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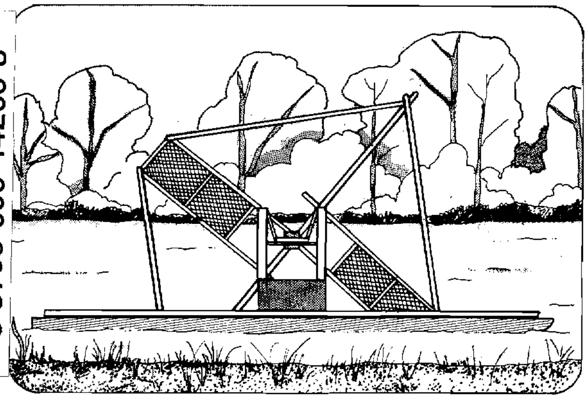
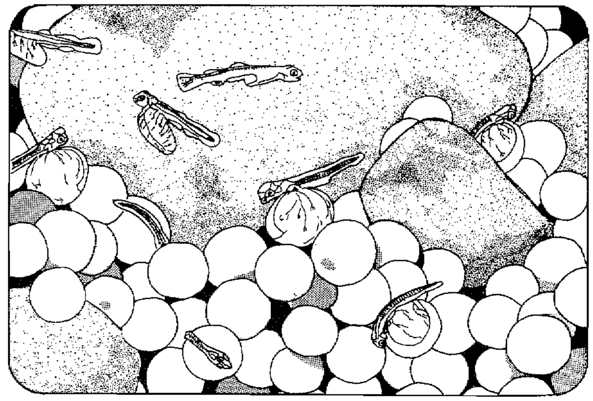
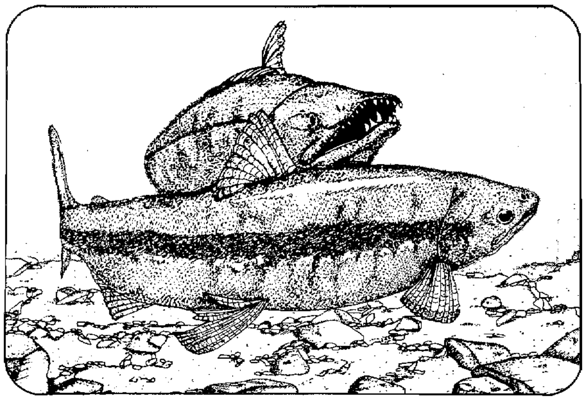
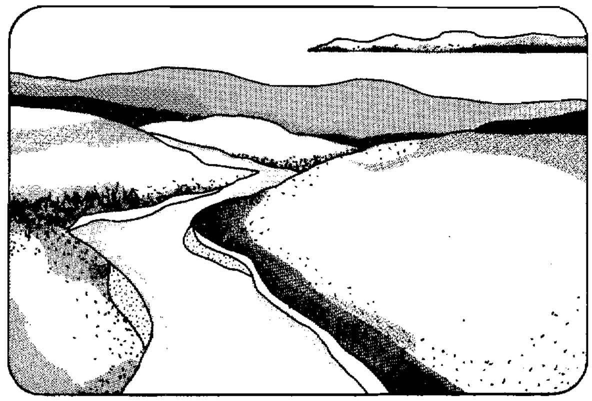

REPORT NO. 5

WINTER AQUATIC INVESTIGATIONS
(SEPTEMBER 1983-MAY 1984)

Volume 1: An Evaluation of the Incubation Life-Phase of Chum Salmon in the Middle Susitna River, Alaska

ALASKA DEPARTMENT OF FISH AND GAME
SUSITNA HYDRO AQUATIC STUDIES REPORT SERIES

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Prepared for:

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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 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 (report number 5) 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.

This report is composed of two separately bound volumes. Volume 1 (presented here) presents an evaluation of the incubation life-phase of chum salmon in the middle Susitna River. Volume 2 (Appendix F) presents an independent evaluation of the surface and intragravel water temperature conditions for incubation study sites identified in Volume 1 as well as additional water temperature monitoring sites located within the middle Susitna River.

WINTER AQUATIC INVESTIGATIONS:

SEPTEMBER, 1983 - MAY, 1984

REPORT NUMBER 5

VOLUME 1

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

By:

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1985

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ABSTRACT

An evaluation of the pattern of survival and development of chum salmon embryos incubated in artificial redds in slough, side channel, tributary, and mainstem habitats of the middle Susitna River was conducted in conjunction with an assessment of the currently available chum salmon incubation habitat conditions within these habitat types. Chum salmon eggs obtained from local stocks were artificially fertilized, placed within modified Whitlock-Vibert Boxes (WVBs) and then implanted in artificial redds in the streambed at selected study sites. At each of these sites, a polyvinyl chloride standpipe was also installed to obtain instantaneous intragravel water quality measurements of temperature, dissolved oxygen, pH, and conductivity which were later correlated to the percent survival of embryos (100% hatched) at each site. In addition, representative substrate samples were obtained at selected study sites using a modified McNeil substrate sampler to characterize the substrate conditions present at incubation study sites.

The survival rates of embryos in slough, side channel and tributary habitats were 17, 9, and 11 percent, respectively. Survival of embryos in mainstem habitat was 19 percent but did not reflect the effects of dewatering and freezing due to a difference in the method of site location. Thus, estimates of percent survival for this habitat type are probably higher than would be expected for natural conditions.

The largest demonstrated cause of embryo mortality at study sites was due to dewatering and subsequent freezing of the streambed. Greater than 47% of the total number of WVBs used to estimate survival became frozen. This effect was greatest in side channels and least in sloughs, and was observed to be directly related to the presence and quantity of upwelling water. Areas particularly vulnerable to the effects of dewatering and freezing include large portions of side channel habitats as well as the mouth areas of slough and tributary habitats which may lack sources of upwelling water.

A quantitative analysis of the effect of each variable on survival was hampered by the high embryo mortality due to dewatering and subsequent freezing of substrate. When frozen embryos were removed from the survival data base, no significant correlations were obtained between measured water quality variables and percent survival of embryos ($p<0.05$). However, the correlation between dissolved oxygen (mg/l) and percent survival of embryos decreased to zero at dissolved oxygen concentrations below 3.0 mg/l. The percent survival of embryos was also correlated to the percent of fine substrate particles (<0.08 in. diameter) contained within WVBs. Although there was no significant correlation, the percent survival of embryos decreased to zero when the percent of fines exceeded 18%.

The rate of embryonic development at study sites was found to be strongly influenced by the degree of upwelling present. Chum salmon embryos which were fertilized on August 26, 1983, and incubated in an upwelling area in a side channel, reached the 100% hatch in late December, whereas those incubated in a non-upwelling area in the mainstem Susitna River experienced delayed development and did not reach 100% hatch until mid-April. Therefore, the presence of upwelling water in middle Susitna River habitats appears to be a key component which maintains the integrity of chum salmon incubation habitats by preventing substrate from dewatering and freezing and by maintaining suitable incubation temperatures which allow embryos to develop properly.

A comparison of the rates of in situ embryo development observed in this study to those observed in the laboratory study of Wangaard and Burger (1983) was hampered by problems encountered with temperature recorders installed at each site. Incomplete temperature records were obtained at study sites used to compare thermal unit requirements for development. However, based on a quantitative assessment of development data collected in these study sites and a previous ADF&G study (ADF&G 1983), it is the opinion of the authors that the predictive equation of Wangaard and Burger are an adequate model to use in predicting rates of chum salmon development of the middle Susitna River.

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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 Susitna River between Talkeetna and Devil Canyon (RM 98-152; Figure 1). The report is based on the results of field studies conducted from August, 1983 to May, 1984.

The middle reach of the Susitna River was selected for study because the most significant changes in existing physical characteristics of fish habitats are expected to occur within this reach due to development of the Susitna Hydroelectric Project (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 used by several species of salmon for spawning and are likely to be directly influenced by project construction and operation. Chum salmon were selected as the target species for this 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, their habitat requirements are similar to those of adult sockeye salmon, the other salmon species of significance which also utilize these habitats for spawning and incubation.

There are four basic life-phases in the life cycle of chum salmon: adult migration, 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 migration life phases. In general, chum salmon spend approximately 20% of their life in freshwater (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, the 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. Major concentrations occur 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 her 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 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 depression to begin excavation of another depression. In this way, the fertilized eggs deposited in the previously attended depression are covered with

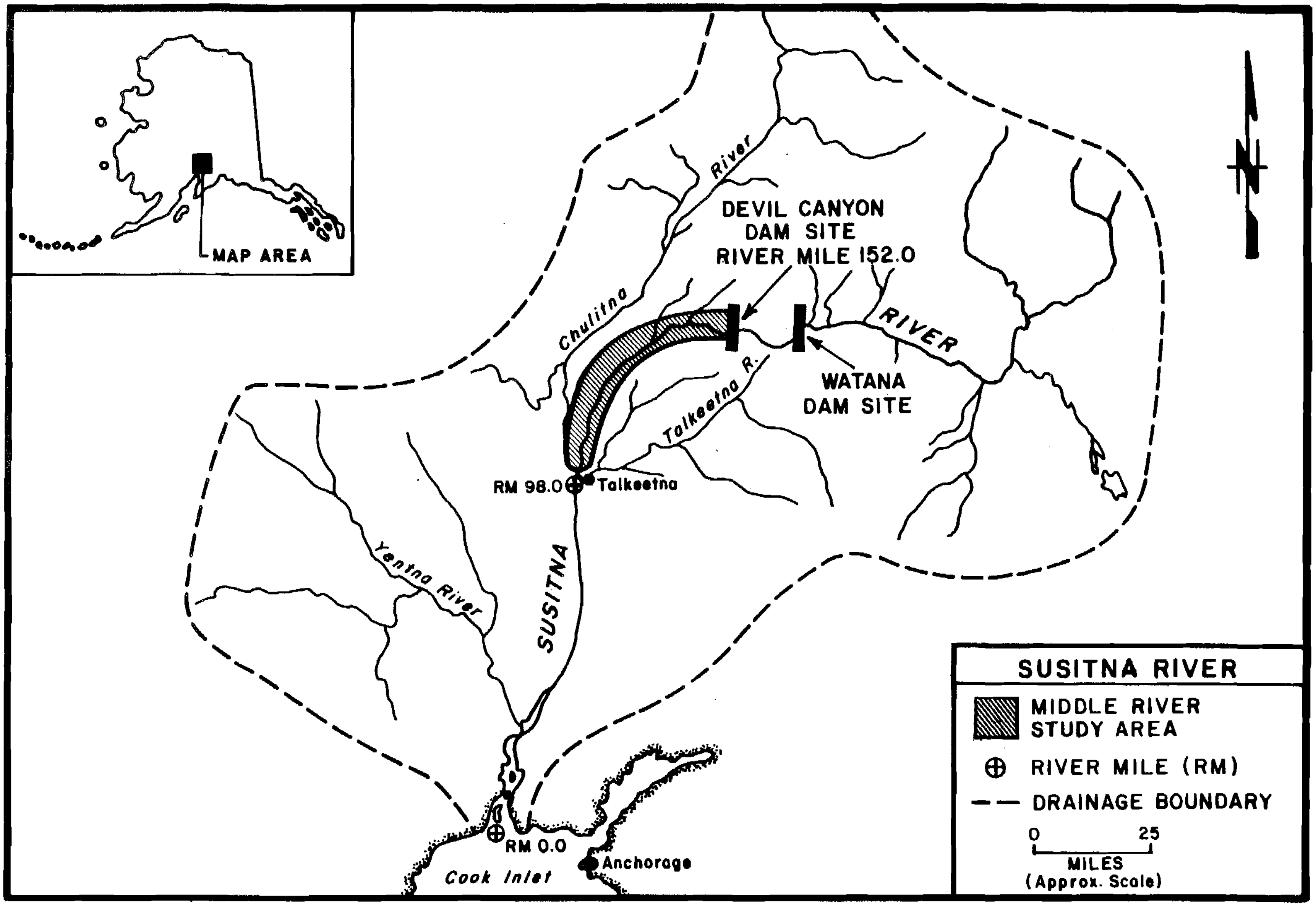

Figure 1. Map of the Susitna River Basin, with delineations of the basin drainage area and the middle reach of river.

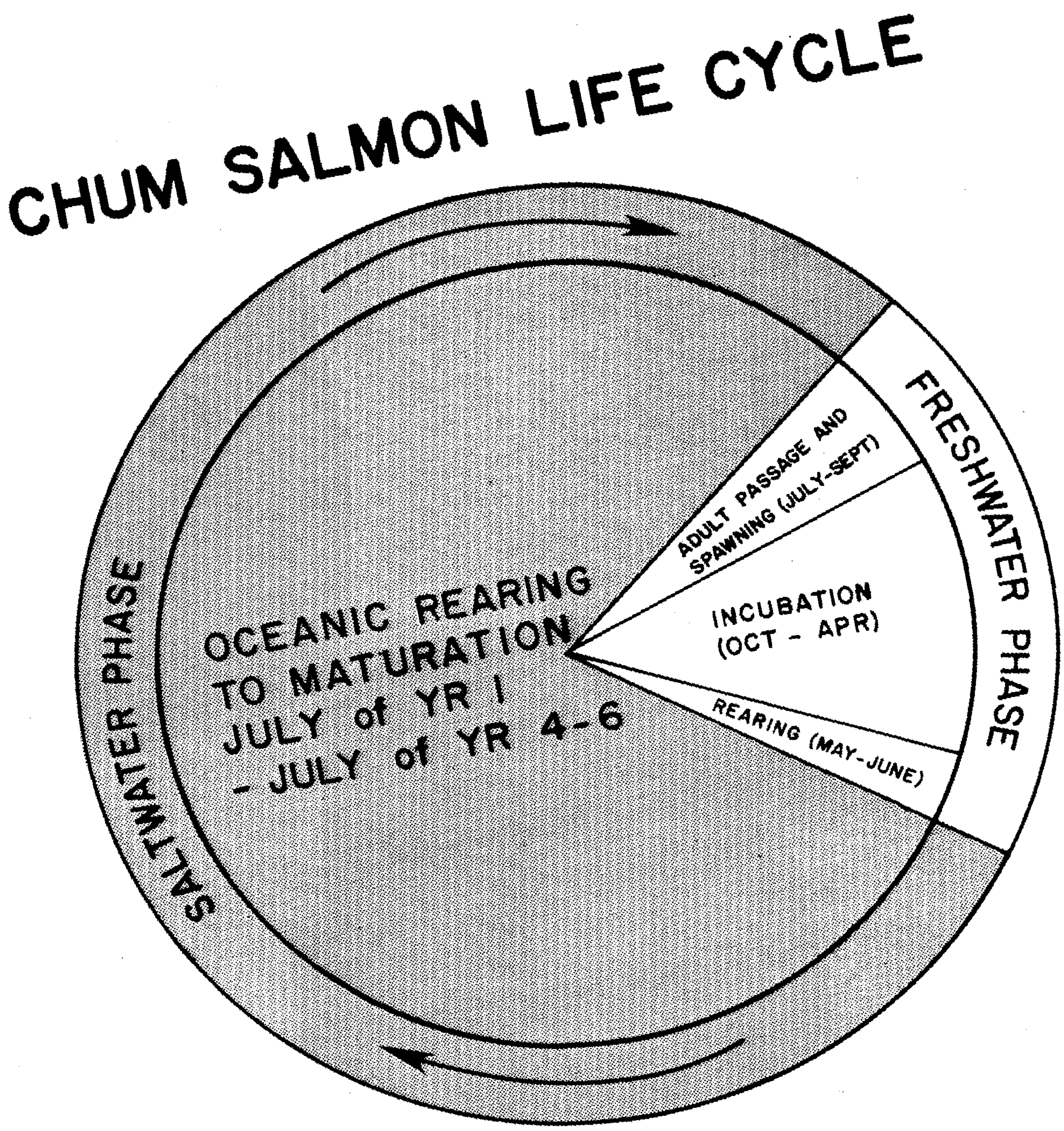

Figure 2. Generalized life cycle of a chum salmon indigenous to the middle Susitna River, Alaska.

substrate materials that are excavated from the new depression. This process is successively repeated until the female has released all her eggs and covered them with gravel, thus completing the formation of the redd. 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 (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, pre-emergent fry, or sac-fry.

Newly hatched alevins (post hatching) remain in the gravel until spring. During this time they obtain nutrients by absorbtion of their large yolk sac. When yolk sac absorbtion is nearly complete, the alevins emerge from the gravel and begin to actively feed thus beginning 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. 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 (Figure 2).

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

Environmental changes which may impact incubating chum salmon in slough and side channels of the middle reach of the Susitna River 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 during winter, 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 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; Chevalier et al. 1984), as well as affecting the timing of fry emergence (e.g., Koski 1966).

Present environmental conditions within the middle reach of the Susitna River are characterized by a high degree of environmental variability. Seasonal discharge levels in the mainstem river often drop sharply in the fall shortly after chum salmon complete their spawning. This results in the exposure of relatively large areas of potential incubation habitat to the harsh subarctic temperature conditions which persist during much of the incubation period. Much of this newly exposed habitat later becomes frozen. Areas that remain unfrozen appear to be restricted to localized areas around upwelling vents or areas located downstream of upwelling water. In addition to the beneficial effects of preventing the dewatering and subsequent freezing of embryos, upwelling increases the rate of replenishment of water to incubating embryos and provides a relatively stable thermal environment (Lister et al. 1980).

The extent to which upwelling is required for successful incubation of chum salmon embryos in the middle Susitna River is presently unknown. However, it is known that chum salmon frequently choose upwelling areas in the middle Susitna River for spawning (ADF&G 1983b: Appendices C, D; Vincent-Lang et al. 1984). That is, they appear to actively select areas where upwelling water is present over similar available habitat where it is absent for spawning. This characteristic feature of chum salmon spawning has been reported for other locations in Alaska (Sheridan 1962; Kogl 1965; Francisco 1977; Wilson et al. 1981; Merritt and Raymond 1982), as well as for the Amur River in Russia (Sano 1966), several river systems in southern British Columbia (Lister et al. 1980) and in the Columbia River (Burner 1951).

1.2 Objectives

The most complete sources of information on the incubation life-phase of chum salmon specific to the middle Susitna River are reported in ADF&G 1983c and Wangaard and Burger 1983. The studies conducted by ADF&G provided good information on the general timing of embryonic development in natural redds in selected Susitna River habitats, but did not include a thorough record of associated water quality conditions during the incubation period. Also, the precision of the timing information was limited because it was based on an assumed date of initial fertilization. The laboratory study conducted by Wangaard and Burger provided specific information on the timing of embryonic development at four different thermal regimes. The results of these two studies were basically consistent.

The objectives of the present study were formulated to compliment the perceived gaps in the existing data base. The primary focus of this study was therefore placed on estimating embryonic survival rather than development, by collecting a more extensive record of existing water quality conditions present in various habitat types used for chum salmon incubation, and by supplementing the in situ estimates of embryonic survival previously reported by ADF&G by obtaining survival estimates from artificially fertilized eggs for which the specific time of fertilization was known.

Therefore, this study was designed to address the following two objectives:

1) Monitor selected physical and chemical conditions at chum salmon incubation sites 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 and development 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

Sixteen 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). Each study site was classified as either primary or secondary based on the type and quantity of data that were collected. In general, greater effort was expended for data collection purposes at primary study sites.

Primary Sites

Data collected at primary study sites included water quality, substrate composition, continuous water temperature, and embryonic survival and development. The data provide a basis for comparing the rate of development and percent survival of chum salmon embryos among habitats types and the factors that affect these differences. Of the eight primary study sites selected, seven were used to evaluate embryo survival, and five were used to evaluate embryo development (Table 1).

In general, primary sites were selected to:

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

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

3) represent a wide range of upwelling conditions;

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

5) represent a wide range in the relative amount of fine substrates (0.08 in. diameter) present in the spawning gravels; and,

6) include locations that were previously used for the incremental spawning habitat analyses in sloughs and side channels (Vincent-Lang et al. 1984).

Secondary Sites

Secondary sites were selected to provide additional winter water quality data in selected habitats used for chum salmon incubation. A limited amount of water quality, substrate composition, and continuous water temperature measurements were collected at these 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

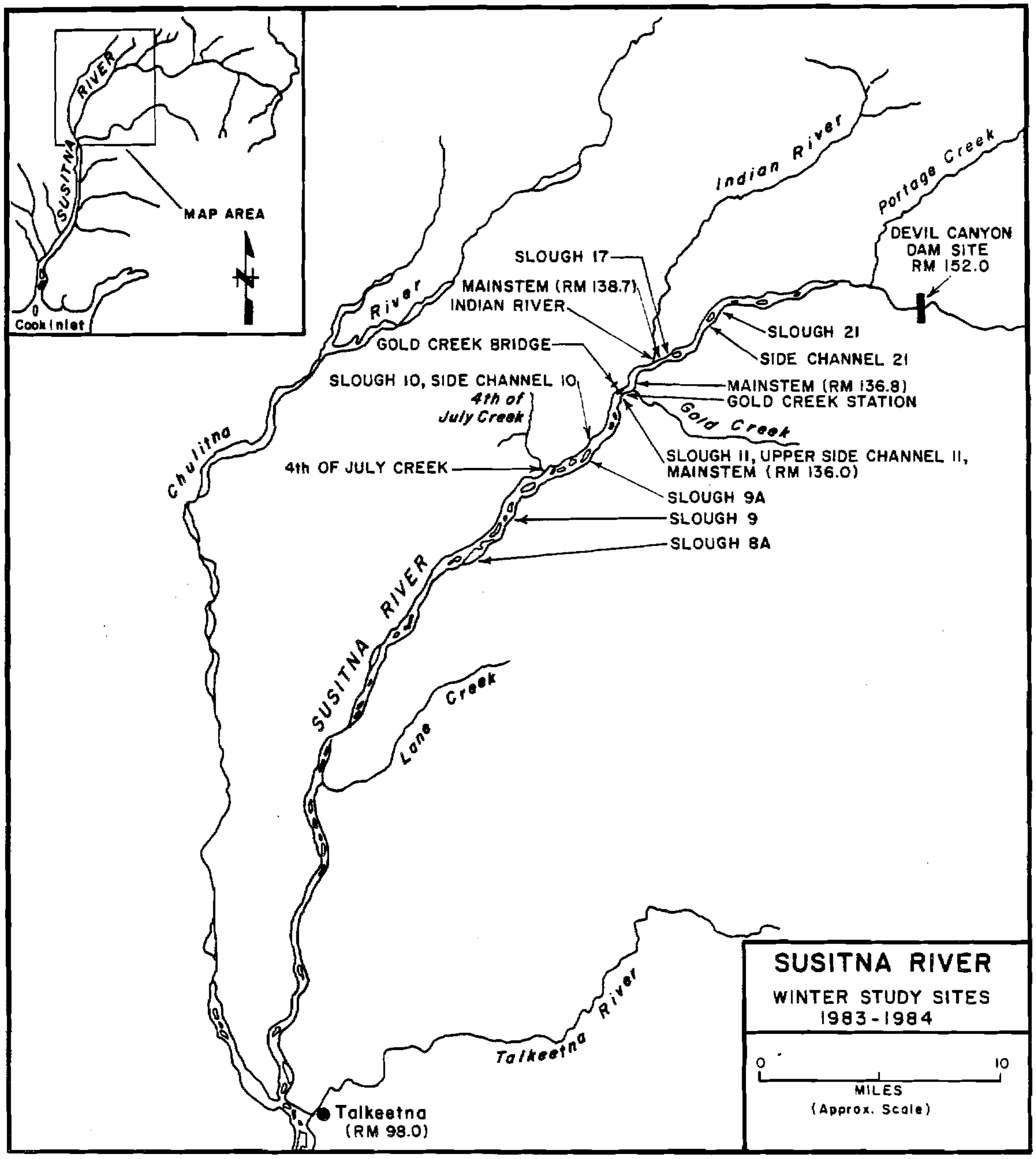

Figure 3. Locations of study sites within the middle reach of the Susitna River (RM 98-152).

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

Site	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	X
Side Channel 10	133.8	Primary	X	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	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.

1983c). Secondary sites include Sloughs 8A, 9, 9A, and 17, three mainstem sites at 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). Specific details are provided only for methods which differed slightly from those presented in the ADF&G Procedures Manual (1984).

The development and survival of salmon embryos is influenced by a variety of interacting physical and chemical variables of the intragravel incubation environment. For the purposes of this study data were collected for selected physical and chemical variables to establish baseline conditions in the intragravel and nearby surface water environment, and to provide information for evaluating development and survival of chum salmon embryos. These variables include water temperature, dissolved oxygen, pH, conductivity, turbidity, water velocity, and substrate composition.

The measurement of physical and chemical variables (other than continuous intragravel water temperature data) of intragravel water required the use of polyvinyl chloride (PVC) standpipes installed into the streambed. Standpipes designed for this study had 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 within the streambed, the perforations allowed intragravel water to pass through the standpipe allowing water quality measurements to be obtained. Construction of the driving rod and standpipe were modified from designs presented in Gangmark and Bakkala (1958) and McNeil (1962) and had the advantages of being 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 approximately 25 cm (10 inches) below the substrate surface. This 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 intragravel water quality measurements to be obtained.

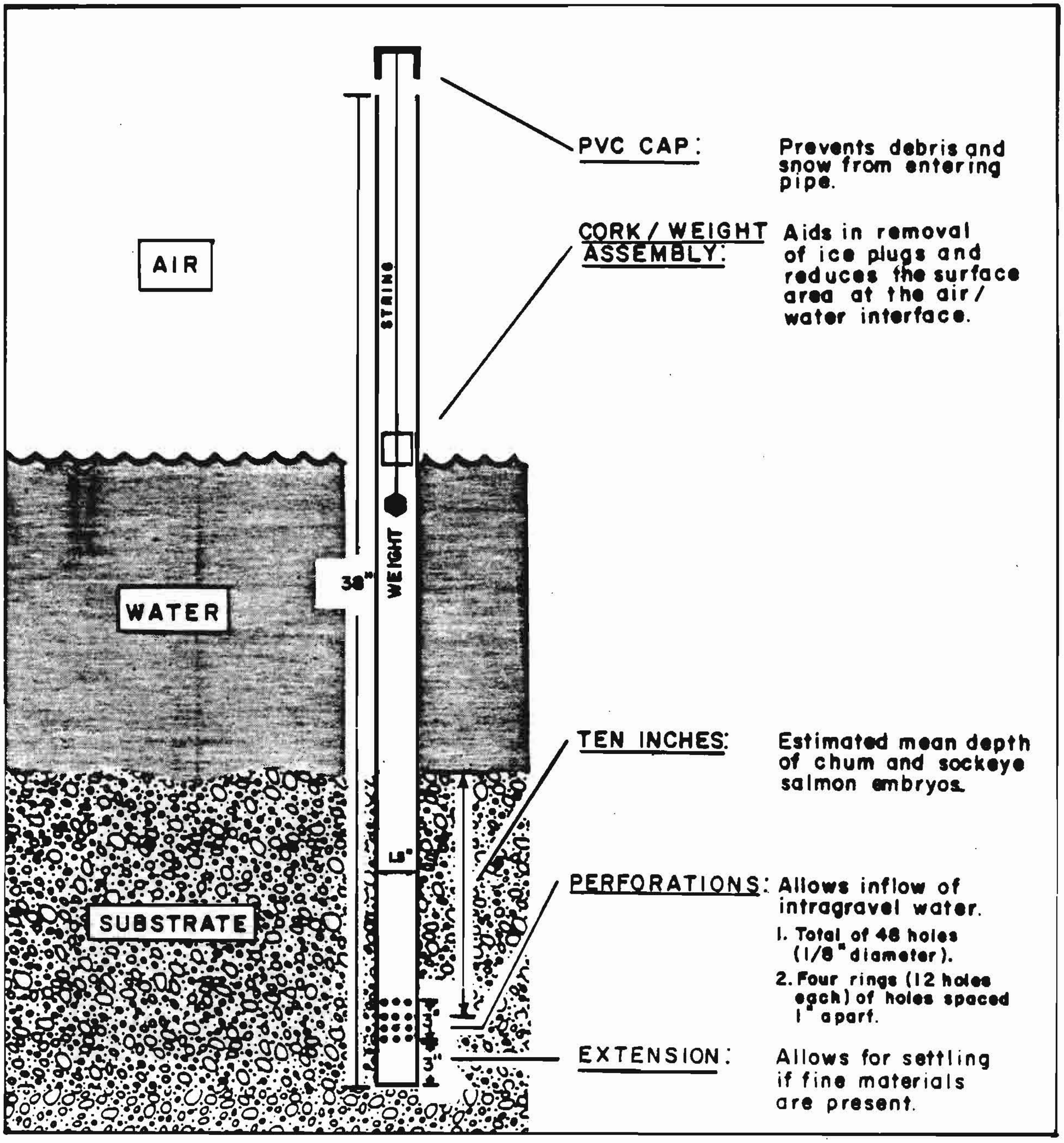

Figure 4. Diagram of a polyvinyl chloride (PVC) standpipe used to evaluate intragravel water conditions in streambeds of salmon spawning habitats in the middle Susitna River, Alaska.

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.

2.2.1 Physical Variables

2.2.1.1 Water Temperature

Instantaneous surface and intragravel water temperatures were measured at all primary and secondary study sites using a Yellow Springs Instrument (YSI) dissolved oxygen/temperature meter (Model 57) and a YSI conductivity/temperature meter. Water temperatures were measured both inside and outside the PVC standpipes at all water quality study sites. On each sampling day, each YSI meter was calibrated with a Hydrolab Model 4041 water quality meter which was calibrated before and after field sampling trips following the procedures outlined in the ADF&G Procedures Manual (1984).

Continuous water temperature data were collected at selected primary study sites using either Omnidata datapod recorders (Model No. 2321) and thermister probes (Model No. 2321), or Ryan (Model J90) thermographs. Due to the limited number of continuous temperature recorders available they were not used at all sites. Specific methods pertaining to these instruments and their use are presented in Appendix A of this report.

2.2.1.2 Substrate Composition

The freeze-core sampler and the McNeil core sampler (McNeil 1966) are two of the primary methods that have previously been used for collecting substrate data in streams (Platts et al. 1983) which were considered for the collection of substrate samples in this study. In a review of the two sampling methods, Platts et al. (1983) concluded that when time and money are considered, the McNeil sampler is the most economical method available to obtain estimates of channel substrate particle size distributions in water up to 12 inches in depth. In this review, he also discussed a laboratory study (Walkotten 1976) in which substrate samples were obtained with both methods (McNeil and single-core methods) which showed that both devices provided representative samples of known sediment mixtures. In addition, freeze-core substrate samplers also involve the use of more costly and elaborate equipment (e.g., CO_2 bottles, hoses, manifolds, probes and sample extractors) than the McNeil sampler and are therefore more expensive and difficult to operate in the field. In contrast, the McNeil sampler is a relatively simple piece of equipment which can be more easily transported in the field and is not subject to as many mechanical and operational problems as is freeze core sampling equipment. Considering these factors, the McNeil sampler was selected for use as it was determined to be best suited towards meeting the study objectives, and for reasons previously mentioned was a more practical sampler for evaluating substrate composition in this study.

Substrate samples were collected at selected study sites using a modified McNeil substrate sampler (Figure 5). At each site, the 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 for storage. After

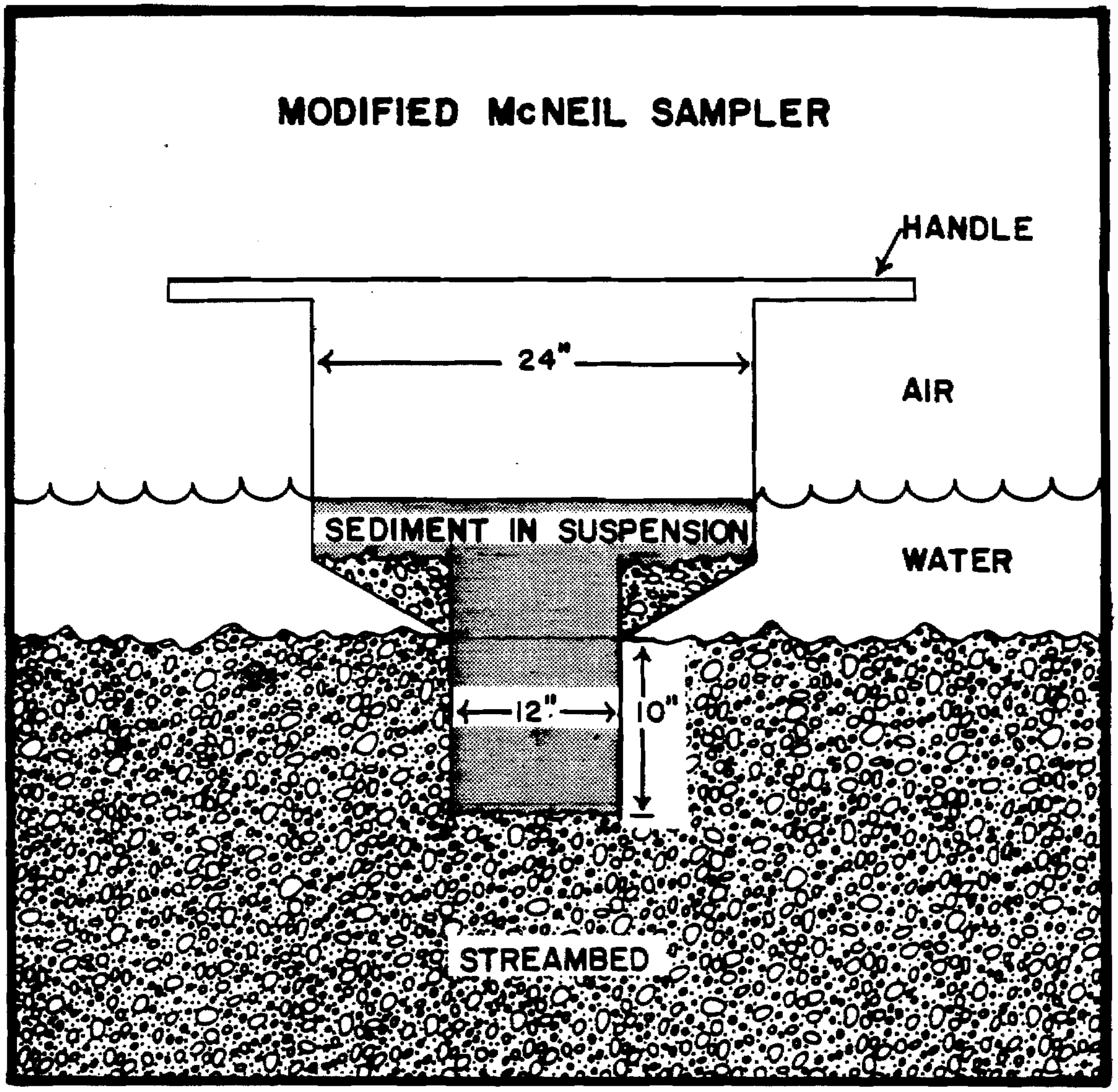

Figure 5. A modified McNeil substrate sampler used to evaluate substrate conditions of salmon spawning habitats in the middle Susitna River, Alaska. Sampler not drawn to scale.

the non-suspended portion of the substrate materials was removed from the sampler, the remaining water (containing the suspended sediments) was agitated to bring additional fines into suspension taking care to avoid formation of a vortex. After thoroughly agitating the water column, a one liter aliquot was removed, placed in plastic containers and returned to the laboratory for further processing. The non-suspended and suspended portions of each substrate sample were subsequently analyzed for size class distributions.

At the laboratory, the non-suspended portion of the substrate samples were dried in an oven for approximately 24 hours at a uniform temperature of 110°C. Once dried, samples were gravimetrically analyzed using a series of six sieves of 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 assessment of substrate materials in spawning areas (Vincent-Lang et al. 1984). After sieving, the dry weight of each size class of non-suspended sediment was measured to the nearest gram and expressed on a percentage basis.

The amount of suspended sediment 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 extrapolated to the entire volume of water inside the McNeil sampler. This quantity was 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.

2.2.1.3 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; water velocities were obtained with a Marsh-McBirney (Model 201) flow meter using procedures described in ADF&G (1984).

2.2.1.4 Turbidity

Turbidity samples were collected in clean 250 ml Nalgene bottles. Bottles were filled approximately two-thirds full and stored in a cool environment until analysis could be completed. Samples were analyzed using an HF Instruments (Model 2100A) turbidimeter.

2.2.2 Chemical Variables

2.2.2.1 Dissolved Oxygen

It was necessary to measure intragravel DO values directly within the PVC standpipe to obtain the most accurate values. Therefore, intragravel dissolved oxygen (DO) measurements were obtained inside the

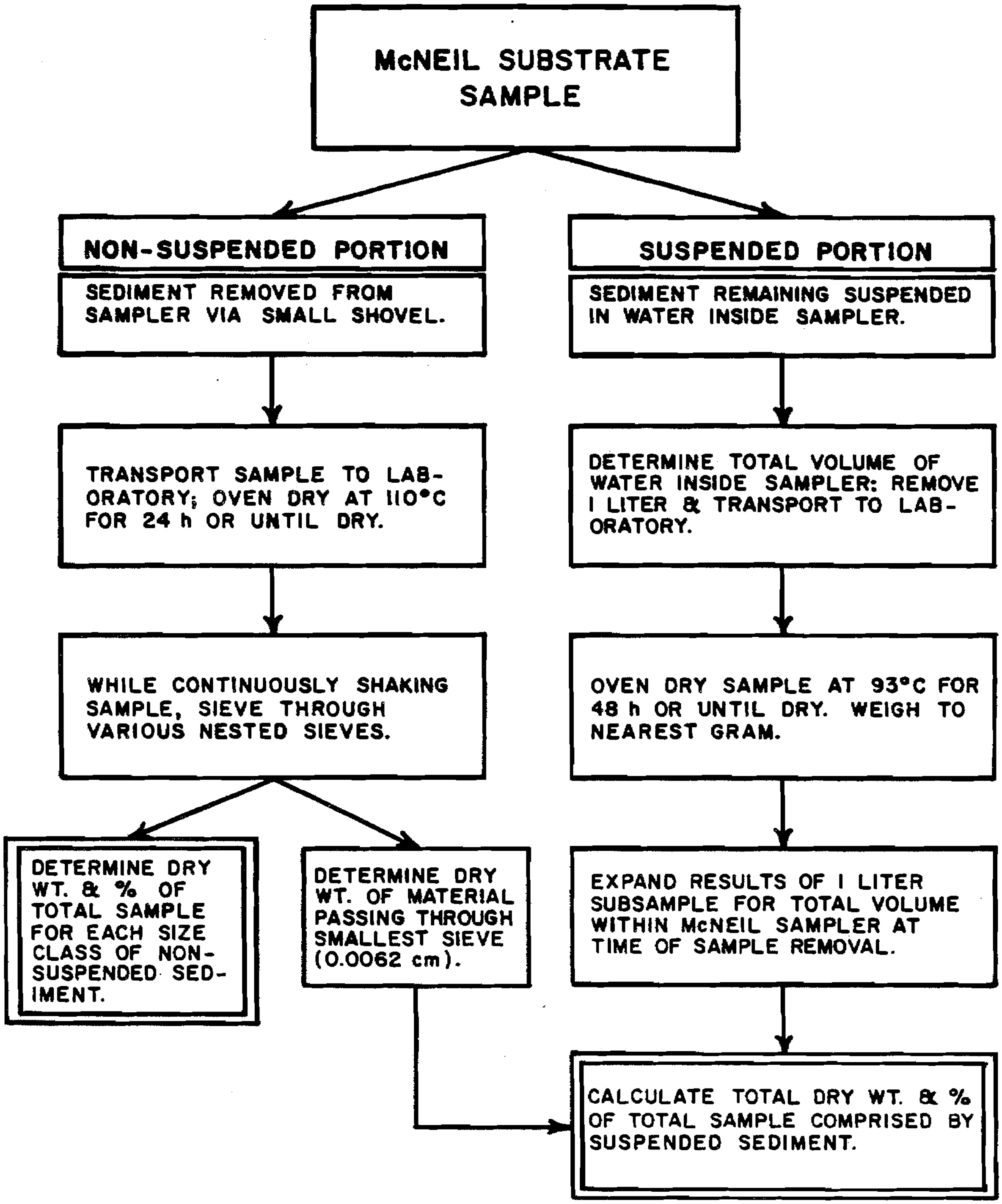

Figure 6. Summary of methods used to evaluate substrate conditions obtained with a modified McNeil substrate sampler.

PVC standpipes using a YSI (Model 57) dissolved oxygen/temperature meter because this meter has a probe that is the proper diameter to fit inside the standpipes used in this study. Dissolved oxygen measurements were obtained 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). The probe was then gently agitated to circulate water over the DO membrane and measurements were recorded when the reading stabilized. 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 surface water DO measurements of surface water outside the standpipe at each site following procedures described in ADF&G (1984).

2.2.2.2 pH

Surface water measurements of pH outside standpipes, and intragravel measurements, were obtained at each site with a Hydrolab (Model 4041) water quality meter following procedures described in ADF&G (1984). Intragravel measurements 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 meter.

2.2.2.3 Conductivity

Intragravel and surface water measurements of conductivity were obtained inside of, and outside of standpipes at each site using a YSI specific conductance/temperature meter (Model 33) 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 Salmon Embryo Development and Survival

2.3.1 Whitlock-Vibert Incubation Boxes

Whitlock-Vibert Boxes (WVBs) have been used in previous studies as experimental incubation chambers for evaluating the effects of environmental variables in survival of salmon embryos (e.g., Reiser and Wesche 1977; Reiser 1981; Reiser and White 1981a). As originally designed, each WVB is constructed from molded polypropylene which is 145 x 90 x 60 mm in size and contains two chambers. The upper chamber used for egg incubation is separated by a grid-like partition from the lower nursery chamber. This two-chambered design has been found to result in an excess accumulation of fine sediment 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.

The modified WVBs were also filled with spawning gravel (1.35-2.5 cm; 0.5-1.0 in. diameter) as an additional measure to reduce the accumulation of fine substrate particles in the boxes and also to simulate near-natural conditions favorable for embryo incubation. The size range of gravel selected provided interstitial spaces large enough to separate eggs and allow free movement of intragravel flow, and yet was small enough to pack conveniently into the WVB's. Fifty fertilized eggs were placed between alternating layers of gravel within each WVB.

To evaluate the degree to which these modifications were successful in reducing the accumulation of fines, a comparision was made between the composition of fine substrates obtained within WVBs (resident in the streambed for a period of 3-5 months) to substrate samples obtained with a McNeil sampler at the same location. Each Whitlock-Vibert Box sample was analyzed in the same manner as the non-suspended sediment portion of the McNeil substrate samples (refer to Section 2.2.1.2) with the suspended portion of the 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 substrate fines to insure that the WVBs were not accumulating excess fines that might affect survival of incubating embryos.

Modified WVB's were used as experimental embryo incubation chambers to assess development and survival of chum salmon embryos at the eight primary study sites. 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 in WVBs. Embryos were allowed to water-harden for two hours and were gently transferred from a large container to the WVBs. The entire process of placing embryos and sifted gravel within the WVBs was conducted inside a dome tent to shield the eggs from harmful ultraviolet rays from the sun (Smoker and Kerns 1977). Embryos were kept in a water bath maintained at local water temperatures.

The WVBs 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. Such areas represented a range of environmental conditions present at each site. At the other two 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 exposed to similar environmental conditions. One additional site used to assess embryo development was physically

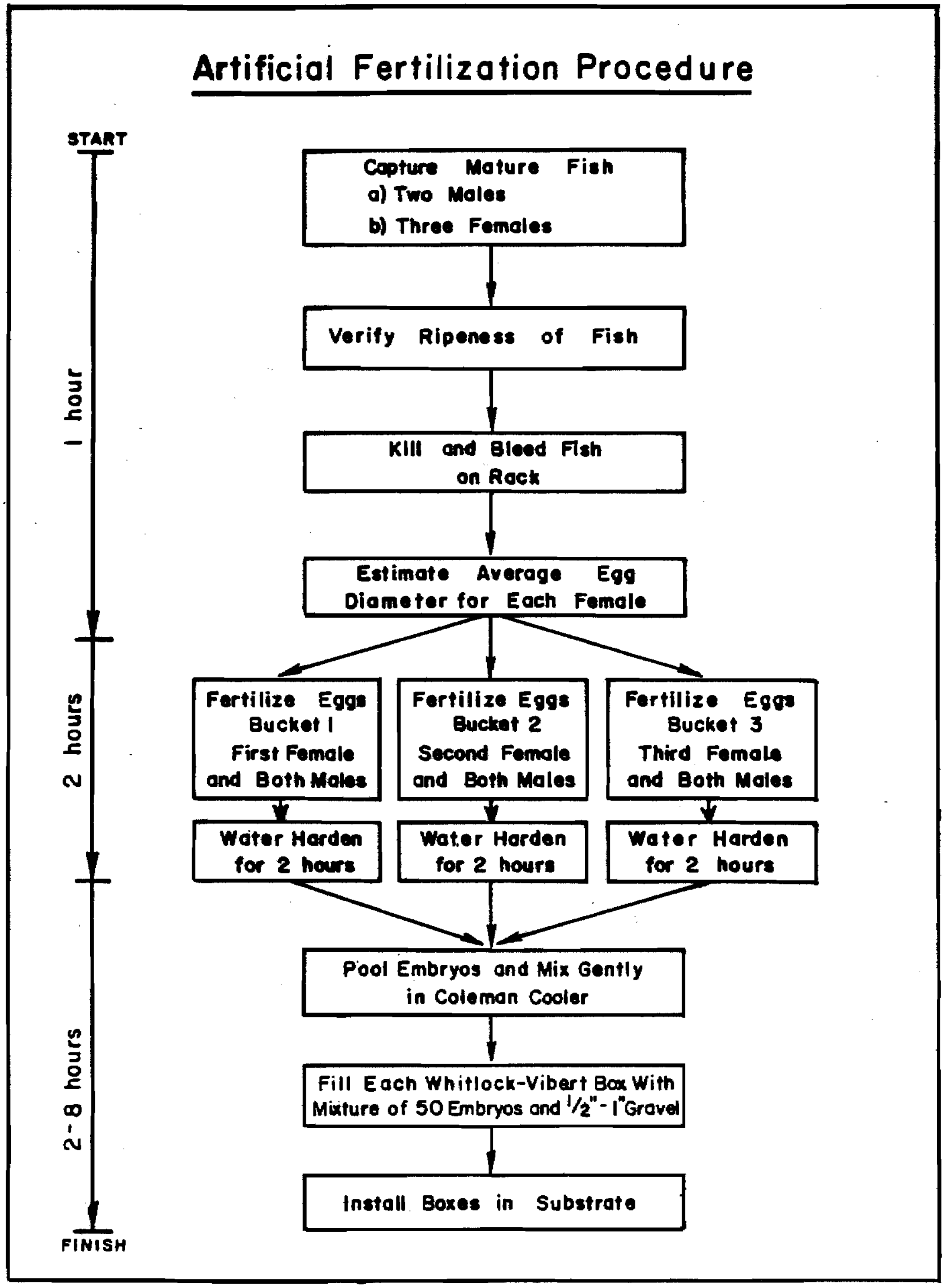

Figure 7. Flow diagram depicting the sequence of events which occurred during the artificial fertilization of salmon eggs and the subsequent installation of artificial incubation chambers (Whitlock-Vibert Boxes) in the streambed.

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 WVBs. Two WVBs and one PVC standpipe were placed in each excavated hole; the holes were subsequently refilled with the surrounding gravel. A nylon cord marked with orange flagging was attached to each WVB and to a large steel spike (30 cm; 12 in.) for future reference. The location of each WVB was also determined using standard survey techniques.

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 (Plate 3). 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 immediately 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.

2.3.2 Analysis of Development and Survival of Embryos

2.3.2.1 Embryonic Development

Embryonic development data collected during this study focused on comparing the rate of embryonic development between slough, side channel, and mainstem habitats. For the purposes of this study, embryo development only included the period of development from fertilization to hatching and did not include the alevin yolk sac absorption period.

Embryonic development was evaluated in this study using both artificially fertilized and naturally fertilized embryos. Because of the advantage of knowing the exact date of fertilization, the majority of the evaluation was devoted towards assessing development of artificially fertilized embryos.

Artificially fertilized embryos were placed in four selected study sites (Slough 11, Upper Side Channel 11, Side Channel 21, and Mainstem RM 136.1) considered representative of embryonic development conditions in

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

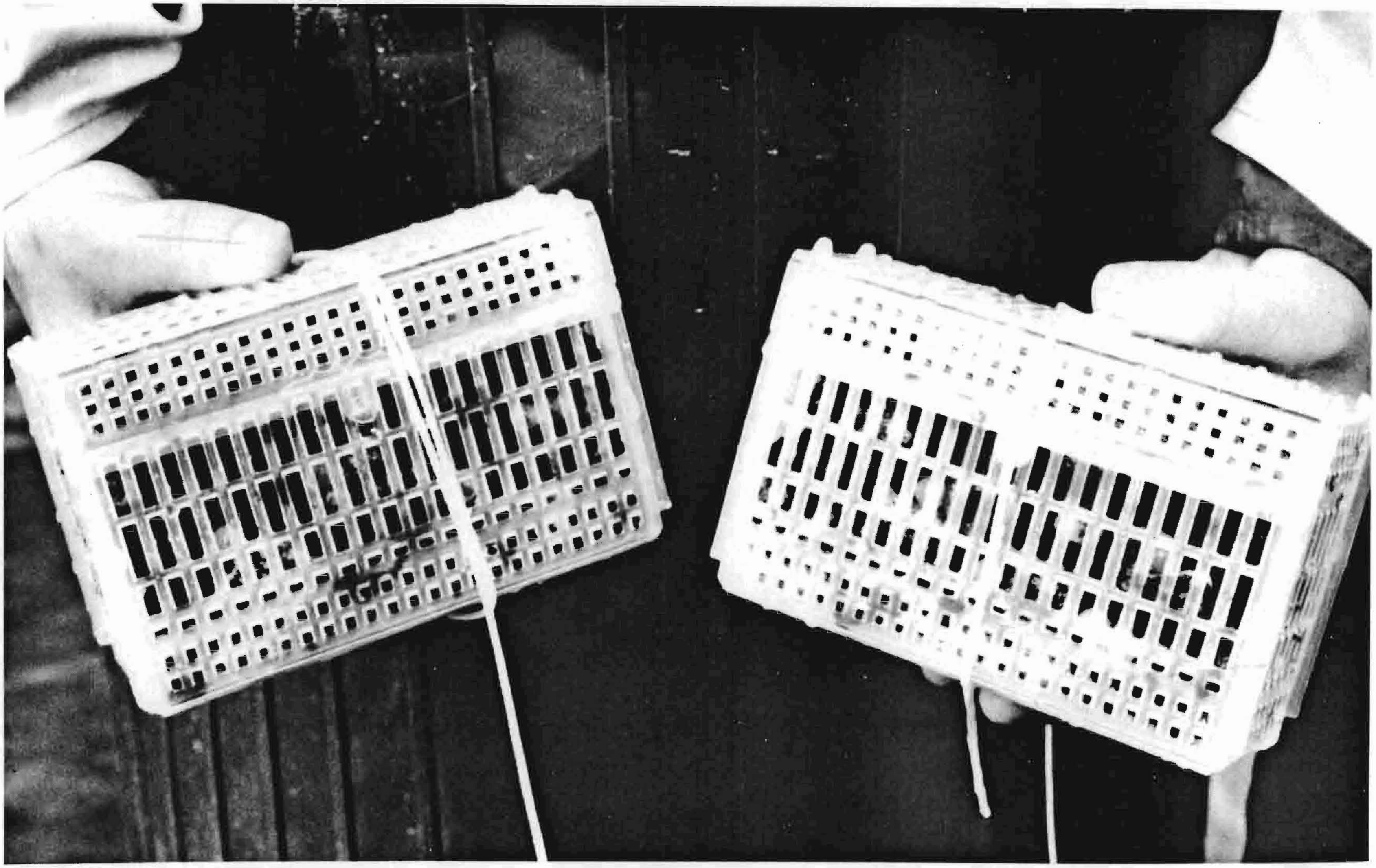

Plate 3. Whitlock-Vibert Boxes each containing sorted gravels and 50 chum salmon embryos, wrapped with a nylon cord. The nylon cords were later used to remove boxes from the substrate.

slough, side channel, and mainstem habitat types. Slough 11 and Upper Side Channel 11 were selected to represent slough and side channel habitats which are strongly influenced by upwelling water that have previously been used by chum salmon for spawning. Side Channel 21 was selected as a comparative side channel site to provide a contrast to Side Channel 11. These two side channel sites are of the same habitat type, yet differ markedly in hydrological characteristics. The site where embryos were installed in Upper Side Channel 11 was strongly influenced by upwelling water, whereas the site in Side Channel 21 did not have observable upwelling vents. The site at Mainstem, RM 136.1, was selected to represent a typical mainstem habitat which was not influenced by upwelling water.

Embryos were implanted in WVBs at three of the above mentioned sites (Slough 11, Upper Side Channel 11, and Mainstem RM 136.1). Embryos for implantation into these sites were obtained from adult chum salmon captured on August 26, 1983 in Slough 11. Embryos were artificially fertilized, placed in WVBs, then temporarily stored in streamside incubators in a small tributary at Slough 9. This temporary storage measure was necessary for two reasons: (1) to allow the stage at Mainstem (RM 136.1) to become low enough to enable WVBs to be properly installed at a location which would not later become dewatered; and (2) to ensure that embryos had developed beyond the stage where they would be adversely affected by near-zero mainstem water temperatures. Since this temporary measure was required in order to implant embryos in the mainstem site, embryos intended for implantation in the other two sites were exposed to identical conditions in order to maintain a uniform experimental design.

The streamside incubators consisted of plastic 30 gallon garbage cans which were modified by cutting numerous vertical openings in the sides to allow ample circulation of water. These incubators were then secured in a deep pool in the tributary at Slough 9 along with a Ryan-Peabody thermograph which was used to obtain a continuous temperature record.

The WVBs placed inside the two incubators were left until 1 October, at which time the stage in the mainstem decreased sufficiently by October 1, 1983 to allow field personnel to install WVBs at the Mainstem RM 136.1 site. Also, by this time, embryos had developed past the point where they would be adversely affected by low mainstem temperatures. At this time the WVBs were transported by boat to each of the three study sites. At each site at least 15 WVB were placed in a trench approximately five feet in length. Boxes were placed at an approximate depth of 10 in. (25 cm) and covered with surrounding substrate. Three polyvinyl chloride standpipes were installed at the upstream side of the trench to allow intragravel water quality variables to be measured. Temperature data was collected at each site with continuous temperature recorders. Ryan-Peabody thermographs were buried in the substrate at Slough 11 and Mainstem (RM 136.1) sites whereas, a datapod temperature recorder was used at Upper Side Channel 11. Procedures for the installation and maintenance of these continuous temperature recorders are summarized in Appendix F.

The WVBs at these sites were removed throughout the embryo incubation period. At this time, embryos were removed from WVBs and preserved in the same manner described above.

Embryos were then transported to a laboratory where the stage of embryonic development was determined. Embryos for implantation into Side Channel 21 were obtained on September 13, 1983 from adult fish captured in Slough 21. Artificially fertilized embryos were placed without using WVBs in two artificial redds dug with a shovel in a portion of the channel which was not expected to dewater. Two standpipes were located in each redd. Embryos were later removed by digging in the redd with a shovel and capturing the dislodged embryos with a small hand net. Embryos were preserved and returned to the laboratory in the manner described above in order to determine other stages of embryonic development.

The stage of development of embryos was determined by observing preserved embryos under a dissecting microscope at 3X magnification. Stockard's solution was selected as a preservative 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.

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 basis 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 4 through 7 show chum salmon embryos at selected stages of development.

It was intended that comparisons of embryonic development between sites would include a presentation of the rate of accumulation of temperature units (TUs).[a] However, the temperature data which was collected at many sites was fragmentary which eliminated this approach as a viable option. As an alternative, comparisons of embryonic development between sites were made by plotting the stage of development at each site on the Y axis and date of collection on the X axis. In cases where several samples were obtained at a site on the same day, the number of embryos at a particular stage were summed and the stage having the largest number of embryos assigned to it was the only stage which was plotted.

Embryo development was also assessed at Fourth of July Creek, Slough 10, Side Channel 10, and Slough 21. Data obtained at these sites, however, did not provide a consistent record of development because data obtained

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[a] Temperature units are derived for a specified period of time by calculating and summing the differences of the mean daily temperature above 0°C for each day in the specified period.

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	Characteristics of Stage: 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

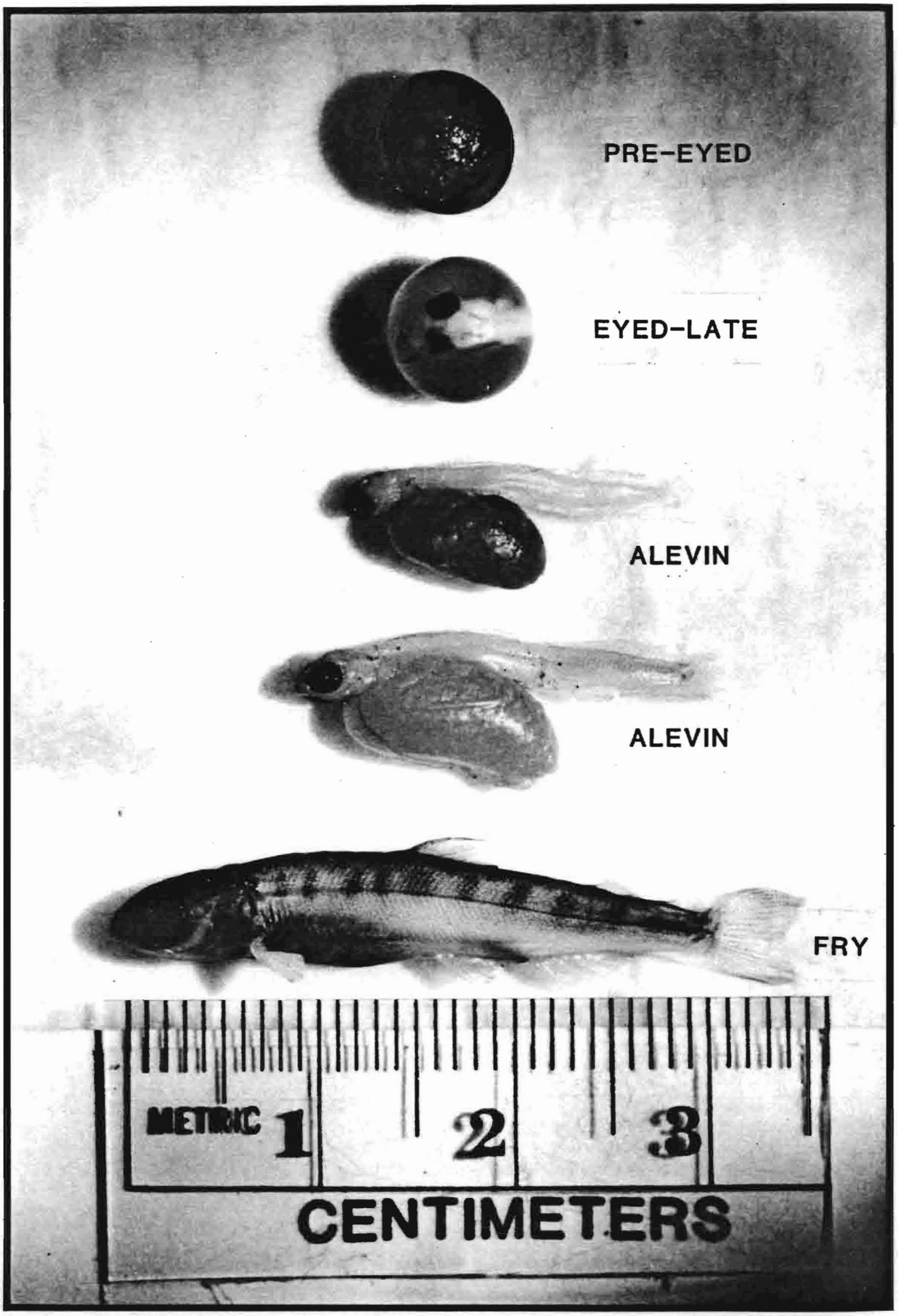


Plate 4. Various stages of embryonic development of chum salmon from fertilization to complete yolk-sac absorption.

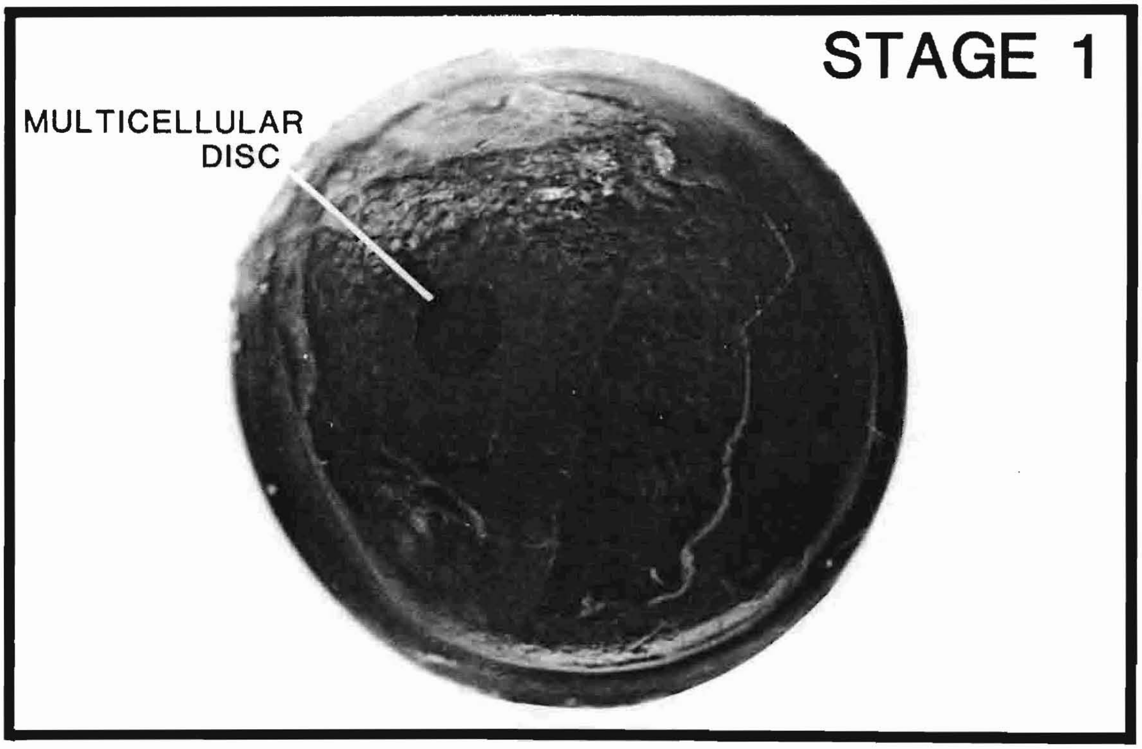


Plate 5. Chum salmon embryo late in the cleavage stage.

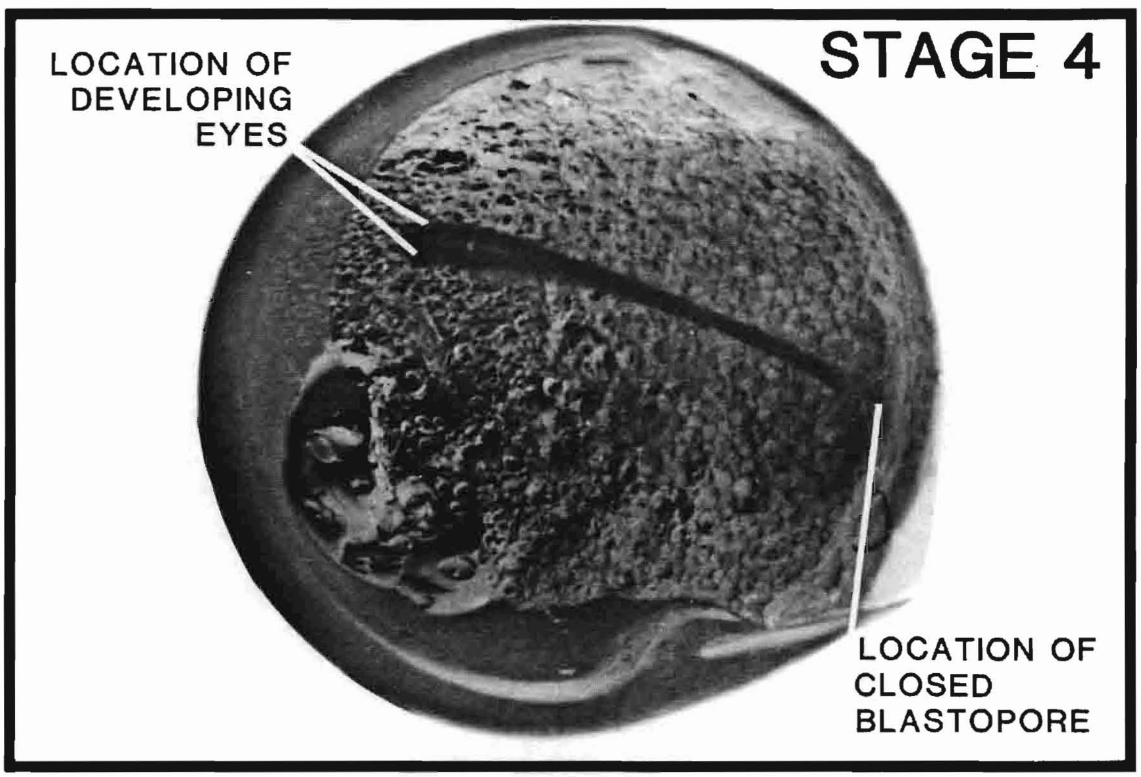
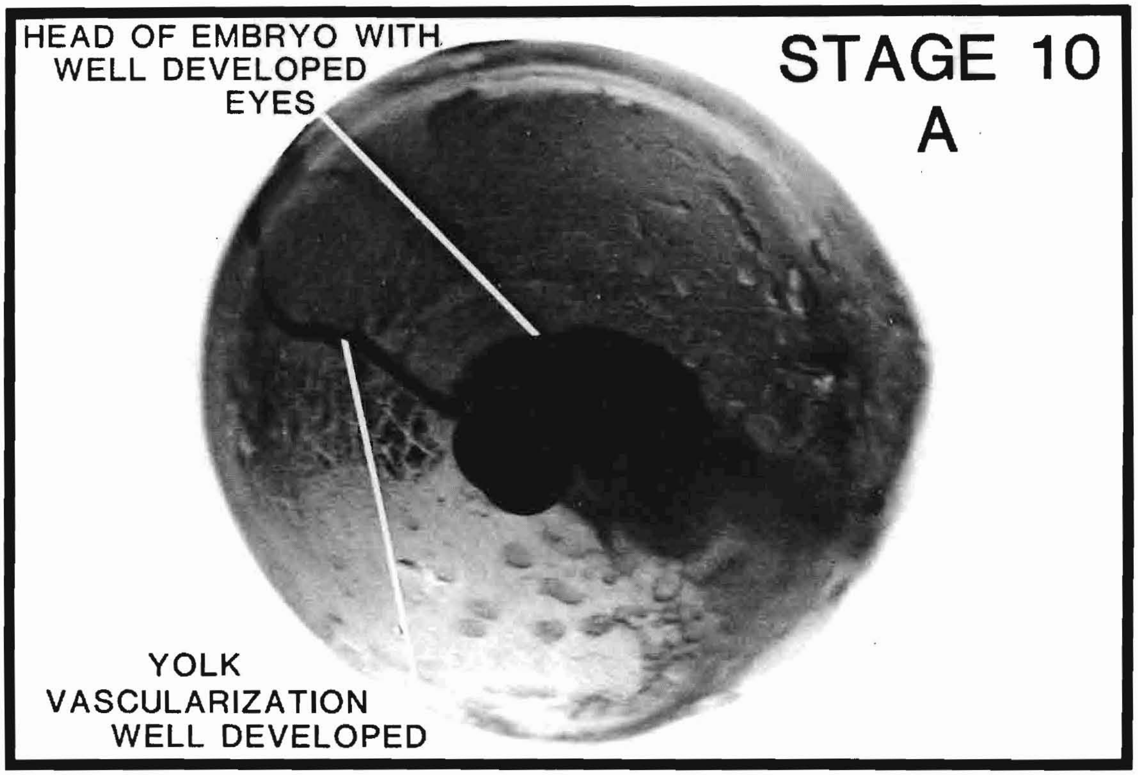


Plate 6. Chum salmon embryo at late gastrulation.



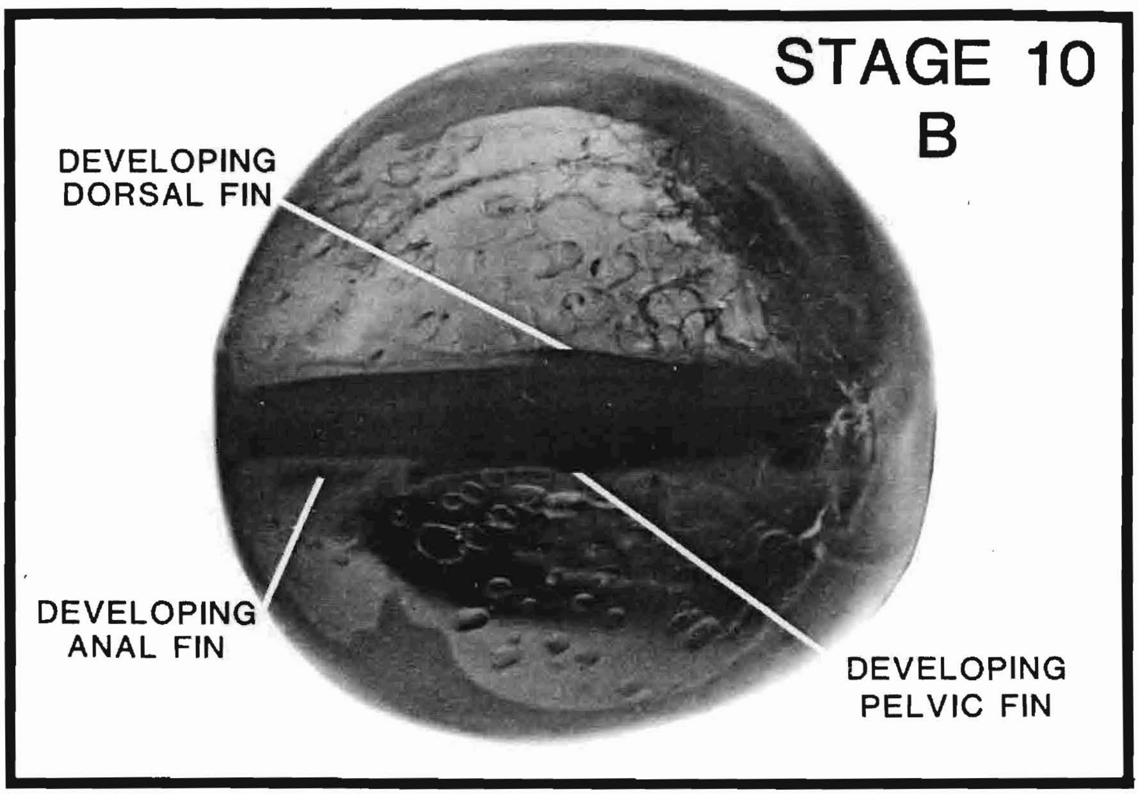


Plate 7. Head (A) and body (B) of a chum salmon embryo at late organogenesis.

at these sites was primarily used to evaluate survival. Because of this, the time of removal of WVBs from these sites did not conform to a uniform pattern. For this reason, development data from these sites are not used in further analyses but are reported in Appendix A.

2.3.2.2 Embryonic Survival

Embryonic survival data collected during this study focused on (1) comparing differences in the survival of embryos in slough, side channel, tributary, and mainstem habitats and (2) evaluating the influence of selected physical, chemical, and water quality variables on the survival of chum salmon embryos. Variables evaluated included substrate fines, pH, conductivity, dissolved oxygen, and temperature.

The survival of chum salmon embryos for this evaluation was determined at all primary sites except upper Side Channel 11. At each site, artificially fertilized chum salmon embryos were placed in WVBs and buried in artificial redds following procedures outlined in Section 2.3.1. At estimated 100% hatch, WVBs containing embryos were removed, placed in a cooler, and transported to a heated field station where embryos were removed from the boxes. Embryos were placed in Stockard's solution and returned to the laboratory for analyses. In the laboratory, 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 whereas dead embryos were often opaque and colonized by fungus. Missing embryos were considered to be dead since field observations indicated that it would be unlikely for hatched alevins to escape the WVB with any portion of the yolk-sac attached.

At many of the study sites, the water level dropped significantly during September and October, resulting in the dewatering and subsequent freezing of many locations where WVBs were installed. Because it was observed that all embryos died in areas that became dewatered and subsequently frozen, the analysis of embryo survival data was separated into two parts to distinguish between the deleterious effects of dewatering and freezing and effects of other habitat variables on embryo survival. The two analyses performed were: (1) one in which the percent survival of chum salmon embryos were determined for all WVB samples; and (2) another in which the percent survival of embryos was determined after all "dewatered and frozen" WVBs were removed from the analysis. Determination of the "dewatered and frozen" condition of WVBs was made by visual observations while in the field.

To compare differences in the survival of embryos at study sites and habitats, histograms of embryo survival at individual study sites and at study sites grouped by habitat were constructed. Equal weight was given to each study site in the development of these histograms regardless of the number of WVBs at a study site. Separate histograms were constructed for both the "complete" and "frozen eliminated" data groups discussed above.

To evaluate the influence that percent substrate fines, pH, conductivity, dissolved oxygen, and temperature have on embryo survival, plots of embryo survival versus these habitat variables were constructed. Only survival data from the unfrozen data group were plotted. For each plot, a coefficient of linear regression was calculated using procedures described in Snedecor and Cochran (1980).

2.3.2.2.1 Handling Mortality

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.

2.3.2.2.2 Flatworms

During the course of the field sampling program, it was noticed that relatively large numbers of embryos were missing from Whitlock-Vibert Boxes retrieved from several study sites. Based on visual assessments at the time of retrieval, an abundance of flatworms (Turbellaria) appeared to coincide with the absence of embryos within the WVBs. In light of these observations, an effort was made to determine if there was a relationship between the presence of flatworms and the absence of embryos within WVBs.

To determine whether the presence of flatworms could be correlated to the absence of embryos in WVBs the abundance of flatworms in each retrieved WVB was visually assessed in the field and subjectively assigned a rank from one to four (one = highest abundance). This rank was later correlated to the number of missing embryos using a Spearman rank correlation coefficient (Snedecor and Cochran 1980).

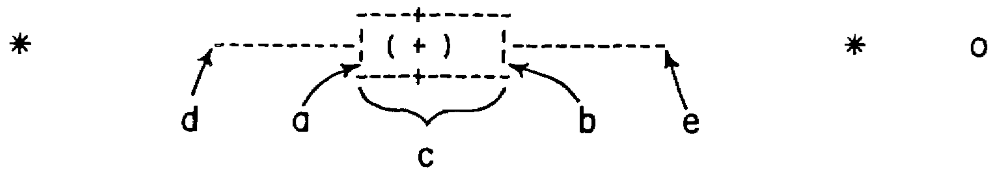
2.4 Interpretation of Figures

Results in this section are shown in several types of figures of which three warrant a description of symbols used. These are referred to as 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). 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 explained in Figure 8.

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 in a figure 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, C=12, etc.).

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



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 percent confidence limit about the median): median $\pm$ 1.58 x (H-spread)/$\sqrt{n}$

Figure 8. Definitions of symbols used in boxplots which summarize water temperature, dissolved oxygen, pH and conductivity data.

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 evaluated (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 evaluated; and (3) an evaluation of the influence of selected physical, chemical and biological characteristics on the survival of chum salmon embryos at study sites and among habitat types.

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

Detailed results of the physical and chemical characteristics of study sites are presented in this section. A summary of these data are presented in Table 3.

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 9 and 10, 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.

Generally, the data show that instantaneous intragravel water temperatures were least variable in mainstem and slough habitats and most variable in tributary and side channel habitats.

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 11-13, respectively. The combined data from the three habitat types are presented in Figure 14. Data used to develop these figures are presented in Appendix C (Table C-2).

Table 3. Summary of physical and chemical water quality data collected during the 1983-84 incubation study presented by study site and habitat type.

Study Site or Habitat Type	Sampling Period	Range of Surface Water Variables: Temperature (°C)	Dissolved Oxygen (mg/1)	pH	Conductivity (umho/cm)	Range of Intragravel Water Variables: Temperature (°C)	Dissolved Oxygen (mg/1)	pH	Conductivity (umho/cm)
Fourth of July Creek	09/14/84 - 12/03/84	-0.3 - 11.1	9.3 - 14.8	6.3 - 7.6	19 - 162	0.0 - 8.2	9.6 - 13.8	6.3 - 7.2	24 - 150
Slough 10	09/15/84 - 12/06/84	0.1 - 9.1	8.1 - 10.9	6.6 - 7.4	106 - 226	0.2 - 7.0	0.4 - 8.3	6.2 - 7.5	134 - 659
Side Channel 10	09/15/84 - 12/06/84	0.1 - 12.7	4.0 - 13.4	6.6 - 7.8	217 - 269	0.0 - 12.5	3.3 - 13.4	6.9 - 7.9	160 - 290
Slough 11	09/15/84 - 12/05/84	0.1 - 8.6	10.5 - 12.8	6.9 - 7.6	226 - 244	0.2 - 7.0	3.8 - 13.5	6.8 - 7.6	195 - 259
Upper Side Channel 11	11/09/84 - 12/08/84	0.2 - 12.0	8.5 - 11.3	7.3 - 7.8	138 - 203	2.0 - 3.0	5.5 - 5.7	7.2 - 7.6	116 - 143
Mainstem (RM 136.1)	11/09/84 - 12/08/84	-0.3 - 0.8	13.5 - 14.1	7.2 - 8.4	138 - 268	0.3 - 1.0	7.9 - 12.8	8.1 - 8.3	185 - 226
Side Channel 21	09/14/84 - 12/03/84	-0.3 - 11.0	10.8 - 14.9	7.3 - 7.9	119 - 194	0.0 - 7.2	6.5 - 14.7	6.6 - 7.5	54 - 184
Slough 21	09/13/84 - 12/02/84	0.8 - 11.9	6.2 - 11.6	6.6 - 7.8	122 - 213	0.9 - 7.0	1.4 - 10.7	6.9 - 7.5	100 - 237
Sloughs	09/14/84 - 12/06/84	-0.3 - 11.9	6.2 - 12.8	6.6 - 7.8	75 - 244	0.2 - 7.0	0.4 - 13.5	6.2 - 7.6	100 - 659
Side Channels	09/14/84 - 12/08/84	-0.3 - 12.7	4.0 - 14.9	6.6 - 7.9	119 - 269	0.0 - 12.5	3.3 - 14.7	6.6 - 7.9	54 - 290
Mainstem	11/09/84 - 12/08/84	-0.3 - 7.0	5.7 - 14.3	6.7 - 8.4	80 - 268	0.3 - 1.0	7.9 - 12.8	8.1 - 8.3	185 - 226
Tributaries	09/14/84 - 12/03/84	-0.3 - 11.1	9.3 - 14.8	6.3 - 7.6	19 - 162	0.0 - 8.2	9.6 - 13.8	6.3 - 7.2	24 - 150

[a] Only primary study sites are presented.

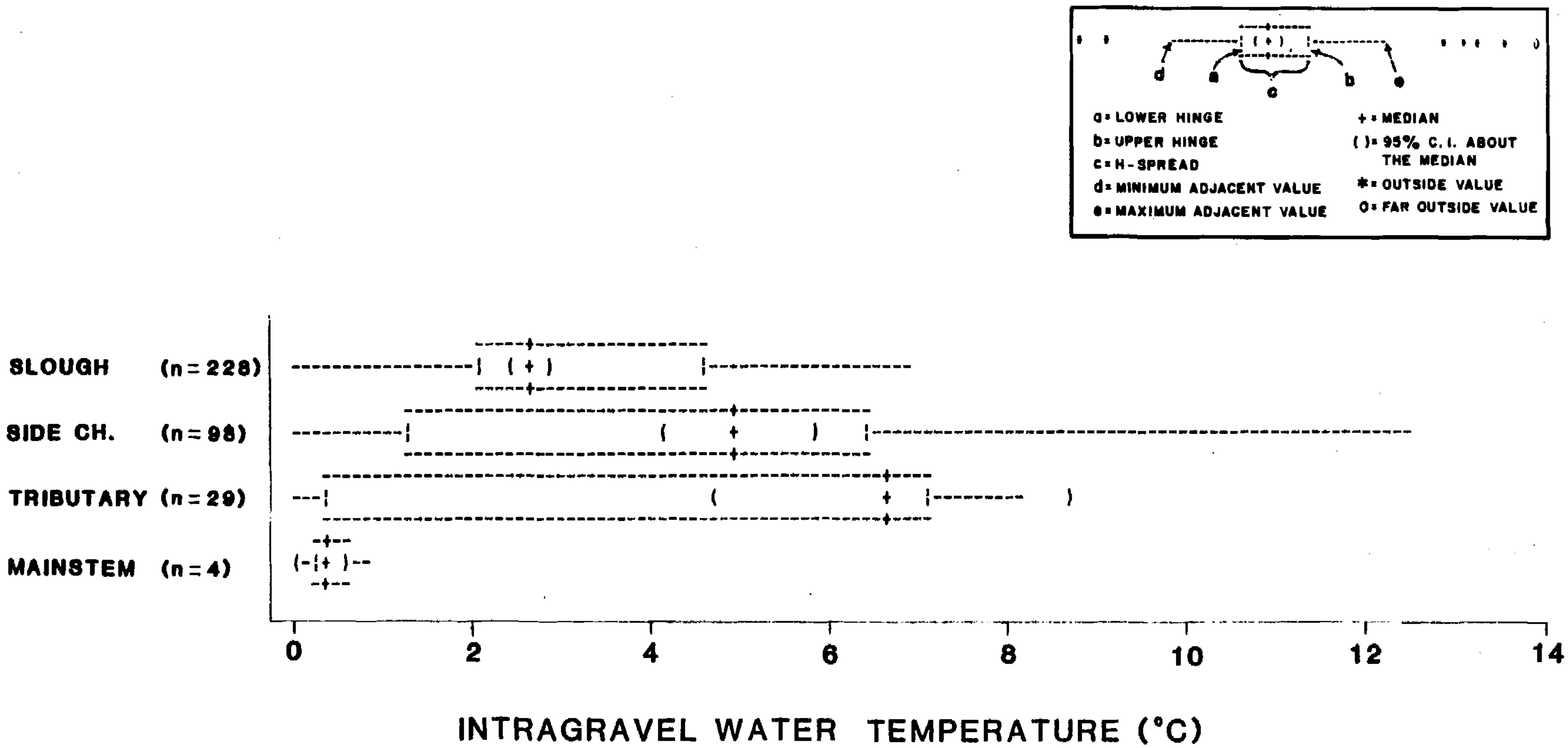


Figure 9. Summary, by habitat type, of the intragravel water temperature data (°C) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

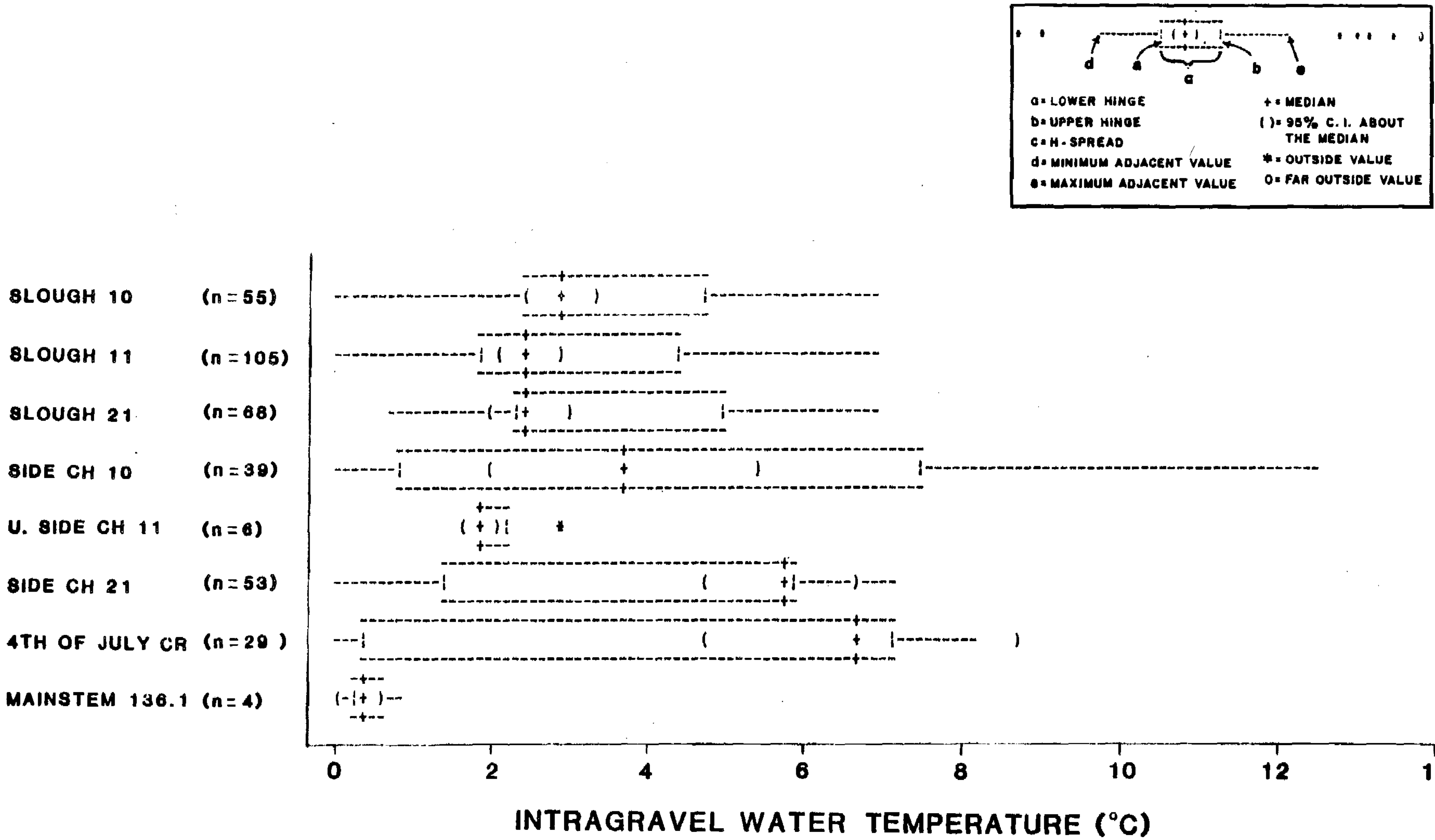


Figure 10. Summary, by study site, of the intragravel water temperature data (°C) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

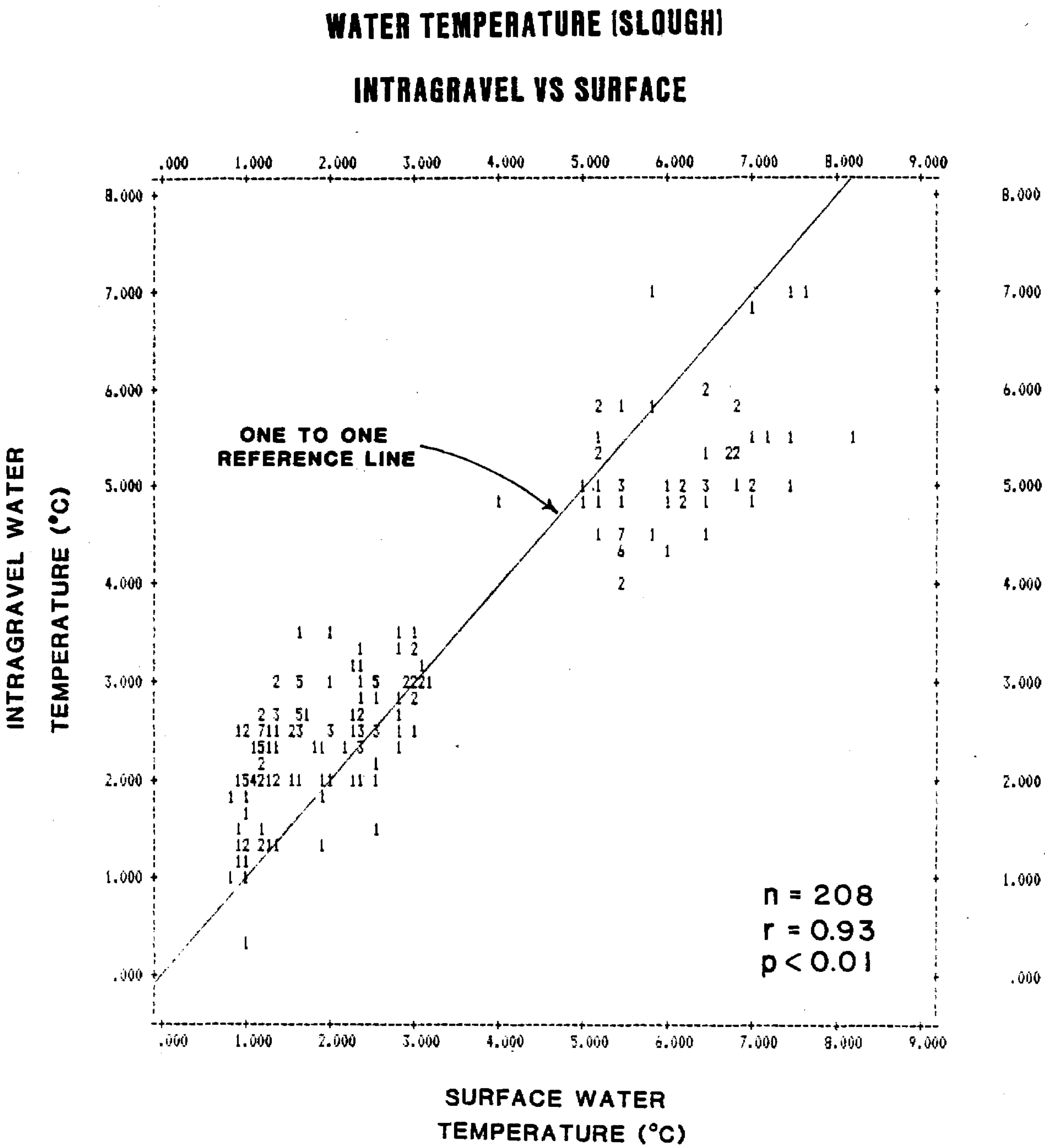


Figure 11. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within slough habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

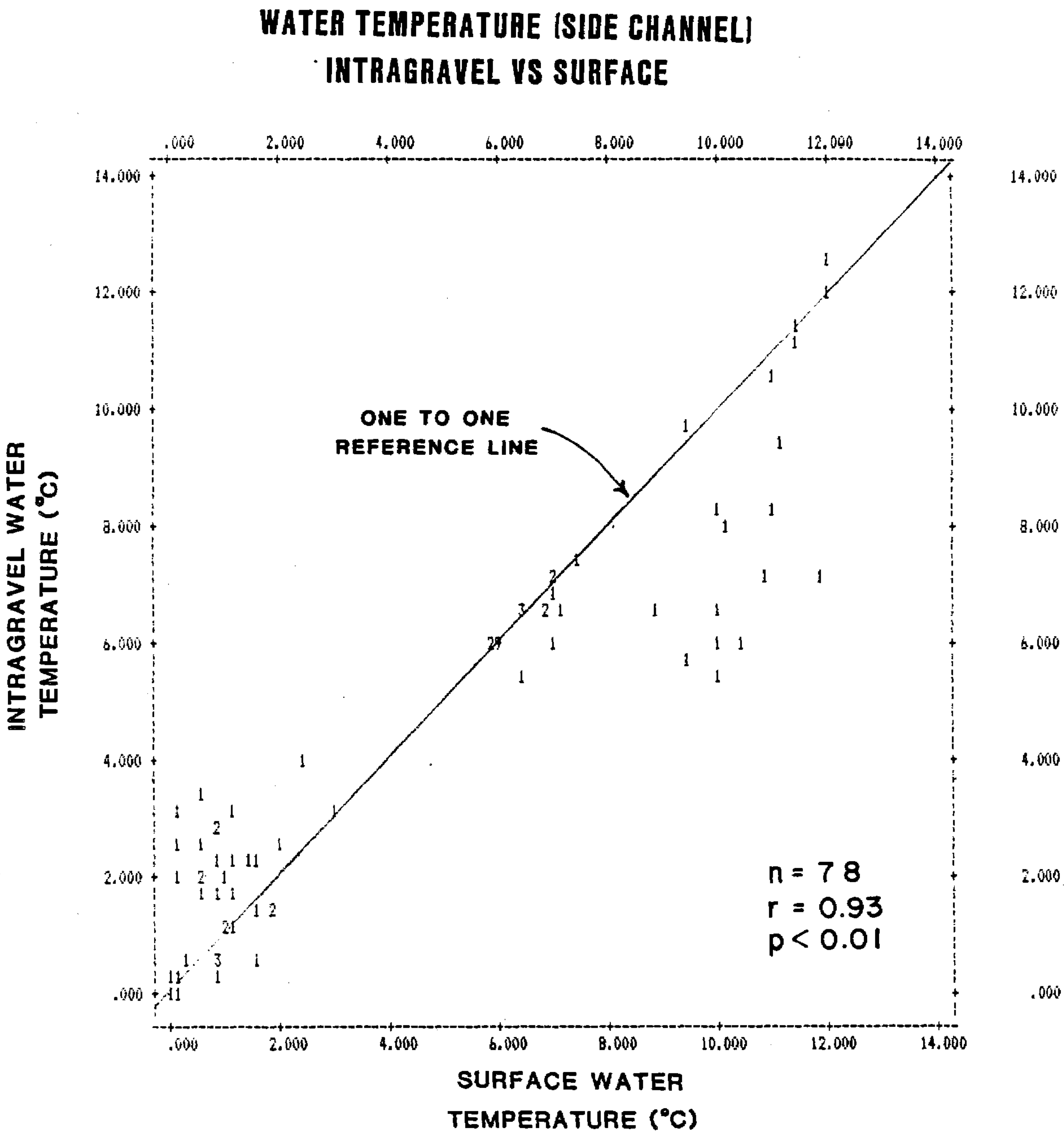


Figure 12. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within side channel habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

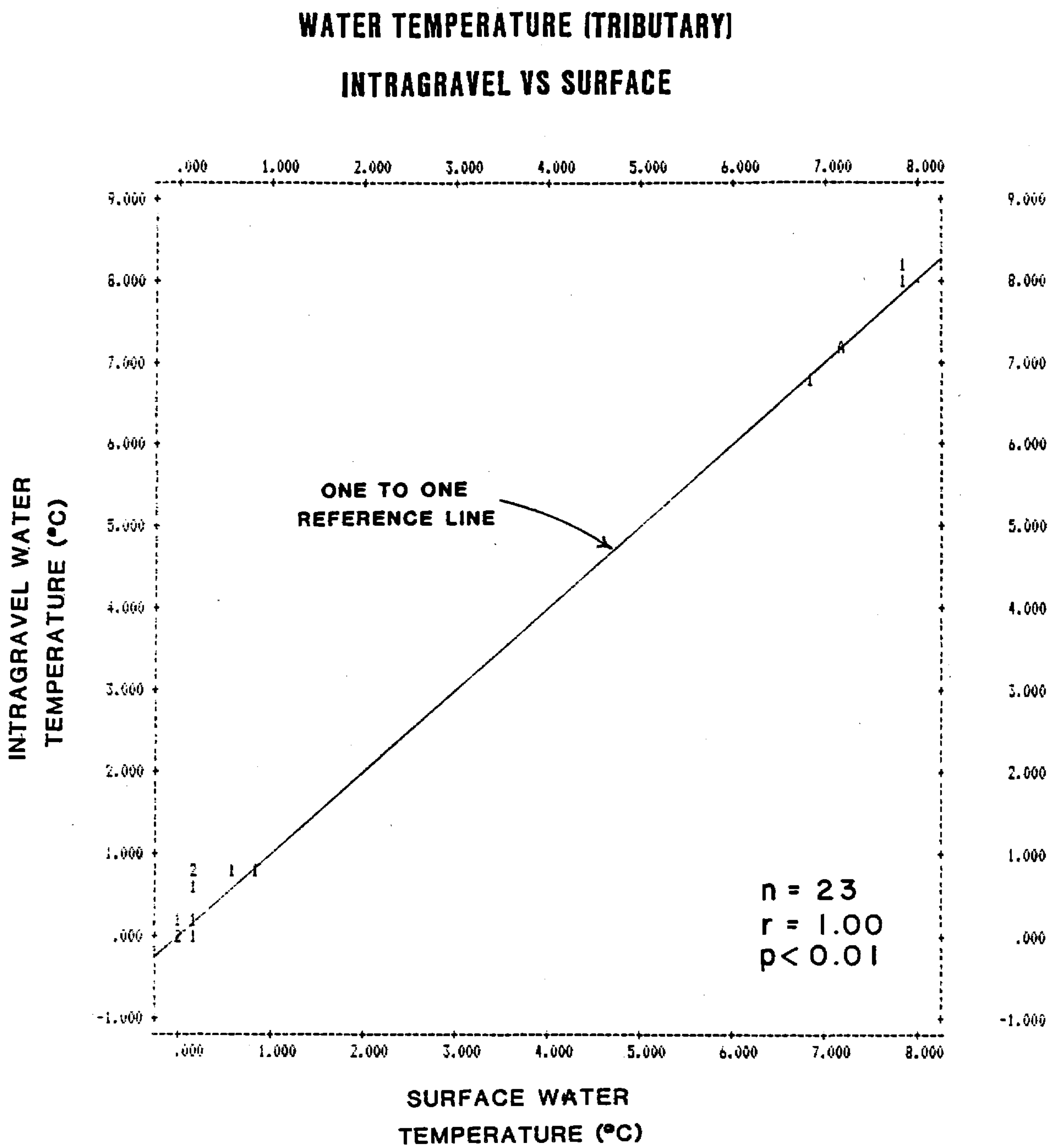


Figure 13. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within tributary habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

WATER TEMPERATURE (COMBINED HABITATS)

INTRAGRAVEL VS SURFACE

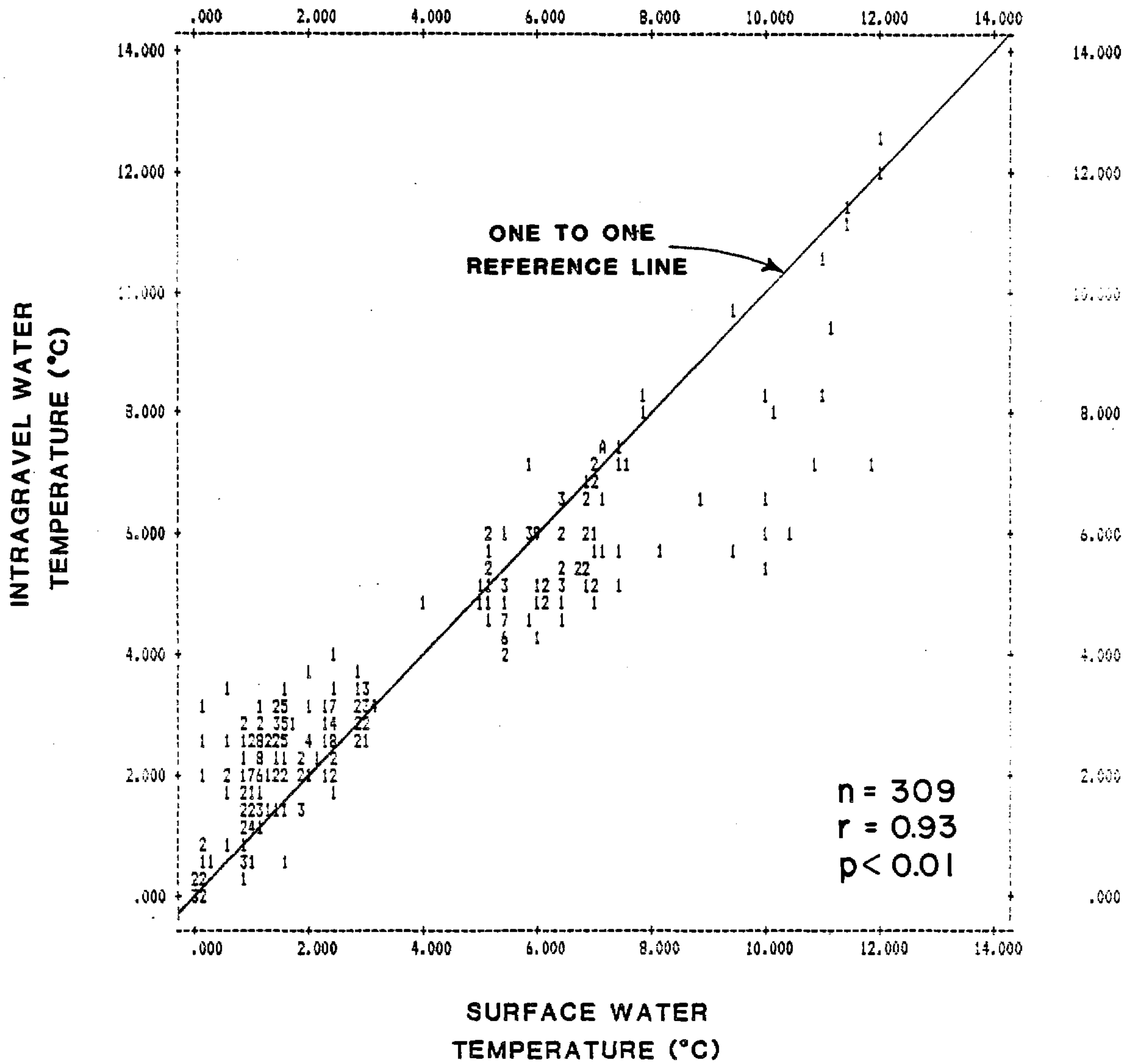


Figure 14. Relationship between intragravel and surface water temperatures (°C) measured at standpipes within slough, side channel, and tributary habitats of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

In each figure, there appears to be a direct relationship between surface and intragravel water temperatures. The effect appears most pronounced in slough habitats (Figure 11) which is likely related to the relatively greater influence of upwelling in this habitat type.

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 is included in Appendix F (Volume 2 of this report). 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 evaluate chum salmon embryo survival and/or development.

Figures 15 through 17 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 18 through 20 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 undergo greater variability over time compared to slough habitats.

In Figure 21, 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 22. 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

The percent dry weight, by size class, of substrate samples obtained with the McNeil sampler over the range of substrate conditions observed

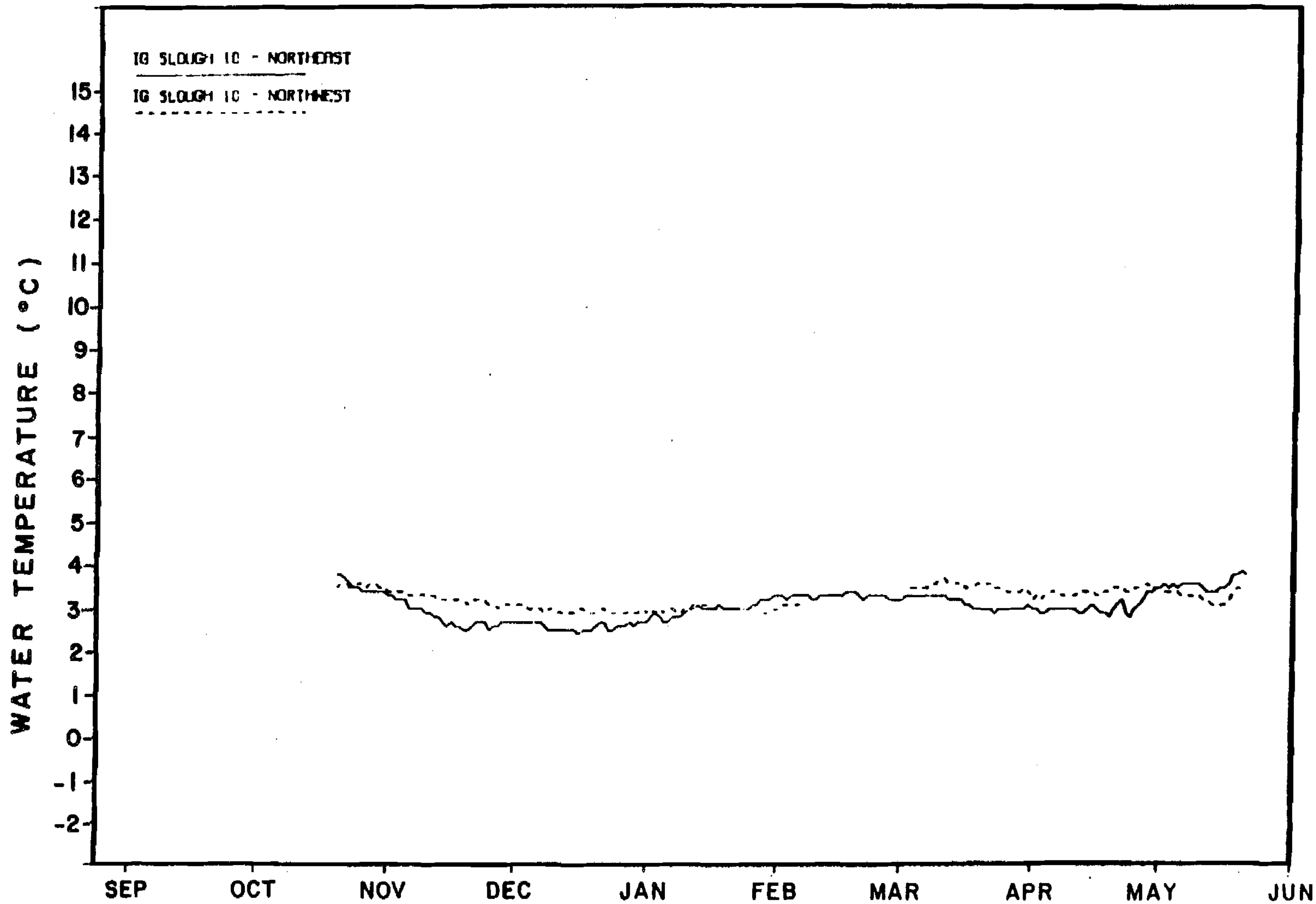


Figure 15. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Slough 10 (RM 133.8), middle Susitna River, Alaska.

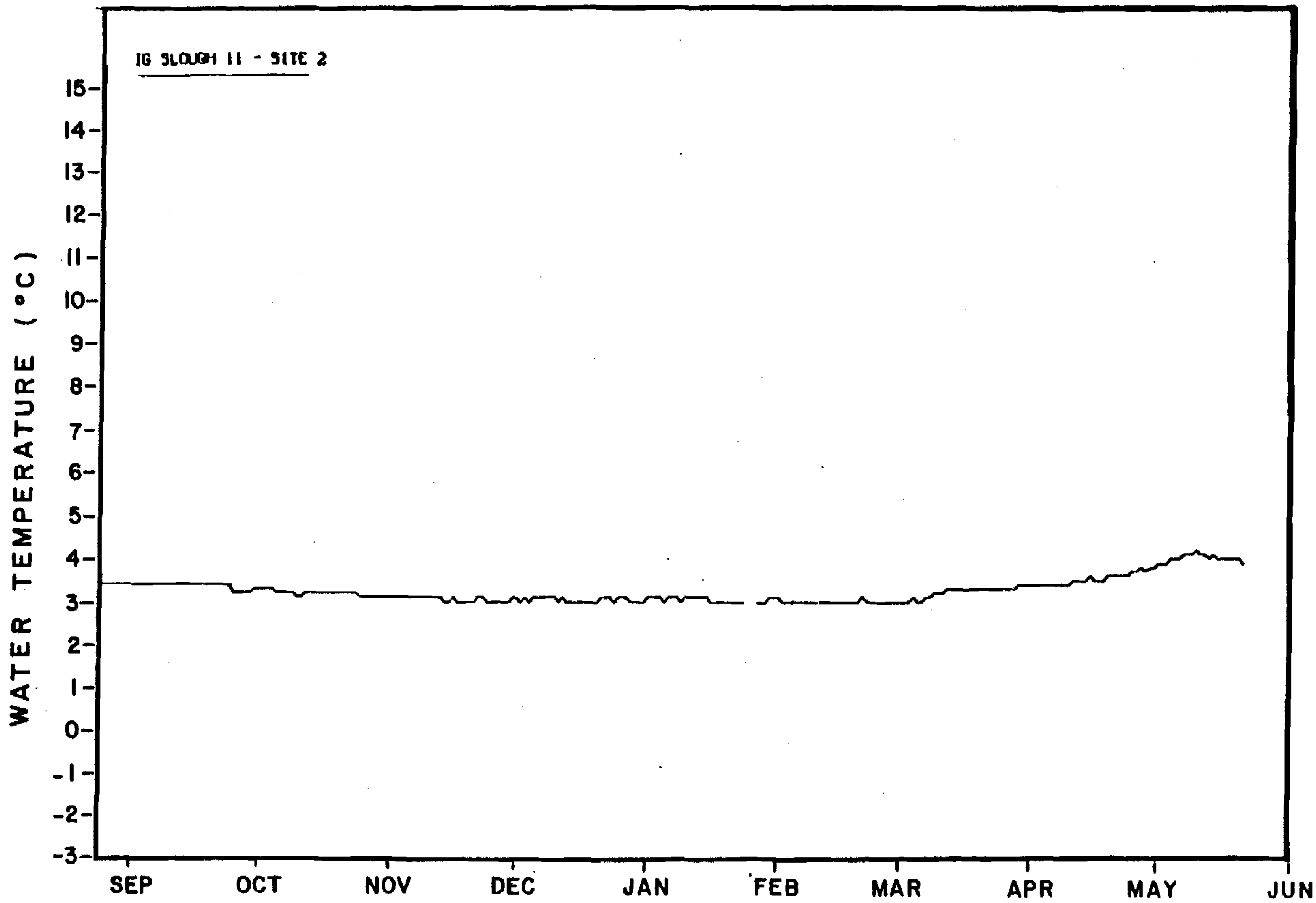


Figure 16. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Slough 11 (RM 135.3), middle Susitna River, Alaska.

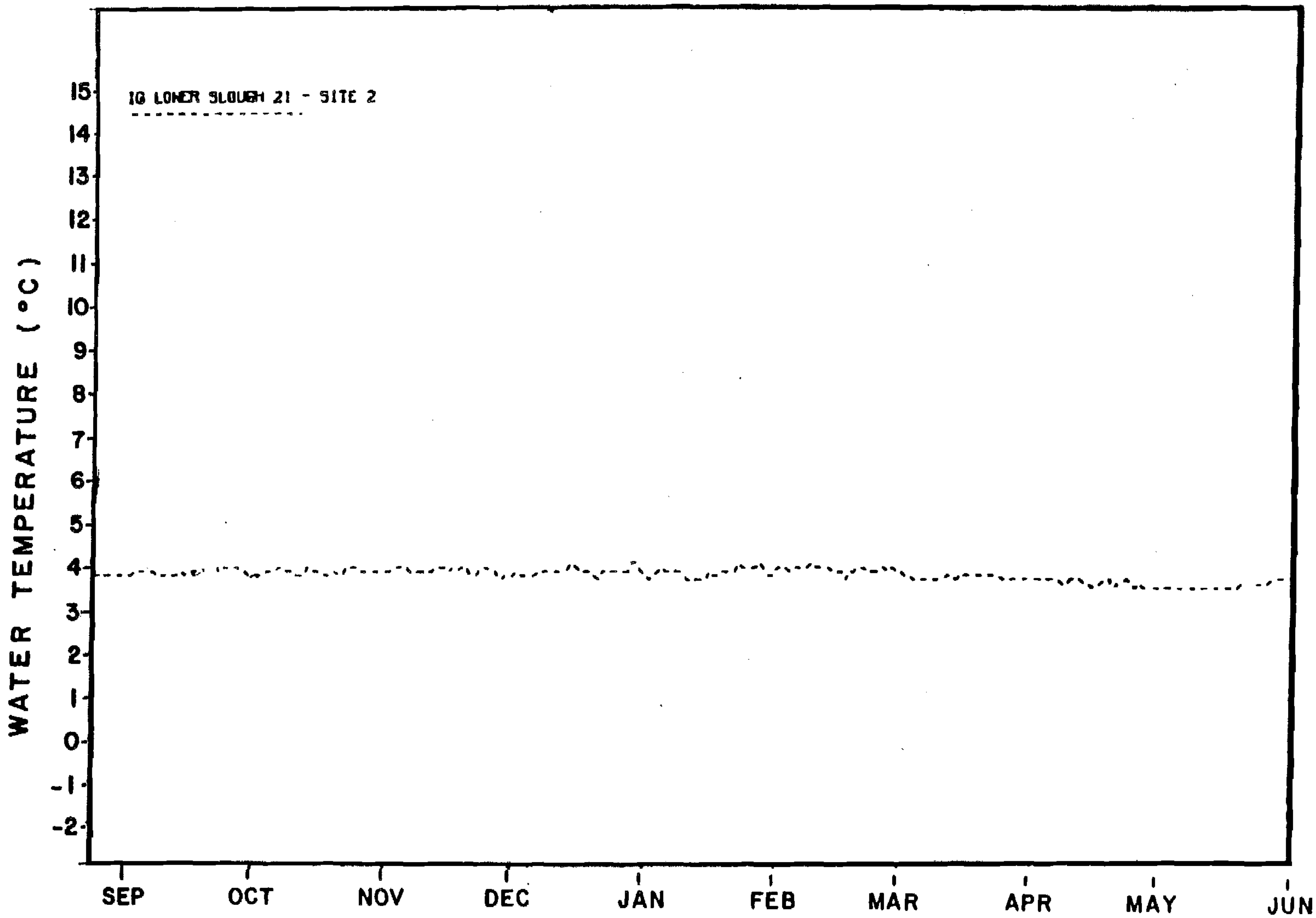


Figure 17. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Slough 21 (RM 141.8), middle Susitna River, Alaska.

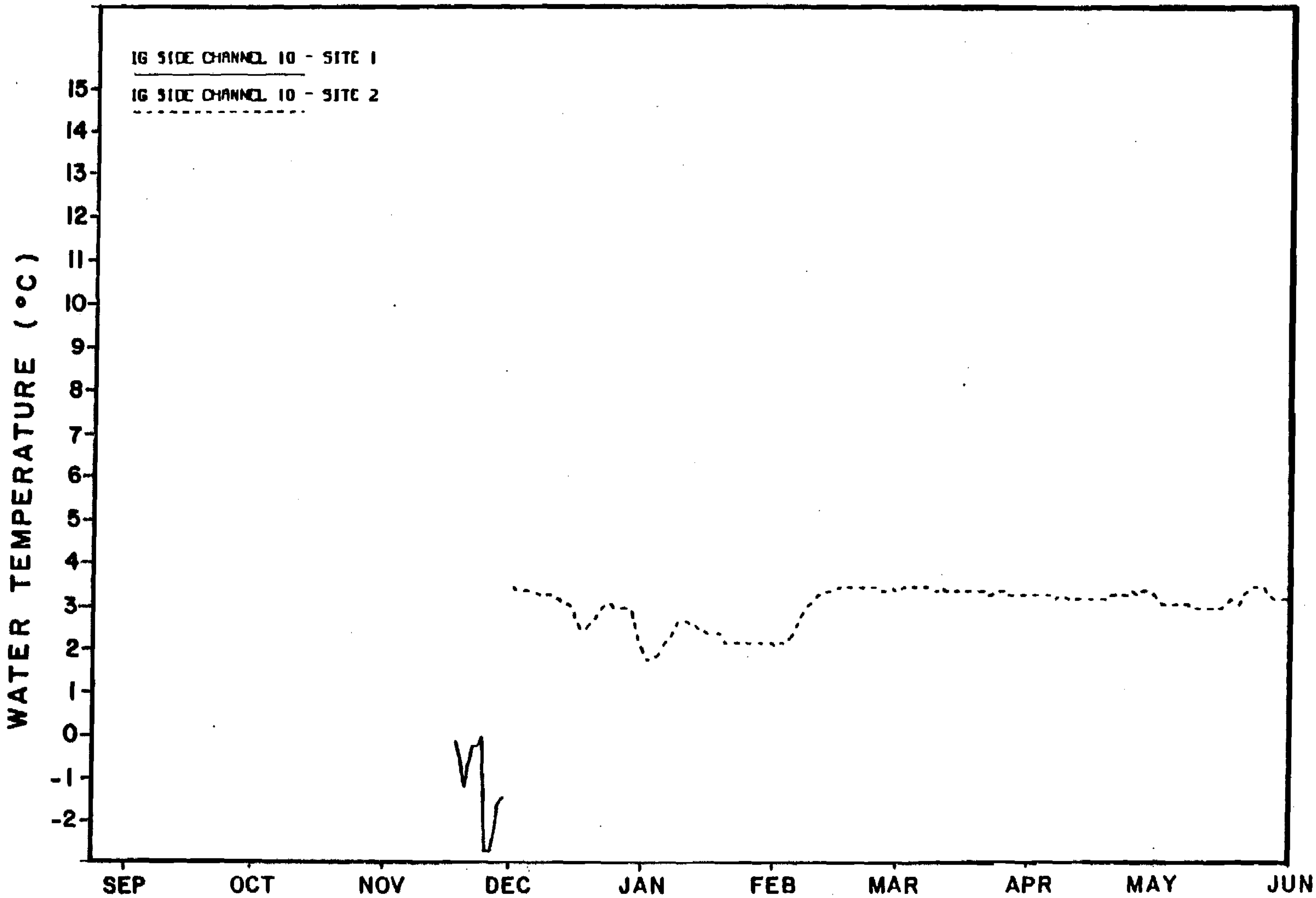


Figure 18. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Side Channel 10 (RM 133.8), middle Susitna River, Alaska.

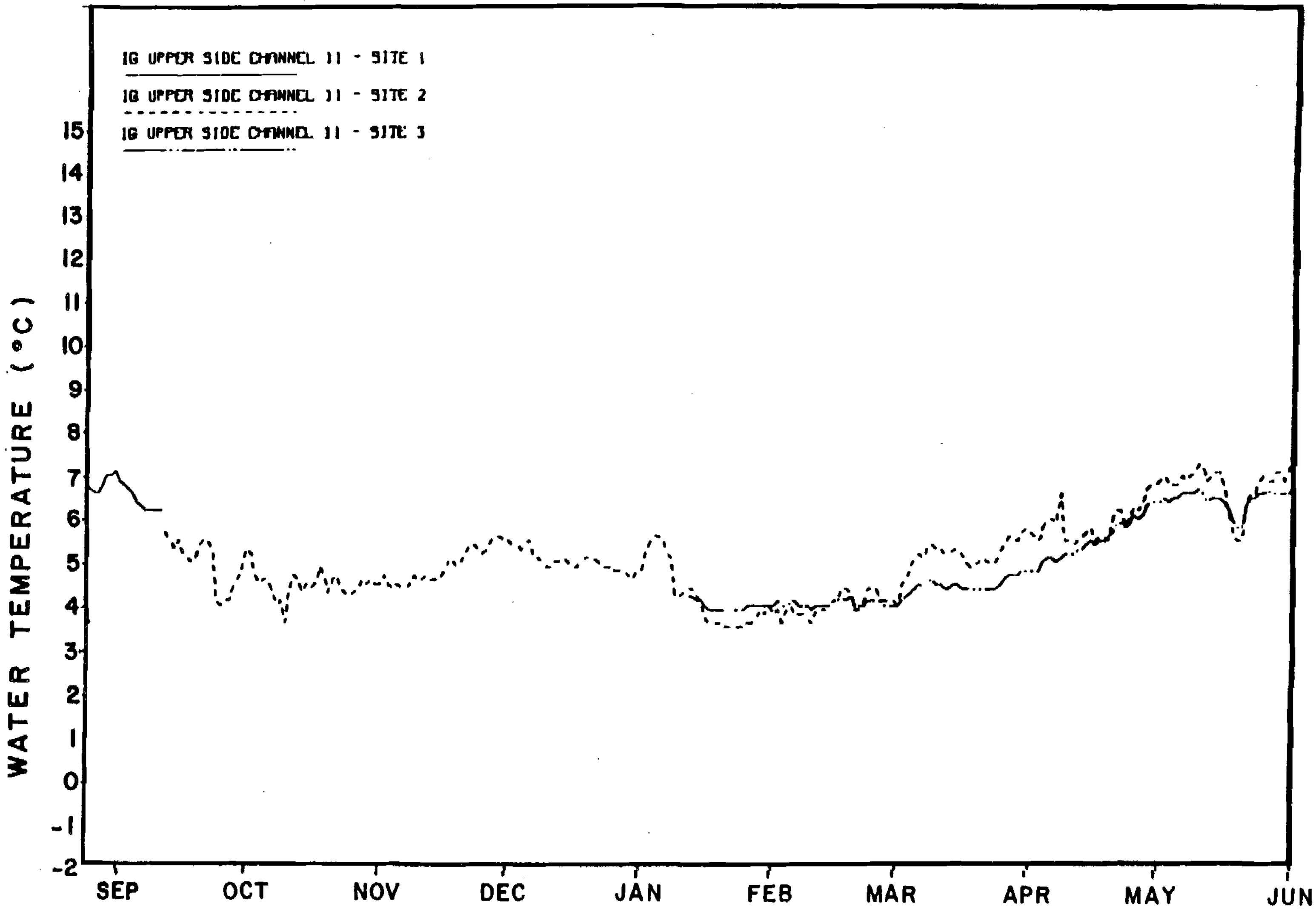


Figure 19. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Upper Side Channel 11 (RM 136.1), middle Susitna River, Alaska.

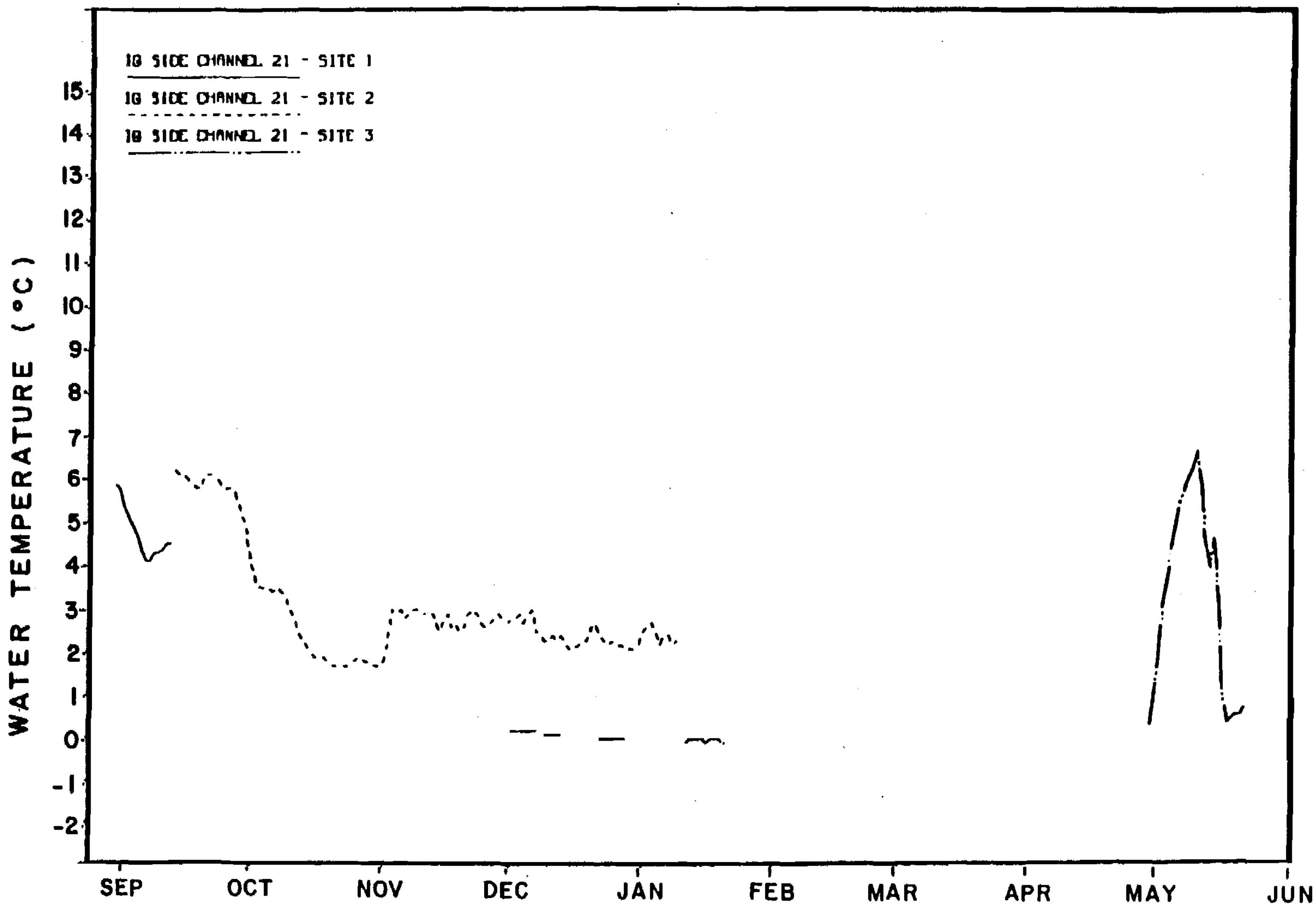


Figure 20. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Side Channel 21 (RM 141.0), middle Susitna River, Alaska.

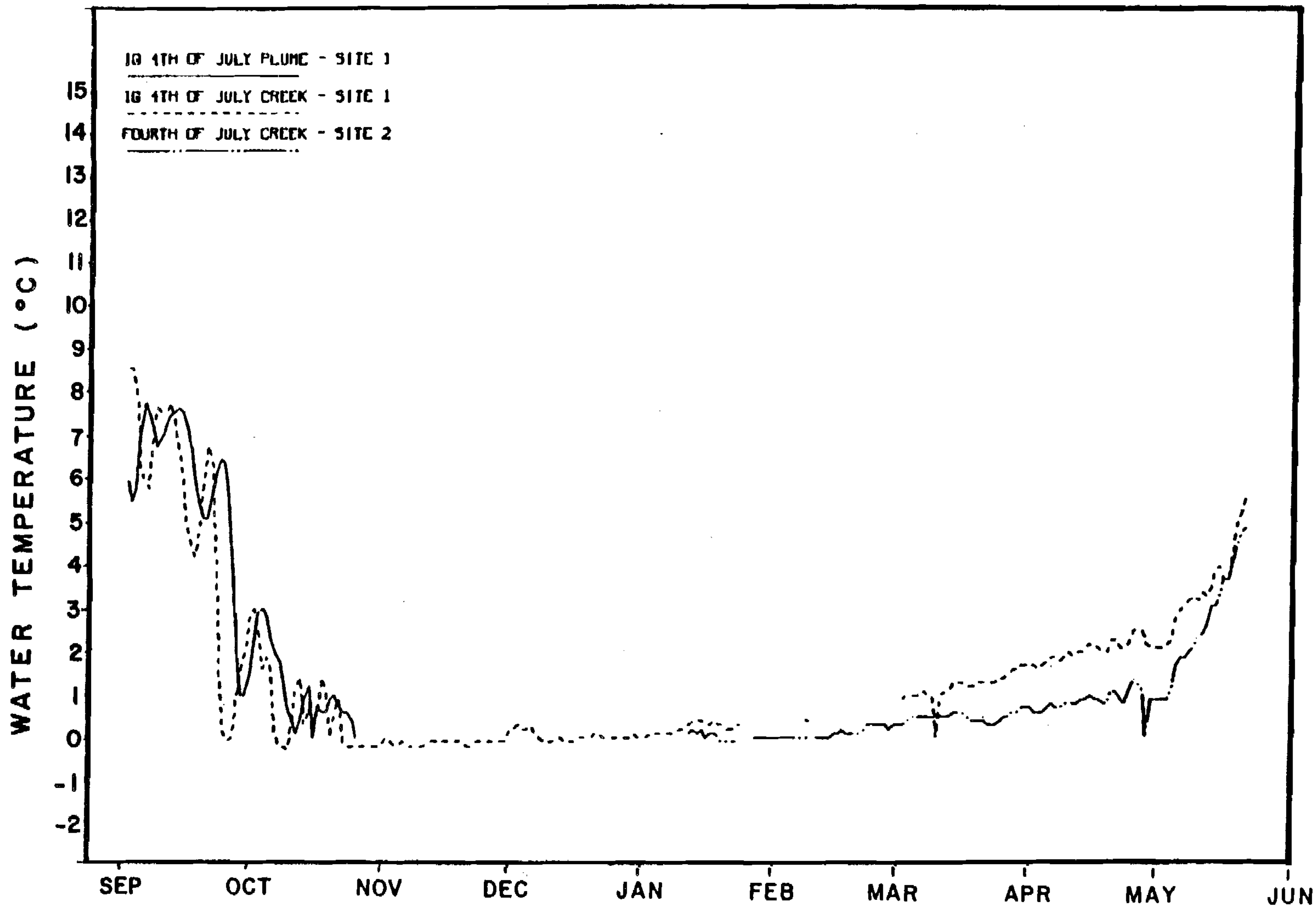


Figure 21. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Fourth of July Creek (RM 131.1), middle Susitna River, Alaska.

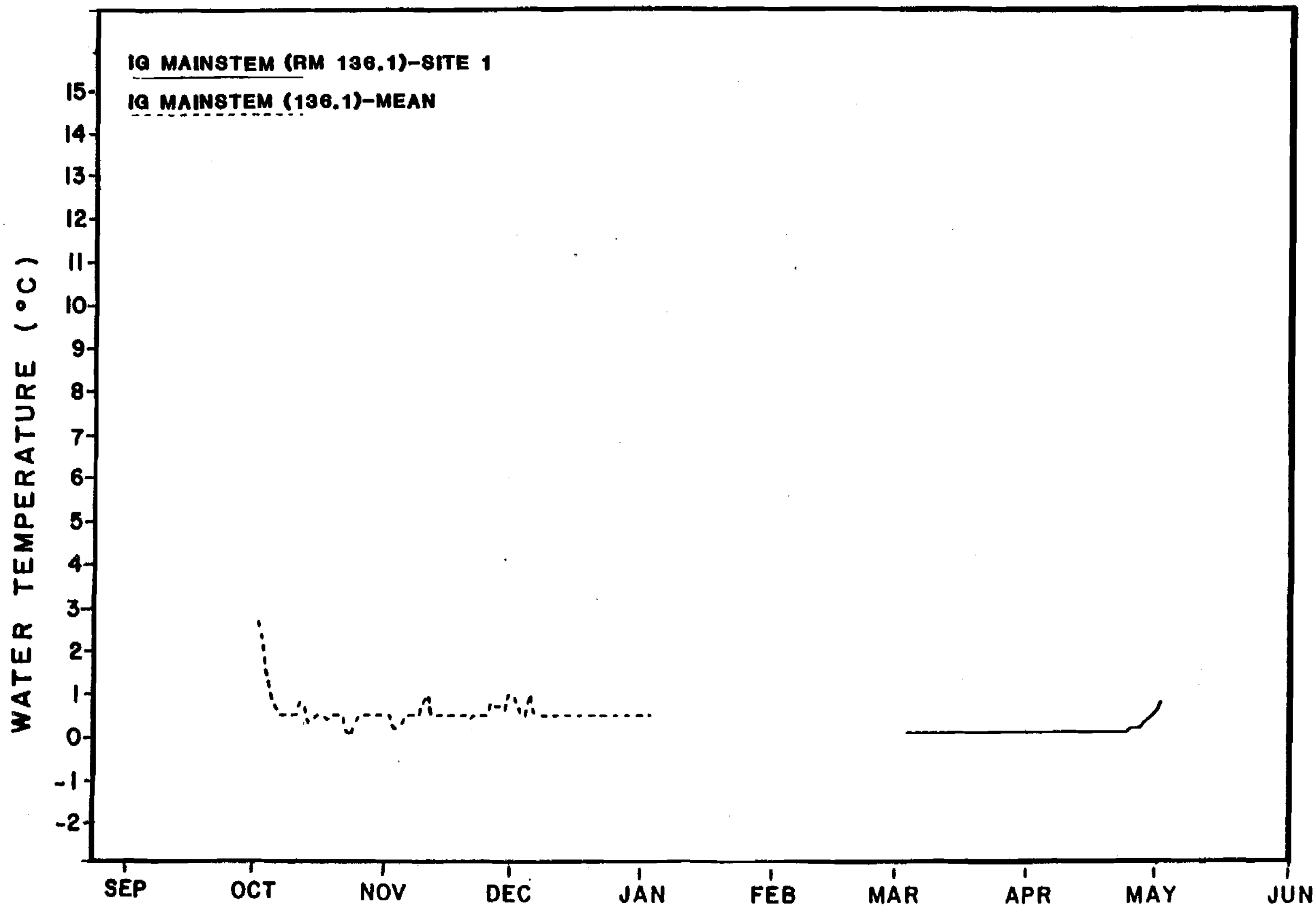


Figure 22. Mean daily intragravel water temperatures (°C) recorded during the 1983-84 winter period at Mainstem (RM 136.1), middle Susitna River, Alaska.

at the nine primary study sites [with the exception of Mainstem (RM 136.1)], are presented, by study site and habitat type in Figures 23 and 24, respectively. The data used to construct these figures are provided in Appendix D (Table D-1). Data for the Mainstem (RM 136.1) site are not available because the excessively large substrate particles at this site prevented proper use of the McNeil sampler. Two McNeil samples, however, were obtained at an alternative mainstem location (RM 138.9) which had substrate similar to that typically selected by chum salmon for spawning. These two samples have been included in the Figure 23 presentation 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 25 and 26, respectively. The total height of each bar represents the combined percent of fines, whereas the internal bar divisions correspond to individual 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 allowing for the accumulation of fines 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 27 and 28, 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 29. 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 composition to that in areas utilized for spawning by chum salmon. It is included for comparative purposes.

The variation in substrate composition at salmon redds is relatively greater for the three largest substrate categories than for the three smallest (Figure 27). 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 variability between the sites in each category is 3.0%, 6.0% and 15.0%, respectively.

Substrate composition for the three smallest size categories are compared between study sites in Figure 29. 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

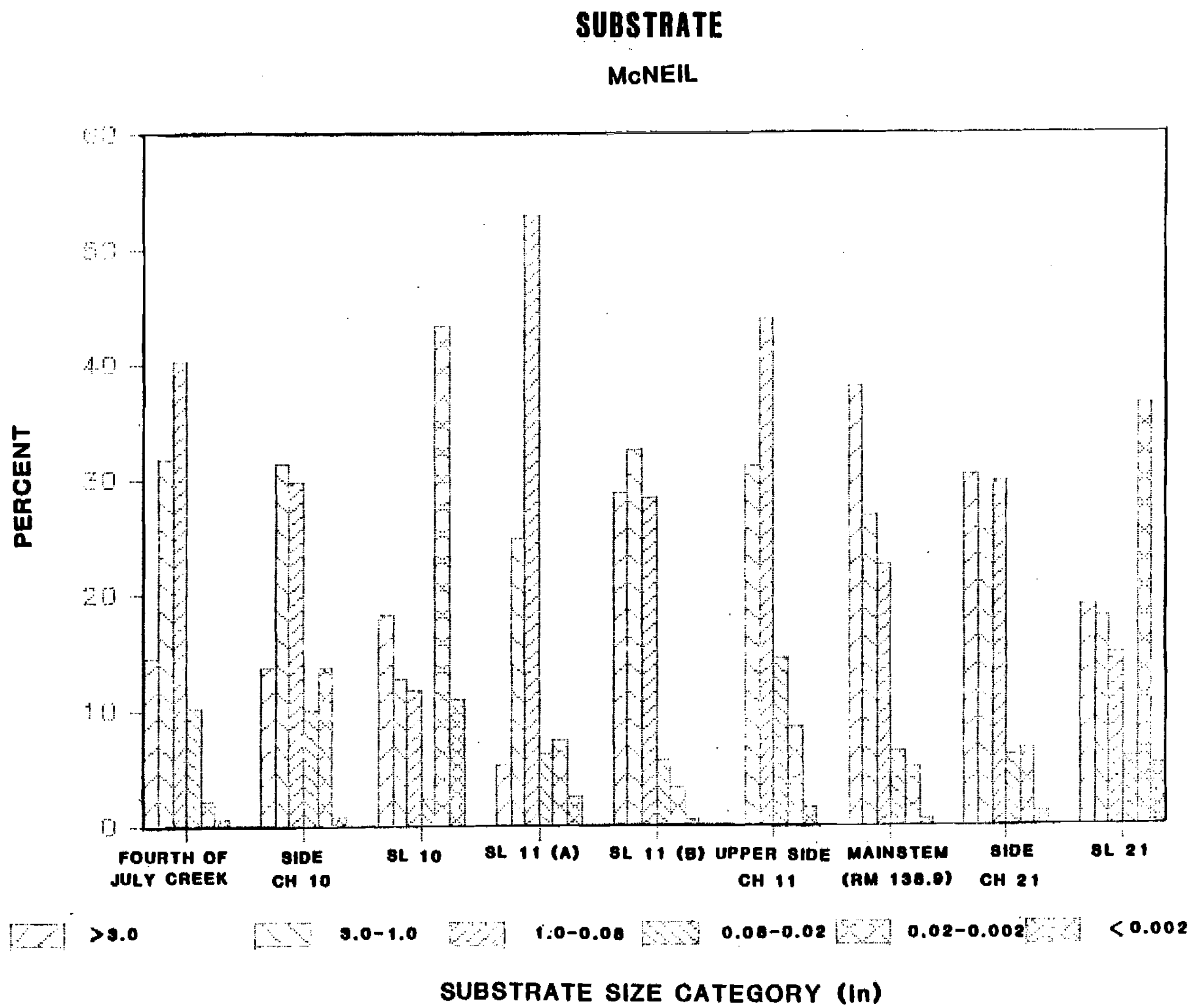


Figure 23. Percent size composition of McNeil substrate samples collected at study sites in the middle Susitna River, Alaska.

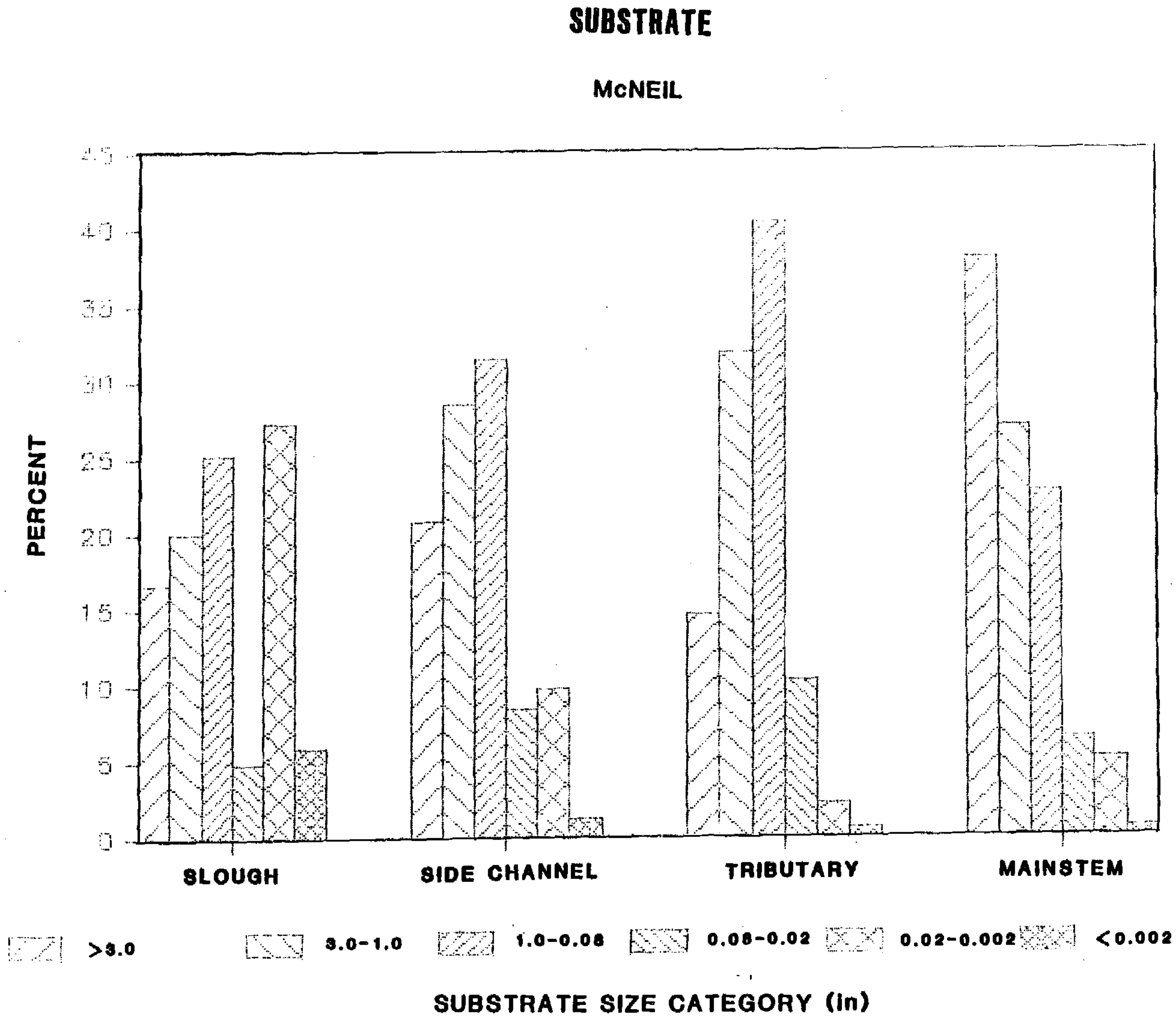


Figure 24. Percent size composition of McNeil samples collected in various habitat types in the middle Susitna River, Alaska.

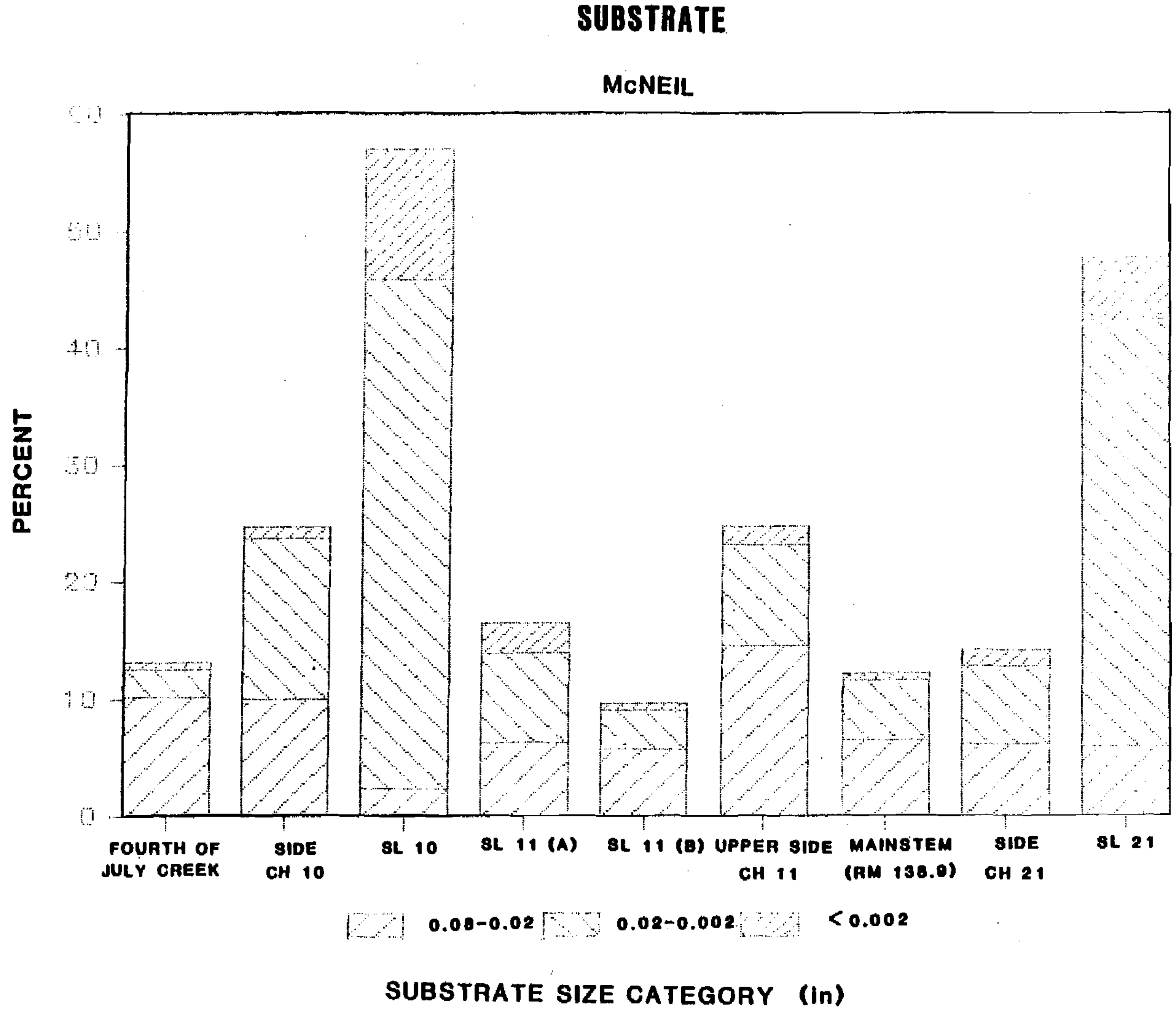


Figure 25. Percent size composition of fine substrate (<0.08 in. diameter) in McNeil samples collected at study sites in the middle Susitna River, Alaska.

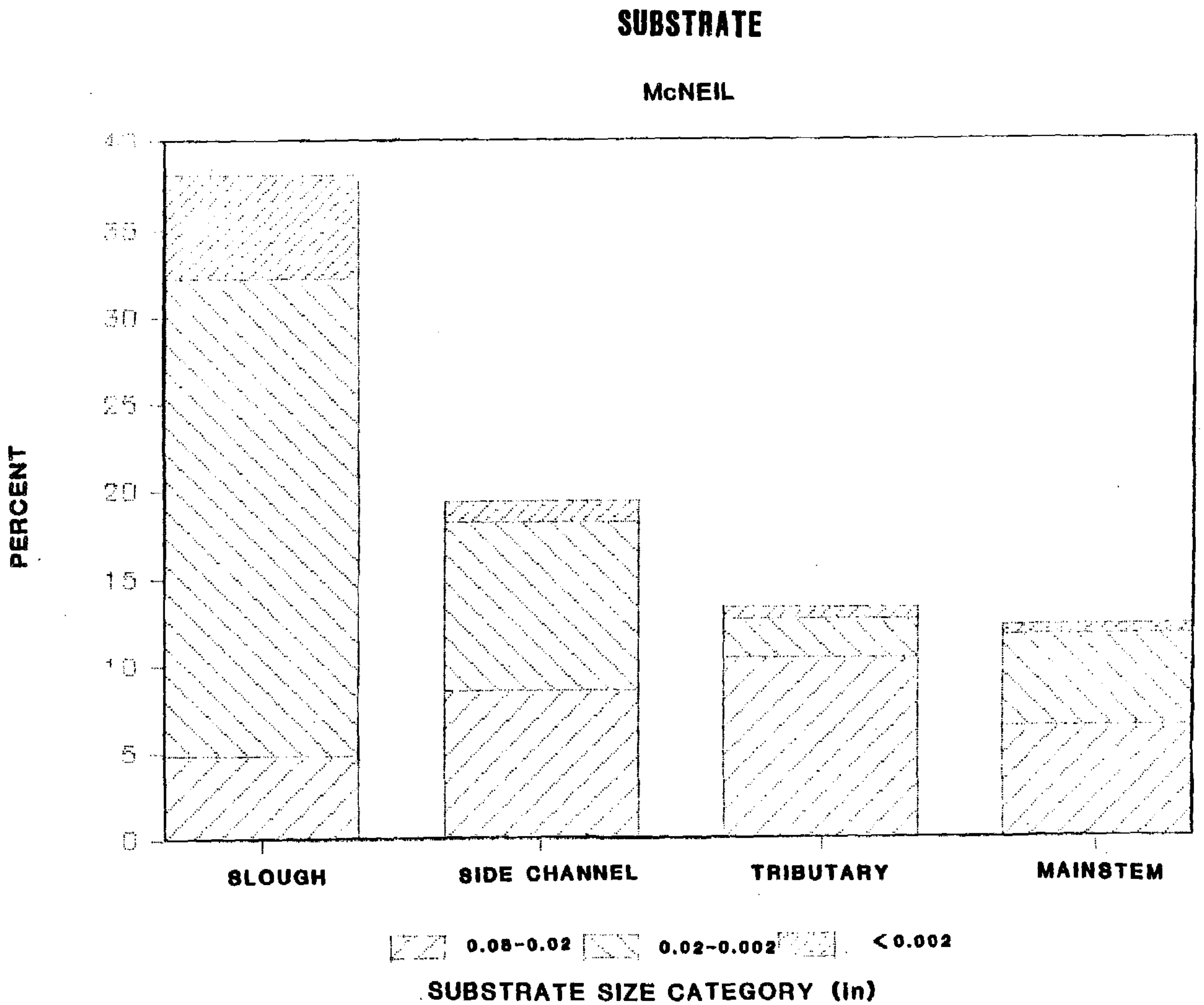


Figure 26. Percent size composition of fine substrate (<0.08 in. diameter) of McNeil samples collected in various habitat types in the middle Susitna River, Alaska.

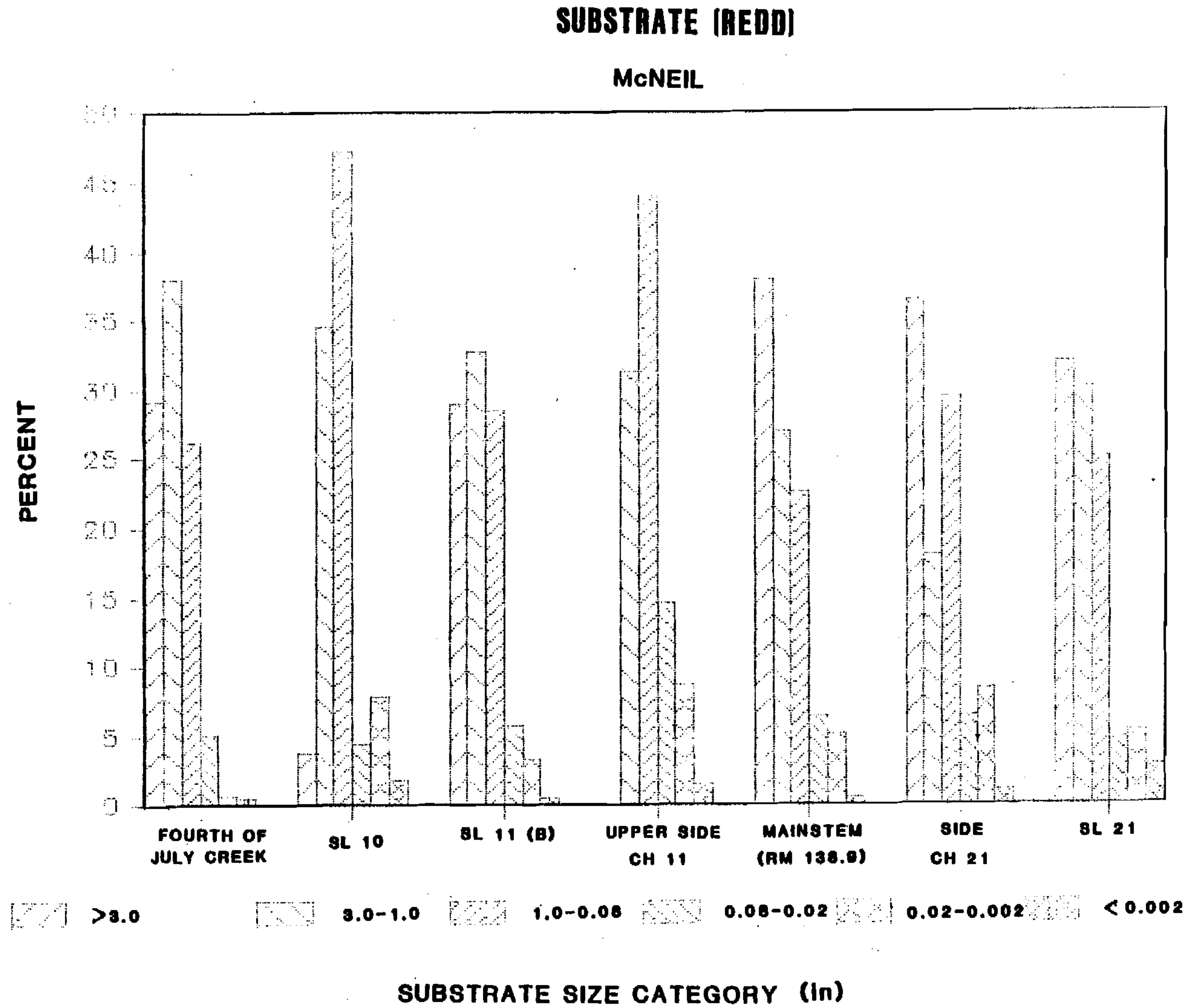


Figure 27. Percent size composition of McNeil substrate samples collected at chum salmon redds during May 1984, in the middle Susitna River, Alaska.

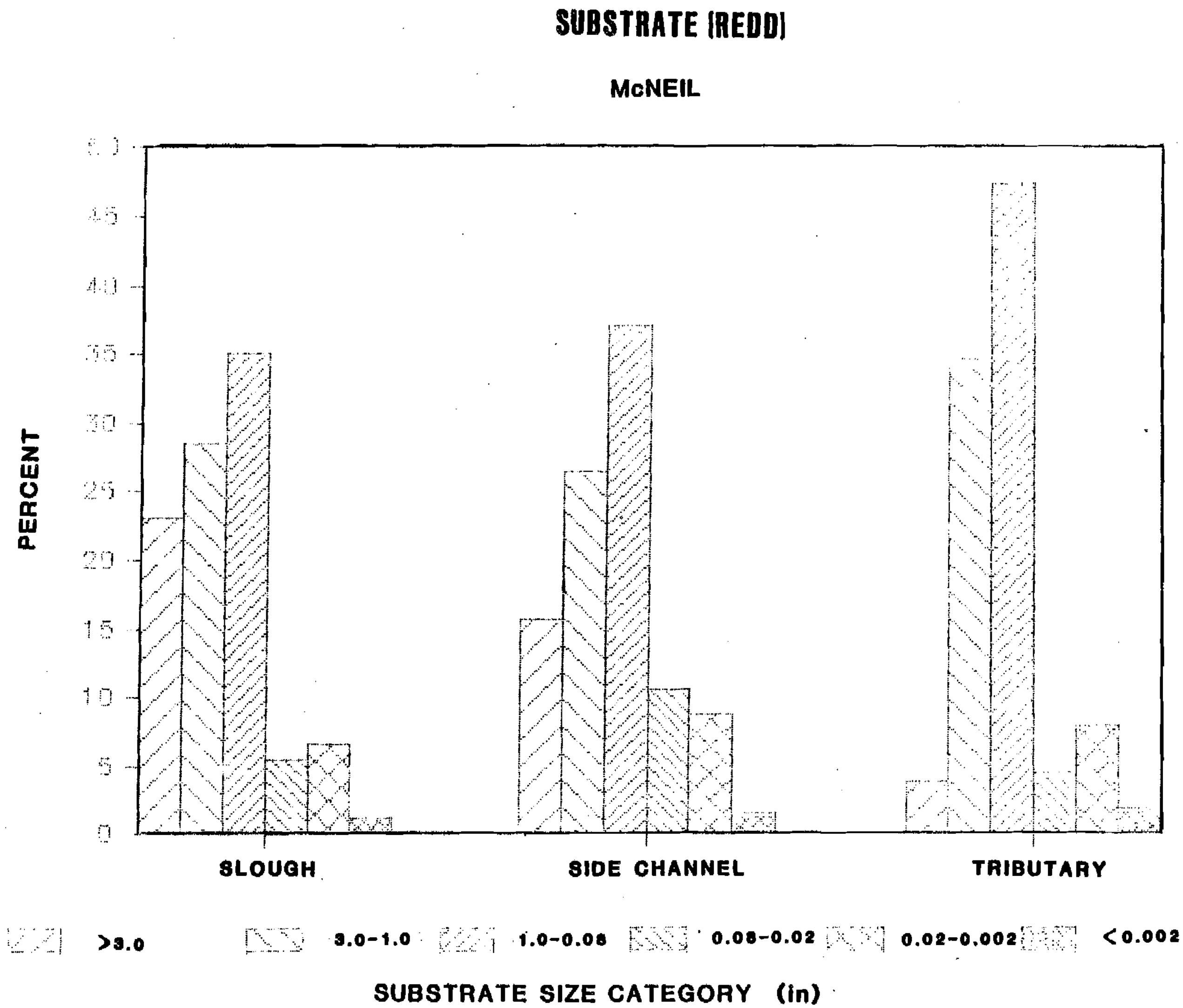


Figure 28. Percent size composition of McNeil substrate samples collected at chum salmon redds during May 1984, in various habitats of the middle Susitna River, Alaska.

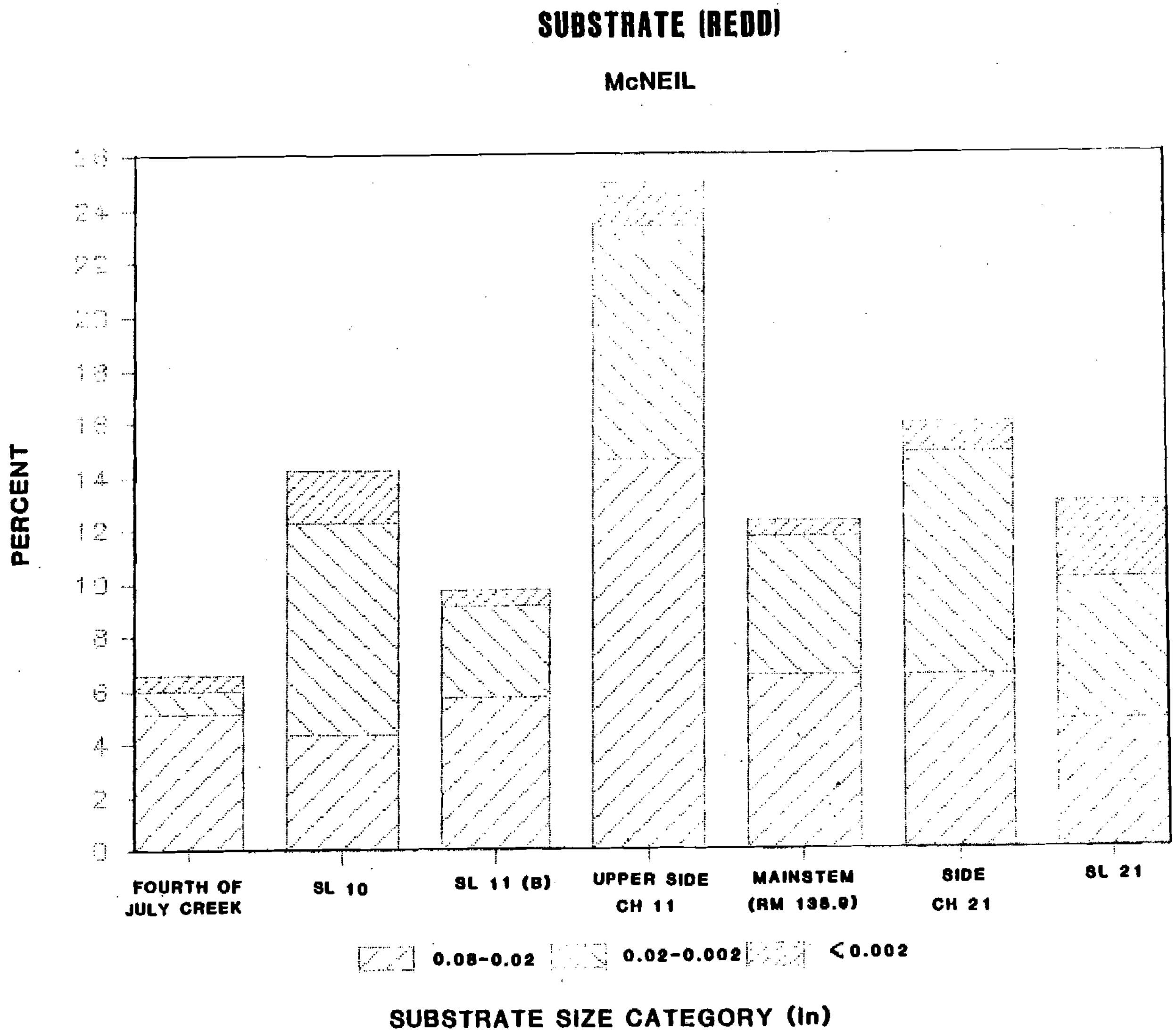


Figure 29. Percent size composition of fine substrate (<0.08 in. diameter) in McNeil samples collected at chum salmon redds during May 1984 in study sites of middle Susitna River, Alaska.

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 28. In general, slough and side channel sites contained greater amounts of fine substrate materials and lesser amounts of large substrate materials compared to tributary sites. However, the areas where salmon established redds (Figure 28) contained fewer fines than the range of substrate materials available in each habitat type (Figure 24). This is likely due to the sorting of gravels by salmon during the digging of the redd.

3.1.2 Chemical Characteristics

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 30-32, respectively. The same data, grouped for all study sites, are presented in Figure 33. Similar plots for dissolved oxygen, expressed as percent saturation, are included in Appendix C. Raw data used to construct both sets of plots are also included in Appendix C.

In each figure, there is a general relationship between surface and intragravel dissolved oxygen levels indicating a relationship between upwelling water and surface waters. The relationship appears strongest for tributary sites (Figure 32) and weakest for slough sites (Figure 30). The relationship for slough habitat 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.

Summary data on intragravel DO concentrations show that median 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 (Figures 34 and 35).

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 36 and 37, respectively. These data grouped for all study sites are presented in Figure 38. 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 37).

A summary of intragravel pH levels is presented by study site and habitat type in Figures 39 and 40, respectively. These data show that,

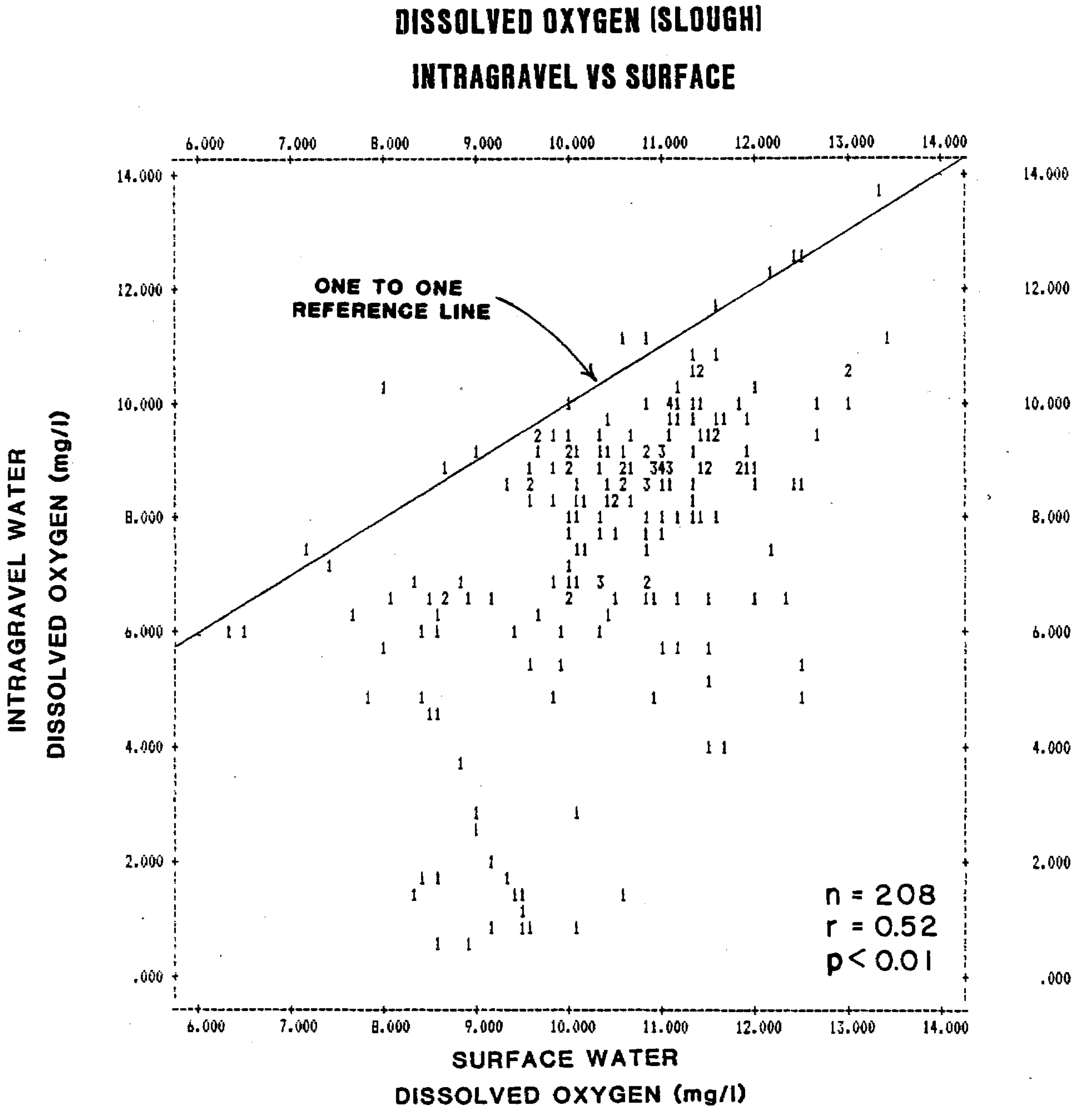


Figure 30. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/l) measured at standpipes within slough habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

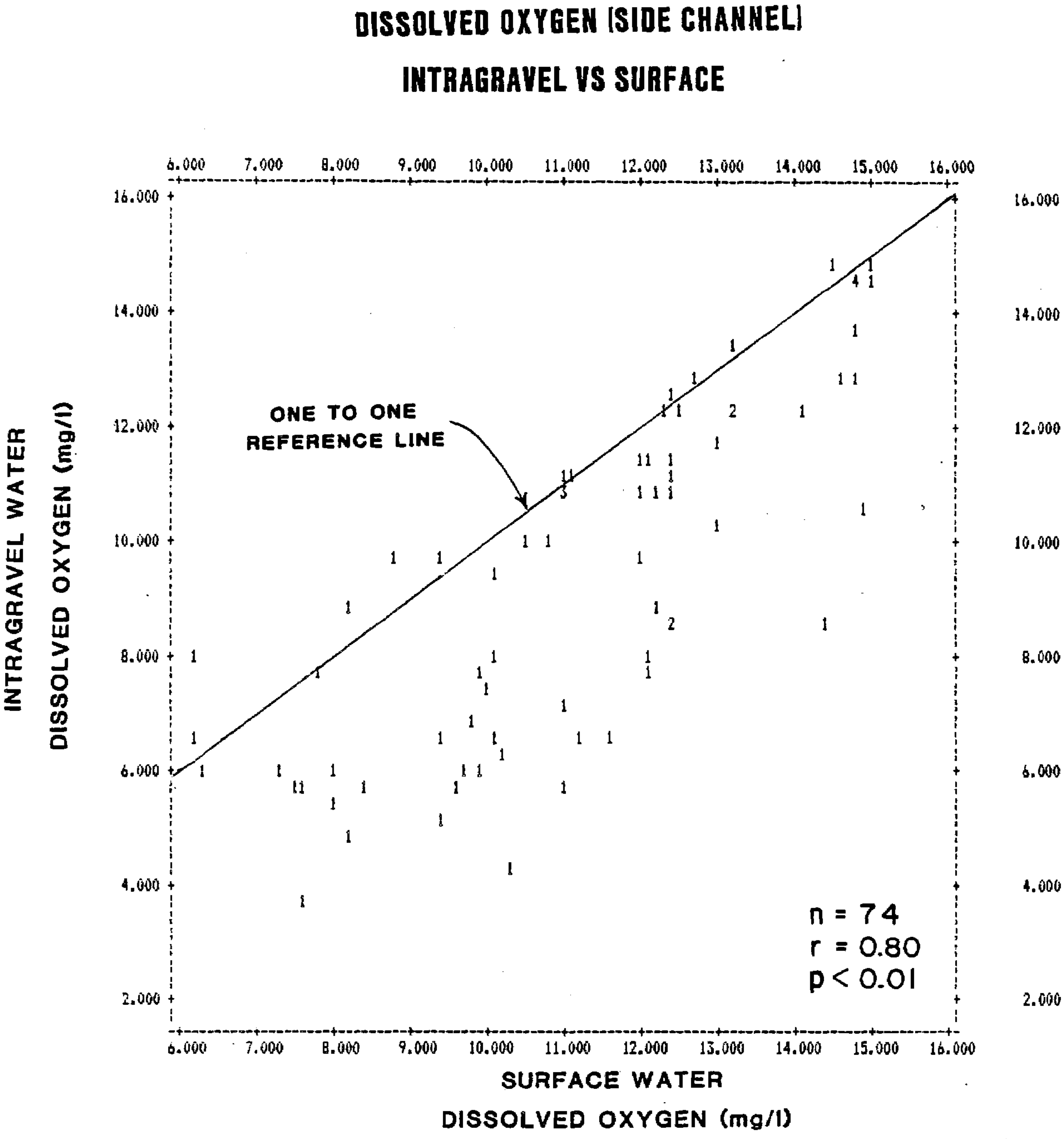


Figure 31. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/1) measured at standpipes within side channel habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

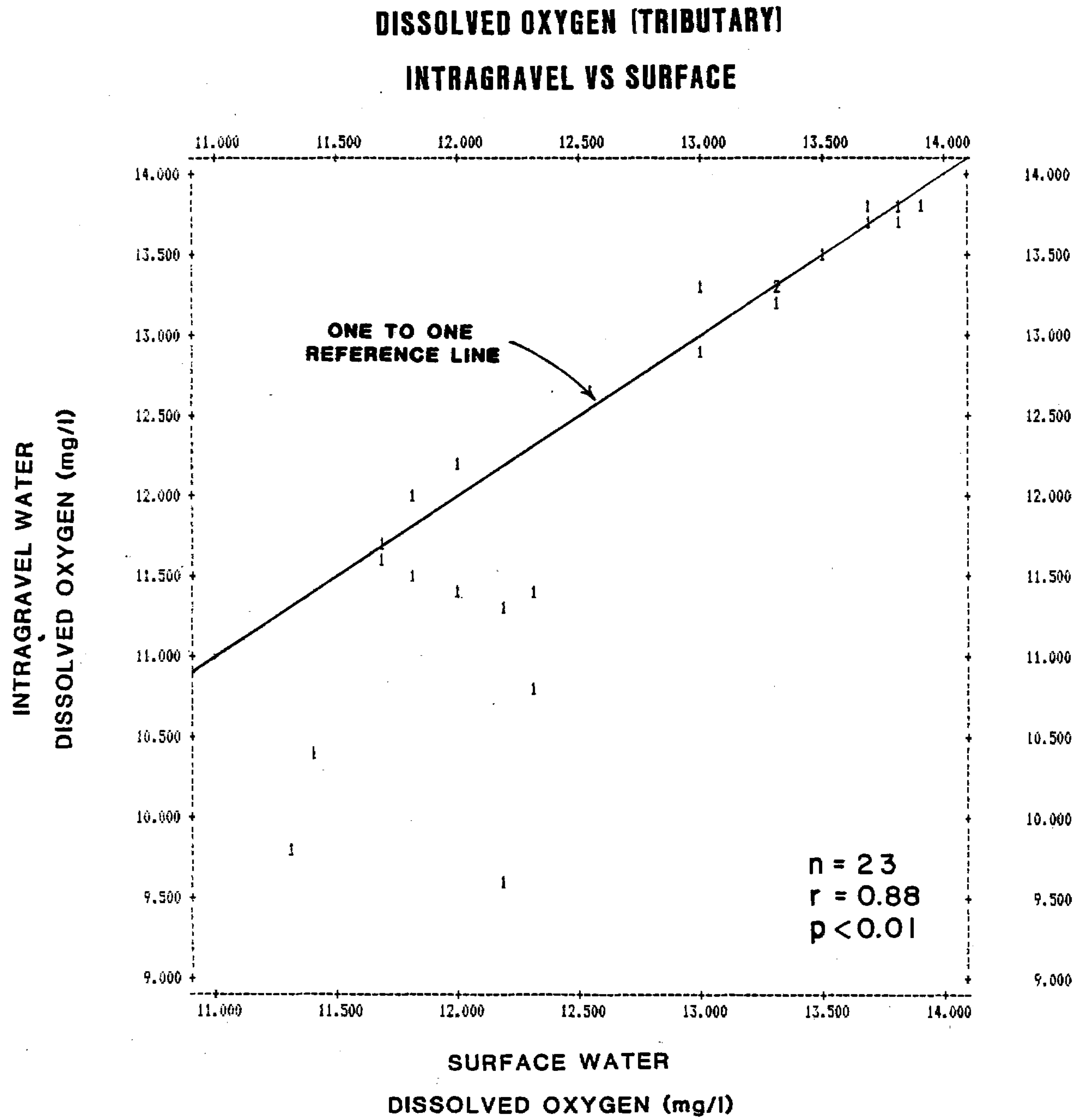


Figure 32. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/l) measured at standpipes within tributary habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

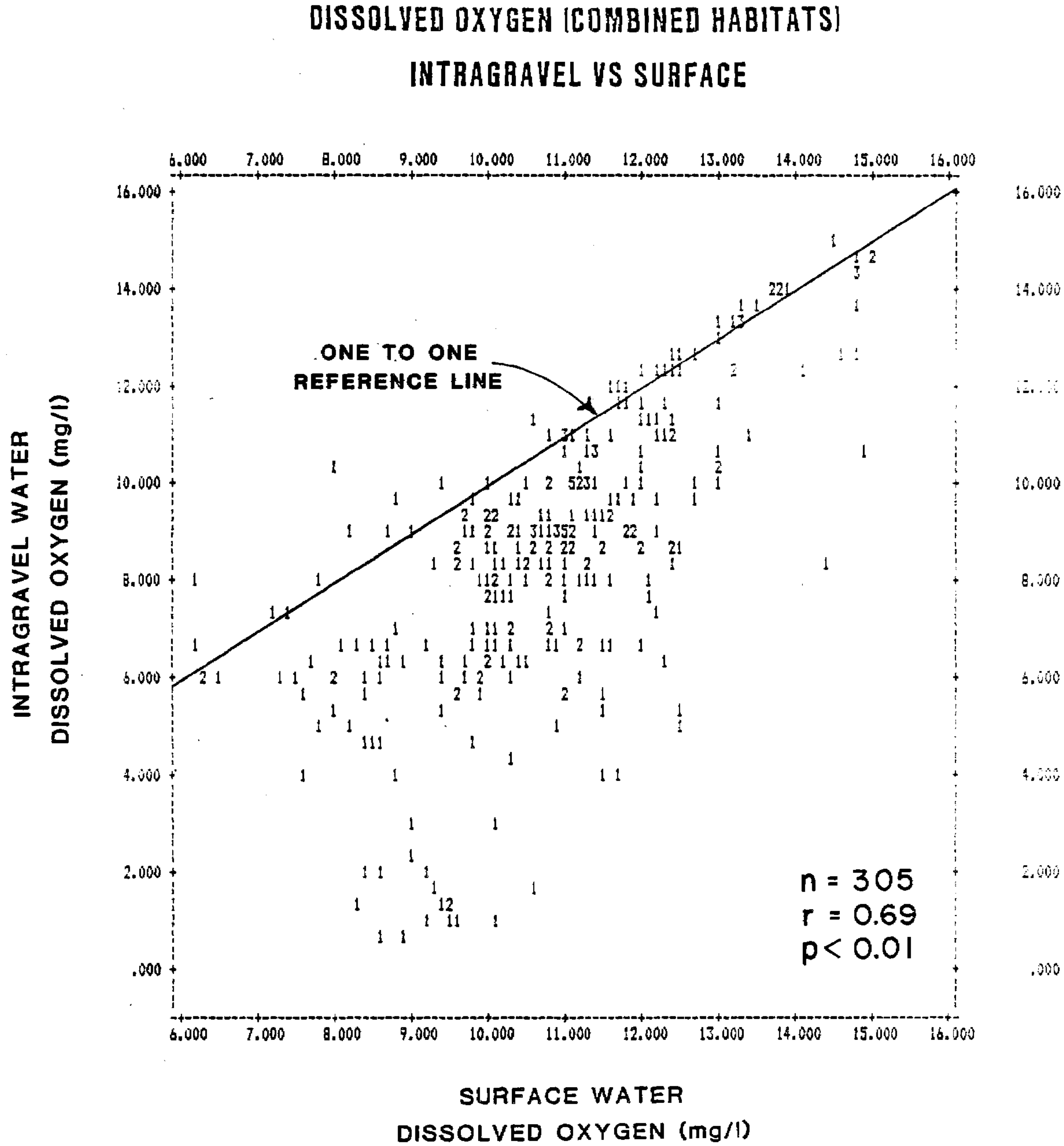


Figure 33. Relationship between intragravel and surface water dissolved oxygen concentrations (mg/1) measured at standpipes within slough, side channel, and tributary habitats of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

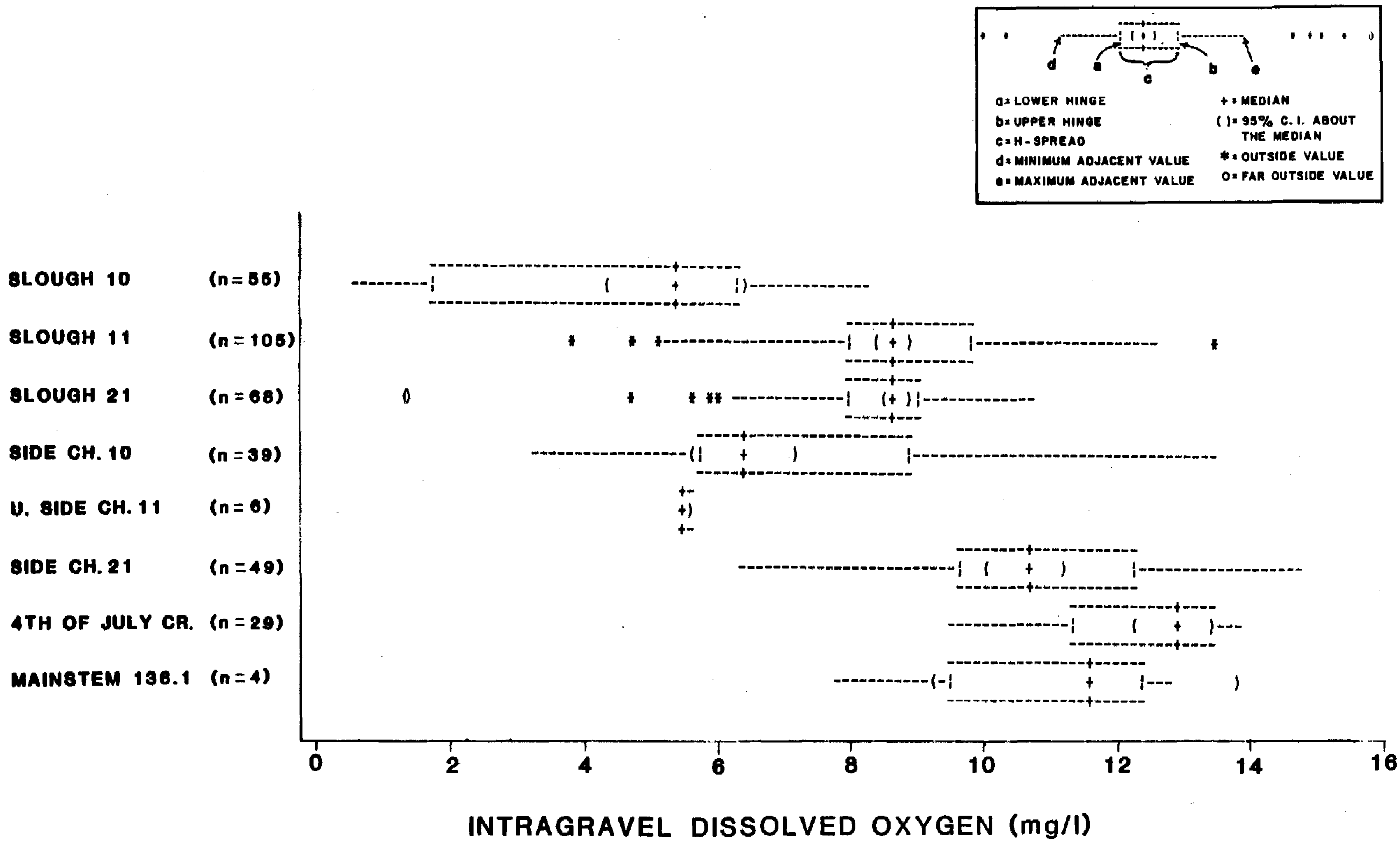


Figure 34. Summary, by study site, of the intragravel dissolved oxygen data (mg/l) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

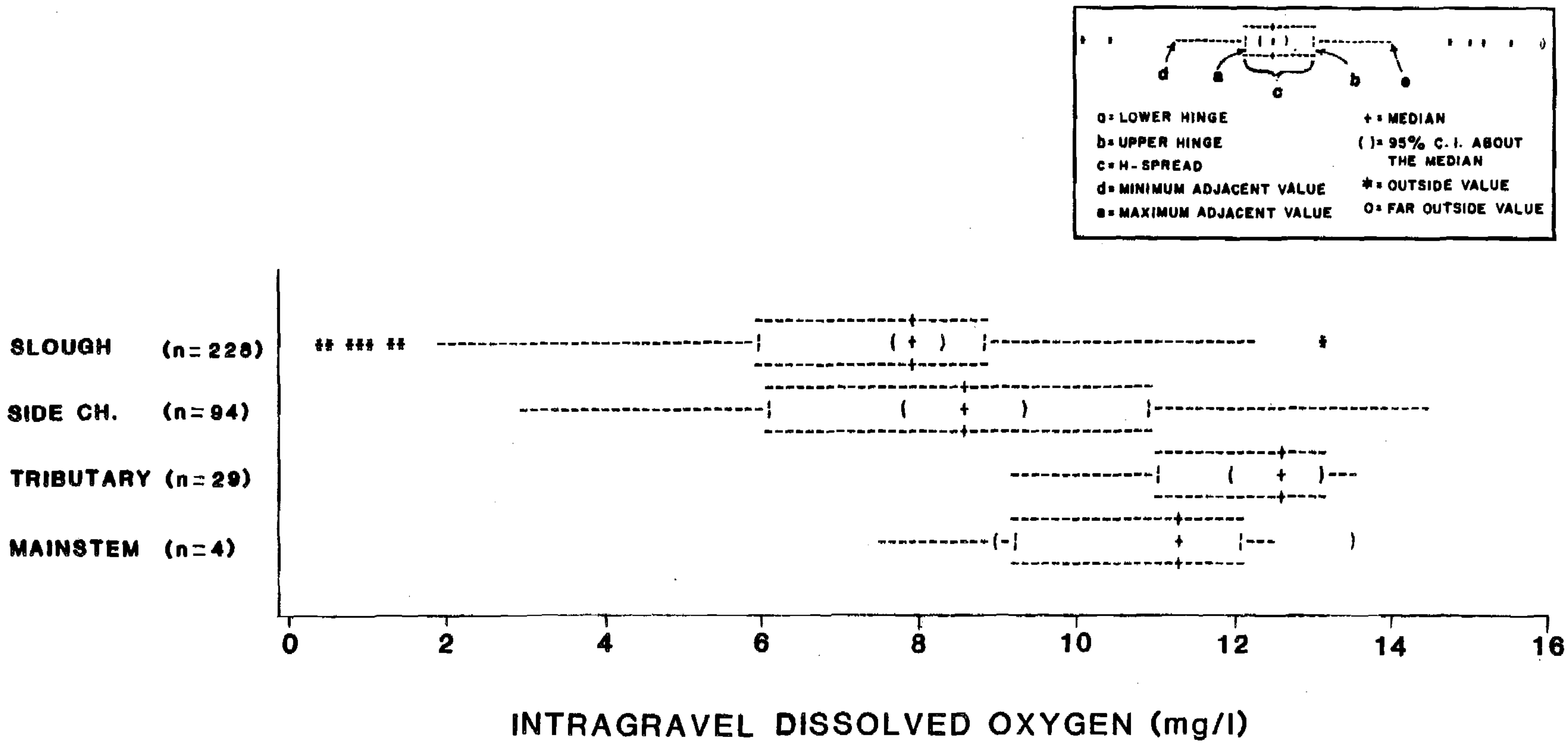


Figure 35. Summary, by habitat type, of the intragravel dissolved oxygen data (mg/l) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

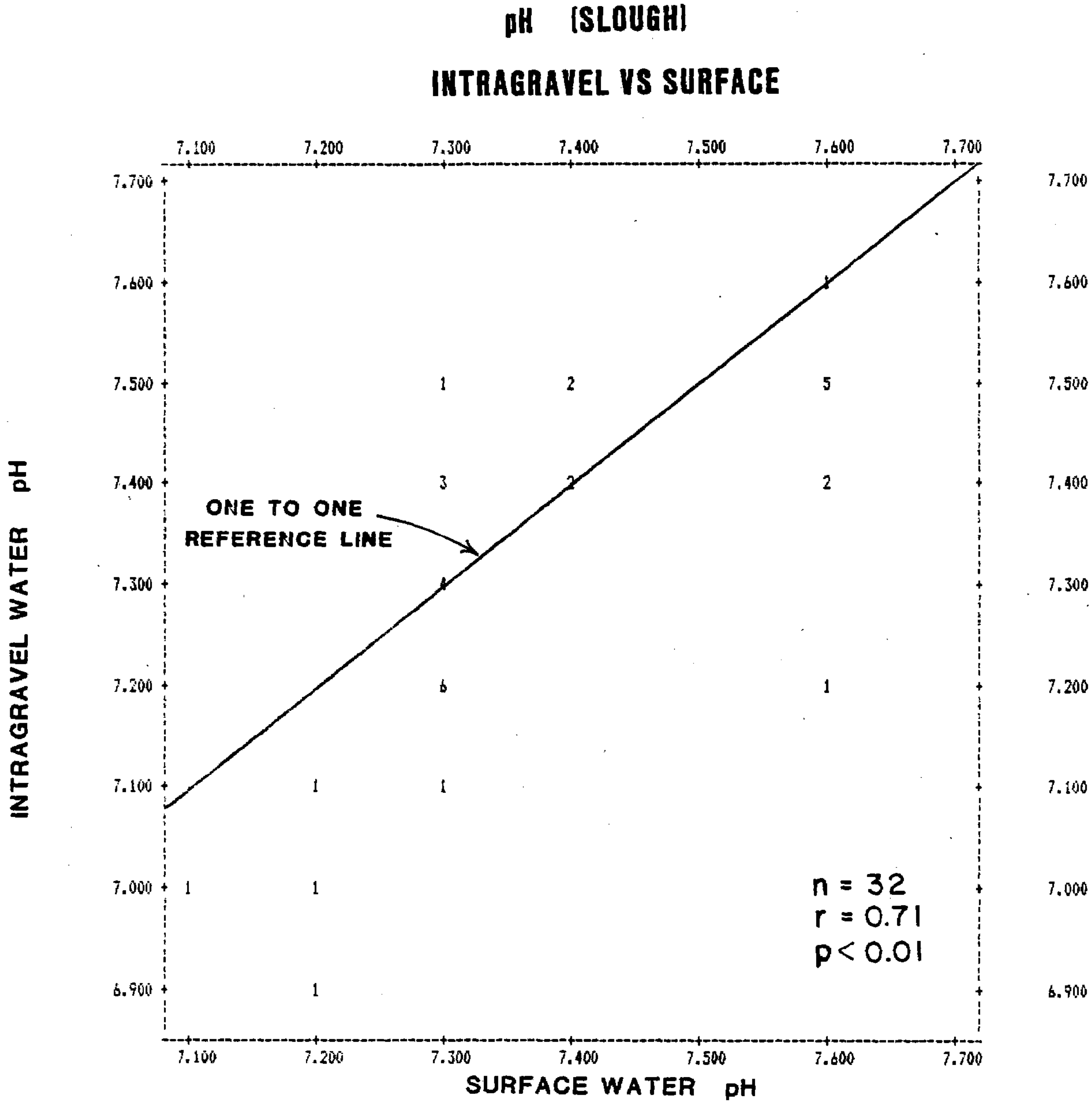


Figure 36. Relationship between intragravel and surface water pH levels measured within slough habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

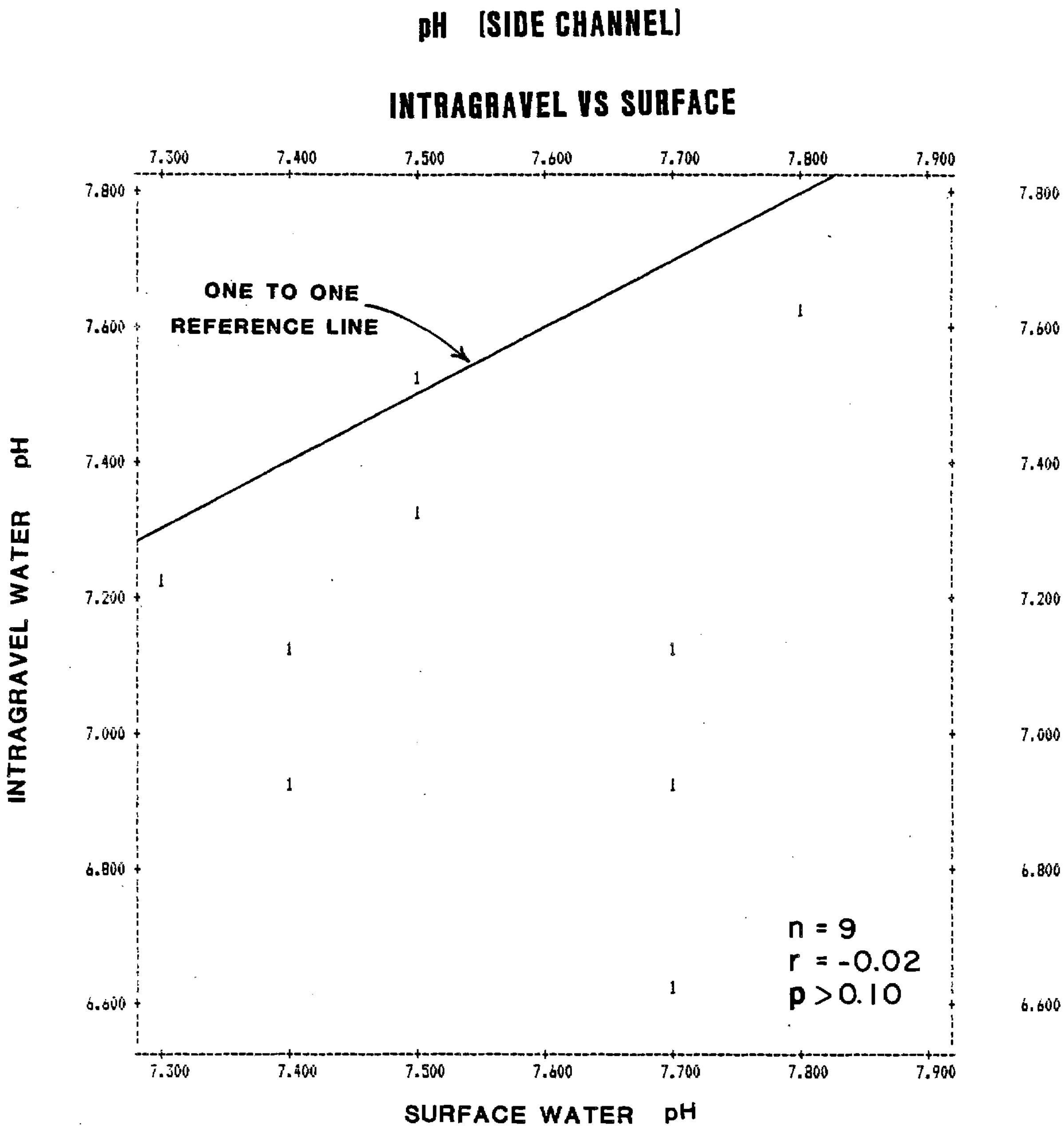


Figure 37. Relationship between intragravel and surface water pH levels measured within side channel habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

pH (COMBINED HABITATS)

INTRAGRAVEL VS SURFACE

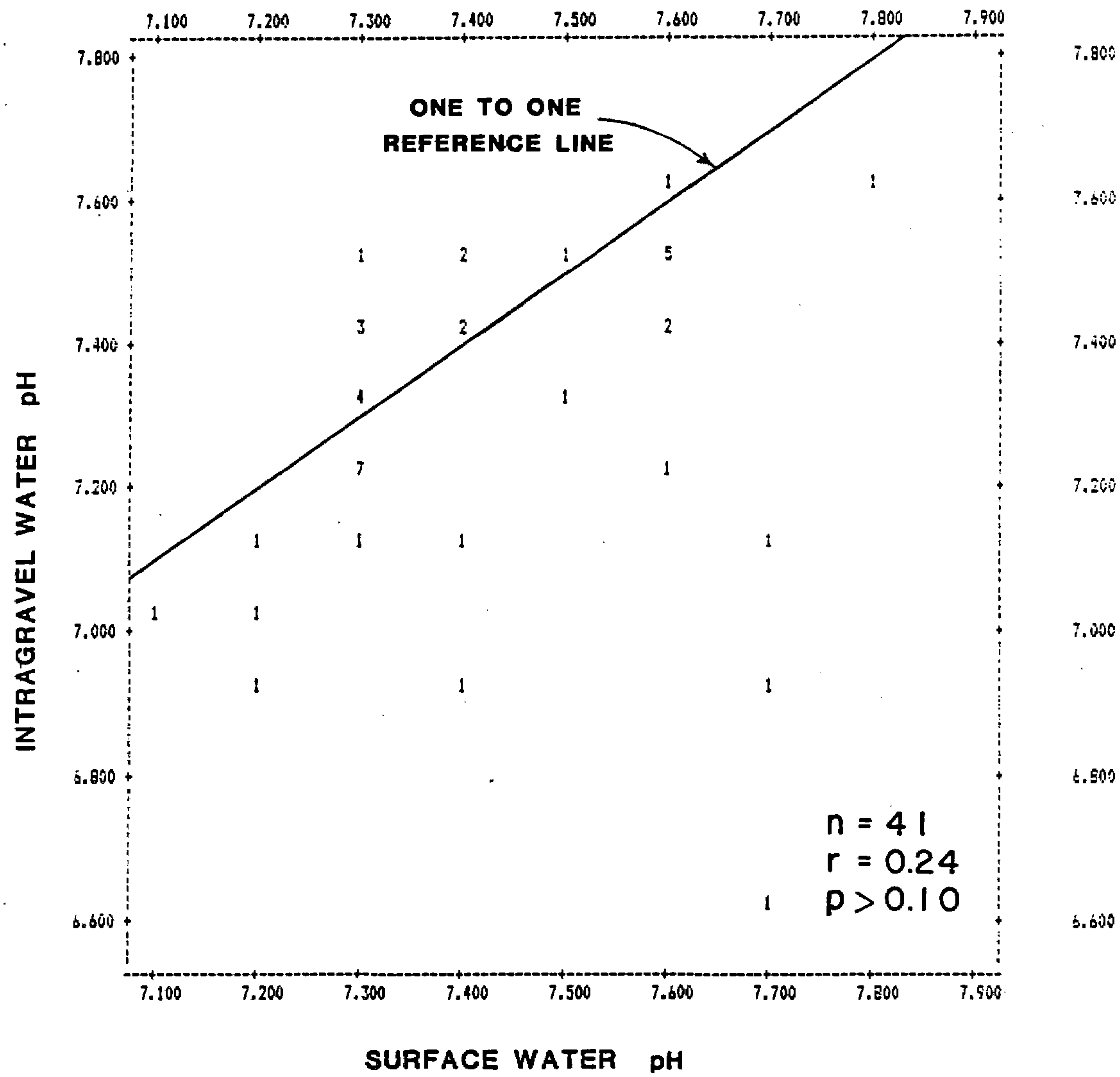


Figure 38. Relationship between intragravel and surface water pH levels measured within slough and side channel habitats of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

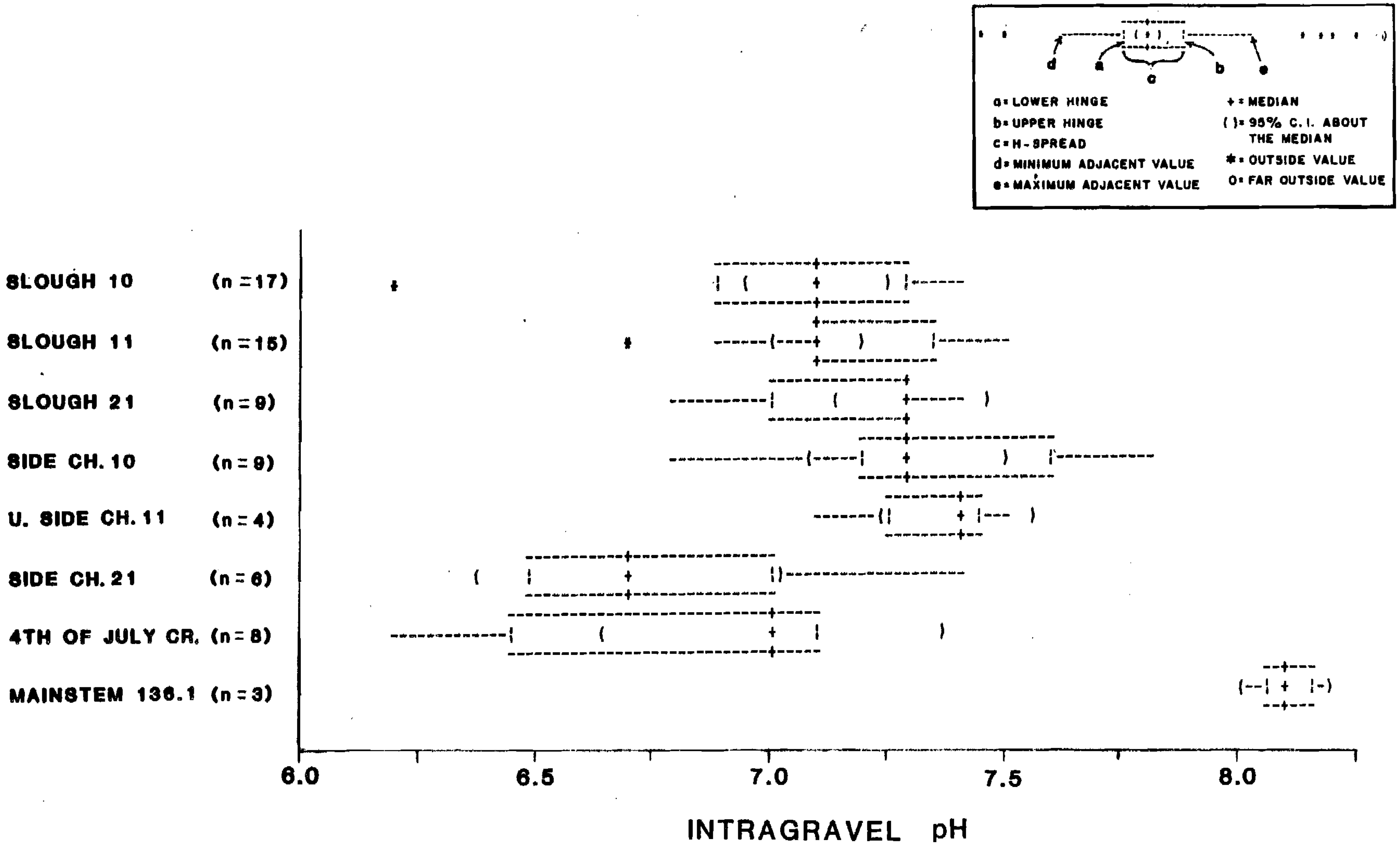


Figure 39. Summary, by study site, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

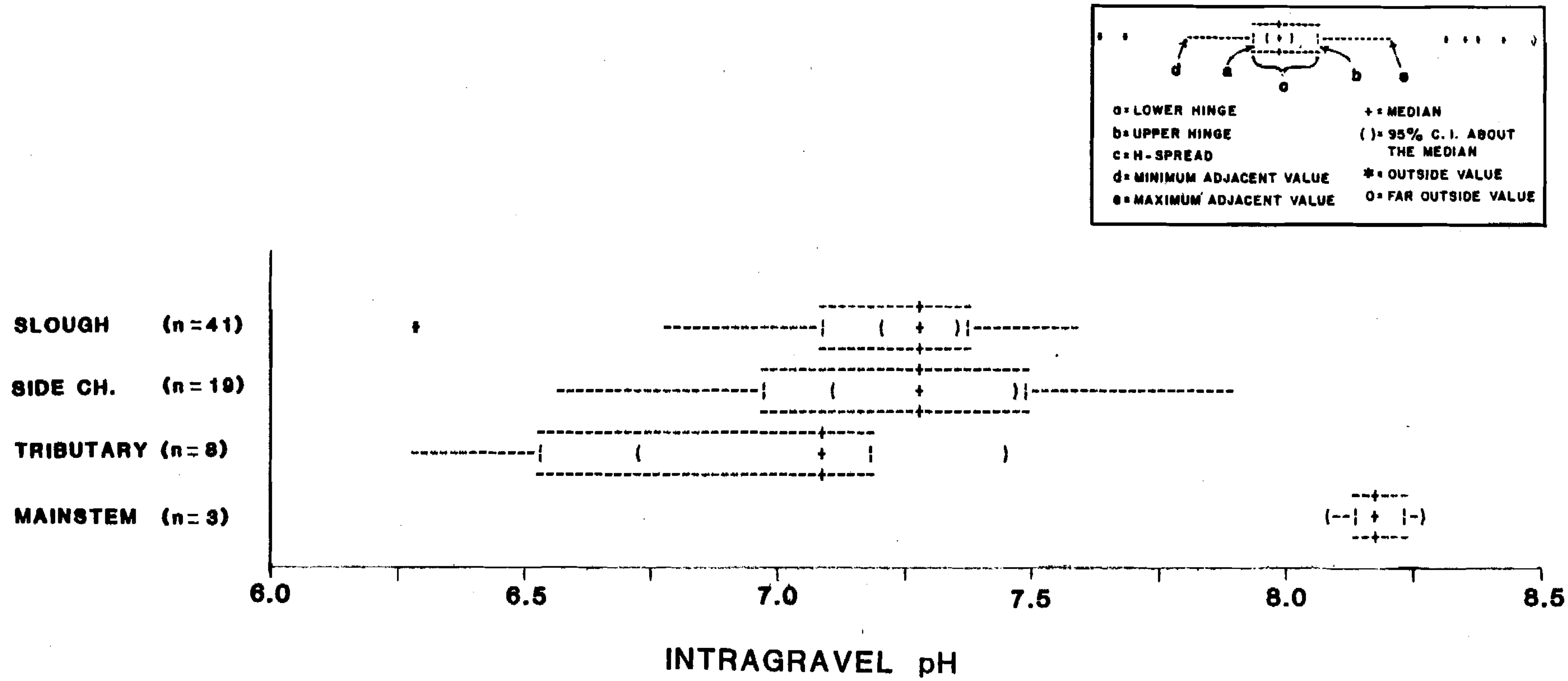


Figure 40. Summary, by habitat type, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

with the exception of Side Channel 21, slough and side channel habitat study sites exhibit relatively similar median pH values which are intermediate between the lower tributary habitat study site levels and the higher mainstem habitat study site levels. Slightly lower pH values were recorded in Side Channel 21 compared with other sites.

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 41-43, respectively. These data are also grouped for all study sites and presented in Figure 44. 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 41), 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 45 and 46, respectively. Slough, side channel, and mainstem habitat study sites have similar conductivity ranges in contrast to the tributary habitat study site, which exhibits distinctly lower conductivity values.

3.2 Comparison of Embryo Survival and Development at Study Sites and Habitat Types

Table 4 provides a summary of the timing of events for installing and removing WVBs used for determinations of embryonic survival and/or development at each study site. A total of 308 WVBs were installed, of which 285 were successfully retrieved. Of the 295 WVBs retrieved, 220 were used to evaluate embryo survival and 111 WVBs were used to evaluate embryo development.

Embryo survival data for the seven primary study sites previously identified in Table 2 are presented in Appendix Table A-1. Embryonic development data is presented for each of the above mentioned sites as well as for Upper Side Channel 11 and a small number of natural redds located in Fourth of July Creek, Slough 21 and Side Channel 21 are presented in Appendix Table A-2. Data presented in this table may include data presented in Appendix Table A-1 since embryos at a specific used to calculate development may also have been used for determining survival. With the exception of data obtained at two sites, all data reported in Appendix Table A-2 were derived from embryos removed from WVBs. Data reported for natural redds were obtained from embryos placed naturally in redds by the adult salmon. Data obtained at Side Channel 21 (subsite C) was obtained from embryos which were artificially fertilized and placed in an artificial redd and then later removed to evaluate development.

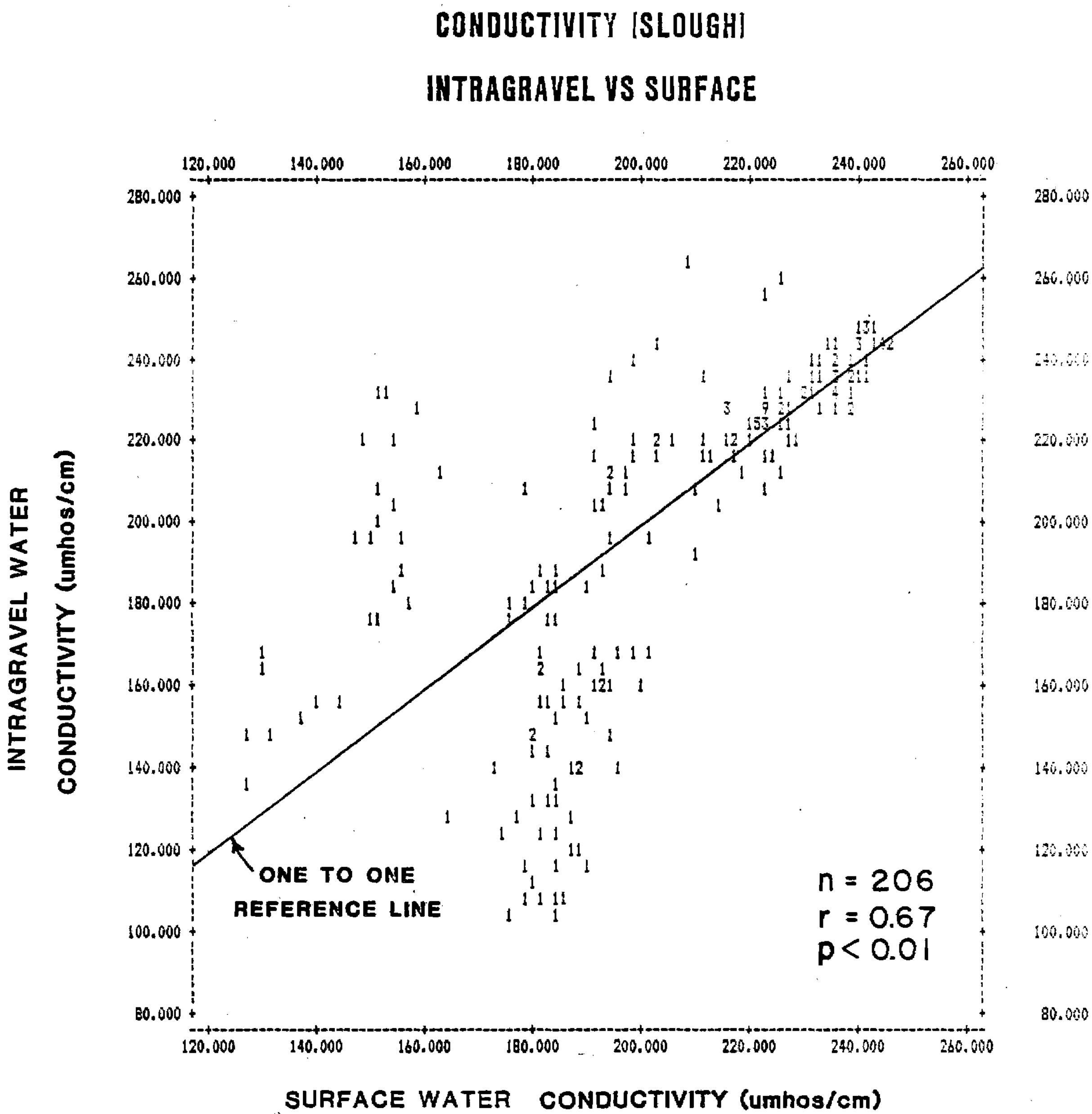


Figure 41. Relationship between intragravel and surface water conductivity levels (umhos/cm) measured within side channel habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

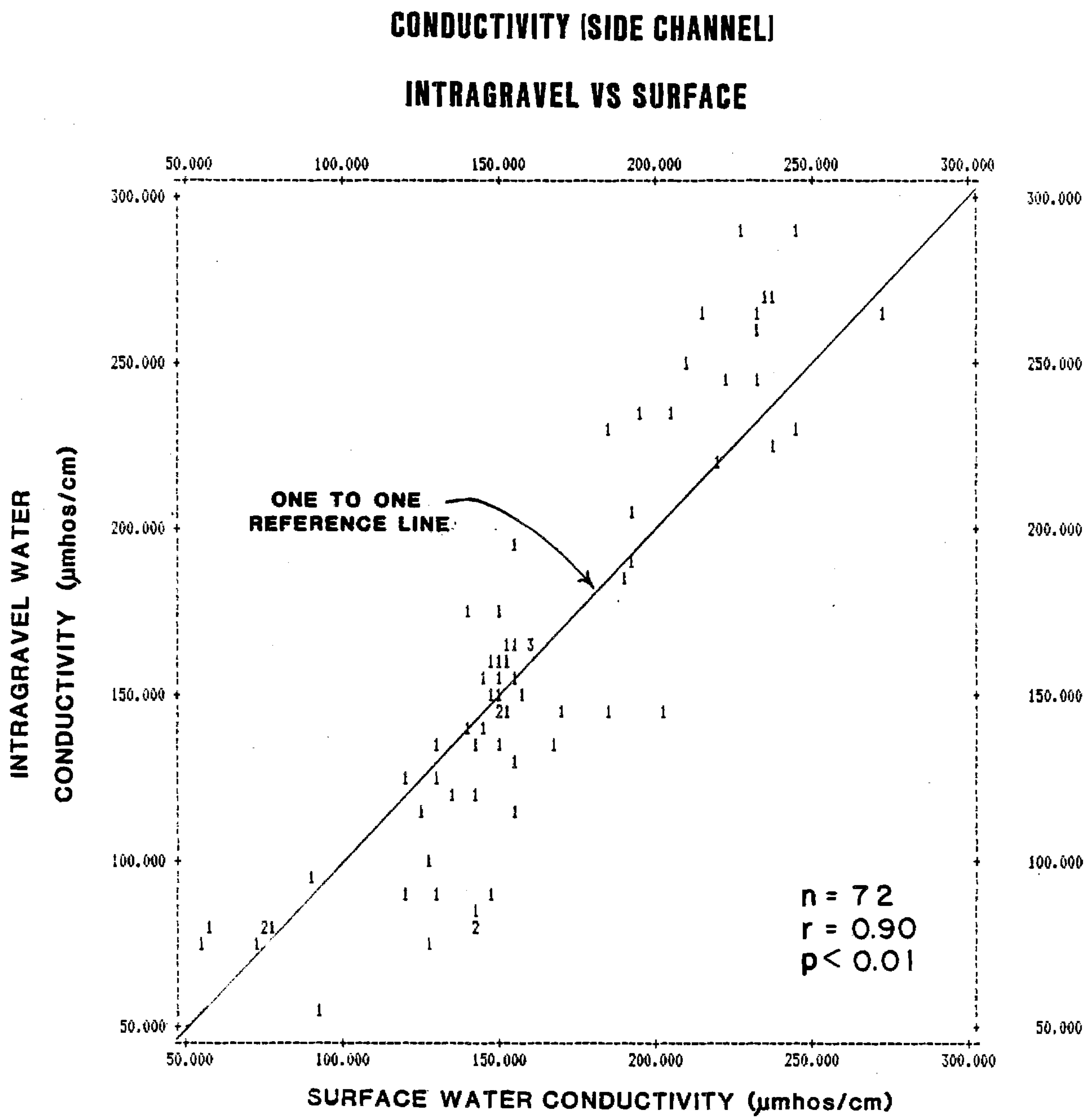


Figure 42. Relationship between intragravel and surface water conductivity levels (umhos/cm) measured within side channel habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

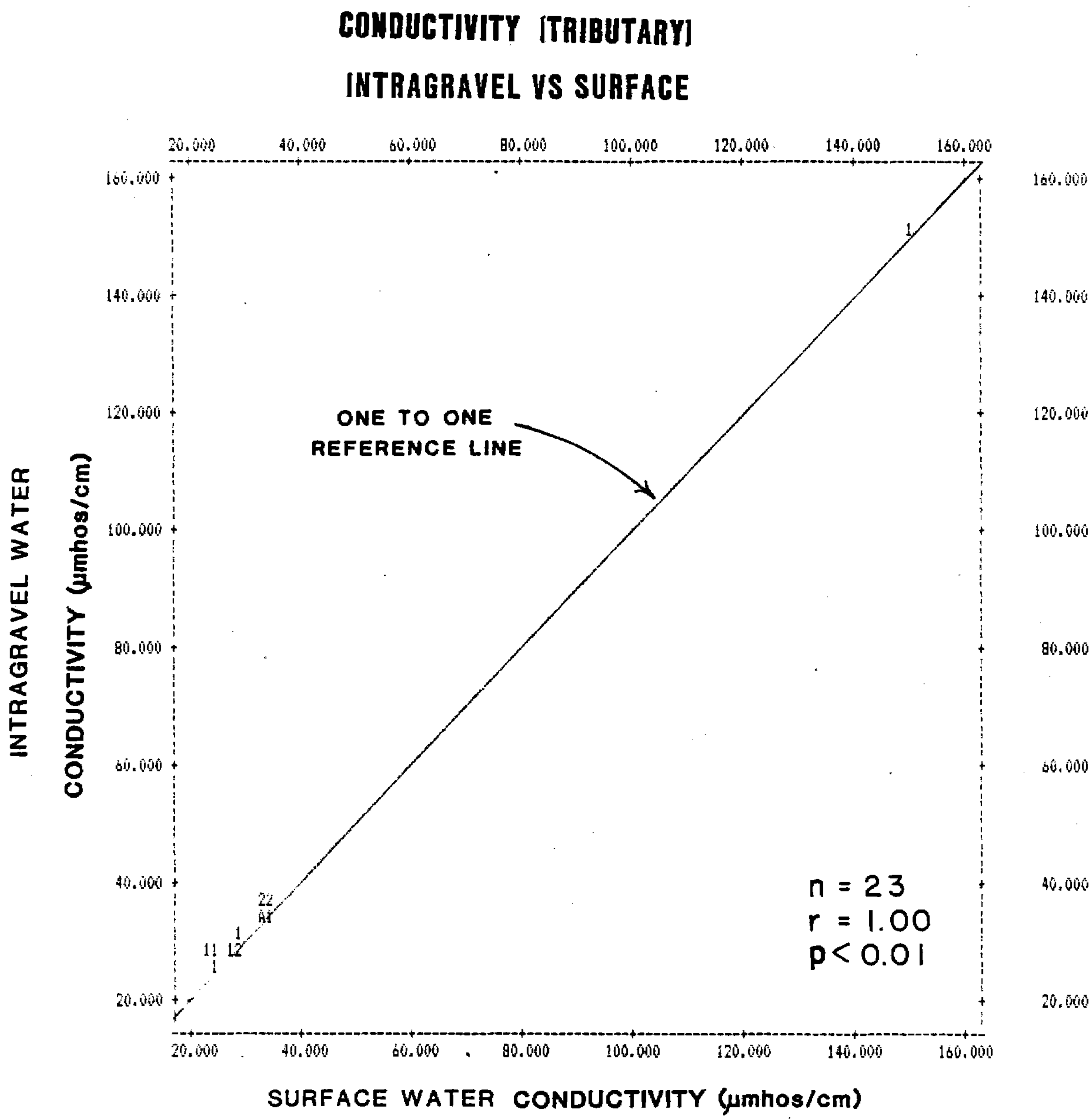


Figure 43. Relationship between intragravel and surface water conductivity levels (umhos/cm) measured within tributary habitat of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

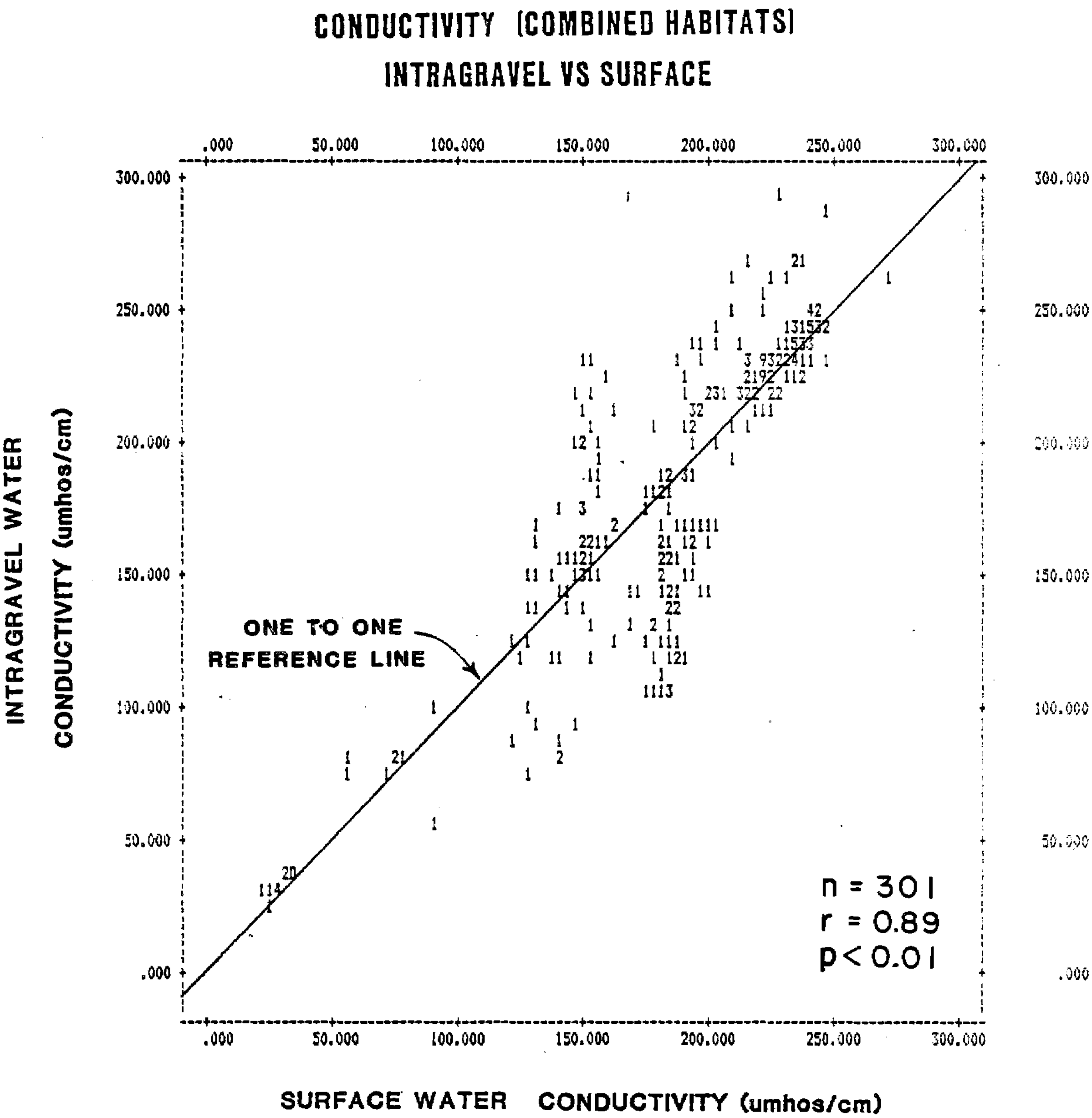


Figure 44. Relationship between intragravel and surface water conductivity levels (umhos/cm) measured within slough, side channel, and tributary habitats of the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

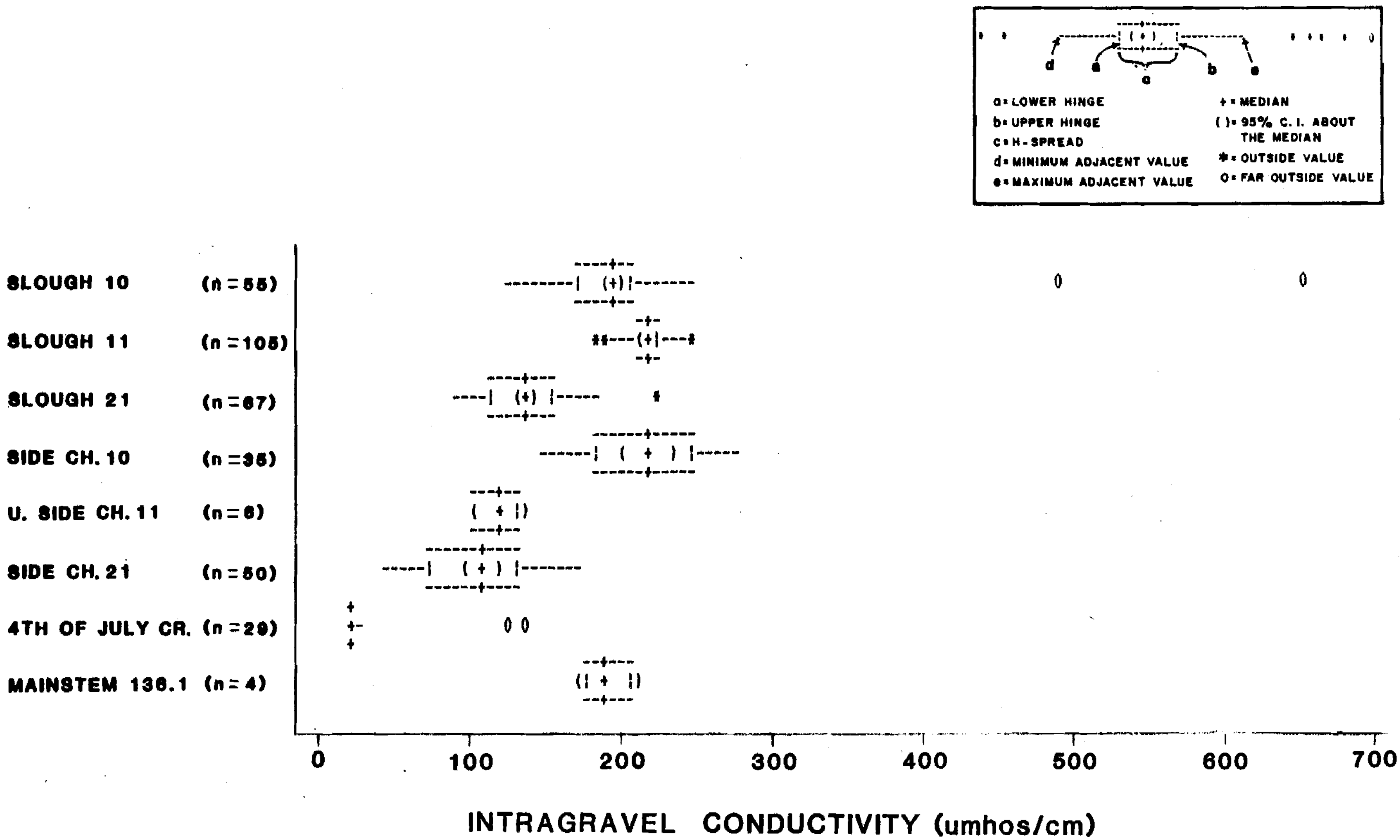


Figure 45. Summary, by study site, of the intragravel conductivity data (umhos/cm) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

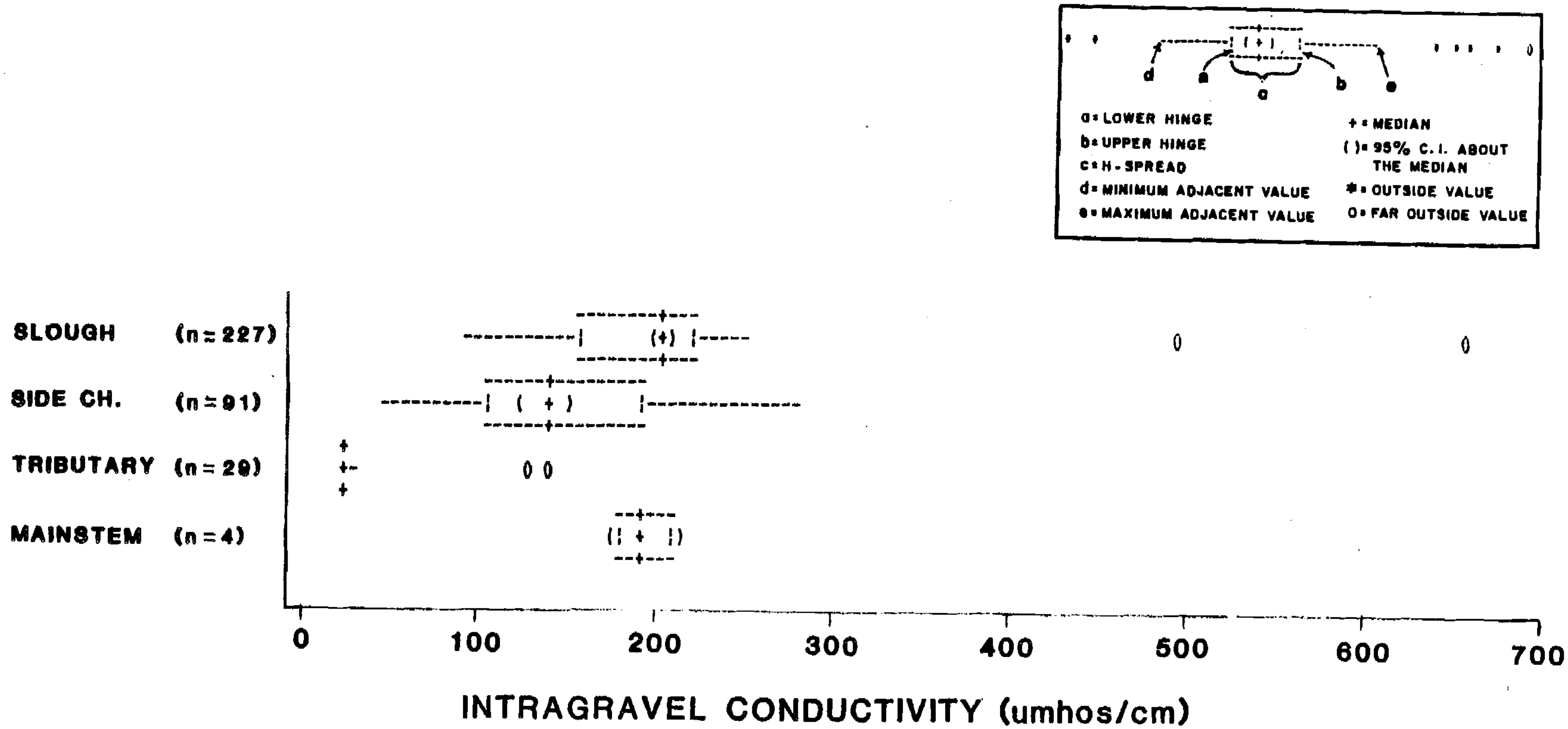


Figure 46. Summary, by habitat type, of the intragravel conductivity data (umhos/cm) periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (refer to Section 2.4 for detailed explanation of figure symbols).

Table 4. Summary of the timing of events for installing and removing Whitlock-Vibert Boxes (WVBs) for analyses of embryonic survival and development.

			Installation and Removal of WVBs				Removal of WVBs for Evaluation of Survival and Development			
Site	Subsite	Egg Source	Date of Installation	Total WVBs Installed	Total WVBs Removed	WVBs Not Accounted For	Survival[a] Removal Period	Number Removed	Development Removal Period	Number Removed
Fourth of July Creek	A	Fourth of July Creek	08/28/83	30	28	2[d]	03/30/84 - 05/10/84	22	10/09/83 - 11/02/84	6
Slough 10	A	Fourth of July Creek	09/09/83	40	40	0	02/08/84 - 04/25/84	34	10/29/83 - 02/29/84	6
Side Channel 10	A	Fourth of July Creek	09/09/83	38	38	0	03/01/84 - 05/10/84	34	10/09/83 - 03/02/84	10
Slough 11	A	Slough 11	08/26/83	40	40	0	01/18/84 - 03/28/84	34	10/09/83 - 02/09/84	9
	B	Varied[e]	Varied[e]	30	30	0	02/01/84	10	08/28/83 - 02/01/84	27
	C	Slough 11	08/26/83	10	8	2[f]	--	--	10/09/83 - 12/30/84	8
Upper Side Channel 11	A	Slough 11	08/26/83	10	6	4[f]	--	--	10/24/83 - 01/19/84	6
Mainstem (RM 136.1)	A	Slough 11	08/26/83	20	19	1[f]	03/30/84 - 04/17/84	8	10/09/83 - 04/25/84	19
Side Channel 21	A	Slough 21	08/24/83	40	38	2[g]	03/29/84 - 06/01/84	34	10/09/83 - 10/27/83	4
	B	Slough 21	09/13/83	20	20	0	03/29/84 - 06/01/84	20	3/28/84 - 4/19/84	6
	C	Slough 21	09/13/83	--	--	--	--	--	10/25/83 - 5/10/84	12[h]
Slough 21	A	Slough 21	08/28/83	30	28	2[g]	01/17/84	24	10/26/83 - 01/17/84	10
Natural Redds	-	Aug-Sept	Aug-Sept	--	--	--	--	--	09/21/83 - 04/13/84	9[h]

a Data provided in Appendix A (Table A-2)
b Data provided in Appendix A (Table A-1)
c Some WVBs used to evaluate development were also used to evaluate survival (refer to Appendix A, Tables A1 and A2).
d WVBs were still frozen into the substrate on 05/10/84. Embryos were presumed to be dead.
e Embryos from Fourth of July Creek, Slough 11 and Slough 21 were installed at this subsite. Dates of installation correspond to those presented in the above table for each individual site.
f Excess WVBs not required for analyses.
g Became buried in silt and lost.
h This number refers to the number of times embryos were collected rather than the number of WVBs removed, and is not included in the column total.

3.2.1 Embryo Survival

3.2.1.1 Accumulation of Fine Substrate Particles

In order to properly estimate embryo survival at study sites, the following two hypotheses had to first be proven: (1) that WVBs did not accumulate fine substrate particles in excess of that of the surrounding substrates; and (2) that the disappearance of embryos from withn WVBs between times of installation and removal was not attributable to alevins leaving the WVBs. Data supporting the first hypotheses are presented below. A complete presentation of the rational supporting the second hypotheses is presented in Section 4.1.

To determine whether WVBs accumulated fine substrate particles in excess of that present in the surrounding substrates, 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 observed in the WVBs at the time of their removal (Figures 47 and 48, respectively). In both cases, there appears to be relatively good correlations (0.81 and 0.76, respectively) indicating WVBs did not accumulate excess fine particles compared to quantities of fines found in the surrounding substrates.

3.2.1.2 Survival Estimates

The percent survival of chum salmon embryos at individual study sites is presented in Figure 49. 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 because WVBs containing fertilized eggs were installed at two different times on August 24, 1983 and September 13, 1983, respectively. 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 eight 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 two [Side Channel 21 (Subsite B) 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 slough, side channel and tributary habitat types are presented in Figure 50. Equal weight was given to each study site, regardless of the number of WVBs within each site. Slough, side channel and tributary habitats had survival rates of 17%, 9% and 11%, respectively.

SUBSTRATE

McNEIL VS WHITLOCK-VIBERT BOX

CATEGORY: < 0.08 in

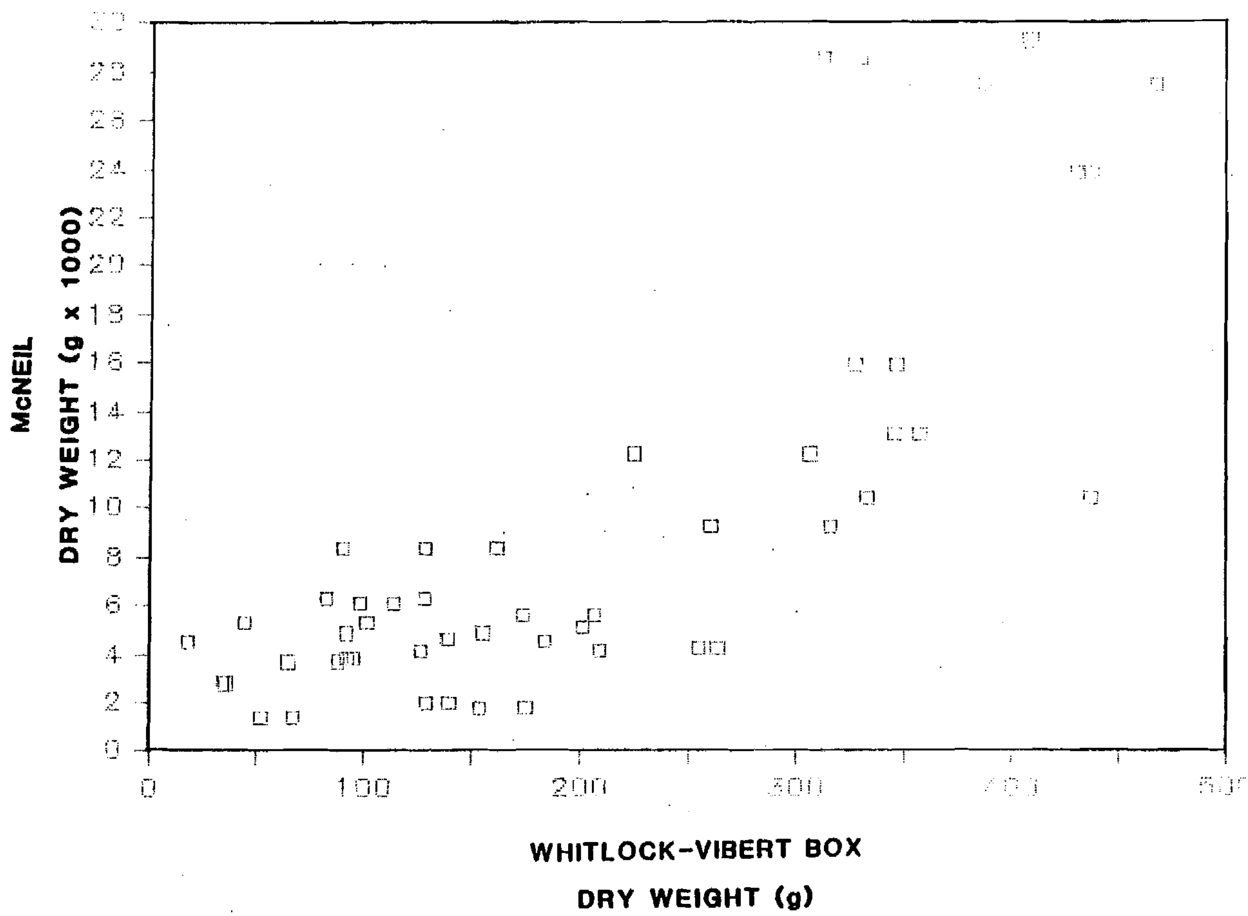


Figure 47. Comparison of the dry weights (g) of fine substrate (< 0.08 in. diameter) obtained from paired samples collected with McNeil and Whitlock-Vibert Box samplers.

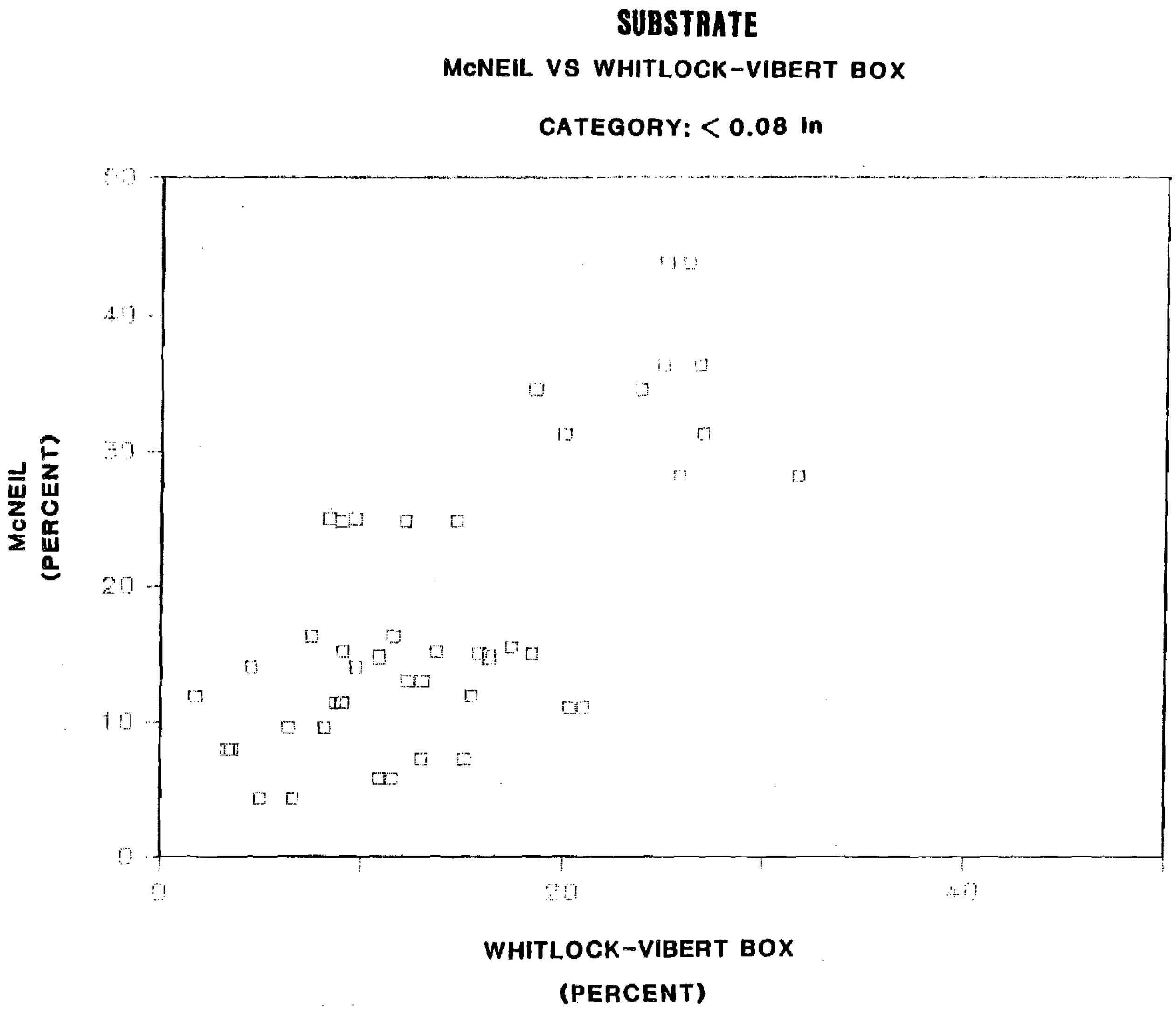


Figure 48. Comparison of percent dry weights of fine substrate (<0.08 in. diameter) obtained from paired samples collected with McNeil and Whitlock-Vibert Box samplers.

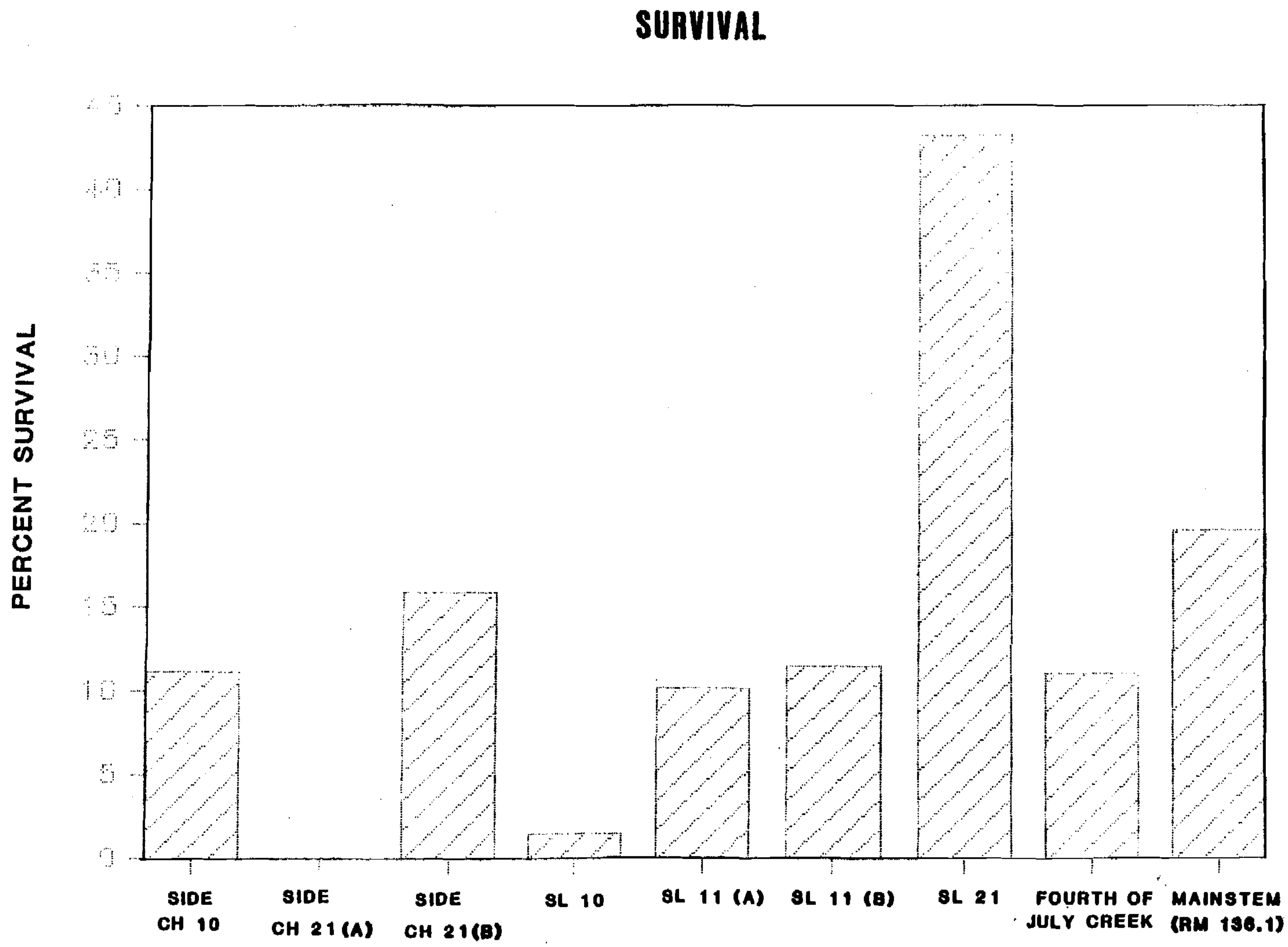


Figure 49. Comparison of percent survival of salmon embryos removed from artificial redds in study sites in the middle Susitna River, Alaska.

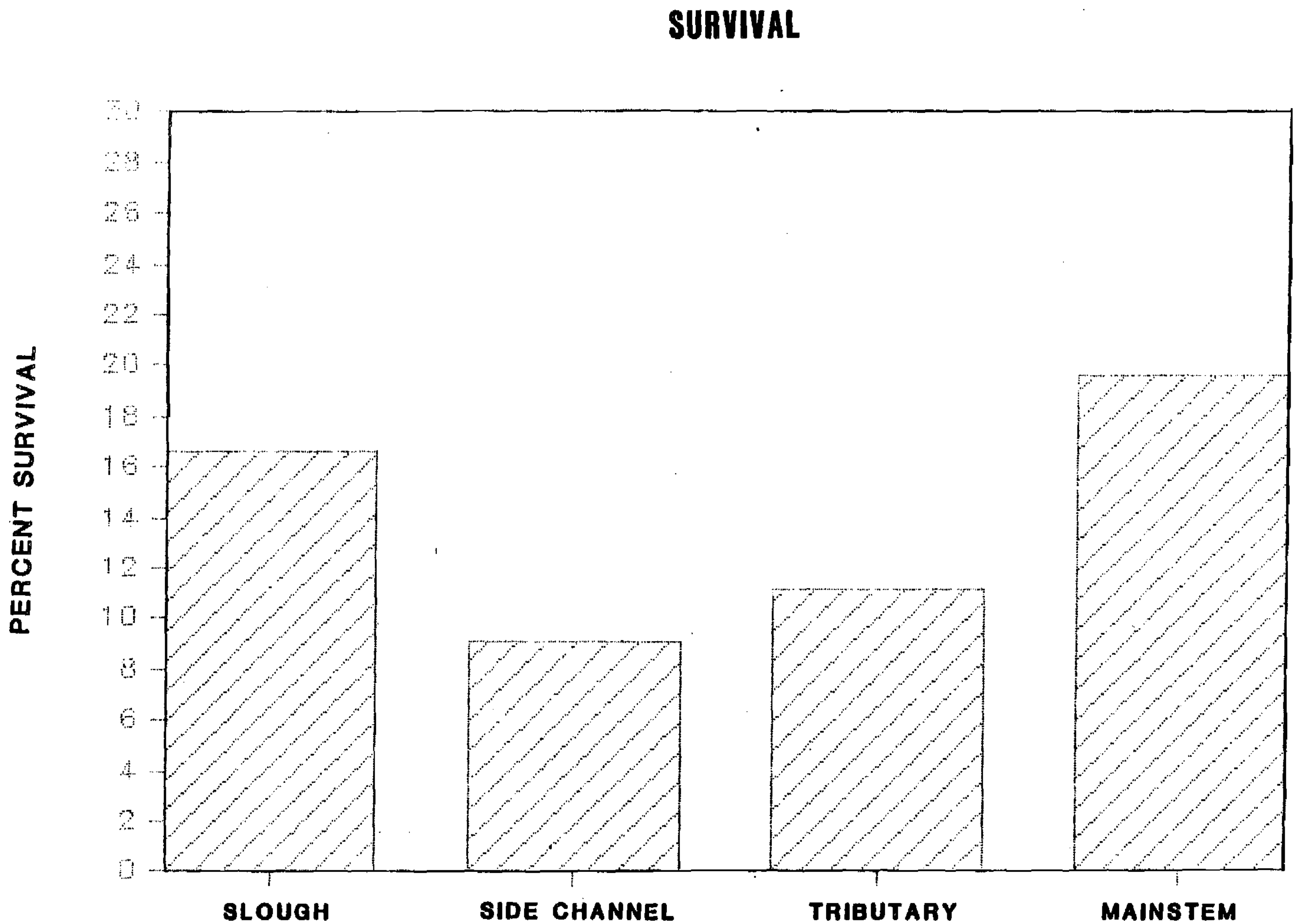


Figure 50. Comparison of percent survival of salmon embryos removed from artificial redds in various habitat types in the middle Susitna River, Alaska.

Survival data for the mainstem habitat study site (Mainstem RM 136.1) are presented in Appendix Table A-2. Although these data show that the mainstem site had a survival rate of approximately 19% these results should not be compared with survival rates from other habitats and therefore are not presented in Figures 49 and 50. The primary objective of this study emphasized the comparison between slough and side channel habitats. As such, mainstem sites were not specifically selected to evaluate embryo survival. The mainstem site was selected to compare the progression of embryo development between a mainstem, slough, and side channel site. Because of this, the mainstem site was specifically selected to avoid problems of dewatering and freezing and WVBs containing embryos were therefore placed in a carefully selected area (i.e., not randomly placed). For this reason, the higher survival rates observed in the mainstem habitat study site may be an artifact of the study methodology.

3.2.2 Embryo Development

A comparison of the pattern of accumulation of temperature units (TUs) at each embryonic development study site could not be presented (refer to Appendix F for temperature data) here because of problems encountered with the continuous temperature recorders. The recorder placed in Slough 11 malfunctioned and no data was obtained at this site until December 30, 1983, at which time a second thermograph was installed. At the mainstem site, the river staged in early January and completely submerged all visual location markers at this site. This prevented the replacement of the thermograph unit or from locating the embryos and installing another thermograph.

An alternative analysis, a progression of the rate of development of embryos placed in Slough 11 (Subsite C) Upper Side Channel 11 (Subsite A) and Mainstem (RM 136.1) (Subsite A), however, is presented in Figure 51. Eggs were fertilized on August 26, 1983 and then temporarily incubated in a tributary at Slough 9 until October 1, 1983 after which the embryos were incubated separately in each of the three habitat types.

Based on the data in this figure, the pattern of embryonic development in Slough 11 and Upper Side Channel 11 was similar. The pattern in both of these sites, however, differed substantially from that of the mainstem site. Completion of hatching (100%) appears to have occurred in Upper Side Channel 11 and Slough 11 by late December 1983 and late January 1984, respectively (Figure 51). In contrast to these sites, the rate of development in the mainstem site was much slower. Hatching at the mainstem site was not completed until mid-April. This is more than a three month delay in development at this site as compared to Upper Side Channel 11 and a two month delay compared to Slough 11.

Such differences in development rates are undoubtedly related to the differences in thermal regimes at these sites. Slough 11 and Upper Side Channel 11 both contain significant upwelling water, whereas no upwelling was detected at the mainstem site. Since upwelling water provides significantly warmer winter water temperatures, it provides an increase in the rate of accumulation of temperature units (TUs) which would accelerate the rate of development of embryos.

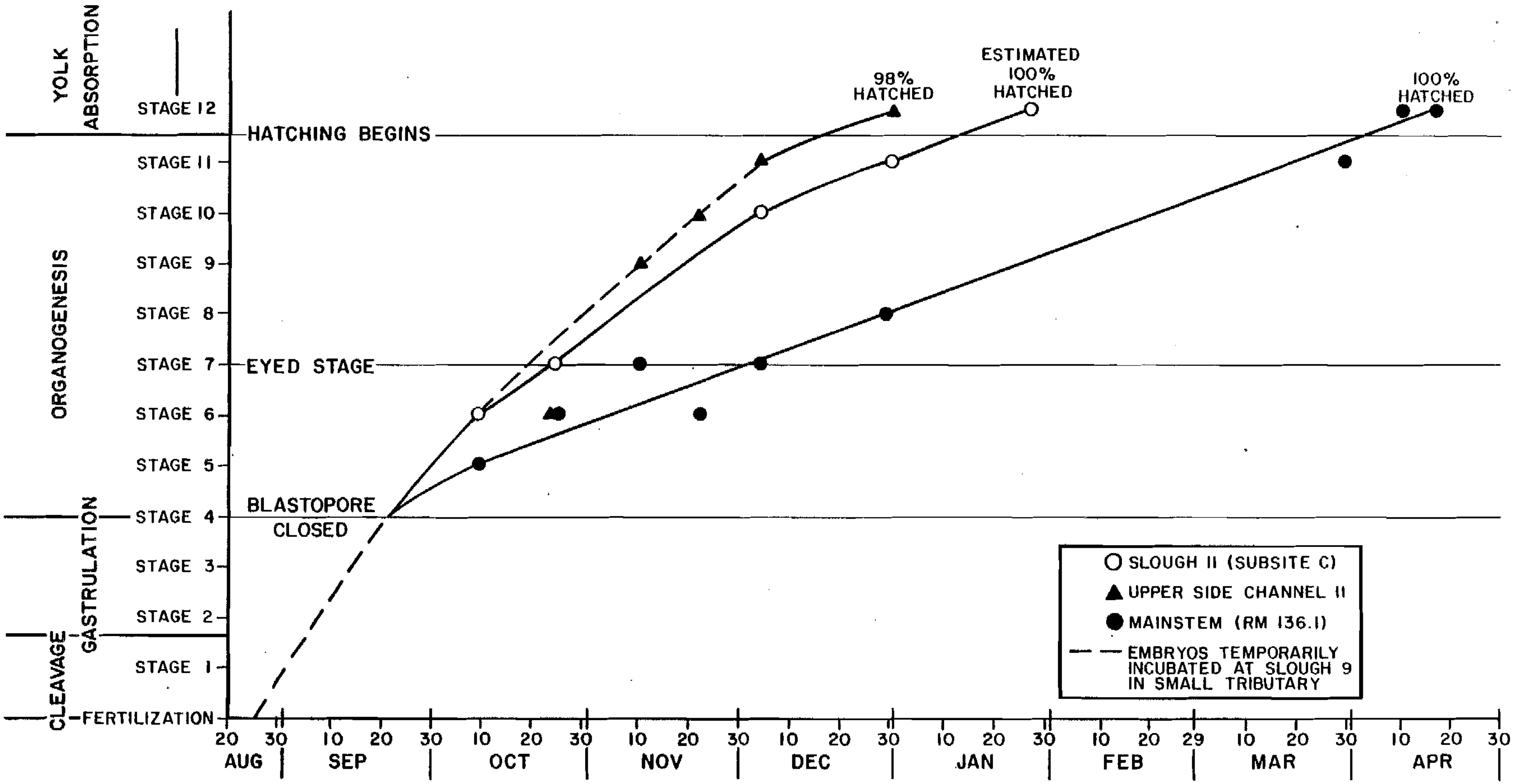


Figure 51. Comparison of the timing of development of chum salmon embryos placed within slough, side channel and mainstem habitats.

A comparison of the rate of embryonic development between Upper Side Channel 11 and Side Channel 21 is presented in Figure 52. Upper Side Channel 11 represents a side channel which is strongly influenced by upwelling water whereas, Side Channel 21 is not strongly influenced by upwelling water in the area where embryos were placed. Although the dates of fertilization were separated by 18 days, the difference in the time of hatching differed by more than 100 days.

This large difference in time of hatching is undoubtedly related to two factors: (1) the difference in the relative influence of upwelling; and (2) the difference in the seasonal pattern of TU accumulation. However, it is not possible to clearly distinguish between these two effects. Upwelling not only provides a more uniform pattern of TU accumulation, but it also provides a faster rate of TU accumulation during the winter months. This factor probably accounts for much of the 100 day difference in hatching between the sites. In the fall, during the time when embryos were implanted, water temperatures were warmer in Side Channel 21 than they were later in the season. Because of this, the accumulation of TUs and development of embryos would be expected to be more rapid for a given period of time. Thus, if embryos were installed 18 days earlier at Side Channel 21 they would have received a substantially greater number of TUs over this 18 day period than they would later in the winter. This probably would have reduced the 100 day delay in hatching by more than 18 days.

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

The effects of selected physical, chemical, and biological habitat variables on embryo survival at study sites and habitat types is addressed in this section. A quantitative evaluation of the effects of selected physical and chemical habitat variables on embryo survival in this study was limited as 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 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 53 and 54, 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. The mainstem study site (Mainstem RM 136.1) is not discussed here because this site was not specifically selected to make these types of comparisons (see Section 3.2).

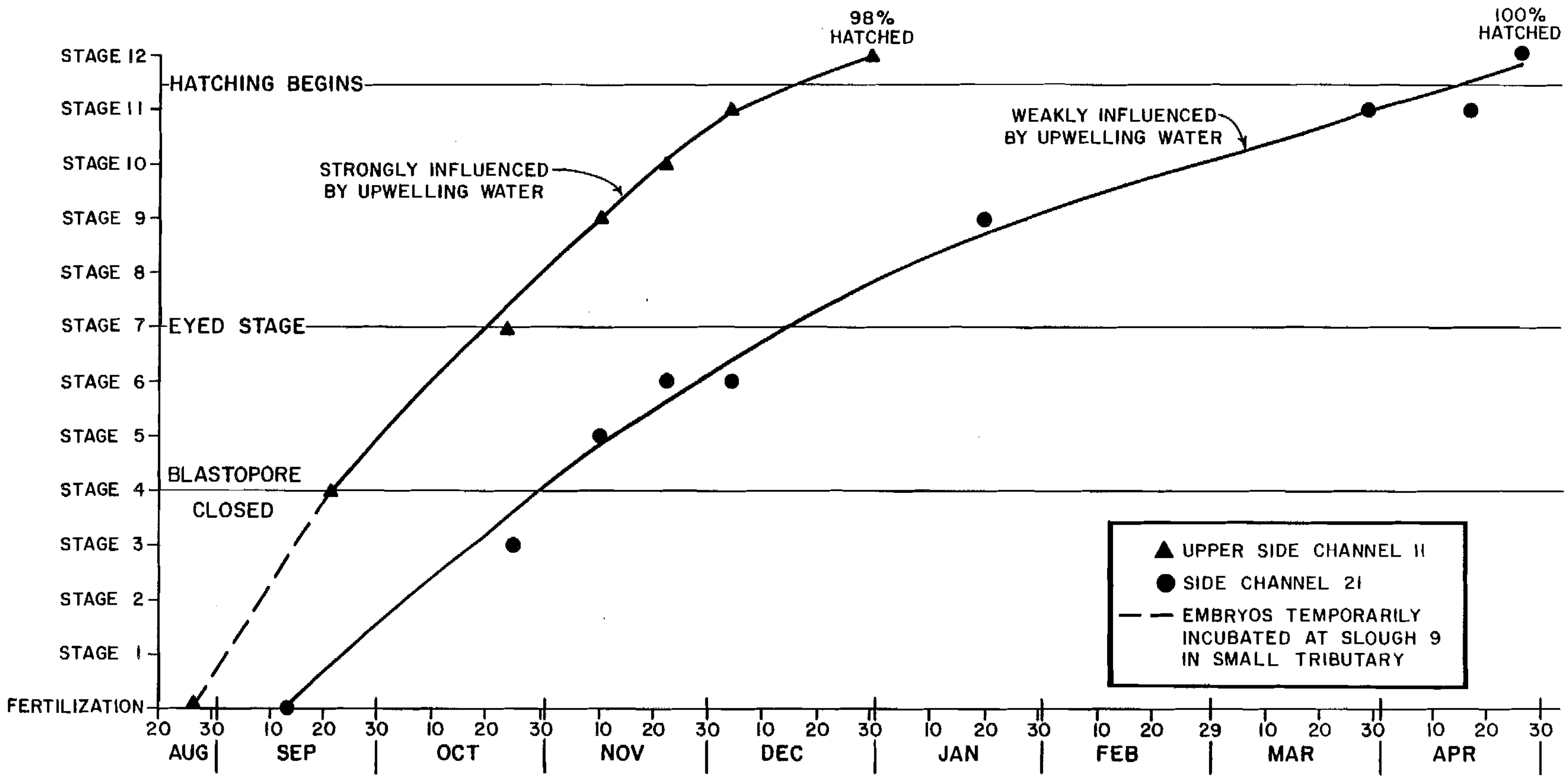


Figure 52. Comparison of the timing of development of chum salmon in two types of side channels; one strongly influenced by upwelling (Upper Side Channel 11) and one where upwelling was not observed (Side Channel 21).

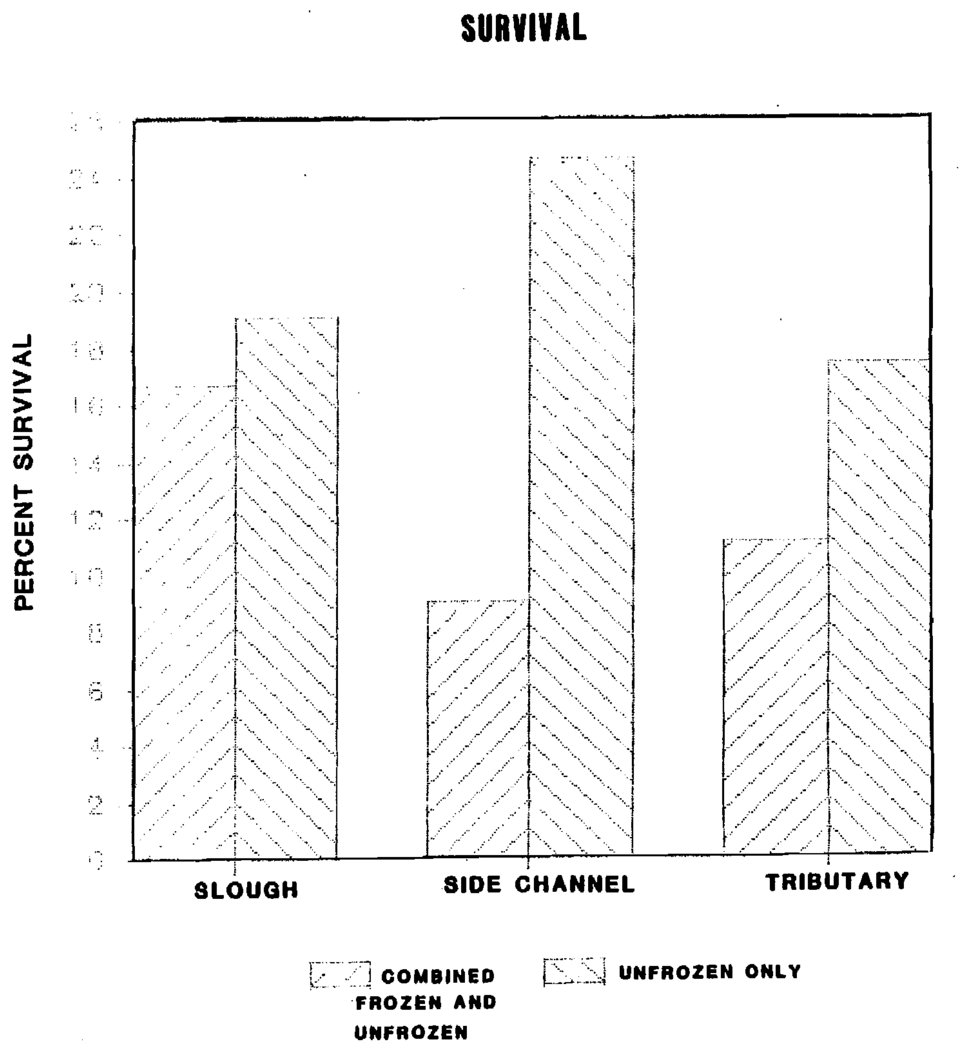


Figure 53. Comparison between the percent survival of embryos for all samples collected within a habitat type (frozen and unfrozen) to the percent survival after frozen samples are removed.

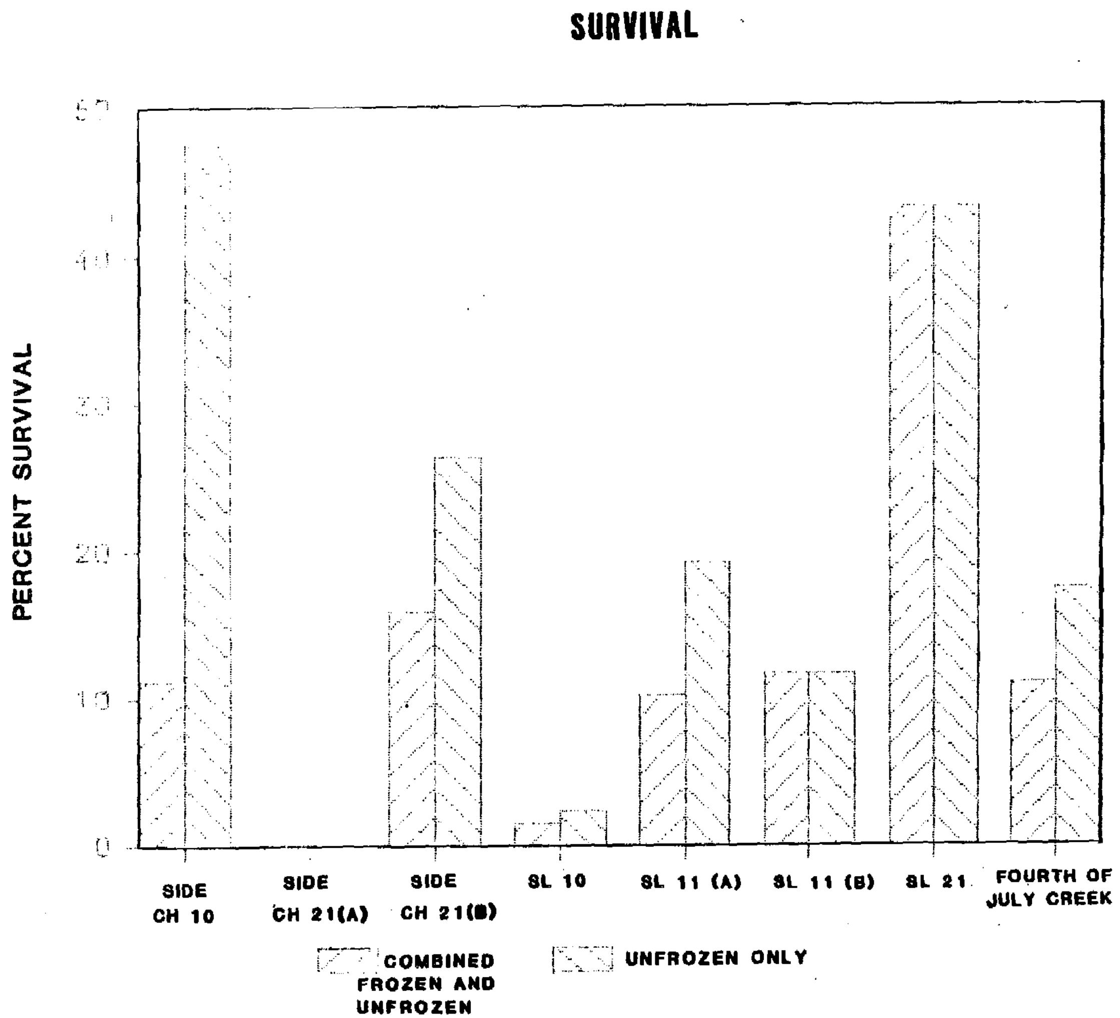


Figure 54. Comparison between the percent survival of embryos for all samples collected within a study site (frozen and unfrozen) to the percent survival after frozen samples are removed.

The data in Figure 53 show that when dewatered and frozen samples are taken into account, survival is highest in slough habitats 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 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 data also show the variable nature that 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. 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. 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 55. 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 a relatively higher rate of intragravel flow at these sites.

The relationship between survival of embryos and intragravel water temperature at the study sites is presented in Figure 56. Over the limited range of 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 57-59. 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 because this value was considered to be most limiting to survival of embryos.

There was no strong correlation 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, no correlation was evident (r=0.08). The plot for pH contained too few data points to enable any firm conclusions to be made. However, the absence of high survival

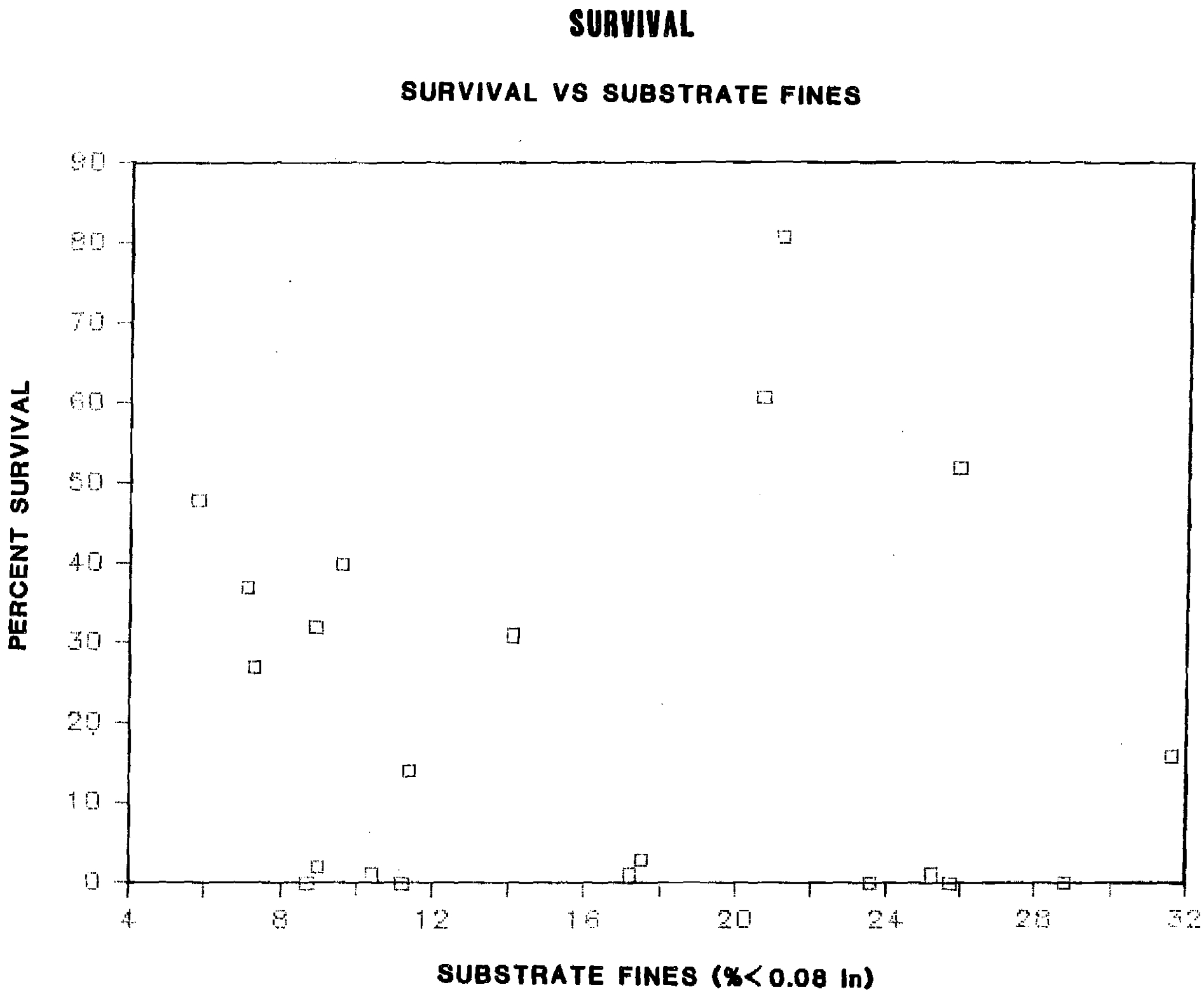


Figure 55. Relationship between percent survival of salmon embryos and the percent of fine substrate (<0.08 in. diameter) within Whitlock-Vibert Boxes removed from artificial redds within selected habitats of the middle Susitna River, Alaska.

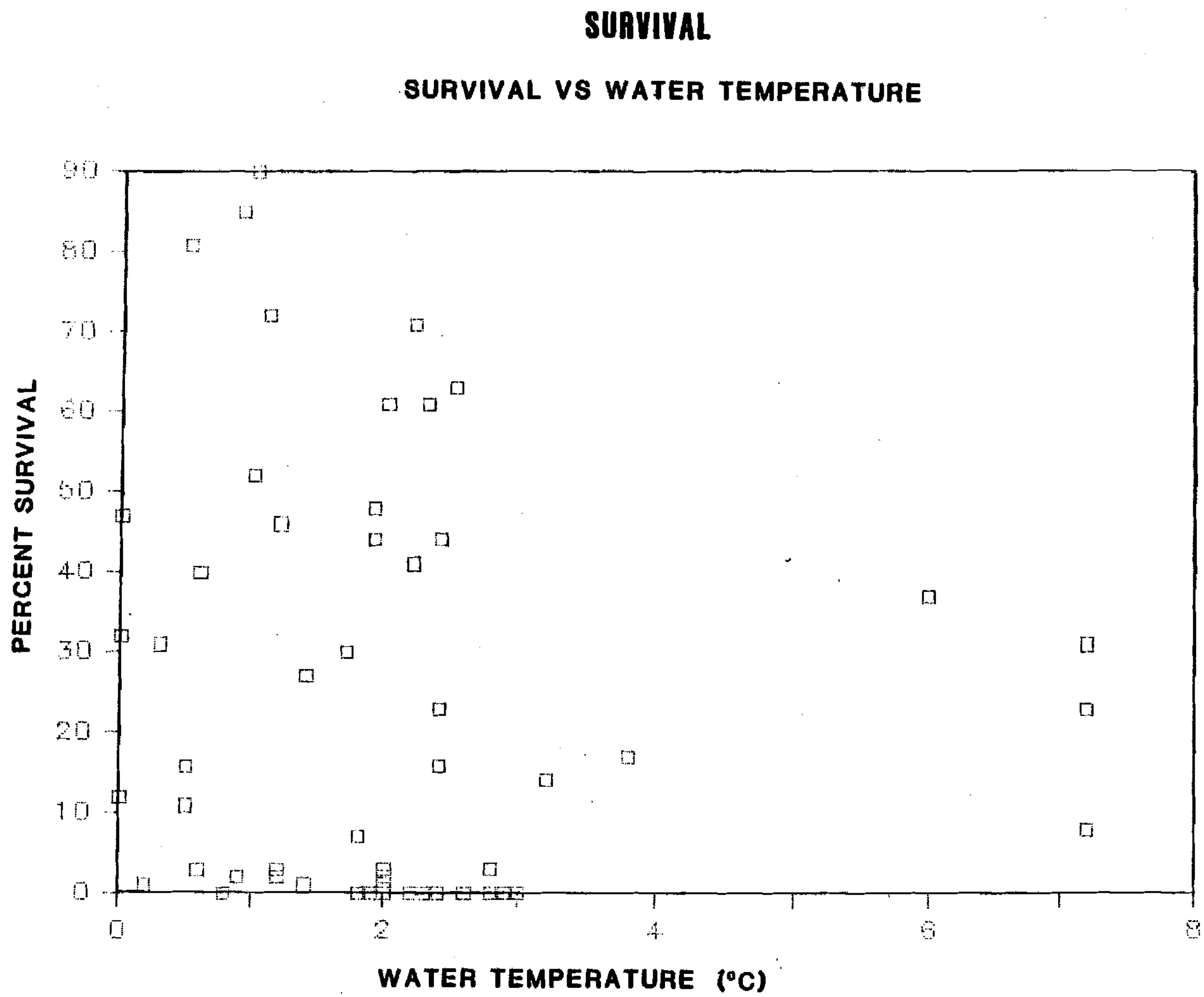


Figure 56. Relationship between percent survival of salmon embryos and intragravel water temperatures determined at artificial redds within selected habitats of the middle Susitna River, Alaska.

SURVIVAL

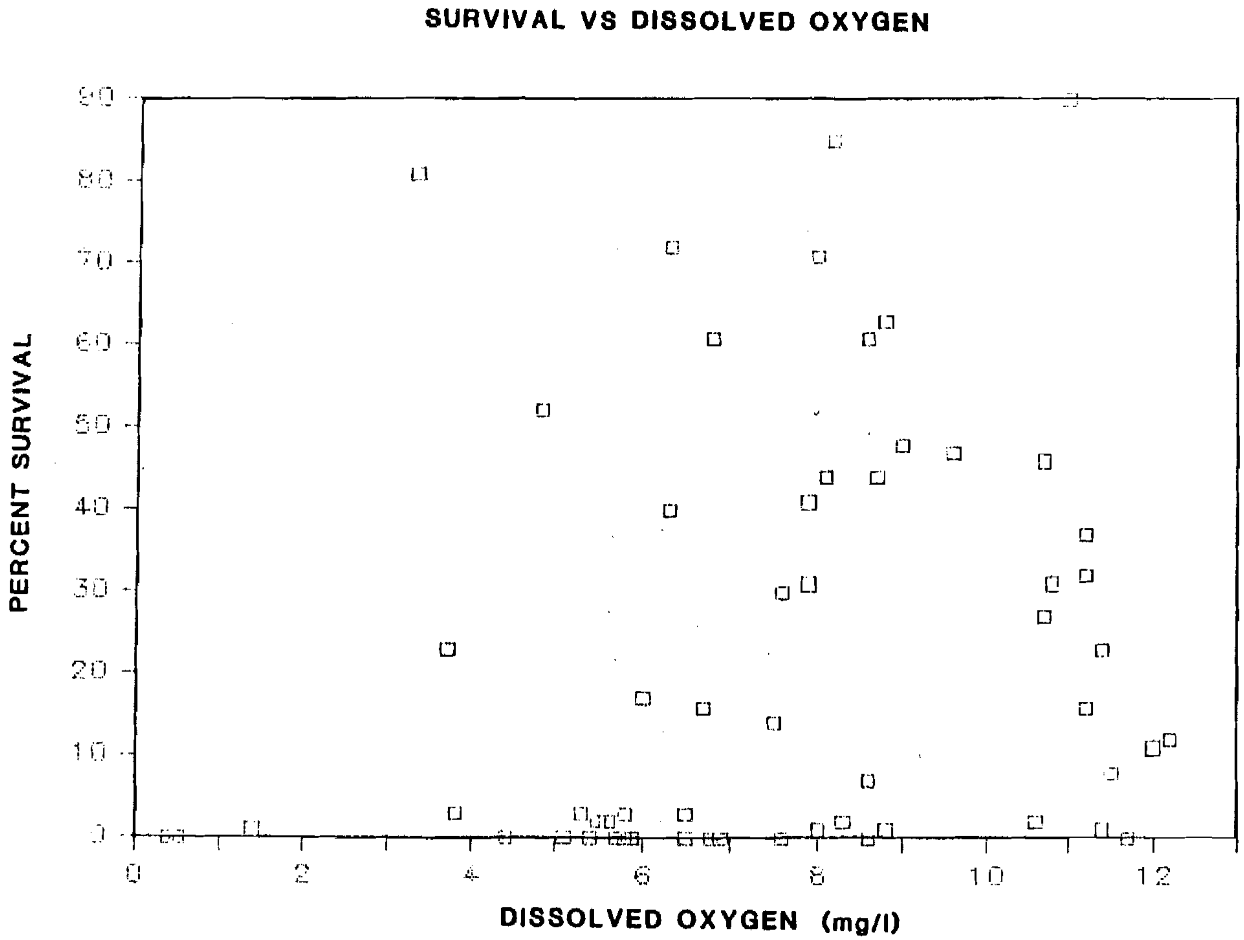


Figure 57. Relationship between percent survival of salmon embryos and concentration of intragravel dissolved oxygen (mg/l) measured at artificial redds within selected habitats of the middle Susitna River, Alaska.

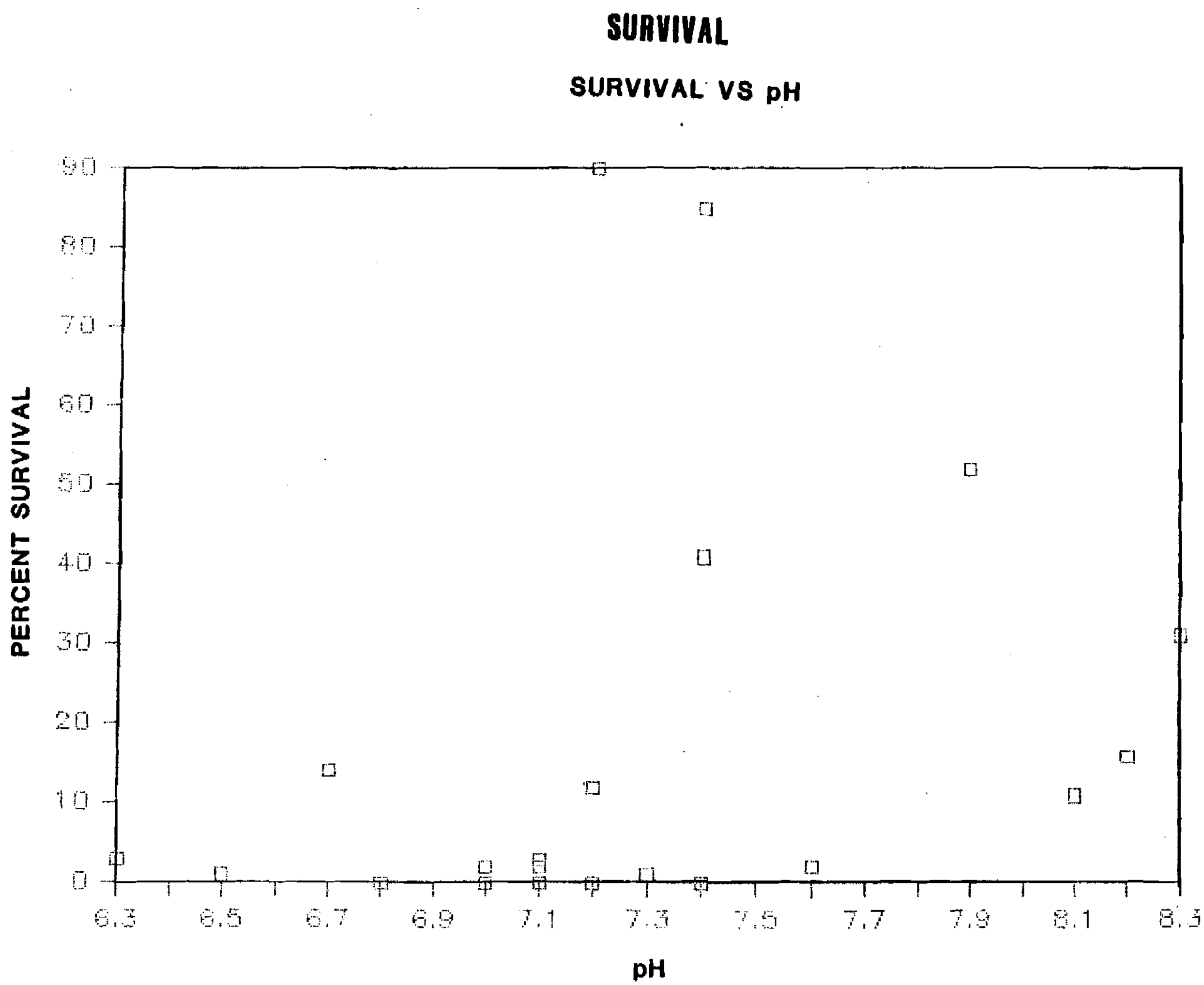


Figure 58. Relationship between survival of salmon embryos and intragravel pH levels measured at artificial redds within selected habitats of the middle Susitna River, Alaska.

SURVIVAL

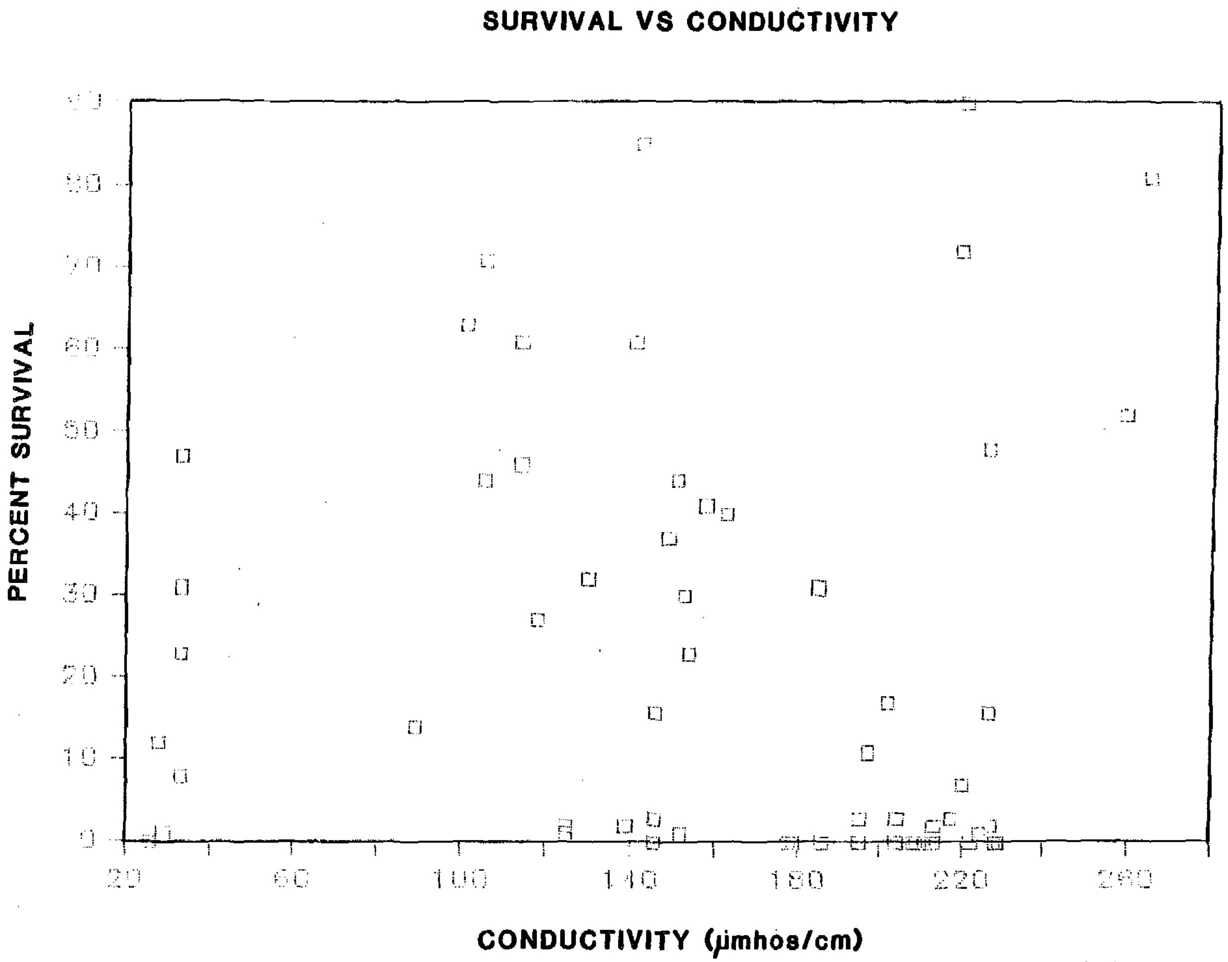


Figure 59. Relationship between survival of salmon embryos and intragravel conductivity levels (umhos/cm) measured at artificial redds within selected habitats of the middle Susitna River, Alaska.

values at low pH indicates that 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

During the course of the field sampling program a problem was encountered which involved the disappearance of salmon embryos from WVBs used to determine survival estimates at study sites. Originally, each WVB contained 50 fertilized eggs. After mid-November, when WVBs were retrieved from the streambed, a relatively large proportion of embryos were missing. The number of embryos missing from each of these WVBs is reported in Table A-2 of Appendix A. The mean number of embryos missing at each site expressed as a percent of the total for each site is 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 consistently observed that large numbers of flatworms were 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 correlated to the number of missing embryos in the box. With a sample size of 207, the Spearman's rank correlation coefficient was significant at the $p < 0.01$ level with an r_s of -0.64. Although this does not necessarily indicate that flatworms consumed dead embryos, it is strong evidence which supports that conclusion.

4.0 DISCUSSION

A discussion of selected physical, chemical, and biological habitat conditions affecting chum salmon incubation in habitats of the middle Susitna River is presented in this section. Incubating chum salmon 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 and survival of embryos is directly related to both the physical and chemical characteristics of the source of water surrounding the developing embryos.

The following sections within this chapter describe those variables required for the survival and development of incubating chum salmon embryos including the assumptions and limitations from which the analyses are derived.

4.1 Assumptions and Limitations

Several assumptions were made in this study to evaluate the influence that selected environmental variables have on the rate of development and survival of chum salmon embryos placed within WVBs in selected habitats in the middle Susitna River. These assumptions are:

1. The hydraulic characteristics at artificial redds were similar to those encountered at natural redds.

2. Intragravel water quality data measured within PVC standpipes was representative of the intragravel water quality conditions encountered by embryos within the WVBs installed near that standpipe.

3. Embryos were removed from each site at 100% hatch enabling estimates of embryo survival to be made between all sites.

4. Embryos missing from within WVBs at the time of retrieval were consumed by egg predators or scavengers (primarily flatworms).

5. The composition of fine substrates (<0.08 in. diameter) within WVBs was representative of that of the surrounding streambed during the incubation period.

6. There is no significant difference between the rate of development and the percent survival between pink and chum salmon embryos installed in WVBs in Fourth of July Creek.

The first assumption is difficult to evaluate since there are numerous factors which may influence the flow of water through a salmon redd (Burner 1951, Vaux 1962). The most obvious differences between artificial redds and natural redds involve the way in which the substrate materials are disturbed during the process of egg deposition. However, the methods used for preparation and placement of the WVBs within the substrate were designed to simulate natural incubation conditions as closely as possible. Therefore, this assumption appears justified.

The second assumption is difficult to evaluate because of the absence of alternative available methods for confidently obtaining true water quality values. The methods used in this study were derived from the methods employed by other researchers (e.g., Wickett 1954, Gangmark and Bakkala 1958) and represent methods which are currently accepted. However, we believe that the data obtained using standpipes may be biased to some extent by surface water contamination. The extent to which this bias may have occurred, however, is not known.

The third assumption was violated in that embryo mortality occurs throughout the process of embryonic development. Therefore, in order for valid comparisons of survival to be made between various study sites or habitat types, embryos must be removed from various sites at the same point in their development. In this study, we attempted to remove embryos at the point of 100% hatch. However, this was not always possible. Thus, estimates of survival are probably somewhat higher for sites removed before 100% hatch, and lower for sites removed after 100% hatch.

Since an estimate of percent survival of embryos at each site was the central focus of this study the fourth assumption, accurately accounting for embryos missing from WVBs, is an important task. For the purpose of this study, missing embryos were presumed dead. The following account presents the evidence which provided the basis for the assumption that embryos were missing from WVBs primarily because dead embryos were being scavenged by invertebrates (primarily flatworms). Four potential means of embryo loss were hypothesized: (1) live embryos were consumed by predators (vertebrate and/or invertebrate); (2) embryos hatched and escaped from the WVBs; (3) embryos died within the boxes and were subsequently consumed by vertebrate (sculpins) or invertebrate scavengers; or (4) a combination of the above factors.

Loss of live embryos due to predation by vertebrate and/or invertebrate predators was eliminated as the primary factor accounting for the missing embryos because the pattern of loss of embryos over time did not support this hypothesis. If live embryos were being consumed by predators, one would expect the magnitude of loss to progressively increase over time. This, however, did not occur. Instead, the pattern of loss of embryos from WVBs was characterized by an abrupt change from few or no missing embryos during the incubation period from late August to mid-November, to a relatively large number of missing embryos by mid January (based on field observations at the time of removal of WVBs). Also, large numbers of potential vertebrate or macroinvertebrate predators were not consistently associated with WVBs from which embryos were missing during this period. Although the absence of potential predators does not preclude their involvement, it supports the idea that they are not of primary importance. Thus, it was concluded that predation by vertebrate and invertebrate predators was not the primary mechanism accounting for the loss of embryos within WVBs.

Alternatively, the relatively abrupt increase in the loss of embryos from WVBs could potentially result from either the hatching and subsequent escape of embryos from WVBs or from decomposition and/or scavenging of dead embryos within WVBs by saprovoric organisms. Hatching and subsequent escape of embryos from WVBs was eliminated from consideration for the following reasons.

1) Generally, WVBs were removed from sites during the period when embryos were beginning to hatch (prior to 50% hatch) with the exception of Fourth of July Creek and Slough 11 (Subsite B).

2) Hand digging with a shovel in the gravel which immediately surrounded the WVB did not consistently result in locating alevins indicating that they were not escaping from the WVBs.

The large yolk-sac of these newly hatched alevins probably prevented the movements of alevins out of the boxes until a substantial portion of yolk was absorbed. This assumption is consistent with our field observations.

For the purposes of this study, embryos missing from WVBs were assumed to have died from unknown causes and were later consumed by flatworms. Decomposition of dead embryos by microorganisms was undoubtedly occurring at each site as documented by the large number of flatworms observed in WVBs where large numbers of embryos were missing. The significant correlation between the rank abundance of flatworms in WVBs and the number of missing embryos is the most direct evidence suggesting that flatworms may be consuming dead embryos (refer to Section 3.3).

The fifth assumption was dependent upon the degree of confidence in the substrate sampling technique which was used. Although the McNeil sampler was determined to be the best sampler for use in this study, Platts (1983) identified the following disadvantages and limitations of this device, (1) it is limited in particle size diameter to the size the coring tube can trap; (2) it completely mixes the core materials so no interpretation can be made of vertical and horizontal differences in particle size distribution; (3) it is limited to the depth the core can enter the channel substrate, a factor controlled by the water depth, length of the collector's arm, and the depth the core sampler can be pushed into the channel; (4) it is biased if the core tube pushes larger particle sizes out of the collecting area; (5) it allows suspended sediments in the core to be lost; and (6) it cannot be used if the particle sizes are too big or the channel substrate too hard or cemented that the core cannot be pushed to the required depth. Despite these limitations, the results of substrate samples (particularly fines) collected with the McNeil sampler and from WVBs showed that the substrates from each were comparable, indicating that this assumption is justified.

Application of assumption six is restricted to the study site at Fourth of July Creek. At this site, pink salmon embryos were placed in five of the fifteen artificial redds. Although this assumption may not be entirely valid, the fact that the ranges of environmental conditions affecting incubation which are selected by Pacific salmon broadly overlap (Reiser and Bjornn 1979) suggests that requirements for successful incubation are also similar indicating assumption six is valid.

4.2 Physical, Chemical, and Biological Habitat Conditions Associated with Chum Salmon Development and Survival

4.2.1 Upwelling

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

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

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

The relationship between surface and intragravel water, and upwelling is not clearly understood in habitats of the middle Susitna River. 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 appear to be 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 due to the higher flows in these habitats the effects of upwelling are less evident. As a result, the beneficial effects of reduced dewatering and freezing of substrate, relatively stable intragravel temperatures, and increased intragravel flow to incubating embryos is afforded to incubating embryos within slough habitats over other habitat types.

4.2.2 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. However, it was observed that upwelling water prevented substrates from freezing in areas where upwelling was active, as well as adjacent downstream areas which were hydrologically influenced by water originating from upwelling vents. Changes in natural Susitna River discharge conditions may affect the presence, absence, or rate of upwelling and may therefore have an influence on dewatering and freezing of habitats. Higher than normal flows during the winter may reduce areas normally affected by dewatering and freezing resulting in increased incubation habitat while lower than normal flows may decrease incubation habitat, due to increased dewatering and freezing of habitats.

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 4.2.3). 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, however, reduces the effects of localized freezing 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 which lacked an upwelling water source. These areas include the mouths of 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 stage decreased with winter flows, these areas progressively became dewatered and were exposed to freezing ambient temperatures. This ultimately resulted in freezing of the 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 on survival 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 outside the deeper section (thalweg) of the site. At this time, the mainstem discharge was approximately 27,000 cfs at Gold Creek causing this side channel to be breached. Approximately two weeks later, the discharge in the mainstem dropped to 11,100 cfs resulting in the side channel being no longer breached and the local flow in this side channel being 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. As the flow continued to decrease throughout the winter, the majority of locations at which these additional WVBs had been installed remained wetted. All the embryos in the forty WVBs which were initially installed during the earlier period (August 26) 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.

4.2.3 Substrate

The composition of substrate is of critical importance in determining the survival of embryos to emergence. 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 (Table 5). 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".

In addition to restricting the 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 amount of fines reported for McNeil samples collected in each habitat type (refer to Figure 26). Based on the small number of samples collected, slough habitats contained more than twice the percent of fines as tributary and mainstem habitats. 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 26), the percent of fines present in chum salmon redds obtained at various sites did not exceed 16% (refer to Figure 29) 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 55 indicate that embryo survival approaches zero when fines exceed 16%.

Of the four middle Susitna River 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

Table 5. 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 (1981)
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 intragravel 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)

Table 5 (Continued).

Species	Method of Substrate Collection/Evaluation	Substrate/Sediment Size Classes	Results	Reference
Chinook, Steelhead	not specified	$<$ 6.4 mm	Recommended limit $<$ 25% fines for successful incubation of salmonid embryos:	Reiser and Bjornn (1979)
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)

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.

Another factor, although not considered in this report, is the effects of flushing flows necessary to provide suitable substrate composition for spawning. Estes (1984) and Reiser and Ramey (1985) discuss flushing flows and methods for determining them. It is suggested that the need, or lack of need, for flushing flows be considered in future preproject evaluations of substrate and associated incubation survival.

4.2.4 Water Temperature

Two primary effects of water temperature on the development and/or survival of salmon embryos involve the effects of temperature on the rate of embryo metabolism and the effects 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 the fish's 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 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 6). 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 of slough and side channel habitats with cold water from the mainstem. The inundation of these habitats with water from the mainstem Susitna River may result in a rapid and significant reduction in the intragravel water temperature. Such an event would alter the timing of develop-

Table 6. 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.

mental 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 contribution 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 21). 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.

An attempt was made in this study to compare <u>in situ</u> estimates of embryonic development rates recorded in slough, side channel, tributary and mainstem habitats with rates predicted in a laboratory study conducted on Susitna River chum salmon by Wangaard and Burger. In order to make this comparison, it was necessary to obtain a complete record of water temperatures at the locations where salmon incubation chambers were installed. However, due to technical problems with temperature recorders and problems of freezing of temperature probes, these data were not obtained. Because of these problems, comparisons of the results of this study to those presented by Wangaard and Burger (1983) can only be done on a qualitative basis.

Wangaard and Burger (1983) compared development rates of chum salmon embryos at four different temperature regimes. These regimes were designed to simulate winter incubation conditions encountered in selected middle Susitna River habitats. Average incubation temperatures ranged from 2.1°C (representing mainstem habitats) to 4.0°C (representing slough habitat strongly influenced by upwelling water). The average temperatures of the two intermediate temperature regimes were 2.9 and 3.9°C. From these and other results derived from available literature, Wangaard and Berger concluded that the rate of embryonic development to 50% hatch and to complete yolk sac absorbtion were predictable from the average incubation temperature. They computed regression equations according to the model Y=mx+6 where the rate of development is expressed as (1000/days) and X equals the average incubation temperature. In each equation, r equals 0.99 and is statistically significant at P = 0.001.

1) Rate of development to 50% hatch = 1.4X + 3.23

2) Rate of development to complete yolk sac absorbtion = 0.59X + 2.25.

From these relationships, it is possible to calculate the number of days required to reach 50% hatch or complete yolk-sac absorbtion for a given average incubation temperature. For example, at an average incubation temperature of 4.0°C the number of days required for embryos to reach to 50% hatch may be computed by using the proper regression equation given above. If X = 4.0°C, the rate of development is computed to be 8.83 (1000/days). By dividing 1000 by 8.83, the estimated number of days to 50% hatch is derived as 113 days.

The data presented in this report are not of sufficient resolution to quantitatively evaluate the predictive equations developed by Wangaard and Burger 1983. However, in light of the fact that no data collected during this study conflicted with data presented by Wangaard and Burger, and that their data was generally consistent with embryonic development data obtained from natural redds reported in ADF&G 1983, it is the opinion of the authors that Wangaard and Burger's predictive equations are an adequate model to use in predicting rates of development of chum salmon under present environmental conditions. This study did not involve the period of yolk absorbtion, and therefore it is not possible to formulate opinions regarding this equation. There are, however, certain limitations in the application of both equations when attempting to predict rates of embryonic development in middle Susitna River habitats.

Water temperature conditions in middle Susitna River habitats during winter do not conform to a conceptual model of a thermal regime as described in Wangaard and Burger 1983. Thermal conditions at most sites evaluated in this study could be more accurately described as a "composite" or "mosaic" of thermal conditions. For example, the presence of upwelling spring areas formed localized areas which had distinctly different thermal characteristics than nearby areas. This resulted in a high degree of variability in intragravel water temperatures which varied from a condition of frozen substrate to intragravel temperatures of 2-4°C. This variability was not quantified in this study and is not obvious when only one or two continuous temperature recorders are placed at each site. Thus, use of the equations in predicting rates of development at particular sites must be accompanied by a quantification of the variability in intragravel temperature conditions within the given site or habitat.

4.2.5 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 6. 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 et al. (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 7). 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.

The concentration of DO in the intragravel environment is a result of the relative contribution of DO from surface and groundwater sources. 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 et al. (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.

4.2.6 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. They 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

Table 7. 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	121.2 268.2 353.0 452.4	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]

Table 7 (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)
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)

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 the mainstem Susitna River typically vary between 7 and 8 during the winter, occasionally dropping below 7 (Acres, 1982). 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.

4.2.7 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).

4.2.8 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 fine substrate composition on the availability of dissolved oxygen to developing embryos.

4.2.9 Flatworms

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 the number of salmon embryos implanted in WVBs at some study sites. Evaluation of other biological variables was outside the scope of this study and therefore are not discussed in this report.

Relatively large numbers of embryos were discovered to be missing from WVBs used to assess survival 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. Field observations indicated that a several week period was required for flatworms to remove dead embryos from WVBs.

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 field observations made during 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 observations made during 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 five weeks, 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.

4.3 Conclusions/Recommendations

4.3.1 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 physical variable affecting the development and survival of salmon embryos incubating in slough and side channel 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. Because of the effects of dewatering and freezing, the amount of available habitat at the time when adult chum salmon are spawning is a poor indicator of the amount of actual habitat

that is available as potential incubation habitat. Estimates of available incubation habitat must take into account the differential effects of dewatering and freezing in various habitat types.

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 relatively high intragravel water temperatures during the fall and spring months with near freezing water temperatures during the intervening winter months;

   b) Slough habitats generally have relatively high, and more stable intragravel water temperatures during most of the incubation period due to the influence of suitable upwelling sources;

   c) Mainstem habitats are similar to tributary habitats; having winter intragravel water temperatures which are strongly influenced by surface water temperatures. However, they differ from tributary habitats by having colder water temperatures during the fall and spring periods; and,

   d) In general, winter intragravel water temperatures 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 discharges increase the incidence of cold mainstem water overtopping slough and side channel habitats having insufficient sources of warmer upwelling or local surface waters in the middle Susitna River during fall and winter. If post-project mainstem water temperatures are substantially warmer than existing winter temperatures, this thermal problem associated with overtopping may be ameliorated.

6. Embryos fertilized on August 26, 1983 and placed in slough, side channel and mainstem habitats reached 100 percent hatch at approximately late January, late December and mid-April, respectively. Embryos in slough and side channel habitats were influenced by warmer upwelling water, whereas embryos in the mainstem were not.

7. 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%, and 12% respectively). However, the substrate composition of established salmon redds in each habitat type contained fewer fines than the range of substrate materials present in each habitat type of the middle Susitna River.

8. With the exception of slough habitats, 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 et al. (1958). Although DO levels in intragravel water of slough habitats are generally lower (0.4 to 13.5 mg/l), the potential adverse effects of low DO are most likely buffered 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) do not appear to be detrimental to embryo survival and development.

10. Conductivity values in incubation habitats of the middle Susitna River (24 to 290 umhos) do not appear to have any direct adverse effects on incubation embryos.

4.3.2 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 over a range of natural discharge conditions for habitats in the middle Susitna River (Vincent-Lang et al. 1984). However, spawning habitats will not produce salmon fry if the intragravel environment becomes dewatered and frozen during the incubation period. Consequently, the survival of salmon should not be based only on the spawning habitat evaluations previously mentioned. Spawning areas must also be evaluated based on the effects of mainstem discharge on dewatering and freezing of redd sites 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 or load following" 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. An evaluation of the significance of flushing flows to Susitna River habitat suitability for incubation and other life-phases is also recommended. If determined to be a significant factor for habitat suitability, an understanding of the duration and magnitude of flushing flows and their relationships to mainstem discharge is required. This information will be required to refine these analyses and is essential for evaluating the impacts of altered temperature and flow regimes of the Susitna River.

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6.0 ACKNOWLEDGEMENTS

Special appreciation is extended to the following people for their contributions to this study.

- -- D. Reiser, Bechtel Group Inc., and R. White, Montana State University, for their valuable technical advice on matters involving the use of Whitlock-Vibert Boxes and options for measuring variables of the intragravel environment.

- -- R. Uberuaga, U.S. Forest Service, Thorne Bay Ranger District, Tongass National Forest, for his advice and information regarding the use of the McNeil substrate sampler.

- -- State of Alaska, Department of Transportation, for assistance in analyzing substrate samples at their laboratory facility.

Funding for this study was provided by the State of Alaska, Alaska Power Authority.

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8.0 APPENDICES

APPENDIX A

EMBRYO DEVELOPMENT AND SURVIVAL DATA

APPENDIX A

EMBRYO DEVELOPMENT AND SURVIVAL DATA

This appendix presents information on embryo development and survival obtained from selected Susitna River habitats. Appendix Table A-1 presents the stages of development of chum salmon embryos in middle Susitna River habitats. Percent survival of embryos is presented in Appendix Table A-2. 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).

Appendix Table A-1. Stages of development of live chum salmon embryos and alevins removed from middle Susitna River habitats, Alaska.

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Box No.	Number of Embryos Evaluated	Cleavage 1	Gastrulation 2	Gastrulation 3	Gastrulation 4	Organogenesis Early 5	Organogenesis Early 6	Organogenesis Early 7	Organogenesis Late 8	Organogenesis Late 9	Organogenesis Late 10	Organogenesis Late 11	Alevin 12
Fourth of July	A	831009	003	1	12						12						
Creek	A	831009	003	2	14						14						
(131.1)	A	831102	007	1	40							07	33				
	A	831102	007	2	42							15	27				
	A	831102	012	1[a]	39							21	18				
	A	831102	012	2	38							38					
Side Channel 10	A	831009	001	1	42			07	03	32							
(133.8)	A	831009	001	2	44					44							
	A	831031	011	1	40						40						
	A	831031	011	2	39						39						
	A	840301	002	1	40								01		31	08	
	A	840301	002	2	41										10	31	
	A	840301	005	1	8										01	07	
	A	840301	005	2	44										02	42	
	A	840301	009	1	9												09
	A	840302	013	1	1											01	
Slough 10	A	831029	002	1	1				01								
(133.8)	A	831031	017	1	26				03	04	19						
	A	831031	017	2	43				10	11	22						
	A	840208	015	1	4											04	
	A	840229	013	1	7							02	05				
	A	840229	013	2	17								06		07		04
Slough 11[b]	A	831009	005	1	49					49							
(135.3)	A	831009	005	2	53					53							
	A	831031	002	1	35					07	28						
	A	831031	002	2	8					03	05						
	A	831031	015	1	46								10	36			
	A	831031	015	2	48								06	42			
	A	840209	001	1	46											46	
	A	840209	001	2	44											44	
	A	840210	012	1	3										02	01	

Appendix Table A-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Box No.	Number of Embryos Evaluated	Stages of Development: Cleavage	Gastrulation			Organogenesis: Early			Organogenesis: Late				Alevin
						1	2	3	4	5	6	7	8	9	10	11	12
Slough 11[b] (continued)	B	830828	S11	1	25	25											
	B	830828	S11	2	25	25											
	B	830828	S21	1	25	25											
	B	830828	S21	2	25	25											
	B	830901	4TH	1	25	25											
	B	830901	4TH	2	25	25											
	B	830915	S10	1	25	25											
	B	830915	S10	2	23	23											
	B	830922	C21	1	21	21											
	B	830922	C21	2	23	23											
	B	831031	4TH	1	37						37						
	B	831031	4TH	2	37						37						
	B	831031	S10	1	45				02	27	16						
	B	831031	S10	2	37				03	22	12						
	B	831031	S11	1	47						16	31					
	B	831031	S11	1	47						16	31					
	B	831031	C21	1	21				02	19							
	B	831031	C21	2	20				03	17							
	B	831031	S21	1	42							42					
	B	831031	S21	2	41						01	40					
	B	840201	C21	1	1											01	
	B	840201	C21	2	2	01											01
	B	840201	S21	1	3											01	02
	B	840201	S21	2	4											02	02
	B	840201	S10	1	28							02	02			03	21
	B	840201	S10	2	18								01		01		16
	B	840201	S11	2	1												01
	C	831009	DEV	1	44					10	34						
	C	831009	DEV	2	47					23	24						
	C	831024	DEV	1	52							44	08				
	C	831024	DEV	2	39							30	09				
	C	831110	DEV	1	44							01	17	26			
	C	831122	DEV	1	38							04	01		33		
	C	831204	DEV	1	36										26	10	
	C	831230	DEV	1	34											34	

Appendix Table A-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Box No.	Number of Embryos Evaluated	Stages of Development											
						Cleavage	Gastrulation			Organogenesis							Alevin
										Early			Late				
						1	2	3	4	5	6	7	8	9	10	11	12
Mainstem (136.1)	A	831009	DEV	1	32					19	13						
	A	831009	DEV	2	44					22	22						
	A	831025	DEV	1	6						06						
	A	831025	DEV	2	29					01	28						
	A	831025	DEV	3	21					04	17						
	A	831110	DEV	1	26							26					
	A	831122	DEV	1	17					01	13	03					
	A	831204	DEV	1	34						12	22					
	A	831229	DEV	1	26							02	21	03			
	A	840330	DEV	1	17											13	04
	A	840330	DEV	2	15											09	06
	A	840330	DEV	3	14											09	05
	A	840410	DEV	1	1												01
	A	840410	DEV	2	16											04	12
	A	840417	DEV	1	10												10
	A	840417	DEV	2	2												02
	A	840417	DEV	3	4												04
	A	840425	DEV	1	5												05
	A	840425	DEV	2	6												06
Upper Side Channel 11 (136.1)	A	831024	DEV	1	47							33	14				
	A	831024	DEV	2	49							25	24				
	A	831110	DEV	1	41								02	39			
	A	831122	DEV	1	42										42		
	A	831204	DEV	1	43										16	27	
	A	831230	DEV	1	48						02						46
Side Channel 21 (141.0)	A	831009	002	1	11				01	10							
	A	831009	002	2	24		01			10	13						
	A	831027	014	1	42						01	38	03				
	A	831027	014	2	38							20	18				
	B	840328	00C	1	28										02	26	
	B	840328	00C	2	19											19	
	B	840329	00D	1	10											10	
	B	840329	00D	2	11											11	
	B	840419	00A	1	12												12
	B	840419	00A	2	2												02

Appendix Table A-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Box No.	Number of Embryos Evaluated	Stages of Development: Cleavage	Gastrulation			Organogenesis: Early			Organogenesis: Late				Alevin
						1	2	3	4	5	6	7	8	9	10	11	12
Side Channel 21	C	831025	DEV	2	19		04	08	07								
(continued)	C	831110	DEV	1	14					07	07						
	C	831122	DEV	1	12					01	11						
	C	831204	DEV	2	20						20						
	C	840119	DEV	1	3									03			
	C	840329	DEV	2	17											14	03
	C	840329	DEV	2	10											10	
	C	840411	DEV	1	8											08	
	C	840417	DEV	1	12											09	03
	C	840426	DEV	1	11												11
	C	840502	DEV	1	14												14
	C	840510	DEV	1	14												14
Slough 21	A	831026	001	1	38				03		35						
(141.8)	A	831026	001	2	39						39						
	A	831229	014	1	41											41	
	A	840113	014	2	13							01			01		11
	A	840117	003	1	40											11	29
	A	840117	005	1	42											30	12
	A	840117	005	2	43											38	05
	A	840117	008	1	5							01			01	02	01
	A	840117	008	2	26							05				14	07
	A	840117	010	1	1												01
Natural Redds		831002	S21	1	4	04											
		831025	S21	2	6						06						
		831026	S21	3	10						03	07					
		831202	S21	3	10									02	08		
		840413	S21	4	8												08
		831024	S11	1	7							02	05				
		831024	S11	2	8							07	01				
		831025	C21	1	11						11						
		831102	4TH	1	4										03		01

[a] Boxes noted with an asterisk contained pink salmon embryos.

[b] Boxes removed from Subsite B during 830828 to 831031 were used to evaluate embryo handling mortality. Twenty-five embryos were inspected from each box, only the number of living is reported.

Appendix Table A-2. Percent survival of hatched and unhatched embryos recovered from Whitlock-Vibert Boxes placed in selected habitats of the middle Susitna River, Alaska.

Site (River mile)	Sub Site	Sampling Date y/m/d	Stand pipe No.	Box No.	Hatched[a] Live No.	Hatched[a] Live %	Hatched[a] Dead No.	Hatched[a] Dead %	Unhatched[a] Live No.	Unhatched[a] Live %	Unhatched[a] Dead No.	Unhatched[a] Dead %	Missing[b] No.	Missing[b] %	Flat-worm Abun-dance Rank	Total[a] Survival %	Total[a] Mortality %	Frozen condi-tion of WVBs[c]
Fourth of July (131.1)	A	840330	015	1	24	48	13	26	0	0	13	26	0	0	04	48	52	1
	A	840330	015	2	22	44	13	26	1	2	13	26	1	2	04	46	54	1
	A	840419	010	1	0	0	33	66	0	0	11	22	6	12	04	0	100	1
	A	840419	010	2[d]	8	16	10	20	0	0	15	30	17	34	04	16	84	1
	A	840419	013	1	16	32	2	4	0	0	10	20	22	44	03	32	68	1
	A	840419	013	2	15	30	5	10	0	0	10	20	20	40	03	30	70	1
	A	840419	014	1	12	24	2	4	0	0	26	52	10	20	04	24	76	1
	A	840419	014	2	0	0	0	0	0	0	50	100	0	0	04	0	100	1
	A	840426	006	1	0	0	0	0	0	0	61	100	0	0	04	0	100	3
	A	840426	006	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840426	008	1[d]	0	0	0	0	0	0	10	20	40	80	03	0	100	1
	A	840426	008	2	1	2	0	0	0	0	25	50	24	48	03	2	98	1
	A	840426	009	1	0	0	0	0	0	0	10	20	40	80	01	0	100	1
	A	840426	009	2[d]	0	0	0	0	0	0	21	42	29	58	04	0	100	1
	A	840502	005	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840502	005	2	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	A	840510	001	1	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	A	840510	001	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840510	004	1	0	0	0	0	0	0	51	100	0	0	04	0	100	3
	A	840510	004	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840510	011	1	12	24	7	14	0	0	21	42	10	20	04	24	76	1
	A	840510	011	2[d]	11	22	5	10	0	0	18	36	16	32	03	22	78	1
Side Channel 10 (133.8)	A	840301	002	1	0	0	0	0	40	80	10	20	0	0	04	80	20	1
	A	840301	002	2	0	0	0	0	41	82	9	18	0	0	04	82	18	1
	A	840301	003	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840301	003	2	0	0	0	0	0	0	52	100	0	0	04	0	100	3
	A	840301	005	1	0	0	0	0	8	16	42	84	0	0	04	16	84	1
	A	840301	005	2	0	0	0	0	45	88	6	12	0	0	04	88	12	1
	A	840301	006	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840301	006	2	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840301	007	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840301	007	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840301	008	1	0	0	0	0	0	0	49	98	1	2	04	0	100	2
	A	840301	008	2	0	0	0	0	0	0	50	100	0	0	04	0	100	2

Appendix Table A-2. (Continued).

Site (River mile)	Sub Site	Sampling Date y/m/d	Stand pipe No.	Box No.	Hatched[a] Live No.	Hatched[a] Live %	Hatched[a] Dead No.	Hatched[a] Dead %	Unhatched[a] Live No.	Unhatched[a] Live %	Unhatched[a] Dead No.	Unhatched[a] Dead %	Missing[b] No.	Missing[b] %	Flat-worm Abundance Rank	Total[a] Survival %	Total[a] Mortality %	Frozen condition of WVBs[c]
Side Channel 10	A	840301	009	1	9	18	16	32	0	0	14	28	11	22	04	18	82	1
(continued)	A	840301	009	2	8	16	26	52	0	0	8	16	8	16	04	16	84	1
	A	840301	010	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840301	010	2	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840301	012	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840301	012	2	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840302	013	1	0	0	0	0	1	2	49	98	0	0	04	2	98	1
	A	840302	013	2	0	0	0	0	39	78	11	22	0	0	04	78	22	1
	A	840302	014	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840302	014	2	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840302	018	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840302	018	2	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	A	840330	004	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840330	004	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840502	015	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840502	015	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840502	019	1	0	0	0	0	0	0	51	100	0	0	04	0	100	3
	A	840502	019	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840510	016	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840510	016	2	0	0	0	0	0	0	52	100	0	0	04	0	100	3
	A	840510	017	1	0	0	0	0	0	0	51	100	0	0	04	0	100	3
	A	840510	017	2	0	0	0	0	0	0	51	100	0	0	04	0	100	3
Slough 10	A	840208	015	1	0	0	0	0	3	6	4	8	43	86	01	6	94	1
(133.8)	A	840228	014	1	0	0	0	0	0	0	5	10	45	90	04	0	100	1
	A	840228	015	2	0	0	0	0	0	0	2	4	48	96	04	0	100	1
	A	840228	018	1	0	0	0	0	0	0	3	6	47	94	02	0	100	1
	A	840229	006	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840229	006	2	0	0	0	0	0	0	51	100	0	0	04	0	100	3
	A	840229	008	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840229	008	2	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840229	009	1	0	0	0	0	0	0	50	100	0	0	04	0	100	1
	A	840229	009	2	0	0	0	0	0	0	50	100	0	0	04	0	100	1
	A	840229	010	1	0	0	0	0	0	0	6	12	44	88	03	0	100	1
	A	840229	010	2	0	0	2	4	0	0	7	14	41	82	03	0	100	1

Appendix Table A-2. (Continued).

Site (River mile)	Sub Site	Sampling Date y/m/d	Stand pipe No.	Box No.	Hatched[a] Live No.	Hatched[a] Live %	Hatched[a] Dead No.	Hatched[a] Dead %	Unhatched[a] Live No.	Unhatched[a] Live %	Unhatched[a] Dead No.	Unhatched[a] Dead %	Missing[b] No.	Missing[b] %	Flat-worm Abun-dance Rank	Total[a] Survival %	Total[a] Mortality %	Frozen condi-tion of WVBs[c]
Slough 10 (continued)	A	840229	011	1	0	0	0	0	0	0	50	100	0	0	04	0	100	1
	A	840229	011	2	0	0	0	0	0	0	50	100	0	0	04	0	100	1
	A	840229	012	1	0	0	0	0	0	0	10	20	40	80	01	0	100	1
	A	840229	012	2	0	0	0	0	0	0	9	18	41	82	02	0	100	1
	A	840229	013	1	0	0	0	0	6	12	41	82	3	6	03	12	88	1
	A	840229	013	2	4	8	0	0	13	26	25	50	8	16	02	34	66	1
	A	840229	014	2	0	0	0	0	0	0	28	56	22	44	03	0	100	1
	A	840229	016	1	0	0	32	64	0	0	11	22	7	14	04	0	100	1
	A	840229	016	2	0	0	36	72	0	0	10	20	4	8	03	0	100	1
	A	840229	018	2	0	0	0	0	0	0	5	10	45	90	03	0	100	1
	A	840229	019	1	0	0	0	0	0	0	3	6	47	94	03	0	100	1
	A	840229	019	2	0	0	0	0	0	0	13	26	37	74	01	0	100	1
	A	840229	020	1	0	0	0	0	0	0	14	28	36	72	02	0	100	1
	A	840229	020	2	0	0	0	0	0	0	13	26	37	74	02	0	100	1
	A	840301	003	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840301	003	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840330	005	1	0	0	0	0	0	0	52	100	0	0	04	0	100	3
	A	840330	005	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840410	001	1	0	0	0	0	0	0	61	100	0	0	04	0	100	3
	A	840410	001	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840425	004	1	0	0	0	0	0	0	50	100	0	0		0	100	3
	A	840425	004	2	0	0	0	0	0	0	50	100	0	0		0	100	3
Slough 11 (135.3)	A	840118	010	1	0	0	0	0	45	90	2	4	3	6	02	90	10	1
	A	840201	010	2	2	4	1	2	25	50	3	6	19	38	01	54	46	1
	A	840209	001	1	0	0	0	0	46	92	3	6	1	2	03	92	8	1
	A	840209	001	2	0	0	0	0	44	88	3	6	3	6	03	88	12	1
	A	840209	003	1	0	0	0	0	0	0	50	100	0	0	02	0	100	3
	A	840209	003	2	0	0	0	0	0	0	49	98	1	2	03	0	100	3
	A	840209	004	1	0	0	0	0	0	0	50	100	0	0	03	0	100	3
	A	840209	004	2	0	0	0	0	0	0	48	96	2	4	01	0	100	3
	A	840209	006	1	0	0	0	0	0	0	50	100	0	0	03	0	100	3
	A	840209	006	2	0	0	0	0	0	0	49	98	1	2	03	0	100	3
	A	840209	007	1	0	0	0	0	0	0	47	94	3	6	02	0	100	3
	A	840209	007	2	0	0	0	0	0	0	50	100	0	0	01	0	100	3

Appendix Table A-2. (Continued).

Site (River mile)	Sub Site	Sampling Date y/m/d	Stand pipe No.	Box No.	Hatched[a] Live No.	Hatched[a] Live %	Hatched[a] Dead No.	Hatched[a] Dead %	Unhatched[a] Live No.	Unhatched[a] Live %	Unhatched[a] Dead No.	Unhatched[a] Dead %	Missing[b] No.	Missing[b] %	Flat-worm Abun-dance Rank	Total[a] Survival %	Total[a] Mortality %	Frozen condi-tion of WVBs[c]
Slough 11 (continued)	A	840209	008	1	0	0	0	0	0	0	41	82	9	18	02	0	100	2
	A	840209	008	2	0	0	0	0	0	0	49	98	1	2	03	0	100	2
	A	840210	009	1	0	0	0	0	0	0	47	94	3	6	01	0	100	2
	A	840210	009	2	0	0	0	0	0	0	50	100	0	0	01	0	100	2
	A	840210	011	1	0	0	0	0	2	4	1	2	47	94	02	4	96	1
	A	840210	011	2	0	0	0	0	1	2	7	14	42	84	02	2	98	1
	A	840210	012	1	0	0	0	0	3	6	41	82	6	12	01	6	94	1
	A	840210	012	2	0	0	0	0	0	0	47	94	3	6	02	0	100	1
	A	840210	013	1	0	0	0	0	0	0	0	0	50	100	01	0	100	1
	A	840210	013	2	0	0	0	0	0	0	3	6	47	94	02	0	100	1
	A	840210	014	1	0	0	0	0	1	2	0	0	49	98		2	98	1
	A	840210	014	2	0	0	0	0	1	2	1	2	48	96	02	2	98	1
	A	840210	016	1	0	0	0	0	1	2	15	30	34	68	01	2	98	1
	A	840210	016	2	0	0	0	0	2	4	0	0	48	96	01	4	96	1
	A	840210	017	1	0	0	0	0	0	0	1	2	49	98	01	0	100	1
	A	840210	017	2	0	0	0	0	0	0	5	10	45	90	02	0	100	1
	A	840210	020	1	0	0	0	0	0	0	45	90	5	10	02	0	100	1
	A	840210	020	2	0	0	0	0	0	0	44	88	6	12	03	0	100	1
	A	840301	018	1	0	0	0	0	0	0	37	74	13	26	03	0	100	3
	A	840328	018	2	0	0	0	0	0	0	43	86	7	14		0	100	3
	A	840328	019	1	0	0	0	0	0	0	47	94	3	6	01	0	100	3
	A	840328	019	2	0	0	0	0	0	0	49	98	1	2	01	0	100	3
	B	840201	4TH	1	0	0	0	0	0	0	2	4	48	96	03	0	100	1
	B	840201	4TH	2	0	0	0	0	0	0	4	8	46	92	02	0	100	1
	B	840201	S10	1	21	42	0	0	8	16	3	6	18	36	02	58	42	1
	B	840201	S10	2	16	32	2	4	3	6	6	12	23	46	01	38	62	1
	B	840201	S11	1	0	0	0	0	0	0	5	10	45	90	02	0	100	1
	B	840201	S11	2	1	2	0	0	0	0	1	2	48	96	02	2	98	1
	B	840201	C21	1	0	0	0	0	1	2	5	10	44	88	02	2	98	1
	B	840201	C21	2	1	2	0	0	0	0	13	26	36	72	01	2	98	1
	B	840201	S21	1	2	4	0	0	1	2	25	50	22	44	01	6	94	1
	B	840201	S21	2	2	4	0	0	2	4	11	22	35	70	01	8	92	1

Appendix Table A-2. (Continued).

Site (River mile)	Sub Site	Sampling Date y/m/d	Stand pipe No.	Box No.	Hatched[a] Live No.	Hatched[a] Live %	Hatched[a] Dead No.	Hatched[a] Dead %	Unhatched[a] Live No.	Unhatched[a] Live %	Unhatched[a] Dead No.	Unhatched[a] Dead %	Missing[b] No.	Missing[b] %	Flat-worm Abun-dance Rank	Total[a] Survival %	Total[a] Mortality %	Frozen condi-tion of WVBs[c]
Mainstem (136.1)	A	840330	DVA	1	4	8	0	0	13	26	33	66	0	0	04	34	66	1
	A	840330	DVA	2	6	12	1	2	9	18	22	44	12	24	04	30	70	1
	A	840330	DVA	3	5	10	0	0	9	18	28	56	8	16	04	28	72	1
	A	840410	DV1	1	1	2	0	0	0	0	44	88	5	10	04	2	98	1
	A	840410	DV1	2	12	24	2	4	4	8	34	68	0	0	04	31	69	1
	A	840417	DV1	1	10	20	1	2	0	0	33	66	6	12	04	20	80	1
	A	840417	DV1	2	2	4	1	2	0	0	51	100	0	0	04	4	96	1
	A	840417	DV1	3	4	8	14	28	0	0	27	54	5	10	04	8	92	1
Side Channel 21 (141.0)	A	840329	012	1	0	0	0	0	0	0	52	100	0	0	04	0	100	3
	A	840329	012	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840329	013	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840329	013	2	0	0	0	0	0	0	48	96	2	4	04	0	100	2
	A	840329	015	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840329	015	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840329	0S4	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840329	0S4	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840329	0S5	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840329	0S5	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840417	003	1	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	A	840417	003	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840417	0S2	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840417	0S2	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840417	0S3	1	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	A	840417	0S3	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840502	007	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840502	007	2	0	0	0	0	0	0	49	98	1	2	04	0	100	2
	A	840502	008	1	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840502	008	2	0	0	0	0	0	0	50	100	0	0	04	0	100	2
	A	840502	0S1	1	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	A	840502	0S1	2	0	0	0	0	0	0	49	98	1	2	04	0	100	3

Appendix Table A-2. (Continued).

Site (River mile)	Sub Site	Sampling Date y/m/d	Stand pipe No.	Box No.	Hatched[a] Live No.	Hatched[a] Live %	Hatched[a] Dead No.	Hatched[a] Dead %	Unhatched[a] Live No.	Unhatched[a] Live %	Unhatched[a] Dead No.	Unhatched[a] Dead %	Missing[b] No.	Missing[b] %	Flatworm Abundance Rank	Total[a] Survival %	Total[a] Mortality %	Frozen condition of WVBs[c]
Side Channel 21	A	840510	005	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
(continued)	A	840510	005	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	A	840601	004	1	0	0	0	0	0	0	50	100	0	0		0	100	3
	A	840601	004	2	0	0	0	0	0	0	50	100	0	0		0	100	3
	A	840601	006	1	0	0	0	0	0	0	46	92	4	8		0	100	3
	A	840601	006	2	0	0	0	0	0	0	47	94	3	6		0	100	3
	A	840601	009	1	0	0	0	0	0	0	49	98	1	2		0	100	3
	A	840601	009	2	0	0	0	0	0	0	49	98	1	2		0	100	3
	A	840601	010	1	0	0	0	0	0	0	50	100	0	0		0	100	3
	A	840601	010	2	0	0	0	0	0	0	50	100	0	0		0	100	3
	A	840601	011	1	0	0	0	0	0	0	50	100	0	0		0	100	3
	A	840601	011	2	0	0	0	0	0	0	50	100	0	0		0	100	3
	B	840329	00B	1	0	0	0	0	5	10	41	82	4	8	03	10	90	1
	B	840329	00B	2	0	0	0	0	32	64	16	32	2	4	03	64	36	1
	B	840329	00C	1	0	0	0	0	27	54	21	42	2	4	03	54	46	1
	B	840329	00C	2	0	0	0	0	19	38	25	50	6	12	03	38	62	1
	B	840329	00D	1	0	0	0	0	10	20	40	80	0	0	03	20	80	1
	B	840329	00D	2	0	0	0	0	17	34	33	66	0	0	03	34	66	1
	B	840329	00F	1	0	0	0	0	26	35	48	65	0	0	03	35	65	1
	B	840329	00F	2	0	0	0	0	15	30	35	70	0	0	03	30	70	1
	B	840419	00A	1	12	24	0	0	0	0	11	22	27	54	03	24	76	1
	B	840419	00A	2	2	4	0	0	0	0	15	30	33	66	02	4	96	1
	B	840419	00H	1	0	0	0	0	0	0	51	100	0	0	03	0	100	1
	B	840419	00H	2	0	0	0	0	2	4	48	96	0	0	03	4	96	1
	B	840502	00G	1	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	B	840502	00G	2	0	0	0	0	0	0	49	98	1	2	04	0	100	3
	B	840510	00E	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	B	840510	00E	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	B	840510	0SA	1	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	B	840510	0SA	2	0	0	0	0	0	0	50	100	0	0	04	0	100	3
	B	840601	0SB	1	0	0	0	0	0	0	49	98	1	2		0	100	3
	B	840601	0SB	2	0	0	0	0	0	0	49	98	1	2		0	100	3
Slough 21	A	840117	002	1	27	54	0	0	0	0	11	22	12	24	01	54	46	1
(142.0)	A	840117	002	2	6	12	1	2	11	22	14	28	18	36	04	34	66	1

Appendix Table A-2. (Continued).

Site (River mile)	Sub Site	Sampling Date y/m/d	Stand pipe No.	Box No.	Hatched[a] Live No.	Hatched[a] Live %	Hatched[a] Dead No.	Hatched[a] Dead %	Unhatched[a] Live No.	Unhatched[a] Live %	Unhatched[a] Dead No.	Unhatched[a] Dead %	Missing[b] No.	Missing[b] %	Flat-worm Abun-dance Rank	Total[a] Survival %	Total[a] Mortality %	Frozen condi-tion of WVBs[c]
Slough 21	A	840117	003	1	29	58	0	0	11	22	5	10	5	10	02	80	20	1
(continued)	A	840117	003	2	21	42	2	4	12	24	9	18	6	12	02	66	34	1
	A	840117	004	1	17	34	1	2	19	38	11	22	2	4	03	72	28	1
	A	840117	004	2	13	26	1	2	12	24	16	32	8	16	01	50	50	1
	A	840117	005	1	12	24	0	0	31	62	8	16	0	0	02	84	16	1
	A	840117	005	2	5	10	1	2	38	76	6	12	0	0	03	86	14	1
	A	840117	006	1	32	64	5	10	2	4	11	22	0	0	03	68	32	1
	A	840117	006	2	22	44	3	6	7	14	17	34	1	2	02	58	42	1
	A	840117	007	1	16	32	3	6	2	4	3	6	26	52	03	36	64	1
	A	840117	007	2	35	70	1	2	8	16	4	8	2	4	04	86	14	1
	A	840117	008	1	1	2	0	0	4	8	45	90	0	0	03	10	90	1
	A	840117	008	2	7	14	0	0	18	36	25	50	0	0	04	50	50	1
	A	840117	009	1	0	0	28	56	0	0	9	18	13	26	04	0	100	1
	A	840117	009	2	14	28	23	46	2	4	9	18	2	4	03	32	68	1
	A	840117	010	1	1	2	0	0	0	0	49	98	0	0	03	2	98	1
	A	840117	010	2	0	0	0	0	0	0	50	100	0	0	04	0	100	1
	A	840117	011	1	5	10	13	26	2	4	28	56	2	4	01	14	86	1
	A	840117	011	2	33	66	5	10	1	2	8	16	3	6	03	68	32	1
	A	840117	012	1	1	2	26	52	0	0	20	40	3	6	03	2	98	1
	A	840117	012	2	0	0	33	66	0	0	16	32	1	2	04	0	100	1
	A	840117	013	1	20	40	10	20	0	0	18	36	2	4		40	60	1
	A	840117	013	2	24	48	9	18	0	0	17	34	0	0	04	48	52	1

[a] Percentages are calculated based on an initial total of 50 embryos placed in each WVB.

[b] Missing embryos are assumed to be dead.

[c] 1 = unfrozen;
2 = presumed frozen;
3 = verified frozen.

[d] Boxes contained pink salmon embryos.

A P P E N D I X B

STUDY SITE LOCATIONS

APPENDIX B

STUDY SITE LOCATIONS

Appendix B includes a table of study site locations and site maps identifying all study areas presented in this report. Appendix Table B-1 provides a list of all study sites, arranged by incrementing river mile location, and includes the primary study conducted at each site. Detailed maps of each study site are presented in Figures B-1 to B-12.

Appendix Table B-1. List of study sites used to evaluate the incubation life-phase of chum salmon in the middle Susitna River.

Site	River Mile	Primary Purpose	Appendix Figure Number
Mainstem LRX 9	103.2	Winter Temperature Study	B-1
Deadhorse Creek	120.9	Preliminary Mitigation Study	B-2
Slough 8A (lower)	125.9	Incubation and Winter Temperature Studies	B-3
Mainstem LRX 29	126.1	Winter Temperature Study	B-3
Slough 9	128.3	Incubation and Winter Temperature Studies	B-4
Fourth of July Creek	131.1	Incubation and Winter Temperature Studies	B-5
Slough 9A	133.6	Incubation Study	B-6
Slough 10	133.8	Incubation and Winter Temperature Studies	B-7
Side Channel 10	133.8	Incubation and Winter Temperature Studies	B-7
Slough 11	135.3	Incubation and Winter Temperature Studies	B-8
Upper Side Channel 11	136.1	Incubation and Winter Temperature Studies	B-8
Mainstem (RM 136.1)	136.1	Incubation and Winter Temperature Studies	B-8
Mainstem (RM 136.8)	136.8	Incubation Study	B-9
Indian River	138.6	Incubation and Winter Temperature Studies	B-10
Mainstem (RM 138.7)	138.7	Incubation Study	B-11
Slough 17	138.9	Incubation Study	B-11
Mainstem (RM 138.9)	138.9	Incubation Study	B-11
Side Channel 21	141.0	Incubation and Winter Temperature Studies	B-12
Slough 21 (lower)	141.8	Incubation and Winter Temperature Studies	B-12
Mainstem LRX 57	142.2	Winter Temperature Study	B-12

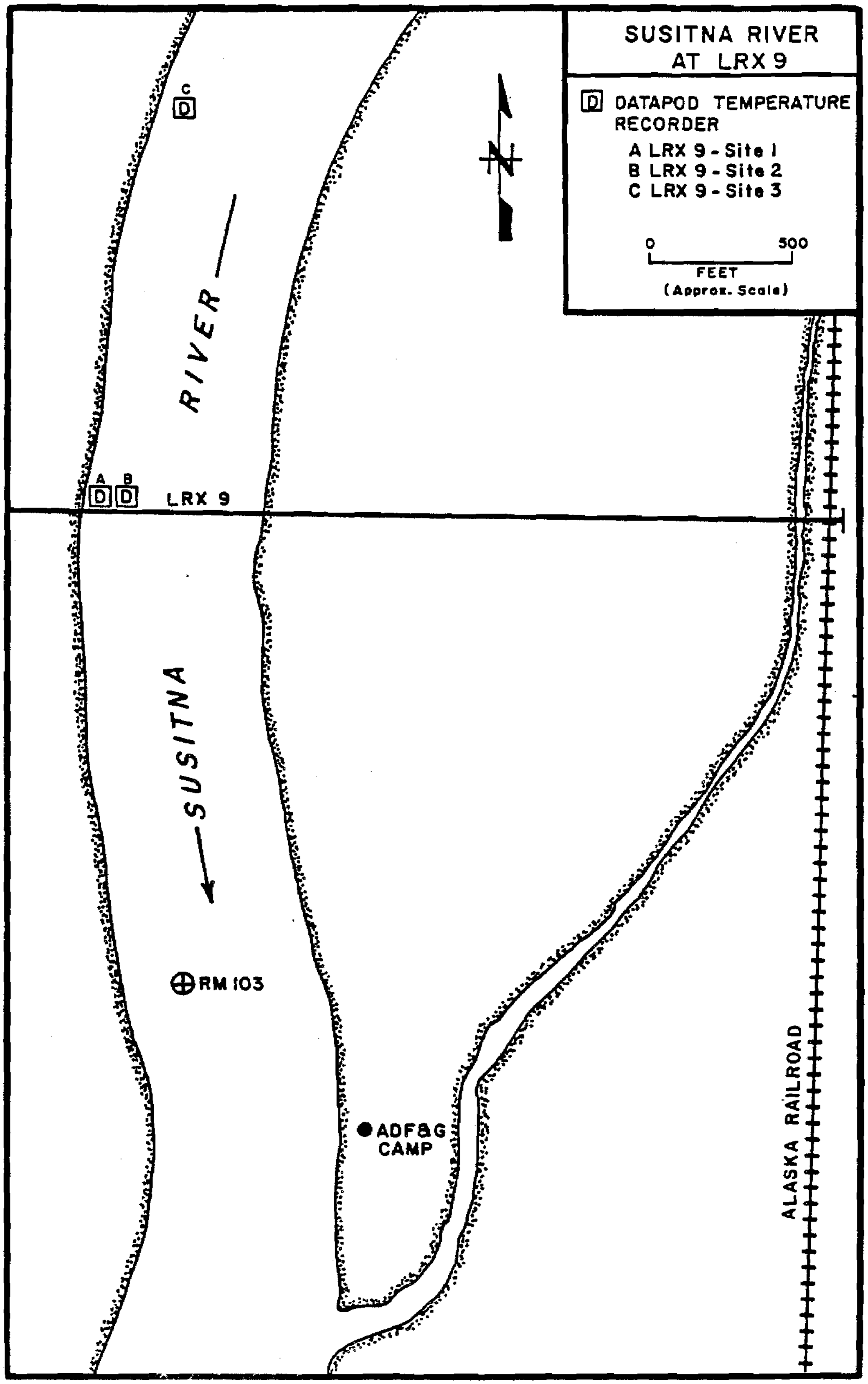

Figure B-1. Study site location at Mainstem LRX 9 (RM 103.2).

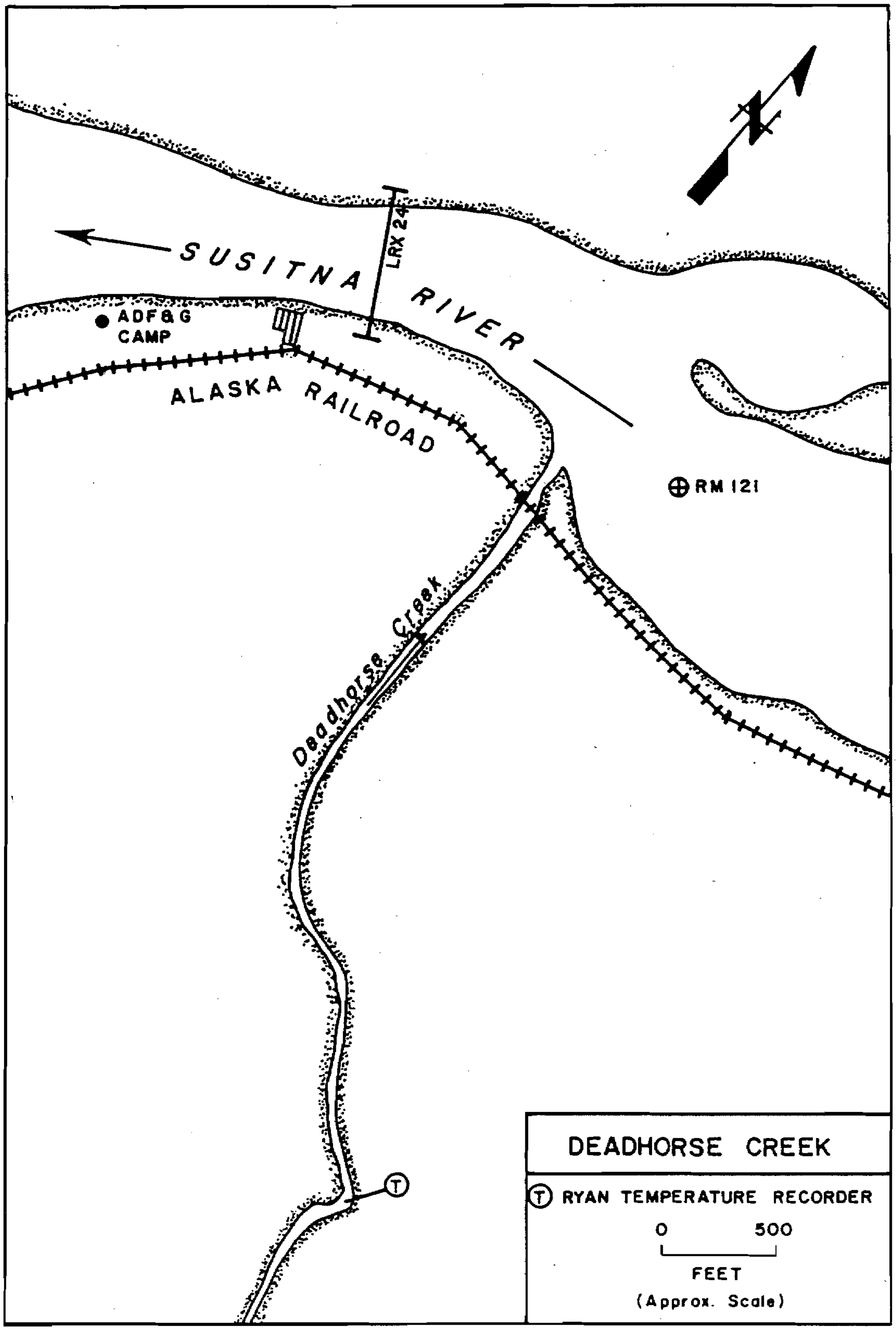

Figure B-2. Study site location at Deadhorse Creek (RM 120.9).

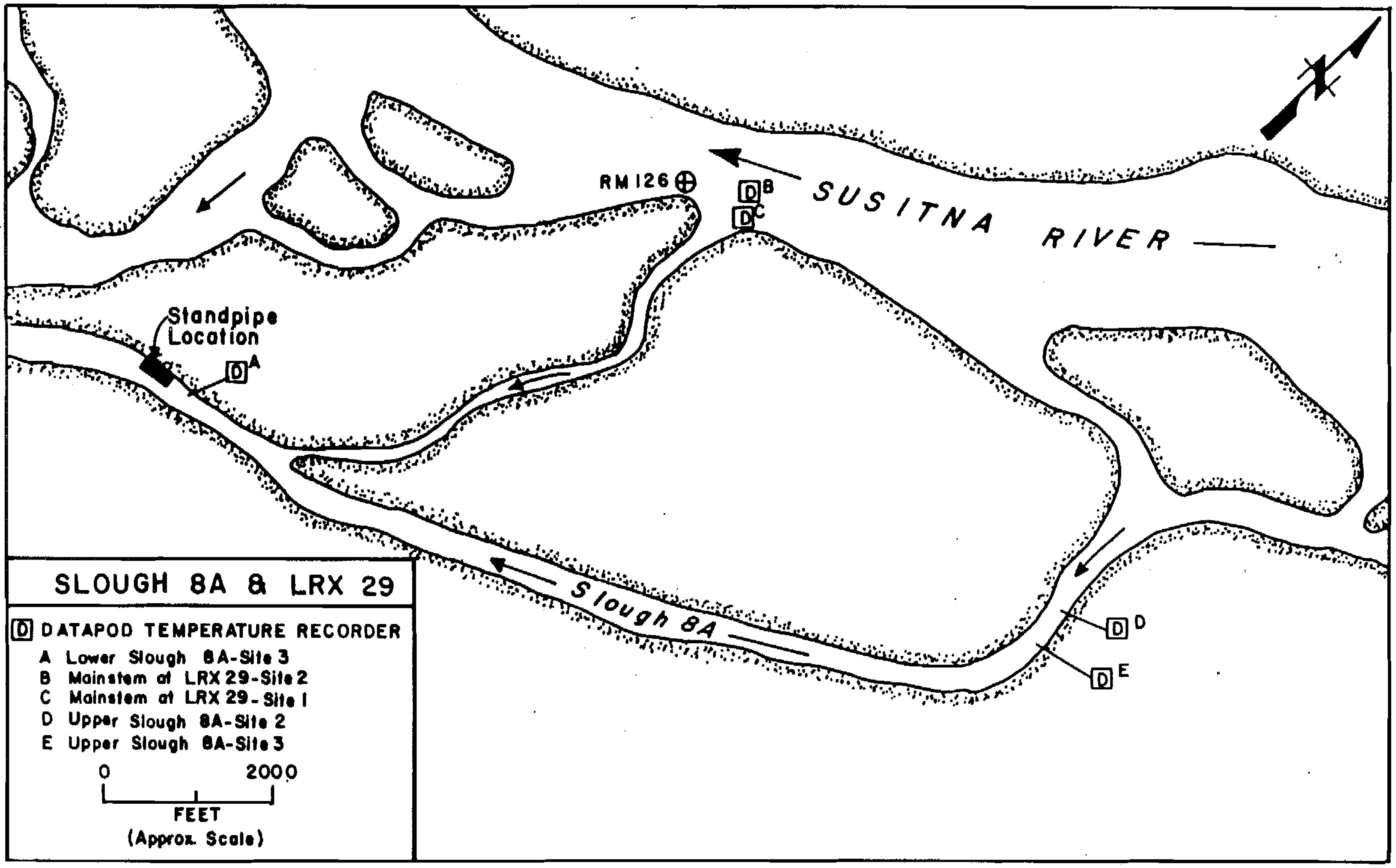

Figure B-3. Study site location at Slough 8A (RM 125.9) and Mainstem LRX 29 (RM 126.1).

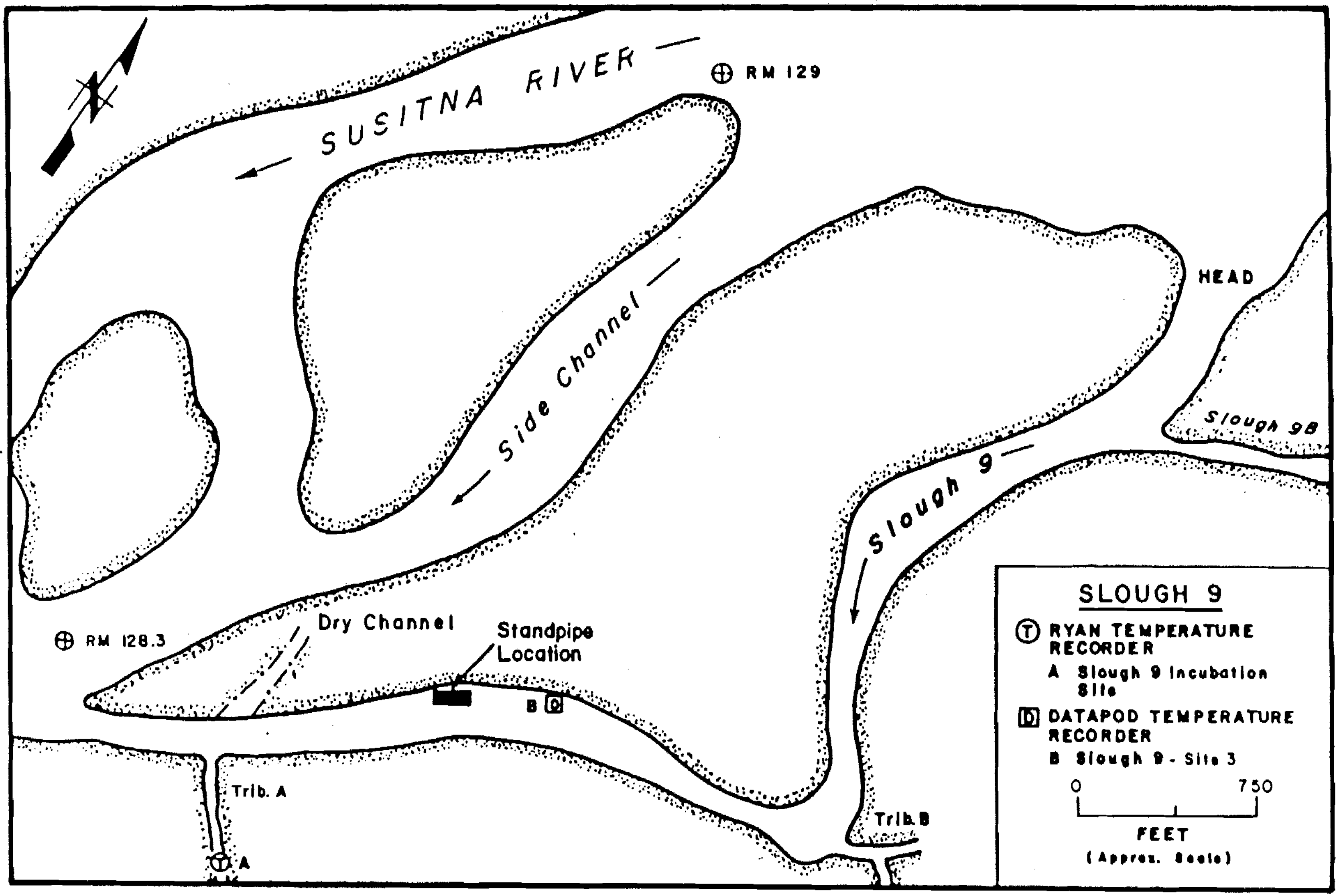

Figure B-4. Study site location at Slough 9 (RM 128.3).

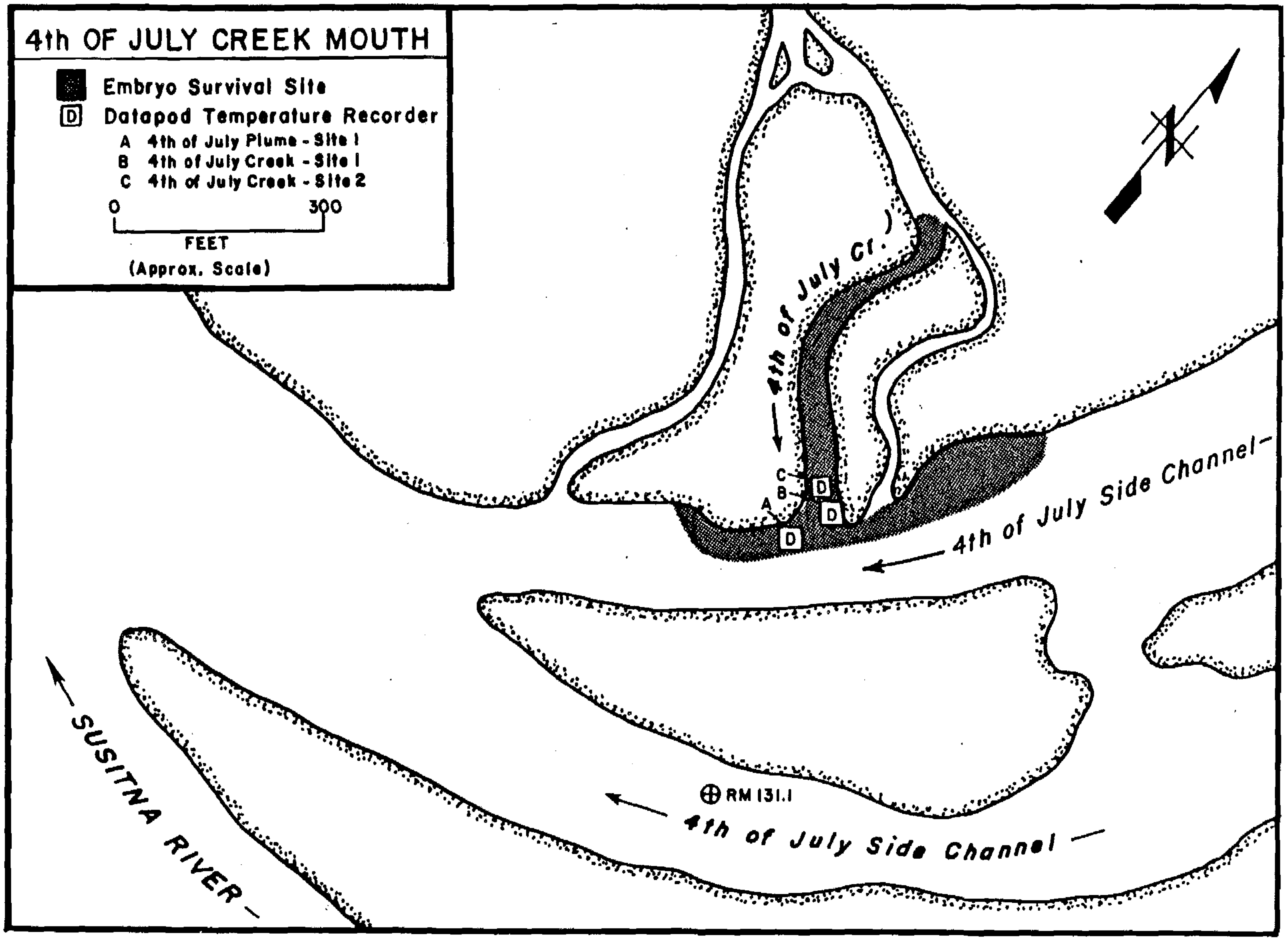

Figure B-5. Study site location at Fourth of July Creek (RM 131.1).

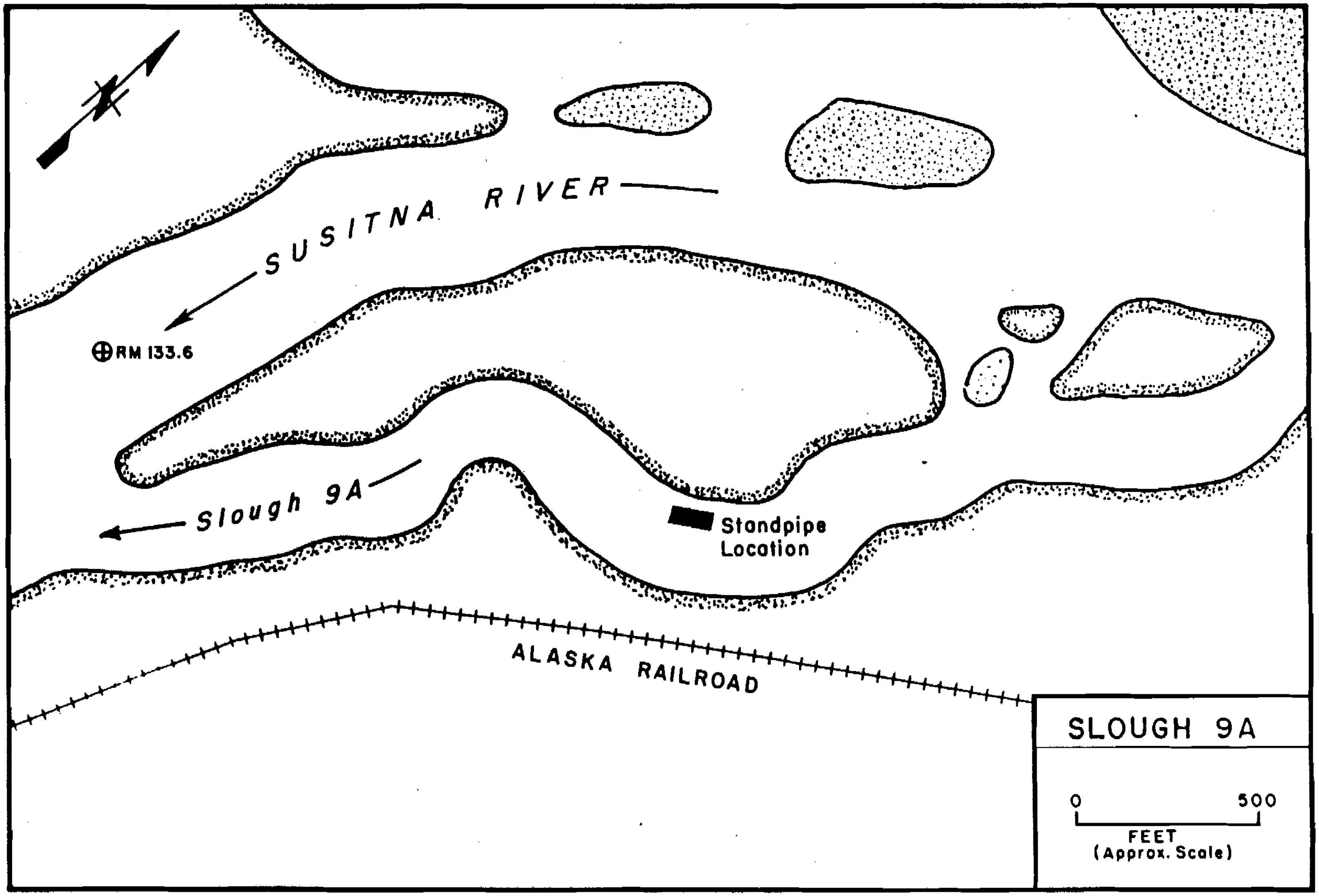

Figure B-6. Study site location at Slough 9A (RM 133.6).

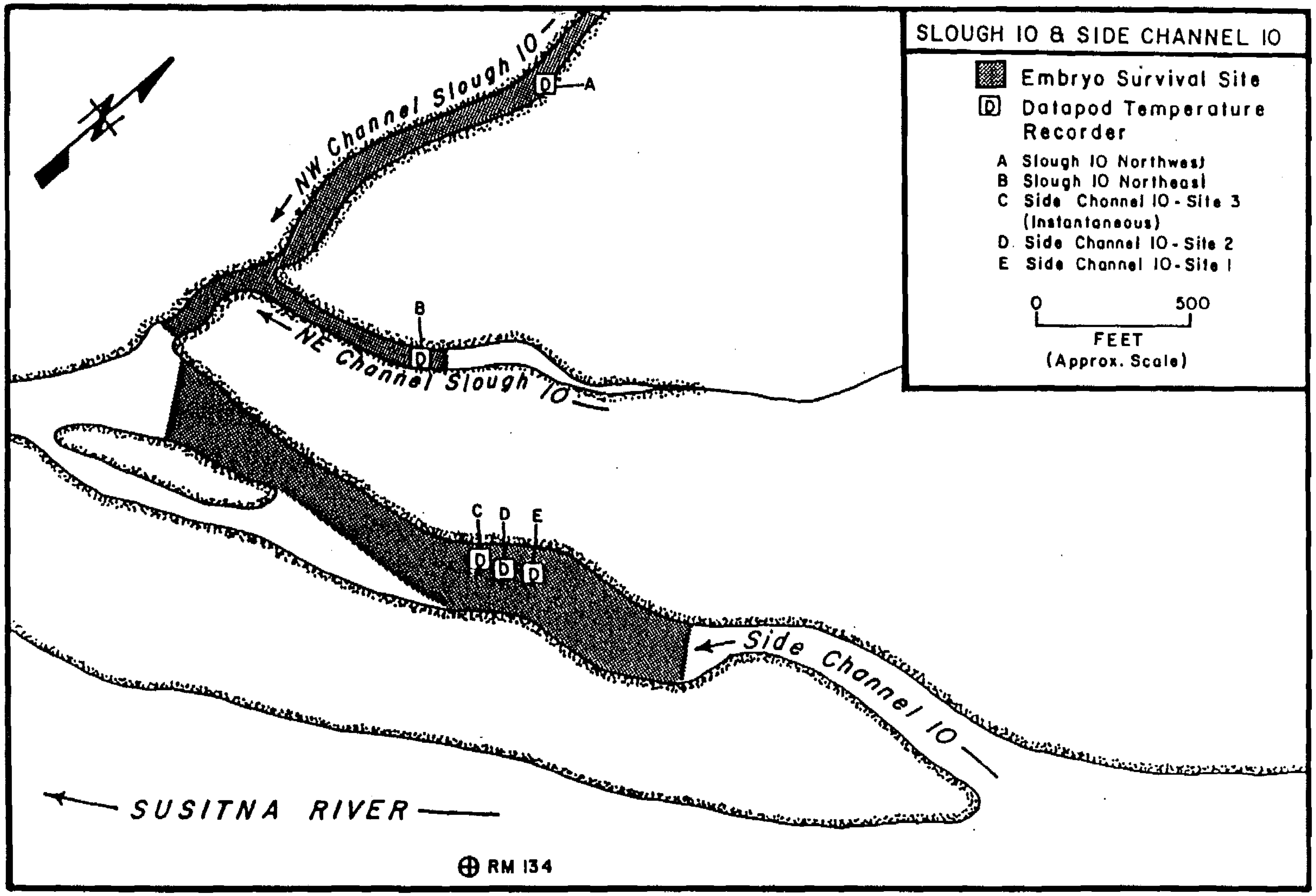

Figure B-7. Study site location at Slough 10 and Side Channel 10 (RM 133.8).

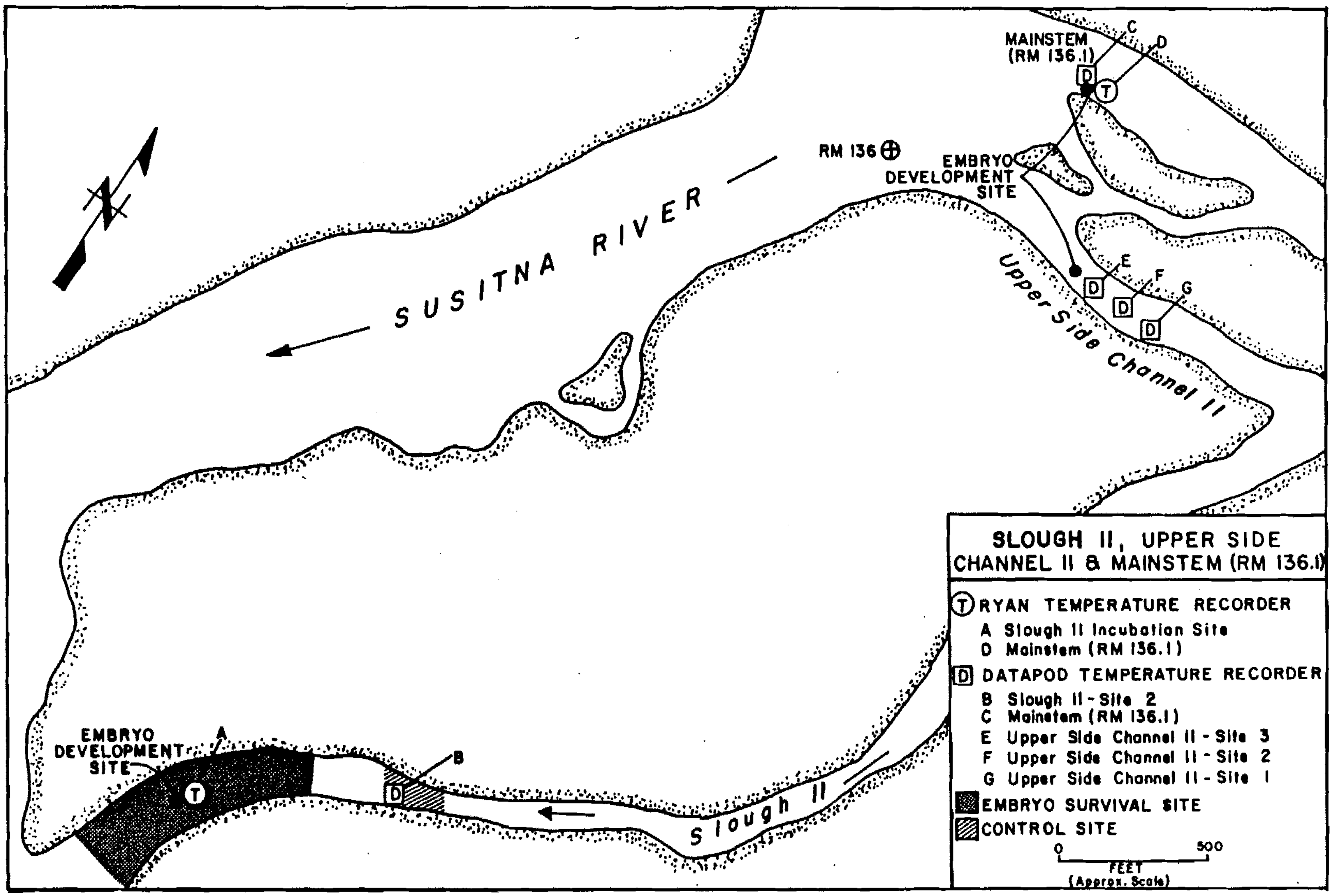

Figure B-8. Study site at Slough 11 (RM 135.3), Upper Side Channel 11 (RM 136.1) and Mainstem (RM 136.1).

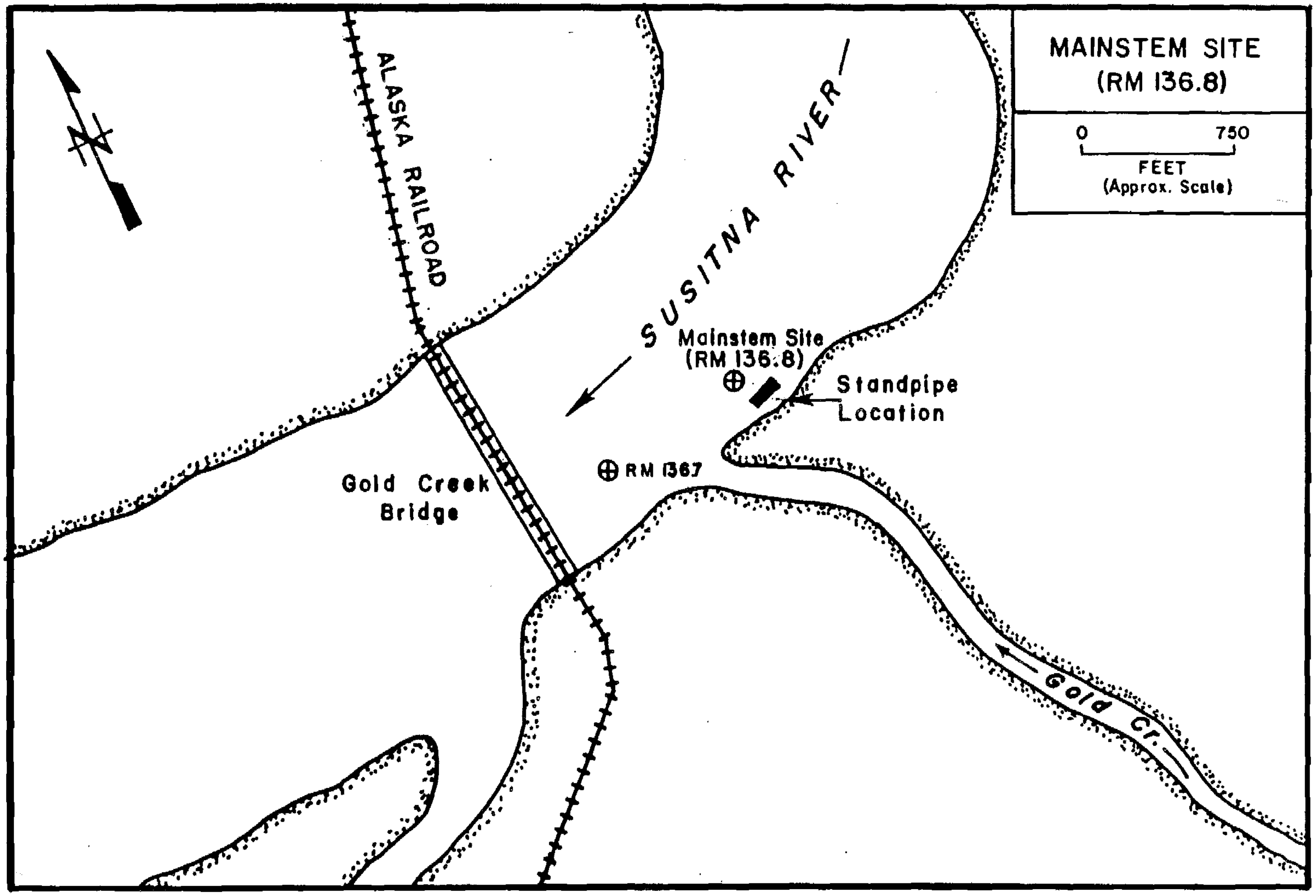

Figure B-9. Study site location at Mainstem (RM 136.8).

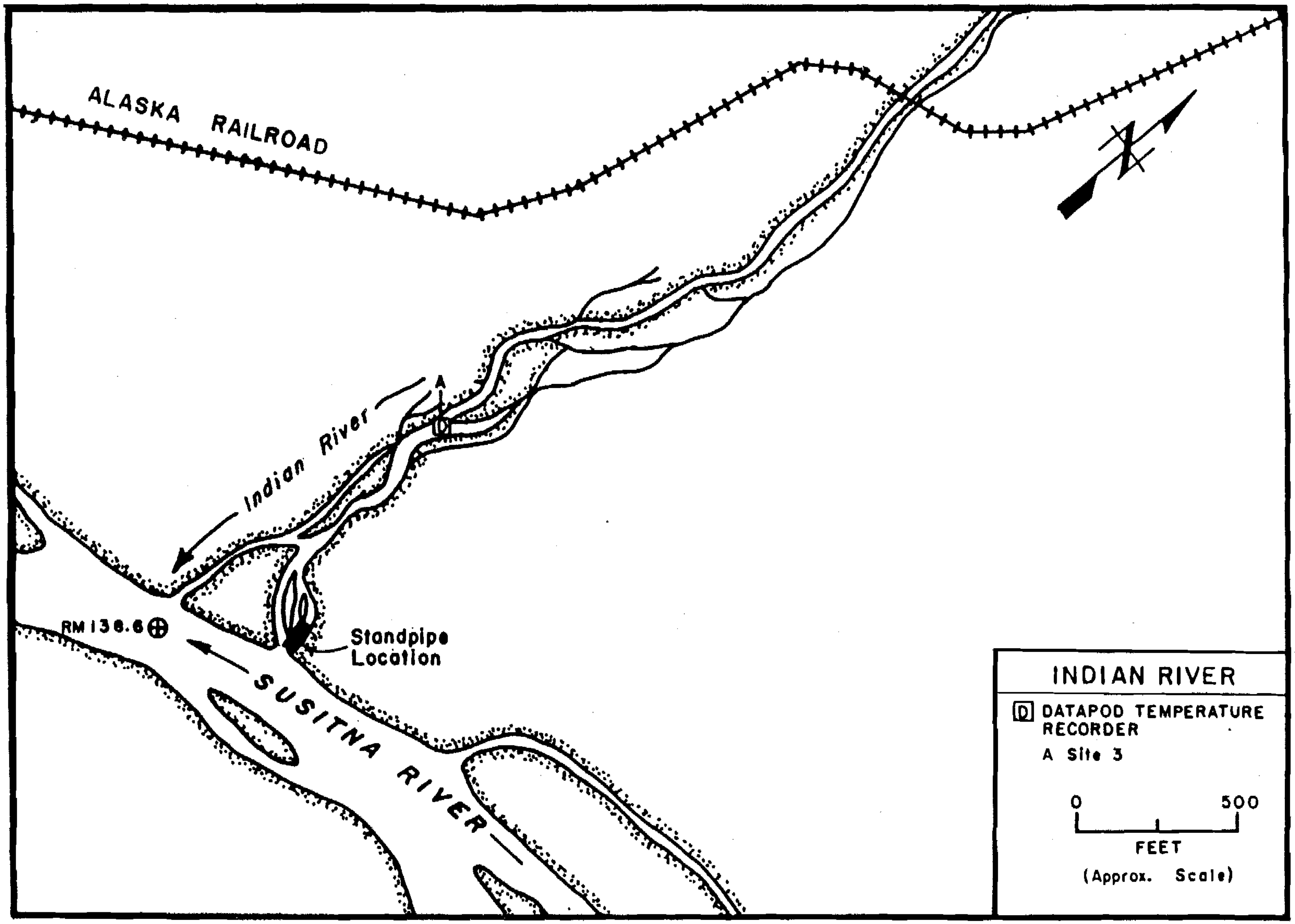

Figure B-10. Study site location at Indian River (RM 138.6).

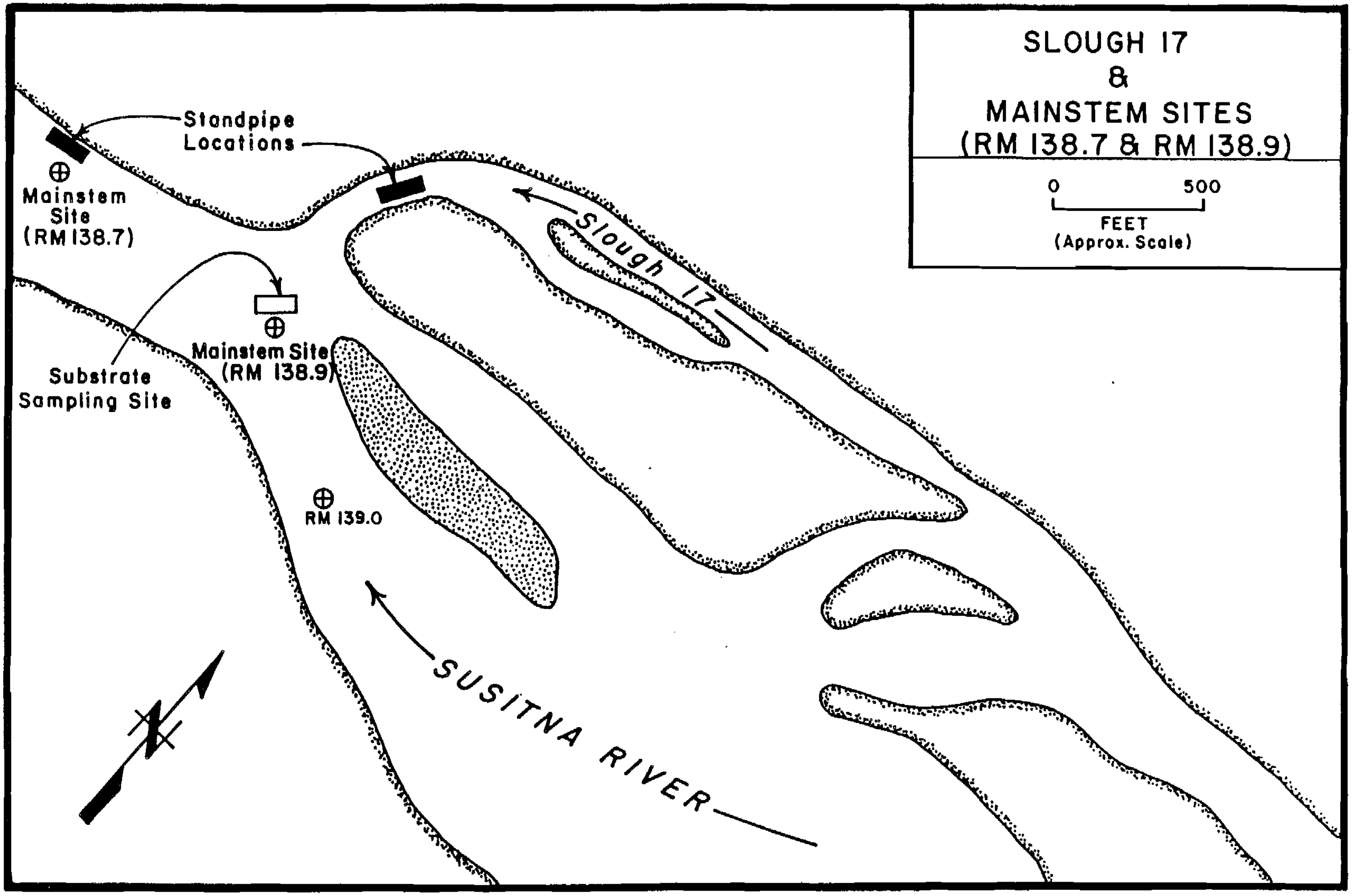

Figure B-11. Study site location at Slough 17 (RM 138.9) and Mainstem sites (RM 138.7 and RM 138.9).

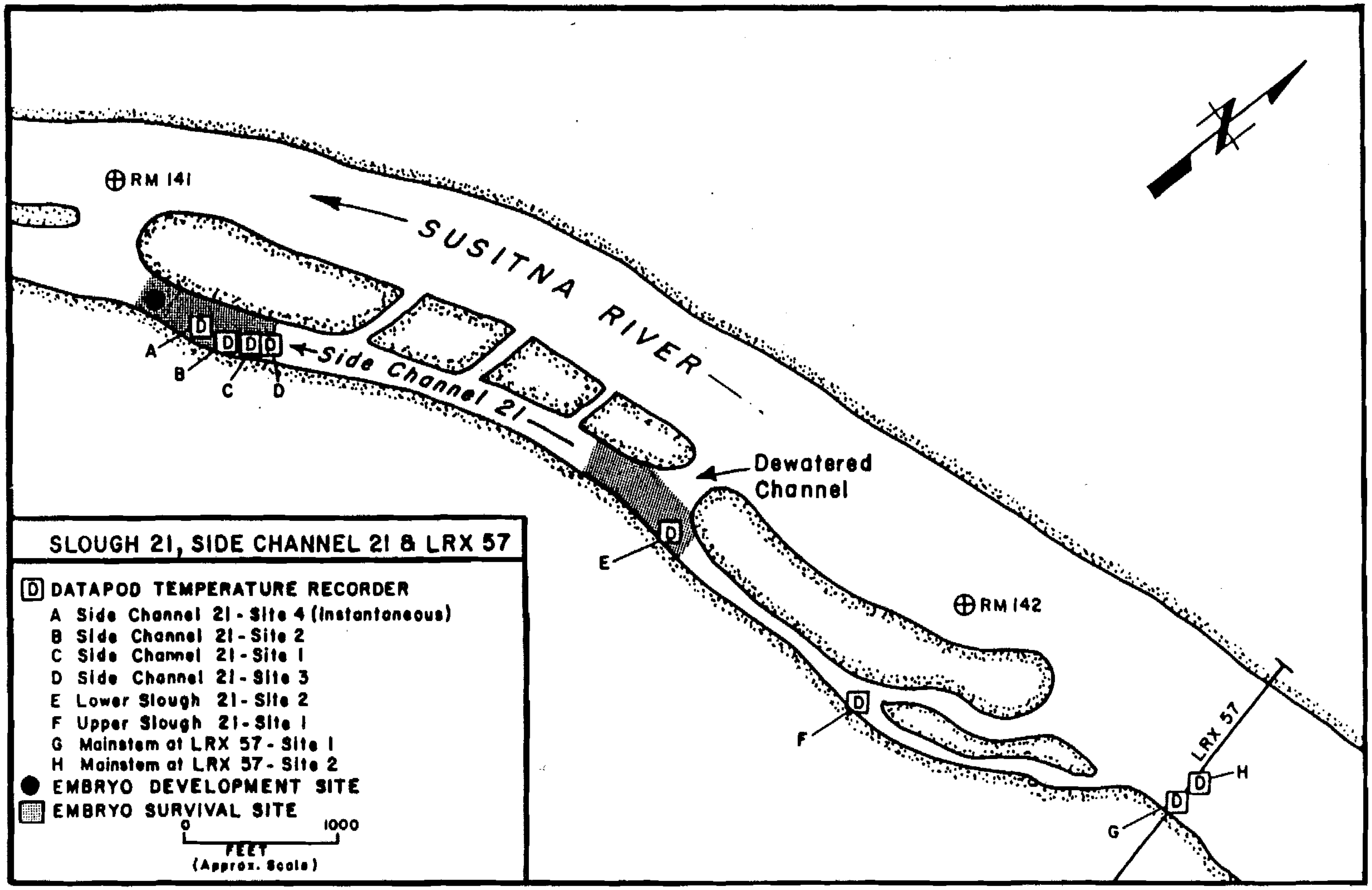

Figure B-12. Study site location at Side Channel 21 (RM 141.0), Slough 21 and Mainstem LRX 57 (RM 142.2).

APPENDIX C

WATER QUALITY DATA

APPENDIX C

WATER QUALITY DATA

Water quality data presented in Appendix C consist of surface and intragravel measurements of water temperature, dissolved oxygen concentrations, pH, conductivity and turbidity. Surface water quality data collected at all study sites are presented in Appendix Table C-1. Intragravel water quality measurements are presented in Appendix Table C-2.

Appendix Table C-1. Surface water quality data collected from August 1983 to May 1984, Susitna River, Alaska.

Site (River mile)	Sampling Date (y/m/d)	Sampling Time	Temperature Air (°C)	Temperature Water (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen % Sat.	pH	Conductivity (umhos/cm)	Turbidity (NTU)
SLOUGH 8A (125.9)	830815	1226	11.6	8.8	----	----	----	152.0	----
	830902	1530	13.5	9.4	9.5	085	----	139.0	----
	831025	1600	1.0	0.8	11.4	081	7.0	147.0	0.8
	831109	1614	2.0	0.8	8.7	062	7.2	177.0	0.2
	831214	1205	-20.6	0.3	8.4	058	7.1	221.0	0.3
	840427	1605	9.8	7.2	11.3	095	7.1	177.0	0.6
	840511	1635	10.0	8.7	----	----	6.8	117.0	0.6
SLOUGH 9 (128.3)	830906	1412	----	8.8	9.9	087	----	141.0	----
	831025	1530	-1.0	0.9	10.6	075	7.0	119.0	0.7
	831109		2.0	0.6	10.5	074	7.3	127.0	0.3
	831214	1310	-20.6	-0.3	9.1	063	7.3	135.0	0.4
	840427	1550	10.9	9.4	10.4	093	6.9	131.0	0.4
	840511	1625	10.0	6.3	----	----	6.7	78.0	0.4
FOURTH OF JULY CREEK (131.1)	830804	1200	13.6	13.2	9.2	089	6.9	35.0	----
	830822	1215	14.0	10.7	----	----	7.6	19.0	----
	830823	1730	11.2	8.7	10.8	094	7.3	122.0	----
	830828	1600	----	10.7	9.6	087	6.8	22.0	----
	830828	1640	----	11.1	9.6	089	6.8	22.0	----
	830914	1840	----	5.8	12.3	100	7.5	162.0	----
	830923	1435	2.7	5.1	13.4	108	7.5	145.0	21.0
	830923	1500	3.4	4.2	13.2	104	6.7	25.0	0.4
	831009	1115	0.7	0.1	14.8	102	6.9	23.0	0.4
	831009	1135	0.7	0.7	11.3	081	6.9	139.0	0.9
	831102	1045	2.8	-0.2	11.1	078	7.0	32.0	0.7
	831102	1325	1.4	-0.2	13.8	097	7.0	30.0	0.7
	831109		0.8	-0.3	13.7	095	7.2	34.0	1.3
	831109		----	----	----	----	----	----	0.5
	831203	1410	-3.0	0.0	13.3	092	7.0	40.0	1.0
	831203	1440	-3.0	0.0	9.3	065	7.0	136.0	0.7
	840330	0920	5.2	0.2	13.7	096	7.3	40.0	0.5
	840426	1315	8.1	0.0	13.8	094	7.0	47.0	0.4
	840427	1535	5.0	0.0	11.7	080	7.1	161.0	0.3
	840502	1515	7.4	1.8	9.6	072	7.4	68.0	----
	840502	1525	7.4	0.1	14.3	100	6.3	38.0	----
	840511	1205	7.0	1.5	13.0	095	6.7	31.0	0.8
	840511	1220	8.0	1.6	12.2	090	7.0	102.0	5.1
SLOUGH 9A (133.6)	831025	1430	-0.8	3.0	7.5	056	6.8	197.0	0.4
	831109		2.0	2.2	10.0	074	7.1	171.0	0.2
	831214	1340	-20.6	0.8	9.3	065	7.3	193.0	0.2
	840427	1525	10.0	8.0	9.6	083	6.8	197.0	0.5
	840511	1535	9.2	8.0	----	----	6.9	207.0	0.8

Appendix Table C-1. Continued.

Site (River mile)	Sampling Date (y/m/d)	Sampling Time	Temperature Air (°C)	Temperature Water (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen % Sat.	pH	Conductivity (umhos/cm)	Turbidity (NTU)
SIDE CHANNEL 10	830915		----	8.6	9.8	085	7.4	217.0	----
(133.8)	830923	1108	2.2	4.1	10.4	083	7.2	255.0	0.3
	831009	1215	0.2	0.8	9.4	067	7.1	256.0	0.6
	831028	1300	0.4	0.7	10.0	072	7.5	268.0	0.3
	831207	1130	-14.0	0.1	4.0	028	6.9	218.0	0.8
	840228	1255	0.1	0.7	9.4	068	7.3	265.0	----
	840228	1315	1.0	0.2	13.4	095	7.8	269.0	----
	840330	1245	8.3	3.8	9.9	078	7.3	251.0	----
	840411	1630	10.6	9.7	10.1	091	7.4	260.0	----
	840425	1220	5.4	11.6	9.5	088	6.6	251.0	0.6
	840502	0940	4.2	4.7	11.0	089	7.2	251.0	----
	840511	1545	8.2	12.7	----	----	7.2	253.0	0.3
SLOUGH 10	830909	1227	----	9.1	10.5	093	----	178.0	----
(133.8)	830909	1240	----	5.2	10.4	084	----	209.0	----
	830909	1250	----	5.7	8.9	072	----	172.0	----
	830915		----	5.4	8.4	068	6.7	172.0	----
	830915		----	5.0	9.7	077	7.0	223.0	----
	830923	1047	1.0	2.6	10.9	083	6.7	187.0	0.3
	831009	1230	0.2	0.8	9.1	065	----	226.0	----
	831028	1330	----	0.9	----	----	7.3	220.0	0.3
	831028	1345	----	0.5	----	----	7.3	167.0	0.4
	831110		----	----	----	----	----	----	0.3
	831110		----	----	----	----	----	----	0.2
	831110		1.8	1.8	9.3	068	7.4	170.0	----
	831206	1130	0.4	1.9	9.0	065	7.1	178.0	----
	831206	1555	0.0	1.8	9.5	069	7.3	219.0	0.3
	831206	1610	0.0	2.2	8.5	063	7.1	169.0	0.3
	840120	1125	----	0.2	10.7	075	7.2	187.0	----
	840208	1530	-16.0	0.9	9.9	072	7.1	177.0	----
	840228	1230	-4.5	1.6	9.5	071	7.4	221.0	----
	840228	1245	-2.4	2.0	8.4	063	7.2	171.0	----
	840330	1135	8.8	3.8	9.0	070	7.2	172.0	0.2
	840330	1140	7.8	3.4	9.9	077	7.4	221.0	0.3
	840330	1150	7.2	4.0	9.9	078	7.3	183.0	0.3
	840411		5.0	3.7	9.1	070	6.7	176.0	----
	840411		5.1	2.4	9.6	072	7.2	217.0	----
	840411	0950	1.8	2.8	9.8	074	7.1	180.0	----
	840412	0915	0.3	1.3	8.1	059	6.6	106.0	----
	840425	1310	----	7.2	10.0	083	6.9	181.0	0.4
	840425	1415	----	6.0	8.8	072	6.9	223.0	0.5
	840425	1420	6.1	7.0	9.1	075	6.7	172.0	0.4
	840511	1550	8.0	6.7	----	----	6.9	148.0	0.4
	840511	1555	1.0	0.1	----	----	6.9	219.0	0.5
	840511	1600	8.1	6.9	----	----	6.7	152.0	0.3

Appendix Table C-1. Continued.

Site (River mile)	Sampling Date (y/m/d)	Sampling Time	Temperature Air (°C)	Temperature Water (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen % Sat.	pH	Conductivity (umhos/cm)	Turbidity (NTU)
SLOUGH 11 (135.3)	830811	1115	14.8	6.1	6.0	050	7.0	232.0	----
	830816	1430	17.6	8.6	14.6	126	7.0	238.0	----
	830827		16.6	8.6	10.7	095	7.3	230.0	0.3
	830915	0840	4.8	4.3	10.8	085	7.2	244.0	----
	830922	1035	7.3	4.7	11.6	094	6.9	242.0	0.7
	831009	1250	1.1	0.5	12.8	091	----	231.0	0.3
	831101	1105	-2.1	1.2	11.2	081	7.3	241.0	0.8
	831109		2.2	1.2	11.4	080	7.6	233.0	0.4
	831205	1200	-5.0	1.3	10.5	075	7.6	241.0	0.3
	831230		-18.0	0.4	10.6	077	7.4	243.0	----
	840201	1310	-7.0	0.7	10.9	079	7.5	239.0	----
	840209	1550	-26.0	0.1	11.4	082	7.5	240.0	----
	840328	1440	10.9	4.1	12.5	098	7.5	232.0	0.2
	840410	1520	7.8	4.7	12.5	100	7.5	227.0	----
	840412	1425	9.7	4.9	11.7	094	7.2	226.0	----
	840427	1510	10.0	6.3	10.9	090	7.2	232.0	0.3
	840503	1035	7.2	4.9	11.4	092	7.3	229.0	----
	840511	1530	8.7	8.5	----	----	7.1	238.0	0.2
MAINSTEM (136.1)	831027		1.0	-0.3	14.1	098	8.0	190.0	----
	831109	1300	----	-0.2	14.0	098	8.4	235.0	0.7
	831207	1620	-8.0	-0.2	13.5	093	7.7	242.0	----
	831208	1400	-12.0	-0.3	13.5	095	8.1	251.0	0.8
	840331	1015	11.4	0.1	14.0	098	8.0	268.0	----
	840410		3.0	0.2	13.6	095	7.9	260.0	----
	840417	1415	8.2	0.1	----	----	7.8	267.0	----
	840425	1605	5.2	0.2	13.5	093	7.9	257.0	0.5
	840511	1520	7.3	0.8	----	----	7.2	138.0	17.0
UPPER SIDE CHANNEL 11 (136.1)	830823	1530	14.2	8.9	11.1	098	7.8	138.0	----
	831109		----	0.7	11.3	081	7.8	182.0	0.7
	841208	1315	-13.0	0.2	8.5	060	7.3	235.0	0.4
	840328	1630	6.4	4.7	10.6	085	7.7	179.0	----
	840427	1500	11.0	8.3	9.4	081	7.3	194.0	0.3
	840503	1400	10.0	9.9	9.7	089	7.3	197.0	----
	840511	1522	9.3	12.0	----	----	7.3	203.0	0.4
MAINSTEM (136.8)	831025	1300	-2.0	1.2	10.8	077	7.0	198.0	0.5
	831025	1330	-2.0	2.1	5.7	042	6.7	209.0	0.8
	831108		-1.2	2.5	8.5	063	7.0	197.0	0.2
	831214	1415	-20.6	0.2	10.8	074	7.3	200.0	0.4
	840427	1440	0.8	6.1	8.8	072	6.7	159.0	0.3
	840427	1445	0.8	2.3	12.2	090	7.4	216.0	----

Appendix Table C-1. Continued.

Site (River mile)	Sampling Date (y/m/d)	Sampling Time	Temperature Air (°C)	Temperature Water (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen % Sat.	pH	Conductivity (umhos/cm)	Turbidity (NTU)
	840511	1515	7.0	7.0	----	---	6.7	150.0	3.2
INDIAN RIVER (138.6)	830727	1200	23.6	9.6	11.4	103	6.8	44.7	-----
	830727	1340	21.8	9.9	11.3	103	6.8	45.7	-----
	830727	1449	23.8	10.5	11.3	104	6.9	46.6	-----
	830727	1540	24.0	11.0	11.1	105	6.6	45.7	-----
	830728	1035	20.9	11.1	11.0	103	7.1	47.6	-----
	830728	1225	24.5	10.1	11.3	---	6.8	64.0	-----
	830728	1445	26.2	11.3	10.6	---	6.8	63.0	-----
	830728	1645	22.4	12.0	10.9	---	6.9	63.0	-----
	830728	2000	-----	14.1	10.5	105	7.0	48.6	-----
	830729	1945	17.0	10.0	10.5	096	7.2	54.4	-----
	831025	1130	-2.8	0.1	14.2	098	7.1	57.0	0.8
	831108		-----	0.3	11.9	083	6.8	59.0	0.3
	831213	1420	-5.2	-0.3	14.3	097	7.1	69.0	0.3
	840427	1420	8.4	3.0	12.1	091	7.1	72.0	0.4
	840511	1415	8.2	4.3	12.1	095	6.9	54.0	0.9
MAINSTEM (138.7)	831025	1100	-3.8	0.1	14.3	099	7.5	176.0	1.3
	831108		-5.0	0.5	11.9	083	7.4	164.0	0.3
	831213	1300	-6.8	1.6	12.1	088	6.7	80.0	0.8
	840427	1405	7.2	3.8	10.9	085	6.8	125.0	0.6
	840511	1505	6.9	1.9	----	---	6.8	123.0	16.0
SLOUGH 17 (138.9)	830820	1440	10.2	4.5	----	---	5.7	77.0	-----
	830901	0920	9.1	4.7	----	---	----	75.0	-----
	831025	1030	-3.8	1.8	11.0	080	6.6	84.0	1.2
	831108		-2.4	1.9	11.8	086	6.8	79.0	0.3
	831213	1450	-6.0	1.3	11.1	080	6.8	86.0	0.6
	840427	1355	9.2	7.8	10.7	092	6.8	86.0	0.4
	840511	1455	8.0	6.0	----	---	6.4	86.0	0.3
SIDE CHANNEL 21 (141.0)	830825	1400	12.0	8.1	10.8	094	7.5	119.0	75.0
	830911	1600	-----	8.3	13.3	113	7.5	164.0	-----
	830914	1525	-----	6.9	11.6	094	----	150.0	-----
	830923	1200	2.8	5.1	13.2	106	7.3	152.0	23.0
	831009	1405	0.2	0.4	14.4	101	----	149.0	1.7
	831027	1350	1.0	0.2	14.9	103	7.7	161.0	0.2
	831108	1330	0.2	-0.3	----	---	----	154.0	0.2
	831204	1305	-3.4	0.0	12.8	088	7.6	156.0	0.4
	840329	1105	5.2	0.7	13.0	093	7.9	-----	0.4
	840417	1535	9.2	6.7	----	---	7.4	172.0	-----
	840427	1340	9.6	6.5	11.9	098	7.4	172.0	0.5
	840502	1335	7.6	2.6	12.4	095	7.6	194.0	-----
	840511	1445	7.4	11.0	11.1	103	7.5	169.0	1.0

Appendix Table C-1. Continued.

Site (River mile)	Sampling Date (y/m/d)	Sampling Time	Temperature Air (°C)	Temperature Water (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen % Sat.	pH	Conductivity (umhos/cm)	Turbidity (NTU)
SLOUGH 21	830819	1500	18.0	9.6	9.9	087	6.8	201.0	----
(141.8)	830825	1200	7.7	11.9	10.9	103	7.8	122.0	85.0
	830831	1315	12.0	5.1	6.2	050	----	196.0	----
	830831	1546	12.0	5.0	8.2	066	----	196.0	----
	830913	1345	----	6.0	9.8	081	6.9	194.0	----
	830913	1345	----	6.1	9.3	077	----	184.0	----
	830913	1500	----	6.1	9.8	080	----	184.0	----
	830921	1130	8.7	4.7	11.6	094	6.6	199.0	0.4
	831009	1340	0.2	1.8	8.9	066	----	190.0	0.3
	831026	1300	-0.4	2.3	10.7	078	7.2	201.0	0.3
	831108	1230	-0.6	2.0	10.5	077	7.6	193.0	0.3
	831202	1115	-5.0	1.4	9.4	067	7.3	200.0	0.4
	831229	1320	-16.0	0.8	9.9	071	7.8	204.0	----
	840117	1210	-3.0	1.4	10.9	079	7.2	199.0	----
	840413	0945	2.4	1.9	10.5	078	7.2	201.0	----
	840426	0915	3.6	3.2	10.5	079	7.3	206.0	0.2
	840511	1435	10.0	9.6	9.0	082	6.9	213.0	0.3

Appendix Table C-2. Intragravel and surface water quality data collected at standpipes from September to December 1983, Susitna River, Alaska.

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 8A	A	001	831109	1610	2.0	3.8	28	7.2	214	----	----	---	----	---
(125.9)	A	002	831109	1610	3.0	5.1	39	7.4	159	1.5	8.8	65	7.2	203
	A	003	831109	1610	4.0	4.1	32	7.3	154	2.0	8.2	61	7.2	223
	A	001	831214	1205	0.8	6.2	44	7.5	283	----	----	---	----	---
	A	003	831214	1205	1.9	4.3	31	7.3	274	0.9	6.8	48	7.1	265
SLOUGH 9	A	001	831109	1535	3.0	6.5	50	7.1	147	1.5	10.4	76	7.3	100
(128.3)	A	002	831109	1535	3.0	6.2	47	7.2	171	1.5	10.4	76	7.3	118
	A	003	831109	1535	3.0	6.4	49	7.0	171	1.5	9.6	70	7.3	127
	A	003	831214	1310	2.2	6.3	46	----	181	0.1	9.3	64	7.3	193
FOURTH OF JULY	A	001	830914	1840	8.0	9.8	85	----	37	7.8	11.3	97	----	33
CREEK	A	002	830914	1840	8.2	10.4	90	----	37	7.8	11.4	98	----	33
(131.1)	A	003	830914	1840	7.8	10.9	94	----	33	----	----	---	----	---
	A	004	830914	1840	7.0	12.0	100	----	134	----	----	---	----	---
	A	005	830914	1840	6.8	12.9	108	----	150	6.8	13.0	108	7.5	150
	A	006	830914	1840	7.2	12.0	100	----	33	7.2	11.8	99	7.5	33
	A	007	830914	1840	7.2	11.6	97	----	33	7.2	11.7	98	----	33
	A	008	830914	1840	7.2	11.4	96	----	33	7.2	12.3	104	----	33
	A	009	830914	1840	7.2	11.7	98	----	33	7.2	11.7	98	----	33
	A	010	830914	1840	7.2	11.5	97	----	33	7.2	11.8	99	----	33
	A	011	830914	1840	7.2	11.4	96	----	33	7.2	12.0	100	----	33
	A	012	830914	1840	7.2	11.3	95	----	33	7.2	12.2	102	----	33
	A	013	830914	1840	7.2	10.8	91	----	33	7.2	12.3	104	----	33
	A	014	830914	1840	7.2	12.2	102	----	33	7.2	12.0	100	----	33
	A	015	830914	1840	7.2	9.6	81	----	33	7.2	12.2	102	----	33
	A	002	831102	1100	0.5	13.3	96	6.6	26	0.2	13.0	92	7.0	25
	A	004	831102	1100	0.5	13.7	99	6.3	24	----	----	---	----	---
	A	005	831102	1100	0.5	13.1	95	----	34	----	----	---	----	---
	A	007	831102	1100	0.8	13.7	99	----	24	0.2	13.7	98	7.0	25
	A	008	831102	1100	0.2	13.7	98	6.5	29	0.2	13.8	99	7.0	27
	A	009	831102	1100	0.8	13.8	100	----	26	0.2	13.7	98	7.0	23
	A	012	831102	1100	0.8	13.8	100	----	28	0.8	13.8	100	7.0	28
	A	014	831102	1100	0.8	13.8	100	----	28	0.6	13.9	100	7.0	28
	A	002	831109	1500	0.0	13.4	93	7.2	29	----	----	---	----	---
	A	007	831109	1500	0.0	13.6	95	7.2	29	----	----	---	----	---
	A	012	831109	1500	0.0	13.5	94	7.0	29	0.0	13.5	94	7.2	29
	A	012	831203	1415	0.1	13.3	93	7.2	32	0.0	13.3	93	7.0	34
	A	014	831203	1415	0.0	13.2	92	7.2	34	0.0	13.3	93	7.0	34
	A	015	831203	1415	0.0	13.3	93	----	34	0.2	13.3	93	7.0	34

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 9A	A	001	831109	----	4.0	6.3	49	7.1	259	3.0	10.0	76	6.8	155
(133.6)	A	002	831109	----	3.5	9.9	76	7.0	255	2.5	6.4	48	6.8	193
	A	003	831109	----	3.5	10.0	77	7.0	127	2.5	10.0	75	6.8	184
	A	001	831214	1345	2.9	9.4	70	----	317	1.2	9.4	67	7.3	261
	A	002	831214	1345	3.0	7.6	57	----	316	1.3	11.2	80	7.3	260
	A	003	831214	1345	----	----	---	----	---	----	----	---	----	---
SIDE CHANNEL 10	A	001	830915	----	7.2	9.1	76	7.3	235	----	----	---	----	---
(133.8)	A	002	830915	----	8.0	7.7	66	----	264	10.2	9.9	89	7.4	216
	A	003	830915	----	8.2	5.9	51	----	287	11.0	9.7	89	7.4	246
	A	004	830915	----	5.2	7.4	59	----	266	10.0	10.0	89	7.4	238
	A	005	830915	----	6.0	6.0	49	----	264	10.5	9.9	90	7.4	234
	A	006	830915	----	7.0	6.7	56	----	244	10.8	9.8	89	7.4	223
	A	007	830915	----	7.0	5.1	43	----	290	11.8	9.4	88	7.4	228
	A	008	830915	----	5.8	5.5	45	6.9	269	10.0	8.4	75	7.4	234
	A	009	830915	----	6.5	6.3	52	----	248	10.0	9.4	84	7.4	210
	A	010	830915	----	5.5	6.5	52	----	231	9.5	10.1	90	7.4	196
	A	011	830915	----	6.5	7.7	64	----	232	8.8	7.8	68	7.4	204
	A	012	830915	----	9.5	9.3	82	----	186	9.5	10.1	90	7.4	192
	A	013	830915	----	12.5	10.9	103	----	163	12.0	11.1	104	7.4	161
	A	014	830915	----	9.2	7.9	70	----	172	11.2	10.1	93	7.4	149
	A	015	830915	----	11.2	10.9	100	----	160	11.5	11.0	102	7.4	155
	A	016	830915	----	11.0	10.7	98	----	161	11.5	11.0	102	7.4	159
	A	017	830915	----	10.5	10.6	96	----	163	11.0	11.0	100	7.4	161
	A	018	830915	----	11.8	10.8	100	----	161	12.0	11.0	103	7.4	153
	A	019	830915	----	8.2	4.2	36	7.1	191	10.0	10.3	92	7.4	156
	A	001	831028	1330	0.5	6.6	47	----	---	----	----	---	----	---
	A	002	831028	1330	0.5	3.3	24	----	---	----	----	---	----	---
	A	003	831028	1330	0.5	3.3	24	7.4	---	----	----	---	----	---
	A	005	831028	1330	2.2	4.8	36	----	---	1.5	8.2	60	7.5	250
	A	006	831028	1330	2.5	5.3	40	----	228	2.0	8.0	60	7.5	246
	A	007	831028	1330	1.8	7.9	59	----	261	0.5	6.2	44	7.5	273
	A	008	831028	1330	3.1	5.8	45	7.3	241	3.0	7.3	56	7.5	233
	A	009	831028	1330	3.8	6.0	47	----	202	2.4	8.0	61	7.5	194
	A	010	831028	1330	3.0	6.2	48	----	216	1.2	10.2	75	7.5	220
	A	011	831028	1330	2.2	6.5	49	----	222	1.2	11.2	82	7.5	239
	A	013	831028	1330	1.0	6.3	46	----	203	----	----	---	----	---
	A	014	831028	1330	0.3	6.5	46	----	199	----	----	---	----	---
	A	016	831028	1330	0.3	9.6	68	----	193	0.3	8.8	63	7.5	---

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SIDE CHANNEL 10	A	017	831028	1330	0.5	8.8	63	----	169	0.8	8.2	59	7.5	---
(continued)	A	019	831028	1330	1.5	3.7	27	7.5	227	0.8	7.6	55	7.5	186
	A	004	831110	1340	0.5	8.2	58	7.9	263	----	----	---	----	---
	A	005	831110	1340	1.0	6.0	43	7.9	259	1.0	6.3	46	----	233
	A	006	831110	1340	1.0	5.7	41	7.7	255	----	----	---	----	---
	A	013	831206	1315	0.6	13.4	94	----	210	----	----	---	----	---
	A	016	831206	1315	0.0	10.8	74	----	215	----	----	---	----	---
SLOUGH 10	A	001	830915	----	5.5	1.3	11	----	242	8.2	9.5	82	----	203
(133.8)	A	002	830915	----	6.2	4.8	39	----	233	----	----	---	----	---
	A	003	830915	----	7.0	6.8	57	----	206	7.5	8.8	74	----	211
	A	004	830915	----	6.0	3.4	28	----	243	----	----	---	----	---
	A	005	830915	----	5.0	1.8	14	6.2	202	5.5	9.2	74	----	191
	A	006	830915	----	5.5	0.7	6	6.3	231	7.0	9.2	77	----	152
	A	007	830915	----	5.0	2.3	18	----	202	6.5	9.0	74	----	155
	A	008	830915	----	5.2	2.7	22	----	217	6.5	9.0	74	----	155
	A	009	830915	----	5.0	1.7	14	----	186	6.2	8.6	70	----	156
	A	010	830915	----	4.8	6.1	48	----	195	6.2	8.6	70	----	156
	A	011	830915	----	5.0	4.5	36	----	178	6.0	8.5	69	----	157
	A	012	830915	----	4.8	7.2	52	----	179	4.0	7.2	55	----	176
	A	013	830915	----	4.8	4.6	36	----	182	6.2	8.4	69	----	155
	A	014	830915	----	4.8	4.4	35	----	161	6.0	8.6	70	----	130
	A	015	830915	----	4.2	5.8	45	6.3	166	6.0	8.6	70	----	130
	A	016	830915	----	4.5	8.3	65	7.1	211	5.8	9.6	78	----	197
	A	017	830915	----	4.5	4.6	36	----	214	5.5	9.8	79	----	191
	A	018	830915	----	5.0	5.4	43	----	218	5.5	9.6	77	----	199
	A	019	830915	----	4.5	5.8	45	----	222	5.5	9.9	80	----	191
	A	020	830915	----	4.5	5.4	42	----	214	5.5	9.9	80	----	199
	A	004	831029	1150	1.1	1.6	12	----	501	----	----	---	----	---
	A	005	831029	1150	2.5	0.8	6	7.5	156	3.0	10.1	77	7.3	195
	A	006	831029	1150	2.8	0.7	5	----	195	2.8	9.5	72	7.3	150
	A	007	831029	1150	2.8	0.8	6	----	217	3.0	9.6	73	7.3	149
	A	008	831029	1150	2.8	1.1	8	7.3	174	3.0	9.5	72	7.3	150
	A	009	831029	1150	2.9	0.4	3	----	194	3.1	8.9	68	7.3	148
	A	010	831029	1150	3.1	6.3	48	----	198	3.1	8.9	68	7.3	151
	A	011	831029	1150	3.0	0.5	4	----	207	3.1	8.6	66	7.3	151
	A	012	831029	1150	3.0	7.1	54	----	181	3.2	7.4	57	7.3	180
	A	013	831029	1150	3.0	3.7	28	----	154	2.9	8.8	67	7.3	140
	A	014	831029	1150	3.2	6.3	48	----	146	2.8	8.7	66	7.3	132
	A	015	831029	1150	3.5	6.5	50	7.4	146	2.8	8.7	66	7.3	127

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 10 (continued)	A	016	831029	1150	3.0	6.8	52	----	211	2.9	10.3	78	7.3	194
	A	017	831029	1150	3.0	5.9	45	----	207	3.0	10.3	78	7.3	197
	A	018	831029	1150	3.4	6.2	48	7.2	208	3.0	10.4	79	7.3	195
	A	019	831029	1150	3.2	6.5	50	----	209	3.0	10.8	82	7.3	195
	A	020	831029	1150	3.2	6.7	51	7.2	204	3.0	10.8	82	7.3	193
	A	007	831110	----	2.0	1.3	10	7.5	225	2.0	9.4	70	7.4	159
	A	008	831110	----	2.0	1.6	12	7.5	229	2.5	9.3	70	7.4	151
	A	018	831110	----	3.0	6.1	47	7.4	214	2.5	9.7	73	7.4	204
	A	019	831110	----	2.5	6.3	48	7.4	218	2.0	10.0	75	7.4	204
	A	004	831206	1305	0.2	3.5	24	----	660	----	----	---	----	---
	A	008	831206	1305	1.5	2.7	20	----	211	2.5	10.1	75	7.1	163
	A	009	831206	1305	2.4	1.7	13	----	261	2.8	8.4	63	7.1	209
	A	010	831206	1305	2.3	5.9	43	7.0	235	2.8	8.4	63	7.1	195
	A	011	831206	1305	2.6	1.2	9	----	206	2.8	8.3	62	7.1	179
	A	012	831206	1305	2.8	6.9	52	7.0	184	----	----	---	----	---
	A	013	831206	1305	2.4	6.4	47	----	173	2.5	8.1	60	7.1	151
	A	014	831206	1305	2.9	4.7	35	----	153	2.5	7.8	58	7.1	144
	A	015	831206	1305	2.8	6.1	46	----	150	2.5	7.7	57	7.1	137
	A	017	831206	1305	1.2	6.5	47	----	218	1.9	9.2	65	7.3	211
	A	018	831206	1305	2.2	6.6	49	7.3	232	1.9	9.8	70	7.3	211
	A	019	831206	1305	1.8	6.6	48	----	218	1.9	10.0	71	7.3	206
	A	020	831206	1305	1.9	6.8	48	7.2	217	1.9	10.1	72	7.3	203
	A	0R1	831206	1305	2.2	5.8	43	----	135	1.8	6.5	48	7.1	128
SLOUGH 11 (135.3)	A	001	830915	----	5.0	11.7	93	7.2	222	5.0	11.6	92	----	223
	A	002	830915	----	5.0	5.3	42	----	230	----	----	---	----	---
	A	003	830915	----	4.8	10.2	80	----	212	----	----	---	----	---
	A	004	830915	----	5.0	8.5	67	----	212	----	----	---	----	---
	A	005	830915	----	5.0	10.9	86	----	231	----	----	---	----	---
	A	006	830915	----	5.0	6.8	54	----	199	----	----	---	----	---
	A	007	830915	----	4.8	9.2	73	----	212	----	----	---	----	---
	A	008	830915	----	4.5	10.2	80	----	214	5.2	12.0	95	----	224
	A	009	830915	----	5.0	8.9	70	----	218	----	----	---	----	---
	A	010	830915	----	4.8	6.3	50	----	252	5.0	10.5	83	----	223
	A	011	830915	----	5.8	8.2	66	----	204	5.8	10.7	87	----	215
	A	012	830915	----	4.8	5.3	42	----	195	----	----	---	----	---
	A	013	830915	----	7.0	11.1	92	----	213	5.8	10.6	86	----	213
	A	014	830915	----	5.8	5.6	46	7.0	213	5.5	11.5	95	----	212
	A	015	830915	----	5.8	3.8	31	----	213	5.2	11.5	91	----	217
	A	016	830915	----	5.5	3.8	31	----	217	5.2	11.7	93	----	217

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 11 (continued)	A	017	830915	----	5.2	5.1	41	----	222	5.2	11.5	91	----	222
	A	018	830915	----	5.0	9.4	75	----	223	5.2	12.7	100	----	225
	A	019	830915	----	5.2	12.2	97	----	222	5.2	12.2	97	----	222
	A	020	830915	----	5.8	5.7	46	6.8	212	5.2	11.2	89	----	219
	A	001	831101	1225	1.2	12.4	90	----	220	1.2	12.4	90	7.3	220
	A	003	831101	1225	0.2	12.3	87	----	224	----	----	---	----	---
	A	004	831101	1225	0.3	8.8	63	----	218	----	----	---	----	---
	A	007	831101	1225	0.9	11.0	81	7.4	224	----	----	---	----	---
	A	008	831101	1225	1.9	9.9	74	----	226	1.2	11.8	86	7.3	226
	A	009	831101	1225	1.4	10.7	79	----	226	0.9	11.3	82	7.3	226
	A	010	831101	1225	1.9	9.8	73	----	219	1.6	10.8	80	7.3	228
	A	011	831101	1225	2.4	6.5	49	----	217	1.5	12.0	88	7.3	229
	A	012	831101	1225	1.2	10.0	73	----	224	----	----	---	----	---
	A	013	831101	1225	3.4	6.5	50	----	213	1.6	11.2	83	7.3	224
	A	014	831101	1225	1.2	12.5	91	----	222	1.4	12.5	92	7.3	222
	A	015	831101	1225	2.9	6.3	48	----	211	1.4	12.3	90	7.3	226
	A	016	831101	1225	2.3	4.7	36	7.1	223	1.3	12.5	91	7.3	227
	A	017	831101	1225	2.9	7.2	55	----	222	1.4	12.2	89	7.3	222
	A	018	831101	1225	1.3	11.0	80	----	230	1.2	13.4	97	7.3	226
	A	019	831101	1225	1.2	13.5	98	----	228	1.3	13.3	97	7.3	223
	A	020	831101	1225	2.4	8.4	64	----	208	1.5	12.0	88	7.3	223
	A	001	831205	1400	1.0	11.0	78	7.5	237	1.0	10.8	77	7.6	238
	A	003	831205	1400	0.9	10.8	77	----	226	----	----	---	----	---
	A	008	831205	1400	1.3	8.8	63	----	241	1.0	10.0	71	7.6	368
	A	009	831205	1400	1.1	9.8	70	----	239	0.9	10.0	71	7.6	232
	A	010	831205	1400	1.1	8.9	64	----	241	1.0	9.0	64	7.6	240
	A	011	831205	1400	2.0	6.6	48	----	230	1.0	10.3	74	7.6	238
	A	012	831205	1400	0.6	9.4	66	----	238	----	----	---	----	---
	A	013	831205	1400	2.0	7.9	58	----	225	1.5	10.3	74	7.6	232
	A	014	831205	1400	1.2	9.3	67	----	233	1.0	10.7	76	7.6	237
	A	015	831205	1400	2.5	7.3	54	----	225	1.0	10.8	77	7.6	238
	A	016	831205	1400	1.2	8.5	61	----	239	0.9	10.8	77	7.6	241
	A	017	831205	1400	2.2	8.4	62	----	234	1.2	10.6	76	7.6	239
	A	018	831205	1400	0.3	10.4	73	----	233	1.0	11.3	80	7.6	240
	A	020	831205	1400	1.9	7.5	54	7.2	228	1.1	10.3	74	7.6	239
	B	04A	830915	----	4.2	10.2	79	----	229	5.5	8.0	64	7.2	223
	B	04B	830915	----	4.2	8.0	62	----	226	5.5	10.8	87	7.2	223
	B	04C	830915	----	4.2	8.5	66	----	224	5.5	10.4	83	7.2	222
	B	10A	830915	----	4.2	9.7	75	----	228	5.5	11.3	91	7.2	215
	B	10B	830915	----	4.0	9.0	70	----	226	5.5	10.4	83	7.2	215

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 11 (continued)	B	10C	830915	----	5.0	8.8	70	----	218	5.5	10.6	85	7.2	220
	B	11A	830915	----	4.2	8.0	62	----	226	5.5	11.4	91	7.2	223
	B	11B	830915	----	4.2	8.0	62	----	224	5.5	11.2	90	7.2	223
	B	11C	830915	----	4.5	7.8	61	----	227	5.5	11.3	91	7.2	223
	B	21A	830915	----	4.5	5.6	44	----	227	5.5	11.0	88	7.2	223
	B	21B	830915	----	4.5	8.2	64	----	227	5.5	11.3	91	7.2	223
	B	21C	830915	----	4.5	8.3	65	----	227	5.5	11.3	91	7.2	223
	B	21D	830915	----	4.8	10.0	79	----	220	5.5	11.1	89	7.2	215
	B	21E	830915	----	4.8	10.1	80	----	220	5.2	11.2	89	7.2	217
	B	21F	830915	----	4.0	9.8	76	----	226	5.5	11.2	90	7.2	215
	B	04A	831101	1400	2.6	9.3	71	----	238	1.6	11.5	85	7.3	235
	B	04B	831101	1400	2.9	9.2	71	7.2	231	1.6	11.4	84	7.3	235
	B	04C	831101	1400	2.9	8.8	67	----	229	1.6	11.4	84	7.3	235
	B	10A	831101	1400	2.6	10.5	80	----	231	1.7	11.4	85	7.3	231
	B	10B	831101	1400	2.9	10.0	77	----	234	1.6	11.4	84	7.3	233
	B	10C	831101	1400	2.5	10.0	76	----	237	1.6	11.3	84	7.3	233
	B	11A	831101	1400	2.4	8.6	65	----	231	1.6	12.0	89	7.3	235
	B	11B	831101	1400	2.9	8.9	68	7.3	229	1.6	11.9	88	7.3	235
	B	11C	831101	1400	3.0	8.8	68	----	225	1.6	11.9	88	7.3	235
	B	21A	831101	1400	2.5	8.7	66	----	237	1.6	11.8	87	7.3	235
	B	21B	831101	1400	2.6	8.7	66	----	233	1.6	11.8	87	7.3	235
	B	21C	831101	1400	2.6	9.2	70	----	234	1.6	11.6	85	7.3	235
	B	21D	831101	1400	2.6	9.6	73	7.2	227	1.4	11.7	86	7.3	228
	B	21E	831101	1400	2.6	9.6	73	----	234	1.6	11.6	85	7.3	231
	B	21F	831101	1400	2.6	10.5	80	----	229	1.6	11.4	84	7.3	231
	B	04A	831205	1610	2.0	8.6	63	----	243	1.0	9.6	69	----	246
	B	04B	831205	1610	2.1	8.5	62	----	246	1.2	9.6	69	----	242
	B	04C	831205	1610	2.5	8.7	64	----	240	1.2	9.8	70	----	240
	B	10A	831205	1610	2.0	9.4	69	----	243	0.9	9.8	70	----	245
	B	10B	831205	1610	1.9	9.0	65	----	246	1.0	9.7	69	----	242
	B	10C	831205	1610	2.5	9.2	68	----	244	1.0	9.7	69	----	244
	B	11A	831205	1610	2.0	8.4	62	----	246	1.4	10.1	73	----	240
	B	11B	831205	1610	2.0	8.2	60	----	246	1.3	10.1	73	----	241
	B	11C	831205	1610	2.2	8.0	59	----	236	1.2	10.1	73	----	242
	B	21A	831205	1610	2.0	8.1	59	----	241	1.1	10.2	73	----	245
	B	21B	831205	1610	2.0	8.2	60	----	246	1.1	9.6	69	----	243
	B	21C	831205	1610	2.0	8.3	61	----	241	1.4	9.3	67	----	242
	B	21D	831205	1610	2.1	9.0	66	----	242	1.2	10.0	72	----	240
	B	21E	831205	1610	1.8	8.6	62	----	241	1.0	10.0	71	----	246
	B	21F	831205	1610	1.9	9.2	67	----	242	1.1	9.7	69	----	245

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 11	C	DVA	831101	1225	2.3	8.4	63	----	230	1.4	12.4	91	7.3	230
(continued)	C	DVB	831101	1225	2.4	8.5	64	7.2	232	1.4	12.5	92	7.3	228
	C	DVC	831101	1225	2.6	5.3	40	----	259	1.4	12.5	92	7.3	226
	C	DVA	831109	----	3.0	8.6	66	7.6	225	2.0	11.5	85	7.6	223
	C	DVB	831109	----	2.5	8.6	65	7.5	228	2.0	11.5	85	7.6	223
	C	DVC	831109	----	3.5	6.4	50	7.5	221	2.0	11.5	85	7.6	223
	C	DVA	831205	1400	2.0	7.7	56	----	241	1.0	10.8	77	7.6	237
	C	DVB	831205	1400	2.0	7.6	55	7.4	241	1.0	11.0	78	7.6	235
	C	DVC	831205	1400	2.2	6.4	47	----	234	1.1	10.9	78	7.6	239
MAINSTEM	A	DVA	831109	----	1.0	7.9	57	8.3	185	0.5	12.6	90	8.4	226
(136.1)	A	DVB	831109	----	0.5	11.2	80	8.2	226	0.5	12.6	90	8.4	226
	A	DVC	831109	----	0.5	12.0	85	8.1	197	0.5	12.6	90	8.4	226
	A	DVA	831208	1400	0.3	12.8	90	----	208	0.0	13.5	94	8.1	272
SIDE CHANNEL 11	A	DVA	831109	----	2.0	5.5	41	7.5	116	----	----	---	----	---
(136.1)	A	DVB	831109	----	2.0	5.6	42	7.5	116	----	----	---	----	---
	A	DVC	831109	----	2.0	5.5	41	7.6	125	1.0	11.0	80	7.8	129
	A	DVA	831208	1315	2.3	5.7	43	----	143	0.1	7.5	53	7.3	170
	A	DVB	831208	1315	2.0	5.5	41	7.2	143	0.1	7.6	53	7.3	185
	A	DVC	831208	1315	3.0	5.6	43	----	142	0.2	9.6	68	7.3	202
MAINSTEM	A	M1A	831108	1555	3.0	7.1	54	7.1	233	3.0	7.0	53	7.0	173
(136.8)	A	M1B	831108	1555	4.0	7.4	58	7.2	251	3.0	7.6	57	7.0	190
	A	M1C	831108	1555	4.0	7.5	59	7.1	251	3.0	8.4	64	7.0	173
	A	M1C	831214	1415	----	----	---	----	---	0.9	10.8	76	7.3	221
INDIAN RIVER	A	001	831108	1515	4.0	9.9	77	6.6	50	4.5	9.9	78	6.8	49
(138.6)	A	002	831108	1515	1.0	13.0	93	6.9	55	0.5	13.2	93	6.8	56
	A	003	831108	1515	1.0	12.2	88	7.0	55	0.5	12.4	88	6.8	56
	A	001	831213	1305	0.3	13.8	96	7.0	57	0.2	13.8	95	7.1	53
	A	002	831213	1305	0.0	14.2	97	7.0	48	----	----	---	----	---
	A	003	831213	1305	0.2	14.0	97	----	57	----	----	---	----	---
MAINSTEM	A	001	831108	----	3.0	8.9	68	6.5	119	----	----	---	----	---
(138.7)	A	002	831108	----	1.0	9.3	67	6.9	129	----	----	---	----	---
	A	003	831108	----	2.0	8.5	63	6.9	116	----	----	---	----	---
	A	002	831213	1340	2.8	10.8	81	6.6	64	----	----	---	----	---

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 17 (138.9)	A	001	831108	----	2.0	2.3	17	6.8	375	2.5	11.7	87	6.8	246
	A	002	831108	----	1.0	8.9	64	6.8	166	----	----	---	----	---
	A	003	831108	----	2.0	9.0	66	6.7	170	3.0	11.5	87	6.8	155
	A	001	831213	1350	1.3	1.6	12	7.2	210	1.5	11.8	85	6.8	78
	A	003	831213	1350	1.9	3.4	25	6.9	81	1.5	11.2	81	6.8	78
SIDE CHANNEL 21 (141.0)	A	001	830914	1525	5.8	6.5	63	----	158	7.0	11.6	98	----	152
	A	004	830914	1525	6.5	9.7	81	----	155	6.8	9.4	79	----	146
	A	005	830914	1525	6.0	12.3	101	----	144	6.0	12.4	101	----	149
	A	006	830914	1525	7.2	12.6	106	----	132	7.5	12.7	108	----	131
	A	007	830914	1525	7.0	9.8	83	----	76	----	----	---	----	---
	A	008	830914	1525	6.0	12.1	100	----	144	6.0	12.3	100	----	149
	A	009	830914	1525	7.0	12.0	100	----	122	----	----	---	----	---
	A	010	830914	1525	6.5	6.9	58	----	170	7.2	11.0	93	----	139
	A	011	830914	1525	6.8	6.5	55	----	184	7.0	6.2	52	----	191
	A	012	830914	1525	6.0	10.1	83	----	96	----	----	---	----	---
	A	013	830914	1525	6.0	10.1	83	----	71	6.0	13.0	106	----	127
	A	014	830914	1525	7.0	8.8	74	----	133	----	----	---	----	---
	A	015	830914	1525	5.8	11.6	95	----	100	5.8	13.0	106	----	128
	A	081	830914	1525	6.5	10.0	84	6.6	77	6.8	10.5	88	----	77
	A	082	830914	1525	6.0	8.0	60	----	113	----	----	---	----	---
	A	083	830914	1525	5.0	10.3	83	----	121	----	----	---	----	---
	A	084	830914	1525	5.2	7.6	61	----	113	----	----	---	----	---
	A	085	830914	1525	6.0	10.3	85	----	86	----	----	---	----	---
	A	001	831027	1345	2.8	8.3	106	----	139	0.8	14.4	101	7.7	145
	A	005	831027	1345	0.2	14.3	99	----	124	0.9	14.8	104	7.7	121
	A	013	831027	1345	2.2	11.2	82	----	71	1.4	12.0	86	7.7	73
	A	015	831027	1345	0.4	----	---	----	94	1.5	14.6	104	7.7	91
	B	00A	830914	1525	5.2	7.5	61	6.7	129	6.5	12.1	101	----	155
	B	00B	830914	1525	6.0	11.2	92	----	149	6.0	12.4	102	----	149
	B	00C	830914	1525	5.8	10.7	88	----	118	5.8	12.4	101	----	142
	B	00D	830914	1525	6.0	10.7	88	----	144	6.0	12.2	100	----	152
	B	00E	830914	1525	6.5	10.9	91	----	155	6.5	12.4	103	----	155
	B	00F	830914	1525	6.0	11.2	92	----	149	6.0	12.1	100	----	157
	B	00G	830914	1525	6.5	9.7	81	----	113	6.5	12.0	100	----	155
	B	00H	830914	1525	6.5	10.6	88	7.5	139	6.5	12.0	100	----	139
	B	08A	830914	1525	7.0	10.0	84	----	76	7.0	10.8	91	----	76
	B	08B	830914	1525	7.0	8.8	74	----	79	7.0	12.2	102	----	76
	B	00A	831027	1345	3.2	10.4	79	6.9	89	0.5	14.9	104	7.7	147
	B	00C	831027	1345	1.2	13.6	97	----	114	1.8	14.8	107	7.7	126
	B	00D	831027	1345	1.4	14.3	102	----	118	1.5	14.8	106	7.7	136

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SIDE CHANNEL 21 (continued)	B	00E	831027	1345	0.5	14.6	102	----	150	0.8	15.0	106	7.7	149
	B	00F	831027	1345	1.3	14.5	104	----	133	1.8	14.8	107	7.7	144
	B	00G	831027	1345	0.5	14.4	100	----	132	0.8	15.0	106	7.7	149
	B	00H	831027	1345	0.9	14.3	100	7.1	148	1.0	14.8	104	7.7	148
	B	0SA	831027	1345	1.0	12.1	86	6.6	70	1.2	12.5	90	7.7	55
	B	0SB	831027	1345	0.2	14.7	101	----	80	0.2	14.5	100	7.7	57
	B	00F	831203	1305	0.0	13.2	92	----	130	0.0	13.2	92	7.6	169
	C	D1A	830914	1525	6.0	8.4	69	----	78	6.0	12.4	101	----	141
	C	D2A	830914	1525	6.0	8.3	69	----	78	6.0	12.4	101	----	141
	C	D2B	830914	1525	6.0	8.0	66	----	82	6.0	12.1	100	----	141
	C	DV1	831027	1345	1.5	12.2	88	----	54	1.2	14.1	100	7.7	92
	C	DV2	831027	1345	2.6	12.6	94	----	87	0.8	14.6	102	7.7	121
	C	DV3	831027	1345	2.2	12.6	93	----	89	0.9	14.8	104	7.7	130
	C	DV1	831108	----	2.5	----	---	----	---	0.5	----	---	----	---
	C	DV2	831108	----	2.0	----	---	----	---	0.5	----	---	----	---
	C	DV3	831108	----	1.5	----	---	----	---	0.5	----	---	----	---
	C	DV2	831203	1305	0.2	12.2	85	----	158	0.0	13.2	92	7.6	149
	C	DV3	831203	1305	0.0	12.2	85	----	157	0.1	13.2	92	7.6	149
SLOUGH 21 (141.8)	A	001	830913	1500	5.0	8.8	70	----	100	7.0	10.6	90	----	184
	A	002	830913	1500	4.7	8.7	69	----	113	7.0	10.7	90	----	178
	A	003	830913	1500	5.2	8.0	64	----	111	6.7	11.0	92	----	180
	A	004	830913	1500	5.2	8.9	72	----	122	6.8	10.6	89	----	184
	A	005	830913	1500	7.0	9.4	79	----	146	7.6	10.3	88	----	180
	A	006	830913	1500	5.2	9.1	73	----	101	6.7	10.8	90	----	175
	A	007	830913	1500	6.8	8.7	73	----	141	7.0	10.3	87	----	183
	A	008	830913	1500	5.5	8.9	72	----	153	7.2	10.3	87	----	182
	A	009	830913	1500	5.0	9.1	73	----	146	7.0	10.0	84	----	180
	A	00A	830913	1500	5.2	8.3	67	----	121	6.8	10.8	90	----	175
	A	00B	830913	1500	4.5	8.3	65	----	122	6.5	11.0	92	----	181
	A	00C	830913	1500	4.8	8.5	68	----	127	6.5	11.1	92	----	178
	A	00D	830913	1500	5.8	6.4	52	----	175	6.8	8.5	71	----	183
	A	00E	830913	1500	5.0	6.6	53	----	181	7.5	8.3	71	----	183
	A	00F	830913	1500	5.5	6.0	49	----	177	7.5	6.3	54	----	179
	A	010	830913	1500	5.0	6.3	50	----	152	6.8	10.0	84	----	183
	A	011	830913	1500	6.0	8.6	71	----	160	6.5	11.0	92	----	181
	A	012	830913	1500	5.8	8.9	73	----	125	6.8	11.0	92	----	164
	A	013	830913	1500	5.0	9.3	74	----	167	6.5	10.0	83	----	181
	A	014	830913	1500	6.0	8.8	73	----	162	6.5	8.7	73	----	181
	A	015	830913	1500	5.0	7.8	63	----	155	6.5	10.0	80	----	186

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 21	A	016	830913	1500	5.0	9.0	72	----	163	6.2	11.0	91	----	189
(continued)	A	001	831026	1230	2.5	9.7	73	7.1	105	2.3	11.1	83	7.2	186
	A	002	831026	1230	2.6	9.9	74	----	105	2.4	11.1	84	7.2	185
	A	003	831026	1230	2.5	9.8	74	----	105	2.4	11.1	84	7.2	181
	A	004	831026	1230	2.6	9.9	74	----	114	2.4	11.1	84	7.2	190
	A	005	831026	1230	2.2	8.4	62	----	142	2.2	10.8	80	7.2	181
	A	006	831026	1230	2.5	9.7	73	----	105	2.5	11.2	84	7.2	179
	A	007	831026	1230	2.0	6.8	50	----	182	2.4	10.8	80	7.2	190
	A	008	831026	1230	2.2	8.7	64	----	174	2.4	10.9	81	7.2	185
	A	009	831026	1230	2.4	6.7	50	----	185	2.0	10.3	76	7.2	182
	A	00A	831026	1230	2.9	9.1	69	----	130	2.4	11.3	85	7.2	180
	A	00B	831026	1230	2.3	9.3	70	----	133	2.4	11.6	87	7.2	185
	A	00C	831026	1230	2.5	9.6	72	7.0	132	2.4	11.9	89	7.2	185
	A	00D	831026	1230	3.1	7.4	56	6.9	188	2.4	10.2	77	7.2	185
	A	00E	831026	1230	3.2	7.4	56	----	187	2.4	10.1	76	7.2	194
	A	010	831026	1230	2.4	4.8	36	----	173	2.5	10.9	82	7.2	175
	A	011	831026	1230	2.3	7.9	59	----	182	2.4	11.6	87	7.2	185
	A	012	831026	1230	2.0	10.7	79	----	139	2.3	11.6	86	7.2	173
	A	013	831026	1230	2.1	9.6	71	----	151	2.5	10.4	78	7.2	184
	A	014	831026	1230	2.4	9.1	68	----	158	2.4	10.1	76	7.2	192
	A	015	831026	1230	2.8	8.5	64	----	157	2.4	10.6	79	7.2	194
	A	016	831026	1230	3.1	8.6	66	----	146	2.3	11.1	83	7.2	194
	A	00C	831108	1230	3.0	9.8	74	----	---	2.5	13.0	96	7.6	---
	A	014	831108	1230	3.0	10.0	75	7.5	164	2.5	12.7	94	7.6	193
	A	015	831108	1230	3.0	10.3	77	7.4	159	2.5	13.0	96	7.6	193
	A	016	831108	1230	3.0	10.4	78	7.5	155	3.0	13.0	98	7.6	188
	A	001	831202	1200	1.6	9.0	65	----	114	1.0	10.8	77	7.3	185
	A	002	831202	1200	2.4	9.2	68	----	118	1.2	11.1	79	7.3	187
	A	003	831202	1200	2.2	8.8	64	----	117	1.2	11.1	79	7.3	189
	A	004	831202	1200	2.3	8.6	63	----	140	1.2	11.0	79	7.3	196
	A	005	831202	1200	0.9	8.2	58	7.4	148	0.8	10.4	74	7.3	190
	A	006	831202	1200	2.6	8.8	65	----	124	1.2	10.9	78	7.3	187
	A	007	831202	1200	2.4	7.7	57	----	157	0.9	10.5	75	7.3	200
	A	008	831202	1200	1.7	7.6	55	----	166	0.8	10.0	71	7.3	192
	A	009	831202	1200	2.4	8.4	62	----	148	----	----	---	----	---
	A	00A	831202	1200	2.4	8.8	65	----	137	1.2	11.0	79	7.3	187
	A	00B	831202	1200	2.4	8.9	66	----	137	1.2	11.0	79	7.3	189
	A	00C	831202	1200	2.6	8.7	64	----	140	1.2	11.1	79	7.3	189
	A	00D	831202	1200	2.6	5.9	44	----	196	2.3	9.4	69	7.3	194
	A	00E	831202	1200	2.4	6.9	51	----	195	1.2	10.0	72	7.3	202

Appendix Table C-2. (Continued).

Site (River mile)	Sub Site	Standpipe No.	Sampling Date (y/m/d)	Sampling Time	Intragravel Water Temp. (°C)	Intragravel Water DO (mg/l)	Intragravel Water DO %Sat.	Intragravel Water pH	Intragravel Water Conductivity (umhos/cm)	Surface Water Temp. (°C)	Surface Water DO (mg/l)	Surface Water DO %Sat.	Surface Water pH	Surface Water Conductivity (umhos/cm)
SLOUGH 21	A	00F	831202	1200	2.6	5.7	42	----	191	1.4	8.0	57	7.3	209
(continued)	A	010	831202	1200	1.4	1.4	10	----	237	1.2	10.6	76	7.3	198
	A	011	831202	1200	2.2	8.7	64	7.4	158	1.2	10.9	78	7.3	185
	A	012	831202	1200	2.4	8.8	65	----	129	1.2	11.0	79	7.3	183
	A	013	831202	1200	1.9	8.1	59	----	167	1.2	10.5	75	7.3	196
	A	014	831202	1200	2.5	8.1	60	7.3	165	1.3	9.8	70	7.3	199
	A	015	831202	1200	2.4	8.2	60	----	165	1.2	10.5	75	7.3	202

DISSOLVED OXYGEN (SLOUGH)
INTRAGRAVEL VS SURFACE

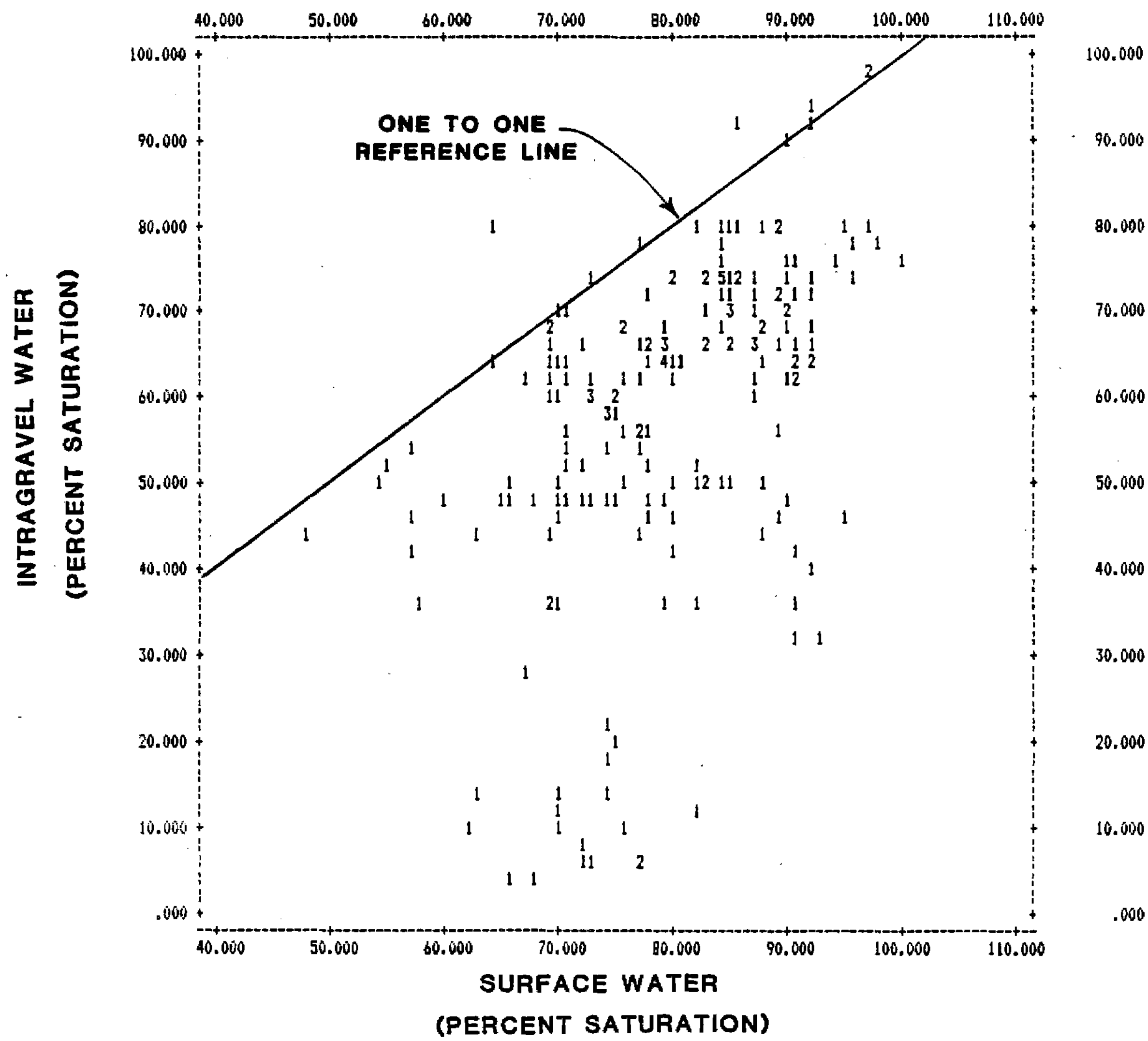

Figure C-1. Relationship between percent saturation of intragravel and surface water dissolved oxygen measured within slouth habitat of the middle Susitna River, Alaska.

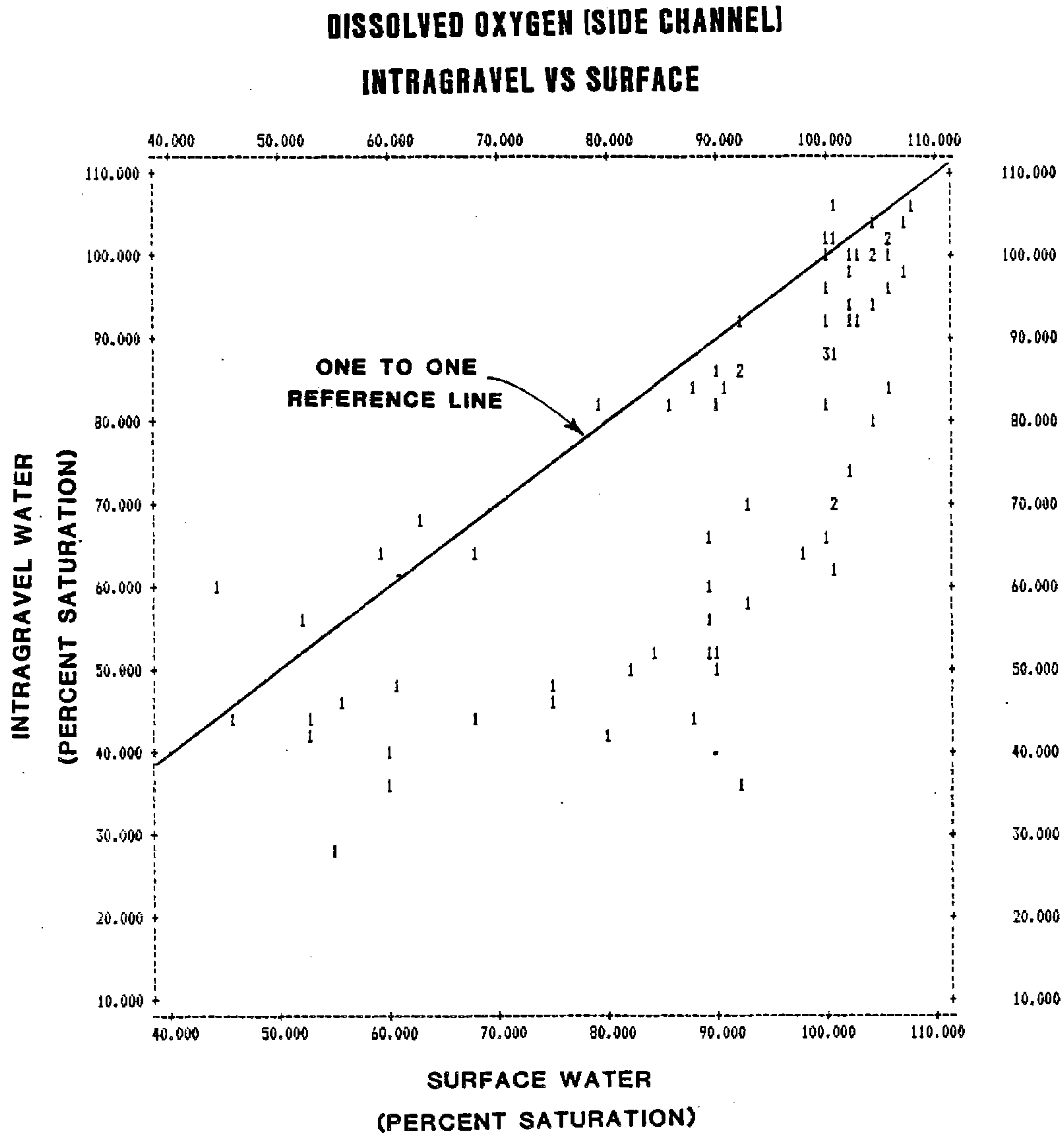

Figure C-2. Relationship between percent saturation of intragravel and surface water dissolved oxygen measured within side channel habitat of the middle Susitna River, Alaska.

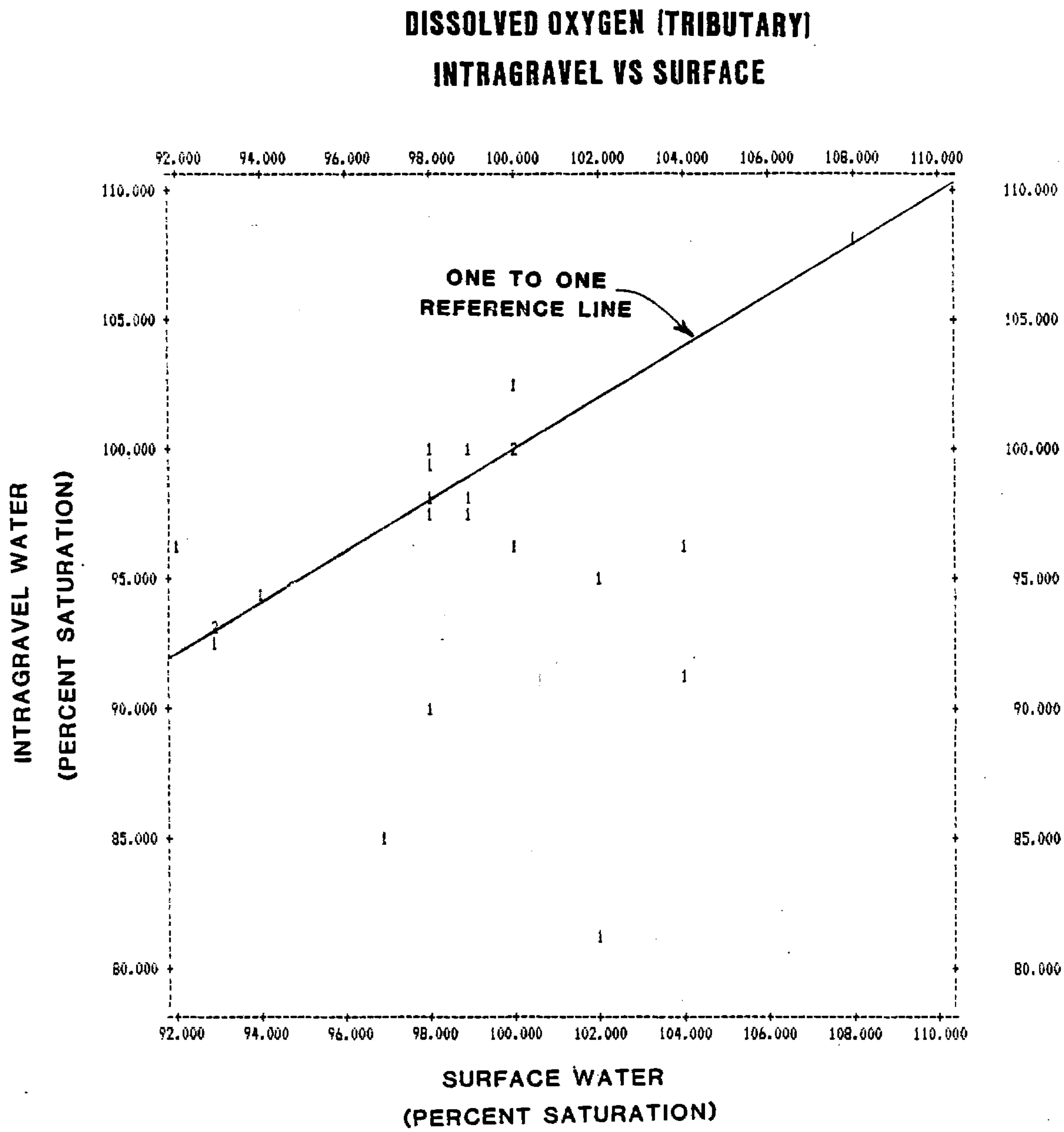

Figure C-3. Relationship between percent saturation of intragravel and surface water dissolved oxygen measured within tributary habitat of the middle Susitna River, Alaska.

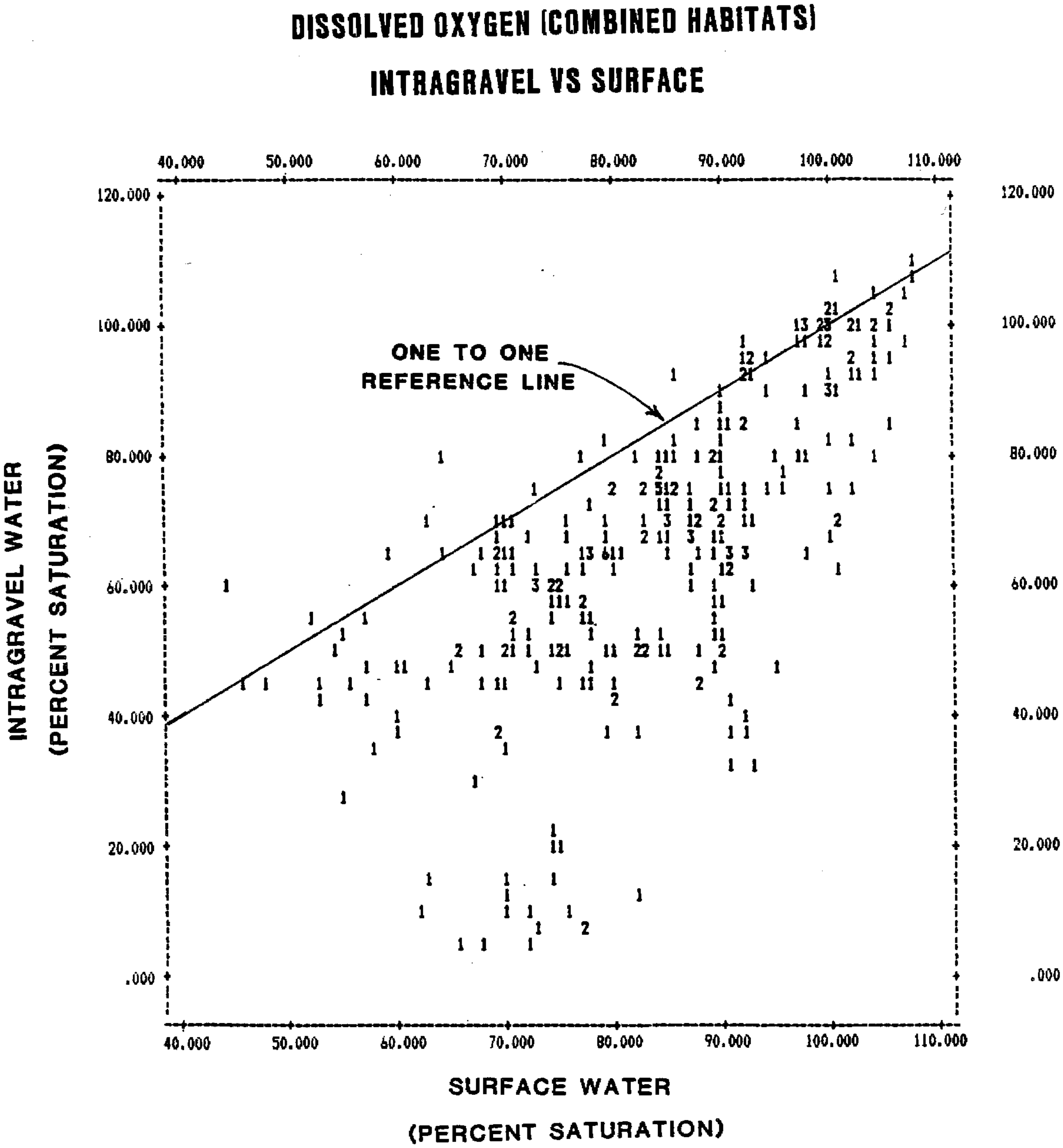

Figure C-4. Relationship between percent saturation of intragravel and surface water dissolved oxygen measured within slough, side channel, and tributary habitats of the middle Susitna River.

APPENDIX D

SUBSTRATE DATA

APPENDIX D

SUBSTRATE DATA

Appendix D presents information on the size composition of substrate in various middle Susitna River habitats. Substrate data presented in Appendix Table D-1 were collected with a modified McNeil Sampler. Substrate data presented in Appendix Table D-2 were collected with Whitlock-Vibert Boxes. Figures D-1 to D-7 present comparisons of the two sampling devices for individual substrate size classes.

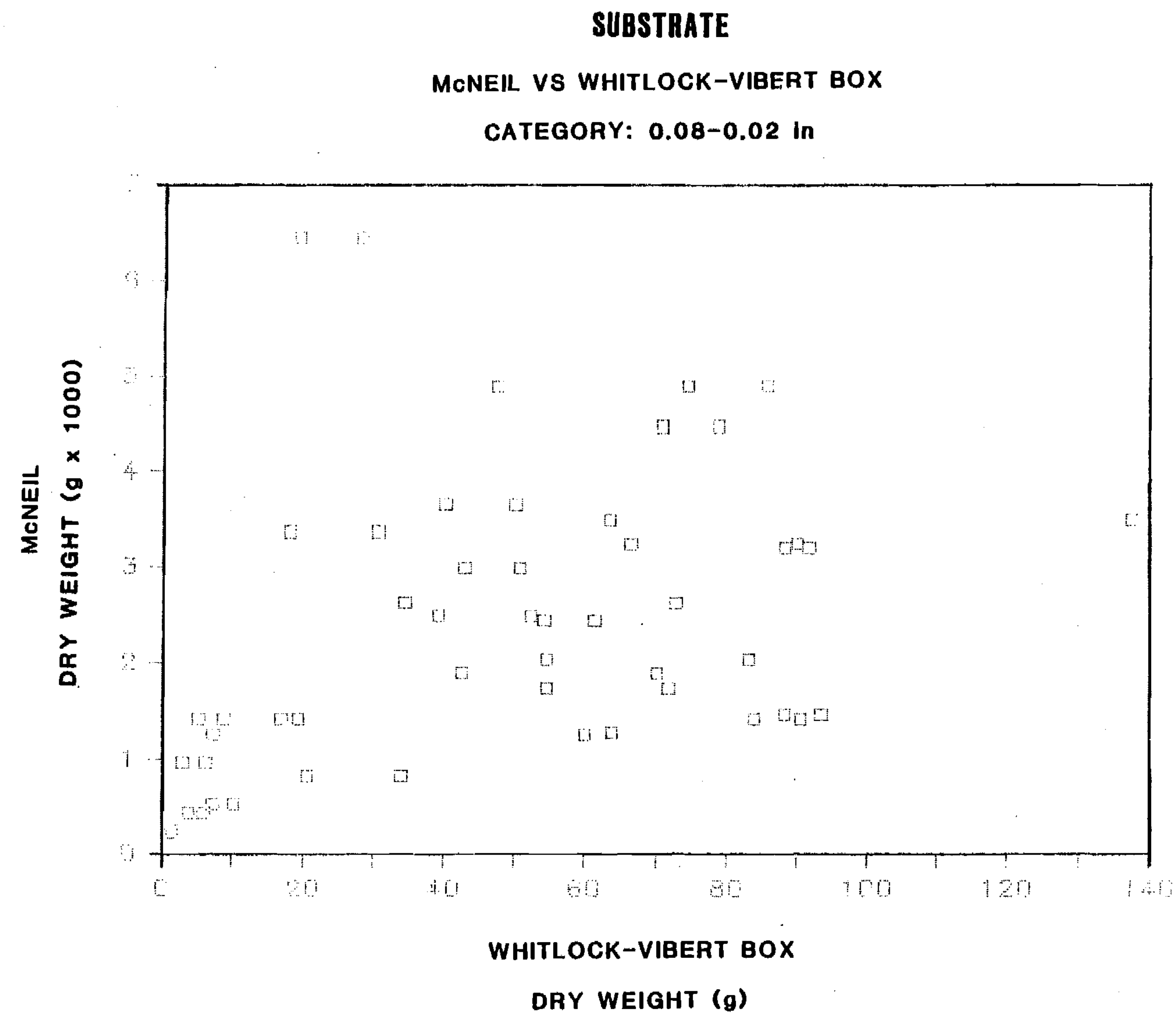

Figure D-1. Comparison of dry weights (g) of fine substrate (0.08-0.02 in. diameter) obtained from paired samples collected with McNeil and Whitlock-Vibert Box samplers.

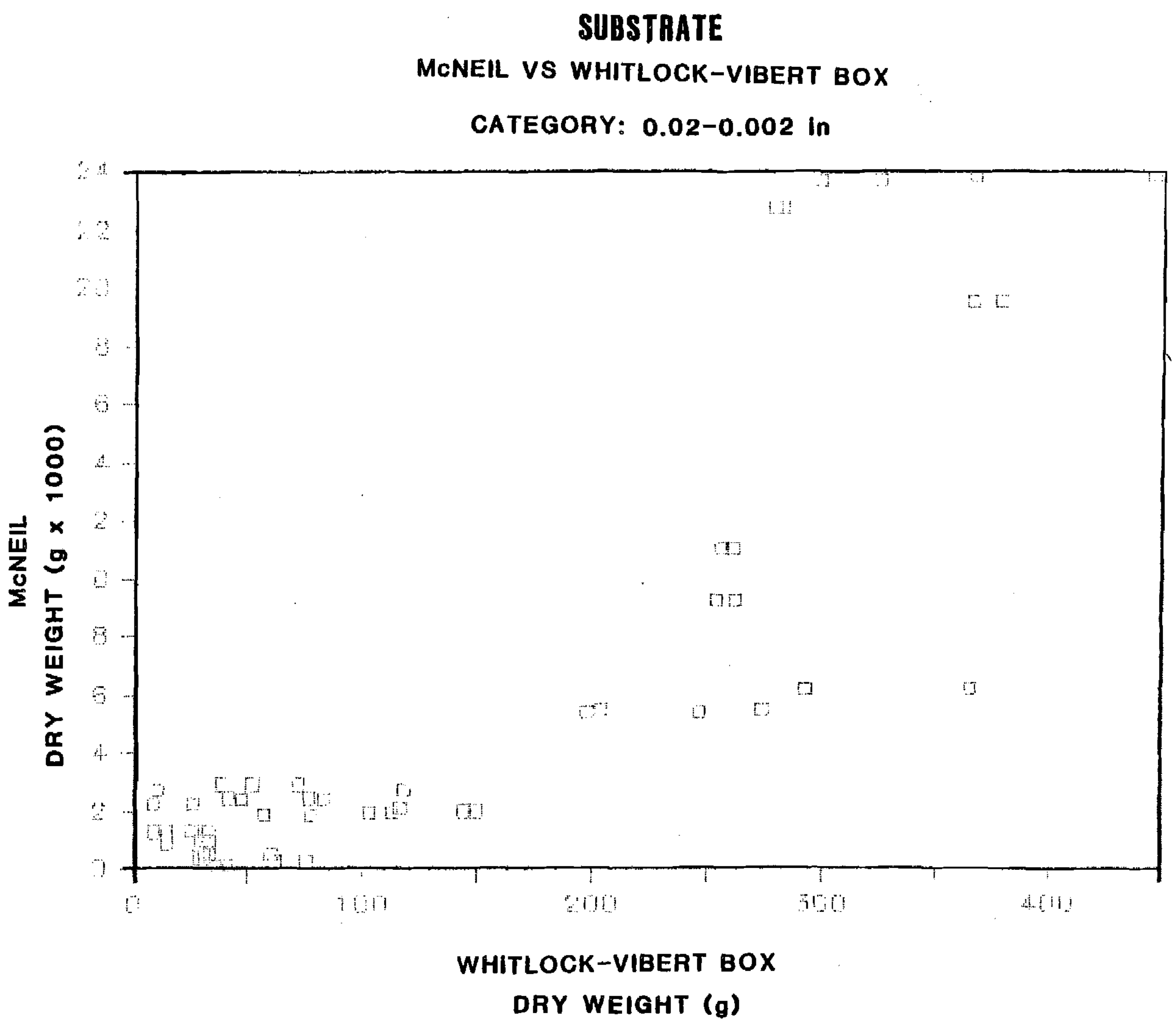

Figure D-2. Comparison of dry weights (g) of fine substrate (0.02-0.002 in. diameter) obtained from paired samples collected with McNeil and Whitlock-Vibert Box samplers.

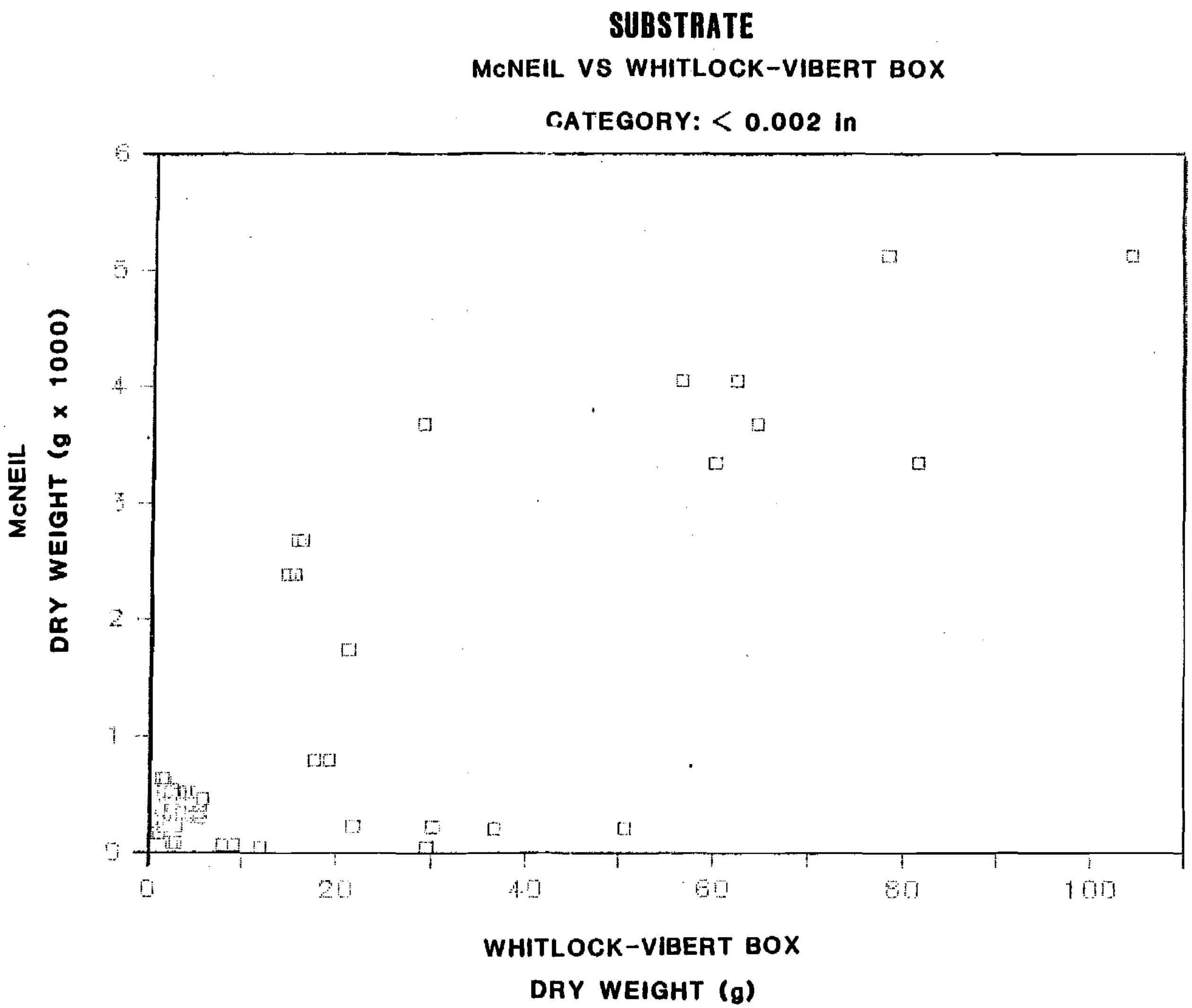

Figure D-3. Comparison of dry weights (g) of fine substrate (< 0.02 in. diameter) obtained from paired samples collected with McNeil and Whitlock-Vibert Box samplers.

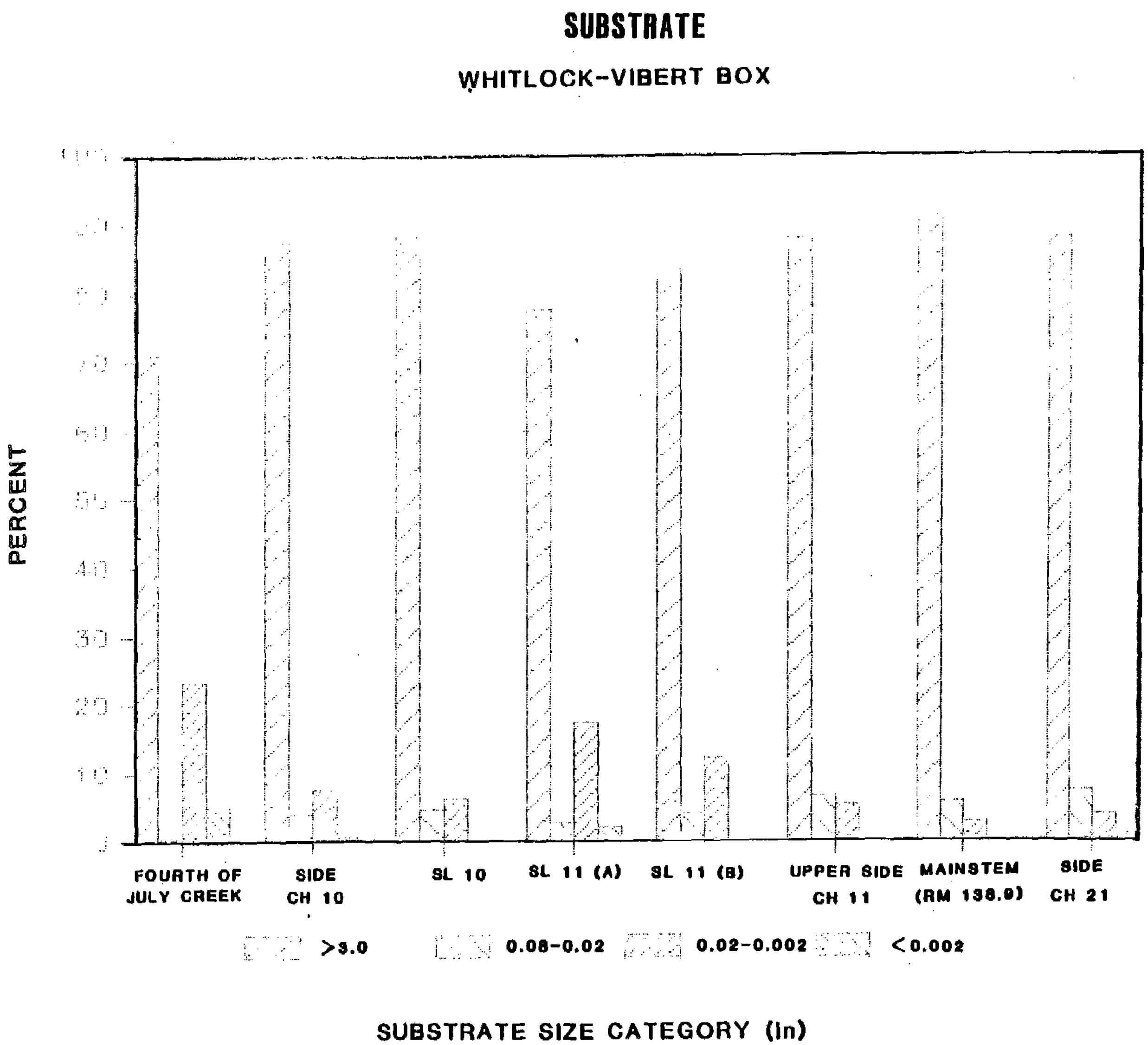

Figure D-4. Percent composition, by size class, of Whitlock-Vibert Box samples collected at study sites in the middle Susitna River, Alaska.

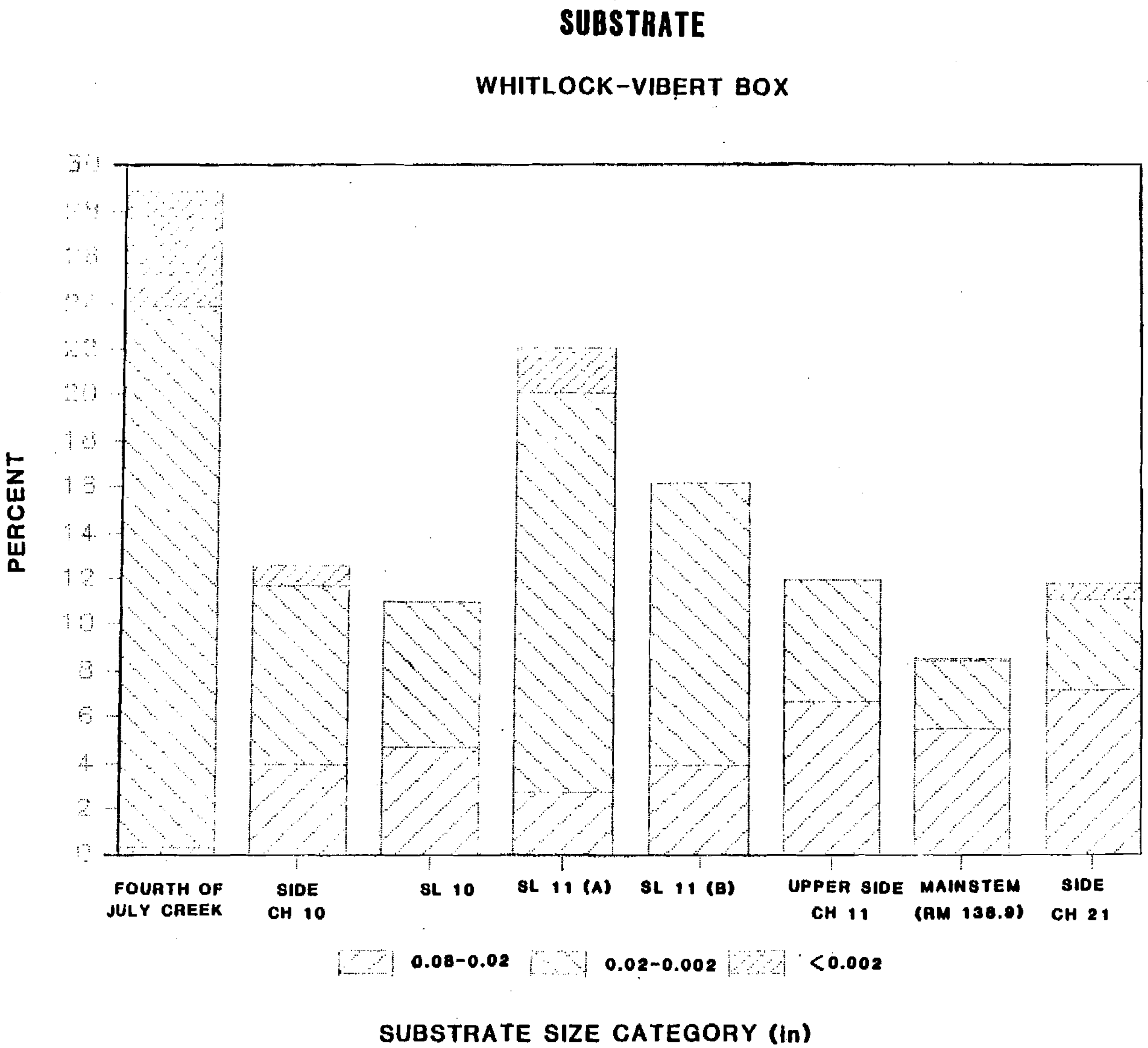

Figure D-5. Percent substrate composition, by size class, of fine substrate (<0.08 in. diameter) in Whitlock-Vibert Box samples collected at study sites in the middle Susitna River, Alaska.

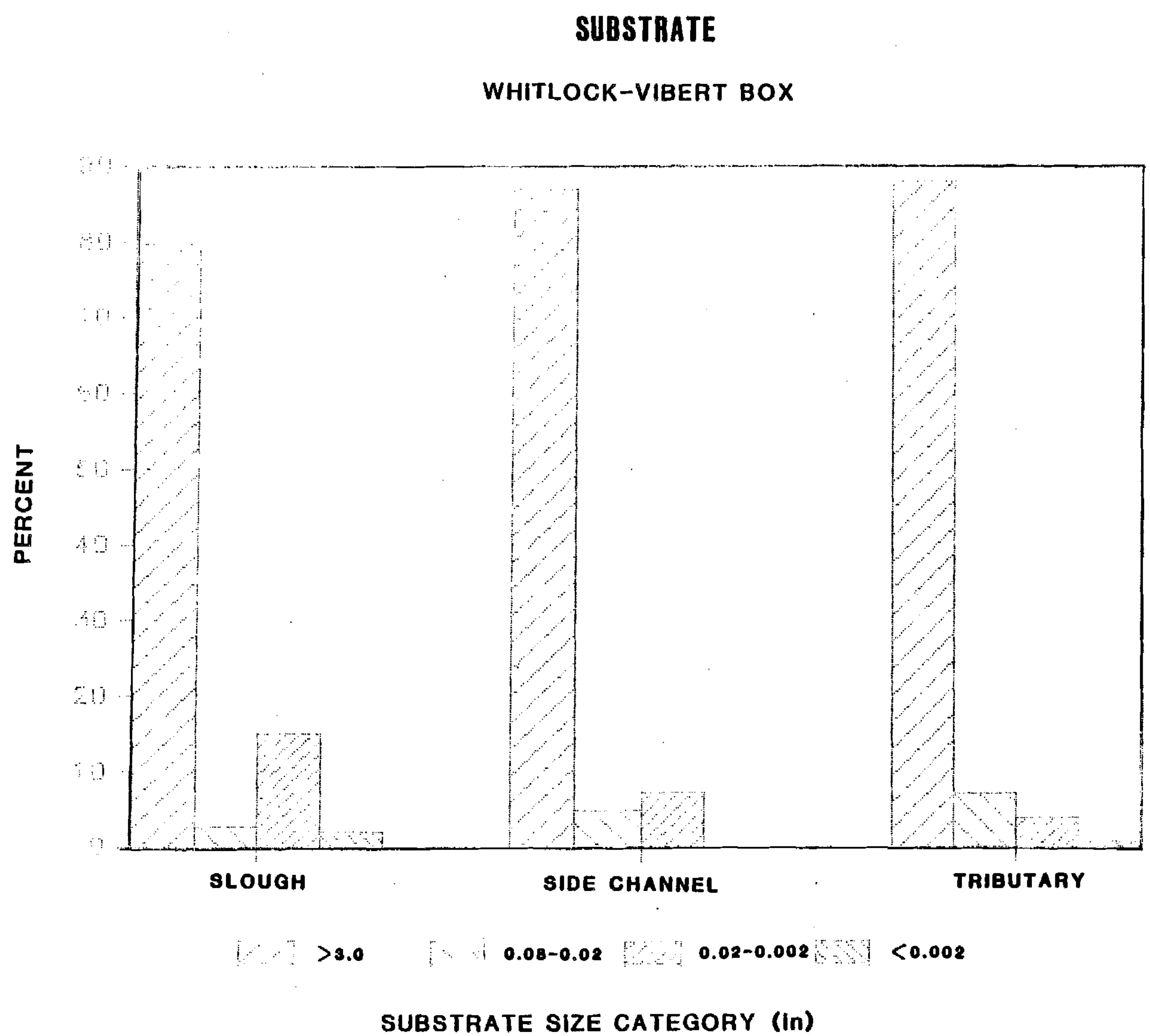

Figure D-6. Percent composition, by size class, of Whitlock-Vibert Box samples collected in various habitat types in the middle Susitna River, Alaska.

SUBSTRATE

WHITLOCK-VIBERT BOX

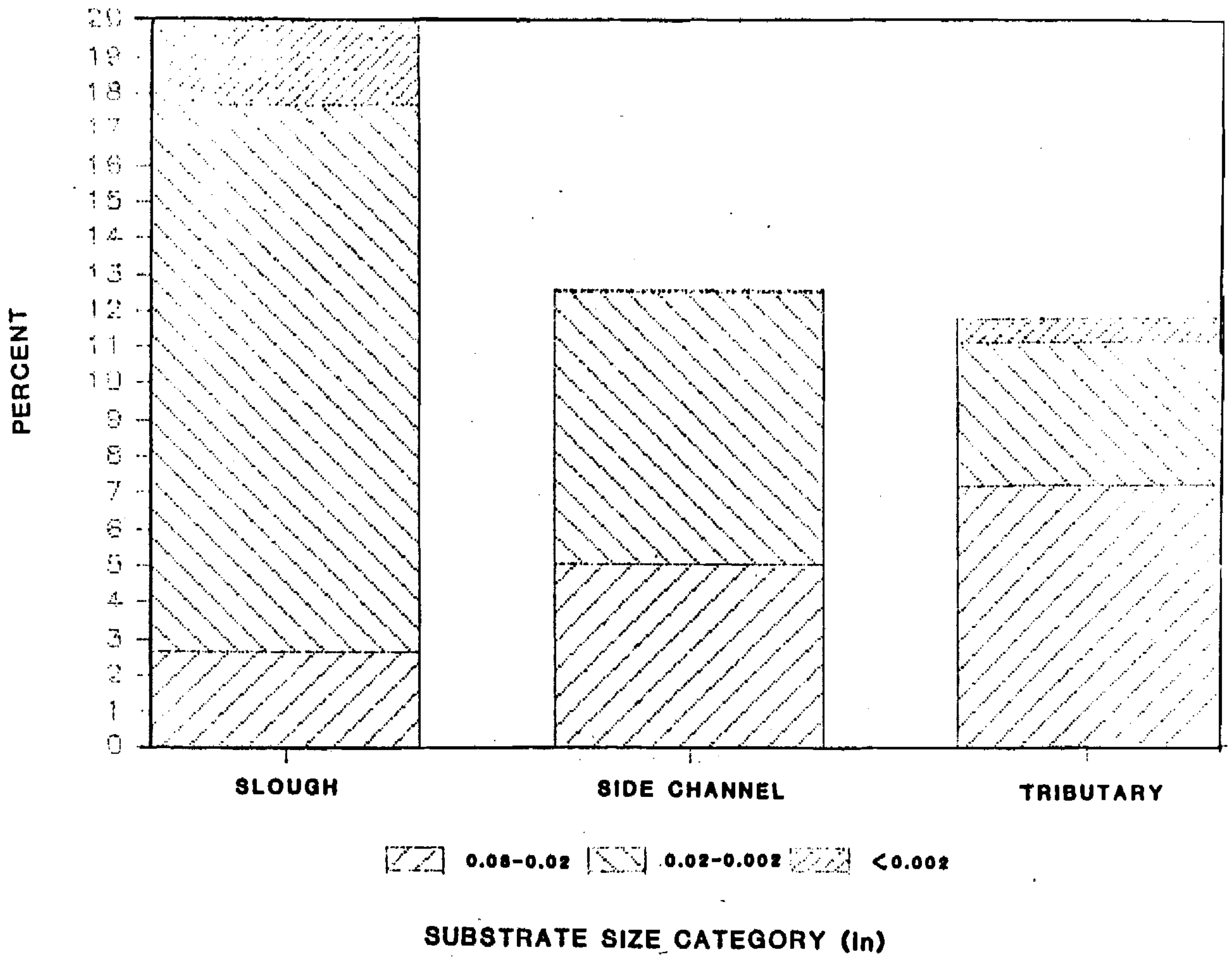

Figure D-7. Percent substrate composition, by size class, of fine substrate (< 0.08 in. diameter) in Whitlock-Vibert Box samples collected in various habitat types in the middle Susitna River, Alaska.

Appendix Table D-1. Substrate composition of samples collected with a modified McNeil substrate sampler in spring 1984, Susitna River, Alaska.

Site (River mile)	Sub-Site	Standpipe No.	Sampling Date y/m/d	Total(Tot.) Dry Wt. (g)	>12.7 Dry Wt. (g)	>12.7 % Tot.	12.7 - 7.6 Dry Wt. (g)	12.7 - 7.6 % Tot.	7.6 - 2.5 Dry Wt. (g)	7.6 - 2.5 % Tot.	2.5 - 0.2 Dry Wt. (g)	2.5 - 0.2 % Tot.	0.2 -0.05 Dry Wt. (g)	0.2 -0.05 % Tot.	0.05 -0.006 Dry Wt. (g)	0.05 -0.006 % Tot.	< 0.006 Dry Wt. (g)	< 0.006 % Tot.
FOURTH OF JULY	A	001	840511	24157	00000	0.0	00000	0.0	04557	18.9	13569	56.2	04471	18.5	01322	5.5	00238	1.0
CREEK	A	004	840511	27783	00000	0.0	00000	0.0	09001	32.4	14680	52.8	03496	12.6	00555	2.0	00051	0.2
(131.1)	A	009	840511	33514	08968	26.8	00929	2.8	11998	35.8	09662	28.8	01472	4.4	00171	0.5	00314	0.9
	A	013	840511	24122	00000	0.0	06959	28.8	09718	40.3	05688	23.6	01421	5.9	00265	1.1	00071	0.3
SLOUGH 10	A	001	840411	29466	00000	0.0	00000	0.0	00085	0.3	00115	0.4	00428	1.5	23702	80.4	05136	17.4
(133.8)	A	003	840411	23849	00000	0.0	00000	0.0	00000	0.0	00000	0.0	00239	1.0	19556	82.0	04054	17.0
	A	019	840411	36137	05096	14.1	07199	19.9	06097	16.9	01907	5.3	01411	3.9	11073	30.6	03354	9.3
	A	020	840411	36973	14120	38.2	05743	15.5	04537	12.3	02191	5.9	00529	1.4	06167	16.7	03686	10.0
	A	0R1	840412	41507	00000	0.0	01607	3.9	14321	34.5	19650	47.3	01846	4.4	03281	7.9	00802	1.9
SIDE CHANNEL 10	A	002	840411	35458	00000	0.0	01026	2.9	09644	27.2	12582	35.5	06441	18.2	05521	15.6	00244	0.7
(133.8)	A	005	840411	35866	00000	0.0	01247	3.5	12536	35.0	09092	25.3	03202	8.9	09251	25.8	00538	1.5
	A	013	840502	38642	00000	0.0	03755	9.7	14121	36.5	14458	37.4	03667	9.5	02470	6.4	00171	0.4
	A	014	840502	37451	07123	19.0	07679	20.5	10161	27.1	08015	21.4	01266	3.4	02742	7.3	00465	1.2
SLOUGH 11	A	003	840405	33545	00000	0.0	04011	12.0	07811	23.3	17893	53.3	02438	7.3	01035	3.1	00357	1.1
(135.3)	A	004	840405	34712	00000	0.0	00000	0.0	10589	30.5	21341	61.5	01414	4.1	00862	2.5	00506	1.5
	A	016	840405	32963	00000	0.0	03112	9.4	10343	31.4	14384	43.6	01279	3.9	02110	6.4	01735	5.3
	A	020	840405	29600	00000	0.0	00000	0.0	04420	14.9	15950	53.9	03005	10.2	05426	18.3	00799	2.7
	B	10B	840412	31130	02488	8.0	07074	22.7	09528	30.6	10677	34.3	00830	2.7	00429	1.4	00104	0.3
	B	11B	840412	36740	08988	24.5	01044	2.8	12801	34.8	08360	22.8	03251	8.8	01956	5.3	00340	0.9
UPPER SIDE CHANNEL 11 (136.1)	A	DV1	840503	33678	00000	0.0	00000	0.0	10495	31.2	14819	44.0	04905	14.6	02936	8.7	00523	1.6
MAINSTEM	A	000	840503	40199	19098	47.5	01252	3.1	08702	21.6	07553	18.8	01638	4.1	01697	4.2	00259	0.6
(138.9)	A	000	840503	37636	07711	20.5	01879	5.0	12227	32.5	09969	26.5	03337	8.9	02294	6.1	00219	0.6
SIDE CHANNEL 21	A	082	840419	34883	06226	17.8	04708	13.5	07536	21.6	10505	30.1	02301	6.6	03069	8.8	00538	1.5
(141.0)	B	00A	840419	31896	00000	0.0	07836	24.6	10415	32.7	08786	27.5	01898	6.0	02436	7.6	00525	1.6
	B	00B	840419	37726	05872	15.6	05172	13.7	10425	27.6	10983	29.1	02629	7.0	02281	6.0	00364	1.0
	B	00D	840419	38317	00000	0.0	09605	25.1	11910	31.1	13120	34.2	01743	4.5	01288	3.4	00651	1.7
	C	DVB	840419	35275	00000	0.0	14730	41.8	05129	14.5	10121	28.7	02217	6.3	02815	8.0	00263	0.7
SLOUGH 21	A	001	840413	35208	01792	5.1	12004	34.1	07284	20.7	09532	27.1	02499	7.1	01866	5.3	00231	0.7
(141.8)	A	004	840413	38223	09162	24.0	01437	3.8	10859	28.4	12519	32.8	02031	5.3	02002	5.2	00213	0.6
	A	009	840413	27479	00000	0.0	00000	0.0	00000	0.0	00000	0.0	00967	3.5	23818	86.7	02694	9.8
	A	010	840413	28551	00000	0.0	00000	0.0	00000	0.0	00000	0.0	03375	11.8	22779	79.8	02397	8.4
	A	015	840413	39761	05803	14.6	05620	14.1	16455	41.4	06085	15.3	00793	2.0	02114	5.3	02891	7.3

Appendix Table D-2. Substrate composition inside Whitlock-Vibert Box placed in, and retrieved from artificial redds; August 1983 to May 1984, Susitna River, Alaska.

					Substrate size classes (cm)									
					Total	2.5 - 0.2		0.2 - 0.05		0.05 - 0.006		< 0.006		
Site (River mile)	Sub Site	Standpipe No.	Box No.	Sampling Date (y/m/d)	Dry wt. (g)	Dry wt. (g)	% Tot.	Dry wt. (g)	% Tot.	Dry wt. (g)	% Tot.	Dry wt. (g)	% Tot.	
FOURTH OF JULY	A	001	1	840510	1169.2	1071.1	92	70.9	6	25.7	2	1.5	0	
CREEK	A	001	2	840510	1175.1	1061.4	90	78.8	7	32.8	3	2.1	0	
(131.1)	A	004	1	840510	1282.6	1073.3	84	137.5	11	59.8	5	12.0	1	
	A	004	2	840510	1156.3	1030.0	89	63.5	5	33.3	3	29.5	3	
	A	008	1	840426	1024.4	917.8	90	66.2	6	37.2	4	3.2	0	
	A	009	1	840326	1120.2	991.0	88	88.2	8	36.7	3	4.3	0	
	A	009	2	840326	1280.3	1140.6	89	93.5	7	40.9	3	5.3	0	
	A	013	1	840420	1156.2	981.0	85	90.5	8	75.6	7	9.1	1	
	A	013	2	840420	1181.2	1027.4	87	83.9	7	61.9	5	8.0	1	
SIDE CHANNEL 10	A	002	1	840411	1207.2	982.6	81	19.4	2	203.9	17	1.3	0	
(133.8)	A	002	2	840411	1280.9	975.6	76	28.2	2	274.2	21	2.9	0	
	A	005	1	840411	1331.5	975.0	73	91.7	7	262.3	20	2.5	0	
	A	005	2	840411	1382.5	1037.6	75	88.2	6	254.3	18	2.4	0	
	A	013	1	840502	1095.3	1012.7	92	40.1	4	41.3	4	1.2	0	
	A	013	2	840502	1106.3	978.3	88	50.0	5	77.0	7	1.0	0	
	A	014	1	840502	1031.3	1013.2	98	7.2	1	10.4	1	0.5	0	
	A	014	2	840502	1190.9	1006.8	85	59.9	5	118.4	10	5.8	0	
SLOUGH 10	A	001	1	840411	1353.0	946.1	70	3.7	0	299.0	22	104.2	8	
(133.8)	A	001	2	840411	1352.3	943.0	70	5.9	0	325.4	24	78.0	6	
	A	003	1	840411	1384.9	947.9	68	1.5	0	379.2	27	56.3	4	
	A	003	2	840411	1392.0	962.1	69	1.3	0	366.5	26	62.1	4	
	A	019	1	840411	1319.3	973.6	74	8.7	1	255.7	19	81.3	6	
	A	019	2	840411	1300.4	974.1	75	5.1	0	261.4	20	59.8	5	
	A	020	1	840411	1286.8	954.9	74	10.1	1	293.0	23	28.8	2	
	A	020	2	840411	1377.8	940.8	68	7.2	1	365.5	27	64.3	5	
SLOUGH 11	A	003	1	840405	1055.9	960.5	91	61.3	6	29.5	3	4.6	0	
(135.3)	A	003	2	840405	1057.1	964.8	91	54.1	5	32.8	3	5.4	1	
	A	004	1	840405	1007.2	971.4	96	19.3	2	14.6	1	1.9	0	
	A	004	2	840405	1019.4	984.9	97	16.9	2	14.2	1	3.4	0	
	A	016	1	840405	1151.8	950.4	83	63.7	6	116.6	10	21.1	2	
	A	020	1	840405	1295.6	1035.6	80	42.9	3	197.9	15	19.2	1	
	A	020	2	840405	1168.0	853.2	73	50.8	4	246.4	21	17.6	2	

Appendix Table D-2. (Continued).

					Substrate size classes (cm)								
					Total	2.5 - 0.2		0.2 - 0.05		0.05 - 0.006		< 0.006	
Site (River mile)	Sub Site	Standpipe No.	Box No.	Sampling Date (y/m/d)	Dry wt. (g)	Dry wt. (g)	% Tot.	Dry wt. (g)	% Tot.	Dry wt. (g)	% Tot.	Dry wt. (g)	% Tot.
SLOUGH 11 (continued)	B	10B	1	840412	1017.4	950.0	93	34.0	3	30.8	3	2.6	0
	B	10B	2	840412	1042.2	990.1	95	20.6	2	28.6	3	2.9	0
	B	11B	1	840412	1119.7	913.0	82	90.0	8	113.2	10	3.5	0
	B	11B	2	840412	1094.0	920.4	84	66.4	6	103.2	9	4.0	0
UPPER SIDE CHANNEL 11 (136.1)	A	DV1	1	840118	1053.1	925.0	88	74.4	7	52.0	5	1.7	0
	A	DV1	2	831204	1094.5	933.0	85	85.7	8	71.9	7	3.9	0
	A	DV1	3	831230	996.7	906.6	91	47.5	5	38.1	4	4.5	0
SIDE CHANNEL 21 (141.0)	B	00A	1	840419	1009.3	917.7	91	42.6	4	47.1	5	1.9	0
	B	00A	2	840419	1130.5	975.5	86	70.1	6	83.3	7	1.6	0
	B	00B	1	840419	1041.1	939.7	90	72.8	7	26.2	3	2.4	0
	B	00B	2	840419	985.2	940.6	95	34.5	4	8.8	1	1.3	0
	B	00D	1	840419	1076.0	988.2	92	71.7	7	14.7	1	1.4	0
	B	00D	2	840419	1016.2	951.4	94	54.6	5	8.5	1	1.7	0
	B	00F	2	840329	1063.4	969.0	91	67.0	6	20.2	2	7.2	1
SLOUGH 21 (141.8)	A	001	1	840413	1125.7	987.0	88	39.2	3	77.8	7	21.7	2
	A	001	2	840413	1067.4	928.0	87	52.3	5	57.0	5	30.1	3
	A	004	1	840413	1295.7	1032.1	80	83.2	6	143.8	11	36.6	3
	A	004	2	840413	1212.7	957.5	79	54.6	5	150.1	12	50.5	4
	A	009	1	840413	1300.6	914.3	70	2.8	0	367.3	28	16.2	1
	A	009	2	840413	1401.0	933.5	67	6.2	0	445.6	32	15.7	1
	A	010	1	840413	1289.0	960.5	75	30.7	2	282.5	22	15.3	1
	A	010	2	840413	1258.7	947.0	75	18.0	1	279.0	22	14.7	1

APPENDIX E

ADDITIONAL HABITAT DATA

APPENDIX E

ADDITIONAL HABITAT DATA

This appendix presents data relating to the physical placement of standpipes, water depths and velocities at standpipe locations, and visual assessments of general substrate conditions at standpipe locations (Appendix Table E-1). Appendix Table E-2 provides a list of symbols used for substrate categories and corresponding size classes. These substrate data were collected according to procedures presented in Vincent-Lang et al. (1984). Appendix Table E-2 provides a description of the criteria used to rank the degree of embeddedness of substrate.

Appendix Table E-1. Physical data collected at primary and secondary study sites in the middle Susitna River, Alaska.

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 8A	A	831109	002				0.10	0.00		
(125.9)	A	831109	003				0.20	0.05		
	A	831214	003	Riffle	Head	Left	0.25	0.00		
SLOUGH 9	A	831109	001	Riffle	Head	Left	0.40	0.05		
(128.3)	A	831109	002	Riffle	Head	Left	0.90	0.20		
	A	831109	003	Riffle	Head	Left	0.10	0.00		
	A	831214	003	Riffle	Middle	Left	0.35	0.00		
FOURTH OF JULY	A	830828	001	Riffle	Middle	Left	2.10	0.15		
CREEK	A	830914	001	Riffle	Middle	Left	0.70	0.00		
(131.1)	A	840511	001	Pool	Middle	Left			SG LG	3
	A	830828	002	Pool	Middle	Left	1.80	0.15		
	A	830914	002	Pool	Middle	Left	0.40	0.10		
	A	840511	002	Pool	Middle	Left			SG LG	3
	A	830828	003	Pool	Middle	Left	1.40	1.20		
	A	830914	003	Pool	Middle	Left	0.00	0.00		
	A	840511	003	Pool	Middle	Left			LG SG	4
	A	830828	004	Pool	Middle	Left	1.20	1.70		
	A	830914	004	Pool	Middle	Left	0.00	0.00		
	A	840511	004	Riffle	Base	Right			LG RU	5
	A	830828	005	Riffle	Base	Right	1.50	0.85		
	A	830914	005	Riffle	Base	Right	0.10	0.00		
	A	840511	005	Pool	Middle	Left			LG SG	2
	A	830828	006	Pool	Middle	Left	1.60	0.50		
	A	830914	006	Pool	Middle	Left	0.60	2.00		
	A	840511	006	Riffle	Middle	Left			RU LG	5
	A	830828	007	Riffle	Middle	Left	1.90	0.20		
	A	830914	007	Riffle	Middle	Left	0.50	0.95		
	A	840511	007	Riffle	Middle	Left			LG RU	5
	A	830828	008	Riffle	Middle	Left	1.10	1.40		
	A	830914	008	Riffle	Middle	Left	0.80	3.10		
	A	831102	008	Riffle	Middle	Left	1.20	0.00		
	A	840511	008	Riffle	Middle	Right			RU LG	5
	A	830828	009	Riffle	Middle	Right	0.90	0.10		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
FOURTH OF JULY	A	830914	009	Riffle	Middle	Right	0.40	1.20		
CREEK	A	831102	009	Riffle	Middle	Right	0.90	0.05		
(continued)	A	840511	009	Riffle	Middle	Right			RU CO	5
	A	830828	010	Riffle	Middle	Right	0.40	2.50		
	A	830914	010	Riffle	Middle	Right	0.40	2.30		
	A	840511	010	Riffle	Middle	Right			RU CO	5
	A	830828	011	Riffle	Middle	Right	1.50	2.40		
	A	830914	011	Riffle	Middle	Right	1.40	2.20		
	A	840511	011	Riffle	Middle	Right			RU CO	5
	A	830828	012	Riffle	Middle	Right	0.80	1.50		
	A	830914	012	Riffle	Middle	Right	0.90	2.10		
	A	831102	012	Riffle	Middle	Left	0.70	2.70		
	A	831203	012	Riffle	Middle	Left	0.50	0.10		
	A	840511	012	Riffle	Middle	Left			CO RU	5
	A	830828	013	Riffle	Middle	Left	0.80	1.70		
	A	830914	013	Riffle	Middle	Left	1.00	1.30		
	A	840511	013	Riffle	Middle	Right			RU CO	5
	A	830828	014	Riffle	Middle	Right	1.10	0.80		
	A	830914	014	Riffle	Middle	Right	1.10	0.95		
	A	831102	014	Riffle	Middle	Right	0.90	1.40		
	A	831203	014	Riffle	Base	Right	0.50	0.60		
	A	840511	014	Riffle	Middle	Right			CO RU	5
	A	830828	015	Riffle	Middle	Right	1.40	1.60		
	A	830914	015	Riffle	Middle	Right	1.60	1.30		
	A	831203	015	Riffle	Base	Right	0.80	0.30		
	A	840511	015	Riffle	Middle	Right			CO RU	5
SLOUGH 9A	A	831109	001	Riffle	Middle	Right	0.60	0.50		
(133.6)	A	831214	001	Pool	Middle	Left	1.10	0.00		
	A	831109	002	Pool	Middle	Left	1.00	0.00		
	A	831214	002	Pool	Middle	Left	0.90	0.00		
	A	831109	003	Pool	Middle	Left	1.50	0.00		
	A	831214	003	Pool	Middle	Left	0.60	0.00		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SIDE CHANNEL 10	A	830910	001	Pool	Base	Left			SA	1
(133.8)	A	830910	002	Pool	Base	Left	0.30	0.00	SA	1
	A	830910	003	Pool	Middle	Left	0.10	0.00	SA LG	2
	A	830910	004	Pool	Middle	Right	0.70	0.00	SA	1
	A	830910	005	Pool	Middle	Right	0.80	0.00	SA LG	1
	A	831028	005	Pool	Middle	Right	0.40	0.00		
	A	830910	006	Pool	Middle	Right	0.80	0.00	LG SA	4
	A	831028	006	Pool	Middle	Right	0.60	0.00		
	A	830910	007	Pool	Middle	Right	0.55	0.00	SA	1
	A	831028	007	Pool	Middle	Right	0.30	0.00		
	A	830910	008	Pool	Middle	Right	0.50	0.00	LG SA	3
	A	831028	008	Pool	Middle	Right	0.20	0.00		
	A	830910	009	Pool	Head	Left	0.65	0.00	SA	1
	A	831028	009	Pool	Head	Left	0.20	0.00		
	A	830910	010	Pool	Head	Left	0.40	0.10	LG RU	4
	A	831028	010	Pool	Head	Left	0.10	0.00		
	A	830910	011	Riffle	Base	Right	0.10	0.00	LG SG	4
	A	830910	012	Riffle	Middle	Left	0.20	0.20	LG SG	4
	A	830910	013	Pool	Middle	Right	0.25	0.00	LG SG	4
	A	830910	014	Riffle	Base	Right	0.30	0.05	RU LG	4
	A	830910	015	Riffle	Head	Left	0.30	0.00	RU LG	3
	A	830910	016	Pool	Middle	Right	0.40	0.00	SA RU	2
	A	830910	017	Pool	Middle	Right	0.50	0.00	SA RU	2
	A	830910	018	Pool	Middle	Left	0.20	0.00	RU LG	3
	A	830910	019	Pool	Middle	Left	1.00	0.00	CO RU	4
SLOUGH 10	A	830910	001	Backwater	Middle	Right	0.60	0.00	SI	1
(133.8)	A	830915	001	Backwater	Middle	Right	0.30	0.00		
	A	830910	002	Backwater	Middle	Right			SI	1
	A	830915	002	Backwater	Middle	Right	0.00	0.00		
	A	830910	003	Backwater	Middle	Right	0.50	0.00	SI	1
	A	830915	003	Backwater	Middle	Right	0.20	0.00		
	A	830910	004	Backwater	Middle	Right	0.20	0.00	SI	1
	A	830915	004	Backwater	Middle	Right	0.00	0.00		
	A	830910	005	Backwater	Middle	Right	0.80	0.00	SI	1
	A	830915	005	Backwater	Middle	Right	0.50	0.00		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 10	A	831028	005	Backwater	Middle	Right	0.10	0.00		
(continued)	A	830910	006	Backwater	Middle	Left	1.10	0.00	SI	1
	A	830915	006	Backwater	Middle	Left	0.75	0.00		
	A	831028	006	Backwater	Middle	Left	0.40	0.10		
	A	830910	007	Backwater	Middle	Left	1.10	0.00	SI	1
	A	830915	007	Backwater	Middle	Left	0.60	0.10		
	A	831028	007	Backwater	Middle	Left	0.40	0.10		
	A	831110	007	Backwater	Middle	Left	0.20	0.00		
	A	830910	008	Backwater	Middle	Left	1.10	0.00	SI	1
	A	830915	008	Backwater	Middle	Left	0.70	0.10		
	A	831028	008	Backwater	Middle	Left	0.50	0.20		
	A	831110	008	Backwater	Middle	Left	0.20	0.15		
	A	830910	009	Backwater	Middle	Left	1.40	0.00	BO SI	3
	A	830915	009	Backwater	Middle	Left	1.00	0.30		
	A	831028	009	Backwater	Middle	Left	0.50	0.70		
	A	831206	009	Riffle	Middle	Right	0.50	0.00		
	A	830910	010	Backwater	Middle	Right	1.30	0.00	CO SI	3
	A	830915	010	Backwater	Middle	Right	1.00	0.15		
	A	831028	010	Backwater	Middle	Right	0.60	0.25		
	A	831206	010	Pool	Base	Right	0.40	0.20		
	A	830910	011	Backwater	Middle	Right	1.00	0.00	BO SI	3
	A	830915	011	Backwater	Middle	Right	0.90	0.10		
	A	831028	011	Backwater	Middle	Right	0.70	0.15		
	A	831206	011	Pool	Middle	Right	0.40	0.00		
	A	830910	012	Backwater	Head	Right	0.50	0.00	SI CO	3
	A	830915	012	Backwater	Head	Right	0.20	0.00		
	A	830910	013	Pool	Base	Right	1.65	0.00	SI RU	4
	A	830915	013	Pool	Base	Right	1.10	0.05		
	A	831028	013	Pool	Base	Right	1.10	0.00		
	A	831206	013	Pool	Middle	Right	1.00	0.00		
	A	830910	014	Pool	Head	Left	0.90	0.00	CO SI	4
	A	830915	014	Pool	Head	Left	0.80	0.01		
	A	831028	014	Pool	Head	Left	0.70	0.05		
	A	831206	014	Pool	Middle	Left	0.60	0.00		
	A	830910	015	Riffle	Base	Left	0.90	0.60	CO SI	4

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Substrate	Embeddedness rank
SLOUGH 10	A	830915	015	Riffle	Base	Left	1.00	0.20		
(continued)	A	831028	015	Riffle	Base	Left	0.90	0.05		
	A	831206	015	Riffle	Base	Left	0.60	0.30		
	A	830910	016	Backwater	Middle	Left	0.80	0.05	SI CO	1
	A	830915	016	Backwater	Middle	Left	0.35	0.10		
	A	831028	016	Backwater	Middle	Left	0.05	0.00		
	A	830910	017	Backwater	Middle	Left	0.60	0.15	SI	1
	A	830915	017	Backwater	Middle	Left	0.40	0.60		
	A	831028	017	Backwater	Middle	Left	0.30	0.55		
	A	831206	017	Riffle	Middle	Left	0.30	0.10		
	A	830910	018	Backwater	Head	Right	0.70	0.32	SI CO	3
	A	830915	018	Backwater	Head	Right	0.60	0.50		
	A	831028	018	Backwater	Head	Right	0.30	0.20		
	A	831110	018	Backwater	Head	Right	0.40	0.35		
	A	831206	018	Riffle	Middle	Right	0.30	0.00		
	A	830910	019	Riffle	Middle	Right	0.50	0.75	SI BO	3
	A	830915	019	Riffle	Middle	Right	0.70	0.40		
	A	831028	019	Riffle	Middle	Right	0.60	0.05		
	A	831110	019	Riffle	Middle	Right	0.50	0.40		
	A	831206	019	Riffle	Middle	Right	0.50	0.30		
	A	830910	020	Riffle	Middle	Left	0.55	0.45	SI BO	3
	A	830915	020	Riffle	Middle	Left	0.50	0.55		
	A	831028	020	Riffle	Middle	Left	0.40	0.45		
	A	831206	020	Riffle	Middle	Left	0.50	0.10		
	A	831206	OR1	Pool	Head	Right	0.80	0.00		
SLOUGH 11	A	830827	001	Pool	Head	Right	1.85	0.00		
(135.3)	A	830915	001	Pool	Head	Right	0.30	0.40		
	A	831024	001	Riffle	Head	Right			LG SG	5
	A	831101	001	Riffle	Head	Right	0.20	0.35		
	A	831207	001	Riffle	Head	Right	0.20	0.10		
	A	830827	002	Riffle	Head	Right	1.80	0.00		
	A	830915	002	Riffle	Head	Right				
	A	831024	002	Riffle	Head	Right			RU SG	5
	A	830827	003	Riffle	Head	Right	1.40	0.00		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 11	A	830915	003	Riffle	Head	Right				
(continued)	A	831024	003	Riffle	Head	Right			RU SG	5
	A	830827	004	Riffle	Head	Right	1.30	0.00		
	A	830915	004	Riffle	Head	Right				
	A	831024	004	Riffle	Head	Right			LG SG	4
	A	830827	005	Riffle	Head	Right	1.25	0.00		
	A	830915	005	Riffle	Head	Right				
	A	831024	005	Riffle	Head	Right			CO LG	3
	A	830827	006	Riffle	Head	Right	1.25	0.00		
	A	830915	006	Riffle	Head	Right				
	A	831024	006	Riffle	Head	Right			LG SG	3
	A	830827	007	Riffle	Head	Right	1.30	0.00		
	A	830915	007	Riffle	Head	Right				
	A	831024	007	Riffle	Middle	Right			LG SG	5
	A	831101	007	Riffle	Middle	Right	0.05			
	A	830827	008	Riffle	Middle	Right	1.60	0.00		
	A	830915	008	Riffle	Middle	Right	0.30	0.00		
	A	831024	008	Pool	Middle	Right			LG RU	4
	A	831101	008	Pool	Middle	Right	0.25	0.00		
	A	831207	008	Pool	Base	Right	0.05			
	A	830827	009	Pool	Base	Right	1.25	0.00		
	A	830915	009	Pool	Base	Right				
	A	831024	009	Pool	Middle	Right			RU LG	4
	A	831101	009	Pool	Middle	Right	0.05			
	A	831207	009	Pool	Middle	Right				
	A	830827	010	Pool	Middle	Right	1.30	0.00		
	A	830915	010	Pool	Middle	Right	0.20	0.00		
	A	831024	010	Riffle	Middle	Left			RU CO	4
	A	831101	010	Riffle	Middle	Left	0.15	0.20		
	A	831207	010	Riffle	Base	Right	0.05			
	A	830827	011	Riffle	Base	Right	1.40	0.00		
	A	830915	011	Riffle	Base	Right	0.20	0.00		
	A	831024	011	Riffle	Middle	Right			CO RU	2
	A	831207	011	Riffle	Middle	Left	0.25	0.00		
	A	830827	012	Riffle	Middle	Left	1.00	0.00		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 11	A	830915	012	Riffle	Middle	Left				
(continued)	A	831024	012	Riffle	Middle	Left			LG RU	4
	A	831101	012	Riffle	Middle	Left	0.25	0.00		
	A	830827	013	Riffle	Middle	Left	1.10	0.00		
	A	830915	013	Riffle	Middle	Left	0.20	0.10		
	A	831024	013	Riffle	Base	Left			RU LG	4
	A	831101	013	Riffle	Base	Left	0.05			
	A	831207	013	Riffle	Middle	Left	0.05			
	A	830827	014	Riffle	Middle	Left	0.70	0.35		
	A	830915	014	Riffle	Middle	Left	0.20	0.20		
	A	831024	014	Pool	Middle	Left			RU LG	4
	A	831101	014	Pool	Middle	Left	0.05			
	A	831207	014	Riffle	Middle	Right	0.05			
	A	830827	015	Riffle	Middle	Right	1.00	0.40		
	A	830915	015	Riffle	Middle	Right	0.50	0.30		
	A	831024	015	Pool	Middle	Left			RU LG	2
	A	831101	015	Pool	Middle	Left	0.40	0.25		
	A	831207	015	Pool	Middle	Left	0.40	0.15		
	A	830827	016	Pool	Middle	Left	0.90	0.45		
	A	830915	016	Pool	Middle	Left	0.50	0.25		
	A	831024	016	Pool	Middle	Left			RU LG	1
	A	831101	016	Pool	Middle	Left	0.40	0.30		
	A	831207	016	Pool	Middle	Left	0.40	0.15		
	A	830827	017	Pool	Middle	Left	0.90	0.45		
	A	830915	017	Pool	Middle	Left	0.50	0.30		
	A	831024	017	Pool	Head	Left			LG RU	2
	A	831101	017	Pool	Head	Left	0.30	0.50		
	A	831207	017	Pool	Middle	Left	0.35	0.35		
	A	830827	018	Pool	Middle	Left	0.50	0.50		
	A	830915	018	Pool	Middle	Left	0.30	0.10		
	A	831024	018	Riffle	Base	Right			LG RU	4
	A	831101	018	Riffle	Base	Right	0.30	0.15		
	A	831207	018	Riffle	Base	Right	0.30	0.10		
	A	830827	019	Riffle	Base	Right	0.30	0.55		
	A	830915	019	Riffle	Base	Right	0.10	0.35		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 11	A	831024	019	Riffle	Head	Right			RU LG	4
(continued)	A	831101	019	Riffle	Head	Right	0.05			
	A	830827	020	Riffle	Head	Right	0.70	0.60		
	A	830915	020	Riffle	Head	Right	0.35	0.40		
	A	831024	020	Pool	Middle	Left			SG SA	1
	A	831101	020	Pool	Middle	Left	0.30	0.50		
	A	831207	020	Pool	Head	Left	0.30	0.30		
	B	830915	04A	Pool	Head	Left	1.25	0.05		
	B	831024	04A	Pool	Middle	Left			RU LG	3
	B	831101	04A	Pool	Middle	Left	1.05	0.05		
	B	830915	04B	Pool	Middle	Left	1.10	0.00		
	B	831024	04B	Pool	Middle	Left			LG RU	4
	B	831101	04B	Pool	Middle	Left	1.10	0.05		
	B	830915	04C	Pool	Middle	Left	1.30	0.00		
	B	831024	04C	Pool	Middle	Left			RU LG	4
	B	831101	04C	Pool	Middle	Left	1.15	0.05		
	B	830915	10A	Pool	Middle	Left	1.50	0.10		
	B	831024	10A	Pool	Middle	Left			CO RU	5
	B	831101	10A	Pool	Middle	Left	1.35	0.05		
	B	830915	10B	Pool	Middle	Left	1.20	0.00		
	B	831024	10B	Pool	Middle	Left			RU LG	5
	B	831101	10B	Pool	Middle	Left	1.20	0.05		
	B	830915	10C	Pool	Middle	Left	1.50	0.05		
	B	831024	10C	Pool	Middle	Left			RU LG	4
	B	831101	10C	Pool	Middle	Left	1.40	0.05		
	B	830827	11A	Pool	Middle	Left	1.00	0.05		
	B	830915	11A	Pool	Middle	Left	0.80	0.05		
	B	831024	11A	Pool	Middle	Left			RU LG	2
	B	831101	11A	Pool	Middle	Left	0.75	0.15		
	B	831207	11A	Pool	Middle	Right	1.30	0.00		
	B	830827	11B	Pool	Middle	Right	0.85	0.05		
	B	830915	11B	Pool	Middle	Right	0.70	0.10		
	B	831024	11B	Pool	Middle	Left			CO RU	4
	B	831101	11B	Pool	Middle	Left	0.70	0.05		
	B	831207	11B	Pool	Middle	Right	1.10	0.00		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 11	B	830827	11C	Pool	Middle	Right	1.00	0.05		
(continued)	B	830915	11C	Pool	Middle	Right	0.80	0.10		
	B	831024	11C	Pool	Middle	Left			RU LG	4
	B	831101	11C	Pool	Middle	Left	0.85	0.10		
	B	831207	11C	Pool	Middle	Right	1.30	0.00		
	B	830827	21A	Pool	Middle	Right	0.85	0.05		
	B	830915	21A	Pool	Middle	Right	0.80	0.00		
	B	831024	21A	Pool	Middle	Left			RU LG	4
	B	831101	21A	Pool	Middle	Left	0.90	0.05		
	B	830827	21B	Pool	Middle	Left	1.20	0.05		
	B	830915	21B	Pool	Middle	Left	1.00	0.00		
	B	831024	21B	Pool	Middle	Left			RU LG	3
	B	831101	21B	Pool	Middle	Left	1.00	0.05		
	B	831207	21B	Pool	Middle	Right	1.50	0.00		
	B	830827	21C	Pool	Middle	Right	1.20	0.05		
	B	830915	21C	Pool	Middle	Right	1.00	0.00		
	B	831024	21C	Pool	Middle	Left			RU LG	4
	B	831101	21C	Pool	Middle	Left	1.10	0.05		
	B	830915	21D	Pool	Middle	Left	1.40	0.00		
	B	831024	21D	Pool	Middle	Left			CO RU	5
	B	831101	21D	Pool	Middle	Left	1.25	0.05		
	B	830915	21E	Pool	Middle	Left	1.35	0.00		
	B	831024	21E	Pool	Middle	Left			CO RU	5
	B	831101	21E	Pool	Middle	Left	1.05	0.05		
	B	830915	21F	Pool	Middle	Left	1.30	0.05		
	B	831024	21F	Pool	Middle	Left			RU LG	5
	B	831101	21F	Pool	Middle	Left	1.25	0.05		
	C	831024	DVA	Pool	Head	Left			RU CO	4
	C	831101	DVA	Pool	Head	Left	0.65	0.20		
	C	831109	DVA	Pool	Head	Left	0.70	0.10		
	C	831207	DVA	Pool	Head	Right	0.70	0.15	RU CO	4
	C	831024	DVB	Pool	Head	Left			CO RU	4
	C	831101	DVB	Pool	Head	Left	0.70	0.20		
	C	831109	DVB	Pool	Head	Left	0.90	0.15		
	C	831207	DVB	Pool	Head	Left	0.80	0.15	CO RU	4

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub- strate	Embeddedness rank
SLOUGH 11	C	831024	DVC	Pool	Head	Right			CO RU	4
(continued)	C	831101	DVC	Pool	Head	Right	0.50	0.25		
	C	831109	DVC	Pool	Head	Right	0.70	0.15		
	C	831207	DVC	Pool	Head	Left	0.60	0.20	CO RU	4
MAINSTEM	A	831108	M1A	Pool	Head	Left	0.10	0.00		
(136.8)	A	831108	M1B	Pool	Head	Left	0.40	0.00		
	A	831108	M1C	Pool	Head	Left	0.20	0.20		
INDIAN RIVER	A	831108	001	Pool	Head	Right	0.20	0.00		
(138.6)	A	831213	001	Pool	Head	Right	0.65	0.00		
	A	831108	003	Pool	Head	Left	1.00	0.50		
SLOUGH 17	A	831108	001	Pool	Head	Left	0.20	0.45		
(138.9)	A	831213	001	Pool	Head	Left	0.25	0.40		
	A	831108	003	Pool	Head	Left	0.30	0.65		
	A	831213	003	Pool	Head	Left	0.35	0.40		
SIDE CHANNEL 21	A	830825	001	Riffle	Middle	Left	2.30	2.10		
(141.0)	A	830911	001	Pool	Head	Left			BO CO	1
	A	830914	001	Pool	Head	Left	0.60	0.05		
	A	831027	001	Pool	Head	Left	0.40	0.20		
	A	830825	002	Riffle	Middle	Right	1.90	1.90		
	A	830911	002	Riffle	Middle	Right			CO RU	3
	A	830825	003	Riffle	Middle	Right	2.10	5.80		
	A	830911	003	Riffle	Middle	Right			CO RU	4
	A	830825	004	Riffle	Middle	Left	1.80	3.20		
	A	830911	004	Riffle	Middle	Left			CO RU	2
	A	830825	005	Riffle	Middle	Right	1.60	3.10		
	A	830911	005	Riffle	Base	Right			CO RU	2
	A	830914	005	Riffle	Base	Right	0.20	0.10		
	A	830825	006	Riffle	Middle	Left	1.60	2.75		
	A	830911	006	Riffle	Middle	Left			CO RU	4
	A	830914	006	Riffle	Middle	Left	0.20	0.00		
	A	830825	007	Riffle	Middle	Right	1.50	2.25		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SIDE CHANNEL 21	A	830911	007	Riffle	Middle	Right			CO RU	5
(continued)	A	830825	008	Riffle	Middle	Right	1.10	2.80		
	A	830911	008	Riffle	Base	Right			CO RU	5
	A	830914	008	Riffle	Base	Right	0.20	0.15		
	A	830825	009	Riffle	Middle	Left	1.40	2.70		
	A	830911	009	Riffle	Middle	Left			CO RU	5
	A	830825	010	Riffle	Middle	Left	1.50	3.35		
	A	830911	010	Riffle	Middle	Left			BO RU	3
	A	830914	010	Riffle	Middle	Left	0.20	0.00		
	A	830825	011	Riffle	Middle	Left	1.70	2.25		
	A	830911	011	Riffle	Middle	Left			CO RU	3
	A	830914	011	Riffle	Middle	Left	0.20	0.00		
	A	830825	012	Riffle	Middle	Right	1.30	3.00		
	A	830911	012	Riffle	Middle	Right			CO RU	4
	A	830825	013	Riffle	Middle	Right	1.80	3.10		
	A	830911	013	Riffle	Middle	Right			CO BO	5
	A	830914	013	Riffle	Middle	Right	0.30	0.10		
	A	830825	014	Riffle	Middle	Left	1.40	2.25		
	A	830911	014	Riffle	Middle	Left			CO RU	1
	A	830825	015	Riffle	Middle	Right	1.80	3.10		
	A	830911	015	Riffle	Middle	Right			CO RU	5
	A	830914	015	Riffle	Middle	Right	0.50	0.30		
	A	831027	015	Riffle	Middle	Right	0.10	0.00		
	A	830825	0S1	Riffle	Middle	Right	1.40	1.75		
	A	830911	0S1	Pool	Base	Right			RU LG	1
	A	830825	0S2	Riffle	Middle	Right	1.00	2.10		
	A	830911	0S2	Pool	Head	Right			CO RU	1
	A	830914	0S2	Pool	Head	Right	0.10	0.00		
	A	830825	0S3	Riffle	Middle	Right	1.20	3.10		
	A	830911	0S3	Riffle	Middle	Right			CO RU	4
	A	830825	0S4	Riffle	Middle	Right	1.00	4.30		
	A	830911	0S4	Riffle	Middle	Right			RU CO	4
	A	830825	0S5	Riffle	Middle	Right	0.80	3.50		
	A	830911	0S5	Riffle	Middle	Right			RU CO	4
	B	830914	00A	Pool	Head	Left	1.10	0.50	CO SG	4

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SIDE CHANNEL 21	B	830914	00B	Riffle	Middle	Right	1.00	0.75	CO RU	5
(continued)	B	831027	00B	Riffle	Middle	Right	0.70	0.30		
	B	830914	00C	Riffle	Middle	Right	0.90	0.35	CO RU	5
	B	831027	00C	Riffle	Middle	Right	0.70	0.20		
	B	830914	00D	Riffle	Middle	Right	0.85	0.60	CO RU	5
	B	831027	00D	Riffle	Middle	Right	0.80	0.20		
	B	830914	00E	Riffle	Middle	Right	0.55	0.50	CO RU	4
	B	831027	00E	Riffle	Middle	Right	0.20	0.00		
	B	830914	00F	Riffle	Middle	Right	0.70	0.60	CO BO	5
	B	831027	00F	Riffle	Middle	Right	0.50	0.70		
	B	830914	00G	Riffle	Middle	Right	0.50	1.25	CO RU	5
	B	831027	00G	Riffle	Middle	Right	0.20	0.20		
	B	830914	00H	Riffle	Middle	Right	0.70	0.70	CO RU	5
	B	831027	00H	Riffle	Middle	Right	0.50	0.40		
	B	830914	0SA	Pool	Base	Right	0.70	0.05	RU LG	1
	B	831027	0SA	Pool	Base	Right	0.30	0.00		
	B	830914	0SB	Pool	Middle	Right	0.50	0.00	RU LG	2
	C	830914	DV1	Pool	Head	Right	0.80	0.40	CO RU	5
	C	830914	DV2	Pool	Head	Right	0.70	0.50	CO RU	5
	C	831027	DV2	Pool	Head	Right	0.50	0.15		
	C	830914	DV3	Pool	Head	Right	1.00	0.60	CO RU	5
	C	831027	DV3	Pool	Head	Right	0.50	0.30		
SLOUGH 21	A	830825	001	Riffle	Middle	Left	1.60	2.60		
(141.8)	A	830910	001	Riffle	Middle	Left			CO RU	2
	A	830913	001	Riffle	Middle	Left	0.70	0.60		
	A	831026	001	Riffle	Middle	Left	0.60	0.70		
	A	830825	002	Riffle	Middle	Left	1.50	2.10		
	A	830910	002	Riffle	Middle	Right			CO RU	2
	A	830913	002	Riffle	Middle	Right	0.60	0.00		
	A	831026	002	Riffle	Middle	Right	0.50	0.00		
	A	830825	003	Riffle	Middle	Right	1.60	1.90		
	A	830910	003	Riffle	Head	Right			CO RU	2
	A	830913	003	Riffle	Head	Right	0.60	0.35		
	A	831026	003	Riffle	Head	Right	0.70	0.40		

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 21	A	830825	004	Riffle	Middle	Left	1.80	2.00		
(continued)	A	830910	004	Riffle	Head	Left			CO RU	2
	A	830913	004	Riffle	Head	Left	0.80	0.15		
	A	831026	004	Riffle	Head	Left	0.90	0.20		
	A	830825	005	Riffle	Middle	Left	1.50	2.35		
	A	830910	005	Riffle	Head	Left			CO RU	2
	A	830913	005	Riffle	Head	Left	0.60	0.05		
	A	831026	005	Riffle	Head	Left	0.80	0.10		
	A	830825	006	Riffle	Middle	Right	1.80	2.20		
	A	830910	006	Pool	Base	Right			SI	1
	A	830913	006	Pool	Base	Right	0.70	0.05		
	A	831026	006	Pool	Base	Right	0.60	0.10		
	A	830825	007	Riffle	Middle	Left	1.70	2.25		
	A	830910	007	Pool	Base	Left			SI	1
	A	830913	007	Pool	Base	Left	0.60	0.05		
	A	831026	007	Pool	Base	Left	0.60	0.35		
	A	830825	008	Riffle	Middle	Left	1.50	2.30		
	A	830910	008	Pool	Base	Left			SI	1
	A	830913	008	Pool	Base	Left	0.30	0.00		
	A	831026	008	Pool	Base	Left	0.30	0.00		
	A	830825	009	Riffle	Middle	Left	1.10	2.55		
	A	830910	009	Pool	Head	Left			SI	1
	A	830913	009	Pool	Head	Left	0.20	0.00		
	A	831026	009	Pool	Head	Left	0.10	0.00		
	A	830913	00A	Pool	Middle	Right	1.10	0.00	BO CO	1
	A	831026	00A	Pool	Middle	Right	1.00	0.00		
	A	830913	00B	Pool	Head	Right	0.70	0.05	BO CO	2
	A	831026	00B	Pool	Head	Right	0.70	0.10		
	A	830913	00C	Pool	Head	Right	0.80	0.00	BO CO	3
	A	831026	00C	Pool	Head	Right	0.70	0.00		
	A	830913	00D	Pool	Middle	Left	0.50	0.00	LG RU	2
	A	831026	00D	Pool	Middle	Left	0.40	0.20		
	A	830913	00E	Pool	Middle	Left	1.80	0.00	SG LG	1
	A	831026	00E	Pool	Middle	Left	1.60	0.00		
	A	830913	00F	Pool	Head	Left	0.70	0.00	RU LG	1

Appendix Table E-1. (Continued).

Site (River mile)	Sub site	Sampling Date y/m/d	Stand pipe No.	Habitat Zone	Location within Zone	Bank	Water Depth (ft)	Velocity (ft/sec)	Sub-strate	Embeddedness rank
SLOUGH 21	A	830825	010	Riffle	Middle	Left	1.90	2.25		
(continued)	A	830910	010	Pool	Head	Left			SI	1
	A	830913	010	Pool	Head	Left	0.40	0.10		
	A	831026	010	Pool	Head	Left	0.40	0.05		
	A	830825	011	Riffle	Middle	Right	1.60	2.15		
	A	830910	011	Pool	Head	Right			BO CO	1
	A	830913	011	Pool	Head	Right	0.80	0.00		
	A	831026	011	Pool	Head	Right	1.10	1.50		
	A	830825	012	Riffle	Middle	Right	1.40	2.00		
	A	830910	012	Pool	Head	Right			BO CO	2
	A	830913	012	Pool	Head	Right	0.80	0.00		
	A	831026	012	Pool	Head	Right	0.90	0.00		
	A	830825	013	Riffle	Middle	Left	1.50	2.59		
	A	830910	013	Riffle	Base	Left			SI	1
	A	830913	013	Riffle	Base	Left	0.40	0.30		
	A	831026	013	Riffle	Base	Left	0.40	0.30		
	A	830825	014	Riffle	Middle	Right	1.30	2.80		
	A	830910	014	Pool	Base	Left			LG RU	2
	A	830913	014	Pool	Base	Left	0.50	0.15		
	A	831026	014	Pool	Base	Left	0.50	0.20		
	A	831108	014	Pool	Base	Left	0.50	0.10		
	A	830825	015	Riffle	Middle	Right	1.60	2.80		
	A	830910	015	Pool	Base	Left			LG RU	2
	A	830913	015	Pool	Base	Left	1.00	0.15		
	A	831026	015	Pool	Base	Left	1.00	0.20		
	A	831108	015	Pool	Base	Left	0.95	0.10		
	A	830825	016	Riffle	Middle	Right	1.10	2.45		
	A	830910	016	Riffle	Base	Right			SI	1
	A	830913	016	Riffle	Base	Right	0.30	0.40		
	A	831026	016	Riffle	Base	Right	0.10	0.00		
	A	831108	016	Riffle	Base	Right	0.10	0.00		

Appendix Table E-2. Substrate classification code used to assess general substrate conditions at standpipe locations (adapted from Vincent-Lang et al. 1984).

Substrate Type	Symbol	Size Class
silt	SI	small fines
sand	SA	large fines
small gravel	SM	1/4-1"
large gravel	LG	1-3"
rubble	RU	3-5"
cobble	CO	5-10"
boulder	BO	10"

Appendix Table E-3. Criteria used to assign a rank for the relative degree of embeddedness of substrate.

Embeddedness[a] Rank	Criteria
5	Gravel, rubble, and boulder particles have less than 5 percent of their surface covered by fine sediment.
4	Gravel, rubble, and boulder particles have between 5 to 25 percent of their surface covered by fine sediment.
3	Gravel, rubble, and boulder particles have between 25 and 50 percent of their surface covered by fine sediment.
2	Gravel, rubble, and boulder particles have between 50 and 75 percent of their surface covered by fine sediment.
1	Gravel, rubble, and boulder particles have over 75 percent of their surface covered by fine sediment.

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