PART 7

Modelling Of Juvenile Salmon And Resident Fish Habitat

MODELLING OF JUVENILE SALMON AND RESIDENT FISH HABITAT

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ABSTRACT

Output from the Instream Flow Group hydraulic models of rearing habitat for juvenile salmon and resident species at seven sites in the Chulitna River confluence to Devil Canyon reach of the Susitna River leads to similar conclusions as those drawn from a habitat model developed by the Susitna Hydro Aquatic Studies group for six additional sites. Overtopping of side slough heads by mainstem discharge causes abrupt changes in rearing habitat which are of positive benefit for some species/life stages and negative for others. Rearing habitat for chinook salmon at the study sites is greatest when the head of the site is slightly overtopped, thus providing turbid water for cover and moderate water velocities. The portions of this reach which are directly influenced by the mainstem provide only limited rearing habitat for coho and sockeye salmon during the open water season, but are likely to be of major importance for all overwintering species. Resident species are associated with levels of turbidity, velocity, and food supply and in general are not abundant in side sloughs when the head is closed unless a tributary is present.

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1.0 INTRODUCTION

The effects of flow regulation on downstream fisheries have long been the subject of investigations whose goal was to predict the status of fisheries after development of hydro power or other types of instream flow regulation. The Instream Flow Incremental Methodology developed by the U.S. Fish and Wildlife Service (Bovee 1982) has gained wide acceptance and is the method most often applied to these types of studies. This method comprises the IFG (Instream Flow Group) PHABSIM (Physical Habitat Simulation System) and has been used in Alaska by Estes et al. (1980), Wilson et al. (1981), and ADF&G (1983a). The Susitna Hydro Aquatic Studies group has used this method for two seasons to simulate changes in available spawning habitat of chum and sockeye salmon as a function of mainstem discharge.

Beginning in the open water season of 1983, we used these IFG hydraulic models and another habitat model developed by ourselves (RJHAB) to investigate the effects of mainstem discharge variations on rearing habitat for juveniles of four species of salmon and juveniles and adults of several resident fish species in the Susitna River.

This paper presents the results of the IFG model habitat simulations for juvenile salmon and resident fishes, compares the IFG models with the RJHAB model (presented in Part 4 of this report), and discusses in general the usefulness and implications of these habitat models in understanding and predicting the effects of discharge changes on rearing habitat.

2.0 METHODS

2.1 Study Locations

Seven IFG model sites and six RJHAB sites located on the Susitna River reach extending from the Chulitna River confluence to Devil Canyon were modelled (Figure 1). Criteria used in IFG model site selection are detailed in Estes and Vincent-Lang (1984). Sloughs 8A, 9, and 21 were selected in 1982 to quantify the response of adult chum and sockeye salmon spawning habitat in sloughs to variations in mainstem discharge. These sloughs are representative of side sloughs in general and also contain critical spawning habitat. In 1983, four IFG side channel study sites were selected as representative sites for the study of responses of mainstem salmon spawning and rearing habitat to variations in mainstem discharge. The RJHAB sites were selected as representative or important juvenile salmon rearing sites (see Part 4 of this report).

Figure 2 shows the sites ordered by the mainstem discharge required to overtop the head of the sites. The two upland slough sites (Slough 5 and Slough 6A) are not included on this figure. It can be seen that, generally, sites which have heads overtopped more than 60% of the time have been named side channels; sites with less frequent overtopping have been called sloughs. All sites to the left of the vertical line were overtopped on more than half the days between June 1 and September 30. The mainstem discharge required to overtop the head of each site is as follows:

Site	Model	Overtopping Discharge [a]
Lower Side Channel 11	IFG-2	5,000
Side Channel 10A	RJHAB	9,000
Side Channel 21	IFG-4	9,000
Upper Side Channel 11	IFG-4	13,000
Slough 9	IFG-4	16,000
Slough 21	IFG-4	18,000 [b]
Side Channel 10	IFG-4	19,000
Slough 22	RJHAB	20,000
Whiskers Slough	RJHAB	22,000
Slough 8	RJHAB	25,000
Slough 8A	IFG-4	33,000
Slough 5	RJHAB	upland slough
Slough 6A	RJHAB	upland slough

a/ Cubic feet per second (cfs). Source: Estes and Vincent-Lang (1984).

b/ This is the discharge level at which a side channel entering the Slough 21 study site begins to convey mainstem water. The head of Slough 21 proper is not overtopped until a discharge level of 23,000 cfs.

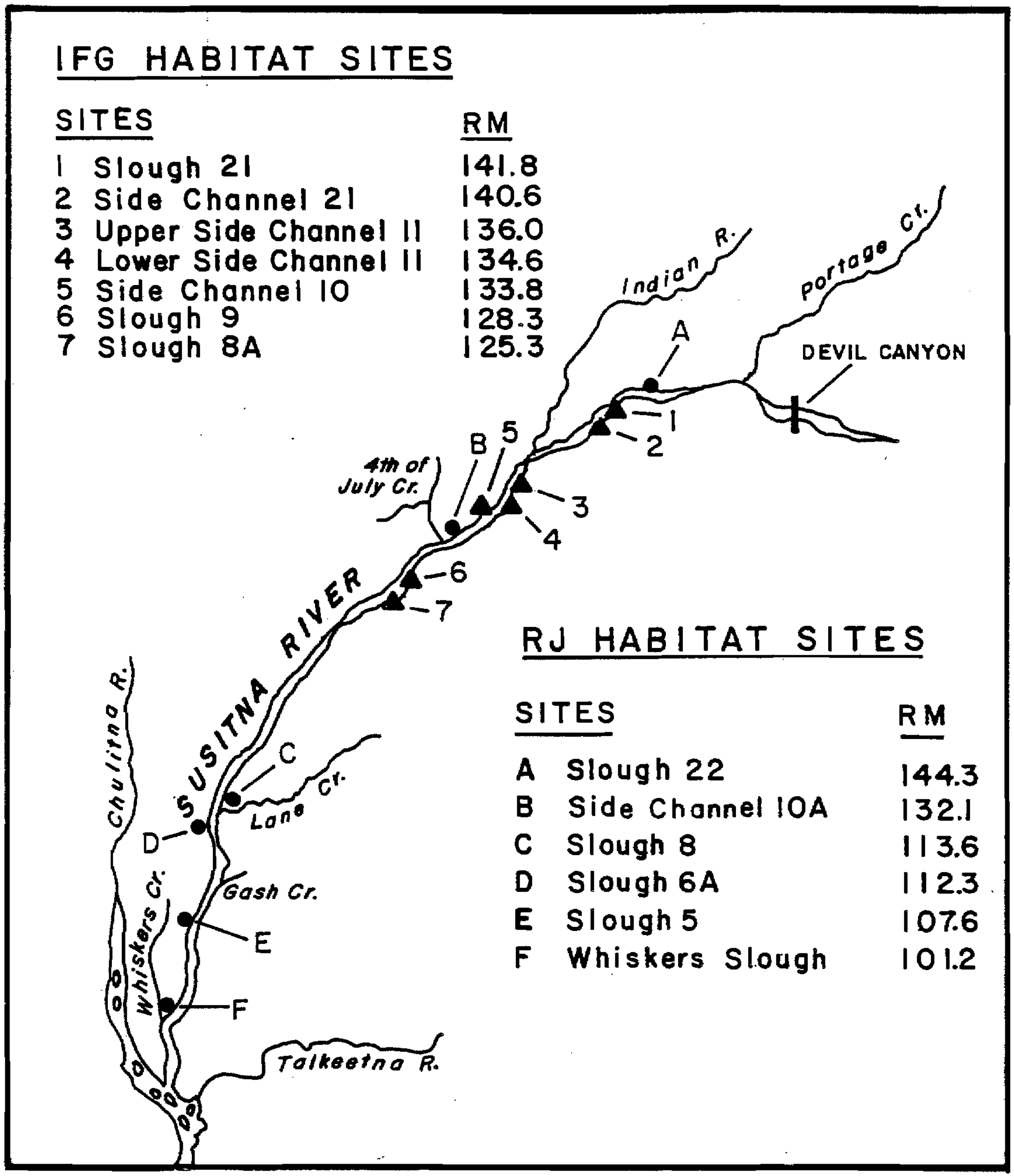


Figure 1. Location of IFG and RJHAB modelling sites.

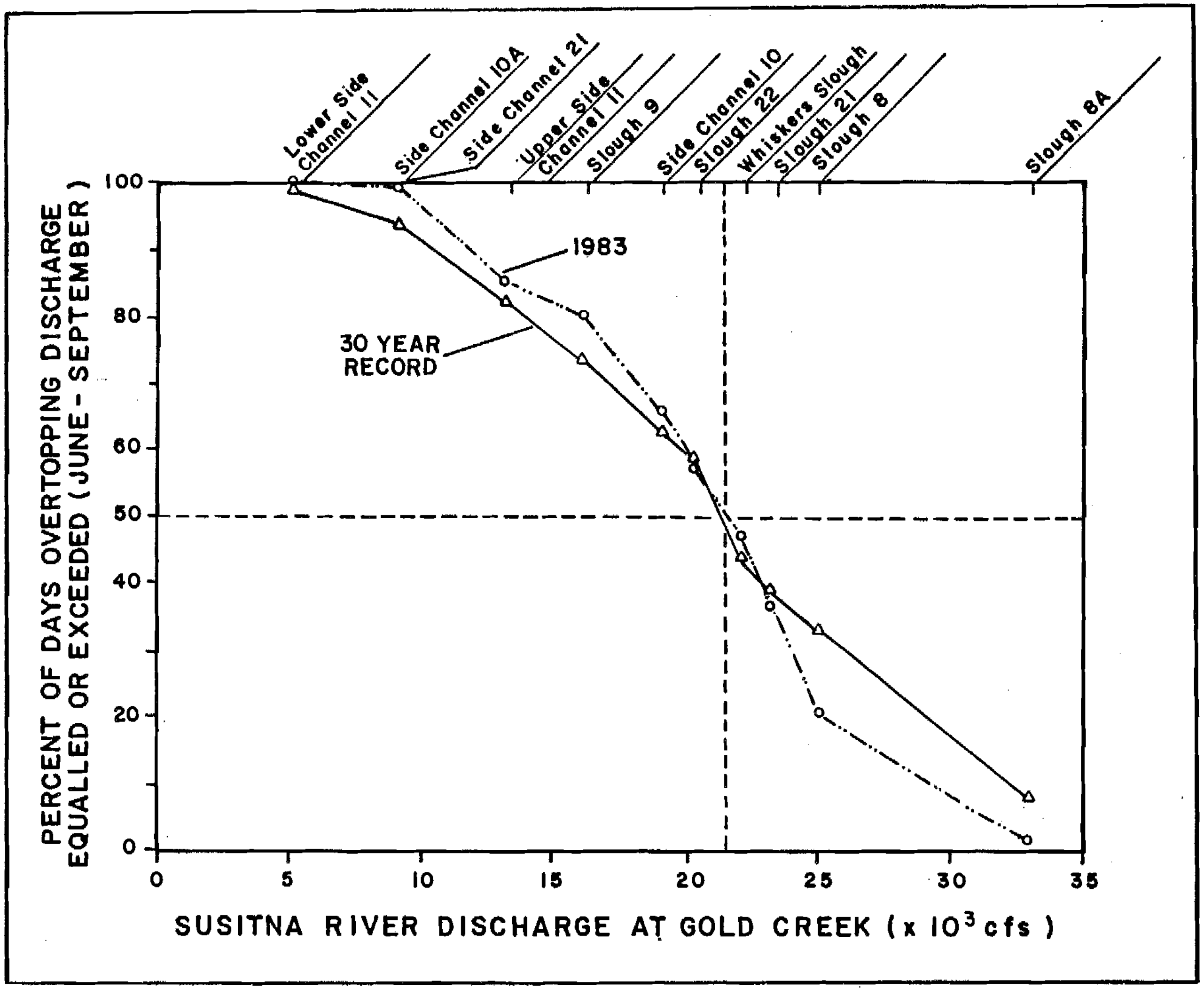


Figure 2. Percent of time that the heads of study sides were overtopped by mainstem discharge.
Sources: 30 year record - Bredthauer and Drage (1982); 1983 discharge - USGS provisional data.

2.2 Physical Habitat Modelling

The models used have been described in other reports (see below) and will only be summarized here. Basically, transects are established at a site and then measurements of depth, mean water column velocity, and cover are made across the transects. Also, the top width of the wetted surface at each transect is measured so that wetted area may be calculated. This is done on three or four different occasions over a range of flows and the information is then input to the models. Output from the models provides either simulated physical parameters and habitat values (IFG) or interpolated habitat values (RJHAB) for any level of discharge over a wide range of discharge.

2.2.1 Instream Flow Group (IFG) PHABSIM Models

Two hydraulic simulation models were used by the Aquatic Habitat section and E. Woody Trihey and Associates during the 1983 open water season (Estes and Vincent-Lang 1984). The IFG-4 model simulates depth and mean water column velocity across horizontal transects at a site over a discharge range from 40% of the lowest calibration flow to 250% of the highest calibration flow (Bovee and Milhous 1978). The IFG-2 model is a water surface profile model that provides the same information as the IFG-4 model but which requires less field data. The IFG-4 model was used for all of the sites except for Lower Side Channel 11, where the IFG-2 model was used.

The models also allow the input of substrate data. However, cover data rather than substrate information were input because it was determined that cover was more important than substrate in influencing the distribution of juvenile salmon (see Part 3 of this report). Substrate was frequently the primary cover type in the cover coding. Consistently good cover data were not obtained at the IFG model sites because most of the sites were primarily intended to be used for simulating habitat for adult spawners. Consequently, cover for some of the transects had to be estimated and may therefore lead to some error in the weighted usable area (WUA) predictions. The cover values on these transects will be obtained during the open water season of 1984 and the output modified accordingly.

2.2.2 RJ Habitat Model (RJHAB)

The RJ Habitat Model, which modelled juvenile salmon habitat at six sites, was described in Part 4 of this report. Transects were established at these sites but, rather than using detailed depth and mean column water velocity measurements across each transect, as do the IFG models, these models use the average depth and average mean water column velocity of 300 sq ft (6 ft wide by 50 ft long) cells which were established along each transect. Usually, there were three cells per transect, but sometimes only two when the channel became too narrow (less than 18 ft in width). This model does not simulate hydraulic characteristics of the site as do the IFG models; instead, it estimates weighted usable area for shoreline and mid-channel portions of the site for those discharge levels at which physical habitat attributes were measured. Estimates of WUA for other discharges are then interpolated.

2.3 Suitability Criteria

The suitability criteria for juvenile salmon input into the models were developed in Part 3 of this report. Suitability indices for cover, velocity, and depth input into the PHABSIM models are presented in Appendix Table A-1 of Part 3. The PHABSIM models linearly interpolate between the point values for depth and velocity input. The cover suitability indices were put into the model in place of substrate; these indices reflect both amount and type of cover. Depth was not thought to be as important as cover and velocity in affecting distribution; therefore, suitability for depth for all species was fixed at 1.00 (i.e., it had no effect on the results) except when depth was less than 0.14 ft and then suitability was fixed at 0.00.

Velocity suitability criteria input into the RJHAB models differed slightly from those input to the IFG models. Suitability indices were constant over an interval of 0.3 ft/sec for velocity. This grouping was made because the limited number of velocity measurements was only an index to hydraulic conditions present and finer resolution was deemed unnecessary. Depth suitability for the RJHAB model was set to 1.0 because depths less than 0.2 ft did not occur.

Suitability criteria for resident fish input into the IFG models were developed and presented in Part 6 of this report. Habitat of juvenile round whitefish and adult rainbow trout, Arctic grayling, round whitefish, and longnose suckers was modelled. The RJHAB models were not run for any resident species. Because of limited data collection, the suitability functions for resident fish are only preliminary.

2.4 Weighted Usable Area Projections

The PHABSIM system can be used to describe the mosaic of physical features of a stream which includes substrate or cover and hydraulic parameters such as depth and velocity. The HABTAT program of PHABSIM incorporates the physical model and the suitability criteria to produce weighted usable area, the habitat potential for a given life stage of a species. Weighted usable area (WUA) is calculated (Bovee 1982) by:

$$WUA = C_{i,s} \times A_i$$

where: $C_{i,s}$ = the composite weighting factor (sometimes called the joint preference factor) for cover, velocity, and depth of the cell (i) for the species and life stage (s)

A_i = the surface area of the cell

The WUA for the study site at a given discharge was calculated by totalling all the individual cell WUA's. The composite weighting factor was calculated by multiplying the suitability indices for cover, velocity, and depth of the cell together. WUA's at each study site were calculated at 10 to 40 incremental flows over the recommended extrapolation range of the hydraulic model.

At RJHAB sites, WUA's were calculated for shoreline and mid-channel portions of the site each time the site was measured. Data were pooled to yield a discharge-specific site WUA instead of calculating individual cell WUA's as in the IFG PHABSIM models. WUA's calculated for the RJHAB sites are generated from habitat measurements which provide an index to conditions at the site. The IFG WUA is standardized to a 1000 ft reach while the RJHAB WUA is dependent on the size of the site.

The output from the IFG models consists of weighted usable area and total surface area predictions for incremental levels of site flow which was in turn related to mainstem discharge by rating curves provided by Estes and Vincent-Lang (1984). RJHAB provides the same information at measured discharges and then plots WUA as a function of discharge. All of the output from RJHAB was presented in Part 4 of this report.

We entered the output of the IFG models into a microcomputer worksheet program to perform additional manipulations of the data. First, plots were constructed of WUA as a function of mainstem discharge. Then we matched WUA predictions with each of the mean daily discharge levels observed from June 1 to September 30, 1983 to obtain a time series of WUA at each of the sites during the open water season. This time series was compared with the catch data at these sites and the outmigration timing data from the downstream migrant traps to better understand the relation between WUA and fish behavior.

All of the possible site/species combinations were run through the IFG models, but only certain ones are presented in this paper because of space limitations; all raw model output is available on request. With a few exceptions, the basic criterion used to select species/site combinations for presentation was that mean catch per cell for the species for the entire season at the site had to be greater than the mean catch per cell at all sites (Table 1). Hence, we are not including weighted usable area predictions for a species at those sites where very few individuals of the species were captured. There are some exceptions to this practice for resident species because the sampling methods used at the modelling sites were not intended for capture of adult resident fish. The species/life stages for which weighted usable area predictions are presented include juveniles of four salmon species (chinook, coho, chum, and sockeye), juvenile and adult round whitefish, and adult rainbow trout, Arctic grayling, and longnose suckers.

To make comparisons among sites which would be independent of the size of the site, we divided the site weighted usable areas at each level of discharge by the total surface area of the site when the mainstem discharge was 23,000 cfs (the area was interpolated from the PHABSIM output of total area as a function of flow). The 23,000 cfs figure was chosen because it is a typical mid-summer discharge (Bredthauer and Drage 1982; Klinger and Trihey 1984) and because it may be integrated with macrohabitat abundance information which was digitized from aerial photographs by E. Woody Trihey and Associates. The resulting habitat index is comparable to the habitat index calculated for the RJHAB sites in Part 4 of this report.

Table 1. Total catch and catch per unit effort of juvenile salmon at the IFG sites, open water season, 1983.

		Catch (catch/cell)			
IFG Site	No. of Cells	Chinook 0+	Coho 0+	Chum	Sockeye 0+
Slough 21	86	91(1.1)*	1(0.0)	417(4.8)*	23(0.3)*
Side Channel 21	23	38(1.6)*	0(0.0)	0(0.0)	0(0.0)
Upper Side Channel 11	21	101(4.8)*	0(0.0)	0(0.0)	0(0.0)
Lower Side Channel 11	21	39(1.9)*	0(0.0)	0(0.0)	0(0.0)
Side Channel 10	62	279(4.5)*	0(0.0)	2(0.0)	0(0.0)
Slough 9	123	227(1.8)*	0(0.0)	74(0.6)*	30(0.2)*
Slough 8A	66	6(0.1)	26(0.4)	129(2.0)	24(0.4)
Sum of IFG sites	402	781	27	205	77
Mean of IFG sites		112(1.9)	4(0.1)	29(0.5)	11(0.2)
Mean of all sites sampled					
Backpack electrofishing		(3.4)	(2.3)	(1.3)	(0.9)
Beach seining		(3.4)	(0.3)	(0.0)	(0.5)

* = Site/species combination selected for presentation.

2.5 Model Verification

Data on fisheries abundance and distribution were collected at the sites; however, program constraints prevented intensive sampling efforts. Composite weighting factors were calculated for each 6 ft X 50 ft cell sampled for fish and this index was then correlated with fish catch in the cell. If cells with large composite weighting factors are associated with higher densities of fish, then it can be assumed that WUA does reflect habitat potential. Correlations or associations between catch and composite weighting factors at the RJHAB sites have been presented in Part 4 of this report. Data were available at the IFG sites for verification of composite weighting factors for juvenile salmon and round whitefish, but not for adult resident species.

The specific hypothesis tested was whether the correlation between a composite weighting factor and catch of chinook and coho salmon/cell [transformed by natural log (x+1)] was greater than zero (in other words, whether there was a significant positive relationship). For sockeye and chum salmon, the null hypothesis was that there was no association between the composite weighting factor and fish presence. Sampling occasions when less than three fish were captured in all cells within a site sampled during a day were deleted from the analysis. This was done because seasonal variations in outmigration from natal areas can lead to low fish density, even in areas that provide good rearing habitat, and inclusion of data from these times could lead to spurious correlations.

3.0 RESULTS

3.1 IFG Model Weighted Usable Area

Juvenile salmon catches and catch per unit effort (CPUE) varied greatly at the seven IFG modelling sites (Table 1). Since discharge levels of more than 33,000 cfs (the level required to overtop the head of the Slough 8A study site) occurred infrequently during the 1983 open water season, this site was not modelled for any species. Juvenile salmon at this slough were primarily caught below the modelling site. The Slough 8A IFG modelling site harbored few juvenile fish because access was restricted from below by several beaver dams and access was restricted from above because the head was only infrequently overtopped.

Juvenile coho catches and CPUE were very low at all the modelling sites and, therefore, no results for coho WUA's are presented. In general, WUA's calculated for coho salmon at the sites were less than 2% of the total surface area of the site. The primary reason for low coho density was the preference of cohos for non-turbid water and cover types infrequently found in the sites modelled (see Parts 2 and 3 of this report). All of the IFG modelling sites, with the exception of Slough 8A, harbored significant numbers of chinook salmon and results from these six sites are presented. Sockeye and chum WUA's are presented for sloughs 21 and 9 as these were the only two sites where these species were relatively numerous. Unfortunately, the four mainstem side channel sites were not sampled for fish density until July; most chum and large numbers of sockeye had moved down river by this time (see Part 1 of this report).

In the time series plots that follow, if a mean daily discharge exceeded the extrapolated range of the model, no WUA value was plotted. No weighted usable areas of zero occurred. If the discharge was less than the extrapolated range, then the WUA was set equal to the WUA value for the lowest discharge in the extrapolated range. WUA at four of the sites was extrapolated to some point below the overtopping flow. WUA did not change very much at flows less than the overtopping flow because the surface areas of the sites remained relatively constant, being affected mainly by site morphology and local hydrology. The lower end of the extrapolated range at Slough 9, Slough 21, and Lower Side Channel 11 was above the overtopping flow.

3.1.1 Chinook salmon

Weighted usable areas for six IFG modelling sites as a function of mainstem discharge and as projected over the June 1 to September 30 time period are presented in Figures 3 through 8. There were two different sets of suitability criteria for chinook salmon; one for a low turbidity level and one for a high turbidity level (Part 3 of this report). We used the low turbidity criteria when the head of a site was closed and the high turbidity criteria when the head was overtopped by mainstem flow. The point of overtopping was taken as the point when mainstem water just began to flow through the head, raising the turbidity level of the site. Chinook juveniles preferred the high turbidity condition when other cover types were not abundant. Therefore, the weighted

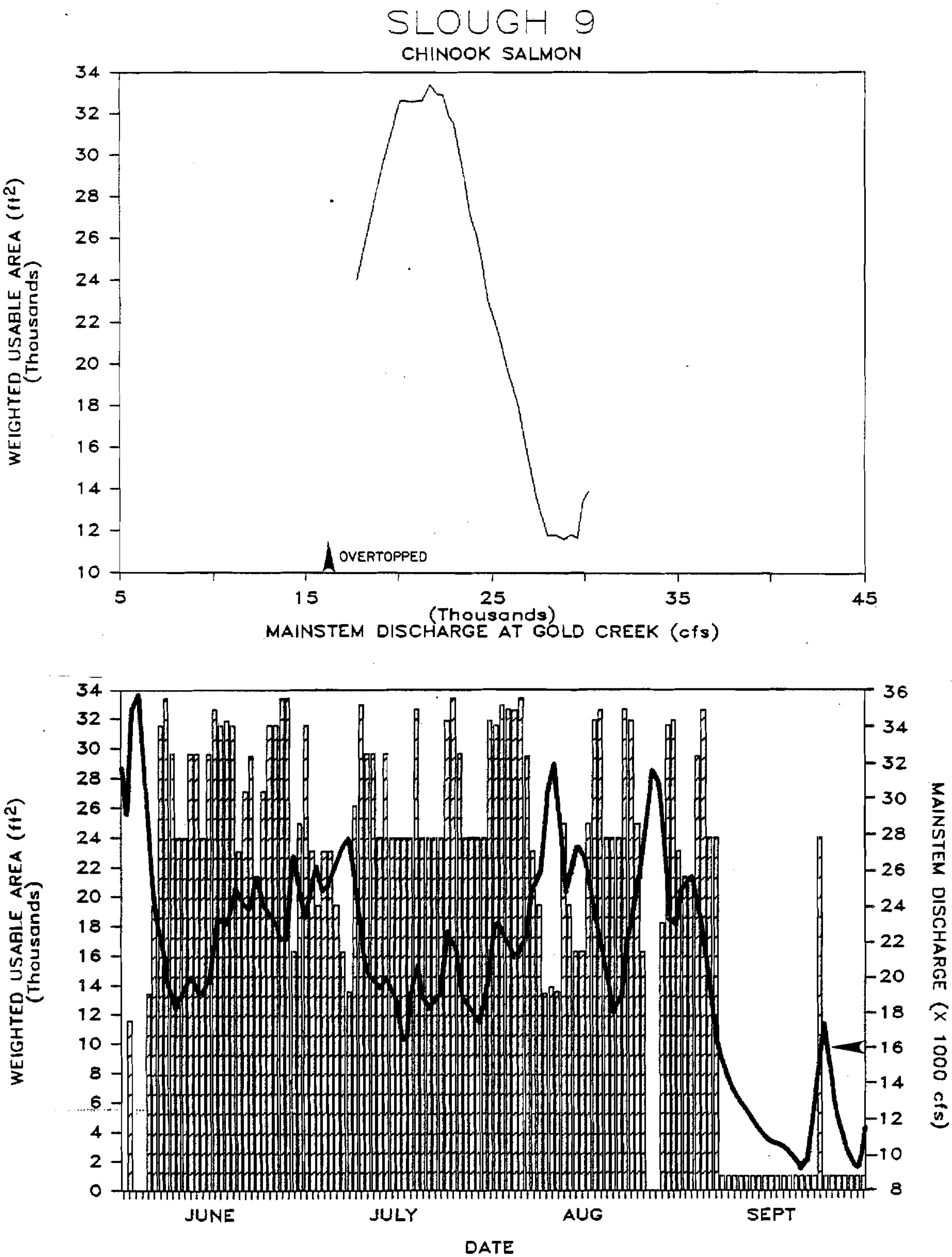


Figure 3. Weighted usable area for chinook salmon at the Slough 9 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

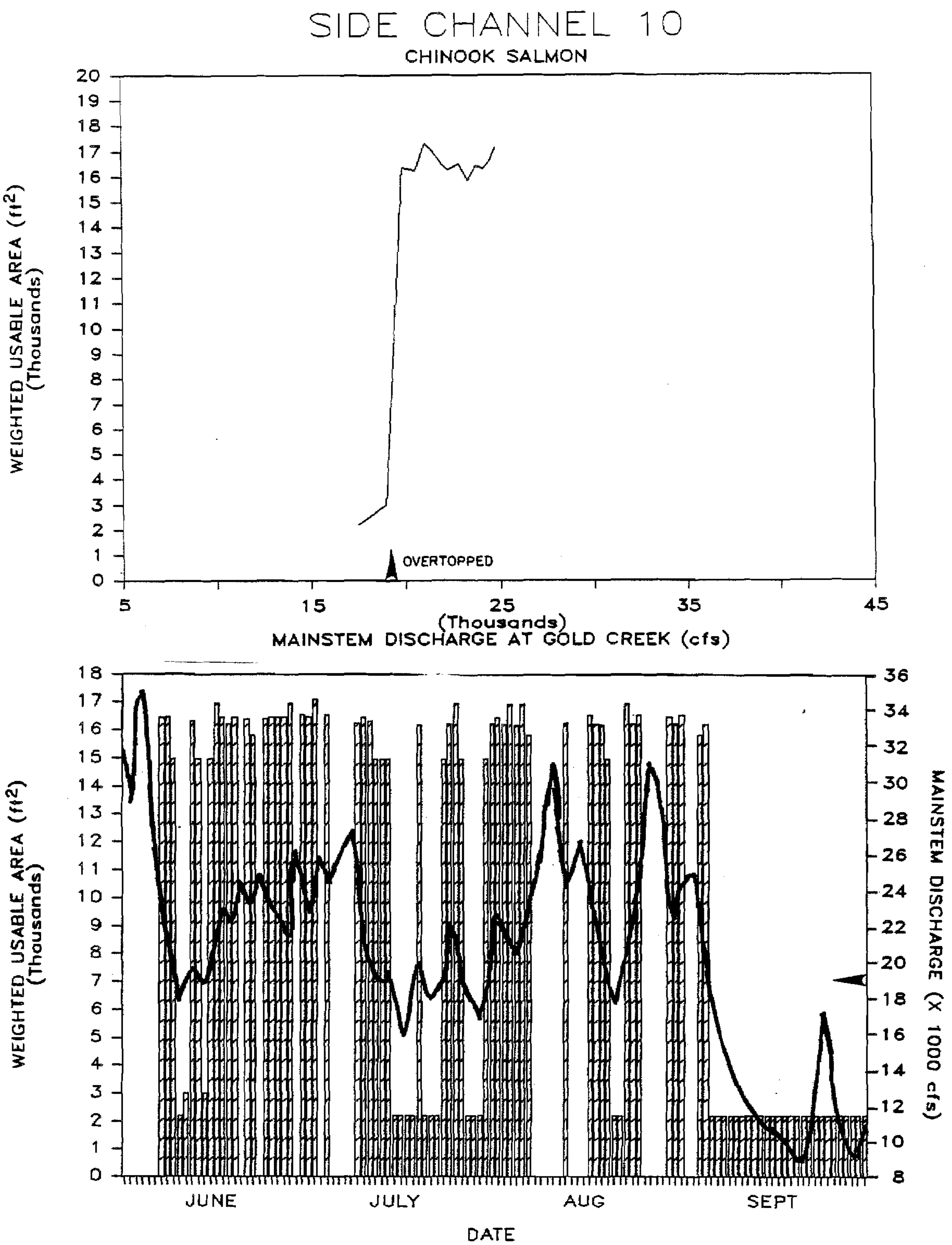


Figure 4. Weighted usable area for chinook salmon at the Side Channel 10 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

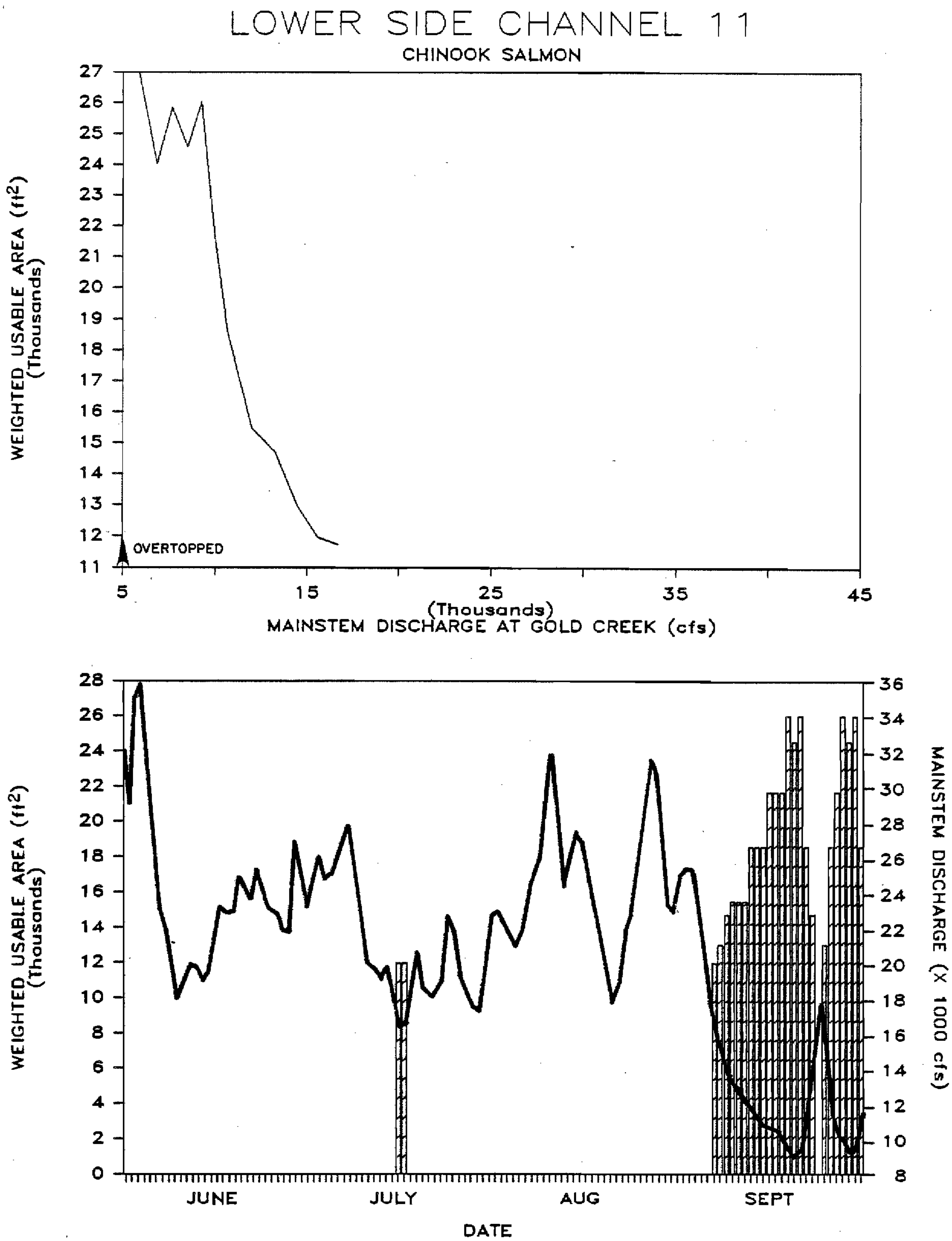


Figure 5. Weighted usable area for chinook salmon at the Lower Side Channel 11 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

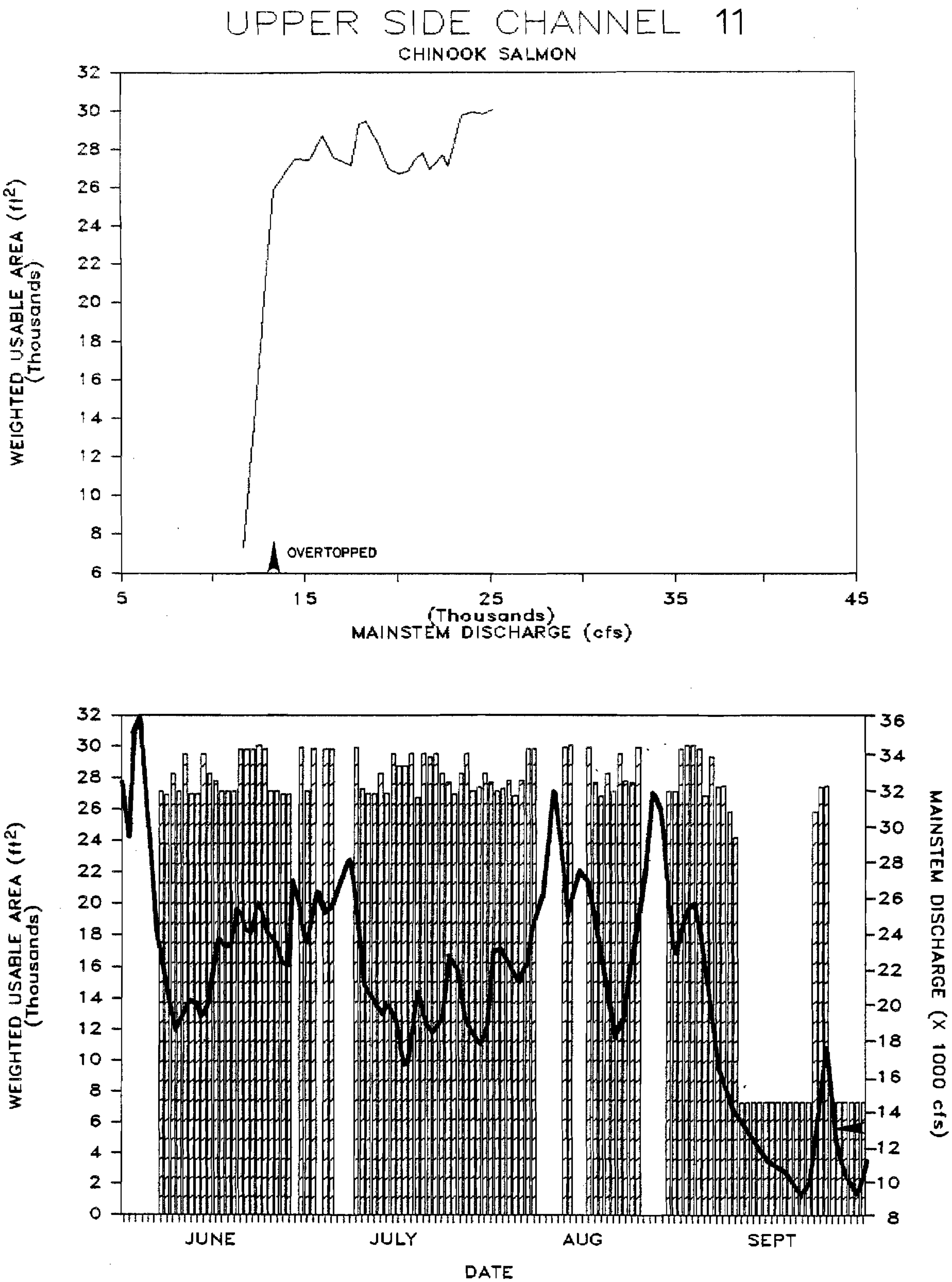
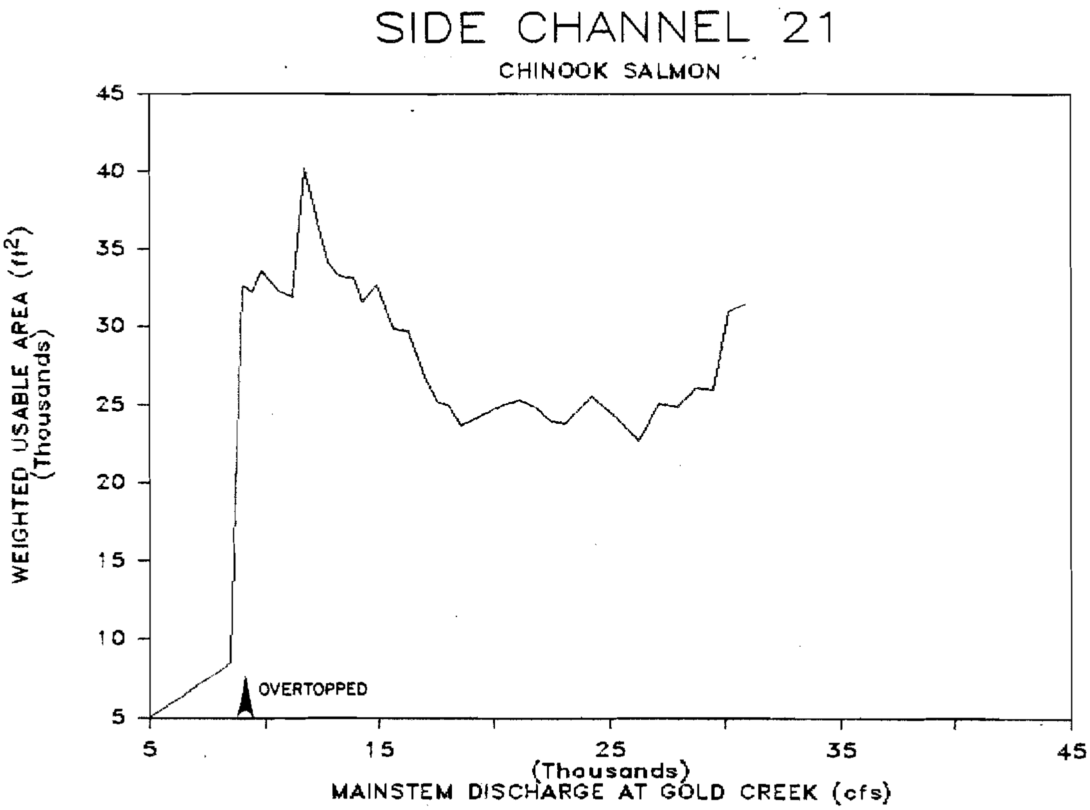


Figure 6. Weighted usable area for chinook salmon at the Upper Side Channel 11 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.



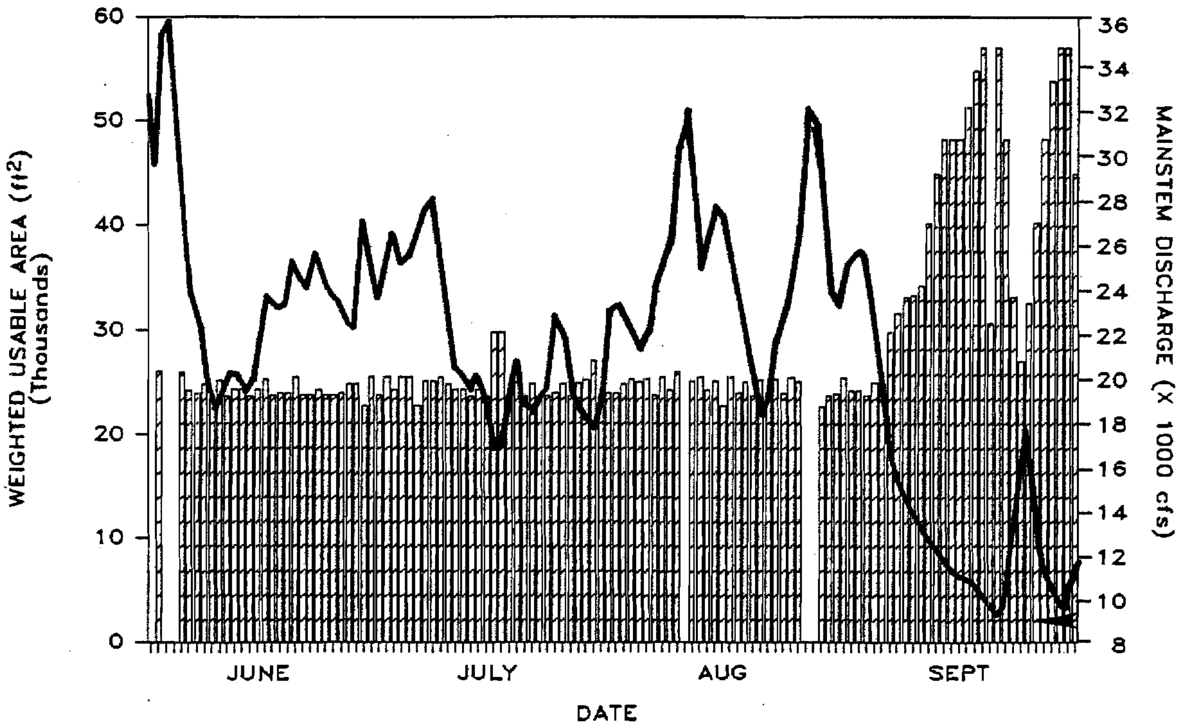


Figure 7. Weighted usable area for chinook salmon at the Side Channel 21 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

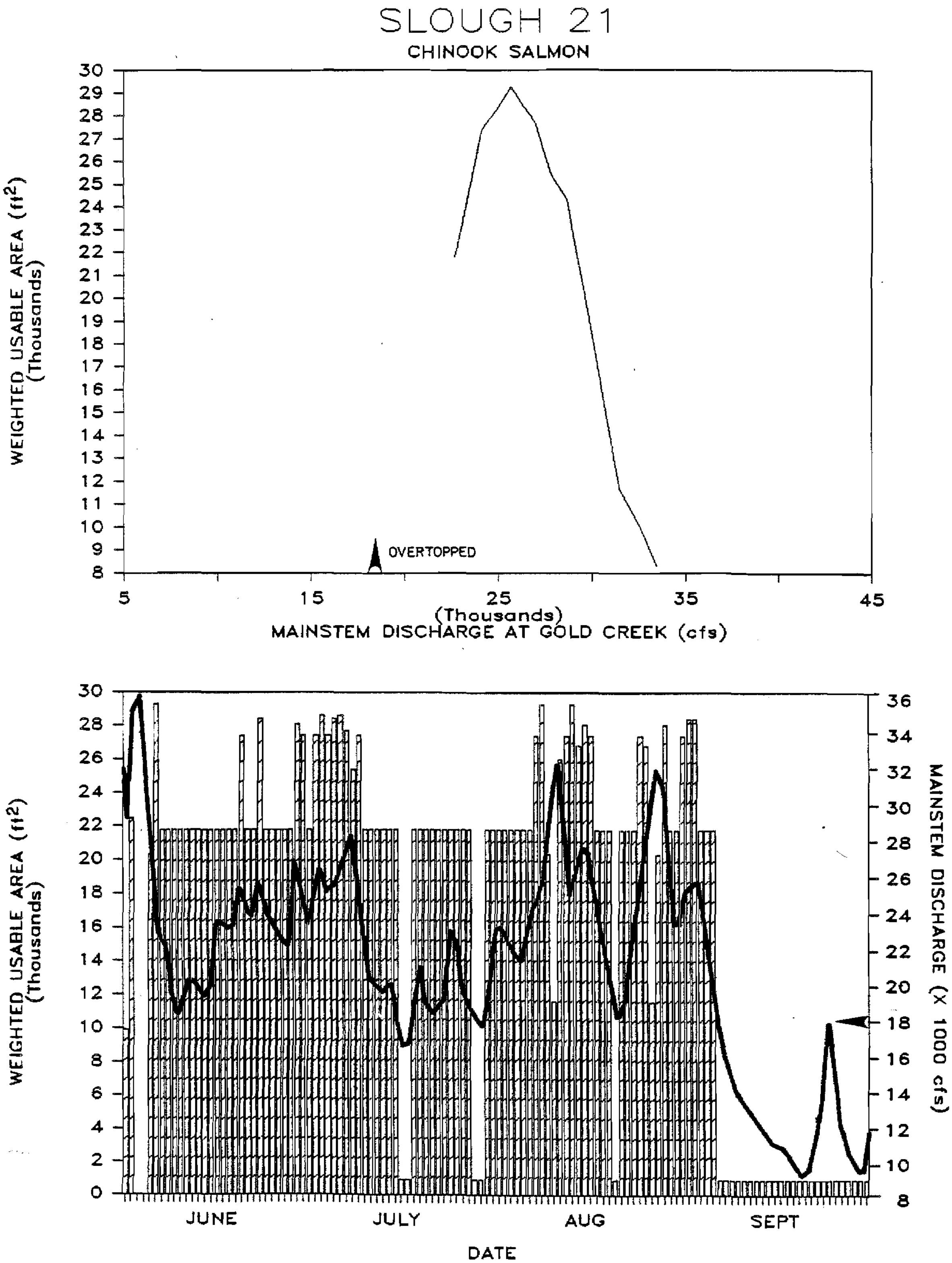


Figure 8. Weighted usable area for chinook salmon at the Slough 21 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

usable area for chinooks drops sharply when discharge levels become low enough so that the head of the site is no longer overtopped by turbid mainstem water. At mainstem discharges less than those required to overtop the head of the site, there is no strong relationship between slough flow and mainstem discharge unless groundwater flow is significantly related to discharge. Calibration ranges of the model at many of the sites limited the calculated responses of WUA to a small range of mainstem discharges. The three peak discharges which occurred in early June and in early and late August exceeded the calibration range of all the sites except for Slough 21.

Typically, peaks in weighted usable area were found at mainstem discharges slightly (within a few thousand cfs) greater than the overtopping discharges. The Slough 21 study site appears (Figure 8) to be an exception to this trend but in fact is not. A small side channel which entered the Slough 21 study site conveyed mainstem water at discharge levels greater than 18,000 cfs, but the amount of mainstem water entering the site did not become substantial until the head of Slough 21 proper became overtopped at 23,000 cfs.

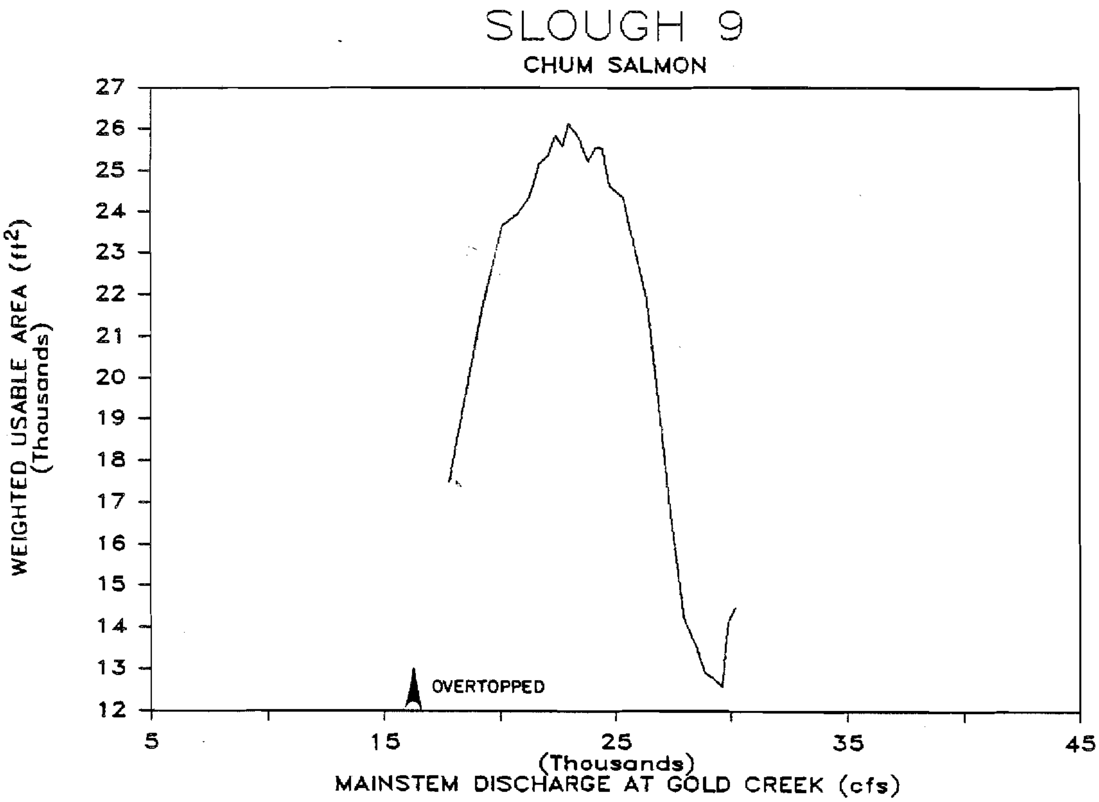
The time when the WUA peaks occurred and, hence, the period when the site was theoretically able to support the maximum number of fish, can be seen from the time series plots. With a few exceptions, sites at which the overtopping flow occurred at a middle level of discharge provided more habitat during the open water season of 1983 than sites which had either a relatively low overtopping flow or a relatively high overtopping flow. With the exception of the two side channels which had low overtopping discharges (Lower Side Channel 11 and Side Channel 21), weighted usable area was low to all sites in September because low mainstem discharge (down to 9,000 cfs) led to reduced velocity, depth, and surface area at these study sites.

3.1.2 Chum and sockeye salmon

Plots of weighted usable area for chum and sockeye salmon as a function of mainstem discharge showed very similar trends (Figures 9 through 12). Chum and sockeye WUA plots were almost identical at both Slough 9 and Slough 21. At both sites, WUA's for chum and sockeye peaked rapidly with small increases in discharge, held constant over a range of approximately 5,000 cfs in mainstem discharge, and then decreased rapidly with further increases in mainstem discharge. At a given site, sockeye WUA's peaked slightly before chum WUA's because slightly lower velocities were more suitable to the sockeye salmon juveniles. Chum and sockeye salmon WUA at these two sites remained relatively high in September as compared to chinook WUA, because chum and sockeye salmon have a preference for lower velocities. However, the chum WUA in September is never used because this species has basically outmigrated from this reach by the end of July.

3.1.3 Resident Fish Weighted Usable Area

Only limited sampling for resident fish was conducted at the IFG modelling sites and, therefore, no site-specific data on adult resident use of the sites are available. Many of the sites are inaccessible to



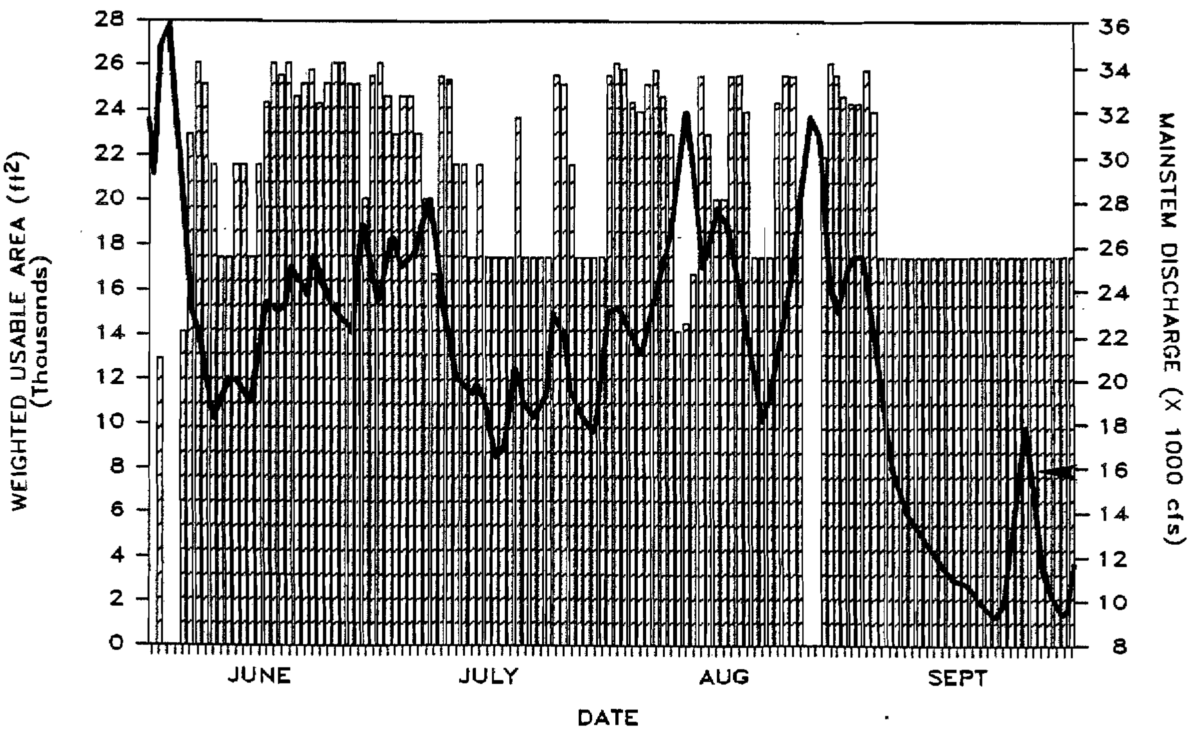


Figure 9. Weighted usable area for chum salmon at the Slough 9 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

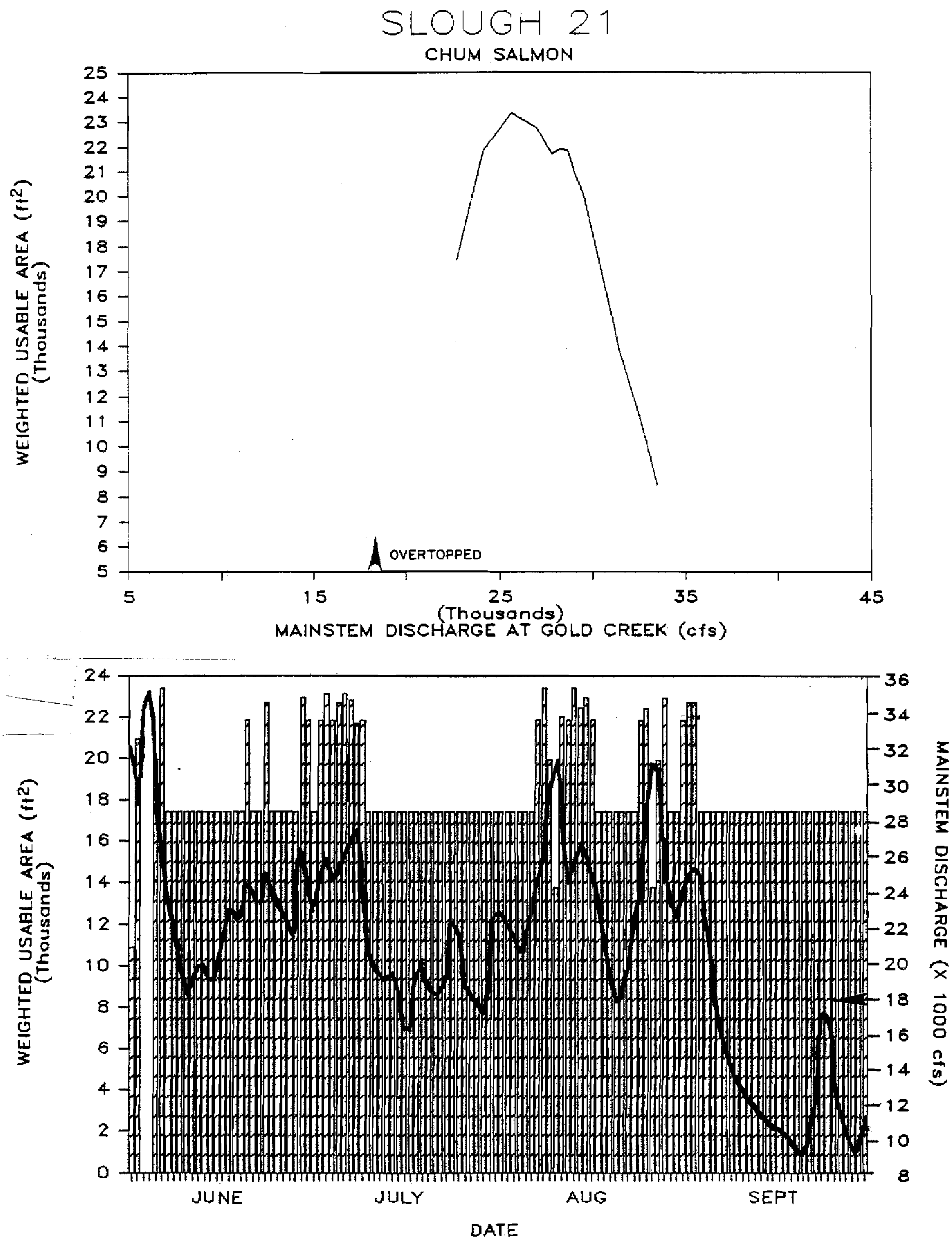


Figure 10. Weighted usable area for chum salmon at the Slough 21 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

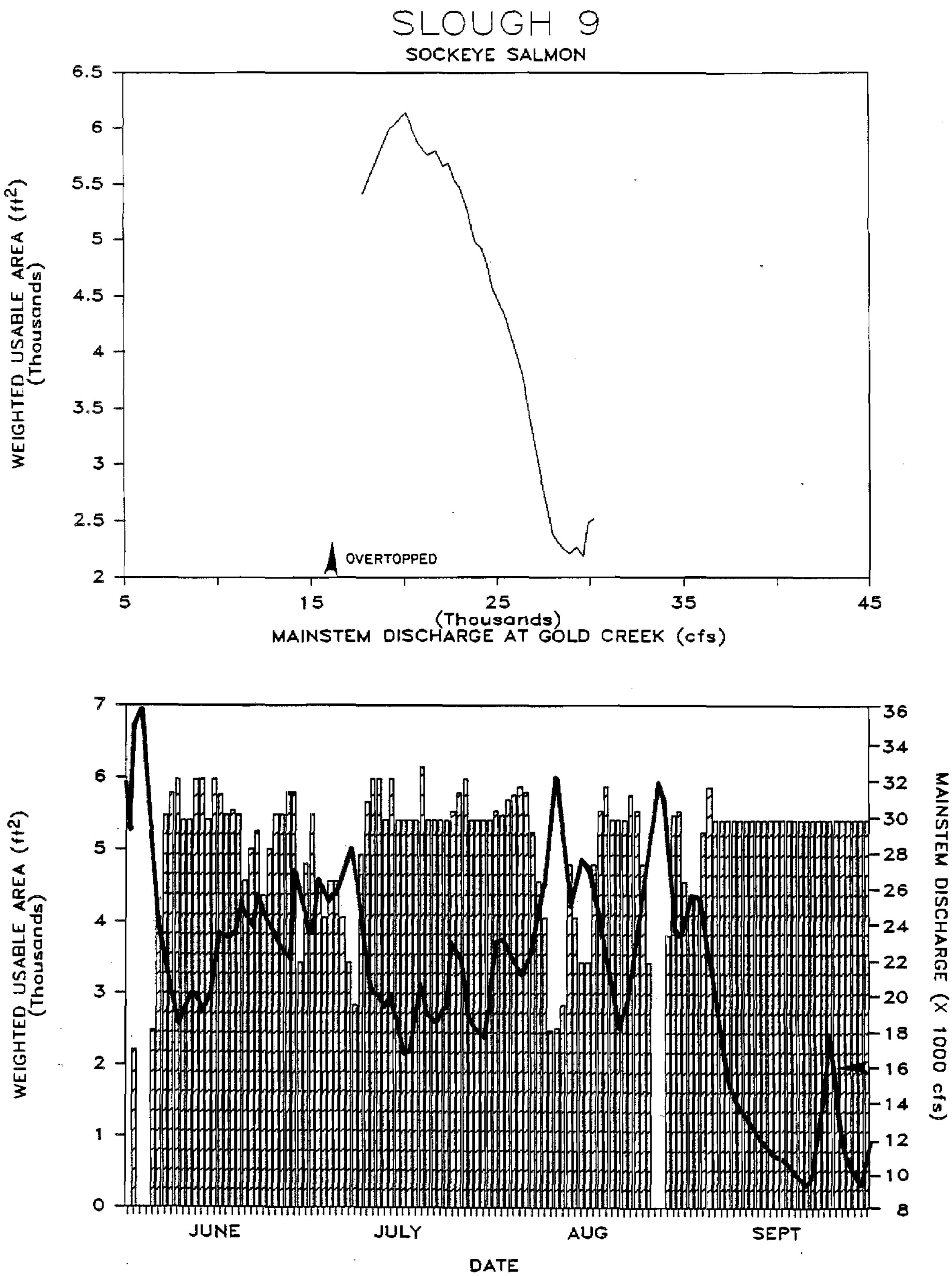


Figure 11. Weighted usable area for sockeye salmon at the Slough 9 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

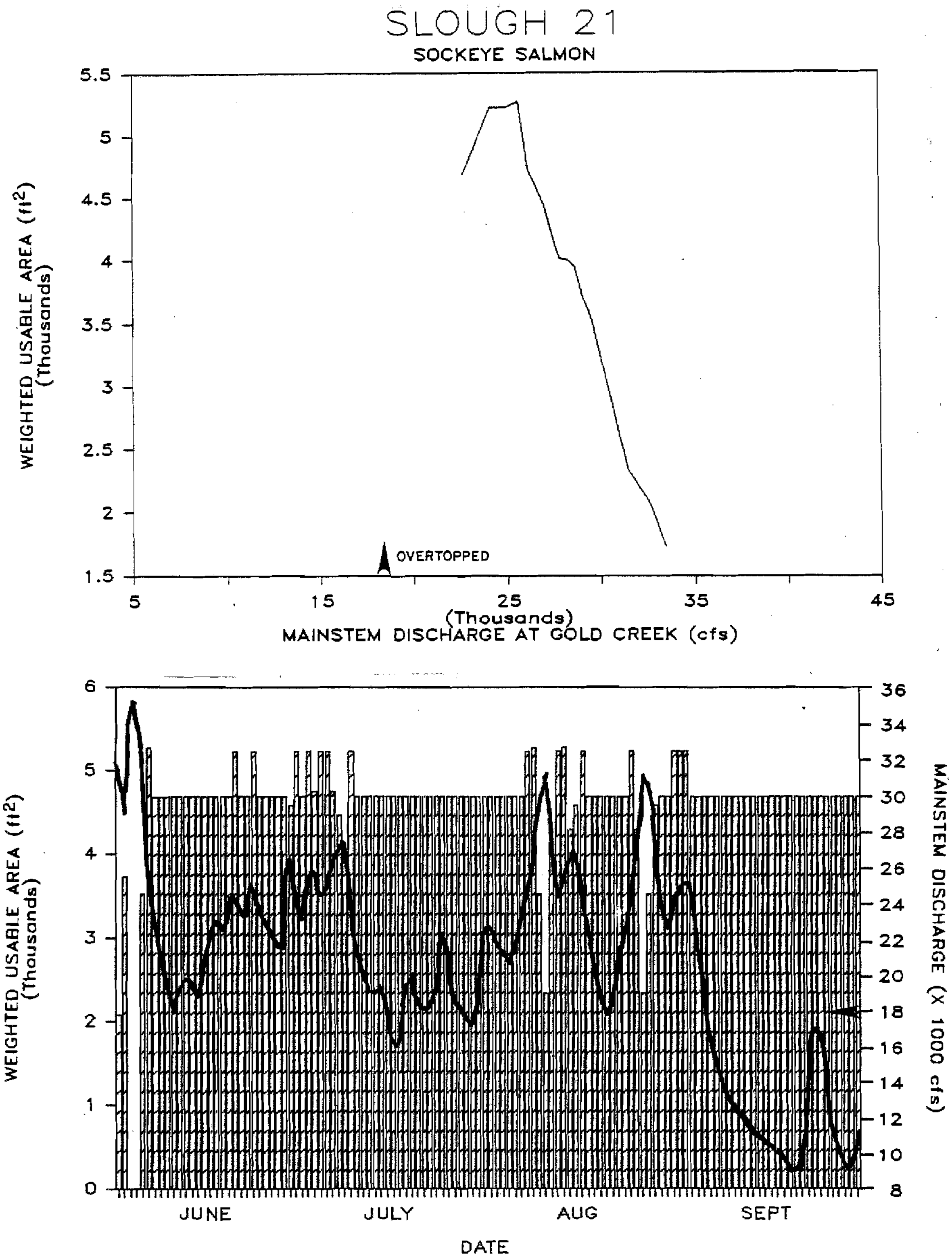


Figure 12. Weighted usable area for sockeye salmon at the Slough 21 study site by level of mainstem discharge at Gold Creek and by date, 1983. In the lower graph, daily WUA's are plotted as bars. No WUA value is plotted if the mean daily discharge exceeded the extrapolated range of the model.

electrofishing boats except during high mainstem discharges. Slough 21 was selected as a representative site to present responses of adult resident fish habitat to changes in mainstem discharge. The relationships between WUA and mainstem discharge for adult rainbow trout, Arctic grayling, round whitefish, and longnose suckers are shown in Figures 14 and 15. Since Arctic grayling are frequently found in side channels during the ice-free months, responses of WUA to mainstem discharge for Arctic grayling at Slough 9 and Side Channel 21 are also presented (Figure 13). Within the extrapolated flow ranges of the site or sites, WUA's for adult rainbow trout, Arctic grayling, and round whitefish increased with flow. WUA for longnose suckers, which prefer low velocities and turbid water, peaked with the overtopping of the site by mainstem discharge and then rapidly decreased with further increases in discharge.

At least 16 juvenile round whitefish were captured at every site with the exception of Slough 8A where none were captured. Results from WUA calculations for juvenile round whitefish are presented for six sites in Figures 16 to 18.

3.2 Model Verification

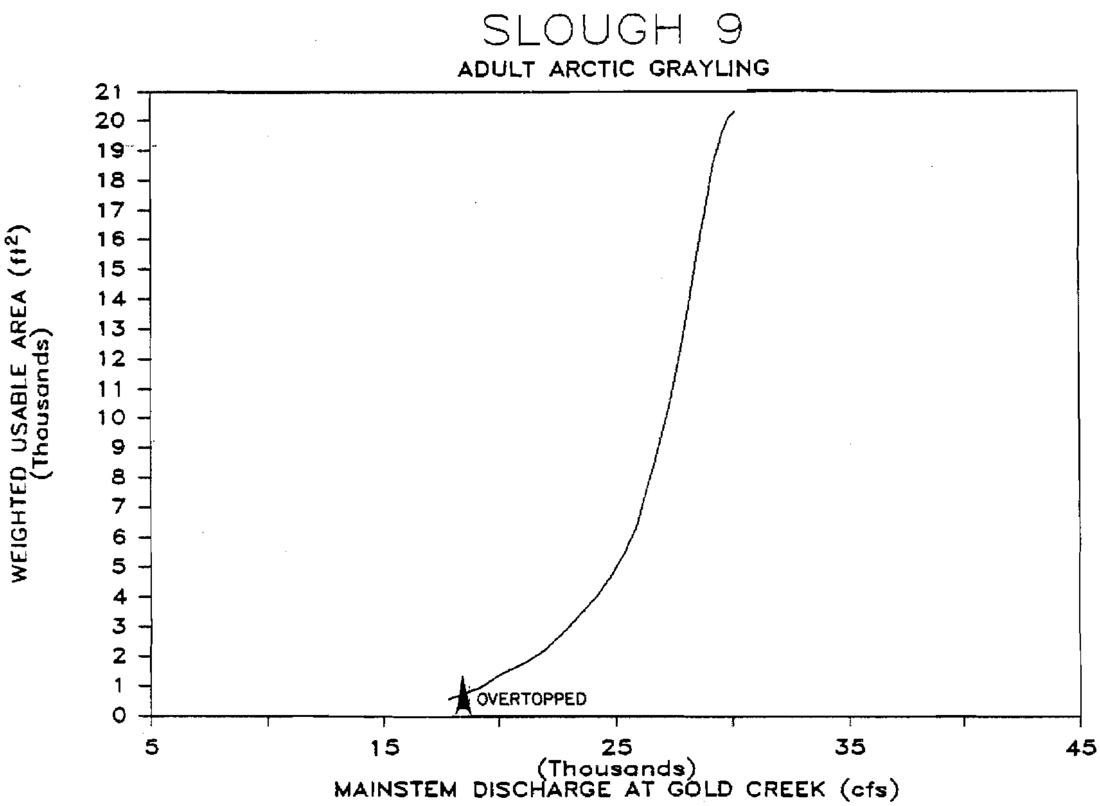
Slough 9 and Side Channel 10 were the only two IFG sites where both a relatively large amount of sampling and catch of juvenile chinook occurred. Correlations between chinook catch and composite weighting factor at Slough 9 and for all seven sites pooled for both clear and turbid conditions were significantly greater than 0.0 (Table 2). At Side Channel 10, however, there was no significant correlation between chinook catch in turbid water and the composite weighting factor.

Data from Sloughs 8A, 9 and 21 were pooled for chi-square contingency tests of chum and sockeye proportional presence by composite weighting factor interval (Table 3). Chum salmon presence was associated with larger composite weighting factors; however, sockeye salmon presence was not.

Correlations between round whitefish catch in turbid ($>$ 30 NTU) water and composite weighting factors were all significantly greater than 0.0 at the 0.01 level. The correlations were 0.35 (n = 54) at Side Channel 10, 0.46 (n = 63) at Slough 9, and 0.52 (n = 188) for all seven IFG sites pooled.

3.3 Habitat Indices

In order to compare modelling sites with one another and to compare IFG model results with RJHAB model results independently of site surface area, habitat indices were calculated by dividing WUA by the total surface area of the site at a mainstem discharge of 23,000 cfs. This discharge level was chosen because it represents typical mid-summer discharge conditions in this reach (Klinger and Trihey 1984).



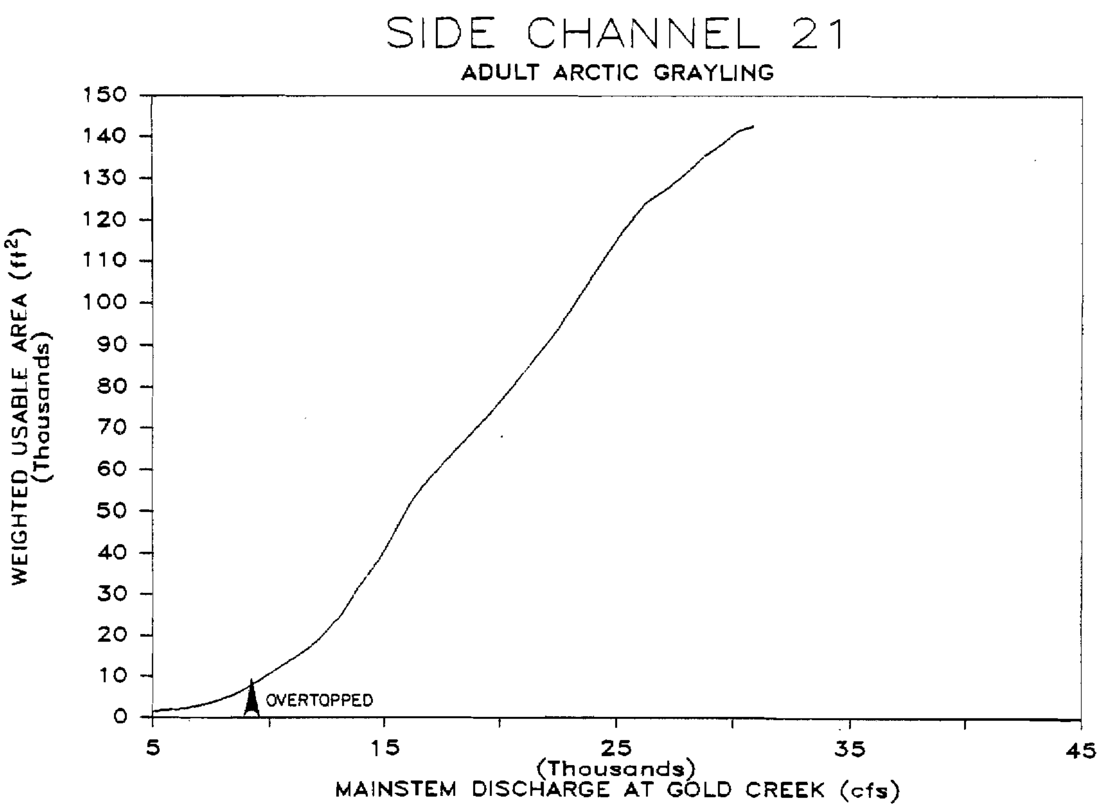
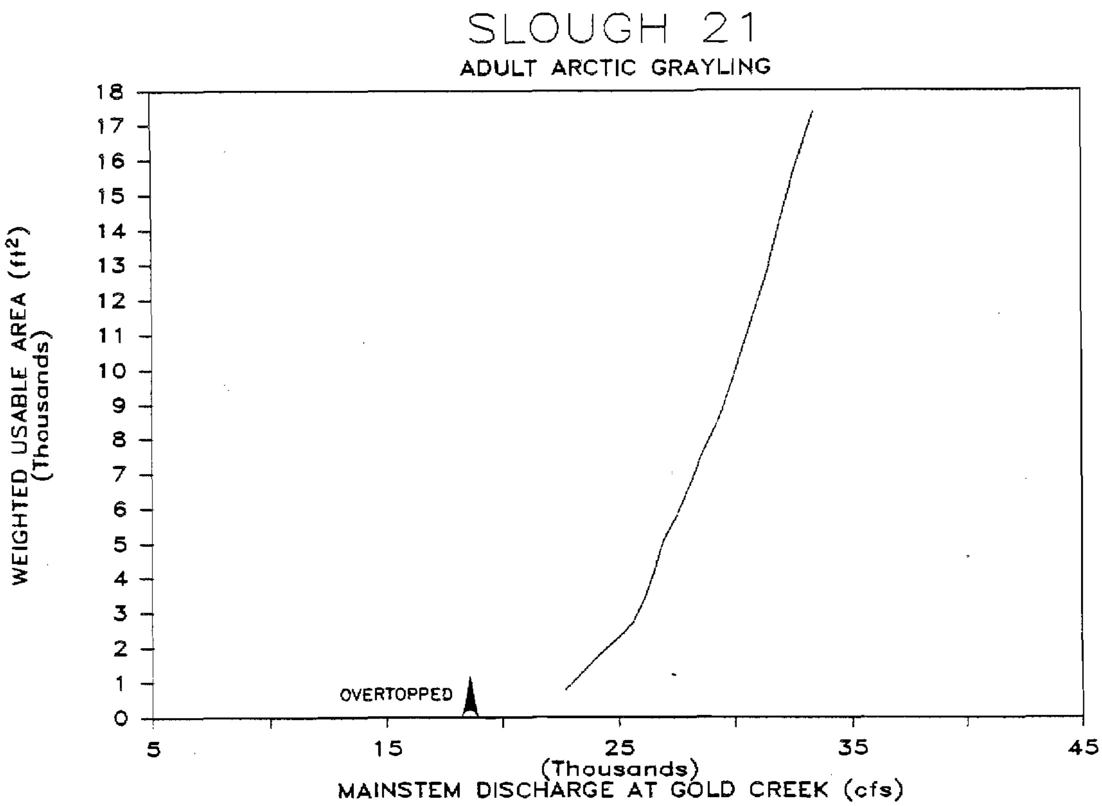


Figure 13. Weighted usable area for adult Arctic grayling at the Slough 9 and Side Channel 21 study sites.



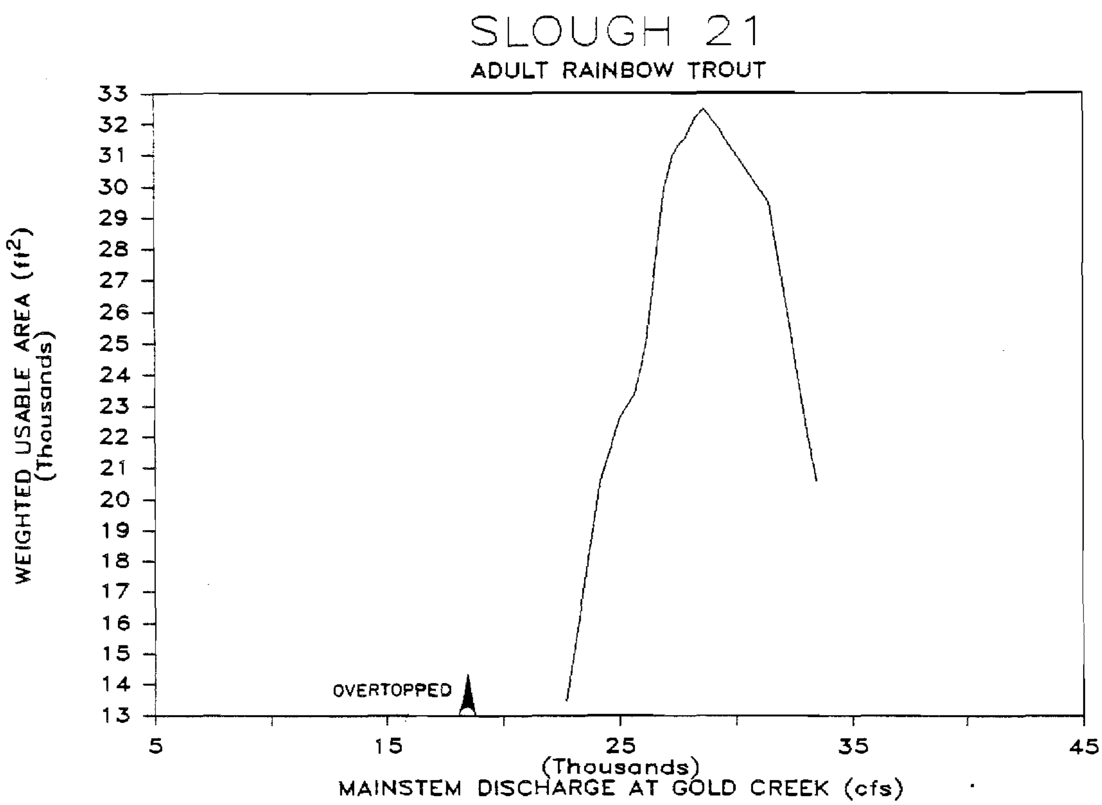
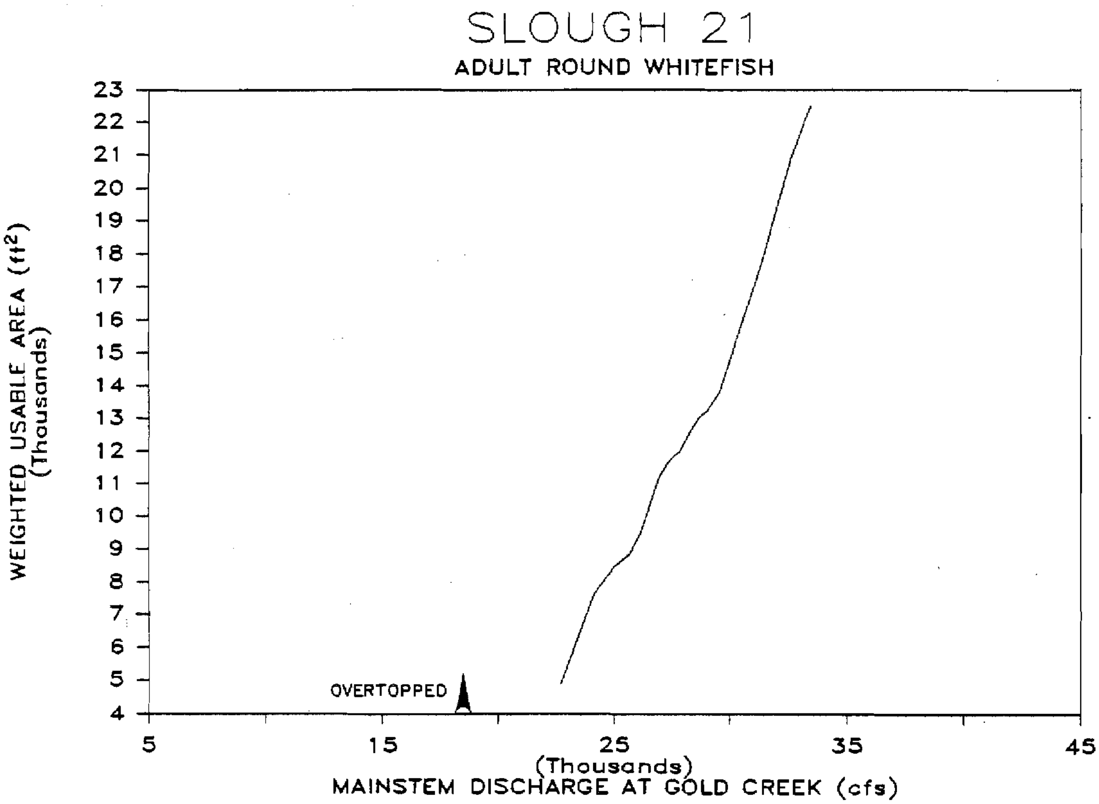


Figure 14. Weighted usable area for adult Arctic grayling and rainbow trout at the Slough 21 study site.



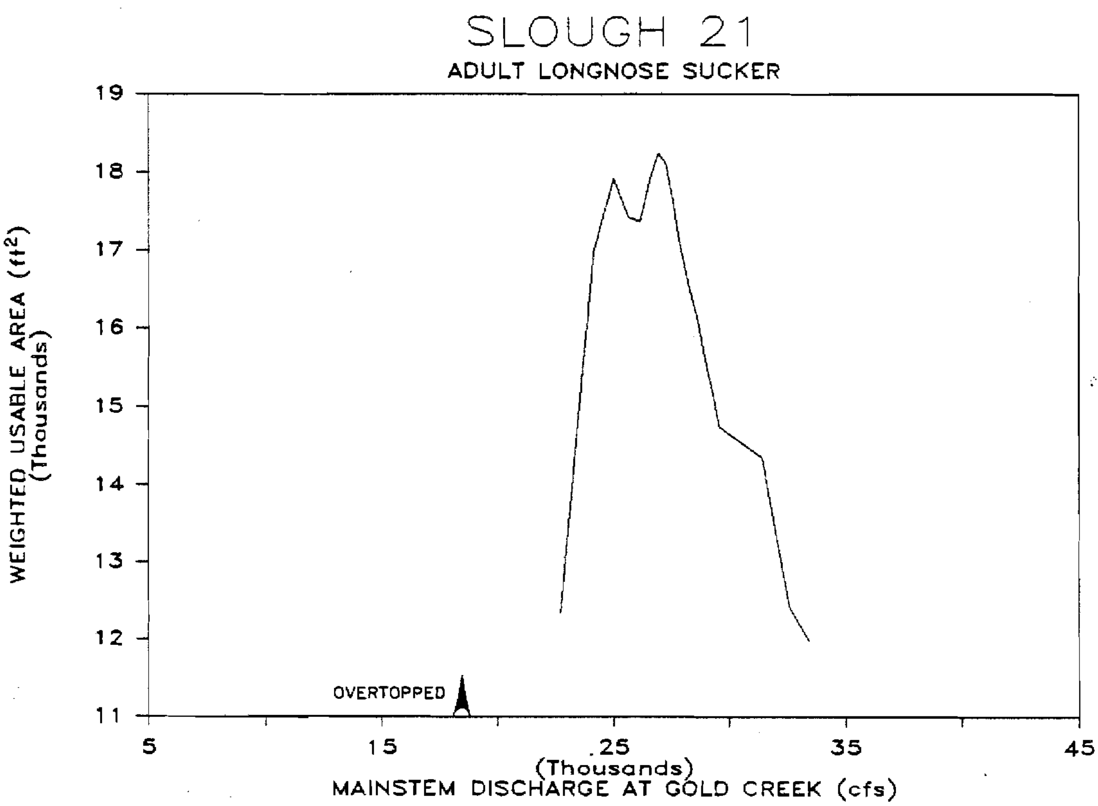
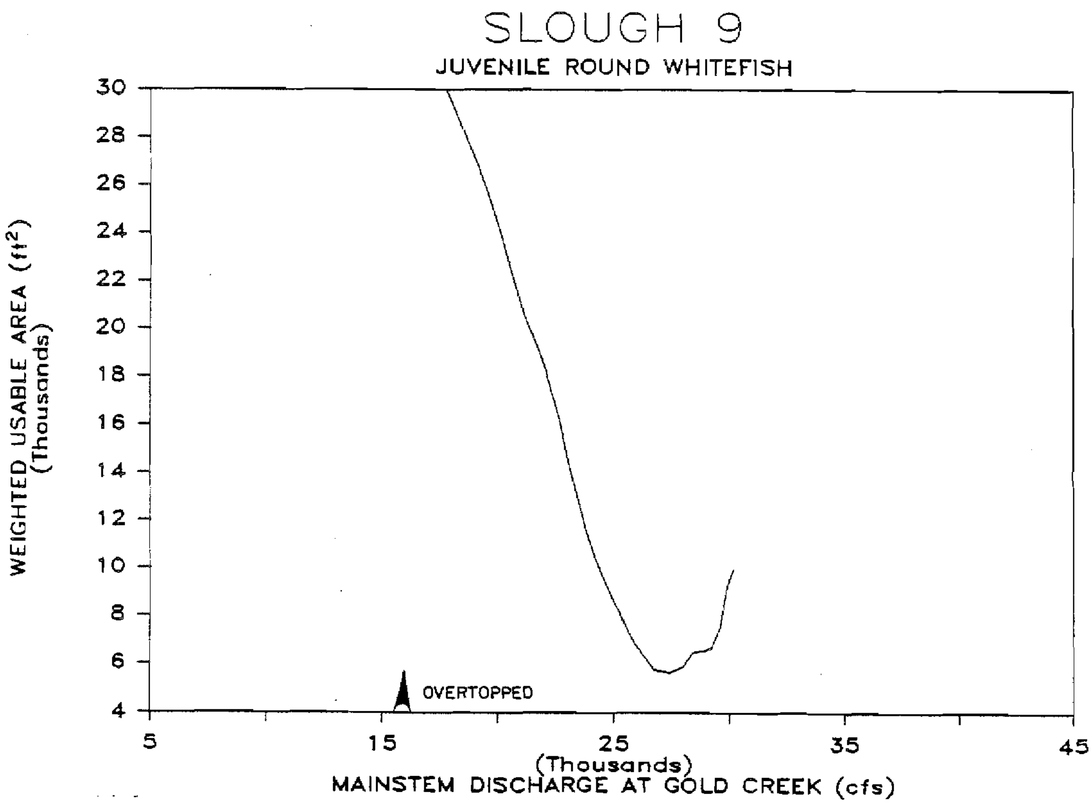


Figure 15. Weighted usable area for adult round whitefish and longnose suckers at the Slough 21 study site.



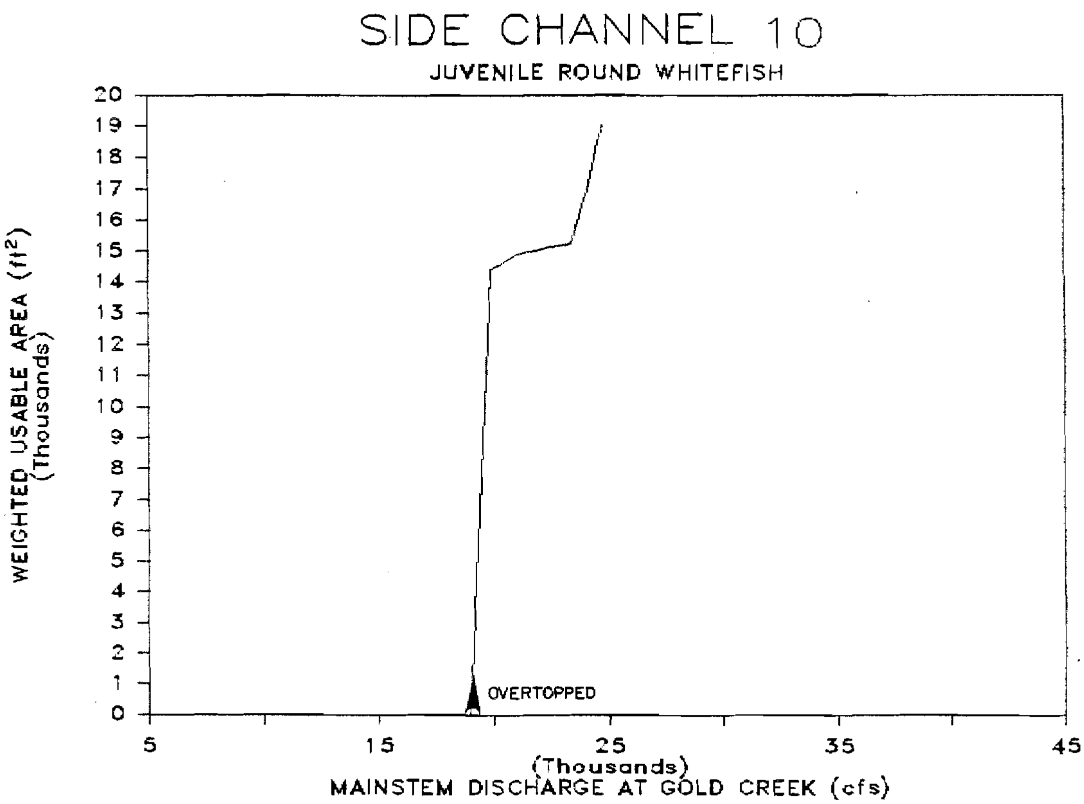
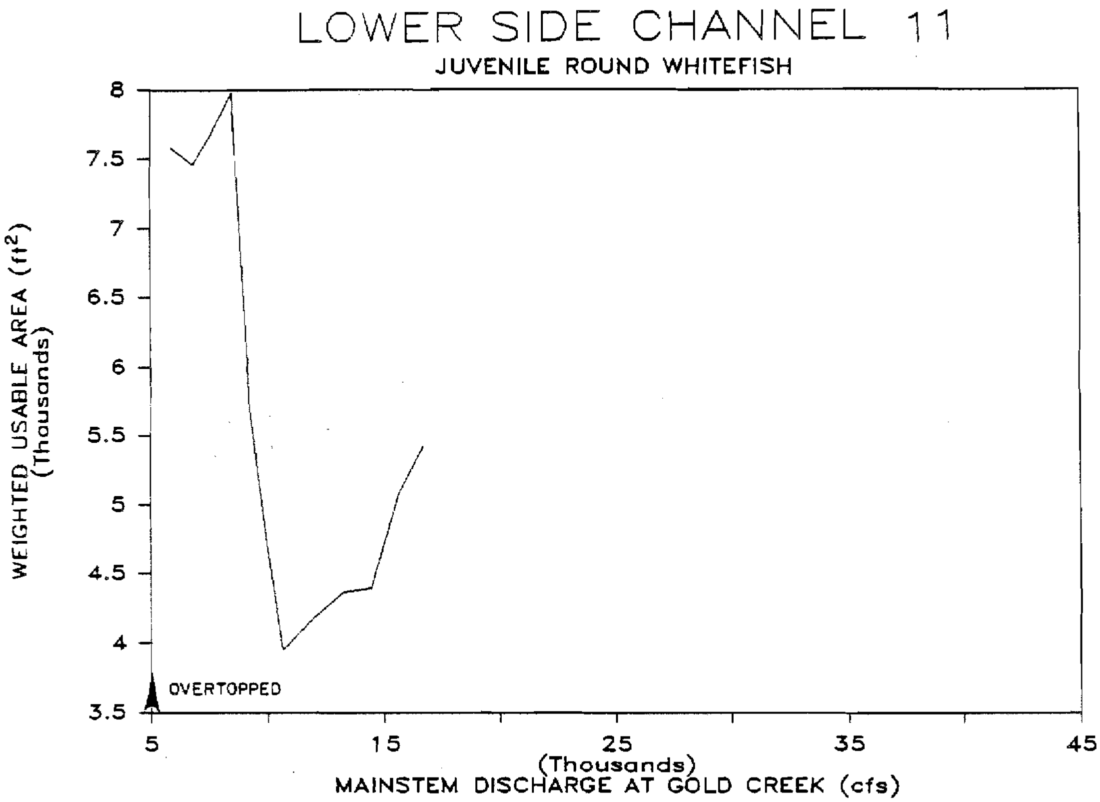


Figure 16. Weighted usable area for juvenile round whitefish at the Slough 9 and Side Channel 10 study sites.



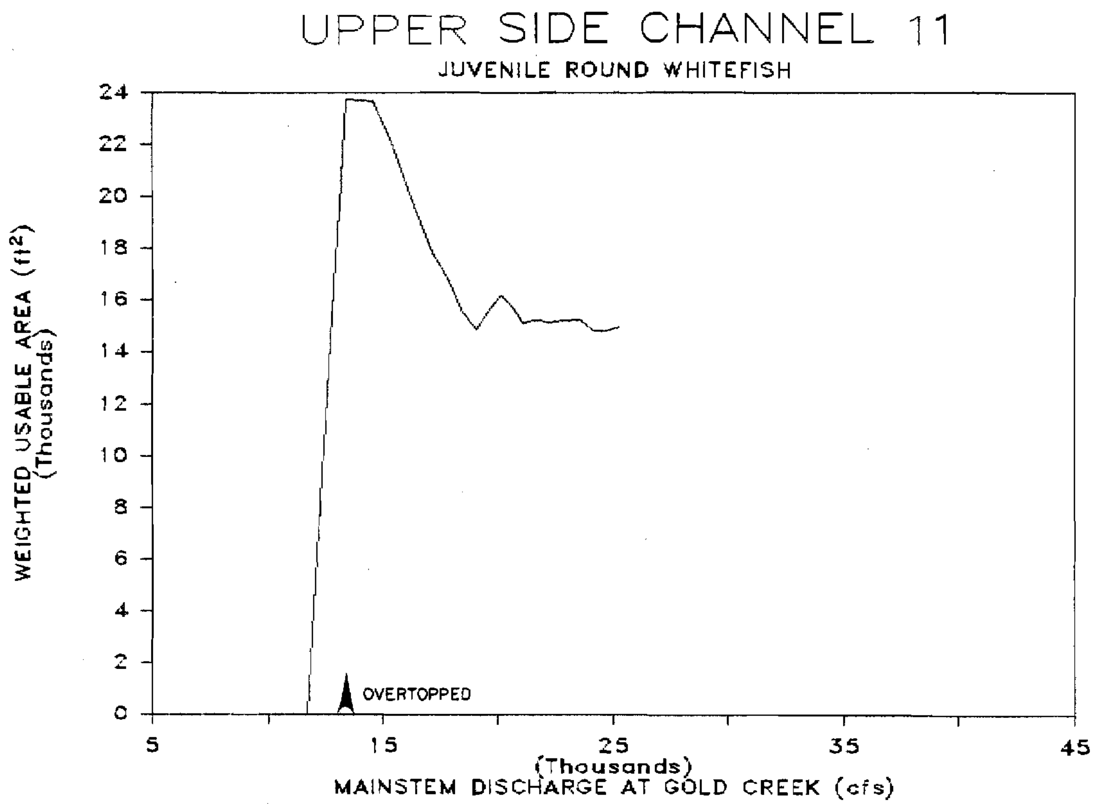
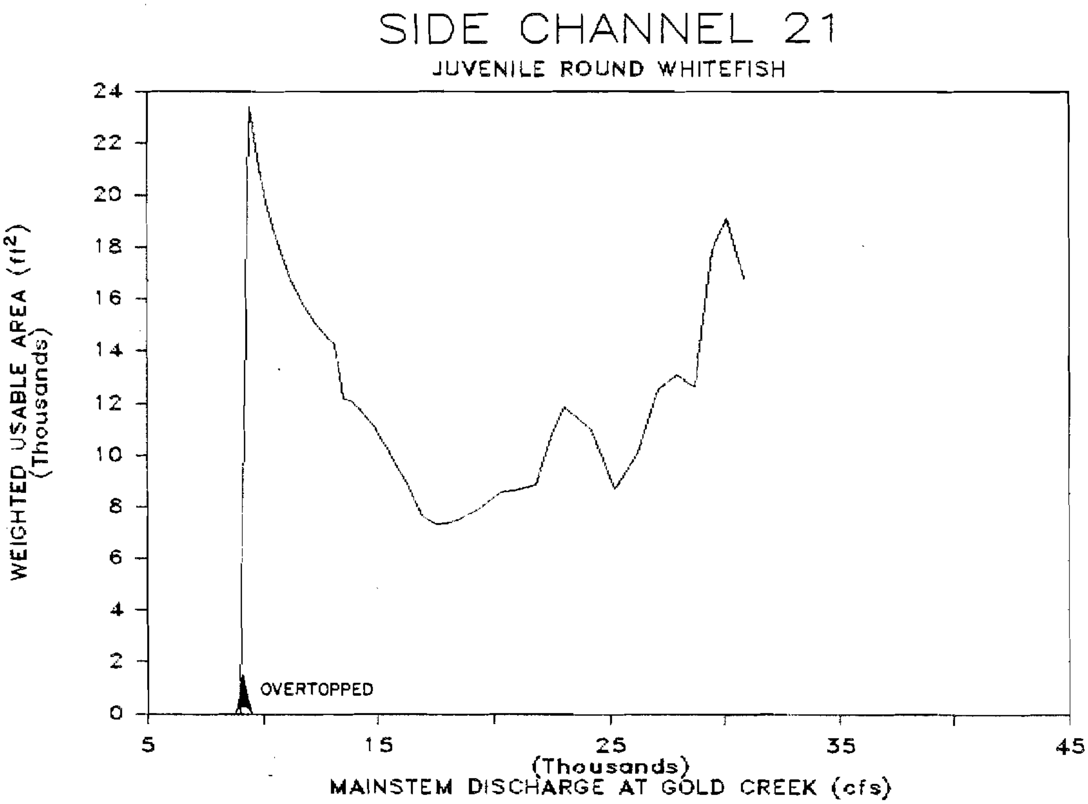


Figure 17. Weighted usable area for juvenile round whitefish at the Lower Side Channel 11 and Upper Side Channel 11 study sites.



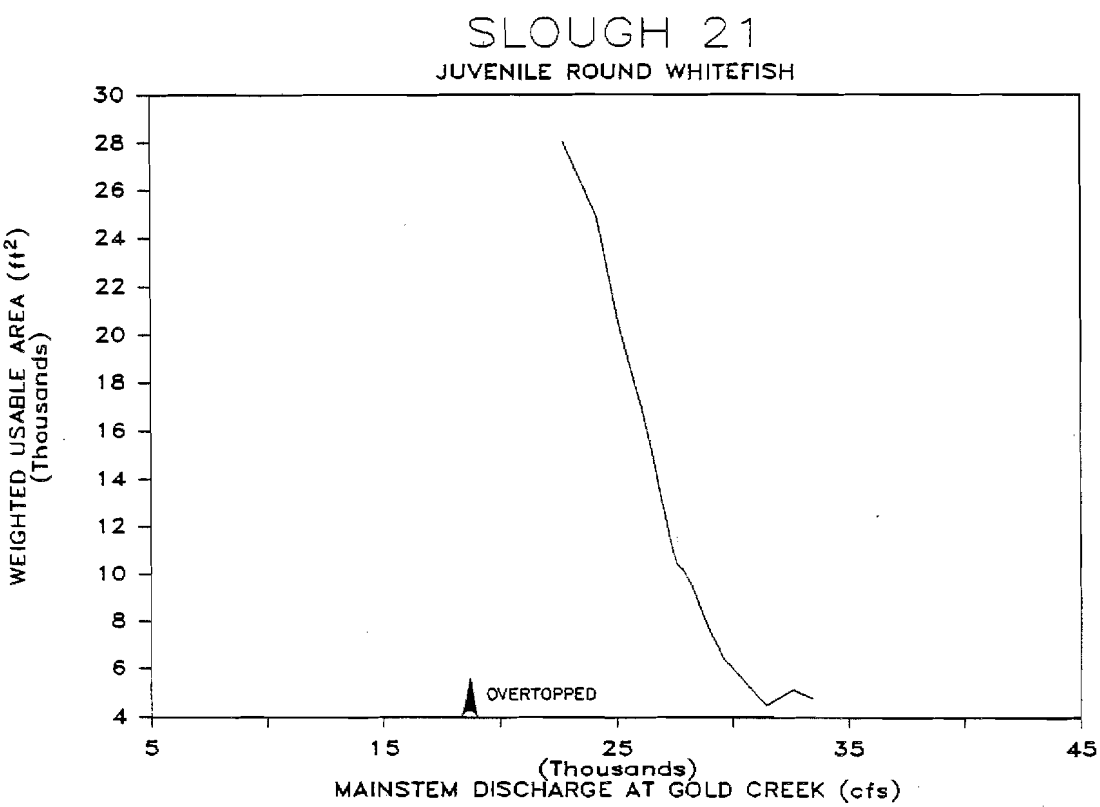


Figure 18. Weighted usable area for juvenile round whitefish at the Side Channel 21 and Slough 21 study sites.

Table 2. Correlations between composite weighting factors and catch transformed by natural log (X+1) for juvenile chinook salmon by selected sites and by all sites pooled.

	Chinook					
	Low turbidity ($\leq$ 30 NTU)			High turbidity ($>$ 30 NTU)		
Site	n	r	Sig [a]	n	r	Sig
Slough 9	48	0.35	0.008	63	0.48	$<$0.001
Side Channel 10	(Insufficient data)			54	-0.08	0.28
All 7 sites pooled	99	0.40	$<$ 0.001	192	0.25	$<$ 0.001

[a] Significance level for rejection of hypothesis that there is no positive correlation between composite weighting factors and catch.

Table 3. Chi-square contingency tests of chum and sockeye salmon proportional presence by composite weighting factor intervals. Data from Sloughs 9, 21, and 8A pooled.

Chum

Composite weighting factor interval	No. of Cells Present	No. of Cells Absent	Total	Proportion Present
0.00-0.28	13	28	41	0.32
0.29-0.44	15	21	36	0.42
0.45-0.55	14	21	35	0.40
0.56-1.00	33	10	43	0.77

$X^2 = 20.05$ df = 3
$p < 0.001$

Sockeye

Composite weighting factor interval	No. of Cells Present	No. of Cells Absent	Total	Proportion Present
0.00-0.07	9	25	34	0.26
0.08-0.14	7	28	35	0.20
0.15-0.38	11	26	37	0.30

$X^2 = 0.92$ df = 2
$p < 0.37$

3.3.1 Juvenile salmon

The response of chinook salmon habitat indices to mainstem discharge varied by site (Figure 19). Habitat indices for juvenile chinook salmon in Sloughs 9 and 21 showed prominent peaks. Side Channel 10 and Upper Side Channel 11 chinook salmon habitat indices increased sharply after the heads were overtopped and then remained fairly constant because velocities did not become limiting at high discharge levels. Chum salmon habitat indices at Slough 9 and Slough 21 were very similar and showed distinct peaks. Sockeye salmon habitat indices at these two sloughs were very low and decreased slowly with discharge.

3.3.2 Resident species

The response of resident fish habitat indices to changes in discharge varied greatly by species. Juvenile round whitefish habitat indices changed in a similar way to chinook salmon habitat indices while Arctic grayling habitat indices steadily increased with discharge (Figure 20). Rainbow trout habitat indices at Slough 21 increased with mainstem discharge while adult longnose sucker habitat indices began to decrease at the higher mainstem discharge levels (Figure 21).

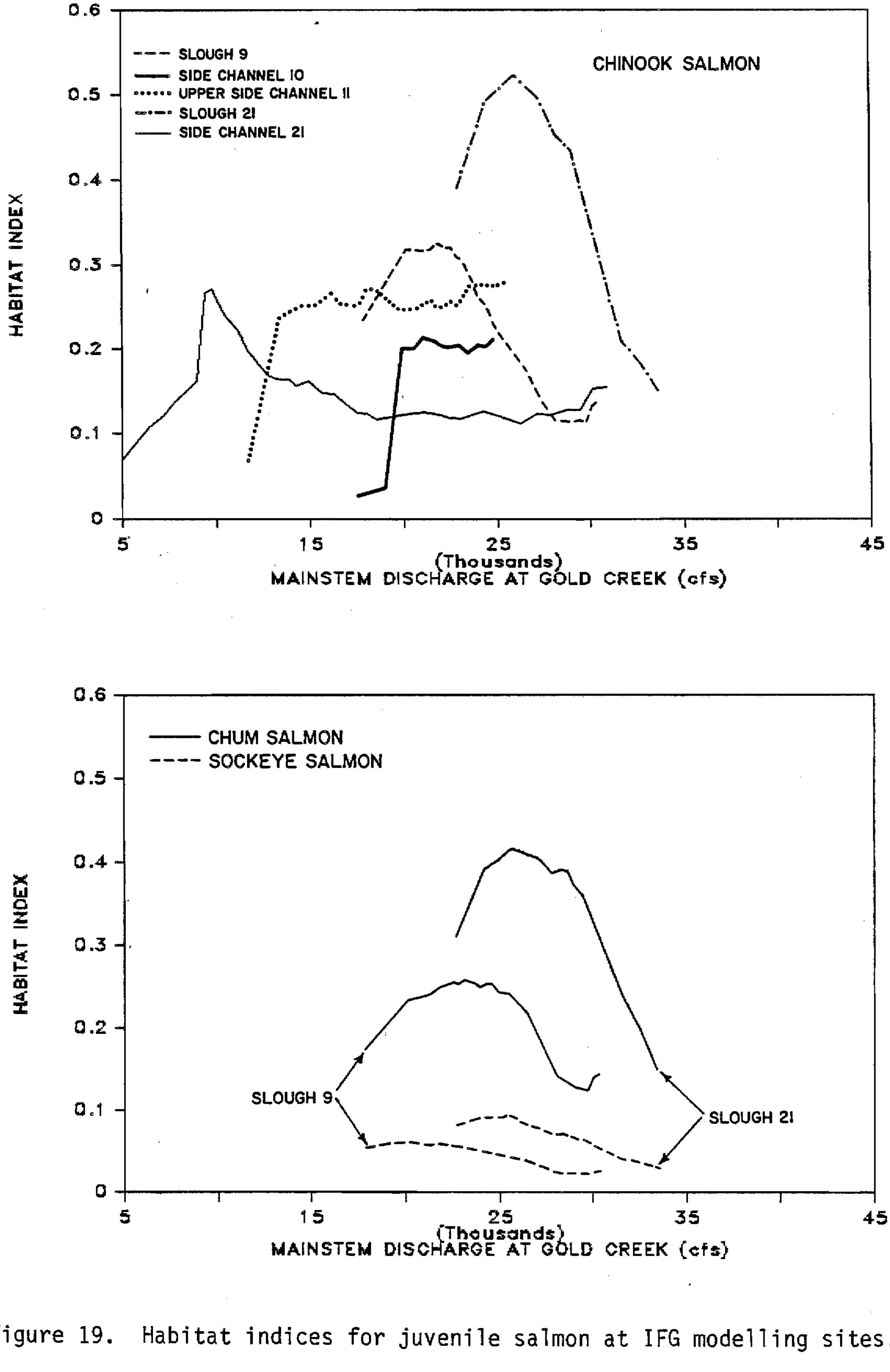


Figure 19. Habitat indices for juvenile salmon at IFG modelling sites.

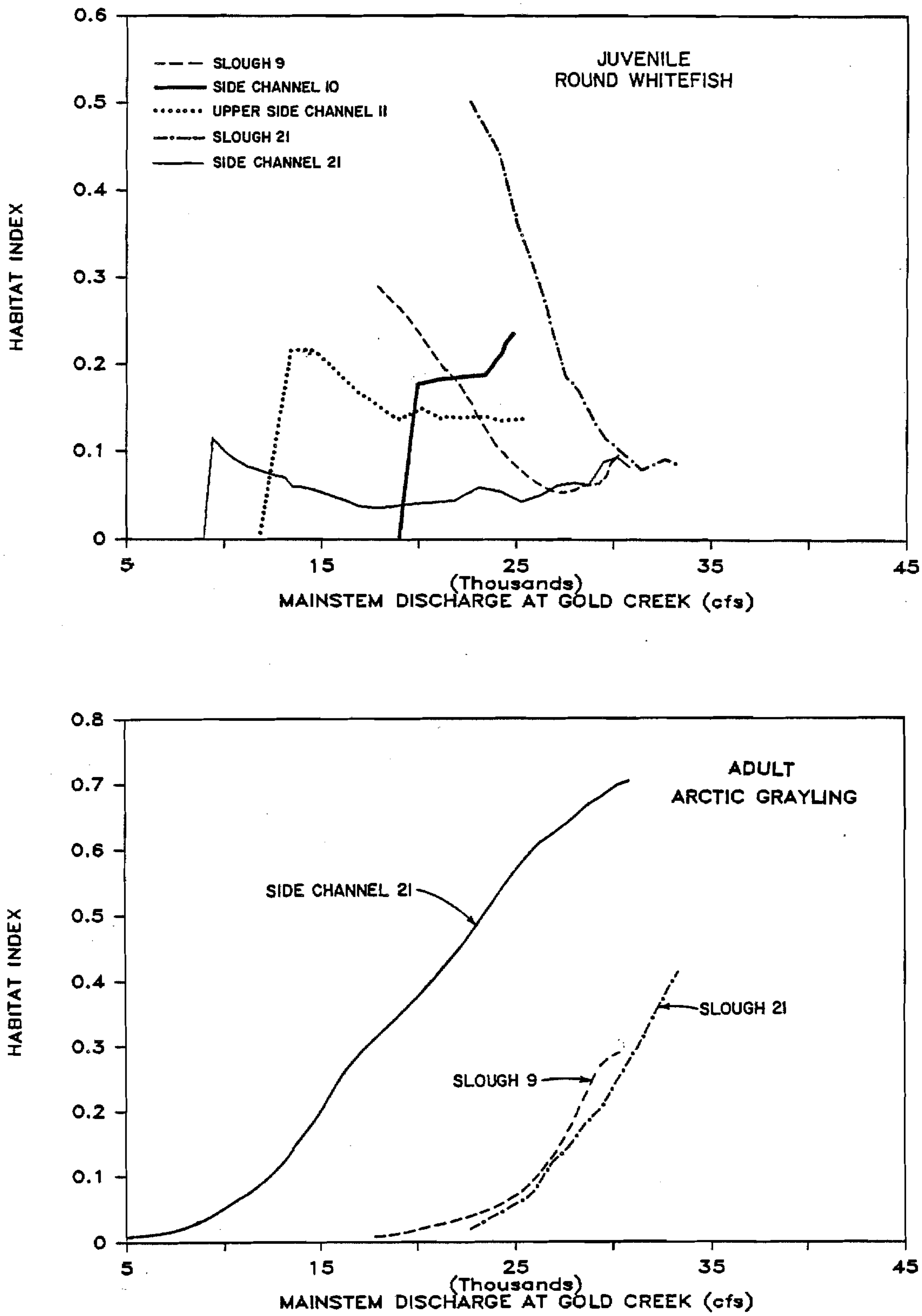


Figure 20. Habitat indices for juvenile round whitefish and adult Arctic grayling at IFG modelling sites.

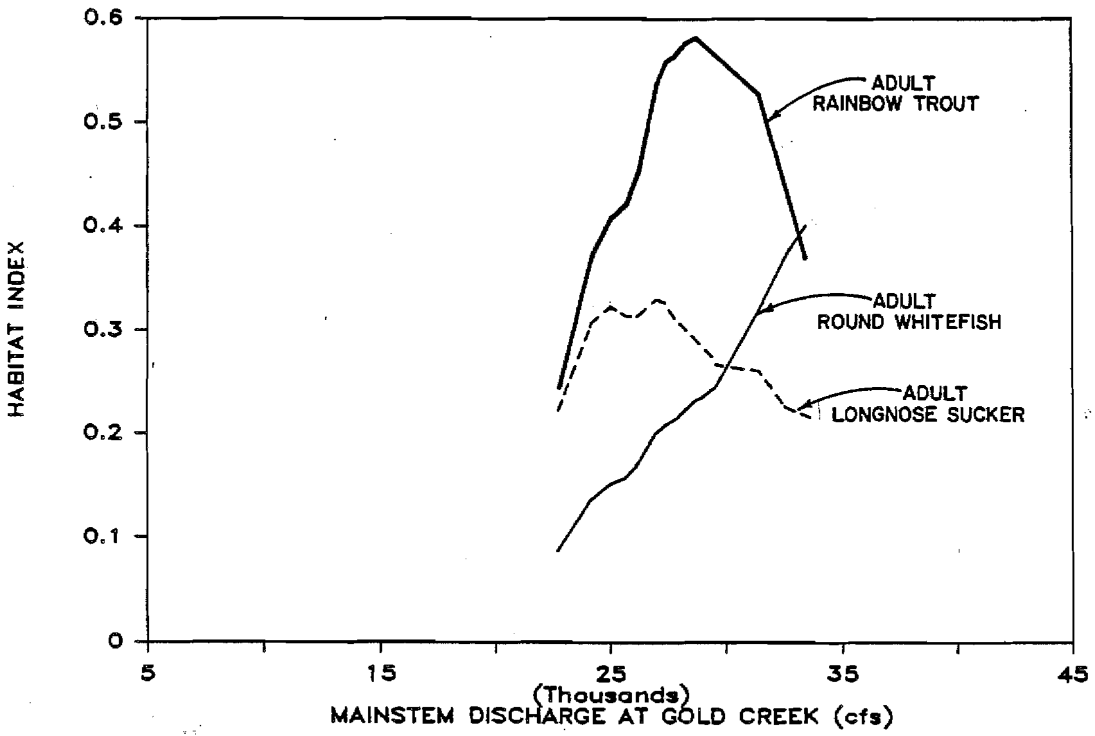


Figure 21. Habitat indices for adult rainbow trout, round whitefish, and longnose suckers at the Slough 21 modelling site.

4.0 DISCUSSION

4.1 Limitations of the Data

The assumptions of the incremental method of habitat analysis by calculating weighted usable areas have been outlined by Orth and Maughan (1982). As applied here, these assumptions are (1) cover, velocity, and depth are the most important variables affecting fish abundance when flow regime changes are considered; (2) the stream channel is not altered by changes in flow; (3) cover, velocity, and depth are independent in their influence on habitat selection by juvenile salmon; (4) the reach can be modelled by reference to a few study areas; and (5) there is a positive relationship between weighted usable area and habitat use.

The initial assumption is a difficult one to evaluate as changes in flow regime may have important effects on such factors as the food supply by affecting water quality. Turbidity is a factor which may have major direct and indirect effects on fish distribution but which was addressed only for chinook salmon indirectly by its use as cover. Analysis is also specific to the ice-free months and no analysis for effects of winter processes has been made. The importance of shoreline area cover to the suitability of offshore areas for rearing juvenile coho is similarly unknown.

Channel morphometry of the sites studies appeared to be stable during the period of study. At Slough 9, however, an IFG-4 modelling site, large amounts of silt were deposited during a flood event in September 1982 (Estes and Vincent-Lang 1984). Long term changes in channel morphometry are therefore possible.

Cover, velocity, and depth are probably not independent in their influence on habitat selection by young salmonids. Analysis of variance indicated that there is a significant interaction between depth and velocity for juvenile chinook and coho salmon catch (Part 3 of this report). Since depth was set to 1.0 over most of the range, this interaction became of little importance. Interactions between cover and velocity are also likely but should not have large effects on WUA projections.

The fourth assumption of the representativeness of the sites studied was probably not met because of several reasons. The study sites showed large variations in response to discharge which makes the concept of a representative site difficult to formulate. The two upland sloughs, in particular, showed large differences in response to changes in mainstem discharge (Part 4 of this report). The Susitna River reach under consideration is a vast mosaic of side channels, side sloughs, and upland sloughs which overtop at many different discharges. The thirteen sites modelled are representative of a large part of the habitat in this reach but do not include the mainstem or the mid-river side channels.

The correlations and proportional presence by composite weighting factor interval for the four species suggest that there is a positive relationship between the weighted usable area and habitat use at the cell level and, by inference, at the site level. Such factors as season and site are also important, however (see Part 2), and much of the variation in catches of fish is not explained by the composite weighting factors.

In summary, some of the assumptions of incremental analysis of habitat may be violated but the effects of these violations on the analysis are difficult to evaluate. The correlation and contingency table analysis, however, suggest that the simulations are related to actual fish use of the sites.

When interpreting the results of the habitat models presented in this paper, it is helpful to consider how close the discharge regime of the open water season of 1983 was to a typical year. Figure 22 shows that June, July, and September discharges were a little lower than the 30 year mean and that the August discharge was higher.

4.2 Comparison of IFG Models with RJHAB

4.2.1 Model characteristics

A comparison of the characteristics of the IFG models and RJHAB as used in this study is summarized in Table 4. The IFG models are based on an underlying theory of hydraulics which enables a simulation of physical conditions that were not actually measured. RJHAB can not simulate physical conditions because cell measurements were not taken in exactly the same physical location each time, and therefore can not be used to project velocities or depths at a study site. It does, however, model habitat which is based on physical measurements and this habitat can be interpolated between actual measurements.

The enormous capacity of the IFG models to predict detailed information on depths and velocities is perhaps overkill when the question to be answered is the availability of rearing habitat. Juvenile salmon and resident fish do not necessarily respond to increments of velocity and depth on the order of 0.1 ft/sec or 0.1 ft. Fish will select an area that has a general range of velocities or depths. Further, factors other than the variables simulated by the IFG models, such as food availability, probably override small differences in depth or velocity in influencing fish density. Restricted access into Slough 8A, for example, caused by beaver dams and lack of overtopping flows limited juvenile chinook use of the site. The IFG models are probably more useful in modelling salmon spawning habitat, where the variables which the IFG model is good at simulating (depth, velocity, substrate) are also of primary importance to the fish. The IFG models in 1983 were mainly used to model salmon spawning habitat; hence, the quality of cover data obtained was lower than would have been desirable from the standpoint of rearing habitat. RJHAB was specifically designed to consider the effect of discharge on cover.

Another benefit of RJHAB is that the field data collection effort required is considerably less than of the IFG models. This enabled us to sample a larger range of habitat types in the reach. Also, RJHAB can be used in more complex sites or sites such as upland sloughs which are primarily backwater areas.

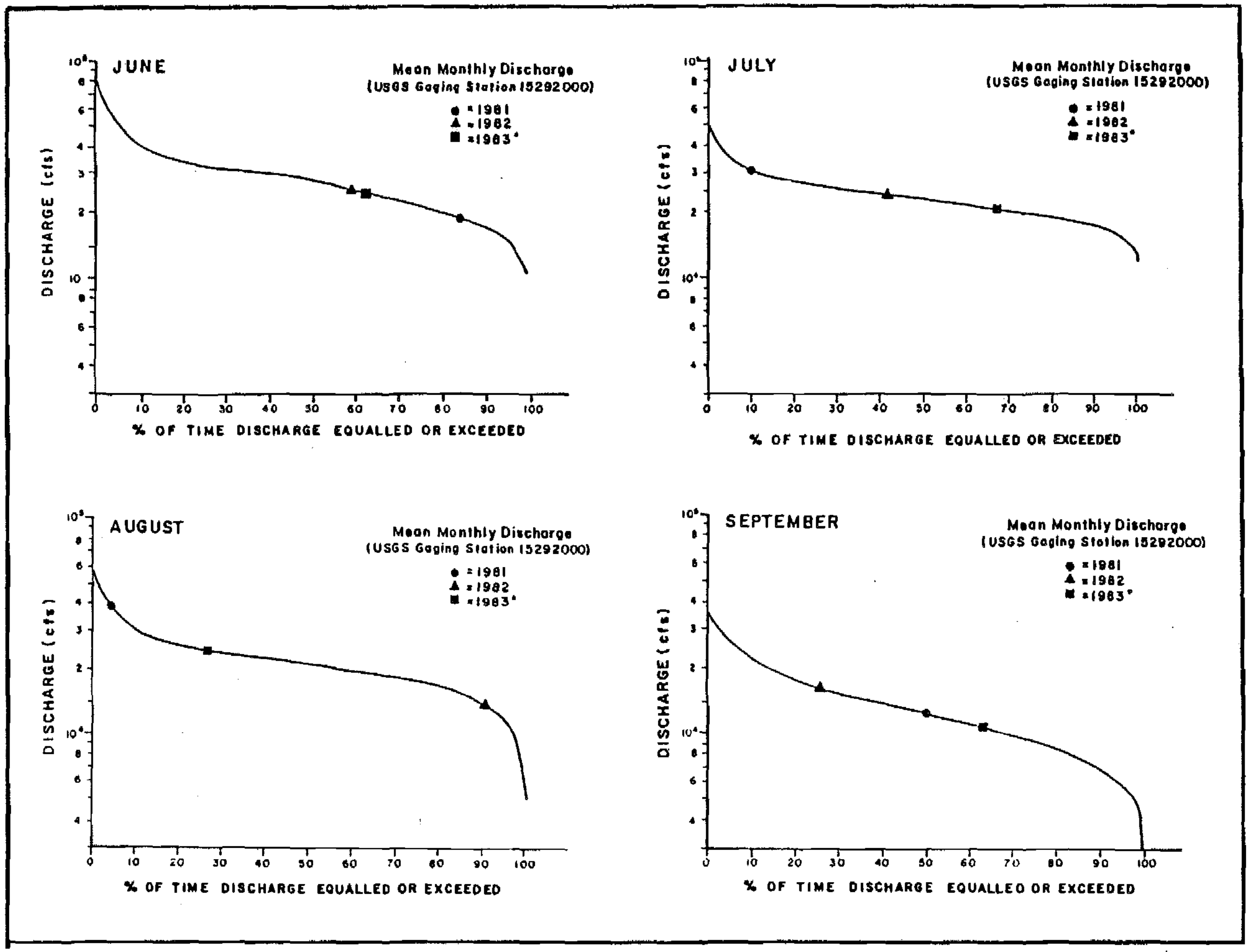


Figure 22. Time duration curves and mean monthly discharges for June, July, and August, and September based on the 30 year record of Susitna River discharge at Gold Creek. Sources: time duration curves - Bredthauer and Drage (1982); mean monthly discharges - USGS (1982), Lamke et al. (1983), and USGS provisional data.

Table 4. Comparison of model characteristics of IFG models and RJHAB.

Parameter	IFG Model	RJHAB
Transects	4 to 11	8 to 9
Measurements	point specific	300 sq ft cells
Data collection	intensive	less intensive
No. of calibration measurements	1 to 4	4 to 6
Extrapolated range	40-250% of calibration range	5,000 to 45,000 cfs
Total surface area	yes	yes
Physical simulation	yes	no
Resolution	fine	coarse
Computer	mainframe	micro
Cost	more	less
Upland sloughs	no	yes
WUA	standardized to 1,000 ft reach	depends on size of site but could be standardized to a 1,000 ft. reach

4.2.2 Model output

The output from the IFG models and RJHAB can be directly compared in at least two different ways: 1) compare percent change in weighted usable area over similar increments of mainstem discharge, and 2) compare the habitat index plots. The actual values of WUA are not comparable without modification because the IFG WUA's are standardized to a linear reach of 1,000 ft while RJHAB was calculated based on the size of the site.

Generally, the shape of the habitat index curves for chinook salmon juveniles are similar for side sloughs and side channels modelled by the IFG models and RJHAB (Figure 23). The RJHAB curves have been smoothed and extrapolated to the discharge range 5,000 to 45,000 cfs. The habitat index for chinook juveniles is the highest at a discharge level which is slightly (within a few thousand cfs) higher than that required to overtop the head of the site. This is because chinooks prefer moderate flows and moderately turbid water. As the discharge levels increase further, the velocity at the sites becomes too great and the habitat index decreases.

The habitat indices calculated for coho salmon from RJHAB are generally low. The same would be true from the IFG models, had we calculated them. The highest habitat indices are from the two upland slough sites, Slough 5 and Slough 6A. This is in agreement with the observed distribution of coho salmon; the density of this species in turbid waters is low (see Part 2 of this report).

Chum habitat indices were similar to those for chinook in that a discharge slightly over the overtopping point produced the maximum habitat index.

Sockeye habitat indices were generally low. The highest indices were for upland sloughs, which are the most lake-like of all the macrohabitat types. Generally, this reach of river is not prime sockeye rearing habitat (see also discussion in Part 1 and Part 2 of this report). There are not very many upland sloughs available. Neither the IFG model or RJHAB successfully predicted the heavy use of side sloughs by sockeye juveniles. This use is more a result of side sloughs being the dominant sockeye spawning grounds in this reach of river than it is a result of the quality of the rearing habitat available in side sloughs.

Sockeye habitat indices increased in side sloughs with increasing discharge as surface area increased. After the heads of the sites were overtopped by mainstem water, the habitat index started to decline sooner than did the habitat indices for chinooks and chums. This reflects the preference of sockeye juveniles for lower velocity water than the other two species.

Habitat indices for all species in upland sloughs increase steadily as mainstem discharge increases. This is mainly a function of increased surface area attributable to the backwater effect of mainstem stage at the mouth of these sites. Similar results were obtained by the 1982

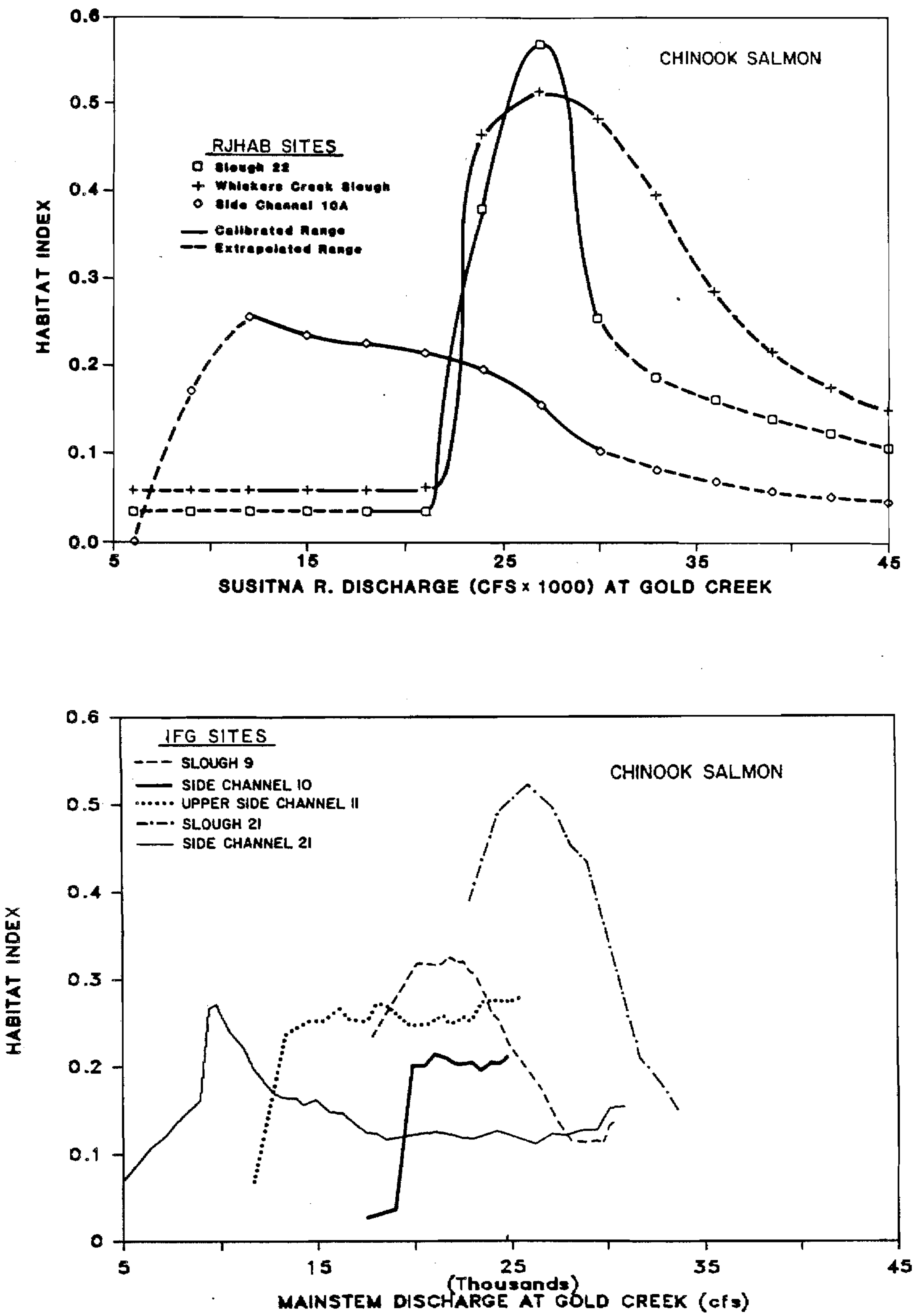


Figure 23. Comparison of RJHAB and IFG habitat indices for juvenile chinook salmon.

study that specifically examined the effect of the backwater phenomenon on rearing habitat (ADF&G 1983c). At very low mainstem discharges, cover may also be lost around the shoreline of sites such as Slough 6A where undercut banks and overhanging riparian vegetation are present.

4.3 Summary of Seasonal Habitat Projections for Rearing Salmon and Resident Fish

An examination of the figures in which chinook weighted usable area is plotted versus mainstem discharge and versus time of season shows that some sites provide the most weighted usable area when discharge is low (e.g., Lower Side Channel 11), some when discharge is at an intermediate level (e.g., Slough 9), and some when discharge is high. The controlling factor is the discharge at which the head of the site is overtopped. The maximum weighted usable area for chinook at most sites occurred at a discharge slightly greater than the overtopping discharge. Therefore, chinook weighted usable area in this reach of river would theoretically be the highest at the discharge level which just overtops the maximum number of sites (the size of each site must also be considered).

There is undoubtedly a correlation between a decline in weighted usable area at the rearing sites and re-distribution of juvenile salmon. If a rearing area is essentially saturated by fish and then weighted usable area decreases, some fish are forced to leave. We have observed this at sites such as Slough 22 where chinook juveniles were abundant when the head was overtopped and less abundant when the water cleared after mainstem water no longer entered the slough. Also, we have demonstrated a positive correlation between composite weighting factors and juvenile salmon density.

The fish that are forced out of a certain site must either seek a new rearing site or, under more extreme conditions, migrate out of that reach of river. In the latter situation, there should be an increase in the capture rate at the downstream migrant traps. It is difficult to discern such a relationship with the 1983 data. The outmigration rate of chinook juveniles was relatively low when the weighted usable area at Slough 9 was high and the outmigration rate was high when WUA at Slough 9 was lowest (disregarding the month of September, when discharge was low). However, this relationship was reversed at other sites. Ideally, only the best rearing sites should be considered in this approach. This relationship may also be obscured by major outmigrations from the tributaries which have little to do with changes in mainstem conditions.

There is also the larger question of whether in fact rearing habitat is limiting to salmon. If the number of fry emerging from the gravel is not enough to saturate the available rearing habitat, then there would be more flexibility with regard to varying discharges. In our experience on the Susitna River, both saturation and under-utilization of rearing habitat occurs. A partial explanation is that there is no substantial amount of spawning above the upper end of this reach. Therefore, when waves of juvenile chinook and coho migrate out of Portage Creek, they probably saturate a certain portion of the available rearing habitat in the Susitna River downstream of the Portage

Creek confluence until they have had sufficient time to re-distribute further downstream. During other periods of time, when few fish are migrating out of Portage Creek, these same rearing areas may not be saturated, especially if an intervening period of poor habitat (discharge too low or too high) has caused the previous occupants to leave the area. We have observed this at such sites as Slough 22 and Slough 21 on occasions when habitat conditions appeared to be relatively good (and weighted usable area was high); yet, fish density was low relative to other times of apparently equal habitat quality.

It seems almost certain that rearing habitat is limiting for sockeye juveniles in this reach of river. The deeper, low velocity, relatively clear water that they prefer does not occur in the reach in large quantities (Klinger and Trihey 1984). A high proportion of the young-of-the-year fish leave this reach (based on downstream migrant trap catch rates, see Part 2). The Age 0+ fish must either rear in the lower river or die, because only a miniscule number of adult sockeyes migrating upstream past the Talkeetna Station outmigrated to the ocean as Age 0+ fish. The majority of adults are 4_2's (Barrett et al. 1984).

It has been conclusively shown (Part 1) that chum salmon rear in this reach of river because they show substantial growth between emergence and outmigration. The correlation of chum catch per hour at the outmigrant traps and discharge was high ($r^2 = 0.79$, see Part 2), suggesting that high water events displace or trigger outmigration by chums rather than contribute to suitable habitat. If rearing habitat became restricted because of low discharge, the fish would probably leave this reach later rather than sooner because of the lack of a high water pulse that might trigger outmigration.

Although few data on winter distribution are available, there are strong indications of substantial changes in macrohabitat use during the winter. Discharge levels are much reduced and the mainstem water becomes clear. Many chinook and coho juveniles move out of tributaries to overwinter in the mainstem. There appears to be a trend in the fall that has been noticed for three consecutive years in which chinook and coho move into the deeper slough areas. There may be a thermal attraction produced by upwelling water in the sloughs.

Resident fish use of both microhabitat and macrohabitat is closely linked to turbidity and apparently to food supply. Juvenile round whitefish are found in the small side channels which have a low flow, so distribution is tied to discharges at which the heads of these side channels are slightly overtopped.

The use of side sloughs by most species of adult resident fish is probably limited by the very small amount of flow through these sites. As heads are overtopped and flows increase, the sites rapidly become more favorable for adult resident fish. These fish also use portions of the mainstem for rearing. The rearing habitat may be limiting but this is not likely due to lack of suitable open water season cover, depths, or velocities. It is more likely to be attributable to other factors such as overwintering mortality or food supply, as densities of residents are low almost everywhere in mainstem-influenced sites with the exception of selected tributary or slough mouths where fish may gather to feed on salmon eggs, outmigrating juvenile salmon, or invertebrates.

In conclusion, the results presented in this part and the data and analysis from parts one through six of this report suggest the following trends:

(1) Of the salmon juveniles rearing in the Susitna River, chinook and chum appear to make the best use of habitats associated with the mainstem and also have the most abundant adult returns (even year pink salmon excluded) in this reach of the river. Juvenile coho salmon apparently rear primarily in tributaries, but will take advantage of the upland slough habitat that is available.

(2) Sockeye salmon appear to be most heavily limited by rearing habitat with highly successful incubation, but limited rearing, occurring in this reach of river. Either rearing survival is low or rearing takes place in the lower river. Successful rearing does occur within limited portions of some of the upland and clear water sloughs but is probably minor when compared to the total population of emergent fry. Apparently, sockeye rearing does not occur in tributaries to any great extent.

(3) Of the habitats affected by mainstem discharge, microhabitat within side channels/side sloughs is most affected, primarily by dewatering, lowered turbidity, and lower water velocity after the head is no longer overtopped by mainstem flows. This habitat is heavily used by chinook juveniles, who appear to be limited by cover when the sites are not turbid (generally associated with the heads not being overtopped). Maximum habitat value for chinook salmon is obtained at a discharge level slightly greater than the overtopping discharge level.

(4) Wintering habitat for all rearing species is heavily dependent on mainstem habitats as indicated by spring and fall migratory movements. The models presented have not been designed to evaluate habitat conditions during the winter.

(5) Resident species using mainstem habitat areas are most predictively associated with levels of turbidity and appear limited by food supply. They often associate with the mouths of clear water tributaries or with spawning salmon. The response of primary productivity of the system may be more indicative of the response of resident species than the values generated by habitat simulation based on hydraulic models.

The results and discussion presented in this report do not conclude the analytical effort required to use this information in a decision making process. It remains to integrate these results with the studies conducted on adult anadromous spawning and to further extrapolate our study sites to the entire reach of river which they were chosen to represent using the surface area information provided by Klinger and Trihey (1984). Further, these results must be weighted with respect to the importance of the harvestable adults of each species. Finally, these results must be portrayed in such a manner as to depict the effects of alternative flow regimes on different species so that the flow requirements of different management goals can be ascertained. Future reports prepared by other investigators will use this report to ultimately provide the above information.

5.0 CONTRIBUTORS

IFG hydraulic model data collection was done by the Aquatic Habitat Group of the Su Hydro Aquatic Studies. Kim Sylvester of the AH group and Diane Hilliard of E. Woody Trihey and Associates calibrated the hydraulic models. Diane Hilliard input cover data, the suitability criteria, and ran the PHABSIM habitat models which generated weighted usable areas. Bob Marshall made some helpful suggestions.

Drafting was done by Sally Donovan and Carol Riedner. The typing was done by Skeers Word Processing Services.

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Part 7
Modelling Of Juvenile Salmon
And Resident Fish Habitat

ALASKA DEPARTMENT OF FISH AND GAME
SUSITNA HYDRO AQUATIC STUDIES

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RESIDENT AND JUVENILE ANADROMOUS FISH
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