SUSITNA
HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION
PROJECT No. 7114

INSTREAM FLOW RELATIONSHIPS REPORT SERIES

RESPONSE OF JUVENILE CHINOOK HABITAT TO DISCHARGE IN THE TALKEETNA-TO-DEVIL CANYON SEGMENT OF THE SUSITNA RIVER, ALASKA

TECHNICAL REPORT No. 5
PART A

PREPARED BY

Trihey & Associates
Aquatic Resource Specialists

UNDER CONTRACT TO

HARZA-EBASCO
SUSITNA JOINT VENTURE

FINAL REPORT

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RESPONSE OF JUVENILE CHINOOK HABITAT TO MAINSTEM DISCHARGE IN THE TALKEETNA-TO-DEVIL CANYON SEGMENT OF THE SUSITNA RIVER, ALASKA

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Under Contract to
Harza-Ebasco Susitna Joint Venture

Prepared for
Alaska Power Authority

Final Report
December 1985

NOTICE

ANY QUESTIONS OR COMMENTS CONCERNING
THIS REPORT SHOULD BE DIRECTED TO
THE ALASKA POWER AUTHORITY
SUSITNA PROJECT OFFICE

PREFACE

The goal of the Alaska Power Authority in identifying environmentally acceptable flow regimes for the proposed Susitna Hydroelectric Project is the maintenance of existing fish resources and levels of production. This goal is consistent with mitigation goals of the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game. Maintenance of naturally occurring fish populations and habitats is the preferred goal in agency mitigation policies.

In 1982, following two years of baseline studies, a multi-disciplinary approach to quantify effects of the proposed Susitna Hydroelectric Project on existing fish habitats and to identify mitigation opportunities was initiated. The Insteam Flow Relationships Studies (IFRS) focus on the response of fish habitats in the middle Susitna River to incremental changes in mainstem discharge, temperature and water quality. As part of this multi-disciplinary effort, a technical report series was planned that would (1) describe the existing fish resources of the Susitna River and identify the seasonal habitat requirements of selected species, and (2) evaluate the effects of alternative project designs and operating scenarios on physical processes which most influence the seasonal availability of fish habitat.

The summary report for the IFRS, the Instream Flow Relationships Report (IFRR), (1) identifies the biologic significance of the physical processes evaluated in the technical report series, (2) integrates the findings of the technical report series, and (3) provides quantitative relationships and discussions regarding the influences of incremental changes in streamflow, stream temperature, and water quality on fish habitats in the middle Susitna River on a seasonal basis.

The IFRR consists of two volumes. Volume I uses project reports, data and professional judgment to identify evaluation species, important life stages, and habitats. The report ranks a variety of physical habitat components with regard to their degree of influence on fish habitat at different times of the year. This ranking considers the biologic requirements of the evaluation species and life stage, as well as the physical characteristics of different habitat types, under both natural and anticipated with-project conditions. Volume II of the IFRR will address the third objective of the IFRR and provide quantitative relationships on a seasonal basis regarding the influences of incremental changes in streamflow, stream temperature, and water quality on fish habitats in the middle Susitna River.

The influence of incremental changes in streamflow on the availability and quality of fish habitat is the central theme of the IFRR Volume II analysis. Project-induced changes in stream temperature and water quality are used to condition or qualify the forecasted responses of fish habitat to instream hydraulics. The influence of streamflow on fish habitat will be evaluated at the microhabitat level and presented at the macrohabitat level in terms of a composite weighted usable area curve. This composite curve will describe the combined response of fish habitat, at all sites within the same representative group (to incremental changes in mainstem discharge).

Four technical reports are being prepared by E. Woody Trihey and Associates in support of the IFRR Volume II analysis. The function of each report is depicted in a flow diagram and described below.

1) Quantify Wetted Surface Area Response

2) Assess the Representativeness of Modeled and Non-modeled Sites

3) Determine Site-Specific Hydraulic Conditions

4) Quantify Streamflow-Dependent Habitat Response Functions for Juvenile Chinook and Spawning Chum Salmon

1) RESPONSE OF AQUATIC HABITAT SURFACE AREAS TO MAINSTEM DISCHARGE IN THE TALKEETNA-TO-DEVIL CANYON SEGMENT OF THE SUSITNA RIVER, ALASKA

This report identifies five aquatic habitat types within the middle Susitna River directly influenced by changes in mainstem discharge and presents the necessary photography and surface area measurements to quantify the change in wetted surface area associated with incremental decreases in mainstem discharge between 23,000 and 5,100 cfs. The report also describes the influence of mainstem discharge on habitat transformations and tabulates the wetted surface area responses for 172 specific areas using the ten representative groups presented in the Habitat Characterization Report. Surface area measurements presented in this report provide a basis for extrapolating results from intensively studied modeling sites to the remainder of the middle Susitna River.

2) CHARACTERIZATION OF AQUATIC HABITATS IN THE TALKEETNA-TO-DEVIL CANYON SEGMENT OF THE SUSITNA RIVER, ALASKA

This report describes the characterization and classification of 172 specific areas into ten representative groups that are hydrologically, hydraulically and morphologically similar. Emphasis is placed on the transformation of specific areas from one habitat type to another in response to incremental decreases in mainstem discharge from 23,000 cfs to 5,100 cfs. Both modeled and non-modeled sites are classified and a structural habitat index is presented for each specific area based upon subjective evaluation of data obtained through field reconnaissance surveys.

Representative groups and structural habitat indices presented in this report provide a basis for extrapolating habitat response functions developed at modeled sites to non-modeled areas within the remainder of the river.

3) HYDRAULIC RELATIONSHIPS AND MODEL CALIBRATION PROCEDURES AT 1984 STUDY SITES IN THE TALKEETNA-TO-DEVIL CANYON SEGMENT OF THE SUSITNA RIVER, ALASKA

This report describes the influence of site-specific hydraulic conditions on the availability of habitat for juvenile chinook and spawning chum salmon. Two aquatic habitat models are applied to quantify site-specific habitat responses to incremental changes in depth and velocity for both steady and spatially varied streamflow conditions. Summaries of site-specific stage-discharge and flow-discharge relationships are presented as well as a description of data reduction methods and model calibration procedures. Weighted usable area forecasts are provided for juvenile chinook at 8 side channel sites and for spawning chum salmon at 14 side channel and mainstem sites. These habitat response functions provide the basis for the instream flow assessment of the middle Susitna River.

4) RESPONSE OF JUVENILE CHINOOK AND SPAWNING CHUM SALMON HABITAT TO MAINSTEM DISCHARGE IN THE TALKEETNA-TO-DEVIL CANYON SEGMENT OF THE SUSITNA RIVER, ALASKA

This report integrates results from the surface area mapping, habitat characterization, and hydraulic modeling reports to provide streamflow dependent habitat response functions for juvenile chinook and spawning chum salmon. Wetted surface area and weighted usable area are the principal determinants of habitat indices provided in Part A of the report for juvenile chinook at each specific area and the ten representative groups identified in the habitat characterization report. Part B of this report provides habitat response functions for existing chum salmon spawning sites. The habitat response functions contained in this report will be used for an incremental assessment of the rearing and spawning potential of the entire middle Susitna River under a wide range of natural and with-project streamflows.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES
(cont.)

LIST OF FIGURES
(cont.)

LIST OF FIGURES
(cont.)

LIST OF FIGURES
(cont.)

LIST OF FIGURES
(cont.)

LIST OF TABLES

LIST OF PLATES

LIST OF PLATES
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1.0 INTRODUCTION

Due to the economic importance of the species, the ecological sensitivity of the life stage, and their extensive use of mainstem-associated habitats, juvenile chinook have been designated as a primary evaluation species to be used in analyses of existing and with-project conditions. Chum salmon spawning and incubation life stages comprise the other two primary species/life stages selected for evaluation (EWT&A and Entrix 1985).

This report addresses the effects of flow variation on the availability and quality of juvenile chinook salmon habitat within the Talkeetna to Devil Canyon reach of the Susitna River. The response of juvenile chinook habitat to changes in streamflow within this middle reach of the Susitna River has been the subject of several years of data collection and modeling studies conducted by the Alaska Department of Fish and Game (ADF&G) and Trihey and Associates (EWT&A). These investigations are part of an extensive environmental assessment program conducted to fulfill licensing requirements for the proposed Susitna Hydroelectric Project.

The Alaska Power Authority (APA), the state agency responsible for developing the hydropower potential of the Susitna River, has indicated a desire to maintain existing fish resources and levels of production within affected reaches of the river (APA 1985). This goal may be attainable through a variety of mitigative options (Moulton et al. 1984). However, to protect existing fisheries resources and to ensure the success of selected mitigation and enhancement efforts, it is necessary to identify and adopt instream flows and reservoir operation schedules which will provide for the needs of the fish species inhabiting the middle Susitna River.

The storage and release of water to meet the instream flow needs of fishes downstream is not necessarily incompatible with hydropower interests. The recharge and storage capabilities of the proposed Devil Canyon and Watana reservoirs [refer to APA (1985) for a description of the design criteria and construction schedule for these facilities] will permit water to be stored during periods when natural runoff exceeds both the water demand for power generation and the instream flow needs of resident and anadromous fishes. This will allow for the controlled release of water during periods of greatest demand for power.

Under the license application presently before the Federal Energy Regulatory Commission the development of the Susitna hydroelectric project is planned to occur in three stages·(APA 1985).

- Stage I is the construction and operation of the Watana dam by 1999 which will provide 2.37 million acre feet of active storage. This is approximately 40 percent of the mean annual flow at the damsite and affords some seasonal regulation.
- Stage II is construction of a dam by 2005 in the narrow Devil Canyon. The principal purpose is to develop head relying upon the Watana dam to regulate flows for power production.
- Stage III involves raising the Watana dam 180 feet by 2012 to increase active storage to 3.7 million acre feet, approximately 64 percent of the mean annual flow.

The license application presents environmental flow cases E-1 through E-VI which are aimed to provide different maintenance levels of habitats most responsive to mainstem flows. Case E-VI is the selected flow case in the application and is designed to maintain 75 percent of the existing chinook salmon side channel rearing habitat in all years except low flow years. There are four projected flow scenarios for Case E-VI depending upon the stage of development of the project. Figure 1 compares natural with simulated with-project mean weekly discharges at Gold Creek for these four scenarios.

The frequency and rate of change of daily flow fluctuations in the middle Susitna River will be highest during Stage I and II. However, by Stage III daily flow fluctuations are expected to be minimal. Over the long-term, use of the combined storage volume of the two reservoirs will result in lower summer and higher winter flows than presently occur.

As the demand for electricity varies over time, so do the instream flow needs of a fish species vary according to their life history stage. Adult chinook spawn exclusively within tributaries of the middle reach of the Susitna River, principally Indian River and Portage Creek. Consequently, the reproductive and early post-emergent fry life stages of chinook (unlike those of chum, pink and sockeye salmon which spawn in both tributary and non-tributary habitats of the middle Susitna River) are not likely to be affected by project operation. The later freshwater life stages of chinook salmon, including juvenile and migratory phases, will be subjected to altered streamflow regimes since they utilize mainstem and mainstem-influenced habitats (Figure 2). The summer growth season is an important period for chinook juveniles since it is at this time that density-dependent factors will typically have their greatest effect on the population.

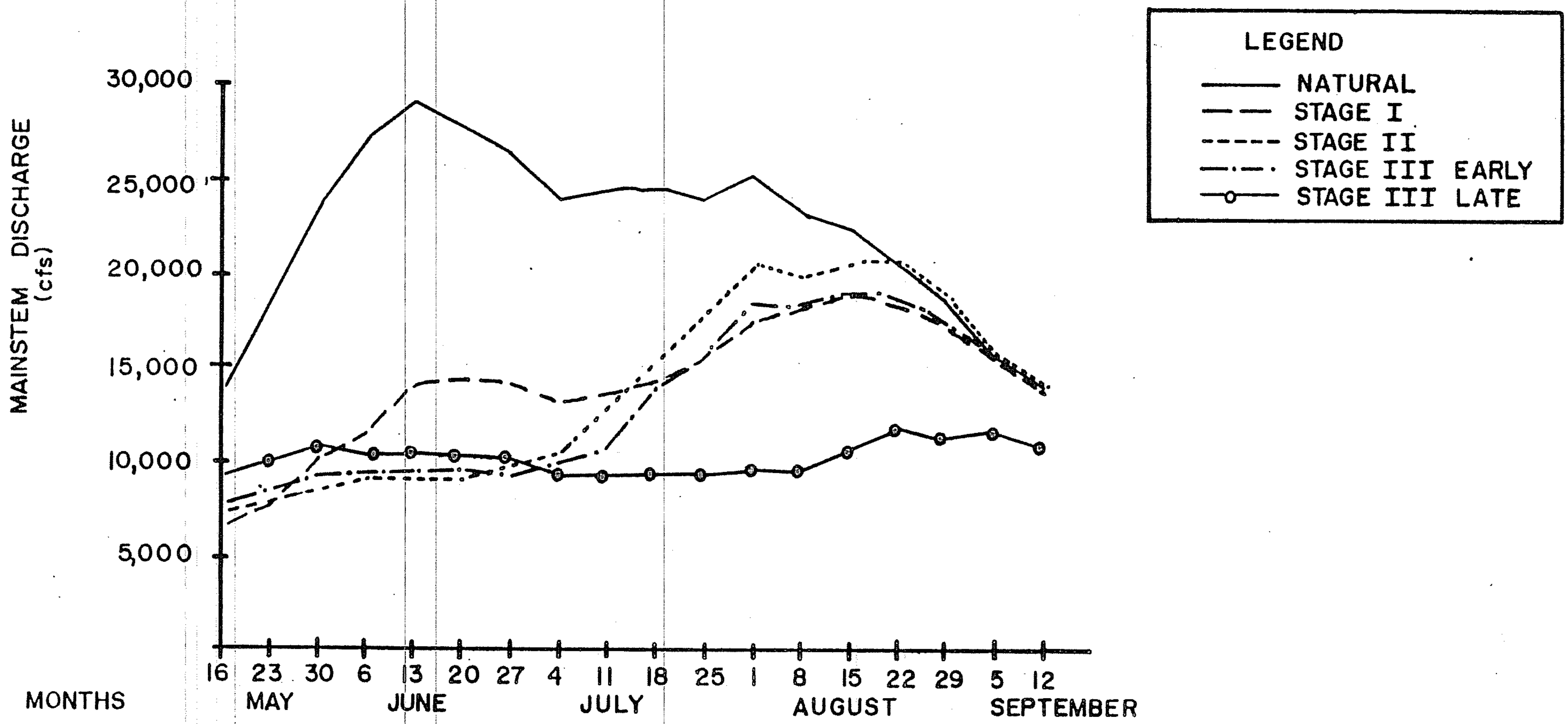


Figure 1. Natural and with-project mean weekly discharges for the middle Susitna River. Natural flows are based on 35 year record (1950-1984) from USGS Station 15292000 at Gold Creek. Simulated with-project flows are based on Case E-VI, demand levels Stage I, Stage II, early and late Stage III (data from APA 1985).

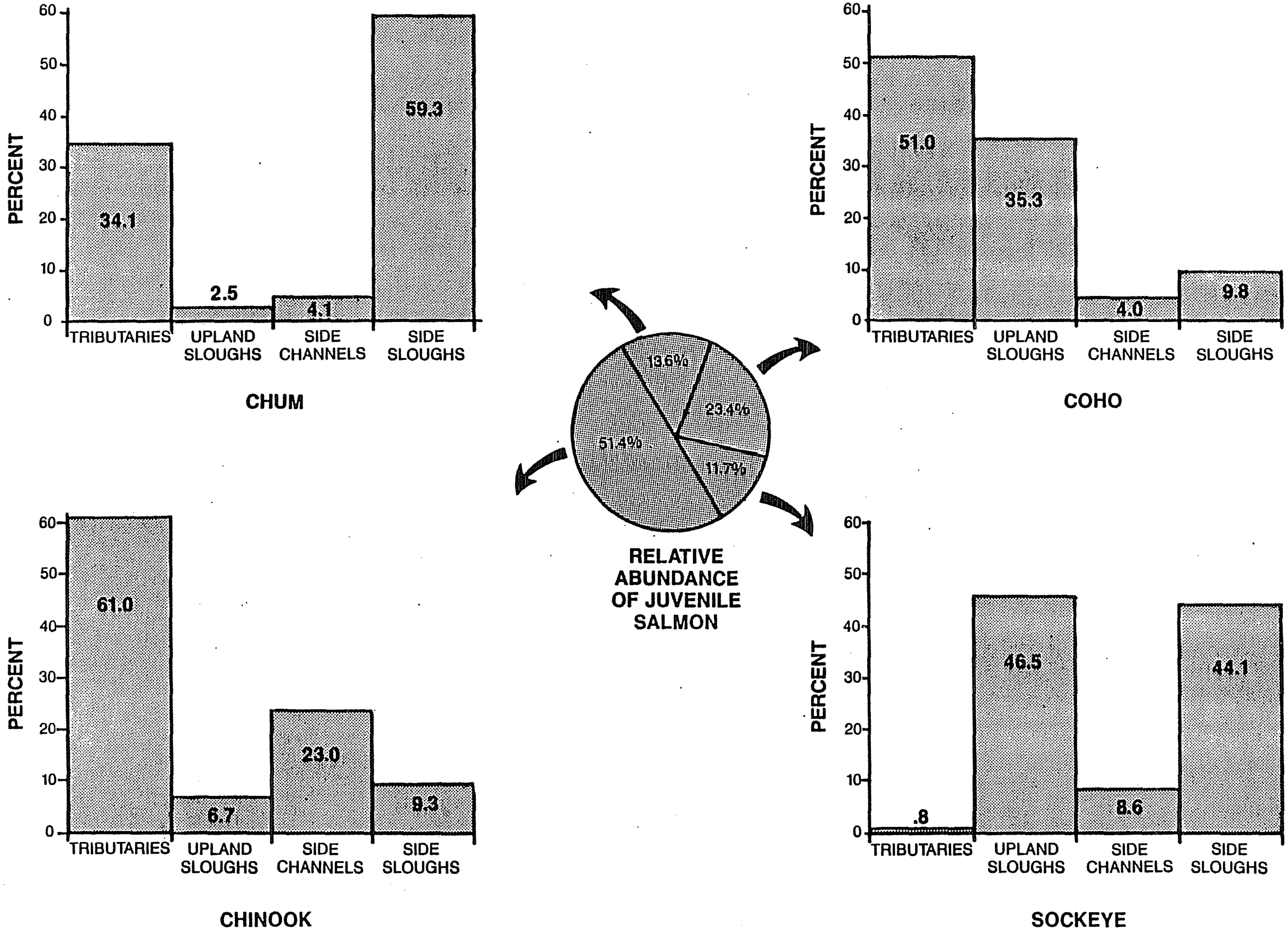


Figure 2. Percentage distribution of juvenile salmon within different habitat types of the middle Susitna River during the open water period (Dugan, Sterritt, and Stratton 1984).

Following emergence in March and April juvenile chinook typically spend several months rearing in their natal streams. However, the numbers and biomass of juvenile fish may exceed the carrying capacity of the tributaries by midsummer and a percentage of the chinook population respond by emigrating to the Susitna River. During the remainder of their freshwater residency, which usually lasts until the spring of the following year, juvenile chinook typically occupy a range of habitats. Densities are highest in tributaries, side channels and side sloughs, respectively, during July to September of the open water season (Figure 3). Chinook distribution during the winter months is not well documented other than a noted tendency for individuals in mainstem and side channel areas to seek relatively warmer upwelling areas in side sloughs. During the fall a significant number of young-of-the-year chinook apparently migrate downstream late in the summer, although it is uncertain whether they overwinter in fresh or saltwater (Dugan et al. 1984).

The biological and physical factors affecting juvenile chinook salmon in their rearing environment and their interrelationships are complex. Milner (1985) reviewed these environmental factors and their potential effects. Food availability, predation, and competition are among the more important biological factors. All are mediated to some degree by the quantity and quality of physical habitat which constitute the fish's living space. Physical habitat includes the combination of hydraulic, structural and chemical variables to which juvenile chinook respond either behaviorally or physiologically. Stream temperature, turbidity, suspended sediment level, water depth and velocity, cover, and substrate texture are important physical habitat variables which are either directly or indirectly influenced by the volume and pattern of streamflow.

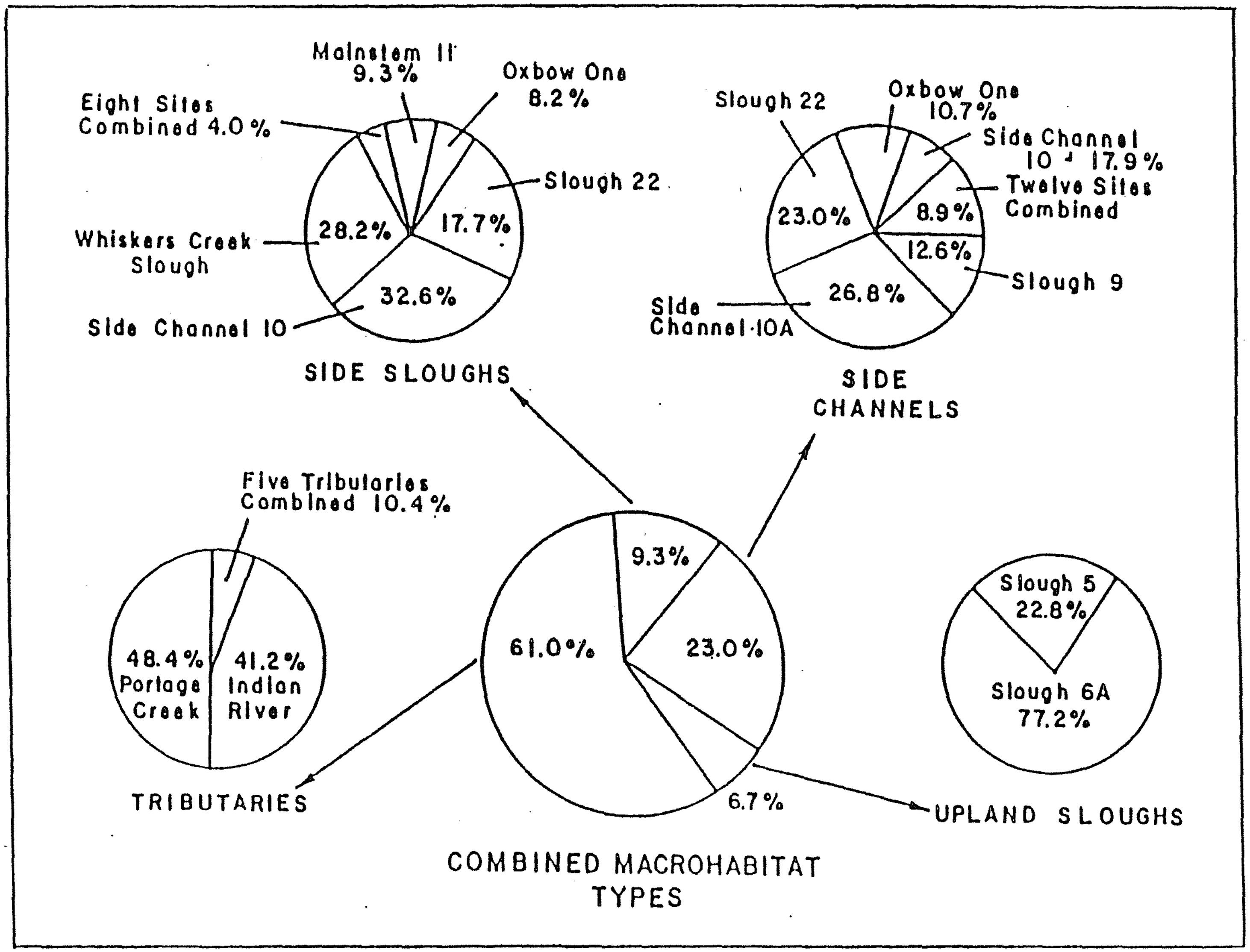


Figure 3. Density distribution of juvenile chinook salmon by macrohabitat type on the Susitna River between Chulitna River confluence and Devil Canyon, May through November 1983. Percentages are based on mean catch per cell (Dugan, Sterritt, and Stratton 1984).

The goal of minimizing potentially adverse effects of flow alterations associated with hydropower generation is possible only if the magnitude of the impacts is known, thereby presenting two major problems. The first relates to the quantification of existing resources and the relationships which sustain them. The second problem is methodological: how can predictions of with-project conditions be superimposed on natural conditions to enable accurate forecasts?

For example, our knowledge of the population dynamics of chinook salmon stocks of the middle Susitna River yields little insight into their likely long-term response to with-project flow regimes. Population adjustments are frequently determined by combinations of environmental properties occuring far in advance of the biological response. Thus, although fish production and its component parameters (i.e., density, mortality, growth, etc.) may eventually reflect the influence of causative environmental factors, the complexity of these relationships is too great and there is too much variability in our estimates to base our forecasts entirely on population studies. We are not limited as much by our ability to conceptualize the relationships linking juvenile chinook to their environment as we are by our ability to measure and test these relationships.

This problem is not a new one. Fisheries biologists faced with the task of identifying acceptable instream flows often make their selection because it appears to make biological sense, and not on the basis of mathematically defined relationships between streamflow and biological response. In the past decade, however, an instream flow assessment methodology has been developed which partially bridges this gap. The Instream Flow Incremental Methodology (IFIM) described by Bovee (1982) provides a computer assisted capability of simulating important components of fish habitat based on site-specific field measurements. The suitability of fish habitat at a given flow is evaluated by reference to preference criteria. These are frequency distributions which describe the probability that a fish will be found in association with a particular level or interval of the habitat component in question. Once the spatial distribution and levels of habitat components are known or are reliably simulated for a range of flows, and the relationships between these components and behavioral preferences have been quantified, then a habitat response index may be calculated for each flow of interest. Following standard IFIM terminology, this habitat response index is termed Weighted Usable Area (WUA). From an assumption that the amount of suitable habitat in a stream varies with flow, the direction and magnitude of WUA may be considered reliable indicators of the probable population response to discharge alterations. This assumption has been verified for some salmonid streams but not for others (Nelson 1980, Loar 1985). Factors other than the amount of usable habitat, such as inadequate food supplies and catastrophic events (e.g., floods), may have been responsible for the conflicting results.

Nevertheless, the concept of habitat preference appears valid for this study and the linkage between biological response and flow-related habitat changes, as indexed by WUA should be strong enough to make inferences concerning the present status and likely trends in juvenile chinook populations.

Included in this report are WUA functions and related habitat indices defining the relationship between mainstem discharge and chinook rearing habitat potential at 20 study (modeling) sites on the middle Susitna River. Modeling results are extrapolated from individual study sites to describe the response of juvenile chinook habitat within a number of different sub-environments of the middle Susitna River. Conventional methods of extrapolating WUA in single channel rivers based on the concept of continuous homogeneous subsegments represented by individual modeling sites are not applicable to large braided rivers like the the Susitna River due to large spatial variations in hydraulic and morphologic character (see Aaserude et al. 1985). Consequently, investigators concentrated on sampling smaller areas or portions of the middle Susitna River possessing relatively uniform yet comparatively distinct hydrologic, hydraulic and water clarity characteristics. This sampling design prompted the development of an extrapolation methodology, first outlined by Steward and Trihey (1984), which weights WUA indices developed for each modeling site according to the portions of the middle reach possessing similar hydrologic, hydraulic and water clarity attributes. Characterizing fish habitat at this level acts to overcome problems associated with the large degree of environmental variability present in the system and improves the applicability of these results to the entire middle Susitna River.

Within the overall framework of the Susitna aquatic habitat assessment program, habitat modeling results obtained for individual habitat types are particularly appropriate since related studies of juvenile fish distribution were conducted at this level (Hoffman 1985). An evaluation of habitat modeling results in combination with fish utilization data will permit an accurate assessment of rearing habitat response to natural and project-induced changes in streamflow for the entire middle Susitna river segment.

Figure 4 illustrates the primary steps in the extrapolation analysis. An outline of the data requirements and steps which comprise the methodology follows in order that the reader gain an appreciation of the utility of the rearing habitat response curves. The results of applying the full extrapolation analysis to existing flow regimes will be detailed in Volume II of the Instream Flow Relationships Report, scheduled for release by EWT&A in December 1985.

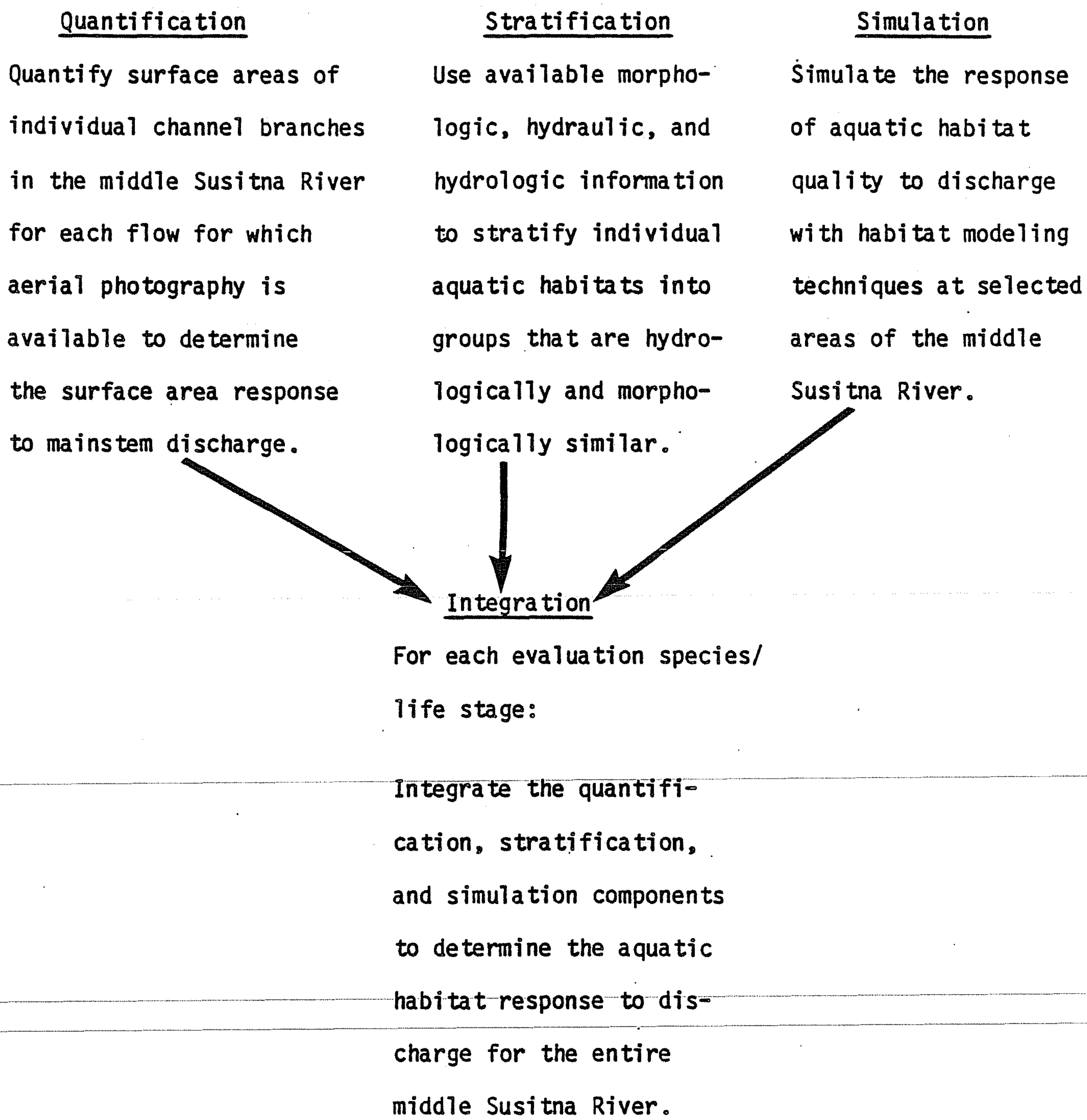


Figure 4. Flow chart indicating steps followed in the extrapolation of site-specific juvenile chinook habitat indices to the entire middle Susitna River.

2.0 METHODS

2.1 Habitat Characterization of the Middle Susitna River

2.1.1 Study Site Classification

For the middle reach of the Susitna River, Klinger and Trihey (1984) describe six habitat types, on the basis of water source and morphology: mainstem, side channel, side slough, upland slough, tributary, and tributary mouth. Rearing habitat modeling sites were initially selected to conform with the concept of aquatic habitat types. The degree to which these habitat types are utilized by juvenile salmon as well as their susceptibility to project impacts determined the extent to which they were represented in modeling studies. Of the large number of locations sampled for juveniles in 1981 and 1982, significant numbers of chum, sockeye, and chinook salmon were found in tributary, side channel, side slough and upland slough locations. Chinook salmon utilization of these habitat types was summarized in Figure 3. Recognizing that rearing habitat in tributaries will not be affected by project operation, investigators excluded this habitat type from modeling studies. Utilization of mainstem and tributary mouth areas by juvenile salmon was low and not intensively studied. The sites chosen for modeling studies of juvenile chinook habitat are identified by river mile and bank orientation (L and R denote left and right bank looking upstream) in Figure 5.

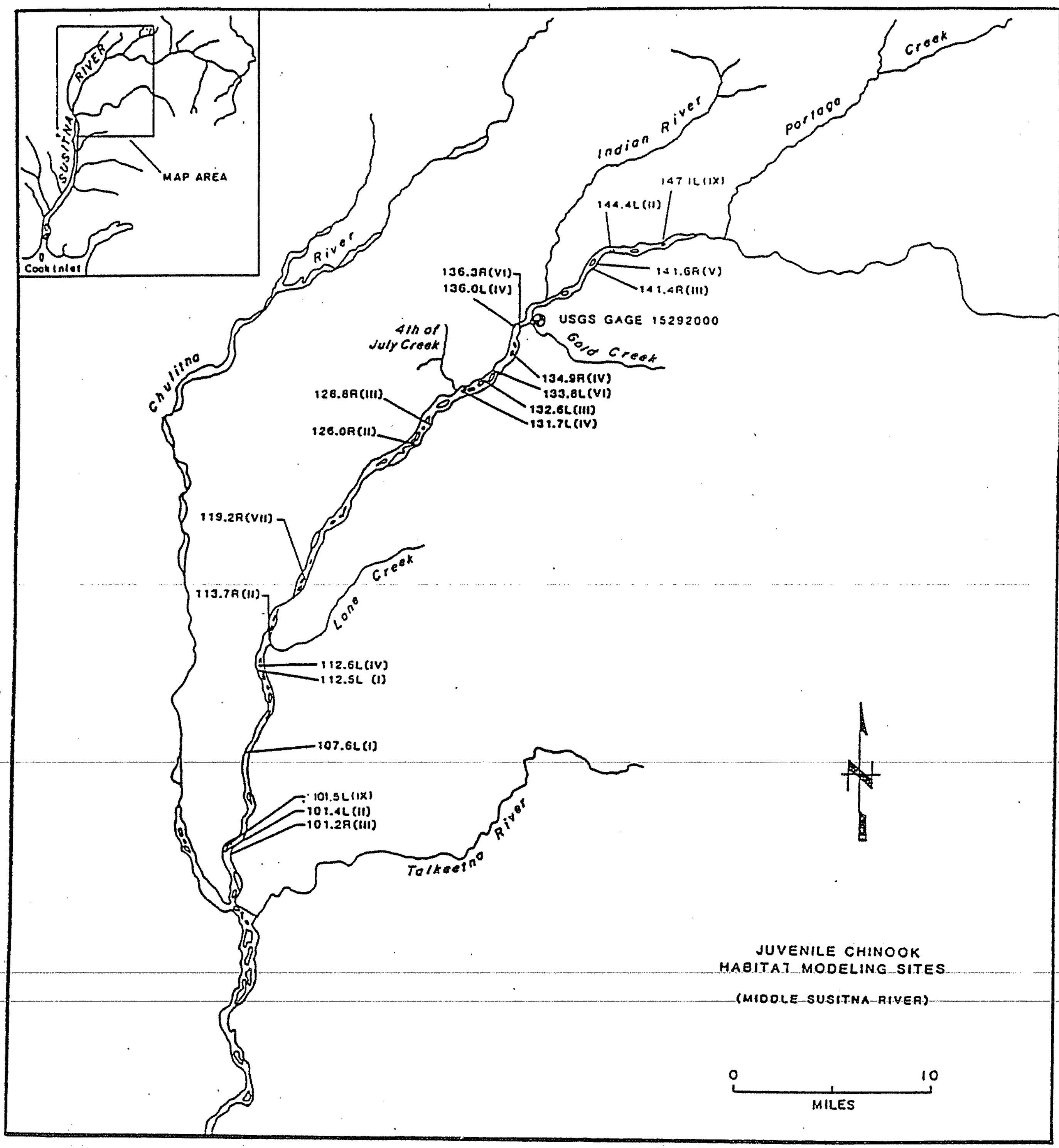


Figure 5. Juvenile chinook habitat modeling sites in the middle Susitna River. Sites are identified by river mile and bank orientation, where L and R denote left and right bank looking upstream.

2.1.2 Representative Groups

While the habitat type concept described by Klinger and Trihey (1984) is useful in the identification of attributes characterizing a particular location within the middle Susitna River at a given time, the static quality implicit in the concept makes it less practical as a means of stratifying the river for extrapolation purposes. The results of the habitat modeling analyses are WUA forecasts for sites which frequently transform from one of these habitat types to another over the range of evaluation flows. The habitat quality and the distribution of the juvenile chinook is dependent upon these transformations and the progressive physical changes which attend them.

In order that the dynamic and site-specific nature of rearing habitat response to a constantly changing aquatic environment be acknowledged by the extrapolation methodology, an alternate means of stratifying the middle Susitna River was developed. The concept of representative groups as a further set of distinct portions of the middle Susitna River and the criteria used by Aaserude et al. (1985) to define them ensures that the modeling sites are truly representative of the habitats of the river they are intended to characterize. Accurate forecasts of the response of juvenile chinook to natural or imposed changes in flow regime require that this condition be satisfied.

Aaserude et al. (1985) delineated 172 specific areas of the middle Susitna River from aerial photography interpretation and field verification studies. Specific areas formerly divided among four habitat types (side channel, side slough, upland slough, and in some cases mainstem habitats) were reassigned among ten representative groups, each characterized by unique and readily identifiable combinations of flow-related attributes. Representative groups and the primary hydrologic, hydraulic and morphologic forms and processes which distinguish them are summarized in Table 1.

Each modeling site is associated with a corresponding specific area; from an analysis of aerial photography and reconnaissance level field data, a modeled specific area may also be determined to be representative of several non-modeled specific areas within the same representative group. Within the framework of the extrapolation methodology, the collection of modeled and non-modeled specific areas which comprise a particular representative group may be thought of as a discontinuous (i.e., spatially discontinuous) yet homogeneous subsegment of the river.

Figure 5 indicates the representative group designation of each rearing habitat modeling site. Because the delineation of representative groups occurred subsequent to study site selection and data collection, some representative groups do not possess specific areas in which modeling studies were conducted. In particular, specific areas which dewater at relatively high mainstem discharges (Group VIII) and mainstem areas which remain shoal-like at most evaluation flows (Group X) are not represented by juvenile chinook habitat modeling sites. The remainder of the representative groups have at least one specific area with an associated modeling study site. This fact is important since the objective is to extrapolate habitat indices from specific areas with modeled sites to non-modeled specific areas, assuming that modeling sites generally reflect the habitat character of non-modeled areas within the same representative group. As

REPRESENTATIVE GROUP	NUMBER OF SPECIFIC AREAS	DESCRIPTION	HABITAT MODELING SITES
I	19	Predominantly upland sloughs. The specific areas comprising this group are highly stable due to the persistence of non-breached conditions (i.e., possess high breaching flows). Specific area hydraulics are characterized by pooled clear water with velocities frequently near 0.0 fps and depths greater than 1.0 ft. Pools are commonly connected by short riffles where velocities are less than 1.0 fps and depths are less than 0.5 ft.	107.6L, 112.5L
II	28	This group includes specific areas commonly referred to as side sloughs. These sites are characterized by relatively high breaching flows (>19,500 cfs), clear water caused by upwelling groundwater, and large channel length to width ratios (>15:1).	101.4L, 113.7R, 126.0R, 144.4L
III	18	Intermediate breaching flows and relatively broad channel sections typify the specific areas within this Representative Group. These sites are side channels which transform into side sloughs at mainstem discharges ranging from 8,200 to 16,000 cfs. Lower breaching flows and smaller length to width ratios distinguish these sites from those in Group II. Upwelling groundwater is present.	101.2R, 128.8R, 132.6L, 141.4R
IV	21	Specific areas in this group are side channels that are breached at low discharges and possess intermediate mean reach velocities (2.0-5.0 fps) at a mainstem discharge of approximately 10,000 cfs.	112.6L, 137.7L 134.9R, 136.0L
V	9	This group includes mainstem and side channel shoal areas which transform to clear water side sloughs as mainstem flows recede. Transformations generally occur at moderate to high breaching discharges.	141.6R
VI	13	This group is similar to the preceding one in that the habitat character of the specific areas is dominated by channel morphology. These sites are primarily overflow channels that parallel the adjacent mainstem, usually separated by a sparsely vegetated gravel bar. Upwelling groundwater may or may not be present. Habitat transformations within this group are variable both in type and timing of occurrence.	133.8L, 136.3R
VII	7	These specific areas are typically side channels which breach at variable yet fairly low mainstem discharges and exhibit a characteristic riffle/pool sequence. Pools are frequently large backwater areas near the mouth of the sites.	119.2R
VIII	24	The specific areas in this group tend to dewater at relatively high mainstem discharges. The direction of flow at the head of these channels tends to deviate sharply (>30 degrees) from the adjacent mainstem. Modeling sites from Groups II and III possessing representative post-breaching hydraulic characteristics are used to model these specific areas.	132.6L, 144.4L
IX	21	This group consists of secondary mainstem channels which are similar to primary mainstem channels in habitat character, but distinguished as being smaller, and conveying a lesser proportion of the total discharge. Specific areas in this group have low breaching discharges and are frequently similar in size to large side channels, but have characteristic mainstem features, such as relatively swift velocities (>5 fps) and visibly coarser substrate.	101.5L, 147.1L
X	13	Large mainstem shoals and the margins of mainstem channels which show signs of upwelling are included in this representative group.	105.81L, 119.11L, 138.71L, 139.41L, 133.81R

Table 1. Primary hydrologic, hydraulic and morphologic characteristics of representative groups identified for the middle Susitna River.

will be discussed later in section 3.8, juvenile chinook habitat response within Group VIII was represented using modeling results from study sites in Groups II and III. The response for Group X was evaluated using Direct Input Habitat (DIHAB) models for spawning chum habitat at five of the sites, as outlined in section 3.10.

Important criteria used to partition specific areas into representative groups are the type and rate of change in hydrologic character documented for the specific areas. The hydrologic component of the method used by Aaserude et al. (1985) to stratify the middle Susitna River focuses on the systematic transformation in habitat type of specific areas within the 5,100 to 23,000 cfs flow range. For example, as flows recede mainstem areas frequently become shallow water shoals, and side channels may transform into side sloughs; both habitat types may eventually dewater as flows decrease further. The emphasis on habitat transformation acknowledges the transient nature of riverine habitat availability and distribution. The dichotomous key in Figure 6 delineates the eleven habitat transformation categories derived from an evaluation of the 172 specific areas and eight streamflows for the middle river. Note that the final categories approximate the original "habitat type" designations used by Klinger and Trihey (1984) and ADF&G (1983). Two important modifications to the habitat type classification system are the inclusion of shoal habitat and the presence/absence of upwelling. Shoals are areas which at high flows are visually inseparable from adjacent mainstem or side channel areas. As flows recede the shoal or riffle character of these sites becomes obvious, even though the boundaries separating shoals and adjacent

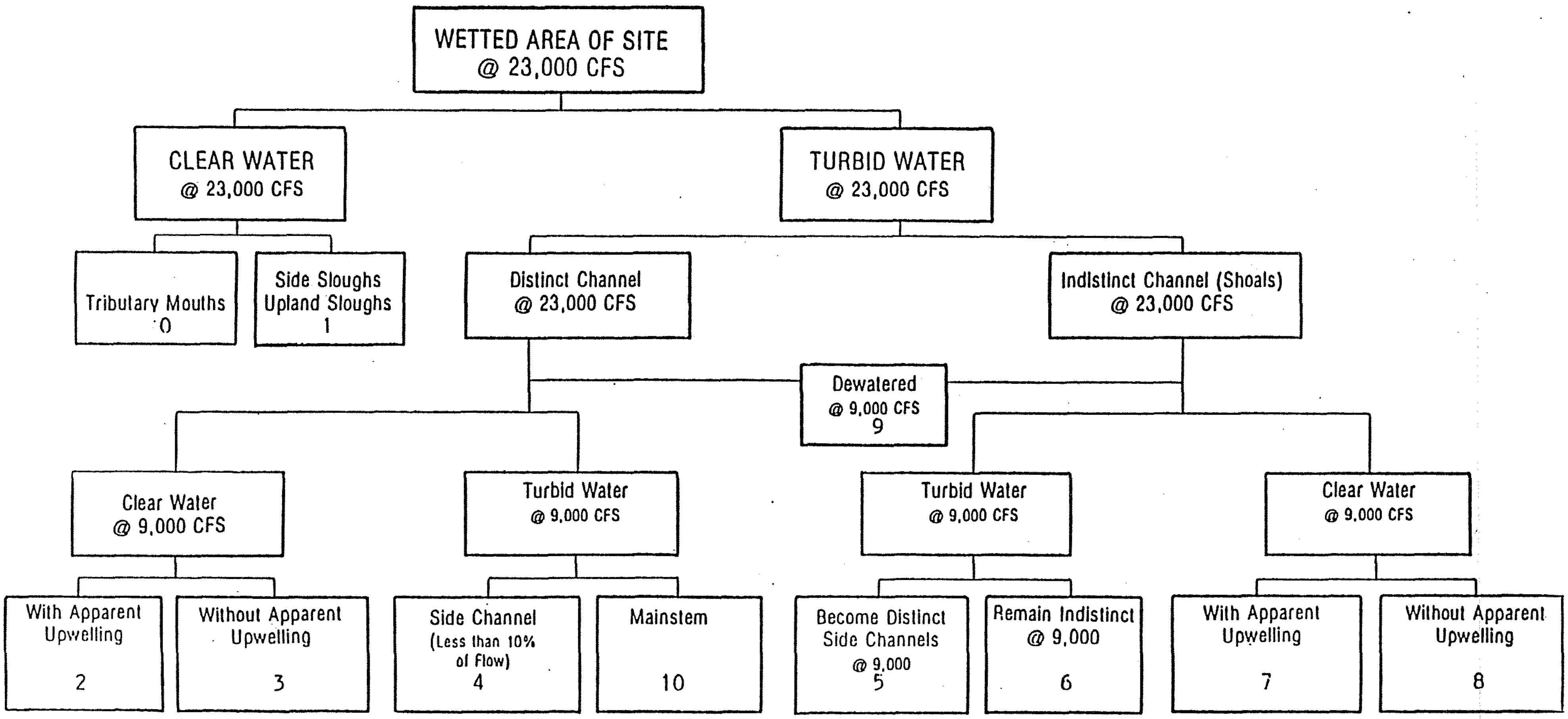


Figure 6. Flow chart for classifying the transformation of aquatic habitat types between two flows (Categories 0-10). It is important to note that habitat transformations can be monitored between any two flows of interest.

habitat types are usually indistinct. Specific areas fitting this description are further distinguished on the basis of whether their boundaries remain indistinct or transform into well-defined channels at lower flows.

Upwelling groundwater, usually discernable in aerial photos by the presence of clear water, is accentuated in the classification step of the extrapolation methodology because of its pronounced effect on the distribution of juvenile and adult salmon within the middle Susitna River.

Using habitat types present at 23,000 cfs as a point of reference, site-specific habitat transformations have been defined for several discharges of 18,000 cfs and less. The sequential changes in habitat type observed within this flow range offers a powerful tool with which to combine specific areas into representative groups. Other hydrologic parameters used with varying degrees of confidence to cluster specific areas into representative groups are breaching flow, cross-sectional profiles of the head berm and adjacent mainstem channel, and upwelling.

Of the hydraulic variables examined by Aaserude et al. (1985), mean reach velocity under breached conditions was considered the most appropriate for classifying specific areas within the middle Susitna River. Unfortunately, the relatively low flows (8,000 - 11,000 cfs) at which field sampling was conducted precluded standardization of mean reach velocities on the basis of a common flow or transformational state. Mean reach velocities were unavailable at sampling flows for two-thirds of the specific areas delineated in the middle Susitna River; the majority of the sites were unbreached during reconnaissance field studies. Nonetheless, the velocity data collected was used to further refine transformation category definitions.

Of more practical value in the development of representative groups were channel morphology indices derived from aerial photo interpretation and on-site visits in the field. Specific areas within the middle Susitna River exhibit sufficient similarities in plan form to provide a theoretically attractive means of grouping sites together. Use of channel geometry, sinuosity, length-to-width ratios and related morphologic indices to classify specific areas according to representative group is justified by the repetitiveness of similar channel features within the middle Susitna River segment.

2.2 Quantification

2.2.1 Description of Wetted Surface Area Responses

Although each specific area is assigned to the same representative group for all flows, the wetted perimeter and therefore its wetted surface area (WSA) varies with discharge. Furthermore, the rate of change in WSA relative to mainstem discharge varies between specific areas. Successful application of the extrapolation methodology requires that the WSA response to mainstem discharge be quantified, since the amount of rearing habitat available within a specific area is dependent on its areal extent at different flows.

The concept of a specific area requires fixed upstream and downstream boundaries. For example, a side slough specific area has a line across the head berm and a line across the mouth which do not change with flow. The WSA response for the side slough is due to flow-induced changes in length, width and convolution of the wetted perimeter within these boundaries. Once the head berm is overtopped, all increases in WSA are related to increases in channel width with increasing flow, as the channel length should remain constant.

The end product of the extrapolation methodology is the Representative Groups' WUA responses to mainstem discharge. Therefore, the WSA response curves should not include WSA response due to any sources other than mainstem discharge. If the WSA response of a site is not correlated with mainstem discharge, i.e., it varies widely or is constant, an average WSA value should be used to show the absence of mainstem influence. If the site WSA is correlated to mainstem discharge, then the WSA response should approximate a loglinear function.

To illustrate these concepts, consider a specific area which transforms from a side slough to a side channel at a mainstem flow of 15,000 cfs. Although for all flows below the 15,000 cfs breaching flow the specific area is a side slough, there are two ways mainstem flow can affect the WSA response of the site. Firstly, a backwater zone at the mouth would increase the WSA with increasing mainstem stage and, secondly, the mainstem may be a source of upwelling which increases the site flow with a concommitant increase in WSA. If these effects are strong, they will approximate a loglinear function, otherwise the site will have a flat WSA response to mainstem discharge. The WSA need not be constant, but may vary widely due to other local variables. Above breaching, the mainstem flow is the driving variable and again WSA should display a log linear relationship depending on the degree of irregularity of the channel geometry. Smooth parabolic cross sections should fit the loglinear relationship better than irregular cross sections.

2.2.2 Aerial Photography Database

Klinger and Trihey (1984) describe a methodology for obtaining wetted surface areas from aerial photographic plates, and are the source of the database of WSA's used in the WUA extrapolation for juvenile chinook salmon. There are two differences between the digitizing methods described for habitat types and those used for specific areas. Delineation of habitat types was not limited by the upstream and downstream boundaries used for specific areas, and, secondly, the control corridors used for habitat types were not employed for specific areas.

The aerial photography database consists of WSA measurements for all specific areas at seven mainstem discharges: 5,100, 7,400, 10,600, 12,500, 16,000, 18,000, and 23,000 cfs. To forecast WUA above 23,000 cfs and below 5,100 cfs, a method of extrapolating WSA beyond the range of the database was required. Since WSA is expected to follow a loglinear function, an extrapolation above 23,000 cfs using a logarithmic regression was the obvious choice. The use of logarithmic regression equations to approximate WSA response below 23,000 cfs would have the added benefit of minimizing errors in the aerial photography database.

The accuracy of the database in forecasting WSA response to mainstem discharge is dependent on two major forms of error:

1. Errors in estimating the true WSA of a specific area. These errors are caused by photographic distortion, shadows which obscure the sites, delineation of the specific area, and digitizing errors. There are two principal types of photographic error. Firstly, the aerial photography was not ground survey controlled, so when mosaics of the photographs were made into plates, there was a significant amount of topological distortion which varied from plate to plate. Second, due to differences in weather conditions at the flight time, slight variations in scale occurred in the sets of photography. These sources of error were not significant in the habitat type analysis since WSA's for each habitat type were summed for each flow, and distortions tended to cancel out. However, the extrapolation methodology follows the WSA response of individual specific areas, and this increased resolution over habitat type analysis is much more susceptible to distortion errors.

The 23,000 cfs photography, taken on June 1, 1982, was obtained at the time of year corresponding to high solar altitude and the deciduous vegetation had not fully leafed-out. This resulted in few shadows, thereby enabling excellent delineation of the wetted perimeter. However, the 5,100 and 7,400 cfs photography, obtained on October 4 and 14, 1984, respectively, have extensive areas of shadows along the south and east shorelines due to the low autumn solar altitude. These shadows obscured the water's edge of some specific areas making WSA delineation difficult and sometimes speculative. The remaining sets of photography have isolated shadow problems.

As mentioned previously, specific areas have upper and lower boundaries. Proper delineation of the WSA necessitates consistent positioning of the boundaries on each plate. The best method for accomplishing this is to first define the boundaries on the 5,100 cfs plate, where control points which may be submerged at a higher flow are readily identifiable, and use these bounds as a template for the higher flows. Unfortunately, the 5,100 and 7,400 cfs plates were not available until early 1985 after the other flows had already been digitized. This fact, and photographic distortion, lead to less than optimal control of WSA delineation. For some specific areas, determination of the wetted perimeter was exacerbated by the difficulty in discriminating between gravel bars and highly turbid water, both of which had approximately the same shade of grey on the black-and-white photography.

The Numonics Digitizing Tablet, used to convert delineated areas to a digital value, is accurate to a thousandth of an inch. However, since the photographic plates are taken at a scale of 1" = 1,000', some specific areas have a WSA value of only a few thousandths of an inch at certain flows and thus have a higher percent error.

2. Error induced by natural covariables. These are not true errors, but simply variables we do not want to include in the WSA responses used in the extrapolation methodology. These covariables fall into two types: firstly, those which affect the water mass, and secondly those related to channel geometry. In the first group, the effects are most noticeable in the nonbreached state. Some sites have large amounts of subsurface intragravel flow which acts as storage. If the hydrograph is falling at the time the photography was taken, there is a time lag between the stage of the nonbreached site and what we expect when the stage has stabilized. This timelag effect was quite pronounced for some sites. Also, local water sources such as small tributaries and runoff, may have greater influence on

the stage of some specific areas, most notably in Representative Groups I and II, than the mainstem when the sites are nonbreached. Since WSA is related to channel geometry as well as flow, any changes in the channel structure between the time different photo sets were taken will cause WSA errors. High-flow events following the 18,000 cfs photography caused small changes at some sites which, although negligible for habitat type summations, made the 18,000 cfs photography inappropriate for several specific areas.

2.2.3 Forecasting WSA with Regression Equations

Regression equations were used to predict WSA for specific areas in order to:

1. Extrapolate beyond the limits of the aerial photography
2. Minimize errors in estimating WSA for the photographic plates
3. Minimize variance of WSA due to "local" variables

The aim of this methodology was to produce WSA response curves which when used in the extrapolation methodology will produce WUA response curves relative to mainstem discharge only. It should be understood that these regression equations do not show observed WSA at a particular flow, but are a good approximation of the rate of change for WSA due to mainstem discharge.

Figure 7, which outlines the quantification process, shows the analytical steps and the direction of flow for particular representative groups. The first step was to identify outliers in the digitized data set; if due to

QUANTIFICATION

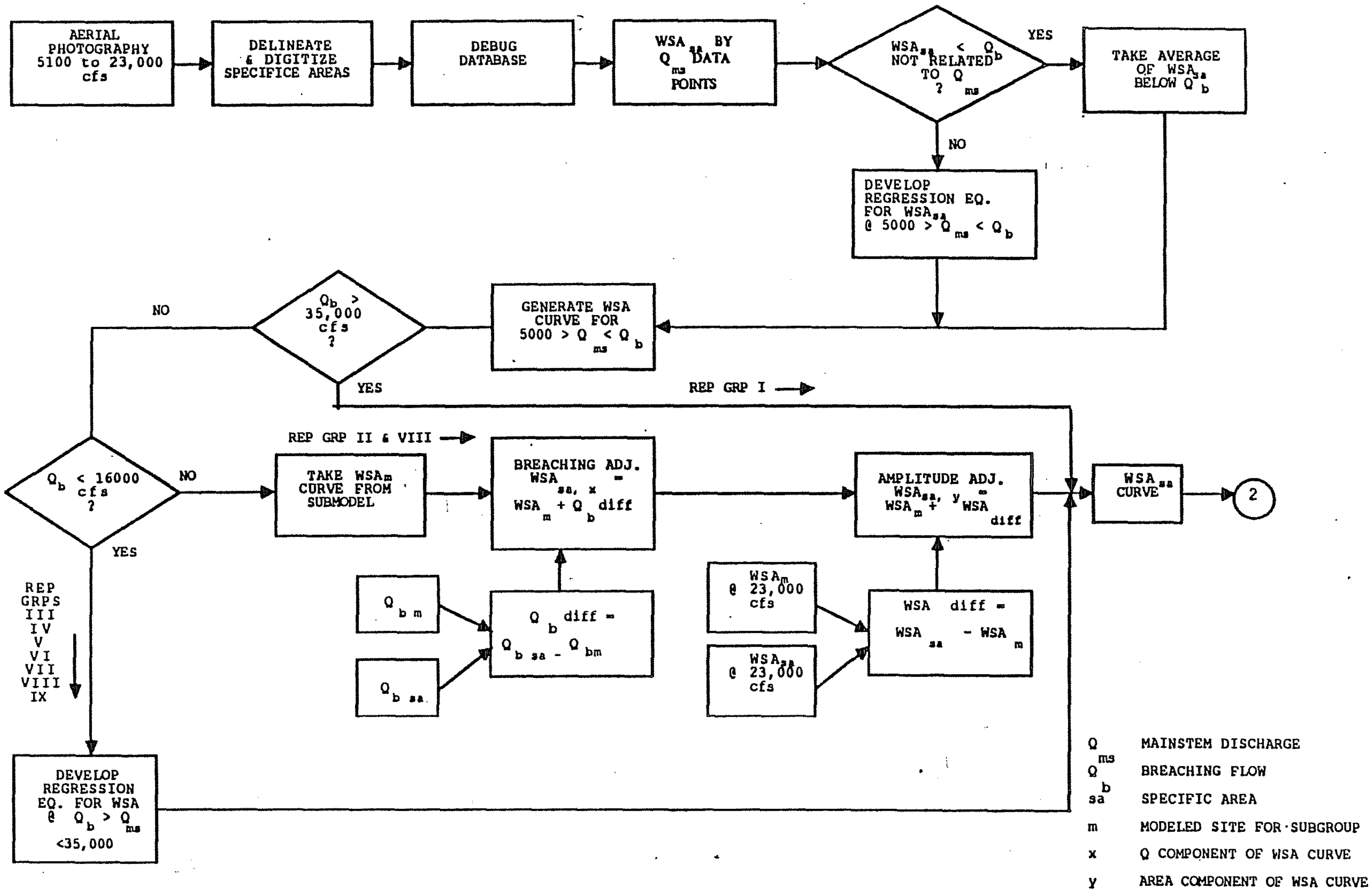


Figure 7. Flow chart indicating the steps followed in the quantification of wetted surface area response to mainstem discharge for specific areas used in the extrapolation methodology.

noncorrectable errors, they were not used in the analysis. If a specific area had a nonbreached range, the data points below breaching were visually inspected for an apparent increasing trend in WSA. If a trend was observable, a loglinear regression was performed and used to predict WSA in this range. If WSA was constant or highly variable below breaching, an average WSA value was computed and subsequently used as a representative WSA for the nonbreached state. Above breaching, if two or more reliable data points were available, a regression was taken and used to forecast WSA for the specific area from the breaching flow to 35,000 cfs. The predictions thus developed were "spliced" at the breaching flow by visual examination.

Unfortunately, specific areas for Representative Group II and some specific areas in V, VI, and VIII did not have enough data points above breaching to develop regression equations. This required an alternative procedure to forecast the WSA of these sites above 23,000 cfs. WSA response for these specific areas were obtained by extrapolating the WSA response of the modeled sites in the respective Representative Group to the nonmodeled sites. This was done using the extrapolation methods, described in section 2.4, with minor revisions. Firstly, the WSA curve from the subgroup model site was adjusted for breaching, thus normalizing the curve to the breaching flow. The amplitude of the curve was then adjusted by raising or lowering the curve to coincide with the aerial photography WSA value for 23,000 cfs.

The WSA responses for specific areas used in the extrapolation process are listed in Appendix C.

2.3 Physical Habitat Modeling Studies

2.3.1 Overview of Modeling Techniques

The quantitative assessment of juvenile chinook rearing habitat response to streamflow in the middle Susitna River is based on investigations conducted by ADF&G and EWT&A from 1982 through 1985. Sufficient data were collected to model chinook rearing habitat potential at 20 modeling sites typical of 9 of the 10 representative groups which characterize the middle Susitna River. These studies utilized two modeling techniques: 1) the Resident Juvenile Habitat (RJHAB) model developed by ADF&G; and 2) the Physical Habitat Simulation (PHABSIM) System developed by the Instream Flow and Aquatic Systems Group of the U.S. Fish and Wildlife Service. Data requirements and sampling methods employed by the two models are similar, and model parameters and standard output variables are identical (Figure 8). The major differences between RJHAB and PHABSIM modeling approaches relate to the resolution of input and output data and the techniques used to process these data. The RJHAB model generates surface area and WUA output only for those discharges for which hydraulic information was collected. The PHABSIM modeling system incorporates hydraulic models which may be used to forecast synthetic hydraulic data for any streamflow within an acceptable calibration range. These data serve as input to a program (HABTAT) which calculates wetted surface area and various habitat indices for the modeling site. WUA forecasts for unobserved flows based on the PHABSIM models are more reliable than those obtained using the RJHAB modeling technique.

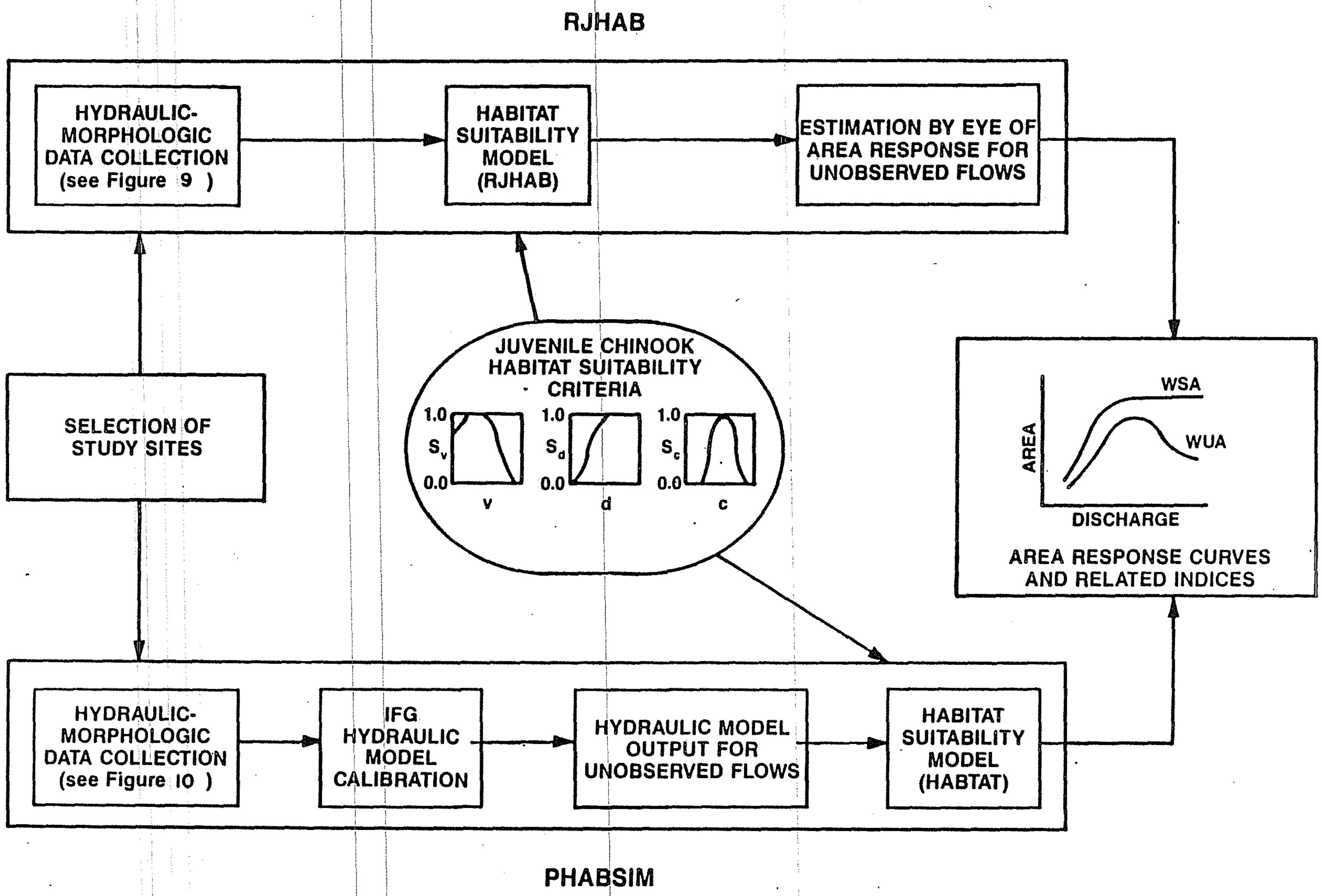


Figure 8. RJHAB and PHABSIM modeling pathways followed in the analysis of juvenile chinook salmon habitat.

Source documents for information relating to RJHAB and PHABSIM model development for middle Susitna River study sites include Estes and Vincent-Lang (1984), Hale et al. (1984), Marshall et al. (1984), and EWT&A and Entrix (1985). Habitat suitability criteria serving as model parameters for HABTAT are described in Steward (1985).

2.3.2 Hydraulic Data Requirements

RJHAB and PHABSIM models applied in this study assess the influence of three key physical habitat variables known to significantly influence juvenile chinook salmon distribution, namely instream and overhead cover, water velocity and water depth. The availability of areas characterized by suitable combinations of these variables varies directly with changes in streamflow. The primary objectives of both habitat models are to quantify the distribution of various combinations of these habitat variables within a representative segment of stream and to describe this distribution in terms of its usability or potential as rearing habitat for juvenile chinook.

In order to describe rearing habitat potential based on the availability of suitable cover, velocity and depth within a study site, field measurements were obtained at discrete intervals along multiple transects. Figures 9 and 10 illustrate the basic differences between the RJHAB and PHABSIM sampling methods, including transect placement, number of verticals where hydraulic variables are sampled and the dimensions of the cells or mapping elements represented by these point measurements. In the case of the RJHAB modeling sites, cover and hydraulic data were collected at four to seven

$$d_i = \frac{\sum_{j=1}^{n} d_j}{n}$$

$$v_i = \frac{\sum_{j=1}^{n} v_j}{n}$$

where d_i = depth (ft) for i^{th} cell
d_j = depth (ft) at j^{th} vertical
d_n = depth (ft) at n^{th} vertical
v_i = velocity (ft/sec) for i^{th} cell
v_j = velocity (ft/sec) at j^{th} vertical
v_n = velocity (ft/sec) at n^{th} vertical
n = number of verticals

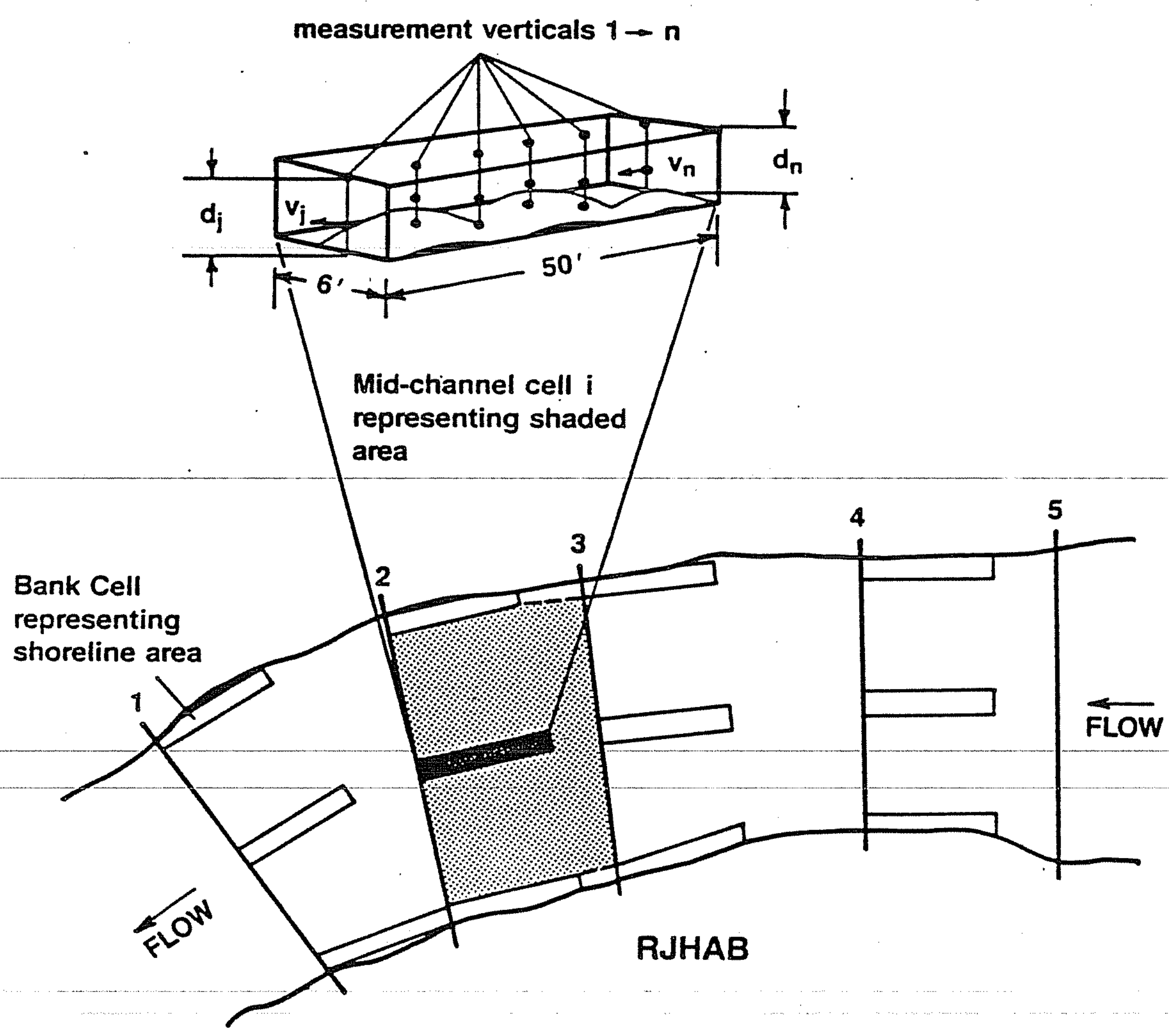


Figure 9. Sampling design for RJHAB modeling sites. The RJHAB model assumes that average values obtained for habitat variables within 6' x 50' bank and mid-channel cells are representative of larger areas within the modeling site.

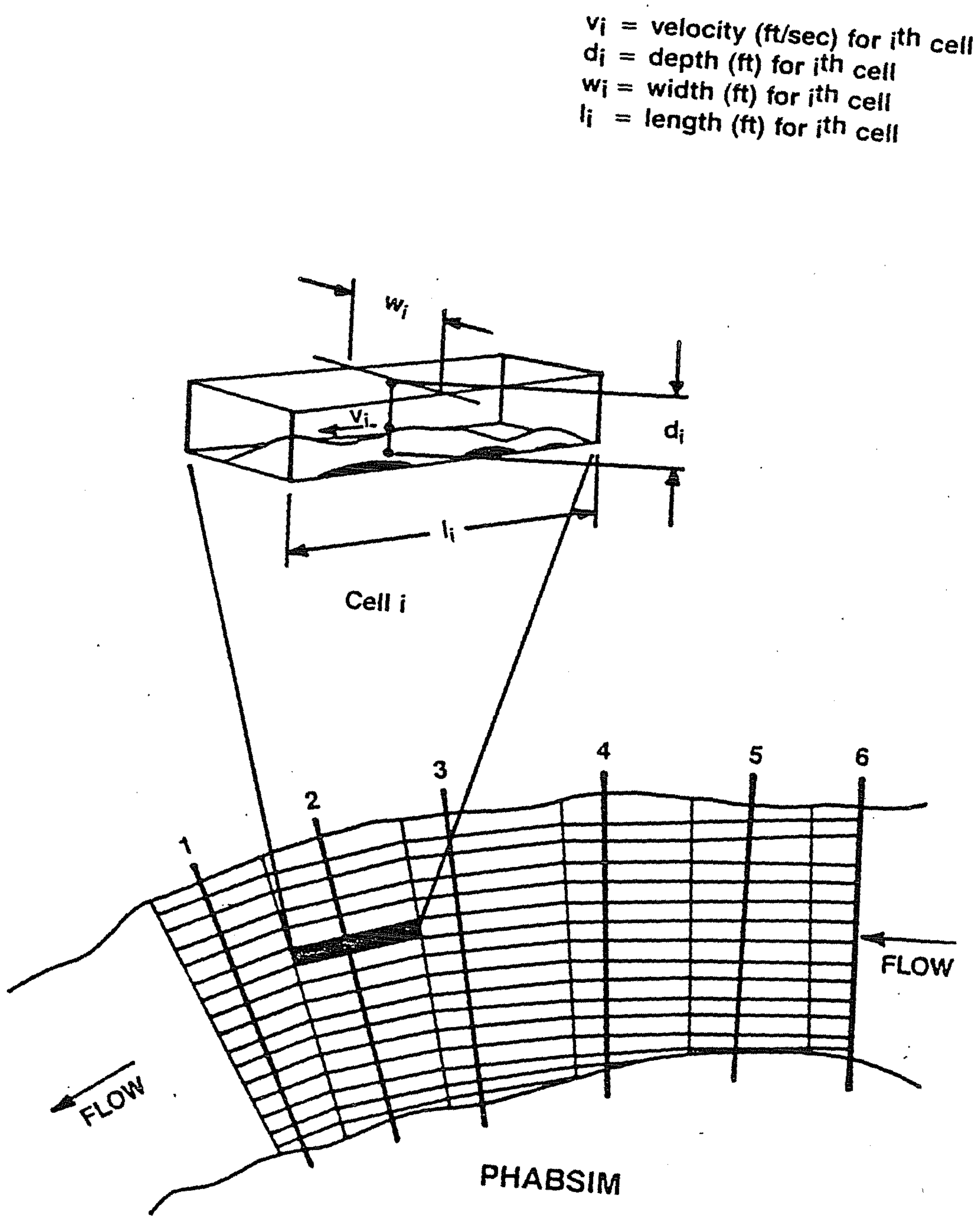


Figure 10. Sampling design for PHABSIM modeling sites.

different discharges. Two bank cells and one mid-channel cell, each 6 ft wide by 50 ft long, were sampled per transect. However, the areas represented as bank cells in surface area and WUA calculations extended 6 ft out from the left or right banks and upstream to the next transect. The mid-channel cells were considered representative of the area located between the 6 foot wide bank cells.

Cover, velocity and depth data for PHABSIM models were collected at several irregularly spaced verticals along the study site transects. The surface area associated with each cell extended halfway to adjacent verticals and transects (Figure 10). In contrast to the RJHAB model, the field data obtained in the PHABSIM analysis are used to calibrate a hydraulic model capable of forecasting depth-velocity combinations for each cell at unsampled discharges. Two types of hydraulic models were used for this purpose, depending primarily on hydraulic conditions at the study site. The IFG-2 model is a water surface profile type model based on the Manning equation and the principle of conservation of mass and energy (Milhous et al. 1984). Data requirements for the IFG-2 model include a single set of velocity data and several measurements of transect water surface elevations. Model calibration involves iterative adjustments of Manning's n values until agreement between observed and predicted water surface elevations is obtained. Once reliably calibrated, the IFG-2 model may be used to predict velocities within each cell across the transect at different discharges.

The second type of model used to simulate hydraulic data in rearing habitat investigations was the IFG-4, which employs linear regression analysis to predict depth and velocity as a function of discharge for each cell. The

IFG-4 model requires a minimum of two hydraulic data sets but is better suited than the IFG-2 model for simulating rapidly varied flow conditions (Trihey and Baldrige 1985).

Estes and Vincent-Lang (1984), Hale et al. (1984), and Hilliard et al. (1985) provide further information on hydraulic data collection and analytical procedures.

2.3.3 Habitat Suitability Criteria

The next stage in the RJHAB and PHABSIM modeling process requires that habitat suitability criteria be developed for the species/life stages of interest. Habitat suitability criteria (curves) indicate the preference of a fish for different levels of a particular habitat variable; suitability curves are needed for each physical habitat variable incorporated in the habitat models. The cover, velocity and depth suitability criteria used in this study to evaluate chinook rearing habitat potential in the middle Susitna River are based primarily on field observations of juvenile chinook densities in side channel and side slough areas of the middle Susitna River (Suchanek et al. 1984). EWT&A and Entrix (1985) and Steward (1985) discuss these data with regard to their applicability to mainstem, side channel and side slough habitats. The juvenile chinook suitability criteria recommended by Steward (1984) and summarized in Figures 11, 12, and 13 were applied in this study.

Of particular interest are the separate velocity and cover habitat suitability criteria which apply under clear and turbid water conditions.

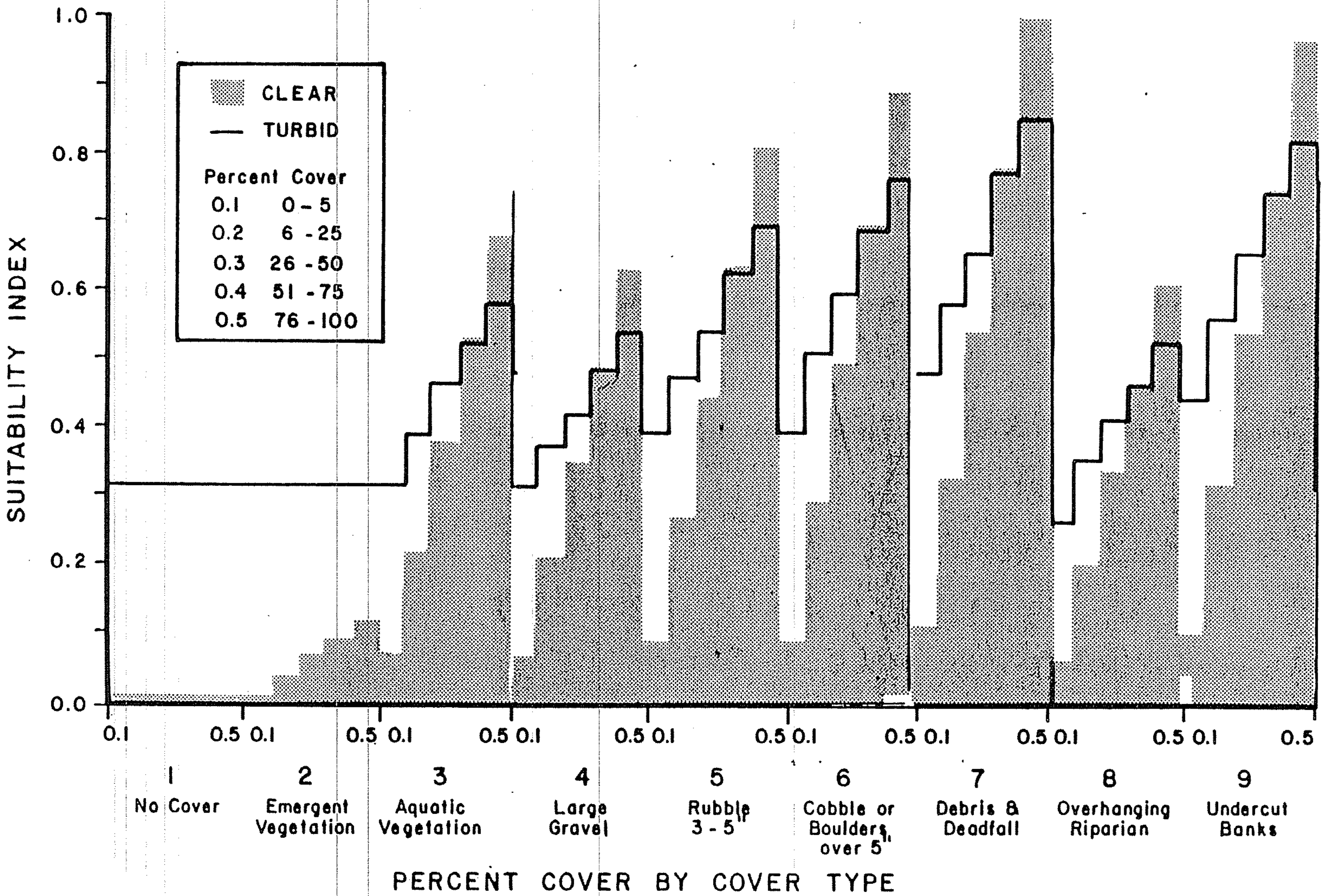


Figure 11. Cover suitability criteria used to model juvenile chinook habitat (WUA) in the middle Susitna River. Separate criteria are presented for clear and turbid water conditions (from Steward 1985).

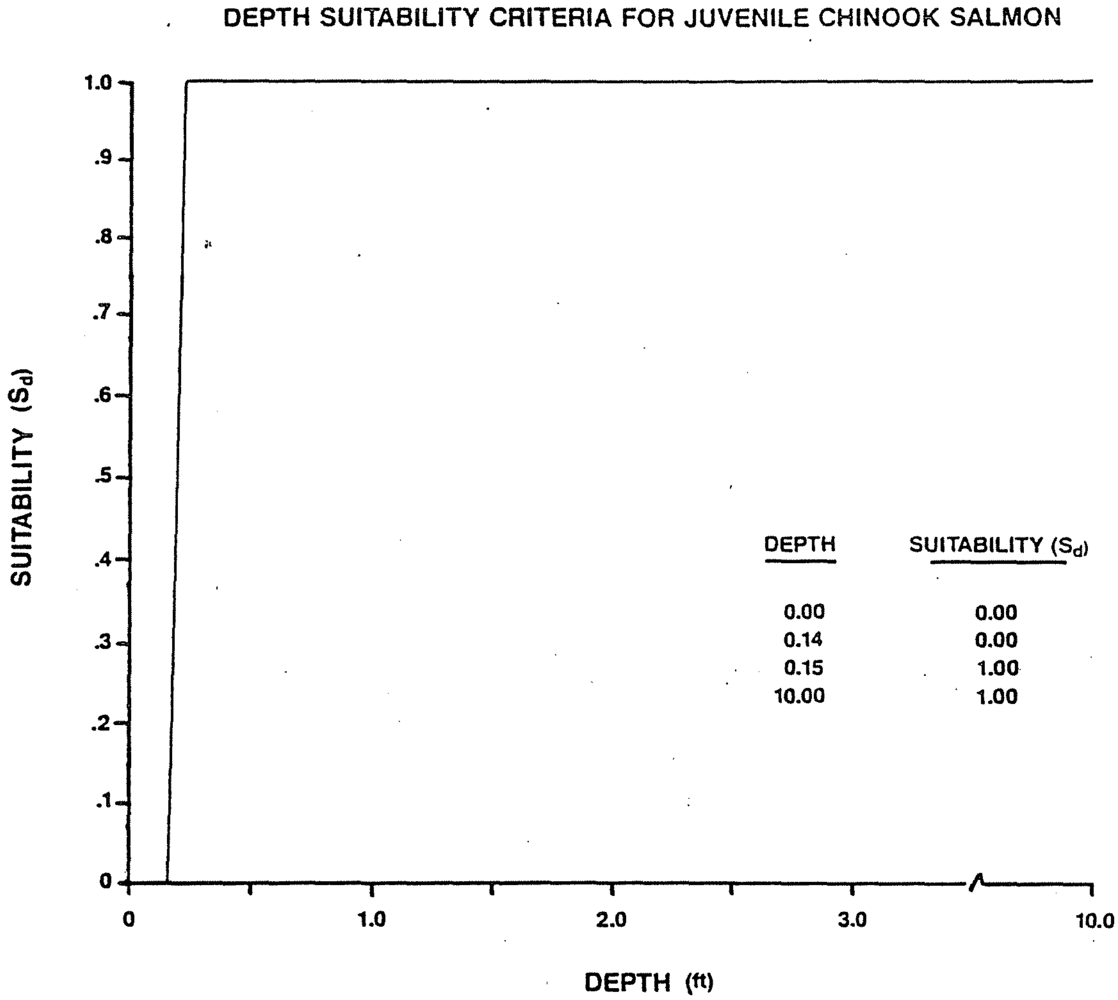
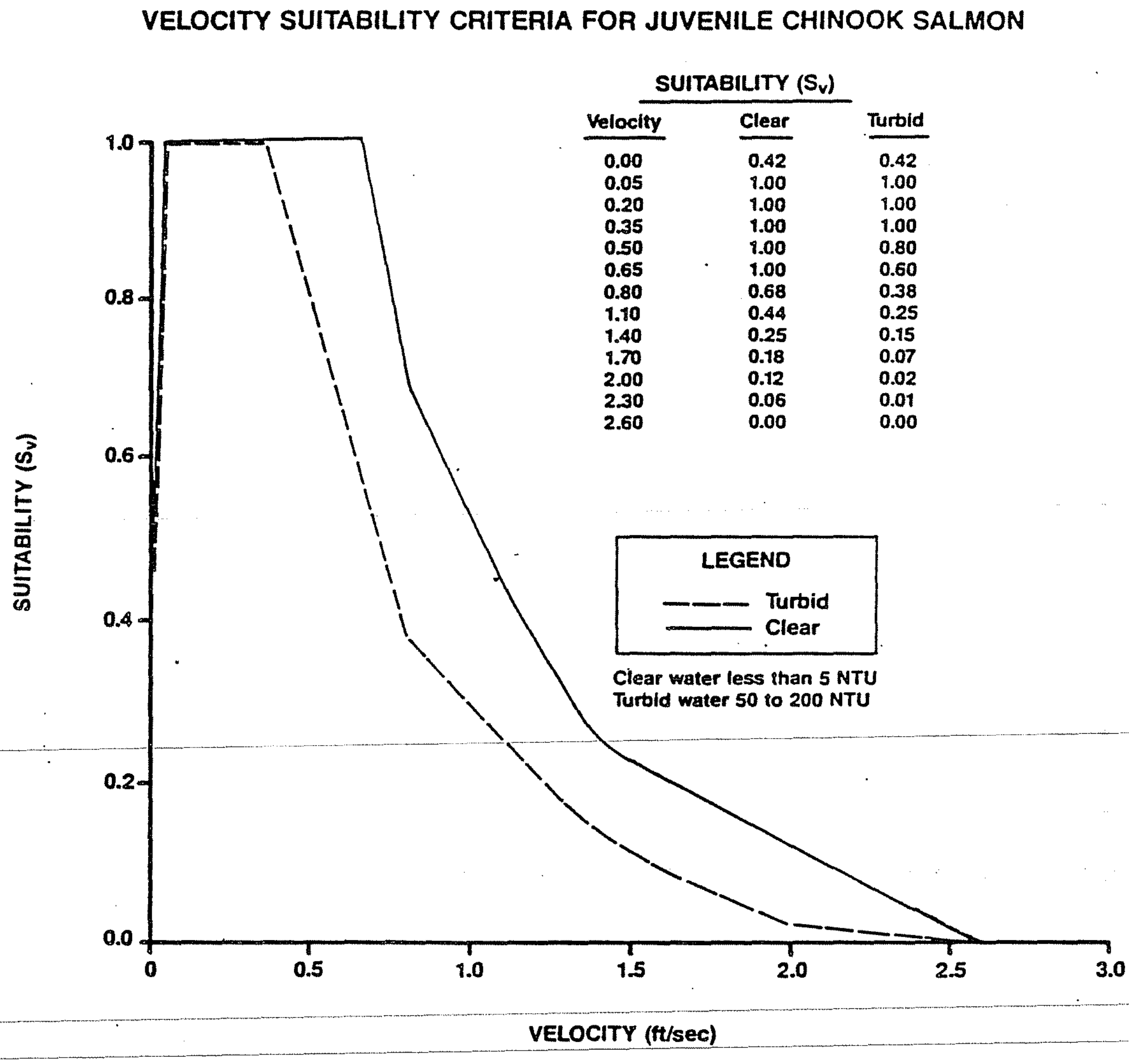


Figure 12. Depth suitability criteria used to model juvenile chinook habitat (WUA) under clear and turbid water conditions in the middle Susitna River (from Steward 1985).



	SUITABILITY (S_V)	
Velocity	Clear	Turbid
0.00	0.42	0.42
0.05	1.00	1.00
0.20	1.00	1.00
0.35	1.00	1.00
0.50	1.00	0.80
0.65	1.00	0.60
0.80	0.68	0.38
1.10	0.44	0.25
1.40	0.25	0.15
1.70	0.18	0.07
2.00	0.12	0.02
2.30	0.06	0.01
2.60	0.00	0.00

Figure 13. Velocity suitability criteria used to model juvenile chinook habitat (WUA) under clear and turbid water conditions in the middle Susitna River (from Steward 1985).

Clear water habitats occur in side channel areas which are not breached by the turbid waters of the mainstem river yet maintain a base flow via groundwater upwelling or tributary inflow. The frequency and duration of this condition depends on the elevation of the thalweg at the head of the site relative to the water surface elevation of the adjacent mainstem. Site flow versus mainstem discharge relationships were used to determine when clear and turbid water velocity and cover criteria were to be applied.

Rearing salmon use cover to avoid predation and unfavorable water velocities. Instream objects such as submerged macrophytes, large substrates and organic debris, and overhanging vegetation in near shore areas can provide cover for juvenile chinook salmon. Instream object cover in most rearing areas of the middle Susitna River is provided by larger streambed materials, primarily rubble (3-5 inch diameter) and boulder (>5 inches) size substrates. The cover suitability criteria presented in Figure 11 and Table 2 suggest that juvenile chinook tend to associate with some form of object cover in both clear and turbid water habitats. Preference generally increases in proportion to the percentage of object cover present, particularly under clear water conditions. The different preferences for the same type and percent of object cover indicated by the clear and turbid water suitability criteria are due to the utilization of turbidity as cover by rearing chinook. Dugan et al. (1984) documented higher densities of chinook in breached, turbid water side channels than were found at the same sites under nonbreached, clear water conditions. This disparity was most pronounced at sampling sites possessing minimal object cover.

Table 2. Cover suitability criteria recommended for use in modeling juvenile chinook habitat under clear and turbid water conditions. Sources: Suchanek et al. 1984; Steward 1985.

Percent Cover	No Cover	Emergent Veg.	Aquatic Veg.	Large Gravel	Rubble 3"-5"	Cobble or Boulders <5"	Debris & Deadfall	Overhanging Riparian	Undercut Banks
Clear Water (Suchanek et al. 1984))									
0-5%	0.01	0.01	0.07	0.07	0.09	0.09	0.11	0.06	0.10
6-25%	0.01	0.04	0.22	0.21	0.27	0.29	0.33	0.20	0.32
26-50%	0.01	0.07	0.39	0.35	0.45	0.49	0.56	0.34	0.54
51-75%	0.01	0.09	0.53	0.49	0.63	0.69	0.78	0.47	0.75
76-100%	0.01	0.12	0.68	0.63	0.81	0.89	1.00	0.61	0.97
Turbid Water (EWT&A and WCC 1985)[1]									
0-5%	0.31	0.31	0.31	0.31	0.39	0.39	0.48	0.26	0.44
6-25%	0.31	0.31	0.39	0.37	0.47	0.51	0.58	0.35	0.56
26-50%	0.31	0.31	0.46	0.42	0.54	0.59	0.67	0.41	0.65
51-75%	0.31	0.31	0.52	0.48	0.62	0.68	0.77	0.46	0.74
76-100%	0.31	0.31	0.58	0.54	0.69	0.76	0.85	0.52	0.82

[1]Multiplication factors: 0-5% - 4.38; 6-25% - 1.75; 26-50% - 1.20; 51-75% - 0.98; 76-100% - 0.85

Water depth is not a significant factor limiting juvenile chinook habitat potential, as indicated by the open ended depth suitability curve in Figure 12. Provided that other microhabitat conditions are suitable, juveniles tend to prefer depths exceeding 0.15 feet to an equal degree. This observation has been corroborated in other habitat utilization studies of juvenile chinook salmon (Steward 1985).

A distinct preference by juveniles for low velocities under turbid water conditions was noted by Suchanek et al. (1984). Turbid water habitat suitability criteria identify optimal velocities in the 0.05 to 0.35 fps range, as compared to 0.05 to 0.65 fps indicated by clear water velocity criteria (Figure 13). The preference for lower velocities in areas of high turbidity may be twofold: 1) at faster currents there is a lack of visual cues to maintain position; and 2) at higher velocities it is more difficult to detect drifting prey items (Milner 1985).

2.3.4 Habitat Model Response Variables

The RJHAB model was modified slightly in order that the methods of calculating various indices of habitat potential, including WUA, and wetted surface areas were consistent for all modeling sites. Wetted surface area (WSA) estimates based on RJHAB and PHABSIM modeling approaches were computed by summing the surface areas of watered cells within the modeling site (Table 3). Flow related increases in wetted surface area at RJHAB sites were apportioned among mid-channel cells of the sites since the dimensions of the area represented by bank cells remained essentially unchanged for all flows. At study sites modeled with IFG-2 or IFG-4

Table 3. Wetted surface area (WSA), weighted usable area (WUA) and related habitat indices used in the evaluation of chinook rearing habitat potential within the middle Susitna River.

Statistic	Equation	Parameters/Units
Calculations Performed for Each Cell (i)		
Surface Area (A_i)	$A_i = w_i l_i$	w_i = cell width (ft) l_i = cell length (ft) (ft^2)
Composite Suitability (S_i)	$S_i = s(c_i)\ s(v_i)\ s(d_i)$	$s(c_i)$, $s(v_i)$ and $s(d_i)$ are weighting factors for cover, velocity and depth (dimensionless)
Weighted Usable Area (WUA_i)	$WUA_i = A_i\ S_i$	(ft^2)
Calculations Performed for a Modeling Site Comprised of (n) Cells		
Wetted Surface Area (WSA)	$WSA = \sum_{i=1}^{n} A_i$	includes all cells (ft^2)
Gross Habitat Area (GHA)	$GHA = \sum_{i=1}^{n} A_i$	includes cells with WUA > 0.0 (ft^2)
Weighted Usable Area (WUA)	$WUA = \sum_{i=1}^{n} A_i\ S_i$	(ft^2)
Habitat Availability Index (HAI)	HAI = WUA / WSA	(dimensionless)
Habitat Distribution Index (HDI)	HDI = GHA / WSA	(dimensionless)
Habitat Quality Index (HQI)	HQI = WUA / GHA	(dimensionless)

hydraulic models, the size and location of cells generally remained constant but the total number of cells increased or decreased as wetted top widths responded to changes in flow. Hence, the cumulative surface area of the IFG modeling sites increased through the addition of new cells along the shoreline.

The composite suitability of each cell within the RJHAB and IFG modeling sites was determined by multiplying the individual suitability values associated with prevailing velocity, depth and cover conditions (Table 3). This method of calculation implies that the physical habitat variables evaluated by the models are assumed to be independent in their influence on habitat selection by juvenile chinook. Weighted usable area is computed for each cell by multiplying the cell's composite suitability by its surface area. The sum of the cell WUAs obtained for a given discharge yields the modeling site WUA; when plotted as a function of discharge, the modeling site WUA curve indicates the response of usable rearing habitat to changes in streamflow.

Habitat simulation results include WUA and WSA estimates for each study site for mainstem discharges ranging from 5,000 to 35,000 cfs as measured at the USGS Gold Creek gaging station. In order to facilitate comparisons between modeling sites, WSA is expressed in units of square feet per linear foot of stream. WSA is therefore proportional to the mean width of the modeling site. These units are less satisfactory for comparisons of WUA since usable habitat at a site is a function of surface area weighted by the suitability of its physical habitat attributes. An interpretation of habitat availability should not be made without reference to the total wetted surface area of the site. As an example, consider two study sites possessing relatively equal amounts of weighted usable area; the smaller site, particularly where there is a large disparity in size, possesses a greater amount of usable habitat relative to the prevailing wetted surface area. Therefore, a more meaningful index of habitat availability is the ratio of WUA to WSA, which is designated the Habitat Availability Index (HAI).

In the context of the extrapolation analysis, the Habitat Availability Index has the added merit of being unitless. Assuming that the HAI of a modeling site is representative of the associated specific area (i.e., both possess the same frequency distributions of cover, velocity and depth), the WUA of the specific area is equal to the product of the HAI and the total wetted surface area of the specific area. Total surface areas are known, as discussed in Section 2.2, and therefore a flow-dependent habitat response curve may be derived for any specific area represented by a modeling site.

The HABTAT program of the PHABSIM modeling system and the RJHAB model were modified to compute the Gross Habitat Area (GHA) for each discharge of interest. The GHA is the cumulative (unweighted) surface area of cells possessing non-zero WUA values within a site. Gross Habitat Area is important because it represents the maximum area of rearing habitat available. Two other habitat response indices, the Habitat Distribution Index (HDI) and the Habitat Quality Index (HQI) are calculated by the following formulas:

$$\text{HDI}~(\%) = \text{GHA}/\text{WSA} \times 100$$

and

$$\text{HQI}~(\%) = \text{WUA}/\text{GHA} \times 100$$

The use of HDI and HQI indices partially overcomes a major criticism of most WUA-based interpretations of habitat potential, namely, that WUA is a quantification of the amount of suboptimal habitat within a study site expressed as an equivalent amount of optimal habitat. In other words, a cell with a surface area of 100 sq. ft. and a joint preference factor of 1.0, that is, optimal cover, velocity and depth conditions, is assumed to provide as much usable habitat as an area ten times its size which possesses a joint preference factor of 0.10. Although flow-related changes in the composite suitability of individual cells (i.e., at discrete locations within the modeling site) were not evaluated, we examined relationships between a modeling site's weighted usable area, gross habitat area and wetted surface area over a range of discharges to gain an understanding of probable changes in habitat quality within cells containing usable habitat.

Surface areas and habitat indices were simulated for site flows corresponding to mainstem flows ranging from 5,000 to 35,000 cfs at Gold Creek. Of the 20 study sites investigated, six were modeled using the RJHAB model and 15 were modeled using the PHABSIM modeling system. One study site, 132.6L (Representative Group III), was modeled using both RJHAB and PHABSIM techniques. In most instances, WSA, WUA and HAI values for unobserved site flows (in the case of RJHAB models) or flows lying outside the recommended extrapolation range of the hydraulic models (a frequently encountered situation in PHABSIM applications) were estimated by interpolation and trend analysis techniques (Hilliard et al. 1985). In fitting curves to data points forecast by the habitat models, reference was made to aerial photographs and site-specific channel geometry and breaching flow information.

2.4 Extrapolation of Modeling Results to Non-modeled Specific Areas

Whereas the general habitat characteristics of a modeling site may be assumed to be representative of the associated specific area, the same combination and quality of habitat attributes may not be found in other specific areas, even those classified in the same representative group. Aaserude et al. (1985) concluded that variations in structural characteristics, including several attributes known to affect the quality of juvenile chinook rearing habitat, are common among specific areas of the same representative group. These differences are significant enough that direct transfer of WUA functions from modeled to non-modeled specific areas is considered impracticable. For this reason, Structural Habitat Indices (SHIs) were developed from field data in order to rank specific areas within the same representative group according to their relative structural habitat quality. As indexed by SHI values, specific areas are evaluated on the basis of six variables: 1) dominant cover type, 2) percent cover, 3) dominant substrate size, 4) substrate embeddedness, 5) channel cross sectional geometry, and 6) riparian vegetation. These variables were weighted according to their relative importance to juvenile chinook salmon. For each variable, specific areas were placed in one of five descriptive categories, ranging from "non-existent" to "excellent" in quality. Each variable category received a corresponding numerical rating factor. A single SHI value was calculated for each specific area, including those containing modeling sites, by summing the products of variable weighting and rating factors. For further details concerning the collection and synthesis of data into structural habitat indices, see Aaserude et al. (1985).

In this, the integration step of the extrapolation methodology, Habitat Availability Indices (HAIs) derived for the modeling sites are used to estimate juvenile chinook WUA for each specific area of the middle Susitna River. As discussed above, the amount of usable rearing habitat at a specific area containing a modeling site may be calculated by multiplying the modeling site's HAI value (i.e., the WUA:WSA ratio obtained as model output) by the wetted surface area of the specific area. For each discharge, this calculation can be represented as

$$WUA_{sa} = HAI_{m,sa} \times WSA_{sa}$$

where the subscripts m and sa refer to the modeling site and the specific area within which it is found. As pointed out earlier, HAI values determined for the modeling site are assumed to be applicable to the entire specific area.

If it were reasonable to assume that the HAI response curves for all specific areas within a representative group were identical, then WUA values for non-modeled specific areas within the same group could be calculated by the above equation using a single HAI function. The structural habitat data of Aaserude et al. (1985), as well as the modeling results presented in this report do not support this assumption. Between-site variations in rearing habitat availability appear to result from dissimilarities in channel morphology (which are reflected by differences in breaching flows and the rate of change in WUA and WSA) and structural habitat quality (as indexed by SHI values). Therefore, each specific area of the middle Susitna River is assumed to possess a unique HAI curve which may nonetheless be patterned after the modeling site within the same representative group having the most similar hydrologic, hydraulic, and morphologic attributes. Specific areas within a representative group with more than one modeling site are divided between modeling sites by morphological similitude based on aerial photography and habitat reconnaissance surveys. Thus, each modeling site may be considered representative of a subgroup of specific areas.

HAI curves are developed for non-modeled specific areas by modifying the HAI functions of associated modeling sites using information obtained in the classification and quantification steps of the extrapolation analysis, including: 1) breaching flows to normalize HAI functions on the discharge axis; and 2) structural habitat indices to adjust for differences in the quality of usable rearing habitat. Table 4 summarizes breaching flow and SHI information used in the development of HAI curves for non-modeled specific areas within Representative Groups I through X.

The discharge at which the head berm of a specific area is breached is the dominant hydrologic variable affecting the availability of chinook rearing habitat. As will be demonstrated later, the vast majority of juvenile chinook HAI functions obtained for the middle Susitna River modeling sites exhibit a maxima just to the right of the breaching flow on the discharge (horizontal) axis. To develop an HAI response curve for a non-modeled specific area, the HAI curve obtained for the associated modeling site is shifted left or right on the abscissa depending on whether the breaching flow for the non-modeled specific area is lower or higher than that of the

GROUP I

	Specific Area	Breaching Flow (cfs)	SHI
0	107.6L	>35,000	0.44
	105.2R	>35,000	0.69
	108.3L	>35,000	0.70
	119.4L	>35,000	0.45
	120.0R	>35,000	0.50
	135.6R	>35,000	0.54
	136.9R	>35,000	0.69
	139.0L	>35,000	0.45
0	112.5L	>35,000	0.68
	102.2L	>35,000	0.83
	121.9R	>35,000	0.72
	123.1R	>35,000	0.45
	123.3R	>35,000	0.67
	127.2M	>35,000	0.58
	129.4R	>35,000	0.44
	133.9L	>35,000	0.67
	134.0L	>35,000	0.89
	135.5R	>35,000	0.32
	139.9R	>35,000	0.74

GROUP II

	Specific Area	Breaching Flow (cfs)	SHI
0	101.4L	22,000	0.54
	115.6R	23,000	0.54
	118.0L	22,000	0.39
	121.8R	22,000	0.27
	125.1R	20,000	0.48
	137.5R	22,000	0.44
	137.8L	20,000	0.54
0	113.7R	24,000	0.51
	113.1R	26,000	0.31
	131.8L	26,900	0.45
	133.9R	30,000	0.50
	137.5L	29,000	0.44
	137.9L	21,000	0.50
	140.2R	26,500	0.50
	142.2R	26,000	0.52
	143.4L	23,000	0.55
+	126.0R	33,000	0.51
	122.4R	26,000	0.29
	122.5R	20,000	0.51
	123.6R	25,500	0.43
	125.9R	26,000	0.56
	126.3R	27,000	0.59
0	144.4L	21,000	0.60
	100.6R	33,000	0.60
	101.8L	22,000	0.65
	117.9L	22,000	0.62
	135.3L	23,000	0.30
	142.1R	23,000	0.60

GROUP III

	Specific Area	Breaching Flow (cfs)	SHI
+	101.2R	9,200	0.56
	100.4R	12,500	0.51
	100.6L	9,200	0.42
	115.0R	12,000	0.55
	117.8L	8,000	0.48
	128.5R	12,500	0.48
	128.7R	15,000	0.49
	130.2R	8,200	0.64
	130.2L	12,000	0.60
	137.2R	10,400	0.49
+	128.8R	16,000	0.46
	110.4L	12,000	0.67
	133.7R	11,500	0.44
+0	132.6L	10,500	0.49
	101.6L	14,000	0.56
	101.7L	9,600	0.46
	119.3L	16,000	0.56
+	141.4R	11,500	0.56

GROUP IV

	Specific Area	Breaching Flow (cfs)	SHI
+	112.6L	<5,100	0.60
	108.7L	<5,100	0.53
	110.8M	<5,100	0.48
	111.5R	<5,100	0.48
	139.4L	<5,100	0.61
	139.6L	<5,100	0.51
+	131.7L	<5,100	0.47
	119.5L	<5,100	0.54
	119.6L	<5,100	0.53
	124.1L	<5,100	0.46
	127.4L	<5,100	0.46
+	134.9R	<5,100	0.56
	100.7R	<5,100	0.49
	114.0R	<5,100	0.43
	116.8R	<5,100	0.48
	121.7R	<5,100	0.48
	125.2R	<5,100	0.56
	129.5R	<5,100	0.56
	140.4R	<5,100	0.48
	145.3R	<5,100	0.53
+	136.0L	<5,100	0.55
	127.0M	<5,100	0.65

GROUP V

	Specific Area	Breaching Flow (cfs)	SHI
+	141.6R	21,000	0.56
	101.7L	9,600	0.48
	117.0M	15,500	0.31
	118.9L	<5,000	0.48
	124.0M	23,000	0.51
	132.8R	19,500	0.57
	139.01L	<5,000	0.37
	139.7R	22,000	0.51
	143.0L	7,000	0.31

GROUP VI

	Specific Area	Breaching Flow (cfs)	SHI
+	133.8L	17,500	0.49
	107.1L	9,600	0.69
	117.9R	7,300	0.49
	119.7L	23,000	0.51
	138.0L	8,000	0.53
	138.8R	6,000	0.31
	139.5R	8,900	0.31
+	136.3R	13,000	0.54
	102.6L	6,500	0.69
	106.3R	4,800	0.53
	135.7R	27,500	0.32
	140.6R	12,000	0.61
	142.0R	10,500	0.53

GROUP VII

	Specific Area	Breaching Flow (cfs)	SHI
+	119.2R	10,000	0.41
	114.1R	<5,100	0.31
	121.1L	7,400	0.43
	123.0L	<5,000	0.39
	125.6L	<5,000	0.52
	127.5M	<5,000	0.31
	131.3L	9,000	0.31

GROUP VIII

	Specific Area	Breaching Flow (cfs)	SHI
*	132.6L	10,500	0.49
	112.4L	22,000	0.27
	117.1M	15,500	0.32
	117.2M	20,000	0.32
	118.6M	14,000	0.36
	119.8L	15,500	0.51
	120.0R	12,500	0.32
	121.5R	19,500	0.32
	121.6R	15,500	0.60
	123.2R	23,000	0.26
	124.8R	19,500	0.46
	132.5L	14,500	0.57
	135.0R	21,500	0.44
	135.1R	20,000	0.44
	144.0M	22,000	0.31
*	144.4L	21,000	0.60
	101.3M	9,200	0.57
	102.0L	10,000	0.43
	104.3M	21,000	0.48
	109.5M	16,000	0.49
	125.6R	26,000	0.44
	128.4R	9,000	0.56
	145.6R	22,000	0.62
	146.6L	26,500	0.48

GROUP IX

	Specific Area	Breaching Flow (cfs)	SHI
+	101.5L	<5,100	0.45
	104.0R	<5,100	0.48
	109.4R	<5,100	0.45
	111.0R	<5,100	0.35
	113.8R	<5,100	0.35
	117.7L	<5,100	0.41
	128.3R	<5,100	0.63
	129.3L	<5,100	0.62
	131.2R	<5,100	0.48
	139.2R	<5,100	0.61
	142.8R	<5,100	0.56
+	147.1L	<5,100	0.57
	105.7R	<5,100	0.53
	108.9L	<5,100	0.58
	127.1M	<5,100	0.53
	129.8R	<5,100	0.56
	135.0L	<5,100	0.48
	141.2R	<5,100	0.69
	141.3R	<5,100	0.69
	144.0R	<5,100	0.53
	144.2R	<5,100	0.53

GROUP X

	Specific Area	Breaching Flow (cfs)	SHI
#	105.81L	MSS	0.57
#	119.11L	MSS	0.41
	121.1R	MSS	0.47
#	138.71L	MSS	0.57
#	139.41L	MSS	0.41
	142.2R	MSS	0.48
#	133.81R	MSS	0.48
	109.3M	MSS	0.48
	111.6R	11,500	0.48
	113.6R	10,500	0.55
	113.9R	7,000	0.48
	139.3L	MSS	0.56
	148.2R	MSS	0.48

KEY:

0 Specific areas with RJHAB model
+ Specific areas with IFG model
# Specific areas with DIHAB model
* Modeled sites from other groups 132.6L from Group III and 144.4L from Group II
MSS Mainstem shoal

Table 4. Mainstem breaching discharges and structural habitat indices (SHI) determined for specific areas within the middle Susitna River.

modeling site. The distance moved is equal to the difference in the sites' breaching discharges. This lateral shift, diagrammed in Figure 14, identifies the horizontal coordinates of the HAI curve for the non-modeled specific area. The lefthand curve in Figure 14 represents HAI values forecast for a hypothetical modeling site. The curve on the right is an HAI function obtained for a related non-modeled specific area (also hypothetical) from the same representative group.

Structural habitat indices are used to determine the magnitude of the HAI response to flow at a non-modeled specific area (i.e., to "fix" the location of the HAI curve with respect to the vertical axis) as illustrated in Figure 14b. For each discharge, the following calculation is made:

$$HAI_{sa} = HAI_m \times (SHI_m/SHI_{sa})$$

In this case, the subscript m refers to the modeling site whose HAI function has been adjusted using the breaching flow of the non-modeled specific area, identified by the subscript sa.

The non-modeled specific area in Figure 14c HAI curve has been shifted to the right and downward to account for the higher breaching flow and the lower structural habitat quality of the non-modeled site relative to the modeled site. An HAI response curve derived in this fashion may be multiplied by wetted surface area estimates to calculate WUA values for each flow of interest. Preliminary HAI functions have been developed for all middle Susitna River specific areas and appear in Section 3.0 and Appendix B of this report.

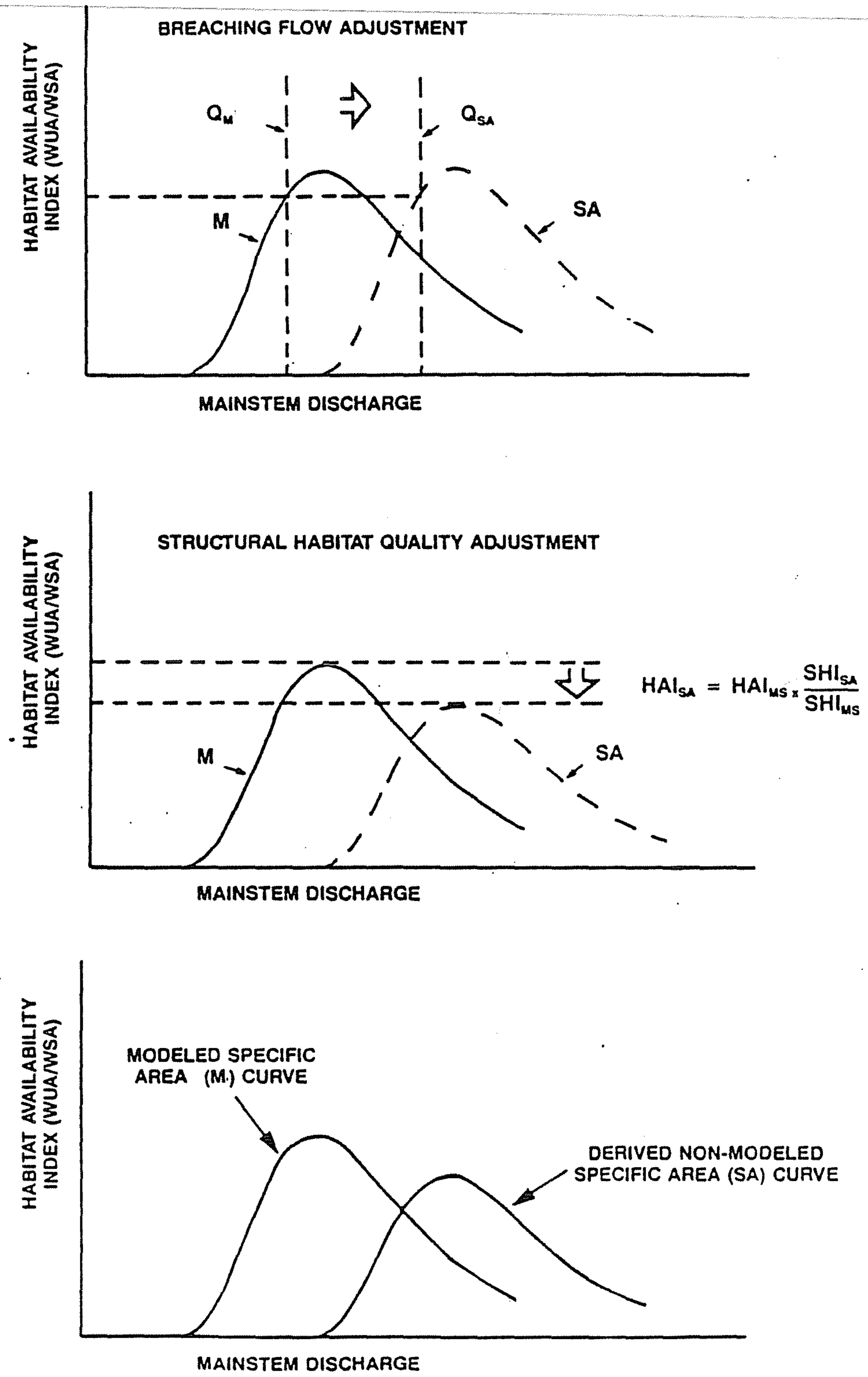


Figure 14. Derivation of a non-modeled specific area (sa) HAI curve using a modeled specific area (ms) HAI curve.
A. Lateral shift to account for differences in breaching discharge (Q_{ms} Q_{sa})
B. Vertical shift proportional to (SHI_{sa}/SHI_{ms}) to account for differences in structural habitat quality.
C. Final hypothetical modeled and non-modeled specific area curves.

2.5 Integration

The data obtained in the stratification, quantification, and simulation steps in the extrapolation analysis are integrated by following the process outlined in Figure 15. Inspection of the flow chart shows the integration is comprised of three nested loops. The inner loop (3) is repeated for each specific area in a subgroup. Functionally, it computes the WUA response curve for a specific area given the model site HAI curve, SHI ratio, and WSA curve for the specific area. The middle loop (2) drives the inner loop through all members of a subgroup and provides the HAI curve for the subgroup model site. The outer loop (1) drives the inner two loops through each representative group. This synthesis provides estimates of juvenile chinook rearing habitat for the 172 specific areas and their summation within each of the ten representative groups.

In regard to the rearing habitat potential of different representative groups, the relative significance of aggregate WUA functions in future decisions will likely be influenced by data concerning present and prospective utilization by juvenile chinook salmon under natural and with-project flow regimes. An assessment of the relative importance of the different representative groups in terms of their utilization by rearing chinook salmon will appear in Volume II of the Instream Flow Relationships Report. When coupled with information relating to food availability, water temperature, suspended sediment and other environmental factors, the aggregate physical habitat response functions will allow for conclusions and recommendations at the management level.

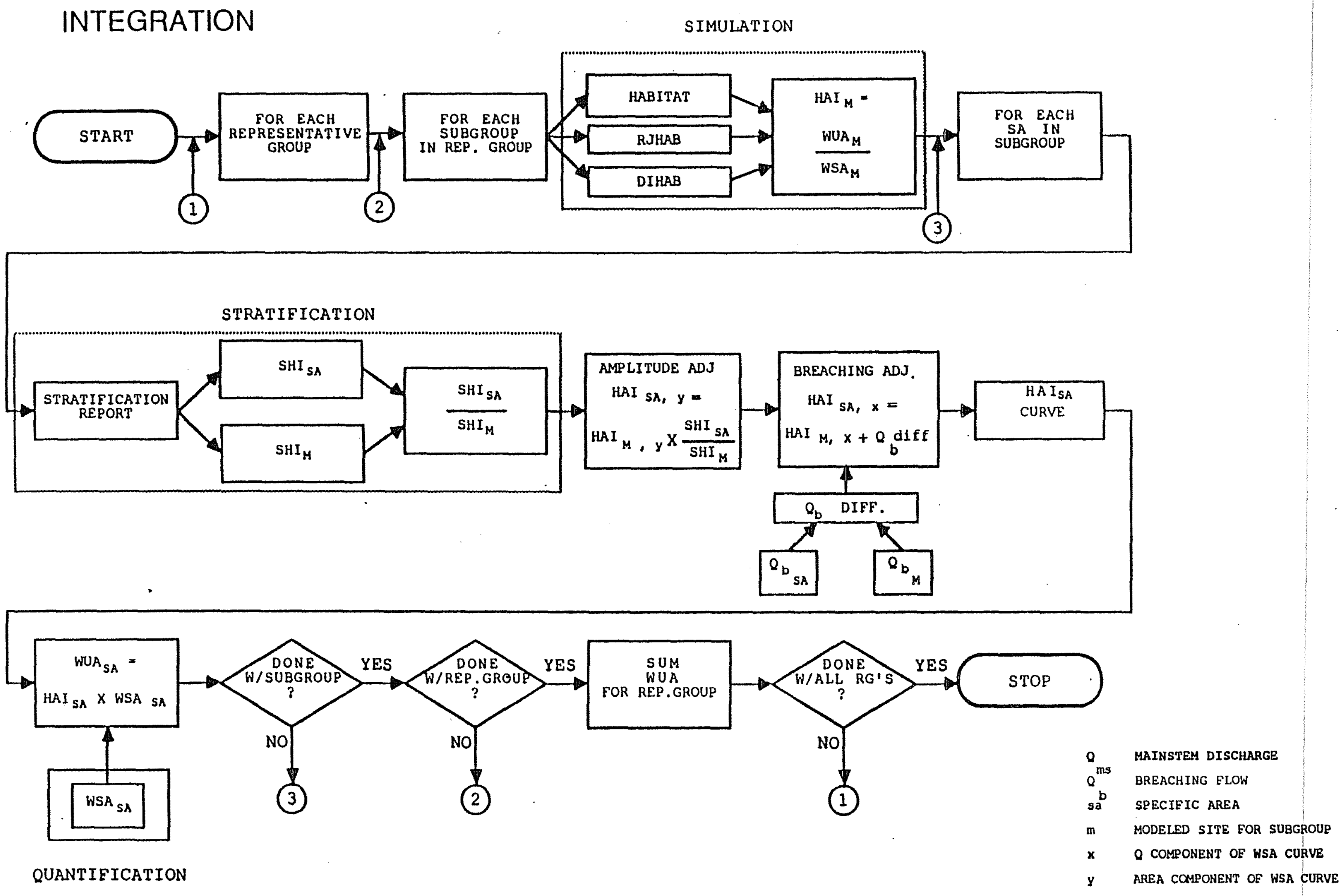


Figure 15. Flow chart indicating the steps followed in the integration of stratification, simulation, and quantification for specific areas used in the extrapolation methodology.

3.0 RESULTS

3.1 Representative Group I

The 19 specific areas within this group include all upland sloughs occuring in the middle Susitna River. Except during flood stage, these sloughs are connected to the main channel only at their downstream end. In addition to high breaching flows and low turbidity levels, typical features of specific areas in Representative Group I include low velocity pools of greater-than-average depth separated by short, higher velocity riffles. Clear water enters these sites via seepage or tributary inflow and maintains relatively stable base flows under non-breached conditions. Substrates are frequently homogeneous over large areas and are often characterized by fine silt/sand sediments overlaying cobble materials. Cover is usually provided by overhanging and emergent vegetation. These sites are used only to a small extent by juvenile chinook salmon (Marshall et al. 1984).

Specific areas assigned to Representative Group I are represented by two RJHAB modeling sites: 107.6L and 112.5L. Photographs of these sites when mainstem discharges were 23,000 and 16,000 cfs are presented in Plates A-1 and A-2 (Appendix A). For much of its length, Site 107.6L is a low gradient, narrow meandering stream. At mainstem discharges above 20,000 cfs, the turbid backwater area at the slough mouth advances upstream and inundates lower sections of the site; this phenomenon accounts for the marked relative increase in wetted surface area indicated in Figure 16.

Usable chinook rearing habitat at Site 107.6L does not respond dramatically to increases in wetted surface area, as evidenced by the WUA and HAI curves

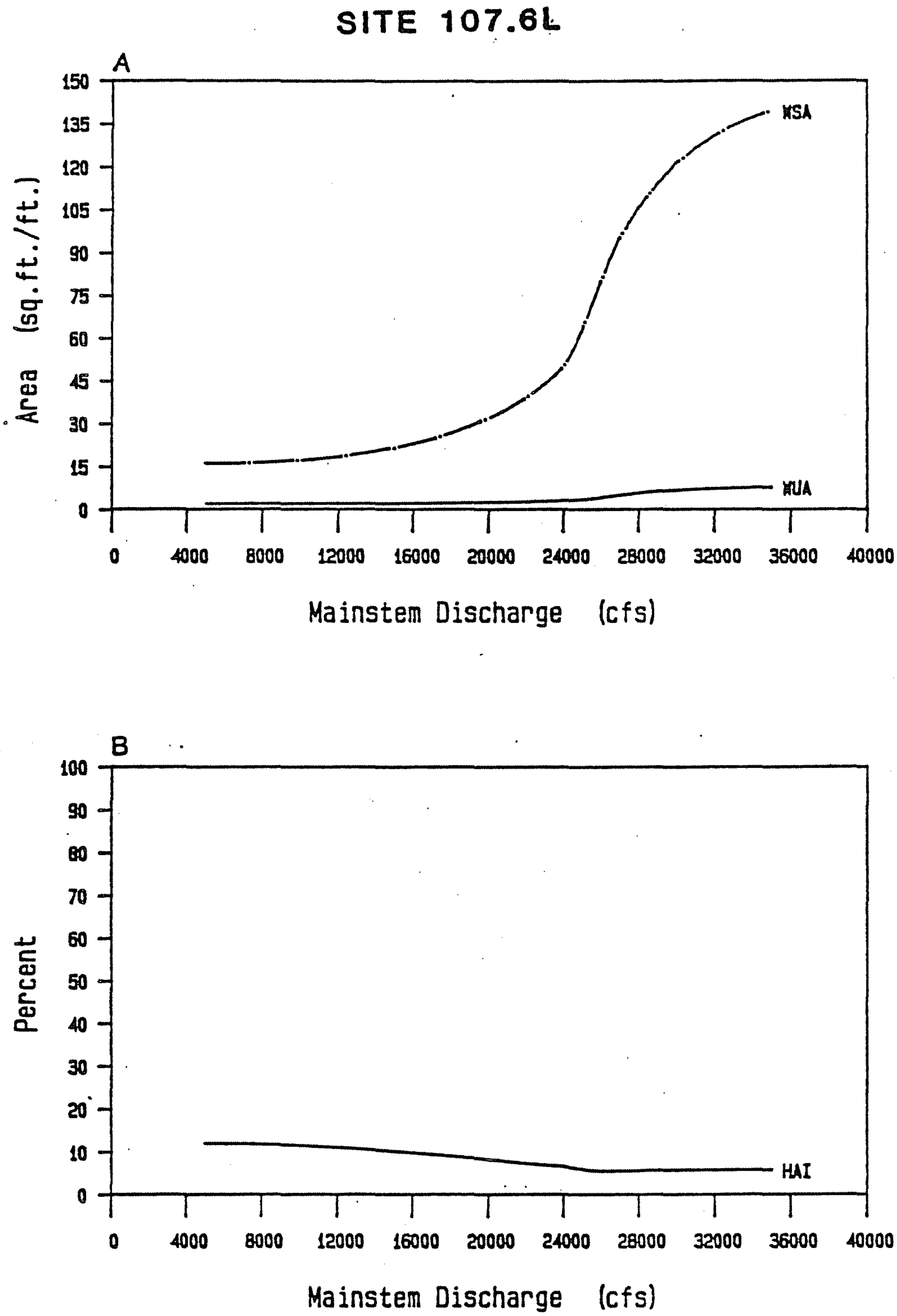


Figure 16. Surface area and chinook rearing habitat index response curves for modeling site 107.6L.
A - Wetted surface area (WSA) and weighted usable area (WUA).
B - Habitat availability index (HAI)

shown in Figure 16. WUA at this site gradually increases at higher flows due to the reduction in water velocity and water clarity caused by rising backwater. Water velocities ranging up to 0.8 fps are common at transects upstream of the backwater pool. Therefore, under clear water conditions nearly ideal velocities exist for juvenile chinook. A silt substrate is dominant, which affords little cover value for juvenile chinook, resulting in a low composite suitability for most cells within the site regardless of the suitability of their depths and velocities. As the extent of the backwater increases, velocities in these cells decrease to 0.0 fps, slightly reducing suitability with respect to this habitat variable, but turbidity levels increase, yielding a higher overall suitability (the weighting factor associated with the "no cover" class of cover using turbid water suitability criteria is 0.31, compared to 0.01 for clear water criteria). When coupled with an increase in surface area, this leads to the slight rise in WUA observed at higher flows. However, because the rate of change in WSA is so great relative to the change in WUA, the proportion of the site containing usable rearing habitat declines as flows increase. HAIs decrease from 11.9 percent at 5,000 cfs to 5.4 percent at 26,000 cfs.

In contrast to Site 107.6L, very little response in WSA, WUA, and HAI to changes in mainstem discharge were observed at Site 112.5L (Figure 17). The latter site is an upland slough with steep banks which prevents large changes in surface area as site water surface elevations change (Plate A-2). As a consequence, physical habitat conditions within this site remain relatively constant and little variation in WUA and HAI results from mainstem flow fluctuations below 35,000 cfs. Slight inconsistencies in ADF&G field data required that an average HAI value (4.2 percent) be used to back

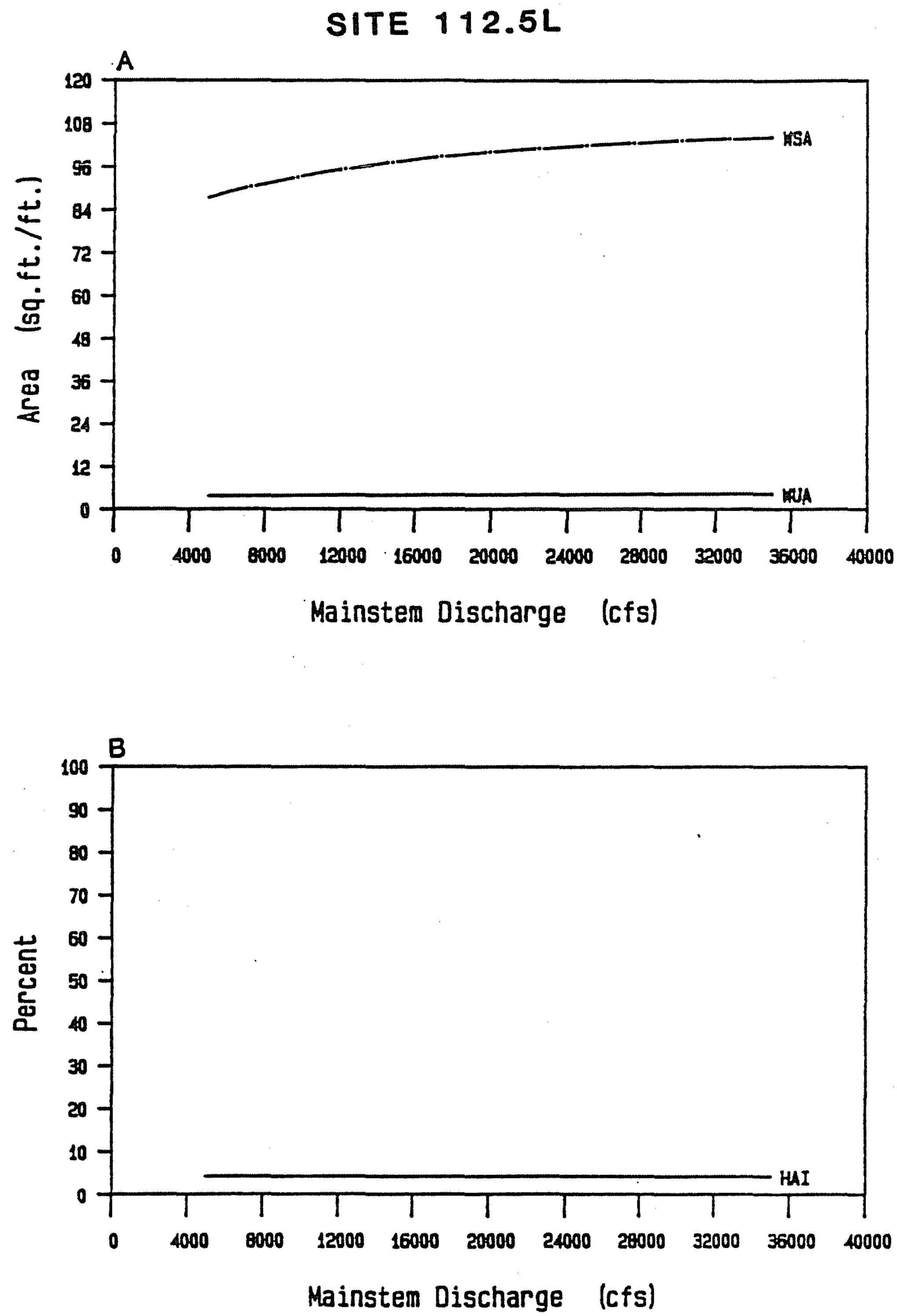


Figure 17. Surface area and chinook rearing habitat index response curves for modeling site 112.5L.
A - Wetted surface area (WSA) and weighted usable area (WUA).
B - Habitat availability index (HAI)

calculate WUA values for Site 112.5L. Values derived for these habitat indices were comparable to those recorded for Site 107.6L.

Specific areas assigned to Representative Group I are former side channels and side sloughs that have become increasingly isolated over time from the mainstem owing to long-term channel activity. Due to the infrequency of breaching events, the primary response in habitat character at these sites results from backwater effects at the upland slough/mainstem interface. Differences between specific areas are related primarily to the extent of backwater areas, and secondarily to the presence or absence of riparian and instream vegetation. Variations in local runoff resulting from precipitation may also affect short-term habitat availability and quality.

Of the two modeling sites in this Representative Group, Site 107.6L represents a subgroup of 8 specific areas whose habitat character is strongly influenced by tributary inflow. Site 112.5L represents the remaining 11 upland sloughs in Representative Group I whose habitat character appears more strongly influenced by groundwater inflow. HAI functions were derived for modeled and non-modeled specific areas associated with each of the modeling sites and are presented in Figures 18 and 19 (see also Appendix B). These HAI curves were not adjusted laterally on the discharge axis since the specific areas within Representative Group I are breached at extremely high mainstem discharges. Differences in habitat availability between specific areas are assumed to be due to dissimilarities in structural habitat quality.

For each specific area included in Representative Group I, HAI ratios representing the amount of usable rearing habitat per unit surface area at

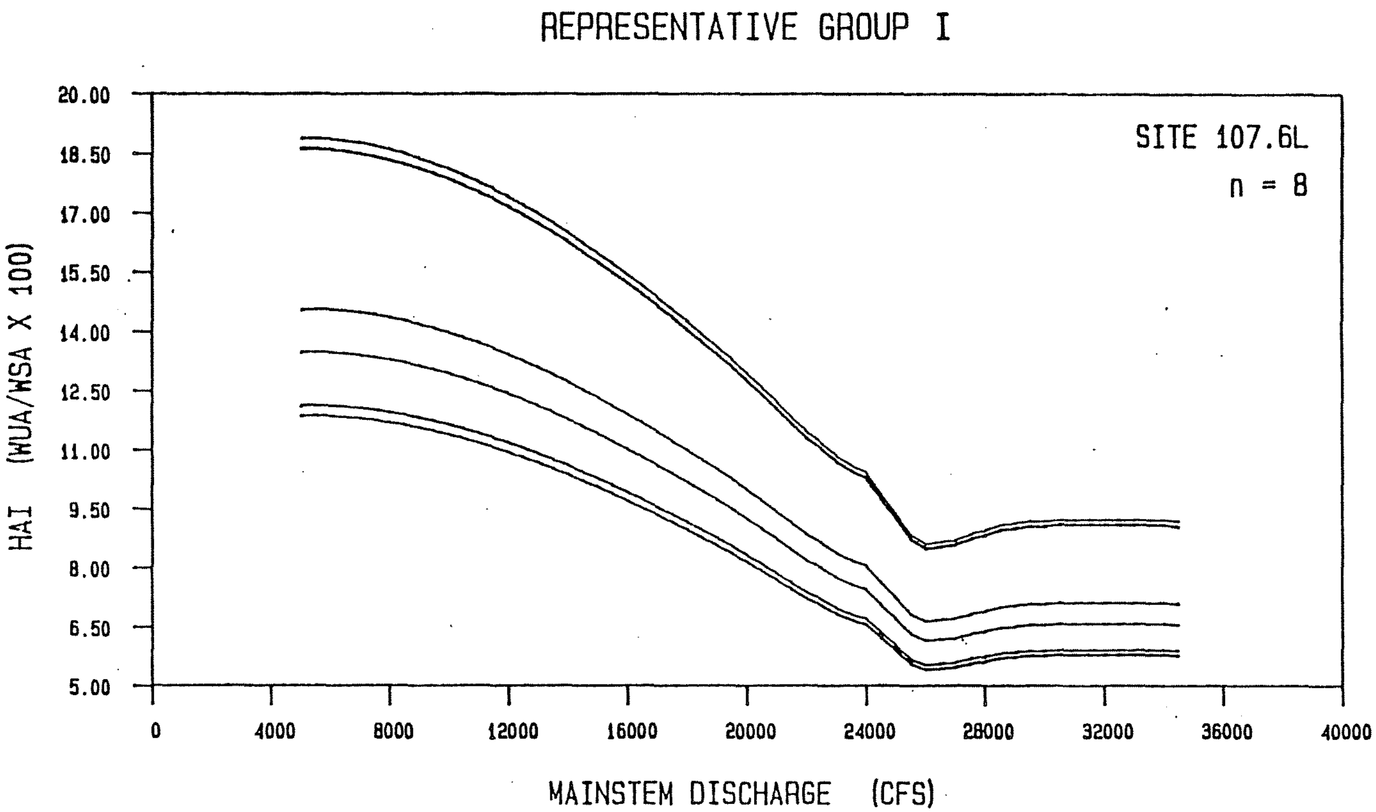


Figure 18. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 107.6L of Representative Group I.

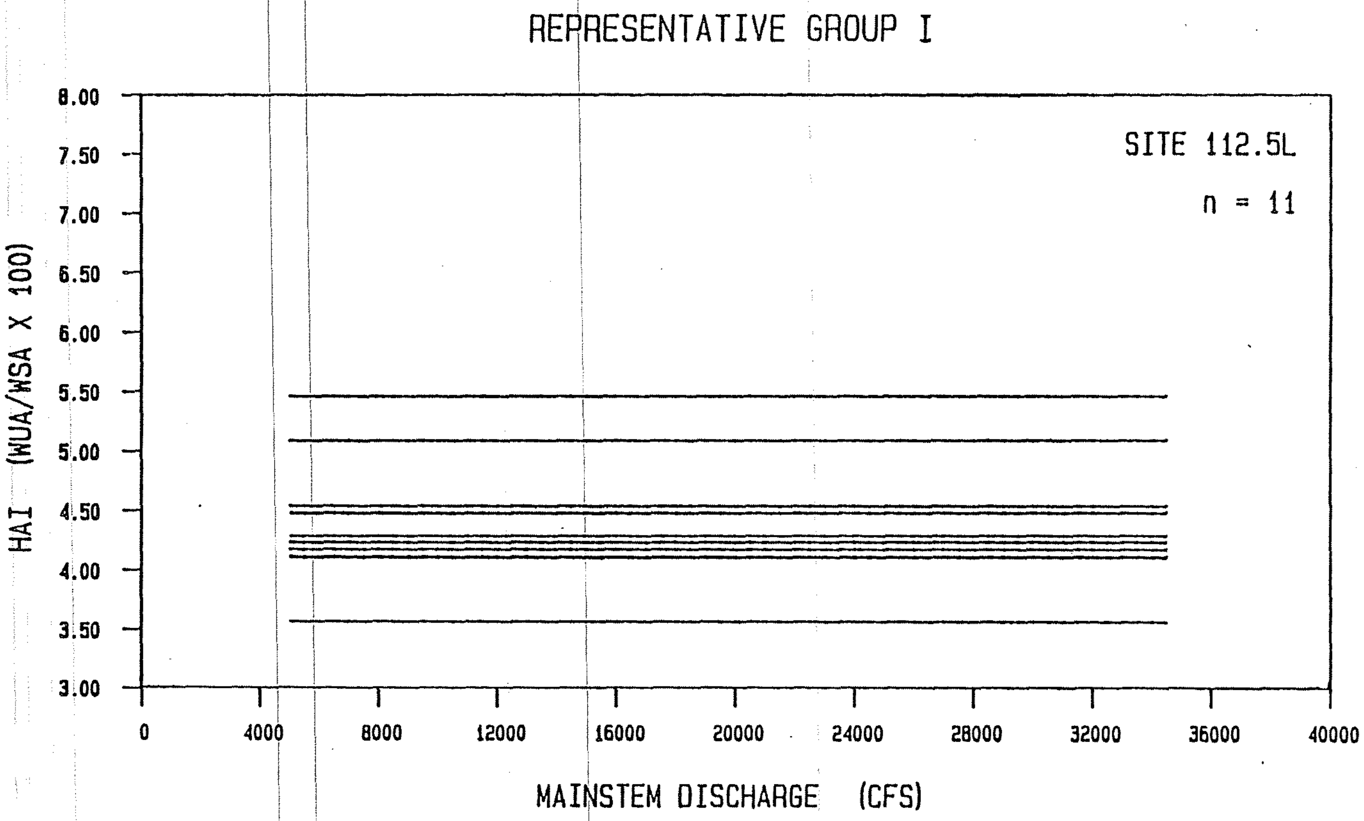


Figure 19. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 112.5L of Representative Group I.

flow increments of 500 cfs were multiplied by corresponding wetted surface area estimates interpolated from areas digitized from scaled aerial photography. The product of flow-specific HAI and WSA values are estimates of the total amount of WUA (in square feet) present at a particular site for mainstem flows ranging from 5,000 to 35,000 cfs. Aggregate WSA and WUA values were obtained for Representative Group I by summing individual specific area WSA and WUA forecasts. The results of these calculations are presented in Figure 20.

The overall response of juvenile chinook habitat for Group I sites is influenced by changes in backwater-related surface area and by the relative constancy of HAI values, particularly at lower flows. WUA tends to increase slightly as flows increase from 5,000 to 16,000 cfs; rearing habitat is maximal at the latter flow. Rearing habitat potential remains fairly constant between 16,000 and 35,000 cfs. It should be noted that the total amount of rearing habitat provided by Group I is small in comparison to other Representative Groups due to their comparatively low surface area and HAI values recorded for its individual specific areas.

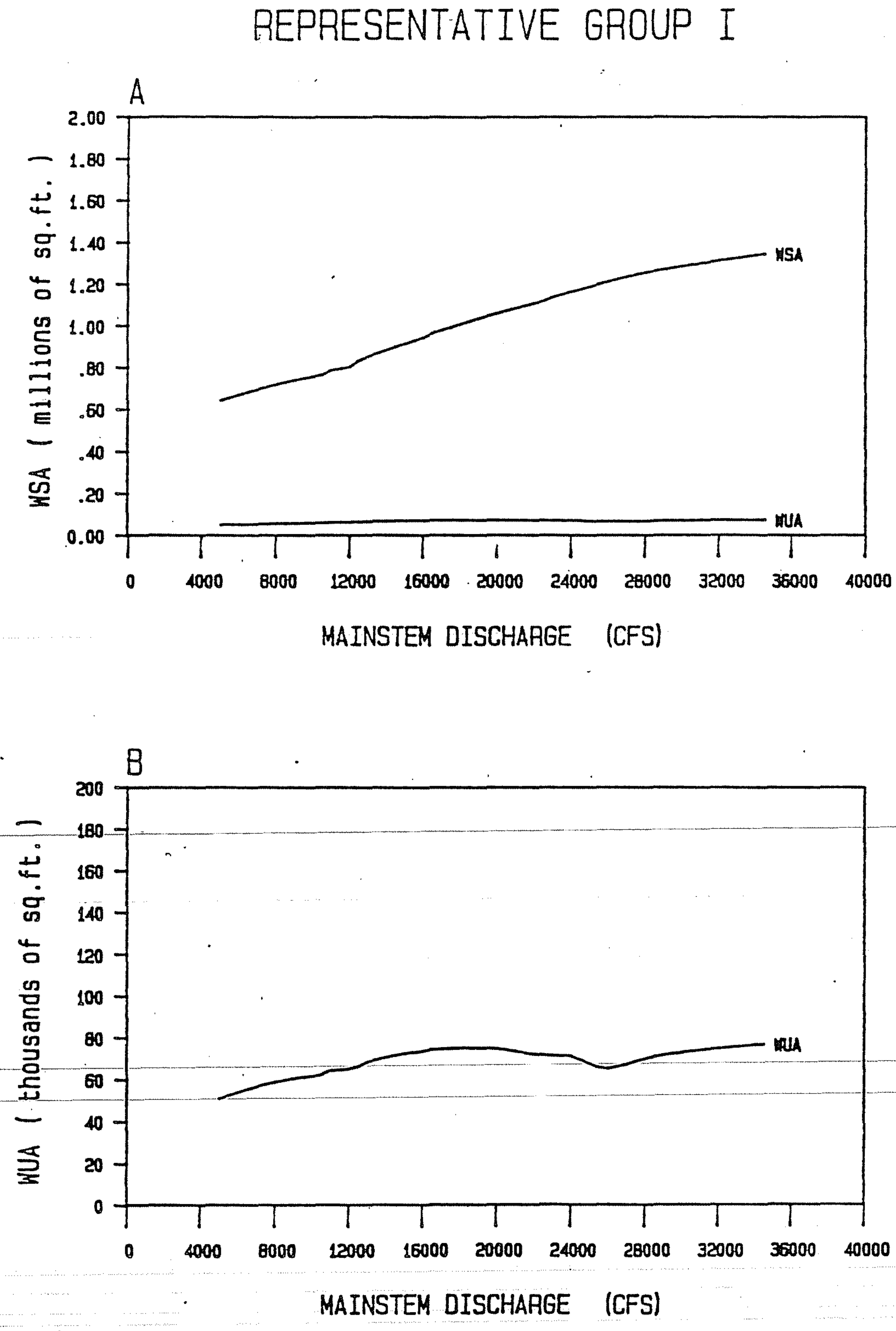


Figure 20. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group I of the middle Susitna River.

3.2 Representative Group II

Associated with this group are modeling sites 101.4L, 113.7R, 126.0R and 144.4L. These sites include side sloughs having moderately high breaching flows (> 20,000 cfs) and enough upwelling groundwater to keep portions of the sites ice-free during the winter months. Side sloughs classified in Representative Group II were found to contain significant numbers of juvenile chinook during the growth season, particularly in their breached state (Dugan et al. 1984).

The 28 specific areas included in this group are typically separated from the mainstem by large, vegetated islands or gravel bars. When breached, these channels convey only a small percentage of the total mainstem flow. Cross-sections vary from relatively broad, uniform and rectangular in shape to narrow, irregular and v-shaped in profile. Head berms generally fall in the former category. Backwater areas occur at the mouths of most specific areas within Group II but their effects on hydraulic conditions and therefore juvenile chinook habitat are not as extensive as those observed for upland sloughs. Substrates range from silt and sand in backwater areas to rubble/cobble/boulder throughout the rest of the site.

Aerial photography indicating the general features of modeling sites 101.4L, 113.7R, 126.0R, and 144.4L and their associated specific areas at 23,000 and 16,000 cfs are presented in Plates A-3, A-4, A-5, and A-6 (Appendix A). The appearance of these sites does not change appreciably at mainstem flows below 16,000 cfs.

Response curves for wetted surface area (WSA) and habitat indices (WUA, HAI) developed for the four modeling sites within Group II exhibit strong similarities in appearance due to the dominant influence of shared hydrologic, hydraulic and morphologic properties (cf Figures 21-24). In the non-breached state, wetted surface areas remain relatively constant, responding primarily to local runoff and upwelling conditions. Following breaching, rapid increases in WSA occur in response to further changes in mainstem flow. Increases in WSA are attenuated as flows approach bank full levels.

Juvenile chinook WUA values simulated for Group II modeling sites are generally constant until the sites are breached, whereupon large increases occur in response to incremental changes in site flow. The amount of usable rearing habitat tends to peak shortly after the head berms are overtopped. This relatively sudden and rapid increase in juvenile chinook habitat results from a combination of factors: 1) the rapid accrual of wetted surface area, 2) the enhanced cover value provided by higher turbidities, and 3) the preponderance of velocities falling within the optimal preference range for juvenile chinook. In general, the magnitude of the WUA increase is proportional to the increase in wetted surface area possessing suitable velocities. Site velocities, however, soon become limiting in mid-channel areas following breaching, leading to a reduction in rearing WUA at higher flows.

On the basis of limited gross habitat (GHA) and habitat quality (HQI) data obtained for Site 126.0R (Figure 23), usable rearing habitat appears to be more uniformly distributed and of better quality at flows associated with

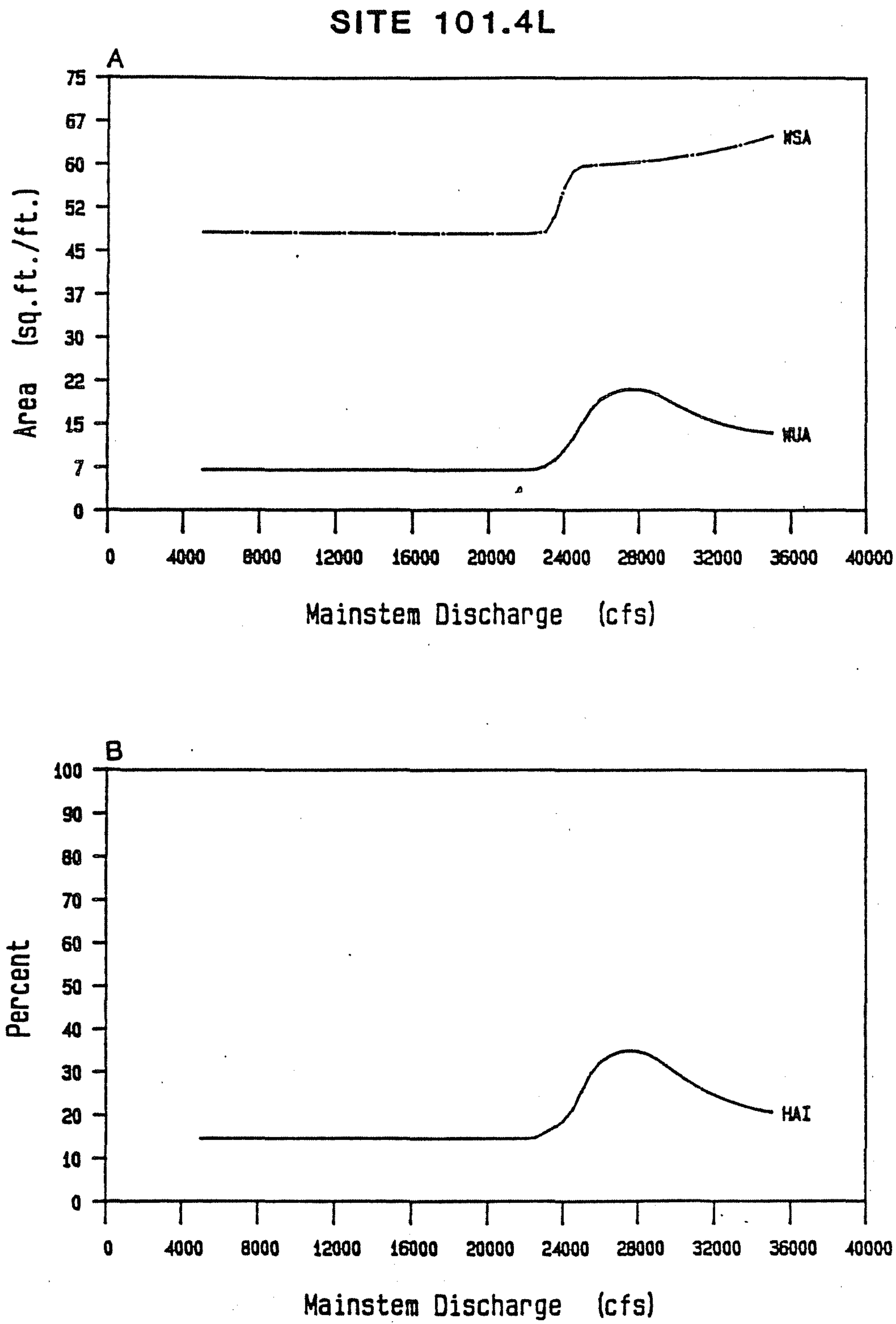


Figure 21. Surface area and chinook rearing habitat index response curves for modeling site 101.4L.
A - Wetted surface area (WSA) and weighted usable area (WUA).
B - Habitat availability index (HAI)

SITE 113.7R

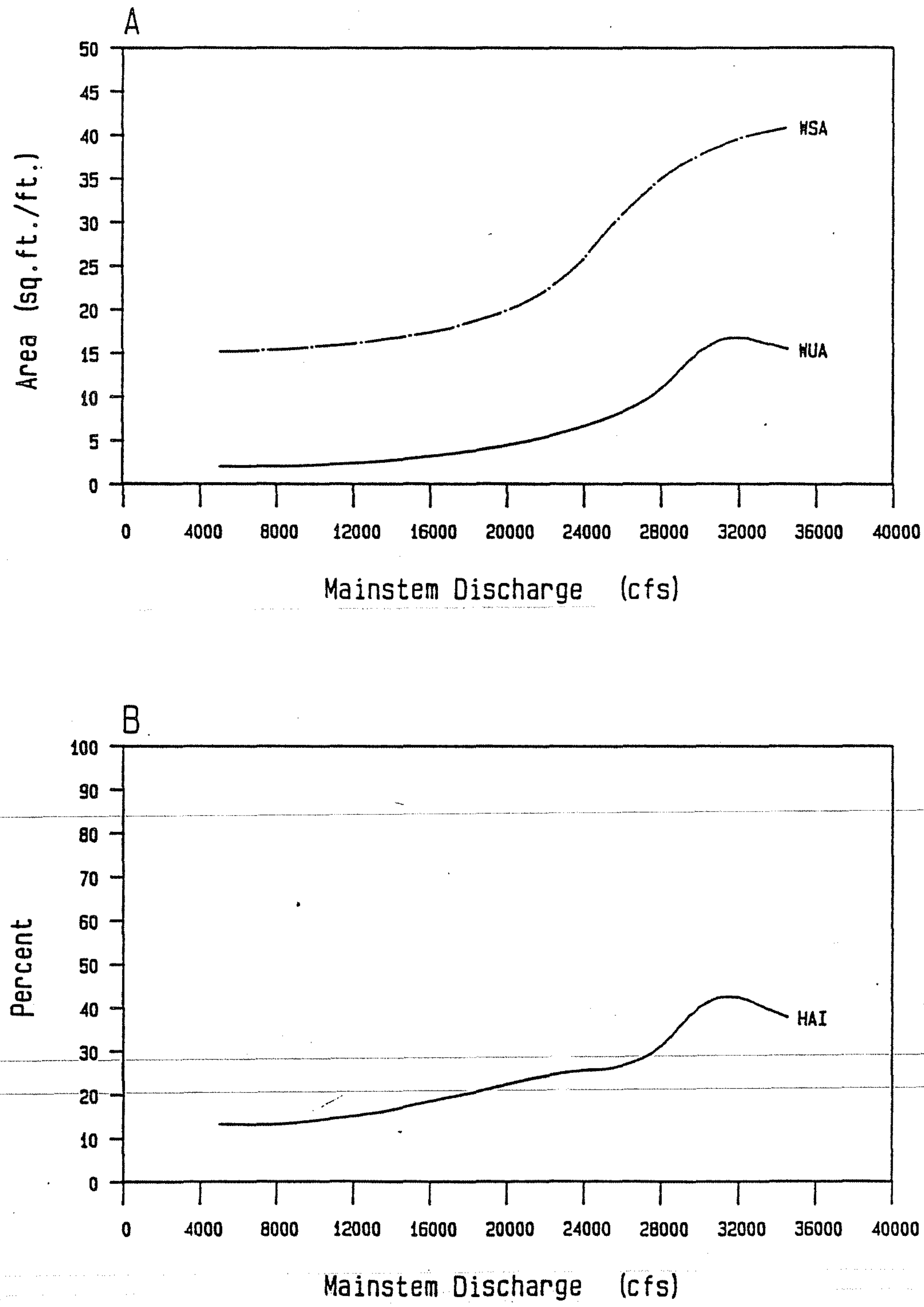


Figure 22. Surface area and chinook rearing habitat index response curves for modeling site 113.7R.
A - Wetted surface area (WSA) and weighted usable area (WUA).
B - Habitat availability index (HAI).

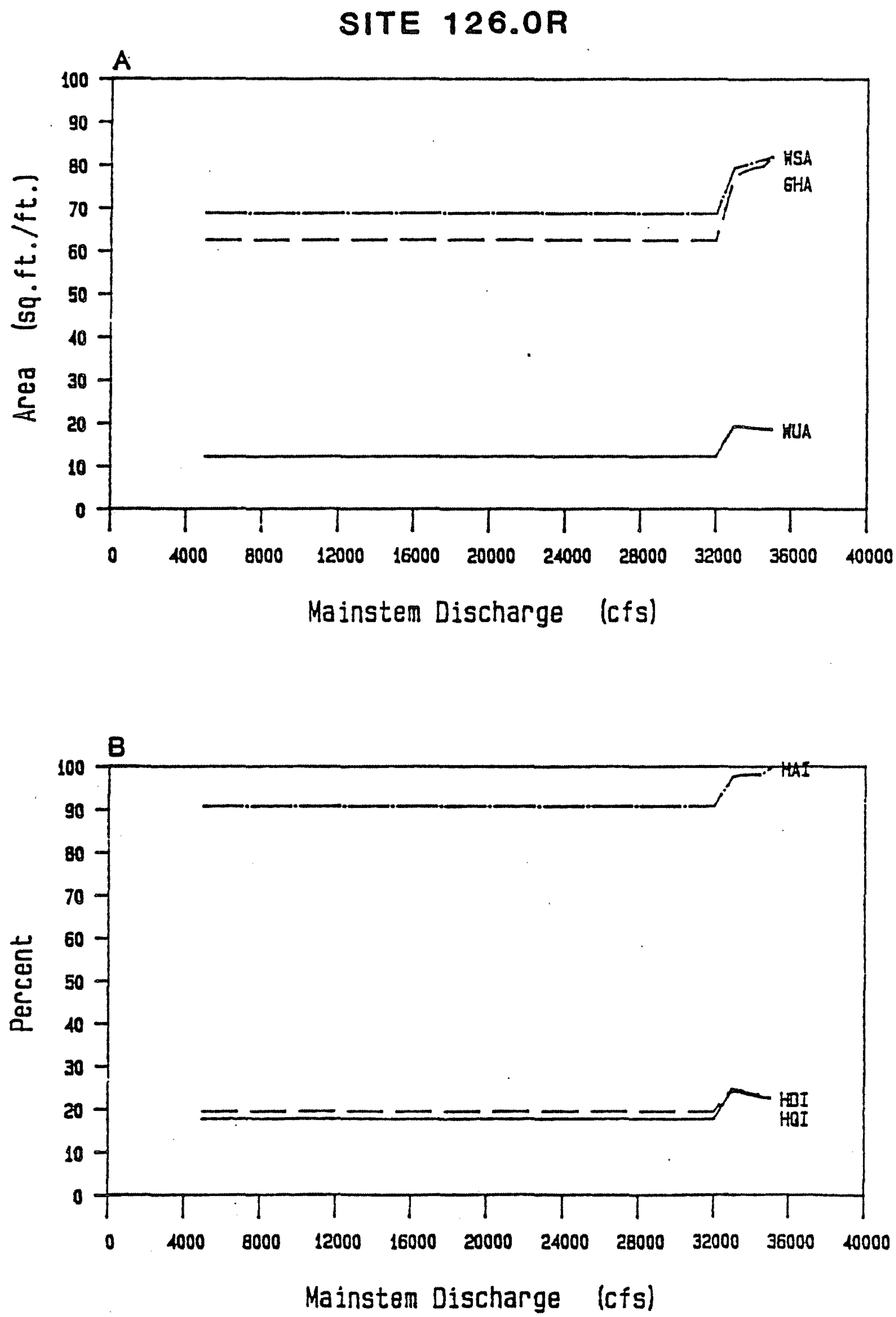


Figure 23. Surface area and chinook rearing habitat index response curves for modeling site 126.0R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

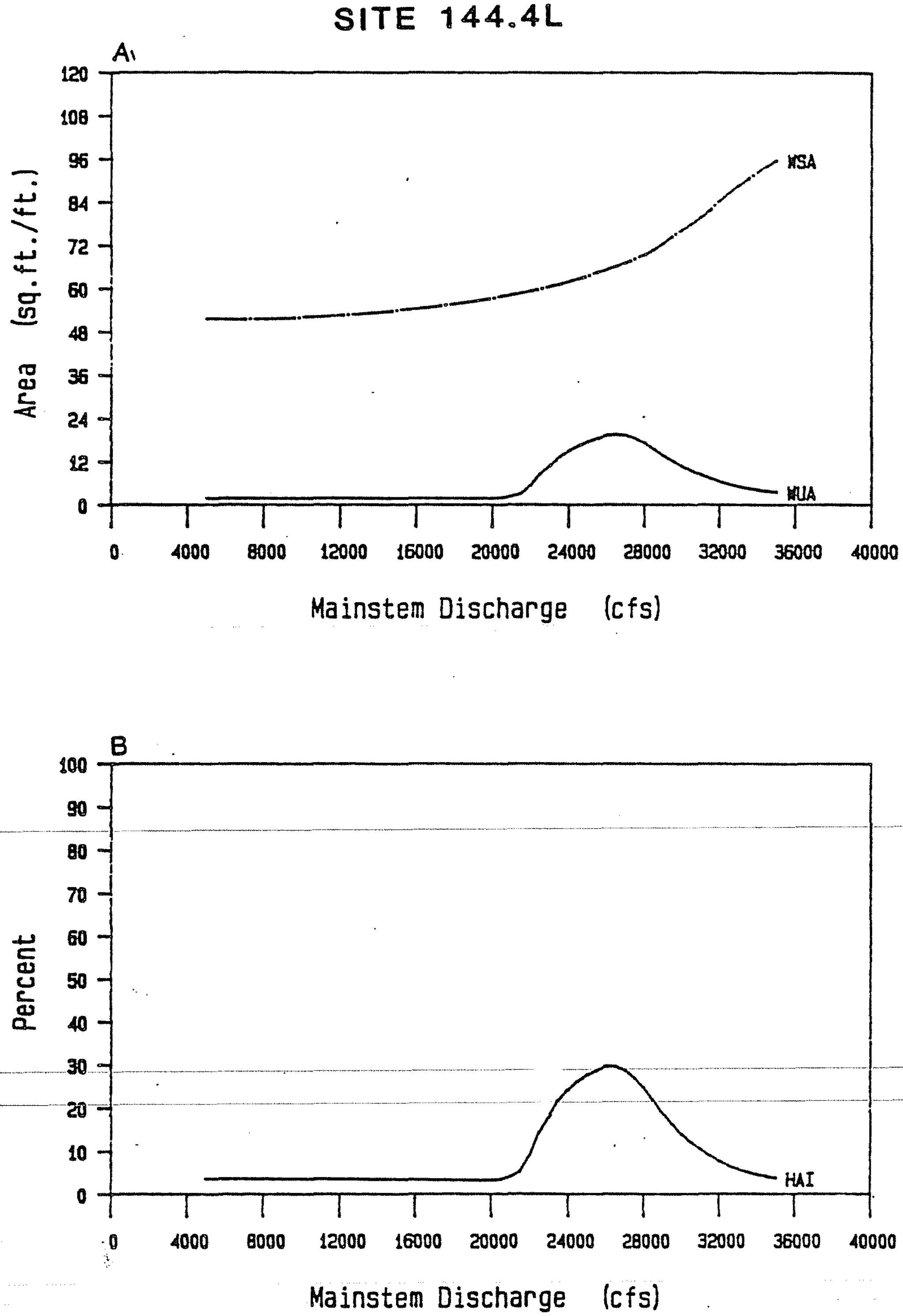


Figure 24. Surface area and chinook rearing habitat index response curves for modeling site 144.4L.
A - Wetted surface area (WSA) and weighted usable area (WUA).
B - Habitat availability index (HAI)

the ascending left hand limb of the WUA curve than at non-breached or high mainstem discharges. Under non-breached conditions, unsuitably shallow depths often occur in riffle areas of the site, resulting in slightly lower HQI values. Although surface area and habitat indices for Site 126.0R were not extrapolated to flows exceeding 35,000 cfs, it is likely that juvenile chinook habitat becomes more restricted to peripheral areas as mid-channel velocities increase.

Specific areas in Representative Group II are listed in four subgroups according to similarities among their morphologic and hydraulic characteristics. Site 101.4L represents 7 specific areas within Group II that have relatively large broad channels. Site 113.7R is associated with 9 smaller specific areas with narrower channels. The 6 specific areas associated with Site 126.0R are all from two similar side slough complexes within several miles of each other. The last subgroup is comprised of 6 specific areas that are similar in size and channel gradient to modeled site 144.4L. HAI functions are plotted for specific areas associated with each of these modeling sites in Figures 25 through 28. HAI values used to plot these curves are tabulated in Appendix B.

Figure 29 depicts the aggregate WUA curve obtained by multiplying Group II specific area HAI values by their wetted surface areas and summing the results for each flow of interest. Because of their high breaching flows, most specific areas exhibit peak HAI values in the range of 20,000 to 30,000 cfs. When adjusted by their wetted surface areas these sites yield cumulative WUA values which increase slowly at low to intermediate flows,

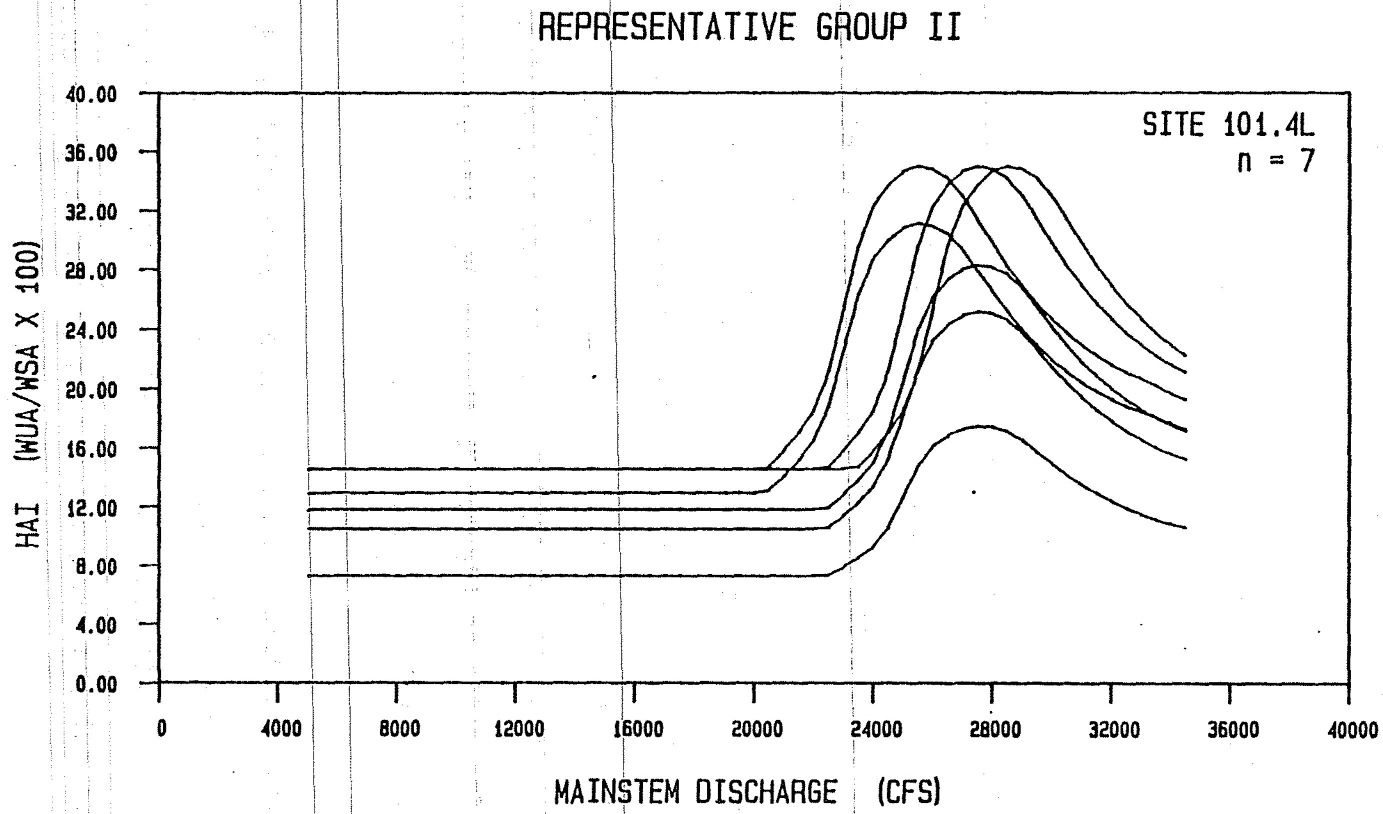


Figure 25. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 101.4L of Representative Group II.

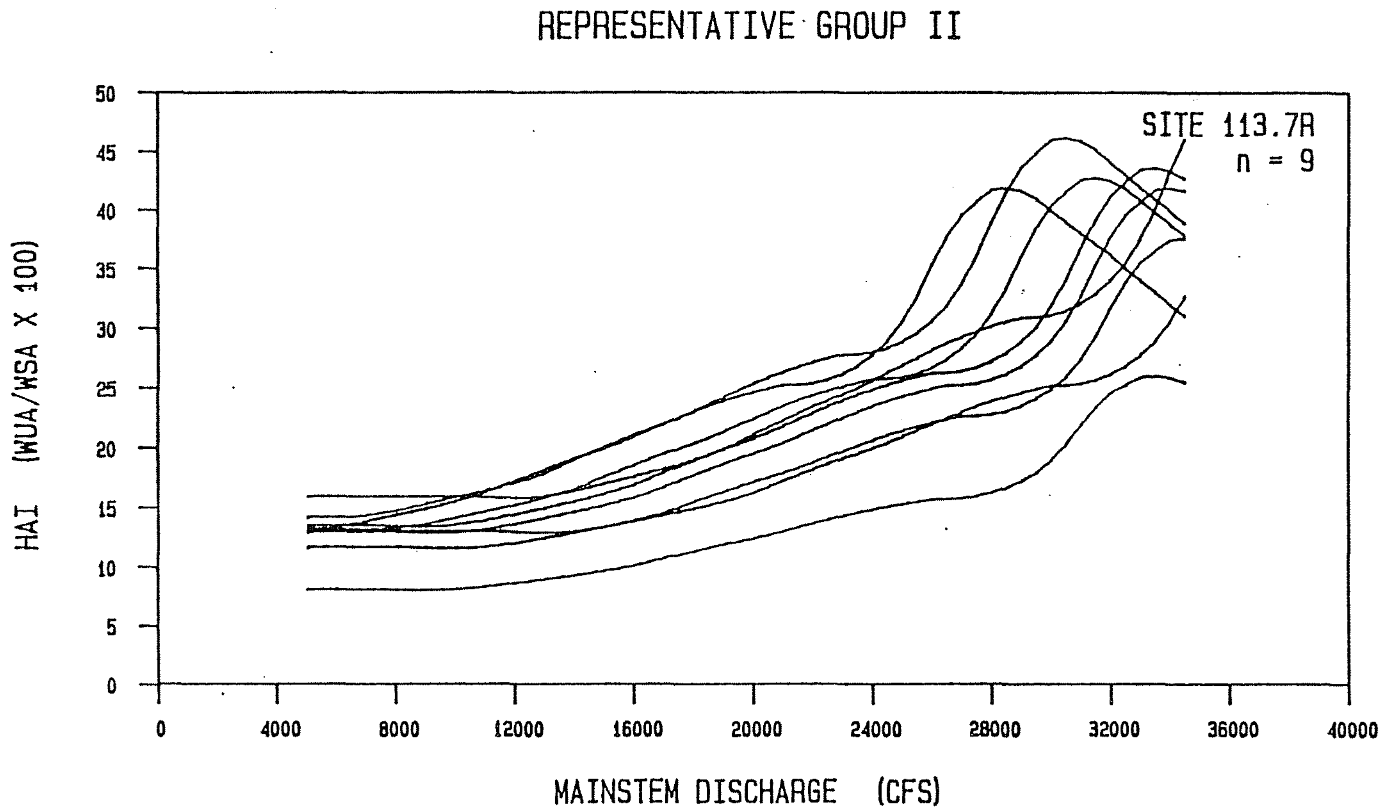


Figure 26. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 113.7R of Representative Group II.

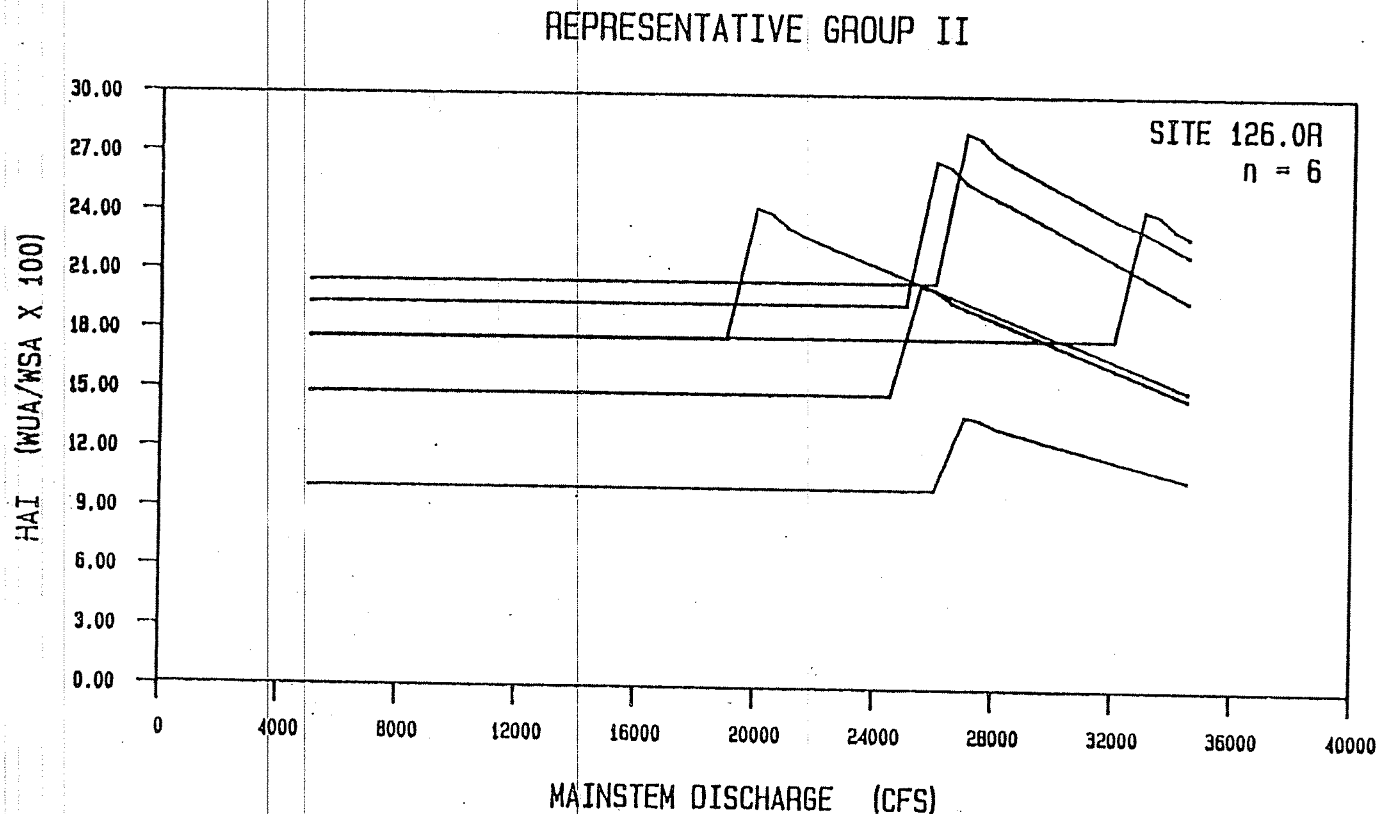


Figure 27. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 126.0R of Representative Group II.

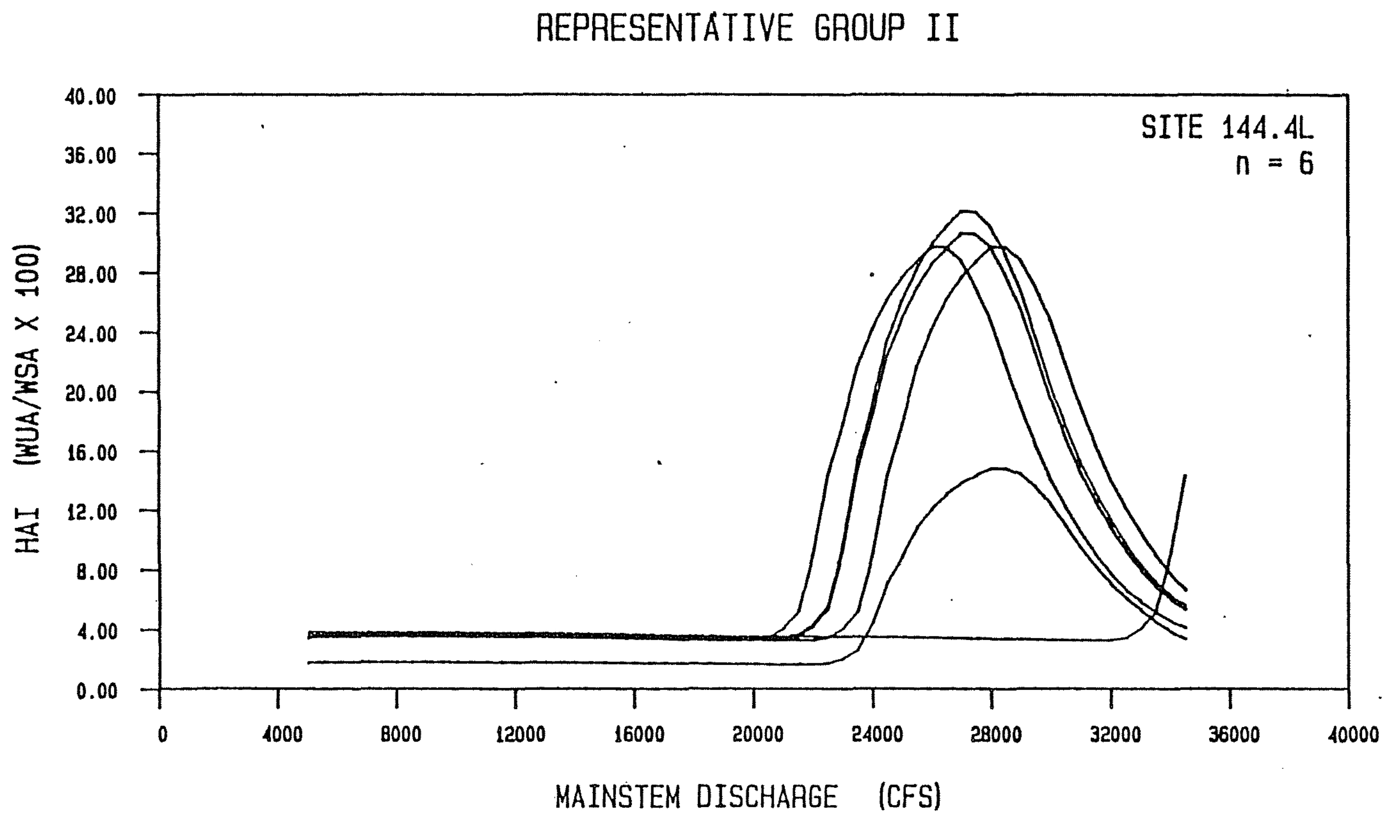


Figure 28. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 144.4L of Representative Group II.

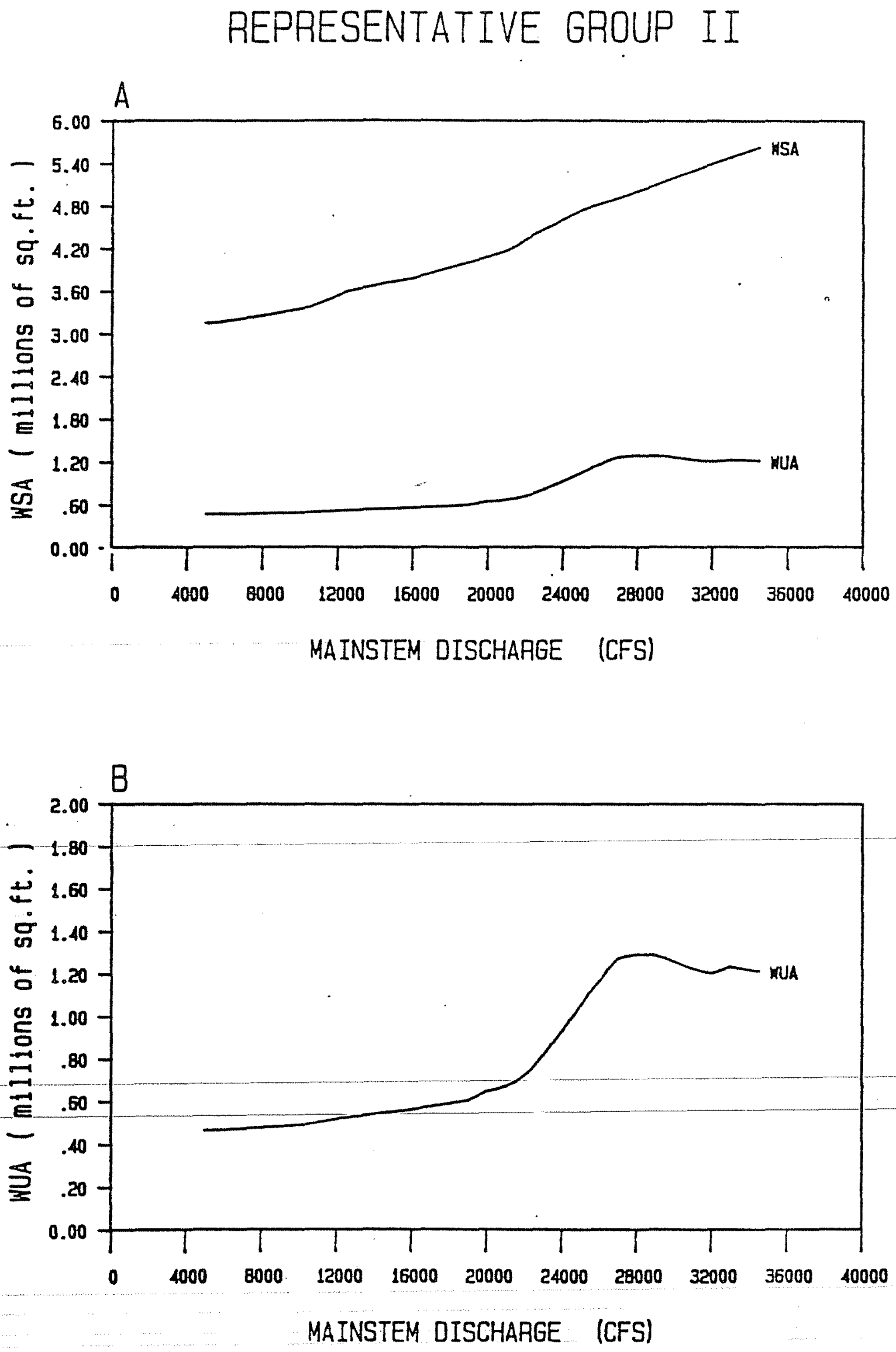


Figure 29. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group II of the middle Susitna River.

increase more rapidly after this point and peak at 29,000 cfs. Approximately 1.2 million square feet of juvenile chinook WUA is provided by Group II specific areas at this discharge. The large differences in WUA over the range of evaluation flows indicate that rearing habitat potential in Representative Group II as a whole may be considered highly sensitive to fluctuations in mainstem flow. Figure 29 also illustrates aggregate WSA response for Representative Group II.

3.3 Representative Group III

Sites 101.2R, 128.8R, 132.6L and 141.4R are all side channels which become nonbreached at intermediate (8,000 to 16,000 cfs) mainstem discharge levels, and transform into side sloughs at lower discharges. These modeling sites and the Group III specific areas they represent, shown in Plates A-7 through A-14 (Appendix A), are larger and convey greater volumes of water when breached than the side sloughs discussed in the preceding section. Site geometry tends toward broad cross-sections. Reach gradients are sufficient to promote mid-channel velocities of 2 to 5 fps following breaching. Upwelling occurs sporadically within these specific areas and in a few cases may be insufficient to provide for passage between clearwater pools formed at low mainstem flows.

The 18 specific areas comprising Group III represent some of the most heavily utilized rearing areas in the middle segment of the Susitna River. Juvenile chinook are found in these areas primarily under turbid water conditions (Dugan et al. 1984).

Surface area and juvenile chinook habitat response curves are portrayed in Figures 30, 31 and 33 for modeling sites 101.2R, 128.8R and 141.4R, respectively. These sites were modeled using IFG hydraulic simulation models coupled with the HABTAT model of the PHABSIM system. A fourth site, 132.6L was modeled using both PHABSIM and RJHAB modeling techniques applied to separate sets of data. Results for this site are found in Figure 32.

An inspection of the aerial photography (Plates A-7 through A-14, Appendix A) WSA curves developed for the modeling sites suggests a rapid response of

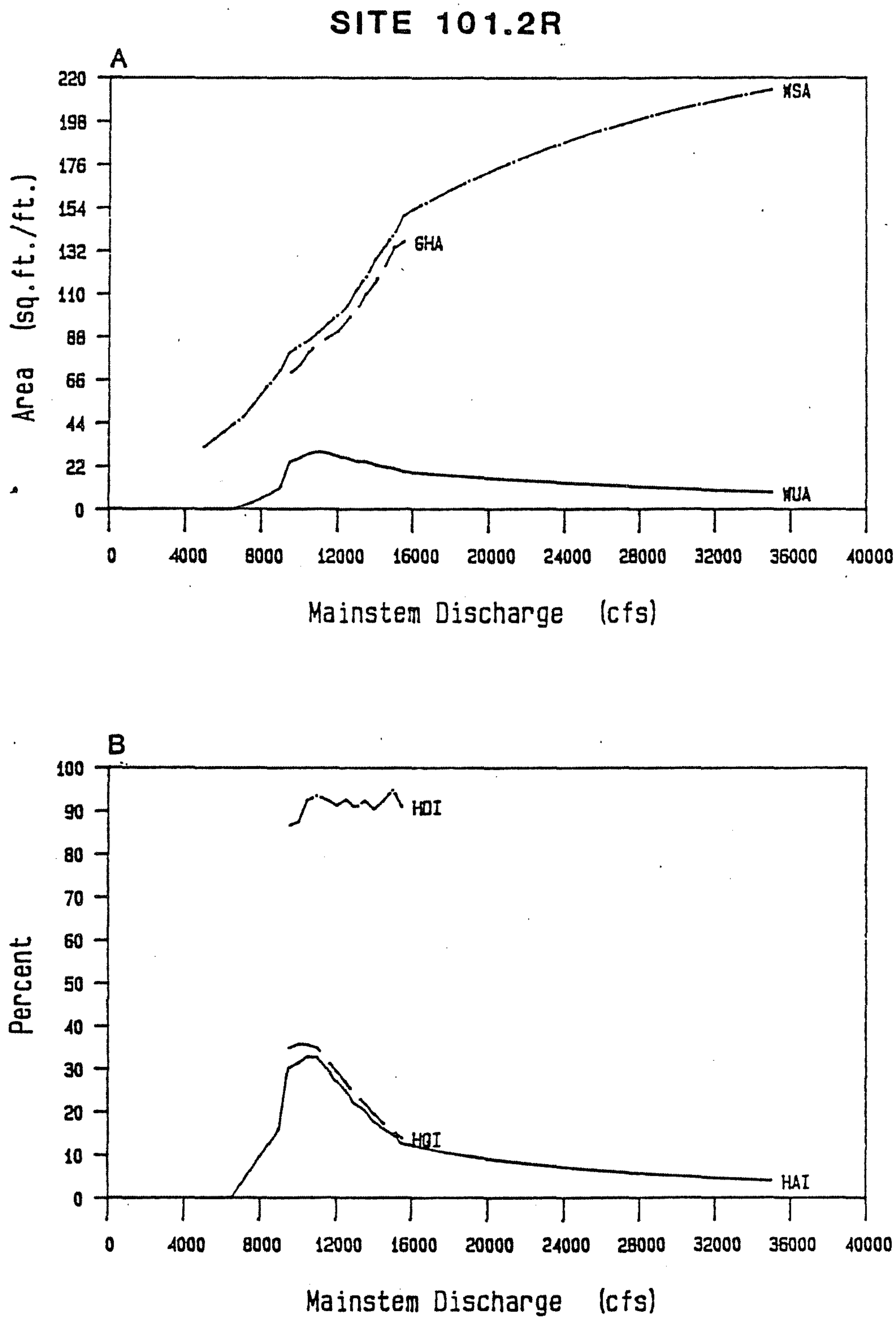


Figure 30. Surface area and chinook rearing habitat index response curves for modeling site 101.2R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

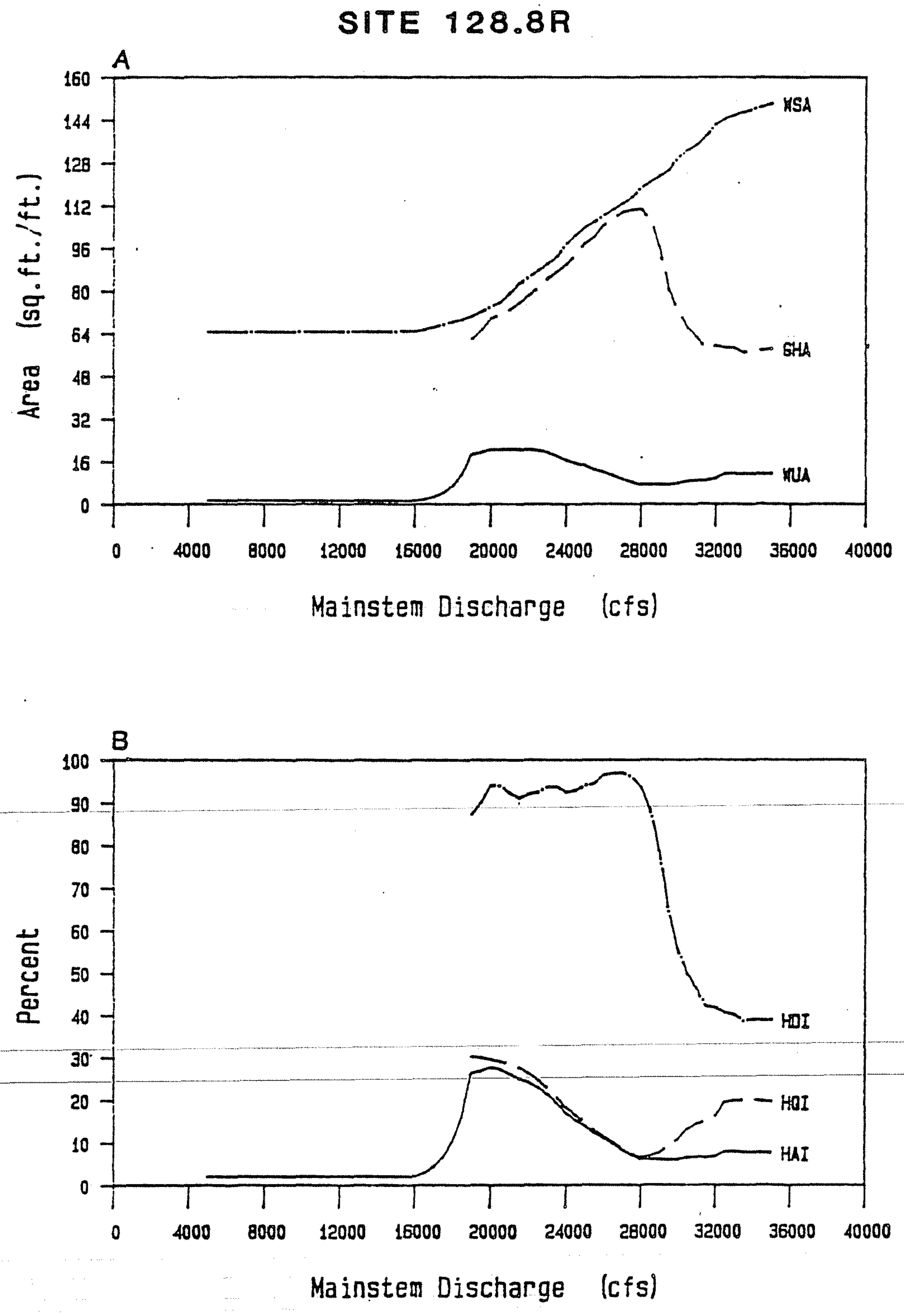


Figure 31. Surface area and chinook rearing habitat index response curves for modeling site 128.8R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

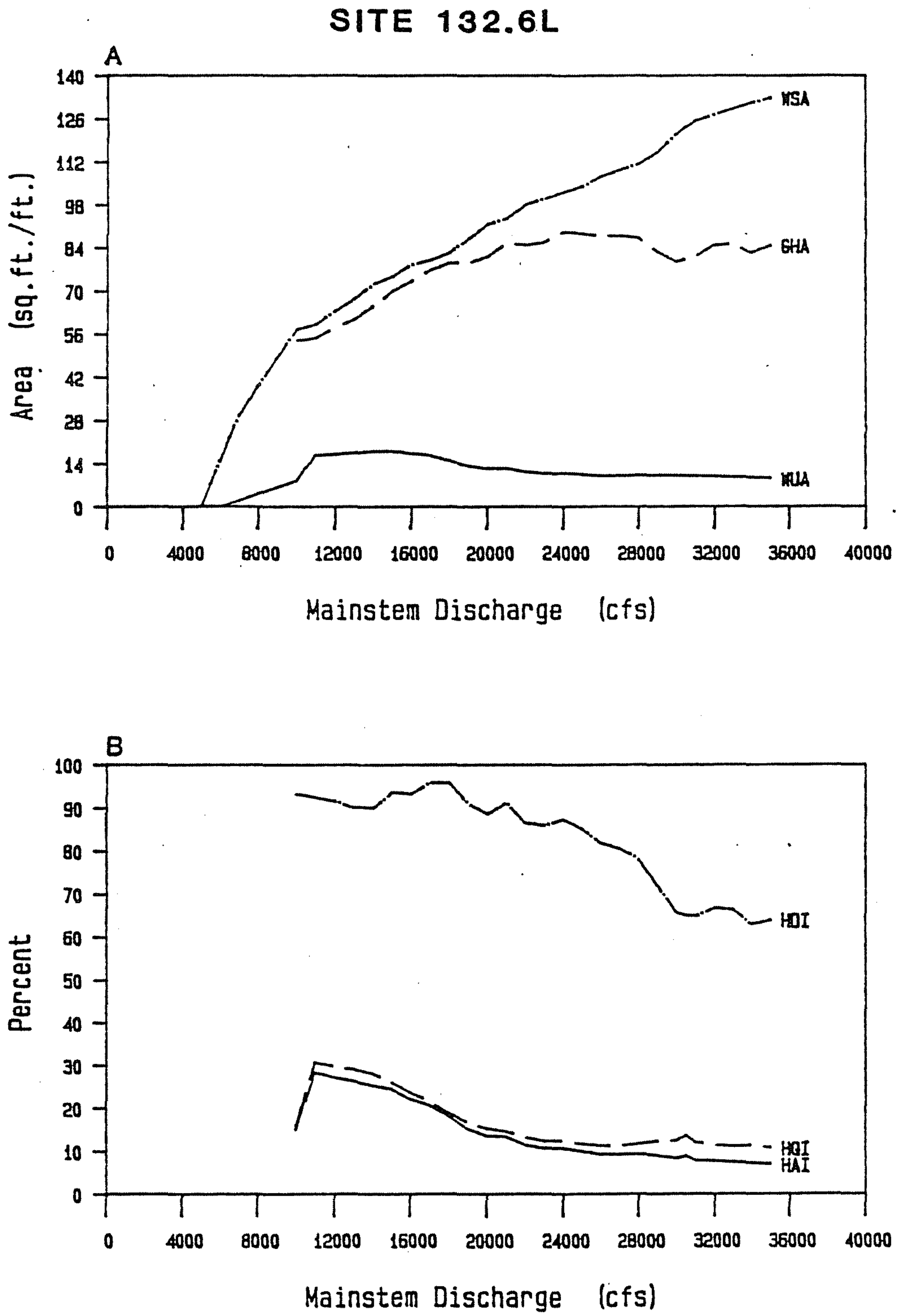
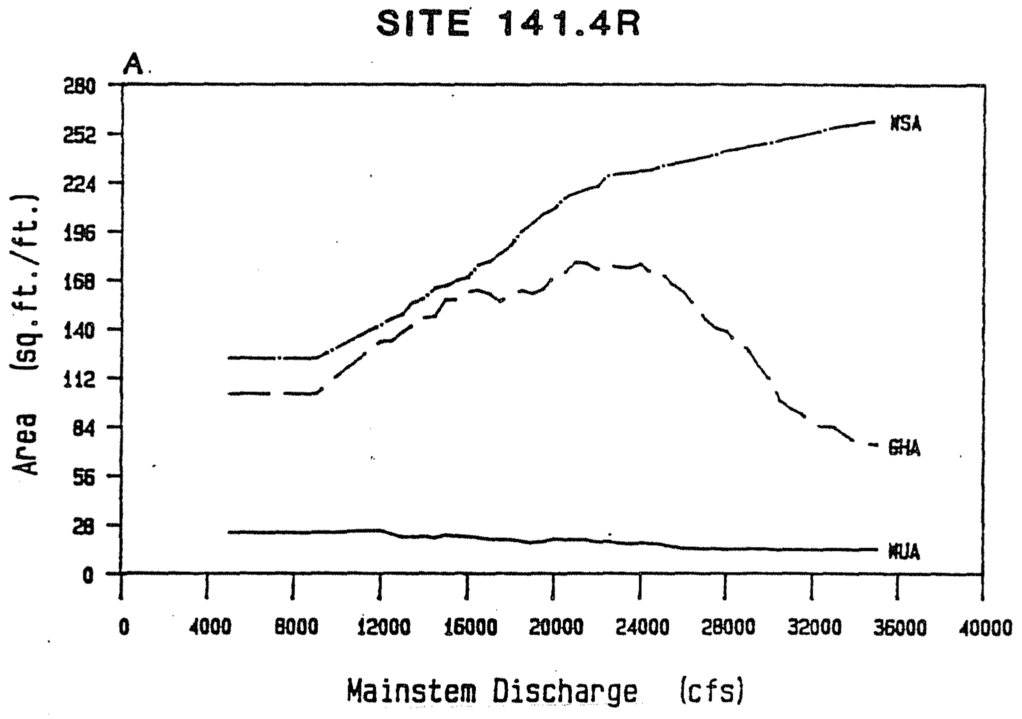


Figure 32. Surface area and chinook rearing habitat index response curves for modeling site 132.6L.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.



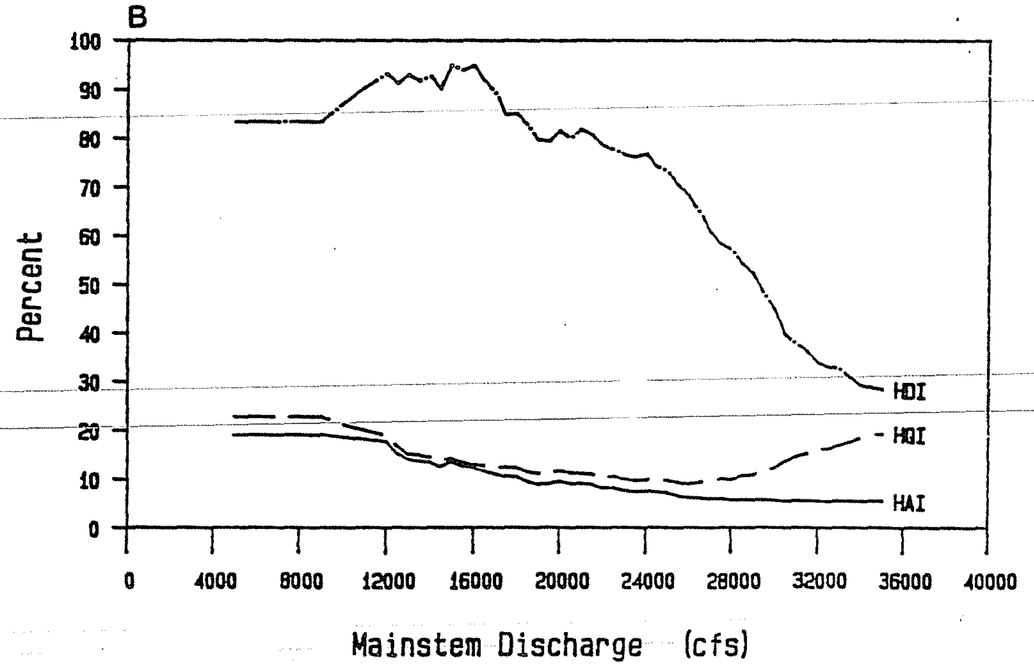


Figure 33. Surface area and chinook rearing habitat index response curves for modeling site 141.4R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

wetted surface area to changes in mainstem discharge following breaching. This response is paralleled by changes in gross habitat area until moderately high flows are attained, when the proportion of wetted surface area possessing usable rearing habitat falls off. Peak HDI values for the modeling sites typically range from 95 to 97 percent. These maxima usually occur at much higher flows than those associated with peak WUA values. Therefore, the quality of usable rearing habitat, as measured by the HQI index, tends to decline at higher flows; i.e., a greater proportion of the total WUA is concentrated in a smaller area within the modeling sites. This decline is caused by shifts in velocities in the majority of cells toward the suboptimal end of the velocity suitability curve.

Of the 18 specific areas classified within Group III, 17 are represented by sites 101.2R, 128.8R, and 132.6L. Site 141.4R is considered atypical due to its larger size and discharge under non-breached conditions. Therefore, this model site only represents that specific area. Site 101.2R was used to develop specific area HAI functions for 10 specific areas with relatively broad shallow channels with mild gradients. Top widths generally exceeded 100 feet and streambeds consisted of large gravels and cobbles. Site 128.8R represents three specific areas possessing long sinuous channels less than 100 feet wide. Site 132.6L was used to represent four specific areas with relatively low velocities and sandy to large gravel substrates.

Figures 34 to 37 illustrate HAI functions derived from modeling site habitat data and underscore the singularity of the habitat response to flow at Site 141.4R. HAI curves developed for the remainder of the other modeling sites in this representative group exhibit a strong unimodal peak in HAI following breaching, whereas the HAI response to increasing discharge at Site 141.4R is to progressively decrease for reasons stated above.

A comparison of the magnitudes and shapes of the WSA, WUA and HAI curves derived for Site 132.6L (Figure 32) suggests that the RJHAB and PHABSIM modeling approaches yield similar results. The RJHAB method appears well-suited to smaller channels where cross-sectional profiles (i.e., velocity and depth distributions) and cover characteristics are relatively homogeneous. We recommend limiting the use of RJHAB modeling techniques primarily to baseline evaluations of fish habitat in lotic subenvironments meeting these constraints.

The aggregate WUA function derived from individual rearing habitat response curves for specific areas in Representative Group III exhibits a pronounced peak in the vicinity of 15,500 cfs (Figure 38). The amount of juvenile chinook habitat provided by this flow (1.3 million square feet) represents an increase of 350 percent over WUA values forecast for 9,000 cfs (0.3 million square feet). This marked increase in usable habitat is directly attributable to the recruitment of side channel habitat within the 9,000 to 12,500 cfs flow range; 12 of the 18 specific areas which comprise Group III breach in this range (refer to Table 4 for site-specific breaching flows). After peaking at 15,000 cfs, juvenile chinook habitat

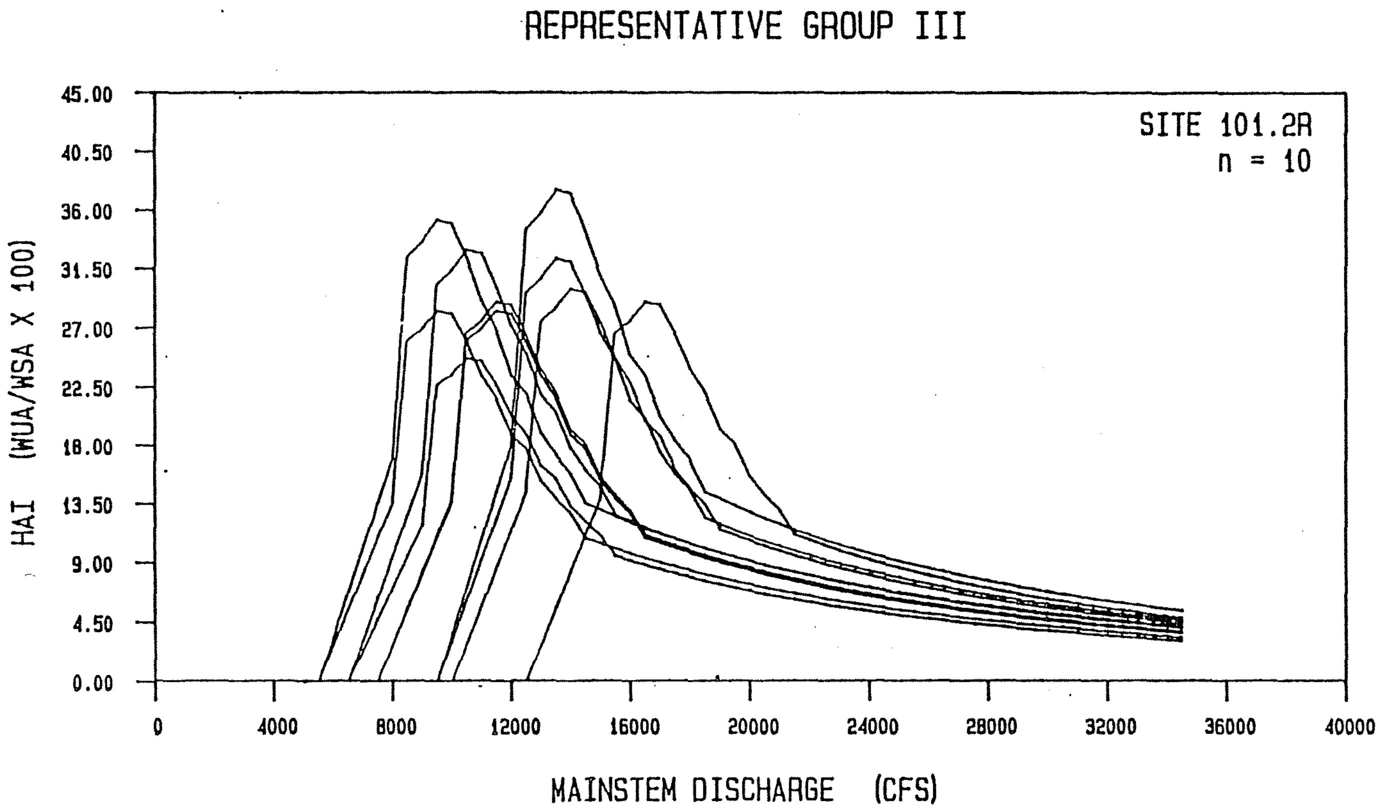


Figure 34. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 101.2R of Representative Group III.

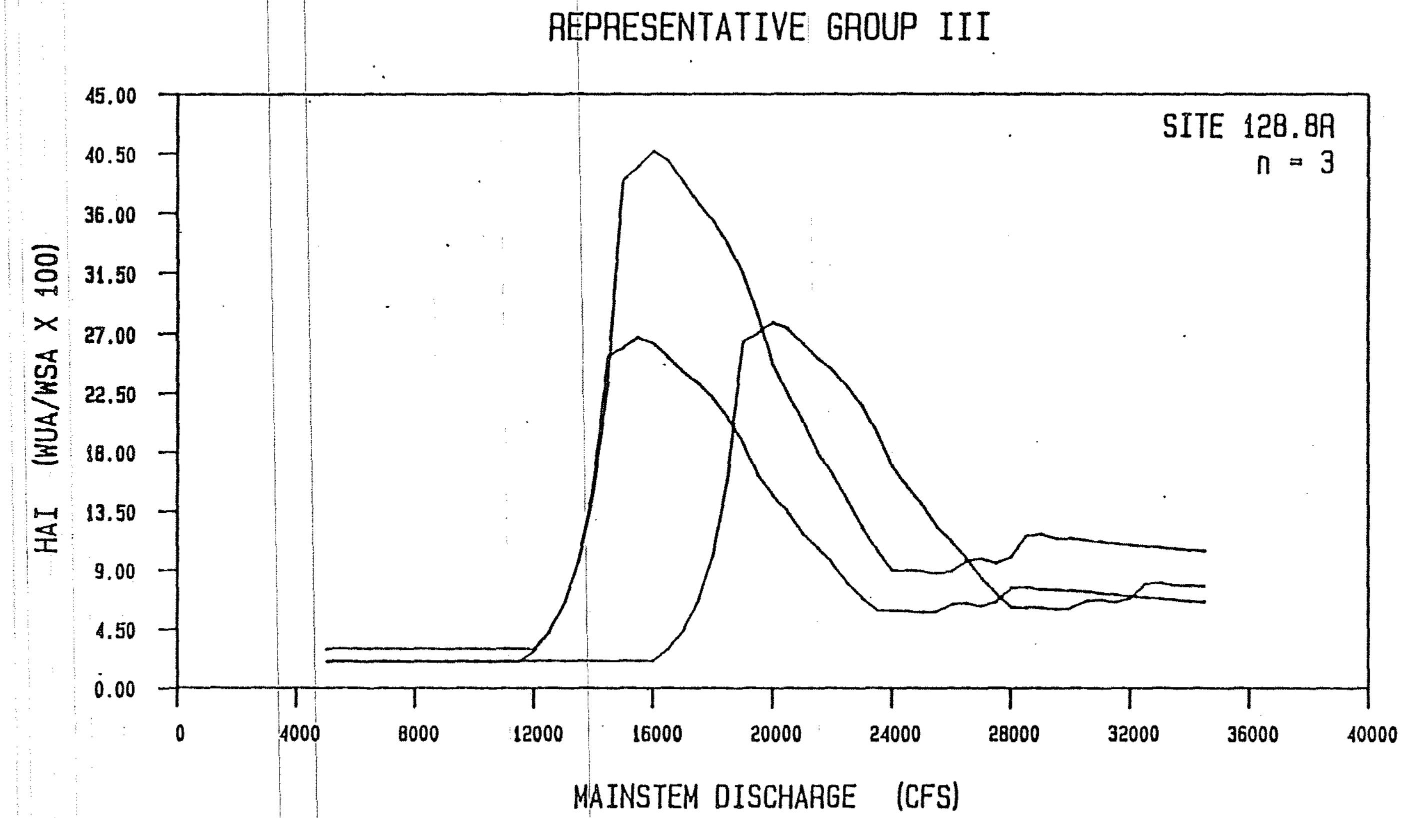


Figure 35. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 128.8R of Representative Group III.

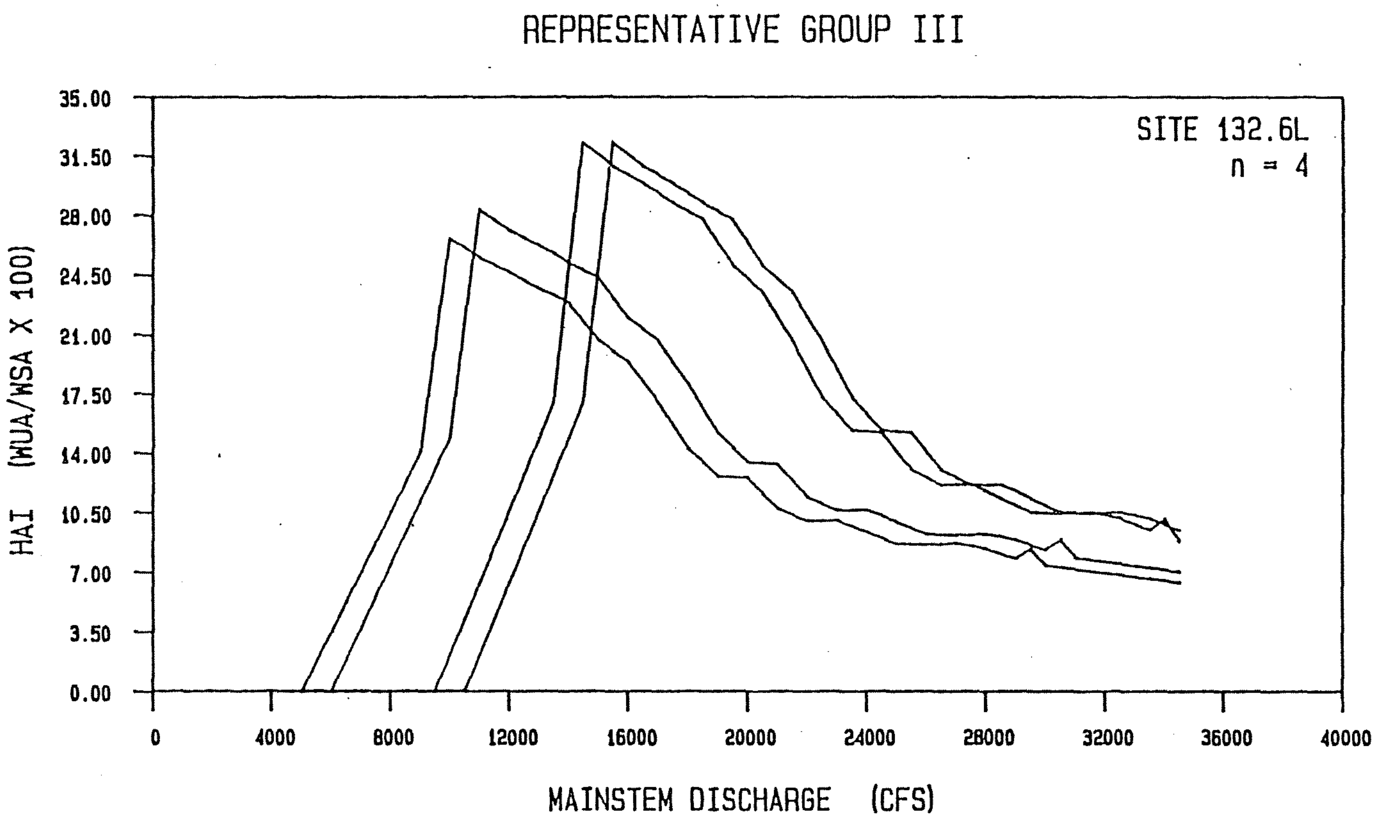


Figure 36. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 132.6L of Representative Group III.

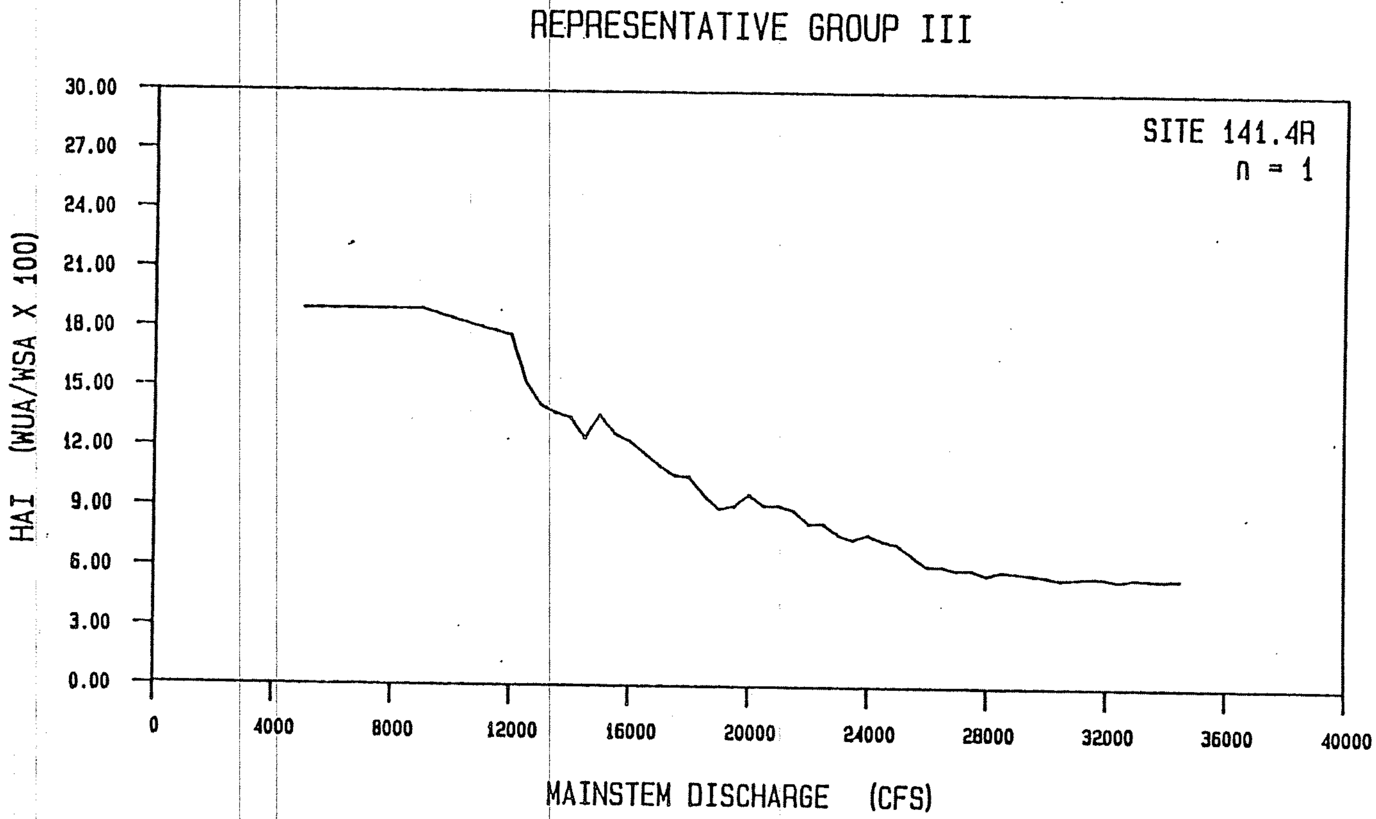


Figure 37. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 141.4R of Representative Group III.

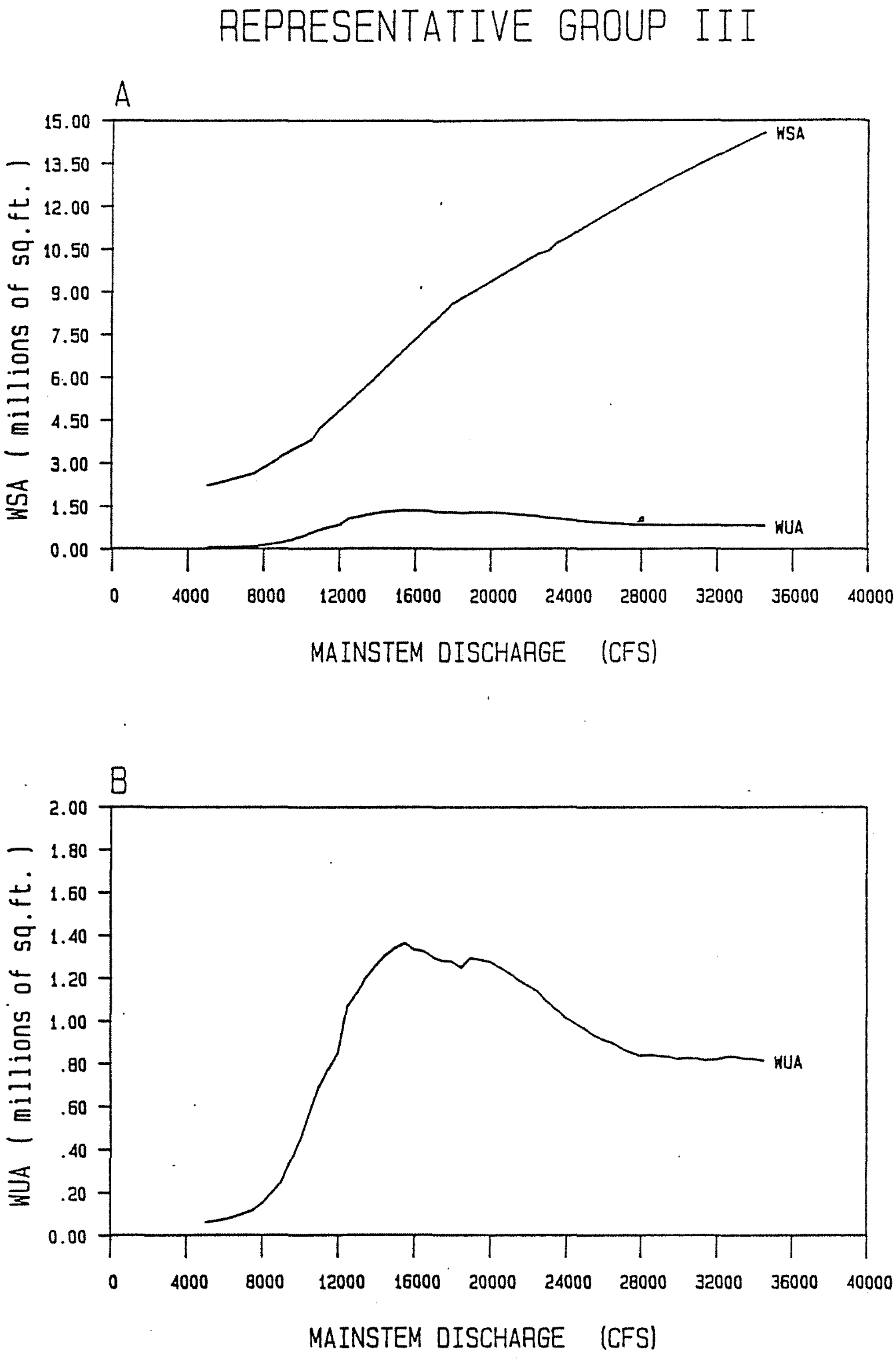


Figure 38. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group III of the middle Susitna River.

gradually declines to 0.9 million square feet at 26,000 cfs and remains at this level through 35,000 cfs. Decreases in HAI values which occur within this range are offset by gains in total wetted surface area, resulting in relatively stable rearing habitat potential at higher flows.

3.4 Representative Group IV

Aaserude et al. (1985) delineates the 22 specific areas within this group on the basis of their low breaching discharges and intermediate to high mean reach velocities. The side channels which comprise these specific areas possess lower mean reach velocities than adjacent mainstem channels. Substrates range primarily from cobble to boulder.

Four modeling sites represent Group IV: 112.6L, 131.7L, 134.9R and 136.0L. Of these, Site 112.6L is the largest and Site 136.0L the smallest of the sites investigated. In spite of their disparity in size, the modeling sites are characterized by similar surface area and habitat index response curves. Compare the aerial photographs of the modeling sites presented in Plates A-15 through A-22 (Appendix A) with the wetted surface curves in Figures 39 through 42. As is typical of most side channels of the middle river, wetted surface area responds to changes in streamflow more rapidly at lower than at higher flows; the rate of change in WSA per 1000 cfs increment in mainstem discharge declines perceptibly at flows exceeding 16,000 cfs. This response pattern is accentuated at sites with wide, shallow channel cross sections such as Site 131.7L (Plates A-17 and A-18, Figure 40).

In terms of juvenile chinook habitat potential, the most remarkable feature of Group IV modeling sites is the comparatively large amounts of WUA they provide at low to moderate mainstem flows. A comparison of the WUA values and, more appropriately, HAI functions (Figures 43 through 46) with estimates obtained for modeling sites from other Representative Groups suggests

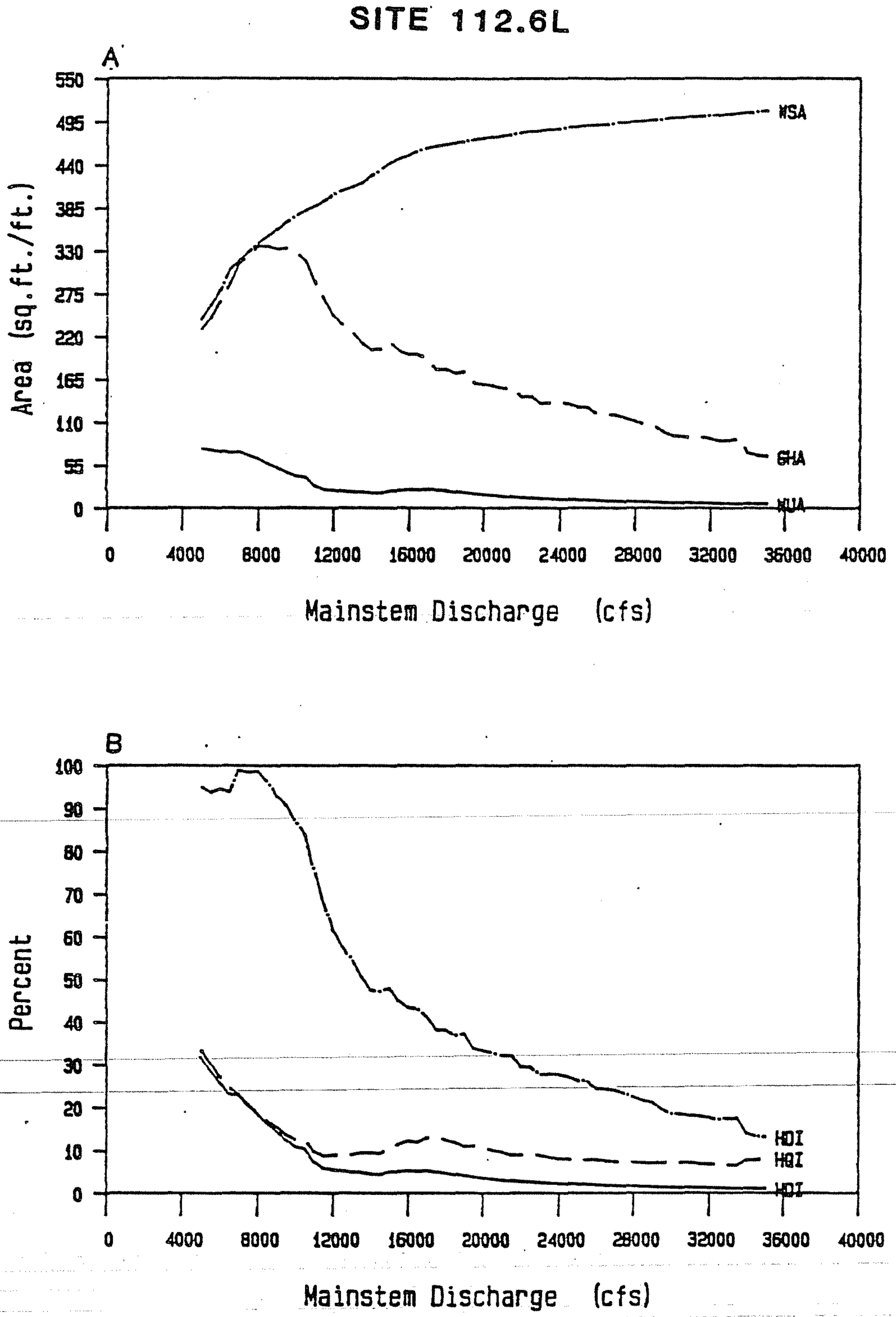


Figure 39. Surface area and chinook rearing habitat index response curves for modeling site 112.6L.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

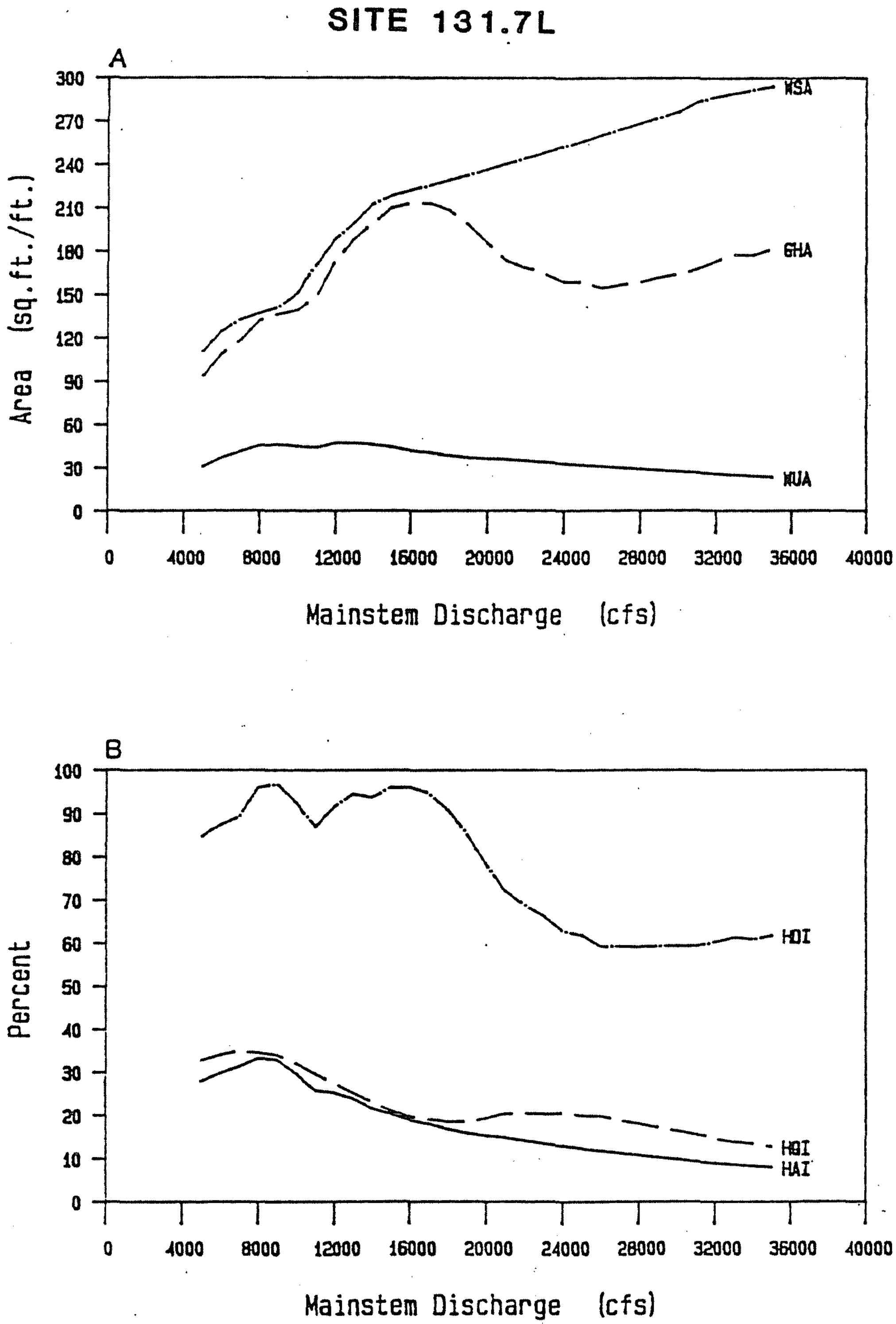


Figure 40. Surface area and chinook rearing habitat index response curves for modeling site 131.7L.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

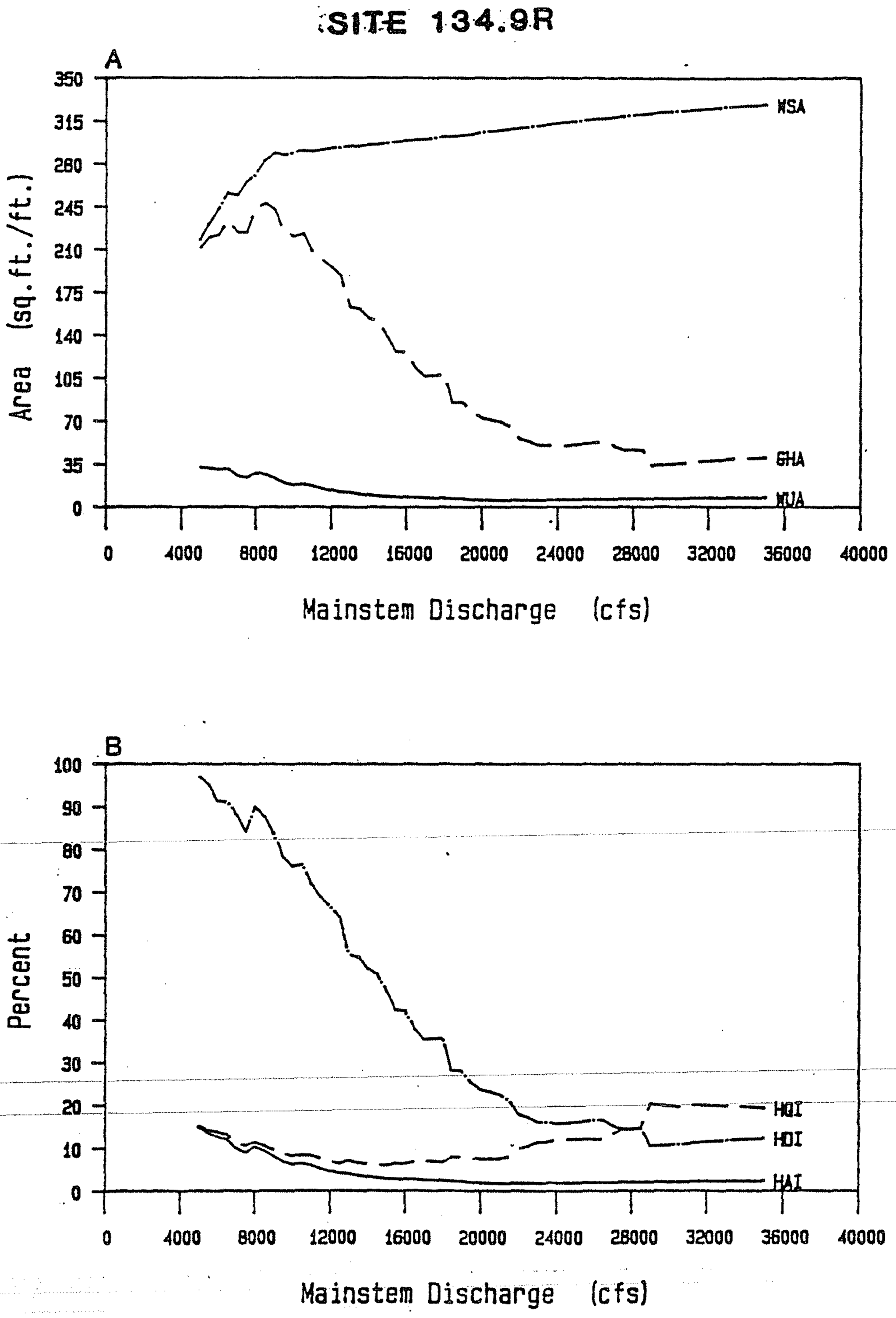


Figure 41. Surface area and chinook rearing habitat index response curves for modeling site 134.9R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

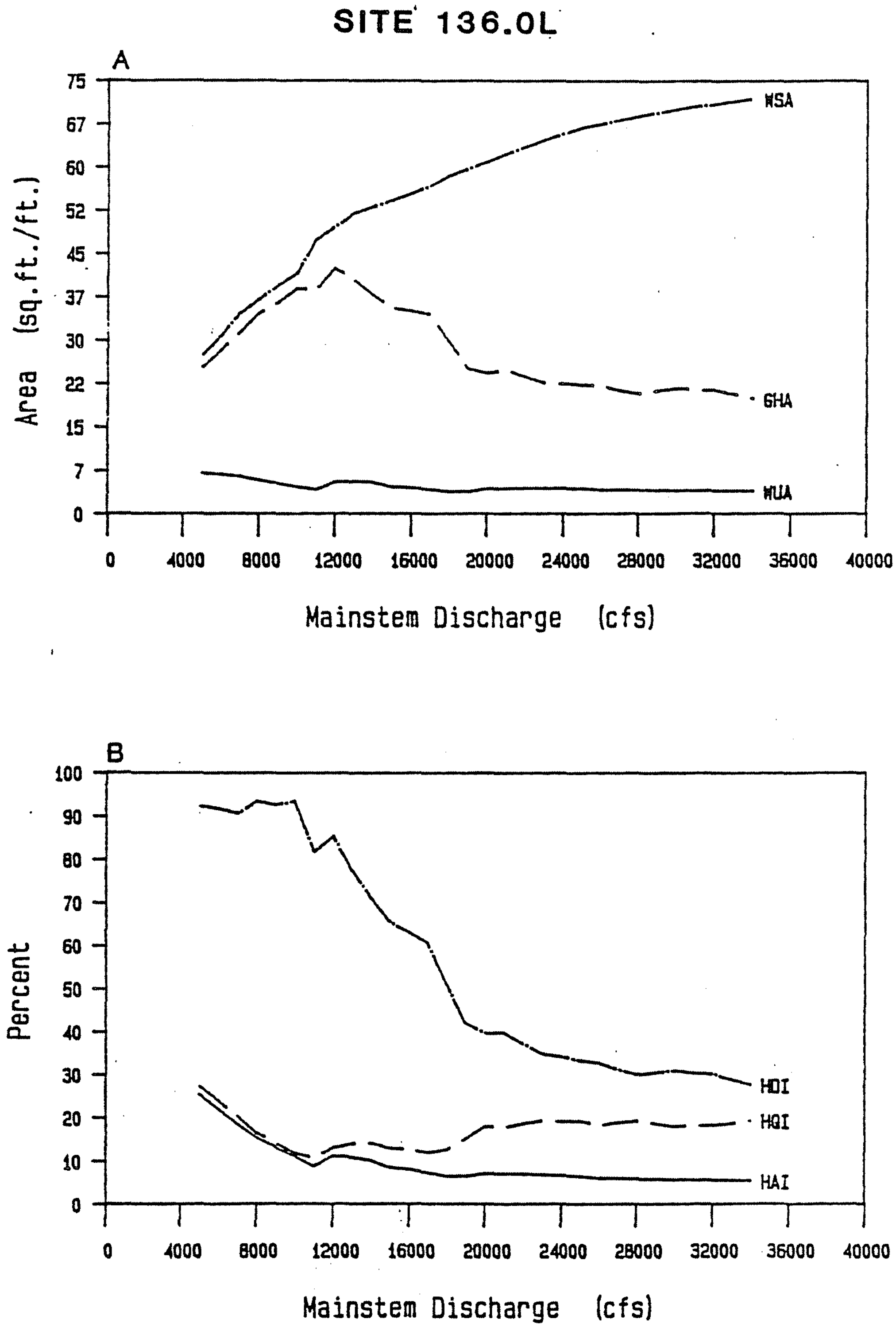


Figure 42. Surface area and chinook rearing habitat index response curves for modeling site 136.0L.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

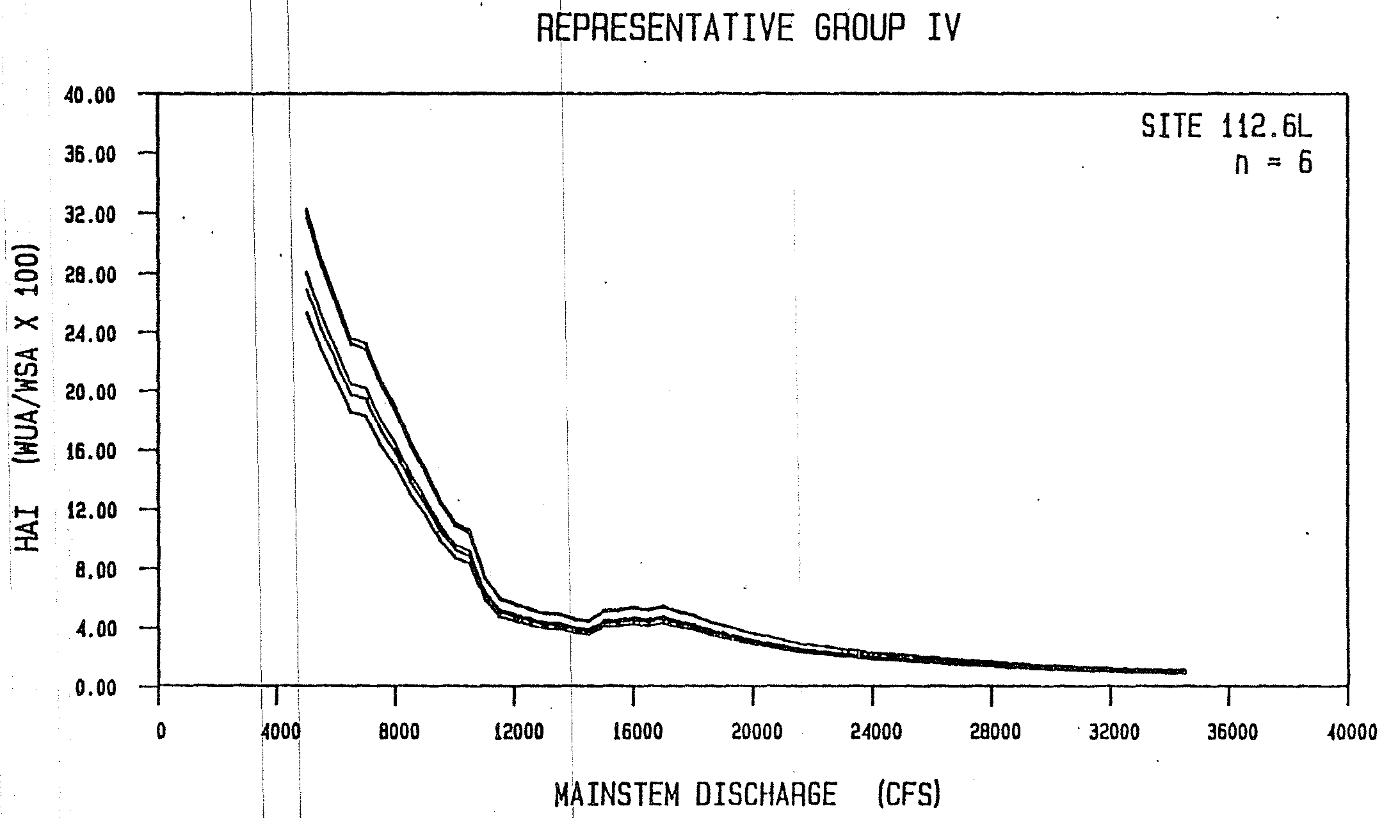


Figure 43. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 112.6L of Representative Group IV.

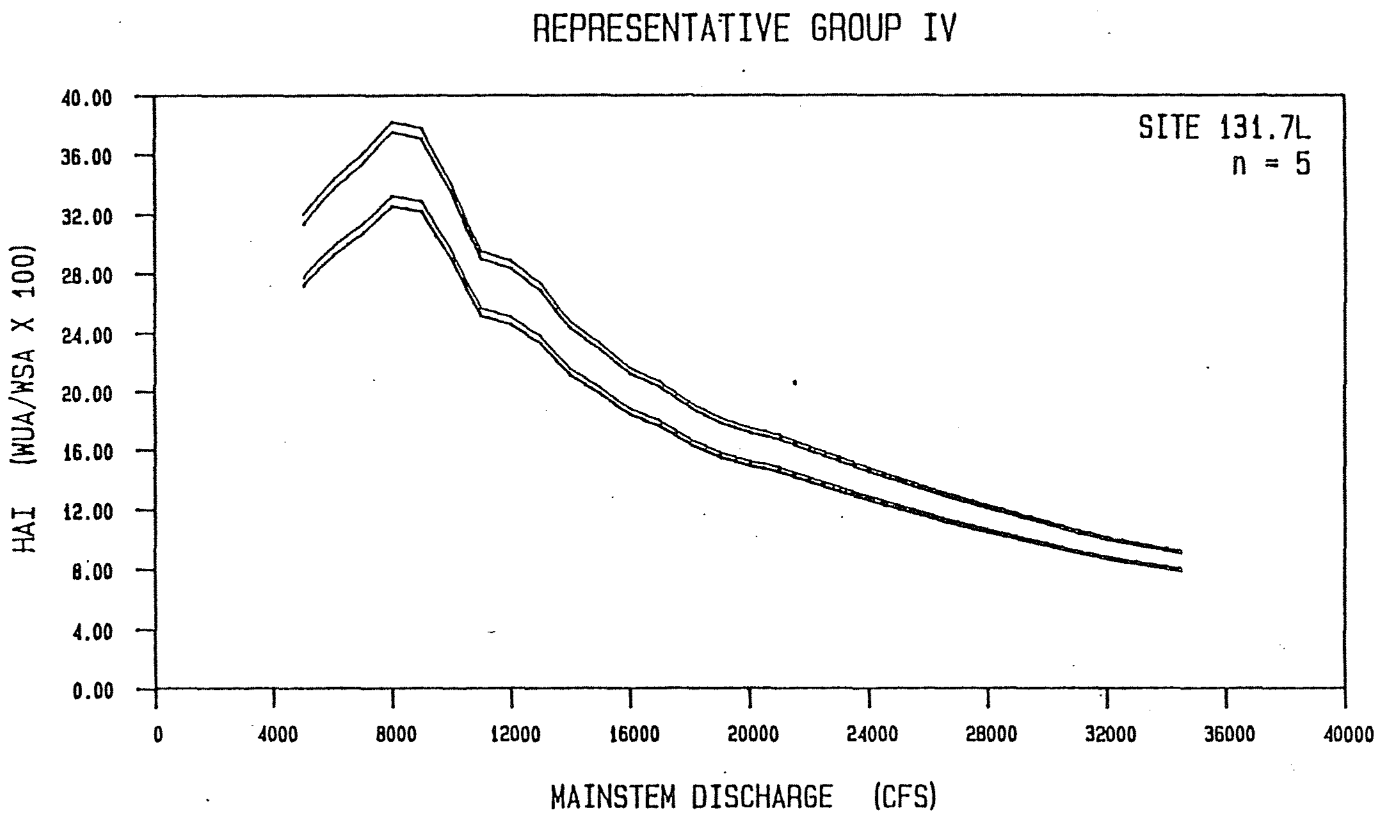


Figure 44. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 131.7L of Representative Group IV.

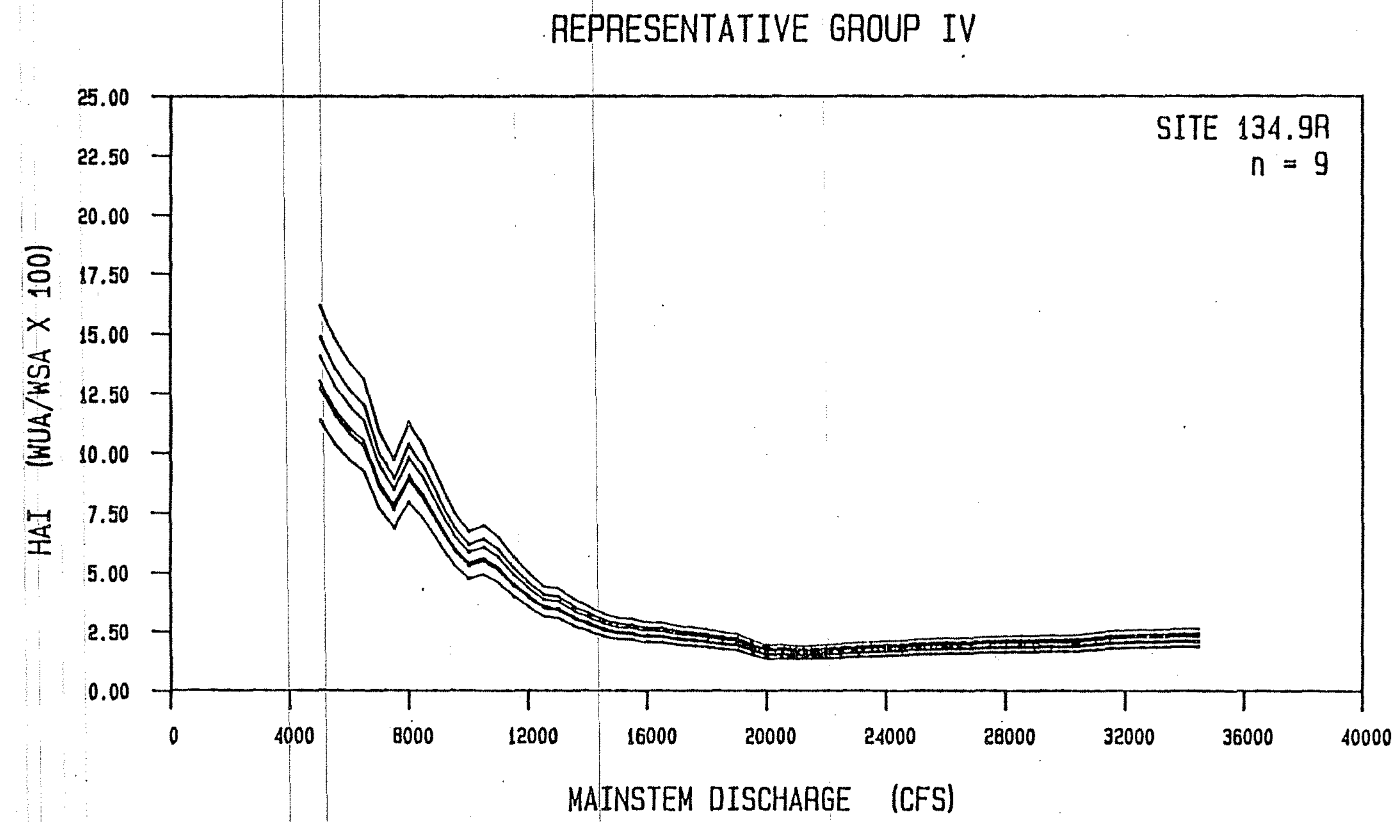


Figure 45. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 134.9R of Representative Group IV.

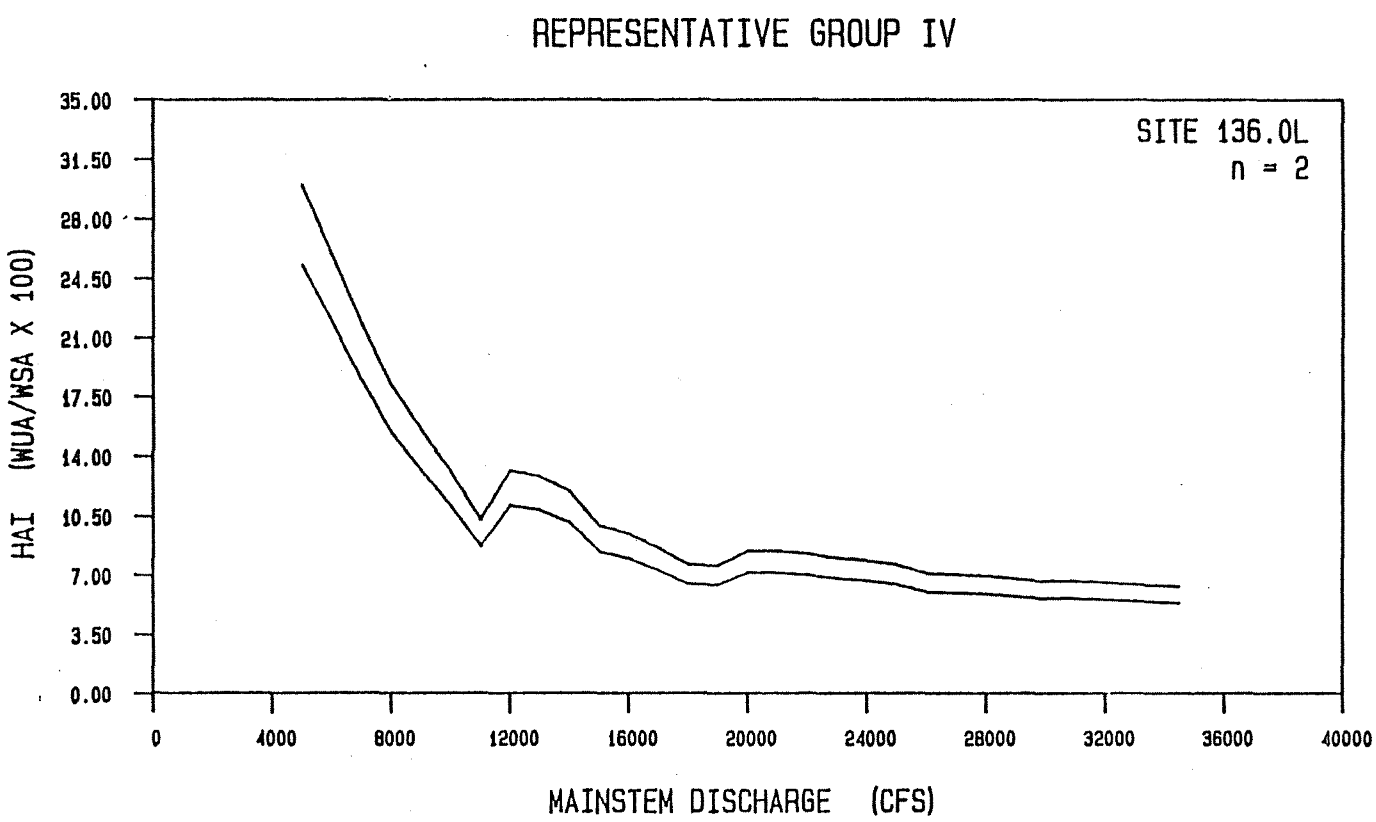


Figure 46. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 136.0L of Representative Group IV.

that Group IV specific areas provide a significant amount of rearing habitat within the middle river. This conclusion is supported by ADF&G sampling data indicating high utilization of these sites by juvenile chinook during the summer months (Dugan et al. 1984).

At all modeling sites except Site 131.7L, usable rearing habitat is greatest at the lowest evaluated flow (5,000 cfs), and after a gradual decline either continues to taper off or remains constant for flows above 16,000 cfs. Turbidity levels are high at all discharges and most areas of the sites possess suitable depths for rearing fish. Changes in WUA and HAI are therefore directly proportional to the increase or decrease in the availability of suitable velocities. As an example, Williams (1985) demonstrated that the total area within Site 112.6L possessing suitable rearing velocities is five times greater at 13,500 cfs than at 33,000 cfs. GHA and HDI curves reveal that the amount of gross habitat at the modeling sites is nearly equal to their total wetted surface area for flows ranging from 8,500 (Sites 112.6L and 134.9R) to 17,000 cfs (Site 131.7L). However, mean reach velocities measured at specific areas within this group averaged 3.3 fps at 10,000 cfs (Aaserude et al. 1985), well above the range of velocities tolerated by juvenile chinook salmon, suggesting that for the group as a whole, the amount and proportion of gross rearing habitat is probably greatest when flows are less than 10,000 cfs. Regardless of discharge levels, the quality and quantity of usable rearing habitat is greatest along the margins of the modeling sites due to the reduction of velocities in these areas.

The specific areas assigned to Representative Group IV have been divided among the four study sites on the basis of breaching flow, channel morphology, size and hydraulic characteristics. Five of the specific areas are grouped with Site 131.7L. All of these sites breach just below 5,000 cfs, and possess large amounts of shallow riffle habitat in comparison to their total wetted surface area. The 9 largest specific areas are grouped with Site 134.9R which are all characterized by deep, swift flows. These sites possess very little pool or riffle habitat. Site 112.6L represents six intermediate sized specific areas which, in general, contain a larger amount of submerged gravel bars and are not as deep or swift as those represented by 134.9R. Site 136.0L represents two small crescent-shaped specific areas with distinct riffle/pool patterns at low flows and high velocity runs at high flows.

The aggregate WSA response for the group is shown in Figure 47. As discussed above, the proportion of the wetted surface area providing usable chinook habitat in Group IV sites, particularly in the lower flow range, is high in comparison to specific areas from other representative groups. This characteristic, when coupled with the fairly large surface areas associated with Group IV specific areas, results in exceptionally large rearing WUA forecasts for Representative Group IV as a whole (Figure 47). The significance of this fact will be discussed in Section 4.0 following presentation of aggregate WUA curves for all representative groups.

Juvenile chinook potential in Group IV sites is highest at mainstem discharges of 10,000 cfs and less. Peak rearing WUA values (approximately 4.1 million square feet) are attained at 8 - 8,500 cfs. This trend is related to the low breaching flows characteristic of specific areas within

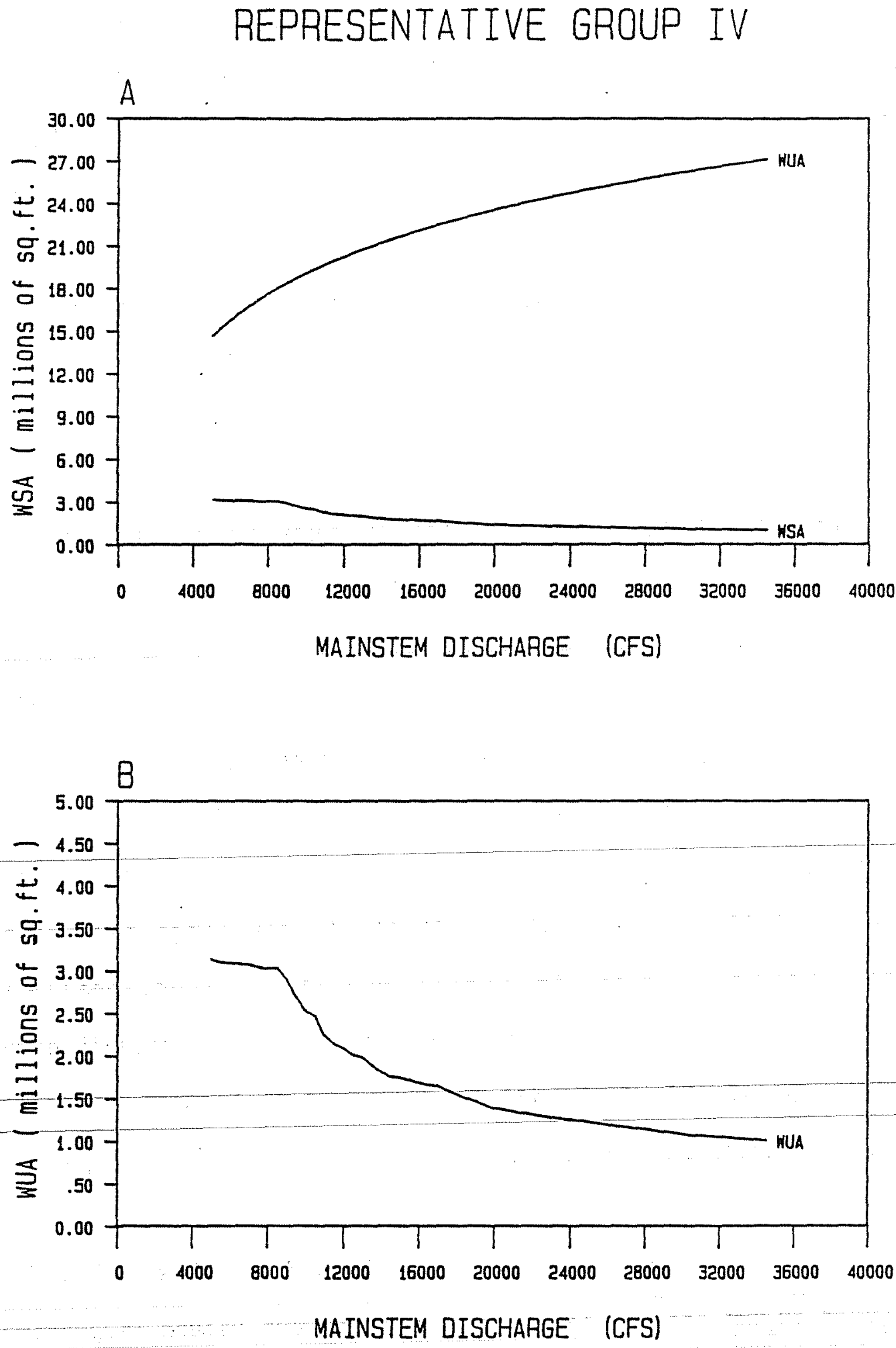


Figure 47. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group IV of the middle Susitna River.

this group. The composite suitability of velocity and depth within these sites decreases rapidly as flows increase; WUA declines concomitantly, reaching a low of 1.6 million square feet at 35,000 cfs.

3.5 Representative Group V

This group, comprised of nine specific areas, includes shoal areas which transform into clear water side sloughs at lower mainstem discharges. A shoal is similar to a riffle in that both are topographic high points in the longitudinal bed profile of the river and are therefore zones of accretion. Shoals, however, are easily distinguished from riffles by their morphological features and the hydraulic processes responsible for their existence. As a general rule, shoals form immediately downstream of point gravel bars located at bends of the river or at the lower end of established islands. Due to reduced velocity in these areas, shoals are characterized by sand and gravels deposited on the falling stages of floods and at low flow. Larger substrates are possible if the shoal has stabilized and begun to take on gravel bar characteristics.

Flow across shoal areas may be transverse to mainstem flow and velocities tend to be slower-than-average due to the drag effect exerted by the streambed. As water levels drop, flow is concentrated in a few small channels which feed a larger single channel on the inside of the shoal. When feeder channels dewater at lower discharges there is usually sufficient mainstem seepage through the head and sides of the channel berm to maintain a small amount of clear water slough habitat at the site.

The general morphologic features described above may be observed in aerial photographs (Plate A-23) of Site 141.6R--the only modeling site found in Representative Group V. Site 141.6R begins to convey mainstem water at 18,000 cfs but is not controlled by mainstem discharge until 22,000 cfs.

Site flows under non-breached conditions average 5 cfs. Wetted surface area and juvenile chinook weighted usable area at Site 141.6R are assumed to remain constant in the non-breached state; the ratio of WUA to WSA, expressed as a percentage, is 13.4 percent (Figure 48). Gross habitat area is estimated to comprise 83 percent of the total surface area when clear water conditions prevail.

As is common with most specific areas of the middle Susitna River, the introduction of turbid mainstem water has an immediate effect on the usability of Site 141.6R by juvenile chinook. Other than turbidity, the most significant factor contributing to the sharp rise in usable habitat is the large increase in wetted surface area. Most of the recruited habitat is shallow and slow velocity areas that may be used to some extent by young chinook. Figure 48 indicates that over 90 percent of the total surface area has at least some rearing habitat value at discharges between 23,000 and 32,000 cfs. Maximum WUA, HAI, and HQI values occur at the lower end of this flow range; each of these habitat indices peak in the range of 24,000 and 25,500 cfs. Habitat index curves are drawn out at their upper ends by the gradual loss of suitable velocity areas. Eventually, flow over the shoals is fast enough to significantly reduce the availability and quality of chinook rearing habitat at the site.

There are nine specific areas within Representative Group V. The areas breach over a wide range of mainstem discharges (<5,000 to 23,000 cfs) and exhibit large variations in structural habitat quality. The HAI function obtained for Site 141.6R, which breaches at 22,000 cfs and has a comparatively high SHI value, was used as a template for deriving HAI curves for all specific areas within the group (Figure 49 and Appendix B).

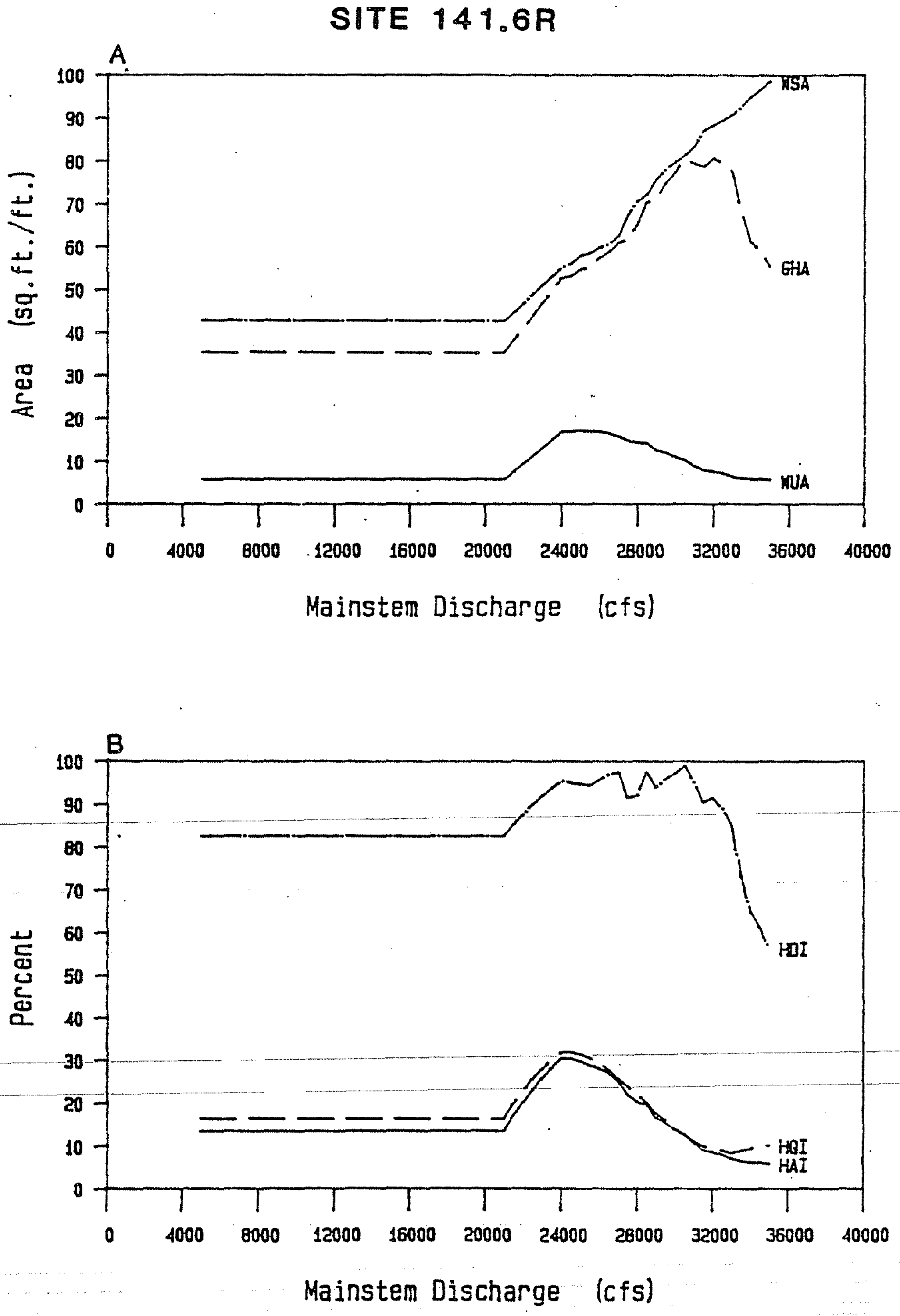


Figure 48. Surface area and chinook rearing habitat index response curves for modeling site 141.6R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

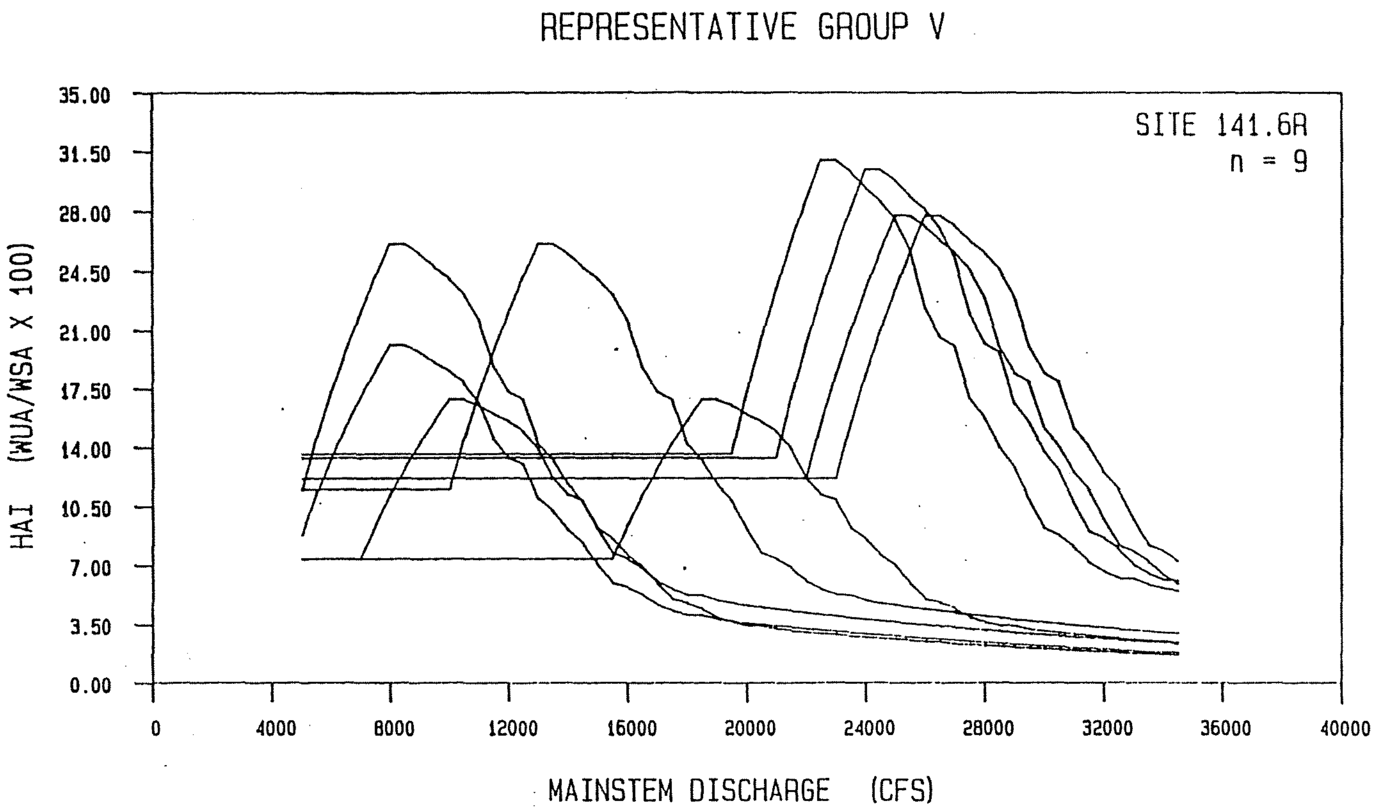


Figure 49. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 141.6R of Representative Group V.

There does not appear to be any correlation between the magnitude of breaching flow and structural habitat quality of peak habitat availability for these specific areas.

Collectively, the specific areas which make up Representative Group V do not provide significant amounts of juvenile chinook habitat, even under ideal flow conditions. The low aggregate WUA values portrayed in Figure 50 result from 1) the small number of specific areas assigned to Group V, and 2) the small amount of total wetted surface area associated with these sites. Overall, less than 0.4 million square feet of rearing WUA is provided by Representative Group V by streamflows within the range of 5,000 to 35,000 cfs. WUA values peak at approximately 26,000 cfs when joint surface area and HAI values are maximized (Figure 50).

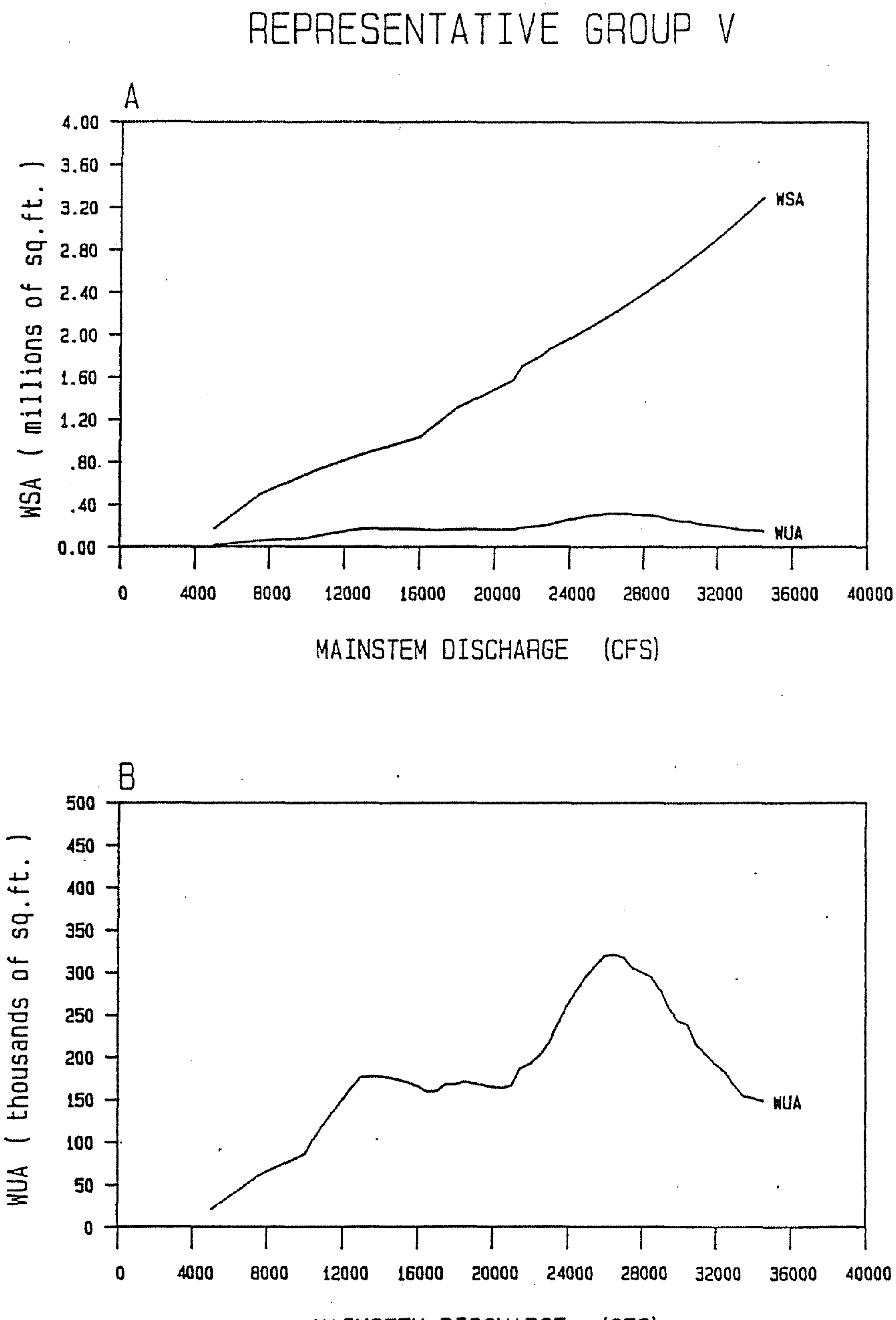


Figure 50. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group V of the middle Susitna River.

3.6 Representative Group VI

The 13 specific areas within this group are products of the channel braiding processes active in the high gradient middle segment of the Susitna River. Included are overflow channels which parallel the adjacent mainstem. Typically separated from the mainstem by a sparsely vegetated bar, these channels may or may not possess upwelling. These specific areas may represent more advanced stages of shoal development in which their gravel bars have stabilized due to the growth of vegetation and further high-stage sedimentation, and mainstem overflow is usually delivered by a single dominant feeder channel. Incision of the lateral channels has gradually occurred over time, leading to lower head berm elevations and coarser substrates. Side channel gradients are usually greater than adjacent mainstem channels as a result of hydraulic processes which adjust channel morphology to maintain transport continuity. The spectrum of shoal-to-side channel developmental stages represented by the specific areas of Group VI is indicated by the wide range of breaching discharges and structural habitat indices recorded by Aaserude et al. (1985).

Included in Representative Group VI are modeling sites 133.8L and 136.3R, which breach at 17,500 and 13,000 cfs, respectively, but remain watered at non-breached mainstem discharges. Plates A-24 through A-26 (Appendix A) give some idea of the morphologic features and wetted surface area response to flow of Group VI modeling sites. A large backwater occurs at their confluence with the mainstem channel. The gravel bar at Site 136.3R appears to be more stable than the bar at Site 133.8L, judging from differences in the type and amount of vegetation cover. Both modeling sites are relatively flat in cross section except for deep narrow channels running along banks opposite the gravel bars. These banks are steep-walled whereas banks formed by the gravel bars are gently sloping. These features are largely responsible for the type of response of juvenile chinook habitat to changes in mainstem discharge observed at the two Group VI modeling sites.

Habitat index and surface area response functions derived for Site 133.8L and 136.3R are conspicuously similar, particularly if allowance is made for differences in mean channel width (Figures 51 and 52). In both cases, the anticipated increase in WUA following breaching occurs, but after attaining moderate levels the amount of rearing habitat remains fairly constant at higher mainstem discharges. This pattern, which is uncharacteristic of more developed side channels (compare, for example, the WUA response curves for sites from Representative Group VI with results for Group III and IV modeling sites), is also apparent in the relationship between gross habitat area and river discharge. The constancy of WUA and GHA values at moderate-to-high mainstem flows results in generally stable habitat quality at the sites, implying that areas suitable for chinook rearing are recruited and lost at comparable rates. Regardless of flow levels, most juvenile chinook habitat at Sites 133.8L and 136.3R is associated with the gravel bar shoreline and backwater area of both sites.

HAI functions developed for the two modeling sites exhibit the expected rise and fall in juvenile chinook habitat availability which attends breaching and further increases in discharge. However, because WUA values remain constant at higher flows, the slope of the descending limb of the HAI curves is not as great as observed for other representative groups. Based on similaries in channel morphology and habitat reconnaissance data

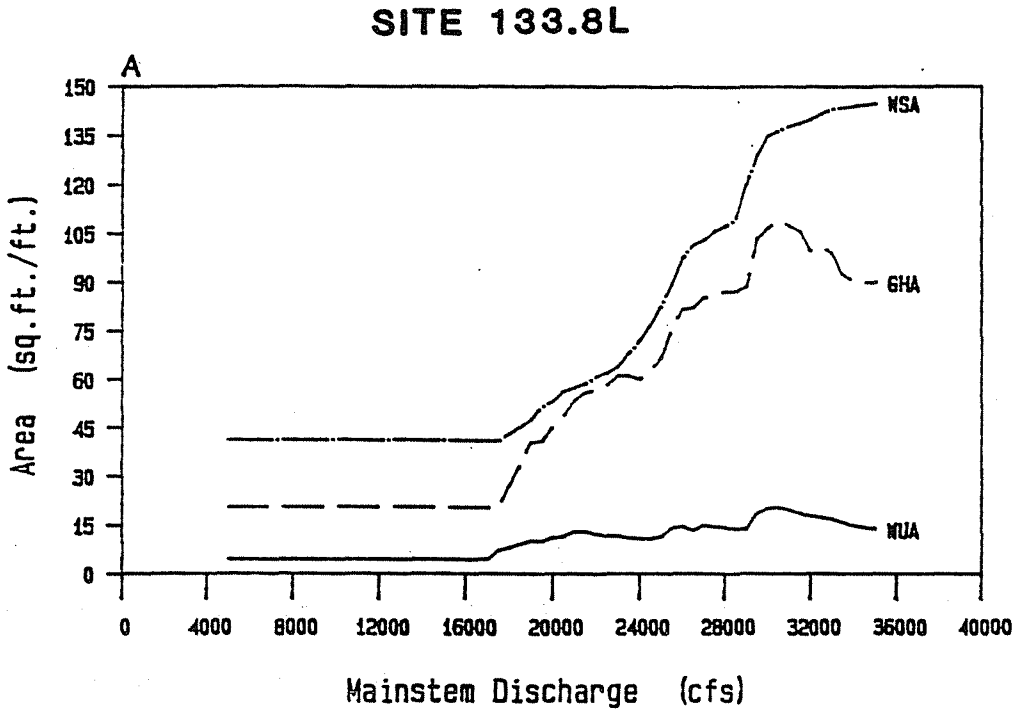


Figure 51. Surface area and chinook rearing habitat index response curves for modeling site 133.8L.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

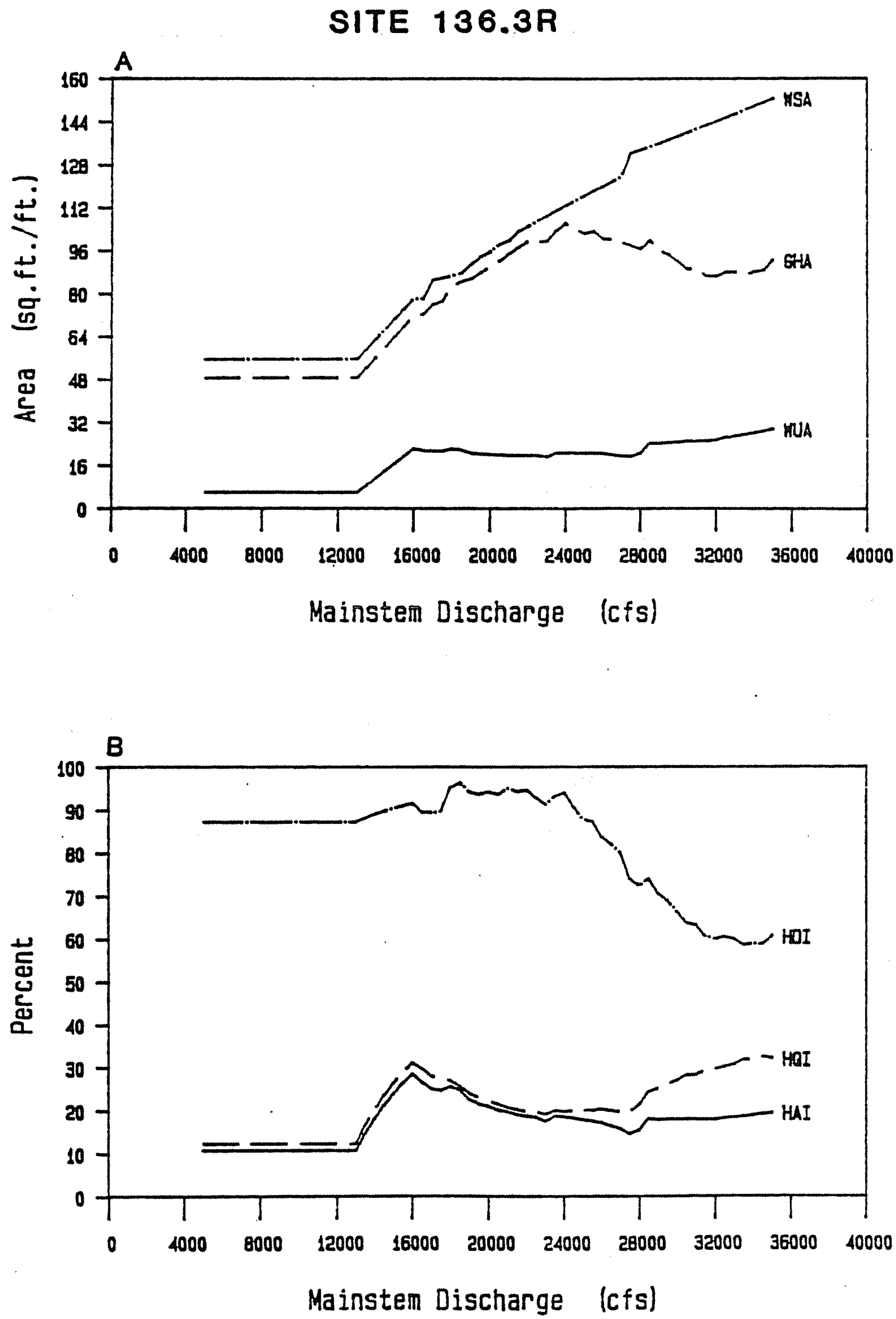


Figure 52. Surface area and chinook rearing habitat index response curves for modeling site 136.3R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

obtained at modeled and non-modeled specific areas in Group VI, 7 of the 13 specific areas are grouped with site 133.8L and 6 with site 136.3R. HAI functions derived from the modeling sites are presented for each subgroup in Figures 53 and 54 and Appendix B.

Due to their relatively high breaching flows and rapid wetted surface area response following breaching (Figure 55), specific areas within Representative Group VI provide considerably more juvenile chinook WUA at high as compared to low mainstem discharges. Figure 55 indicates the aggregate rearing WUA function derived as the sum of individual specific area habitat values for flows ranging from 5,000 to 35,000 cfs. Rearing habitat potential increases steadily as a function of flow throughout this range. The amount of juvenile chinook WUA forecast for 35,000 cfs (1.3 million square feet) represents over 30 times the amount of WUA forecast for 5,000 cfs (0.04 million square feet). The correlation between wetted surface area and aggregate rearing WUA values is more pronounced in Group VI than in other representative groups due to the relative constancy of HAI values across all flows.

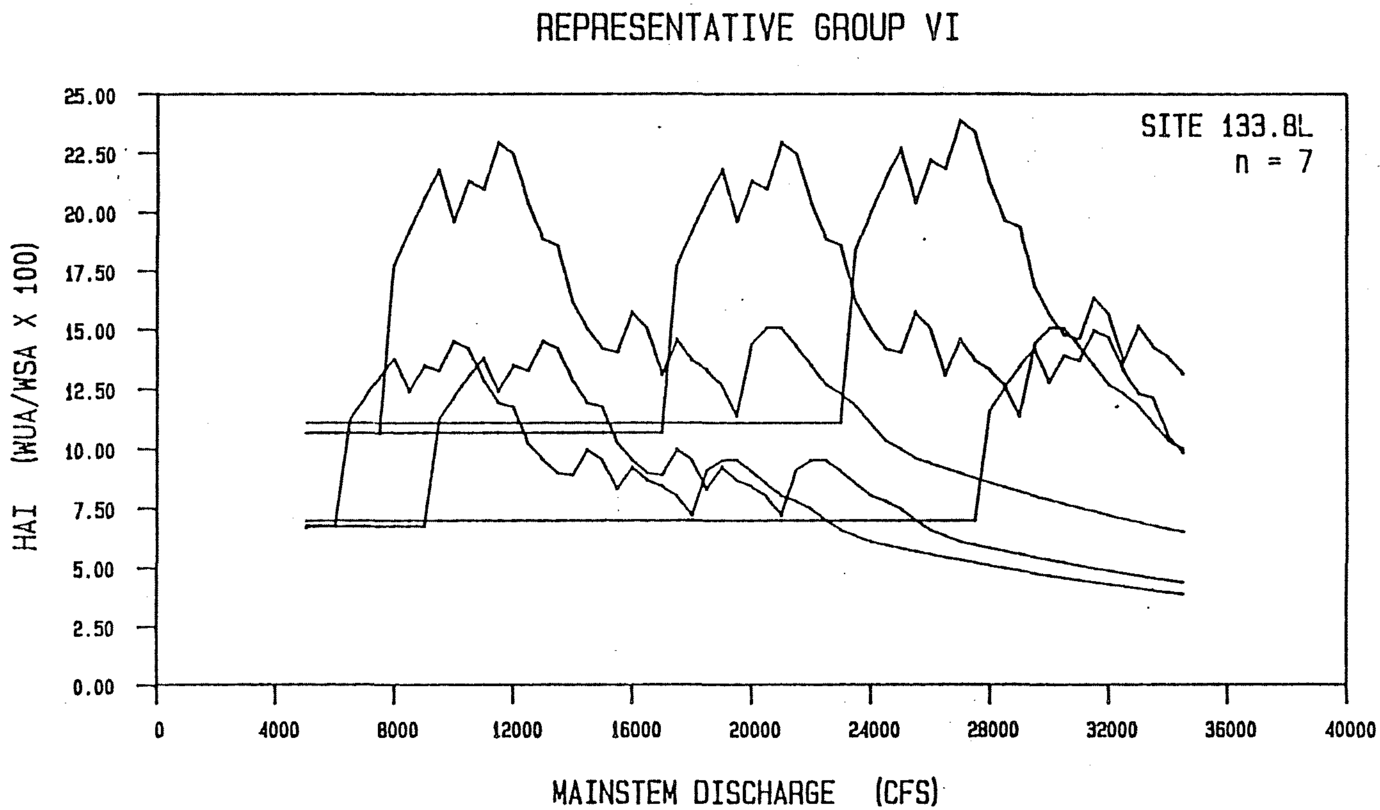


Figure 53. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 133.8L of Representative Group VI.

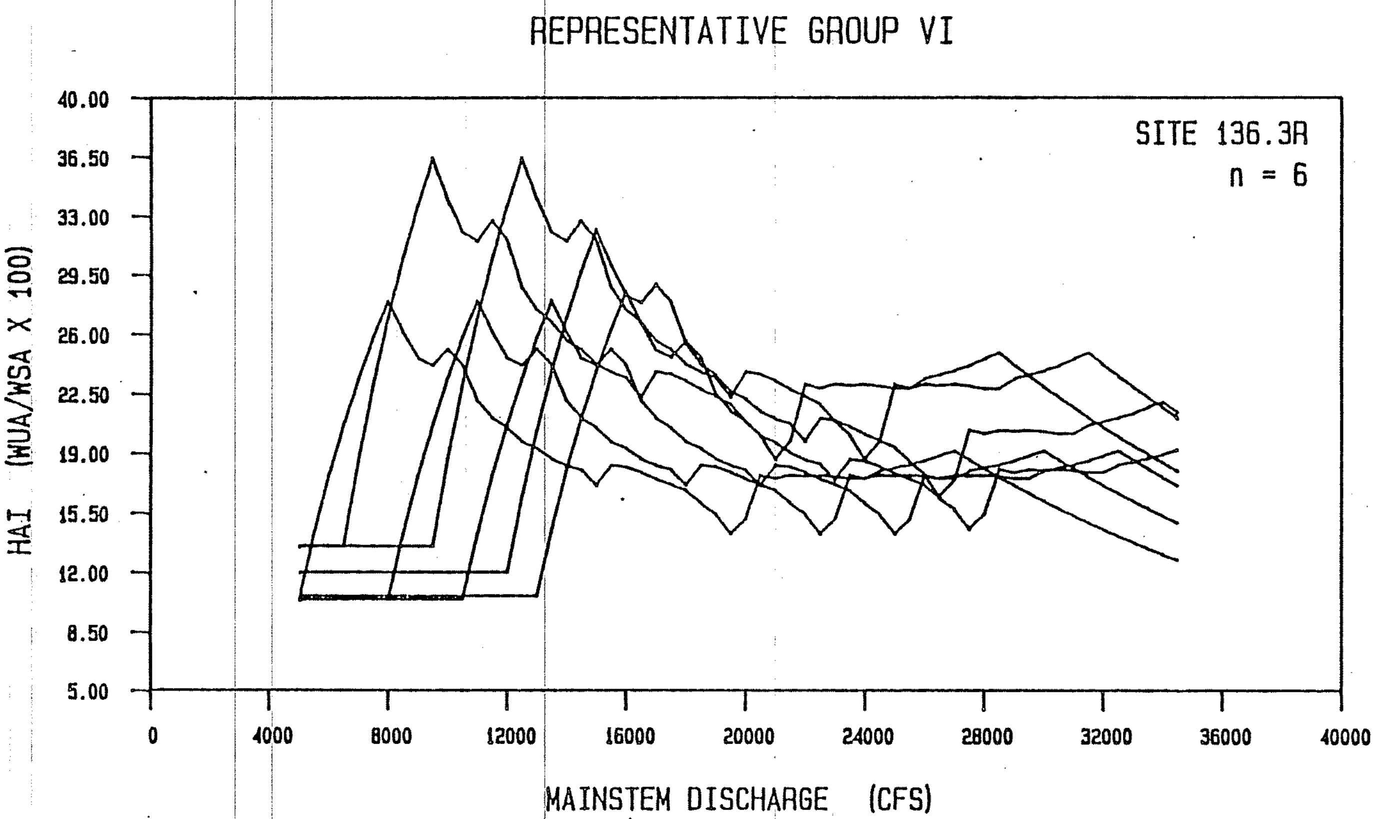


Figure 54. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 136.3R of Representative Group VI.

REPRESENTATIVE GROUP VI

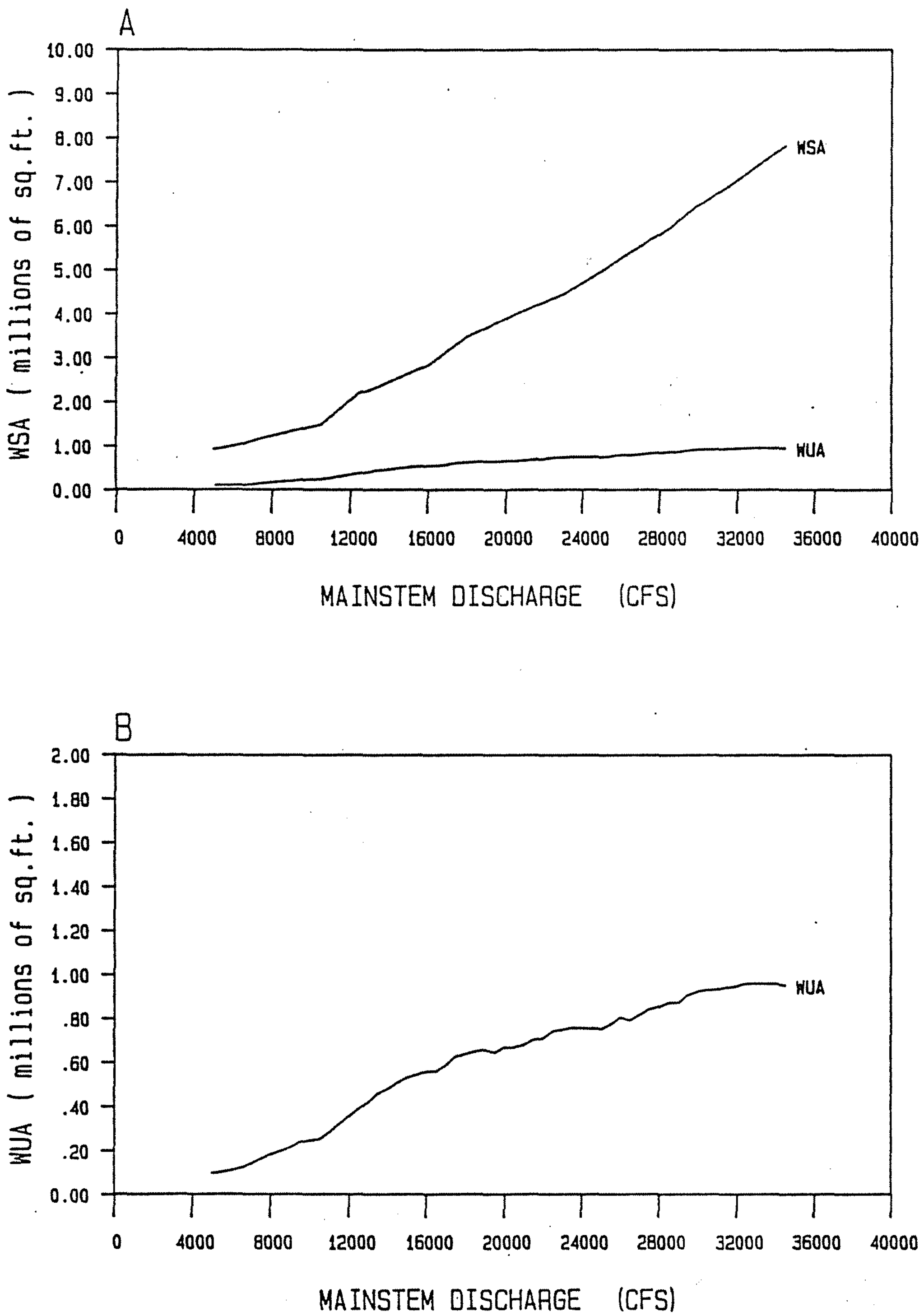


Figure 55. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group VI of the middle Susitna River.

3.7 Representative Group VII

This group of seven specific areas is dominated by side channels possesing low breaching discharges and organized into distinctive riffle/pool flow patterns. In most cases, the specific areas are comparatively short with small length:width ratios and are composed of a single riffle extending from the head of the site down to a large backwater area at the mouth. The transition from riffle to backwater pool is defined by an abrupt step in bed and water surface profile. Head berms are generally broad-crested and the riffles of greater-than-average slope. The steep riffle gradients tend to increase in streamflow tends to mimimize the staging effect of rising mainstem flows at the mouth of the site. Consequently, the rate of change in backwater area is less than is observed at lower gradient sloughs and side channels over a comparable range of discharges. Backwater area varies at Group VII sites primarily by expanding or contracting laterally as flows change. Flow characteristics within backwater pools include near zero velocities and a calm surface, as compared to the broken and rapidly moving water of riffles.

Considerable longitudinal variation in streambed texture occurs in Group VII specific areas. Riffles are composed of rubble and boulder size substrates, whereas backwater areas tend to have sandy beds. Periodic high flows may temporarily expose coarse sediment in backwater pools which is subsequently covered by sand and silt during periods of low flow. High turbidities also prevail at these sites since upwelling is not present.

Modeling Site 119.2R is the sole representative of the 7 specific areas classified within Group VII. This site possesses the typical riffle/pool sequence characteristics just described (Plates A-27 and A-28 in Appendix A). As indicted in Figure 56, a basal level of wetted surface area and juvenile chinook WUA is maintained under non-breached conditions by backwater effects. Peak rearing habitat potential occurs shortly after the berm at the head of the site is overtopped and the riffle area is inundated. The relatively broad width and uniform elevation of the head berm strongly influences the distribution and amount of juvenile chinook habitat at Site 119.2R. Areas of usable habitat within the riffle rapidly expand until local velocities begin to exceed tolerable limits which in turn prompts a decline in rearing habitat. Maximum WUA values are forecast for discharges of 12,500 to 13,000 cfs, when juvenile chinook WUA is nearly four times greater than WUA present under non-breached conditions (39.3 versus 10.5 sq.ft./ft.).

Gross habitat is widely distributed throughout Site 119.2R at flows ranging up to 17,000 cfs, as demonstrated by the GHA response to discharge in Figure 56. However, habitat availability and quality, as indexed by HAI and HQI values, begins to diminish appreciably around 12,000 cfs. Peak HAI and HQI estimates were similar at 40 percent, a fairly high value in comparison to other modeling sites. The minimum HAI value was 3 percent at 35,000 cfs. This HAI value was estimated by extending the WSA and WUA curves by eye for discharges exceeding 20,000 cfs (Hilliard et al. 1985). The HQI curve was not extrapolated past 20,000 cfs, but HQI values may be expected to be higher than HAI values to a degree which is proportional to the difference between gross habitat area and wetted surface areas at high discharges.

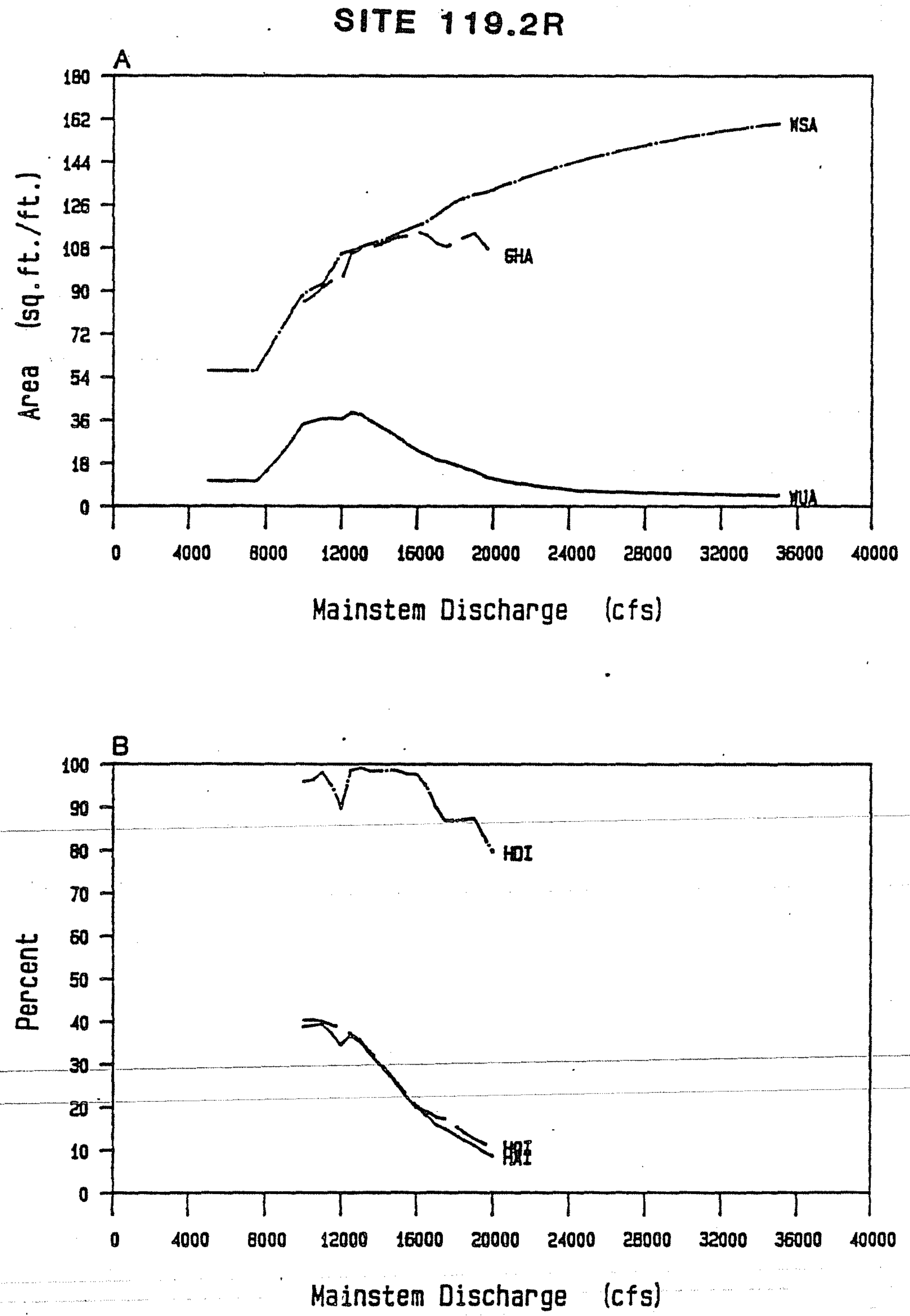


Figure 56. Surface area and chinook rearing habitat index response curves for modeling site 119.2R.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

HAI functions derived from modeling results for Site 119.2R display the low breaching flows and comparatively large habitat potential at low discharges associated with specific areas of Representative Group VII (Figure 57 and Appendix B). Within a narrow range of low mainstem discharges (10,000 to 13,000 cfs), HAI values compare favorably with peak HAI values recorded for specific areas from other groups. The marked decline in habitat availability at higher flows and the overall poor structural habitat quality (i.e., low SHI values) of Group VII sites suggests that hydraulic geometry plays a more important role than does object cover in determining the collective rearing habitat potential of this group.

As was the case for side channels comprising Representative Group IV, which are characterized by similarly low breaching discharges, the seven specific areas of Group VII provide notably greater amounts of usable rearing habitat at low than at high mainstem flows, as evidenced by the aggregate WUA function in Figure 58. This results from the comparatively high HAI values which occur immediately subsequent to breaching and their rapid decline at higher flows. Juvenile chinook WUA peaks at 0.3 million square feet at 8,000 cfs, remains at this level through 13,000 cfs and declines to 0.08 million square feet at 35,000 cfs.

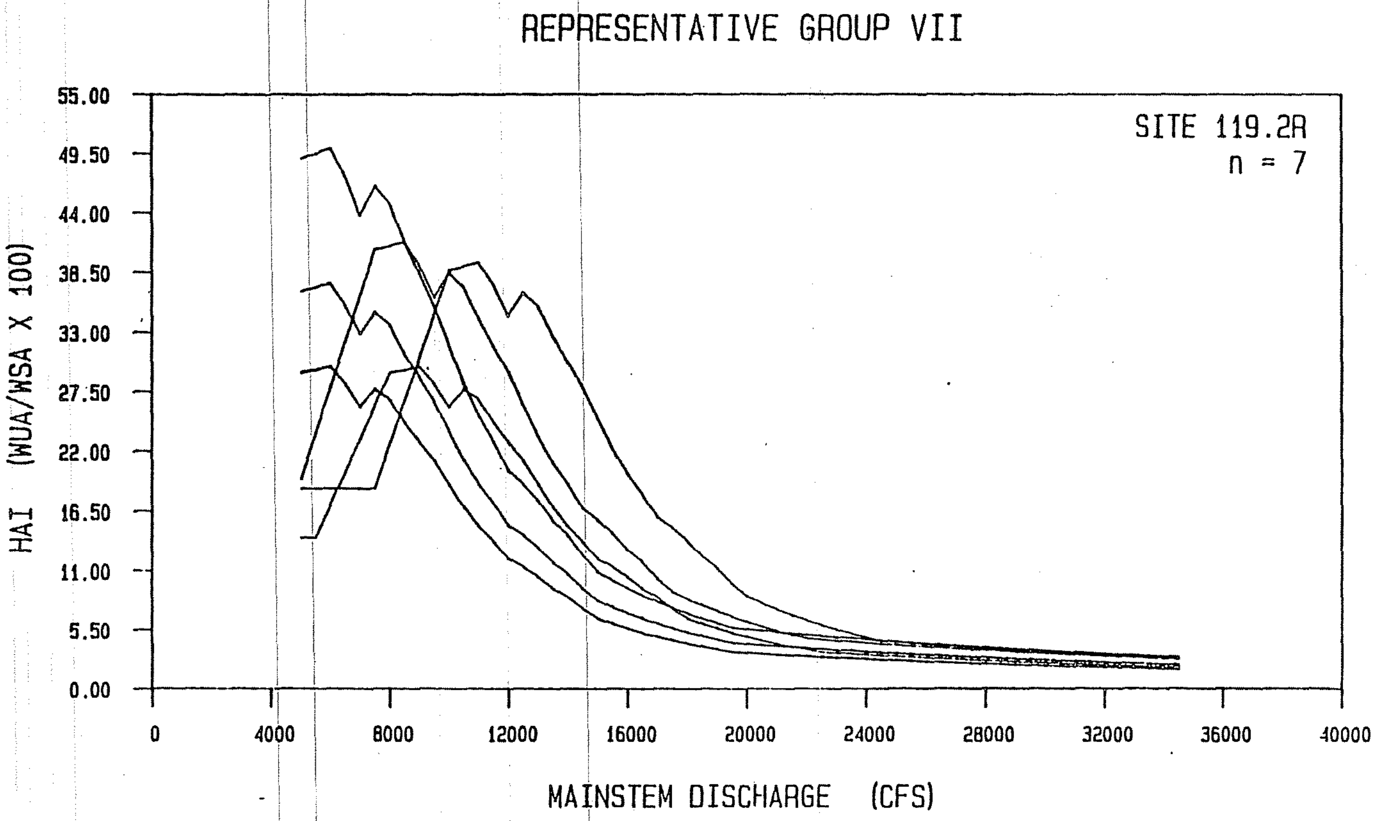


Figure 57. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 119.2R of Representative Group VII.

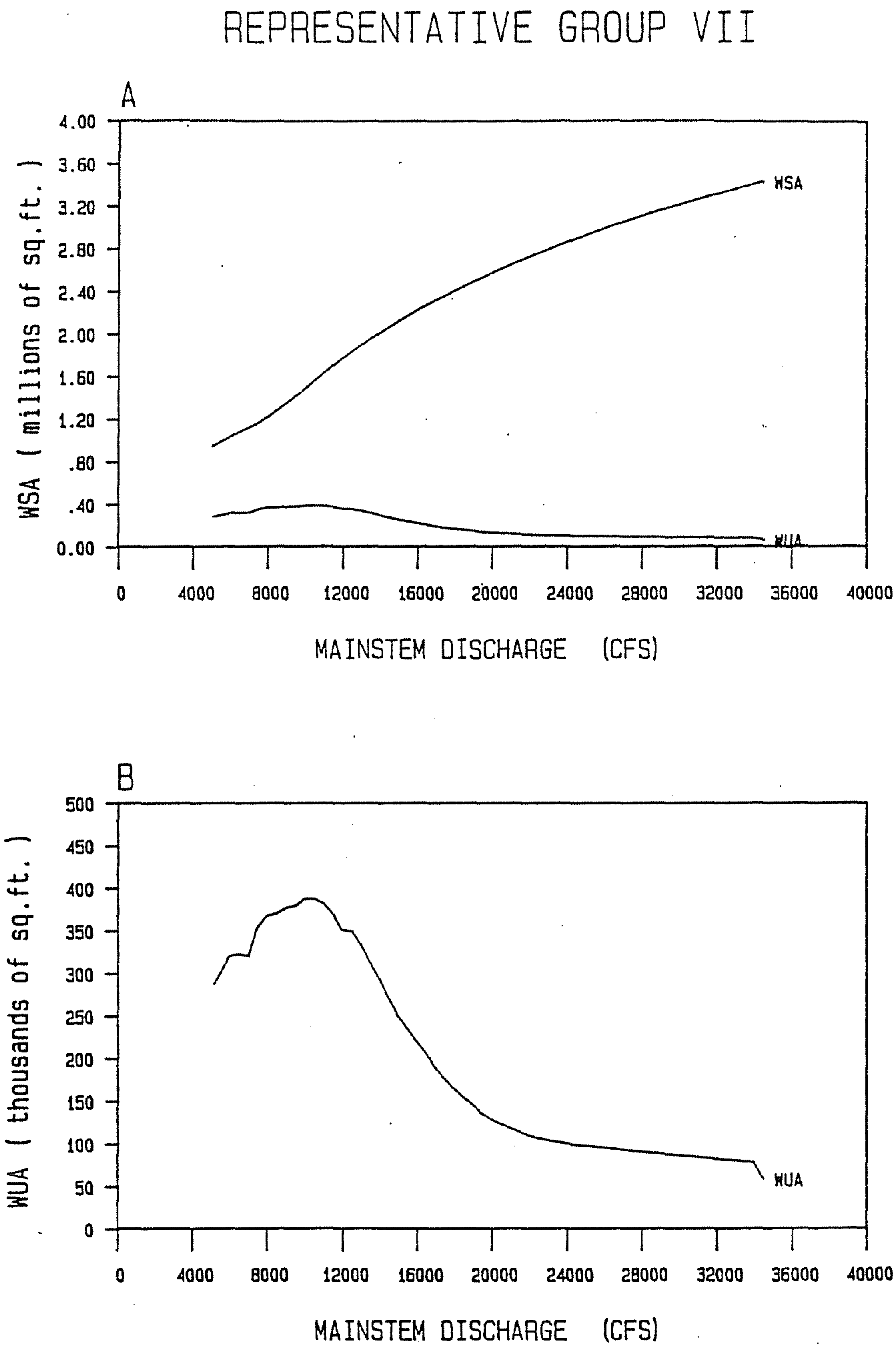


Figure 58. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group VII of the middle Susitna River.

3.8 Representative Group VIII

This group is comprised of 22 specific areas which tend to dewater at intermediate to high mainstem discharges. The absence of an upwelling groundwater supply may be due to the local structural geology and the location of the channels relative to sources of subsurface flow. Aaserude et al. (1985) noted that the heads of channels included in Group VIII were frequently oriented at a 30^{o}+ angle to the adjacent mainstem channel. Apparently groundwater flow is either diverted away from these sites or occurs at a lower elevation than the bed elevation of the exposed channels.

In spite of their tendency to dewater, specific areas in Group VIII are similar to specific areas assigned to Groups II and III in their hydrologic, hydraulic, and morphologic properties. Therefore, because Group VIII does not possess a specific area with a rearing habitat modeling site, HAI functions based on modeling sites from Representative Groups II and III were used to represent Group VIII in the habitat extrapolation process. An obvious requirement was that the habitat functions for modeling sites selected to represent this group be modified to reflect the total loss of rearing habitat as mainstem stage declines below head berm elevations. Candidate modeling sites include Site 144.4L from Group II and Site 132.6L from Group III. The first modeling site is recommended by its high breaching discharge, its morphological similitude with several Group VIII specific areas, and by the general shape of its habitat response curves. Figure 24 illustrates the WSA, WUA and HAI curves which have been derived from Site 144.4L to represent a subclass of Group VIII specific areas. Note that the lefthand limb of the curves have been truncated at a breaching flow of 21,000 cfs.

Site 132.6L has been selected to represent the subclass of specific areas from Group VIII which dewater at intermediate discharges. Based on an examination of aerial photography obtained at several mainstem flows, these specific areas and Site 132.6L possess similar longitudinal and cross sectional profiles. Site 132.6L, which breaches at 10,500 cfs, eventually dewaters at 6,000 cfs as the water surface elevation drops below the elevation of the groundwater table (Figure 32). However, the revised modeling site habitat response curves have been truncated at 10,500 cfs to accurately reflect the rapid dewatering which occurs at Group VIII specific areas.

HAI curves are presented in Figures 59 and 60 with aggregate WSA as Figure 61. All specific areas in this Representative Group dewater at intermediate discharge levels. Specific areas were grouped on the basis of exposed streambed composition. The 15 specific areas represented by site 132.6L all possess streambeds lined with sand indicating low velocity or backwater influenced hydraulic conditions exist when these sites are breached. The 9 specific areas associated with site 144.4L have channel beds consisting of large gravels and cobbles indicating that these specific areas possess much higher velocities when breached.

Since all of the specific areas associated with Group VIII are dewatered by 8,000 cfs, juvenile chinook habitat does not exist at flows below this value. This is reflected in the aggregate rearing WUA curve developed for Group VIII (Figure 61). WUA accumulates rapidly as the specific areas become breached and peak values (0.7 million square feet) are attained at 29,500 cfs. Rearing habitat potential declines slightly at higher flows.

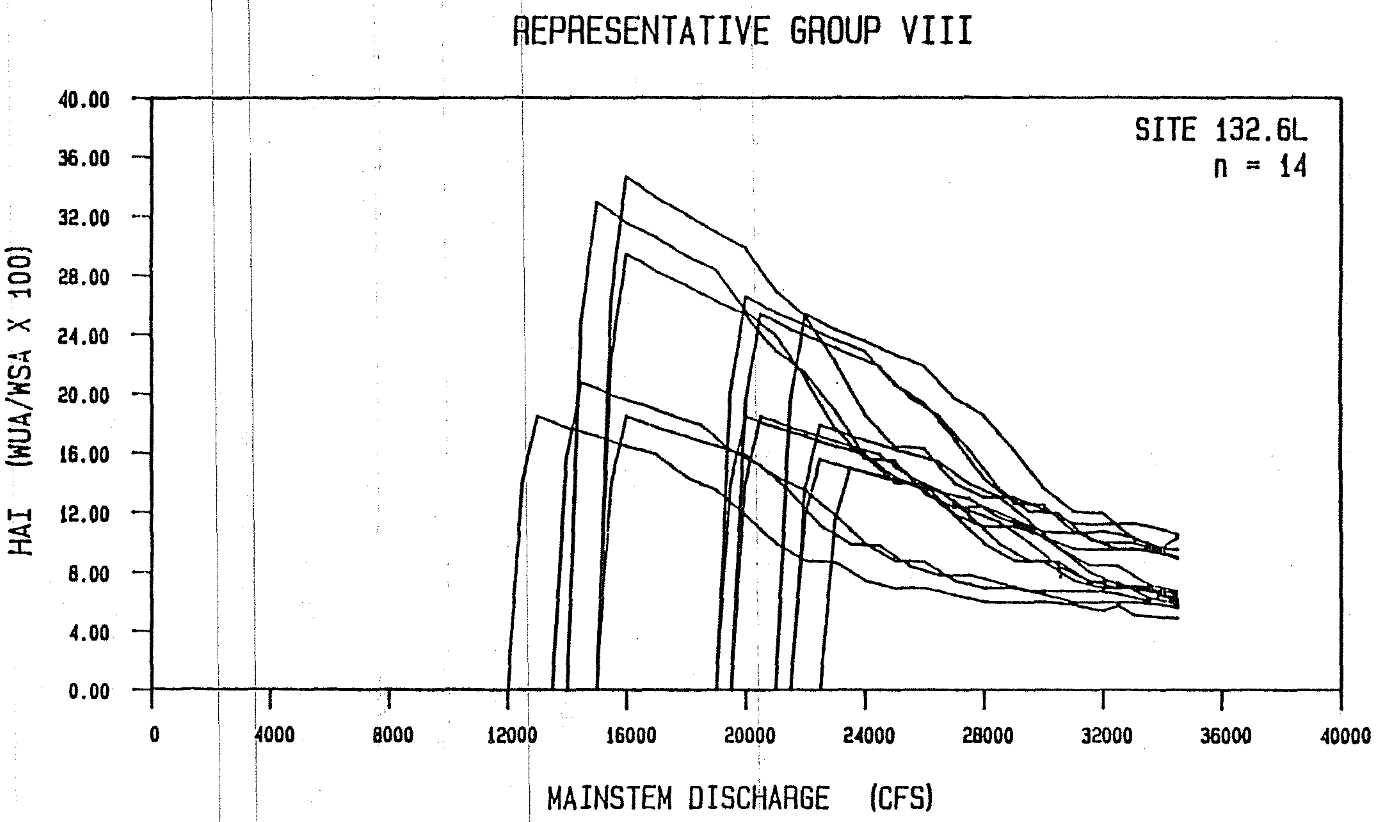


Figure 59. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 132.6L of Representative Group VIII.

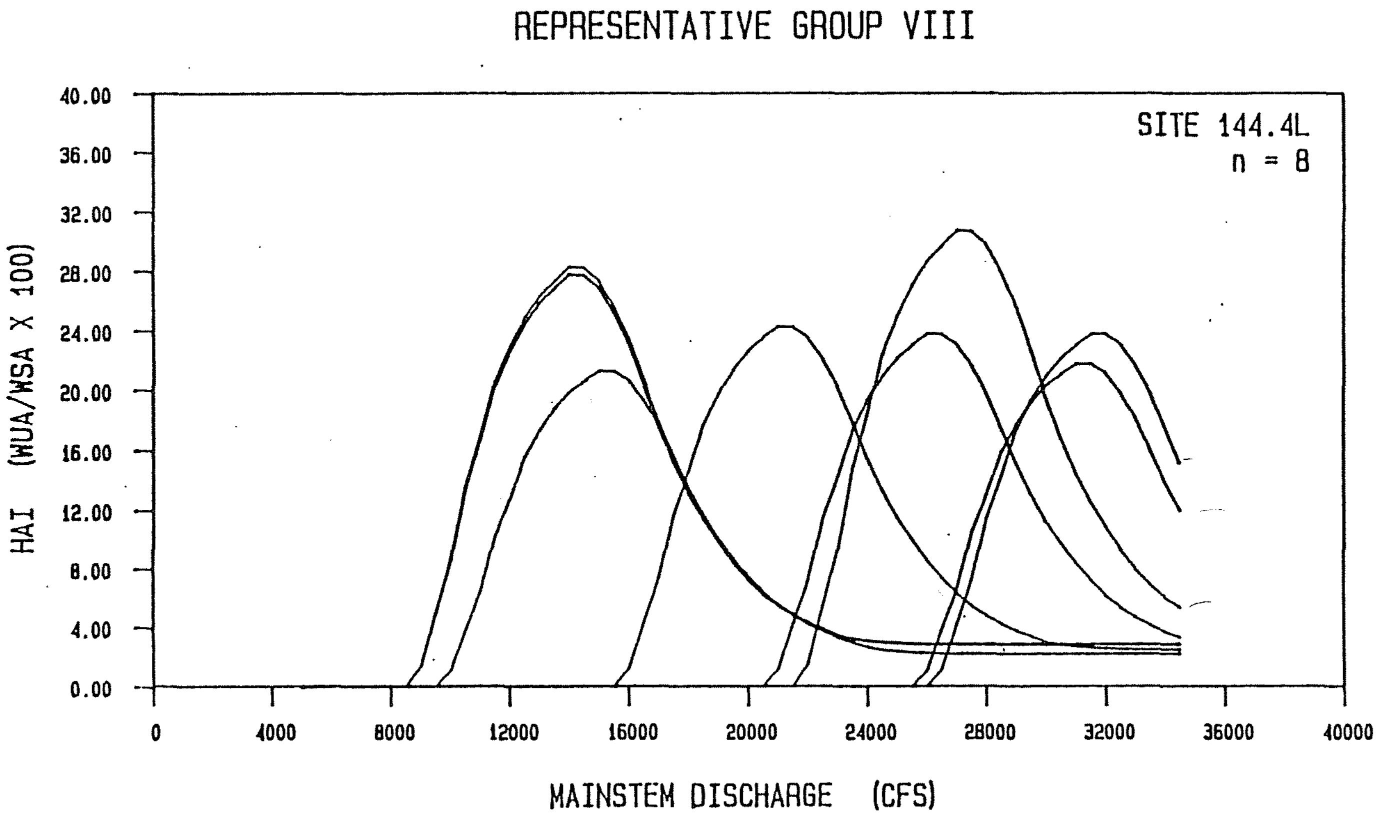


Figure 60. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 144.4L of Representative Group VIII.

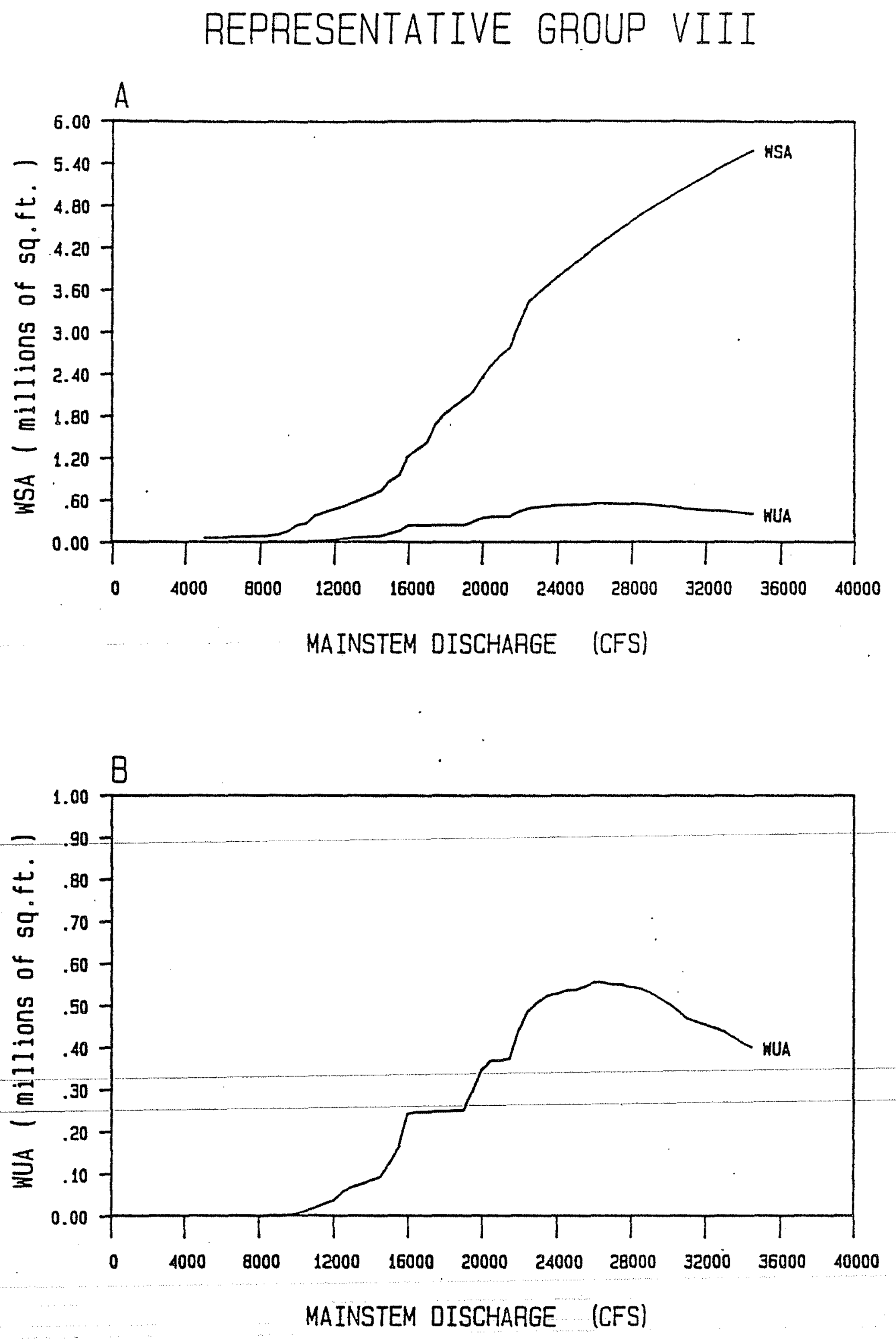


Figure 61. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group VIII of the middle Susitna River.

3.9 Representative Group IX

This group contains 21 specific areas categorized as mainstem and mainstem shoal habitat with mean reach velocities greater than 5 fps at 10,000 cfs. These sites usually convey a significant percentage of the total discharge, and possess small length to width ratios.

Modeling sites 101.5L and 147.1L are large channels classified as mainstem habitat over the entire 5,100 to 23,000 cfs flow range (Plates A-29 through A-32 in Appendix A). Site 101.5L represents those specific areas which are generally shallower and possess lower velocities than those represented by Site 147.1L. As many areas possess velocities greater than 2.5 fps the modeling sites provide little juvenile chinook habitat in relation to the total volume of water they convey. This conclusion is strengthened by the large differences observed between WSA and GHA estimates and the low rearing WUA values forecast for all mainstem discharges (Figures 62 and 63). Wetted surface areas change at comparatively slow rates as discharge varies at both sites due to their large size and a tendency to compensate for varying flow more through adjustments in water depth and velocity than in top width.

Both GHA and WUA increase slightly at higher mainstem discharges; thus, the availability of usable rearing habitat and its distribution within the modeling sites tends to remain constant throughout the range of evaluation flows. In a detailed analysis of cross section velocity profiles at Sites 101.5L and 147.1L, Williams (1985) noted that suitable rearing areas are confined to nearshore zones in the channels, primarily along the gently sloped island banks, due to high mid-channel velocities. The ratio of

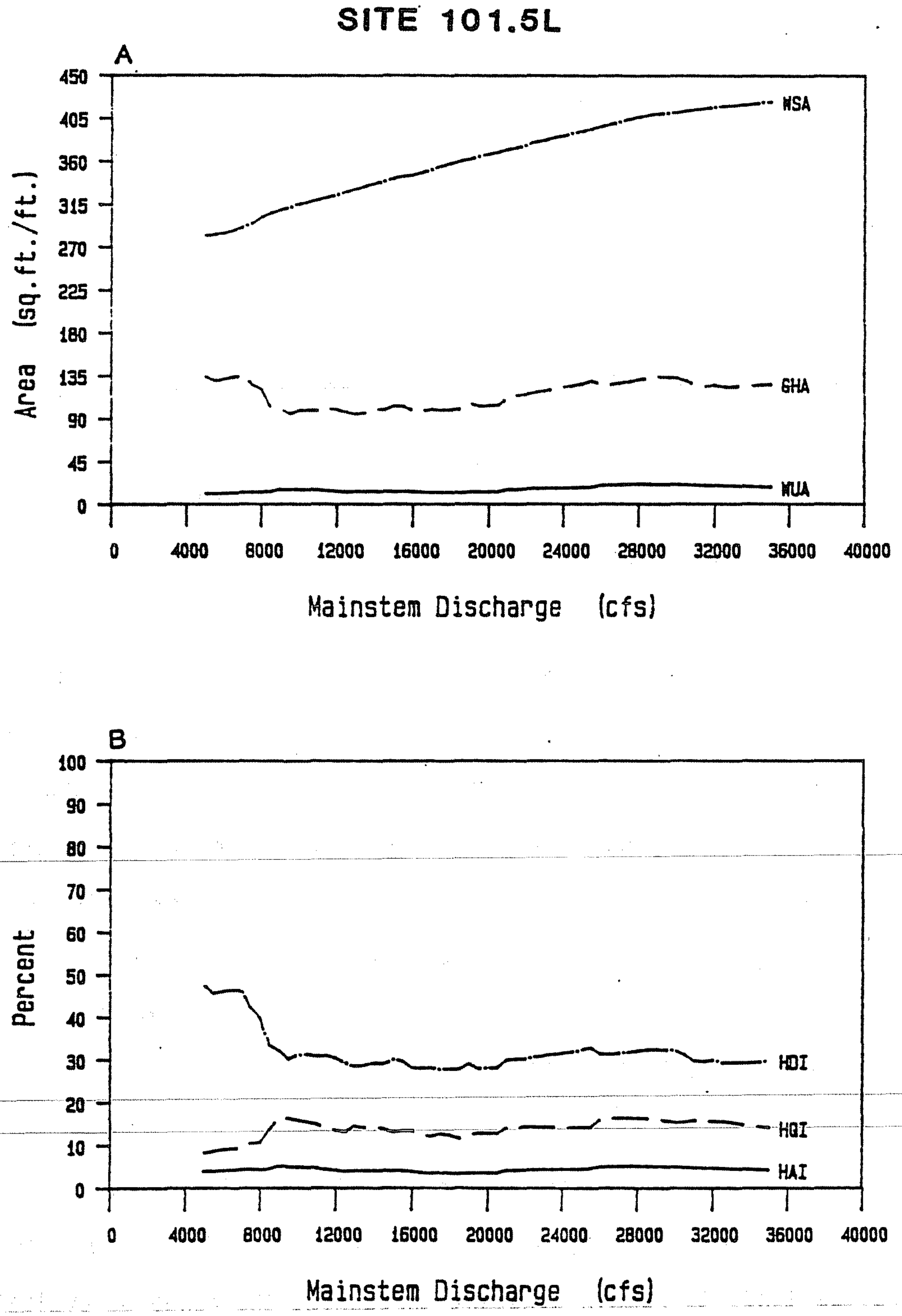


Figure 62. Surface area and chinook rearing habitat index response curves for modeling site 101.5L.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

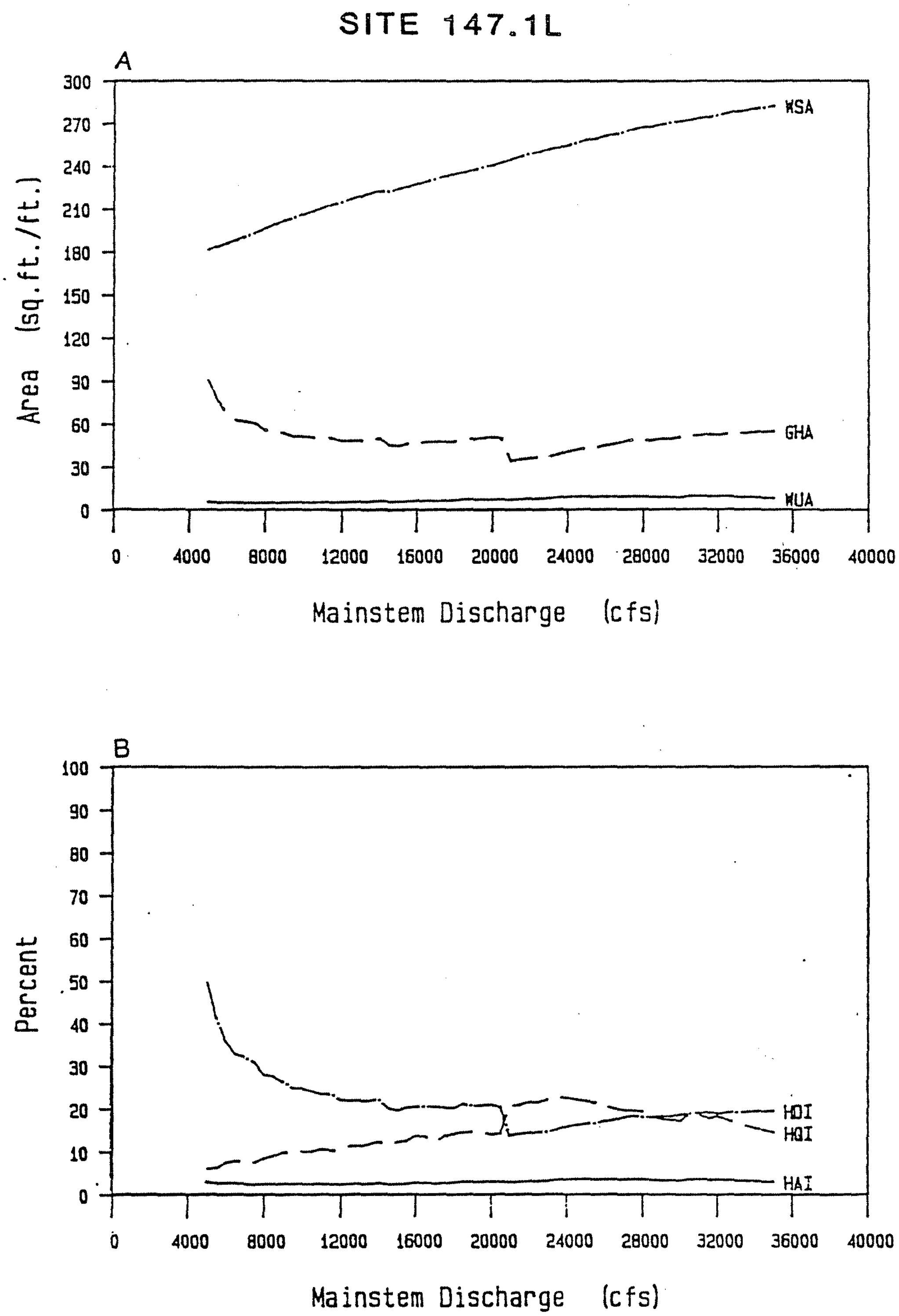


Figure 63. Surface area and chinook rearing habitat index response curves for modeling site 147.1L.
A - Wetted surface area (WSA), gross habitat area (GHA) and weighted usable area (WUA).
B - Habitat availability index (HAI), habitat distribution index (HDI) and habitat quality index (HQI) response functions.

juvenile chinook WUA to wetted surface area at these sites is very low, on the order of 5 percent or less. These values are considerably lower than HAI estimates obtained for modeling sites from other representative groups. The ratio of WUA to GHA is predictably higher, ranging up to 22 percent, but also slightly lower than HQI ratios calculated for other sites. Taking these indices into account, the juvenile chinook habitat potential within Group IX specific areas is judged to be inferior in quality.

Using the HAI functions developed for Sites 101.5L and 147.1L as templates, HAI curves were derived for specific areas within Group IX. Adjustments were made to account for differences in breaching flow and structural habitat quality. In regard to structural habitat, the mean SHI value for specific areas in this group is high compared to other representative groups. This results from the large substrate sizes which predominate in the high velocity channels and the high cover value assigned to them in the SHI calculations. Eleven of the 21 specific areas within Group IX have been grouped with Site 101.5L; the remaining 10 sites are represented by site 147.1L. HAI functions derived for modeled and non-modeled specific areas are presented in Figures 64 and 65 and the aggregate WSA response curve for Group IX in Figure 66.

The collective rearing habitat potential of the 20 specific areas in Group IX increases from 0.3 million square feet at 5,000 cfs to a peak of 0.6 million square feet at 27,500 cfs (Figure 66). Aggregate WUA values increase steadily over this flow range although the rate of change is very low in comparison to other representative groups, with the exception of Group I (upland sloughs), being only slightly greater than the rate of change in wetted surface area. Juvenile chinook WUA remains constant at

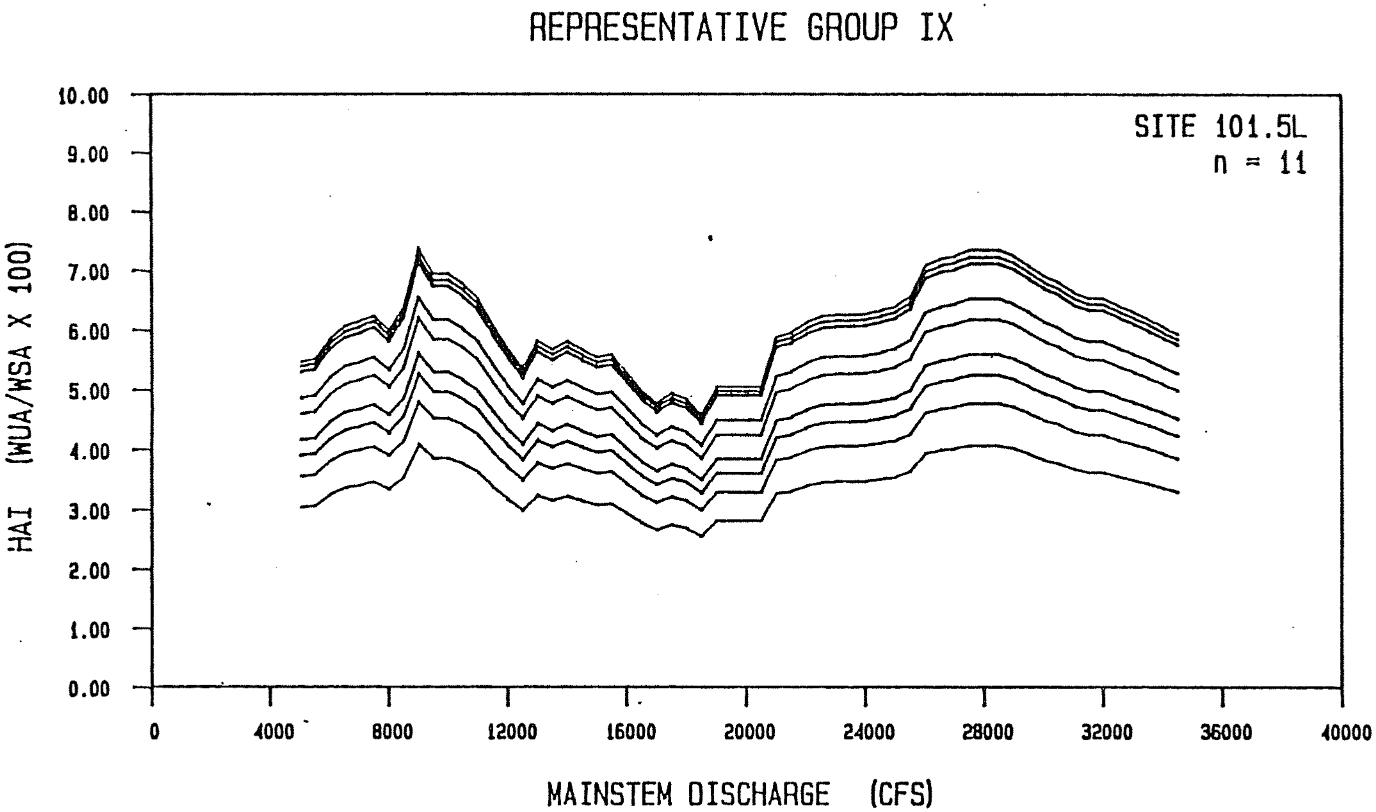


Figure 64. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 101.5L of Representative Group IX.

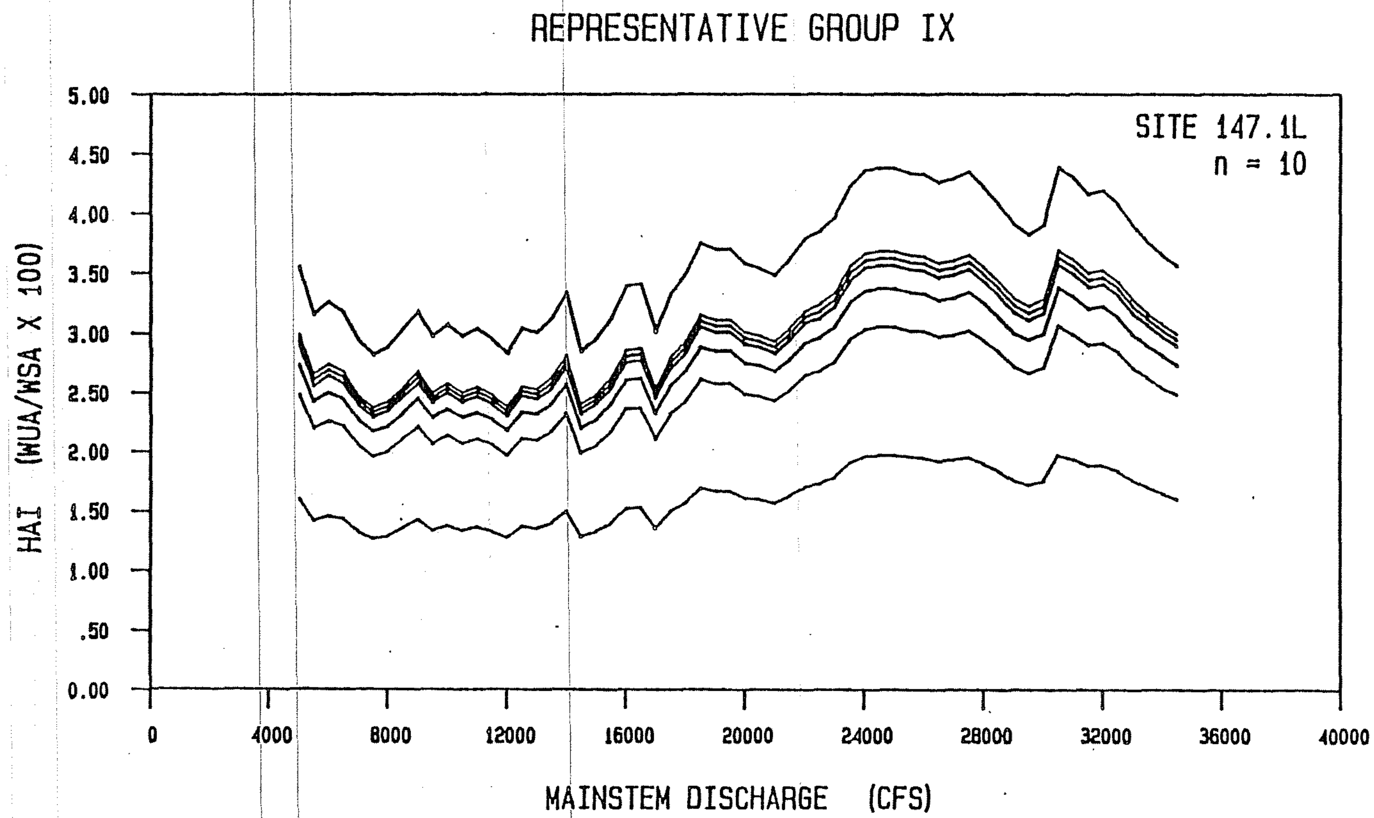
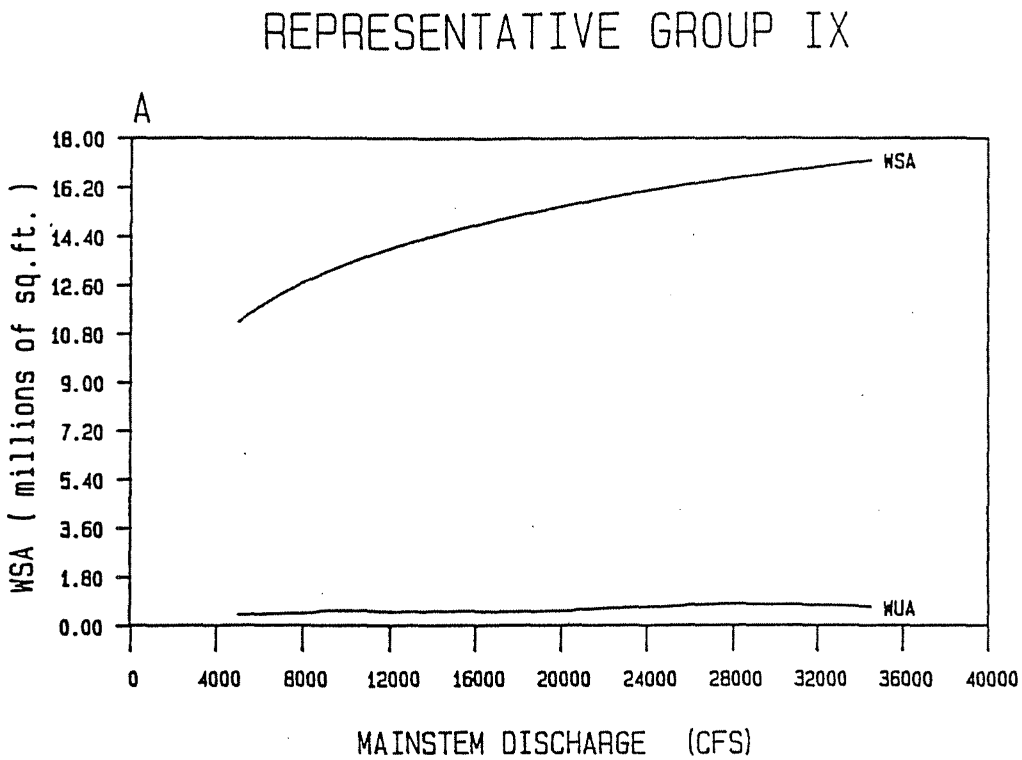


Figure 65. Response of chinook rearing habitat availability to mainstem discharge within non-modeled specific areas of the middle Susitna River which are associated with modeling site 147.1L of Representative Group IX.



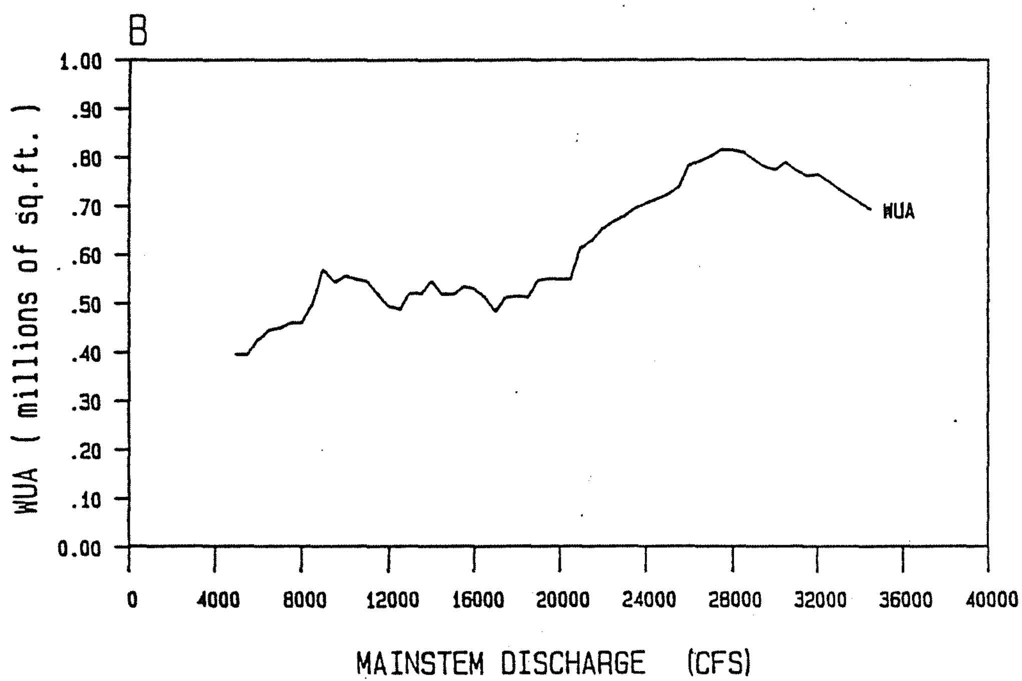


Figure 66. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group IX of the middle Susitna River.

higher flows as increases in wetted surface area are offset by gradual reductions in rearing habitat availability.

3.10 Representative Group X

Representative Group X is made up of mainstem shoals and mainstem margins which displayed signs of upwelling in the winter aerial photography.

As discussed in the methods section, Representative Group X did not possess RJHAB or PHABSIM models. Unlike Group VIII, which was in a similar position, none of the other models available were representative of the specific areas in this group. Therefore a WUA response curve was developed using Direct Input Habitat (DIHAB) models for spawning chum habitat which were available for five of the sites. These sites are illustrated in Plates A33 through A42.

The DIHAB model uses substrate composition and upwelling data from one or more cross sections as well as measured depths and velocities for several mainstem discharges to calculate WUA and WSA at each observed streamflow. WUA and WSA indices for unobserved streamflows within the range of observed values are determined by linear interpolation between calculated WUA and WSA indices. Outside the range of observed values, WUA and WSA indices may be estimated on the basis of trend analysis and field experience (Hilliard et al. 1985).

The chum spawning DIHAB models were converted to juvenile chinook DIHAB models as follows. Depth and velocity suitability curves for spawning chum were replaced by depth and velocity suitability curves for juvenile chinook. The substrate suitability curve for spawning chum was replaced by the cover suitability criteria for juvenile chinook under turbid water conditions. The upwelling criteria was eliminated.

WUA and WSA response curves were developed for each of the five modeled sites. They were extended beyond the range of available data by regression analyses to encompass the mainstem discharge range 5,000 to 35,000 cfs. Trends , apparent from the plotted points, indicated where more than one relationship was required to describe the response of WSA or WUA to mainstem discharge.

In all cases WSA increased with mainstem discharge. The maximum WSA for each site was determined by summing the product of cross section width and representative reach length for all cross sections within the site. Cross section plots, with water surface elevations at various mainstem discharges superimposed, were used to identify those discharges at which the relationship between WSA and mainstem discharge might be expected to change. For Representative Group X sites such changes were coincident with discharges at which shoals become inundated.

WUA generally decreased with mainstem discharge. Some fluctuations were noted. They were due to the optimal habitat at the cross sections of a site peaking at different mainstem discharges. Velocity data and cross sectional geometry were used to verify WUA forecasts beyond the range of data.

HAI values were calculated (as WUA/WSA x 100) for each discharge associated with a data set, for each discharge where a change in the relationship between WSA or WUA and mainstem discharge had been noted, and for 5,000 cfs and 35,000 cfs. Through linear interpolation, HAI values for 5,000 to 35,000 cfs in 500 cfs increments were obtained. The HAI curves for the five modeled sites were very similar. In all cases the HAI was maximum at 5,000 cfs, and the rate of decline decreased with mainstem discharge.

Values of WSA for the eight nonmodeled sites of Representative Group X were obtained through the use of aerial photography. The areas were digitized from 1" = 250' scaled aerial photos taken when mainstem discharge was 5,100, 10,600, 16,000, and 23,000 cfs. Regression analyses provided WSAs for 5,000 to 35,000 cfs in 500 cfs increments.

To calculate WUA for the eight nonmodeled sites, a composite HAI curve was first developed. Extrapolation of the HAI response curves for the modeled sites to the nonmodeled sites consisted of averaging the curves after first normalizing them to an SHI of 0.50.

$$HAI_{0.50} = HAI_{SHI} \times (0.50/SHI)$$

The composite curve was similarly adjusted for the SHI of each nonmodeled site before applying it to the corresponding WSA curve, or:

$$HAI_{SHI} = HAI_{0.50} \times (SHI/0.50)$$

HAI curves are given in Figure 67 and the summation of the WUA and WSA values for the thirteen sites in Figure 68.

This representative group contains a small subpopulation of shoal areas and mainstem margins which contain upwelling and retain a small amount of wetted surface area at low mainstem discharge levels. A much larger population of shoal areas become dewatered as mainstem flow decreases. Surface

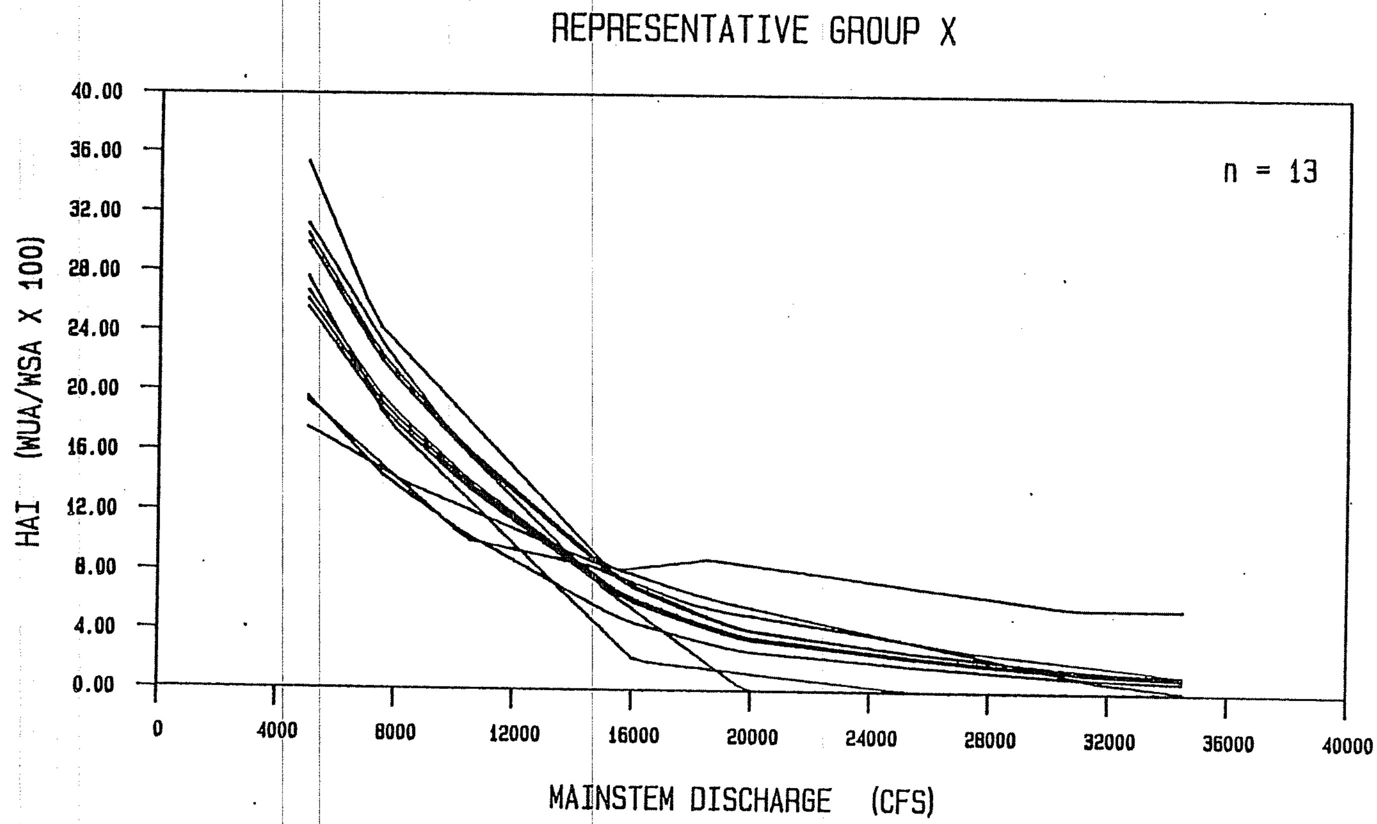


Figure 67. Response of chinook rearing habitat availability to mainstem discharge for specific areas of the middle Susitna River within Representative Group X.

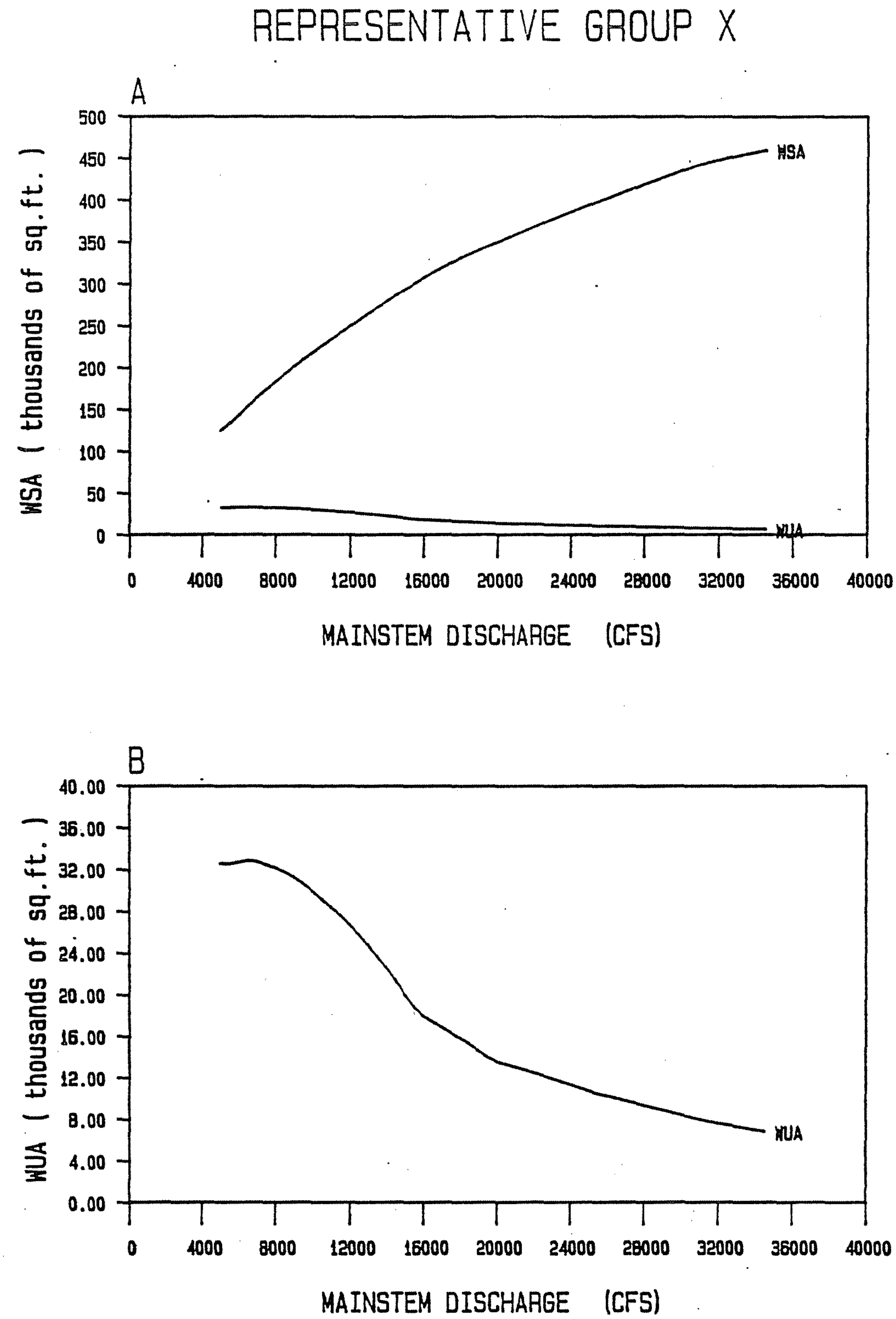


Figure 68. Aggregate response of A - wetted surface area (WSA) and B - chinook rearing habitat potential (WUA) to mainstem discharge in specific areas comprising Representative Group X of the middle Susitna River.

area measurements of exposed gravel bars (Klinger Kingsley 1985) indicated that dewatered surface area increases by approximately 1,037 acres as mainstem discharge decreases from 23,000 cfs to 10,600 cfs.

Because of the difficulty locating upwelling areas during moderate to high flow periods, the entire subpopulation of shoal areas with upwelling are not contained in Representative Group X. From examination of air photo mosaics it is apparent that at low mainstem discharges a large amount of shoal surface area is present that was not included in Representative Group X. Therefore, the surface area and WUA curves for this group are not directly compatible with the curve sets for other representative groups as they contain entire populations of specific areas belonging to a particular habitat type. In addition, the 13 specific areas which are included in Representative Group X all possess similar HAI curves (Figure 67) and result in a composite WUA curve (Figure 68) which is relatively insensitive to changes in mainstem discharge. Therefore, WUA forecasts for Representative Group X will be excluded from further consideration in the extrapolation process.

4.0 SUMMARY

The physical habitat modeling presented in this report provides a quantitative evaluation of the response of juvenile chinook weighted usable area to incremental changes in streamflow for the middle Susitna River. Underpinning the extrapolation methodology are several assumptions related to physical habitat modeling and river stratification procedures.

The primary assumption of the habitat modeling studies is that weighted usable area (WUA) is an index of physical habitat conditions and changes in WUA are attended by adjustments in the distribution and relative abundance of juvenile chinook populations. Although other physical and non-physical components of fish habitat not included in the calculation of WUA may influence the survival and growth of juvenile chinook salmon, the physical environment affects to a substantial degree biotic processes of the aquatic community. Moreover, considerable data exist which indicate the importance of individual microhabitat variables for influencing the distribution of juvenile chinook within different subenvironments of the middle Susitna River. Hence, physical habitat modeling is an appropriate method for assessing the influence of project-induced changes in streamflow on juvenile chinook habitat.

Numerous environmental variables influence the availability of chinook rearing habitat and these variables are typically not independent of one another. Under some circumstances, however, the availability or quality of juvenile chinook habitat may be governed primarily by one or two variables whose influence is more pronounced than the combined effect of all other environmental variables. An example is the positive correlation during the summer growing period between juvenile chinook distribution and turbid water. This may reflect the value of turbidity as cover for juvenile chinook as reported by Dugan et al. (1984) or it may reflect a greater abundance of drifting invertebrate prey in the turbid mainstem and side channel habitats than in clear water sloughs.

Water clarity was treated as a cover variable in the physical habitat modeling studies since our present understanding of turbidity, food availability, and juvenile chinook distribution does not warrant an evaluation of the relationship of turbidity to food supply. Nevertheless, if it is drifting invertebrate prey associated with turbid mainstem and side channel flow which juvenile chinook are responding to rather than the cover value of turbidity, the physical habitat model remains valid. It is the influence of turbidity on juvenile chinook distribution, not the cause, which is being modeled.

The influence of water clarity was incorporated into the modeling process through the application of separate clear and turbid water habitat suitability criteria for juvenile chinook. Clear water velocity and cover suitability criteria were used to calculate rearing WUA indices for modeling sites under non-breached conditions. Following breaching high turbidities prevailed at the modeling sites and turbid water criteria were applied.

The results of the rearing habitat modeling studies conducted at individual modeling sites indicate surface area and rearing habitat response curves are generally more similar within representative groups (where two or more modeling sites occur) than between groups. The amount of rearing habitat available at a particular site is strongly affected by the mainstem discharge at which its upstream berm is overtopped. Under non-breached conditions, juvenile chinook habitat is typically relatively small. The combination of the influx of turbid water to the channel and the increase in its wetted surface area which accompany breaching typically increases the availability of rearing habitat significantly. Positive gains of WUA continue, but at a gradually declining rate, as mainstem discharge increases and water velocities at the site remain favorable. Juvenile chinook habitat tends to decrease more rapidly in smaller channels as mainstem discharge increases than in larger channels due to a more gradual response of near shore velocities to changes in flow in large channels. Thus, relatively small changes in the availability of rearing habitat occur as flows increase or decrease in the large side channels and mainstem. It should be emphasized, however, that these large side channels and the mainstem contribute a disproportionately small amount of habitat in relation to their wetted surface area.

Based on the delineation of specific areas and their classification into the representative groups described by Aaserude et al. 1985, we have developed aggregate rearing habitat response functions for the majority of the subenvironments which directly respond to changes in mainstem discharge. These are summarized in Figure 69. We have not combined WUA values for the representative groups to obtain an aggregate WUA value for the entire middle Susitna River. Evidence of variability in juvenile chinook abundance and distribution between representative groups is provided by Hoffman (1985), suggesting that WUA indices for different

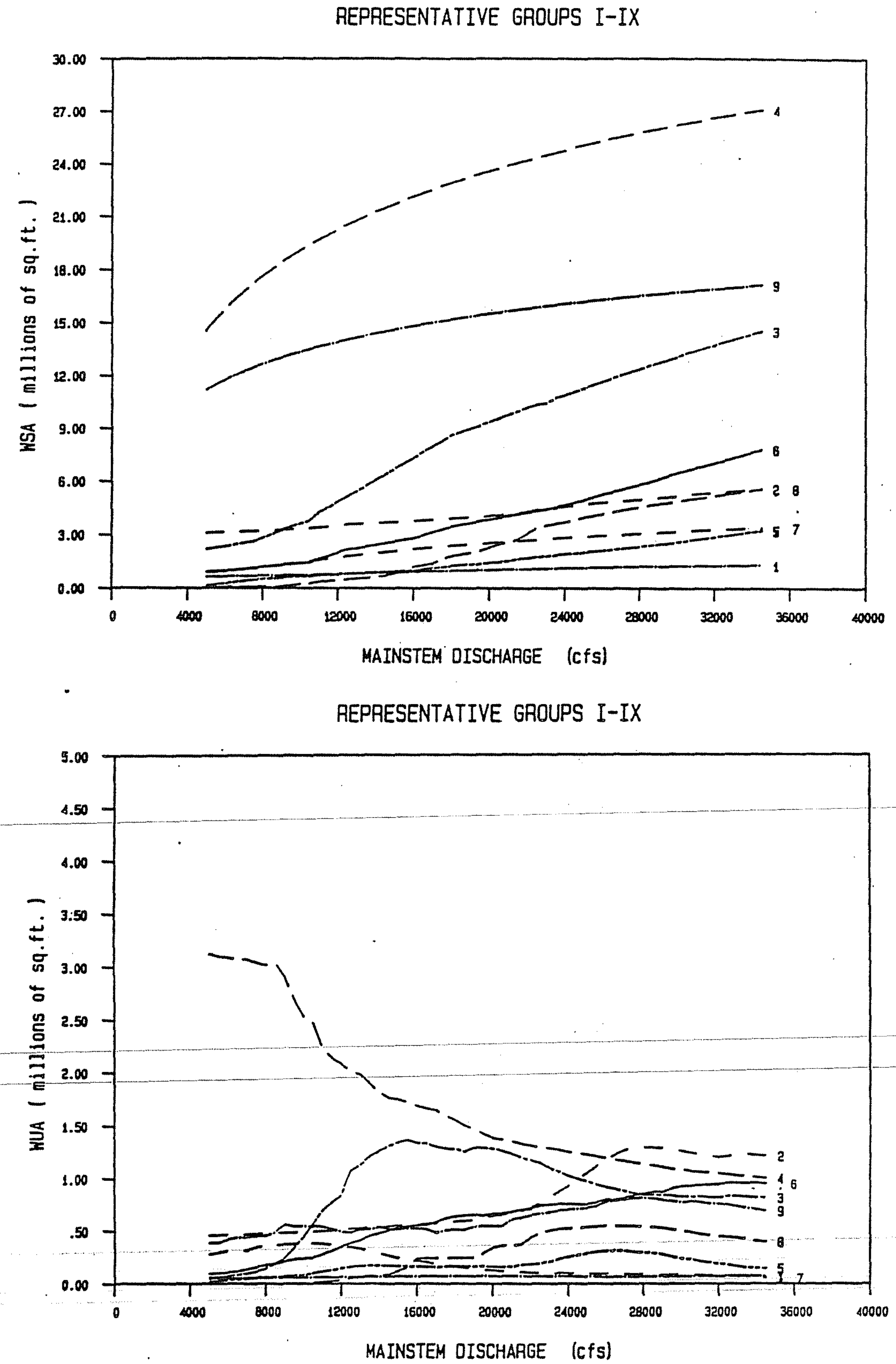


Figure 69. Comparison of the aggregate response of chinook rearing habitat [WUA] for Representative Groups I through IX.

representative groups may require adjusting for utilization prior to being aggregated.

Other considerations which should be addressed prior to drawing final conclusions from the habitat response functions provided in this report are the influences of food availability and water temperature on the quality of rearing habitats. In addition such seasonal aspects as availability of chinook overwintering habitat should be considered. The habitat modeling results presented in this report are not directly applicable to evaluations of winter habitat since hydraulic characteristics and fish behavior are different at this time of year. In regard to the open water period, however, time series and habitat duration analyses at the representative group level are recommended for comparisons between groups and flow regimes. Whereas the primary utility of the WUA response functions is their application to existing habitat conditions, the general shape of the WUA response functions are also well-suited to assessing with-project effects on juvenile chinook habitat.

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LITERATURE CITED

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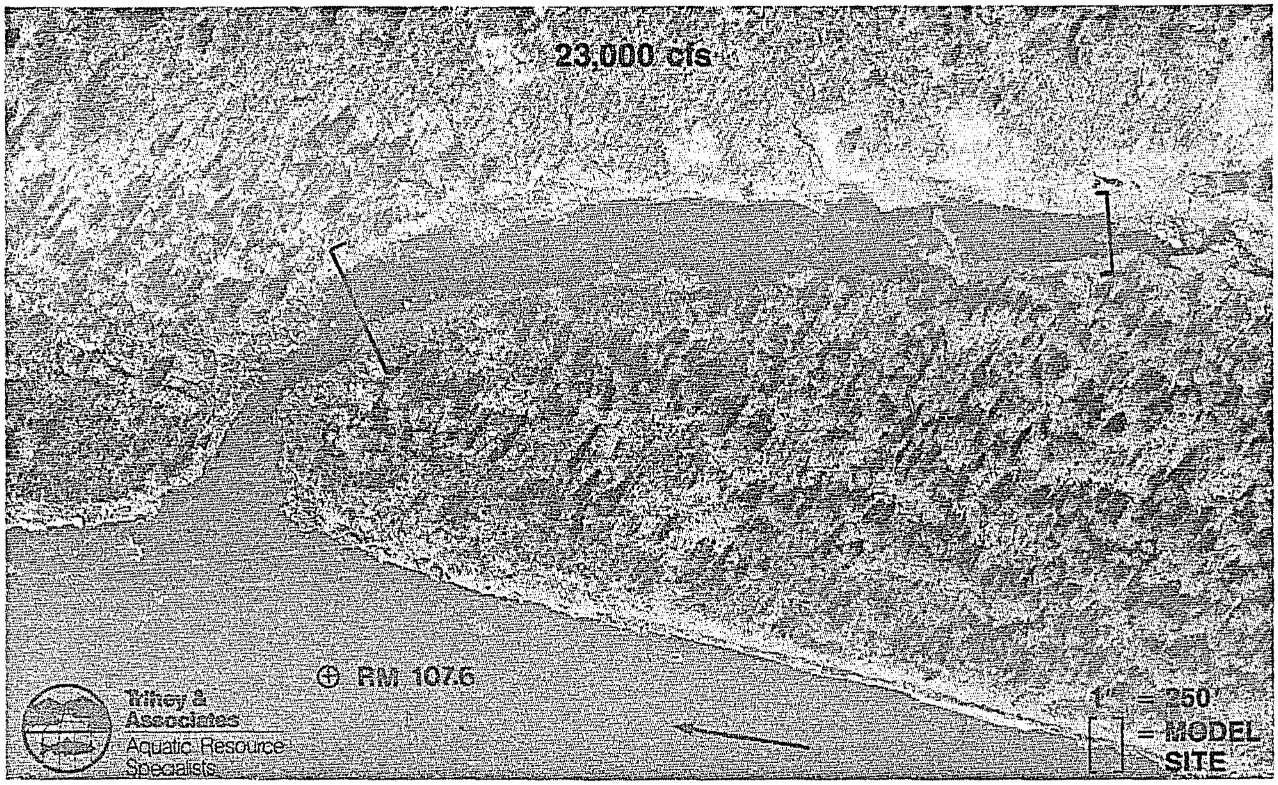
APPENDICES

APPENDIX A

AERIAL PHOTOGRAPHY OF MODELING SITES

(PLATES A-1 THROUGH A-42)



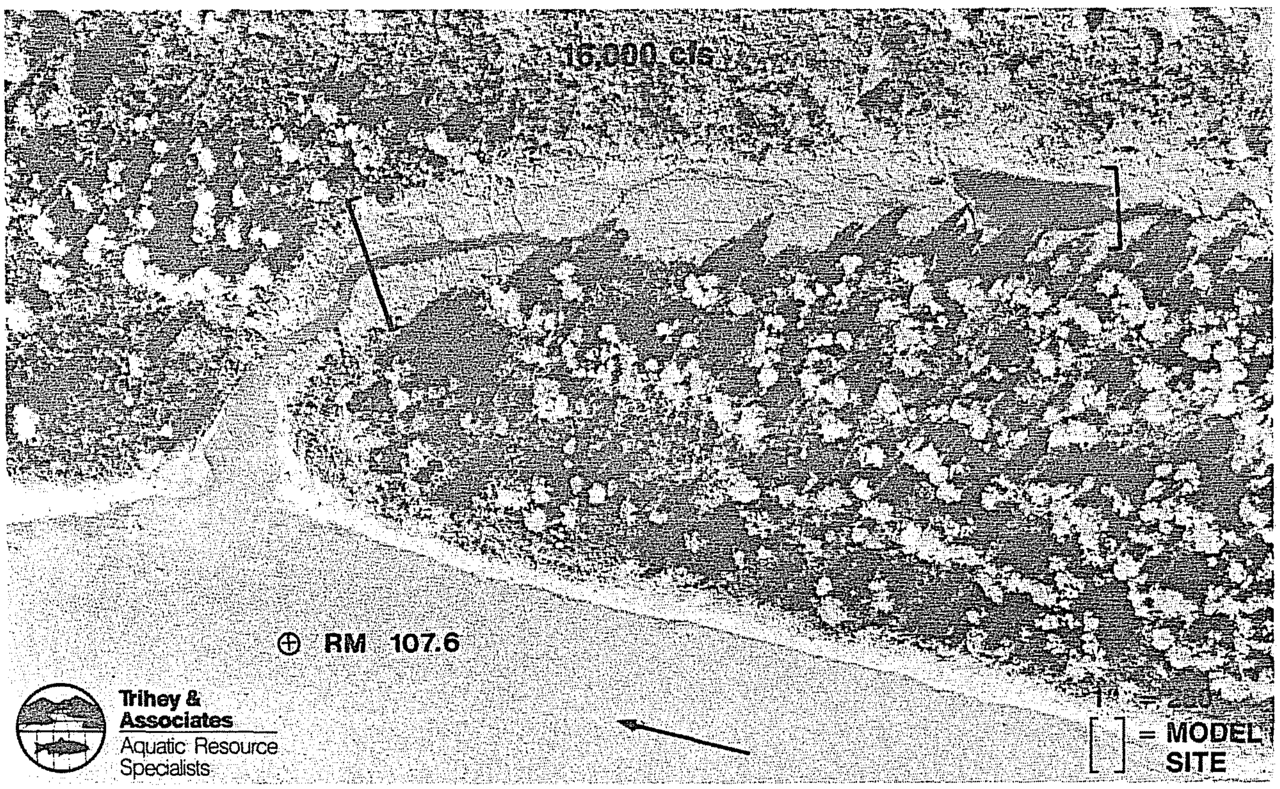
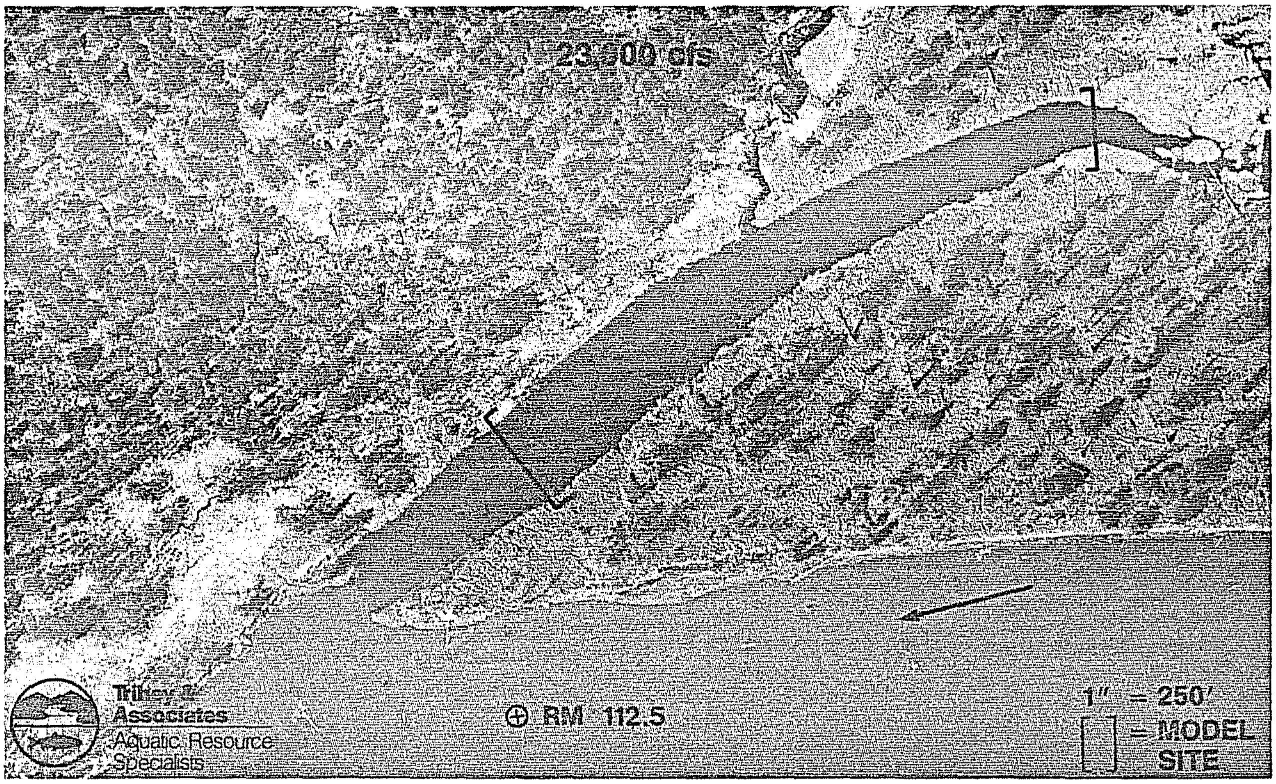


Plate A-1 Aerial photography of modeling site 107.6L at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at > 35,000 cfs and is included in Representative Group I.



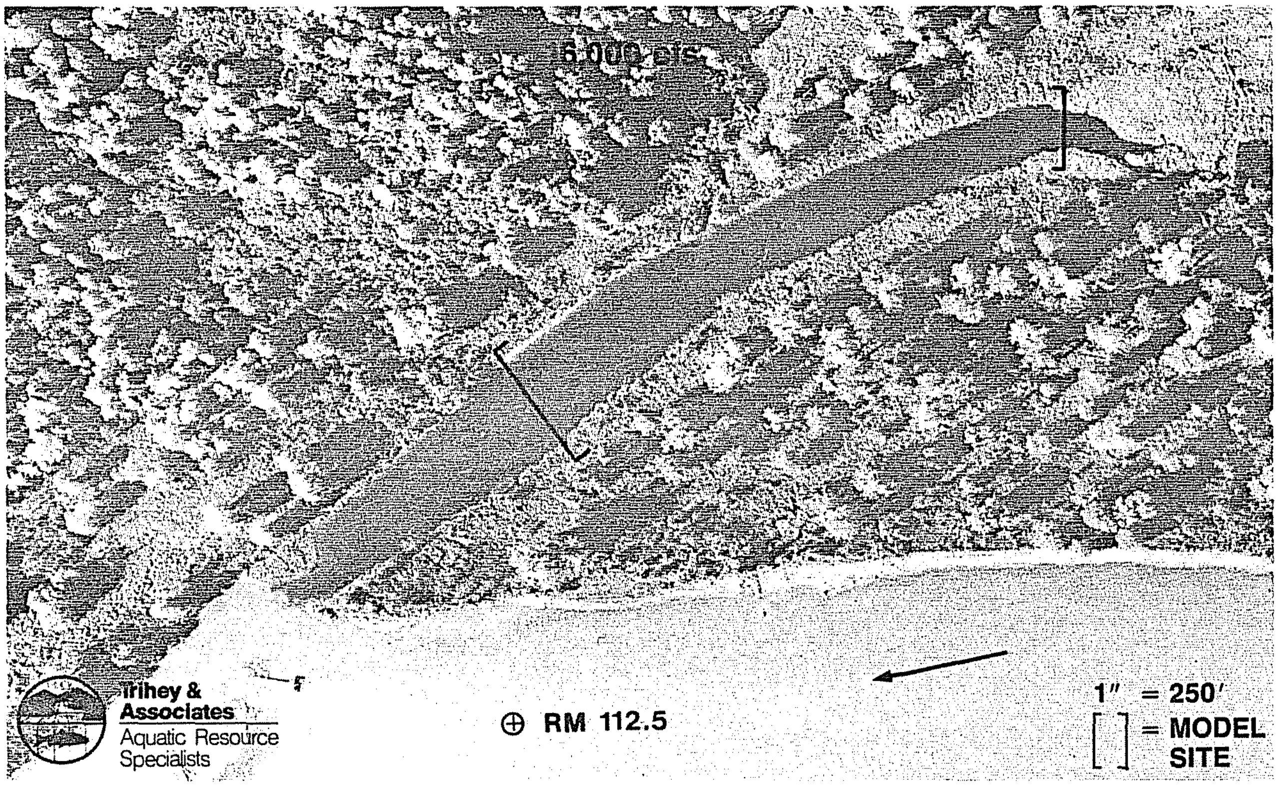
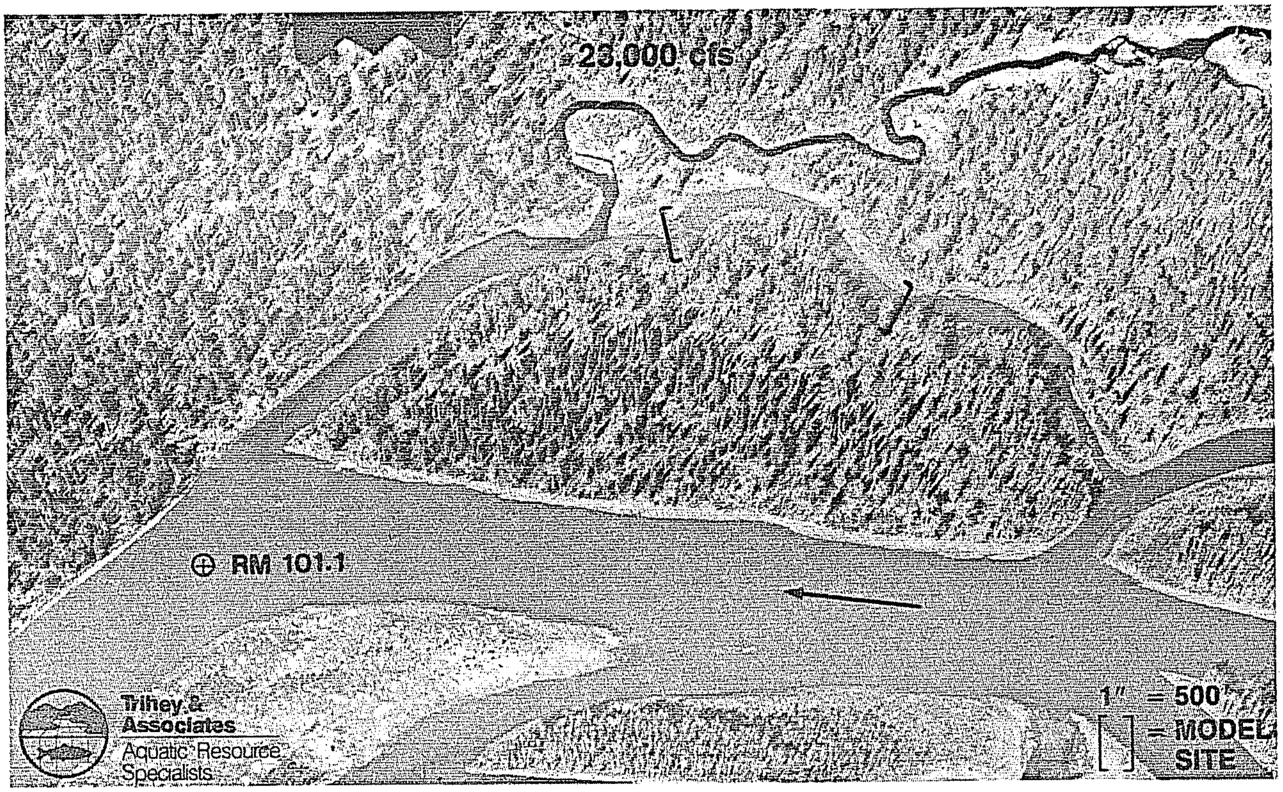


Plate A-2 **Aerial photography of modeling site 112.5L at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at > 35,000 cfs and is included in Representative Group I.**



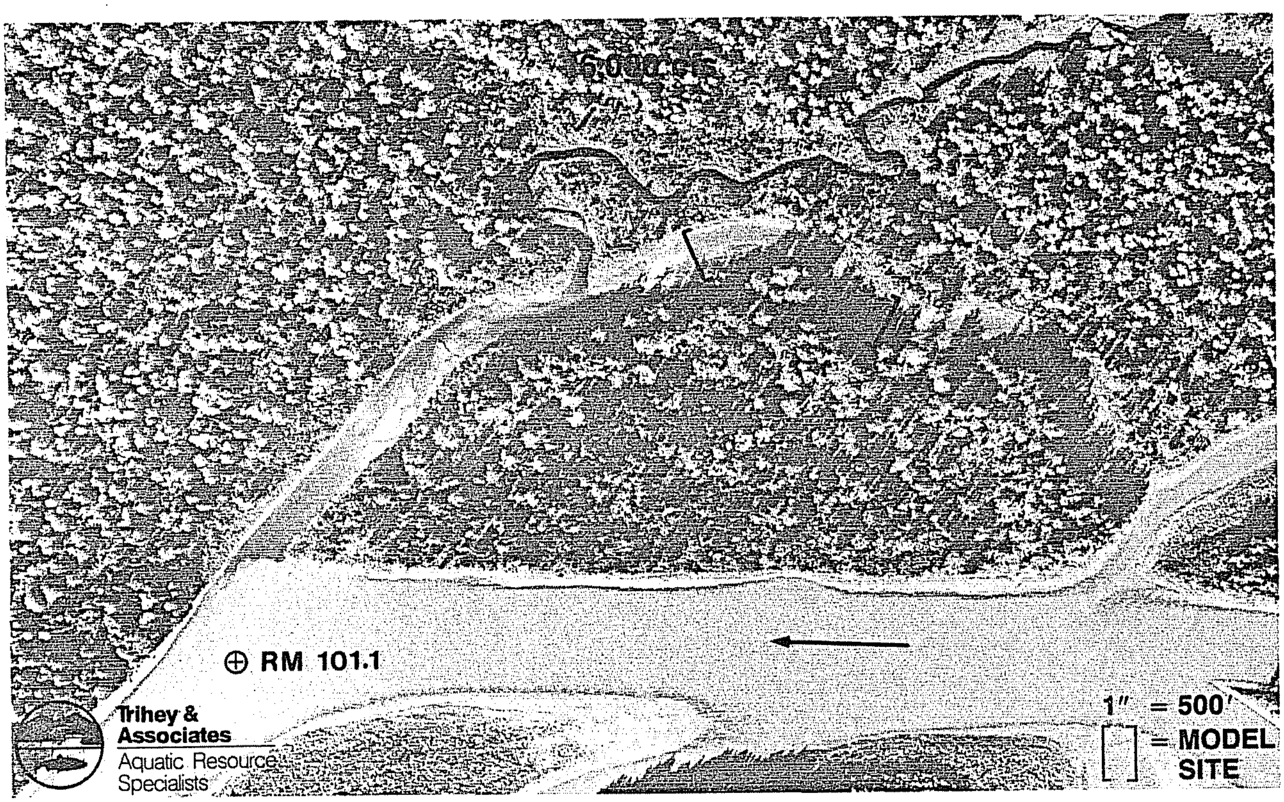
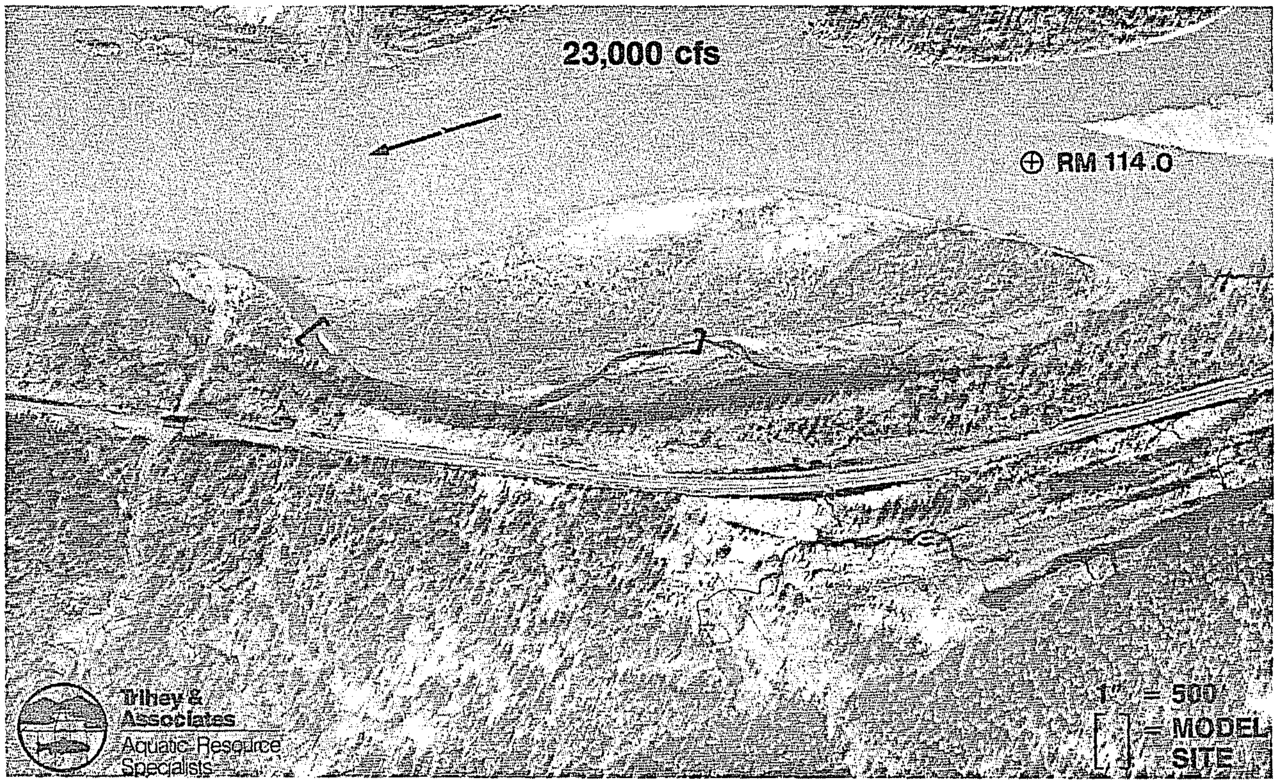


Plate A-3 Aerial photography of modeling site 101.4L at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at 22,000 cfs and is included in Representative Group II.



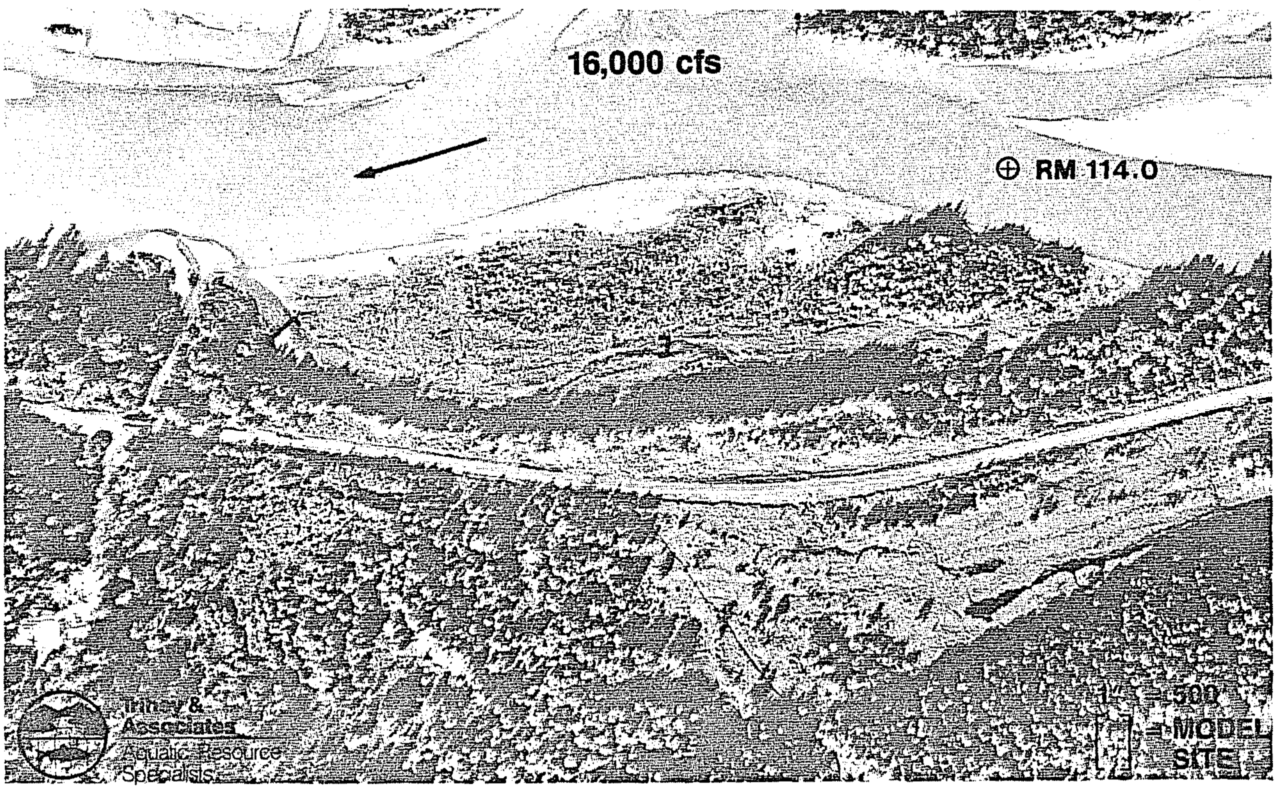
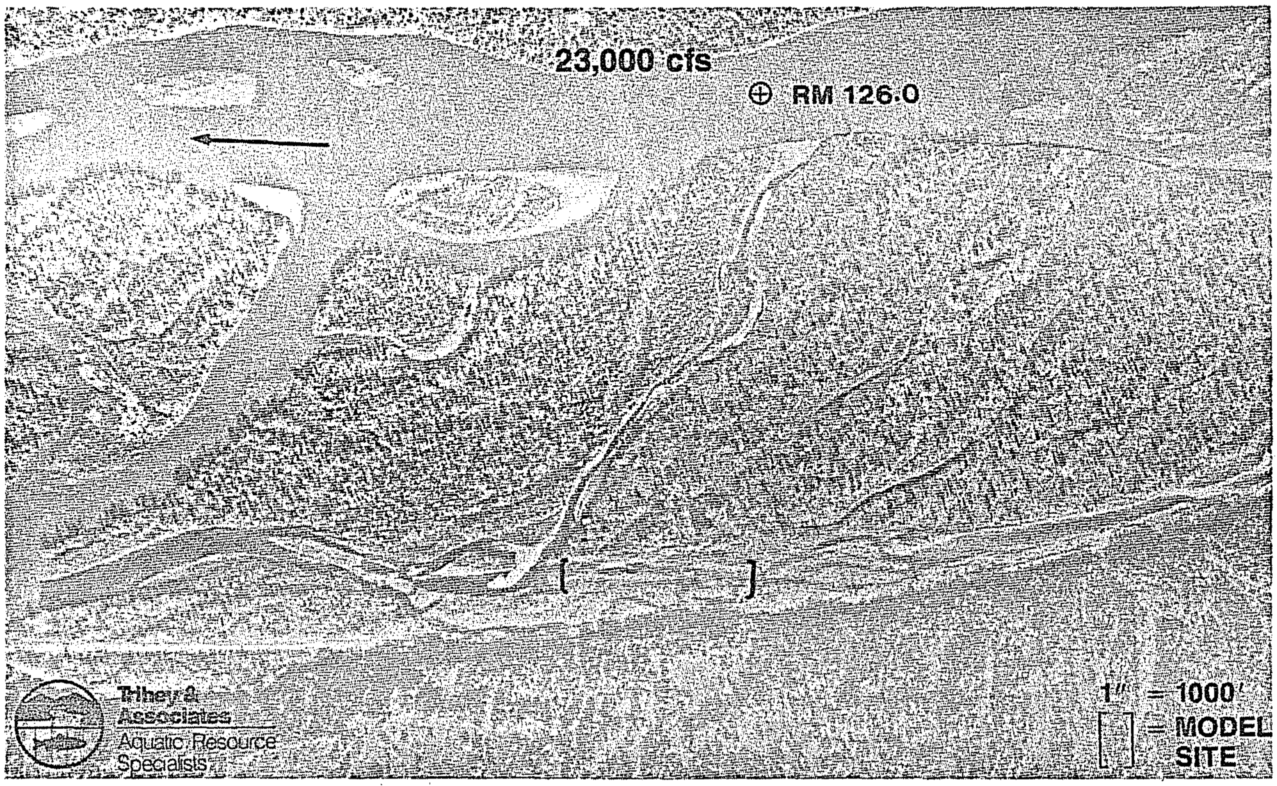


Plate A-4 Aerial photography of modeling site 113.7R at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at 24,000 cfs and is included in Representative Group II.



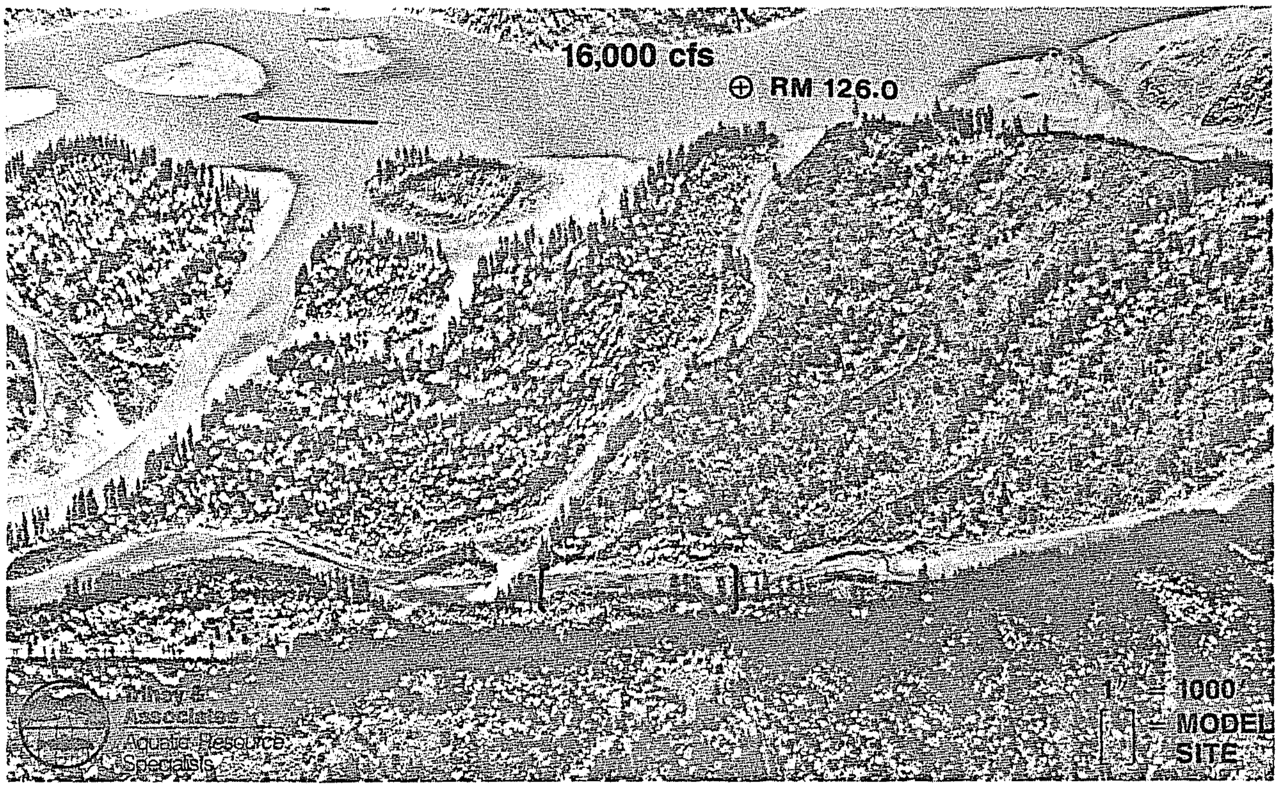
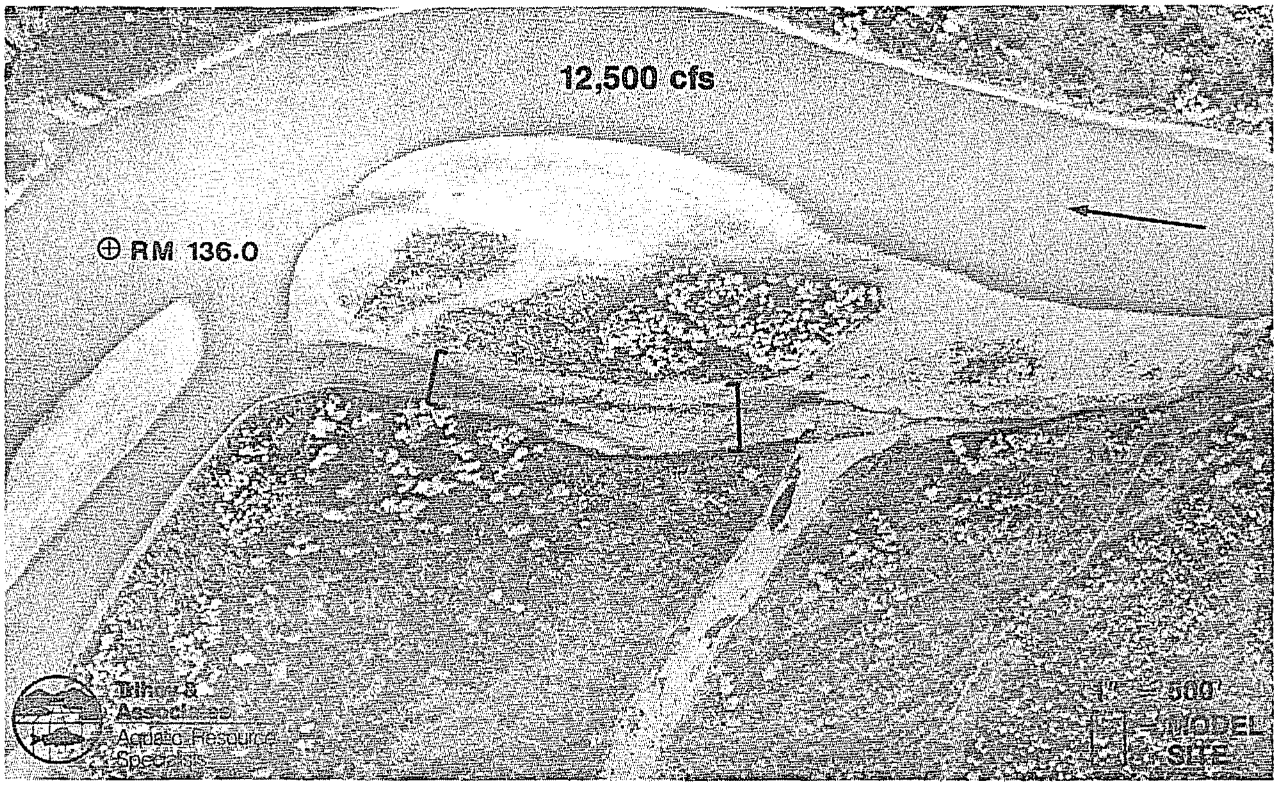


Plate A-5 Aerial photography of modeling site 126.0R at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at 33,000 cfs and is included in Representative Group II.



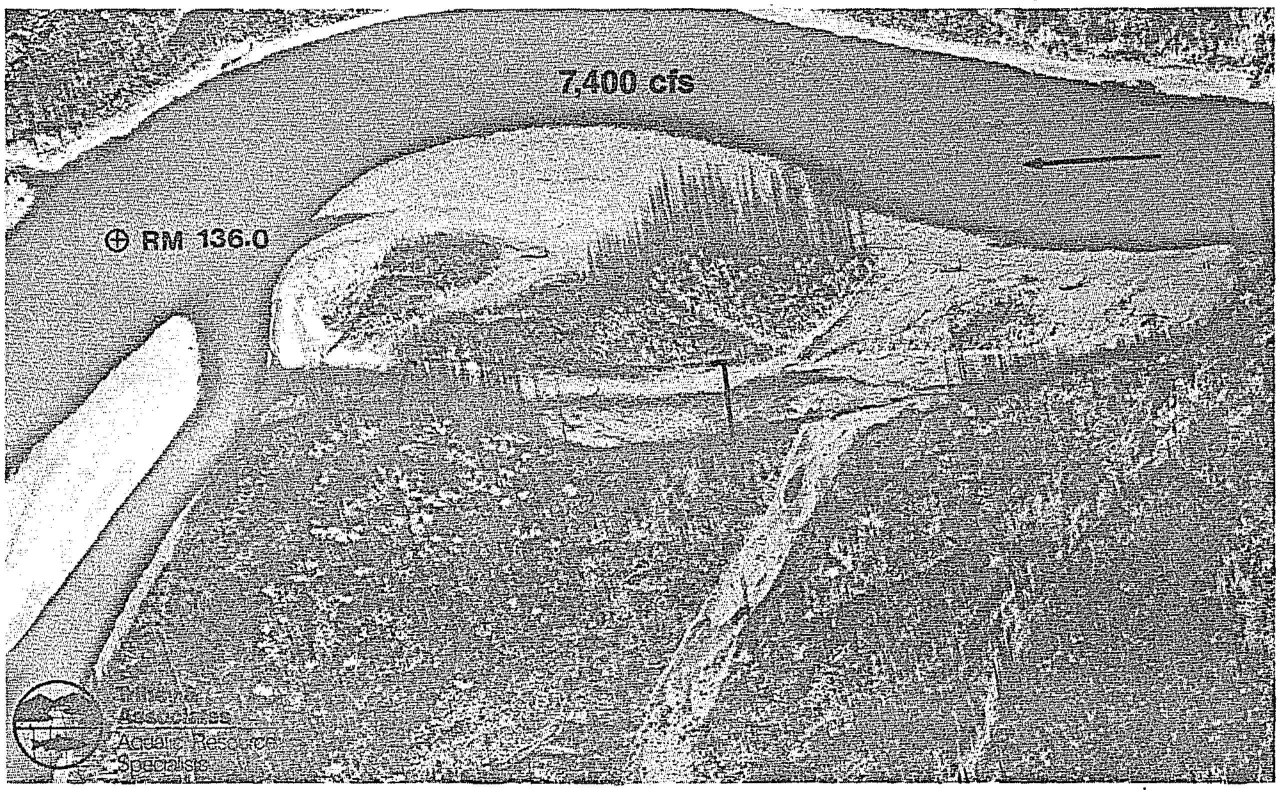
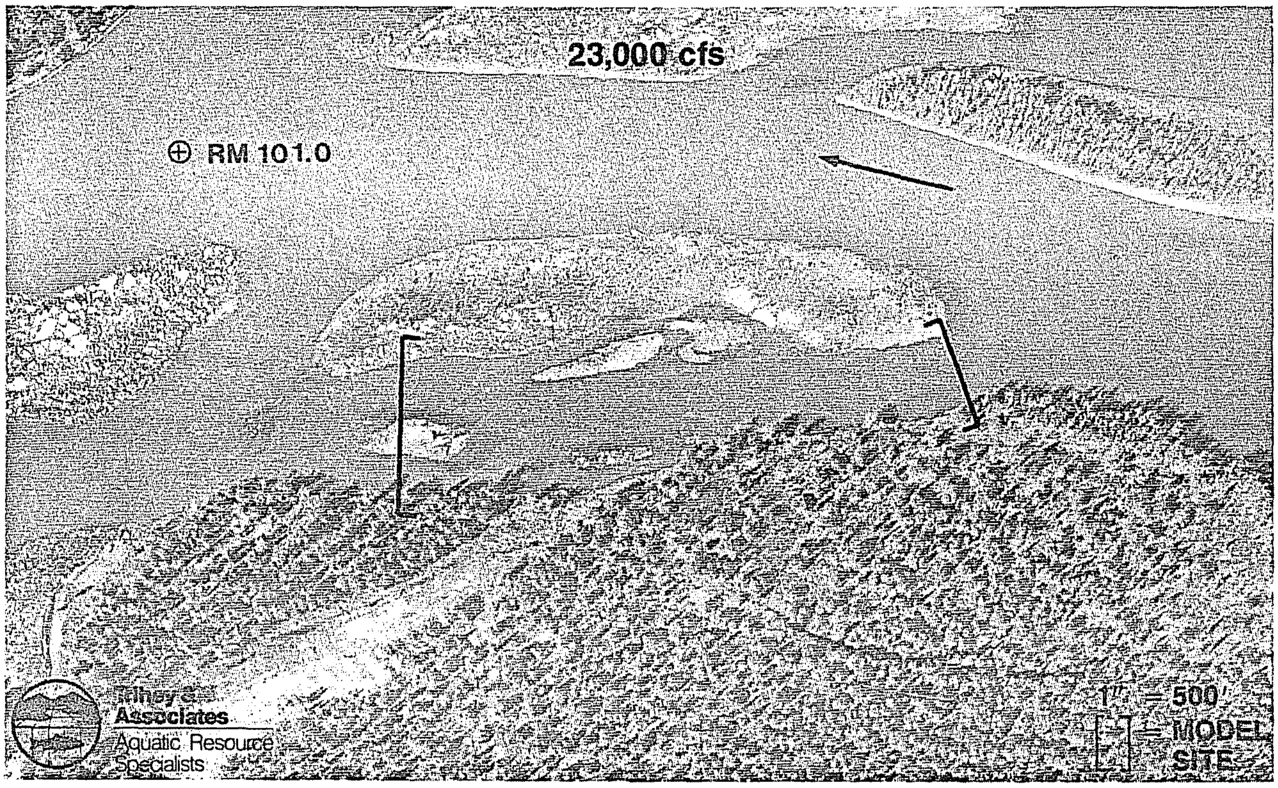


Plate A-26 Aerial photography of modeling site 136.3R at mainstem discharges of 12,500 cfs and 7,400 cfs. Site breaches at 13,000 cfs and is included in Representative Group VI.



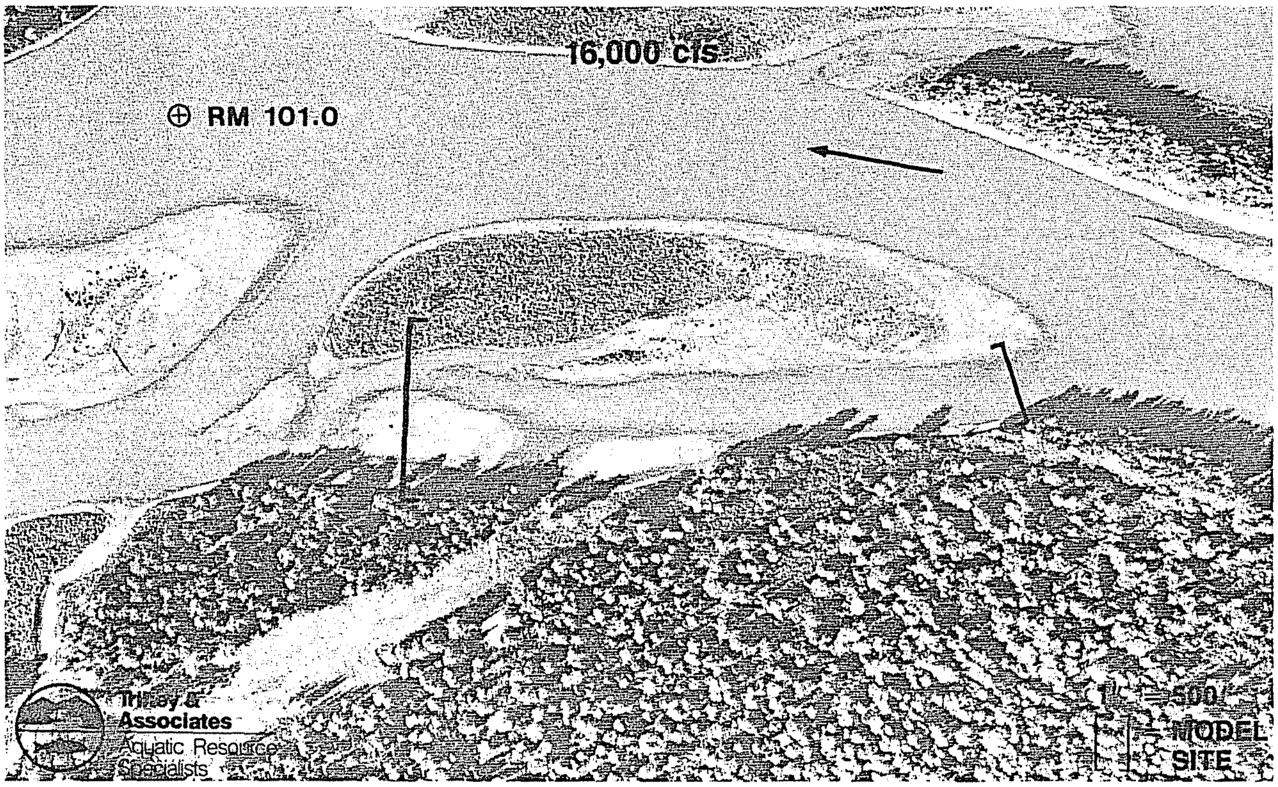
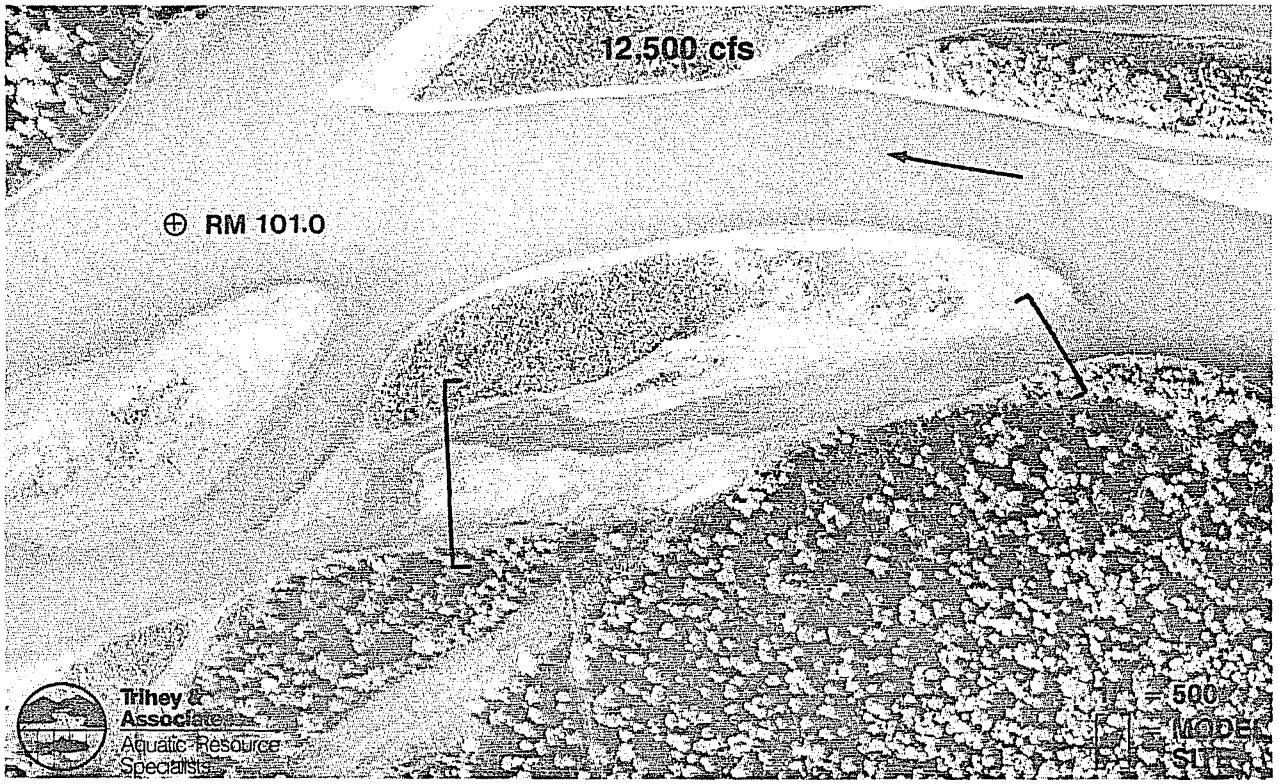


Plate A-7 Aerial photography of modeling site 101.2R at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at 9,200 cfs and is included in Representative Group III.



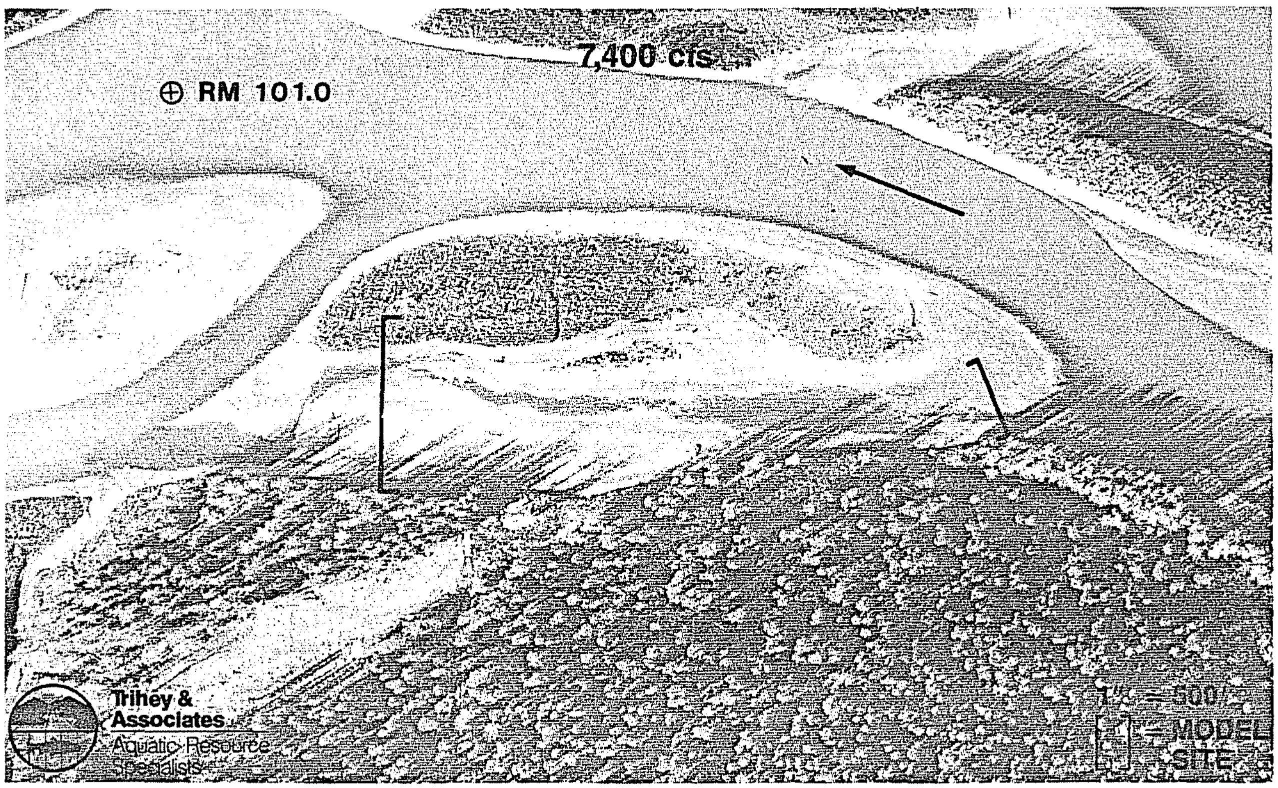
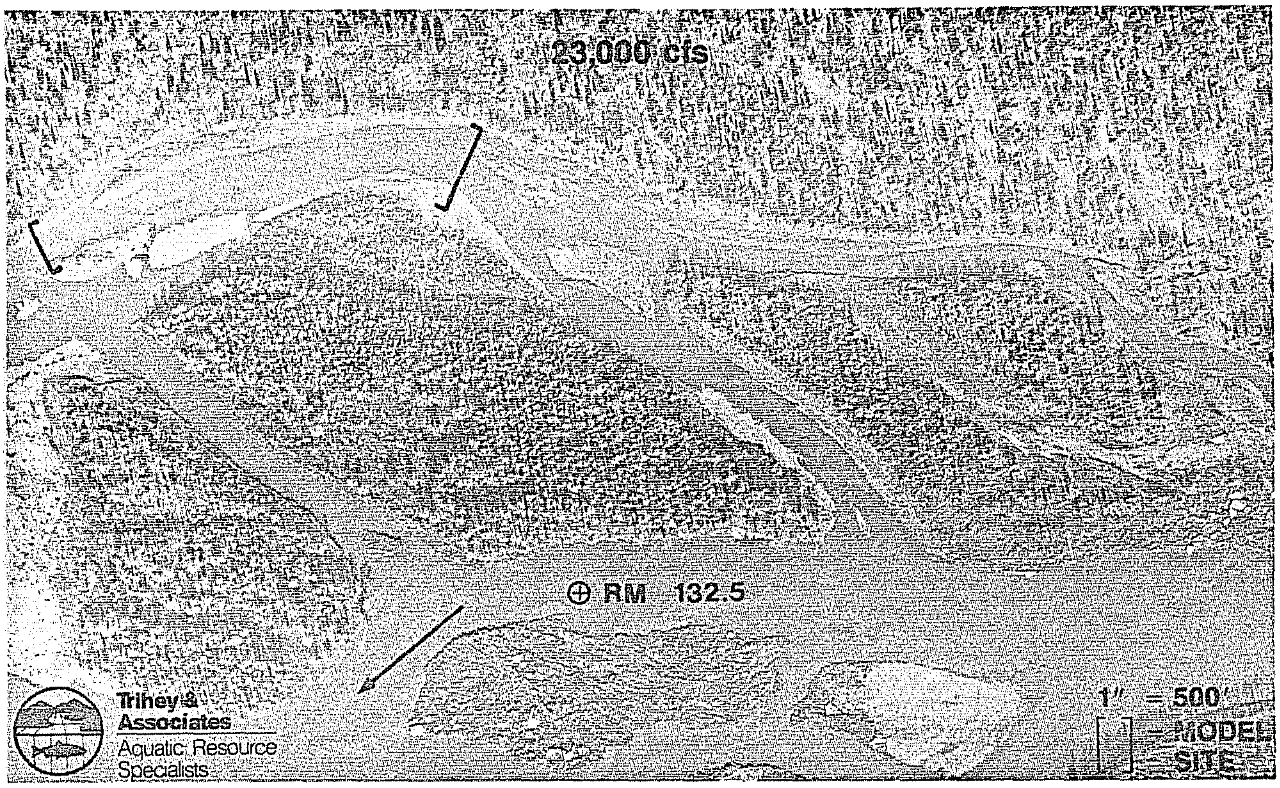


Plate A-8 Aerial photography of modeling site 101.2R at mainstem discharges of 12,500 cfs and 7,400 cfs. Site breaches at 9,200 cfs and is included in Representative Group III.

Plate A-10 Aerial photography of modeling site 128.8R at mainstem discharges of 12,500 cfs and 7,400 cfs. Site breaches at 16,000 cfs and is included in Representative Group III.



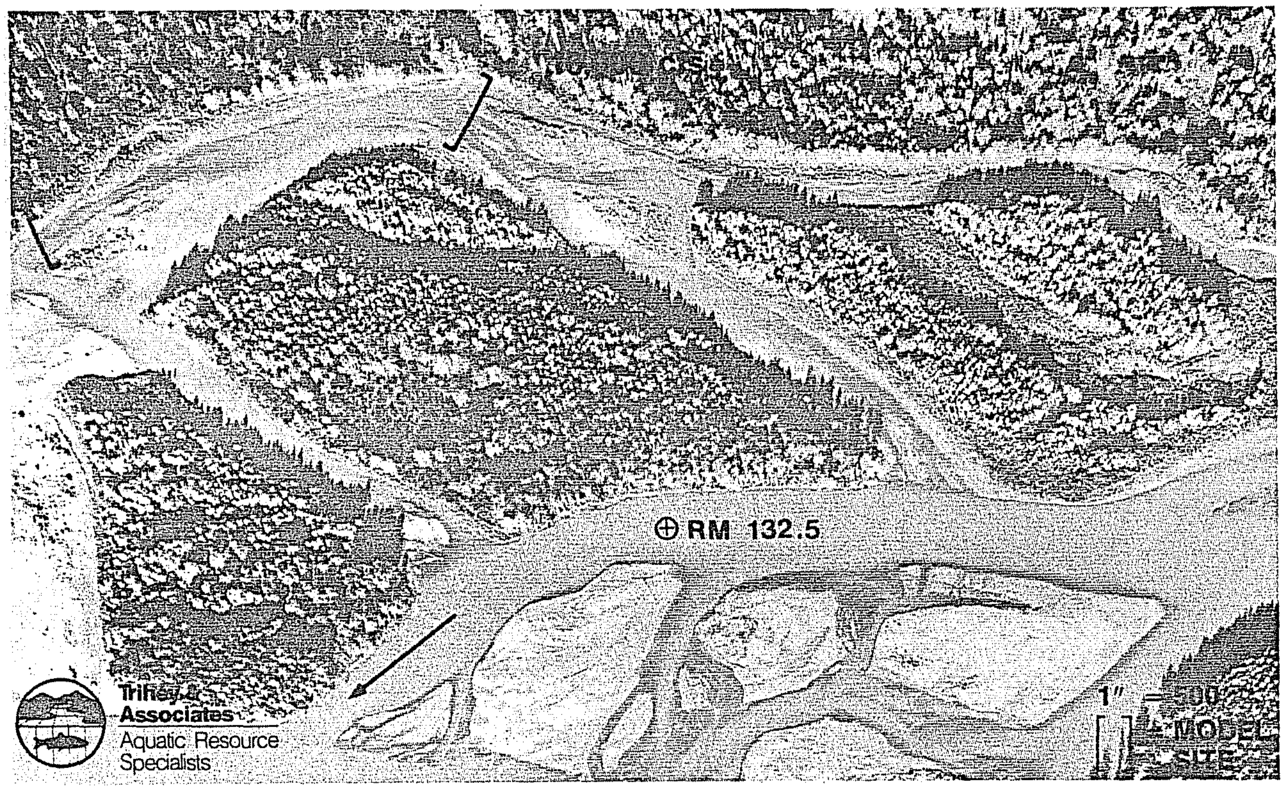
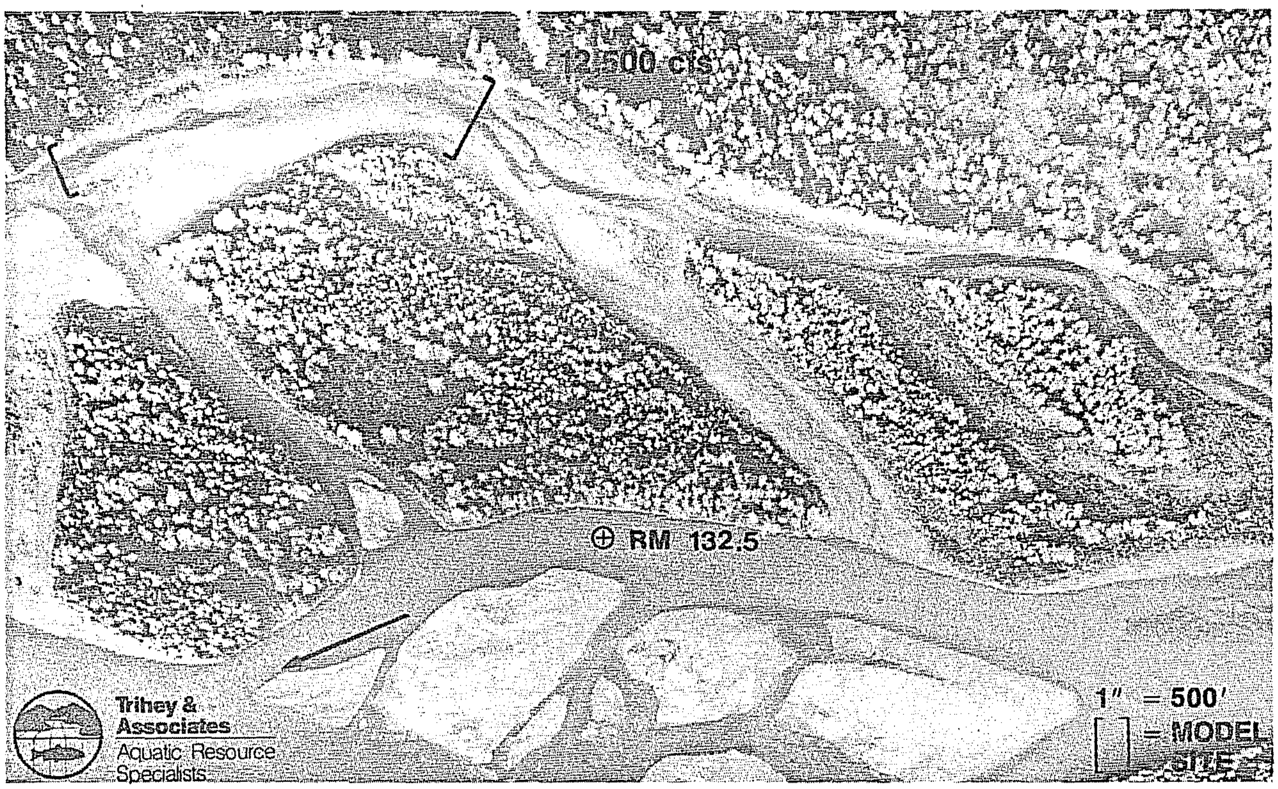


Plate A-11 Aerial photography of modeling site 132.6L at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at 10,500 cfs and is included in Representative Group III.



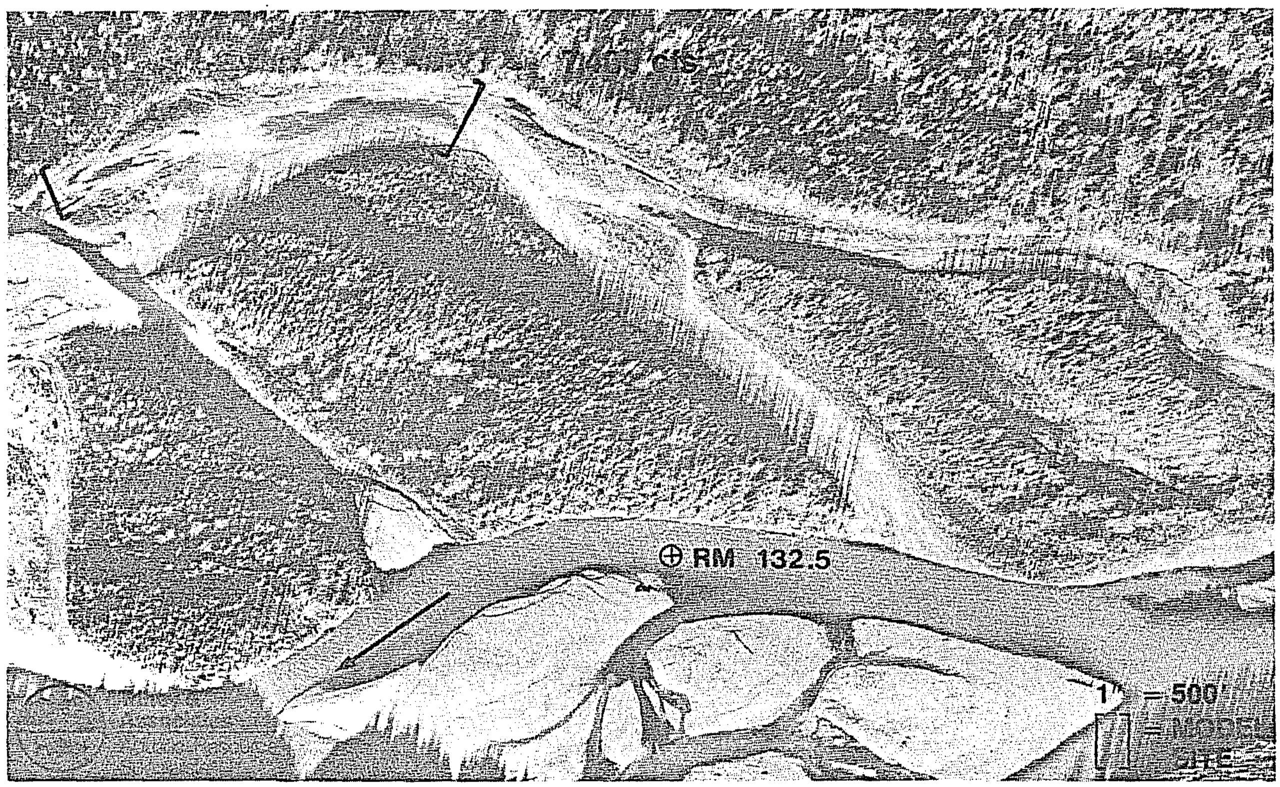


Plate A-12 Aerial photography of modeling site 132.6L at mainstem discharges of 12,500 cfs and 7,400 cfs. Site breaches at 10,500 cfs and is included in Representative Group III.

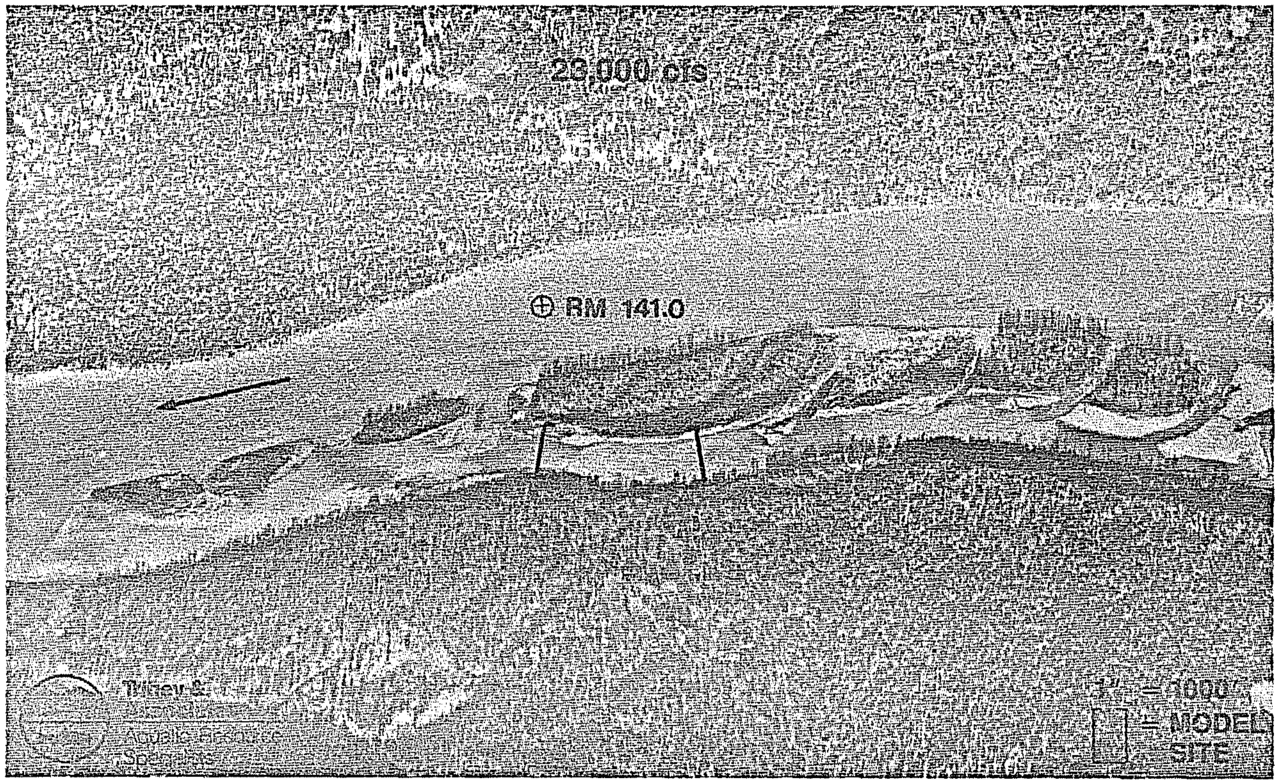


Plate A-13 Aerial photography of modeling site 141.4R at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at 11,500 cfs and is included in Representative Group III.

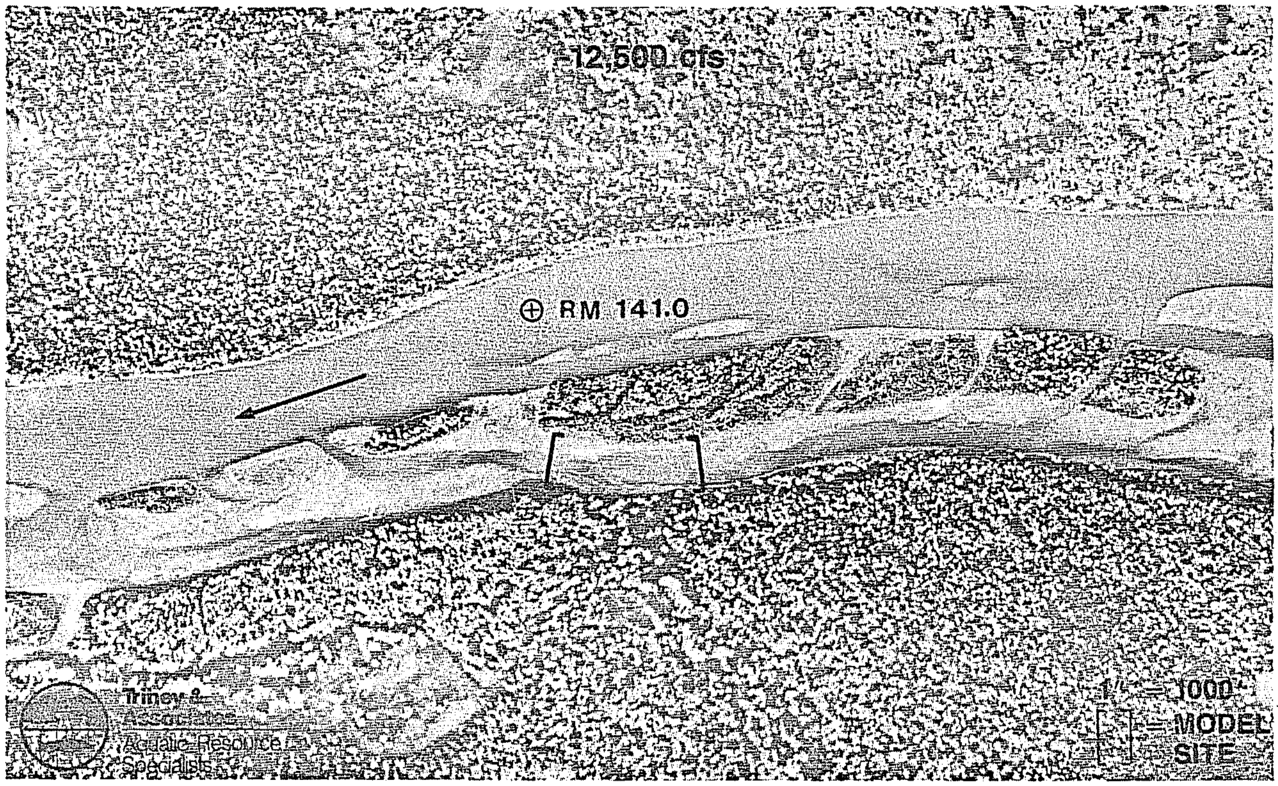
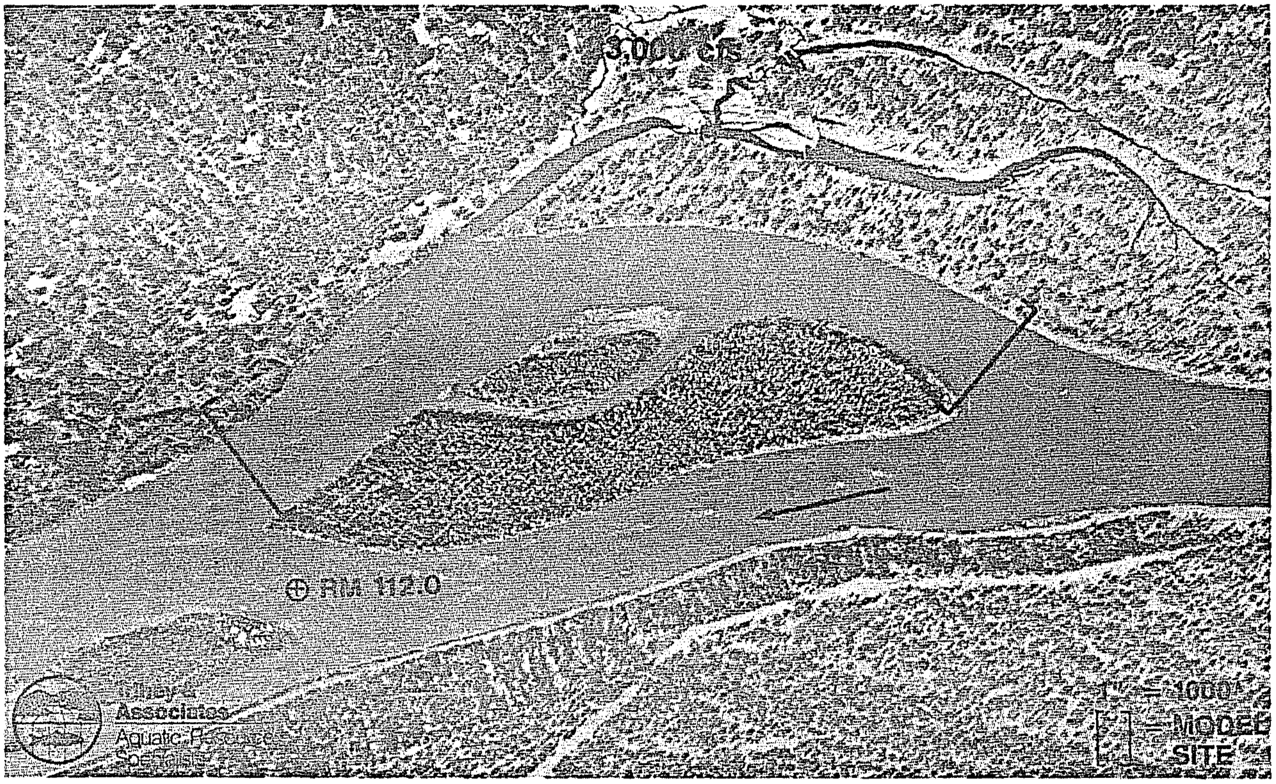


Plate A-14 Aerial photography of modeling site 141.1R at mainstem discharges of 12,500 cfs and 7,400 cfs. Site breaches at 11,500 cfs and is included in Representative Group III.



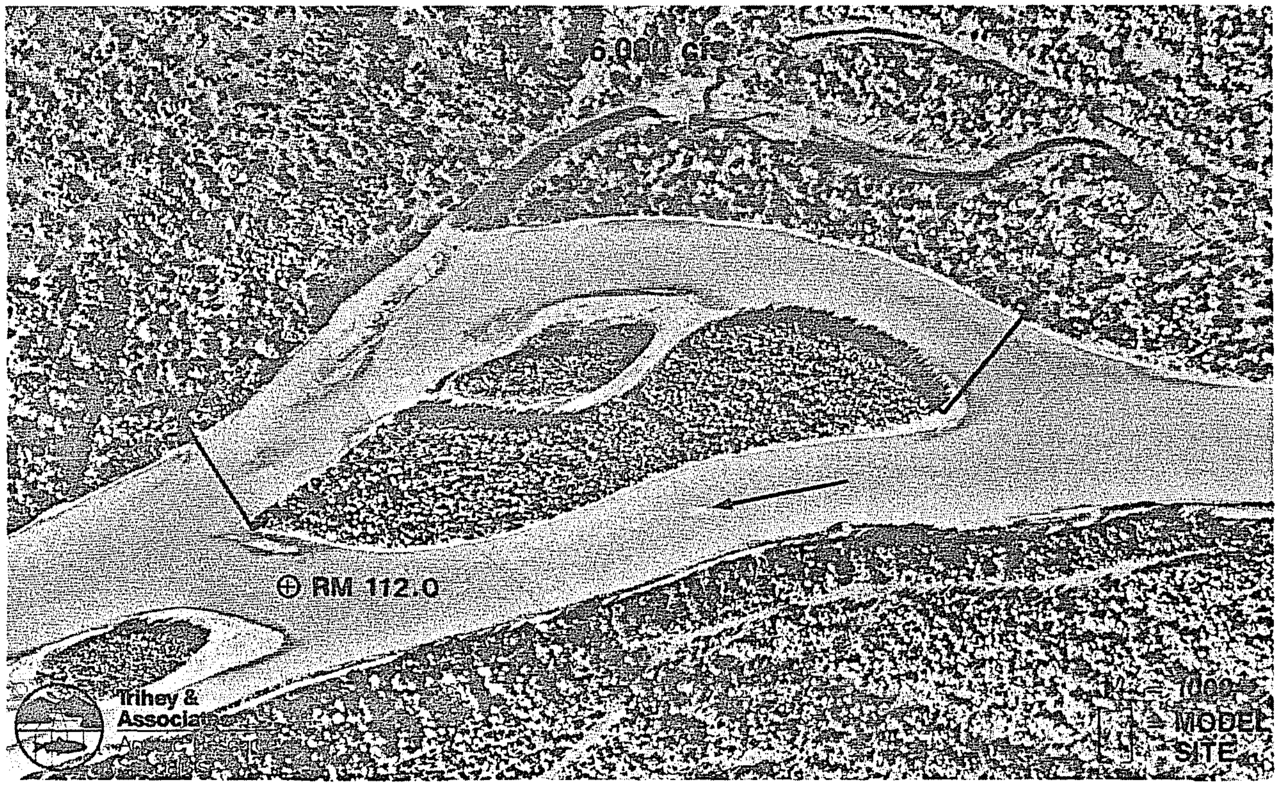


Plate A-15 Aerial photography of modeling site 112.6L at mainstem discharges of 23,000 cfs and 16,000 cfs. Site breaches at < 5,100 cfs and is included in Representative Group IV.