PART 4

Juvenile Salmon Rearing Habitat Models

JUVENILE SALMON REARING HABITAT MODELS

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ABSTRACT

The effects of mainstem discharge on rearing habitat of juvenile salmon in the Susitna River reach between the Chulitna River confluence and Devil Canyon were quantified by use of habitat models. Six slough and side channel sites were sampled at four to seven different levels of mainstem discharge during the 1983 open water season. Data were collected on hydraulic characteristics, cover, water quality, water surface area, and fish density. Suitability criteria were integrated with the habitat data to calculate weighting factors for cover and velocity for selected species at each site. These weighting factors, which were calculated for both shoreline and mid-channel areas, were then combined with area to produce weighted usable areas for the site. A habitat index was then calculated for site comparisons. Peaks in habitat indices for chinook salmon occurred when slough or side channel heads were overtopped. Upland slough habitat indices steadily increased with mainstem discharge. Lack of cover may limit juvenile salmon use of many of the sites.

JUVENILE SALMON REARING HABITAT MODELS

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF PLATES

LIST OF APPENDIX TABLES

1.0 INTRODUCTION

Five species of Pacific salmon spawn in the Susitna River between the Chulitna River confluence and Devil Canyon. This reach of river provides rearing habitat for chinook, coho, sockeye, and chum salmon during the juvenile portion of their life cycle. Pink salmon outmigrate immediately after emergence. The proposed hydroelectric project on the Susitna River will create turbidity, temperature, discharge, and other physical-chemical conditions which are substantially different from preproject conditions (Acres, 1982). This is one of three interrelated studies attempting to determine the effects of lowered flows on the capability of this reach of the Susitna River to support juvenile salmon rearing during the ice-free season.

Studies during 1981 and 1982 (ADF&G 1981; 1983a) demonstrated large scale distribution and habitat utilization patterns of these species. Other studies (ADF&G 1983b, appendices E, F and G) investigated the response of selected macrohabitat areas to mainstem discharge using "hydraulic zones" to characterize sections of the slough and tributary mouth areas. The surface area of these zones, as a function of mainstem discharge, were compared to the relative use of the zones by each species. The result of the analysis was an index of habitat availability for each species as a function of mainstem discharge. During the course of that study we noticed that microhabitat parameters within the zones were responding to discharge changes at rates higher than the zone surface areas being evaluated. These microhabitat factors included cover and turbidity.

The present study incorporates these microhabitat parameters into simulations of mainstem Susitna River discharge effects on juvenile salmon rearing habitat. Our experimental design emphasizes the measurement of cover at sites that are characteristic of the macrohabitats utilized by juvenile salmon. Otherwise, the methodology is similar to, but less data intensive than Instream Flow Group (IFG) hydraulic methods (Bovee 1982) of calculating the amount of optimum habitat called weighted usable area. Each site/discharge description is developed from parameters measured in shoreline and mid-channel area cells specified by a fixed sampling grid. Our experimental design evolved because it enabled us to develop models at several sites encompassing the full range of macrohabitat types. The intensive effort required to develop IFG models would have limited the number of sampling sites.

Concurrent with the collection of habitat modelling data, fisheries data were collected at less rigidly specified grids at 29 additional sites. The two data bases were used to develop estimates of: 1) abundance of cover type and percent cover, turbidity, velocity and depth versus mainstem discharge at the six sites, and 2) univariate suitability functions for velocity, depth, cover type, and percent cover for sampling cells at all sites. The suitability function study is reported separately (Part 3 of this volume). In this report, the environmental descriptions are combined with the suitability functions to yield weighted usable rearing areas for the species as a function of mainstem discharge at the six sites. The weighted usable areas for each species, site, and mainstem discharge were then divided by the surface area of the site at a typical midsummer mainstem discharge of 23,000 cfs to produce habitat indices. The index values are plotted as a function of mainstem discharge by species so that the weighted usable areas can be compared independently of each site's surface area at a fixed mainstem flow.

The results of these calculations have application to two concurrent projects. The results from juvenile habitat simulation studies using IFG hydraulic models (Part 7 of this volume) will be integrated with those presented here to produce best estimates of habitat indices for the juvenile salmon species at the macrohabitat types identified in the Susitna River reach between the Chulitna River confluence and Devil Canyon.

Secondly, incremental estimates of total usable rearing area in the Chulitna River confluence to Devil Canyon reach impacted by mainstem flows will be made from the product of the integrated indices and macrohabitat abundance as a function of mainstem Susitna River discharge. To accomplish this, the area of each macrohabitat type is being mapped from aerial photographs taken at different mainstem flows. The total area of each macrohabitat type in the reach as a function of mainstem discharge will be provided by E. Woody Trihey and Associates.

2.0 METHODS

2.1 Field Sampling Design

2.1.1 Study site location and selection criteria

Much of the juvenile salmon studies program has been directed towards collection of CPUE data over widely ranging spatial and temporal habitats of the species (ADF&G, 1982; 1983c). A product of these studies has been the identification of critical juvenile rearing "macrohabitat" types affected to varying degrees by variation in mainstem flow. These areas of the riverine environment, depending on the mainstem stage, are characterized as side channels, side sloughs or upland sloughs. For this study, six study sites representative of these three macrohabitat types were chosen to complement the IFG hydraulic modelling sites. All these macrohabitats are affected by mainstem stage and flow and contain significant numbers of rearing juvenile salmon. Side Channel 10A was chosen because it possessed potential habitat for rearing juvenile chinook salmon and represented side channel macrohabitats strongly affected by mainstem discharge. Two upland slough sites, Slough 5 and Slough 6A, were chosen because juvenile sockeye salmon rear in these areas and because they are representative of sites that do not have mainstem discharge passing through; the predominant influence of the mainstem on these sites is the backwater created by mainstem stage at the mouth of the site. Three sites, Slough 8, Slough 22, and Whiskers Slough, which progressed from side sloughs to side channels at high mainstem flows, were also modelled (Figure 1). A side slough is considered a side channel when turbid mainstem water flows through (overtops) the head of the site. These six sites represented a cross section of three morphological habitat types present in this reach which are known to support significant rearing of juvenile salmon.

2.1.2 Sampling grid design

Habitat data at the modelling sites was collected at a grid of fixed transect markers. The locations of the transects at each site are illustrated on aerial photographs in Plates 1 through 6. The grids at each site were placed to maintain a relatively uniform water chemistry condition and to maximize the diversity of cover, depth, and velocity parameters to be sampled in the area.

The eight or nine pairs of the transect markers spanning the selected reach (typically 1,000 ft) of the site were installed during the first visit to the sampling site. The location of up to three cells (6 ft by 50 ft) per transect were specified for each subsequent sampling. (Figure 2). Two shoreline and one mid-channel area cells were always specified if the wetted area at the transect crossing was 18 or more ft in width. When the site was between 12 and 18 ft in width, two shoreline cells were specified; for widths under 12 ft, one shoreline cell was specified.

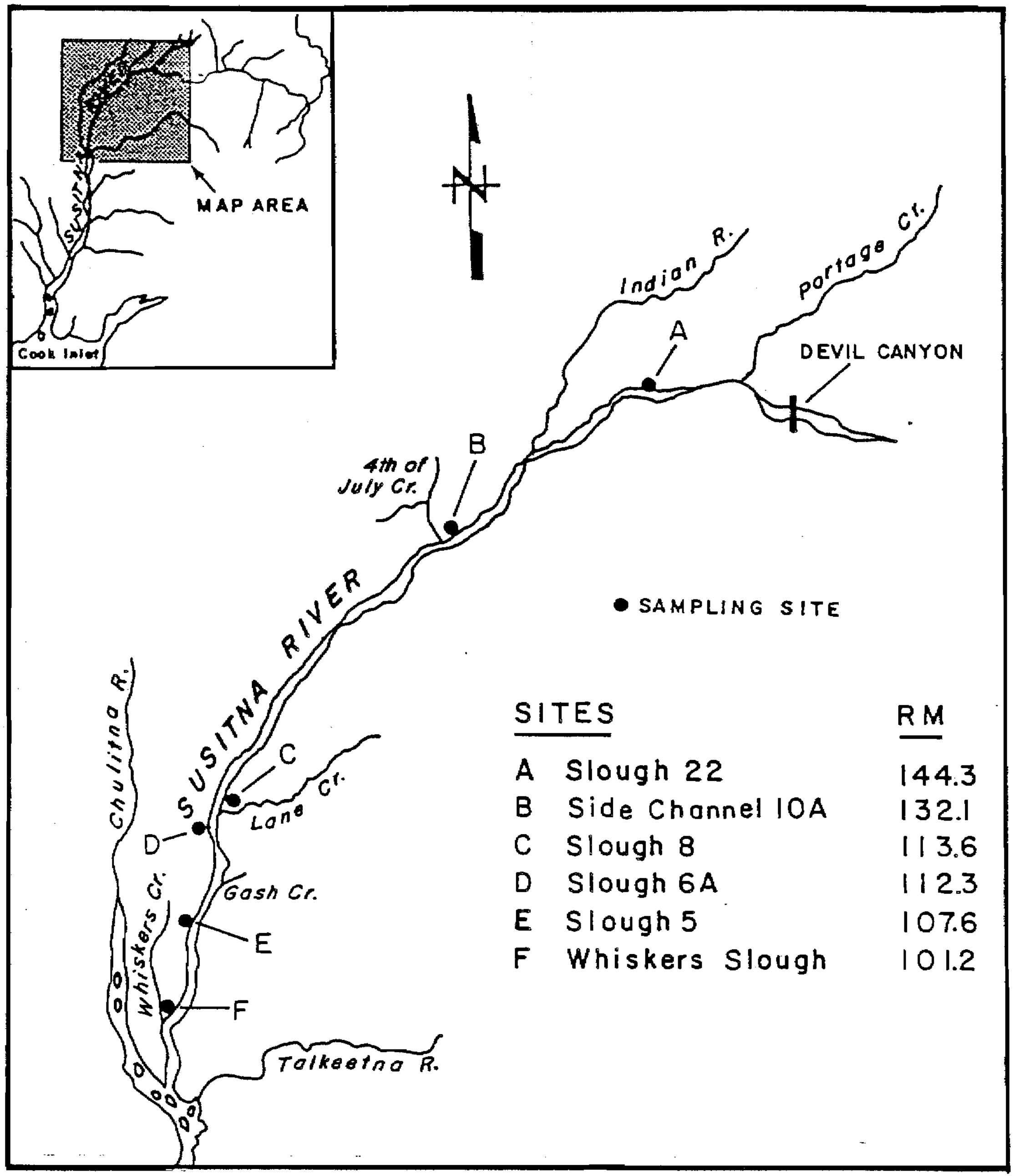


Figure 1. River mile and relative location of the juvenile salmon rearing habitat model study sites.

Plate 1. Aerial photograph of Side Channel 10A (RM 132.1), September 1983. The pool between transects 1-5 and the island was excluded from the study area.

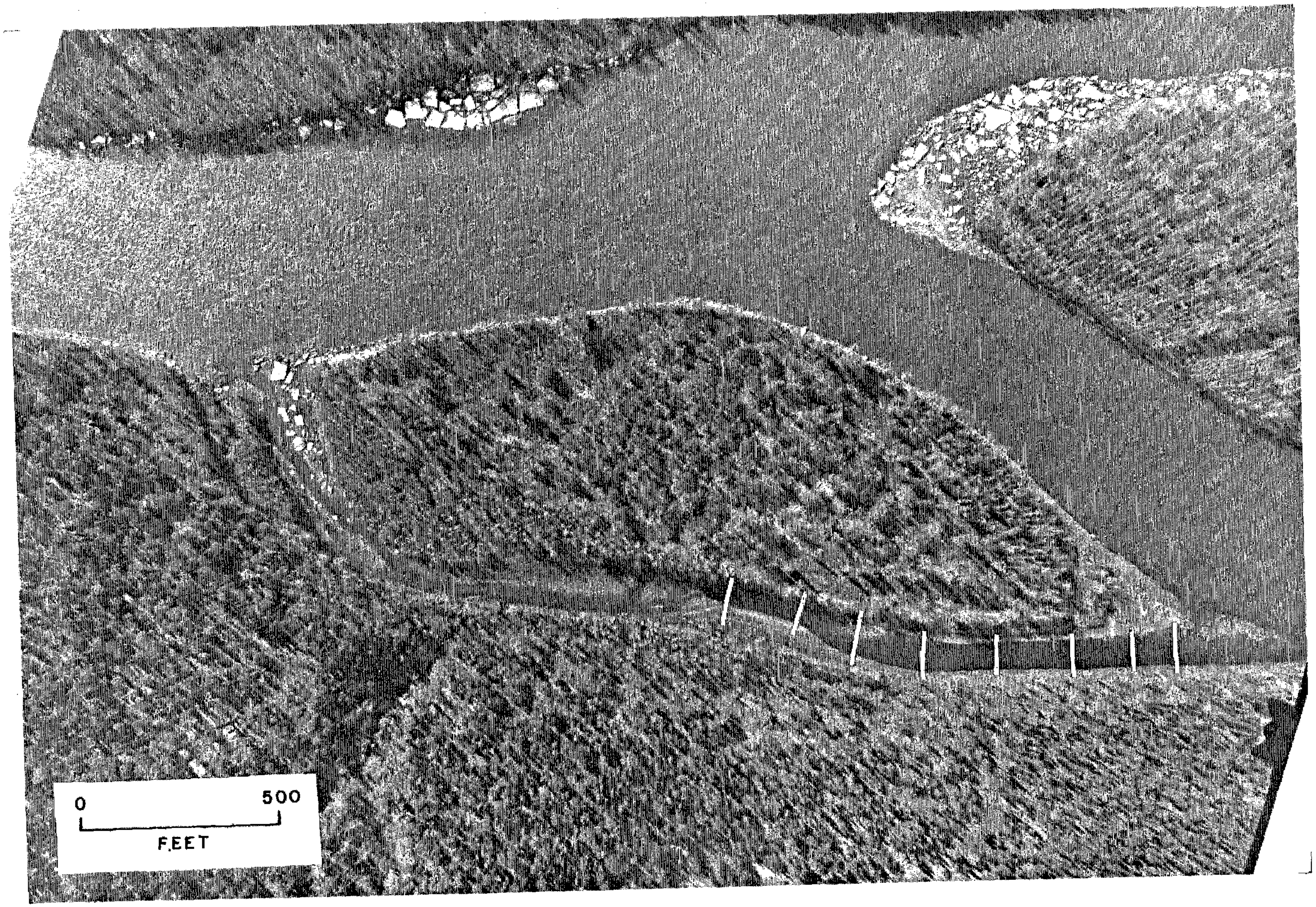


Plate 2. Aerial photograph of Slough 22 (RM 144.3), May 1982.

Plate 3. Aerial photograph of Whiskers Creek Slough (RM 101.2), September 1983.

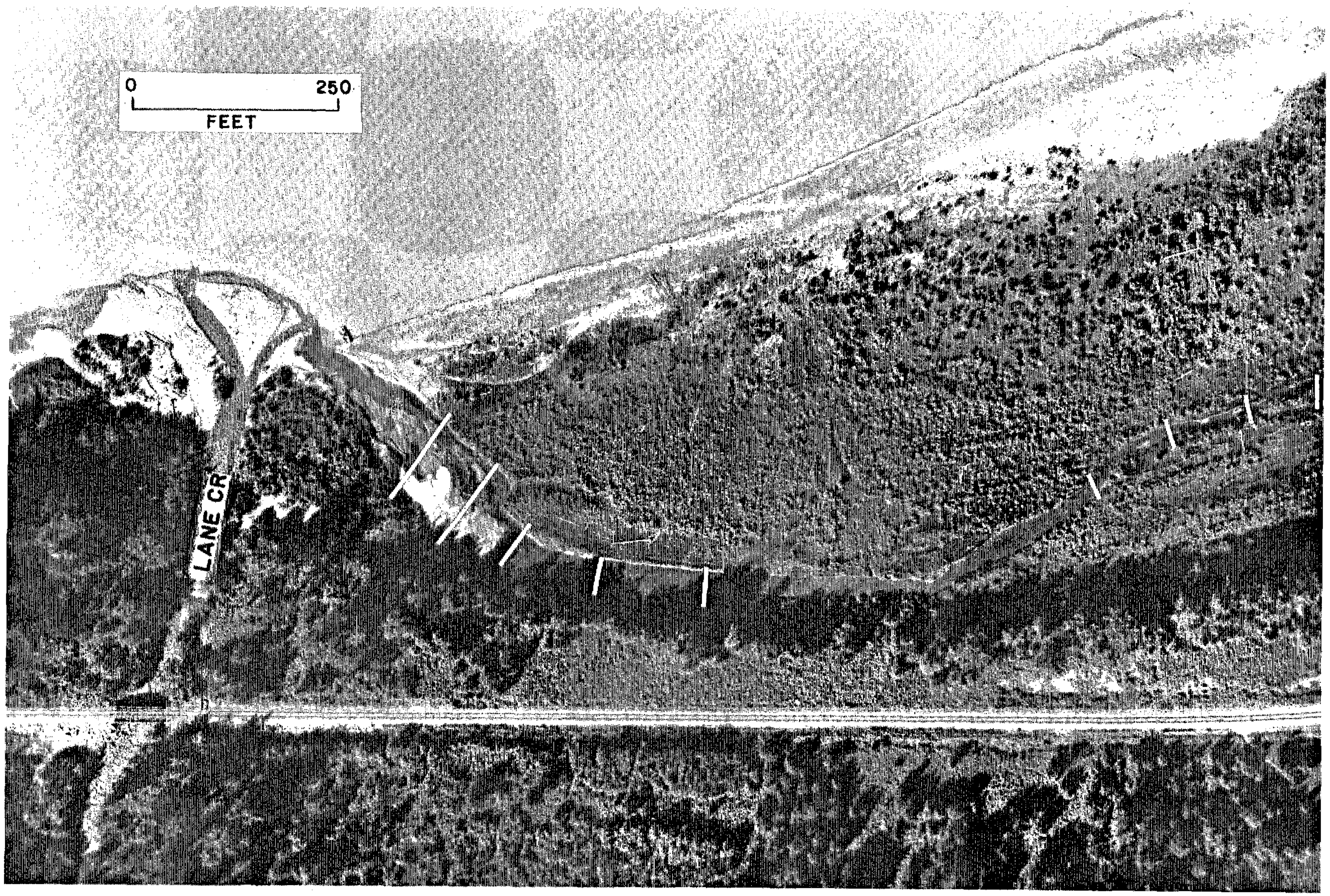


Plate 4. Aerial photograph of Slough 8 (RM 113.6), August 1982.

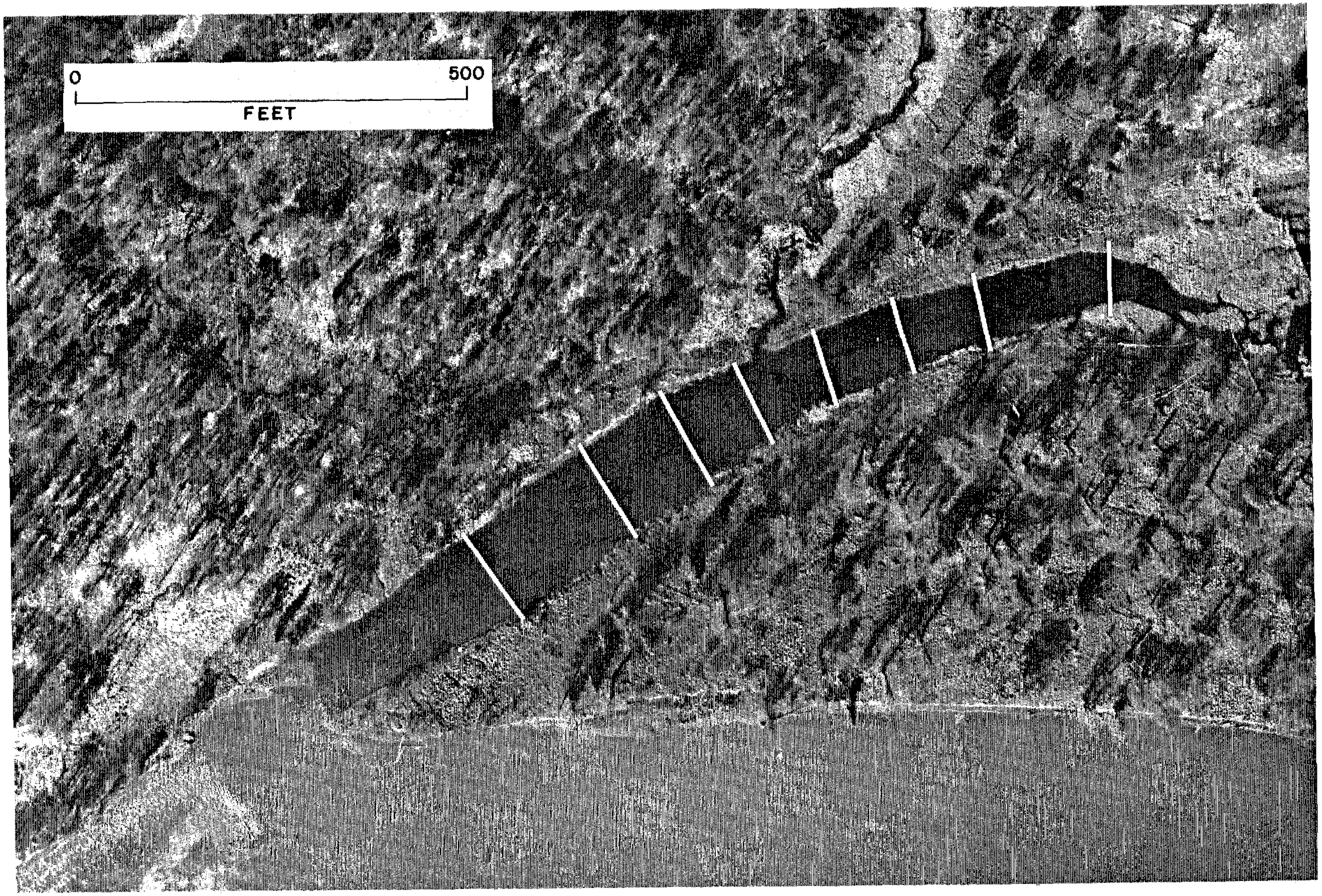


Plate 5. Aerial photograph of Slough 6A (RM 112.3), May 1982.

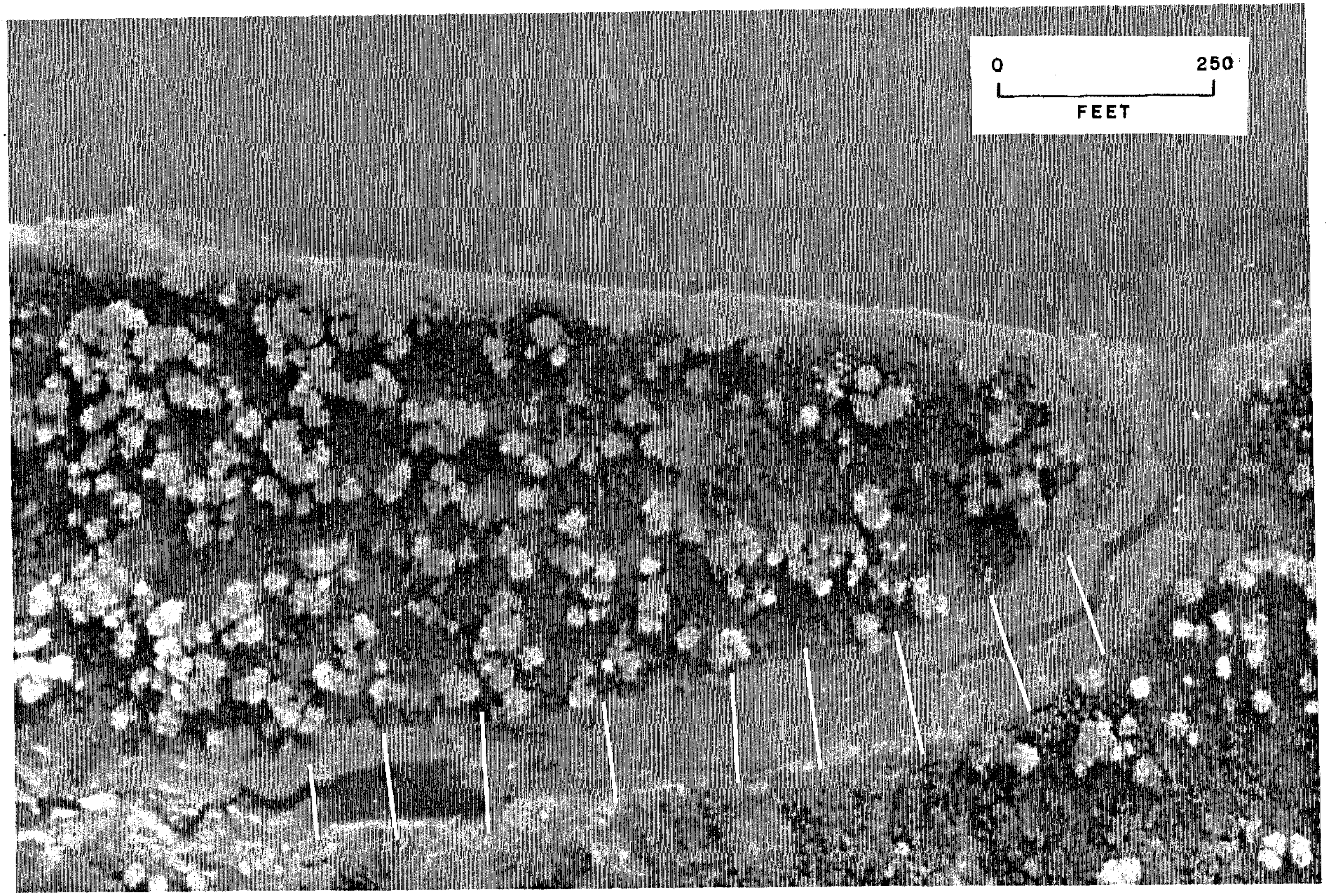


Plate 6. Aerial photograph of Slough 5 (RM 107.6), September 1983.

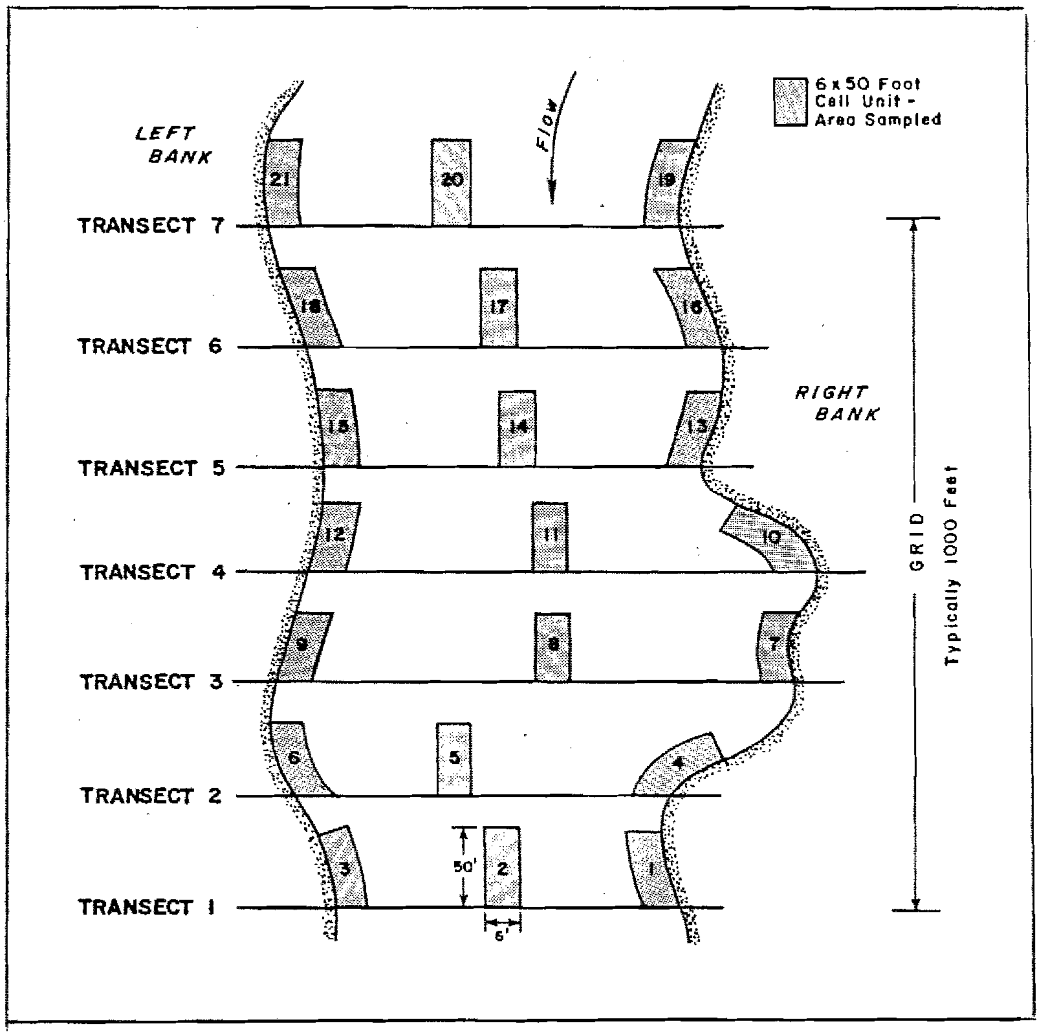


Figure 2. Illustration of the grid and cell sampling scheme employed at habitat modelling study sites.

Characterization of the physical parameters of each site by the cell measurements was made over as wide a range of mainstem discharge as was practically possible. Relative water surface elevations at each study site were recorded from staff gages at each sampling. Mainstem Susitna River discharges for each sampling were taken from USGS provisional records of flows measured at the Gold Creek gaging station, 15292000.

2.1.3 Cell measurements

Eight or nine mid-channel cells and 16 to 18 shoreline cells were created by the grid of transects established at each site. During each sampling, average depth, and mean water column velocity was measured in each cell and total percent cover, and the dominant cover type was estimated. In nearly all cases, cells in a grid were assigned a common water chemistry measurement of temperature, turbidity, pH, dissolved oxygen, and conductivity. If obvious water quality differences existed across the grid, two or more groupings of the cells were made by water quality parameters. In one case (Slough 8), two grids of transects were used to sample regions having similar water quality but very different morphological characteristics.

The mean depth of a cell was estimated from several measurements taken with a graduated wading rod midway along the length of the cell. Cell velocity was determined using a Price Model AA velocity meter at one to three characteristic mid-cell locations. The total percent of object cover available to juvenile fish was visually estimated, as was the primary object cover type. Nine cover types and six categories of percent cover (Table 1) were developed. Prior to the sampling season, a field trip was made to promote consistent ratings among the four raters. Percent cover in this study is defined as the ratio of horizontal or obliquely viewed concealing, hiding or protecting area potentially available to a (30-100 mm) juvenile fish, relative to the surface area of the cell. To reduce variances introduced by raters, rating categories were kept broad and the training introduced common concepts of how to rate percent cover. The percent cover rating is thus an estimate of the square feet of cover per cell (300 ft^2).

Table 1. Percent cover and cover type categories

Percent Cover	Cover Type
0-5%	No object cover
6-25%	Emergent vegetation
26-50%	Aquatic vegetation
51-75%	Debris/deadfall
76-95%	Overhanging riparian vegetation
96-100%	Undercut banks
	Gravel 1" to 3" (in diameter)
	Rubble 3" to 5"
	Cobble or boulders > 5"

Water temperature, pH, dissolved oxygen, and conductivity were measured at mid-site with a Hydrolab model 4001 multiparameter meter. Polypropylene bottles stored grab samples for turbidity measurements using an HF model DRT-15 turbidometer calibrated over a 0 to 200 NTU range.

The procedures and techniques used to collect the fisheries data have been described in detail in ADF&G (1984) and also are summarized in Part 2 of this report.

2.2 Data Analysis

An overview of the data analysis performed in this study is shown in Figure 3. Field procedures and recording forms specified in ADF&G (1984) were used throughout. The field data were initially input to a mainframe computer data base management system and reformatted for examination.

Following completion of the field season, the catch per unit effort data for the juvenile salmon species at the six model sites were examined to determine which sites should be integrated with the species suitability data for weighted usable area (WUA) projections (Table 2). All sites with species catches greater than mean catch per cell for all six sites combined were selected for modelling. Mean catch at these six sites was very similar to mean catch at all sites sampled during 1983 even though very high mean catches were recorded at tributary sites. Slough 5 was modelled for coho and sockeye as these two species were most abundant at this site. Whiskers Creek Slough, Slough 8, and Slough 22 were modelled during both their side slough and side channel states (clear and turbid conditions).

2.2.1 Surface areas

Surface areas were calculated from the distance between each transect bench marker and the wetted edge of the water measured during each field sampling (during one visit to each habitat site the distances and compass bearings between transect bench markers were measured). These data were input to a computer program which calculated the wetted surface area of the study site on each occasion. The "mid-channel" area present between six feet wide "shoreline area" strips was also calculated and by subtracting this area from the total surface area for each sampling, the wetted shoreline area was computed.

Total surface areas of each of the study sites for mainstem flows outside the range of conditions observed during the 1983 open water season were estimated using a variety of techniques. The methods used at each study site are noted on figures presented in the results section. Since a wide range of mainstem discharges was desired for the incremental analysis (6,000 to 45,000 cfs), an extrapolation of the measured surface area curve shapes based on a knowledge of general study site morphology was required in some cases. Surface area projections at high mainstem flows were not made for the Slough 8 site.

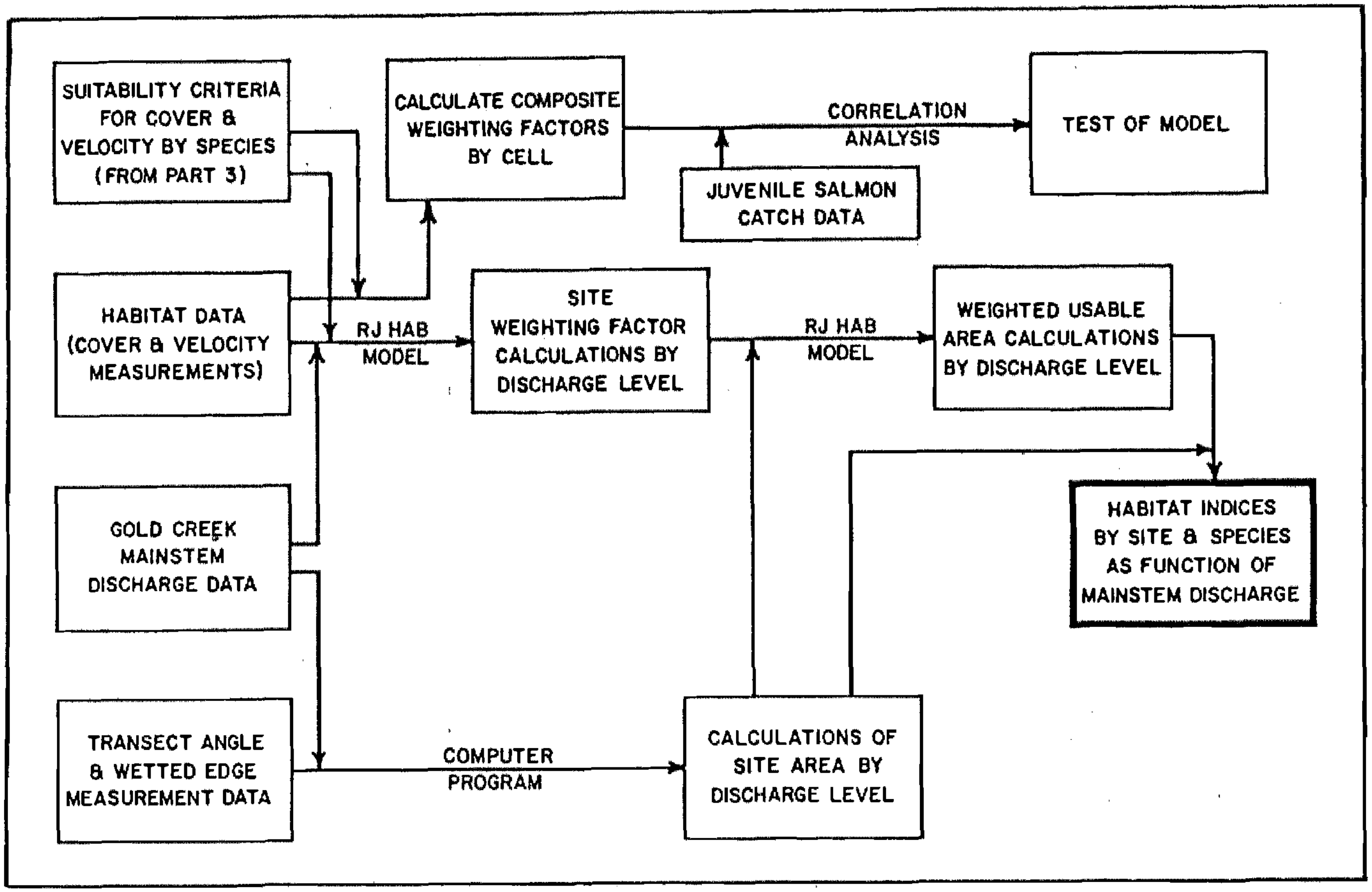


Figure 3. Data analysis flow chart for juvenile salmon rearing habitat models.

Table 2. Catch, catch per cell, and delineation of site and species combinations modelled.

Site	No of cells fished (effort)	Catch (catch per cell)			
		Chinook	Coho	Sockeye	Chum
Whiskers Creek Slough	67	260(3.9)[a]	291(4.3)	24(0.4)	5(0.1)
Slough 5	50	20(0.4)	88(1.8)	27(0.5)	0(0.0)
Slough 6A	77	108(1.4)	286(3.7)	169(2.2)	11(0.1)
Slough 8	72	65(0.9)	198(2.8)	131(1.8)	73(1.0)
Side Channel 10A	64	406(6.3)	0(0.0)	1(0.0)	0(0.0)
Slough 22	52	260(5.0)	5(0.1)	0(0.0)	1(0.0)
Total (model sites)	382	1119(2.9)	868(2.3)	352(0.9)	90(0.2)
Total of all cells sampled during 1983[b]	1260	4395(3.5)	2020(1.6)	1006(0.8)	1157(0.9)

[a] If underlined, the species response to mainstem discharge was modelled at the site.

[b] Taken from Part 3 of this report.

2.2.2 Resident Juvenile Habitat (RJHAB) Model

The Resident Juvenile Habitat (RJHAB) model presented here is a simplified method for calculating weighted usable area (WUA) without using hydraulic models. Our method divides the modelling site into shoreline and mid-channel areas and then calculates a WUA for both of these portions of the site. The site WUA is the sum of the shoreline and mid-channel WUA. The WUA for a shoreline or mid-channel portion of the site (i) having area (A) at Susitna River discharge (q) for rearing species (s) is calculated as follows:

$$(1)\ WUA_{i,s,q} = WF(c) \times WF(v) \times WF(d) \times A$$

The weighting factors WF(c), WF(v) and WF(d) are shoreline or mid-channel overall suitability values for cover (both amount and type integrated), velocity, and depth for any given i, s, and q. The depth weighting factor was set to 1.0 because data from part 3 of this report indicated it had little effect on fish distribution in comparison to velocity and cover. Examples of the calculations required to obtain the weighting factors for cover and velocity are described in text and equations 2 and 3 below. The factors i, s, and q are held constant in the following equations.

The weighting factor for cover (WF(c)) can be calculated in the form:

$$(2)\ WF(c) = \frac{\sum_{j=1}^{n} (C_j \times S(a)_j \times S(t)_j)}{\sum_{j=1}^{n} C_j}$$

Where:

$S(a)_j$ = Value of the habitat suitability function for value of percent cover in cell #j.

$S(t)_j$ = Value of the habitat suitability function for measured value of cover type t in cell #j

C_j = surface area of cell #j.

n = number of cells sampled in either shoreline or mid-channel portions

Since there were nine cover types (t) and five present cover categories (a), a total of 45 percent cover by cover type combinations were possible.

The weighting factor for velocity was calculated by expressing the velocity data as proportional frequencies of occurrence after measured values were grouped into 0.3 ft/sec categories (intervals) with 0.0

remaining a unique data point. The weighting factor for velocity (WF(v)) is calculated as follows:

$$(4) \quad WF(v) = \sum_{k=1}^{m} (P_k \times S(v)_k)$$

Where:

m = number of velocity categories

k = velocity category code

$S(v)_k$ = value of the habitat suitability function for velocity in interval k

$P_k = \sum_{l=1}^{r} C_l \Big/ \sum_{j=1}^{n} C_j$ = proportion of cells within velocity interval k

r = number of cells in velocity interval k

n = number of cells in either shoreline or mid-channel portions

These computations were carried out on a microcomputer using commercial spreadsheet software. The calculated weighting factors WF(c) and WF(v) were output as graphs for each site and species for both shoreline and mid-channel areas of the site as a function of mainstem discharge. For chinook salmon juveniles, the weighting factors were also plotted for both low and high turbidity mainstem conditions. These plots were interpreted with respect to the changing environmental conditions and data scatter and a line was fit to the data by hand. This interpretation required that the frequency distribution of each attribute's values (in the shoreline and mid-channel areas of the site), at each discharge be viewed with respect to the suitability curve for the attribute. The analysis of the weighting factor plots enabled some conclusions to be drawn from the data which were not obvious from the plots. Following slough breaching for example, chinook salmon mid-channel area velocity weighting factors at two similar discharges may have been about the same value. The two velocity frequency distributions, however, occasionally had median points falling on opposite sides of the peak in the velocity suitability function plot; hence, the implication of peak suitability between the two points and falling suitability (with increasing velocities) after. Similarly, the slight displacement of maximum suitabilities for high and low turbidity chinook salmon velocity values occasionally inferred refinements between the plots. For example, a downwards trend of the weighting factors (with increasing discharge) in a low turbidity plot could be used to project the slope of a downwards trend in the high turbidity plot at higher velocities where no data were available. Based on the shape of the composite weighting factor (f(c) x f(v)) plot, WUA curves were drawn to fit the data.

Weighting factors for flows well beyond those observed were estimated from the trends occurring in the cover and velocity data and from the shape of the suitability criteria curves. Accumulated field experience at the site, and comparisons to other sites where similar conditions existed were additional criteria used to make the projections. The velocity weighting factors extrapolated for side channels at high mainstem discharges are the most uncertain of these projections.

The last step in the data analysis was to calculate "habitat indices" for the species. Habitat indices were calculated as the WUA divided by the surface area present in the study site sampling grid at a mainstem discharge of 23,000 cfs. The 23,000 cfs figure was chosen because it is a representative summer streamflow and it also may be integrated with macrohabitat abundance information provided by E. Woody Trihey and Associates from aerial photographs of the upper Susitna reach at this discharge.

The individual cell measurements and weighting factor plots are not presented in this report. Bound volumes of the data can be obtained for inspection at the Susitna Hydro Aquatic Studies office.

During the analytical process the data base was screened for errors and inconsistencies. Some data collected at closely related mainstem flows were averaged to eliminate scatter not related to mainstem discharges. The largest single change made to the raw data was to substitute a representative mean cell cover value for the individual (instantaneous) mid-channel cell readings. The desirability for this change arose because of the considerable difficulty with consistently determining substrate cover values in deep, rapid or turbid water mid-channel cell areas. Roughly 750 habitat cells were characterized for the analysis. Several field observations were changed because we believed they were recorded erroneously.

2.2.3 Model verification

Data on fish abundance and distribution were collected at the sites to validate WUA projections. However, time constraints prevented an intensive sampling effort. A composite weighting factor was calculated for each cell sampled for fish and this factor was correlated with fish catch in the cell. If cells with high composite weighting factors are associated with higher densities of fish as expressed in the catch, then it can be assumed that if changes in mainstem discharge raise or lower an entire site's composite weighting factor, the associated potential for fish use will also be raised or lowered.

In order to test for a relationship between cell composite weighting factors and fish catch, the following procedures were carried out. The composite weighting factor in each cell was calculated by multiplying suitability values for cover and velocity together. Coho and chinook catches were transformed by natural log (X+1) in an attempt to normalize variances. Pearson correlation coefficients were then calculated between the composite weighting factor and coho and chinook catch by cell. For chum and sockeye, chi-square contingency tables were run between proportional presence and composite weighting factor value intervals (to test for associations between these two factors). Sampling occasions when less than three fish were captured in all the cells within a site (in a day of sampling) were deleted from analysis. This was done because low densities of fish are often due to seasonal movements rather than to within site habitat conditions. If fish sampling data from sites without fish were used in a correlation analysis, the correlations might become statistically insignificant even if the correlations between composite weighting factor and fish catch were large.

3.0 RESULTS

3.1 Surface Areas

The total wetted surface areas at each site are plotted as a function of mainstem Susitna River discharge on Figures 4 through 10. These figures also contain schematic notes concerning important changes which occurred over the range of flows which were observed. The range of surface areas calculated from observational data are highlighted with solid lines. Extrapolated data are noted with dotted lines.

The total weighted usable areas (WUA's) calculated for the species at sites where fisheries data support projecting habitat use are presented in Section 3.2 through 3.7. The total weighted usable areas projected for each site and species at mainstem discharge increments of 3,000 cfs are also tabulated in Appendix A.

3.2 Side Channel 10A

Chinook salmon were the only juvenile species captured in abundance at this site. Because suitability functions for cover, velocity, and depth at turbidities above and below 30 NTU were different for this species of juvenile salmon, WUA projections for high and low turbidity mainstem flows are calculated (Figure 11). All WUA units are in square feet. The solid line labelled "calibrated range" in the WUA plots is the estimated WUA at observed flows. The dotted line labelled "extrapolated range" is the extrapolated WUA at flows which were not observed during the open water season of 1983. The total weighted usable area in each plot is the sum of the WUA's calculated for the shoreline and mid-channel areas of the study site. At any mainstem discharge, the WUA for the shoreline or mid-channel area is the product of the weighting factors WF(c) and WF(v) and the surface area for the shoreline or mid-channel area at that mainstem discharge. The weighting factor plots calculated for this species and site under high and low turbidity mainstem flow conditions are included here (Figures 12 and 13) as an example. Weighting factor plots for the other sites are available at the Su Hydro Aquatic Studies office.

The difference between the WUA's projected for high and low turbidity conditions reflects the differences in suitability for the cover and velocity values measured at the study site over the range of observed and extrapolated mainstem flows. Especially noticeable are the effects of suitability for cover: under the low turbidity condition the weighting factors (and thus the WUA's) are greatly reduced. Similarly, the difference in the shape of the velocity weighting factor curves for the two turbidity conditions explains much of the differences between the shapes of the two plots.

3.3 Slough 22

Chinook salmon were the only juvenile species captured in abundance at this site. Weighted usable area projections for juvenile chinook salmon were calculated for both high and low mainstem turbidities (Figure 14). At mainstem flows above 20,200 cfs, the head of this slough is

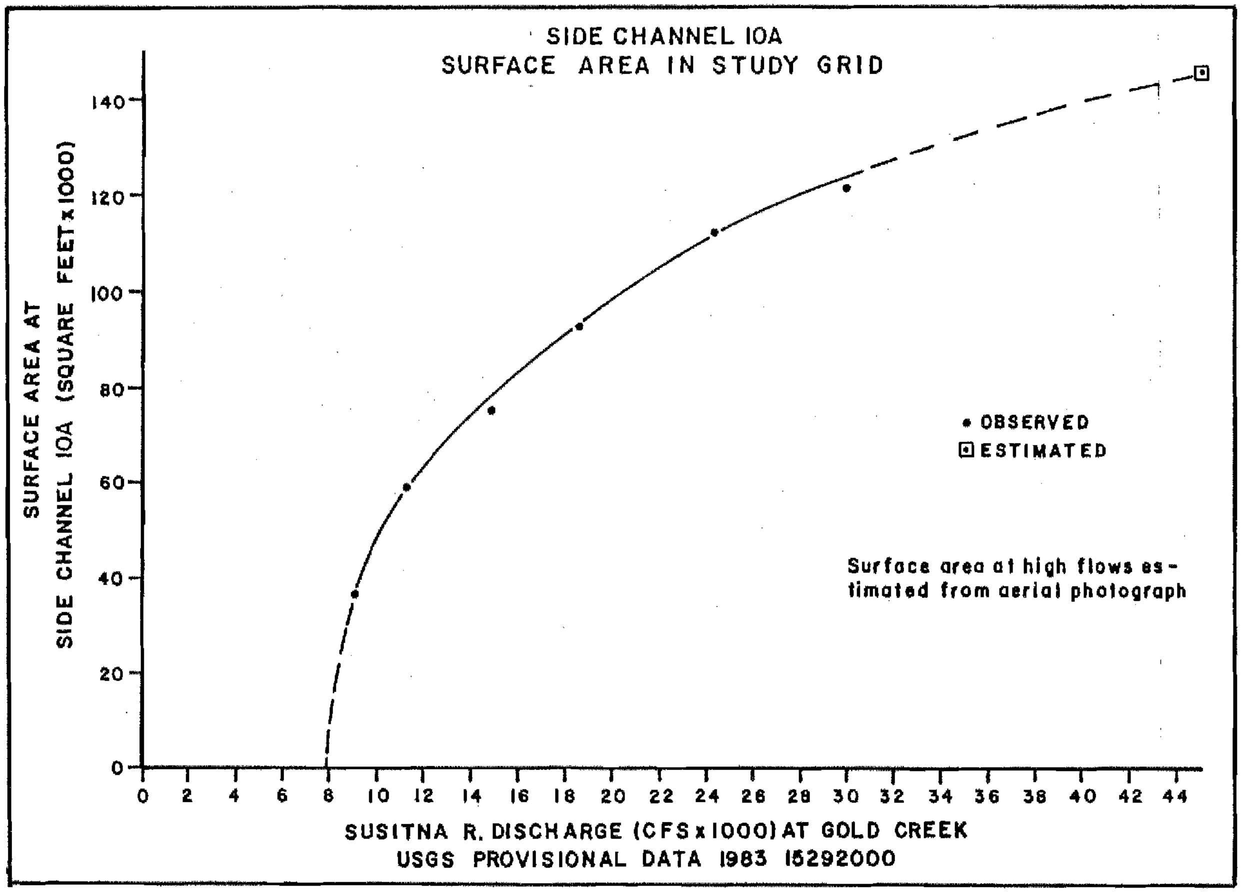


Figure 4. Total wetted surface areas measured and extrapolated in the Side Channel 10A habitat model study site.

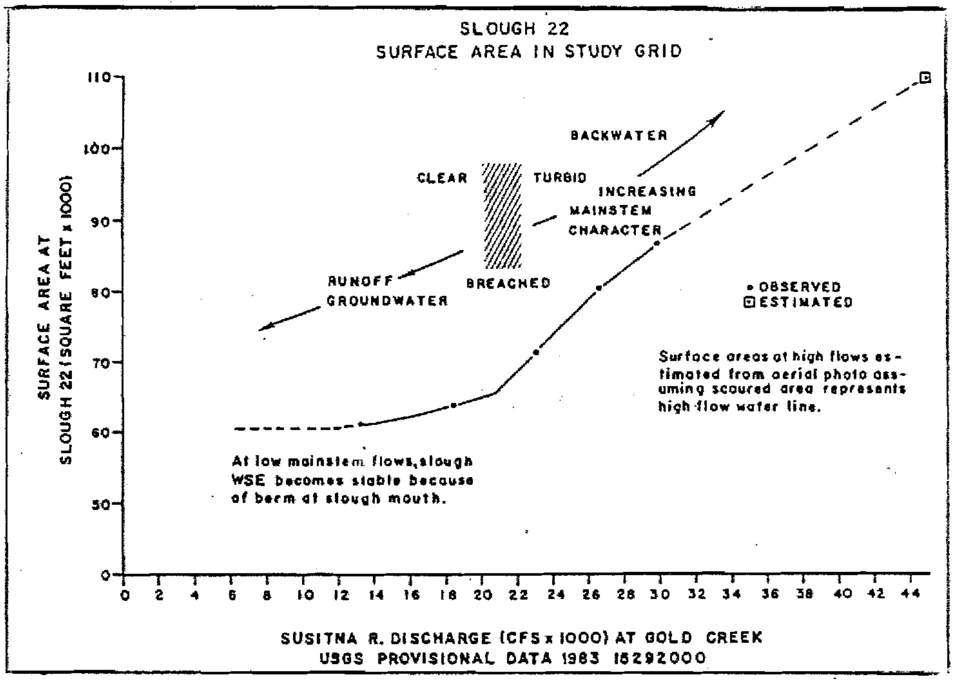


Figure 5. Total wetted surface areas measured and extrapolated in the Slough 22 habitat model study sites.

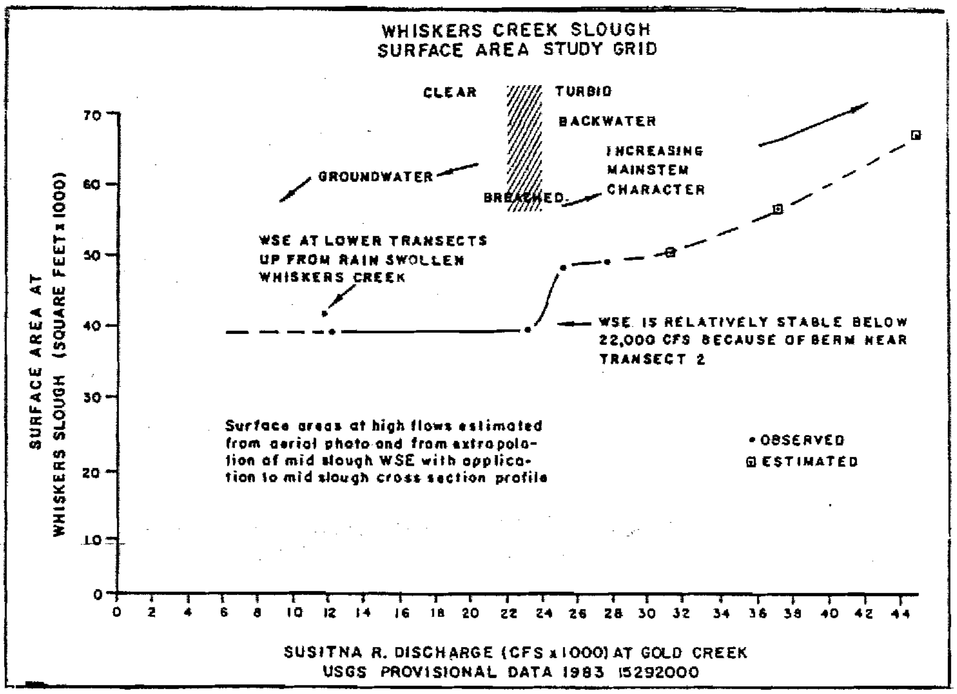


Figure 6. Total wetted surface areas measured and extrapolated in the Whiskers Creek Slough habitat model study site.

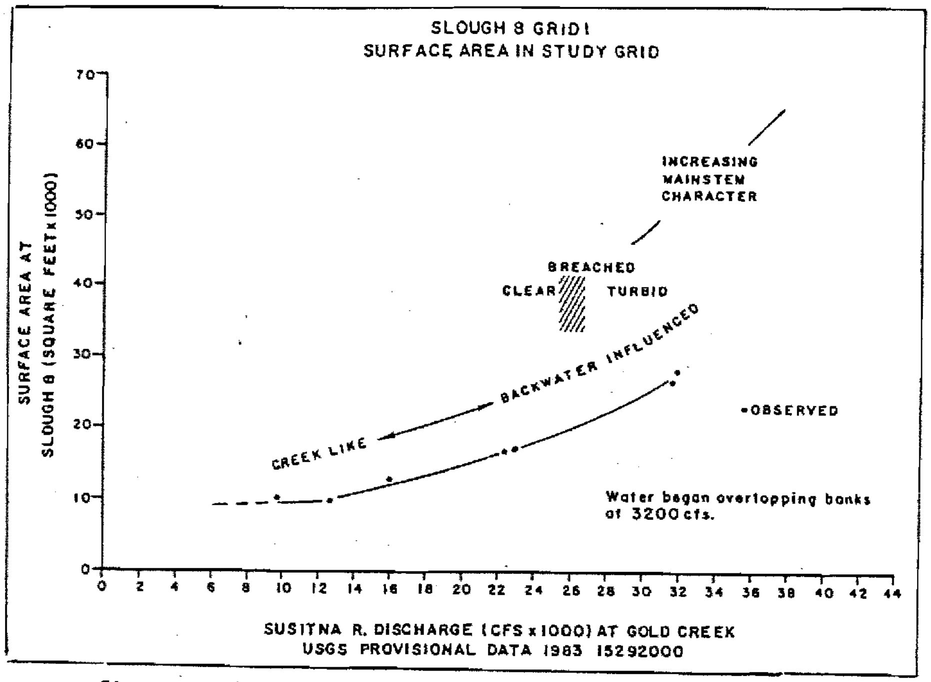


Figure 7. Total wetted surface areas measured and extrapolated in the Slough 8 grid 1 habitat model study site.

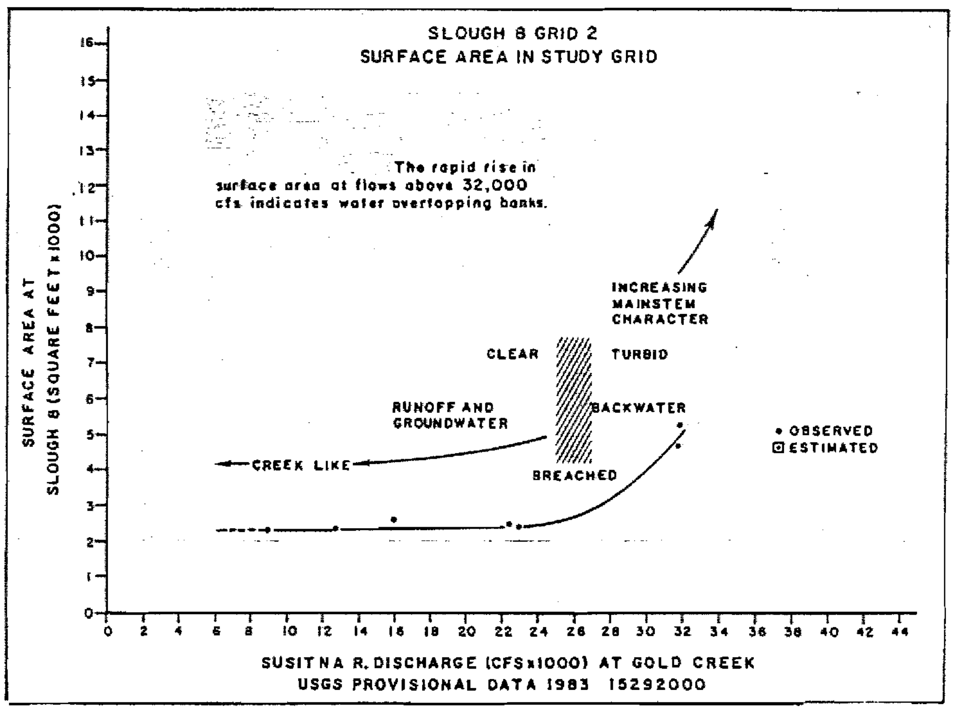


Figure 8. Total wetted surface areas measured and extrapolated in the Slough 8 grid 2 habitat model study site.

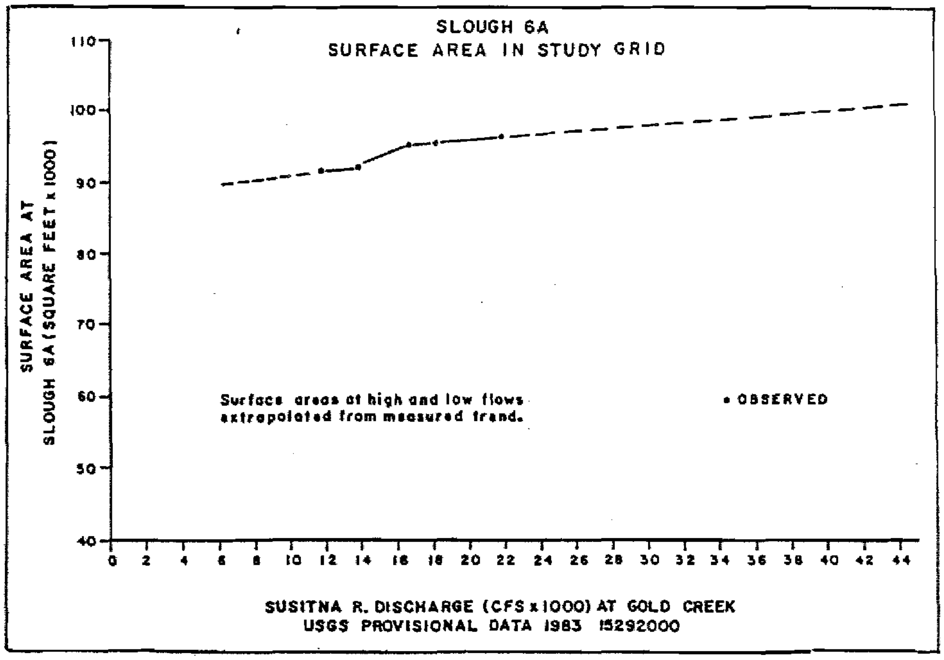


Figure 9. Total wetted surface areas measured and extrapolated in the Slough 6A habitat model study site.

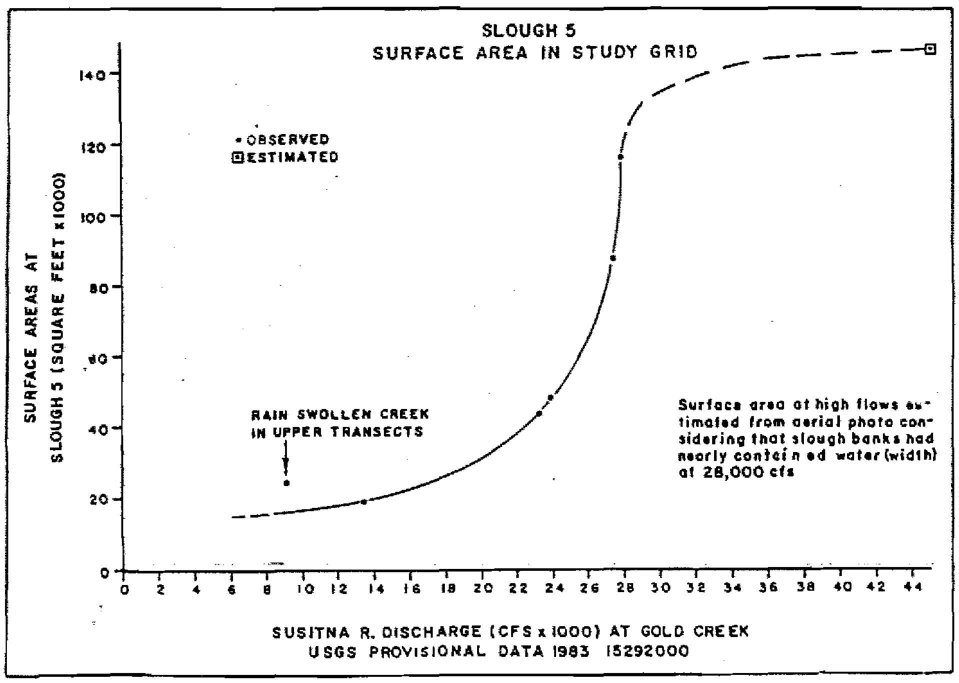


Figure 10. Total wetted surface areas measured and extrapolated in the Slough 5 habitat model study site.

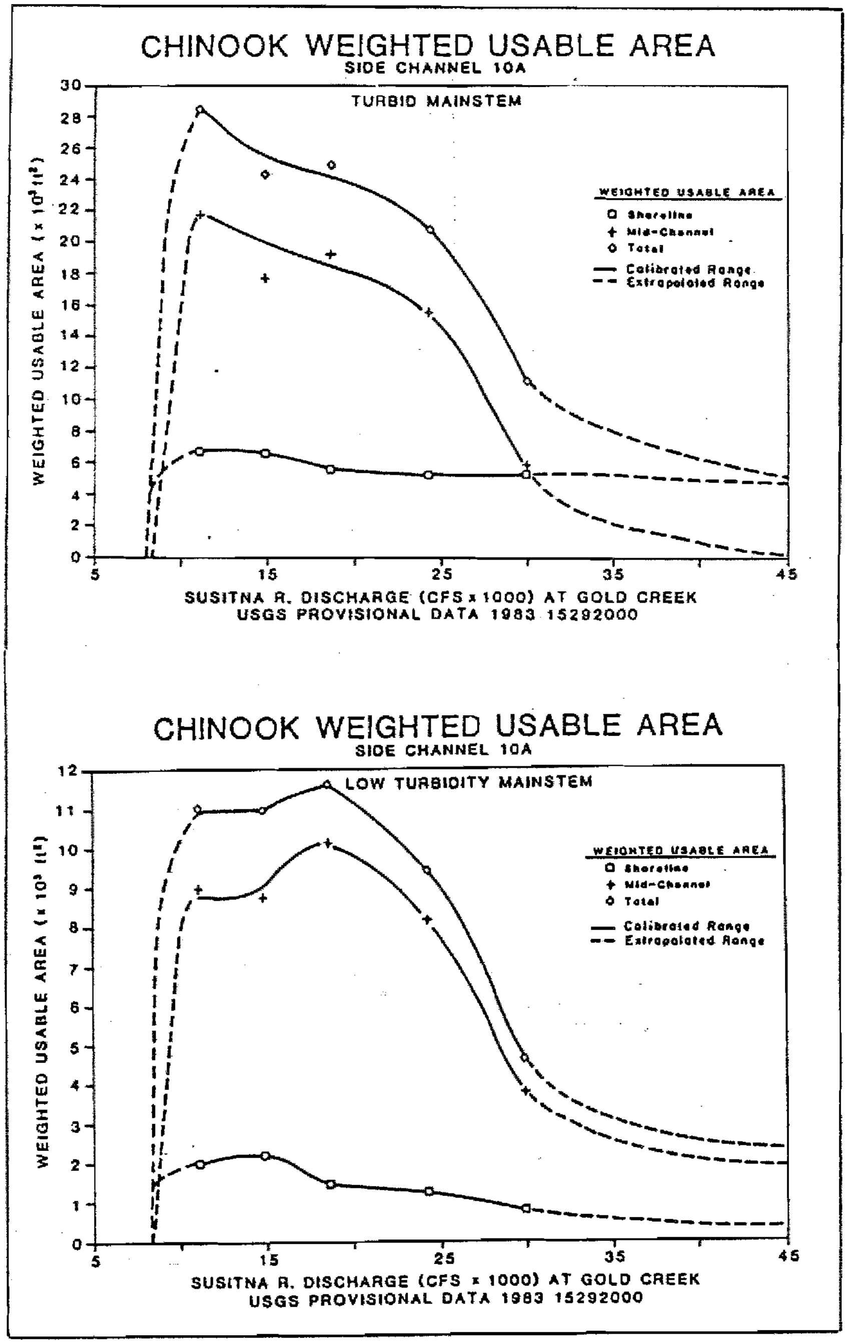


Figure 11. Weighted usable area projections for juvenile chinook salmon at the Side Channel 10A modelling site.

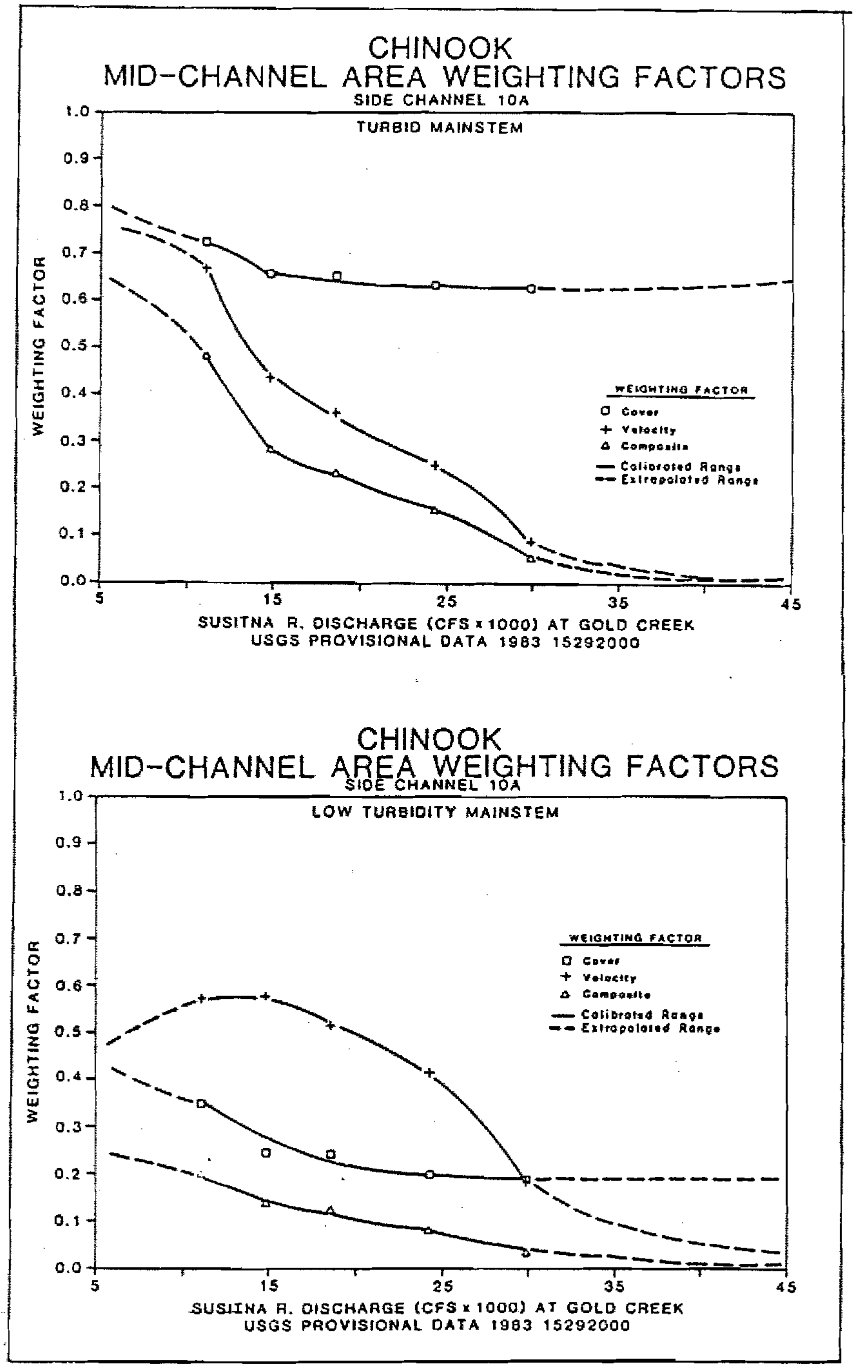


Figure 12. Mid-channel area weighting factors for juvenile chinook salmon at the Side Channel 10A modelling site.

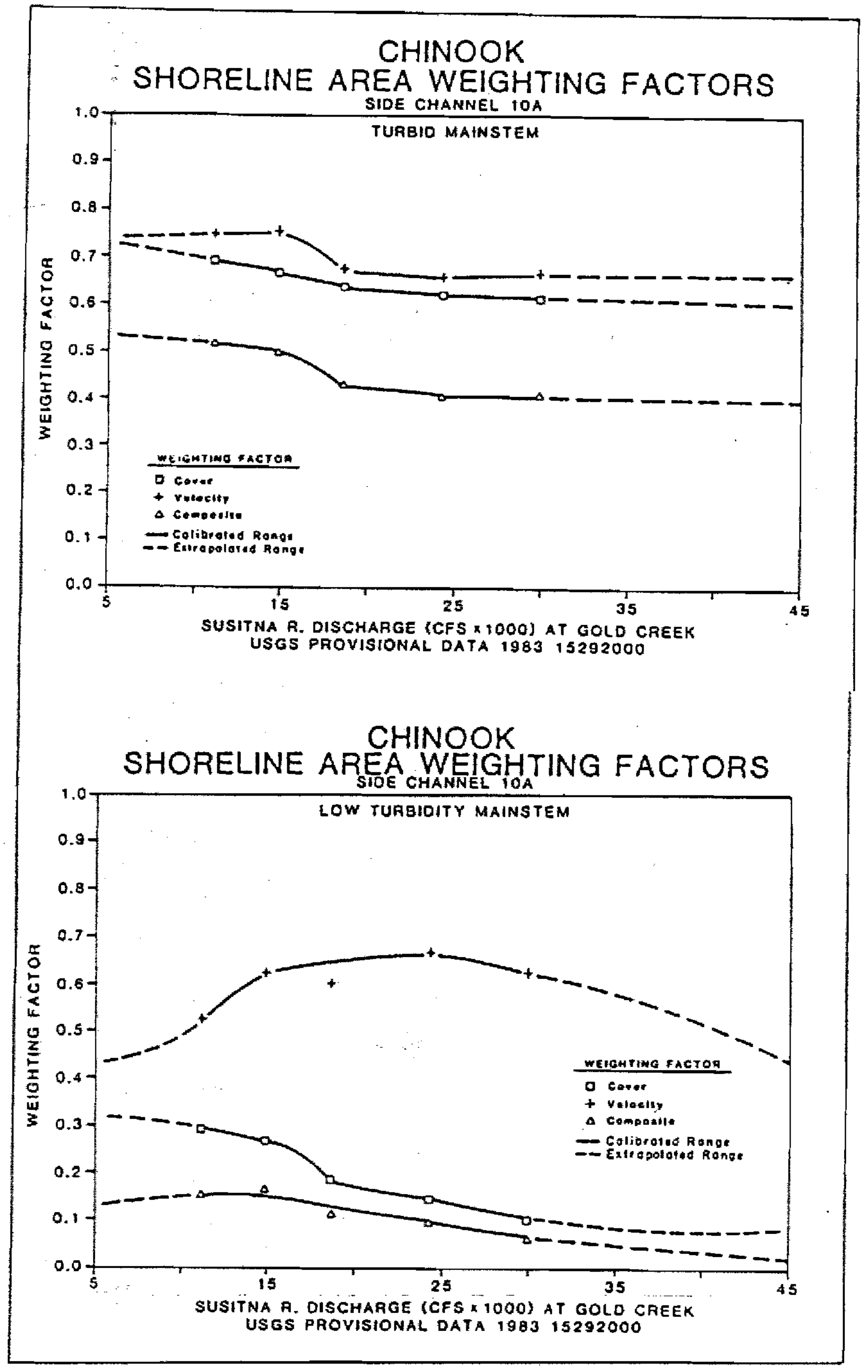


Figure 13. Shoreline area weighting factors for juvenile chinook salmon at the Side Channel 10A modelling site.

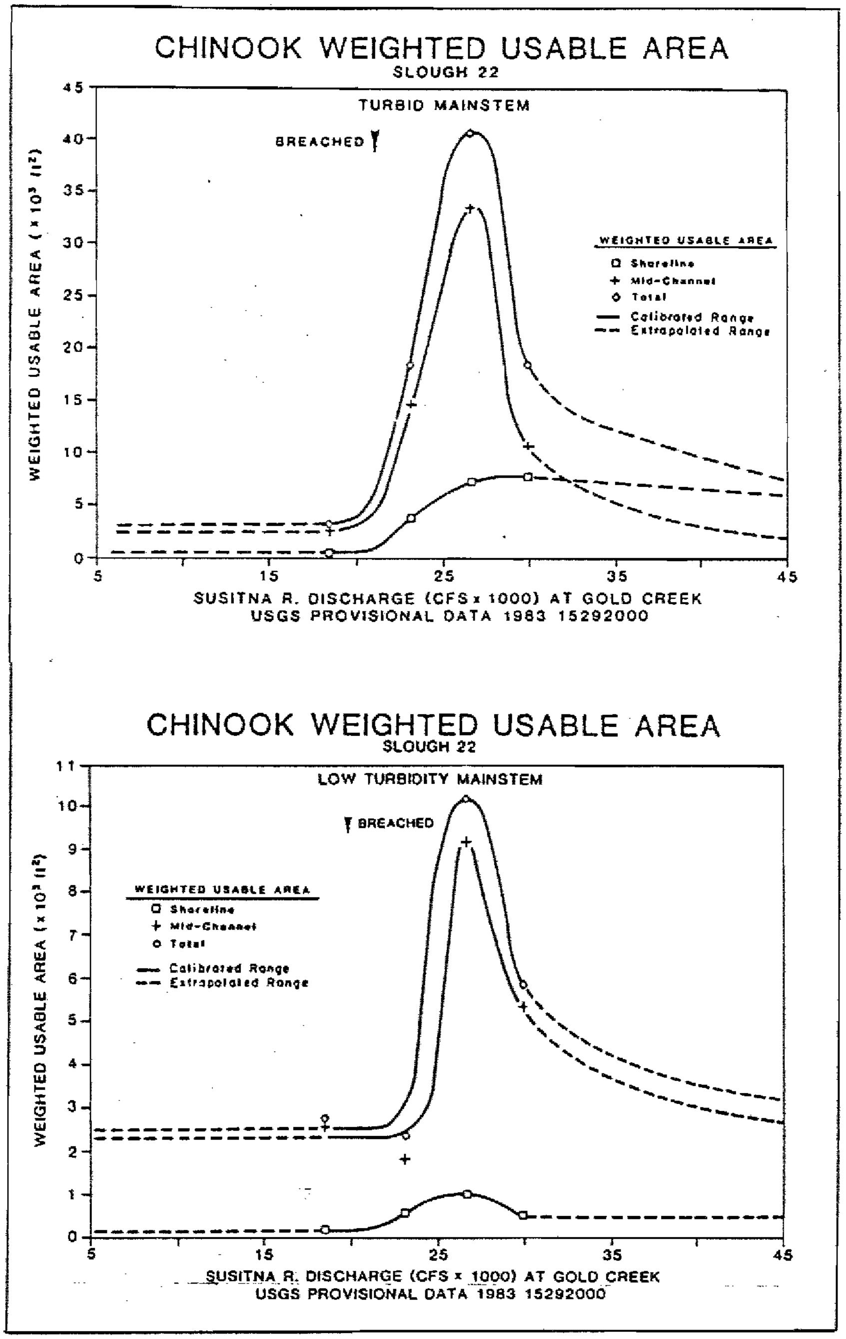


Figure 14. Weighted usable area projections for juvenile chinook salmon at the Slough 22 modelling site.

overtopped, and in both the low and high turbidity models WUA is affected by the changing velocity conditions. A greatly increased suitability for cover at the higher turbidity is again manifest in the projected WUA's.

3.4 Whiskers Creek Slough

The shapes of the weighted usable area plots projected for chinook salmon juveniles at this site (Figure 15) are very similar to those for the Slough 22 site. The Whiskers Slough site has more cover and hydraulically approaches mainstem conditions at a faster rate following the breaching event than does the site at Slough 22.

Weighted usable areas were also projected for coho salmon at this site (Figure 16). Preferences for different turbidity conditions for juvenile coho salmon were not demonstrated because of the lack of occurrence of juvenile coho at turbid sites. The WUA plots for this species do not reflect use of turbid conditions. Compared to chinook WUA's for the site, cohos WUA's are roughly 25% smaller under low turbidity slough conditions, and 50 to 80% smaller during either low or high turbidity side channel conditions.

3.5 Slough 8

Juvenile coho, sockeye, and chum salmon were captured in abundance at this site. Seventy-five percent of the chums were captured during the one sampling in May, so the seasonal mean catch/cell data presented in Table 2 for chum salmon are somewhat misleading. Modelling at mainstem discharges above the calibrated range was dropped for lack of supporting fisheries data and because projections for surface areas at high mainstem discharges were so uncertain that robust predictions for WUA's were impossible.

Weighted usable areas for coho, sockeye, and chum salmon in both study grids were calculated up to a mainstem discharge of 31,900 cfs (Figures 17 through 19). The shapes of these plots largely reflect velocity changes as backwater moved into and nearly covered the site before the head breached. The cover weighting factors however, are responsible for the very large differences in the WUA's calculated for each species. Weighted usable areas around 4,400 ft^2 for chum salmon are associated with mean cover weighting factors of 0.44 and 0.34 for the shoreline and mid-channel areas of the site, respectively. Weighted usable areas around 1,400 ft^2 for sockeye salmon are associated with mean cover factors of 0.27 and 0.12 for the shoreline and mid-channel areas of the site. The site is least suitable to coho. WUA's for that species are around 380 ft^2 with mean cover factors of 0.14 and 0.02 for the shoreline and mid-channel areas.

3.6 Slough 5

Slough 5 is an upland slough which is not normally connected with the mainstem Susitna River except at its mouth. Juvenile coho and sockeye salmon were captured in moderate abundance at this site. At mainstem

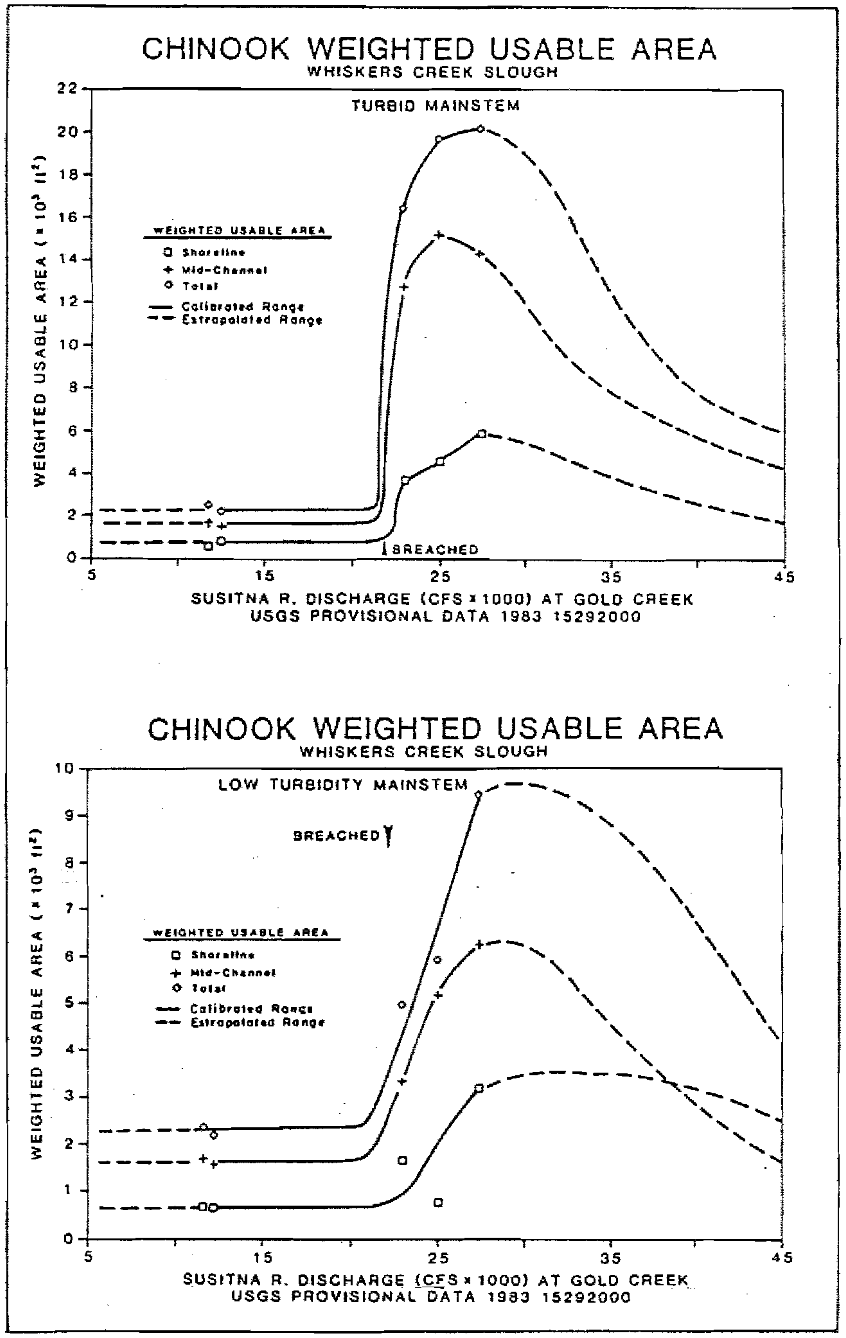


Figure 15. Weighted usable area projections for juvenile chinook salmon at the Whiskers Creek Slough modelling site.

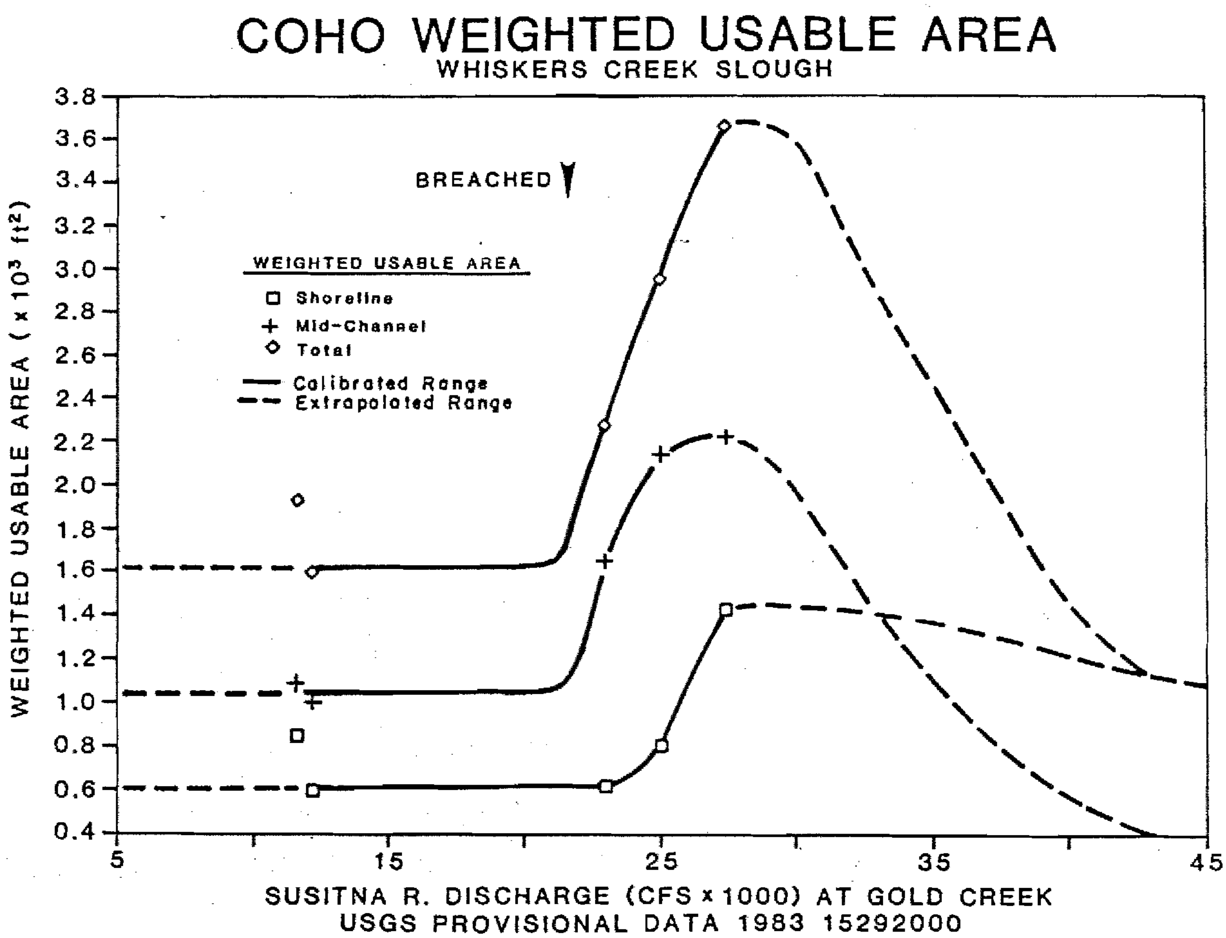


Figure 16. Weighted usable area projections for juvenile coho salmon at the Whiskers Creek Slough modelling site.

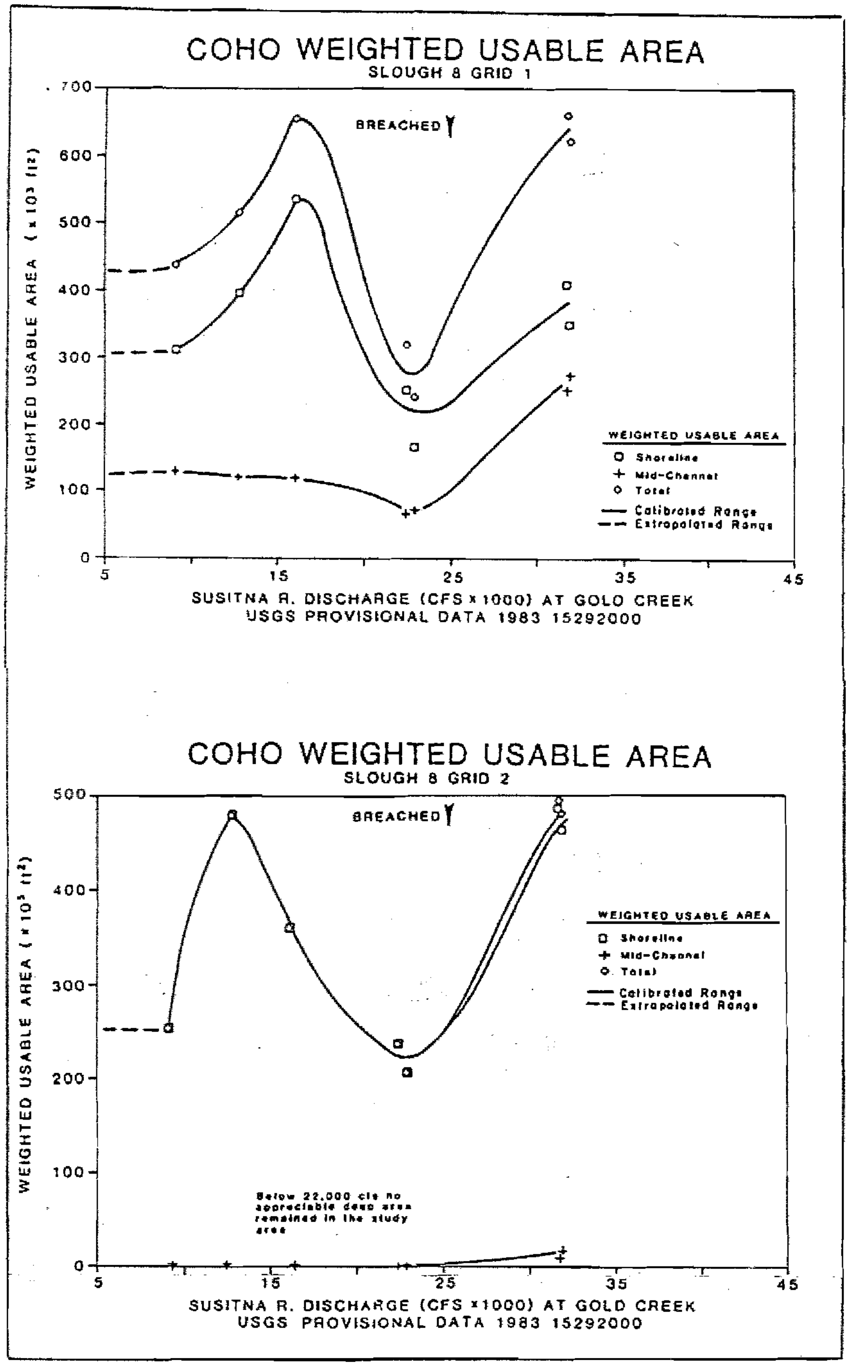


Figure 17. Weighted usable area projections for juvenile coho salmon at the Slough 8 modelling site.

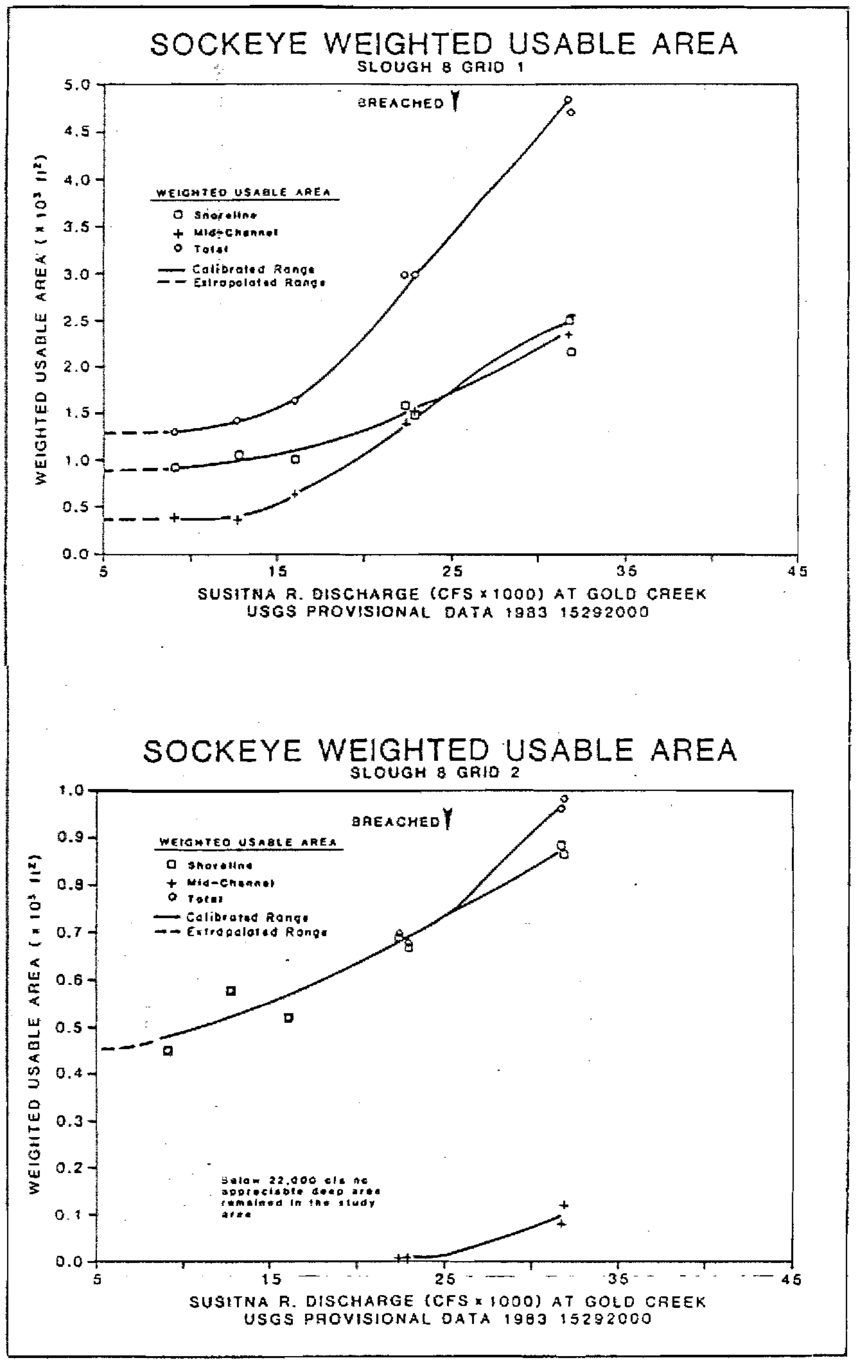


Figure 18. Weighted usable area projections for juvenile sockeye salmon at the Slough 8 modelling site.

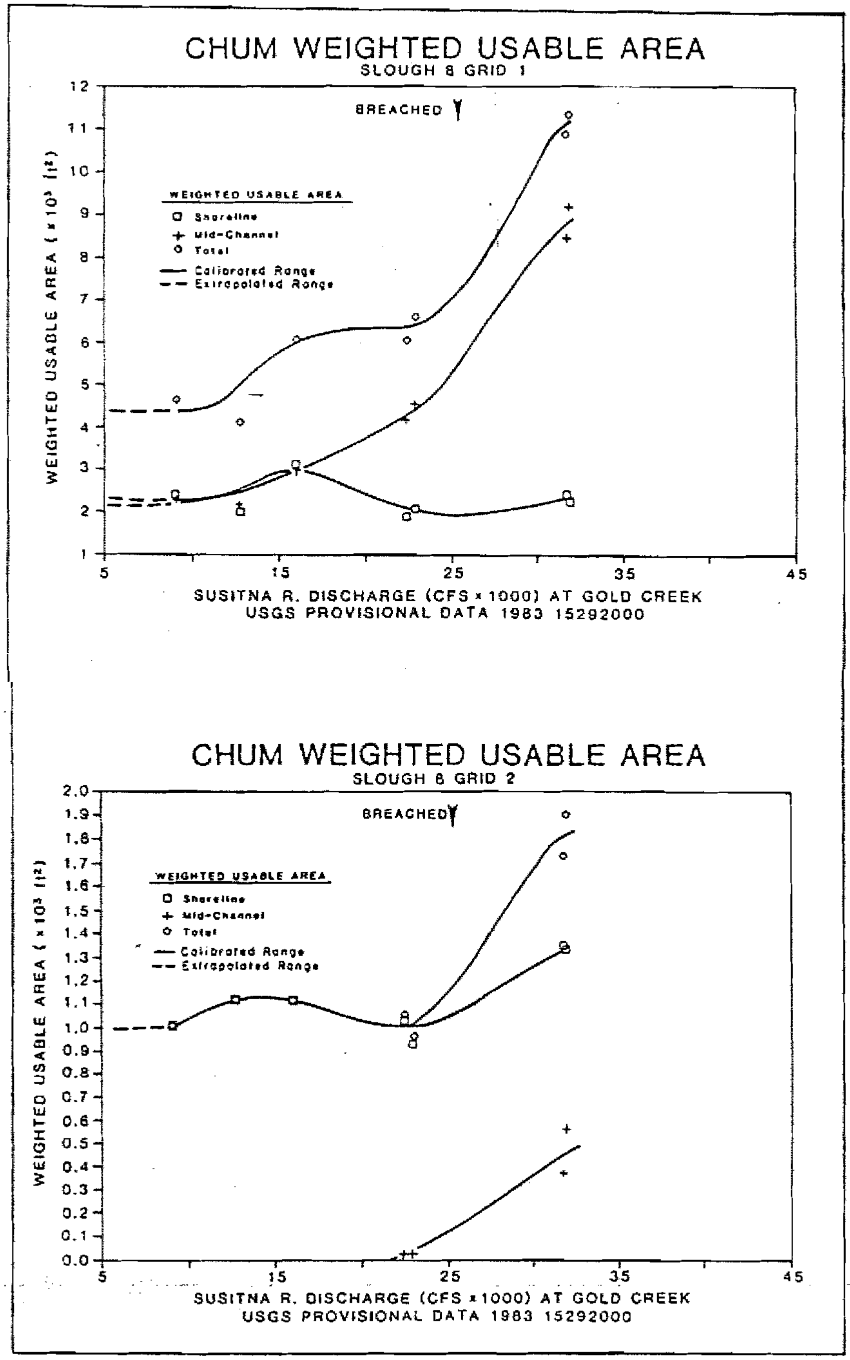


Figure 19. Weighted usable area projections for juvenile chum salmon at the Slough 8 modelling site.

discharges under about 15,000 cfs, the majority of Slough 5's wetted surface is divided between a steep-sided channel at the mouth and a shallow meandering stream, often only a few feet in width. At higher discharges, rising backwater progressively floods large areas of the study site. The increase in WUA for both species, with increasing mainstem stage, was projected to be lower than the physical measurements indicated (Figure 20). The downwards adjustment of WUA's was made to reflect less than optimal conditions which existed following the initial flooding event when submerged vegetation was so dense that it restricted juvenile movements and caused the water to stagnate. Because increasing water depths improved habitat conditions in the flooded areas, the weighted usable areas indicated by the physical data at mainstem discharges around 28,000 cfs were used for the species at 45,000 cfs. This adjustment is reflected in the projected cover indices at discharges greater than 25,000 cfs. Relatively lower velocity and cover weighting factors are responsible for the lower WUA's calculated for cohos than those calculated for sockeye at this site.

3.7 Slough 6A

Slough 6A is an upland slough with steep banks which prevent large changes in surface areas from occurring over the range of mainstem discharges observed. All species of juvenile salmon except pink salmon were captured at the site, although only coho and sockeye juveniles were captured in abundance relative to catches at other sites.

Smaller WUA's for both species (Figure 21) at mainstem discharges below 25,000 cfs reflect loss of cover in the shoreline areas of the site. Differences in the magnitude of the cover and velocity weighting factors in all areas of the site are responsible for the much lower overall suitabilities calculated for coho juveniles.

3.8 Model Verification

Strong positive (i.e., significantly greater than 0.0) correlations between coho and chinook catch and combined weighting factors by cell were found for most sites modelled (Table 3). Correlations between chinook catch and combined weighting factors in low turbidity waters ranged from 0.61 to 0.81. In high turbidity water, the correlations were much lower in absolute value and sometimes not significant by site at the 0.05 level although the correlation coefficient for the sites pooled was highly significant. Coho salmon catches were significantly correlated with combined weighting factors at all sites, and ranged from 0.48 to 0.63.

Sockeye proportional presence was strongly associated with large values of the combined weighting factor (Table 4). Chum salmon were not significantly associated with the combined weighting factors but the sampling effort was very small.

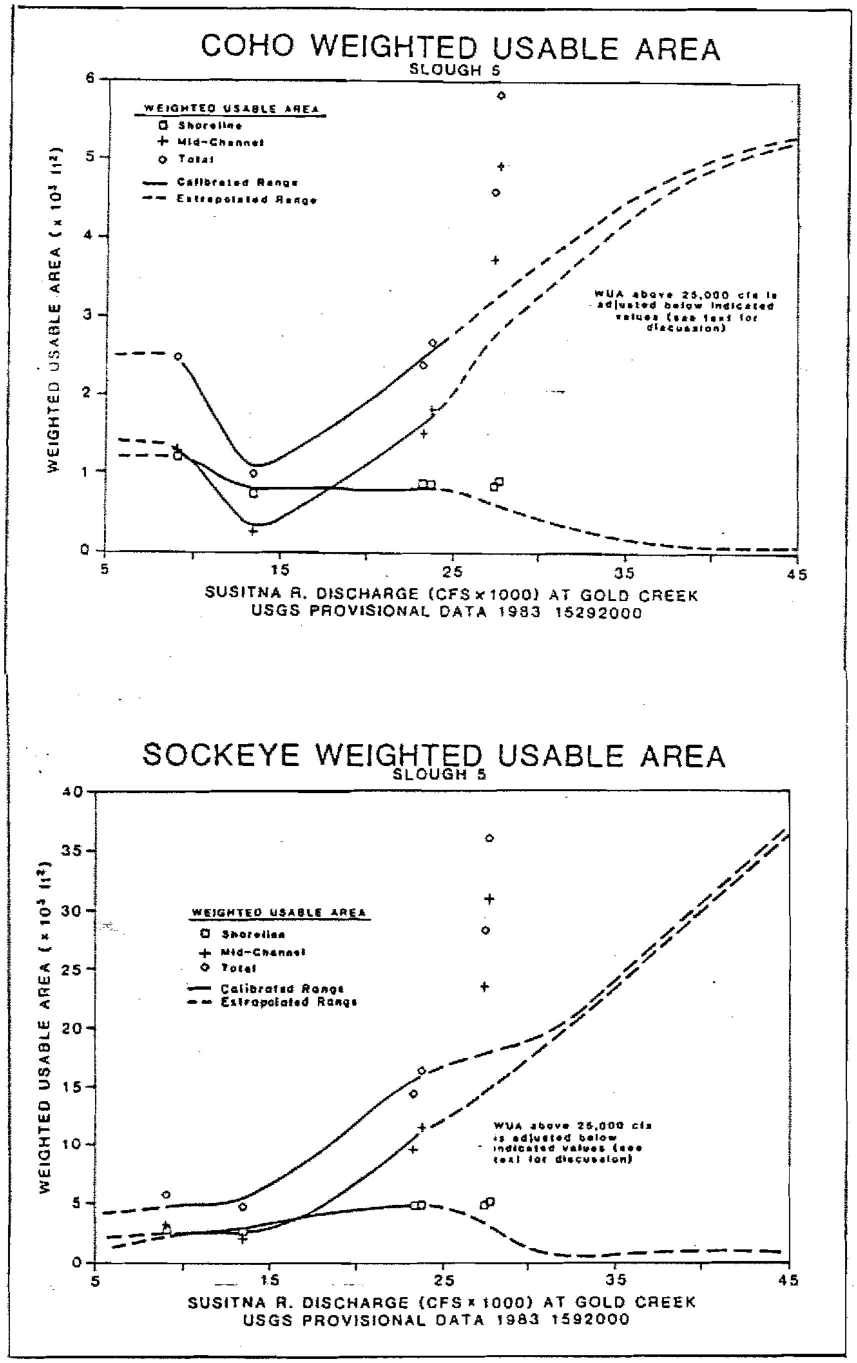
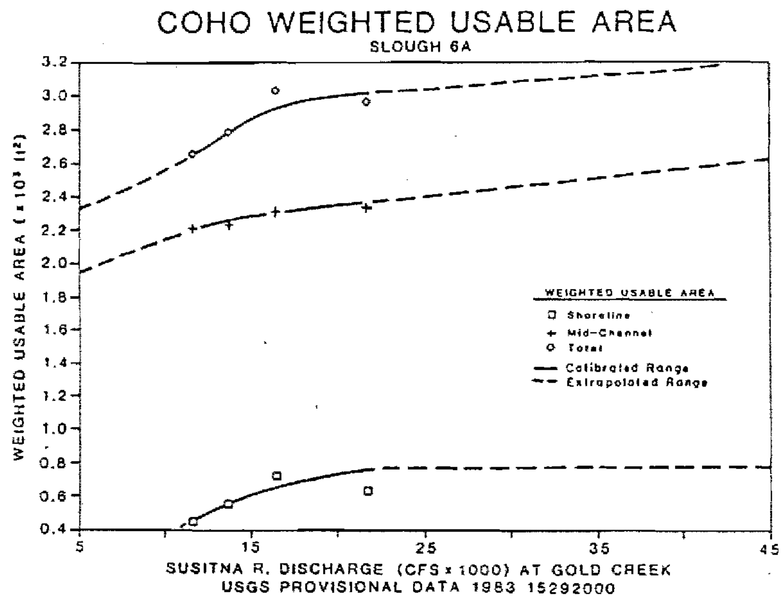


Figure 20. Weighted usable area projections for juvenile coho and sockeye salmon at the Slough 5 modelling site.



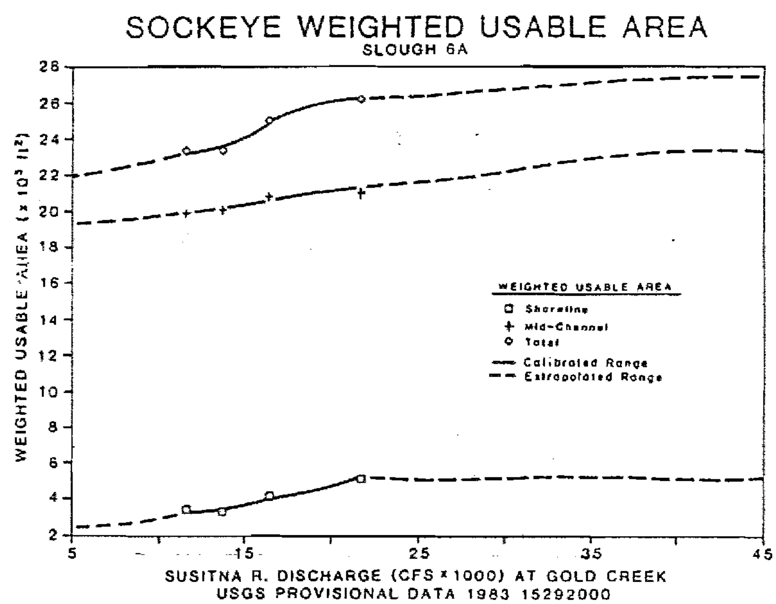


Figure 21. Weighted usable area projections for juvenile coho and sockeye salmon at the Slough 6A modelling site.

Table 3. Correlations between composite weighting factors and catch transformed by natural log (X+1) for juvenile coho and chinook salmon by site and by all sites pooled.

	Chinook					
	Low Turbidity (≤ 30 NTU)			High Turbidity (> 30 NTU)		
	n	r	Sig[a]	n	r	Sig
Whiskers Creek Slough	30	0.61	0.001	37	0.40	0.066
Slough 22	35	0.81	0.001	17	0.73	0.001
Side Channel 10A	14	0.77	0.001	50	0.19	0.065
Pooled	79	0.72	0.001	104	0.29	0.009

	Coho		
	n	r	Sig
Whiskers Creek Slough	67	0.48	0.001
Slough 6A	62	0.50	0.001
Slough 8	51	0.63	0.001
Slough 5	39	0.58	0.001
Pooled	219	0.45	0.001

[a] Significance level for rejection of hypothesis that there is a positive correlation between composite weighting factors and catch.

Table 4. Chi-square contingency tests of juvenile sockeye and chum salmon proportional presence by composite weighting factor intervals.

Sockeye (Data from Sloughs 8, 6A, and 5 pooled)

Combined weighting factor interval	No. of cells Present	Absent	Total	Proportion Present
0.03-0.12	6	30	36	0.17
0.13-0.22	12	25	37	0.32
0.23-1.00	24	15	39	0.62

$X^2 = 16.7$ df = 2
Significant at $P < 0.001$

Chum (Data from Slough 8)

Combined weighting factor interval	No. of cells Present	Absent	Total	Proportion Present
0.24-0.34	4	4	8	0.50
0.41-0.66	5	5	10	0.50

$X^2 = 0.0$ df = 1
Not significant at 0.05 level

4.0 DISCUSSION

The weighted usable area models for juvenile salmon at critical upland slough, side slough, and side channel habitat locations indicate that both species-specific and site-specific trends exist. The trends reflect fish suitability for hydraulic conditions, including changes in surface area. Significantly, most of the weighted usable area estimates are affected strongly by the availability of suitable cover. In the environments modelled, suitable cover for juvenile chinook salmon includes turbidity. In all three side channel habitats, peaking of the weighted usable area function occurs in a narrow range of flows which occur following the overtopping event. In side and upland slough habitats, the changes in WUA values for all juvenile salmon species are related to mainstem backwater effects.

Habitat indices were calculated from the smoothed WUA projections (Appendix A). In this calculation, the weighted usable areas interpolated at 3,000 cfs increments of mainstem discharge are expressed as the fraction of the total area available at the site when mainstem discharge was 23,000 cfs. Plotting these normalized values as a function of mainstem discharge results in habitat indices by macrohabitat type for each juvenile salmon species. Habitat index values are compared with the IFG modelling results in Part 7 of this report.

4.1 Chinook Salmon

Juvenile chinook habitat was modelled at three study sites for turbidity levels above and below 30 NTU (Figure 22). The difference in habitat index values for the two turbidity conditions largely reflects the differences in suitability for cover at the sites. Slough 22 appears roughly as usable as Whiskers Creek Slough under turbid conditions but is much less usable with low turbidity flows. This reflects the relatively cover-poor environment at Slough 22. The shape of all three side channel plots shows that the available habitat becomes less suitable for juvenile chinooks as velocity increases at large mainstem discharges. Since each side channel habitat is breached by mainstem water at slightly different mainstem discharges, a larger sampling of side channels which are breached by mainstem water at different discharges is required to formulate average index values for a particular mainstem discharge.

4.2 Coho Salmon

Habitat indices for coho salmon at four sites are plotted in Figure 23. The habitat indices are much lower than those for chinook and reflect generally poor rearing habitat for coho in mainstem influenced environments of the Susitna River. The index for Slough 5 increases primarily because of a large increase in surface area of the site. These low indices in generally are primarily the result of a lack of suitable cover for coho.

The Whiskers Creek Slough site was unusual among the sites sampled because coho were captured there when turbid water was present. This was related to the proximity of the slough to a natal area, Whiskers Creek.

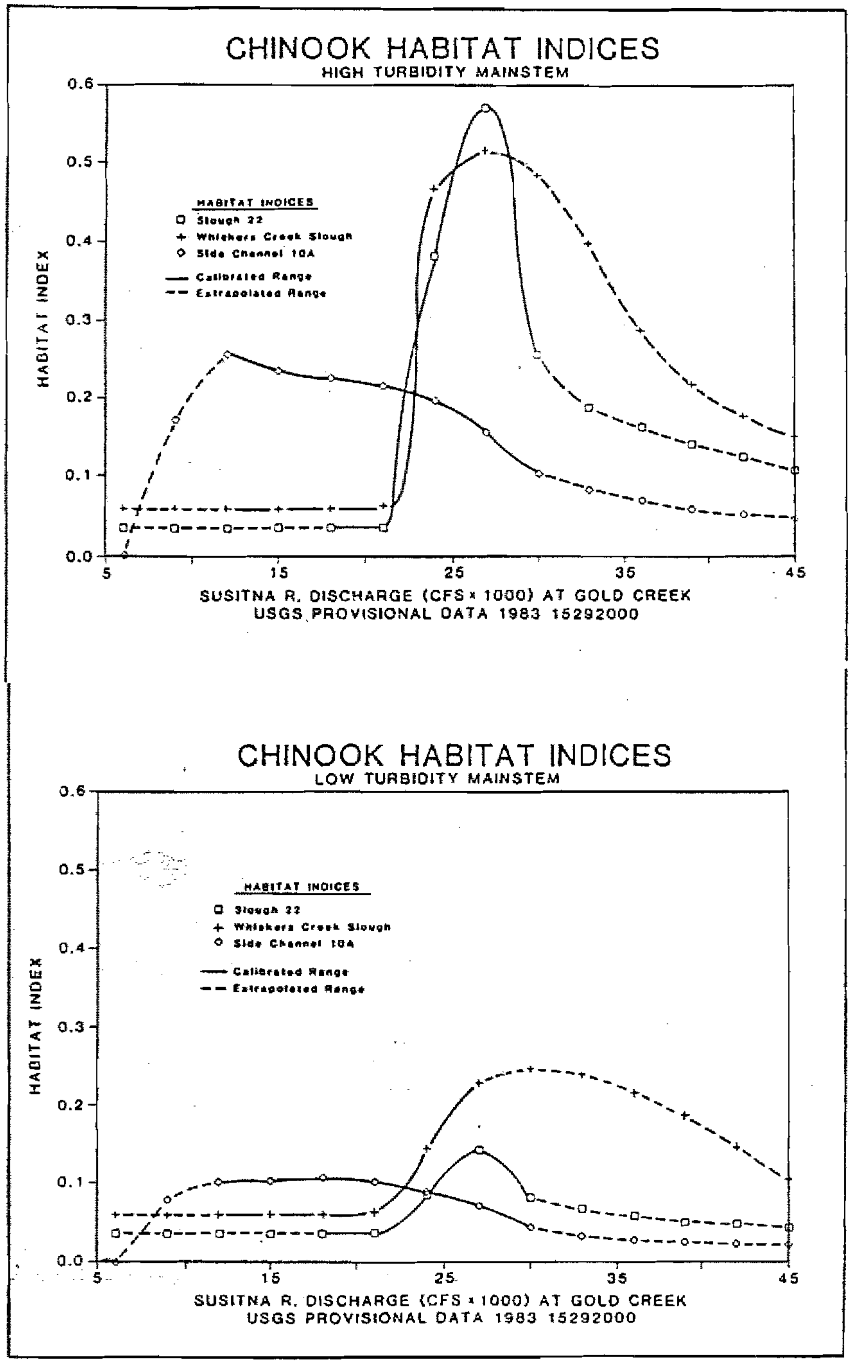


Figure 22. Habitat indices for juvenile chinook salmon.

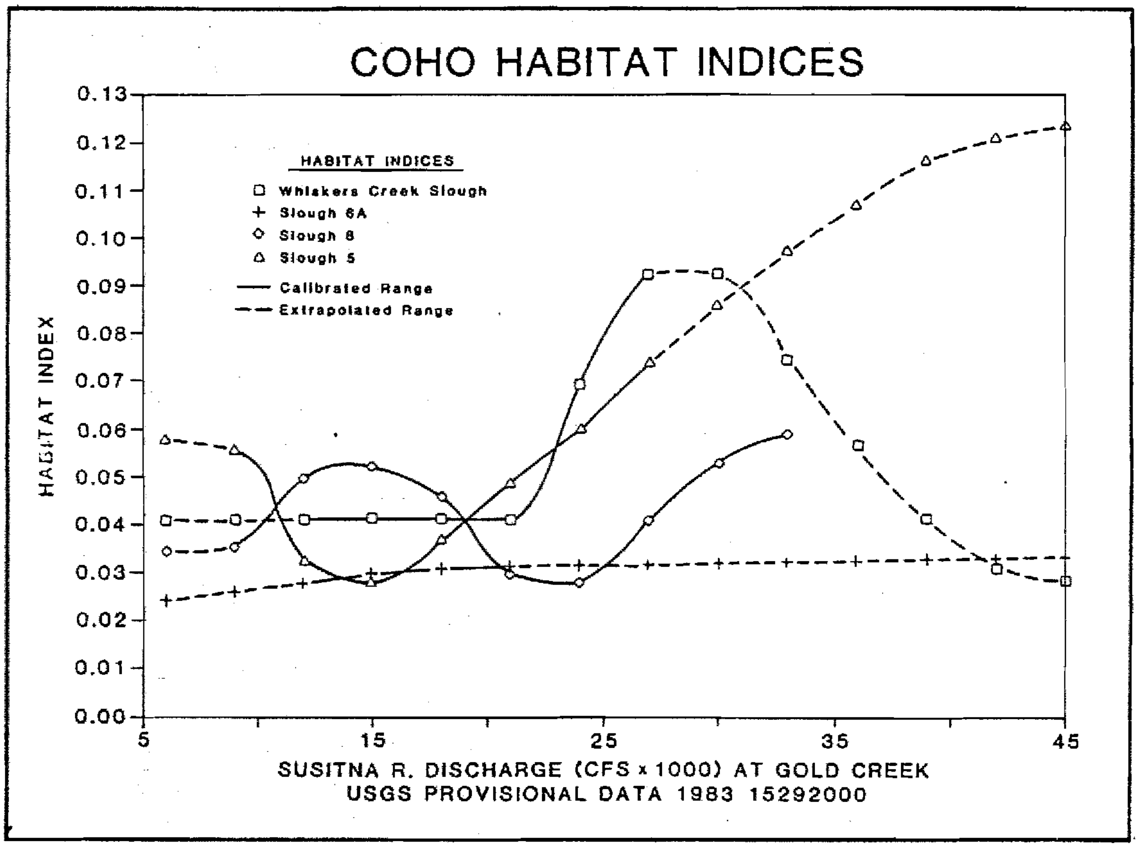


Figure 23. Habitat indices for juvenile coho salmon.

4.3 Sockeye and Chum Salmon

Sockeye salmon habitat indices increased with discharge over the modelled range (Figure 24). Upland sloughs (Slough 6A and 5) become increasingly important habitats for juvenile sockeye salmon as mainstem discharge increases due to the backwater effects. These two sloughs represent the extremes in changes of conditions possible for this type of habitat; Slough 6A has a steep banked, well defined channel and Slough 5 has very low gradient banks which are quickly overtopped by backwater. Only Slough 8 was modelled for chum salmon and the habitat index increased with mainstem discharge (Figure 25). With further increases in mainstem discharge, however, the indices for both chum and sockeye at Slough 8 would decline due to velocity becoming important in limiting distribution.

4.4 Limitations of the Models Regarding Methodology

The methods employed in this study were intended to provide a rapid and quantitative estimation of the overall effects of mainstem Susitna River discharge on the suitability of selected rearing habitats for juvenile salmon. Simultaneously, IFG-2 and IFG-4 models were developed at companion side slough and side channel sites (Part 7). Because habitat parameters were measured at only three cells along each transect in this study, we do not expect that these predictions will provide the same degree of resolution that will result from using well calibrated multi-cell hydraulic models.

The WUA calculations projected for mainstem flows not observed are generally subject to review. In the case of projections for low mainstem flows at side sloughs, however, conditions were nearly static so that extrapolations to 6,000 cfs (mainstem discharge) are reasonably solid. In contrast, forecasts for high flow conditions at mainstem side channels should be used as preliminary estimates.

However, we believe that in large glacial systems, like this reach of the Susitna River, catastrophic hydraulic events and the availability of cover are major factors related to the distribution and relative abundance of juvenile salmonids. Our model is designed to provide the resolution necessary to observe overall changes related to these phenomena, and we believe that it does.

4.5 Model Verification

Chinook salmon distribution in low turbidity waters was strongly correlated to the composite weighting factor index but the correlations for chinook salmon in turbid water were much lower. The lower correlations in turbid water may reflect gear efficiency problems because beach seines were used in turbid water and their efficiency varies

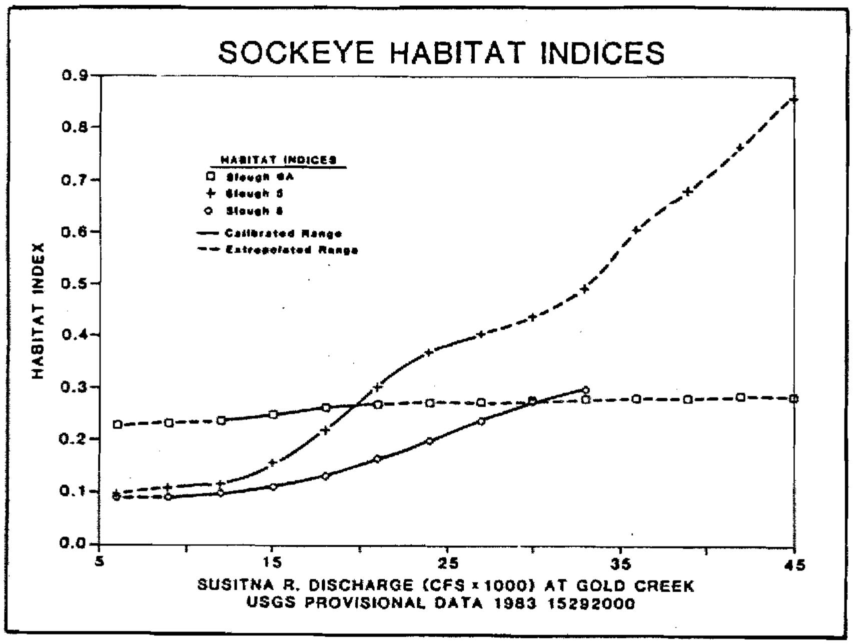


Figure 24. Habitat indices for juvenile sockeye salmon.

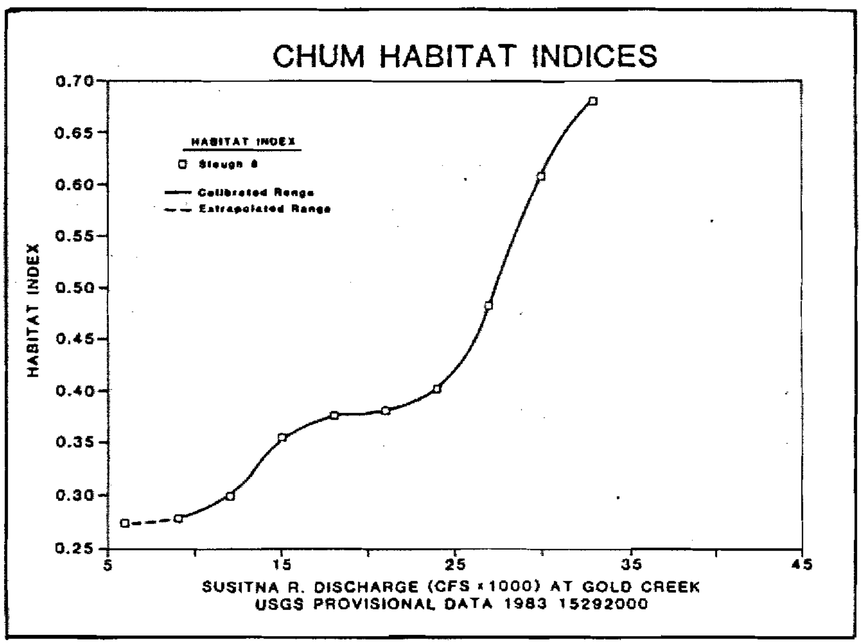


Figure 25. Habitat indices for juvenile chum salmon.

widely with cover type and other habitat conditions (Part 2 of this report). Electrofishing gear, used as a sampling method in clearer waters, was believed to be more reliable when sampling diverse habitat.

Coho and sockeye salmon also were correlated to or associated with the calculated composite weighting factors. Chum salmon catches were so limited at the six model sites that the relationship of composite weighting factors to fish use remains unproven. Factors such as season, of course, are strongly related to fish abundance and obscure the relationships. The analysis is also specific to the ice free months and no analyses of winter processes have been made. Since there is a positive relationship between the composite weighting factors and fish catch at the cell level and by inference between WUA and fish use at the site level, the models are verified on at least a general basis although many refinements in the model are possible.

5.0 CONTRIBUTORS

Woody Trihey and Steve Hale provided helpful discussions. Larry Dugan and Dave Sterritt helped collect the field data. Tommy Withrow, Jodi Miller, Pat Morrow, and Chris Kent installed our staff gages. Allen Bingham and staff managed the mainframe computer data base. Sally Donovan and Carol Riedner did the art work for the final copy. Woody Trihey, Allen Bingham, and Kathrin Zosel reviewed a draft of this paper and provided helpful comments.

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APPENDIX A

Weighted Usable Area and Habitat Indices Tablulated by Site and Species

Weighted usable area (WUA) and habitat index (HI) projections for species captured in abundance at the juvenile salmon rearing habitat model study sites during the summer of 1983 (Appendix Tables A1 through A6). The habitat index is calculated as the weighted usable area divided by the sites surface area at a mainstem Susitna River discharge of 23,000 cfs.

Appendix Table A-1. Weighted usable area and habitat indices for Side Channel 10A.

Mainstem Discharge (cfs)	Chinook Salmon			
	Turbidity WUA	30 NTU HI	Turbidity WUA	30 NTU HI
6,000*	0	0.000	0	0.000
9,000*	18,580	0.171	8,400	0.078
12,000	27,700	0.256	11,000	0.102
15,000	25,500	0.236	11,000	0.102
18,000	24,400	0.226	11,500	0.106
21,000	23,300	0.216	10,800	0.100
24,000	21,100	0.195	9,500	0.088
27,000	16,800	0.156	7,600	0.070
30,000	11,300	0.105	4,600	0.043
33,000*	9,000	0.083	3,500	0.032
36,000*	7,500	0.069	3,000	0.028
39,000*	6,400	0.059	2,700	0.025
42,000*	5,700	0.053	2,400	0.022
45,000*	5,100	0.047	2,300	0.021

The surface area at 23,000 cfs was 108,000 ft^2

* Data at this discharge extrapolated.

Appendix Table A-2. Weighted usable area and habitat indices for Slough 22.

Mainstem Discharge (CFS)	Chinook Salmon: Turbidity > 30 NTU WUA	HI	Turbidity ≤ 30 NTU WUA	HI
6000*	2500	0.035	2500	0.035
9000*	2500	0.035	2500	0.035
12000*	2500	0.035	2500	0.035
15000*	2500	0.035	2500	0.035
18000*	2500	0.035	2500	0.035
21000[a/]	2500	0.035	2500	0.035
24000[b/]	27100	0.382	6000	0.085
27000	40500	0.570	10100	0.142
30000	18200	0.256	5800	0.082
33000*	13300	0.187	4800	0.068
36000*	11500	0.162	4100	0.058
39000*	10000	0.141	3600	0.051
42000*	8800	0.124	3400	0.048
45000*	7600	0.107	3100	0.044

The surface area at 23,000 cfs was 71,000 ft.

a/ = Side slough condition

b/ = Side channel condition

*Data at this discharge extrapolated

Appendix Table A-3. Weighted usable area and habitat indice for Whiskers Creek Slough.

Mainstem Discharge (CFS)	Chinook Salmon: Turbidity > 30 NTU WUA	HI	Turbidity ≤ 30 NTU WUA	HI	Coho Salmon: All Turbidity WUA	HI
6000*	2300	0.059	2300	0.059	1600	0.041
9000*	2300	0.059	2300	0.059	1600	0.041
12000	2300	0.059	2300	0.059	1600	0.041
15000	2300	0.059	2300	0.059	1600	0.041
18000	2300	0.059	2300	0.059	1600	0.041
21000[a/]	2400	0.062	2400	0.062	1600	0.041
24000[b/]	18200	0.467	5600	0.144	2700	0.069
27000	20100	0.515	8900	0.228	3600	0.092
30000*	18900	0.485	9600	0.246	3600	0.092
33000*	15500	0.397	9300	0.238	2900	0.074
36000*	11200	0.287	8400	0.215	2200	0.056
39000*	8500	0.218	7300	0.187	1600	0.041
42000*	6900	0.177	5700	0.146	1200	0.031
45000*	5900	0.151	4100	0.105	1100	0.028

The surface area at 23,000 cfs was 39,000 ft.

a/ = Side slough condition

b/ = Side channel condition

*Data at this discharge extrapolated

Appendix Table A-4. Weighted usable area and habitat indices for Slough 8.

Mainstem Discharge (CFS)	Chum Salmon WUA	Chum Salmon HI	Coho Salmon WUA	Coho Salmon HI	Sockeye Salmon WUA	Sockeye Salmon HI
6000*	5300	0.273	670	0.035	1750	0.090
9000	5400	0.278	690	0.036	1780	0.092
12000	5800	0.299	960	0.049	1910	0.098
15000	6900	0.356	1010	0.052	2160	0.111
18000	7300	0.376	890	0.046	2550	0.131
21000	7400	0.381	580	0.030	3200	0.165
24000	7800	0.402	540	0.028	3860	0.199
27000	9350	0.482	790	0.041	4600	0.237
30000	11800	0.608	1020	0.053	5320	0.274
33000	13200	0.680	1140	0.059	5780	0.298

The surface area at 23,000 cfs was 19,400 ft^2.
*Data at this discharge extrapolated

Appendix Table A-5. Weighted usable area and habitat indices for Slough 5.

Mainstem Discharge (CFS)	Coho Salmon WUA	Coho Salmon HI	Sockeye Salmon WUA	Sockeye Salmon HI
6000*	2500	0.058	4200	0.098
9000	2400	0.056	4700	0.109
12000	1400	0.033	5000	0.116
15000	1200	0.028	6700	0.156
18000	1600	0.037	9400	0.219
21000	2100	0.049	13000	0.302
24000	2600	0.060	15900	0.370
27000	3200	0.074	17400	0.405
30000*	3700	0.086	18800	0.437
33000*	4200	0.098	21200	0.493
36000*	4600	0.107	26000	0.605
39000*	5000	0.116	29200	0.679
42000*	5200	0.121	32800	0.763
45000*	5300	0.123	36900	0.858

The surface area at 23,000 cfs was 43,000 ft.
*Data at this discharge extrapolated

Appendix Table A-6. Weighted usable area and habitat indices for Slough 6A.

Mainstem Discharge (cfs)	Coho Salmon WUA	Coho Salmon HI	Sockeye Salmon WUA	Sockeye Salmon HI
6,000*	2,350	0.024	22,000	0.227
9,000*	2,510	0.026	22,600	0.233
12,000	2,670	0.028	23,200	0.240
15,000	2,870	0.030	24,100	0.249
18,000	2,970	0.031	25,400	0.262
21,000	3,000	0.031	26,200	0.271
24,000*	3,020	0.031	26,400	0.273
27,000*	3,040	0.031	26,600	0.275
30,000*	3,060	0.032	26,900	0.278
33,000*	3,080	0.032	27,000	0.279
36,000*	3,110	0.032	27,200	0.281
39,000*	3,140	0.032	27,400	0.283
42,000*	3,170	0.033	27,500	0.284
45,000*	3,200	0.033	27,600	0.285

The surface area at 23,000 cfs was 96,800 ft^2
* Data at this discharge extrapolated.

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Part 4
Juvenile Salmon Rearing Habitat Models

ALASKA DEPARTMENT OF FISH AND GAME
SUSITNA HYDRO AQUATIC STUDIES

REPORT NO. 2

RESIDENT AND JUVENILE ANADROMOUS FISH
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