at the surface of pre-hatched fish embryos is influenced by the processes of diffusion and convection (Daykin 1965;

O'Brien et al. 1978). As the respiring embryo acts as an oxygen sink by removing DO from the diffusion layer surrounding the outer surface of the egg capsule, oxygen is replenished to the diffusion layer via convection (O'Brien et al. 1978). In turn, the rate of replenishment of DO to the surface of the egg capsule membrane is influenced by a variety of other environmental factors, including the concentration of DO in the intragravel water, the gradient of the stream surface profile, permeability of the gravel, and interchange of oxygenated surface water.

Both the concentration and the rate of exchange of dissolved oxygen are important characteristics which determine the suitability of the habitat for successful incubation of salmon (Coble 1961). However, recommended levels for both criteria differ. For example, McNeil and Bailey (1975) recommend threshold DO levels of 6.0 mg/l whereas Reiser and Bjornn (1979) recommend 5.0 mg/l. Similarly, the recommended rate of intragravel flow proposed by Reiser and Bjornn was 20 cm/h whereas Bell (1973) recommends a rate of 110 cm/h. It is likely that these differences in estimates arise from differences in experimental conditions. However, the criteria provided by Reiser and Bjornn seem to be a bit low when compared to the experimental results performed on chum salmon by Alderdice (1958). In these tests, 7.19 mg/l DO at an intragravel flow rate of 85 cm/h was established as the critical oxygen level, below which the respiratory demand would not be adequately met (refer to Table 6). These threshold criteria were developed for embryos nearly ready to hatch (452 TUs) and thus are estimates at the time when the demand for dissolved oxygen is greatest.

Table 6. Documented effects of low dissolved oxygen (DO) levels on incubating salmonids, based on a review of selected literature.

Species	Location/Habitat	Approximate Stage of Development	Days After Fertilization	Associated Temperature (°C)	Temperature Units[a]	DO values (mg/l)	Results	Associated Conditions	Reference
Chum	Nile Creek, British Columbia	pre-eyed		8		4	Threshold to just maintain full metabolism	apparent velocity 25mm/hr; n=10 embryos	Wickett (1954)
	Nile Creek, British Columbia	pre-eyed pre-eyed pre-eyed early eyed	0 5 12 85	3.7-5.2 8.0-8.2 0.1-0.7 3.6-4.9		0.72 1.67 1.14 3.70	Critical values of DO, below which basic metabolism is not met. DO levels below these values contribute to increased mortality.	apparent velocity averaged 5 to 36 mm/hr	Wickett (1954)
(laboratory)[b]	Nanaimo Station, British Columbia		12 48	10 10 10 10	121.2 260.2 353.0 452.4	3.96 5.66 6.60 7.19	Critical oxygen levels (those at which respiratory demand is just satisfied): a measure of DO requirements for successful incubation.	apparent velocity = 850 mm/hr	Alderdice et al. (1958)
(laboratory)[b]	Nanaimo Station, British Colubmia		12-48	10	121.2-452.4	0.4-1.4	Median lethal DO levels when exposed to these conditions for 7 days.	apparent velocity = 850 mm/hr	Alderdice et al. (1958)
(laboratory)[b]	Chena River, Alaska	embryos				2	Good survival rates	strong intra-gravel water flow	Kogl (1965)
	Amur River, Siberia	post-hatch (early)				0.28	Oxygen threshold: alevins survived	strong intra-gravel water flow	Levanidov (1954)
	Not specified	pre-eyed to emergence				3.0	Timing of emergence was delayed; survival decreased rapidly below 3.0 mg/l DO		Koski (1975)[c]
Sockeye (laboratory)[b]	Sweltzer Creek Field Station, British Columbia	newly hatched alevins		8	1,200	3.0-11.9	Growth and development were retarded at low DO concentrations.	apparent velocity = 1800 cm/hr	Brannon (1965)
Chinook (laboratory)[b]	Oregon State University Corvallis, Oregon	fertilization to hatching		11		1.6-11.7	Good hatching (near 97%) but delayed 4-5 days when reared in 2.5 mg/l DO water. "0" hatching at 1.6 mg/l DO.	apparent velocity = 82-1370 cm/hr	Silver et al. (1963)
Chinook, Steelhead	not specified	fertilization to fry				various	Reduced levels of DO or velocity delayed hatching, produced smaller fry.	at known water velocities	Silver (1960)[d]
Coho (laboratory)[b]	Oregon State University, Corvallis, Oregon	fertilization to fry		9-11		3.0-11.0	Hypoxial stress at the lower DO range resulted in smaller fry, higher mortality.	apparent velocity = 223 cm/hr	Mason (1969)
Coho, Steelhead	Alsea River Basin, Oregon	embryos				3.5-10	Intragravel DO must average 8 mg/l for high survival; positive correlation between percent survival and mean DO.		Phillips and Campbell (1961)[e]

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Table 6 (Continued).

Species	Location/Habitat	Approximate Stage of Development	Days After Fertilization	Associated Temperature (°C)	Temperature Units[a]	DO values (mg/l)	Results	Associated Conditions	Reference
Coho, Rainbow Trout	not specified	embryos				< 7 (avg.)	Survival to hatching was < 25%		Phillips and Campbell (1961)[e]
Coho, Steelhead (laboratory)[b]	Oak Creek, Oregon	fertilization to fry		9.0-10.8		2.5-11.2	Median hatching time was delayed 1-2 weeks at lower DO; size increased with DO concentration.	apparent velocity = 3-800 cm/hr	Shumway et al. (1964)
Steelhead	Alsea River Basin, Oregon	fertilization to hatching		5.6-12.2		2.6-9.2	Embryonic survival (range = 16-62%) was positively correlated with DO concentration; effects from intragravel velocity and DO were interdependent.	apparent velocity = 5.5-108.5 cm/hr	Coble (1961)
(laboratory)[b]	Oregon State University, Corvallis, Oregon	fertilization to hatching		9.5		1.6-2.6	Good hatching (near 80%) but delayed 3-4 days when reared in 2.6 mg/l DO water; "0" hatching at 1.6 mg/l.	apparent velocity = 6-750 cm/hr	Silver et al. (1963)
Atlantic Salmon	Not specified	eyed hatching	25 50	10 10		3.1 7.1	Critical DO levels.		Hayes et al. (1951)[g]
Lake Trout (laboratory)[b]	Ontario, Canada	fertilization to hatching		2.5-10		2.5-10.5	Retarded growth and development, delayed hatching, head and trunk abnormalities at low DO levels (2.5-4.5 mg/l); total mortality just prior to hatching at 2.5-4.2 mg/l DO and 10°C.	investigated development (18 stages)	Garside (1959)
Salmonids	Not specified	embryos				5.0	Lower threshold (recommended limit)	at or near saturation	Reiser and Bjornn (1979)

[a] Temperature (thermal) Units = 1 degree C/24 hr (e.g., 6 days incubation at 5°C = 30 TU's)

[b] A laboratory includes artificial or simulated conditions

[c] Cited in paper by Wickett (1954)

[d] Cited in paper by Coble (1961)

[e] Cited in review paper by Reiser and Bjornn (1979)

[f] Cited in paper by McNeil (1966)

[g] Cited in paper by Wickett (1954)

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To a large extent, the concentration of DO in the intragravel environment is a result of the concentration of DO in surface and sources and their relative contribution of these two sources to the intragravel water supply. In the middle Susitna River, the relative contribution of these two sources of water varies between two extremes. In general, upwelling apparently dominates as the primary intragravel water supply of slough habitats whereas surface water dominates in tributary habitats (mainstem and side channel habitats seem to vary between these two extremes).

In general, the concentration of dissolved oxygen (DO) in intragravel water was consistently lower than surface water concentrations in each habitat evaluated. However, the difference between intragravel and surface water DO levels was greatest for slough habitat and least for tributary and mainstem habitats. Differences were intermediate in side channel habitats. Thus, with the possible exception of sloughs, the DO levels in most of the incubation habitat evaluated appear to be above the recommended levels of 7.19 mg/l established by Alderdice (1958). However, in sloughs, the potentially adverse effects of lower DO levels are undoubtedly ameliorated by the possible influence of in providing a relatively consistent intragravel flow. In turn, the rate of intragravel flow is intimately related to the permeability of the substrate and is therefore discussed more fully in section 4.1.3.

4.1.6 pH

A relatively broad range of pH values are considered acceptable for successful incubation of salmon embryos. Leitritz and Lewis (1976) report that values between 6.7 and 8.2 are acceptable, and that values outside this range should be regarded with suspicion. The authors note, however, that this range of values does not account for varying degrees of sensitivity to pH between species and/or species life-phases.

Rombough (1982) evaluated the sensitivity of pacific salmon embryos to low pH levels (3.5 to 6.0) and found that sensitivity to pH varied with species and developmental stage. He compared the sensitivity of each species at three specific developmental stages (eyed embryos, newly hatched alevins, and buttoned-up alevins), and found that the sensitivity to low pH levels increased for each species with increasing stage of development, but that the relative sensitivity of each species varied depending on developmental stages. For example, chum and pink salmon were the most sensitive during the eyed and buttoned-up alevin stages, but were less sensitive than coho, chinook or sockeye salmon during the stage of nearly hatched alevins. In each of the three developmental stages tested, pH levels were below 6.0. However, Rombough (1982) also reported that he observed aberrant behavior in buttoned-up alevins of pink and chum salmon at pH levels of 6.0-6.1.

Levels of pH in the 6.0 to 6.5 range are not typical of habitats in the mainstem of the middle Susitna River. Natural pH levels in tne mainstem

Susitna River typically vary between 7 and 8 during the winter, occasionally dropping below 7 (Exhibit E). However, adjacent slough, side channel, and tributary habitats generally have lower pH values, often ranging below 7, with occasional values below 6.5. In this study, low survival rates occurred with low pH values, indicating that pH may have an effect on embryo survival at lower pH values.

In the spring, a drop in the pH levels in the mainstem river coincides with increased runoff from the Susitna Basin (Acres 1982). This phenomenon is common to Alaskan streams where tundra runoff is typically acidic. If mainstem flows in the Susitna River are reduced during the spring runoff period during project operations, a relatively greater proportion of the flow in the mainstem will originate from acidic tundra runoff. This relationship is likely to result in pH values which are lower than present and historical values.

The effect of lowered pH values in the mainstem may be indirectly harmful to embryos or pre-emergent fry, depending upon the levels of other variables. For example, Bell (1973) reports that low levels of pH affect the tolerance of fish to low concentrations of dissolved oxygen and that the sensitivity of fish to toxic levels of sodium sulfide, cyanide, ammonia, and various metallic salts increases with decreases in pH. Also, the synergistic effects of two or more elements (particularly metallic ions) may have adverse effects at much lower levels than either one individually (Bell 1973). Thus, the effects of lowered pH values cannot be evaluated independently, but must be considered in concert with anticipated changes in the overall ionic composition of the water in each habitat where embryos are present.

4.1.7 Conductivity

Conductivity is a measure of the capacity of water to conduct an electric current. As such, it is an indication of the total concentration of dissolved ionic matter in the water and is also directly related with both water hardness and alkalinity (Lind 1974). However, this variable is not of direct consequence to fish, but rather is a general water quality indicator which is intricately related to the variables above.

Below Devil Canyon, winter conductivity values in the mainstem river range from 160-300 umhos (micro-mhos) while corresponding values of total hardness and total alkalinity range from 60-120 mg/l and 45-145 mg/l, respectively (Acres 1982). These values are at the lower end of the suggested "optimal range" for fish (120-400 mg/l) provided by Piper et al. (1982). This is significant, because at very low alkalinities, water loses its ability to buffer against changes in acidity and may result in wide fluctuations in pH values which in turn may be detrimental to fish. In this study, however, there does not appear to be any relationship between observed conductivity values and embryo survival (Figure 54).

4.1.8 Turbidity

The specific effects of various turbidity levels on the incubation life-phase of salmon in the middle Susitna River are presently unknown. However, excessive turbidity levels can have adverse effects on the incubation life-phase by smothering fish embryos (Piper et al. 1982). This problem is treated as part of a larger problem involving the evaluation of the role of substrate composition on the availability of dissolved oxygen to developing embryos.

4.1.9 Flatworms

It should be noted that there are many biological variables which could potentially affect the development and survival of incubating salmon embryos. Among these are effects due to vertebrate egg predators such as sculpins, and invertebrate egg predators such as caddisfly and stonefly larvae. In addition, loss or death of embryos can occur due to bacterial, viral, protozoan, or fungal agents. This section is limited to a discussion on flatworms which appeared to be associated with a decrease in salmon eggs at some study sites. Evaluation of other biological variables was outside the scope of this study and they are not discussed in this report.

Relatively large numbers of embryos were discovered to be missing from Whitlock-Vibert Boxes at the time of removal. Missing embryos were assumed dead for the purposes of this study; but the actual cause of their disappearance remains undetermined. Because relatively large numbers of flatworms were present in WVBs in which embryos were missing, it was suspected that they were scavenging on dead embryos. A simple experiment conducted to establish the rate of scavenging by flatworms was not conclusive, but indicated that it required more than a two month period. The role of planarians in the removal of embryos from Vibert Boxes was previously investigated by Heard (1978) in a stream in southeast Alaska. After conducting tests with various combinations of planarians and live and dead salmon eggs and alevins, he concluded that the test planarians did not prey on and were not toxic to live embryos, and did not feed on dead eggs unless the chorion was broken and egg contents exposed. Based on the results of the experiment conducted in this study and the conclusions presented by Heard (1978), the following hypothesis is proposed as a plausible explanation for the disappearance of embryos.

The most familiar type of feeding pattern followed by planarians involves the protrusion of a muscular pharynx out through the mouth where soft and disintegrating animal tissues are sucked up into the gastrovascular cavity (Pennak 1978). Thus, if the egg capsule is intact, it is likely that planarians are not able to utilize them as a food source. This is consistent with Heard's conclusion that planarians did not feed on dead eggs unless the chorion was broken or egg contents exposed.

Additional evidence from the experiment conducted in this study suggests that colonization of dead eggs with fungi may be a necessary "conditioning process" which must occur before planarians can successfully scavenge dead eggs. Presumably, the fungal hyphae penetrate the egg capsule and cause the egg to "break apart." After this occurs, the egg contents would be exposed and suitable for successful scavenging by planarians. Although the initial "processing" of the egg capsule by fungi appears to require at least two months, it is suspected that complete removal of the egg contents by planarians would be a much more rapid process in areas where planarian densities are high.

4.2 Conclusions/Recommendations

4.2.1 Conclusions

1. Dewatering and freezing of salmon redds were identified as the most important factors contributing to the high levels of embryo mortality found in habitats used for chum salmon incubation in the middle Susitna River. In general, these factors were most pronounced in side channel habitats and least pronounced in slough habitats which were protected from cold surface water overtopping and where upwelling was more prevalent.

2. Upwelling was the most significant environmental factor affecting the development and survival of salmon embryos incubating in slough, side channel and some mainstem habitats of the middle Susitna River. The importance of upwelling to incubating embryos is due to the following reasons:

a) It eliminates or reduces the likelihood of dewatering or freezing of the substrate environment from occurring;

b) It provides a relatively stable intragravel incubation environment, buffering it from variations in local surface water and climatic conditions; and,

c) It increases the rate of exchange of intragravel water over the embryos which enhances the replenishment of dissolved oxygen and the removal of metabolic wastes.

3. The total surface water area of wetted habitat available at the time when adult salmon are spawning is not a good indicator of the success of that area as incubation habitat. The wetted surface area in terms of incubation primarily depends upon the relationship of wetted surface area to the availability of wetted intragravel environments occurring after the spawning period.

4. The pattern of accumulation of thermal units for developing salmon embryos varies between spawning habitat types for the middle Susitna River. A general thermal regime describing the incubation period for each habitat type can be stated as follows:

a) Tributary habitats typically have intragravel water temperatures which are strongly influenced by surface water temperatures. This results in high intragravel water temperatures during the fall and spring months with near freezing water temperatures (0.0 to 8.0°C) during the intervening winter months;

b) Slough habitats generally have stable, relatively high, intragravel water temperatures (0.0 to 6.9°C) throughout the incubation period due to the influence of suitable upwelling sources;

c) Mainstem habitats typically have winter intragravel water temperatures (0.1 to 0.9°C) which are strongly influenced by surface water temperatures, similar to tributary habitats except for colder water temperatures during the fall and spring periods; and,

d) In general, winter intragravel water temperatures (0.0 to 12.5°C) in side channel habitats are quite variable and may reflect any of the patterns exhibited by the other habitat types depending upon the relative influences of and relationships between upwelling and surface water sources.

5. Significant mortalities of salmon embryos due to thermal stress are anticipated if altered flows increase the incidence

of cold mainstem water overtopping slough and side channel habitats having insufficient supplies of warmer upwelling or local surface waters in the middle Susitna River during fall and winter. If post-project mainstem water temperatures are warmer than existing winter temperatures, this thermal problem associated with overtopping will be ameliorated.

6. In general, slough habitats of the middle Susitna River contain greater amounts of fine substrate (38%) compared to side channel, tributary and mainstem habitats (19%, 13%, 12% respectively).

7. Areas where salmon established redds in each habitat type contained fewer fines than the range of substrate materials available in each habitat type of the middle Susitna River.

8. With the exception of slough habitat, dissolved oxygen (DO) levels in most incubation habitats of the middle Susitna River during the winter period are generally above the recommended levels of 7.19 mg/l established by Alderdice (1958). Although DO levels in intragravel water of slough habitat are generally lower (0.4 to 12.3 mg/l), the potential adverse effects of low DO are undoubtedly ameliorated by the influence of upwelling, depending upon site specific conditions.

9. The pH levels present in incubation habitats of the middle Susitna River (6.2 to 8.3) are within the lower range of

acceptable limits but do not appear to be detrimental to embryo survival and development. However, the indirect effects of low pH levels interacting with other water quality parameters may result in unpredictable side effects.

10. Conductivity values in incubation habitats of the middle Susitna River (24 to 283 umhos) are within acceptable limits and do not appear to have any direct adverse effects on incubation embryos.

11. The relationship between sediment composition, flushing flows (Estes 1985), and mechanical ice processes are unknown in these habitats, but may become a significant factor for successful incubation under post-project conditions.

4.2.2 Recommendations

The results of this study have provided some preliminary conclusions describing the environmental conditions affecting the incubation life-phase of chum salmon in the middle Susitna River. The recommendations outlined below are designed to strengthen and expand these conclusions.

One area requiring additional investigation is an evaluation of the "effective spawning" area. Milhous (1982) defines this concept as the spawning area that does not dewater during the following incubation period. Previous studies have developed weighted useable area curves describing the spawning habitat area available for both pre-project and post-project conditions on the middle Susitna River. However, spawning habitats will not produce salmon fry if the intragravel environment becomes dewatered during the incubation period. Consequently, the survival of salmon embryos in spawning areas must be evaluated based on the incubation flows during the winter months. With the present understanding of the deleterious effects of freezing on dewatered spawning habitat, the need to fully evaluate the effective spawning area becomes more apparent.

In addition to evaluating the effective spawning area, the effect of "power peaking" on incubating salmon embryos in the middle Susitna River requires investigation. The concept of power peaking refers to the change in stage of mainstem flows throughout the winter as a function of energy demand during project operations. Of particular interest, is the extent to which the proposed winter flows will water/dewater incubating embryos based on fluctuating flows from power peaking. Since the results of this study indicate that dewatered areas invariably freeze, power peaking effects may increase the proportion of embryo mortalities caused by freezing.

Insufficient data are available to project the influence of mainstem discharge on sources of local flow such as upwelling during unbreached conditions. This information will be required to refine these analyses and is essential for evaluating the impacts of proposed post-project temperature and flow scenarios and mitigation options designed to compensate for impacts.

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