SUSITNA
HYDROELECTRIC PROJECT

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

VOLUME 1
MAIN TEXT

PREPARED BY

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Aquatic Resource Specialists

UNDER CONTRACT TO

HARZA-EBASCO
SUSITNA JOINT VENTURE

FINAL REPORT

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Prepared for
Alaska Power Authority

Final Report
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Alaska Department of Fish and Game Susitna Hydro Aquatic Studies Team (ADF&G Su Hydro) provided essential support for the successful completion of the field studies, stage-discharge analysis and model calibration. In addition, ADF&G Su Hydro had lead responsibility for data base management and preparation of the three appendices which accompany the main text. The ADF&G Su Hydro staff members who participated in the field studies, analyses, and report preparation are listed below:

Andy Hoffmann
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John McConnaughy developed and applied numerous computer programs which facilitated data reduction and model calibration. In addition he produced the preliminary site-specific WUA and time series plots. Allen Bingham selected the statistical analyses and assembled the data base necessary to test the degree to which models were calibrated. Special recognition is given to Karen Meier for completing the stage-discharge analysis and drafting Part II of this report as well as coordinating the ADF&G Su Hydro effort which supported the preparation of this work.

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.

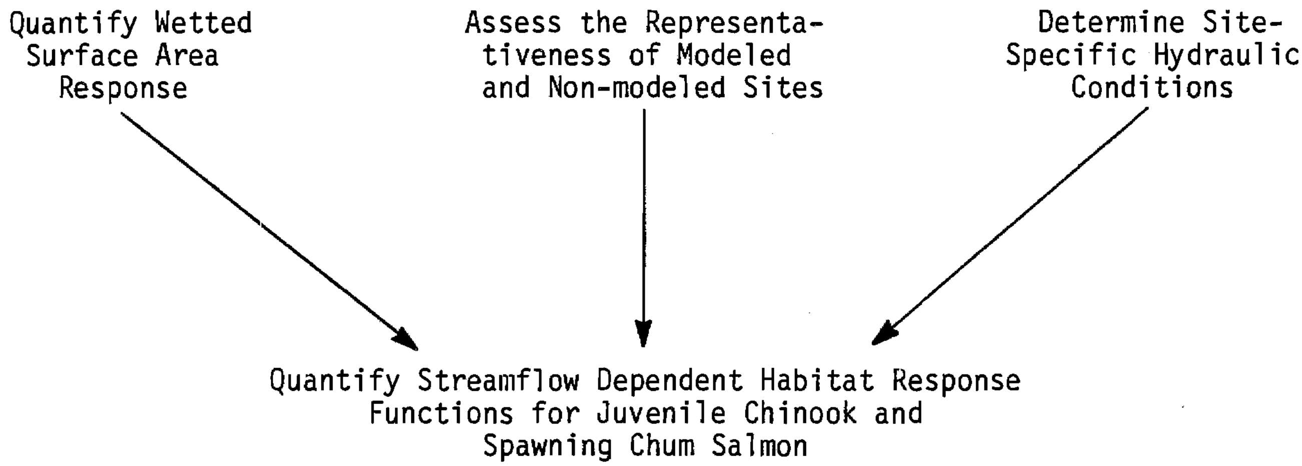
In 1982, following two years of baseline studies, a multi-disciplinary approach to quantify effects of the proposed Susitna Hydroelectric Project on existing fish habitats and to identify mitigation opportunities was initiated. The Instream Flow Relationships Studies focuses on the response of fish habitats 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) integrate the findings of the technical report series, and (3) provide 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 judgement available before March 1985 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 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 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.



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.

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.

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.

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.

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PART I

INTRODUCTION

This report presents data reduction methods and results of the 1984 field studies conducted by E. Woody Trihey and Associates (EWT&A) with assistance from the Alaska Department of Fish and Game Su Hydro Aquatic Studies Team (ADF&G Su Hydro). These studies were undertaken in the Talkeetna-to-Devil Canyon segment of the Susitna River, hereafter referred to as the middle Susitna River, to describe anticipated changes in site-specific hydraulic conditions due to altered streamflows and to assess the response of fish habitat to incremental changes in depth and velocity.

Although field studies and analyses described in this report were completed by a joint EWT&A and ADF&G Su Hydro study team, EWT&A is responsible for the field study design, hydraulic model calibration and analyses presented in this report. Thus, the information and technical interpretations contained in this report are those of EWT&A and do not necessarily represent the viewpoint of the Alaska Department of Fish and Game.

The primary evaluation species for the middle Susitna River have been identified as juvenile chinook salmon (Oncorhynchus tshawytscha) and spawning chum salmon (O. keta) (EWT&A and WCC 1985). Therefore, the habitat modeling results presented in this report are limited to these species and life stages. Due to the marked difference in hydraulic conditions typically associated with the habitats occupied by these species and life stages, two habitat modeling concepts were applied.

Central to the middle Susitna River analysis is the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM) and its associated hydraulic models (IFG-2 and IFG-4). These models are intended for use where streamflow is a primary determinant of fish habitat and instream hydraulics can be classified as being gradually varied and within a rigid channel (Trihey 1979; Trihey and Baldrige 1985). When evaluating rearing conditions for juvenile chinook in the middle Susitna River these requisites generally prevail. Thus, application of the IFIM models is well-suited for the habitat conditions being evaluated.

In contrast, chum salmon spawning typically occurs in side channel backwater areas or along shore margins (Barrett, Thompson, and Wick 1984), where hydraulic conditions are often spatially varied or possess near zero velocity. Neither of these conditions is compatible with the theoretical assumptions of the IFG hydraulic models. Therefore, an alternative approach which did not require that gradually varied flow exist in a defined channel, was developed for calculating the response of chum spawning habitat to incremental changes in mainstem discharge. This model is referred to in this report as the Direct Input Habitat, or DIHAB, model.

The IFIM and DIHAB models used in the analyses calculate wetted surface area (WSA) and weighted usable area (WUA). The DIHAB model produces identical results as the IFIM HABTAT model using the same habitat suitability criteria within both models to calculate WUA. Habitat suitability criteria used in the models are based on data collected in middle Susitna River habitats by ADF&G Su Hydro (Suchanek et al. 1984, Estes and Vincent-Lang, eds. 1984c) and further described by EWT&A and WCC 1985 and Steward 1985.

This report is organized into a general introduction (Part I) and three technical sections (Parts II through IV). Each technical section is supported by an appendix which contains field data and intermediate analytic results. Part II of the report describes water surface elevation and site-flow analysis and presents various relationships between mainstem discharge, site-specific flow, and water surface elevations (stage). These relationships are extensively used in Parts III and IV of the report to calibrate and validate IFG hydraulic models, estimate water surface elevations at modeling sites corresponding to unobserved mainstem discharges, and convert the mainstem streamflow hydrograph into site-specific flow hydrographs. Part III of the report describes the calibration procedures for the IFG hydraulic models and presents WUA forecasts for juvenile chinook in side channel and mainstem habitats based on evaluations of turbidity, structural cover, depth and velocity. Part IV describes application of the DIHAB model developed by EWT&A and presents site-specific WUA forecasts for spawning chum salmon in side channel and mainstem habitats based on evaluation of upwelling, substrate composition, depth and velocity.

PART II

RELATIONSHIPS BETWEEN MAINSTEM DISCHARGE, SITE FLOW AND WATER SURFACE ELEVATION

The hydraulic parameters of depth, velocity, and wetted surface area influence aquatic habitat availability in the middle Susitna River. Their magnitudes are dependent on the discharge and the water surface elevation, or "stage," of the river. This section presents the relationships, and the methods used to determine them, of stage to mainstem discharge, the flow in side channels to mainstem discharge, and the flow in side channels to stage (hereinafter referred to as stage-discharge, flow-discharge, and flow-stage, respectively).

A notable transition is expected to occur in existing mainstem and side channel habitat as a result of project-induced changes in the natural flow regime of the middle Susitna River. Aerial photography and relevant project literature (ADF&G Su Hydro 1981; ADF&G Su Hydro 1983a; Barrett, Thompson, and Wick 1984) provided the basis for selecting candidate areas for evaluating project effects on juvenile chinook and spawning chum salmon habitats. As a result, 130 juvenile chinook side channel and mainstem sites, and 43 spawning chum side channel and mainstem margin sites were identified. Potential juvenile chinook study sites were either known or suspected rearing habitat. Potential spawning chum study sites were of two types: areas where chum salmon spawning had been observed, and areas with apparent upwelling based on open thermal leads in the March 1983 aerial photography where spawning chum salmon had not been previously reported (upwelling is discussed in detail in Part IV).

The candidate study sites, for both juvenile chinook and spawning chum, were classified into eleven "representative groups" according to the habitat transformation they underwent as the mainstem discharge decreased from 23,000 to 5,100 cfs (Aaserude, Theile, and Trudgen 1985). Included in each representative group are sites for which habitat models were developed. Eight juvenile chinook and 14 spawning chum salmon sites were selected for habitat modeling in 1984. Inherent to the habitat models are the hydraulic relationships of stage-discharge, flow-discharge, and flow-stage.

To collect the data for the stage-discharge, flow-discharge, and flow-stage relationships, staff gages were installed during the 1984 field season at cross sections within the 22 sites (Figure II-1). The stage at varying numbers of cross sections at each site was monitored throughout August, September, and October and site flows were measured periodically at side channel sites. The data collected were used to develop relationships between stage and mainstem discharge at each cross section where a staff gage was installed. In addition, one cross section at each of the nine side channel sites was chosen to develop a relationship between site flow and both stage and mainstem discharge.

A mainstem discharge range of 5,000 to 35,000 cubic feet per second (cfs) was selected as the ideal range for evaluating hydraulic conditions and for assessing juvenile rearing habitat potential in the middle Susitna River. This range is appropriate because it encompasses nearly all mean daily discharges that have occurred during the rearing season, May 20 to September 15, as well as the mean daily discharges that are expected to occur during the open water season under with-project conditions, from about April to October.

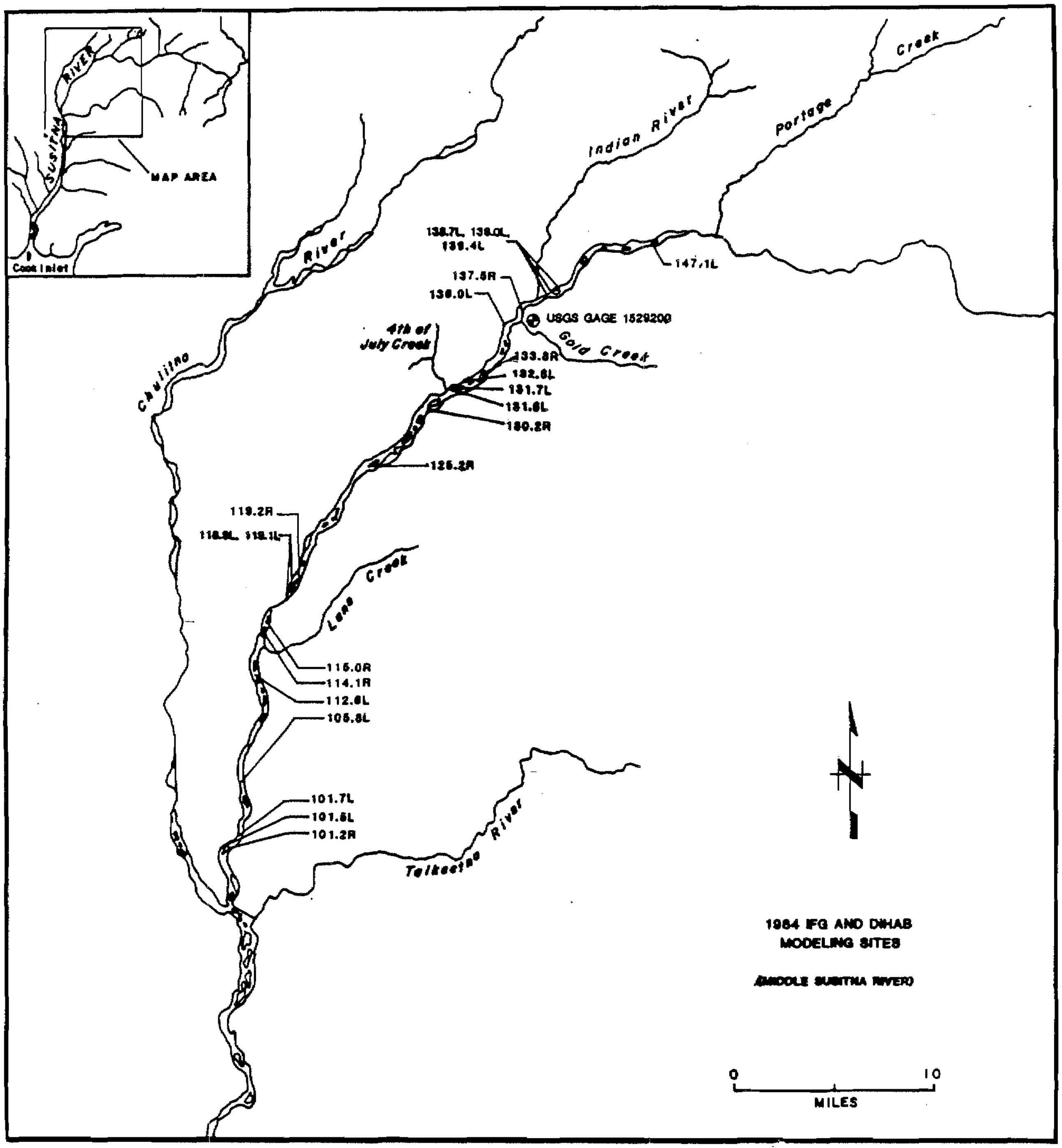
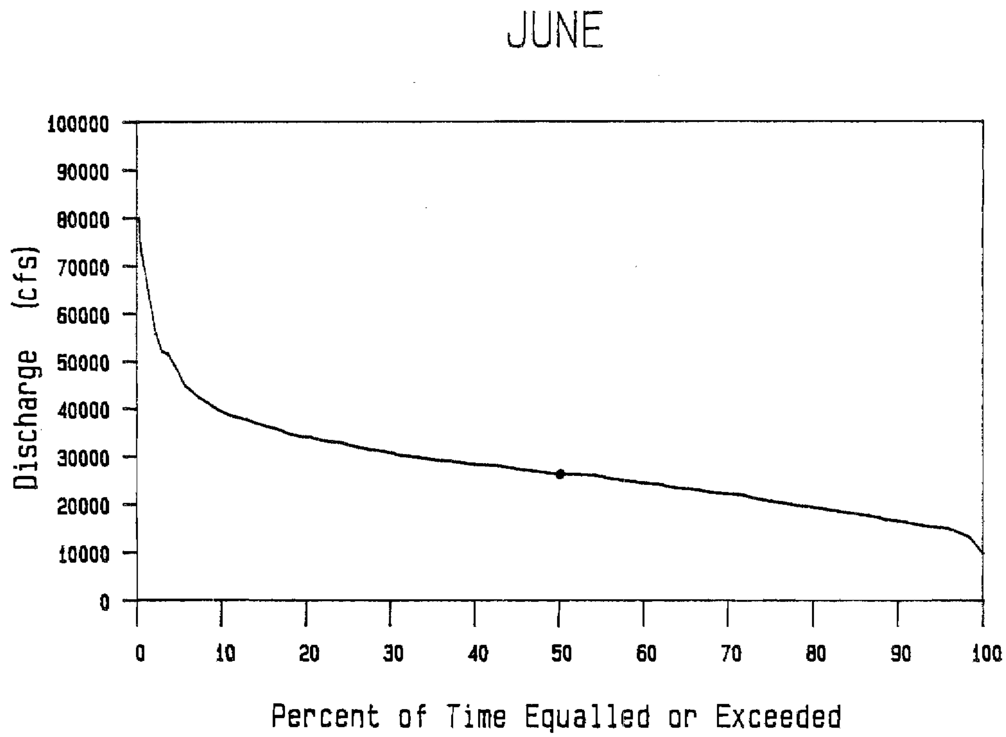


Figure II-1. Middle Susitna River modeling sites.

Flow-duration analyses for both natural and with-project conditions for this period indicate this is an appropriate evaluation range (Williams 1985). Associated with the 90, 50, and 10 percent exceedance values at that time were discharges of 13,600; 21,900; and 33,200 cfs for the natural conditions and 8,100; 9,400; and 12,600 cfs for with-project conditions.

Included in the juvenile rearing evaluation period is the chum salmon spawning period (August 12 to September 15). A mainstem discharge range of 5,000 to 25,000 cfs was selected for assessing spawning habitat potential for this period. Separate flow-duration analysis were not undertaken for the spawning season as it is encompassed within the rearing season. Discharges occurring in June, July, August and September 1984 correspond to exceedance values of 49.9, 29.3, 51.8 and 73.1, respectively. This indicates for the first three months of the open water season the discharges were average or slightly higher than normal whereas in September, the discharges were lower than normal (Figures II-2 and II-3).

Aerial photographs of the middle Susitna River have been obtained at the following discharges: 5,100; 7,400; 10,600; 12,500; 16,000; 18,000; and 23,000 cfs. These photographs were used extensively in determining the breaching discharges at each study site. A breaching discharge is that mainstem discharge at which mainstem stage at the channel entrance is sufficient to overtop the head berm, thereby initiating the flow of turbid mainstem water through the site. The photographs were also used to determine the mainstem range over which the relationships that were developed could be applied.



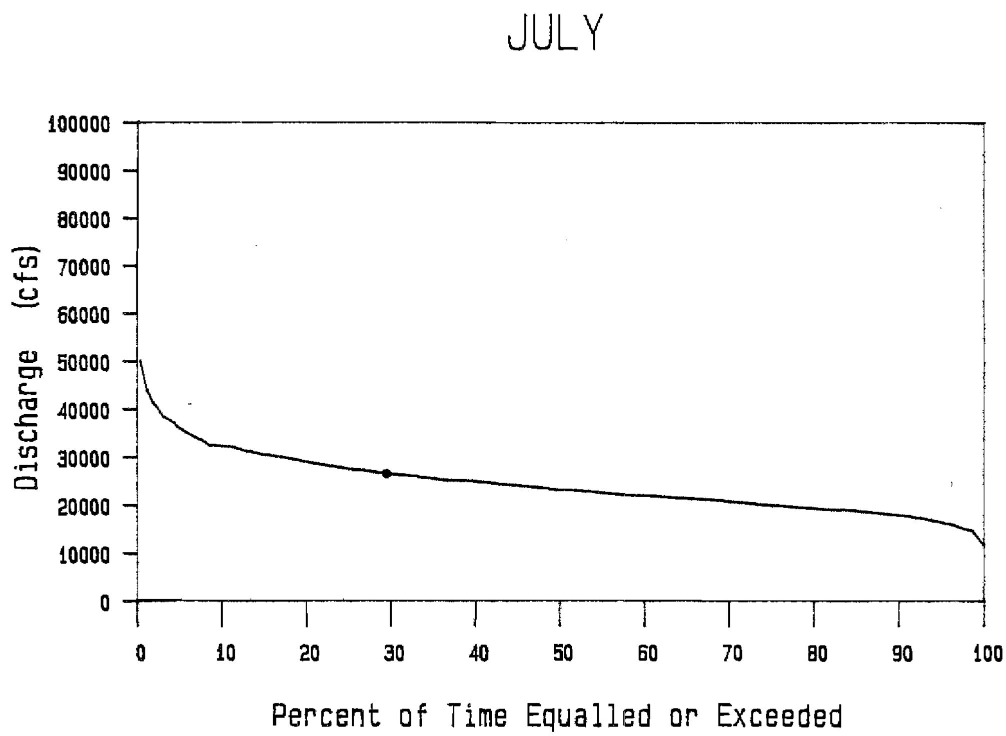
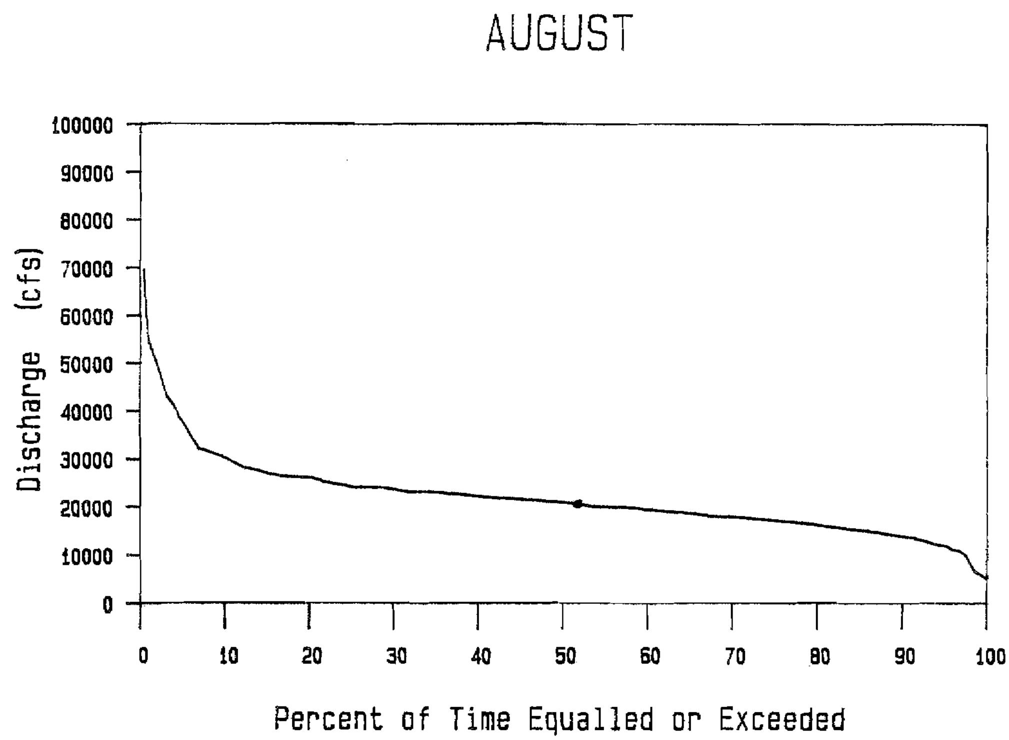


Figure II-2. Flow-duration curves for June and July based on mean daily Susitna River discharges at Gold Creek, 1950-1984 and corresponding exceedence values for 1984 mean monthly discharges.



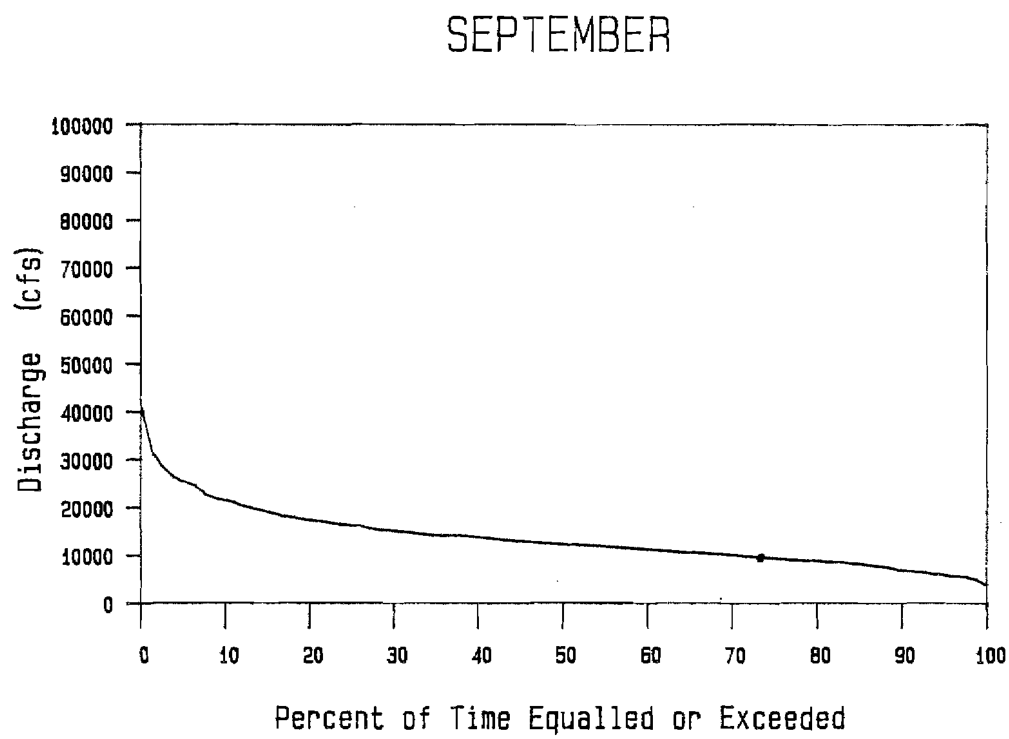


Figure II-3. Flow-duration curves for August and September based on mean daily Susitna River discharges at Gold Creek, 1950-1984 and corresponding exceedence values for 1984 mean monthly discharges.

In this report, the word "flow" is consistently used in association with site-specific streamflow, while "discharge" refers to Susitna River streamflow as gaged at Gold Creek.

FIELD PROCEDURES

The collection of site-specific data to develop the relationships described above entailed locating and installing staff gages, measuring stage over a wide range of mainstem discharges, and periodically measuring site flow at the side channel sites.

Staff gage location and installation: At each study site, a varying number of Leopold and Stevens staff gages were installed. Cross sections were established within each study reach and represented unique subreaches based on channel hydraulics and habitat characteristics. At cross sections where the standard gage height, 3.33 feet, was inadequate to monitor the full range of stages that occurred during August, September, and October, as many as three gages were installed in a tiered formation. Staff gages were identified by river mile (RM), location within the site, position relative to flow level, (low, medium, high) and the associated cross section number (Table II-1). Aquatic study teams conducted differential level surveys between the top of each staff gage and a point of known elevation (project datum), established by R&M Consultants, Inc. between 1980 and 1982.

Further information regarding staff gage installation may be found in the 1984 ADF&G Su Hydro Procedures Manual (ADF&G Su Hydro 1984).

Table II-1. Identification codes for staff gages.

Location in Site	Code	Flow Level	Code
Mainstem	M	High	A
Side Channel	S	Medium	B
Side Channel Mouth	W	Low	C
Side Channel Head	H		
Other	X		
Spawning Sites	P		

Stage measurements: Staff gages were typically read three to five times and covered a range of mainstem discharges. Stage was read to the nearest 0.01 ft. When a staff gage was dewatered, the water surface elevation was obtained through differential level surveying. Water surface elevations were also obtained during cross section and streambed profile surveys. Whether the channel was breached (that is, receiving flow from the mainstem) or unbreached at the time of the stage measurement was also recorded.

Flow measurements: Site flow was measured at each of the side channel modeling sites at a minimum of three different mainstem discharges. One cross section at each site was selected as the flow measurement cross section. This section was ideally located in a portion of the site where channel shape and slope were stable and where flow was relatively uniform across the channel. A top-set wading rod and either a Marsh-McBirney or Price AA flow meter were used to measure depth and velocity. Depth was measured to the nearest 0.05 ft and velocities were measured to 0.1 feet per second (fps). Measurements were taken across each cross section at 20 to 25 verticals in accordance with standard methods of the U.S. Geological Survey (Buchanan and Somers 1969). The flow angle was also recorded when the flow was not perpendicular to the cross section.

DATA ANALYSIS

Mainstem discharge: Mean daily streamflows for the Susitna River at Gold Creek were obtained from USGS for the years 1950 - 1984 (USGS 1950 - 1984).

Relationship between stage and mainstem discharge (WSEL vs. Q): As mainstem discharge in the middle Susitna River increases, the stage at each of the cross sections within the 22 modeling sites also increases. The extent to which stage increases depends on channel geometry and channel morphology, whether the site is breached, and whether the site is affected by mainstem backwater. The stage at cross sections within pool habitats remain relatively constant until site flow is sufficiently high enough to drown out the riffles and pools and occur as a run. In riffle or run habitats, stage typically increases steadily with increases in mainstem discharge. A site which is unbreached may be dewatered except at the mouth, where mainstem backwater may be present.

Mathematical formulae were developed to relate stage to discharge at each cross section. A linear regression using a least squares method was used. Straight line functions were obtained by logarithmically transforming both variables, and equations were thus, of the form:

$$WSEL = 10^a Q^b + C$$

where:

WSEL = true water surface elevation in ft

Q = mean daily discharge at Gold Creek in cfs

a,b = coefficients determined from regression analysis

C = a reference elevation in ft, used in the analysis to allow one full log cycle to represent 1 to 10 ft of stage.

More than one equation was often required to relate stage to discharge at a single cross section. This was due to physical attributes of the site, such as geometry at the head berm and hydrologic and hydraulic characteristics of the other channels in the vicinity. Equations could not be developed for mainstem discharges less than the breaching discharge since site flow and stage is then controlled by local runoff or groundwater inflow rather than by the mainstem.

Aerial photography and field observations were used in determining the discharges at which changes in stage-discharge relationships might be expected. Stage-discharge plots are included in Figures II-4 to II-27 and Figures A-1.1 to A-1.30 for the 22 study sites. Also shown on the plots are the equations which were developed, the application range of each equation, the number of data points (n) used in the regression analysis, and the coefficient of determination (r^2).

Relationship between site flow and mainstem discharge (q vs. Q): Like the stage-discharge relationship, the relationship between site flow and mainstem discharge is a straight line function when both variables are logarithmically transformed. Equations were developed through linear regression analyses for the side channel modeling sites and were of the form:

$$q = 10^a Q^b$$

where:

q = site flow in cfs

Q = mean daily discharge at Gold Creek in cfs

a,b = coefficients determined by regression analysis

Site flow may be present when a side channel is unbreached, due to tributary inflow, upwelling, and local runoff. Once the channel is breached, however, site flow includes flow from the mainstem. Site flow is said to be "controlled" by the mainstem when local sources are insignificant in comparison to inflow from the mainstem. These controlling discharges were identified primarily by distinct breaks in the flow-discharge plots. For some sites, the breaching discharge and controlling discharge are the same. For others, the controlling discharge is as much as 2,000 cfs higher than the breaching discharge.

Aaserude, Thiele, and Trudgen (1985) demonstrated that site flow in a channel with gently sloped sides at the head berm would increase rapidly with small increases in mainstem stage. At a site with the same breaching discharge and a narrow, incised channel entrance, site flow will increase at a much lower rate for the same increases in mainstem stage. The flow-discharge curve will be steep for the first channel type and flat to moderate for the second type. In addition, a major grade break in channel geometry at the entrance may result in a transition from a flat flow-discharge curve to a steep one, or vice versa. More than one equation would thus be required to relate site flow to mainstem discharge.

The need for multiple flow-discharge equations at a site could also be due to additional channels becoming active. The channels may contribute additional flow to the site and thus effect a steeper curve. Conversely, the site flow could level off as other channels are breached and mainstem water is diverted before it reaches the site, thus resulting in a flatter curve.

In the regression analyses, site flows were generally correlated to mean daily discharges at Gold Creek. When discharge was rising or falling rapidly, however, it was not appropriate to use the mean daily value. To estimate the instantaneous mainstem discharge at the site in this case, a time-lag analysis was used which incorporated the distance of the site from Gold Creek, the average mainstem velocity, and the time of day that the site flow measurement was made.

Flow-discharge plots for the side channel modeling sites are included in Figures II-4, II-5, II-9, II-14, II-16, II-19, II-20, II-22, and II-27. Also shown on the plots are the equations that were developed, the application range of each equation, the number of data points (n) used in the regression analysis, and the coefficient of determination (r^2).

Relationship between site flow and stage (q vs. WSEL): Equations to relate site flow to stage were developed for each of the flow measurement cross sections at the side channel modeling sites. Both variables were logarithmically transformed, and an equation developed through linear regression by the least squares method. Equations were of the form:

$$q = 10^a(WSEL - C)^b$$

where:

q = site flow in cfs

WSEL = true water surface elevation in ft

a,b = coefficients determined by regression analysis

C = a reference elevation in ft used in the analysis to allow one full log cycle to represent 1 to 10 ft of stage

Flow-stage plots for the side channel modeling sites are included in Figures II-4, II-5, II-9, II-14, II-16, II-19, II-20, II-22, and II-27. Also shown on the plots are the equations that were developed, the application range of each equation, the number of data points (n) used in the regression analysis, and the coefficient of determination (r^2).

The plots of each of the three relationships (stage-discharge, flow-discharge, flow-stage) developed at the flow measurement cross sections are presented on the same page and are aligned in such a manner as to allow simultaneous inspection of the relationships developed from a common data base. The plots also show the application range of the equations in relation to the data from which they were developed.

RESULTS

The following section provides site-specific descriptions at the 22 modeling sites of the flow conditions, relationships between stage, flow and discharge as well as the appropriate application ranges for each relationship. Data used in the plots and in the development of the regression equations are presented in Appendix A.

Site 101.2R: This side channel becomes breached at 9,200 cfs. Below 9,200 cfs, ponded water is present throughout the site with only the backwater area near the mouth connected to the mainstem. The small overflow channel in the right side of the study site becomes breached at 14,000 cfs.

Staff gages were installed and stage monitored at each of the nine cross sections that were established. A stage-discharge equation for breached conditions was developed for each cross section. The lower limit of the application range of the stage-discharge equations is 9,200 cfs for all cross sections except cross sections 2 and 5. These cross sections do not extend beyond the small overflow channel into the main channel; the lower application limit, therefore, is 14,000 cfs. The highest mainstem discharge for which stage was recorded at all nine cross sections was 23,000 cfs. The stages at cross sections 1 and 2 were also recorded at 27,700 cfs. This additional data point was in line with the other points on the log-log plot, and indicated no changes in the stage-discharge relationship between 23,000 and 27,700 cfs. Above 27,700 cfs, however, it appears from cross section plots and aerial photography that hydraulic conditions in the site may change significantly. The upper limits of the stage-discharge relationships therefore, were set at 27,700 cfs for all nine cross sections.

Although the channel is breached at 9,200 cfs, flow is not controlled by the mainstem until 10,300 cfs. Flow was measured at cross section 8 when mainstem discharge was 11,200, 15,300, and 17,400 cfs and the resulting flow-discharge curve is very steep. When the equation is applied to 35,000 cfs, a site flow of 120,000 cfs is produced. The upper limit of the application range was thus, set at 17,400 cfs. The lower limit is the controlling discharge of

10,300 cfs. Additional data is required to determine the mainstem discharge at which there is an inflection point in the flow-discharge curve.

A flow-stage equation was also developed at cross section 8 and has the same application range as the flow-discharge relationship of 10,300 to 17,400 cfs.

Plots and equations for the three relationships at cross section 8 are shown in Figure II-4. The plots and equations for the stage-discharge relationships at the other eight cross sections in this study site are shown in Figures A-1.1 through A-1.4. A staff gage was also installed at the head of the site in the mainstem. The plot and equation for this gage are shown in Figure A-1.5.

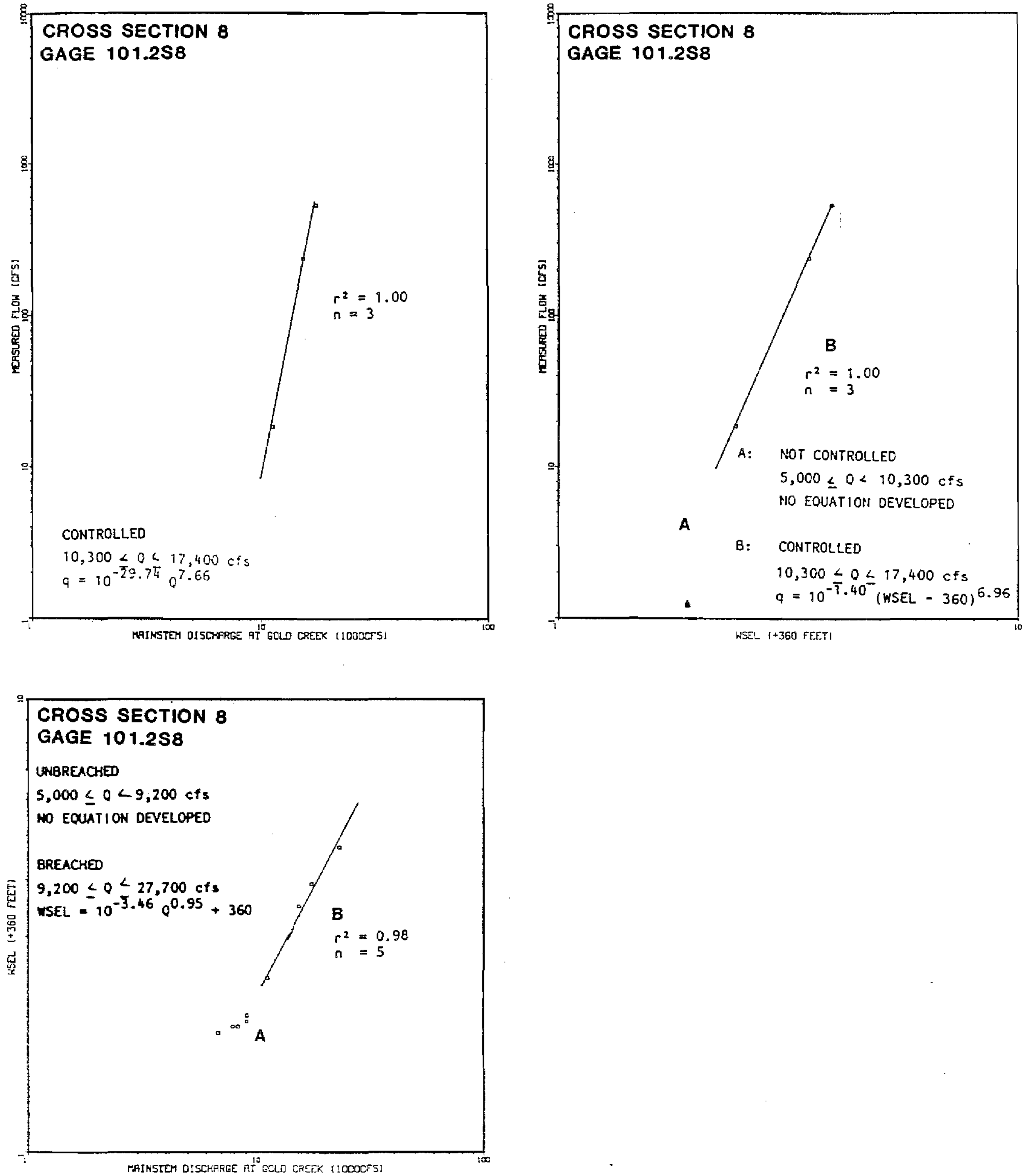


Figure II-4. Stage-discharge, flow-discharage, and flow-stage relationships for cross section 8 at site 101.2R.

Site 101.5L: This large side channel becomes breached at a mainstem discharge less than 5,100 cfs. Stage was monitored at two of the five cross sections, numbers 2 and 5, in 1982 and 1983, and stage-discharge relationships were developed (Estes and Vincent-Lang, eds. 1984a). In 1984, an additional staff gage was installed at cross section 1. The data base for the equations at cross sections 2 and 5 were relatively large with both indicating a distinct change in the relationship between stage and discharge. This change is identified by an inflection point at 7,980 cfs (cross section 2) and at 16,400 cfs (cross section 5). The slope of the lower portion of the curve at cross section 2 is quite flat and reflects mainstem backwater influence. The change in slope at the inflection point is less pronounced for cross section 5, however, with the break in the stage-discharge relationship due to cross sectional geometry. In developing a stage-discharge relationship at cross section 1, only six points, considerably less than the others, were available. Since cross section 1 is downstream from cross section 2, however, an inflection point in the stage-discharge relationship at about 8,000 cfs due to mainstem backwater effects was also expected to occur, and the relationship was broken at 7,830 cfs. The data base covered the mainstem range of 6,210 to 28,900 cfs at cross section 1 and 4,500 to 26,600 cfs at cross sections 2 and 5. The lower limit of the application range was standardized at 5,000 cfs at each of the three cross sections and the upper limits at 35,000 cfs since applying the formulas beyond the data range did not produce questionable results.

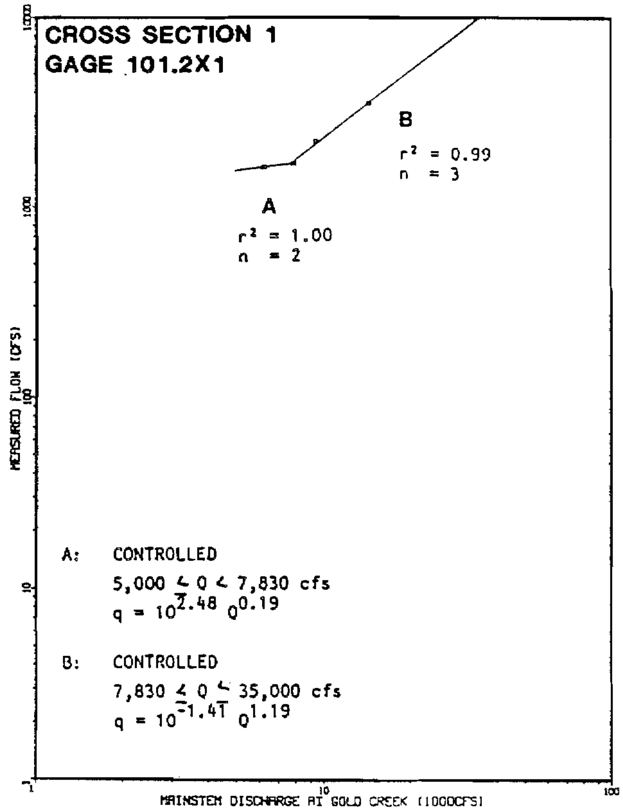
Channel hydraulics in this side channel are controlled by the mainstem for the entire evaluation range of 5,000 to 35,000 cfs with site flow slightly influenced by tributary inflow and distributary outflow. In addition, Whiskers

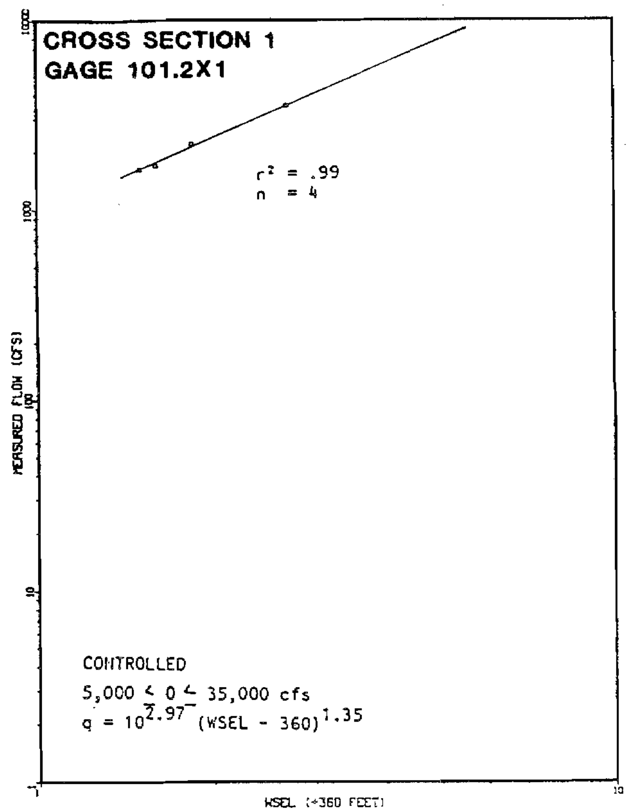
Creek flows into the site just below cross section 2 but does not contribute significantly to the total site flow. An overflow channel on the right bank of the study site between cross sections 3 and 4 redirects flow back into the mainstem at discharges greater than 12,000 cfs, but outflow amounts to less than ten percent of the total site flow.

Flow measurements in this study site were made at cross sections 3, 4, and 5. However, the two relationships involving site flow (q vs. Q and q vs. WSEL) were developed at cross section 1 as it was the only cross section for which stage had been monitored in conjunction with the site flow measurements.

The flow-discharge relationship was broken at 7,830 cfs, the discharge at which mainstem backwater effects are diminished at cross section 1. The highest discharge at which flow was measured was 14,400 cfs with the relationship determined to be valid for up to 35,000 cfs. An equation was also developed to relate stage and flow at cross section 1 and it is applicable to the entire evaluation range of 5,000 to 35,000 cfs.

Plots and equations for the three relationships at cross section 1 for this site are shown in Figure II-5. Stage-discharge relationships the cross sections 2 and 5 are shown in Figure A-1.6. No stage data was collected at cross sections 3 and 4.





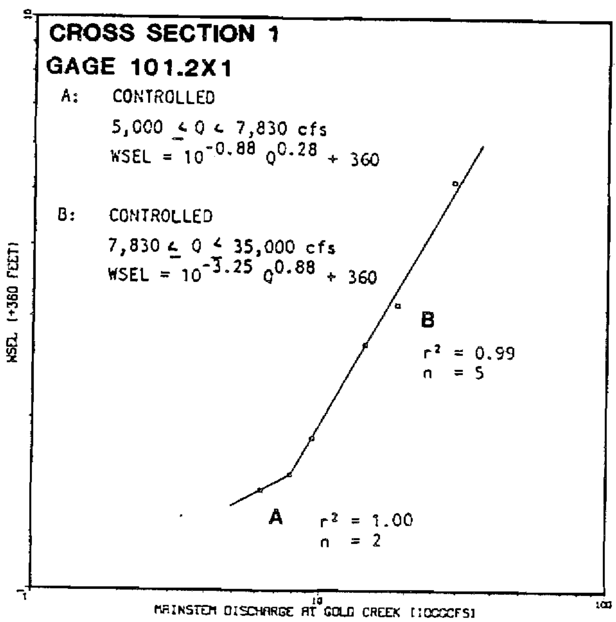


Figure II-5. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 1 at site 101.5L.

Site 101.7L: The gravel bar that constitutes the right bank of this side channel becomes overtopped near cross section 2 at 9,600 cfs. Below 9,600 cfs mainstem backwater extends from the mouth of the side channel (about 125 ft downstream of cross section 1) up to cross section 2. Once the side channel is breached (at 9,600 cfs), backwater extends up to cross sections 3 and 4. At 23,000 cfs, the head of the site, which is about 100 ft upstream of cross section 4, is also breached.

Staff gages were installed at cross sections 1, 3, and 4. One stage-discharge relationship was developed for each cross section from data collected when the mainstem discharge was greater than 9,600 cfs. The upper limit of the application range was extended only slightly beyond the range of available data to 23,000 cfs (from 21,200 cfs) at cross section 1 and to 35,000 cfs (from 29,800 cfs) at cross sections 3 and 4.

The plots and equations for the stage-discharge relationships at this site are shown in Figures II-6 and II-7.

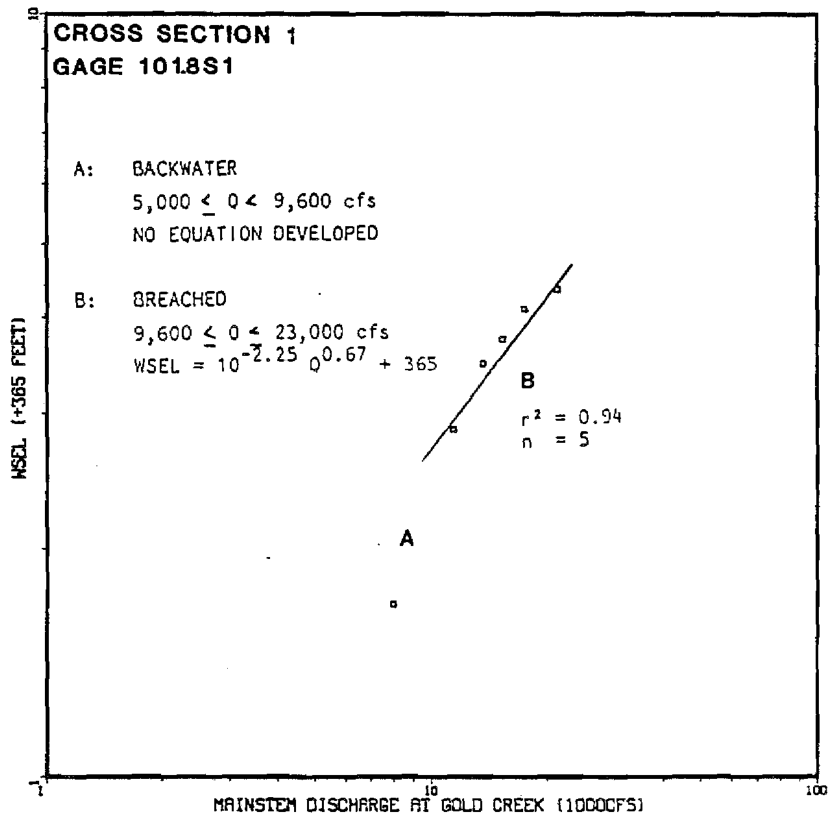
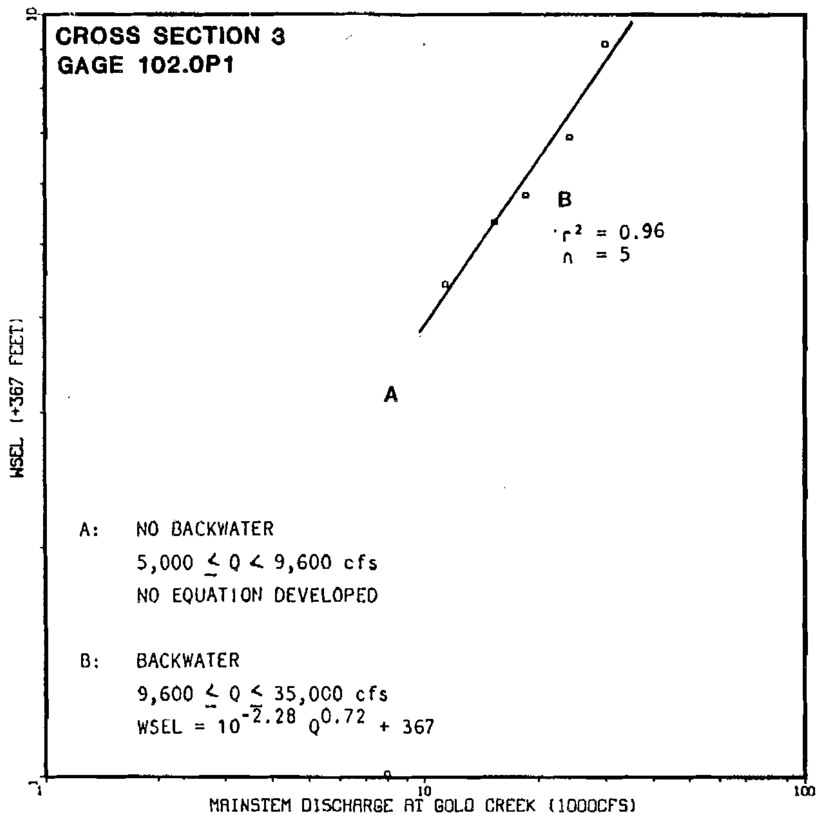


Figure II-6. Stage-discharge relationship for cross section 1 at site 101.7L.



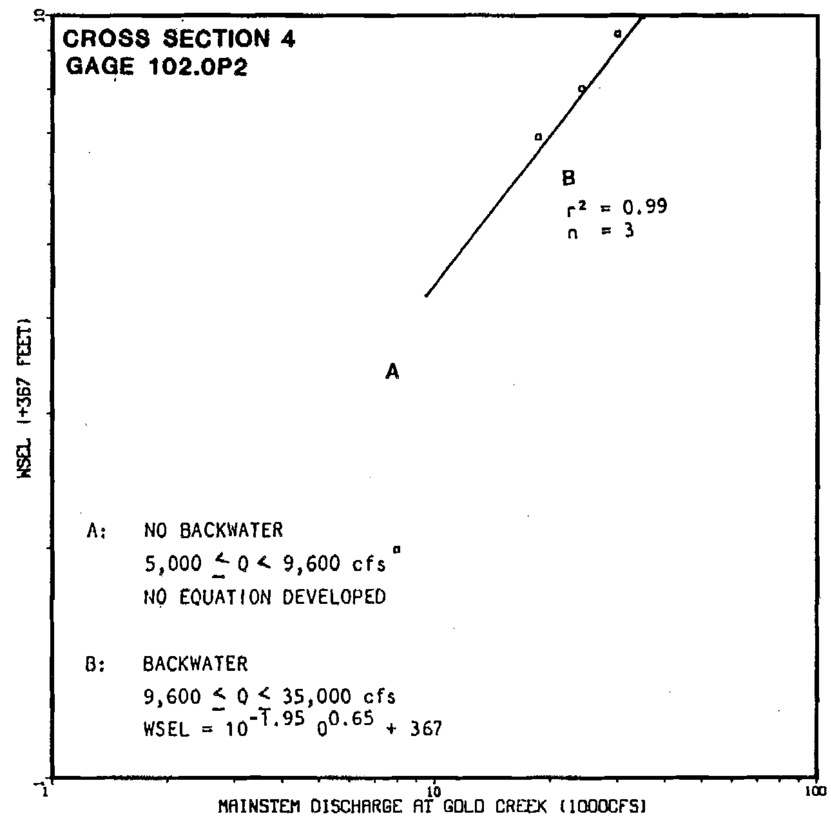


Figure II-7. Stage-discharge relationships for cross sections 3 and 4 at site 101.7L.

Site 105.8L: This site is located on the left bank of the mainstem. Staff gages were installed at two of the four cross sections, numbers 1 and 4. The available data at cross section 1 is limited and covers the mainstem range of 7,320 to 9,330 cfs with the application range of the stage-discharge relationship was limited to the range of available data. The data for cross section 4 covers the range of 7,320 to 29,800 cfs with the plot indicating an inflection point at 24,000 cfs. The change in slope of the stage-discharge relationship at this cross section may be due to a cross-sectional grade break. Because of the high correlation coefficient calculated for the lower portion of the curve, the lower limit of the application range was extended to the standardized 5,000 cfs. The application range for the upper portion of the curve at cross section 4 was limited to the range of available data since only two points were used to develop the equation.

Figure II-8 shows the plots and equations for the stage-discharge relationships at this site.

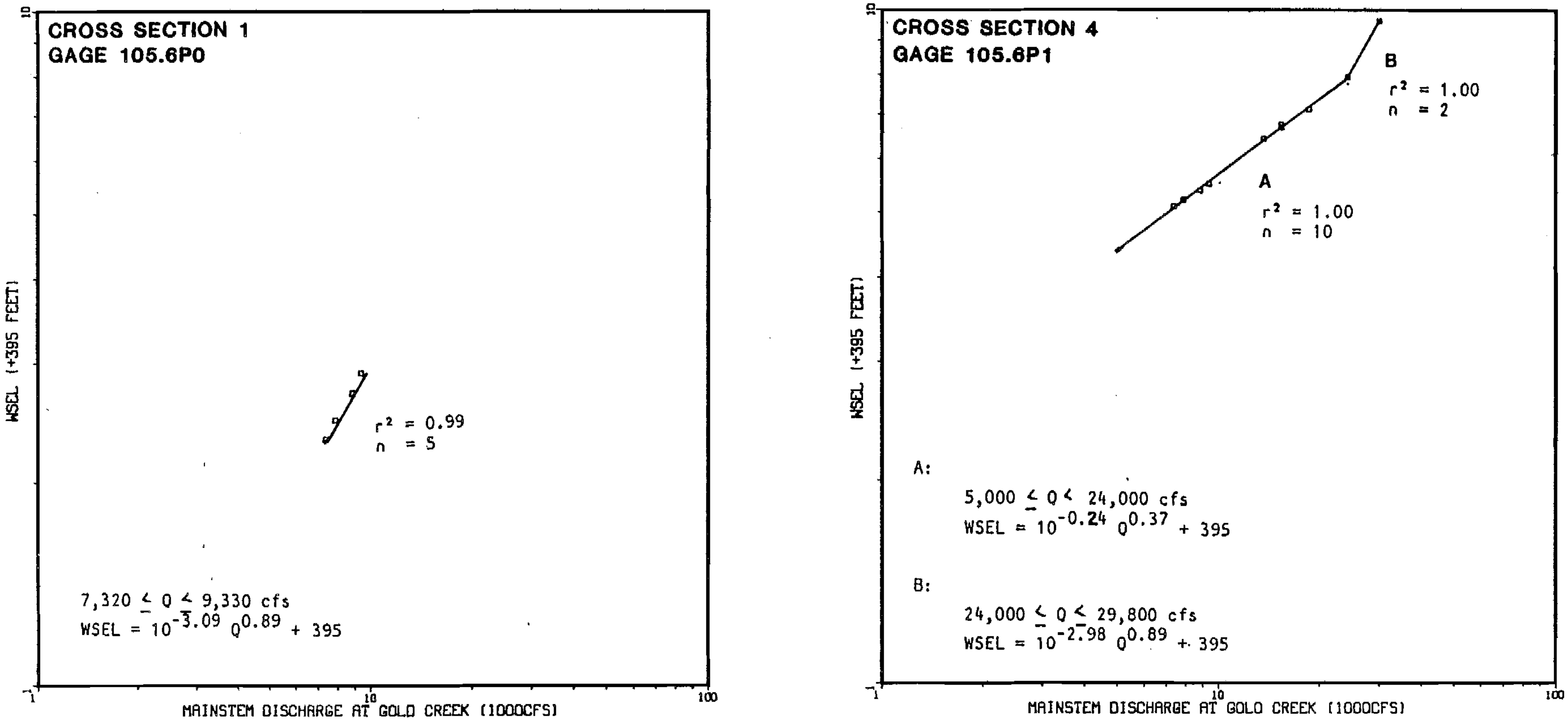


Figure II-8. Stage-discharge relationships for cross sections 1 and 4 at site 105.8L.

Site 112.6L: This large side channel with nine cross sections, becomes breached at a mainstem discharge less than 5,100 cfs. Mid-channel gravel bars divide the flow at the head of the site at cross section 8 and at the lower end at cross sections 1, 2, 3, 3A, and 4. Due to the gravel bars, the water surface elevation is not constant across the sections, and staff gages had to be installed on both banks. Stage-discharge relationships were developed for each gage and were generally defined for the range of available data. The application range for gages that corresponded to the largest portion of channel conveyance at each cross section was extended to 5,000 cfs on the lower end and 35,000 cfs on the upper end. Insufficient data was available at cross sections 3A and 4 to describe the stage-discharge response over the entire range of 5,000 to 35,000 cfs.

Channel hydraulics for this site are controlled by the mainstem for the entire evaluation range of 5,000 to 35,000 cfs. Five flow measurements were made at cross section 7. When developing the flow-discharge relationship, a high correlation coefficient was calculated using the lowest four data points. When the fifth data point was incorporated, a much lower correlation coefficient resulted and a flow of 40,000 cfs was predicted for a mainstem discharge of 35,000 cfs. The relationship was thus, broken at 10,800 cfs. When the upper portion of the curve was applied to a mainstem discharge of 35,000 cfs, a site flow of 17,000 cfs was produced. The physical explanation for the inflection is probably head berm geometry; at 10,800 cfs the mainstem stage at the channel entrance may coincide with a cross-sectional grade break. The data base covers the mainstem range of 6,210 to 24,000 cfs with the application range at 5,000 to 35,000 cfs.

The flow-stage relationship at cross section 7 was developed from data corresponding to the mainstem range of 6,210 to 10,800 cfs. The application range was not extended beyond the range of available data.

The plots and equations developed for the three relationships at cross section 7 are shown in Figure II-9. The plots and equations developed for the stage-discharge relationships at the other eight cross sections of this study site are shown in Figures A-1.7 through A-1.17.

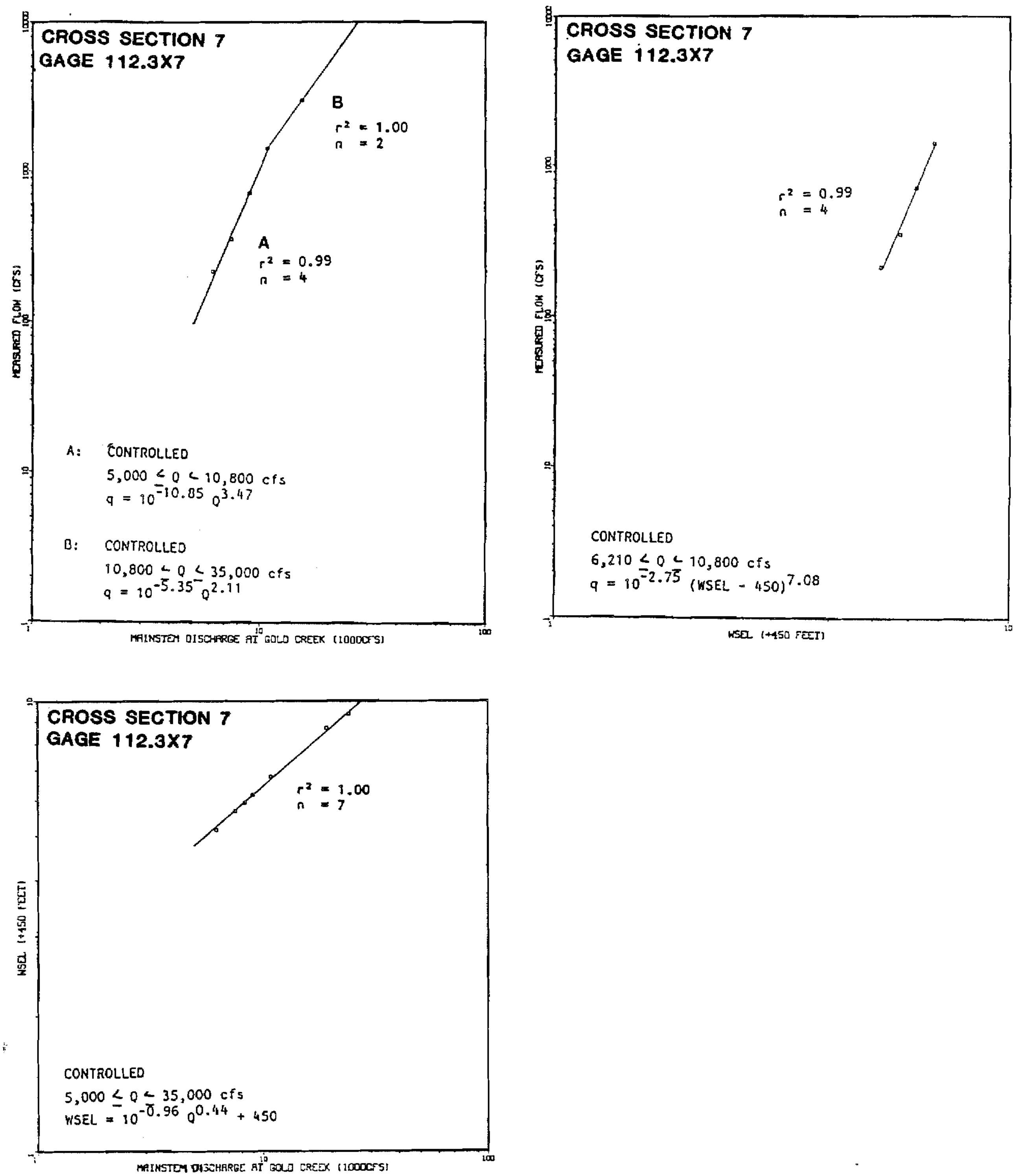


Figure II-9. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 7 at site 112.6L.

Site 114.1R: Two channels direct flow into this study site. The larger channel becomes breached at a mainstem discharge of less than 5,100 cfs, and the smaller one at 10,000 cfs. One staff gage was installed in the study site and was located at cross section 2. The stage remains relatively constant for mainstem discharges below 8,800 cfs, suggesting no mainstem backwater influences. Above 8,800 cfs, however, stage increases rapidly and a stage-discharge relationship was developed from data covering the mainstem discharge range 8,800 to 19,000 cfs. The application range of the equation was not extended beyond the range of available data as only four points were used to develop the relationship and these were not evenly distributed within the range of available data.

Figure II-10 shows the plot and equation developed from the stage-discharge data for this site.

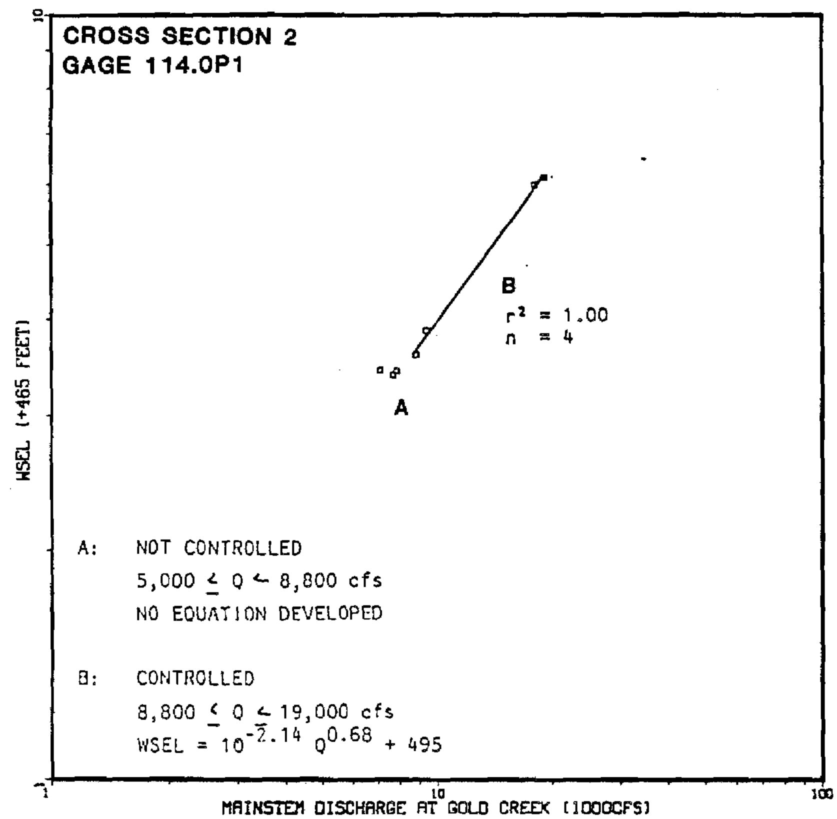


Figure II-10. Stage-discharge relationship for cross section 2 at site 114.1R.

Site 115.0R: Two channels direct flow into this study site. One becomes breached at 12,000 cfs and the other at 23,000 cfs. One staff gage was installed and was located at cross section 1. Stage is relatively constant below 10,400 cfs and is influenced primarily by upwelling and local runoff in the upper reach of the study site. Above 10,400 cfs, stage is backwater-influenced. One stage-discharge equation was developed for the site from data covering the mainstem range of 10,400 to 31,700 cfs with an application range of the equation at 10,400 to 35,000 cfs.

The plot and equation for the stage-discharge relationship at this site are shown in Figure II-11.

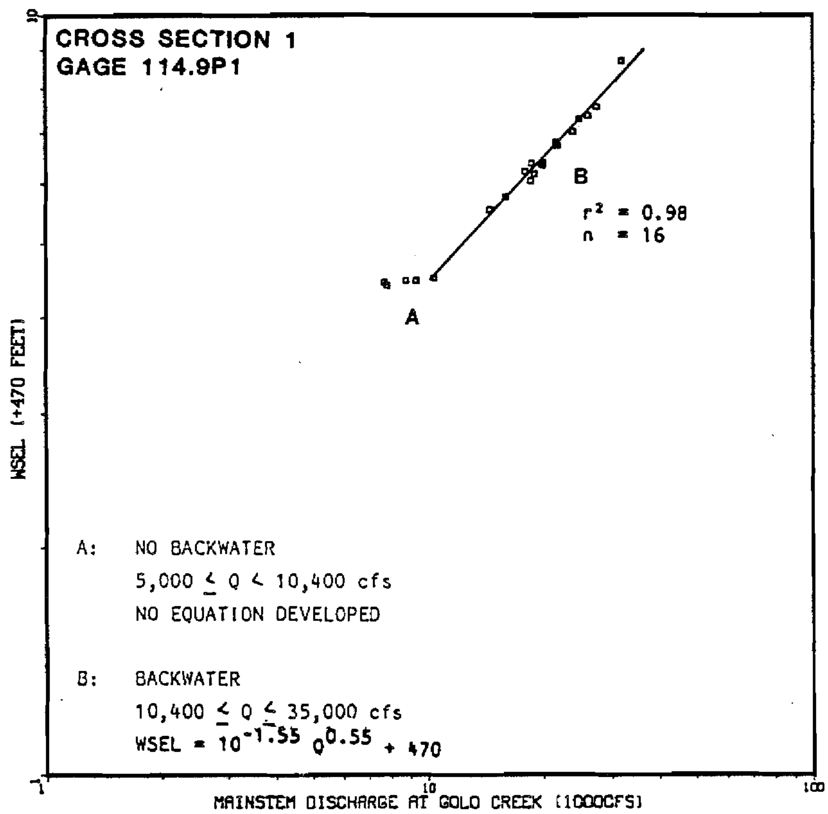


Figure II-11. Stage-discharge relationship for cross section 1 at site 115.0R.

Site 118.9L: This site is located on the left bank of the mainstem. Stage was measured at cross section 2 for discharges between 7,380 and 19,000 cfs with one relationship developed from the data, applicable to the mainstem discharge range of 5,000 to 23,000 cfs. Figure II-12 shows the plot and equation of this stage-discharge relationship.

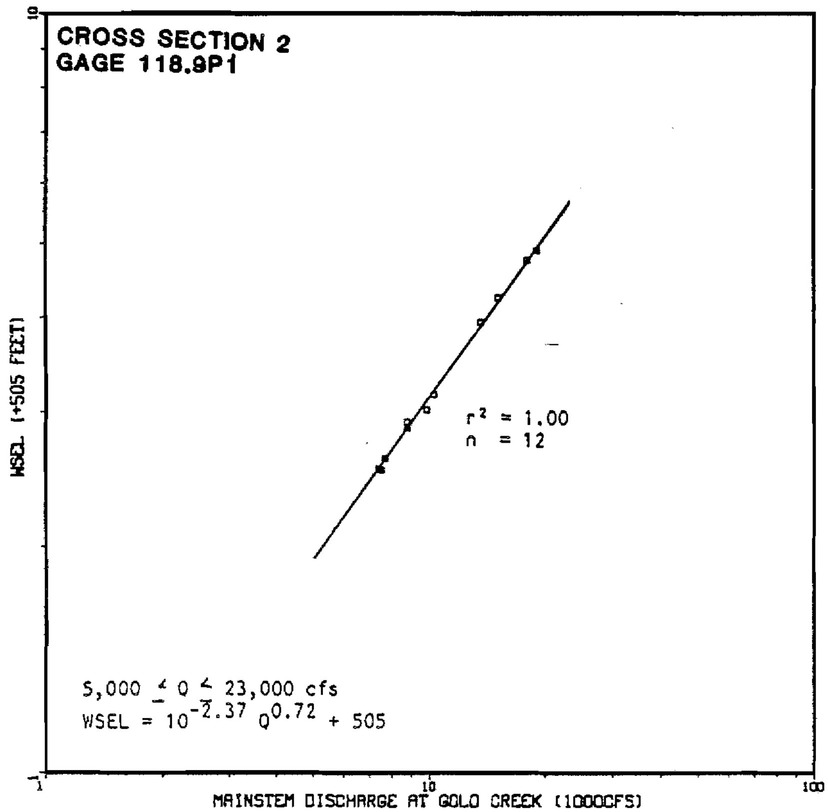


Figure II-12. Stage-discharge relationship for cross section 2 at site 118.9L.

Site 119.1L: This site is located on the left bank of the mainstem. Stage was measured at cross section 2 for discharges between 7,380 and 19,000 cfs with one relationship developed from the data, applicable to the mainstem discharge range of 5,000 to 23,000 cfs. Figure II-13 shows the plot and equation of this stage-discharge relationship.

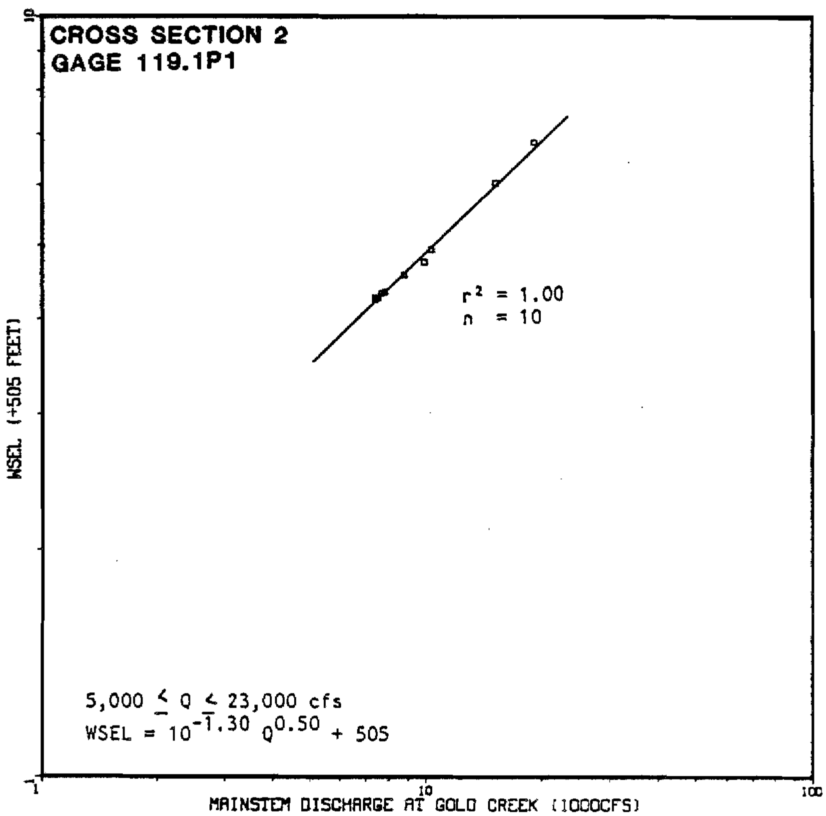


Figure II-13. Stage-discharge relationship for cross section 2 at site 119.1L.

Site 119.2R: This side channel site becomes breached at 10,000 cfs. Below 10,000 cfs, mainstem backwater is present in the lower end of the study site, with the upper end dewatered. Mainstem backwater effects persist in the lower end at higher discharges. Stage was monitored at all six of the cross sections over the mainstem discharge range of 7,080 to 24,500 cfs and one curve was fit to the stage-discharge data for each cross section. The relationships for the lower four cross sections (the mouth and numbers 1, 2, and 3) are applicable to mainstem discharges of 5,000 to 24,500 cfs and for the upper two cross sections (numbers 4 and 5), 10,000 to 24,500 cfs.

Site flow was measured at cross section 3 when mainstem discharge was 13,600, 17,400 and 22,700 cfs. The lower limit of the application range for the flow-discharge relationship is the breaching discharge of 10,000 cfs with the upper limit at 23,000 cfs. The application range was not extended beyond 23,000 cfs because the banks become inundated, changing the channel hydraulics and suggesting an inflection point.

The flow-stage relationship developed for cross section 3 is applicable to the mainstem range of 10,000 to 23,000 cfs.

The plots and equations of the three relationships developed for cross section 3 are shown in Figure II-14. The plots and equations for the stage-discharge relationships at the other four cross sections at this site are shown in Figures A-1.18 through A-1.20.

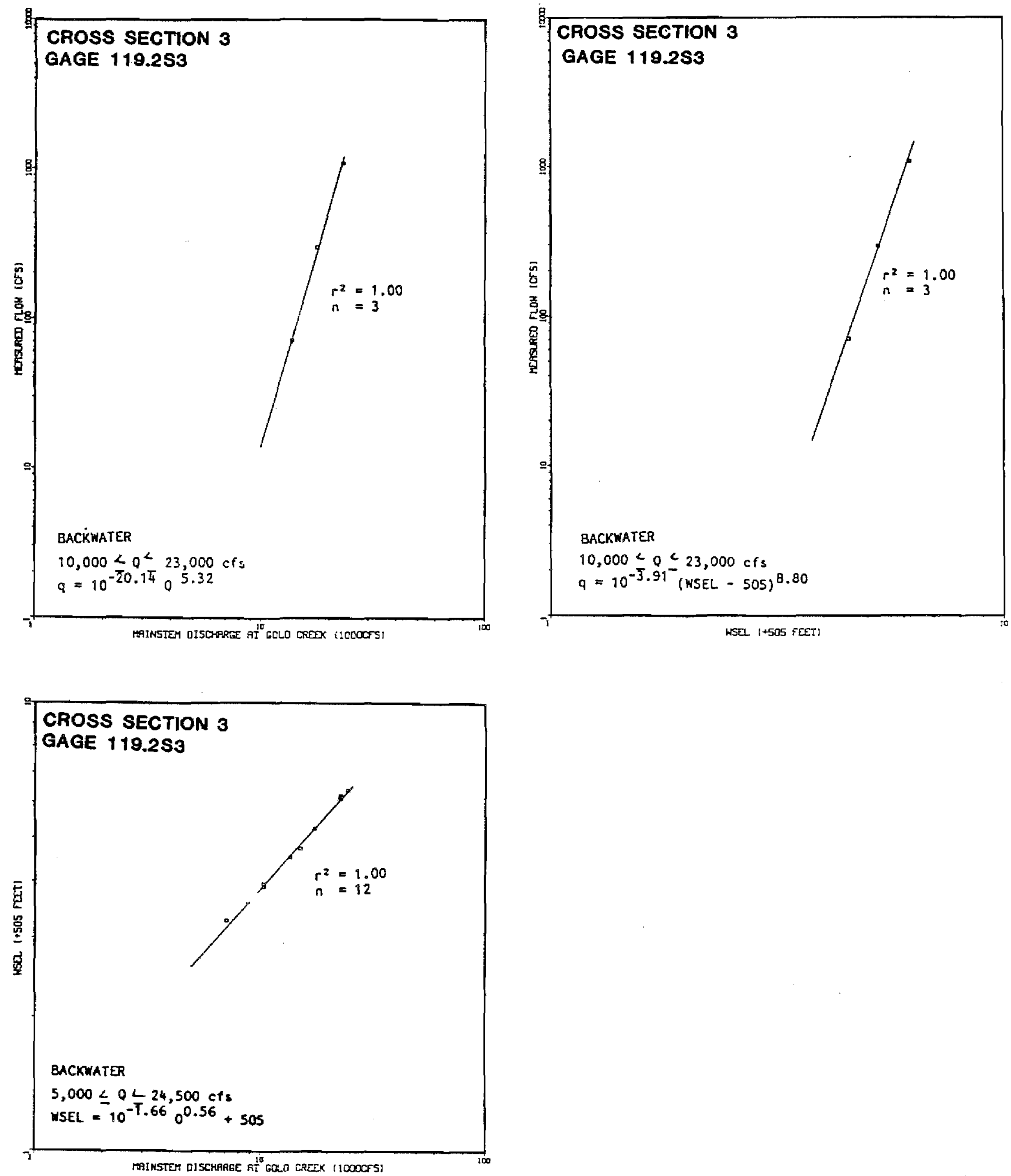


Figure II-14. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 3 at site 119.2L.

Site 125.2R: This side channel becomes breached at a mainstem discharge of less than 5,100 cfs. Even though it is breached at a low discharge, the amount of turbid mainstem water that enters the site is limited by head berm geometry. Flow at this site is also derived from upwelling and local runoff. At some mainstem discharge, stage at the head berm coincides with a cross-sectional grade break and side channel hydraulics become controlled by the mainstem. This is reflected in the stage-discharge plot at cross section 2. Stage at cross section 2 was observed for mainstem discharges ranging from 4,300 to 19,100 cfs, and the lowermost data point did not align with the other ten points. Two stage-discharge equations were thus, developed with the breakpoint at 6,120 cfs. The equation for the lower portion of the curve is applicable to the range of 4,300 to 6,210 cfs, and for the upper portion, 6,210 to 23,000 cfs.

Stage was also monitored at cross section 1 over the mainstem discharge range 6,210 to 19,100 cfs, and one equation was developed from the data, applicable to the range of 6,210 to 23,000 cfs.

Site flow was measured at cross section 2 at mainstem discharges of 4,300, 6,210, 7,680, and 9,000 cfs. Since site flow becomes controlled by the mainstem between 4,300 and 6,210 cfs, the lowermost data point was not used in developing the flow-discharge equation. When the equation is applied to 23,000 cfs, it produces a site flow of 19,000 cfs, suggesting an inflection point in the relationship. The application range of the flow-discharge equation is thus, the range of available data from 6,210 to 9,000 cfs.

Two equations were developed for the flow-stage relationship at cross section 2. One is applicable to the mainstem range of 4,300 to 6,210 cfs when channel hydraulics are not controlled by the mainstem, and the other is applicable to the range of 6,210 to 9,000 cfs.

The plot and equation of the stage-discharge relationship at cross section 1 are shown in Figure II-15. The plots and equations of the three relationships developed at cross section 2 are shown in Figure II-16.

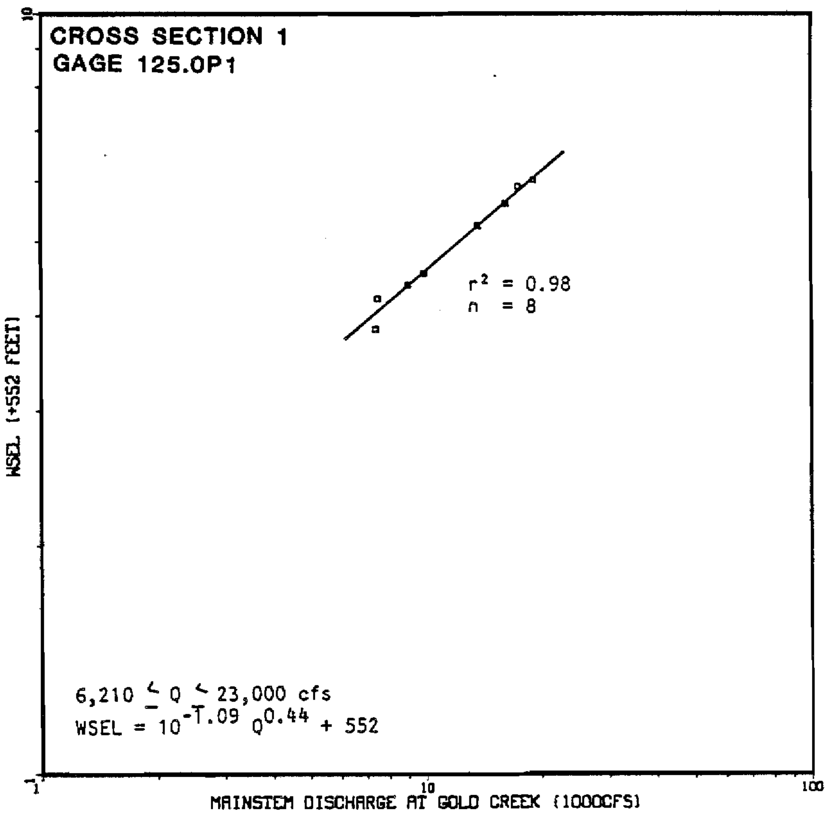


Figure II-15. Stage-discharge relationship for cross section 1 at site 125.2R.

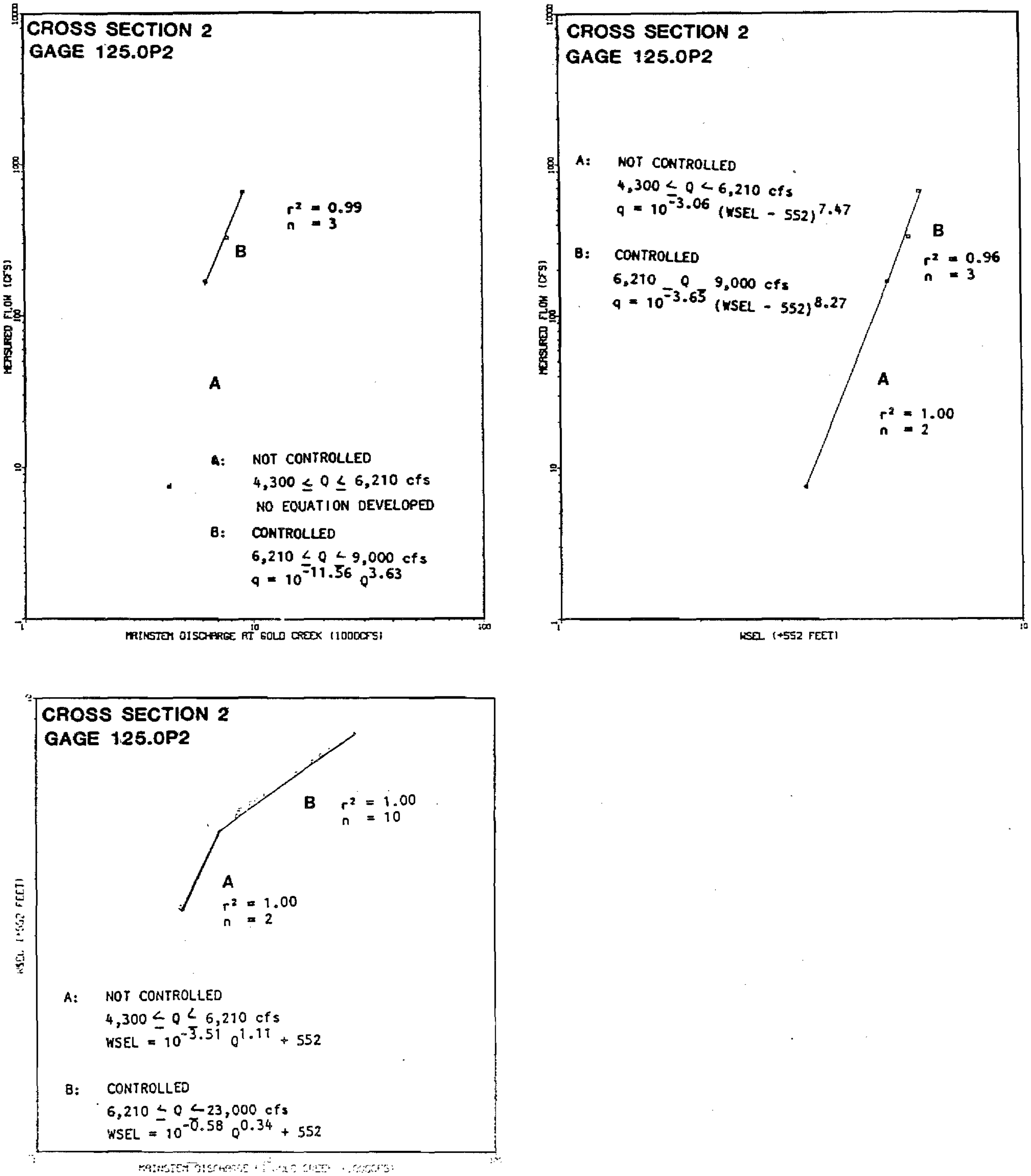


Figure II-16. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 2 at site 125.2R.

Site 130.2R: This study site is located at the mouth of a large side channel. In aerial photography taken when mainstem discharge was 18,000 cfs and less, water is present in the study site but is separated from the main conveyance area of the side channel by a gravel bar. The presence of water in the study site at these discharges is due to backwater influences with some flow also across the gravel bar. In aerial photography taken at 23,000 cfs, the gravel bar is submerged and side channel flow encompasses the study site.

Three cross sections were established at this site. Stage was measured at cross section 2 at mainstem discharges ranging from 7,380 cfs to 31,700 cfs. The lower nine data points from 7,380 to 16,100 cfs were used to develop a stage-discharge equation for the unbreached condition, and the upper five data points from 19,900 to 31,700 cfs for the breached condition. Solving the equations simultaneously yielded a break point of 18,200 cfs. The equation for unbreached conditions is valid for mainstem discharges of 5,000 to 18,200 cfs and for breached conditions of 18,200 to 35,000 cfs.

The plot and equations of the stage-discharge relationship for this site are shown in Figure II-17.

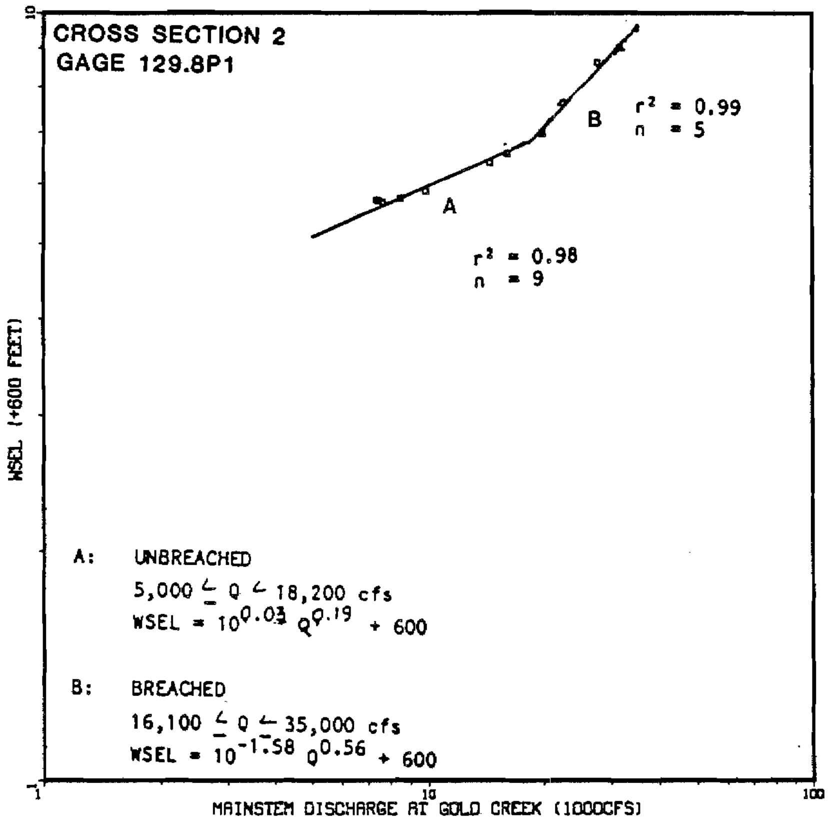
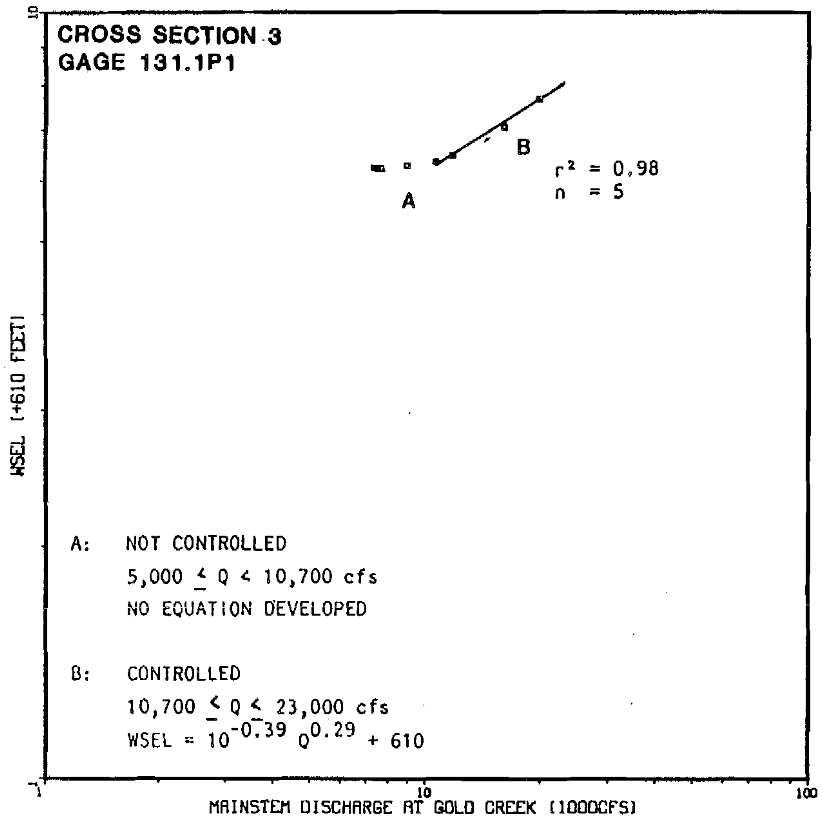


Figure II-17. Stage-discharge relationship for cross section 2 at site 130.2R.

Site 131.3L: Four cross sections were established at this side channel site. The lower reach, below cross section 3, becomes breached at 9,000 cfs and the upper reach becomes breached at 10,700 cfs. Water is present throughout the site in unbreached conditions due to groundwater upwelling. Stage was monitored at cross sections 1 and 3, and one equation was developed for each cross section. The stage-discharge equation for breached conditions at cross section 3 was developed from data covering the mainstem discharge range of 10,700 to 19,900 cfs with the upper limit of the application range extended to 23,000 cfs. The stage-discharge equation for breached conditions at cross section 1 was developed from limited data, covering the mainstem discharge range 9,000 to 11,800 cfs. The application range, therefore, was not extended beyond the data range.

The plots and equations of the stage-discharge relationships at cross sections 1 and 3 for this study site are shown in Figure II-18.



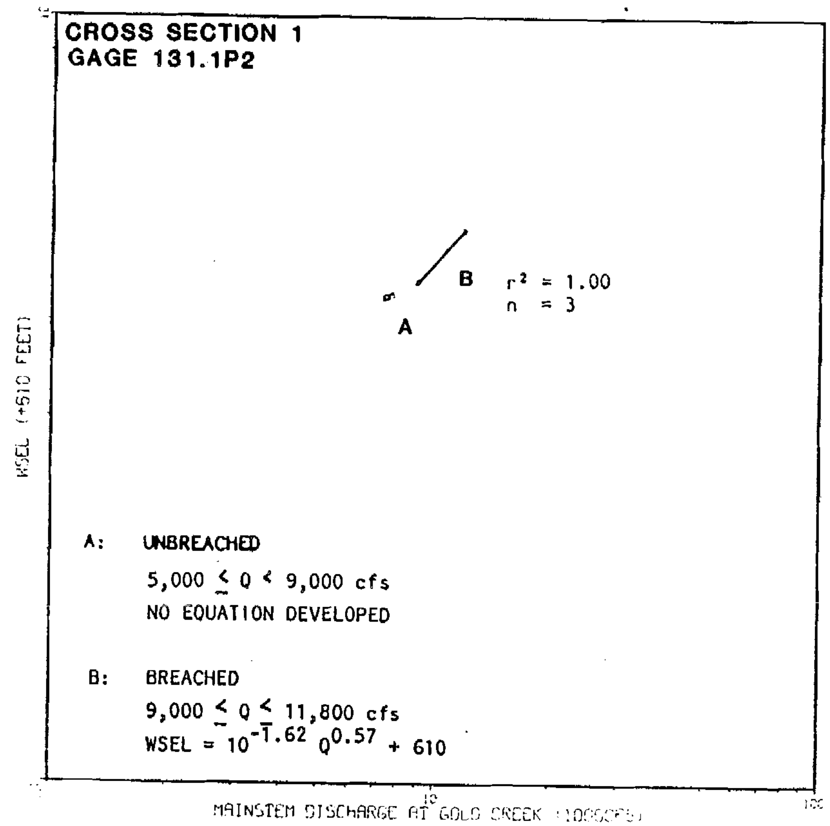


Figure II-18. Stage-discharge relationships for cross sections 3 and 1 at site 131.3L.

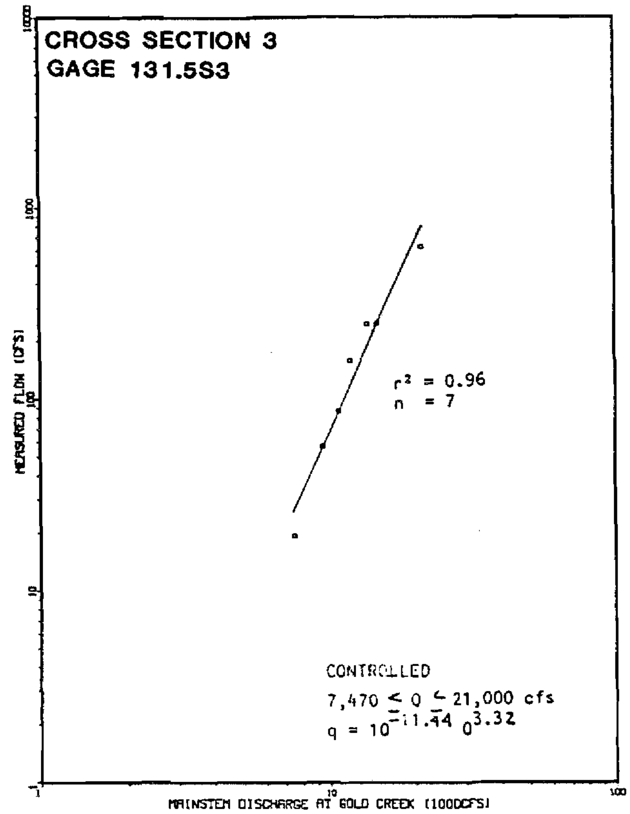
Site 131.7L: This study site is located in the lower reach of a side channel that becomes breached at 5,000 cfs. Two other channels that direct flow into the side channel become breached at 10,500 and 14,500 cfs. The entrances of the three channels are more than 3,000 ft upstream of the study site.

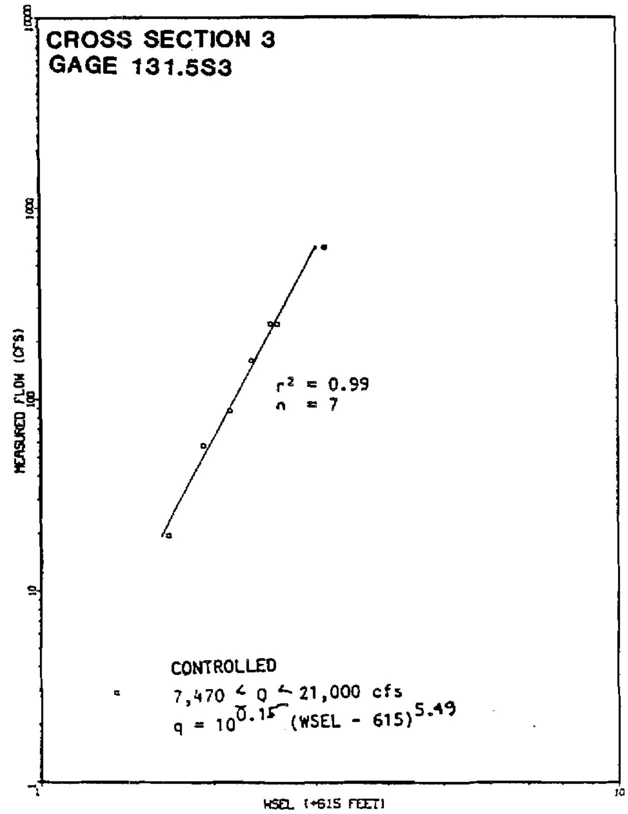
Seven cross sections were established at the study site. Only one staff gage was installed and was located at cross section 3. Stage was monitored over the mainstem discharge range 6,210 to 27,700 cfs. Although the channel becomes breached at 5,000 cfs, stage at cross section 3 is also influenced by upwelling and local inflow. Aerial photography shows that stage became controlled by the mainstem at about 7,400 cfs. The lowermost stage-discharge point of 6,210 cfs was thus, not used in developing the stage-discharge equation, and the range for which the equation is valid is 7,470 to 27,700 cfs.

Site flow was measured at cross section 3 when mainstem discharge was 6,210 to 21,000 cfs. For the same reasons discussed above, the lowermost data point was not used in developing a flow-discharge equation and the mainstem discharge range for which the equation is valid is 7,470 to 21,000 cfs.

A flow-stage equation was developed for cross section 3 and is also applicable to the discharge range 7,470 to 21,000 cfs.

The plots and equations of the three relationships at cross section 3 in this site are shown in Figure II-19.





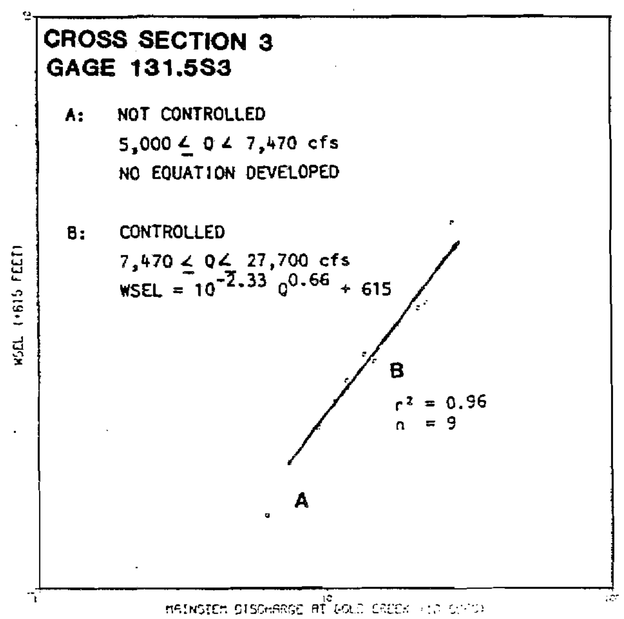


Figure II-19. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 3 at site 131.7L.

Site 132.6L: Two channels direct flow into this side channel. One becomes breached at 10,500 cfs with the other at 14,500 cfs. Below 10,500 cfs, ponded water is present throughout the study site but eventually dries up. Flow just downstream of the study site is augmented by the confluence of another side channel, which becomes breached at 5,000 cfs.

Staff gages were installed at each of nine cross sections that were established in this channel. Stage was monitored over the mainstem discharge range of 10,700 to 27,700 cfs and additional stage data were available at 8,800 cfs at some of the cross sections. At discharges greater than 23,100 cfs, stage in the lower portion of the study site (cross sections 1 and 2) is influenced by backwater from the side channel downstream that becomes breached at 5,000 cfs. One stage-discharge equation was developed for each cross section. The equations for cross sections 1 and 2 are applicable to the mainstem discharge range 10,500 to 23,100 cfs and for cross sections 3 through 9, 10,500 to 27,700 cfs. The upper limit of the application range was not extended beyond the range of data because an overflow channel begins to direct flow out of the site from the right bank between cross sections 4 and 5 at a mainstem discharge of 25,000 cfs, thereby altering the channel hydraulics.

Site flow was measured when mainstem discharge was 10,700, 12,700, and 21,500 cfs. A flow-discharge equation was developed from data collected at cross section 3 with the equation valid for the mainstem discharge range of 10,500 to 25,000 cfs.

The flow-stage equation for cross section 3 is also applicable to the mainstem discharge range 10,500 to 25,000 cfs.

The plots and equations for the three relationships at cross section 3 in this site are shown in Figure II-20. The plots and equations for the stage-discharge relationships at the other eight cross sections are shown in Figures A-2.21 through A-2.24.

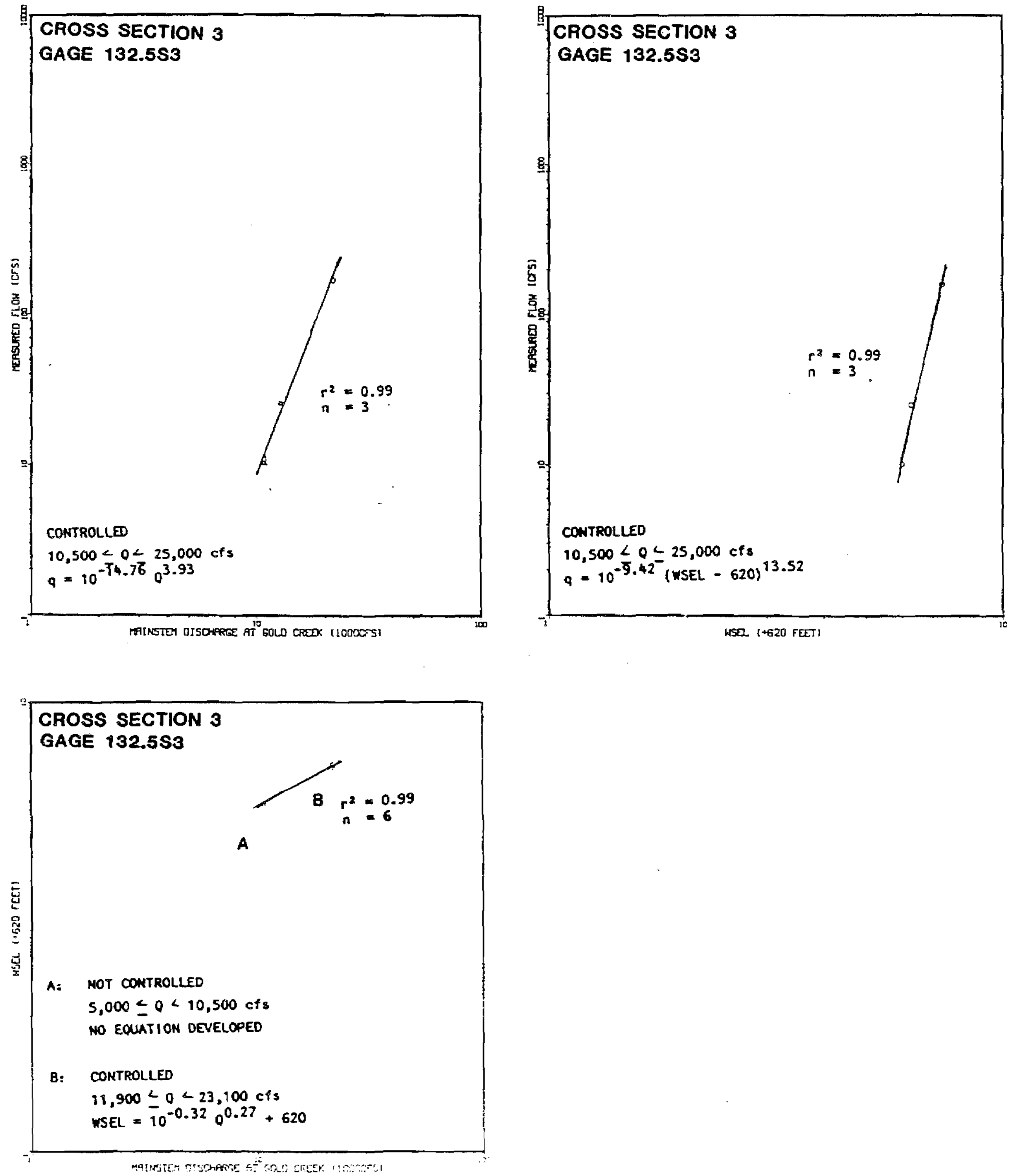


Figure II-20. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 3 at site 132.6L.

Site 133.8R: This site is located on the right bank of the mainstem. One staff gage was installed at the site and was located at cross section 3. Two equations were developed from the stage-discharge data with the equation for the lower portion of the curve developed from data covering the mainstem discharge range of 7,680 to 10,400 cfs and for the upper portion, 16,100 to 31,700 cfs. The mainstem discharge at which the inflection occurred (15,600 cfs), was determined by simultaneously solving the equations for stage. The inflection is probably due to a cross-sectional grade break. The equation for the lower portion of this curve is applicable to the mainstem discharge range of 5,000 to 15,600 cfs and for the upper portion, 15,600 to 35,000 cfs.

The plot and equations for the stage-discharge relationship at this site are shown in Figure II-21.

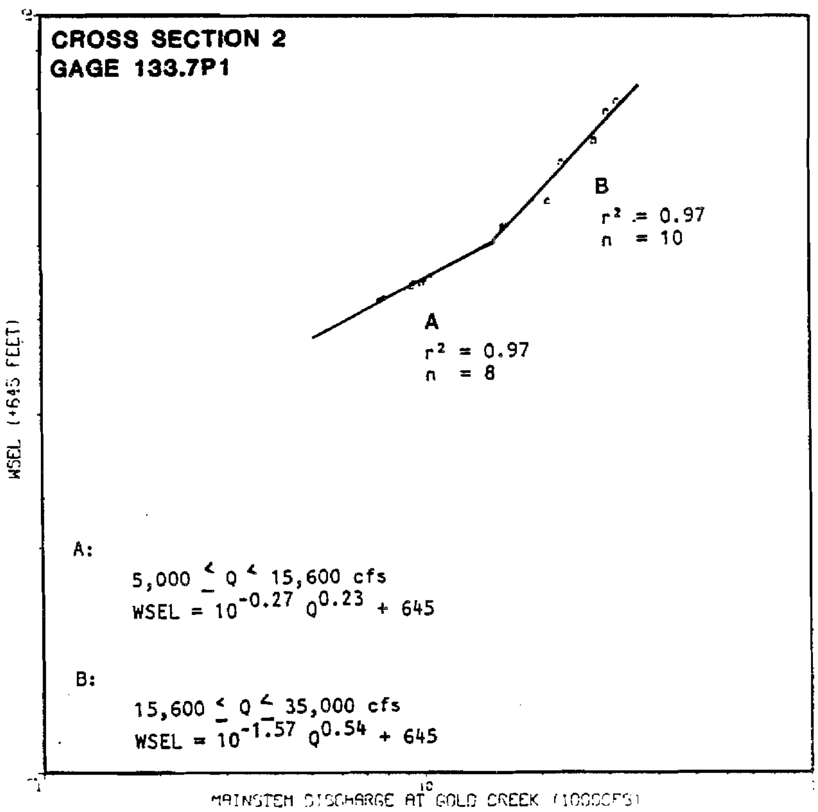
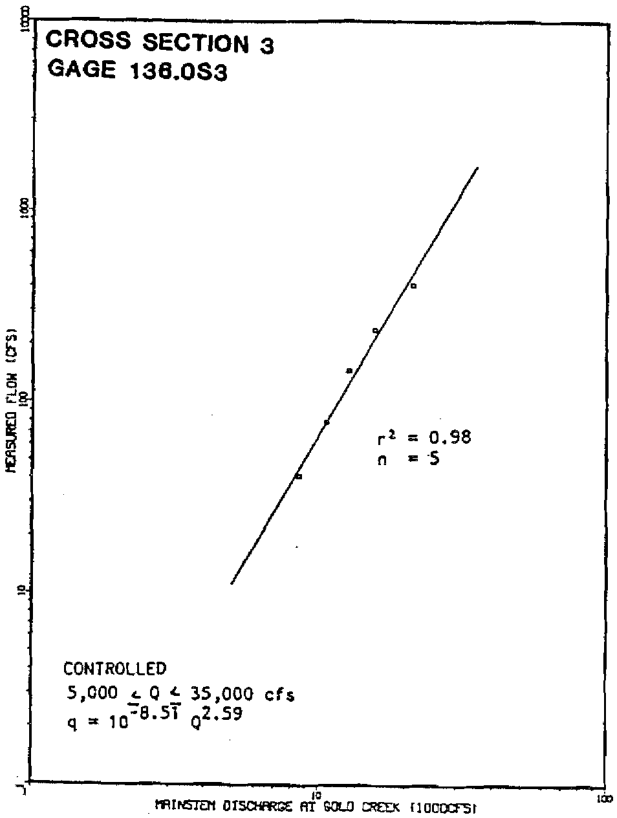


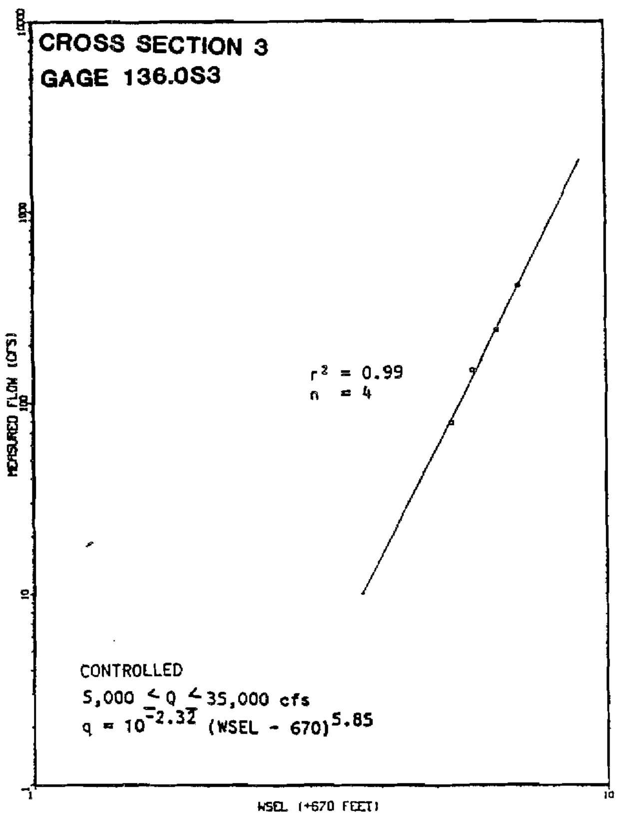
Figure II-21. Stage-discharge relationship for cross section 3 at site 133.8R.

Site 136.0L: This side channel becomes breached at a mainstem discharge of less than 5,100 cfs. Six cross sections were established at the site and a staff gage was installed at each. Stage was observed when mainstem discharge was 7,680 to 27,700 cfs and one stage-discharge equation was developed for each cross section. The application range of all equations is 5,000 to 35,000 cfs.

Site flow was measured at cross section 3 when mainstem discharge was 8,520, 10,600, 12,700, 15,600, and 21,000 cfs with the flow-discharge equation valid for the mainstem discharge range of 5,000 to 35,000 cfs. The flow-stage equation developed for cross section 3 is also applicable for the range of 5,000 to 35,000 cfs.

The plots and equations of the three relationships at cross section 3 at this site are shown in Figure II-22. The plots and equations of the stage-discharge relationships at the other five cross sections are shown in Figures A-1.25 through A-1.27.





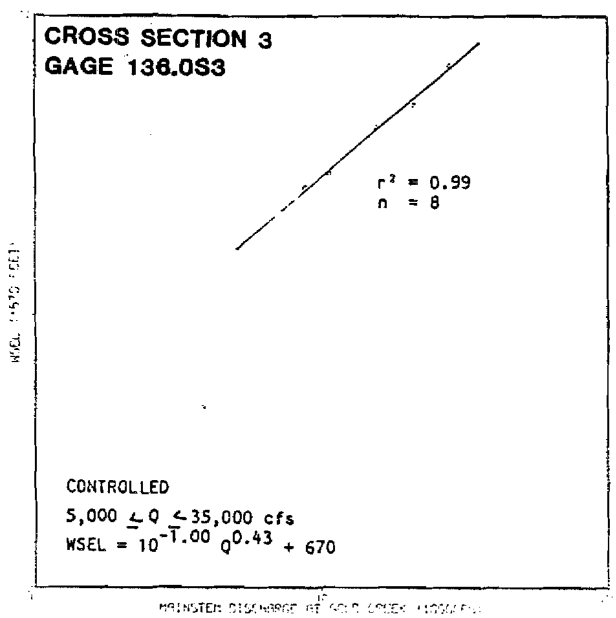
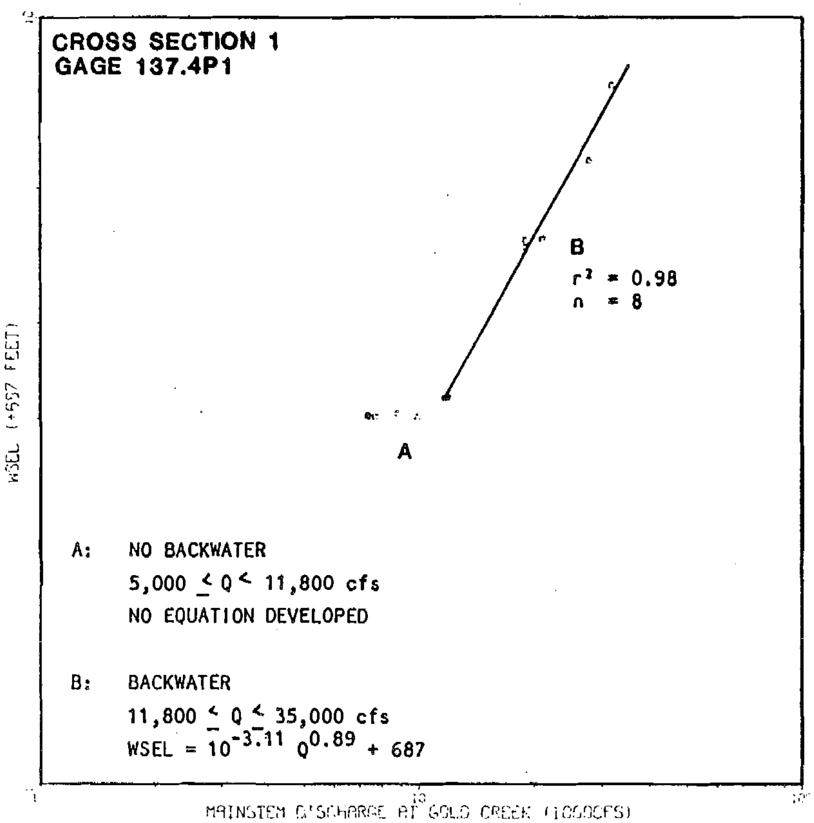


Figure II-22. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 3 at site 136.0L.

Site 137.5R: This site is located along the right bank of the mainstem and is separated from the main conveyance area by a large gravel bar. The site becomes breached at 22,000 cfs. At very low mainstem discharges, site flow is maintained by upwelling. As discharge increases, backwater from the mainstem extends into the site. Three cross sections were established, and staff gages were installed at cross sections 1 and 2. From the stage-discharge plots, stage at both cross sections is influenced by the mainstem at about 11,800 cfs. A stage-discharge equation was developed for cross section 1 and the data used covered the mainstem discharge range 11,800 to 31,700 cfs. The upper limit for the application range was extended to 35,000 cfs with the lower limit at 11,800 cfs. Stage measurements at cross section 2 when stage was governed by the mainstem were limited to two very similar discharges and thus, no equation was developed.

The plot and equation of the stage-discharge relationship at cross section 1 and the plot of cross section 2 data at this site are shown in Figure II-23.



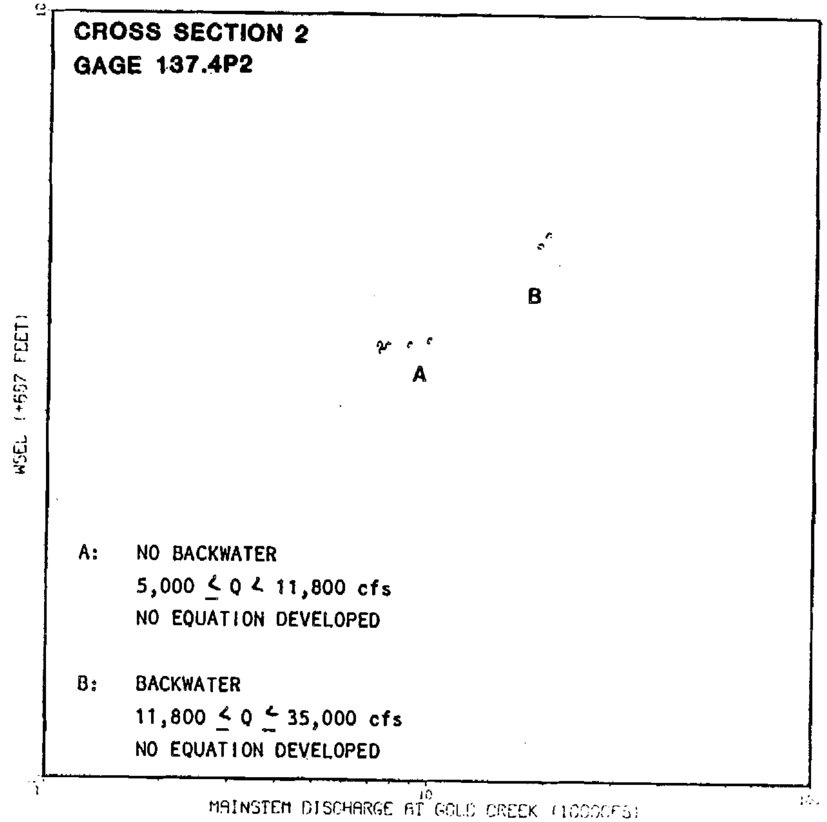


Figure II-23. Stage-discharge relationships for cross sections 1 and 2 at site 137.5R.

Site 138.7L: This site is located on the left bank of the mainstem. Stage was monitored at cross section 2 over the mainstem discharge range of 9,890 to 19,900 cfs with the stage-discharge equation applicable to the range of 5,000 to 23,000 cfs.

The plot and equation of the stage-discharge relationship at this site are shown in Figure II-24.

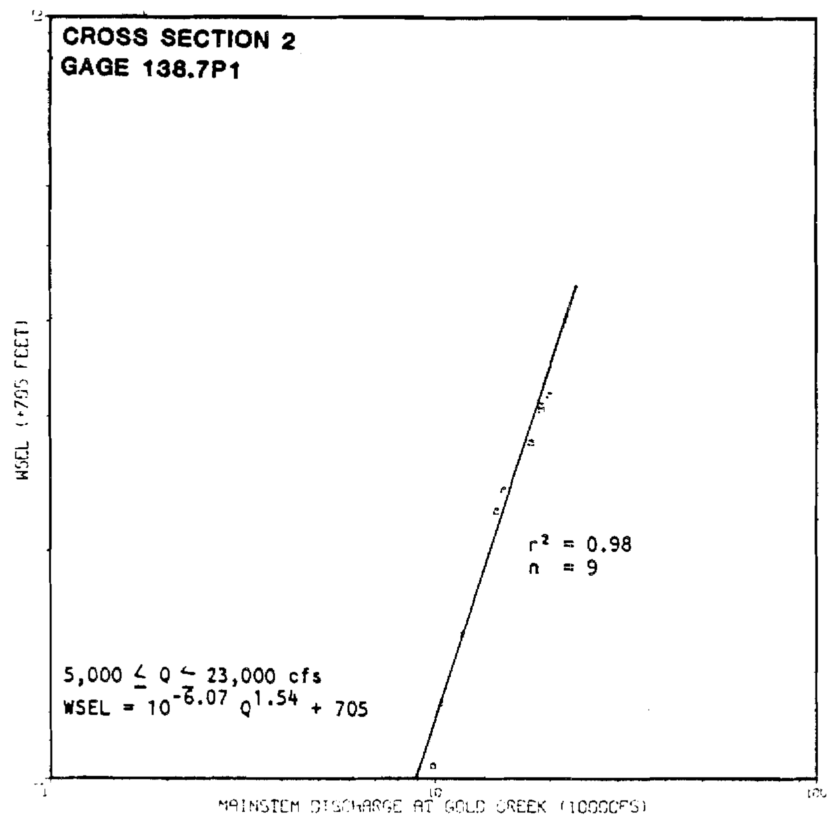


Figure II-24. Stage-discharge relationship for cross section 2 at site 138.7L.

Site 139.0L: This site is located on the left bank of the mainstem and is separated from the main conveyance area by a large gravel bar. At low mainstem discharges, cross sections 3 and 4 are dry and upwelling may be detected. The site gradually becomes breached over a wide range of mainstem discharges and turbid mainstem water begins to flow laterally over the lower end of the gravel bar at about 12,000 cfs. At 23,000 cfs the gravel bar is entirely submerged.

Stage was monitored at cross section 2 over the mainstem range of 9,890 to 31,700 cfs. Above about 11,800 cfs, stage at cross section 2 is primarily influenced by mainstem discharge rather than by upwelling, as indicated by the stage-discharge plot. The equation developed from the data is valid over the mainstem range of 11,800 to 35,000 cfs.

The plot and equation for the stage-discharge relationship at this site is shown in Figure II-25.

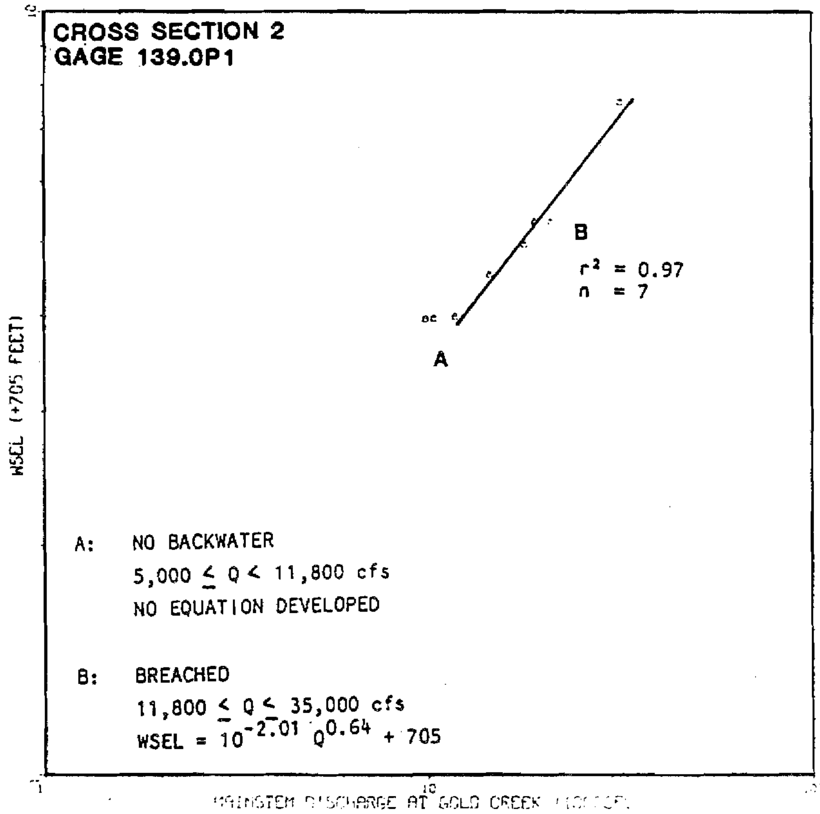


Figure II-25. Stage-discharge relationship for cross section 2 at site 139.0L.

Site 139.4L: This side channel becomes breached at a mainstem discharge of less than 5,100 cfs. Stage was monitored at cross section 2 over the mainstem discharge range of 7,410 to 19,900 cfs and one equation was developed. The application range for which the equation is valid was extended slightly beyond the range of available data to 5,000 cfs on the lower end and 23,000 cfs on the upper end.

The plot and equation for the stage-discharge relationship are shown in Figure II-26.

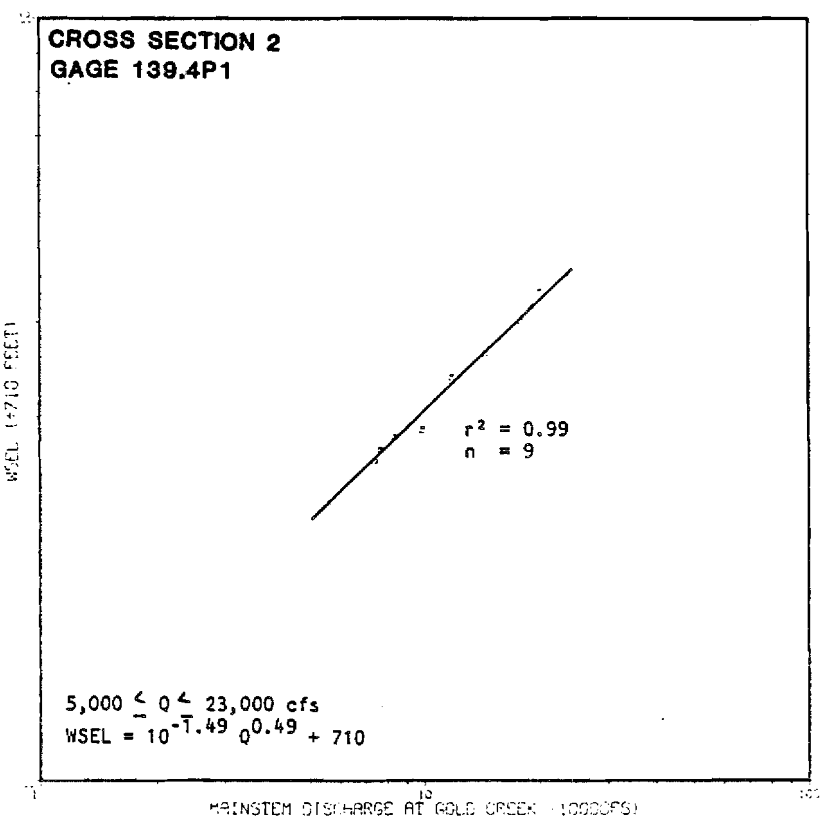


Figure II-26. Stage-discharge relationship for cross section 2 at site 139.4L.

Site 147.1L: This large side channel becomes breached at a mainstem discharge of less than 5,100 cfs. Six cross sections were established at the site, and a staff gage was installed at each of them. Stage observations covered the mainstem range of 8,130 to 20,000 cfs, and one stage-discharge equation was developed for each cross section. The side channel is not influenced by overflow channels or cross flow from the mainstem and the application range for the stage-discharge curves is thus, 5,000 to 35,000 cfs.

Site flow was measured at cross section 4 when the mainstem discharge was 8,130, 9,000, and 17,400 cfs with the application range for the flow-discharge equation set at 5,000 to 35,000 cfs.

A flow-stage equation was developed for cross section 4 and is valid for mainstem discharges of 5,000 to 35,000 cfs.

The plots and equations for the three relationships at cross section 4 are shown in Figure II-27. The plots and equations for the stage-discharge relationships at the other five cross sections in this site are shown in Figures A-1.28 through A-1.30.

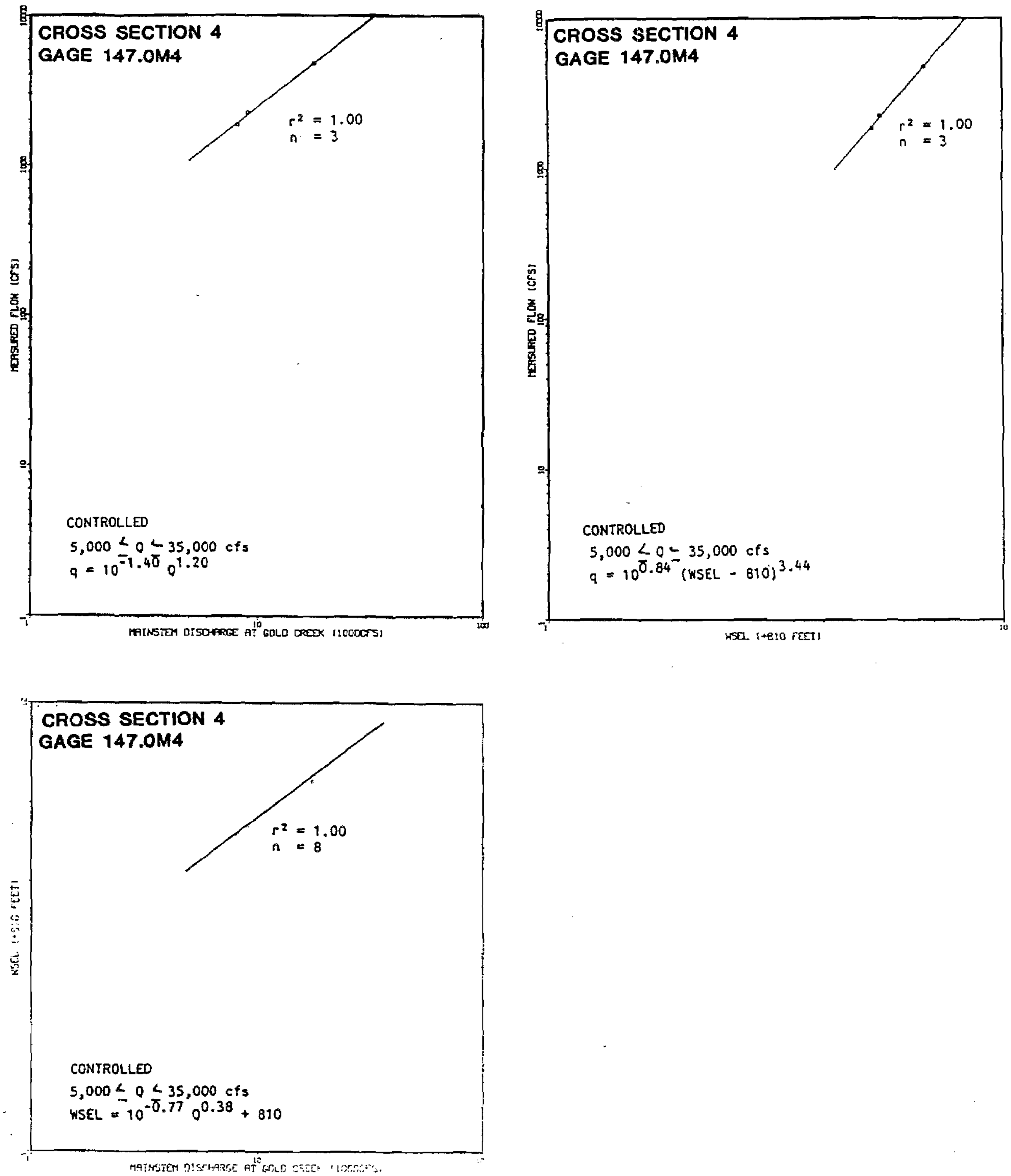


Figure II-27. Stage-discharge, flow-discharge, and flow-stage relationships for cross section 4 at site 147.1L.

DISCUSSION

The equations developed in this section provide the basis for evaluating the response of juvenile chinook and spawning chum salmon habitat to mainstem discharge. Discharge directly affects stage, and stage influences the hydraulic parameters of aquatic habitats, such as depth velocity, and wetted surface area.

For the 14 DIHAB study sites, the stage-discharge curve was used to estimate depths at unobserved streamflows, further refining the habitat response curve (Part IV). For the eight IFG study sites, the stage-discharge, flow-discharge and flow-stage equations were required to calibrate the hydraulic models. The flow-discharge equations were also used to relate simulated channel hydraulics to mainstem discharge (Part III). Further discussion as to how the results from Part II were used in subsequent analyses can be found in the following sections.

PART III

CALIBRATION AND APPLICATION OF IFG HYDRAULIC MODELS

This section deals with calibration and application of the IFG hydraulic models at eight study sites and the WUA forecasts for juvenile chinook salmon at those sites. Two different hydraulic models were used in the analysis - the IFG-2 and IFG-4. The IFG-2 model is a water surface profile program (or step-backwater model) which is based on uniform flow theory. This model is most applicable to stream reaches with relatively mild gradients and uniform cross sections (or gradually varied flow conditions). The IFG-4 mode is an empirical model based on regime theory and regression analysis. This model provides greater latitude for application to stream reaches with non-uniform gradients and irregular cross sections (or rapidly varied flow conditions). One or two sets of data are recommended for calibration of the IFG-2 model, whereas a minimum of three data sets are recommended for calibration of the IFG-4 model (Bovee and Milhous 1978).

Selection of one hydraulic model over the other depends on three considerations. These include: (1) the level of resolution of the aquatic habitat microhabitat desired, (2) the level of effort available for commitment to field data collection and, (3) site-specific considerations. Both IFG hydraulic models are based on the assumption that steady flow conditions exist within a rigid stream channel. Streamflow is defined as "steady" if the depth of flow and velocity at a specific location remains constant throughout the time interval under consideration. This definition is commonly accepted to mean that the discharge remains constant through the study site during the time interval required to collect a set of calibration data. A stream channel is "rigid" if it (1) does not change shape during the time period required to collect all sets of calibration data, and (2) does not change shape while conveying natural streamflows of the magnitude to be simulated (Trihey 1980).

The quantity of rearing habitat for juvenile chinook salmon at each study site is described by the relationship between WUA and mainstem discharge. The hydraulic models are calibrated to reproduce stage and horizontal velocity distributions observed at desired streamflow conditions. Both models use stream channel geometry and velocity data from several cross sections within a relatively short stream reach. Each cross section can be subdivided into as many as 100 cells (conveyance areas) to facilitate detailed analysis of the spacial distribution of depth and velocity combinations. Once it is properly calibrated, the computer program will calculate stage and the respective horizontal velocity distribution at each cross section for all desired discharges. The simulated depth and velocities are then used in the HABTAT model (Main 1978).

Within the HABTAT program, surface areas associated with the occurrence of various combinations of depth and velocity values are calculated by multiplying the width of the cell by the reach length. The utility of each cell is evaluated at a specified flow by calculating a joint preference factor defined in this study as the product of the individual suitability values associated with the velocity, depth and cover conditions. The WUA is calculated for each cell by multiplying its surface area by its joint preference factor. The WUA for the study site is the sum of the WUA's for the individual cells.

When the hydraulic models were calibrated, the flow-discharge functions were used to convert data collected on channel hydraulics to specific mainstem discharges. The channel hydraulics, in addition to the habitat parameters and suitability criteria from a previous study summarized by Estes and Vincent-Lang, eds. (1984d) are then combined with the HABTAT program to determine WUA and WSA for given site flows. Beyond the application range of the different functions, alternative methods were employed to determine WUA and WSA values.

A total of eight study sites were selected for detailed analysis from 130 candidate sites (Part II). The locations of the study sites are idetified in Figure III-1 with the type of hydraulic model for each site listed in Table III-1. Plots describing the relationship between WUA and mainstem discharge are provided for each study site. In addition, time series WUA plots based on the 1984 USGS record of average daily streamflows for the Susitna River at Gold Creek are also provided to indicate the temporal stability of rearing conditions at the study sites throughout the open water growing season (May 20 - September 15).

FIELD PROCEDURES

Field procedures included site installation, cross section and streambed profile surveys, depth and velocity measurements, and collection of substrate and cover information.

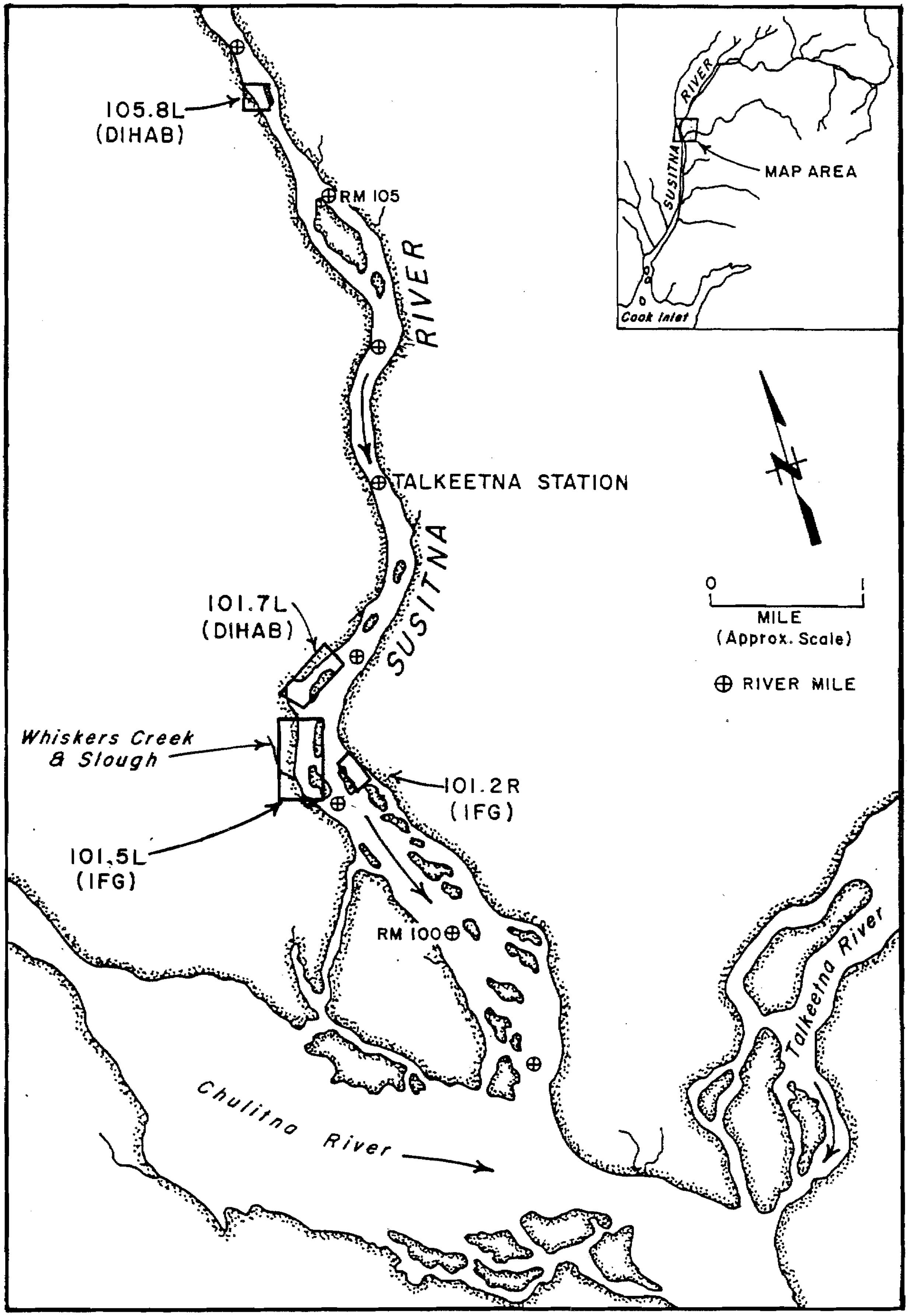


Figure III-1. Middle Susitna River IFG and DIHAB modeling sites.

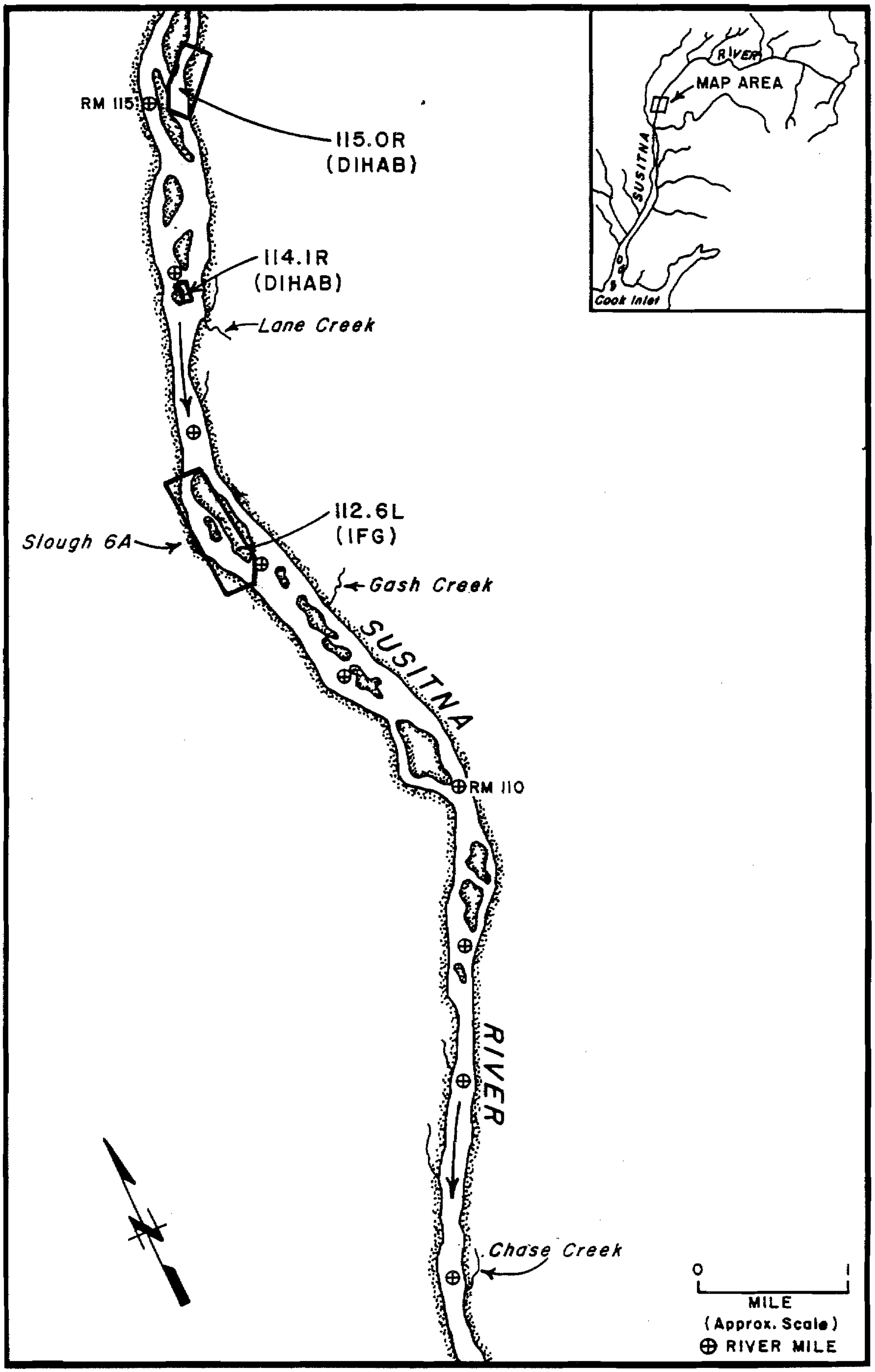


Figure III-1 (Continued).

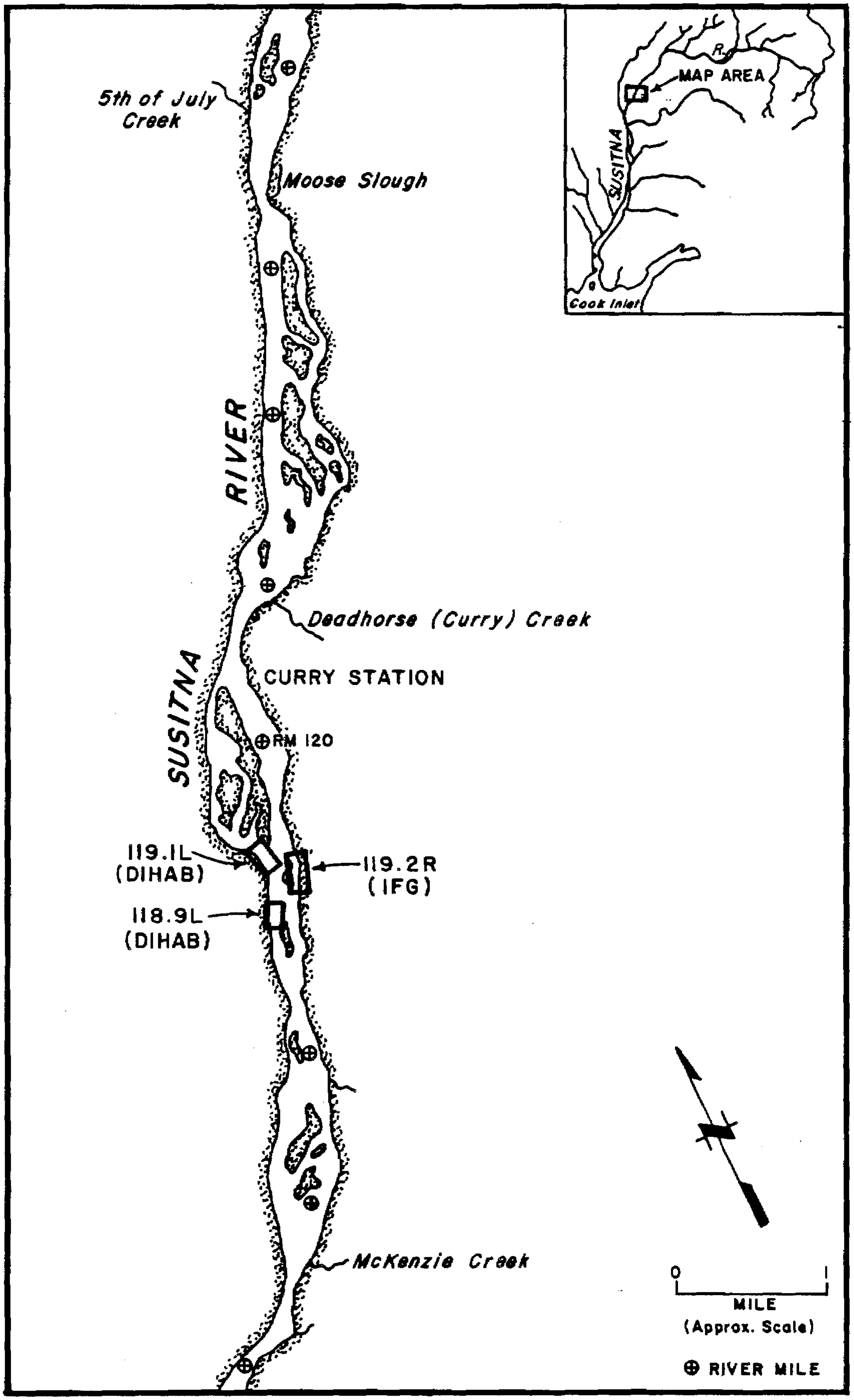


Figure III-1 (Continued).

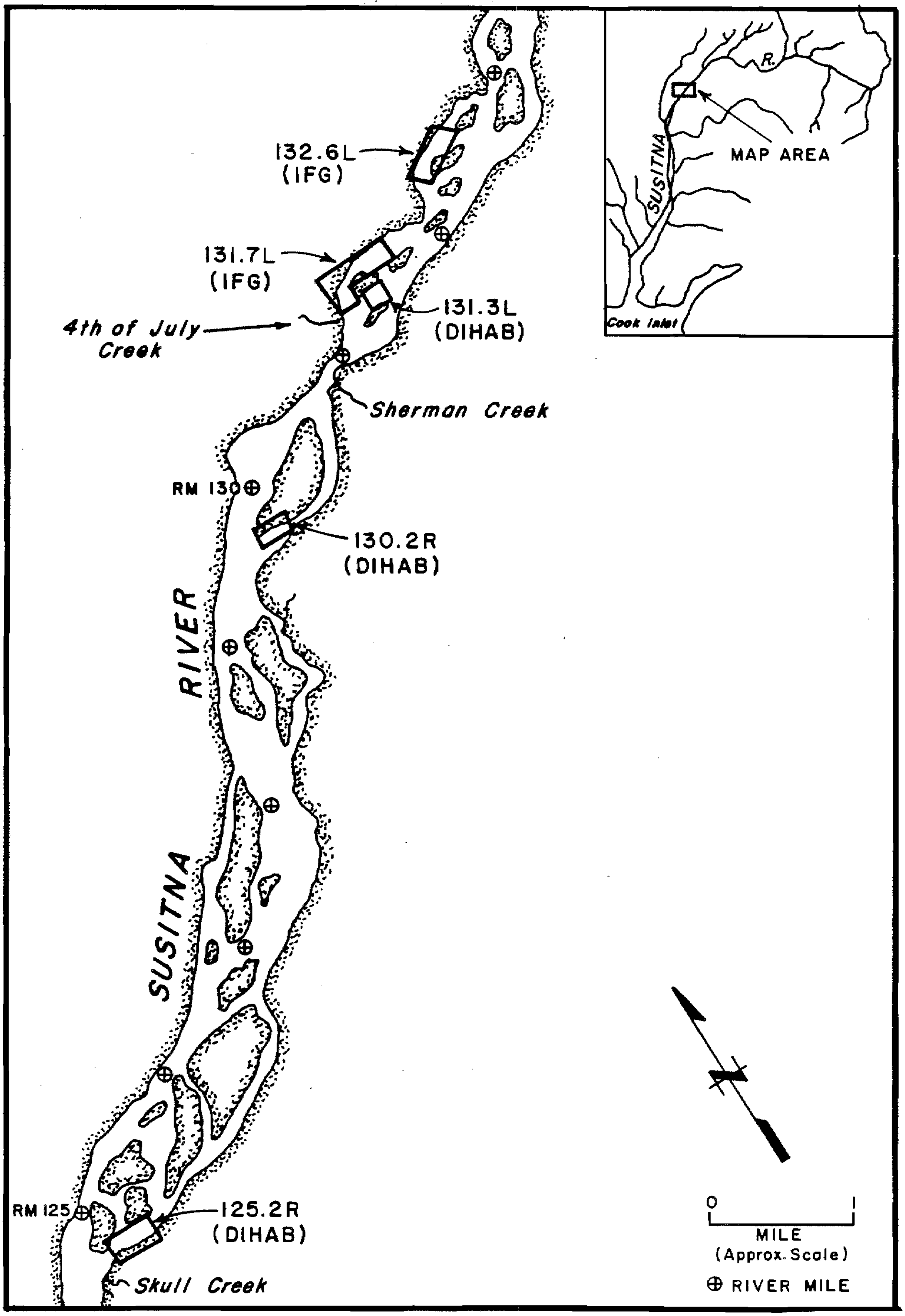


Figure III-1 (Continued).

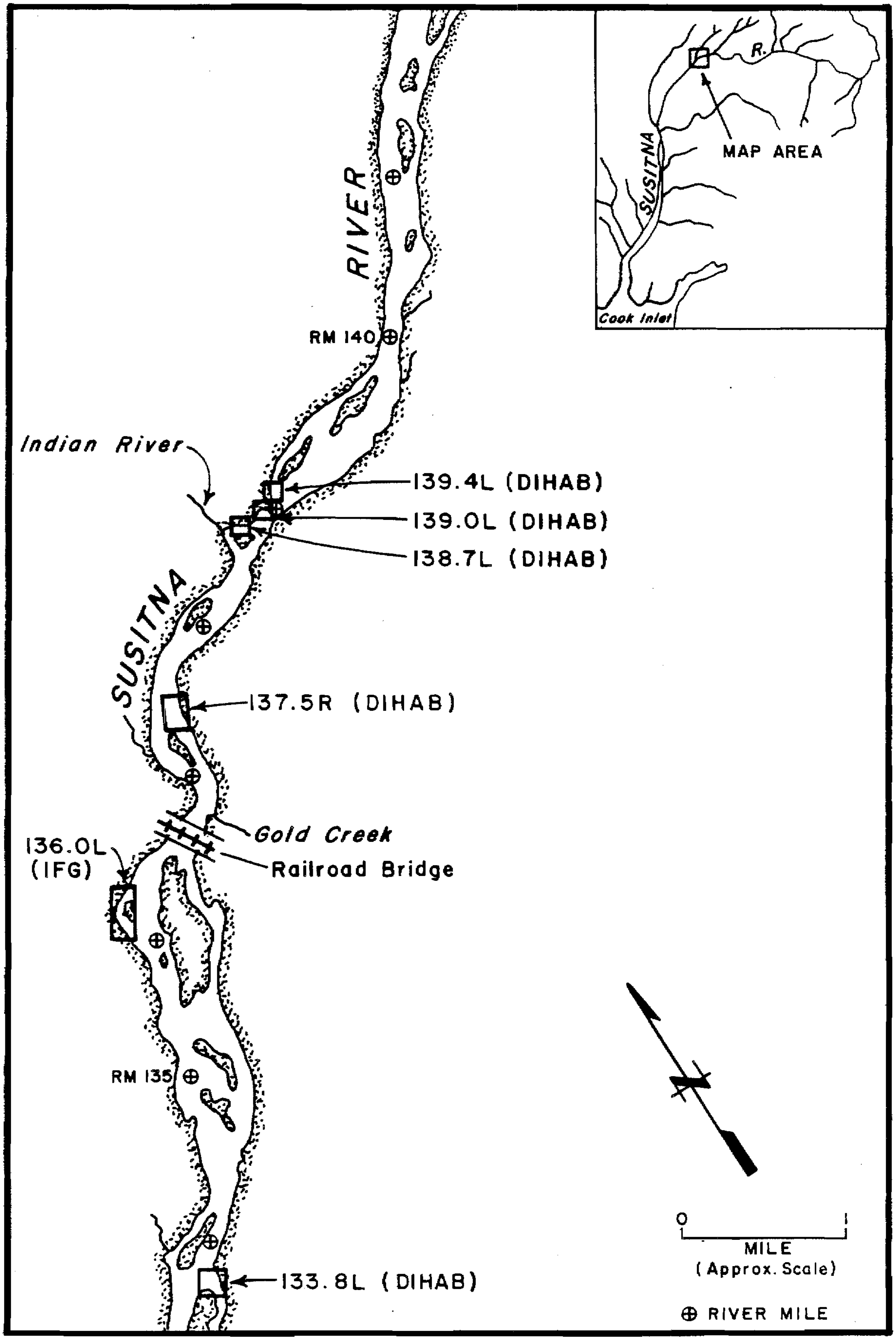


Figure III-1 (Continued).

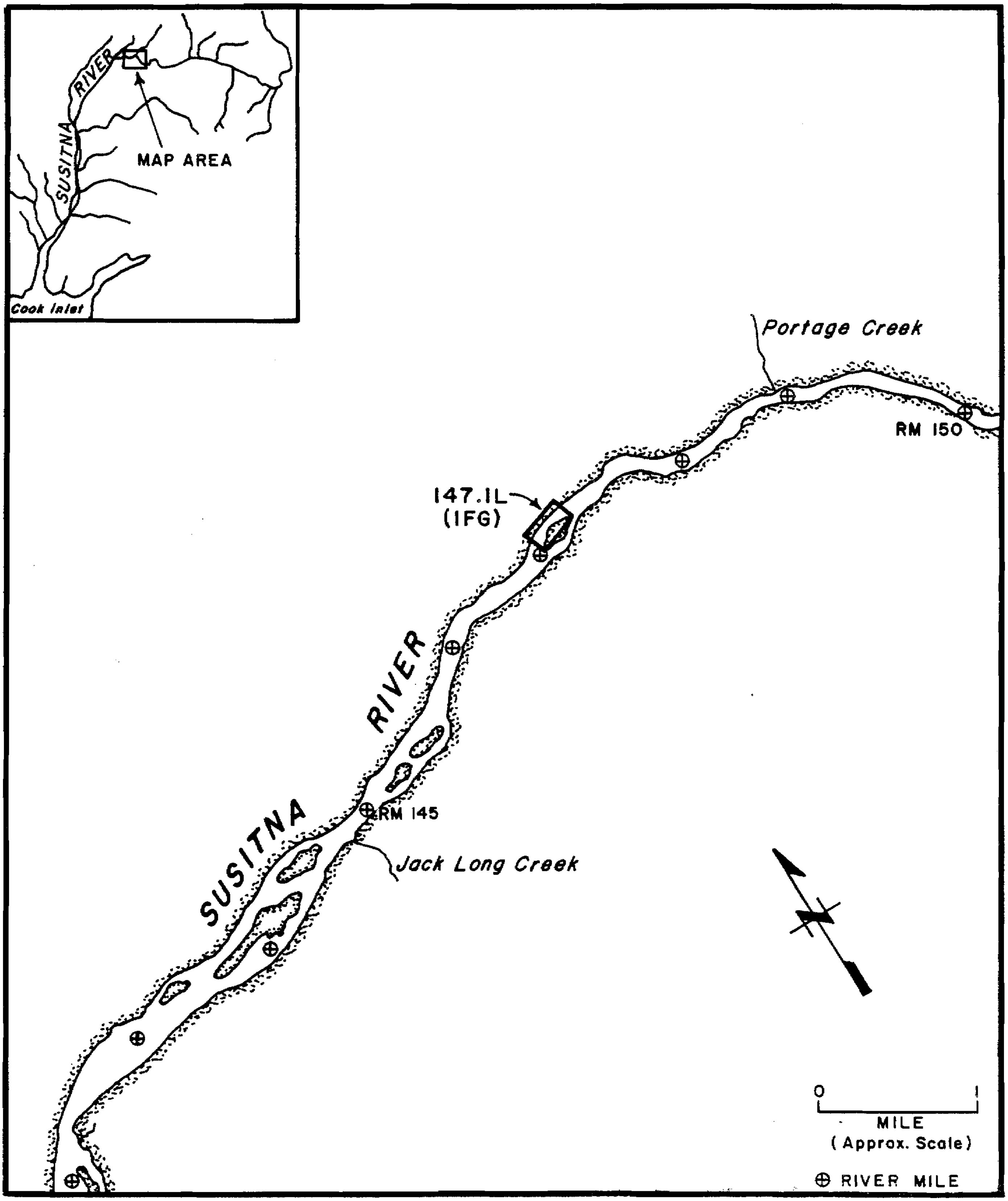


Figure III-1 (Continued).

Table III-1. Types of hydraulic models applied at 1984 middle Susitna River modeling sites for rearing chinook.

Site	Type of Model
101.2R	7 cross section IFG-4
101.5L	5 cross section IFG-2
112.6L	9 cross section IFG-2
119.2R	5 cross section IFG-2
131.7L	7 cross section IFG-4
132.6L	9 cross section IFG-4
136.0L	6 cross section IFG-4
147.1L	6 cross section IFG-2

Site Installation: A varying number of cross sections were established and staff gages installed at each study site to describe pools, riffles, and runs. Cross sections were also located at the transitions between riffles and pools. Methods for installing staff gages are described in Part II of this report and the ADF&G Su Hydro Procedures Manual (1984).

Cross Section and Streambed Profile Surveys: Cross section profiles were determined for each cross section with a level and survey rod. Horizontal distances between headpins were measured to the nearest 1.0 ft by stadia survey or measuring tapes. Streambed elevations were measured to the nearest 0.1 ft using differential leveling techniques. In conjunction with the cross section survey, the stage was determined at the left and right edges of the cross section, and depth was measured at a minimum of three points. Streambed profile surveys were completed using procedures described in Su Hydro Procedures Manual (1984). The results of the surveys are presented in Figures B-1.1 through 1.3 and Tables C-1.1 through 1.3.

Calibration of the IFG-4 hydraulic model requires the stage at which no flow occurs for each cross section. Therefore, for these sites, the stage of zero flow was determined at each cross section. The "stage of zero flow" corresponds to the lowest streambed elevation for riffles and runs or the elevation of the hydraulic control immediately downstream of pools. A hydraulic control is identified by a change in the cross sectional dimensions in a relatively short distance such as sudden contractions and expansions vertical, horizontal or both (Chow 1959). The surveyed streambed profile was used to evaluate the stage of zero flow when the cross sections were not located on hydraulic controls.

Depth and velocity: Information on depth and velocity necessary for model calibration were collected at each site using a Marsh-McBirney or Price AA velocity meter and a top-set wading rod. Water depth was measured to the nearest 0.05 ft and velocities were measured to 0.1 fps. These measurements were classified as either "calibration" or "shoreline" data. Calibration data were collected for use with the IFG-4 model at the smaller study sites and were obtained at verticals across an entire cross section. Shoreline data were collected at the larger study sites and were obtained at verticals on that portion of the cross section extending from each bank out into the channel until either the depth or velocity were unsafe for field personnel (depth $>$ 4 ft or velocity $>$ 4.5 fps). Shoreline data were used to calibrate the IFG-2 model and to provide high resolution along the channel margins where fish habitat might exist. In mid-channel cells of the IFG-2 model sites, depths were estimated from cross section and water surface profiles. When cross section profiles were not available, the continuity equation was used.

The continuity equation assumes that the volume rate of flow at cross section 1 is equal to the volume rate of flow at cross section 2, written in the form

$$V_1 A_1 = V_2 A_2$$

where:

V = velocity in fps

A = area in ft^2

The equation was applied by assuming the same flow in adjacent cross sections. The mid-channel flow was calculated by subtracting the flow along the channel margins from the total site flow. The velocity for the mid-channel was determined by dividing the mean cell depth from the mid-channel flow.

Substrate and Cover: Substrate composition and the cover value for juvenile chinook salmon were visually estimated across each cross section and recorded. Substrate composition was classified using the criteria presented in Table III-2 and cover was described according to criteria presented in Table III-3.

GENERAL TECHNIQUES FOR HYDRAULIC MODEL CALIBRATION

Input data requirements for an IFG-4 model include streambed elevations, stationing, reach lengths and stage of zero flow for each cross section, as well as individual cell velocities for each calibration flow. Input data requirements for the IFG-2 model include streambed elevations and stationing for each cross section, Manning's "n" values for each individual cell and a stage at the lowermost cross section for each flow. Data reduction and coding

Table III-2. Substrate code classification.

Substrate	Visually Estimated Particle Size	Classification
Silt		1
		2
Sand		3
		4
Small Gravel	1/8-1"	5
		6
Large Gravel	1-3"	7
		8
Rubble	3-5"	9
		10
Cobble	5-10"	11
		12
Boulder	>10"	13

Table III-3. Cover code classification.

COVER	CODE	PERCENT COVER	CODE
silt, sand	1	0-5	.1
emergent vegetation	2	6-25	.2
aquatic vegetation	3	26-50	.3
1-3" gravel	4	51-75	.4
3-5" rubble	5	76-100	.5
> 5" cobble, boulder	6		
debris	7		
overhanging riparian vegetation	8		
undercut bank	9		

procedures suggested by Trihey (1980). Calibration of the IFG-4 model was undertaken following recommended IFG guidelines (Main 1978; Milhous, Wegner, and Waddle 1984) as supplemented by Trihey and Hilliard (1984). Guidelines suggested by Trihey and Hilliard include:

1. Forecast depths and velocities for streamflows representing the anticipated extrapolation limits of the calibrated model during the initial calibration runs.

2. Visually examine water surface profile plots for each calibration discharge as well as the streamflows representing the upper and lower extrapolation limits of the model.

   If the observed and predicted water surface profiles do not agree, or the forecast water surface profiles for the upper and lower extrapolation flows appear unreasonable (i.e., water flowing uphill or conflicting with the slope of the calibration profile), the following procedures were completed through an iterative process.

   a. The stage of zero flow was examined to see that it has been correctly defined.

   b. The cross section coordinates were checked that they were correctly calculated and transferred to the IFG-4 input deck.

c. The right and left bank stages were checked that they were properly used to provide a horizontal water surface across the cross section. If a large discrepancy existed between the right and left bank stages, the streambed elevations were adjusted to cause a horizontal stage across the cross section. To do this, the stage for the area with the majority of flow was extended across the cross section. The difference between this stage and the measured stage was added to the streambed elevations.

d. The calculated stages were adjusted at each cross section within the following limits to provide more realistic forecasts of water surface profiles for the extrapolation flows:

flat gradient ± 0.02 ft

steep gradient ± 0.05 ft

e. If steps "a" through "d" did not result in reliable water surface profiles for the extrapolation flows, it was quite possible that the stage-discharge relationship was non-linear and that more reliable hydraulic simulations would result from high and low flow models used in combination rather than from model to simulate the entire flow range of interest. If this was the case, separate the field data into two subsets and develop two hydraulic models following the guidelines and procedures described.

3. The velocity adjustment factors (VAF's) were reviewed in accordance with the IFG guidelines (Milhous, Wegner, and Waddle 1984) after reasonable water surface profiles are forecast by model.

While reviewing the VAF's for this study, measured velocities were adjusted ±0.10 fps in low velocity areas or ±10 percent when in excess of 2 fps, and extremely small non-zero velocities (.01 to .05 fps) or abnormally large Manning's "n" values (.1 to .9) were assigned to pool and shoreline areas where zero velocity was reported in order to improve the predictive capability of the IFG-4 model over the range of extrapolation flows. Assigning a small non-zero velocity to a cell steepens the stage-discharge relationship more than assigning a large "n" value: A steeper stage-discharge relationship predicts higher stage at the upper end of the relationship and lower stage at the lower end.

Calibration of IFG-2 models also followed recommended IFG guidelines and was supplemented by procedures developed by EWT&A (Milhous, Wegner, and Waddle 1984). These procedures utilized the shoreline depth and velocity data collected over a wide range of flows, and the stage-discharge and flow-discharge curves established for several cross sections in the study site. Manning's "n" values were adjusted for each cell of the cross section until predicted shoreline velocities and water surface profiles conformed to field data.

Required input data for an IFG-2 model includes the stage at the downstream cross section for each streamflow to be simulated. These elevations were obtained from the stage-discharge relationship developed for each cross section (Part II). Stage-discharge curves developed at the other cross sections in the study site provided target stages with which to compare predicted water surface profiles. If the stage predicted by the model was lower than the measured stage, the "n" values were increased. If the predicted stage was too high, "n" values were decreased.

Once the desired water surface profile was attained for the calibration flow(s), the distribution of velocities across each cross section was compared with the available field observations. Plots of observed-predicted velocities were used to identify cells where an adjustment in the "n" value was required. Changes in individual "n" values for large conveyance areas (mid-channel cells) significantly altered the stage at the cross section, whereas changes in individual "n" values for small conveyance areas, or shoreline cells resulted in little or no changes in the stage.

Roughness or n-modifiers are utilized in the IFG-2 model to account for decreases in "n" values with increases in discharge (Milhous, Wegner, and Waddle 1984). N-modifiers are necessary to maintain the characteristic shape of the velocity distribution across the cross section. All the "n" values at each cross section were multiplied by a constant factor for every flow. Typical n-modifier values ranged from 1.02 for low flows to 0.60 for extremely high flows. The apparent skewness between n-modifiers for low and high flows exists because most calibration and shoreline data were collected during low flow conditions. Minimal adjustment was necessary to simulate low flow conditions compared to high flow conditions.

A single IFG-2 model was not always adequate to reliably predict both low and high flow hydraulic conditions. This inadequacy was primarily due to the interaction between channel geometry and flow that altered the stage-discharge relationship, such as the overtopping of gravel bars or transformation of a riffle pool sequence to a run. Unrealistic velocity distributions between low and high flow predictions, especially along the shorelines, indicated a need to utilize two models for a particular cross section.

GENERAL TECHNIQUES FOR HYDRAULIC MODEL VERIFICATION

The quality of each calibrated IFG-4 or IFG-2 hydraulic model was evaluated at two levels. Level one is a qualitative assessment of the model's overall performance with regard to four evaluation criteria. Level two evaluations are analytical procedures and are applied when the calibrated IFG-2 or IFG-4 model was not assigned an excellent rating by the level one evaluation. In the level one evaluations, each model was given a numeric rating depending upon its degree of compliance with each criteria. Numeric ratings were based on a comparison of model performance with criteria and professional judgment. Professional judgment was based on: an understanding of open channel hydraulics, familiarity with the study site, experience with the model, and knowledge of how the model would be used in the habitat analysis.

Numeric ratings of 0, 1 or 2 for each of the four criteria were added and used to indicate the overall quality of the calibrated models according to the following scale:

Excellent	8 (maximum possible score)
Good	7
Acceptable	5-6
Unacceptable	<5; or zero for any evaluation category

IFG MODEL EVALUATION: LEVEL ONE

The evaluation criteria and appropriate ratings for the level one evaluation for IFG models are described below.

Criteria 1: How well does the model conform to the IFG and EWT&A calibration guidelines?:

Plot water surface profiles, stage of zero flow, and streambed profile. Are they reasonable? To be reasonable, water must flow downhill; an increase in discharge should cause the pool/riffle sequence to drown out and cause the water surface profile to become more uniform in gradient; a decrease in discharge should cause the water surface profile to more distinctly reflect changes in stream bed gradient and pool/riffle profiles.

After examining the stage forecast by the calibrated model, the predicted stages were checked over a broad range of discharges to see if they are coincident with the stage-discharge curves for each site.

After comparing predicted depths and velocities at the calibration flows to field data, the predicted flows were checked for agreement with the flows measured in the field for each cross section (IFG-4 model only). Also, were the predicted velocities realistic? Were there more than a few outliers for the extrapolated flows?

Ratings:

2 = A model that can forecast both stages and velocities accurately.

1 = A model that can define stages and velocities accurately at the calibration flows but may not be able to reliably define both stage and velocities near the limits of the extrapolation range.

0 = A model that cannot accurately reproduce stages or velocities at the calibration flow.

Criteria 2: How well does the extrapolation range of the calibrated model conform to the desired range?

Subreaches of the overall extrapolation range of the calibrated model were rated excellent, good, acceptable or not acceptable depending upon the degree to which predicted stages coincide with the stage-discharge curve and the degree to which VAF's coincide with IFG guidelines. The first assumption made in this evaluation is that accurate stage-discharge curves are available for several cross sections in the study site. The ability to evaluate the forecasting capabilities of the model improve with an increase in the number of well-defined stage-discharge curves. Were there sufficient changes in local channel geometry, or flow patterns (such as additional flow contributions from other channels become breached at higher mainstem discharges) to invalidate the stage-discharge relationship beyond the range of available data. These changes were also noted by reviewing aerial photography and incorporating field experience.

Ratings:

2 = A model that can forecast stages coincident with the stage-discharge curve while retaining VAF's between 0.9 and 1.1 throughout the entire extrapolation range.

1 = A model that can forecast either VAF's or stages within the extrapolation range.

0 = A model that cannot forecast acceptable VAF's or stages within the defined extrapolation range.

Criteria 3: Are the hydraulic models appropriately calibrated for the species and life stage being considered?

Study sites established to evaluate a particular species or life stage may not accurately represent microhabitat conditions important to another species and/or life stage. For example, a good rearing site may not be an acceptable spawning site due to substrate composition or absence of upwelling. The microhabitat characteristics of the study site were reviewed in reference to life history requirements of the species or life stage being evaluated. Were the cross sections properly located to accurately define the channel morphology important to the species and/or life stage of interest. Verticals should divide each cross section into cells that provide an accurate description of the depth and velocity distribution.

Ratings:

2 = A model that provides sufficient precision in its hydraulic forecasts to be applied to both adult and juvenile life stages with an equally high level of confidence.

1 = A model that can provide a high level of precision for evaluating the life stage for which the study site was primarily established, but hydraulic forecasts are only considered "acceptable" for other species and/or life stages. If cross sections and verticals within the study site had been laid out differently, additional data collected, or a separate hydraulic model calibrated, a "2" rating would have been possible.

0 = Insufficient data were collected to calibrate the hydraulic model in the flow range of interest for the species or life stages to be evaluated.

Criteria 4: How well does the range of forecast depths and velocities compare with the depth and velocity suitability criteria?

The occurrence of predicted depths and velocities were checked within a range of values for which suitability indices are not sensitive even though the model may not accurately reproduce depths or velocities. These ranges are unique to the particular set of habitat suitability criteria being applied. In general, hydraulic models for juvenile salmon should be accurate at low velocities (0.8 fps), but need not be as accurate when velocities exceed 2 fps. Hydraulic models for spawning salmon should be able to accurately predict velocities up to 2 fps, and depths up to 1.0 ft. Water depths greater than 0.15 ft need only be approximate and are of little consequence in steep-sided channels where an error in the stage will not cause a significant change in top width.

Ratings:

2 = The hydraulic model provides accurate forecasts of depths and velocities present in the study site throughout the full ranges of depths and velocities for which suitability criteria are defined.

1 = Hydraulic forecasts are sufficiently accurate to describe the order of magnitude of the suitability index and therefore will result in a reliable habitat model even though the precision of the hydraulic forecasts are questionable.

0 = The hydraulic model is incapable of accurately identifying the order of magnitude of the habitat suitability index.

IFG MODEL EVALUATION: LEVEL TWO

Level two evaluation criteria were applied when the calibrated IFG-2 or IFG-4 model was not assigned an excellent rating by the level one evaluation. These analytical techniques can also be incorporated as additional steps in recommended model calibration procedures for other studies using the IFG hydraulic models. Separate procedures were required for the IFG-2 and IFG-4 models due to their inherent differences.

IFG-4 Model:

A visual comparison was made between scatterplots of the observed and predicted depths and velocities at all cross sections for each calibration flow. An accurate model should reproduce the observed data and plot as a straight line on the scatterplots. A quantitative assessment of observed and predicted data can be made by computing several statistics which describe the differences between a set of values (Willmott 1981). Pearson's Product-Moment Correlation Coefficient (r), Coefficient of Determination (r^2), the slope (b) and intercept (a) of a least squares regression between observed and predicted values are measures of a model's predictive capabilities. The predictive capability of the model may also be evaluated through the use of the systematic and unsystematic components of the root mean square error

$$RMSE_S = [N^{-1} \sum_{i=1}^{n} ((a + bO_i) - O_i)^2]^{0.5}$$

and

$$RMSE_U = [N^{-1} \sum_{i=1}^{n} (P_i - (a + bO_i))^2]^{0.5}$$

as well as the total root mean square error

$$RMSE = [N^{-1} \sum_{i=1}^{n} (P_i - O_i)^2]^{0.5}$$

where:

$i = 1,2,.........n$ (sample size of the number of predicted cells)

O = observed or field measured data

P = model predicted data.

If $RMSE_U$ was equal to or similar in value to the RMSE, the model was expected to be well-calibrated (Willmott 1981). An index of agreement, "d", was also calculated to determine the degree to which a model's predictions are error-free. The index of agreement was computed by

$$d = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} [\,|P_i - \overline{O}| + |O_i - \overline{O}|\,]^2}$$

The value of d varies between 0.0 and 1.0 where a computed value of 1.0 indicates perfect agreement between the observed and predicted observations, and 0.0 denotes complete disagreement.

IFG-2 Model:

A visual comparison was made of the observed and predicted velocity distribution plots for the IFG-2 models, where most of the observed data was obtained near the shoreline. In general, cells in the IFG-2 model do not coincide with verticals where field measurements were made, but rather with distinct changes in channel geometry, roughness, or habitat suitability. A representative velocity distribution "shape" using calibration flow data, therefore, was developed for each cross section.

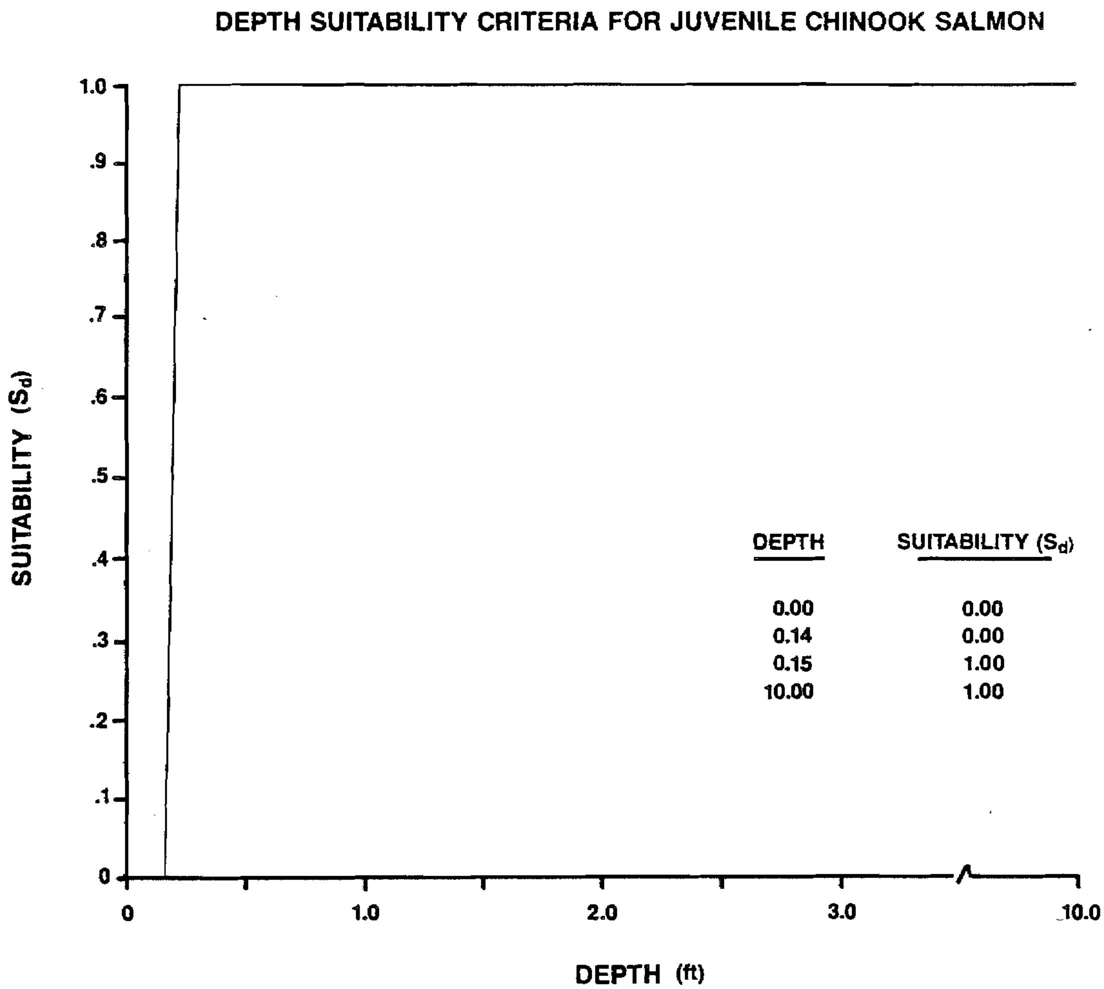
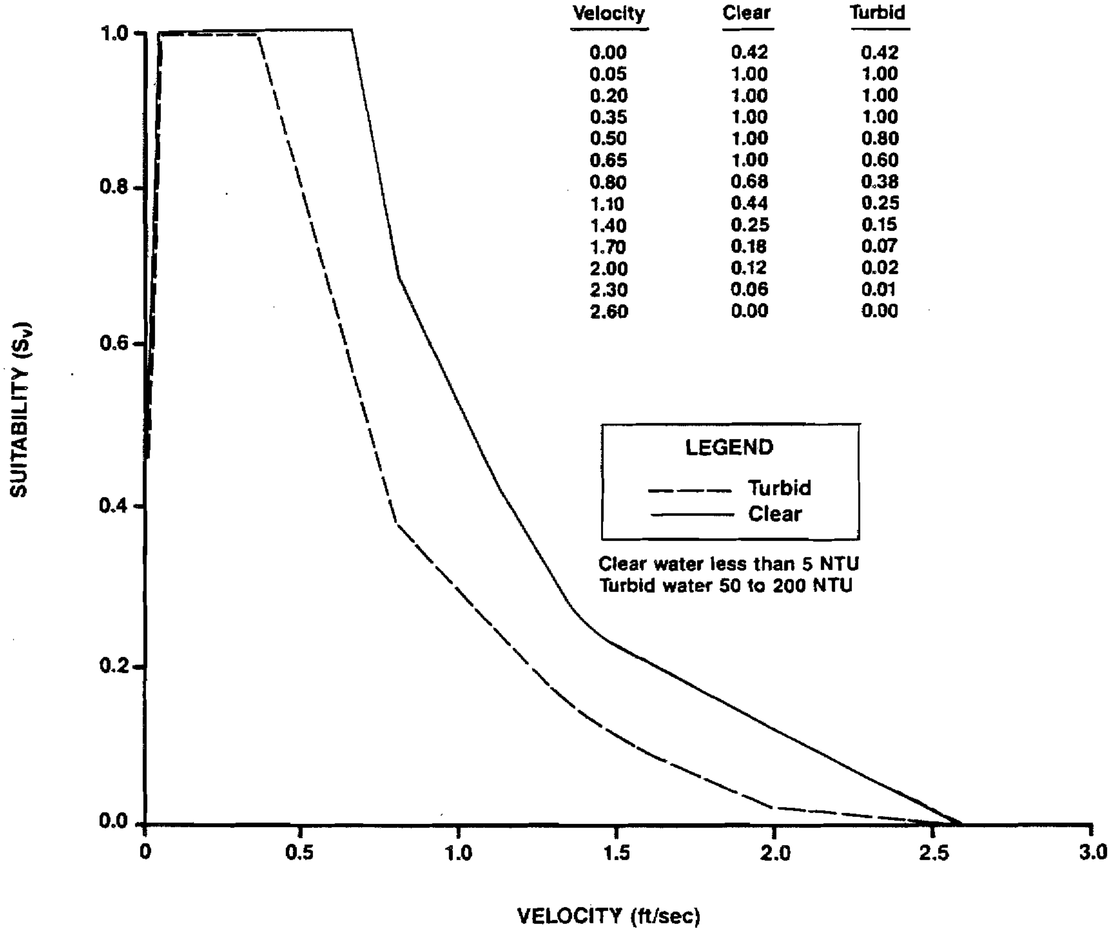


Figure III-2. Juvenile chinook salmon suitability criteria for depth applicable to clear and turbid water habitats. Source: Suchanek et al. 1984; EWT&A and WCC 1985.

VELOCITY SUITABILITY CRITERIA FOR JUVENILE CHINOOK SALMON



	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 III-3. Juvenile chinook salmon suitability criteria for velocity applicable to clear and turbid water habitats. Source: Suchanek et al. 1984, EWT&A and WCC 1985.

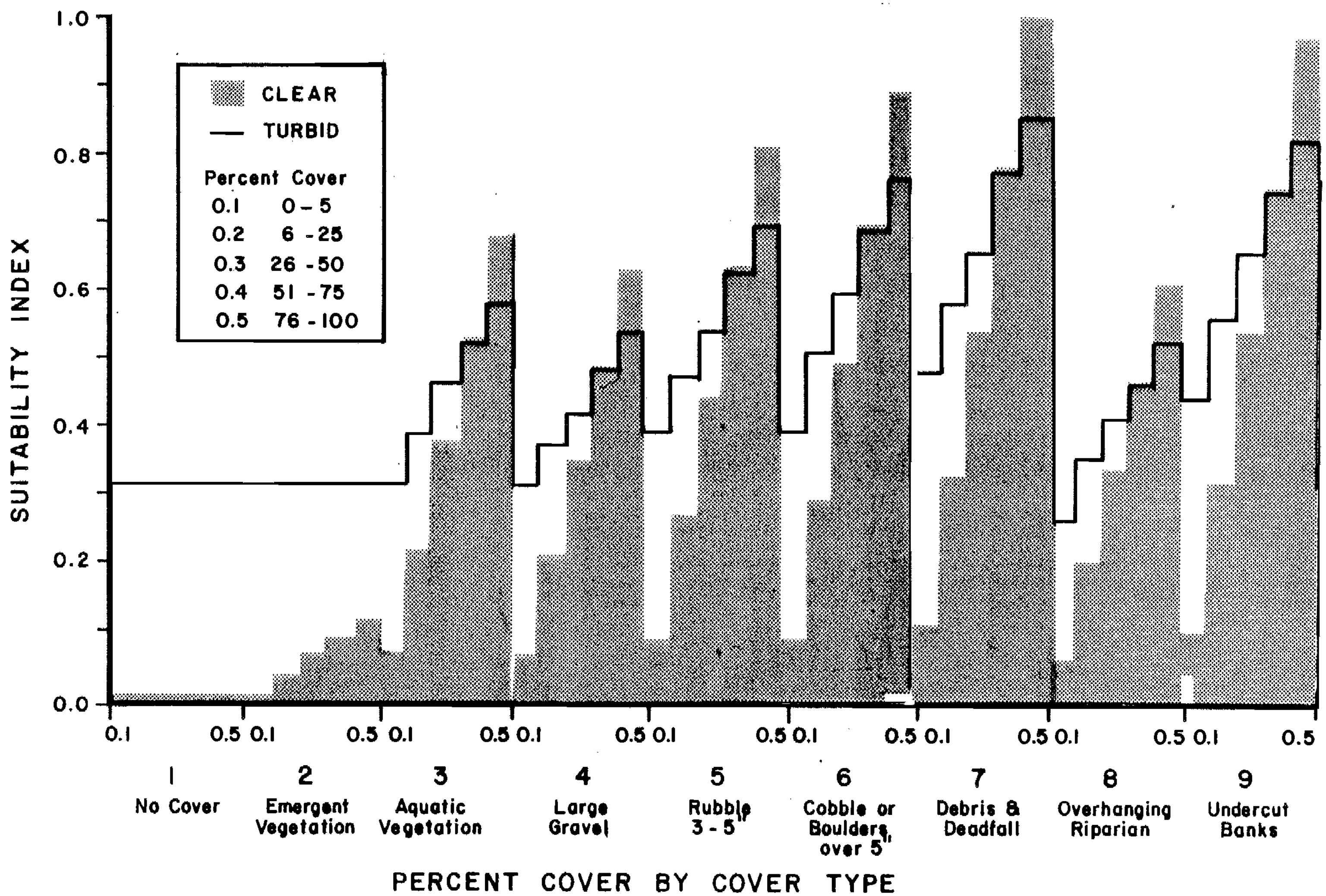


Figure III-4. Juvenile chinook salmon suitability criteria for cover applicable to clear and turbid water habitats. Source: Suchanek et al. 1984, EWT&A and WCC 1985.

Table III-4. Juvenile chinook salmon cover suitability criteria, applicable to clear and turbid water conditions. Sources: Suchanek et al. 1984; EWT&A and WCC 1985.

Percent Cover	No Cover	Emergent Veg.	Aquatic Veg.	Large Gravel	Rubble 3"-5"	Cobble or Boulders 5"	Debris & Deadfall	Over-hanging Riparian	Undercut Banks
Clear Water (Suchanek et al.)									
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)[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

Where only shoreline data was available, the horizontal velocity distribution was modeled either by using measured values obtained at a similarly shaped cross section where a complete data set was available, or by simply estimating a mid-channel velocity distribution based on the channel geometry and the continuity equation. The highest velocities should correspond to the deepest portion of the channel.

Applying the IFG-2 model at discharges other than the calibration flow produces velocity distributions similar to the calibration flow velocity distribution. When inconsistencies between field data and predicted velocities occurred at high flows, a second model was developed similar to the first model. At high flows, the velocity increases more rapidly, along the shoreline than at lower flows. The second or high flow model can thus more accurately, predict the velocities in this area.

GENERAL TECHNIQUES FOR HYDRAULIC MODEL APPLICATION

The calibrated hydraulic models and habitat suitability criteria from previous studies were linked with the HABTAT model to forecast WUA for juvenile chinook salmon as a function of streamflow. The habitat suitability criteria as demonstrated in curves for each physical habitat variable were derived from field observations of juvenile chinook in side channel and side slough areas (Suchanek et al. 1984) as described by EWT&A and WCC 1985. These suitability criteria are summarized in Figures III-2, III-3, III-4 and Table III-4. Two of the criteria, velocity and cover, are different under clear and turbid water conditions. Clear water habitats are those which occur in unbreached side channel areas conveying base flows derived from groundwater or tributary inflow.

Total WSA and WUA curves for juvenile chinook were obtained at the eight hydraulic modeling sites corresponding to a range of mainstem discharge from 5,000 to 35,000 cfs at Gold Creek. WUA was calculated and expressed in units of square feet per 1,000 linear feet of stream. When plotted as a function of discharge, the study site WUA indicates the site-specific response of fish habitat to changes in flow. WSA and WUA values for site flows outside the recommended extrapolation range of the hydraulic models were estimated using trend analysis and professional judgment. Instances where this was necessary are documented in Tables B-6.1 through B-6.8. Both the WUA and WSA response to mainstem discharge as predicted by the HABTAT model were reviewed for all the sites for their application ranges. The expected responses beyond the application range was estimated using professional judgment based on comparison with other sites having similar morphologic characteristics and aerial photography. A decreasing exponential rate of increase function was determined for each of those sites with application ranges less than 5000 to 35,000 cfs.

A time series plot of available juvenile chinook habitat was also developed for each site, and hydrographs of site flows were generated using the regression equations developed in Part II and the mean daily mainstem discharges for the 1984 rearing season (May 20 to September 15). The resulting figures enable evaluation of habitat conditions on a site-by-site basis over the summer period.

IFG MODEL RESULTS

The following section provides a description of important physical habitat components found in each of the IFG model sites and anticipated changes in these components with respect to different mainstem discharge. WSA, WUA curves and time series plots of WUA are presented at the eight study sites corresponding to a range of mainstem discharges from 5,000 to 35,000 cfs.

Site 101.2R

Site Description: This site is located 2.2 miles above the confluence of the Chulitna River with the Susitna River on its east bank (Plate III-1). The study reach is 1,500 ft in length and varies in width from 350 ft in the lower half of the site to 250 ft in the upper half. Substrate is mainly cobble and large gravel throughout the site with a layer of silt in the left channel. Cover is available predominately from the rubble and cobble substrate, although some debris is present. Cross sections 1, 3, 4 and 9 are located in the shallow, high velocity areas while cross sections 7 and 8 are sited in a deep, slow velocity area (Figure III-5). Cross section 6 separates the two areas. Cross sections 2 and 5, within the small right channel, did not extend across the main channel, as the hydraulic conditions at adjacent cross sections were similar. Cross sections 3 and 4 extend across a small backwater channel along the left bank.

This study site was selected to represent side channels that become dewatered at low discharges. Upwelling was suspected to maintain low baseline flow

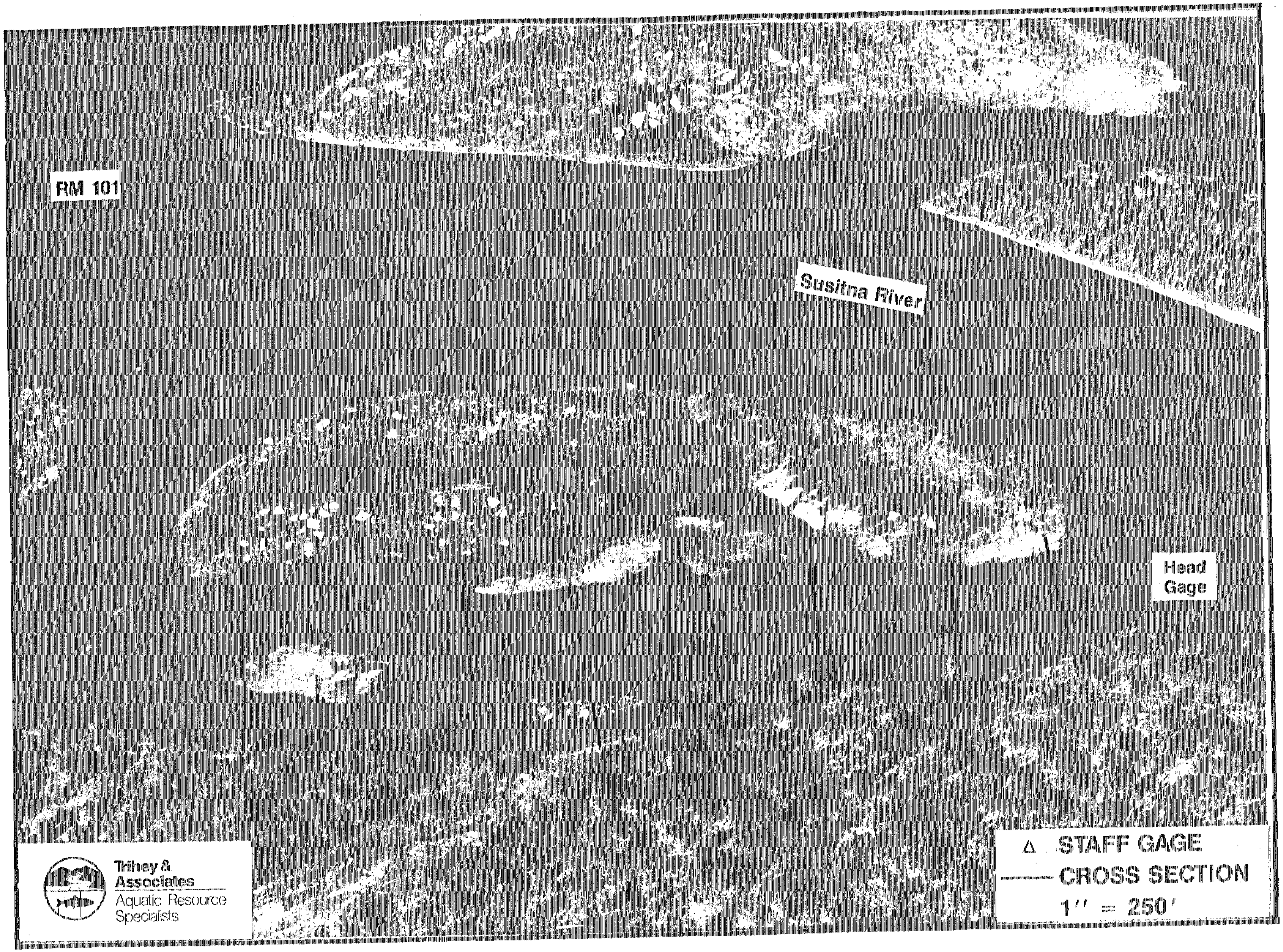


Plate III-1. Modeling site 101.2R on June 1, 1982 at mainstem discharge: 23,000 cfs.

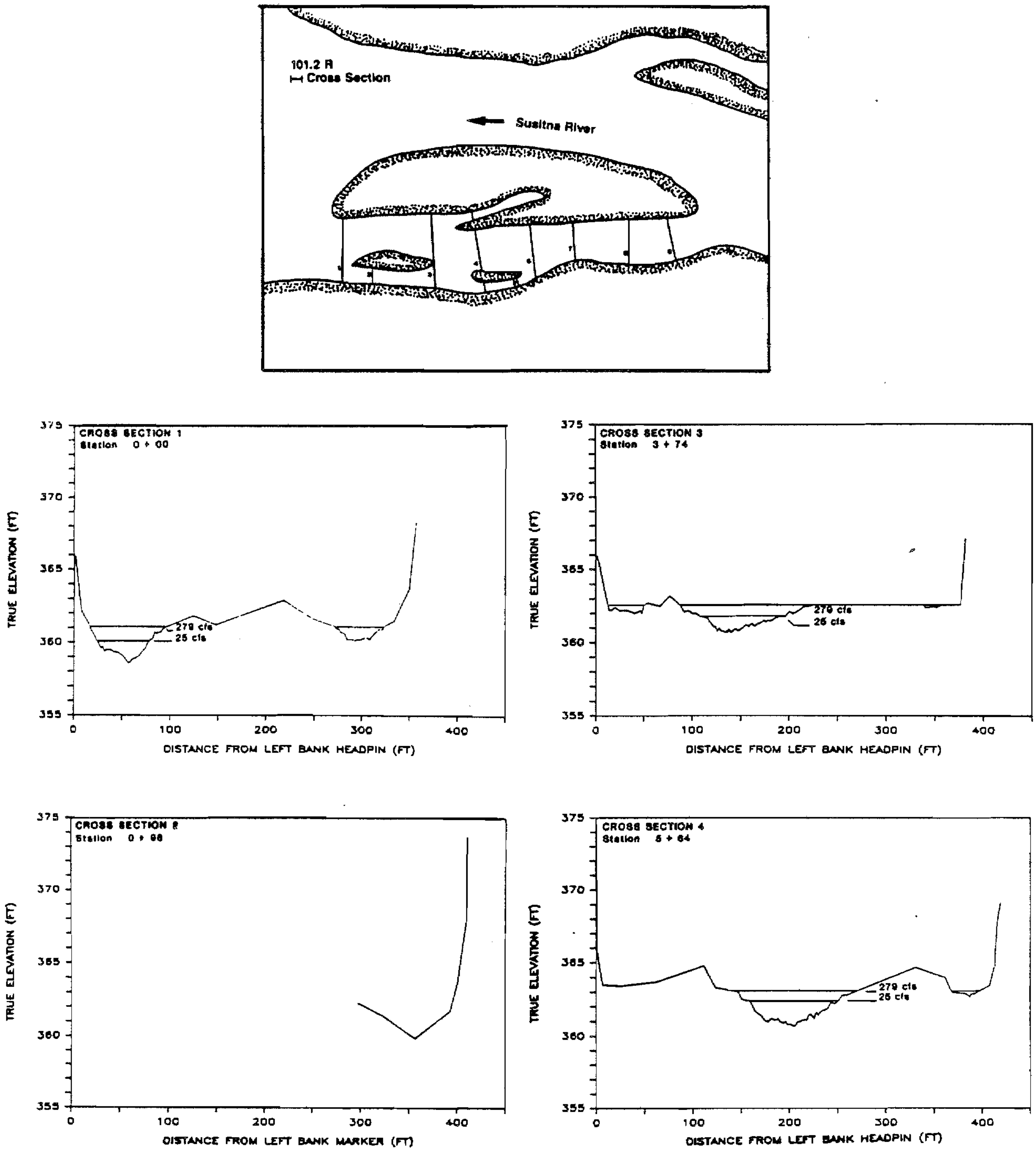


Figure III-5. Cross sections for site 101.2R depicting water surface elevations at calibration discharges of 25 and 279 cfs.

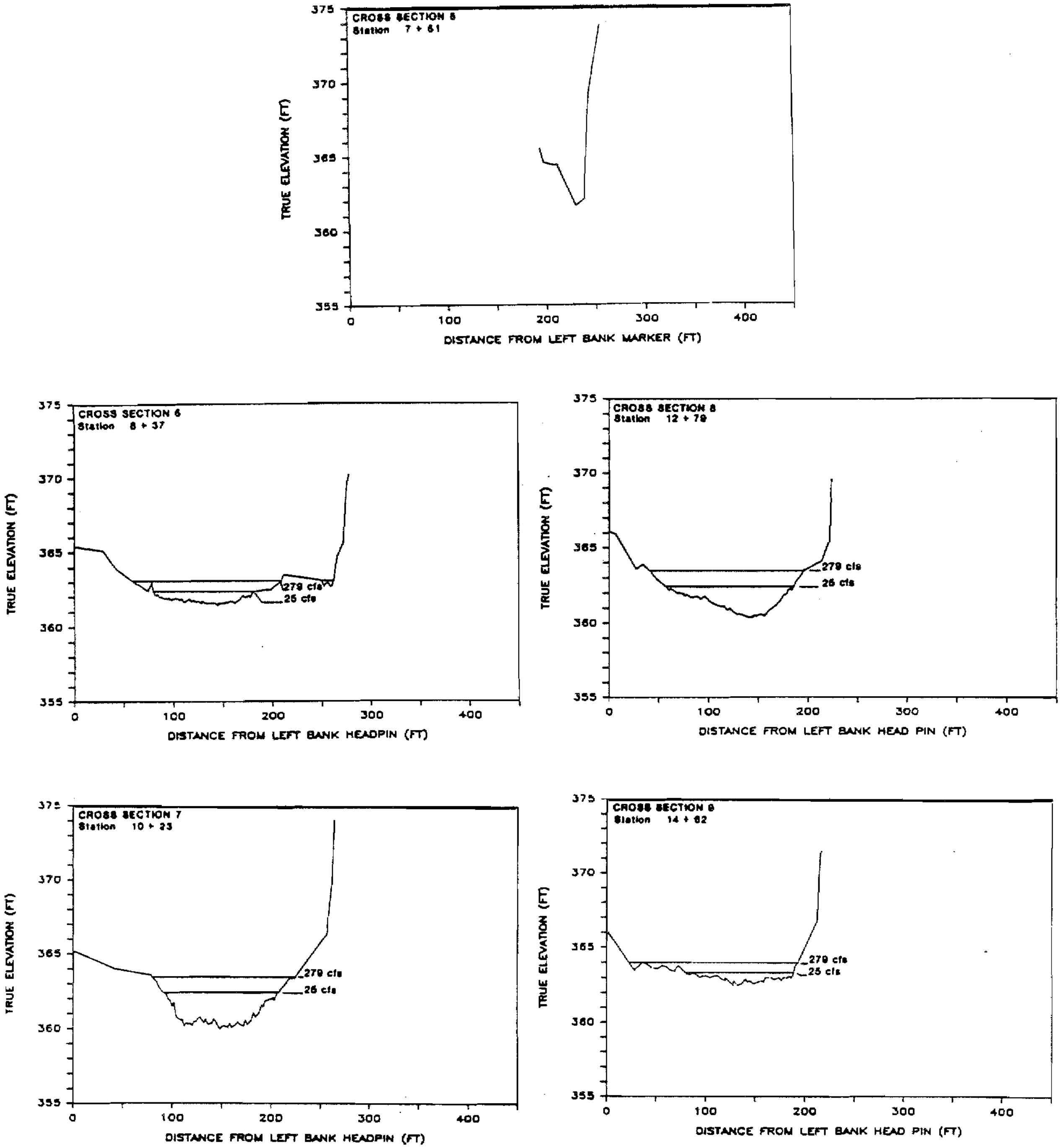


Figure II-5 (Continued).

conditions and the site appeared to have potentially good rearing habitat, although no previous utilization has been documented. An IFG-4 model was selected because of the non-uniform flow conditions present and the channel size. Chum salmon adults have been observed to use the site but no redds were detected. Some juvenile chinook salmon have been observed in the site (Hoffman 1985).

Calibration: Table III-5 lists the data used to calibrate the hydraulic model for this site. Depth and velocity measurements were made across each cross section at every calibration flow. Because the hydraulic model was established to describe the depths and velocities in the main channel, cross sections 2 and 5 were not included, as they do not extend across the main channel.

Table III-5. Hydraulic data available to calibrate the IFG-4 model for site 101.2R.

Date	Site Flow* (cfs)	Mainstem Discharge (cfs)
840830	279	15,300
840903	25	11,200

* Mean site flow

At discharges greater than 14,000 cfs, flow entered the right channel. The stages in the main and right channels differed across cross sections 1, 3 and 4. The streambed elevations were raised in the right channel to maintain a horizontal stage across a cross section (Figure III-6). The backwater area

MEASURED ADJUSTED

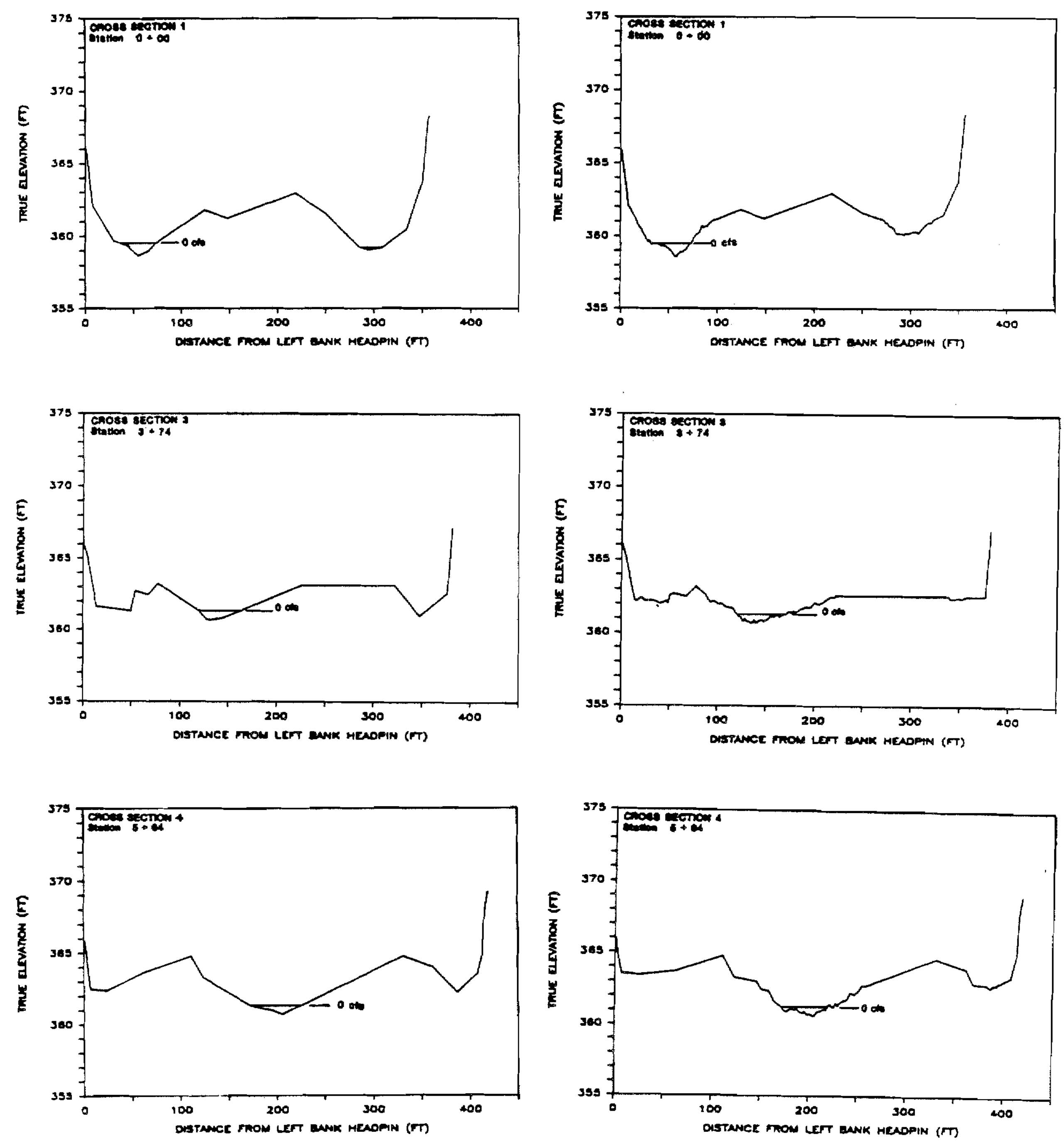


Figure III-6. Comparison between measured and adjusted cross sections 1, 3 and 4 at site 101.2R.

at the mouth of the left channel also had different stages than the main channel. The streambed elevations in the left channel were raised to maintain horizontal stages at cross sections 3 and 4.

Observed and predicted water surface profiles from the calibrated model are shown in Figure III-7. The extrapolation limits are also plotted. The IFG-4 model was calibrated with respect to depth by making comparisons between the stage-flow curves and the model predicted stages. The comparison made at the discharge cross section is illustrated in Figure III-8; similar comparisons were made at each cross section.

Verification: To compare the predictive capabilities of the model, an analytical analysis was made. Scatterplots comparing the observed and predicted depths and velocities (Figure B-2.1) indicate the model is capable of accurately predicting hydraulic data. Statistical tests were also made and the results summarized in Table B-5.

Application: An excellent rating was assigned for the range of 9,200 to 17,600 cfs mainstem discharge. As discussed in Part II of this report, the flow-stage relationship changes as the gravel bar which separates the main and right channels becomes overtopped. Because there is no data available to describe exactly how this change affects the flow-stage relationship, the upper limit of the excellent rating was set at 17,600 cfs, the upper limit of the discharge measurements. Above 17,600 cfs the predictive capabilities are no longer reliable.

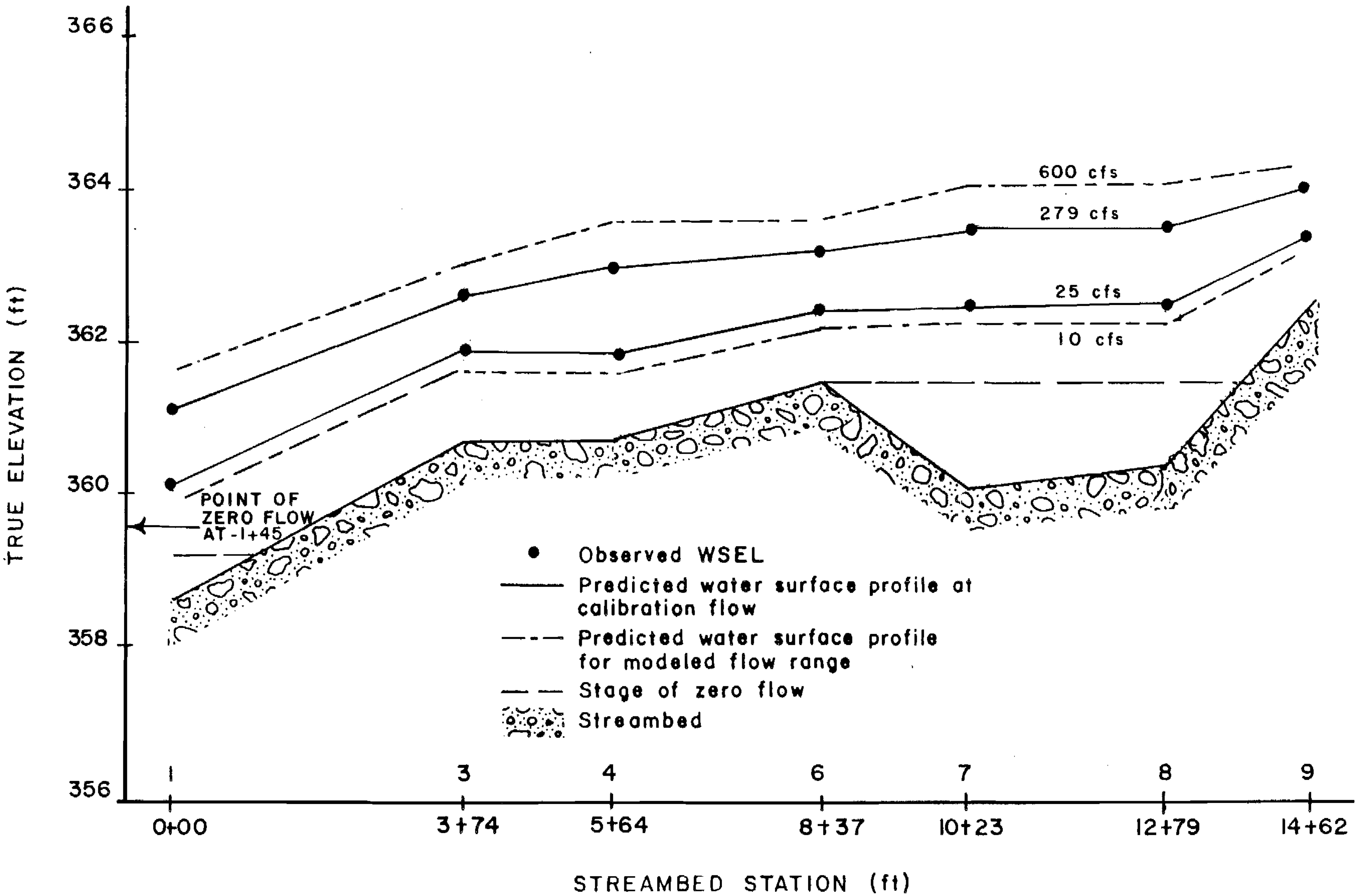


Figure III-7. Comparison of observed and predicted water surface profiles from calibrated model at site 101.2R.

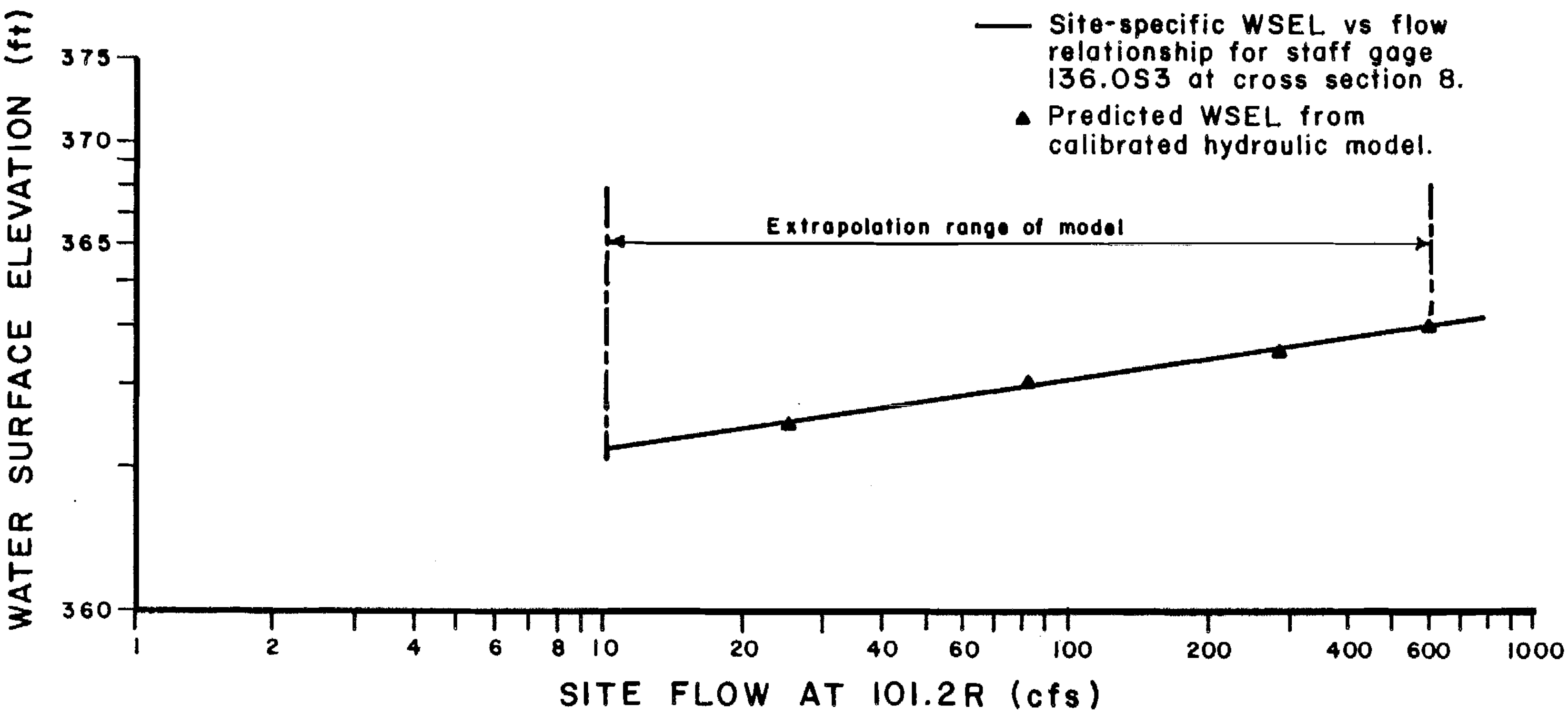
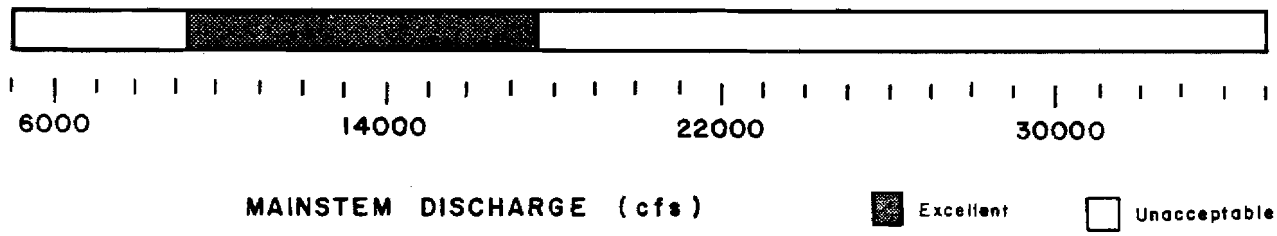


Figure III-8. Comparison between water surface elevations forecast by the calibrated hydraulic models and the stage-flow relationship for 101.2R cross section 8.

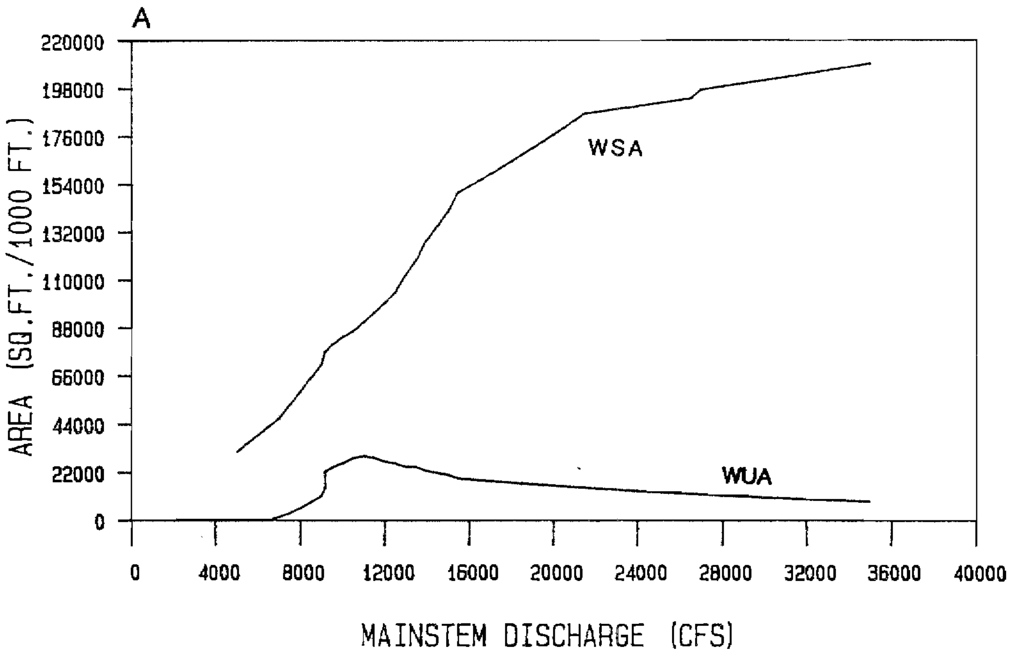
The application ranges and ratings are summarized in the bar chart below.



WSA and WUA curves for study site 101.2R are provided in Figure III-9. The curves are plotted to the vertical scale of sq ft/1,000 ft of stream reach and a comparison of them indicates the relative proportion of WSA which contain rearing habitat for juvenile chinook.

Rearing habitat for juvenile chinook in the side channel is maximized at mainstem discharges in the vicinity of 11,000 cfs. The sharp rise in WUA which occurs near 9,000 cfs is caused by the site becoming breached and the associated increase in turbidity which provides additional cover value for juvenile chinook.

The WUA curve is also plotted in Figure III-9b at an expanded vertical scale to accent the response of rearing habitat to incremental changes in discharge. The presence of turbid water and the distribution of water velocity are the primary determinants of the WUA response curve at this site. Although much of the site exists as riffle-run habitat, the channel gradient is low enough that water velocities do not become limiting to juvenile chinook until mainstem discharges exceed 16,000 cfs. The large vegetated gravel bar which separates the side channel from the mainstem and another large gravel bar in the lower



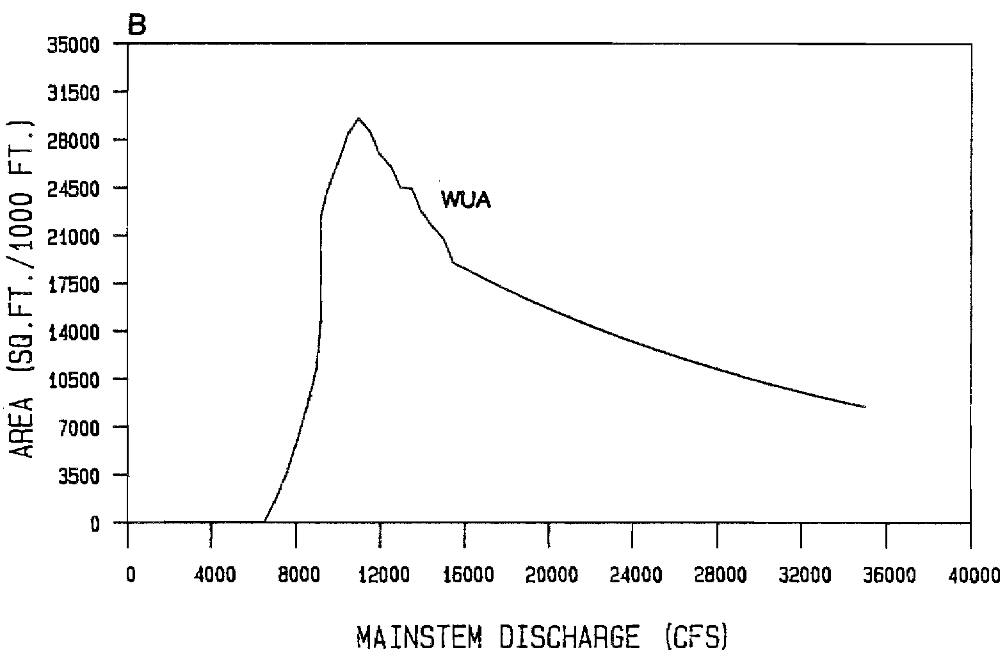


Figure III-9. Surface area and juvenile chinook habitat response curves for site 101.2R. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

portion of the study site which is exposed at low flows do not provide any appreciable increase in rearing habitat at higher flows due to the low cover value of their sand and gravel substrates. Nevertheless, this study site possesses fairly good habitat for juvenile chinook in the lower flow ranges (Figure III-9a).

Because of this limited extrapolation range of the IFG-4 model at 101.2R, the WUA and WSA curves were estimated for mainstem discharges less than 9,200 cfs and greater than 16,000 cfs.

The WSA of the channel was estimated at 31,600 and 46,500 sq ft/1,000 ft for discharges of 5,100 and 7,400 cfs, respectively, using digitized measurements obtained from aerial photography, as described in Klinger-Kingsley (1985). Low turbidity habitat suitability criteria were used to forecast juvenile chinook WUA at 9,200 cfs (breaching discharge for this side channel) and the amount of rearing habitat available under unbreached conditions was assumed to decline to zero at a constant rate between this discharge and 6,500 cfs. This assumption is supported by numerous field observations of clear standing water which is cut off from the mainstem. Although still contributing to total WSA, clear ponded water provides progressively less suitable habitat for juvenile chinook as mainstem flows recede.

At mainstem discharges exceeding 16,000 cfs (the upper extrapolation limit of the IFG-4 model), estimates of the WSA at 23,000 and 27,000 cfs were also obtained from aerial photography. Surface areas associated with discharges between 16,000 and 27,000 cfs were interpolated. Surface area estimates for discharges greater than 27,000 cfs were obtained by extending the surface area curve to a maximum of 210,000 sq ft/1,000 ft at 35,000 cfs.

Above 16,000 cfs, the WUA curve for juvenile chinook was assumed to decay exponentially. This trend is evident at other middle Susitna River side channels for which high flow hydraulic models are available. Extension of the WUA curve beyond 16,000 cfs using this exponential decay does not appear inconsistent with the rate of decline forecast by the calibrated model for discharges less than 16,000 cfs. Additional information is provided in Table B-6.1.

Time series WUA and site flow plots for this study site are presented in Figure III-10a and b. Low site flows during late May and early September corresponding to mainstem discharges of 9,000 to 13,000 cfs resulted in comparatively high rearing habitat forecasts for these periods. High site flows during the intervening months produced low rearing habitat forecasts.

Site 101.5L

Site Description: This site is located 2.2 miles above the confluence of the Chulitna River with the Susitna River on its west bank (Plate III-2). The study reach is 3,100 ft long and 430 ft wide. A large backwater area is present throughout the lower half of the site for the entire discharge range of 5,000 to 35,000 cfs. Cobble and rubble substrate predominate throughout the site and a thick layer of sand exists along the right bank of the mouth. Large substrate, with less than 25 percent considered acceptable, provides the available cover. One cross section is located in the backwater area with a

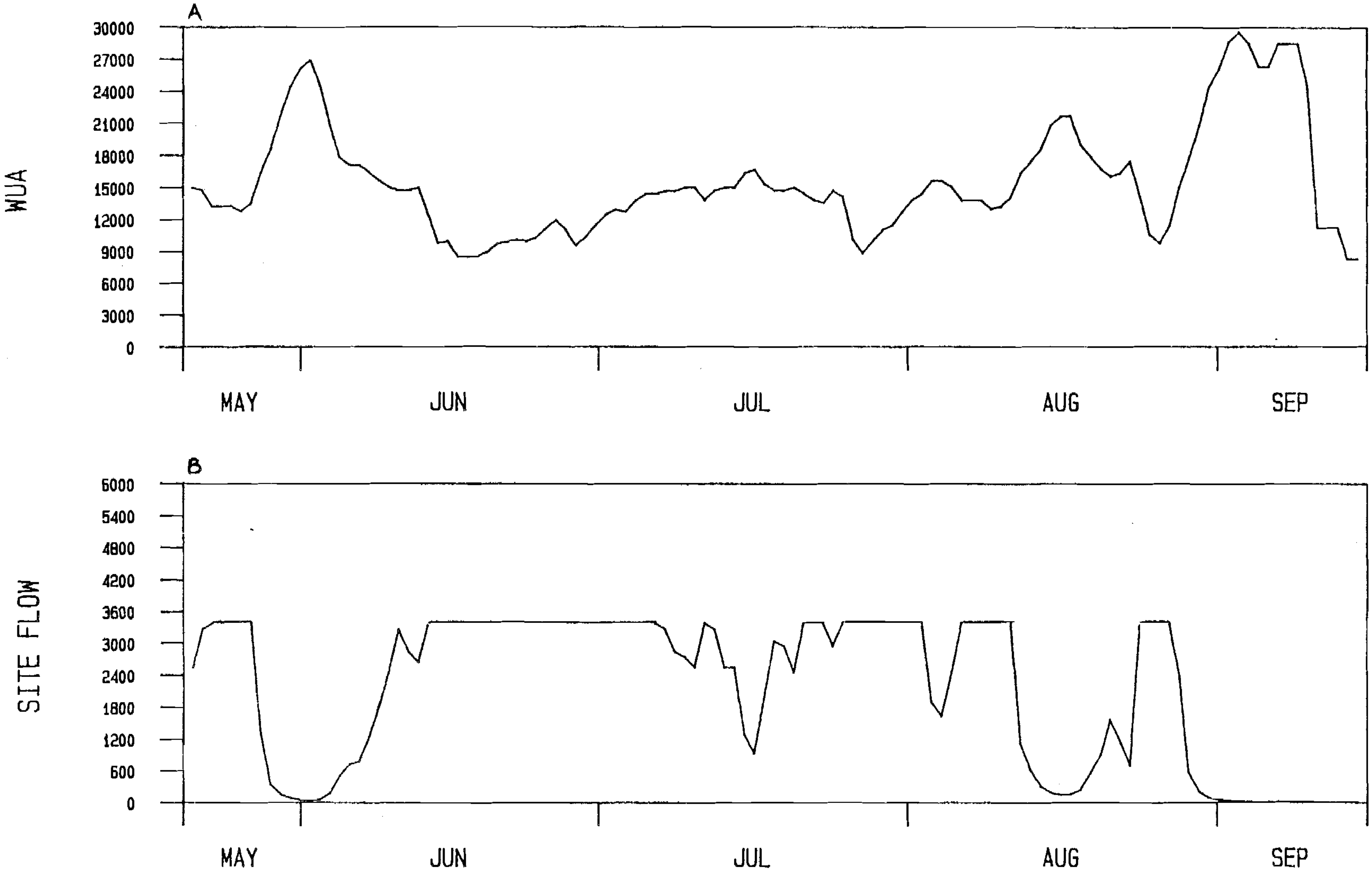


Figure III-10. Time series plots as a function of time for site 101.2R. A - Juvenile chinook WUA. B - Site flow.

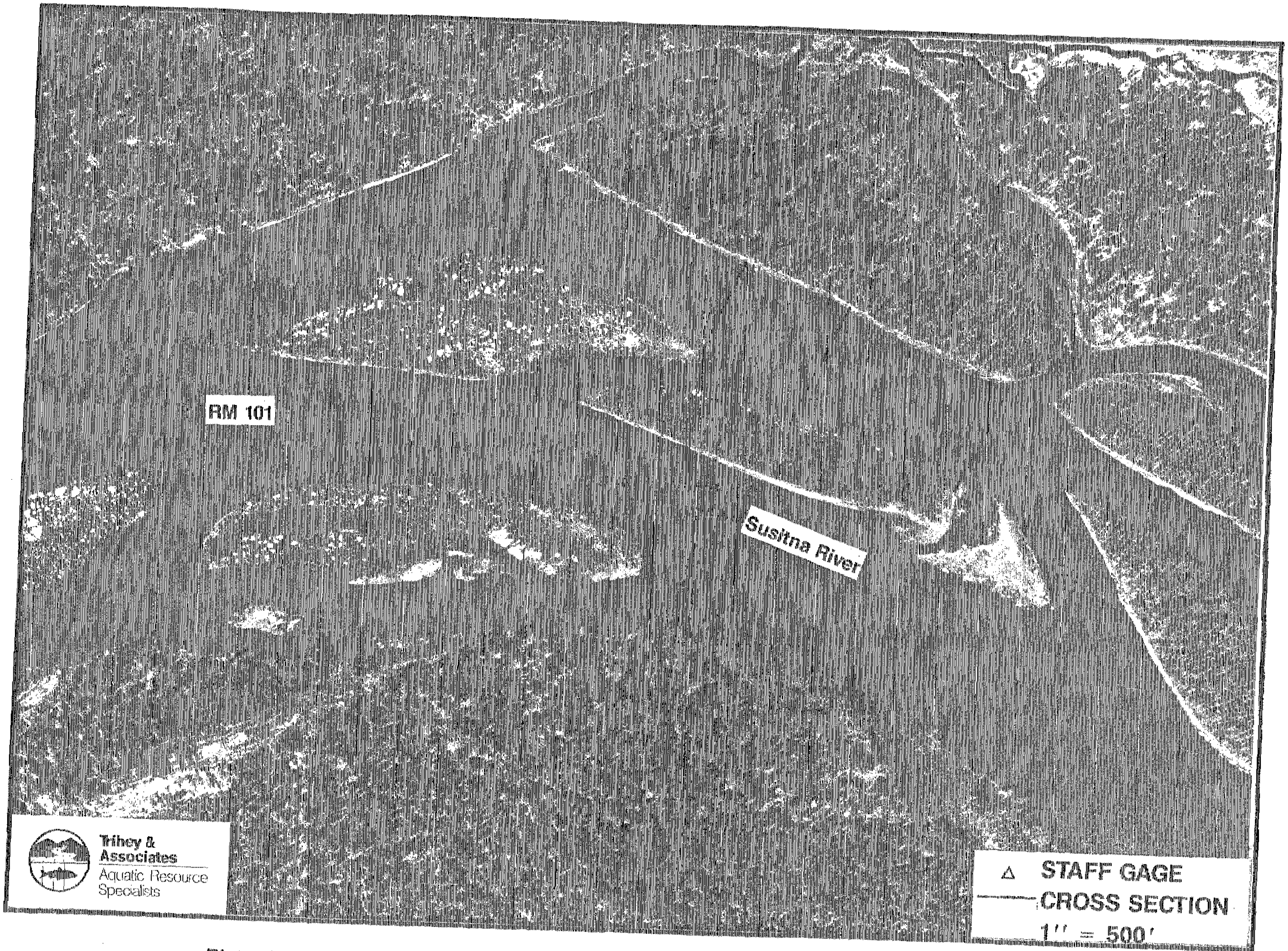


Plate III-2. Modeling site 101.5L on June 1, 1982 at mainstem discharge: 23,000 cfs.

second at the transition between the low and high velocity areas. In addition, three cross sections are located in the deep, fast area in the upper half of the study reach (Figure III-11).

This study site was selected to represent large side channels which remain side channels from 5,000 to 35,000 cfs. An IFG-2 model was selected because of the large size of the channel and its uniform shape. In addition, field reconnaissance indicated that rearing habitat was limited to the stream bank margins, therefore, a small amount of data would be adequate to simulate channel hydraulics.

Three channels were identified and labeled A, B and C. Channel B conveys mainstem flow at all discharges and Channel C at 10,000 cfs (Plate III-2). Channel A breaches at 12,000 cfs and redirects less than ten percent of the flow from the side channel to the mainstem. It was therefore considered negligible. Spawning salmon have not been observed in the side channel at this site. Juvenile chinook, coho and sockeye salmon have been identified in the site, however (Hoffman 1985).

Calibration: The data available to model the site included level surveys for cross sections 1, 2, and 5; stage-discharge curves developed by ADF&G Su Hydro at cross sections 2 and 5 (Estes and Vincent-Lang, eds. 1984); and the hydraulic data summarized in Table III-6. Cross sections 3 and 4 were developed from the discharge measurement notes and were not surveyed.

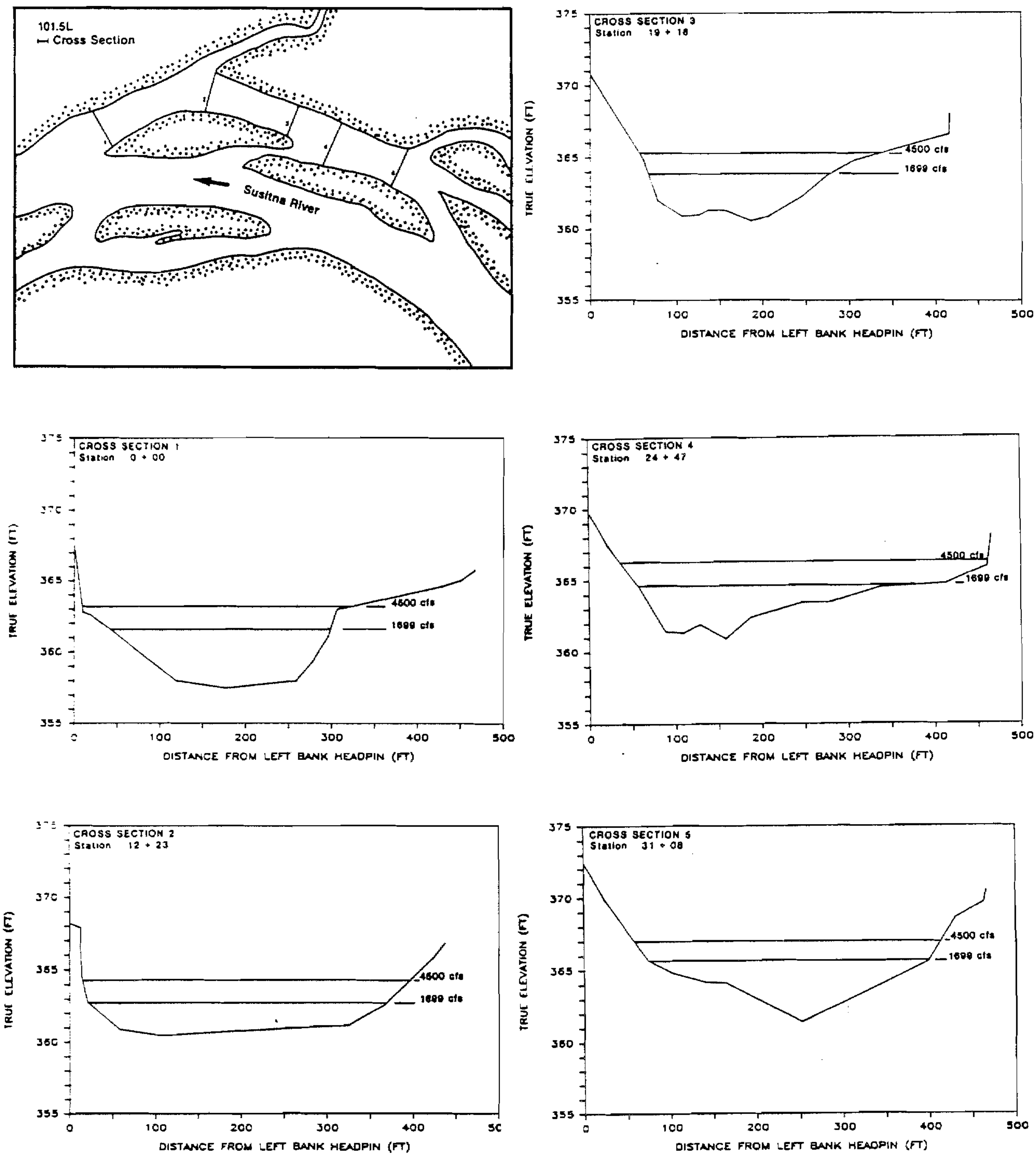


Figure III-11. Cross sections for site 101.5L depicting water surface elevations at calibration discharges of 1696 and 2213 cfs.

Table III-6. Hydraulic data available to calibrate the IFG-2 model for site 101.5L.

Date	Site Flow (cfs)	Mainstem Discharge (cfs)	Calibration Cross Section(s)	Type*
841012	1622	6210	4	D
841001	1696	7830	5	D
			1, 2	S
840911	2213	9330	3	D
840921	2250	11,400	1, 2, 5	S
940831	3530	14,300**	3	D
840820	4500	18,500	1, 2, 5	S

* D = Discharge measurements (includes mid channel and shoreline measurements)
S = Shoreline measurements (does not include mid channel measurements)
** = Adjusted to instantaneous discharge

Two models were required to accurately describe the site for mainstem discharges of 5,000 to 35,000 cfs. Velocity profiles for site flows of 1,696 and 2,250 cfs at cross sections 1, 2, and 5 were similar. However, simulation of the velocity distribution across the channel at a site flow of 4,500 cfs required a different set of "n" values. Velocities increased gradually with distance from the water's edge at low flows, but rose quickly and approached maximum channel velocity much closer to shore at high flows.

The velocity profiles for the two measured flows at cross section 3 were very similar and represented low and medium flows through the site. Only low flow data were available for cross section 4.

In calibrating the two models with respect to depth, predicted stages at cross sections 2 and 5 were compared to the corresponding elevations calculated from the rating curves. Stages for cross sections 3 and 4 were checked by comparing the predicted top widths with the top widths determined from the discharge measurements. Figure III-12 shows water surface profiles based on IFG-2 output for the calibration flows of 1,696, 2,250, and 4,500 cfs, water surfaces corresponding to discharges of 5,000 and 35,000 cfs and the observed and rating curve stages.

Verification: Figures B-2.2 and B-2.3 show velocity profiles produced by the two IFG-2 models at cross section 5 for calibration flows of 1,696 and 4,500 cfs. The observed shoreline velocities for those flows are also plotted. The figures demonstrate that the set of "n" values that produces the proper velocity profile at the low flow does not accurately produce that of the high flow, and vice versa.

Application: The low flow IFG-2 model represents site conditions for mainstem discharges up to 10,600 cfs, while the high flow model is applicable to mainstem discharges greater than 10,600 cfs. This breakpoint corresponds to a site flow of 2,500 cfs. The limits for which the models can be considered excellent extend beyond the range of available data as evaluated by utilizing all available site information, including aerial photography, channel geometry, and field experience. The models were extrapolated beyond the data range to 5,000 cfs on the lower end of the low flow model and 23,000 cfs for the upper end of the high flow model. At 23,000 cfs, the channel geometry suggests that the total flow loss through channel A is less than ten percent

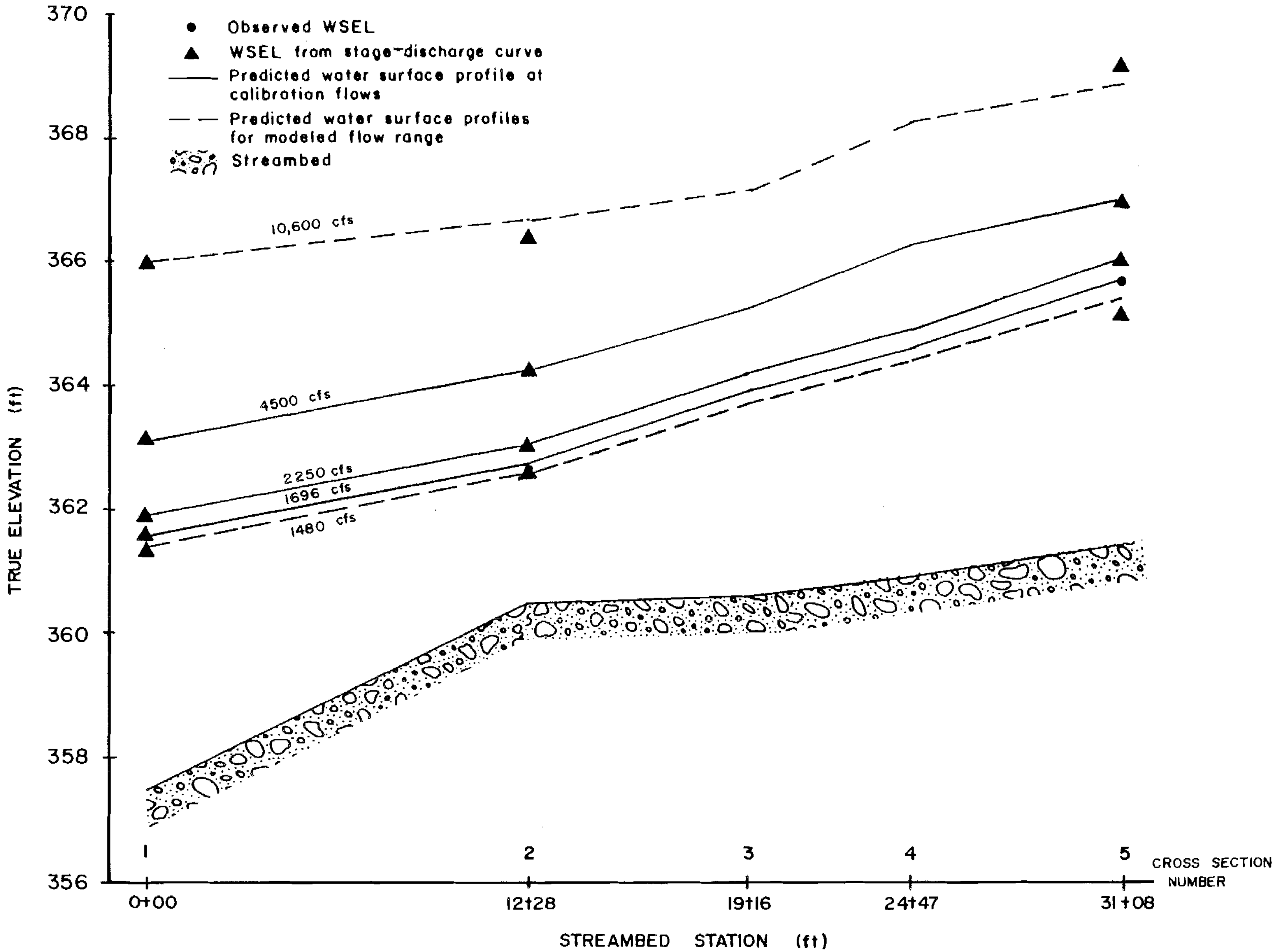
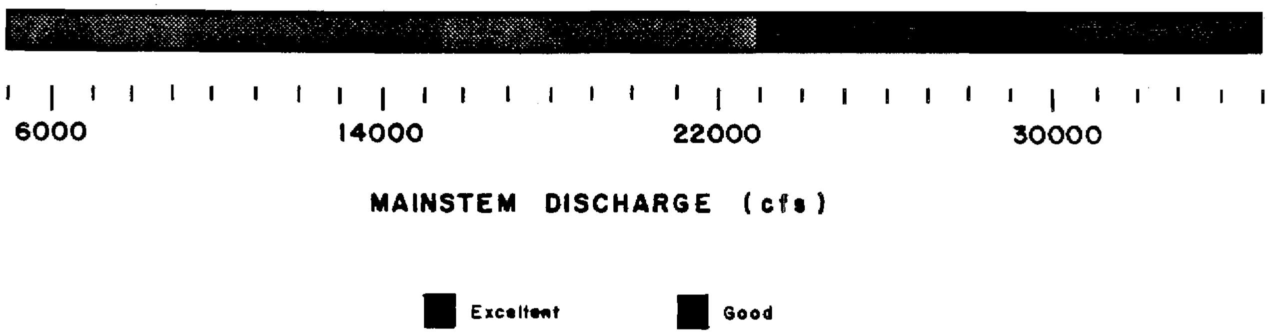


Figure III-12. Comparison of observed and predicted water surface profiles from calibrated model at site 101.5L.

and is therefore considered negligible. Because this outflow is minor, the upper model limit was extrapolated from 23,000 to 35,000 cfs with the overall rating for the high flow model for the mainstem range of 23,000 to 35,000 cfs considered good.

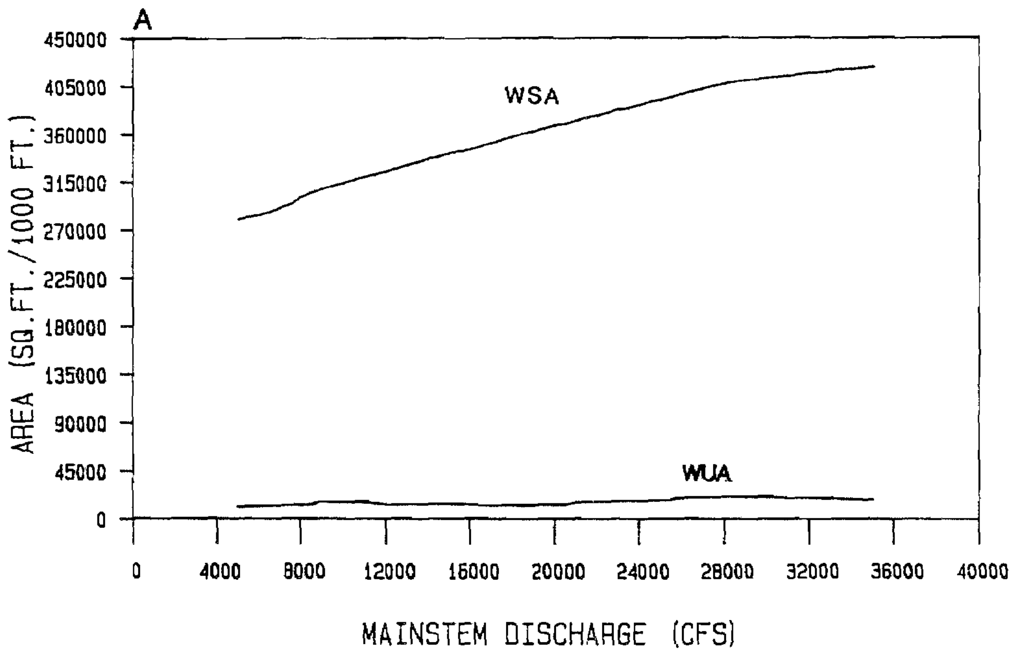
The application ranges and ratings are summarized in the bar chart below.



The WSA and juvenile chinook WUA curves for the study site are presented in Figure III-13. In this figure, the WUA and WSA curves are plotted to the same scale and expressed in identical units; i.e., sq ft/1,000 ft of stream. A comparison of the two curves gives an indication of the proportion of the study site which contains rearing habitat.

This site is distinguished by a comparatively narrow range of juvenile chinook WUA for mainstem discharges between 5,000 and 35,000 cfs, suggesting that areas suitable for chinook rearing are generally gained and lost at comparable rates. Most of the rearing habitat is located in a narrow band along the right shoreline where velocities are not limiting (Williams 1985).

The response of the WUA curve to variations in mainstem discharge is plotted on an expanded vertical scale in Figure III-13b. The WUA forecasts are higher



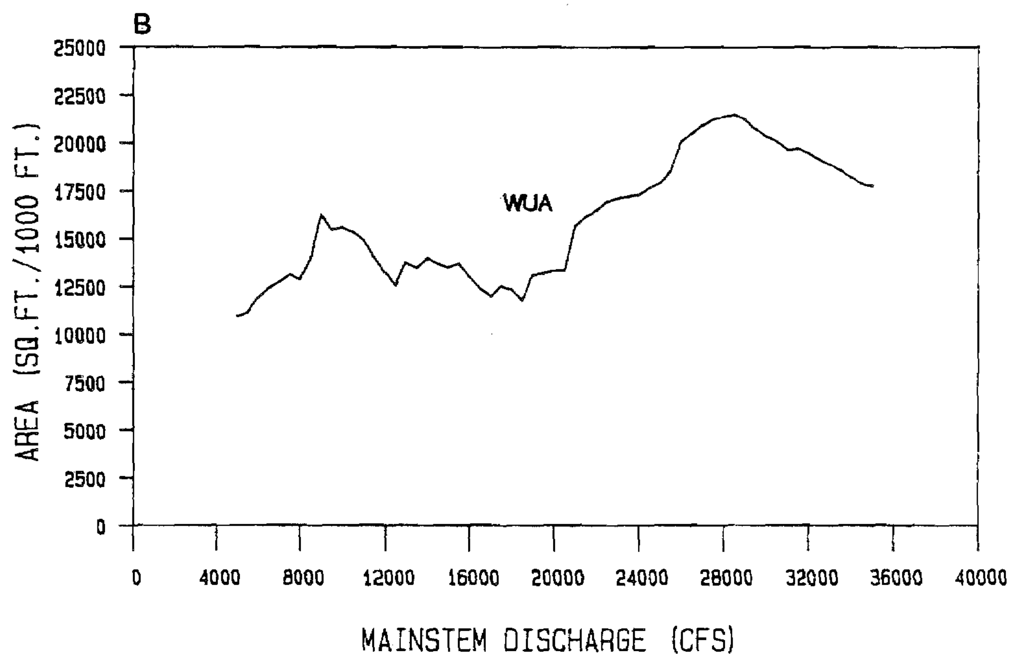


Figure III-13. Surface area and juvenile chinook habitat response curves for site 101.5L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

at low mainstem discharges in comparison to high discharges. This can primarily be accounted for by the high velocities at high discharges that are unsuitable for juvenile chinook salmon. The WUA forecasts at lower flows at this site reflect the combined effect of overtopping discharges (in both overflow and secondary feeder channels) and the channel geometry on nearshore velocities. At higher flows the small increases observed in juvenile chinook habitat are due to the progressive development of a low-velocity backwater area at the lower end of the study site. The significance of these changes in habitat potential in response to streamflow, however, becomes relatively insignificant when viewed in relation to the total WSA of the side channel.

The WUA was forecast using low- and high-flow IFG-2 models to account for flow-dependent variations in shoreline velocity distribution when using the HABTAT model. The WUA for juvenile chinook was forecast using only turbid water conditions because the side channel conveys turbid water at a mainstem discharge of less than 5,000 cfs. Application of low- and high-flow WUA models resulted in separate WUA functions which were joined together to form the single habitat response curve presented in Figure III-13. This was accomplished by overlapping the WUA forecasts from the low- and high-flow models and choosing a discharge value resulting in the smoothest transition from one habitat response curve to the other. The discharge value selected in this transition was 8,500 cfs (Table B-6.2).

The time series plot of WUA for juvenile chinook bears a strong resemblance to the daily streamflow record at the site for the May 20 to September 15, 1984 period (Figure III-14). Site flows during this period typically vary between 4,000 and 8,000 cfs, accompanied by changes in habitat potential ranging from 12,000 to 22,000 sq ft/1,000 ft. The seasonal variability of WUA is small, with the exception of a few high flow periods, site flows and juvenile chinook habitat at site 101.5L show a remarkable degree of temporal stability during the rearing season.

Site 112.6L

Site Description: This site is located approximately 2 miles downstream of Lane Creek on the west bank of the Susitna River (Plate III-3). The study reach is 4,100 ft long and varies between 500 and 700 ft wide. Substrate composition is cobble and rubble with layers of silt and sand found in pool areas and in the backwater area located at the mouth. The large substrate provides cover. Eight cross sections were initially established during high mainstem discharges occurring in early August: cross sections 1, 2, 5, 6 and 7 are located in low velocity areas and 3, 4 and 8 in high velocity areas. As flows receded during the fall, cross section 4 was relocated and an additional cross section, 3A, was added in the shallow, high velocity area midway through the site (Figure III-15).

The side channel breaches at mainstem discharges less than 5,000 cfs while the overflow channel along the right bank conveys side channel flow at discharges above 20,000 cfs. Below 10,000 cfs, pool and riffle sequences dominate the site and a gravel bar below the confluence of Slough 6A is exposed at cross sections 3, 3A, and 4. At discharges above 10,000 cfs, the channel becomes a large run.

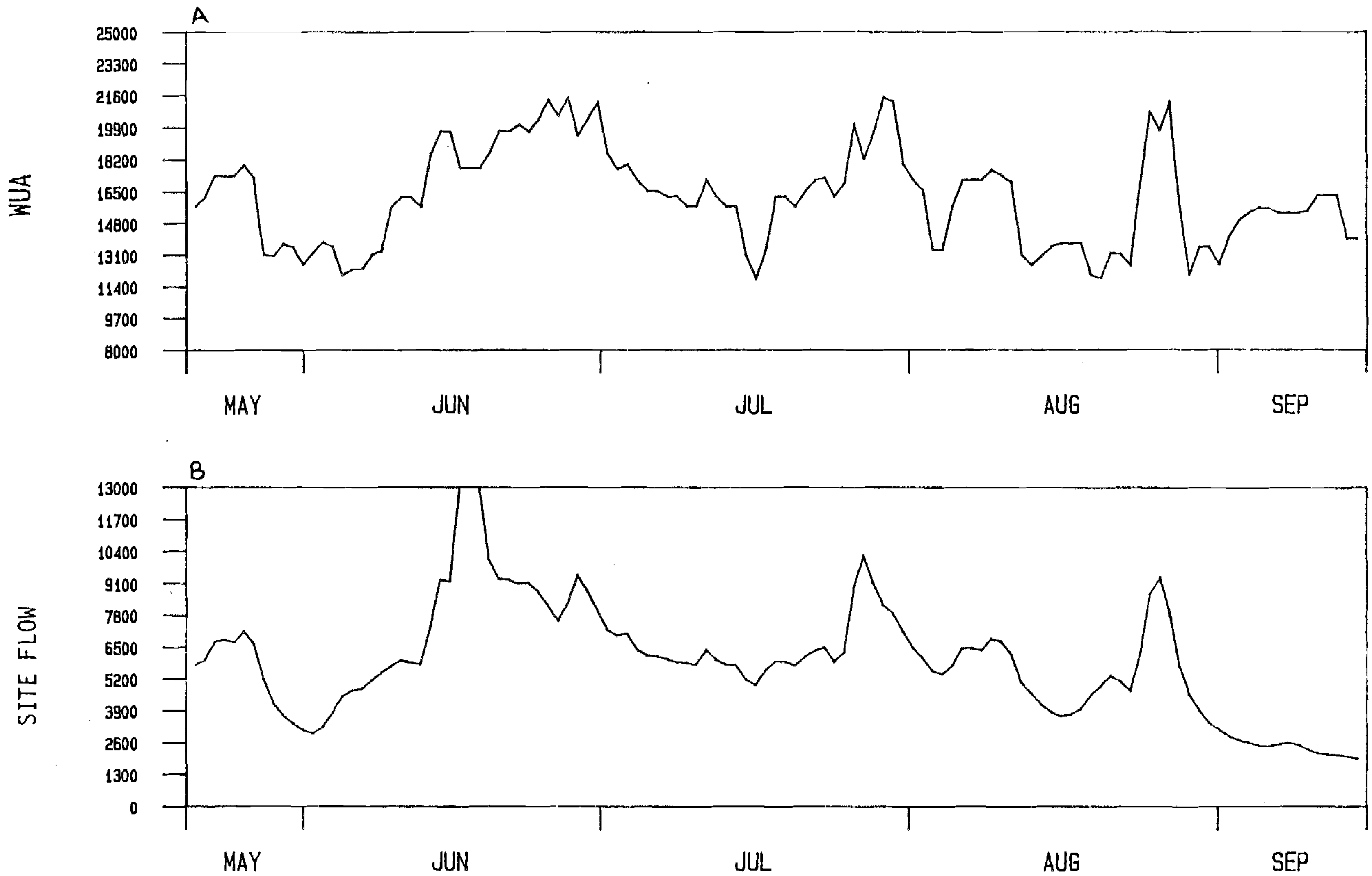


Figure III-14. Time series plots as a function of time for site 101.5L. A - Juvenile chinook WUA. B - Site flow.

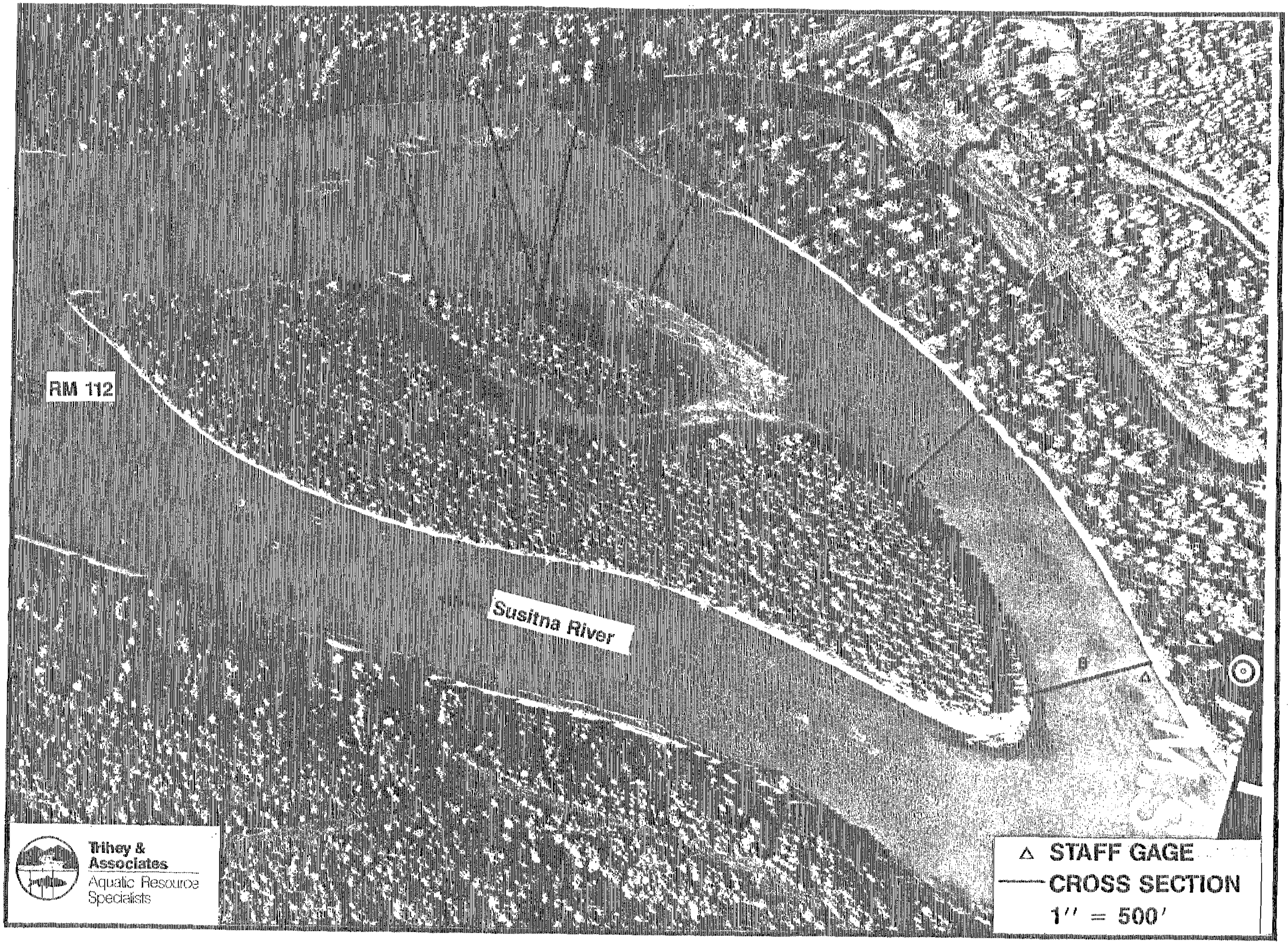


Plate III-3. Modeling site 112.6L on September 6, 1983 at mainstem discharge: 16,000 cfs.

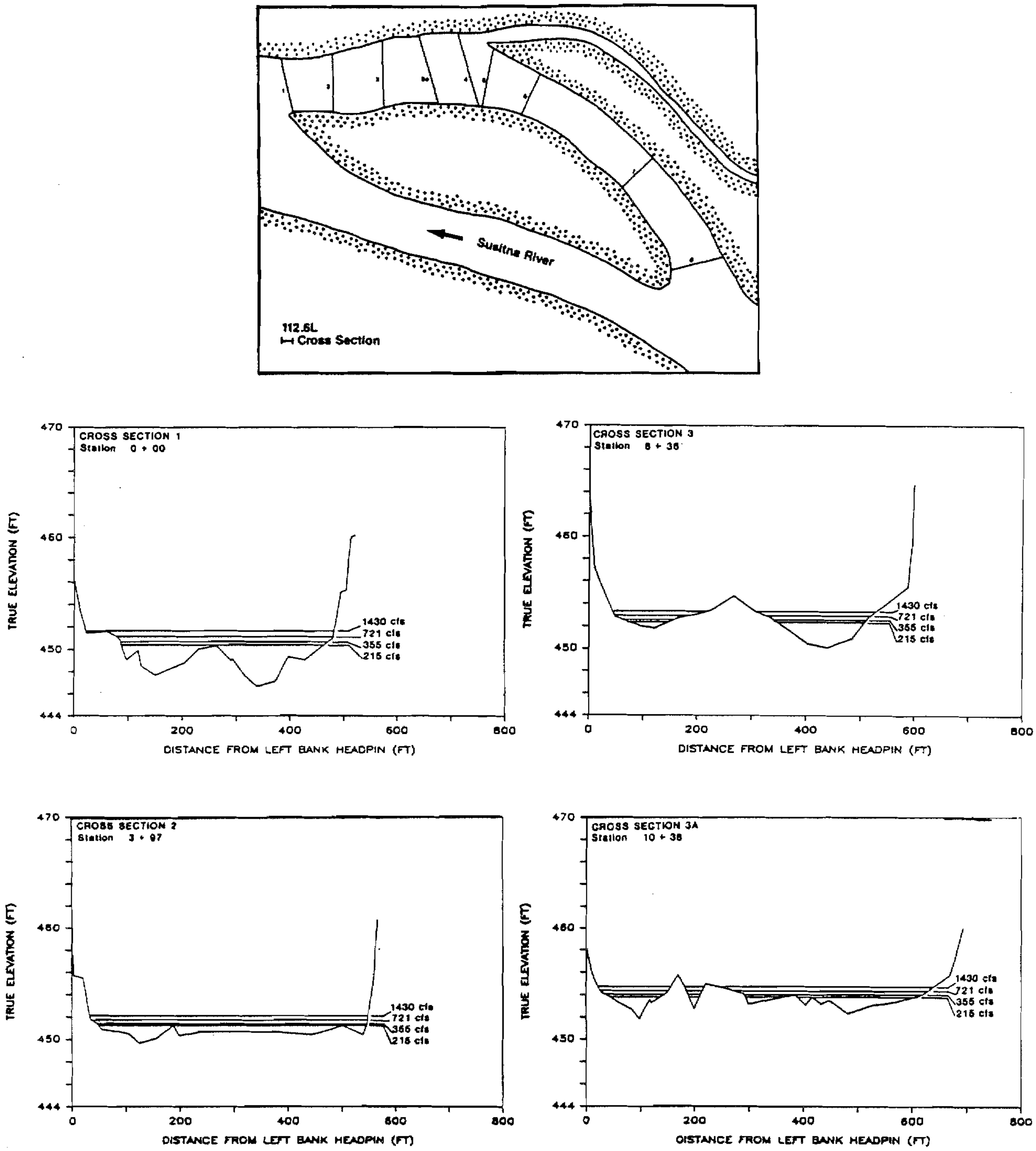


Figure III-15. Cross sections for site 112.6L depicting water surface elevations at calibration discharges of 355, 721, 1430 and 2980 cfs.

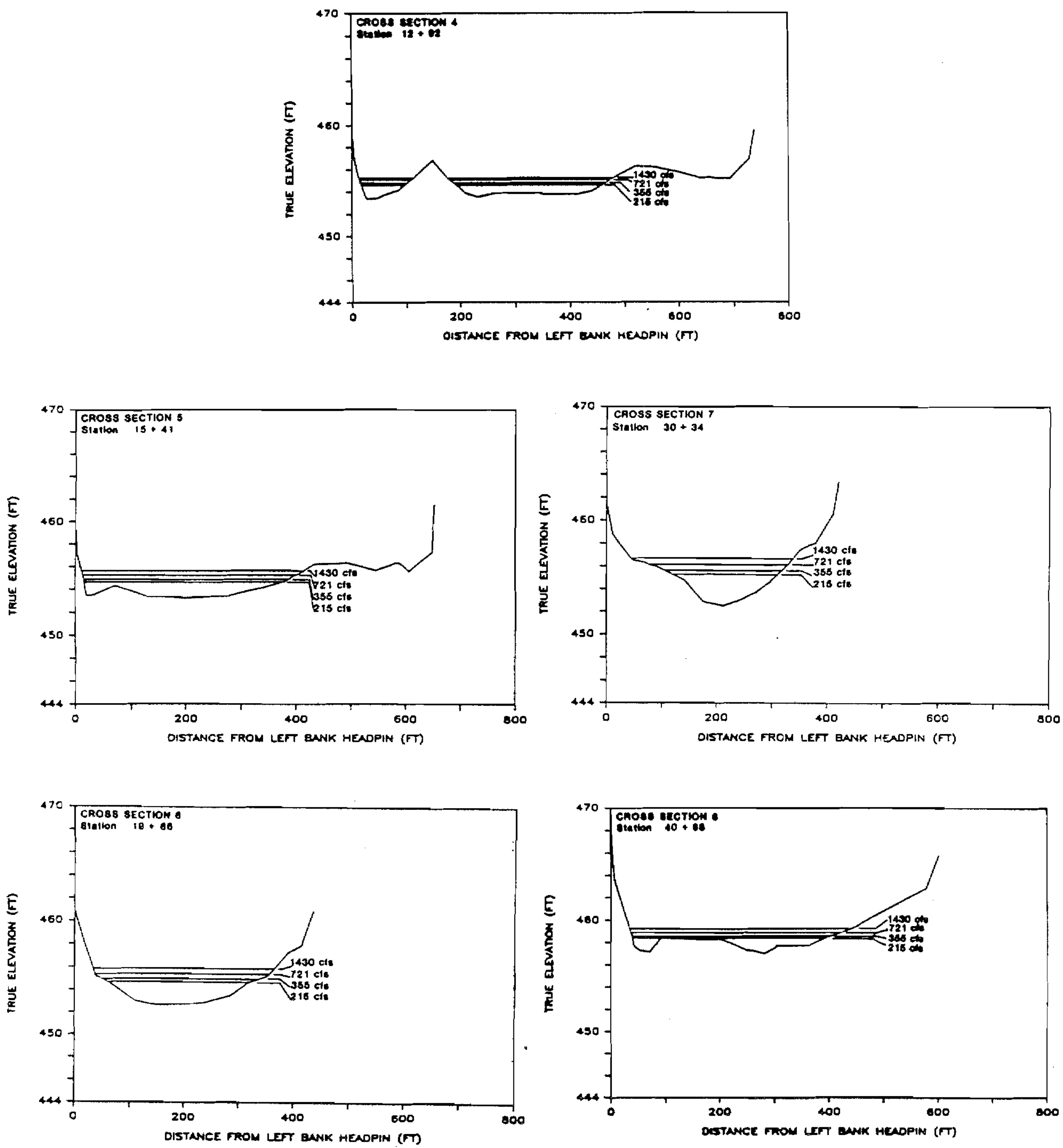


Figure III-15 (Continued).

This large study site was selected to represent large side channels which reduce to small side channels at low discharges. An IFG-2 model was selected due to the large size of the channel. Field reconnaissance indicated that rearing habitat was limited to streambank margins at high discharges, therefore a small amount of data would be adequate to simulate channel hydraulics with the IFG-2 model. Salmon have not been observed spawning in the site but chinook fry have been observed using the channel, particularly below the confluence of Slough 6A (Hoffman 1985).

Calibration: The data available to model the site consisted of level surveys for all nine cross sections and the hydraulic data summarized in Table III-7.

Table III-7. Hydraulic data available to calibrate the IFG-2 model for site 112.6L.

Date	Site Flow (cfs)	Mainstem Discharge (cfs)	Calibration Cross Section(s)	Type*
841012	215	6210	7	D
840930	355	7500	6, 8	D
			1,2,3,3A,4,5,7	S
840913	721	9000	7	D
840904-05	1430	10,800	8	D
			1,2,3,3A,4,5,6,7	S
840830	2980	15,300	6	D
840822	4820	19,100	1,2,3,4,5,6,7,8	S

* D = Discharge measurements (includes mid channel and shoreline measurements).
S = Shoreline measurements (does not include mid channel measurements).

Adjustments were made to cross section survey data to create a horizontal stage at some cross sections. Observed depths for the calibration site flow of 355 cfs were plotted with the cross section survey data. Cross sections 2, 3, 3A, and 4 did not have horizontal stages and were modified as described. A comparison of the measured and adjusted cross sections is shown in Figure III-16.

Stage-discharge curves were not available at cross sections 3A and 4, therefore these cross sections were calibrated by comparing the predicted velocity profile with the measured profiles. Overtopping of the gravel bar in the lower reach affecting cross sections 2 through 4 during high flow events caused a transformation in the velocity distribution across the site, and two hydraulic models were required to accurately describe the different distribution in this area.

In calibrating the models with respect to depth, predicted stages at all cross sections except 3A and 4 were compared to the corresponding elevations calculated from the stage-discharge curves. Figure III-17 shows water surface profiles based on IFG-2 output for the calibration flows, the flows corresponding to 5,000 and 35,000 cfs, observed stages, and stage-discharge curve stages for the model limit flows.

<u>Verification</u>: Figures B-2.4 and B-2.5 show the velocity profiles produced by the two IFG-2 models at cross section 3 for calibration flows of 355 and 4,820 cfs. The observed velocities for these flows are also plotted. The figures demonstrate that the set of "n" values that produces the proper velocity

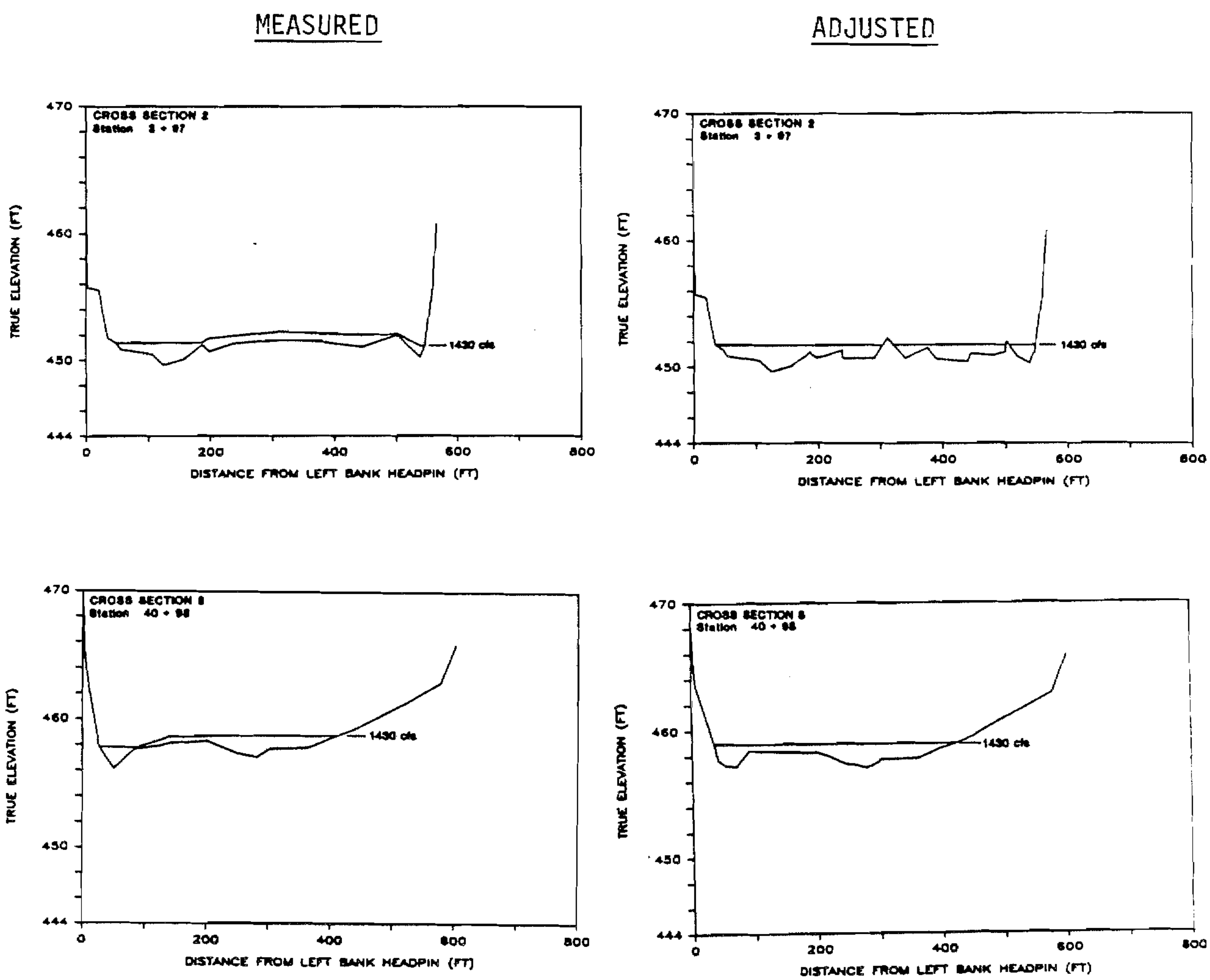


Figure III-16. Comparison between measured and adjusted cross sections 2, 3 and 3A at site 112.6L.

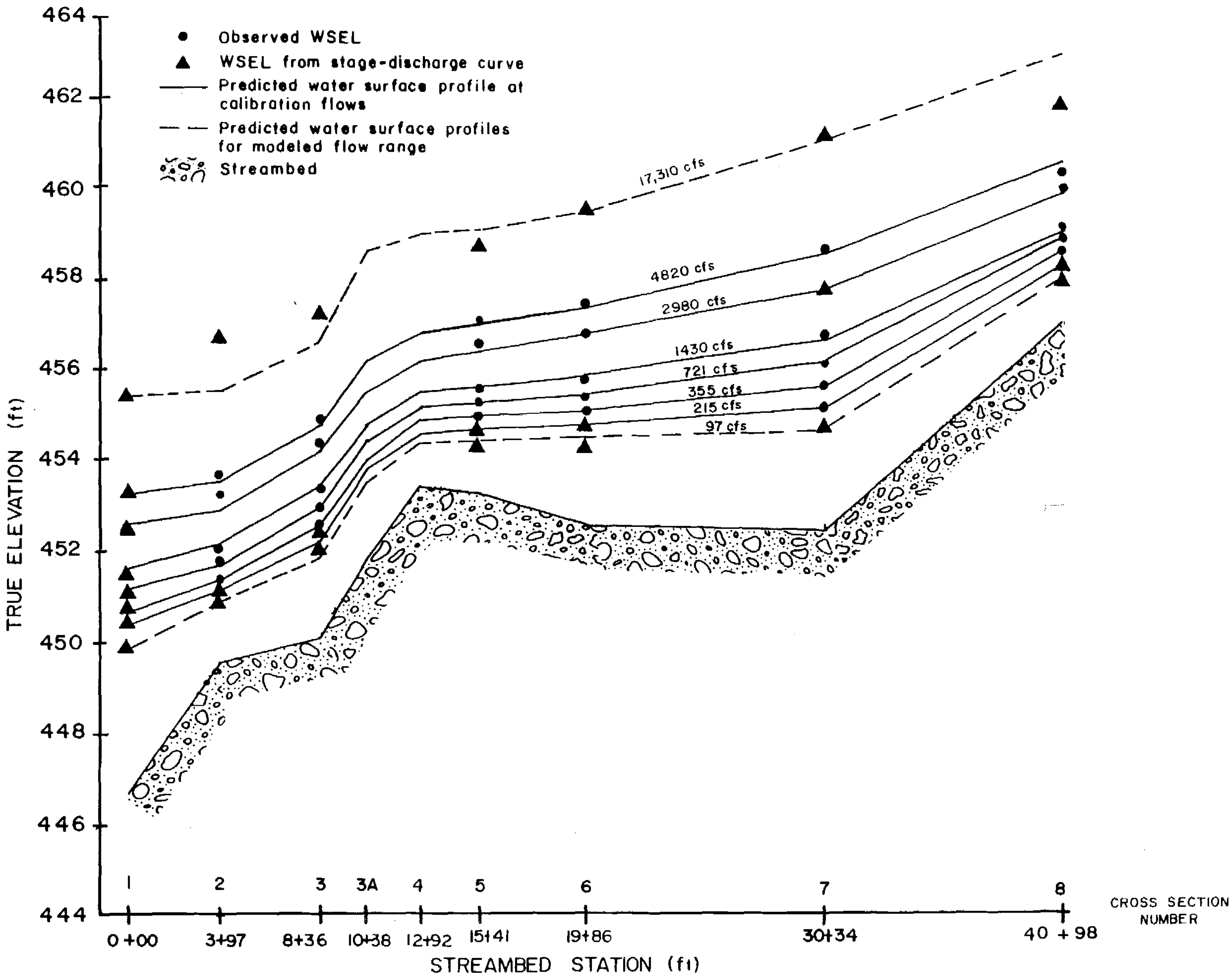
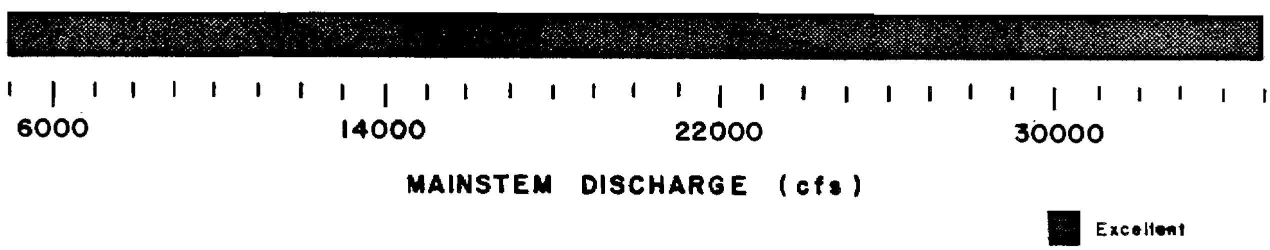


Figure III-17. Comparison of observed and predicted water surface profiles from calibrated models at site 112.6L.

profile at the low flow does not accurately produce that of the high flow, and vice versa.

Application: Both models were given an excellent rating from 5,000 cfs to 35,000 cfs. The low-flow model describes depths and velocities present in the channel for mainstem discharges up to 10,000 cfs with the high-flow model applicable to site flows corresponding to mainstem discharges greater than 10,000 cfs. The transition from low- to high-flow model occurs at a site flow of 1,070 cfs. Because of the limited data available to calibrate cross sections 3A and 4 at high flows, the high velocities are projected throughout the entire extrapolation range. However, these cross sections represent only about 10 percent of the total area of the site and actual velocities at the high flow are probably beyond the usable range on the suitability curve, therefore the overall model rating was not reduced from excellent.

The application ranges and ratings are summarized below in the bar chart.



In Figure III-18a, WSA and juvenile chinook WUA are presented at the same scale per 1,000 ft of stream. Figure III-18b is plotted at an expanded vertical scale.

At discharges below 8,000 cfs the side channel conveys less than 10 percent of the total mainstem discharge and contains an extensive amount of low velocity turbid water habitat. Hence the WUA values for juvenile chinook are quite

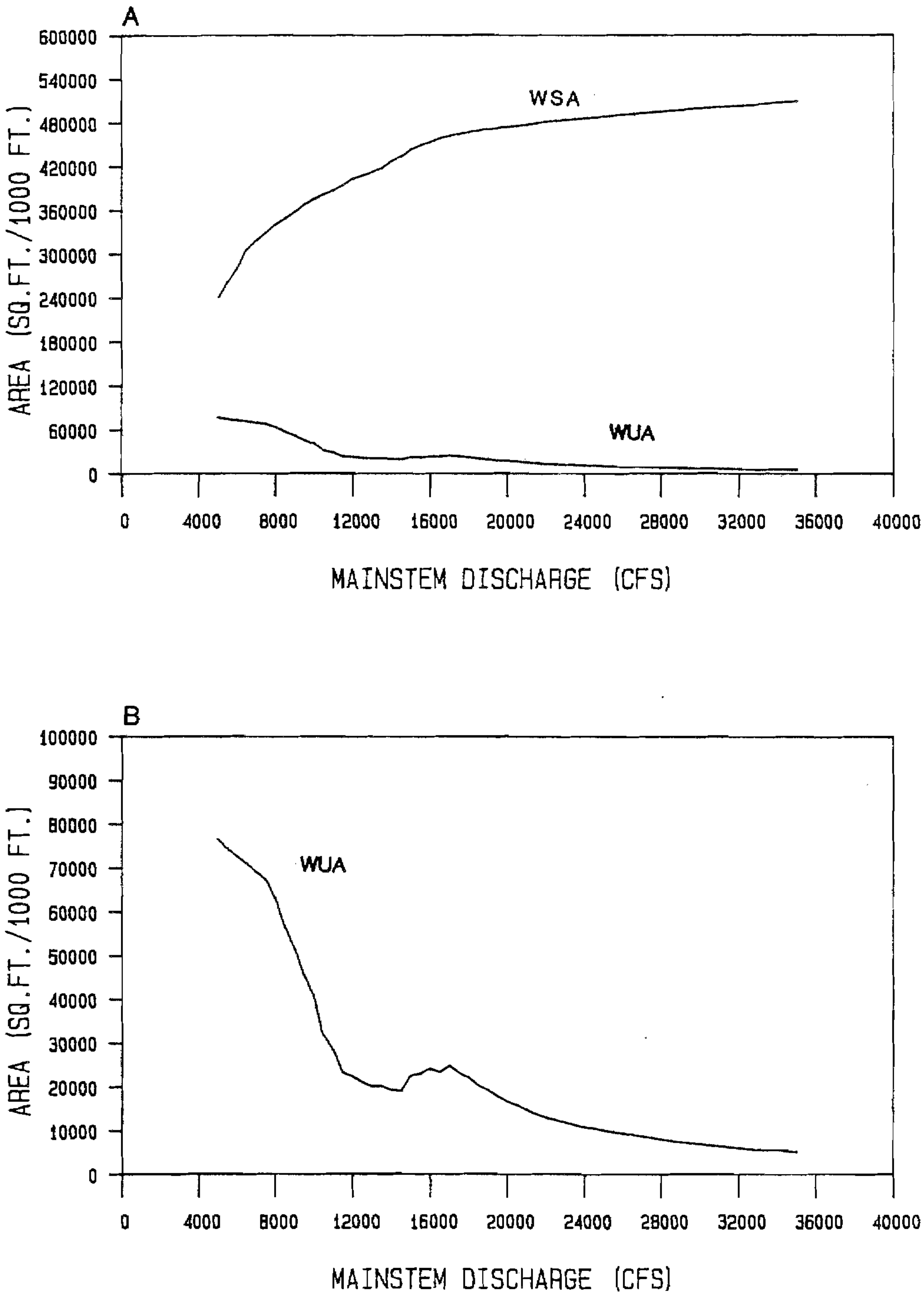


Figure III-18. Surface area and juvenile chinook habitat response curves for site 112.6L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable ARea (WUA).

large. Williams (1985) demonstrated that the shoreline area within Side Channel 6A, possessing suitable chinook rearing velocities, is five times greater at 13,500 cfs than at 33,000 cfs. The WSA possessing suitable velocities more than doubles as discharge decreases from 13,500 to 8,000 cfs.

The WUA response curve plotted in Figure III-18 accents the rapid decline in habitat potential which accompanies an increase in mainstem discharge above 8,000 cfs. The secondary WUA peak, occurring near 16,000 cfs, results from the overtopping of a large mid-channel gravel bar in the lower portion of the study site. At higher discharges, velocities increase throughout the site and decrease its value to juvenile chinook.

WUA values were forecast using low- and high-flow IFG-2 models linked with the HABTAT model. Because this side channel breached at mainstem discharges less than 5,000 cfs, turbid water suitability criteria were used for all habitat simulations. Separate WUA response curves were forecast using the high- and low-flow HABTAT models. The single habitat response curve presented in Figure III-18a was developed by overlapping the WUA forecasts from the low- and high-flow models, then averaging the corresponding WUA values within the area of overlap to obtain a smooth transition (Table B-6.3).

Figure III-19 shows time series plots of the 1984 site flow and WUA indices which reflect considerable variation in habitat potential.

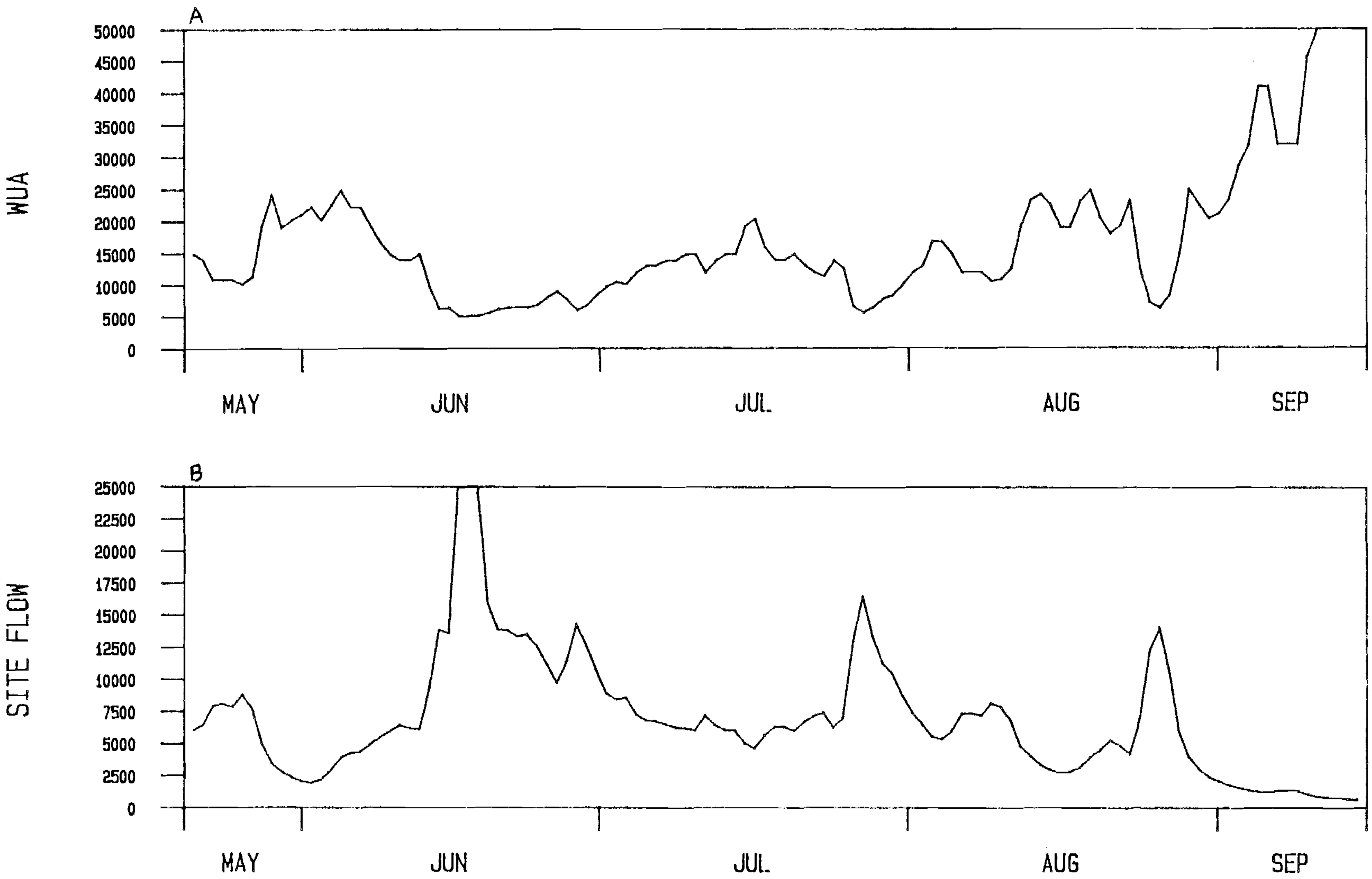


Figure III-19. Time series plots as a function of time for site 112.6L. A - Juvenile chinook WUA. B - Site flow.

Site 119.2R

Site Description: This site is approximately 1.5 miles below Curry Station on the east bank of the Susitna River (Plate III-4). The study reach encompasses the entire side channel which is 1,800 ft long and 180 ft wide. Substrate varies from cobble and rubble at the upper two cross sections to silt in the backwater area. Riprap from the railroad is present along the right side of the channel and provides 5 to 25 percent acceptable cover. Three cross sections were established in the deep, low velocity area at the mouth and two cross sections in the shallower, faster velocity area near the head of the channel (Figure III-20). A large backwater area is present at all flows and extends from the mouth up to cross section 3. Upwelling and groundwater seepage occur near cross sections 3 and 4 along the right bank, and a small tributary enters from the right bank upstream cross section 3.

This small side channel was selected to represent channels with high velocities at the head and low velocities at the mouth. An IFG-2 model was selected to describe the channel hydraulics because of the small amount of data available. Spawning salmon have not been observed in the side channel but small numbers of juvenile chinook and sockeye salmon were identified (Hoffman 1985).

Calibration: The data available to model the site consisted of cross section surveys for all cross sections and the hydraulic data summarized in Table III-8.

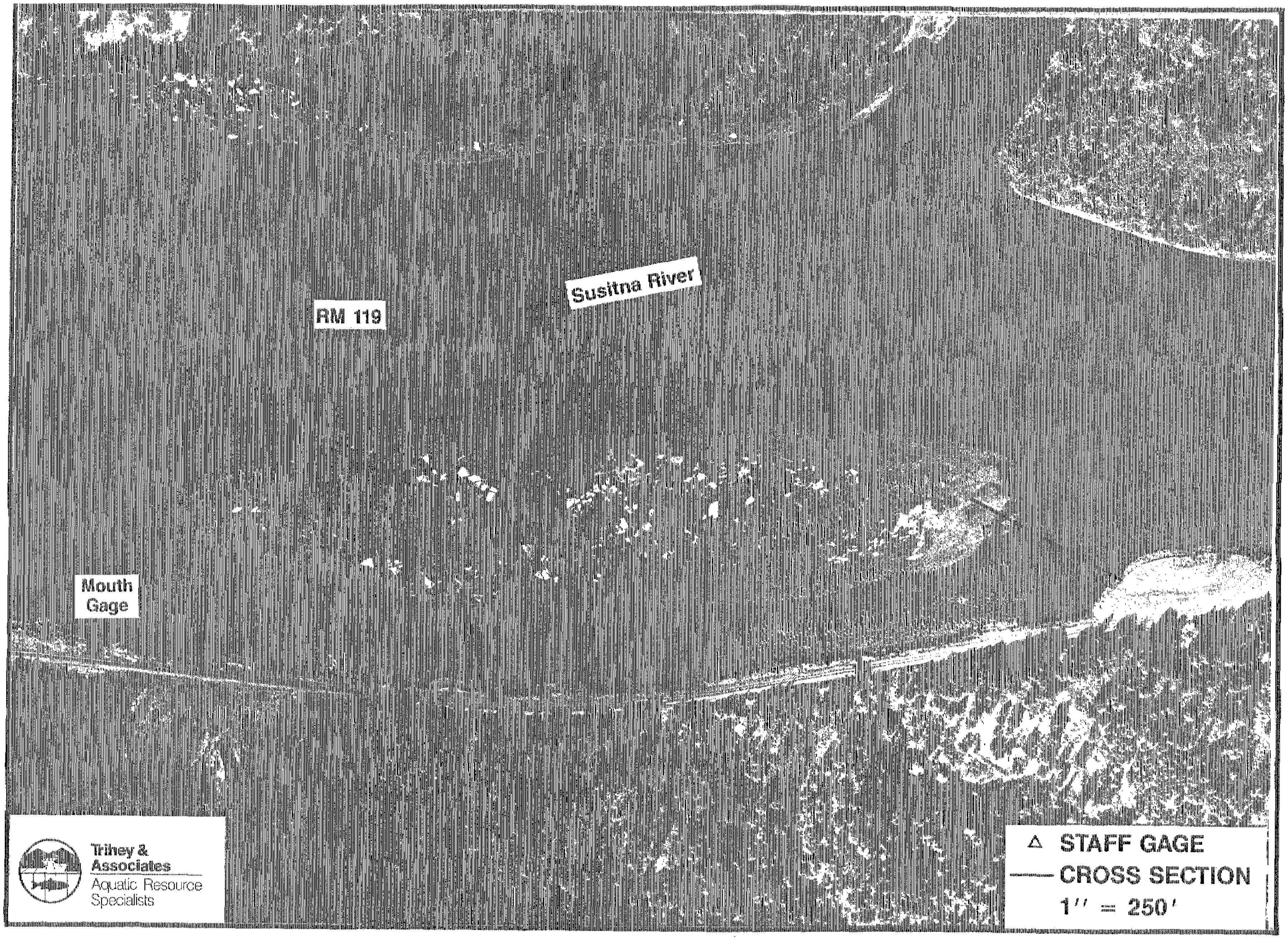


Plate III-4. Modeling site 119.2R on June 1, 1982 at mainstem discharge: 23,000 cfs.

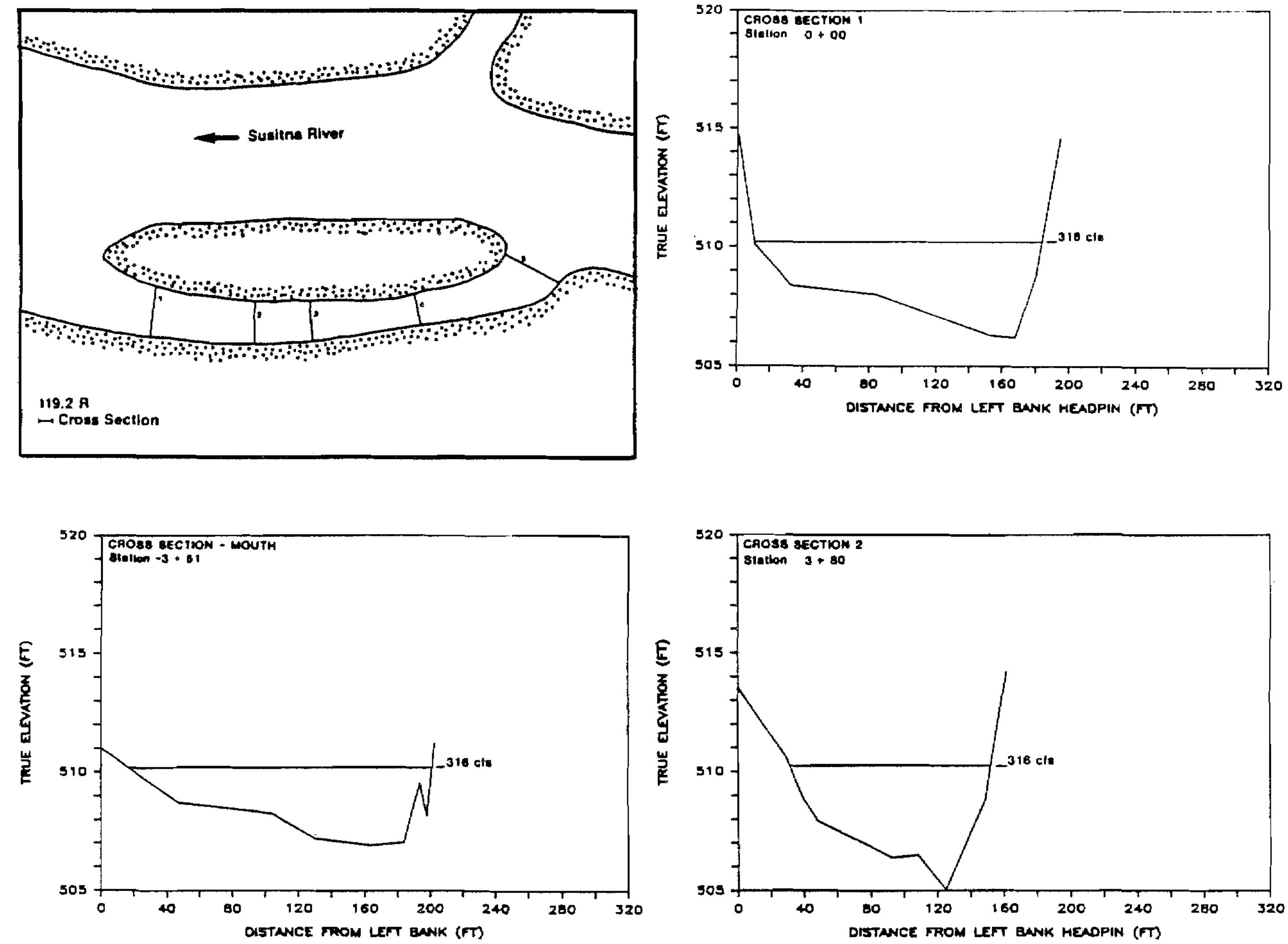


Figure III-20. Cross sections for site 119.2R depicting water surface elevations at calibration discharge of 316 cfs.

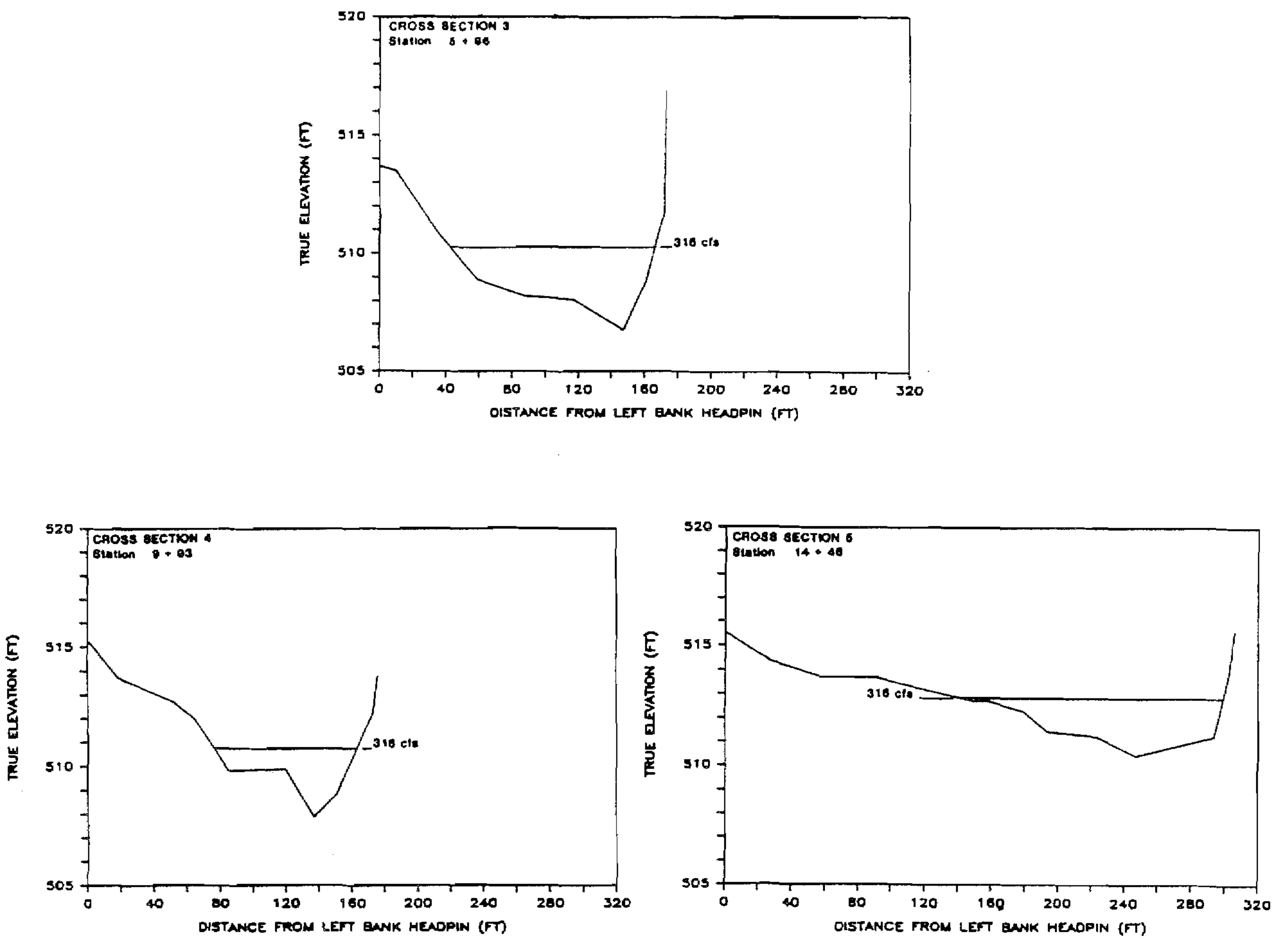


Figure III-20 (Continued).

Table III-8. Hydraulic data available to the calibrate IFG-2 model for site 119.2R.

Date	Site Flow (cfs)	Mainstem Discharge (cfs)	Calibration Cross Section(s)	Type*
840831	71	13,600	3	D
840819	316	17,400	1,2,3,4,5	D
840824	1090	22,700	3	D

* D = Discharge measurements (includes mid channel and shoreline measurements
S = Shoreline measurements (does not include mid channel measurements)

From August 24 to 29, the streambed elevations were lowered due to the scouring from high flows in the mainstem. Because most of the data was taken before the high flow event, the cross section elevations were determined by subtracting the depth of flow from the water surface elevations as recorded during a discharge measurement rather than by using the elevations determined from the cross section survey (Figure III-21).

A velocity profile was developed for each cross section, based on the site flow of 316 cfs. Velocities associated with the other two flows were available only at cross section 3. Velocities predicted by the model were judged to be reasonable at all cross sections throughout the application range of 10,000 to 23,000 cfs (mainstem) based on channel geometry. Unreasonable velocities (large differences from cell-to-cell) were forecast by the model at discharges greater than 23,000 cfs.

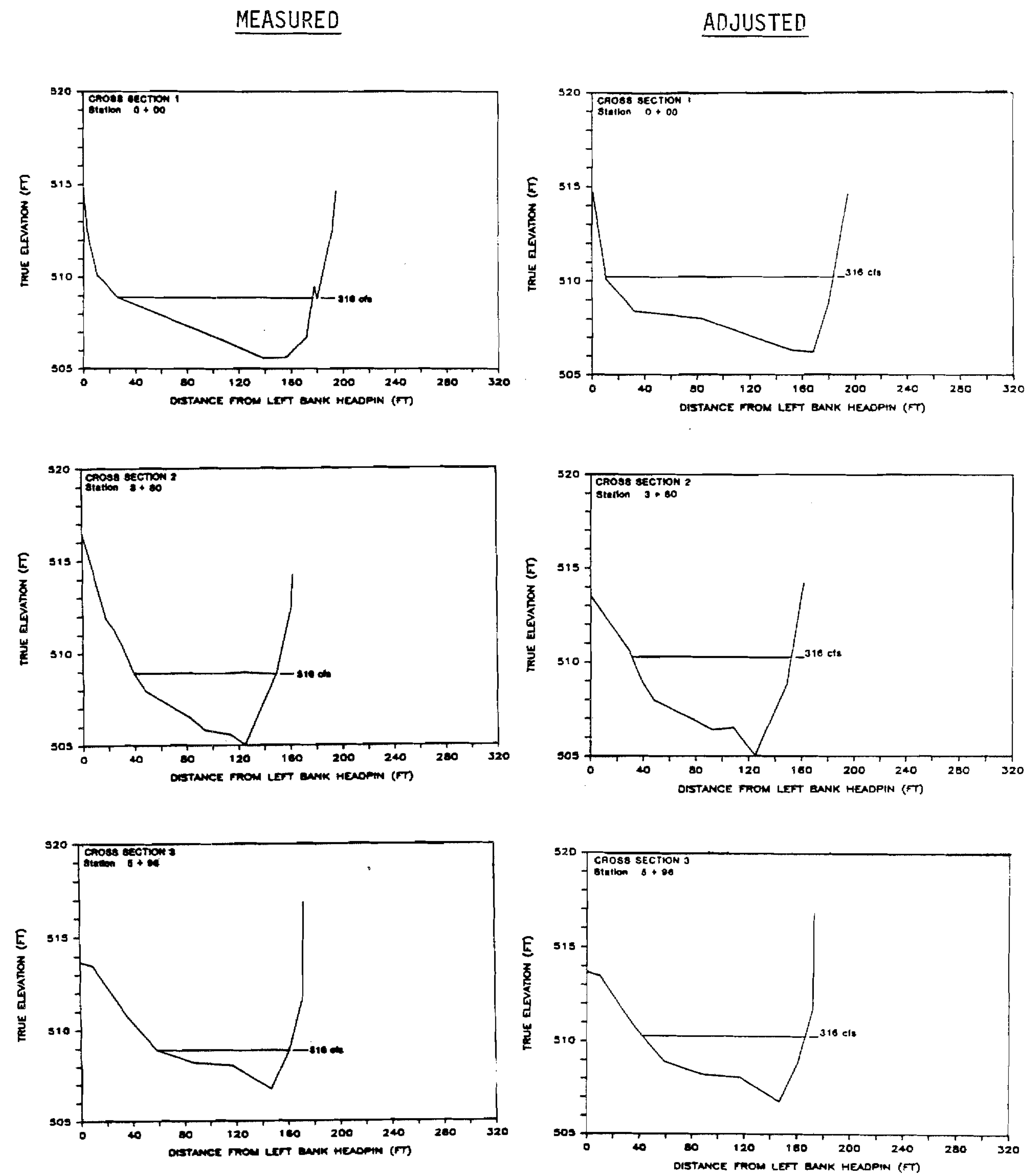


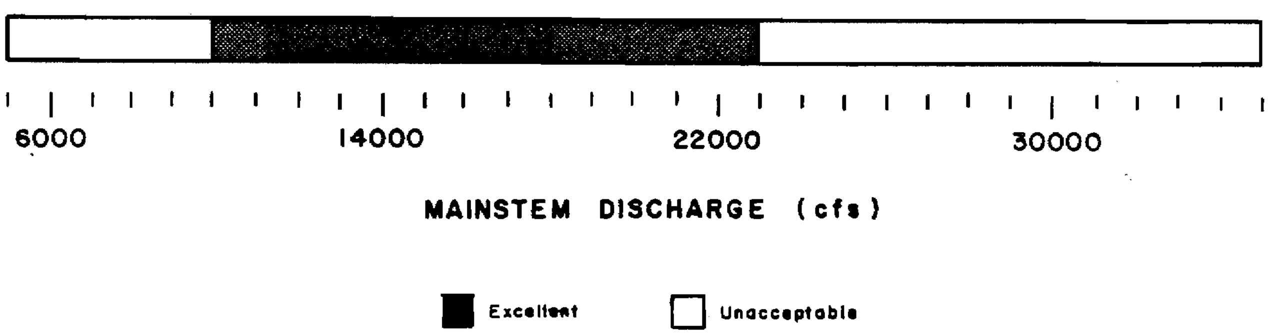
Figure III-21. Comparison between measured and adjusted cross sections 1, 2 and 3 at site 119.2R.

To calibrate the model with respect to depth, comparisons were made between observed and model-predicted stages. Water surface profiles based on IFG-2 output for the three calibration flows and for the flows corresponding to discharges of 10,000 and 23,000 cfs are shown in Figure III-22. Observed stages for the calibration flows and stages determined from the stage-discharge relationship for the model limit flows are also shown.

Verification: One model adequately reproduces the velocities over the range of available data (Figure B-2.6).

Application: The IFG-2 model was assigned an excellent rating for site flows of 15 to 1,240 cfs, corresponding to mainstem discharges of 10,000 to 23,000 cfs. At very high mainstem discharges, the flow regime at the site changes such that the large volume of water flowing through the site drowns out the backwater area, and the silty, vegetated left bank becomes inundated. The distribution of predicted velocities at the upper cross sections become unrealistic at flows above 23,000 cfs. Therefore, an unacceptable rating was assigned to the mainstem range of 23,000 to 35,000 cfs.

The application range and ratings are summarized below in the bar chart.



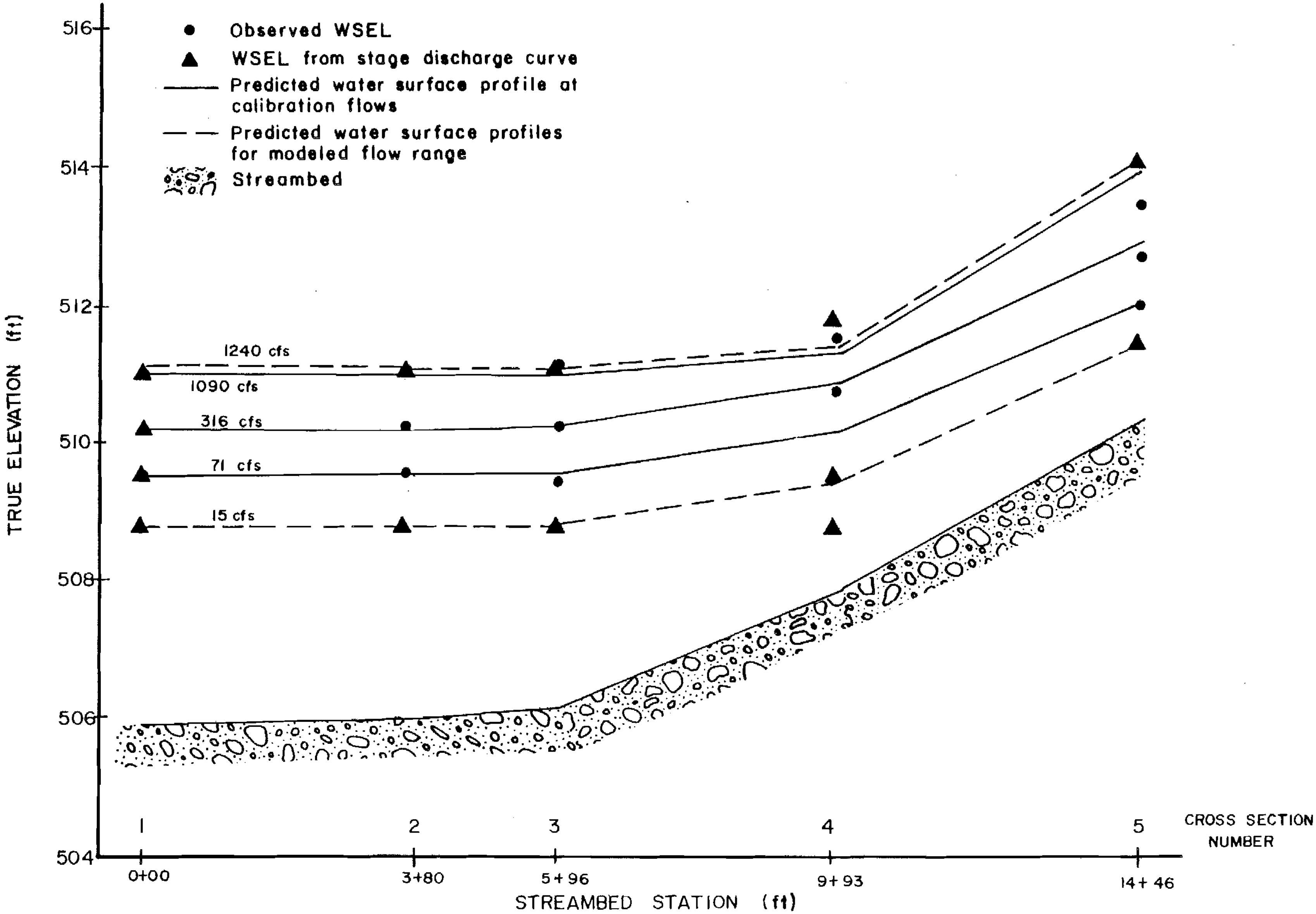


Figure III-22. Comparison of observed and predicted water surface profiles from calibrated model at site 119.2R.

The WSA and juvenile chinook WUA curves are presented in Figure III-23a. Both curves are plotted to the same scale and expressed in identical units; i.e., sq ft/1,000 ft of stream. The largest amount of rearing habitat for juvenile chinook is available at mainstem discharges between 10,000 and 12,000 cfs.

The WUA curve plotted in Figure III-23b at an expanded vertical scale accents the rapid increase in rearing habitat associated when this site breaches near 10,000 cfs. This marked increase is attributed to turbid mainstem water entering the site and significantly increasing the cover value afforded juvenile chinook. As mainstem discharge increases beyond 13,000 cfs velocities begin to reduce the rearing potential at this site. Above 24,000 cfs available rearing habitat is restricted to shoreline margins where sufficient object cover is available to retard velocity.

It was necessary to estimate WSA and juvenile chinook WUA beyond the extrapolation limits of the hydraulic model. The WSA was evaluated by digitizing enlarged air photographs obtained at mainstem discharges of 5,100, 7,400 and 10,600 cfs. The surface area measurements at 5,100 and 7,400 cfs were equal. The ratio of the digitized surface area at 10,600 cfs to that forecast by the hydraulic model at the same flow was 0.47. This ratio was used to adjust the digitized surface areas from aerial photography at 5,100 cfs and 7,400 cfs before using these surface areas to extend the WSA curve from 10,000 cfs to 5,000 cfs.

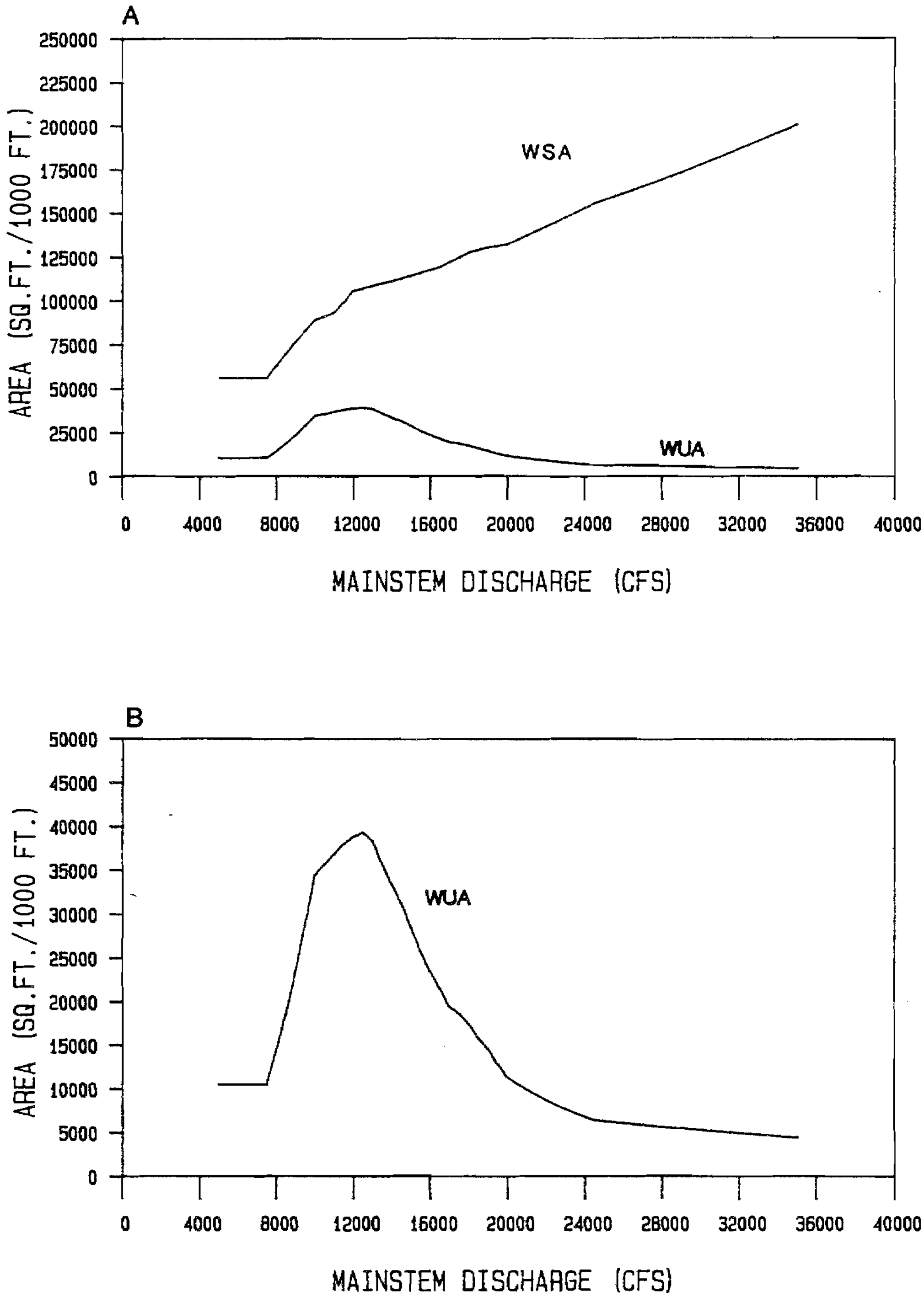


Figure III-23. Surface area and juvenile chinook habitat response curves for site 119.2R. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

Juvenile chinook WUA estimates for unbreached conditions are based on the assumption that rearing habitat potential declines at a constant rate as mainstem discharge declines from 10,000 to 7,400 cfs. The percentage of the WSA providing potential rearing habitat at 7,400 cfs was assumed to be approximately 0.5, the proportion of clear water habitat present immediately preceding breaching. The WUA values for mainstem discharges between 7,400 and 10,000 cfs were linearly interpolated. Since WSA remained constant as mainstem discharge declined from 7,400 to 5,100 cfs, WUA for juvenile chinook was assumed to remain constant.

An exponential decay function was used to extend the WUA curve beyond the upper extrapolation range of the calibrated hydraulic model. The decay function selected reproduced a habitat response trend similar to other middle Susitna River side channel sites. The habitat area curve was extended from 22,000 to 35,000 cfs using a positive exponential function. Similar trends in the WSA curves are present at other modeling sites. Both the WSA and WUA curves should be applied with discretion in the 23,000 to 35,000 cfs range. Table B-6.4 contains further details regarding the synthesis of surface area and WUA response curves for this site.

Time series plots of WUA and average daily site flow (Figure III-24) indicate that fairly low habitat potential for juvenile chinook exist at this site during mid-summer, but comparatively high WUA indices are associated with early summer and fall site flows. Rearing habitat is maximized at this site when the mainstem discharges range between 10,000 and 14,000 cfs (Figure III-23b), the WUA values within this range are over five times greater than

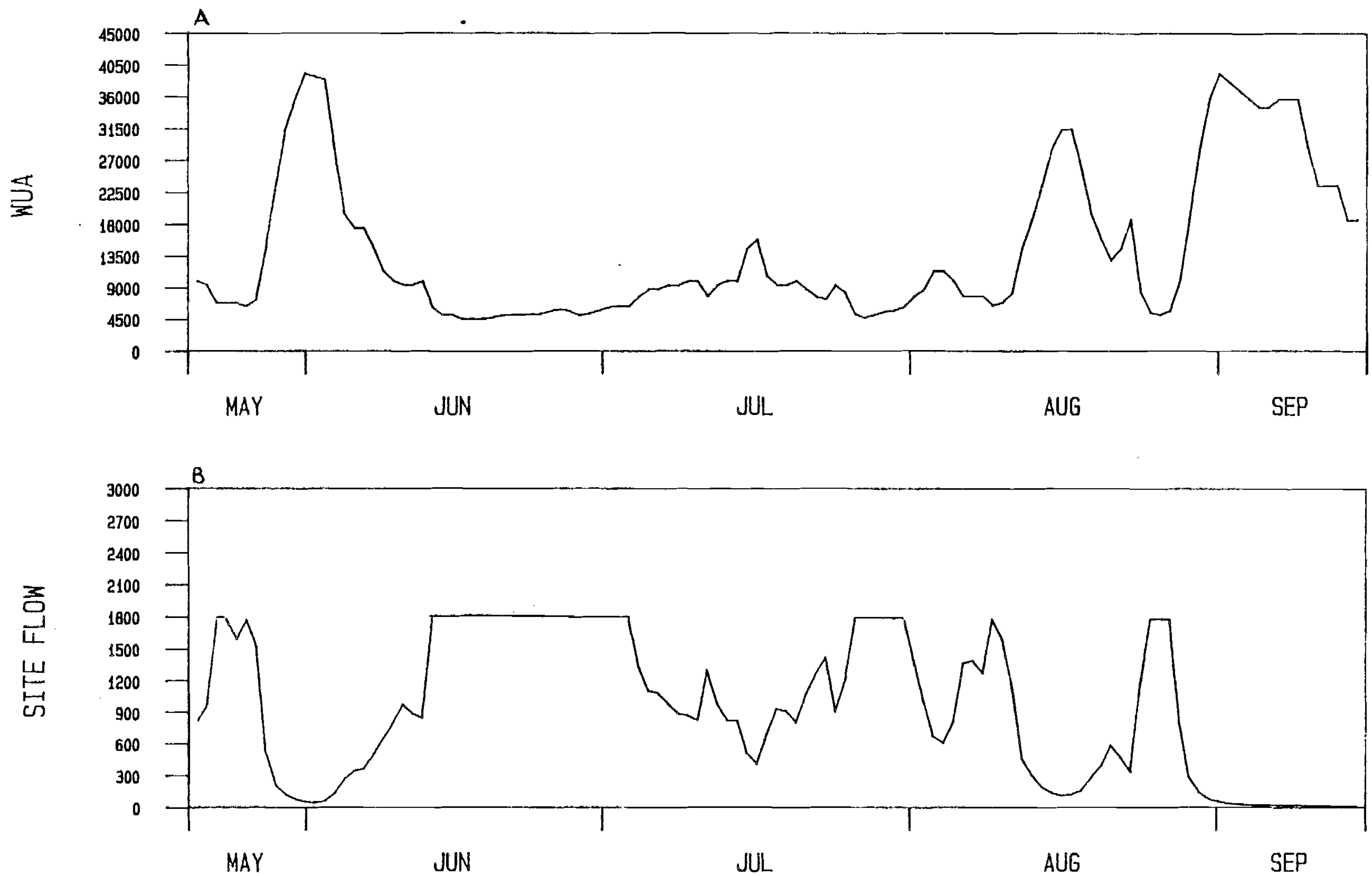


Figure III-24. Time series plots as a function of time for site 119.2R. A - Juvenile chinook WUA. B - Site flow.

WUA values associated with typical mid-summer discharges (20,000 to 25,000 cfs). Hence, the time series plot reflects greater fluctuations in juvenile chinook habitat at this site compared to other side channel study sites.

Site 131.7L

Site Description: This site is located directly above the confluence of Fourth of July Creek along the west bank of the Susitna River (Plate III-5). The study reach is 1,900 ft long and ranges from 250 ft wide in the lower half of the site to 400 ft in the upper half. Cobble and rubble are the principle substrates found in the lower half of the site while gravel and rubble substrate dominate the upper half. Silt and sand deposits exist in pool areas and backwater zones and cover is provided by the larger substrate and two debris zones found in the site. Three cross sections are located in the deep, low velocity area and two cross sections are located in the shallow, high velocity areas. In addition, two cross sections were established in the transition areas below low and high velocity areas (Figure III-25).

This study site was selected to represent side channels that remain side channels for a broad range of discharges. Upwelling was suspected to maintain baseline flows and the site appeared to have good rearing habitat. An IFG-4 model was selected because of the non-uniform flow conditions and channel size. Chum salmon and juvenile chinook have been observed to utilize the channel (Hoffman 1985).

Calibration: To calibrate the IFG-4 model for the site, four data sets were collected at each cross section (Table III-9).

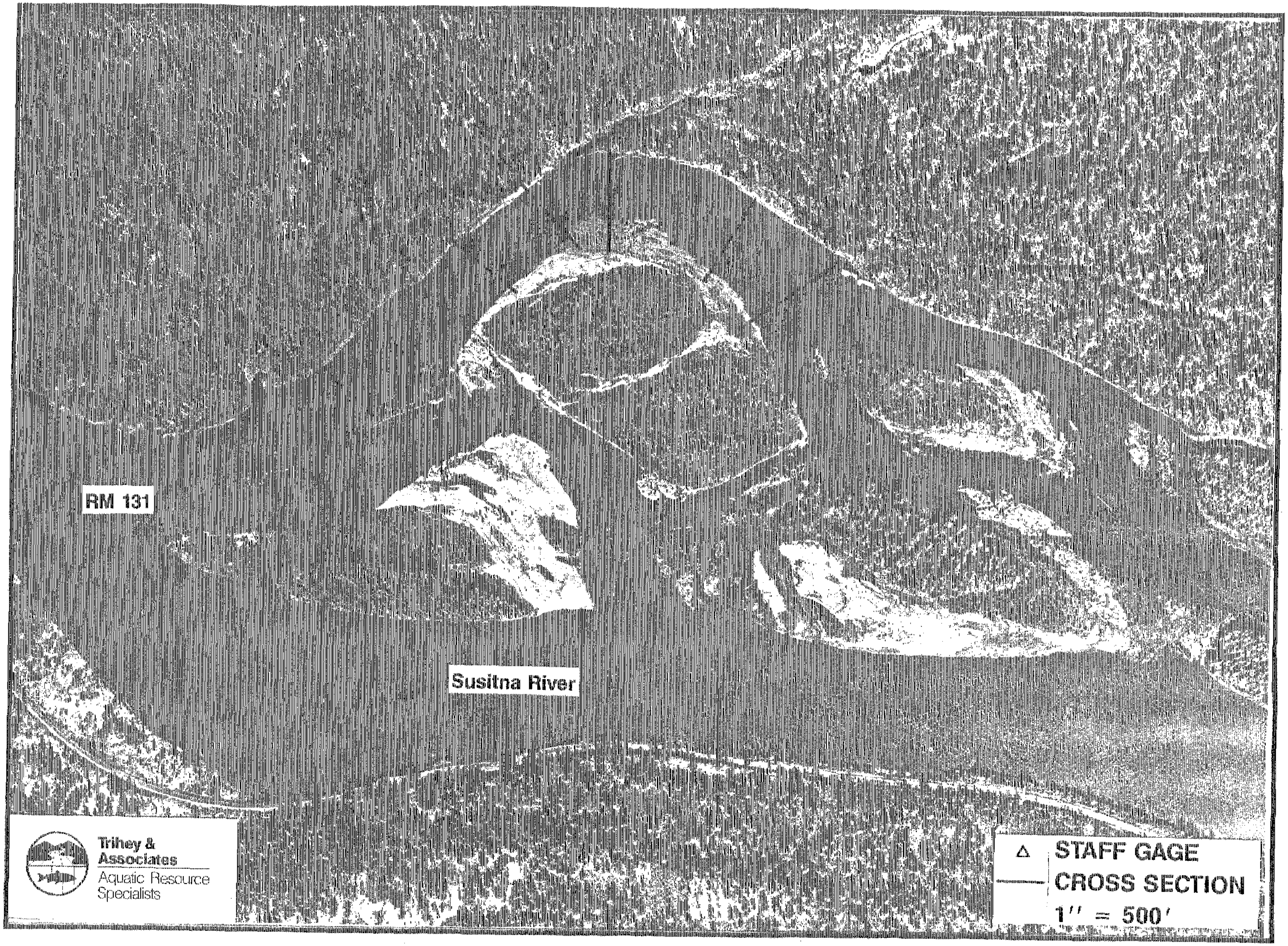


Plate III-5. Modeling site 131.7L on June 1, 1982 at mainstem discharge: 23,000 cfs.

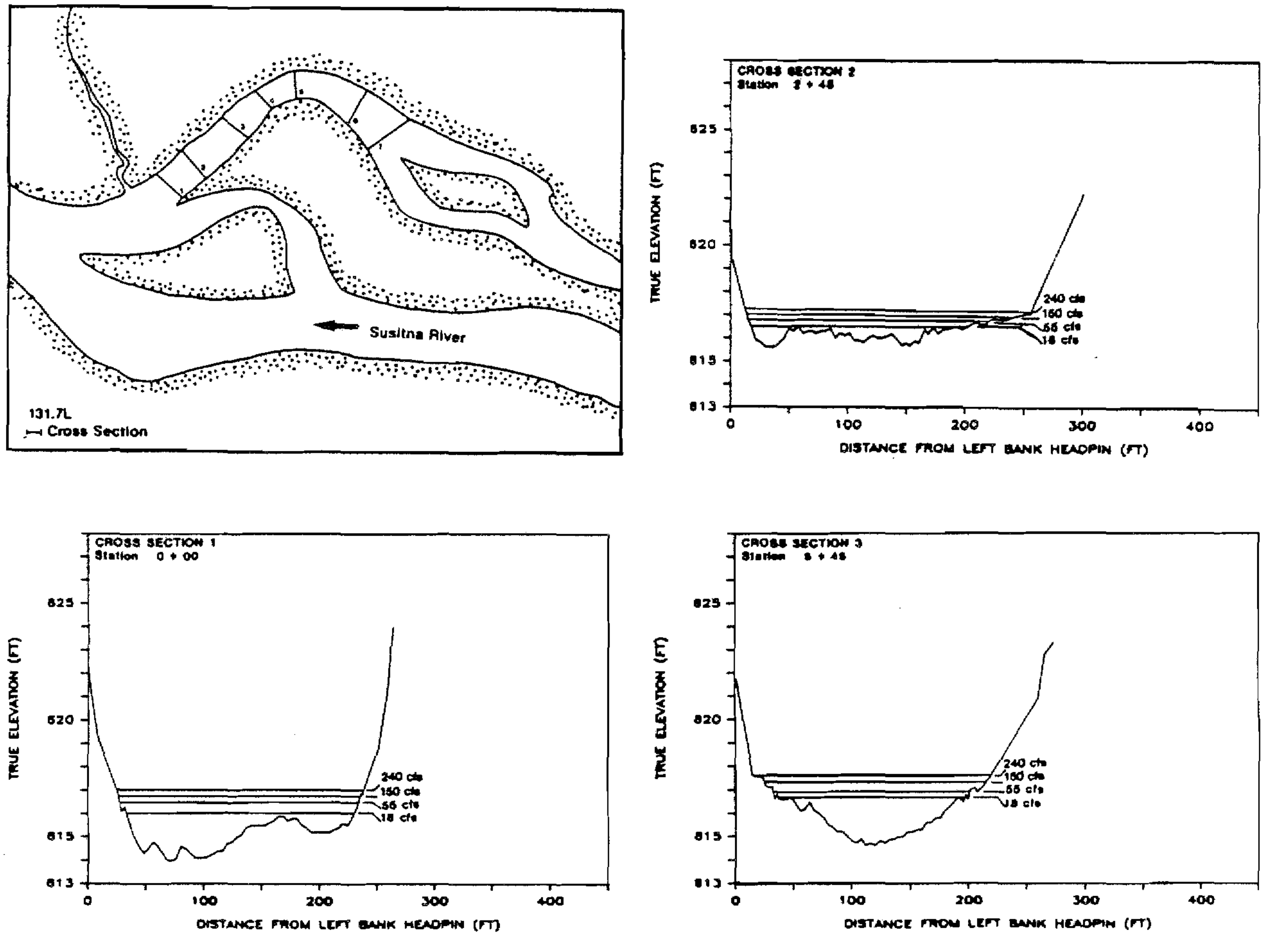


Figure III-25. Cross sections for site 131.7L depicting water surface elevations at calibration discharges of 18, 58, 150 and 240 cfs.

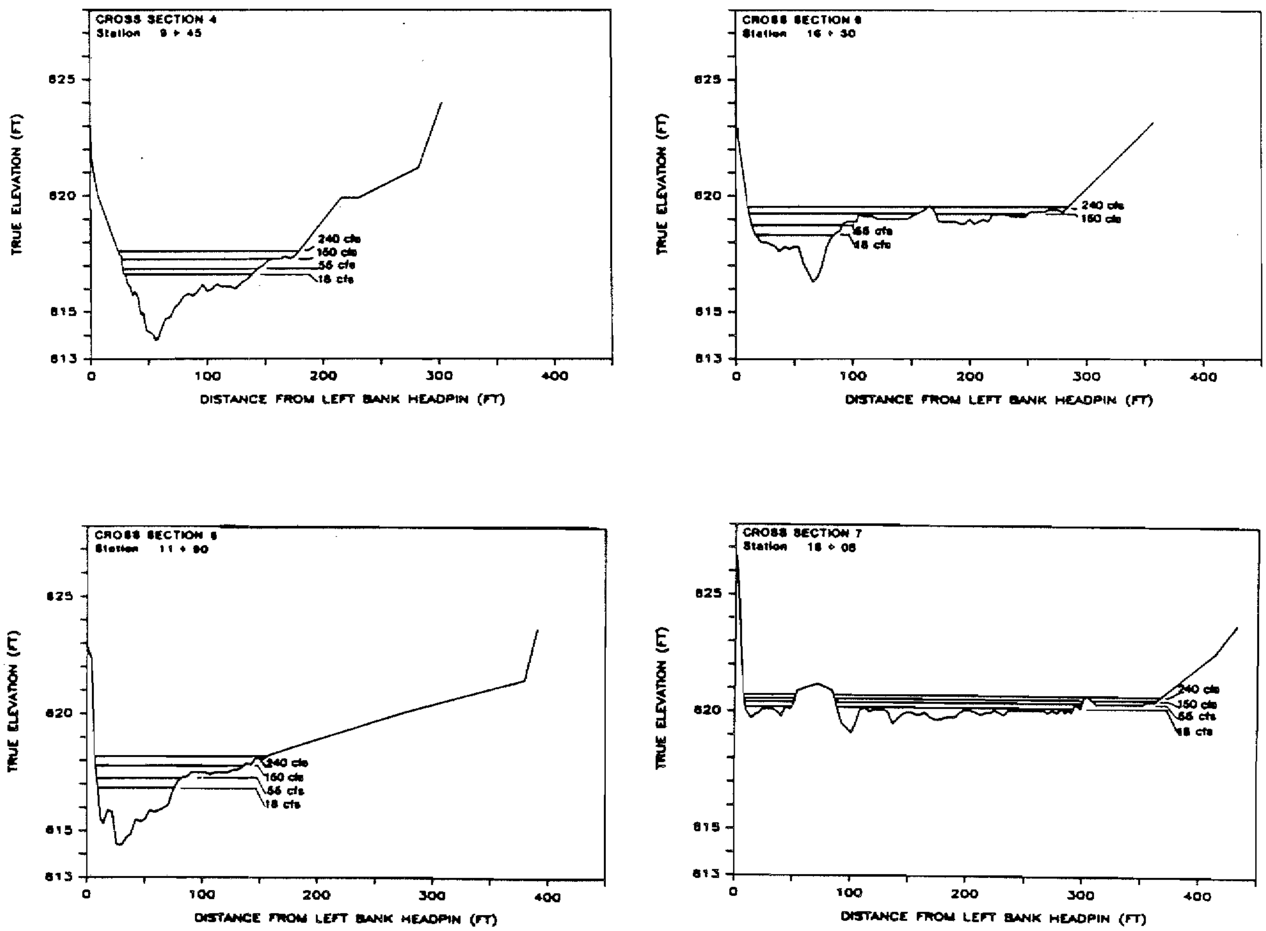


Figure III-25 (Continued).

Table III-9. Hydraulic data available to calibrate the IFG-4 model for site 131.7L.

Date	Site Flow* (cfs)	Mainstem Discharge (cfs)
840927	18	7470
840919	55	9390
840902	150	11800
840817	240	14800

* Mean site flow

The input data required that a stage of zero flow value be assigned to each cross section. Because a streambed profile was not surveyed for the site, the stage of zero flow at cross section 1 was estimated during the iterative calibration process. A large riffle area below the study site controlled the stage of zero flow at cross section one.

Horizontal stages were not maintained across three cross sections in the site. At cross section 2, the backwater area along the left bank had a lower water surface than the main channel and was raised as much as 0.4 ft to maintain a horizontal water surface. Along the right bank at cross sections 6 and 7, a shoal area raised the water surface to higher elevations than the main channel. The streambed was lowered in this area nearly 0.3 ft at both cross sections to maintain horizontal water surfaces. Also, along the left bank at cross section 7 there was a backwater area which had a lower water surface than the main channel. The streambed elevations for these cross sections were also raised (Figure III-26).

A plot depicting the observed and predicted water surface profiles for the calibration flows as well as profiles for the extrapolation limits is shown in Figure III-27. Above 600 cfs, the reliability of the stage and velocity predictions decrease.

To calibrate the IFG-4 model with respect to stage, comparisons were made between the flow-stage curve and the model-predicted stages (Figure III-28). Flows were forecast in the model including several beyond the IFG recommended extrapolation range (7 to 600 cfs). Although similar comparisons were made at each cross section only the discharge cross section is shown in the figure.

The performance of the calibrated model can be evaluated by comparing the observed and predicted stages, discharges and velocity adjustment factors (Table B-4.2). The difference between observed and predicted stages is generally less than 0.03 ft. The largest difference in observed and predicted discharges is 5 percent. The velocity adjustment factors ranging from 0.92 to 1.04 indicate that the models are suitably calibrated.

Verification: Figure B-2.7 illustrates the scatterplots of observed and predicted depths and velocities. The one-to-one relationship between observed and predicted velocities demonstrates that the model predicts accurately. The results of the statistical tests are shown in Table B-5. For both depth and velocity comparison, the $RMSE_U$ is nearly equal to the RMSE, an indication that the model is calibrated. The index of agreement is 0.99 for both depth and velocity.

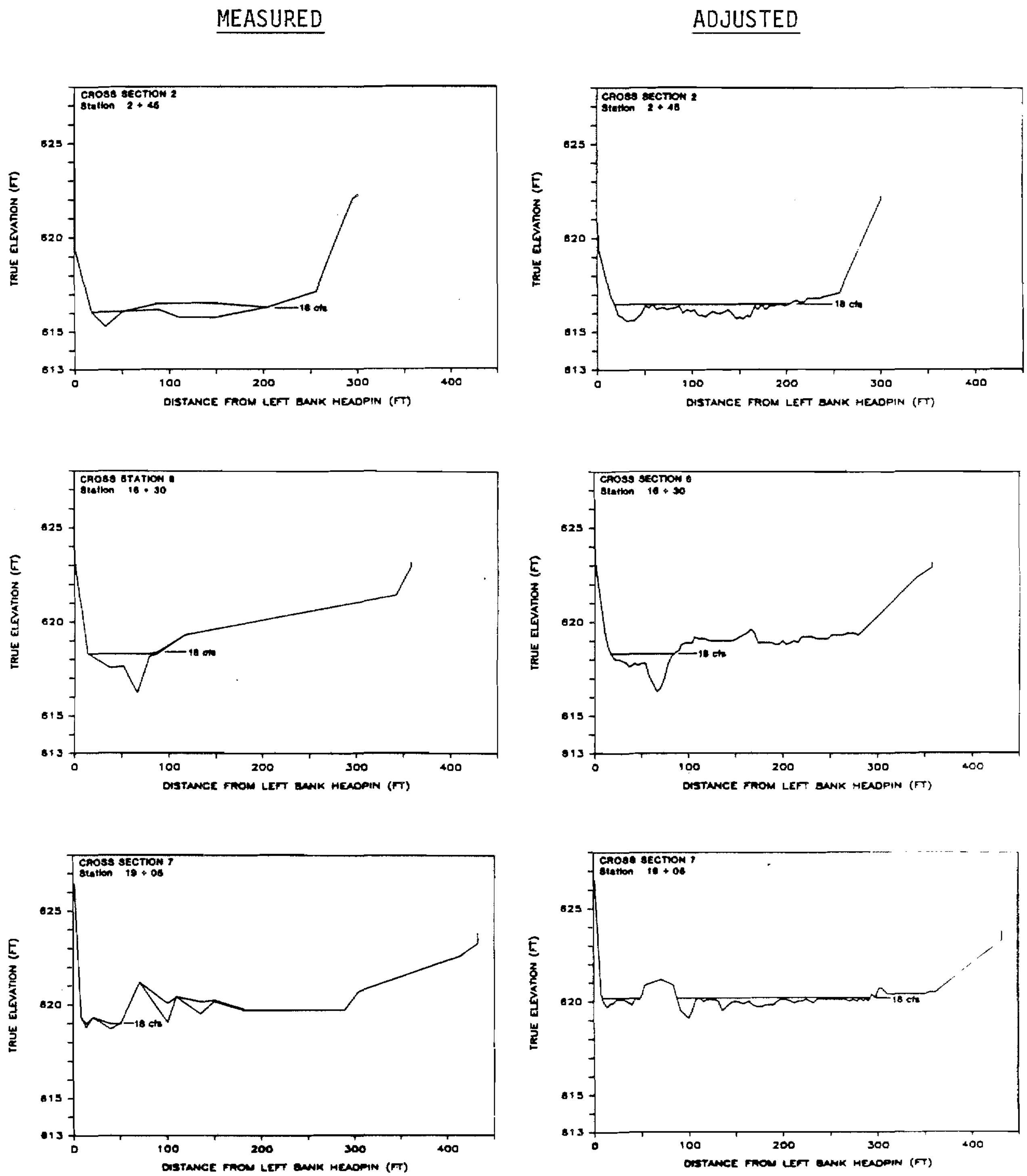


Figure III-26. Comparison between measured and adjusted cross sections 2, 6 and 7 at site 131.7L.

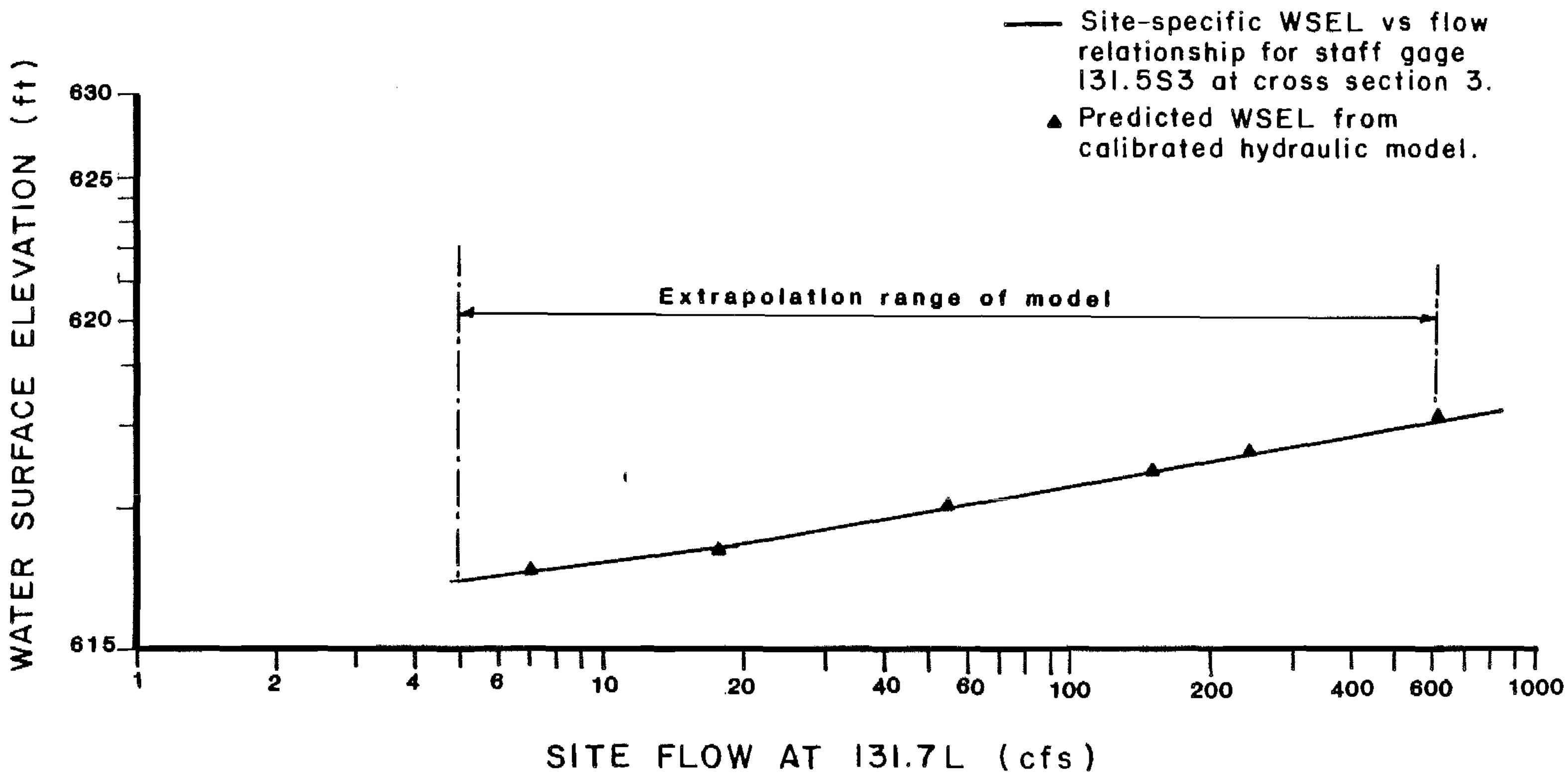


Figure III-28. Comparison between water surface elevations forecast by the calibrated hydraulic model and the stage-flow relationship for 131.7L cross section 3.

Application: The IFG-4 model is calibrated for baseline flow conditions of 5, 10 and 15 cfs occurring at 5,000, 6,000, and 7,000 cfs mainstem, respectively. For site flows of 15 to 600 cfs (7,400 to 19,300 cfs mainstem), an excellent rating was assigned. An overall rating of unacceptable was assigned to the model between 19,300 and 35,000 cfs due to the breakdown in the depth and velocity predictions from the model.

The application range and ratings are summarized below in the bar chart.

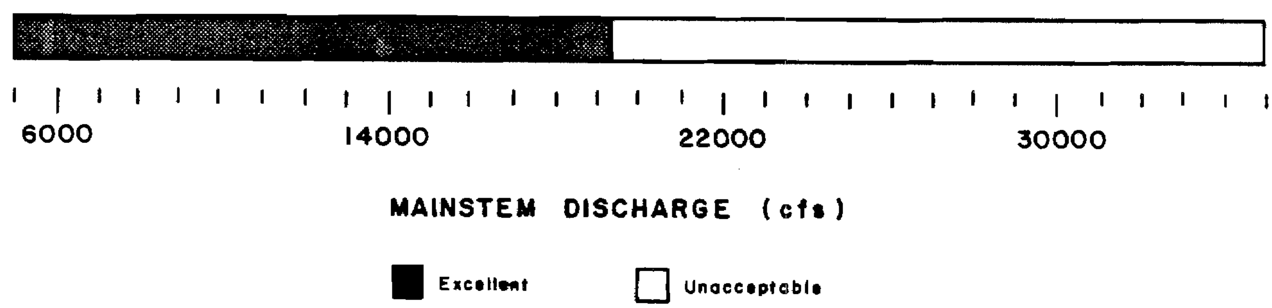


Figure III-29a depicts the WSA and WUA response curves for this site. Because this side channel conveys mainstem water at 5,000 cfs, turbid water suitability criteria were used for juvenile chinook. The pronounced increase in WUA as mainstem discharge increases from 5,000 to 8,000 cfs (Figure III-29b) is associated with a rapid increase in WSA with suitable rearing velocities, rather than with a change from clear to turbid water habitat as is the case at other study sites.

An extensive gravel bar located on the inside of the bend near the head of this site (Plate III-5) exerts the greatest influence on the shape of the WUA curve at this site. As mainstem discharge increases above 5,000 cfs, a large shallow riffle develops which provides significant amounts of juvenile chinook rearing habitat. At higher flows this shoal area is characterized by

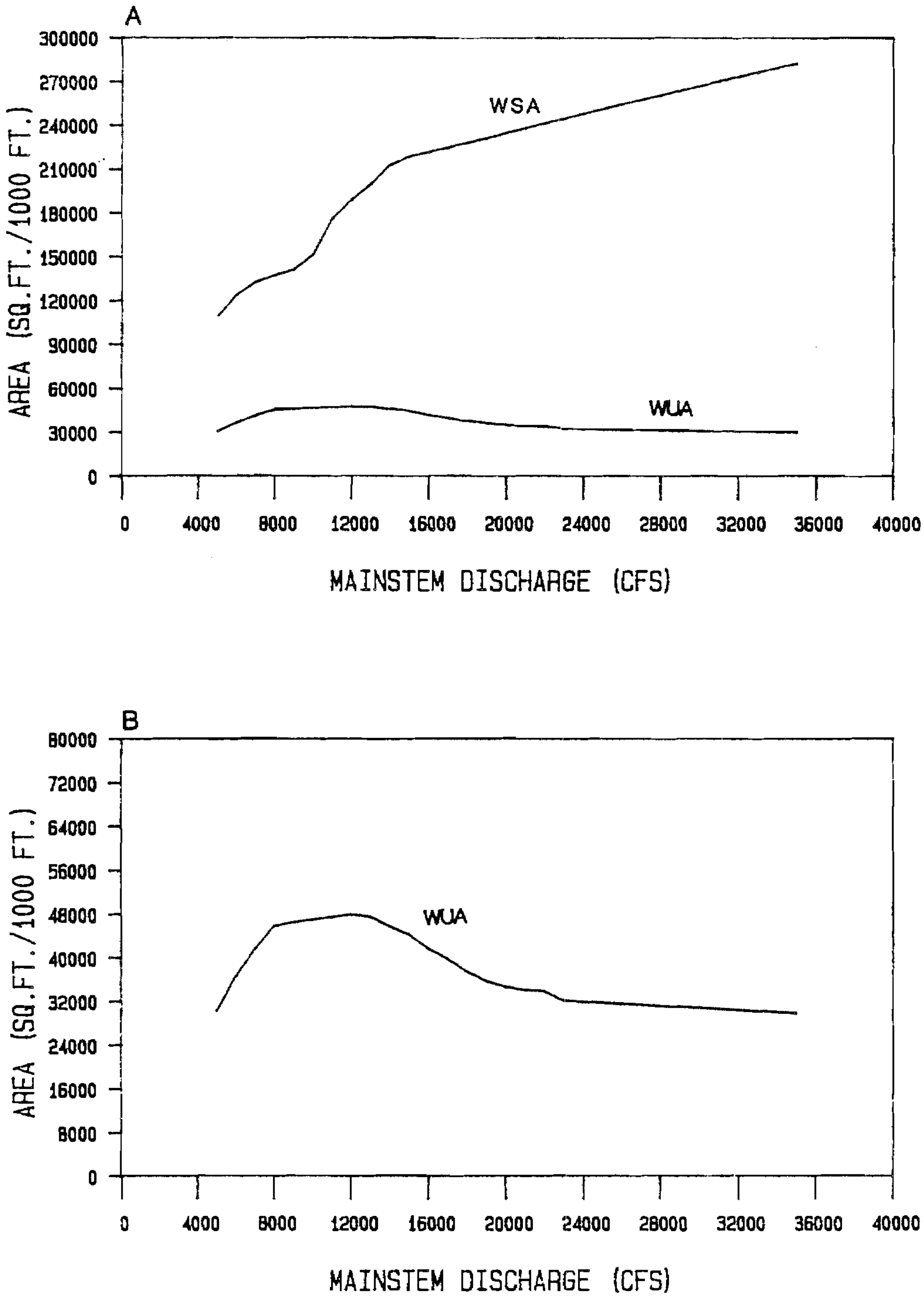


Figure III-29. Surface area and juvenile chinook habitat response curves for site 131.7L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

unsuitably high water velocities and the habitat potential of the site diminishes accordingly.

The WUA and WSA response curves for this site were forecast using the HABTAT model linked to an IFG-4 hydraulic model calibrated for a range of mainstem discharge from 5,000 to 23,000 cfs. A constant rate of change was assumed for both curves as mainstem discharges increased to 35,000 cfs (Table B-6.5).

Time series plots (Figure III-30) indicate relatively constant juvenile chinook habitat within the side channel during the mid-summer months, however, fairly large variations in habitat exist between mid-summer and late spring or early autumn habitat forecasts. A notable feature of this site is the large amounts of rearing habitat provided during the rearing period relative to other study sites.

Site 132.6L

Site Description: This site is located in the channel immediately upstream of site 131.7L on the west bank of the Susitna River (Plate III-6). The study reach is 1,140 ft long and ranges in width from 140 ft at the mouth to 180 ft at the upper end. Silt and sand substrate is present throughout the deep area while cobble and rubble substrate is generally found in the shallow areas. Vegetation, including horsetails, lines the left bank of the channel and provides some cover. Cross sections 1, 3 and 9 are located in the fast, shallow areas. Cross sections 2 and 4-8 are site in the deep, slow velocity

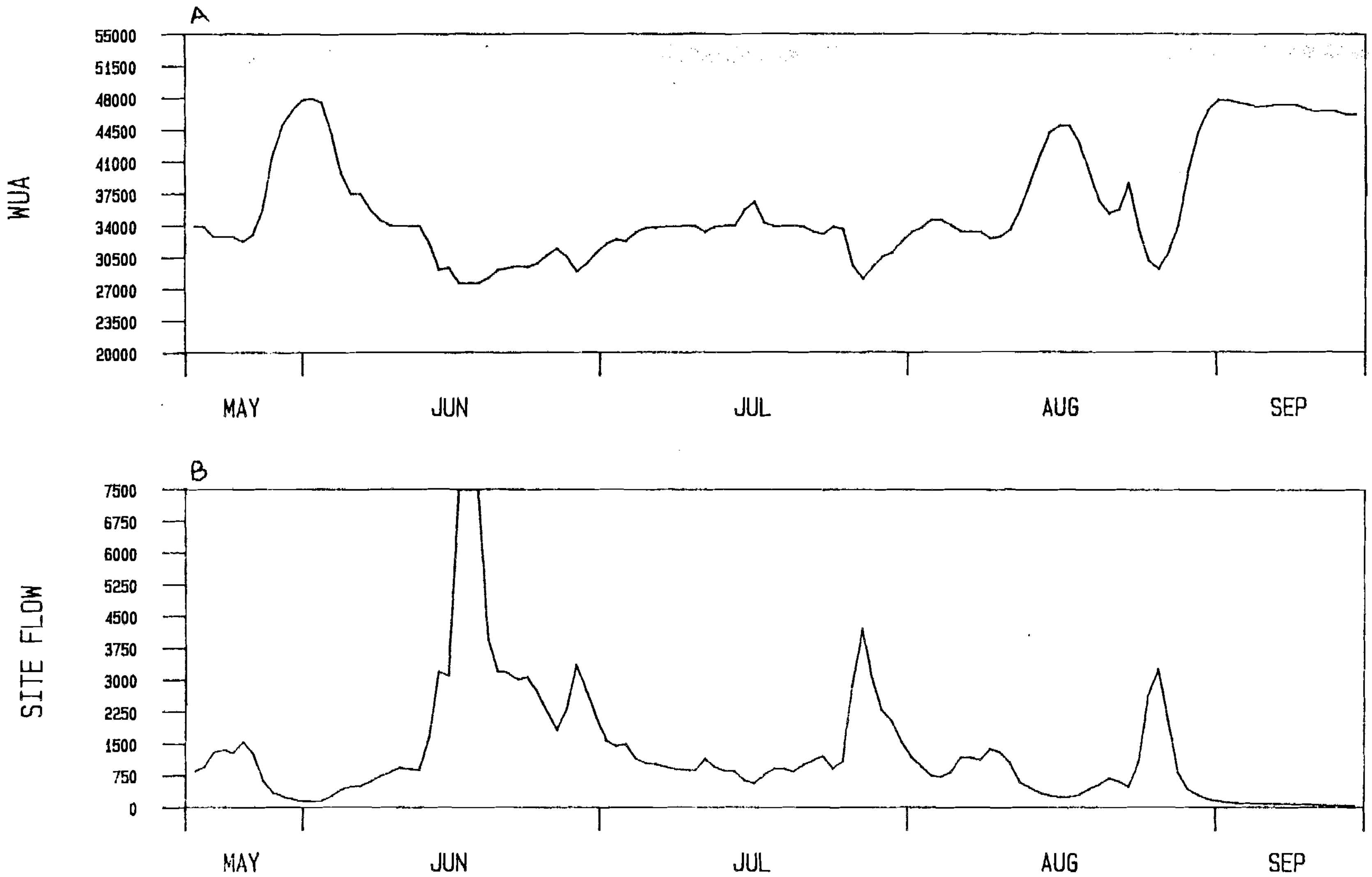


Figure III-30. Time series plots as a function of time for site 131.7L. A - Juvenile chinook WUA. B - Site flow.

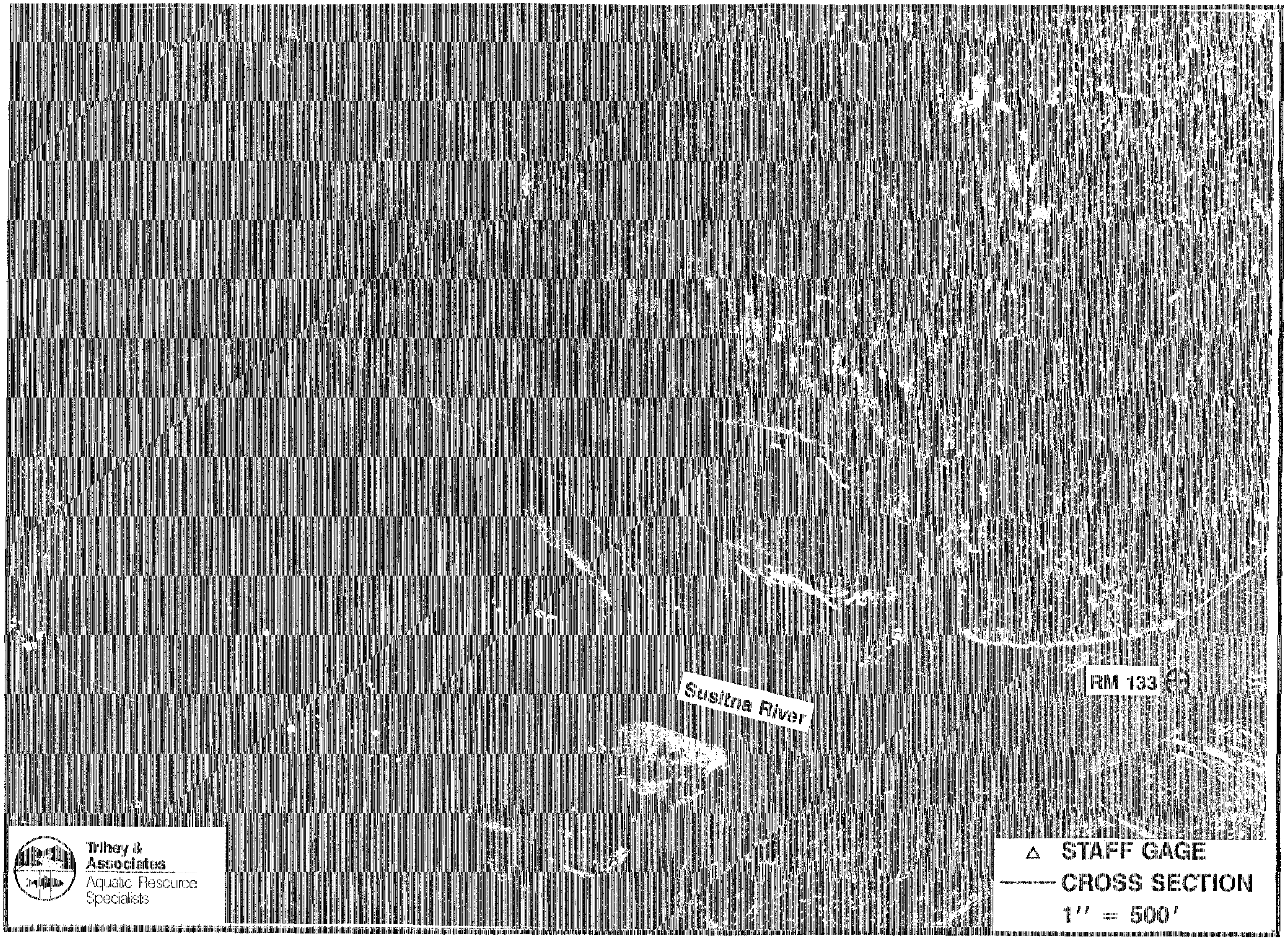


Plate III-6. Modeling site 132.6L on June 1, 1982 at mainstem discharge: 23,000 cfs.

areas. A small backwater area is present on the left bank of cross section 9 (Figure III-31).

Three channels were identified and labeled A, B & C. Channels B and C breach at mainstem discharges of 10,000 and 14,500 cfs, respectively. Below 10,000 cfs, the water in the study area is ponded and eventually dries up. An overflow channel along the right bank conveys a small amount of site flow at 25,000 cfs into Channel A. In addition, a backwater area is present from the mouth through cross section 2 at mainstem discharges greater than 23,100 cfs.

This site was selected to represent small side channels that remain small throughout a large range of discharges. An IFG-4 model was selected because of the small channel size and the non-uniform channel conditions. No adult salmon have been observed in the site. However, a large number of chinook juvenile rear in the site (Hoffman 1985).

Calibration: To calibrate the IFG-4 model for this site, two data sets were collected at each cross section. These are summarized in the following table.

Table III-10. Hydraulic data available to calibrate the IFG-4 model for site 132.6L.

Date	Site Flow* (cfs)	Mainstem Discharge (cfs)
940901	27	12,700
840708	141	21,500

* Mean site flow

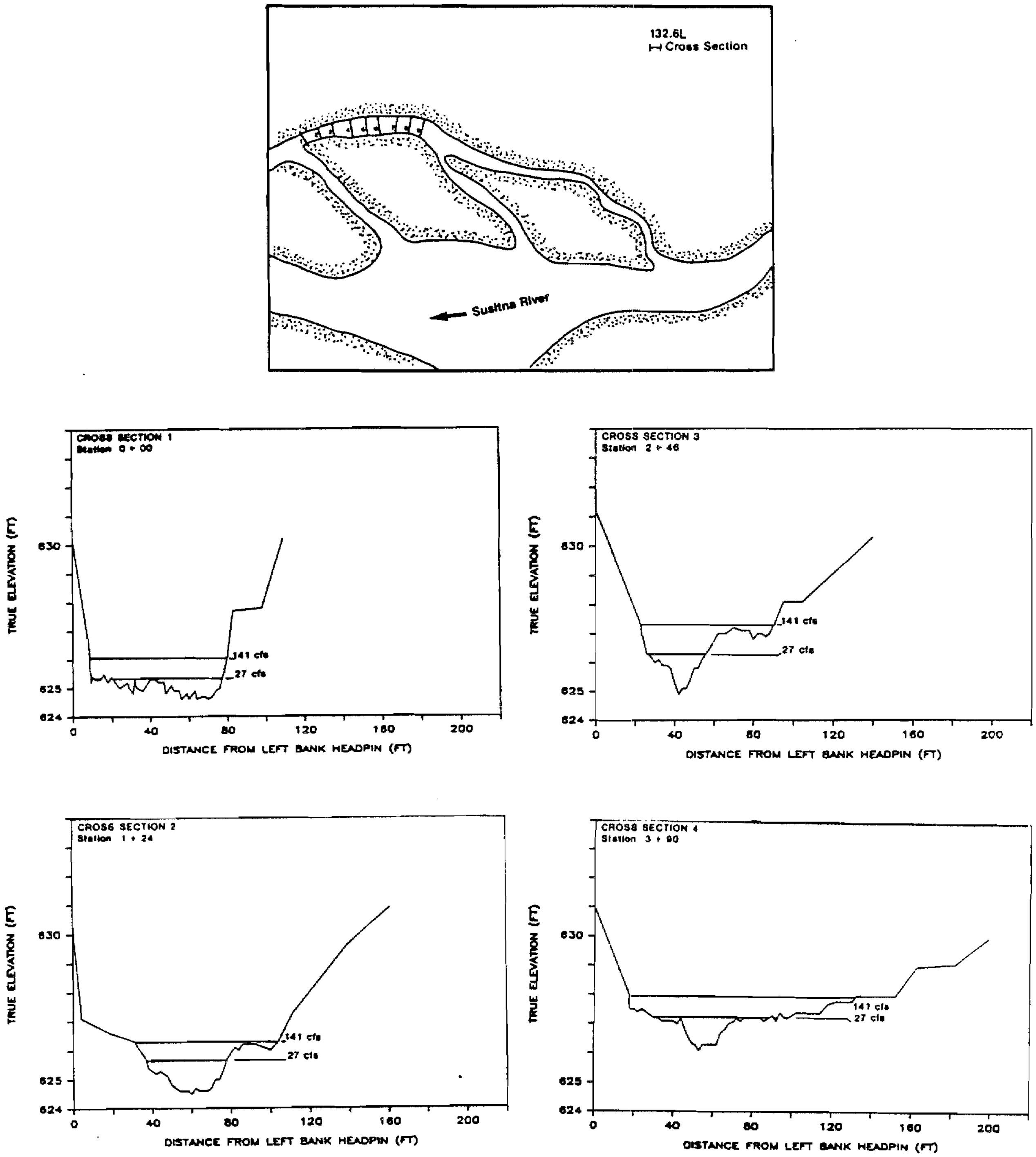


Figure III-31. Cross sections for site 132.6L depicting water surface elevations at calibration discharges of 27 and 141 cfs.

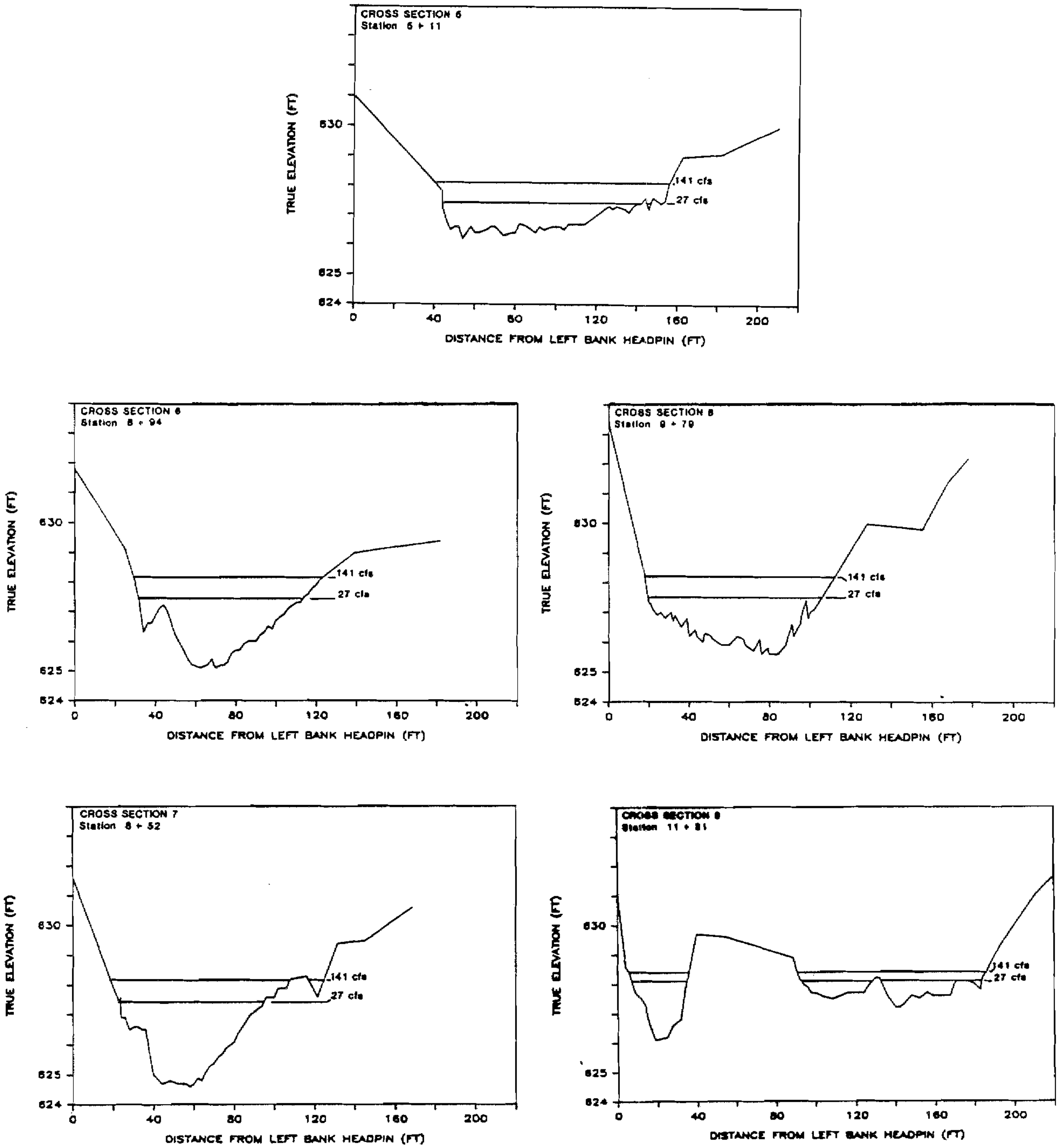


Figure III-31 (Continued).

Due to the small backwater area on the left side of the channel a horizontal stage did not occur at cross section 9. The streambed elevations in this area were raised so that the left and main channel water surfaces had the same elevation (Figure III-32).

A plot depicting the observed and predicted water surface profiles for the calibration flows as well as profiles for the extrapolation limits is shown in Figure III-33. Because only two data sets are used in the model, the predicted stages are equal to the observed elevations. The discrepancy between expected and predicted depths and velocities above a site flow of 300 cfs are unacceptable, therefore, 300 cfs was set as the upper limit of the model.

The IFG-4 model was calibrated using the guidelines previously described. Figure III-34 shows a comparison between the flow-stage curve and the model-predicted stages for the discharge cross section in the site. Similar comparisons were made for each cross section. After model calibration, the observed and predicted stages are identical. The predicted discharges vary greatly from the mean at cross sections 1 and 8, as did the actual field measurements. The velocity adjustment factors ranged from 0.87 to 1.02.

Verification: The IFG-4 model is based on regression analysis and two data sets. For this two-point model, scatterplots (Figure B-2.8) and statistical tests (Table B-5) were made to compare the observed and predicted depths and velocities. False precision is implied with a nearly perfect one-to-one relationship in the scatterplots and with the index of agreement (0.99).

MEASURED ADJUSTED

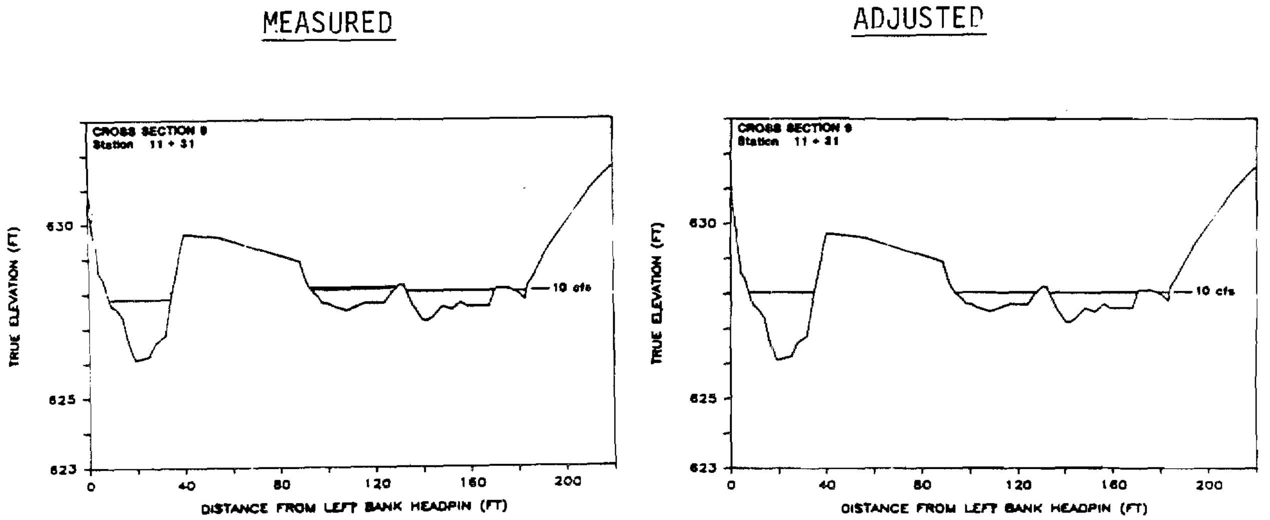


Figure III-32. Comparison between measured and adjusted cross section 9 at site 132.6L.

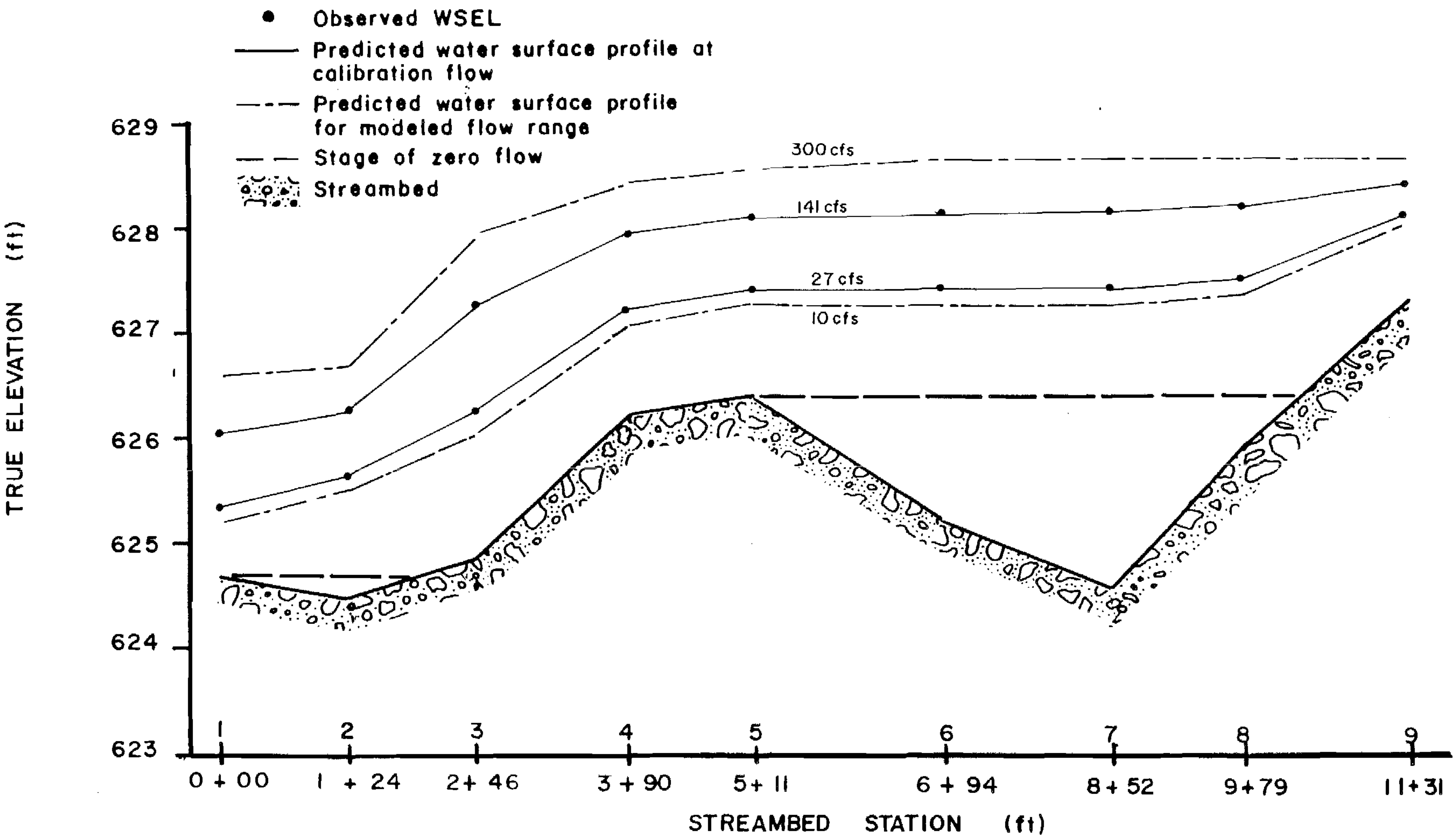


Figure III-33. Comparison of observed and predicted water surface profiles from calibrated model at site 132.6L.

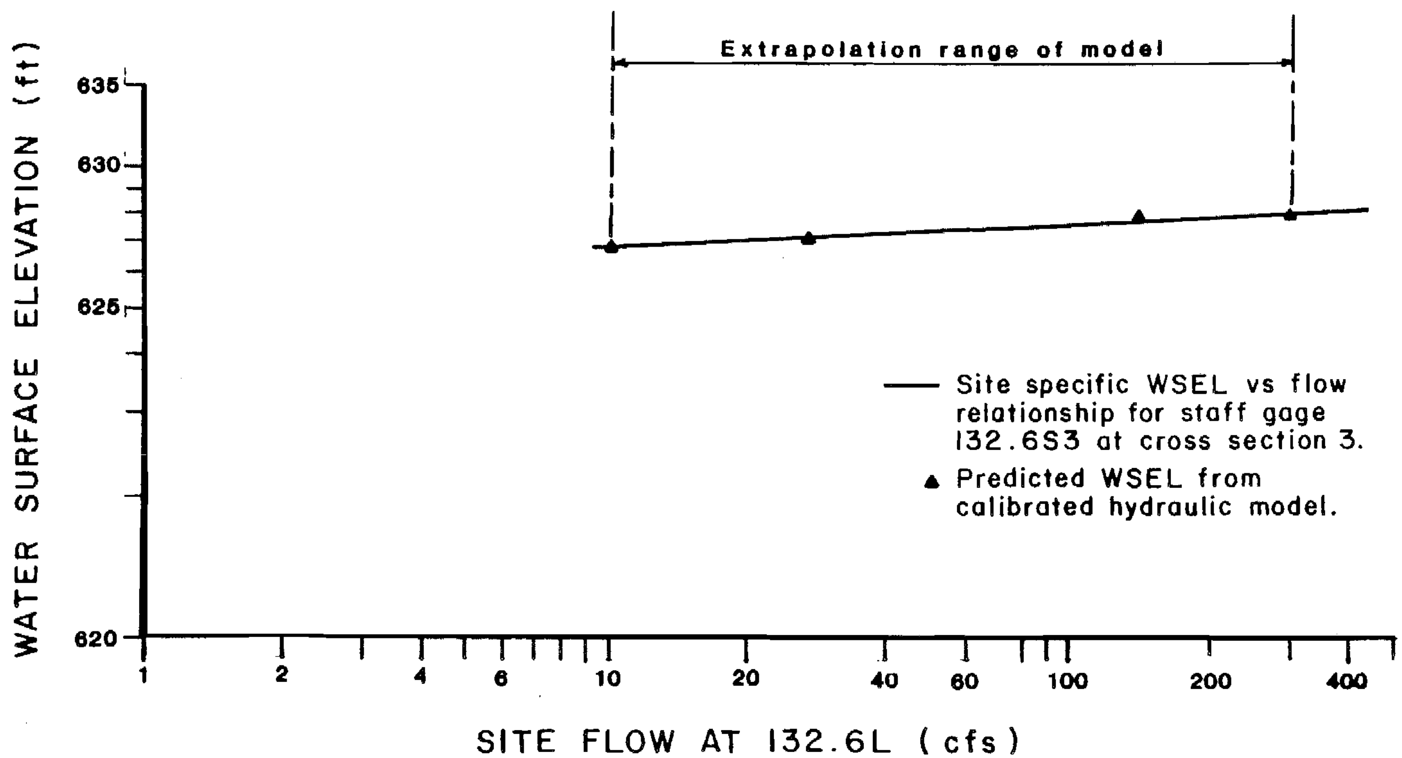
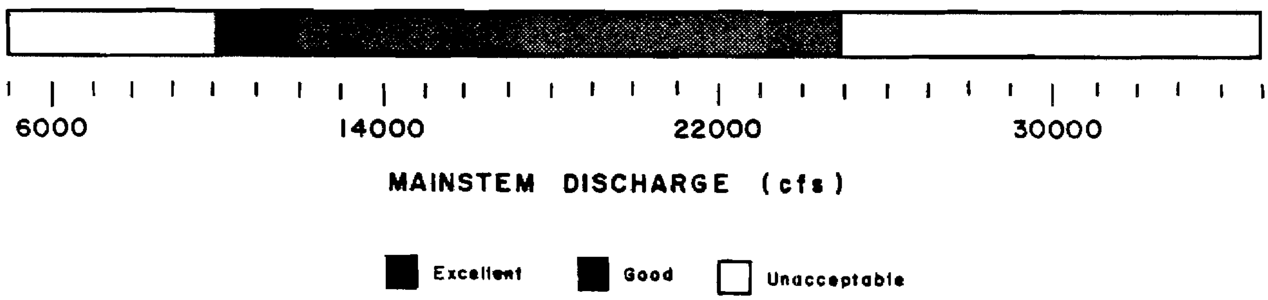


Figure III-34. Comparison between water surface elevations forecast by the calibrated hydraulic model and the stage-discharge relationship for 132.6L cross section 3.

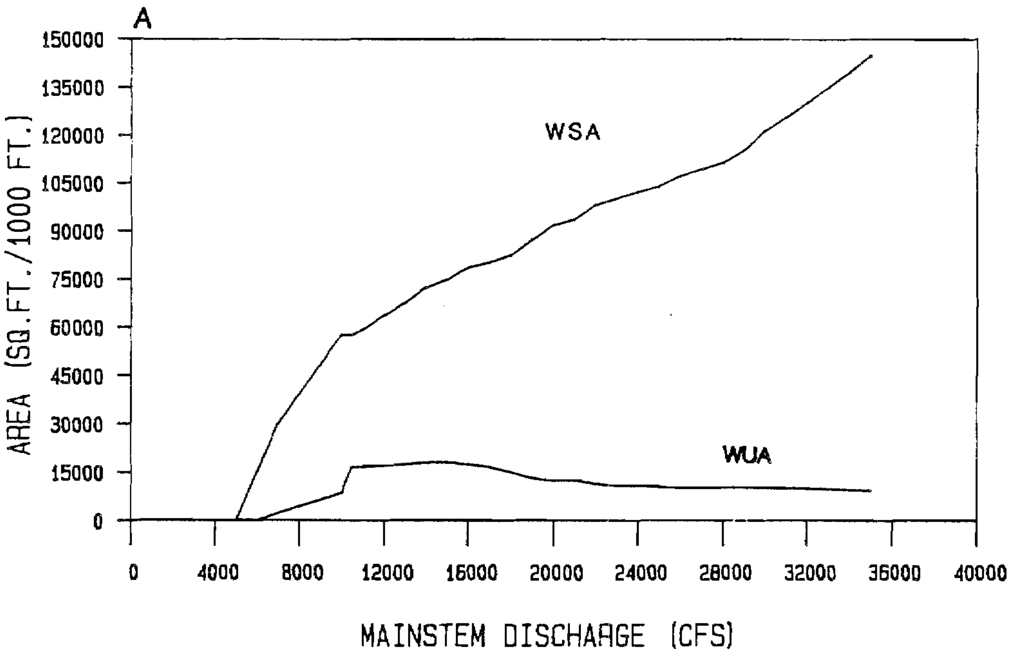
<u>Application</u>: Baseline flow at this site is estimated as 10 cfs for discharges below 10,000 cfs. For site flows of 10 to 17 cfs (10,000 to 11,900 cfs mainstem), the model is not able to forecast velocities accurately, thereby reducing the rating for this flow range from excellent to good. The site was assigned an excellent rating, however, for the 17 to 300 cfs range (11,900 to 25,000 cfs mainstem). Above 25,000 cfs the model was assigned an unacceptable rating.

The application range and ratings are summarized below in the bar chart.



The WSA and juvenile chinook WUA curves for site 132.6L are plotted at the same vertical scale in Figure III-35a, and the WUA curve is replotted at an enlarged scale in Figure III-35. In both figures, WSA and WUA are expressed as sq ft/1,000 ft of side channel. A comparison of the two curves indicates that the ratio between WUA and WSA is approximately 0.3 at 12,000 cfs and declines to 0.1 at 25,000 cfs.

This study site is breached at a mainstem discharge of 10,000 cfs and dewaters as mainstem flows continue to decline. The associated rapid decline in both WSA and WUA is evident in Figure III-35. In addition, the juvenile chinook WUA curve drops suddenly when the side channel transforms from the breached to the unbreached condition at 10,000 cfs. This drop is attributable to the site



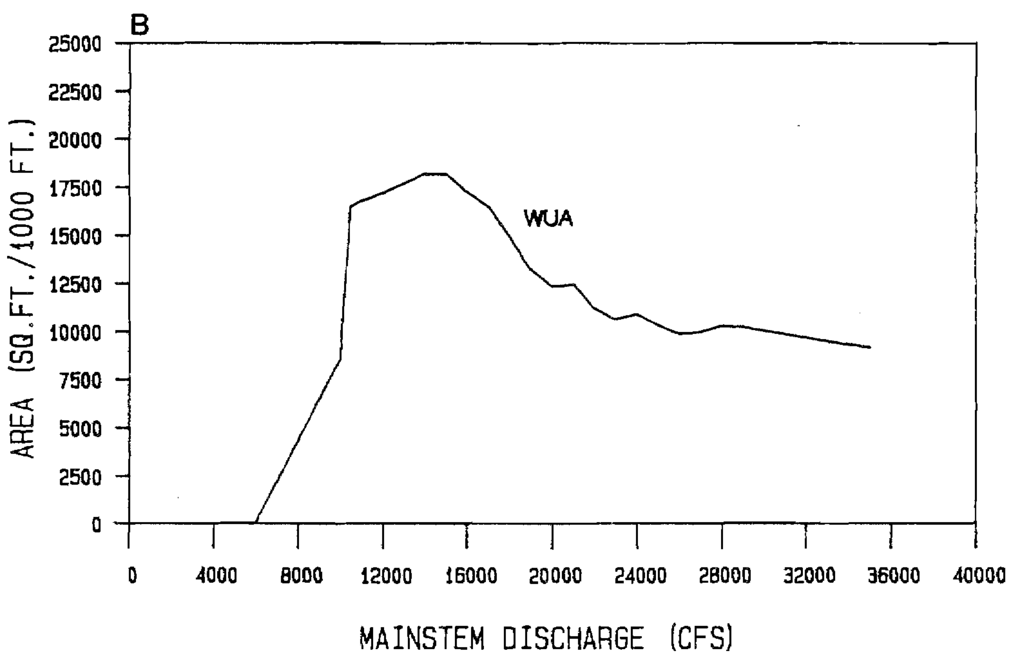


Figure III-35. Surface area and juvenile chinook habitat response curves for site 132.6L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

flow becoming non-turbid, thereby eliminating the high cover value associated with turbid water. As mainstem discharge declines toward 5,000 cfs, both the WSA and WUA approach zero.

The WSA and habitat response curves were forecast with the HABTAT model and the IFG-4 hydraulic model calibrated for mainstem discharges between 10,000 and 25,000 cfs. For mainstem discharges between 25,000 and 35,000, both curves were extended using exponential functions as indicated in Table B-6.6.

For mainstem discharges less than breaching (10,000 cfs), WSA and WUA estimates were obtained by using clear water criteria for juvenile chinook at 9,000 and 10,000 cfs to determine the magnitude of change in WUA attributable to the site flow clearing and enlargement were then reviewed. At 7,400 cfs, clear ponded water exists while the 5,100 cfs photography indicates that the site is nearly dry. Digitized surface area measurements of ponded water connected to the mainstem at 7,400 and 5,100 cfs were used as a basis for interpolating surface areas between discharges of 10,000 and 5,000 cfs. The WUA was assumed to decrease to zero at a constant rate through this range.

Time series analysis of 1984 site flow and juvenile chinook WUA are presented as Figure III-36. Rearing habitat was fairly stable throughout mid-summer 1984 with notable increases being apparent in late spring and early fall when mainstem discharges were approximately half their mid-summer level.

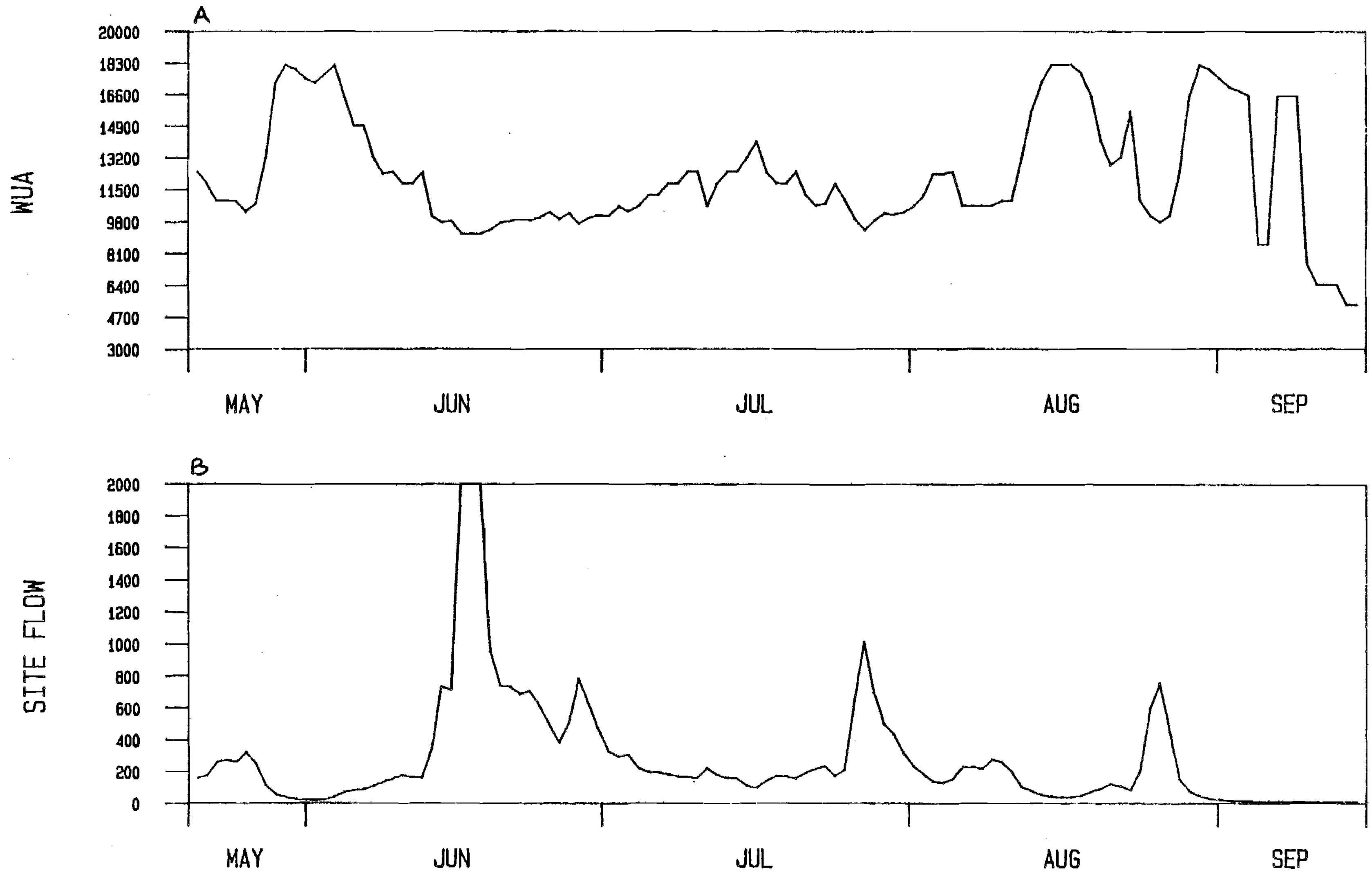


Figure III-36. Time series plots as a function of time for site 132.6L. A - Juvenile chinook WUA. B - Site flow.

Site 136.0L

Site Description: This site is located approximately 1 mile downstream of Gold Creek along the west bank of the Susitna River (Plate III-7). The study reach is 580 ft long and 80 ft wide with steep banks. The substrate is composed of cobble, rubble, and gravel throughout the site. Debris and log jams are present along the right bank and provide cover. Slough 14 enters the channel 20 ft above the study site. Cross sections 1-4 and 6 are located in shallow high velocity areas while cross section 5 is located in a deep, slow velocity area (Figure III-37). The channel has been observed breached at mainstem discharges as low as 5,000 cfs. At moderate to high discharges, the channel appears to be a run.

This small study site was selected to represent small side channels that remain side channels. An IFG-4 model was selected because of the small size of the channel. Relatively few spawning coho and chum have been observed in the site with juvenile chinook were caught in the side channel (Hoffman 1985).

Calibration: In order to calibrate the IFG-4 model for this site, three data sets were collected at each cross section (Table III-11).

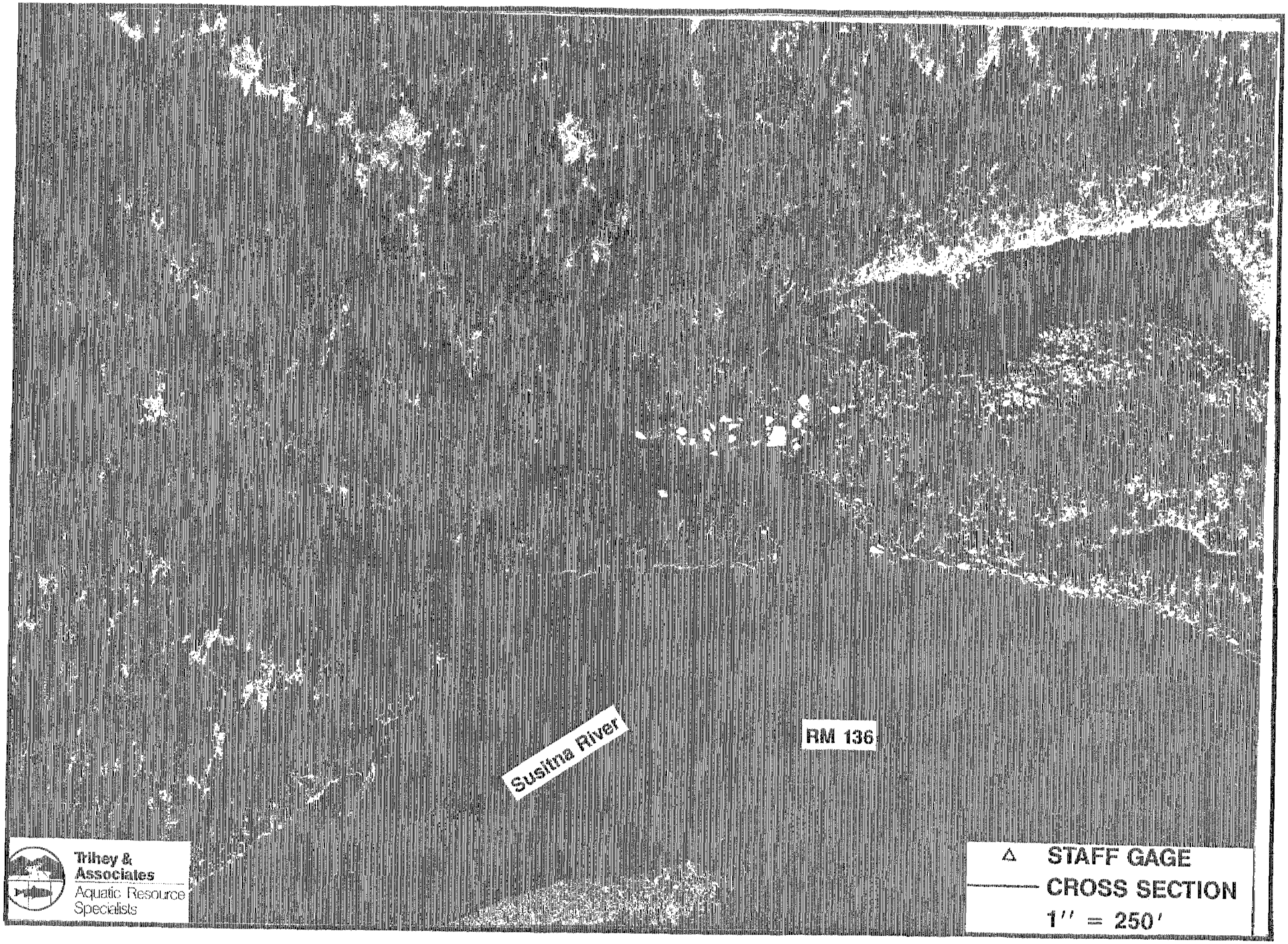


Plate III-7. Modeling site 136.0L on June 1, 1982 at mainstem discharge: 23,000 cfs.

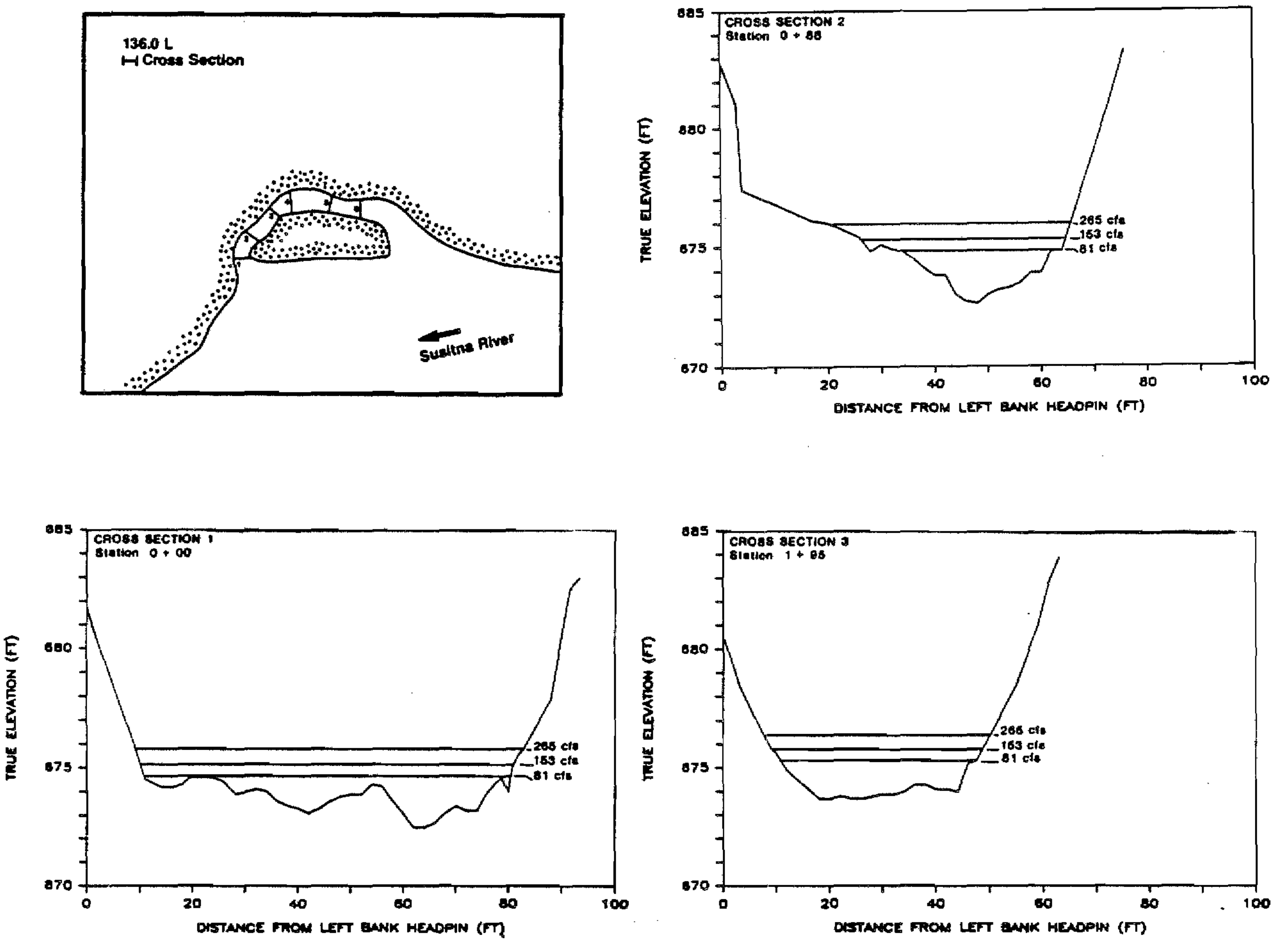


Figure III-37. Cross sections for site 136.0L depicting water surface elevations at calibration discharges of 81, 153 and 265 cfs.

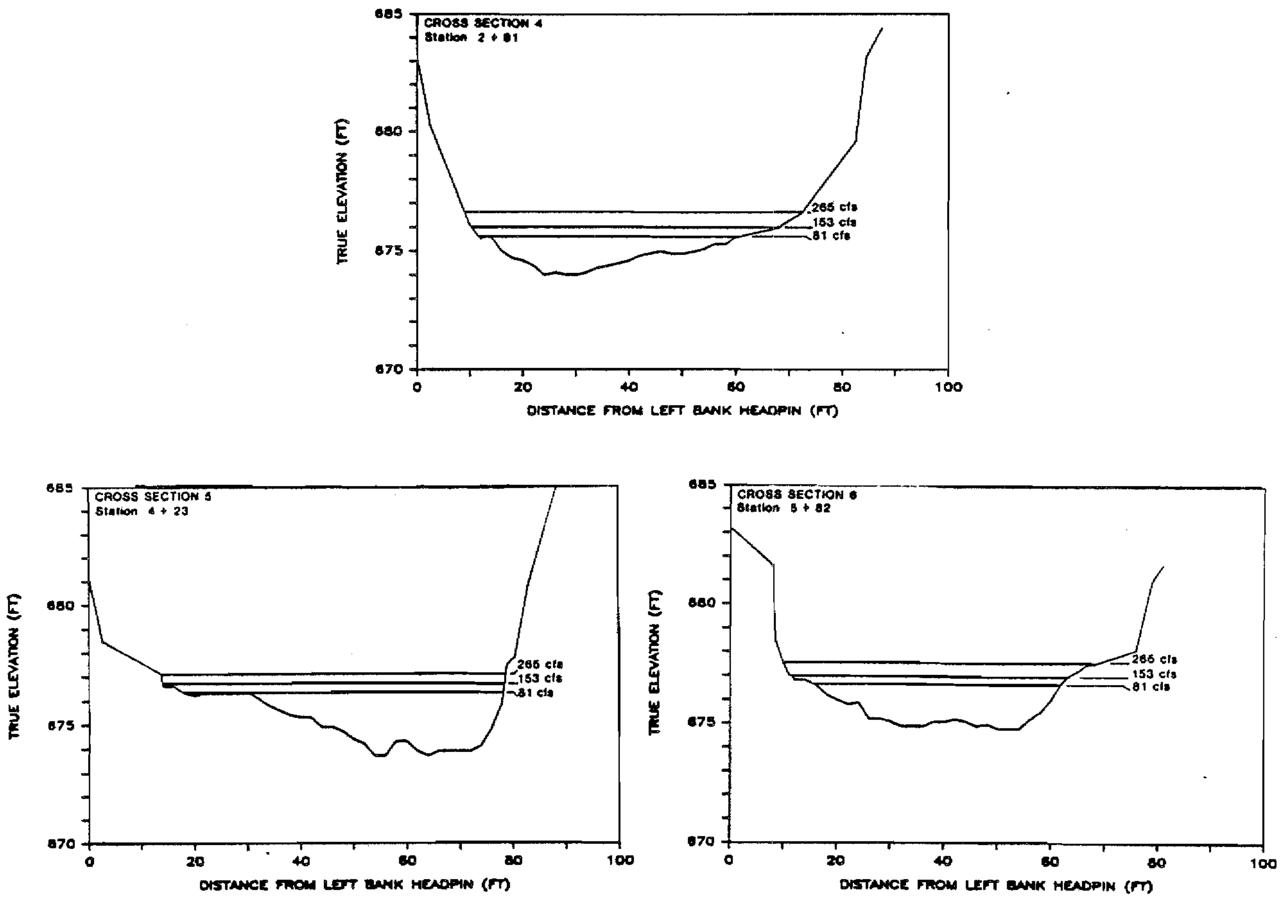


Figure III-37 (Continued).

Table III-11. Hydraulic data available to calibrate the IFG-4 model for site 136.0L.

Date	Site Flow* (cfs)	Mainstem Discharge (cfs)
840909	81	10600
840901	153	12700
840818	265	15600

* Mean site flow

No unique problems were encountered at this site in following the calibration guidelines. Figure III-38 shows the observed and predicted water surface profiles for the calibration flows as well as profiles for the extrapolation limits. To calibrate the IFG-4 model with respect to stage, comparisons were made between the flow-stage curve and the model-predicted stages for the discharge cross section (Figure III-39). Similar comparisons were made for each cross section.

The performance of the calibrated model is evaluated by comparing the observed and predicted stages, discharges and velocity adjustment factors (Table B-4.4). The difference in observed and predicted water surface elevations is 0.02 ft at each flow and each cross section with cross sections 4 and 6 having as much as 0.7 ft difference. The largest difference in observed and predicted discharge is 3 percent. The velocity adjustment factors range from 0.99 to 1.01.

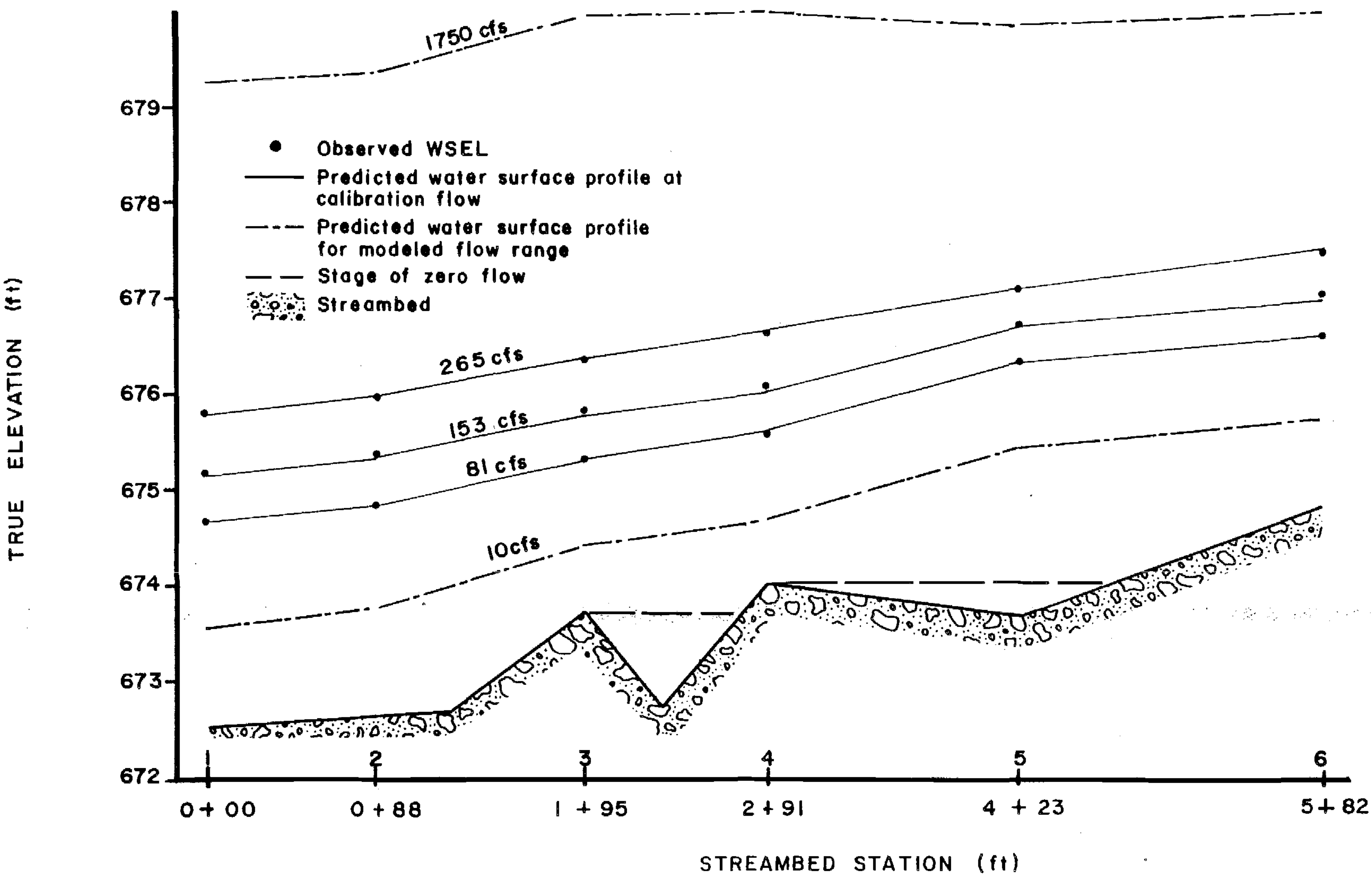


Figure III-38. Comparison of observed and predicted water surface profiles from calibrated model at site 136.0L.

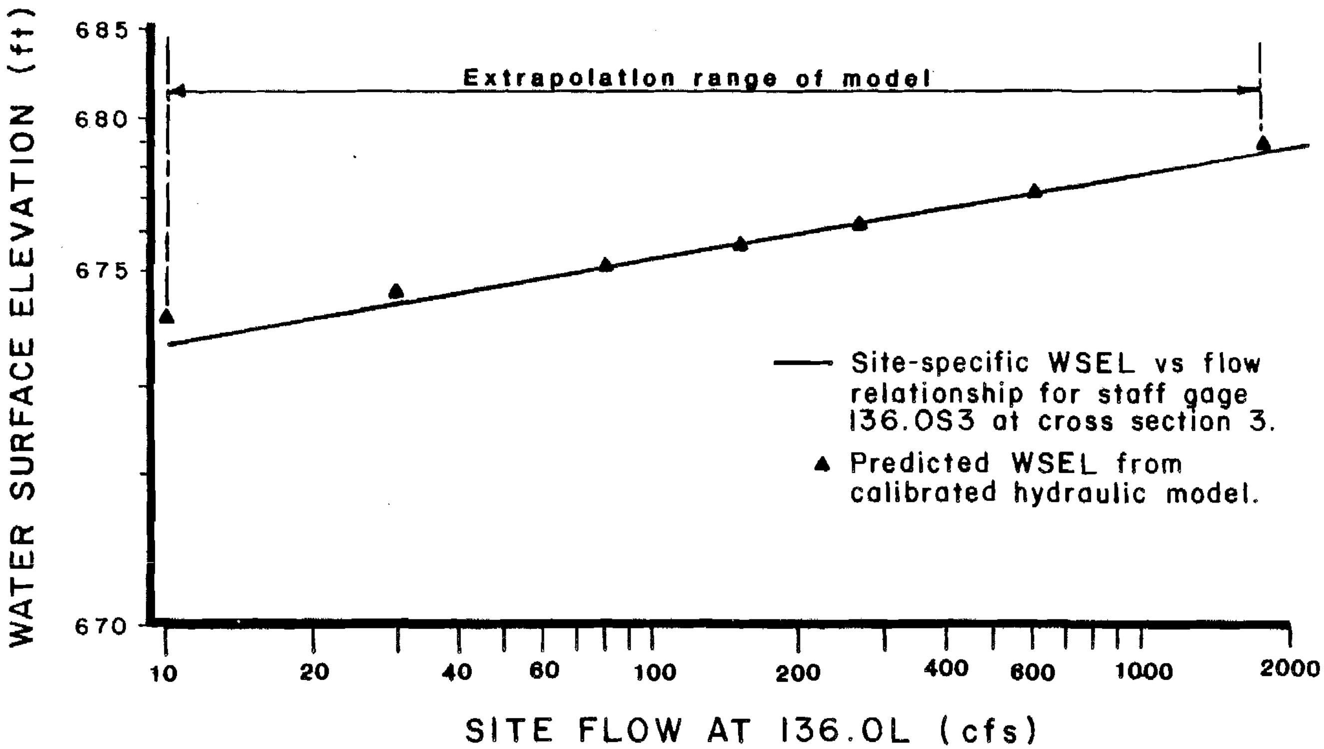
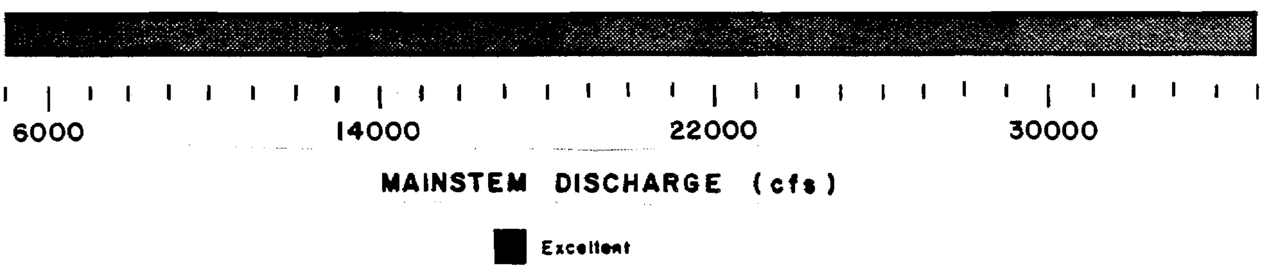


Figure III-39. Comparison between water surface elevations forecast by the calibrated hydraulic model and the stage-flow relationship for 136.0L cross section 4.

Verification: The scatterplots of observed and predicted depths and velocities are shown in Figure B-2.9. There appears to be more scatter in the depths than velocities but a one-to-one relationship can be observed from the plot. The results of the statistical tests are shown in Table B-5. Both depth and velocity comparisons of the $RMSE_U$ are nearly equal to the RMSE (.167 compared to .170 and .157 compared to .165). The index of agreement for both variables is 0.99.

Application: An excellent rating was assigned for site flows of 10 to 1,750 cfs corresponding to 5,000 to 35,000 cfs mainstem, as shown below in the bar chart.



WSA and WUA forecasts are provided for a mainstem discharge between 5,000 and 35,000 cfs (Figure III-40a and b). In the first figure both curves are plotted using a common vertical scale and are expressed in the same units. An eightfold increase in the vertical scale is used with Figure III-40b. Both the WSA and WUA curves for this site were forecast using an IFG-4 hydraulic model calibrated for mainstem discharges ranging from 5,000 to 35,000 cfs.

Five of the six cross sections established at this small, high gradient side channel were located in riffle zones. The channel cross section lacks the gently sloped stream banks and gravel bars associated with other side channels. Consequently, velocities throughout this site tend to exceed those

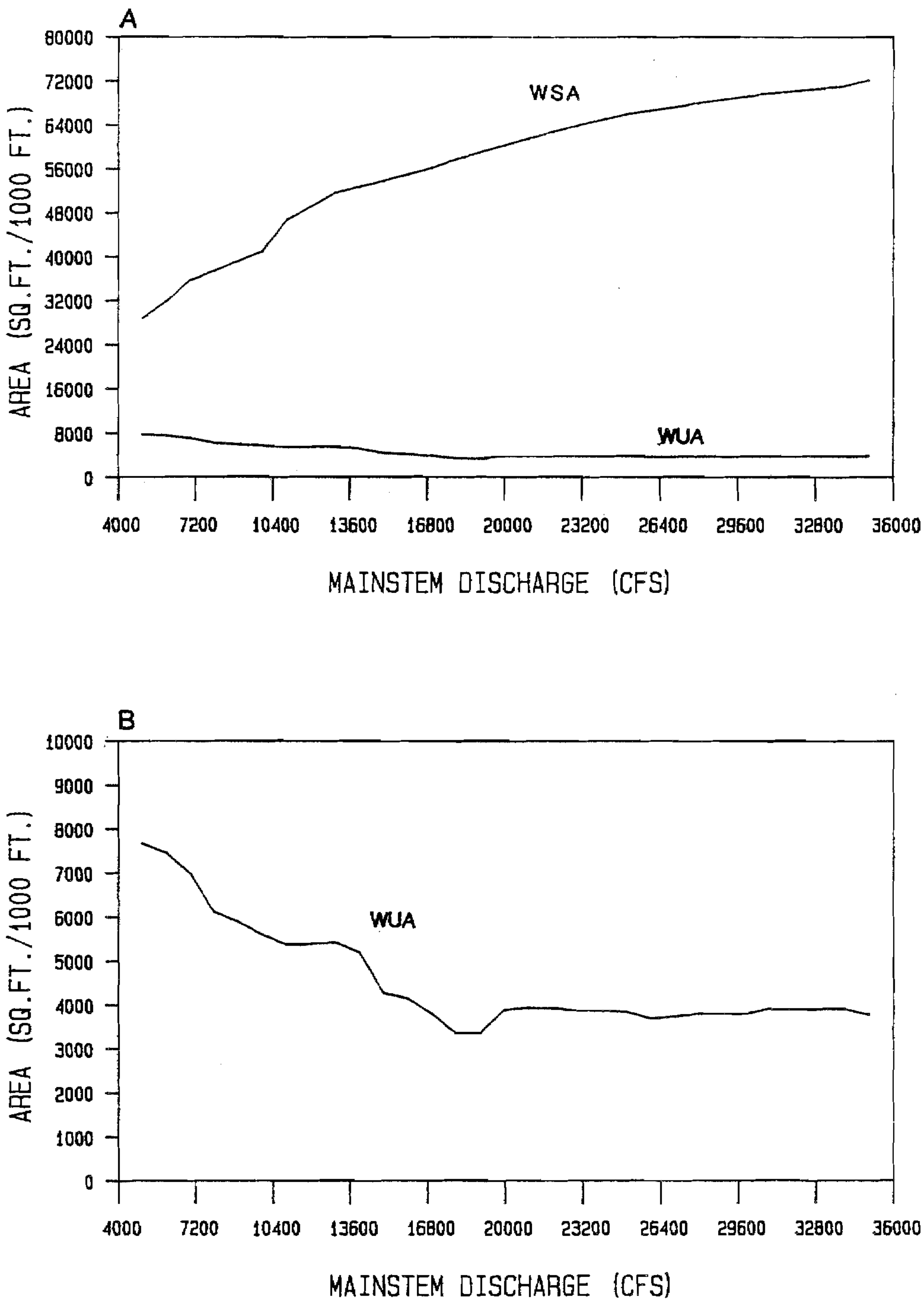


Figure III-40. Surface area and juvenile chinook habitat response curves for site 136.0L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

preferred by juvenile chinook salmon. Hence, the rearing habitat potential steadily decreases between 5,000 and 18,000 cfs, but remains at nearly the same level through 35,000 cfs. This is primarily attributed to the large amount of shoreline debris and undercut banks which exist at this site. When this habitat response curve is compared to WUA curves for other sites, it is apparent that this site provides less rearing habitat on a per 1,000 ft basis than most other side channels. However, because the WSA of this side channel is also small, the proportion of the study site possessing suitable chinook habitat is actually greater than the proportion at some of the larger side channels.

Shoreline debris and undercut banks influence the temporal stability of chinook rearing habitat at this site as shown in the time series plots presented in Figure III-41. Despite the rather erratic pattern of daily site flows, corresponding WUA values are notably stable. Although low early summer and fall streamflows result in an increase in available habitat, this increase is not as pronounced as that which occurs at other side channel sites.

Site 147.1L

Site Description: This site is located on the left of Fat Canoe Island on the west bank of the Susitna River (Plate III-8). The study reach extends the entire length of the site (1,780 ft) and ranges from 350 ft wide at the mouth to 250 ft wide at the head. The substrate is large cobble and boulder with a thick layer of sand along the right bank of the lower three cross sections. The available cover is created by the large substrate. Six cross sections

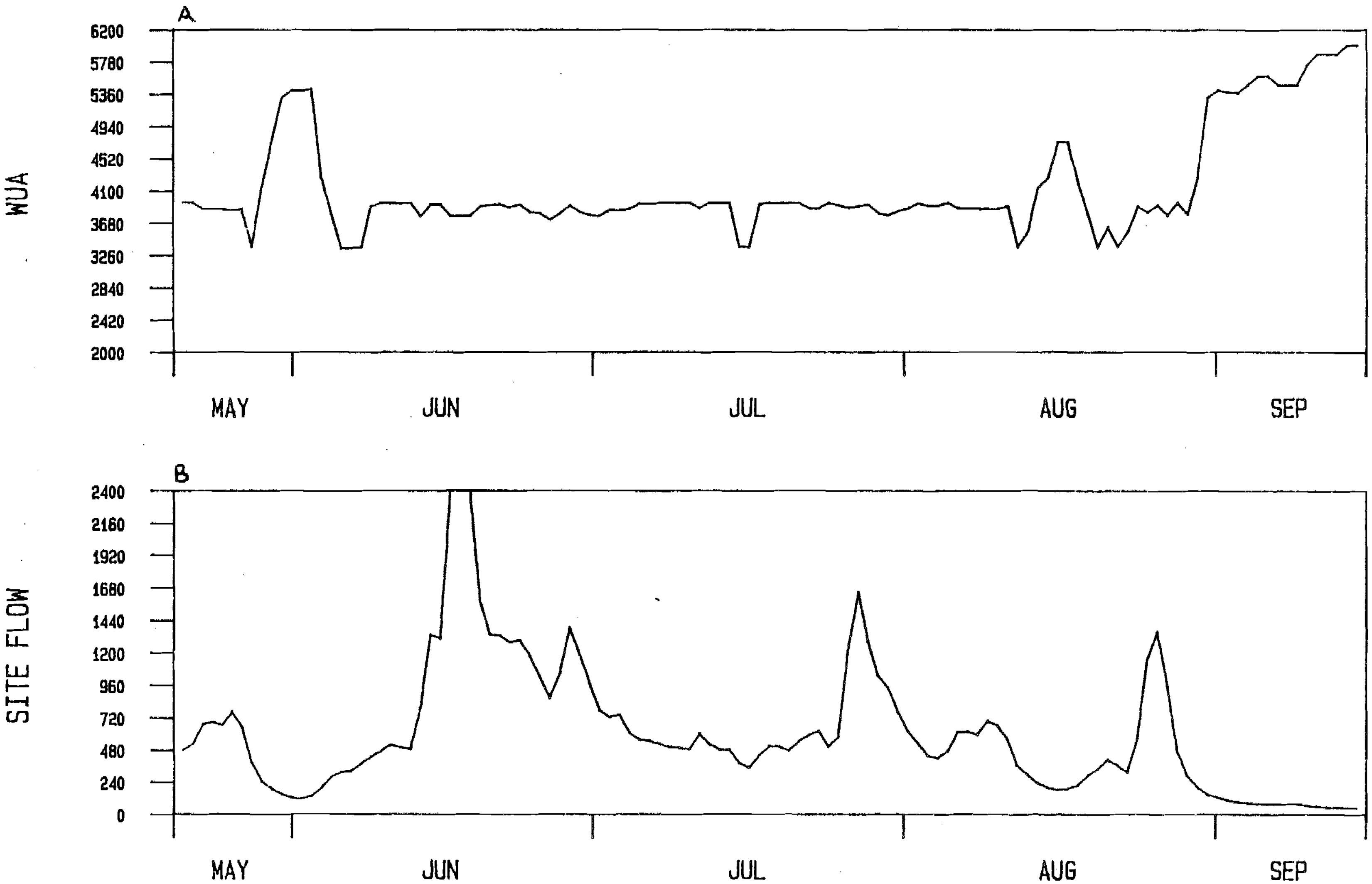


Figure III-41. Time series plots as a function of time for site 136.0L. A - Juvenile chinook WUA. B - Site flow.

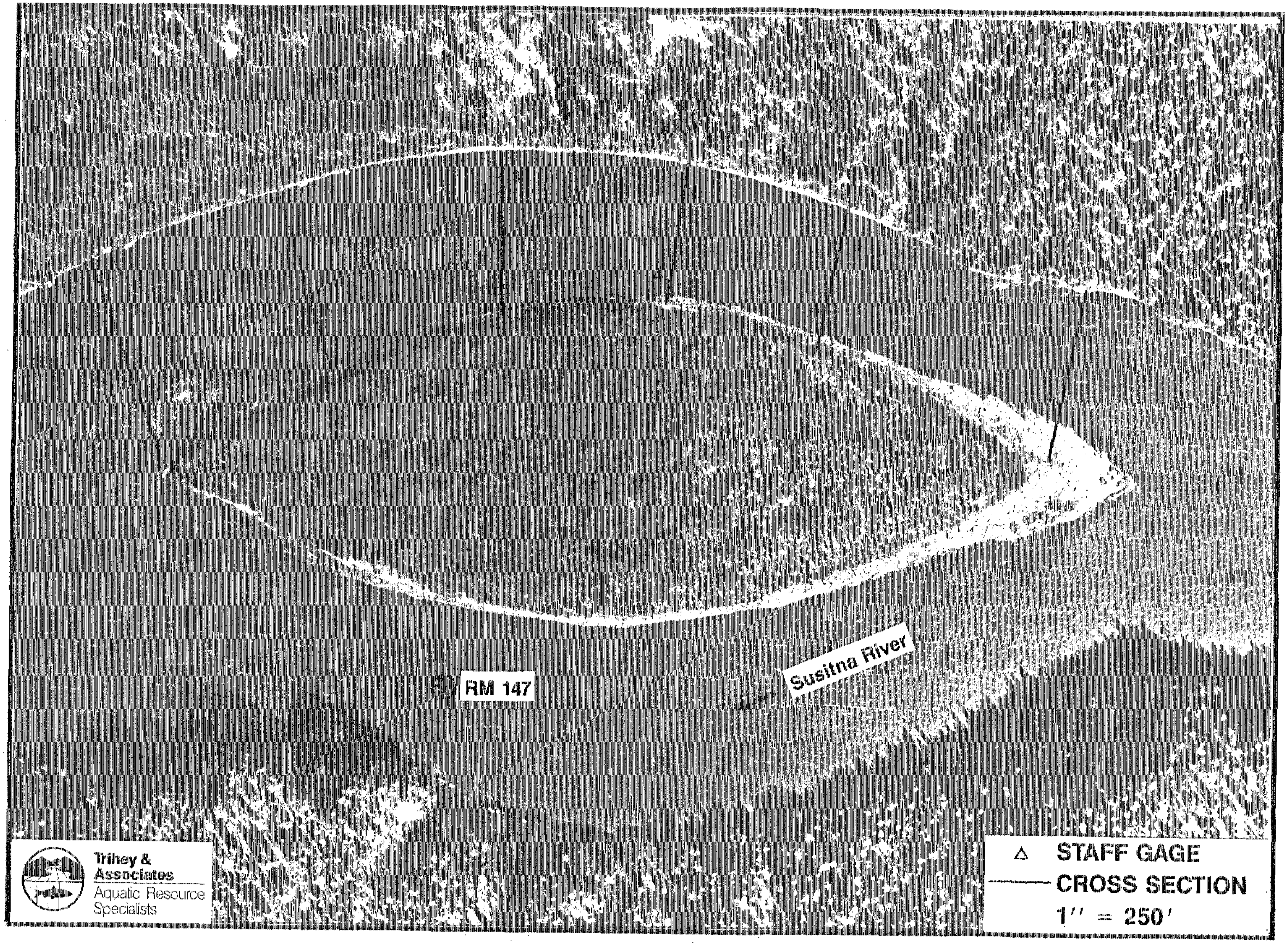


Plate III-8. Modeling site 147.1L on June 1, 1984 at mainstem discharge: 23,000 cfs.

were established in areas with deep, fast velocities in the channel (Figure III-42).

This large study site was selected to represent large side channels that remain side channels at low mainstem discharges. An IFG-2 model was selected because of the large size of the channel and its uniform shape. Previous reconnaissance to the site indicated that rearing habitat was limited to the right streambank margin and a limited amount of data would be required to model this site with an IFG-2 model. Shoreline velocities were collected along both streambank margins.

Calibration: The data available to model the site included level surveys for all six cross sections and the hydraulic data which is summarized in Table III-12.

Table III-12. Hydraulic data available to calibrate the IFG-2 model for site 147.1L.

Date	Site Flow (cfs)	Mainstem Discharge (cfs)	Calibration Cross Sections	Type*
840917	1907	8130	2,4	D
			1,3,5	S
840913	2154	9000	4	D
840907	2650	10,700	1,2,3,4,5,6	S
840829	4742	17,400	5	D
840828	5300	19,000**	1,2,3,4,5,6	S
840821	5600	20,000**	1,2,3,4,5,6	S

* D = Discharge measurements (includes mid channel and shoreline measurements).
S = Shoreline measurements (does not include mid channel measurements)
** = Adjusted to instantaneous discharge

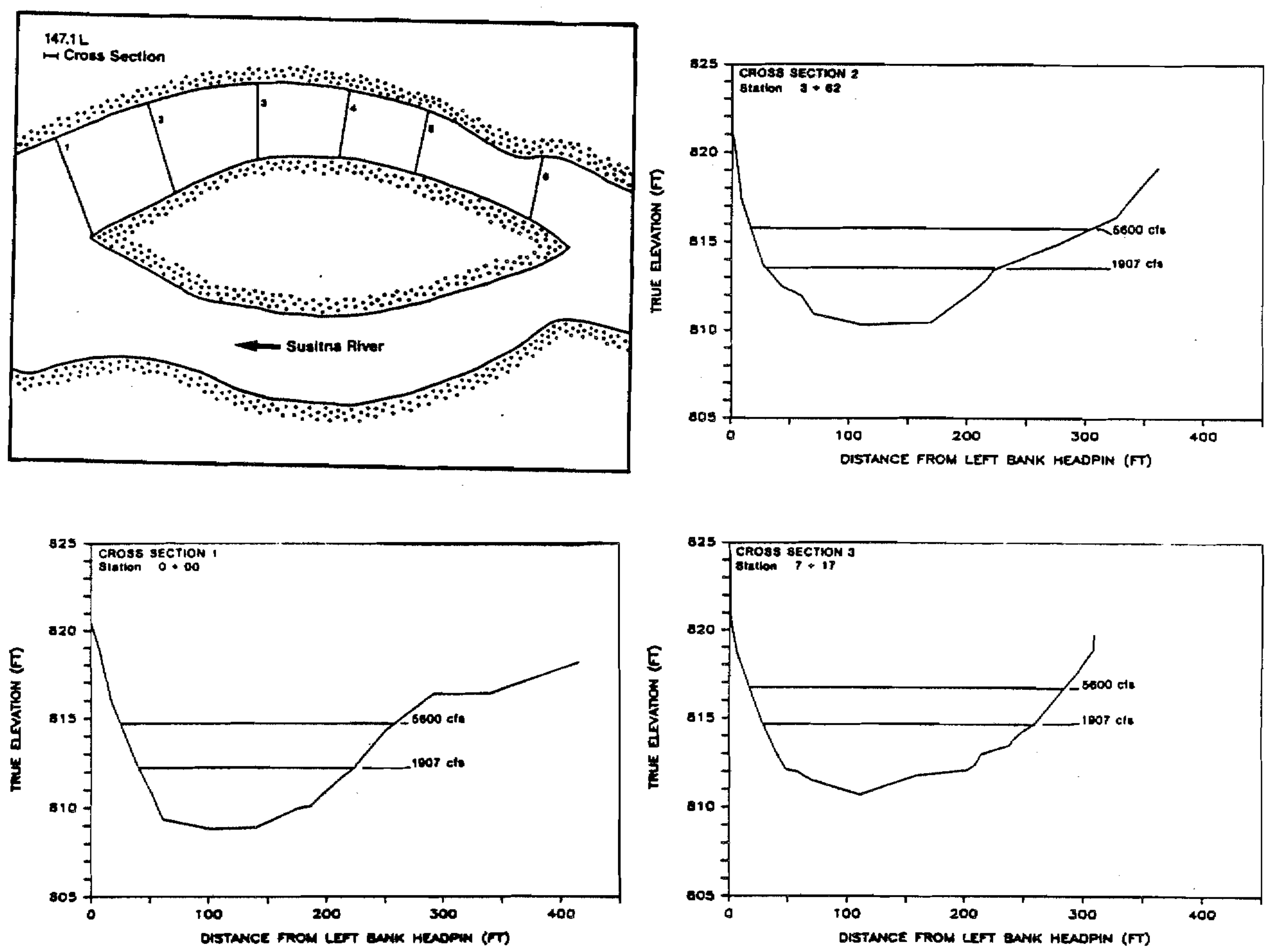


Figure III-42. Cross sections for site 147.1L depicting water surface elevations at calibration discharges of 1860 and 2236 cfs.

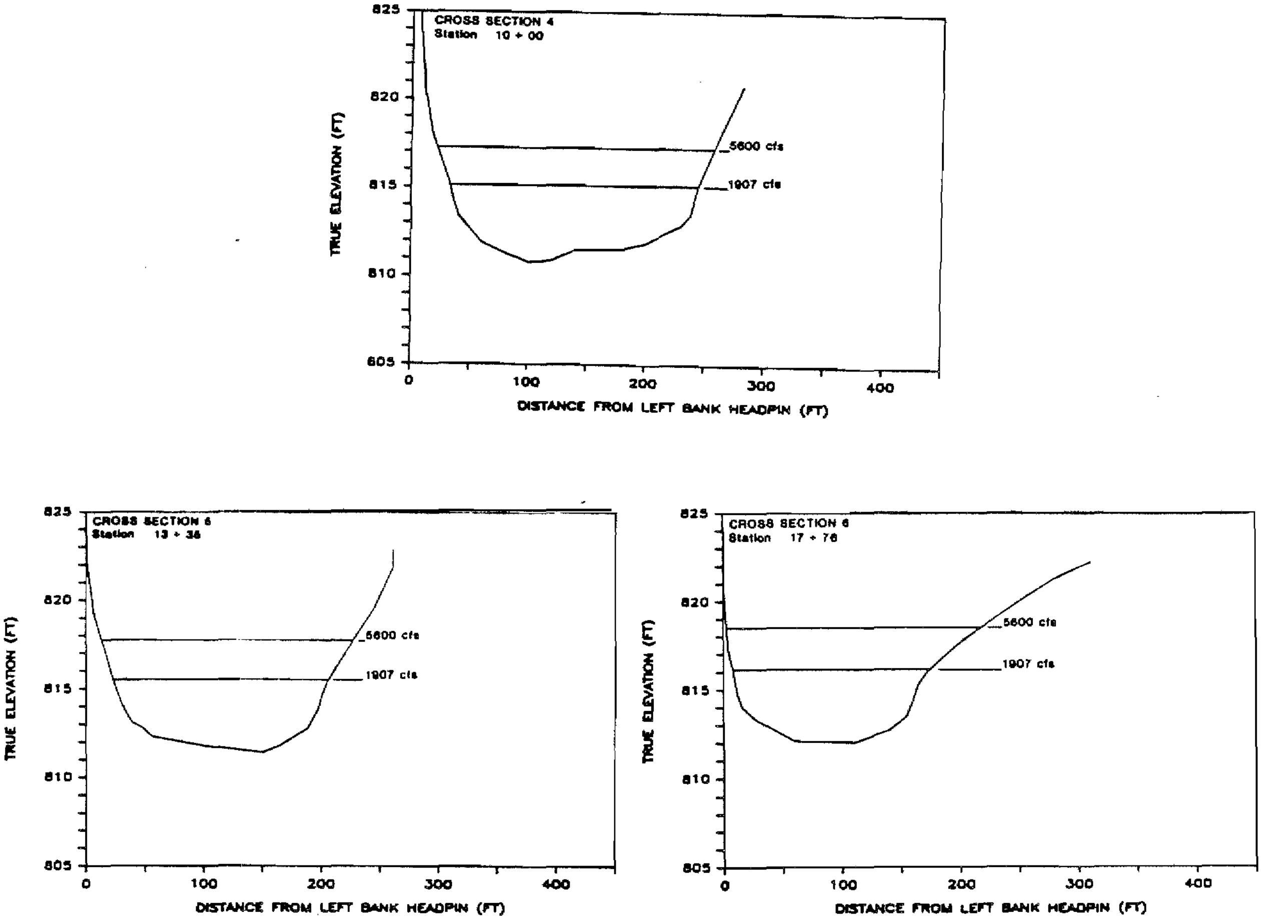


Figure III-42 (Continued).

Two models were required to simulate side channel hydraulics over the mainstem range of 5,000 to 35,000 cfs. This was mainly due to the increasing proportion of side channel conveyance in the shelf area along the right bank at high flows. Velocity profiles were developed at each cross section based on the site flows of 1,907 and 5,600 cfs for the low and high flows hydraulic models, respectively. In calibrating the two models with respect to depth, predicted stages at cross sections 2 through 6 were compared to stages calculated from the stage-discharge curves over a wide range of flows. Figure III-43 shows water surface profiles based on IFG-2 output for the calibration flows of 1,907, 2,154, 2,650, 4,742, and 5,300 cfs, and the flows corresponding to mainstem discharges of 5,000 and 35,000 cfs.

Verification: Figures B-2.9 and B-2.10 show velocity profiles produced by the two IFG-2 models at cross section 2 for calibration flows of 1,907 and 5,600 cfs. The observed velocities for those flows are also plotted. The figures demonstrate that the set of "n" values that produces the proper velocity profile at the low flow does not accurately produce that of the high flow, and vice versa.

Application: The low-flow model represents site conditions for mainstem discharges up to 13,500 cfs, while the high-flow model is applicable for mainstem discharges greater than 13,500 cfs with the breakpoint corresponding to a site flow of 3,500 cfs. Limits for which the models can be considered excellent exceed the range of available stage information, as the models were extrapolated beyond the data range down to 5,000 cfs in the low flow model and up to 35,000 cfs in the high flow model. The overall rating for both models is excellent.

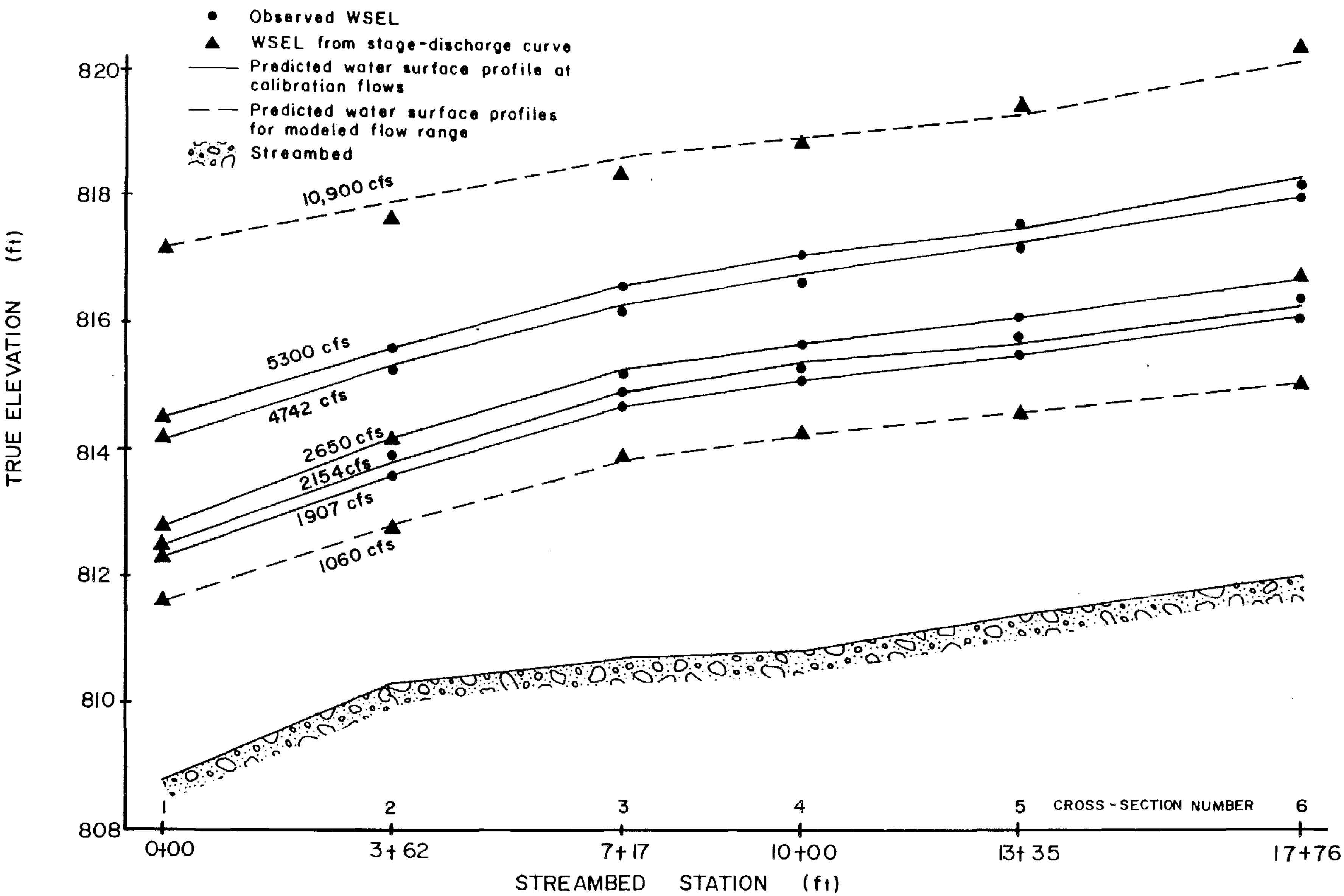
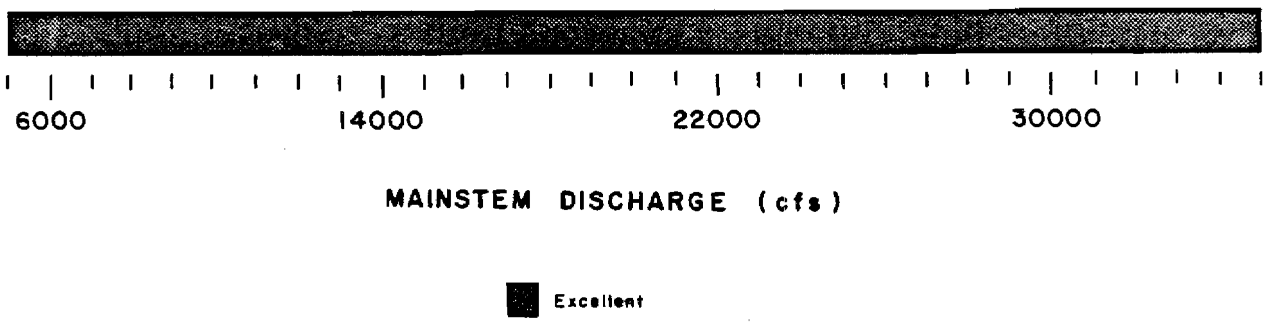


Figure III-43. Comparison of observed and predicted water surface profiles from calibrated model at site 147.L.

The application range and ratings are summarized below in the bar chart.



The WSA and juvenile chinook WUA response functions for this study site, shown in Figure III-44a and b may be considered fairly representative of mainstem areas. The ratio of juvenile chinook WUA to WSA at this site is very low. Williams (1985) demonstrated that suitable rearing areas in large side channels of the middle Susitna River are primarily confined to nearshore zones, due to high (non-suitable) velocities existing elsewhere in the channels. Figure III-44b indicates a slight increase in juvenile chinook WUA with increasing discharge. However, when viewed in perspective with WSA, juvenile chinook WUA may be considered relatively constant between 5,000 and 35,000 cfs.

The WSA and WUA response functions were forecast using the high- and low-flow IFG-2 models previously described and the HABTAT model. Because this large side channel conveys mainstem water at discharges well below 5,000 cfs, the turbid water suitability criteria were used. The separate WUA curves forecast by the high and low flow models were similar within the range of overlap and intersected between 20,000 and 21,000 cfs. Therefore, WUA predicted by the low-flow model was used for discharges of up to 20,500 cfs; above this discharge the high-flow model was used.

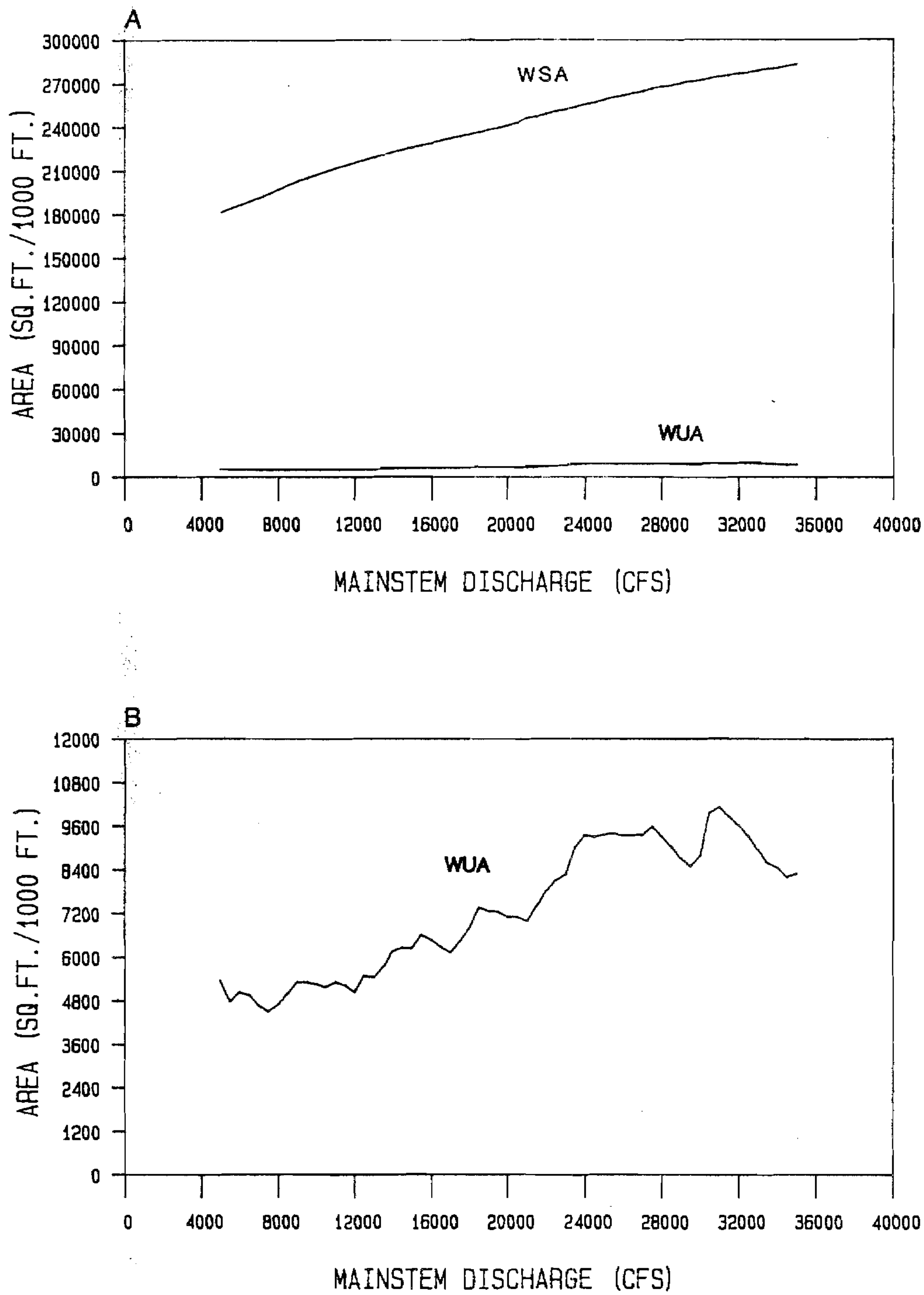


Figure III-44. Surface area and juvenile chinook habitat response curves for site 147.1L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

Because of its large size and low breaching discharge, the site flow hydrograph strongly resembles that for the mainstem throughout the open water season (Figure III-45). The time series plot for juvenile chinook WUA has little response to streamflow fluctuation because of the relatively constant amount of shoreline habitat that exist. A similar time series response is evident for the 136.0L site where rearing habitat is also restricted to shoreline margins because of unsuitable mid-channel velocities.

DISCUSSION

The results of this section show that side channel study areas appeared to have both increasing and decreasing trends in the WUA as a function of mainstem discharge with these areas limited by depths at lower discharges. As discharges increased, the depths became usable. Also, as the velocities exceeded 0.65 fps, the WUA values decreased. The amplitude of the WUA curve was determined by both the amount and quality of cover present within the site.

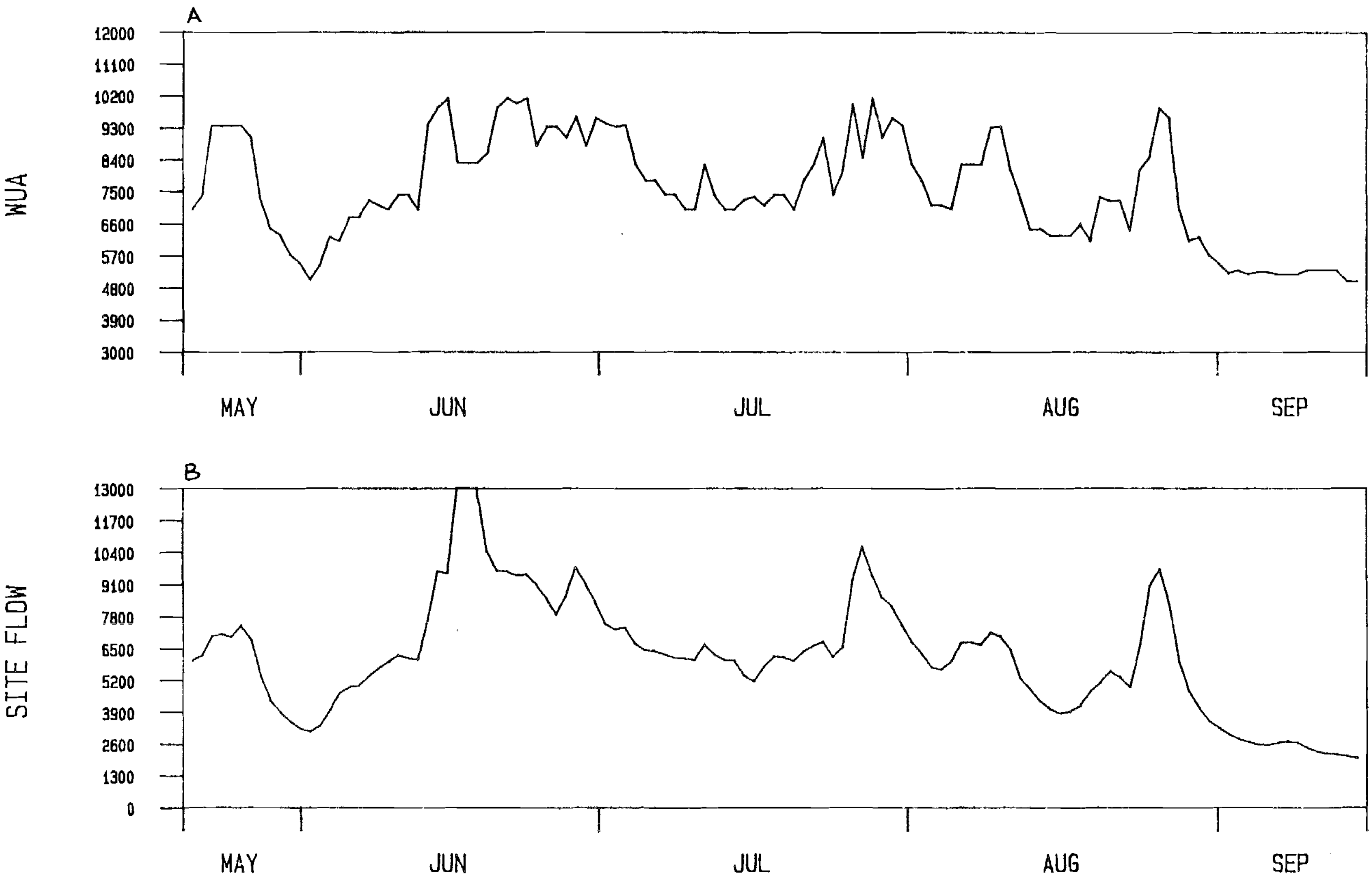


Figure III-45. Time series plots as a function of time for site 147.1L. A - Juvenile chinook WUA. B - Site flow.

PART IV

APPLICATION OF DIRECT INPUT HABITAT MODELS

This section describes the application of the Direct Input Habitat (DIHAB) model at fourteen side channel and mainstem study sites in the middle Susitna River. Chum salmon often spawn in backwater areas or the shoreline margins of side channel and mainstem habitats (Barrett, Thompson, and Wick 1984). Applications of the IFIM hydraulic models, as described in Part III, was not appropriate at the majority of these spawning areas because streamflow conditions were not consistent with the hydraulic theory upon which the IFIM hydraulic models are based.

The IFIM hydraulic models simulate depths and velocities for unobserved streamflows based on the assumption that steady, gradually varied streamflow exists in a rigid channel (Trihey 1979). The DIHAB model was developed by EWT&A as an alternative for calculating the response of chum spawning habitat to incremental changes in mainstem discharge at those sites where steady, gradually varied flow did not exist.

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

The influence streamflow variations may have on spawning habitat is generally evaluated using three microhabitat variables: depth, velocity and substrate. However, upwelling groundwater is also considered important for successful chum salmon spawning in the middle Susitna River habitats (ADF&G 1984b). Of the four microhabitat variables used in the modeling processes, upwelling appears to be the most important variable influencing the selection of redd sites by spawning chum salmon (Trihey et al. 1985). Because of this strong preference, a binary criterion was used in the DIHAB model for this microhabitat variable. The habitat suitability criterion for upwelling assumes optimal suitability for areas with upwelling and non-suitability for areas without upwelling. Habitat suitability criteria for the other microhabitat variables are based on field observations and data obtained in the middle Susitna River habitats by ADF&G Su Hydro (Estes and Vincent-Lang, eds. 1984) as described by Steward 1985.

Fourteen sites were chosen for detailed study from among the 50 candidate study ares to represent three types of habitat: 1) side channel areas influenced by backwater, 2) side channel areas not influenced by backwater, and 3) mainstem margin areas (Table IV-1, Figure III-1). Spawning chum salmon were reported at six of these areas, by ADF&G SU Hydro (ADF&G Su Hydro 1981; ADF&G Su Hydro 1983a; Barrett, Thompson, and Wick 1984) with the other eight sites suspected of upwelling; however spawning chum salmon had not been reported at these sites prior to 1984 (Table IV-2).

Table IV-1. Forty-three candidate areas for side channel and mainstem chum spawning evaluation.

Specific Area	Spawning Reported	Model	Specific Area	Spawning Reported	Model
100.6 R	1981, 1983		128.7 R	1982	
100.7 R			129.4 R	1981, 1982	
101.2 R		IFG-4	130.2 R	1981	DIHAB
101.7 L		DIHAB	131.3 L	1981	DIHAB
105.2 R			131.7 L	1982, 1983	IFG-4
105.81L		DIHAB	133.8 L		IFG-4
110.4 L			133.8 R		DIHAB
112.6 L		IFG-2	134.9 R		IFG-2
113.8 R		IFG-2	136.3 R	1981, 1982, 1983	IFG-4
114.1 R		DIHAB	136.8 RMS	1983	
115.0 R	1982, 1983	DIHAB	137.5 R	1982	DIHAB
115.6 R			138.0 L		
115.9 LNR			138.71L		DIHAB
117.8 L			139.01L	1982, 1983	DIHAB
118.91LMS	1983	DIHAB	139.41L		DIHAB
119.11LMS		DIAHB	139.7 R		
119.3 L			140.2 R	1981, 1982, 1983	
119.5 L			141.2 R		
124.0 L			141.4 R[1]	1981, 1982, 1983	IFG-4
125.2 R	1981, 1983		142.0 R		
125.1 R			148.2 M	1982	No open lead
127.1 M					

[1] Side Channel 21 identified as side slough spawning escapement in ADF&G reports.

Table IV-2. 1984 middle river spawning study areas.

Site	Reported Spawning	Type of Study Site: Back Water	Mainstem Margin	Side Channel
101.7 L	No	X		
105.8 L	No		X	
114.1 R	No			X
115.0 R	1982, 1983			X
118.9 L	1983		X	
119.1 L	No		X	
125.2 R	No			X
130.2 R	1981, 1982			X
131.3 L	1981, 1982			X
133.8 R	No		X	
137.5 R	1982	X		
138.7 L	No		X	
139.0 L	1982, 1983		X	
139.4 L	No			X

In this report, WUA for spawning chum salmon is provided at twelve modeling sites for a range of mainstem discharge from 5,100 to 25,000 cfs. WUA forecasts are not presented for two modeling sites at which upwelling was not observed and which were not utilized by spawning chum salmon. Site-specific time series plots of WUA are also provided based on average daily streamflows of the Susitna River throughout the 1984 spawning season (August 12 to September 15).

FIELD PROCEDURES

Field data included water depth and velocity measurements, substrate and cover descriptions, observations of upwelling, fish utilization and streambed profile surveys.

Depth and Velocity: Procedures followed for measuring depth and velocity were similar to those used in measuring discharges at the IFG model sites (Part III). Depth and velocity data were collected along cross sections established perpendicular to flow over one to five mainstem discharges (usually 3) from 4,300 to 31,700 cfs. A minimum of 10 verticals (cells) were measured for each data set. Verticals were referenced by horizontal distance from left bank streambed marker. Depth of water, mean column velocity (6/10ths of the depth beneath the water surface) and nose velocity (0.4 ft above the streambed when the depth was greater than 1 ft) measurements were collected until depths or velocities were unsafe for the field personnel. In addition, upstream and downstream distances of the representative habitat were estimated for each cross section. Extrapolation for depths and velocities were also made beyond the last measured vertical based on habitat conditions.

Substrate and Cover: Substrate type was visually assessed to determine mean particle size and was coded using criteria in Table III-2. Cover type and percent of site were coded using criteria in Table III-3. Water clarity (turbid or clear) was also noted.

Upwelling: Presence of upwelling was determined at the DIHAB study sites using the combination of the following data sources: 1) field observations during the 1984 open-water season, 2) two winter field reconnaissance trips in 1985, 3) winter temperature data for site-specific intragravel water compared to mainstem surface water, and 4) location of chum salmon redds. The relative extent and strength of upwelling areas within a study site were determined during the winter reconnaissance field trip with suspected upwelling areas confirmed if site intragravel temperature were significantly warmer than surface waters of the mainstem. Since chum salmon selectively utilize areas of upwelling for spawning, for the purpose of this study, areas of observed active spawning and redd locations were assigned a "slight" strength of upwelling.

Upwelling areas were sketched on aerial photographs and field notes and referenced to cross section or identifiable land marks. The extent of the upwelling was measured and the strength recorded as slight, moderate or strong, based on visual observations. Table IV-3 gives the criteria used to determine the strength of upwelling. Figure IV-1 is an example of a map that summarizes the upwelling data for study site 131.3L.

Table IV-3. Criteria used to determine the strength of upwelling.

STRENGTH OF UPWELLING	CRITERIA
SLIGHT	Areas within open thermal leads where less than 20 percent of the area was affected by upwelling or detectable bank seepage. Areas where upwelling was observed during the open water season or indicated by intragravel temperature data but produced no open thermal leads during the winter observations. Areas where chum salmon were actively spawning or redds were identified during the open water season.
MODERATE	Areas in open thermal leads where 20 to 79 percent of the area was affected by upwelling or obvious bank seepage.
STRONG	Areas in open thermal leads during winter observations where 80 percent or more of the area was affected by upwelling or bank seepage or flowing water.

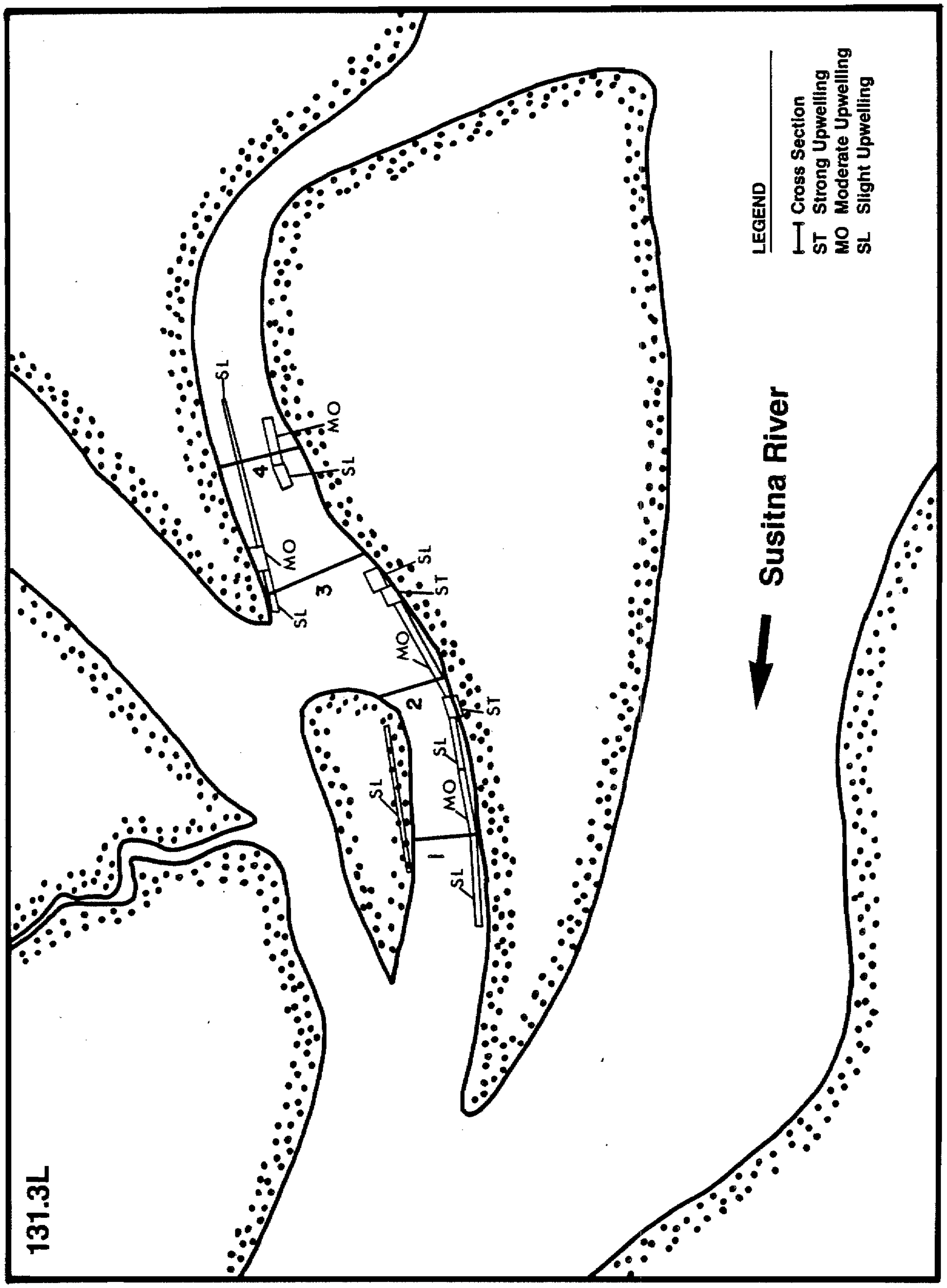


Figure IV-1. Summary location of upwelling areas at DIHAB modeling site 131.3L.

Fish Utilization: Fish utilization data was recorded in the field by observation of presence, location, life stage, number of fish and species information.

Streambed Profile Surveys: Streambed profile surveys were completed for six of the study sites in the side channel and backwater areas using procedures described in the ADF&G Su Hydro Procedures Manual (1984). The results of the surveys are presented in Figures C-1.1 through 1.6 and Tables C-1.1 through 1.7.

INPUT REQUIREMENTS OF DIHAB MODEL

Input data required by DIHAB are mainstem discharge, stage, water depth, velocity, substrate type, and upwelling information at each x-coordinate. Suitability criteria for spawning chum salmon developed for the middle Susitna River were used to assign habitat value to each cell. Reach lengths associated with the representativeness of the hydraulic conditions at each cross section were determined based on field estimates and aerial photography interpretation. These lengths were used to extend the cross section up and downstream an appropriate distance.

Mainstem Discharge: For each data set, average daily streamflows for the Susitna River were obtained from the USGS Gold Creek gaging station. Mainstem discharges were correlated from these to changes in physical habitat.

Stage: Stages for each cross section were determined from stage-discharge curves developed at each study site (Part II). Normally, one stage-discharge curve per study site was sufficient to determine stage. Stages at cross sections within study areas were approximately the same for any given mainstem discharge due to gentle gradients and relatively short reaches between cross sections. At five study areas, as many as three stage-discharge curves were developed to account for differences in stage between cross sections.

Depth and Velocity: Depth and velocity values were assigned to each cell by direct measurement or estimation. To expedite field data collection, it was necessary to interpolate (skip unnecessary measurements) and extrapolate (use field observation) some depth and velocity values in each data set. In addition, direct field measurements of depth and velocity were not always measured at each cell because of the uniformity of the hydraulics along a cross section. All depths were used to calculate streambed profiles by subtracting depth from stage at each cross section for each discharge. An average elevation was determined for each cell in the cross section (Tables C-2.1 through C-2.14. At mainstem margin sites, the last velocity measurement was extended further into the mainstem to the end of the cross section. Although the velocities were greater further into the mainstem, the effect on WUA was negligible since little or no upwelling was recorded in these areas and the 0.05 suitability index was assigned to these typically high velocities (2.5 - 3.0 fps). Interpolated and extrapolated depth and velocity values are listed in Tables C-3.1 through C-3.14.

Substrate and cover: Substrate and cover codes for each cell are presented in Tables C-3.1 through C-3.14.

Upwelling Information: A suitability index value of 0.0 was entered for cells where there was no upwelling. Slight, moderate and strong upwelling were coded as 1, 2 and 3 to assist in future analysis. For purposes of this report all three strengths are assigned a suitability value of 1.0 to be consistent with binary criteria used in previous studies (Estes and Vincent-Lang, eds. 1984c).

The x-coordinates bounding upwelling areas were estimated by reviewing aerial photography, cross section profiles and lengths of effective areas associated with each cell were estimated from field observations. For example, at cross section 3 slight upwelling was estimated to occur from x-coordinates 48 to 54 ft with an effective length of 20 ft. At the same cross section, moderate upwelling was estimated to occur from x-coordinates 54 to 60 ft with an effective length of 175 ft. Table C-4 summarizes upwelling surface areas and strengths for the DIHAB modeling sites. Table C-5 is an example input data check for the DIHAB model at site 131.3L.

Habitat Suitability Criteria: Habitat suitability criteria curves for spawning chum salmon have been identified for the middle Susitna River and are presented in Figures IV-2 through IV-4.

OUTPUT OF THE DIHAB MODEL (Weighted Usable and Wetted Surface Area Curves)

Output of the DIHAB model includes WSA and WUA values with corresponding mainstem discharge. Summaries of DIHAB output for each study area are presented in Table C-6. Procedures to develop WUA and WSA curves are presented below.

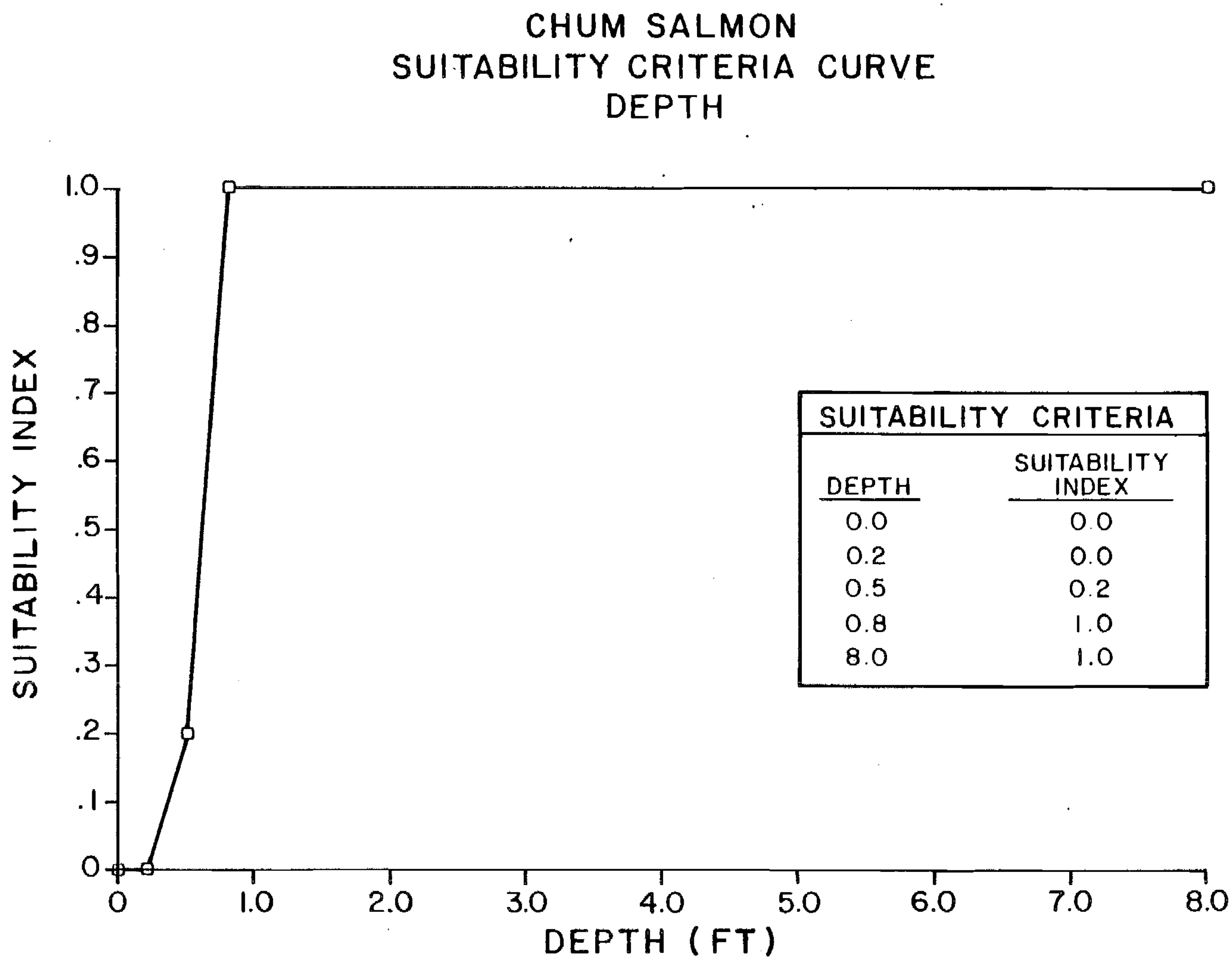
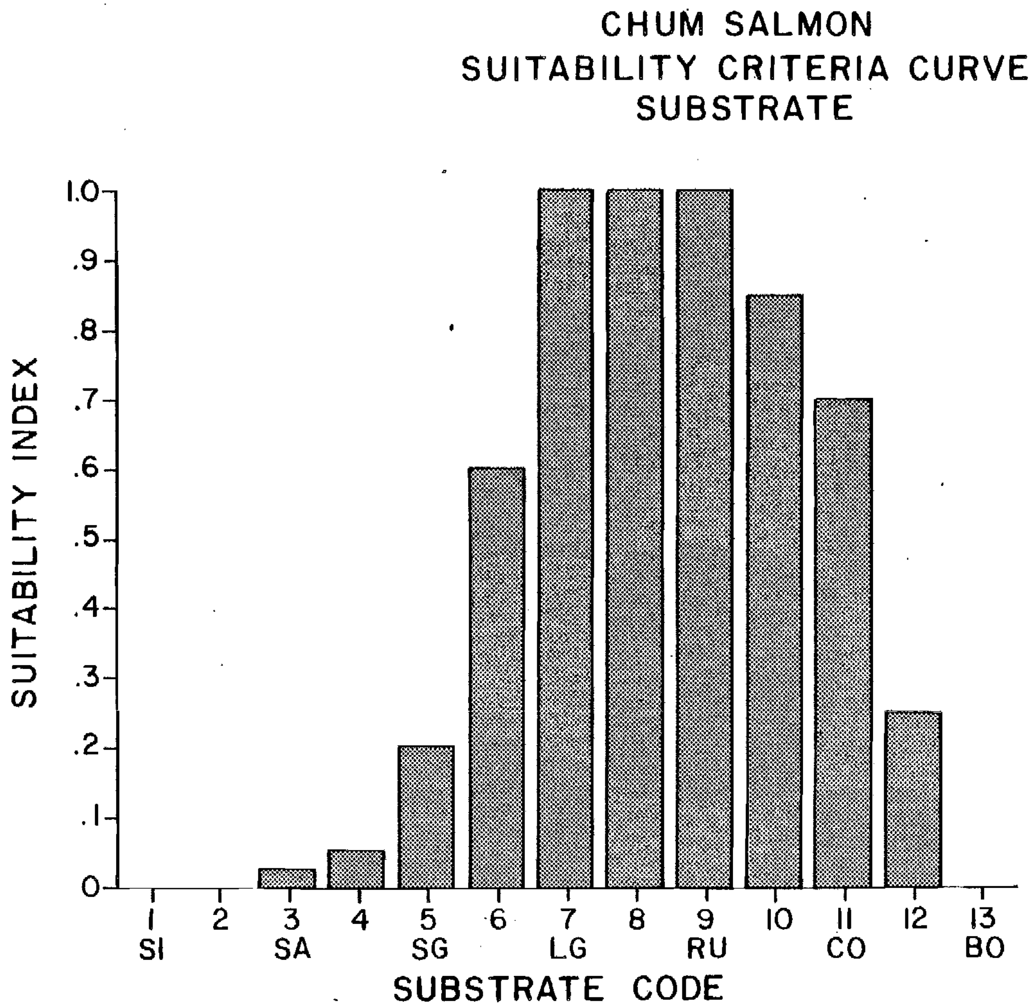


Figure IV-2. Spawning chum salmon suitability criteria for depth. Source: Estes and Vincent-Lang 1984.



SUITABILITY CRITERIA

SUBSTRATE CODE		PARTICLE SIZE	SUITABILITY INDEX
1	SI	SILT	0.00
2			0.00
3	SA	SAND	0.025
4			0.05
5	SG	1/8 - 1"	0.20
6			0.60
7	LG	1-3"	1.00
8			1.00
9	RU	3-9"	1.00
10			0.85
11	CO	5-10"	0.70
12			0.25
13	BO	>10"	0.00

Figure IV-3. Spawning chum salmon suitability criteria for velocity. Source: Estes and Vincent-Lang 1984.

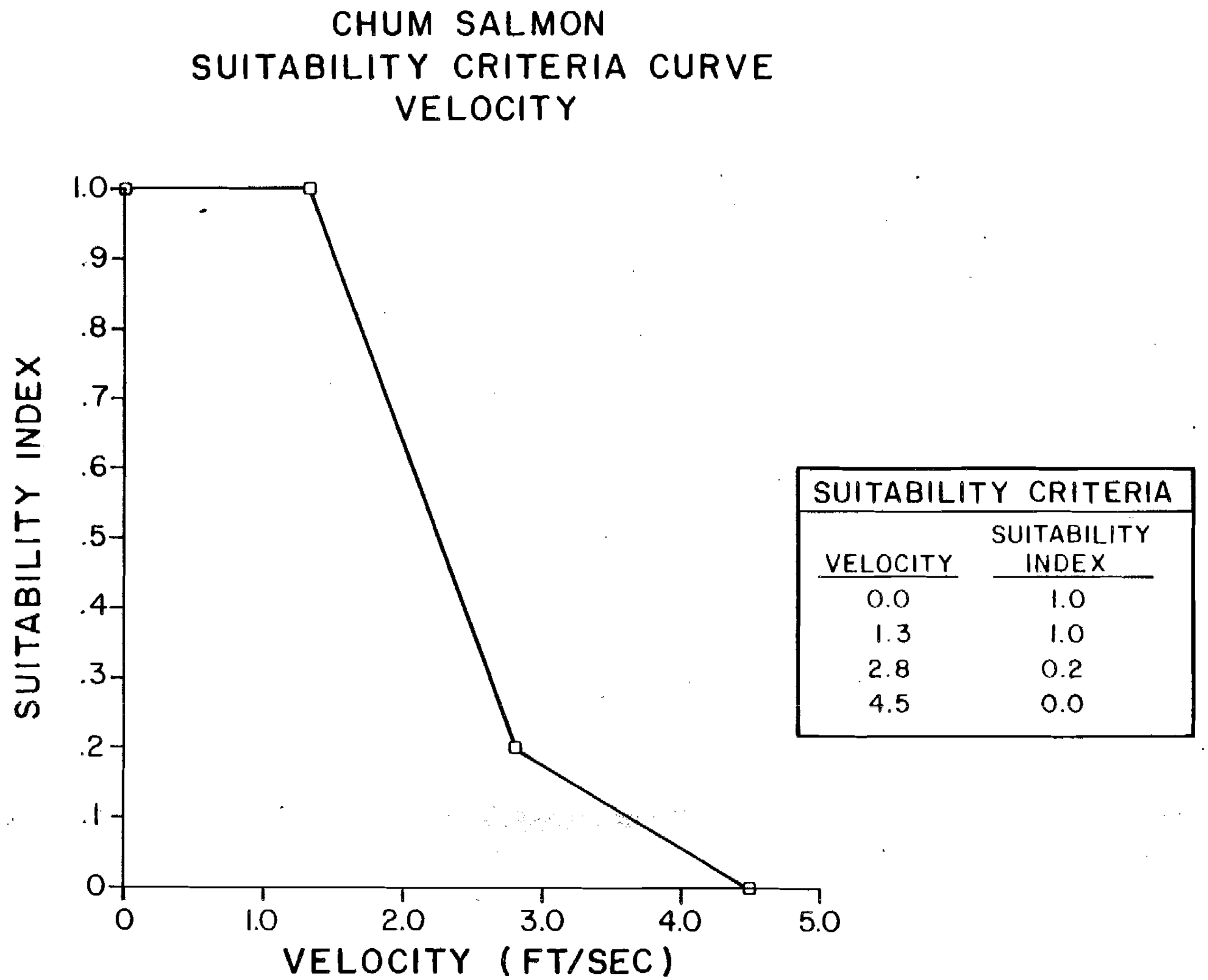


Figure IV-4. Spawning chum salmon suitability criteria for substrate. Estes and Vincent-Lang 1984.

Weighted Usable Area Curves: Plots of WUA values as a function of mainstem discharge were made for the period of the study using DIHAB output for each study area. Curves were developed assuming linearity between plotted values. The WUA values were generally available for mainstem discharges ranging from 7,600 to 18,000 cfs.

The chum salmon spawning season has been identified as August 12 to September 15 (EWT&A and WCC 1985). During this period, mainstem discharge generally ranges from 5,000 to 25,000 cfs. To extend the curves to describe this flow range, it was necessary to develop additional WUA values. These were calculated using stage-discharge curves, cross sections and measured velocity data.

Where data gaps occurred, estimated stages were determined for additional mainstem discharges (Q_A) using the stage-discharge curves developed for each study area (Part II). Water depths corresponding to Q_A were determined by subtracting streambed elevations at each cross section from extrapolated stages. In this manner, simulated depths were determined for each cell.

To obtain velocities for each cell at additional mainstem discharges, the following linear relationship was used:

$$V_A = \frac{Q_A}{Q_M} V_M$$

where:

V_A = cell velocity, in fps of additional discharge

Q_A = mainstem discharge in cfs of an additional data set

Q_M = mainstem discharge in cfs of a measured data set with similar hydraulic condition similar to Q_A

V_M = measured cell velocity in fps

Estimated cell depths and velocities were combined with substrate and upwelling codes and cell areas to calculate WUA using the standard calculation procedure identified by Milhous, Wenger, and Waddle (1984). Habitat response curves were plotted for discharges ranging from 5,000 to 25,000 using WUA values based on measured and simulated values.

Wetted Surface Area Curves: Plots of WSA values as a function of mainstem discharge were made for each study area. These curves were developed similarly to the habitat response curves and are based on the same measured and simulated data sets. Insufficient cross section information was available to calculate WSA for Q_A greater than the highest Q_M. For each cross section, wetted top width was determined by projecting the stage for each cross section. Surface areas were calculated for each cross section as the product of wetted top width and reach length. By summing the surface areas associated with each cross section, the WSA was determined for each Q_A.

Time Series Curves: Plots of WUA and mainstem discharge as a function of time were made for the period from August 12 to September 15, 1984 using mean daily mainstem discharges for each study site. These curves are valuable to evaluate changes in habitat during the spawning period.

DIHAB MODEL RESULTS

The following section provides a description of important physical habitat components found in each of the DIHAB model sites and anticipated with-project changes in these components with respect to different mainstem discharges. WSA, WUA curves and time series plots of WUA are presented at 12 of the 14 study sites corresponding to a range of mainstem discharges from 5,000 to 25,000 cfs. Two of the study sites had no confirmed upwelling and therefore no WUA values are presented. Limited fish utilization observations are also included.

Site 101.7L

Site Description: This site is located about 0.5 miles upstream of the mouth of Whiskers Slough on the west bank of the Susitna River (Plate IV-1). The study reach is 2,450 ft long and 150 ft wide. The substrate is predominately cobble and rubble with a thick over layer of silt and sand in the upper half of the site. Three cross sections were established to describe the shallow, low velocity backwater area in the upper two-thirds of the study site with a fourth cross section placed to describe the deeper, fast flowing channel at the lower end of the study site (Figure IV-5).

The sparsely vegetated gravel bar located at the upper end of this site (Plate IV-1) is overtopped at mainstem discharges greater than 23,000 cfs. At discharges greater than 9,600 cfs, the gravel bar which separates the channel from the mainstem is overtopped and directs flow into the channel.

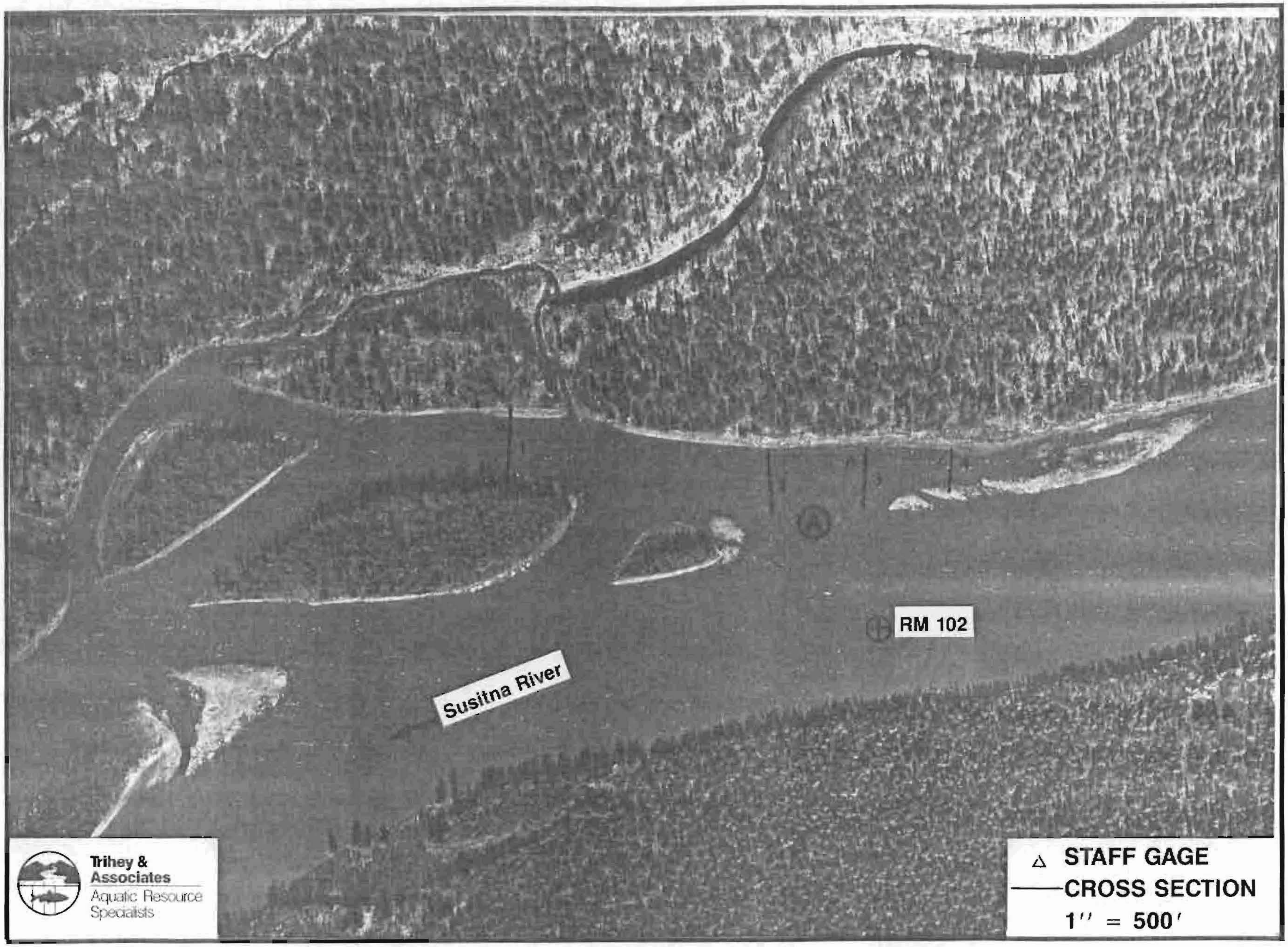


Plate IV-1. Modeling site 101.7L on June 1, 1982 at mainstem discharge: 23,000 cfs.

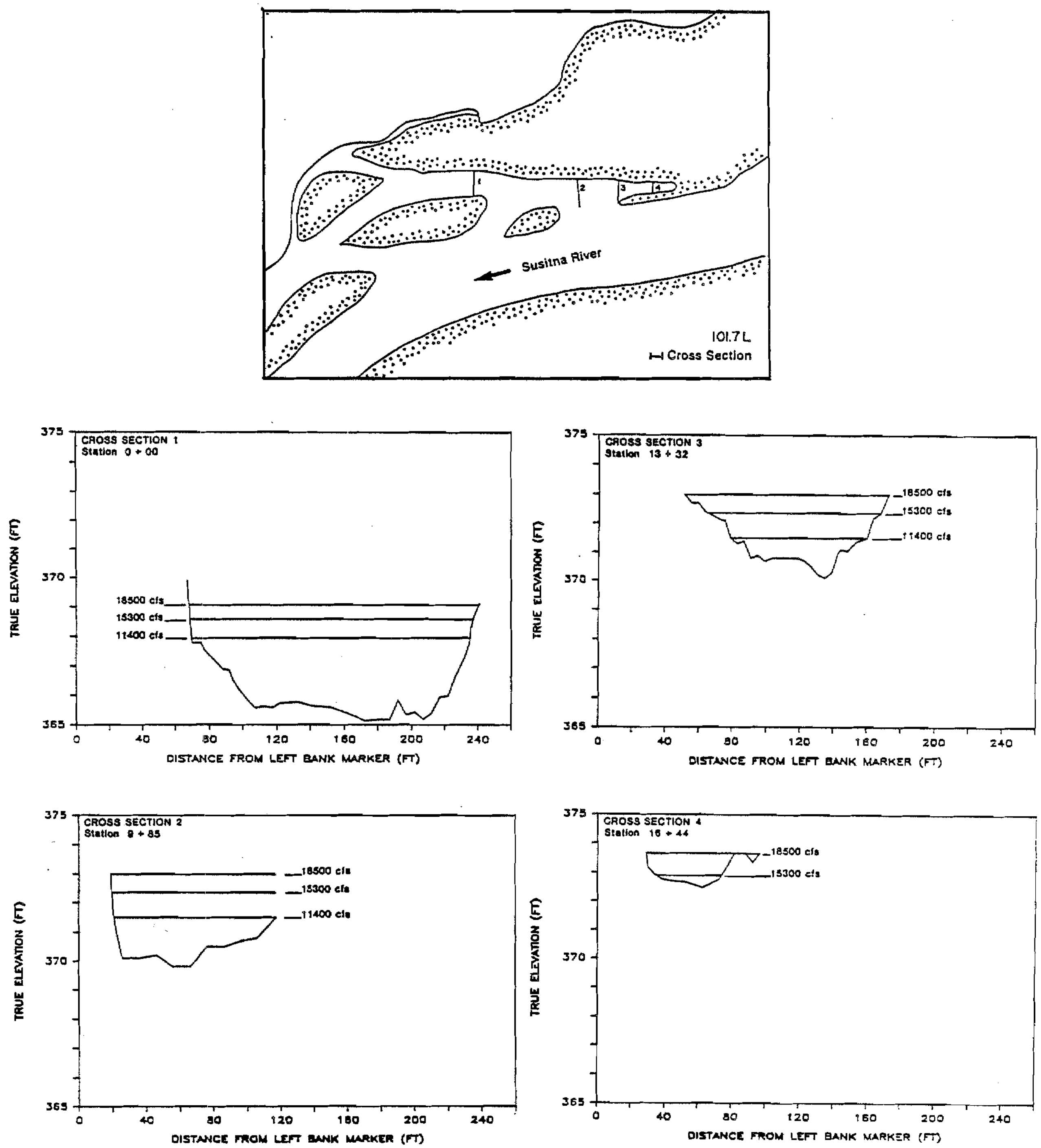


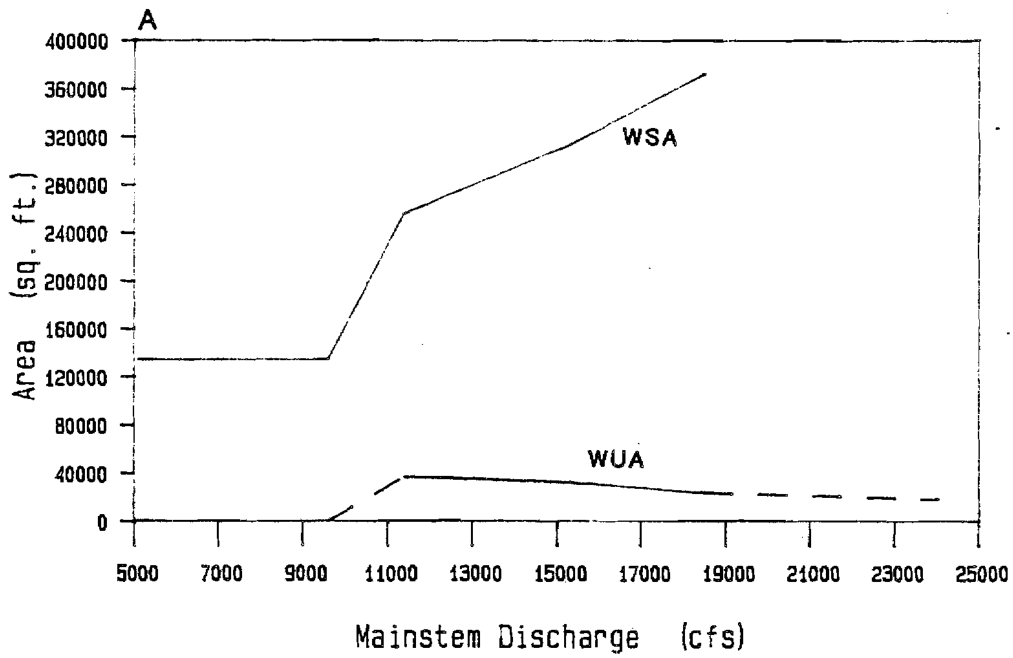
Figure IV-5. Cross sections for site 101.7L depicting water surface elevations at discharges of 11,400, 15,300 and 18,500 cfs.

This backwater site was selected for study because of a substantial amount of upwelling was suspected, but no utilization by spawning chum salmon was recorded (Hoffman 1985). Upwelling was observed in varying strengths upstream of cross section one throughout the study site. During winter, warm ground water influences created an open lead downstream of cross section 1.

Spawning Habitat: The WSA and WUA curves are provided in Figure IV-6a for this site. Figure IV-6b is plotted at an expanded vertical scale to emphasize the response of WUA discharge.

The range of depth and velocity measurements extended from 11,400 to 18,500 cfs and a backwater area is present from cross section 1 to 2 at mainstem discharges below 9,600 cfs. Upwelling was observed at the upper two cross sections but, is too shallow to be utilized by spawning chum salmon. Above 9,600 cfs, the gravel bar along the right side of the channel is overtopped. The areas that were previously too shallow to support spawning are no longer limiting. As the mainstem discharge increases, the velocities in the upwelling areas increase, which in turn decreases the usable habitat.

Because the range of mainstem discharges (11,400 to 18,500 cfs) for which site-specific depth and velocities were measured was so small, additional simulated data sets were developed for discharges of 5,100 and 24,000 cfs using aerial photography and data obtained from streambed surveys. To determine the WSA at 5,100 cfs, the wetted area digitized from enlarged aerial photographs at mainstem discharges of 5,100 and 7,400 cfs were determined to be the same. This was an indication that the total WSA throughout the study



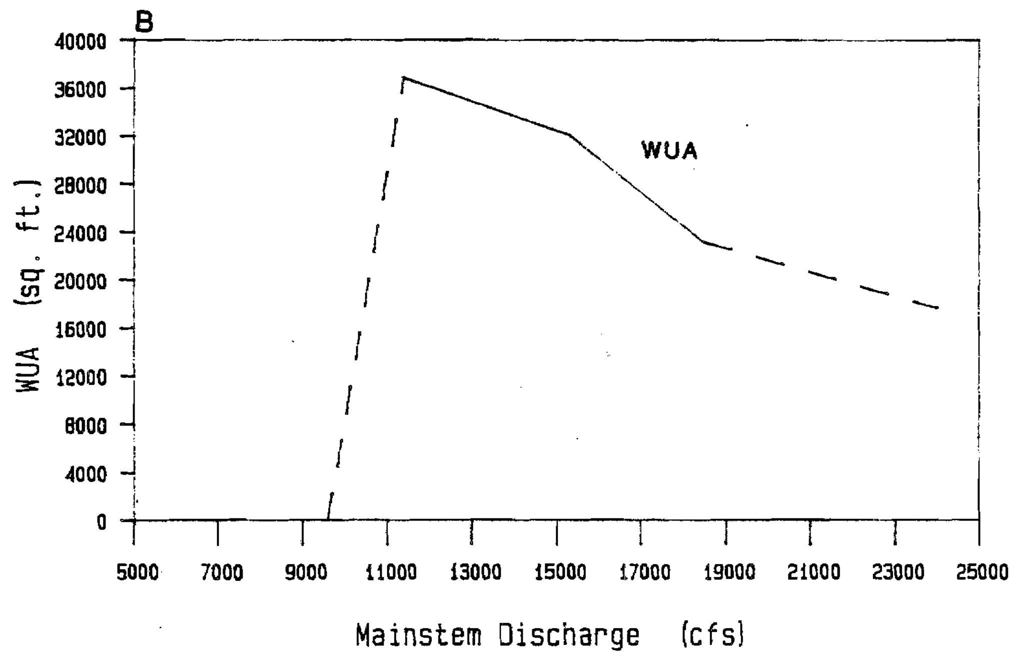


Figure IV-6. Surface area and spawning chum habitat response curves for site 101.7L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

reach remains constant in unbreached conditions (mainstem discharges less than 9,600 cfs). Stages measured in the streambed profile survey, completed in unbreached conditions were used in conjunction with the cross section elevations to determine the depth of flow in the upwelling areas. These depths did not exceed 0.2 ft, therefore the WUA at unbreached conditions was assigned a zero value.

The stage-discharge curves for the site (Part II) were used to develop a data set at 24,000 cfs which corresponded with an August 10 site visit when the upstream berm (Channel A, Plate IV-1) was overtopped and the backwater area was a flowing channel. Due to the influence of this high velocity, the WUA index decreased at higher discharges. This agrees with the habitat response curves for other side channel sites in the middle Susitna River. The WUA curve was therefore, extended to 25,000 cfs to encompass the desired range of discharges. Actual WUA values used to plot this curve are presented in Table C-6. Time series plots of WUA and average daily mainstem discharge are presented in Figure IV-7.

Site 105.8L

Site Description: This study site is located approximately 2 miles upstream of Talkeetna Camp on the west bank of the Susitna River (Plate IV-2). The study area is 1,000 ft long and located along the mainstem margin. Large boulders are predominate throughout the site. Four cross sections were established to describe the mainstem margin (Figure IV-8).

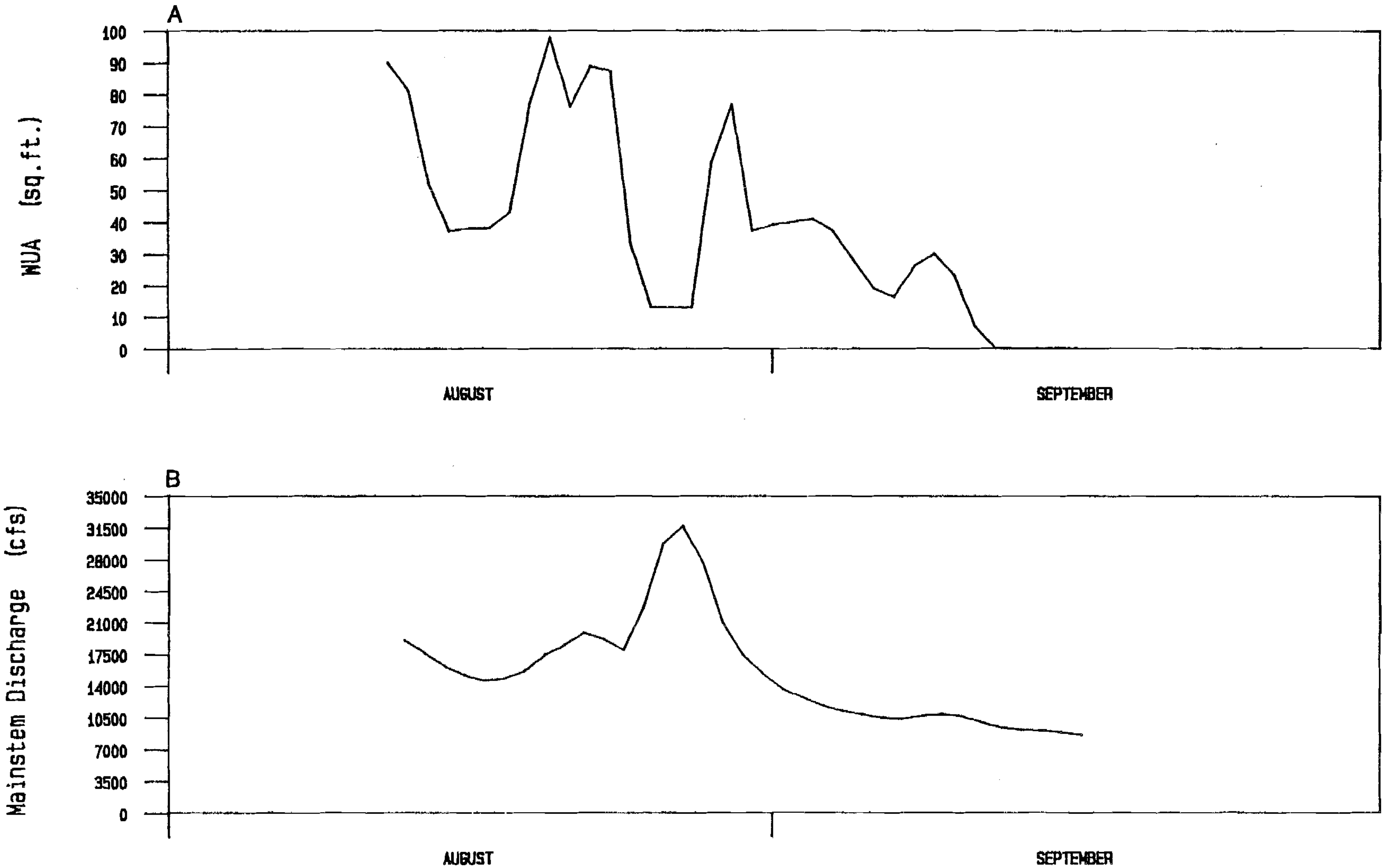


Figure IV-7. Time series plots as a function of time for site 101.7L. A - Spawning chum WUA. B - Mainstem discharge.

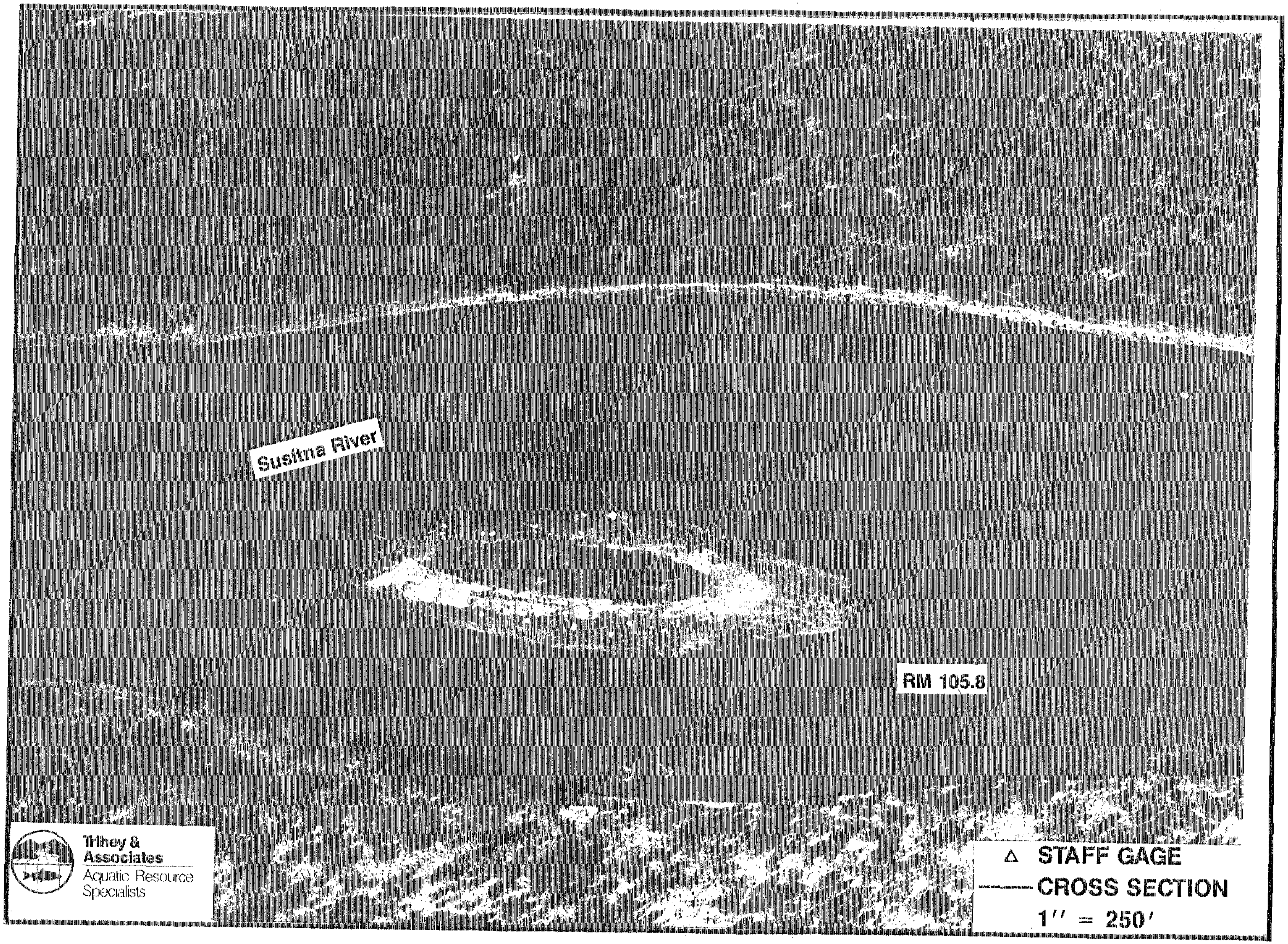


Plate IV-2. Modeling site 105.8L on June 1, 1982 at mainstem discharge: 23,000 cfs.

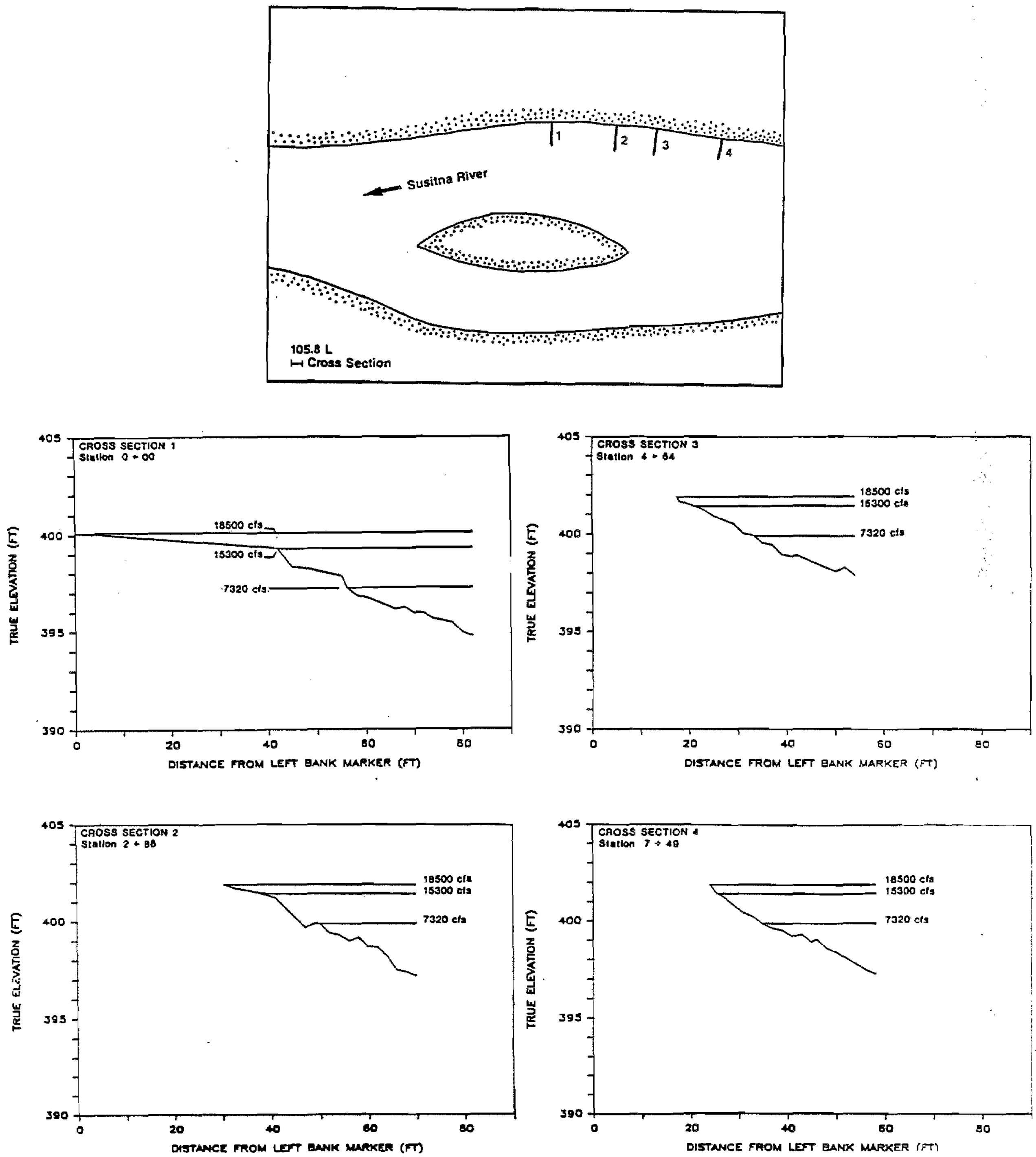


Figure IV-8. Cross sections for site 105.8L depicting water surface elevations at discharges of 7,320, 15,300 and 18,500 cfs.

This mainstem margin study site was selected because of the assumed presence of upwelling, although chum salmon spawning had not been reported prior to 1984. Open thermal leads in the ice were recorded in the 1983 winter photography and during our winter reconnaissance visits. Upwelling and bank seepage was identified throughout the study area with the upwelling strength decreasing to moderate above cross section 3. No spawning or juvenile salmon were observed at the site in 1984 (Hoffman 1985).

Spawning Habitat: The WUA response curves shown in Figure IV-9a are plotted with WSA and WUA at the same scale. Figure IV-9b provides a plot of the habitat response curve at an expanded vertical scale.

Data sets were collected at 7,320, 15,300 and 18,500 cfs. The stage-discharge curve presented in Part II of this report indicates that the stage response to mainstem discharge throughout this range of discharges remains constant up to a 24,000 cfs. Bank seepage was observed along the channel margins. The substrate throughout the site is generally too large to be used by spawning chum, explaining the small amplitude of the habitat response curve. The depths over the upwelling areas, however, are sufficient for spawning at discharges above 7,000 cfs. An increase in mainstem discharge causes the velocities at the upwelling areas to increase above the range for spawning thereby decreasing WUA with increasing discharge.

Additional data sets were developed for mainstem discharges of 5,100 and 24,000 cfs. The latter discharge corresponds to conditions observed during a trip to the study site on August 10. Stage-discharge curves for cross

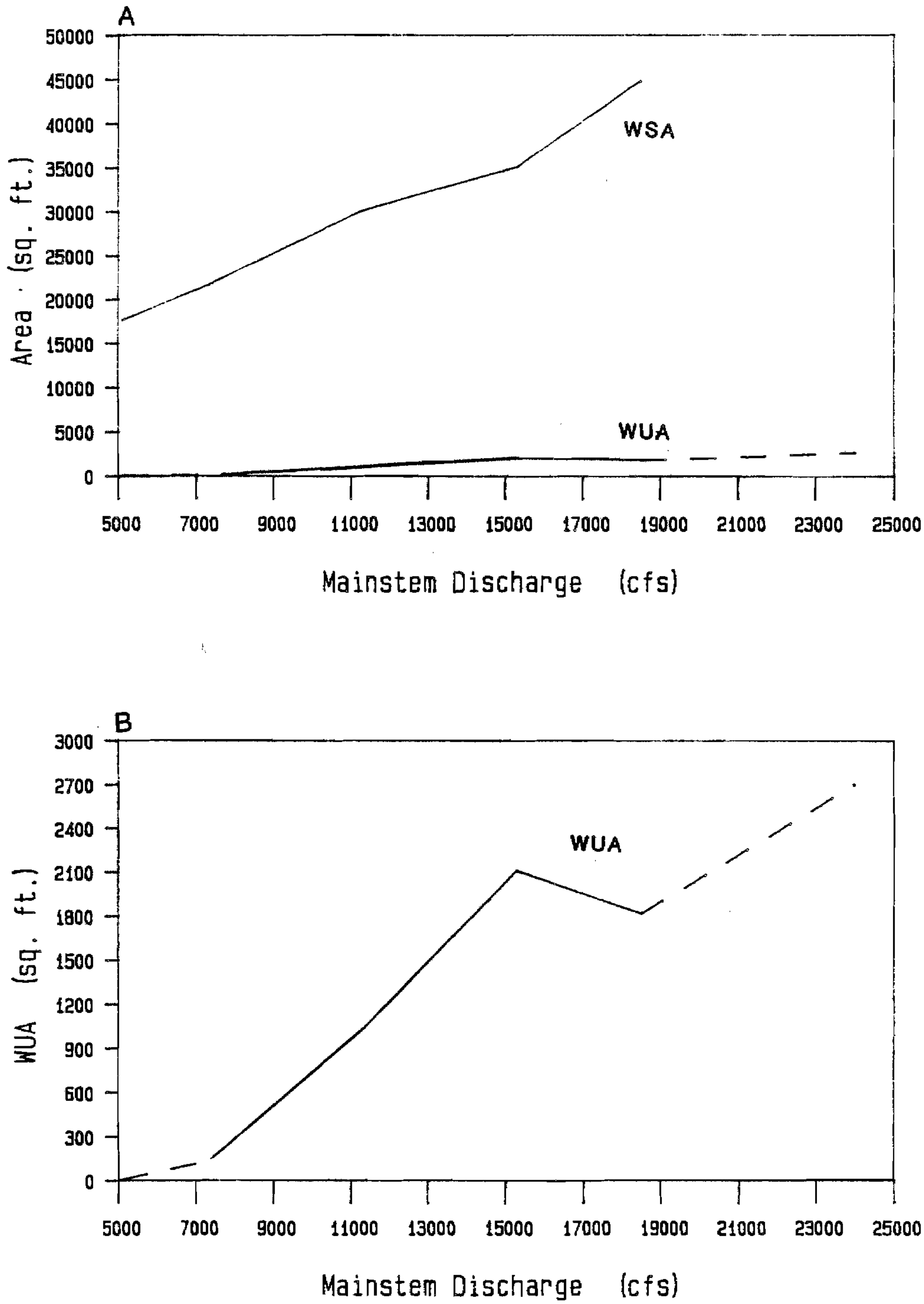


Figure IV-9. Surface area and spawning chum habitat response curves for site 105.8L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

sections 1 and 4 were used to determine the stages at both discharges. Nearly all the upwelling area had estimated depths of less than 0.2 ft at the 5,100 cfs flow level. Thus, the WUA rapidly decreases from 7,320 cfs to 5,100 cfs. Velocities at this site are generally marginal for spawning chum at all discharges and become nearly unacceptable for spawning at high discharges. Time series plots of WUA and average daily mainstem discharges are plotted in Figure IV-10.

Site 114.1R

Site Description: This site is located 0.4 miles upstream of Lane Creek in mid-channel on a vegetated gravel bar (Plate IV-3). The study reach is 675 ft long and 60 ft wide. Large gravel and rubble are predominate in the upper half of the study reach, and sand is present in the lower half. Cross section 1 is located in a backwater area at the mouth of the channel. Cross sections 2 and 3 define the shallower, high velocity area (Figure IV-11).

This study site was selected because of the open thermal leads in the ice which were visible in the March 1983 photography. No previous spawning had been reported at this location (Hoffman 1985) but spawning chum salmon were observed in moderate numbers during the 1984 field season. During winter 1984, upwelling was identified in slight to moderate amounts concentrated along the left bank. The upwelling begins below cross section 1 and extends upstream of cross section 3.

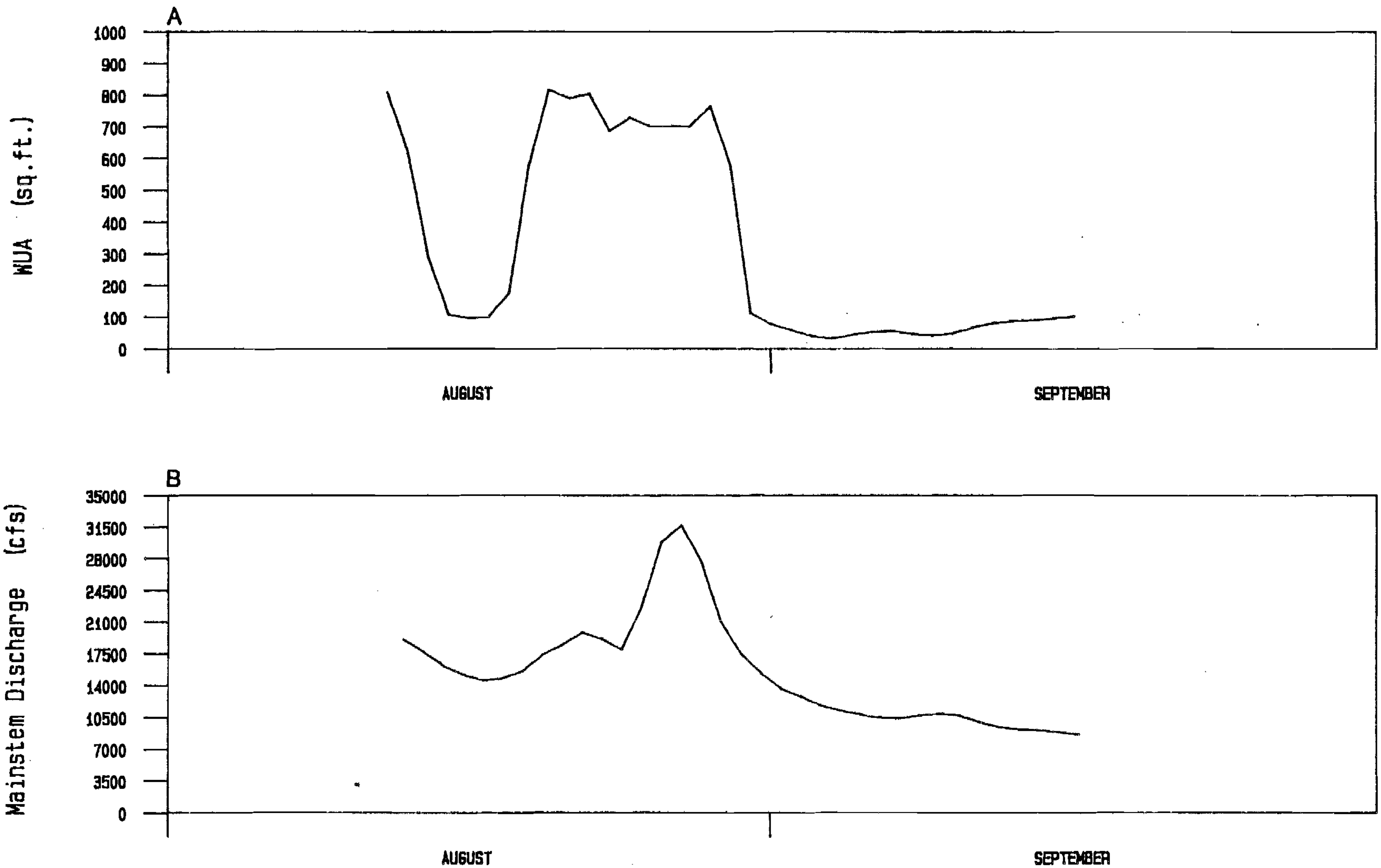


Figure IV-10. Time series plots as a function of time for site 105.8L. A - Spawning chum WUA. B - Mainstem discharge.

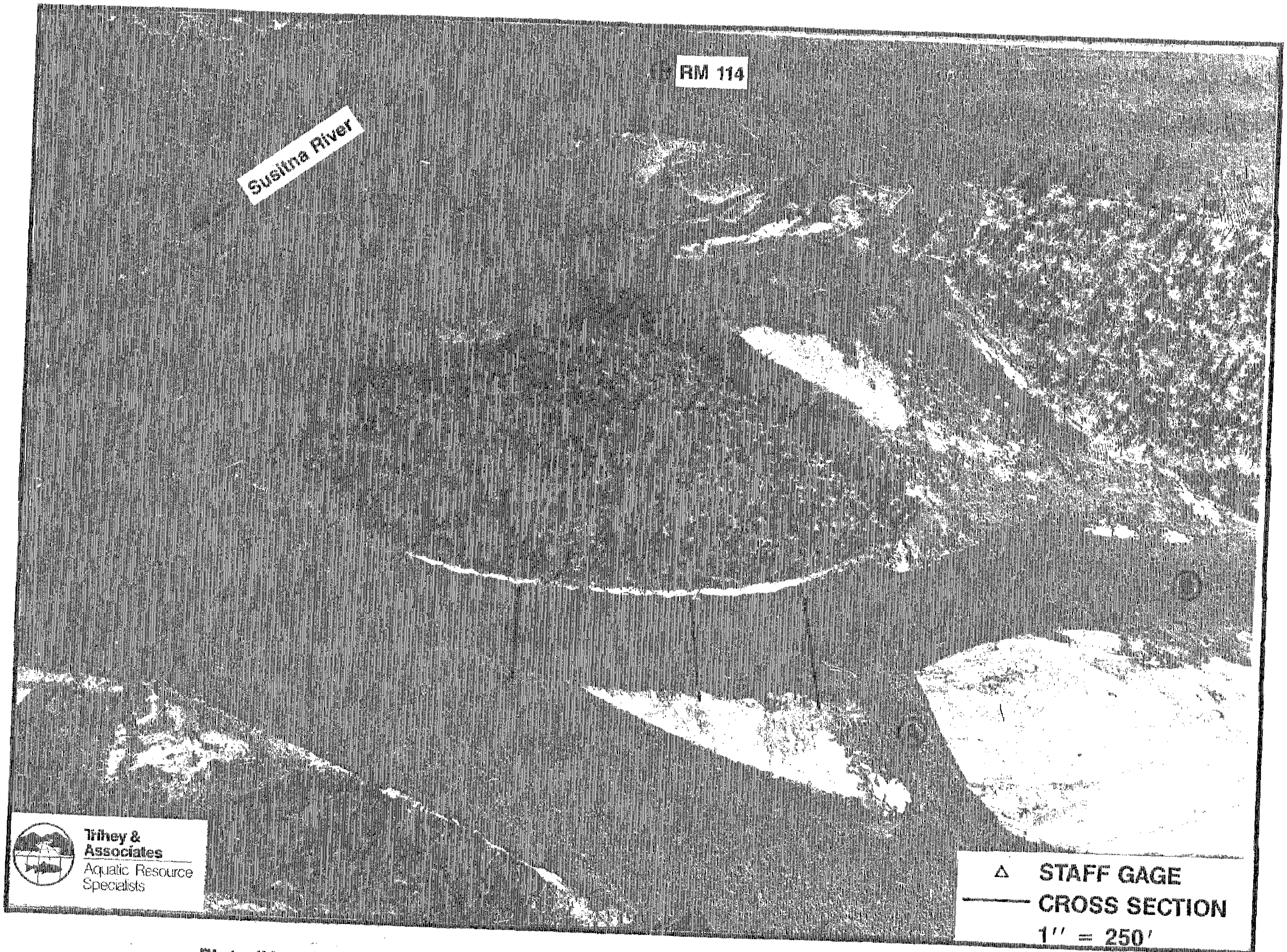


Plate IV-3. Modeling site 114.1R on June 1, 1982 at mainstem discharge: 23,000 cfs.

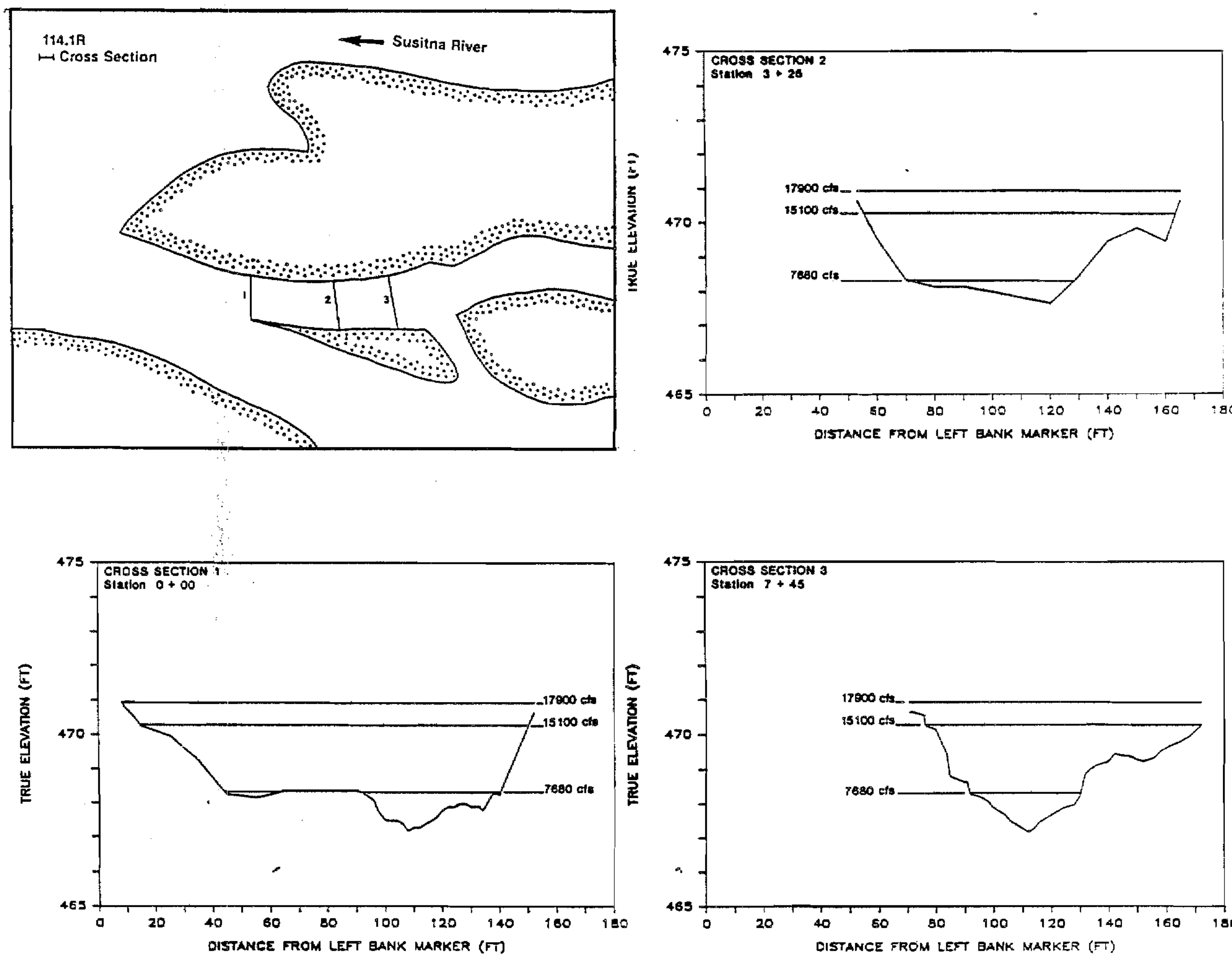


Figure IV-11. Cross sections for site 114.1R depicting water surface elevations at discharges of 7,680, 15,100 and 17,900 cfs.

Spawning Habitat: WSA and WUA curves for this study site are provided in Figure IV-12a and b with the values provided in Table C-6. A comparison of the two curves in Figure IV-12a indicates that a very small proportion of the WSA provides usable habitat over a broad range of mainstem discharges. However, Figure IV-12b, plotted at an expanded vertical scale, indicates that WUA indices are highest for mainstem discharges in the range of 11,000 to 15,100 cfs.

Three data sets were collected at discharges ranging from 7,680 to 17,900 cfs (Table C-3.3). Below 8,800 cfs, the stage remains constant, suggesting that the WSA of the channel is stable during unbreached conditions. At 7,680 cfs, the depths in the upper portion of the study site are shallow, and unsuitably small substrate is present in the upwelling areas. As the channel conveys additional flow, these upwelling areas are no longer limited by shallow depth, and WUA indices for spawning chum peak near 11,000 cfs. Above this discharge, velocities exceed the maximum velocities preferred by chum salmon (3 fps), thereby causing a decrease in WUA. This agrees with field observations made from September to October.

Additional simulated data sets were determined for mainstem discharges of 5,100 and 23,000 cfs. Field personnel were at the site when the discharge was 23,000 cfs. Since the stage for unbreached conditions remain unchanged, the WUA response curve was assumed constant, thereby extending the curve to 5,100 cfs. Comparisons between the cross section and stage-discharge data reveal that depths are too shallow in the upper half of the study site for spawning. A backwater at the lower end of the study site provides the majority of the

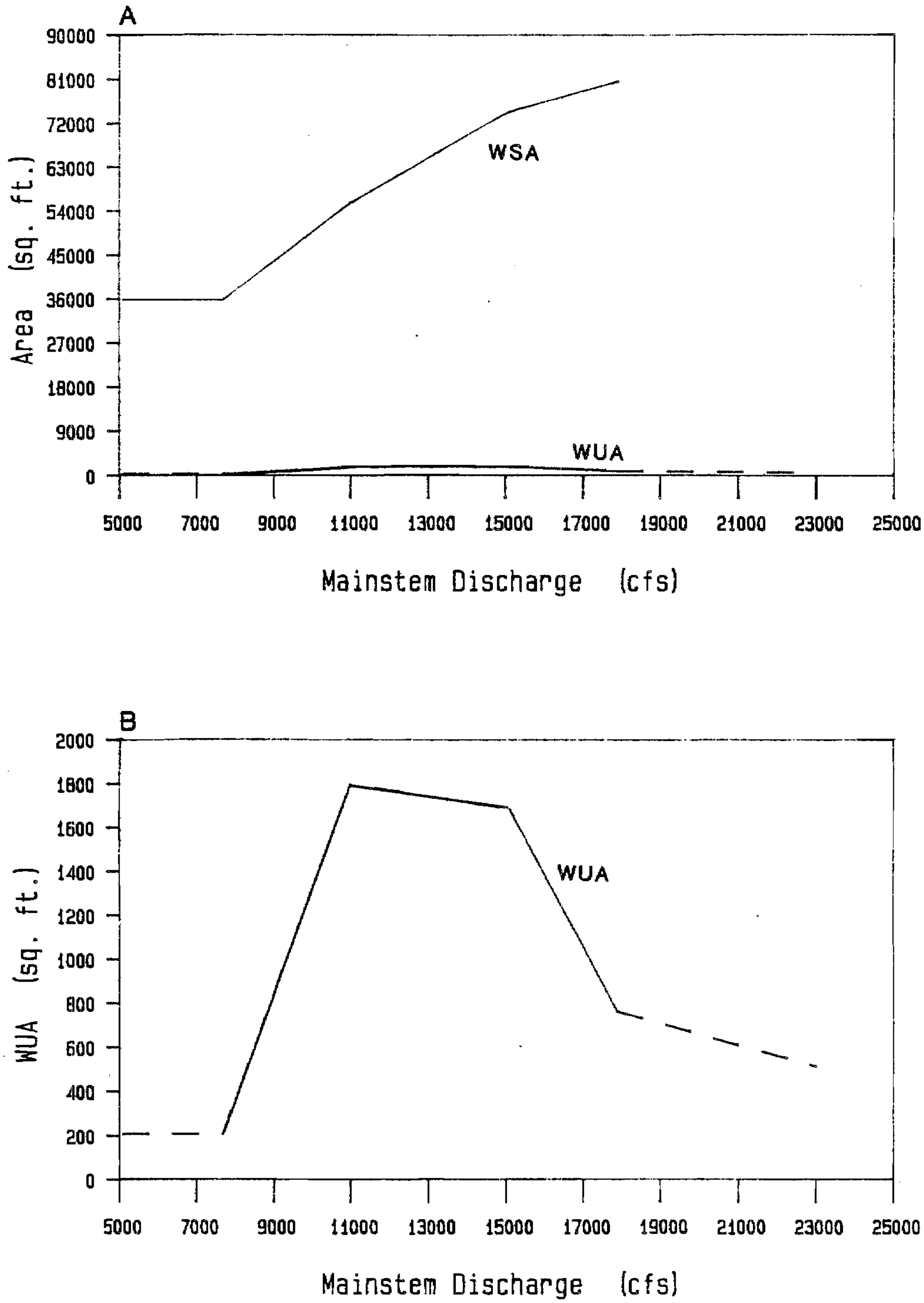


Figure IV-12. Surface area and spawning chum habitat response curves for site 114.1R. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

usable spawning habitat at low discharges. Time series plots of WUA and mainstem discharges from August 12 to September 15, 1984, are shown in Figure IV-13.

Site 115.0R

Site Description: This site is located in the lower portion of Mainstem II Side Channel on the east bank of the Susitna River (Plate IV-4). The study reach is 1,525 ft long and varies from 40 to 80 ft wide. Rubble is present throughout the study area with an overlay of sand in the pool area. Two channels (A and B, Plate IV-4) direct mainstem flow into the study site. Cross section 1 was established to define the large backwater area present in the lower half of the site (Figure IV-14). Cross section 2 described a riffle area just upstream of the backwater. Above this cross section, the channels divide but the study site is confined to Channel B. Cross section 3 defines a deep pool; cross section 4, a shallow low velocity run.

Channels A and B breach at 12,000 and 23,000 cfs, respectively. When the channels are unbreached, a large backwater area extends from the mouth of the side channel upstream nearly to the confluence of channels A and B.

This study site was selected as a known upwelling area where chum spawning had been observed in previous years (Hoffman 1985). Upwelling varies between slight and moderate at the cross sections. Bank seepage was noted along both banks at cross section 1. Adult chum, coho, and sockeye salmon have been observed in the side channel. Juveniles of the same species have also been observed in the site.

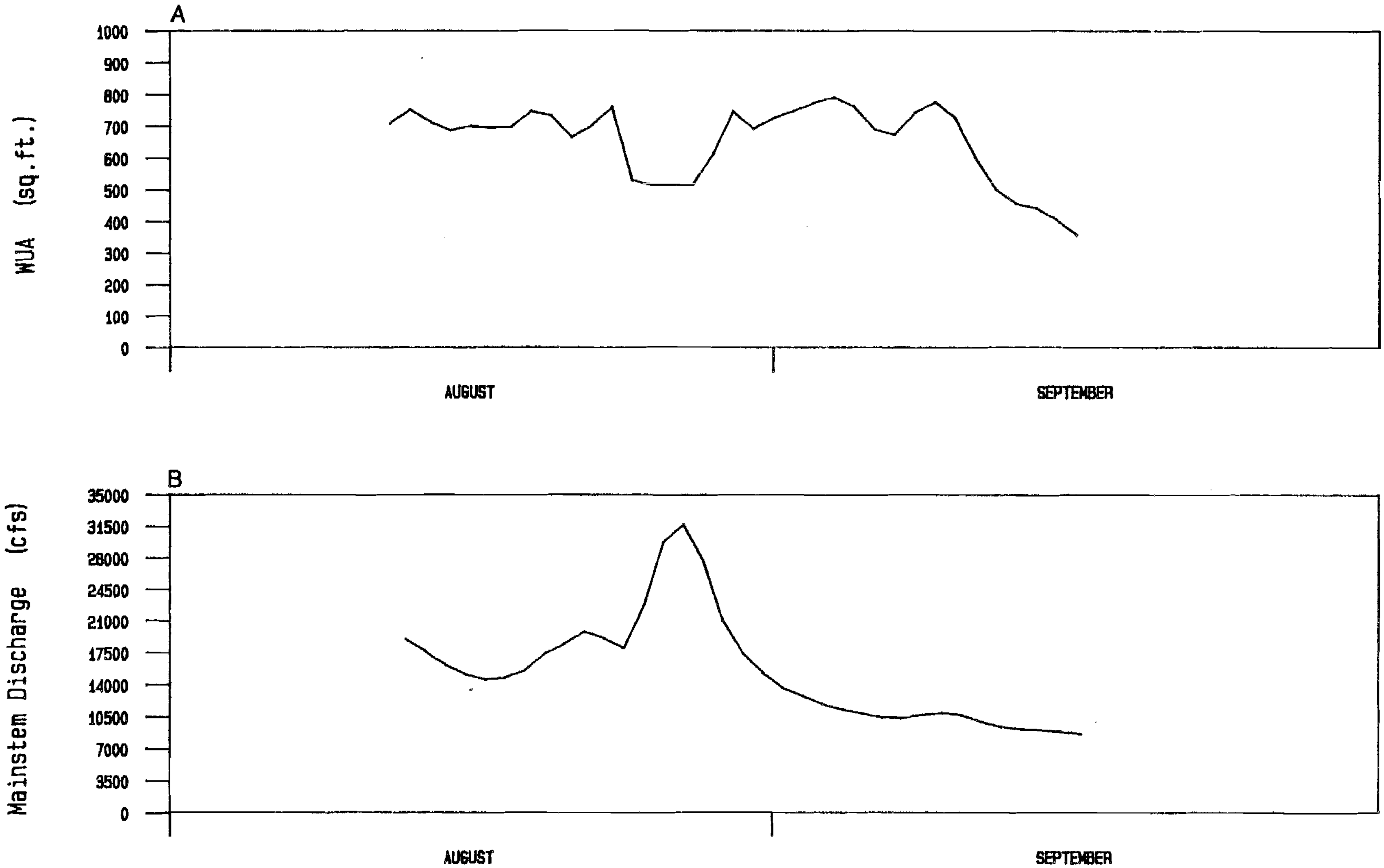


Figure IV-13. Time series plots as a function of time for site 114.1R. A - Spawning chum WUA. B - Mainstem discharge.

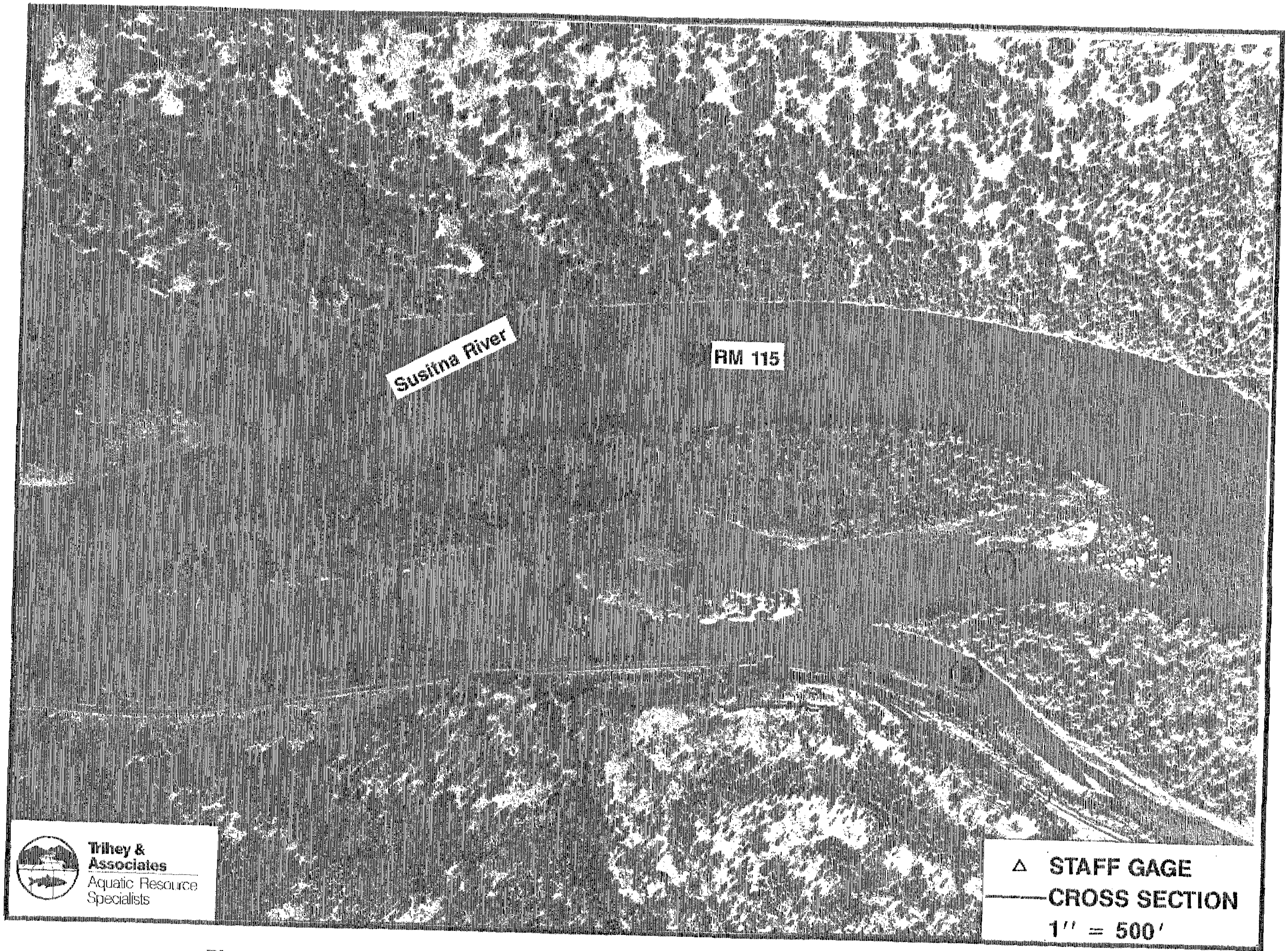


Plate IV-4. Modeling site 115.0R on June 1, 1982 at mainstem discharge: 23,000 cfs.

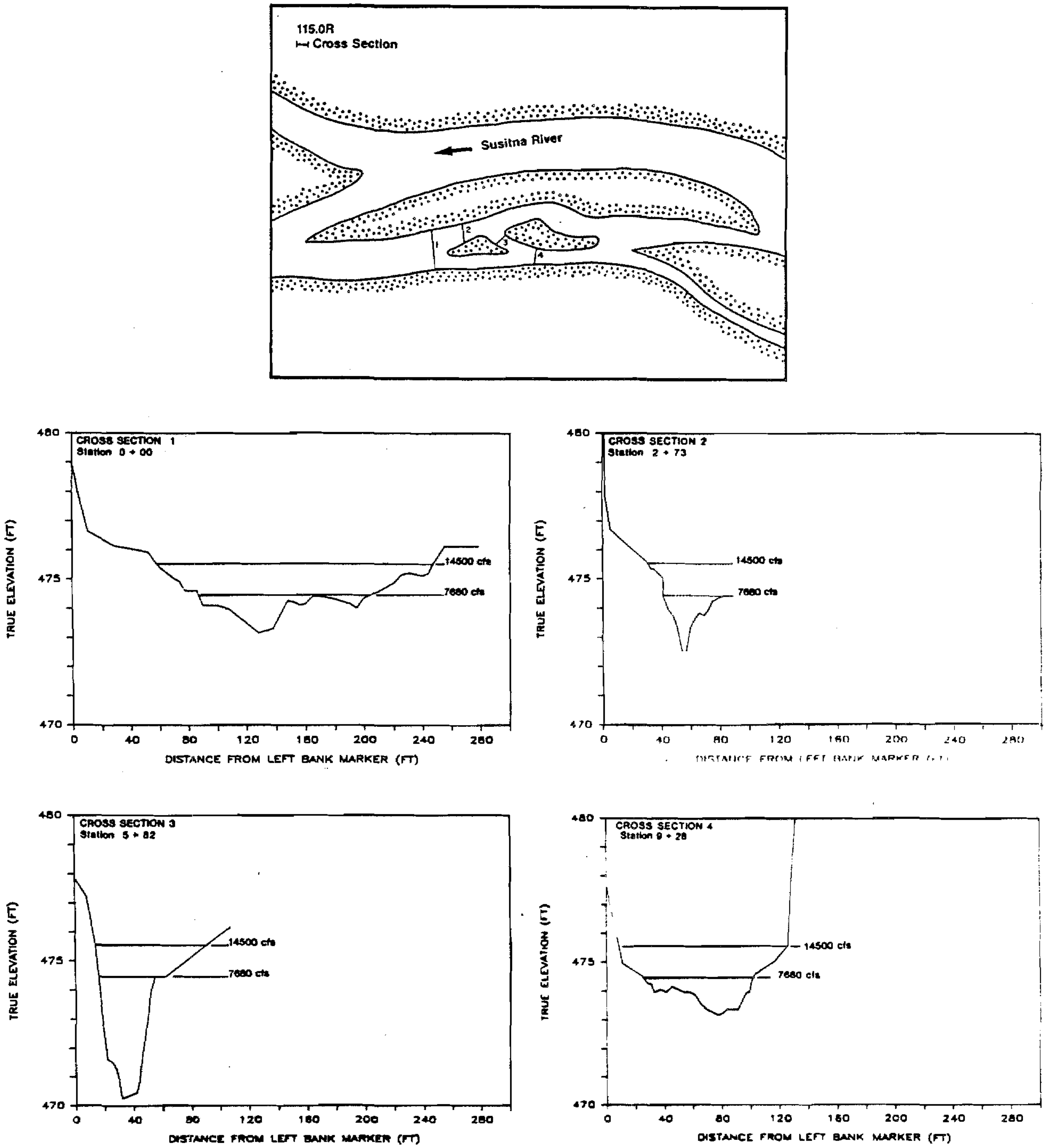


Figure IV-14. Cross sections for site 115.0R depicting water surface elevations at discharges of 7,680 and 14,500 cfs.

Spawning Habitat: Figure IV-15a is a plot of the total wetted surface area and WUA curves. Figure IV-15b is the same WUA curve plotted on an expanded vertical scale.

Depths and velocities were measured at all cross sections for two mainstem discharges, 7,680 and 14,500 cfs. The northwest channel head berm was breached at the time field data were obtained at 14,500 cfs. Neither head berm was breached when depth and velocity data were collected at 7,680 cfs. The WUA remains relatively constant at discharges below 10,400 cfs. Above this discharge, the influence from the mainstem increases the stage of the backwater and depth of flow in the upwelling areas at cross sections 1 and 2, creating slightly more usable spawning habitat. The WUA continues to increase with increasing discharge up to 14,500 cfs, where it remains nearly constant until the northeast channel is breached at 23,000 cfs. No information has been obtained regarding the influence of higher stream flows on velocities at the upwelling areas.

Additional simulated data sets were developed for discharges of 5,100, 12,000 and 23,000 cfs. The stage-discharge curve developed for cross section 1 indicates that the stage is constant for mainstem discharges below 10,400 cfs. Therefore, the WUA and WSA measured at 7,680 cfs was assumed to be applicable to 5,100 cfs. At 12,000 cfs, the stage-discharge curve was used to determine the stage at cross section 1 and 2. The upstream portion of the study site, at cross sections 3 and 4, provide the same WUA and WSA at all discharges until the northeast channel (B) is breached at 23,000 cfs. An additional simulated data set was developed for a mainstem discharge of 23,000 cfs by

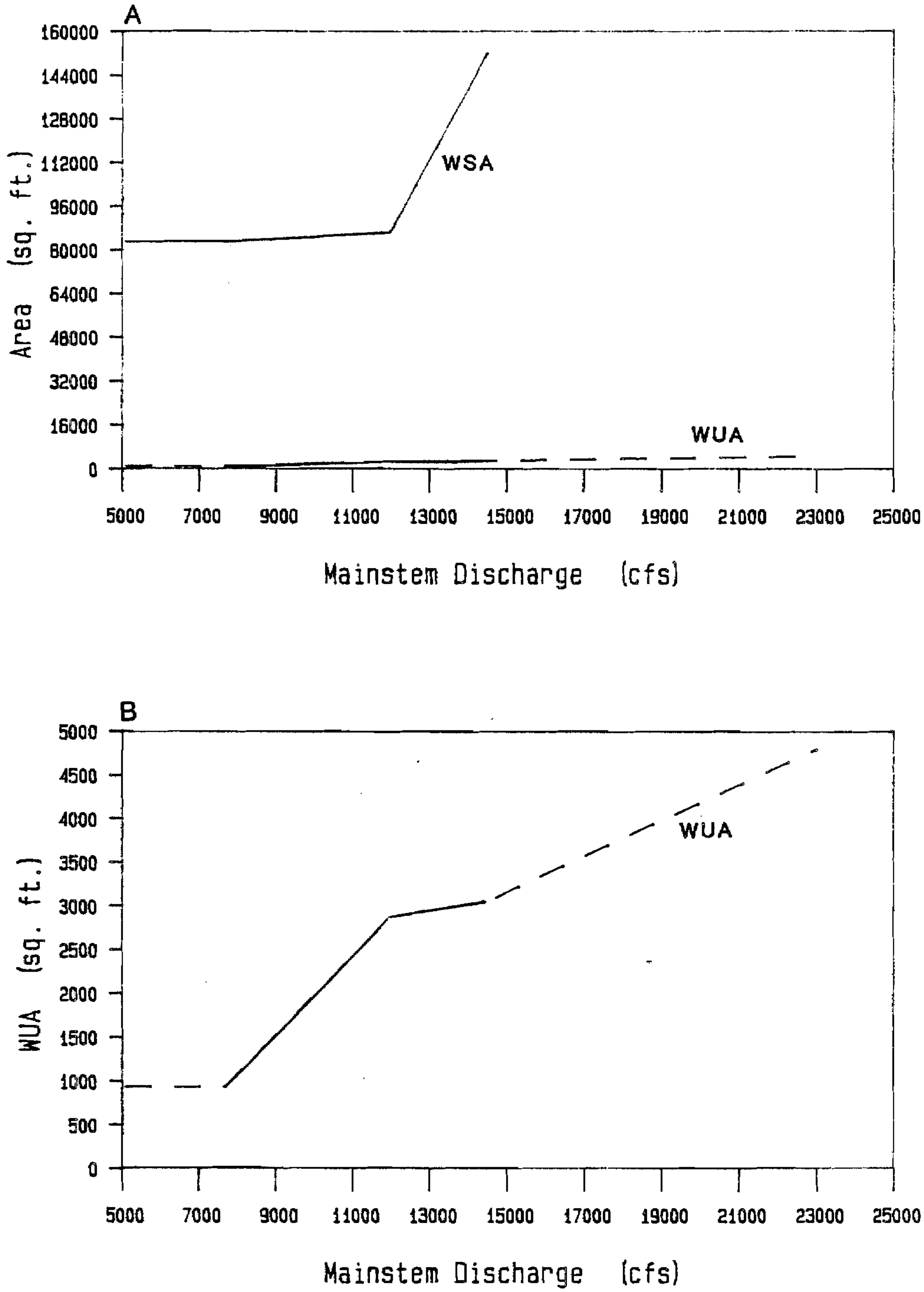


Figure IV-15. Surface area and spawning chum habitat response curves for site 115.0R. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

assuming that the linear trend in velocities occurring at cross sections 3 and 4 between mainstem discharges of 7,680 and 14,500 cfs would continue to 23,000 cfs. Above 23,000 cfs, the habitat response curve is expected to decrease, as the velocities in the upwelling areas are expected to increase above the preferred range. This response is similar to the responses forecast for other study sites in the middle Susitna River where data are available. Time series plots of WUA and mainstem discharge for the 1984 chum spawning season (August 12 to September 15) are shown in Figure IV-16.

Site 118.9L

Site Description: This site is located along the mainstem margin approximately 1.7 miles downstream of Curry Station on the west bank of the Susitna River (Plate IV-5). Rubble and cobble predominate throughout the site with a layer of silt and sand deposited along the bank at the upper end. Three cross sections were established in the study area which is 475 ft long (Figure IV-17). A small tributary enters the mainstem just above the site. At mainstem discharges less than 23,000 cfs, a small channel is evident immediately downstream of the tributary and extends downstream of cross section 3.

This mainstem margin study site was selected because spawning chum salmon were previously recorded at this location (Hoffman 1985). In addition, chum salmon were observed spawning at the site during the 1984 field season. During April 1985 open thermal leads were observed throughout the study area. Small amounts of bank seepage kept the area from freezing for part of the winter.

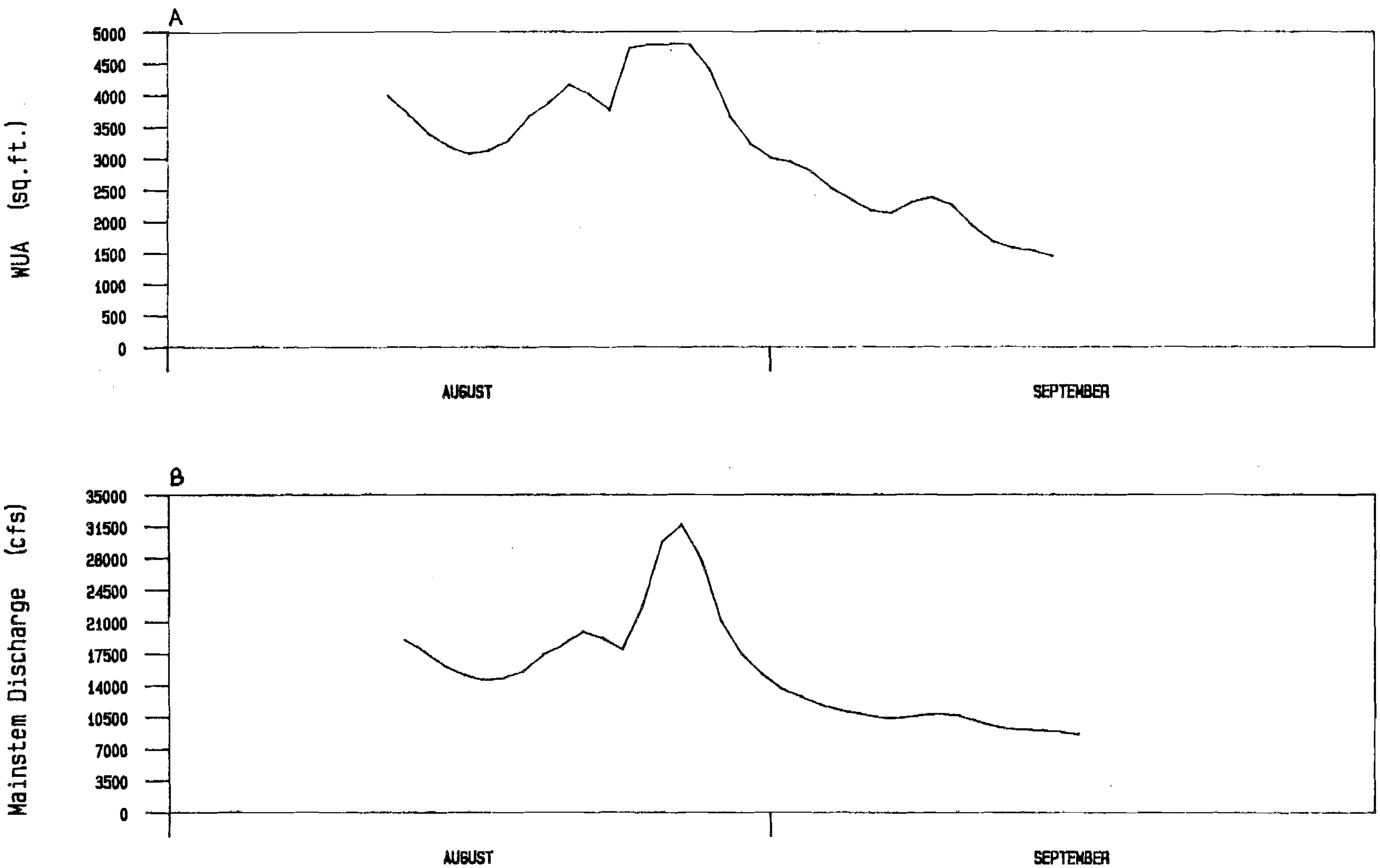


Figure IV-16. Time series plots as a function of time for site 115.0R. A - Spawning chum WUA. B - Mainstem discharge.

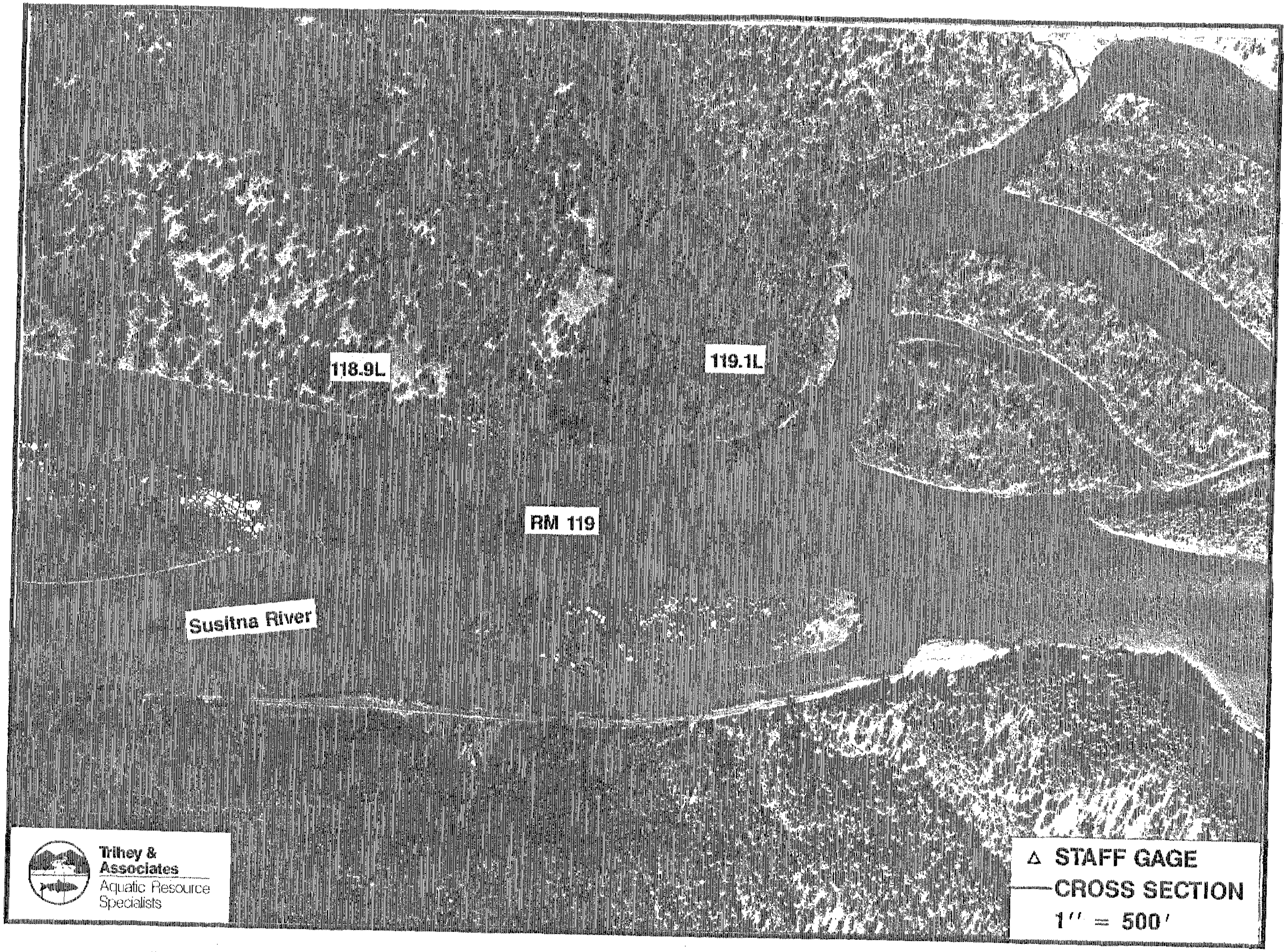


Plate IV-5. Modeling sites 118.9L and 119.1L on June 1, 1982 at mainstem discharge: 23,000 cfs.

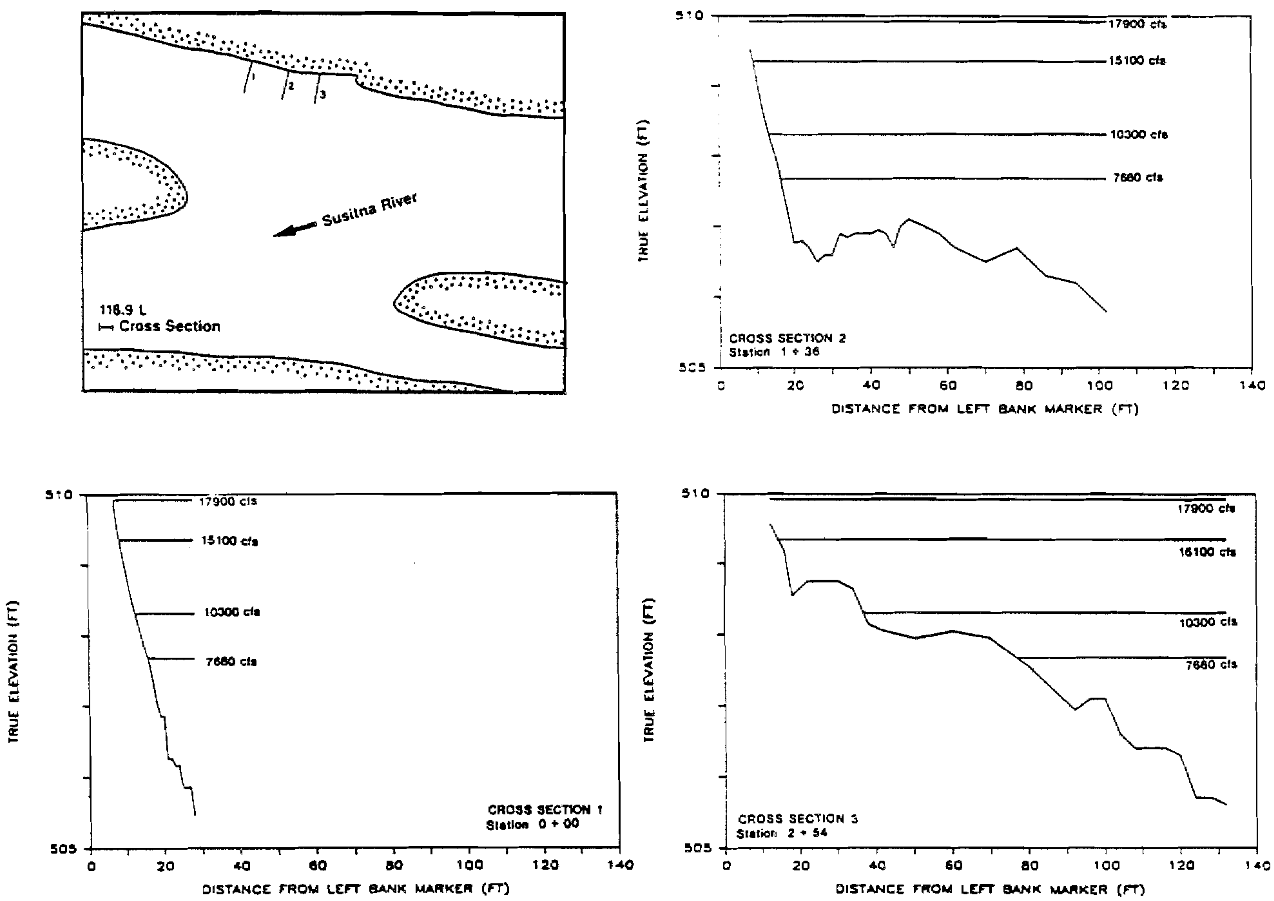


Figure IV-17. Cross sections for site 118.9L depicting water surface elevations at discharges of 7,680, 10,300, 15,100, and 17,900 cfs.

Spawning Habitat: The WSA and WUA curves for spawning chum are presented in Figure IV-18a, with the WUA curve replotted to an enlarged scale in Figure IV-18b.

Four data sets were collected from mainstem discharges of 7,680 to 17,900 cfs. From Part II of this report, the stage-discharge curve indicates that the relationship between stage and mainstem discharge remains constant from 5,000 to 23,000 cfs. The lower end of the gravel bar which extends from above the study area to midway between cross sections 2 and 3 provides shallow depths in upwelling areas. As discharge increases up to 15,100 cfs, the depth of flow increases in the upwelling areas until the entire area is optimal for spawning habitat. The WUA function begins to decrease as high velocities limit spawning in the upwelling areas.

To expand the discharge range covered by the WUA curve, additional simulated data sets were developed at 5,100 and 23,000 cfs. The stage-discharge curve for cross section 2 was used to determine the stage at both discharges. A gravel bar influences the stage at the upper end of the study area, particularly in the upwelling areas. At low discharges, the upwelling area appears as bank seepage and is too shallow for spawning. The mainstem begins to flood the upwelling above 7,680 cfs and continues until the entire area is flooded at 15,100 cfs. Above 15,100 cfs, velocities begin to exceed 1.3 fps, the highest optimum usable velocity for spawning chum salmon. This decreasing WUA trend is similar to the habitat response at other side channel sites in the middle Susitna River. Time series plots of WUA and mainstem discharge are shown in Figure IV-19 for site 118.9L.

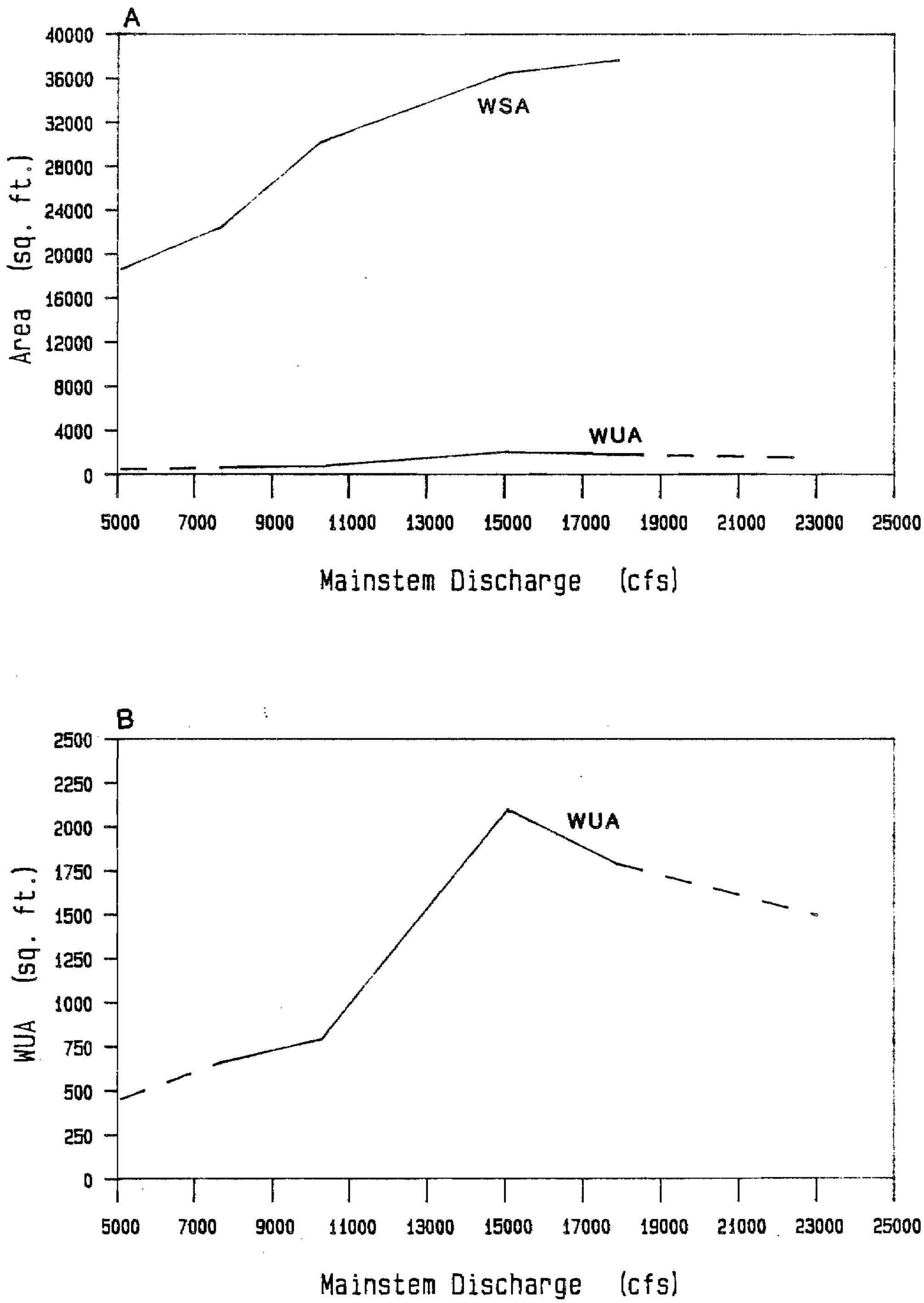


Figure IV-18. Surface area and spawning chum habitat response curves for site 118.9L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA. B - Weighted Usable Area (WUA).

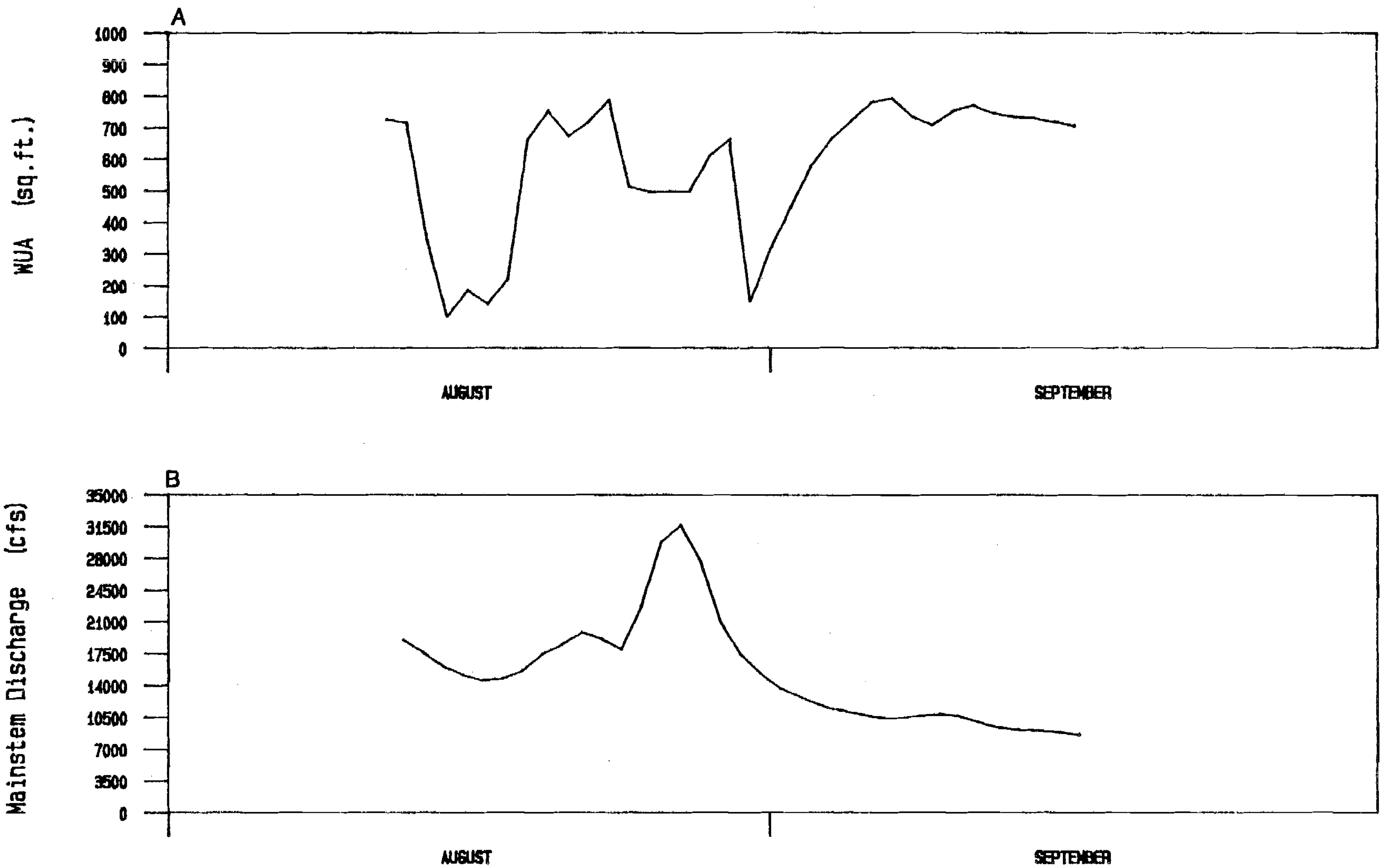


Figure IV-19. Time series plots as a function of time for site 118.9L. A - Spawning chum WUA. B - Mainstem discharge.

Site 119.1L

Site Description: This site is located approximately 1.5 miles downstream of Curry Station on the west bank of the Susitna River (Plate IV-5). A large side channel enters the mainstem at the upstream end of the study area. The study area, located along the mainstem margin, is 425 ft long. Cobble and large gravel are present throughout the site with some silty sand deposits along the bank and larger substrate in the mainstem. Three cross sections were established to describe the mainstem margin with a fourth cross section established at a clear backwater area (Figure IV-20). Below discharges of 18,000 cfs, the backwater area is dewatered.

This mainstem study site was selected as a suspected upwelling area, however, chum salmon had not been observed at the site prior to 1984 but both adult chum and juvenile chinook salmon were observed in the study site during 1984. No obvious upwelling areas were observed in this study site, however, redd locations were coded assuming the upwelling strength was slight.

Spawning Habitat: WSA and WUA curves are presented in Figure IV-21 with the WUA replotted on an expanded sale in Figure IV-21b. Data sets were collected at 7,680, 10,300 and 15,100 cfs. Figure IV-21a shows that WSA remains relatively constant however WUA shows a sharp increase at 10,300 cfs. The upwelling areas are covered sufficiently for spawning at 15,100 while the area in which cross section 4 describes first becomes usable at 18,000 cfs.

Data sets were developed for 5,100 and 23,000 cfs. The upwelling areas are dewatered at 5,100 cfs causing a WUA value of zero. At 23,000 cfs, the

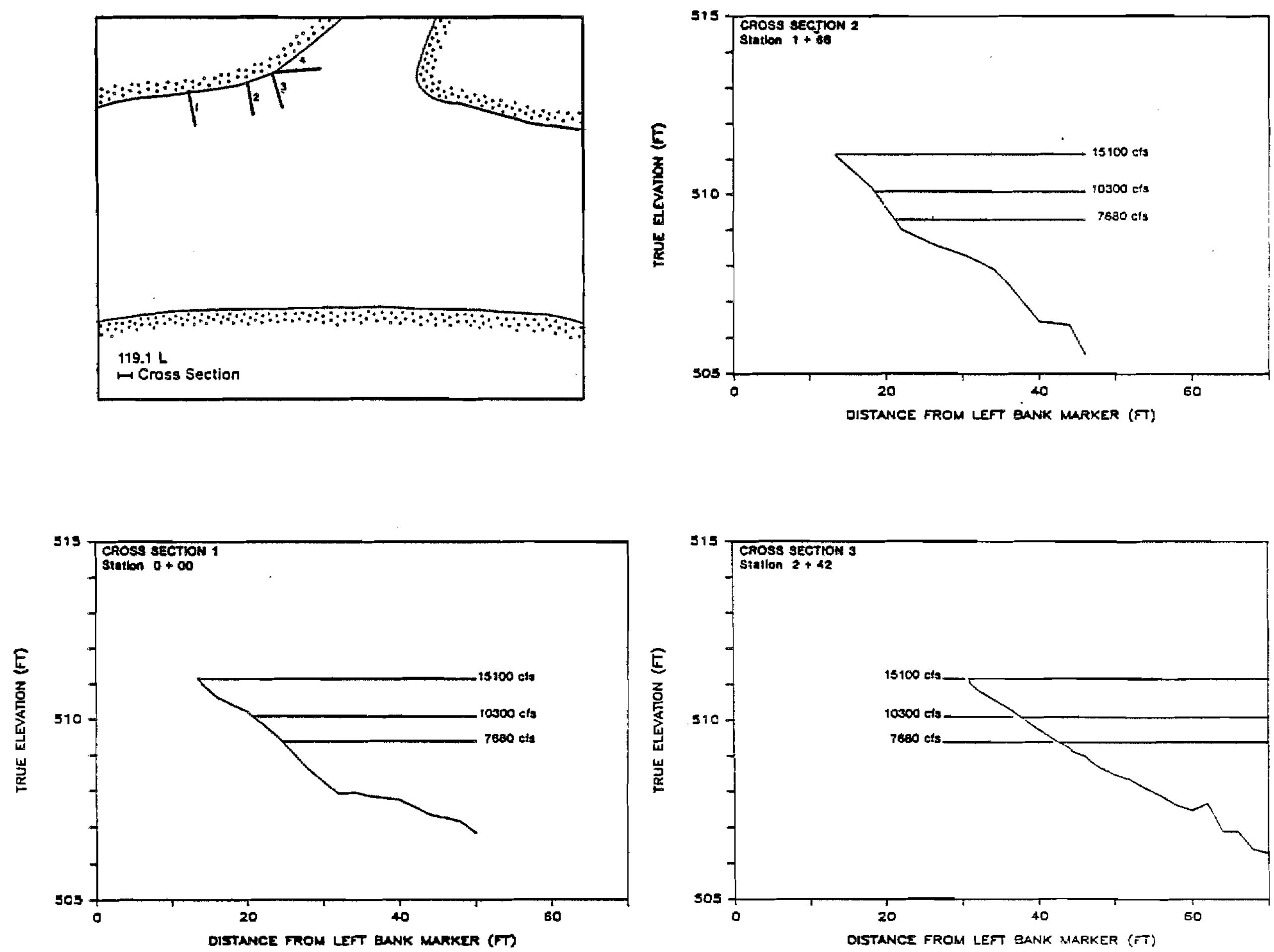


Figure IV-20. Cross sections for site 119.1L depicting water surface elevations at discharges of 7,680, 13,600 and 19,100 cfs.

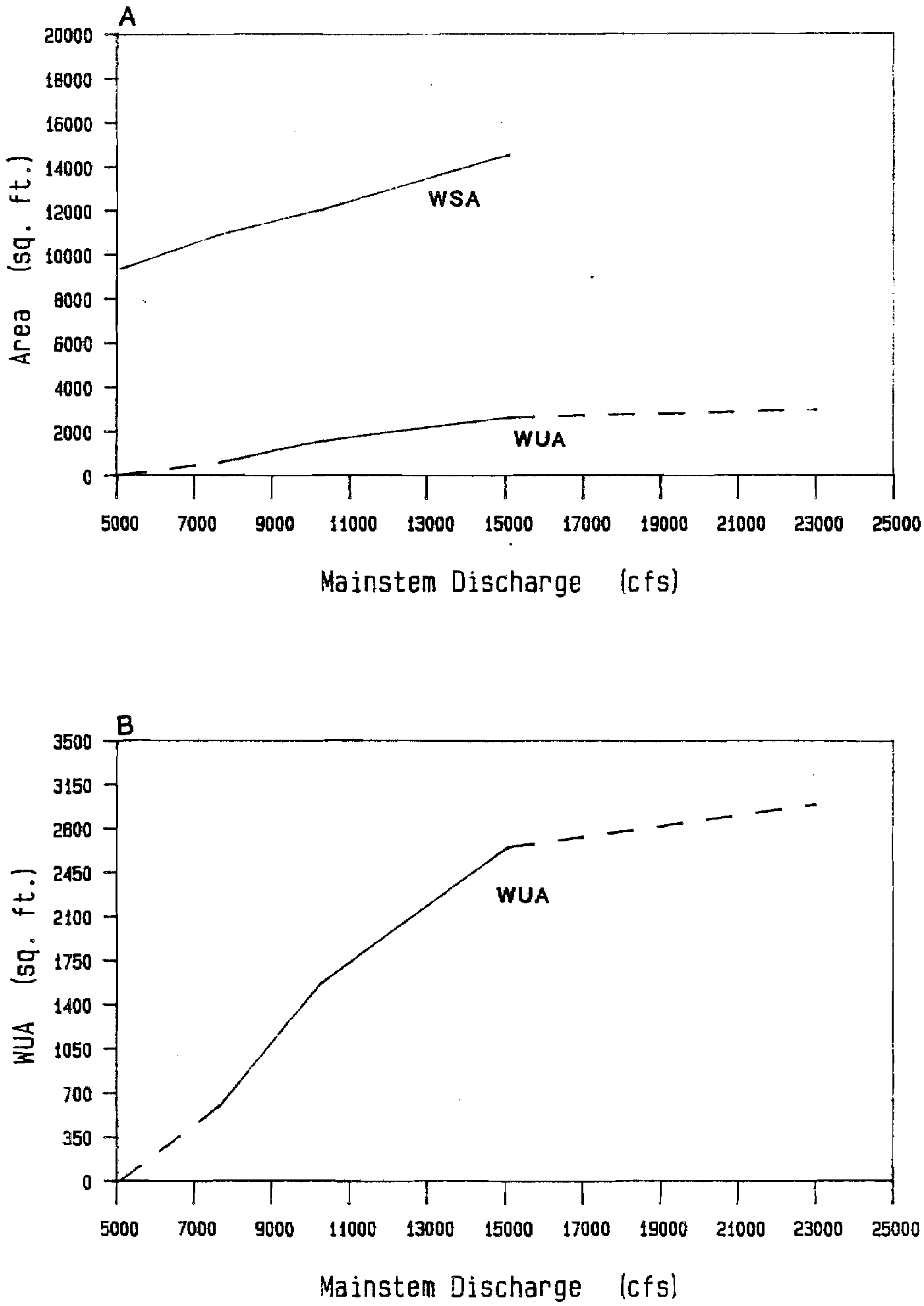


Figure IV-21. Surface area and spawning chum habitat response curves for site 119.1L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

velocities are at the peak of the optimum spawning range providing a large amount of WUA. A decreasing trend in the habitat response curve can be expected at higher discharges. Figure IV-22 includes time series plots of WUA and mainstem discharge.

Site 125.2

Site Description: Skull Creek is located downstream of this study site on the east bank of the Susitna River (Plate IV-6). The study reach is 1,475 ft long and 250 ft wide with sharp, flat gravel and rubble substrate is present throughout the site, unlike the typical, smooth round substrate generally present throughout the river. Two cross sections were established to describe the high velocities present throughout the mid-channel (Figure IV-23). A deep, low velocity area is present along the left bank of cross section 1. A large shoal area is present along the left bank of cross section 2. At low mainstem discharges, a gravel bar varies the stage across cross section 2.

This side channel study site was selected because of suspected upwelling, and chum salmon adults were previously recorded. Adult chum and pink salmon and chinook fry were also observed using the site in 1984 (Hoffman 1985). Open thermal leads were recorded during winter 1984 in the entire channel. Strong upwelling was observed along the left bank of cross section 1 with slight amounts of upwelling recorded along the mid-channel and right bank. At cross section 2, moderate amounts of upwelling were present along the mid-channel and right bank.

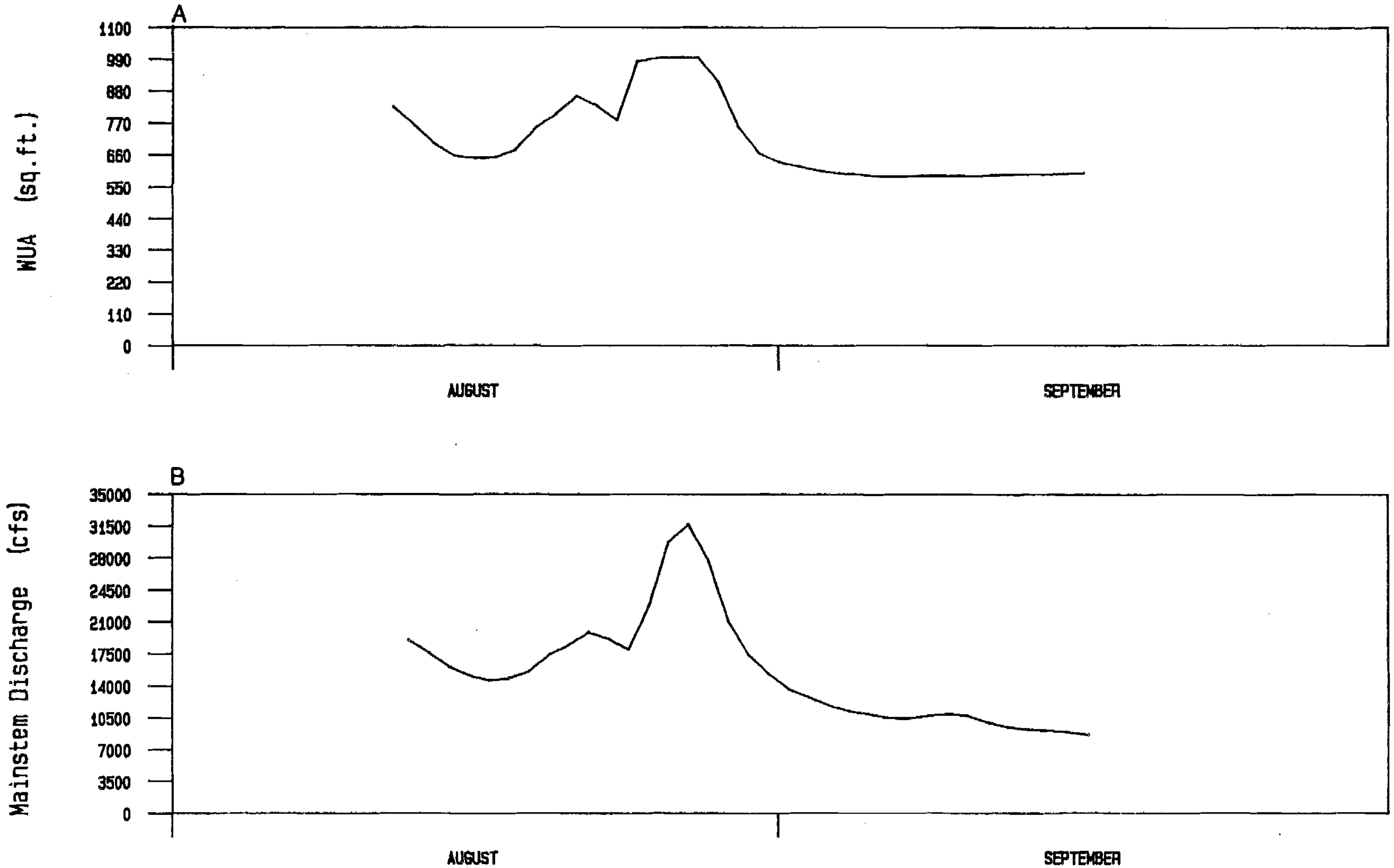


Figure IV-22. Time series plots as a function of time for site 119.1L. A - Spawning chum WUA. B - Mainstem discharge.

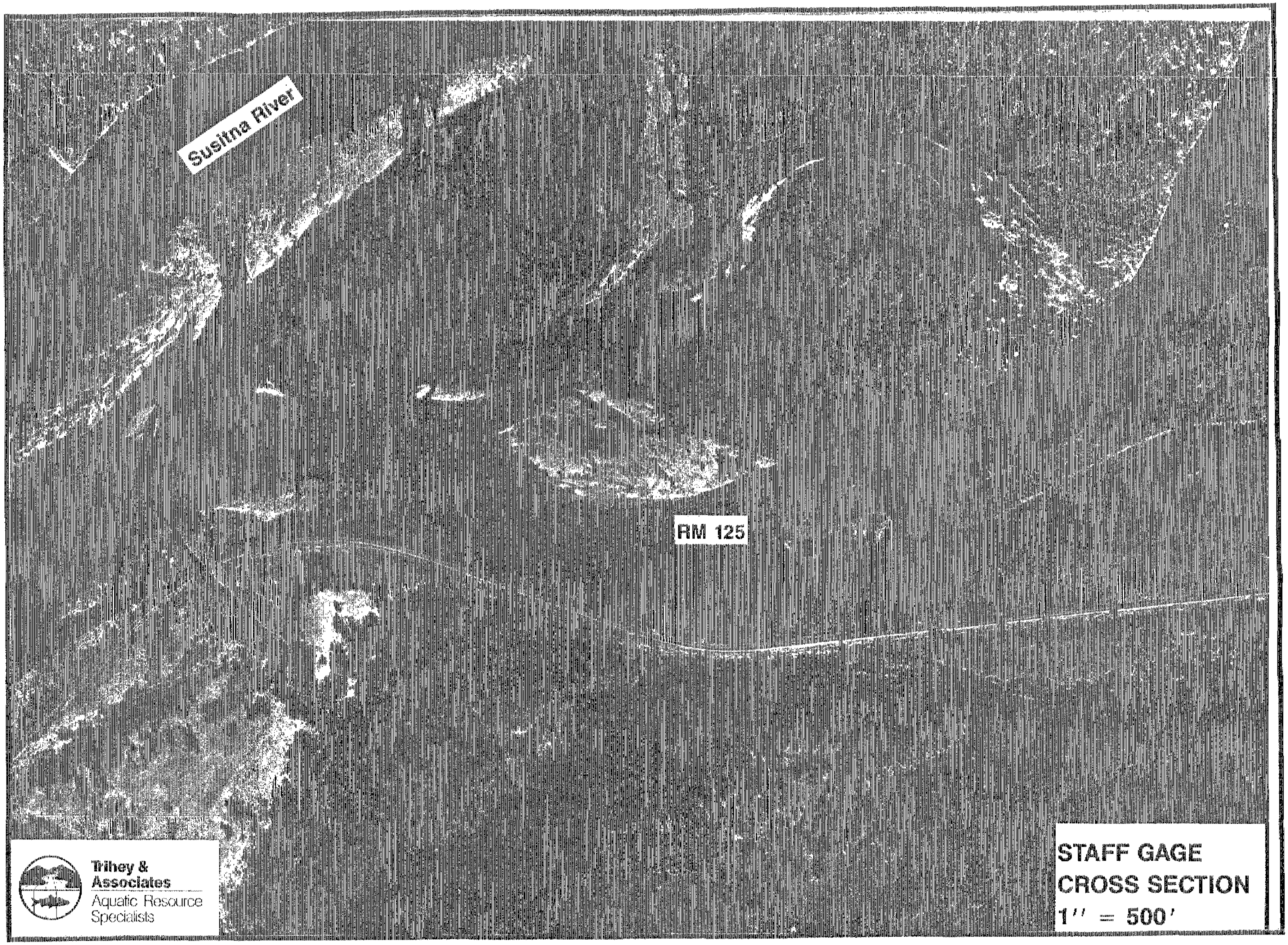


Plate IV-6. Modeling 125.2R on June 1, 1982 at mainstem discharge: 23,000 cfs.

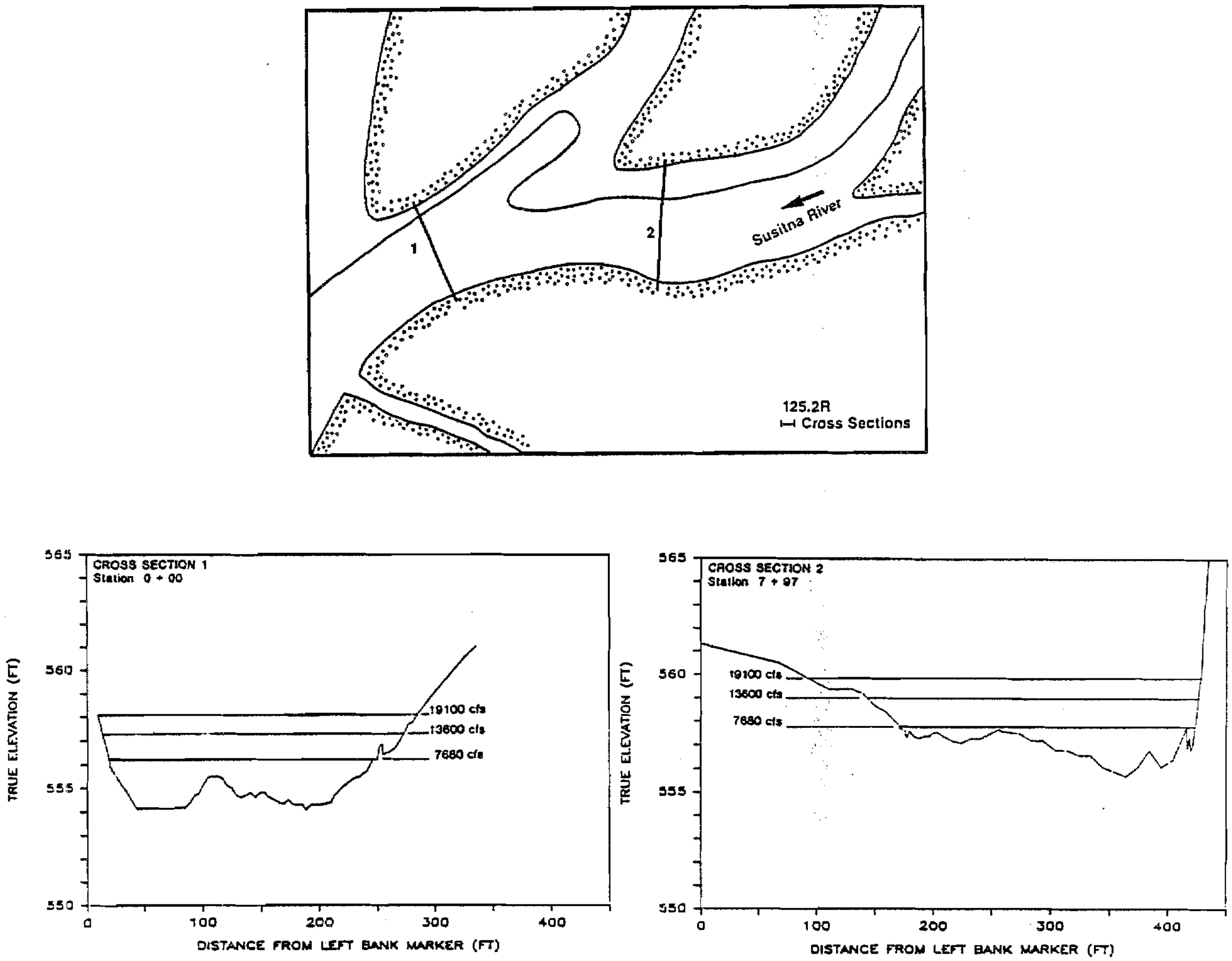
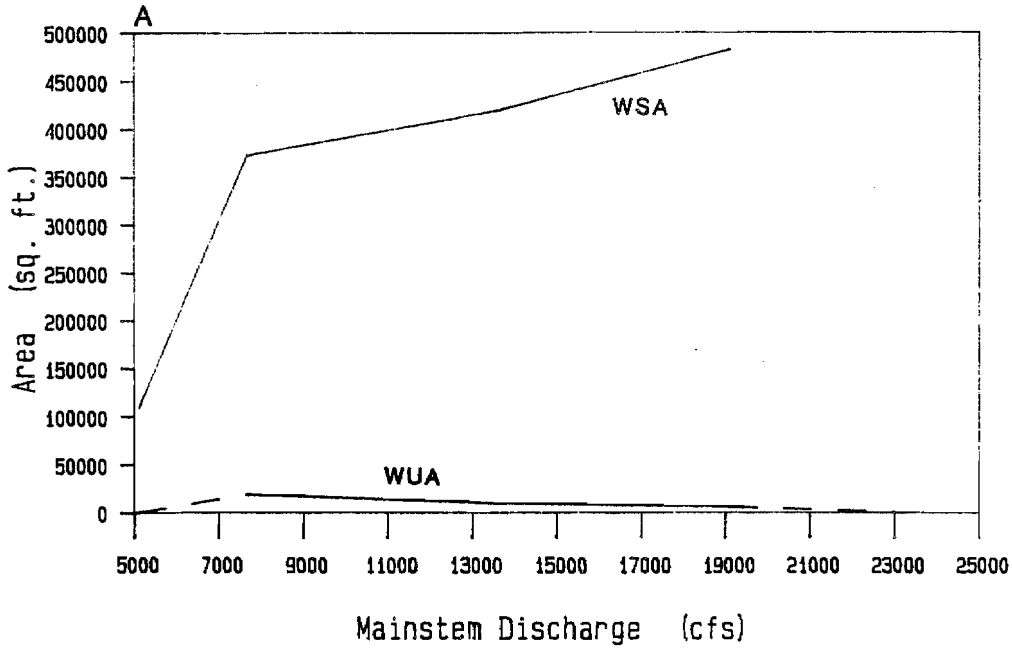


Figure IV-23. Cross sections for site 125.2R depicting water surface elevations at discharges of 7,680, 13,600, and 19,100 cfs.

Spawning Habitat: The WSA and chum salmon WUA response curves for this site are representative of medium to large side channel areas (Figure IV-24a and b). WSA and WUA response curves are presented in Figure IV-24a for site 125.2R. A relatively narrow range of WUA is predicted at mainstem discharges between 5,100 and 23,000 cfs indicating usable habitat remains constant. This is probably caused by comparable rates of availability of habitat at the site. The upwelling areas located along both banks range in strength from slight to strong. Most of the suitable spawning habitat occurs along the left bank at cross section 1 in the large backwater area where velocities are not limiting through the range of measured mainstem discharges.

The response of WUA as a function of mainstem discharge is shown in Figure IV-24b plotted on an expanded scale. The increase in WUA is due to the shallow upwelling areas becoming usable. As the discharge increases, the upwelling areas along the left bank reach usable depths, while the velocities along the right shore begin decreasing in suitability. The substrate in the study reach is not of optimal quality, thus explaining the small amplitude in the response curve.

Data sets were estimated for discharge of 5,100 and 23,000 cfs. The 23,000 cfs data set was estimated based on stage-discharge curves, cross sections and aerial photography. At 23,000 cfs, the high velocities in the spawning areas limited the upwelling. A field reconnaissance trip was made to the study site when the mainstem discharge was 4,300 cfs. At that discharge, much of the upwelling areas along both banks, with the exception of the backwater area at cross section 1, were too shallow for use. Time series plots of WUA and mainstem discharge are presented in Figure IV-25.



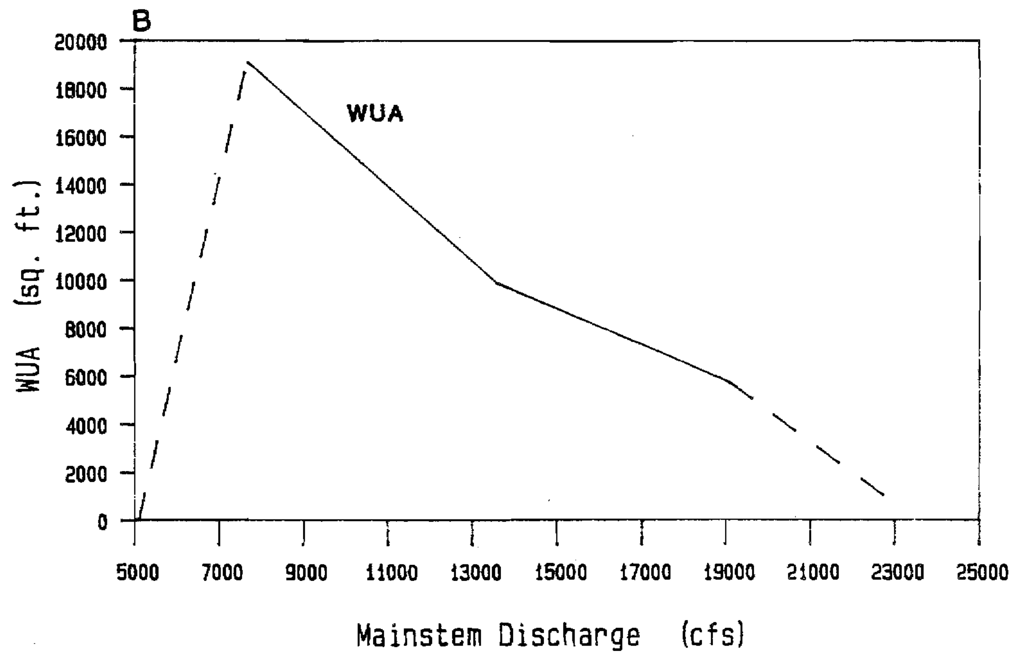


Figure IV-24. Surface area and spawning chum habitat response curves for site 125.2R. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

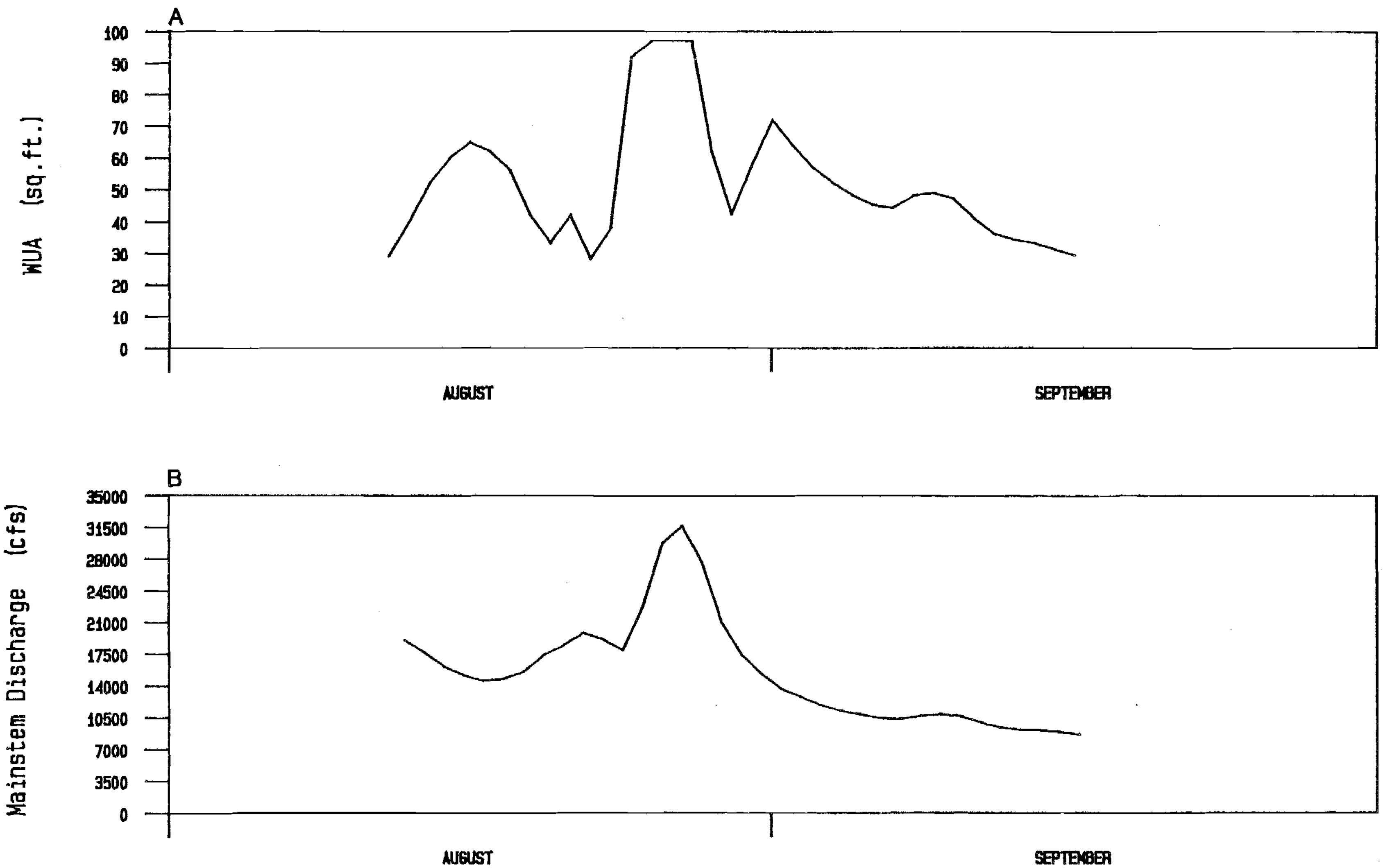


Figure IV-25. Time series plots as a function of time for site 125.2R. A - Spawning chum WUA. B - Mainstem discharge.

Site 130.2R

Site Description: Sherman Creek is located just upstream of this large side channel along the east bank of the Susitna River (Plate IV-7). At discharges below 15,000 cfs, a small backwater area can be observed separate from the side channel. Cobble and rubble is present throughout the upper half of the site while the lower half is covered with a layer of silt and sand. The study reach is 700 ft long and varies between 100 ft at the downstream end, to 30 ft wide at the upper end. Three cross sections were installed in the shallow, low velocity area (Figure IV-26).

This backwater study site was selected as a suspected upwelling area with no previously observed spawning activity. Chinook juvenile salmon were observed to utilize the site (Hoffman 1985). No upwelling was noted throughout the site.

Spawning Habitat: Because upwelling areas were not observed throughout the 1984-85 field seasons, habitat response curves were not developed for this site.

Site 131.3L

Site Description: This study site is located between vegetated gravel bars immediately upstream from the confluence of Fourth of July Creek and the Susitna River on its west bank (Plate IV-8). The substrate is predominately gravel and rubble throughout the site with a layer of silty sand in the

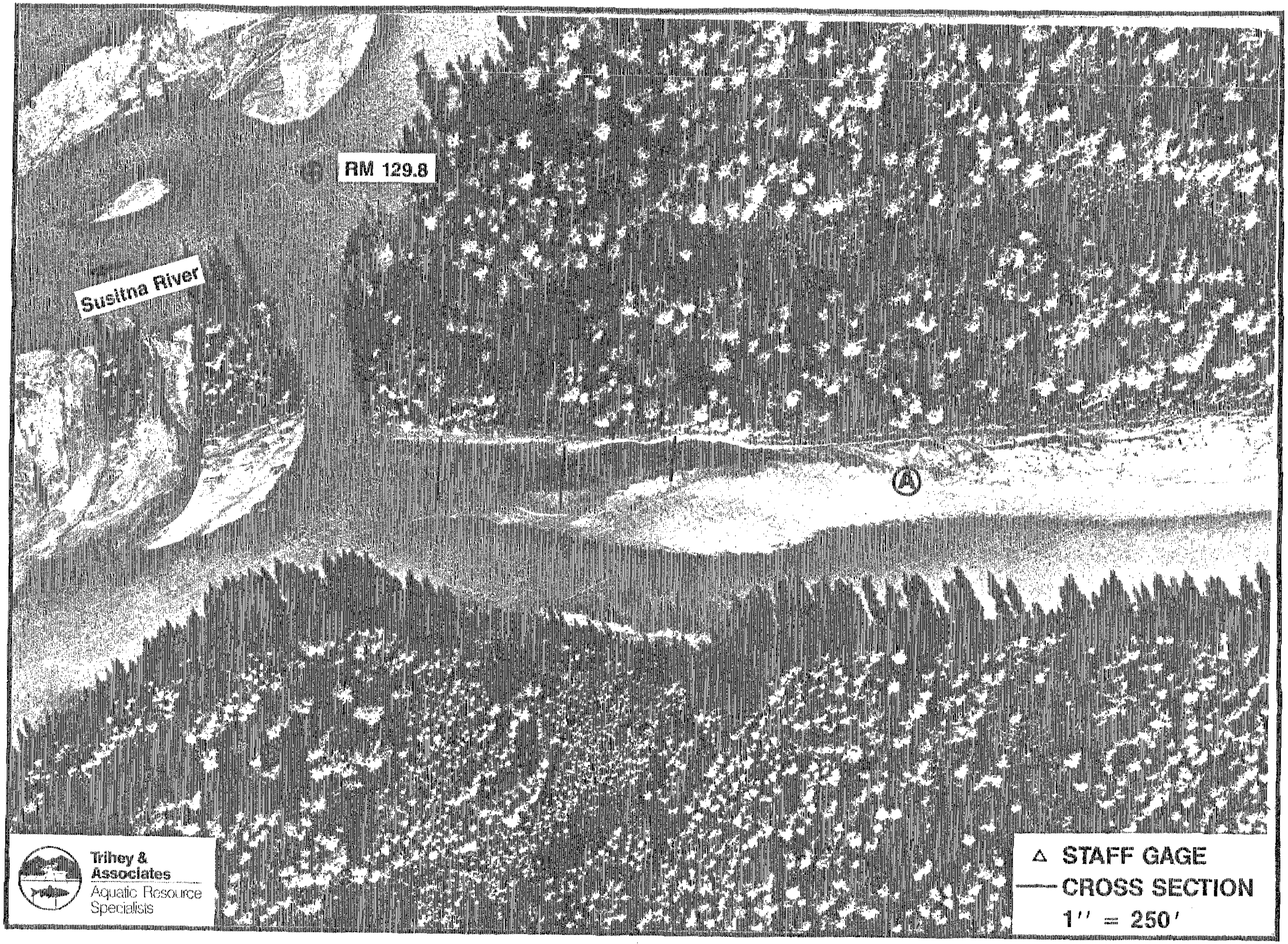


Plate IV-7. Modeling site 130.2R on September 6, 1983 at mainstem discharge: 16,000 cfs.

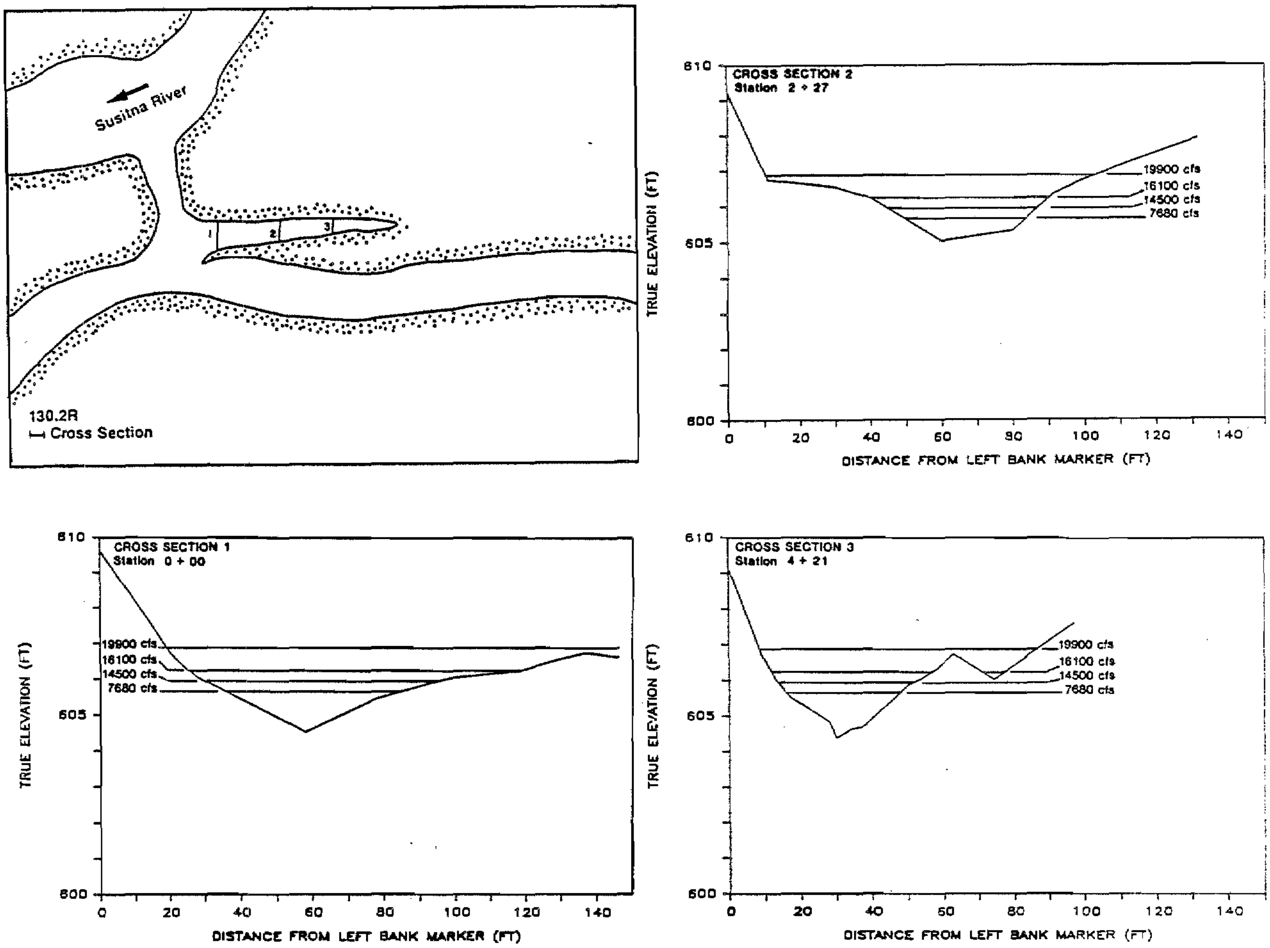


Figure IV-26. Cross sections for site 130.2R depicting water surface elevations at discharges of 7,680, 14,500, 16,100 and 19,900 cfs.

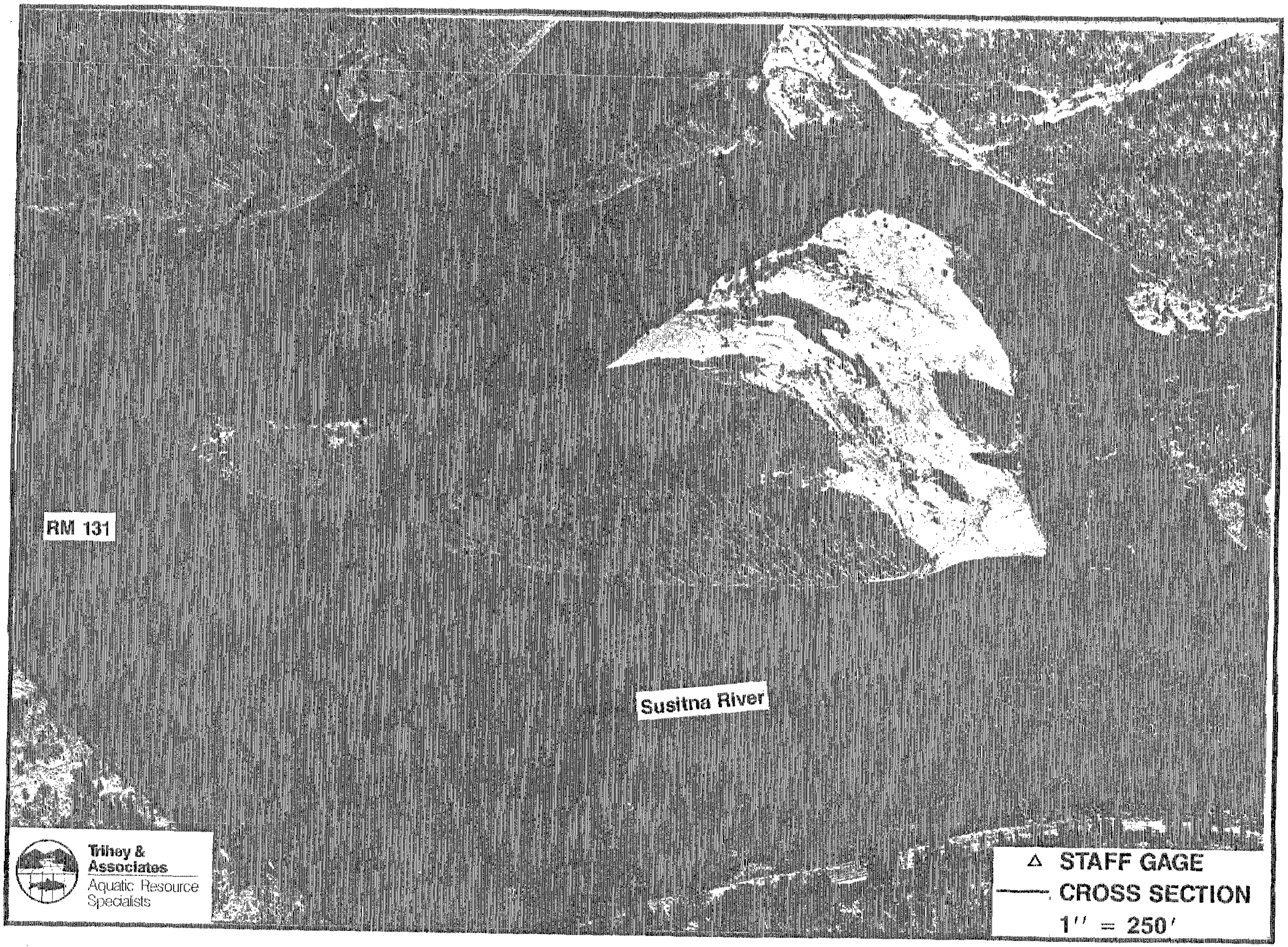


Plate IV-8. Modeling site 131.3L on June 1, 1982 at mainstem discharge: 23,000 cfs.

backwater area at the mouth of the channel. The study reach is 1,075 ft long and 130 ft wide. Four cross sections define the habitat in the study area: cross section 1 is located in a deep low velocity area; cross sections 2 through 4 are in faster, shallower areas (Figure IV-27). Two channel heads (A and B) direct flow into the site at 9,000 and 10,700 cfs respectively. Below breaching discharges, groundwater maintains flow through the study reach.

This side channel study site was selected because it was known to have upwelling and to be a chum salmon spawning area. Chum salmon were observed spawning in the area, in 1984 particularly along the right bank. Chinook fry were also collected during sampling efforts (Hoffman 1985). Moderate to strong upwelling was noted along the right bank in the lower half of the study site and moderate upwelling was observed along the left bank in the upper half of the site.

Spawning Habitat: The WSA and WUA curves for 131.3L are plotted in Figure IV-28a using the same vertical scale. The WUA curve is replotted with an enlarged vertical scale in Figure IV-28b.

The range of depth and velocity measurements extend from 7,680 to 19,900. Below 9,000 cfs, flow is maintained through the site by groundwater inflow. Above 9,000 cfs, the gravel bar on the left side of the channel is overtopped, directing flow into the lower portion of the study site allowing upwelling areas that were previously too shallow for utilization to become available. The habitat response curve rises as the channel head berm breaches near 10,700 cfs. At medium and high discharges the stage in the lower half of the channel

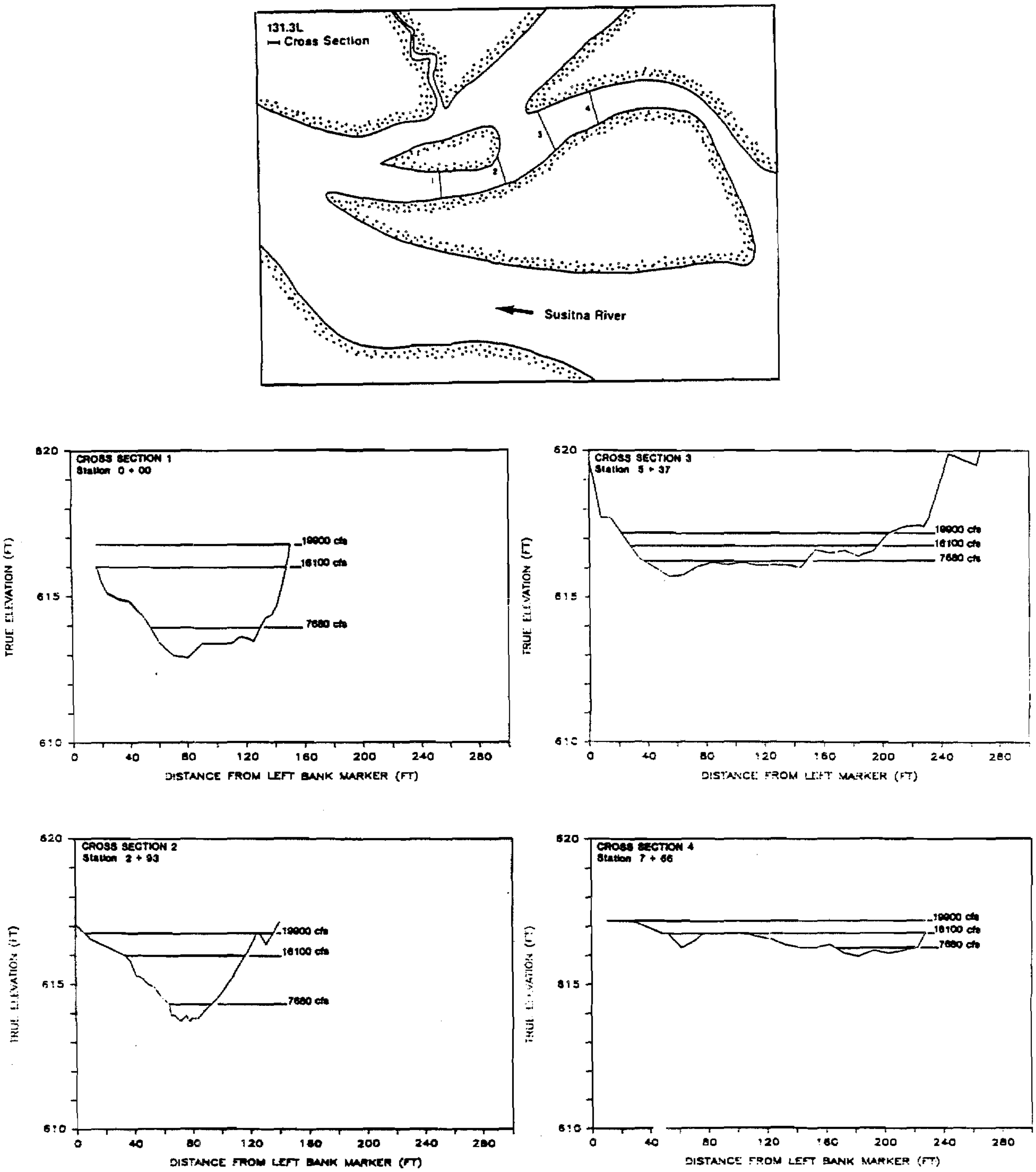
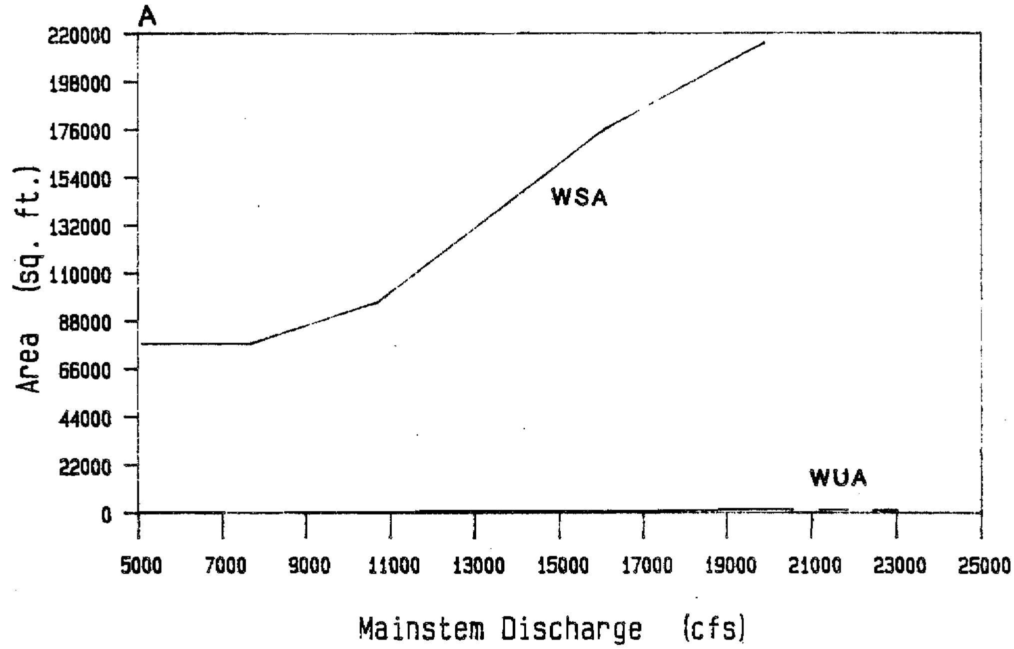


Figure IV-27. Cross sections for site 131.3L depicting water surface elevations at discharges of 7,680, 16,100 and 19,900 cfs.



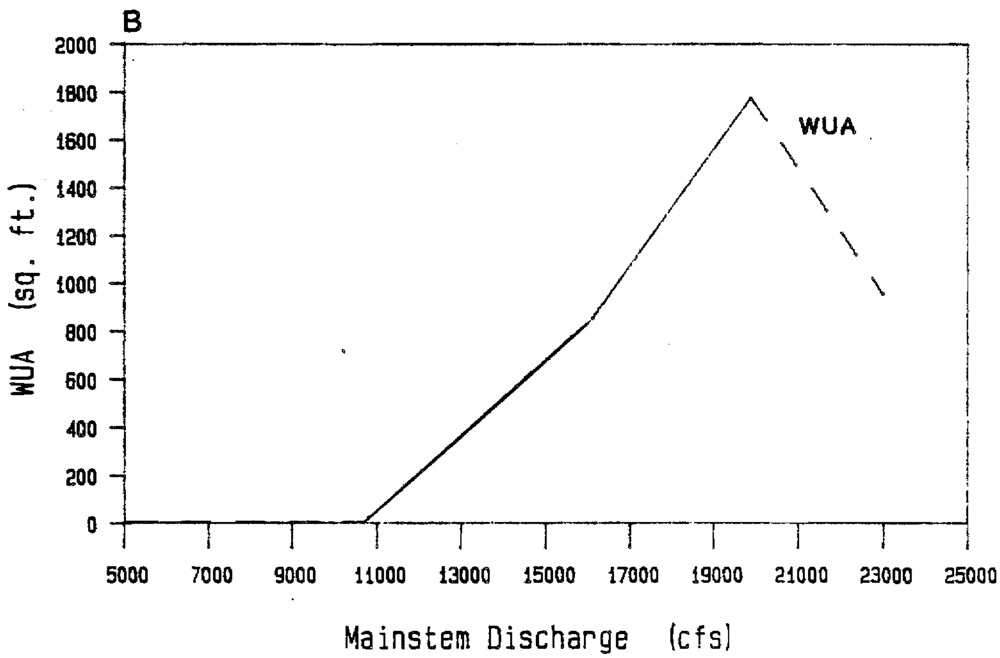


Figure IV-28. Surface area and spawning chum habitat response curves for site 131.3L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

creates a backwater area, which deposits a layer of silt. Substrate such as silt and sand are too small to be used by spawning chum which decreases the magnitude of the habitat response curve. Velocities become limiting to the spawning chum salmon above 19,900 cfs, also decreasing the trend in the habitat curve.

Data sets were estimated at mainstem discharges of 5,100 and 23,000 cfs. The stage throughout the study reach is constant below 9,000 cfs, with indicating the WUA in this range also is constant. The same WUA value determined for the 7,680 cfs data sets was assigned to 5,100 cfs. At 23,000 cfs, the velocities in the upwelling areas become too fast for spawning which decreases the WUA curve. Time series plots of WUA and mainstem discharge are plotted in Figure IV-29.

Site 133.8R

Site Description: This study site is located at the head of Slough 9A on the east bank of the Susitna River (Plate IV-9). The substrate throughout this area varies from silt along the shore to cobble in the main channel. Three cross sections were established beginning on the right bank and converging at a common point on a gravel bar. These cross sections describe the fast velocity area along the mainstem margin (Figure IV-30). Below 15,600 cfs, the shoal area along the mainstem margin begins to have a pronounced effect on depths and velocities.

This mainstem margin study site was selected because upwelling was suspected, although no spawning chum salmon have been previously recorded. No adult or

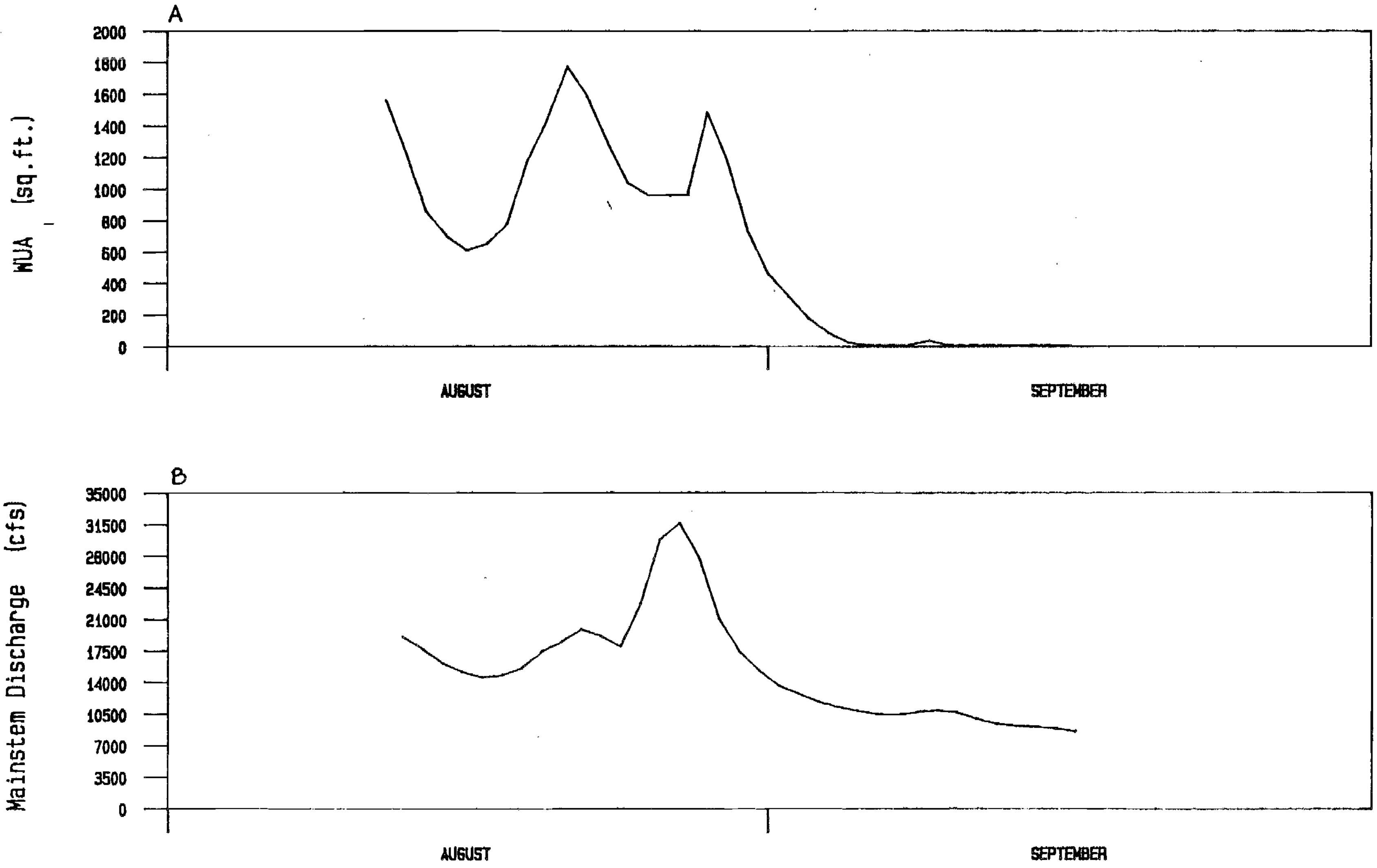


Figure IV-29. Time series plots as a function of time for site 131.3L. A - Spawning chum WUA. B - Mainstem discharge.

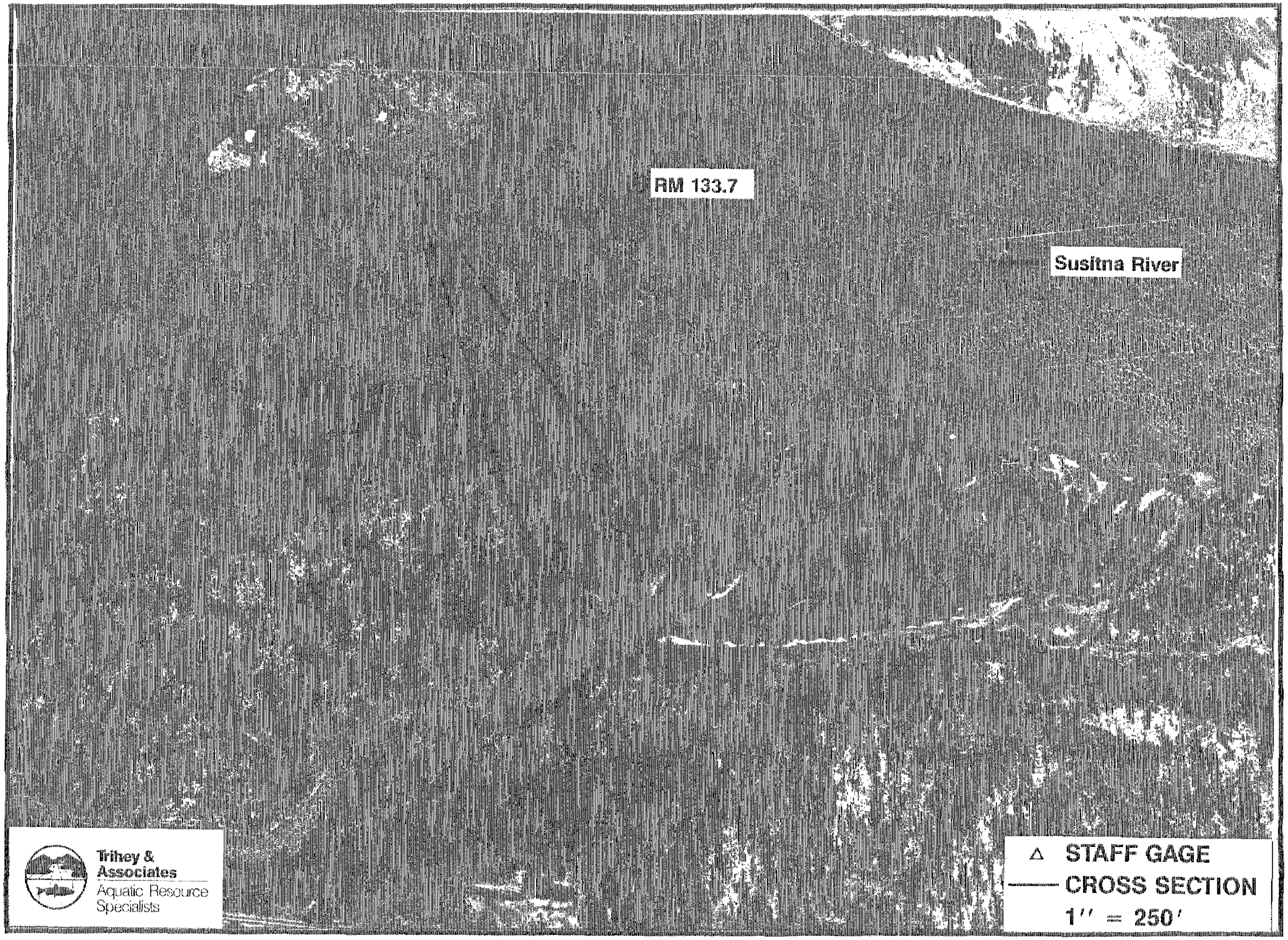


Plate IV-9. Modeling site 133.8R on June 1, 1982 at mainstem discharge: 23,000 cfs.

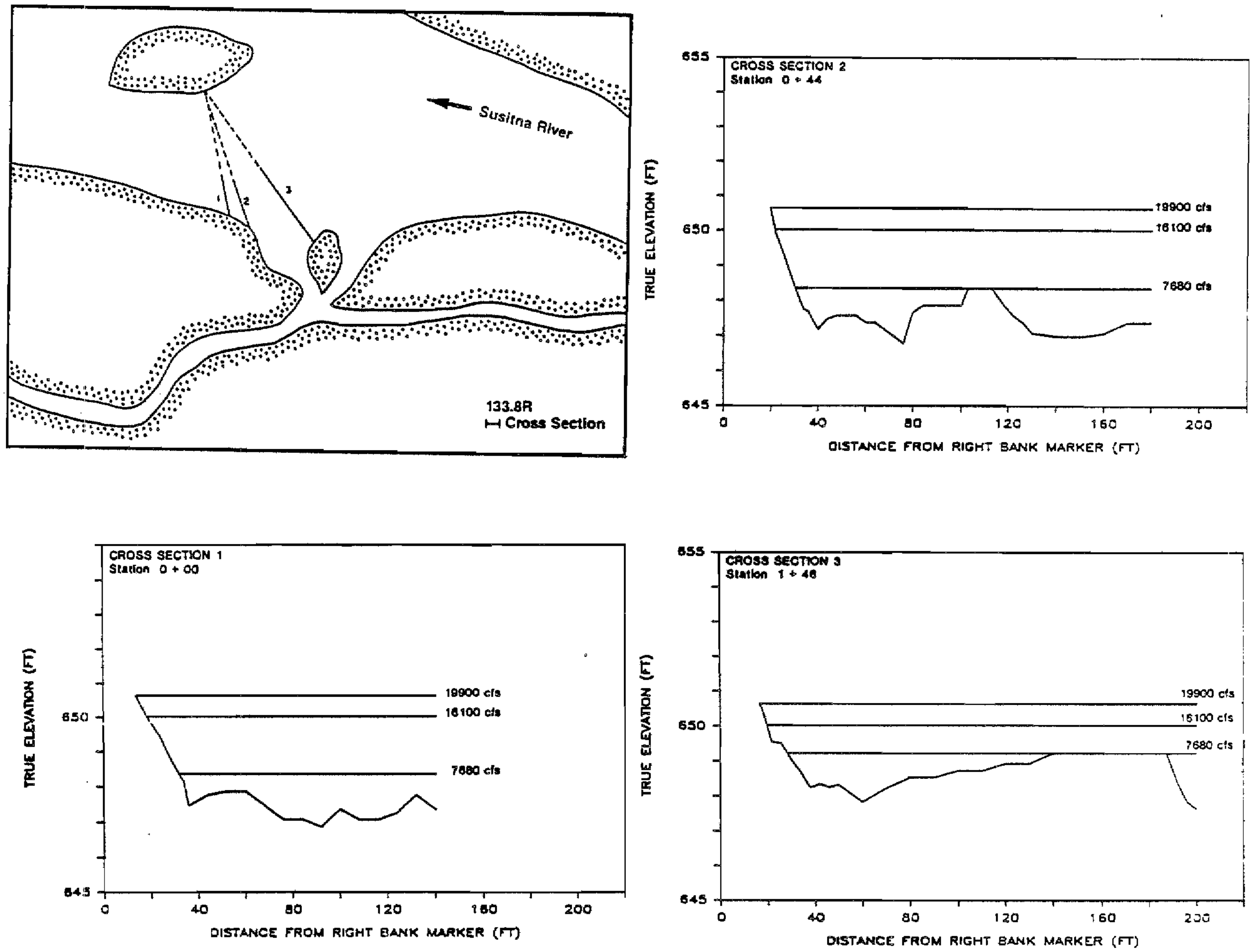


Figure IV-30. Cross sections for site 133.8R depicting water surface elevations at discharges of 7,680, 16,100 and 19,900 cfs.

juvenile salmon activity was observed in 1984 (Hoffman 1985). Small upwelling and open thermal leads in the ice were observed along cross section 1 and 2. The upwelling is assumed to be slight to moderate in strength, as the area was frozen over during part of the winter season.

Spawning Habitat: WSA and WUA curves for spawning chum salmon are presented in Figure IV-31a. The WUA curve was replotted to an enlarged scale in Figure IV-31b. Figure IV-31 shows that WUA remains relatively constant from 5,000 to 35,000 cfs.

Data sets were collected at discharges of 7,680, 16,100 and 19,900 cfs. Throughout this range, the depths in the upwelling areas are sufficient for spawning and substrate is also good. However, there are only three small upwelling areas present within the site, thus the small amplitude of the habitat response curve. An increase in mainstem discharge above 10,000 cfs causes the velocities at the upwelling areas to increase beyond the range of suitable velocities for spawning.

Additional simulated data sets were developed for discharges of 5,100, 10,400 and 22,700 cfs. The latter two discharges corresponded to conditions observed during trips to the study site on September 22 and August 24, 1985. The stage-discharge curve for cross section 3 was used to determine the stage at the three discharges. Most of the upwelling areas have depths greater than 0.2 ft at the two lower discharges with becoming the entire area optimal at 22,700 cfs. Velocities at this site are usually unsuitable for spawning chum salmon at all discharges explaining the decreasing trend in the WUA curve.

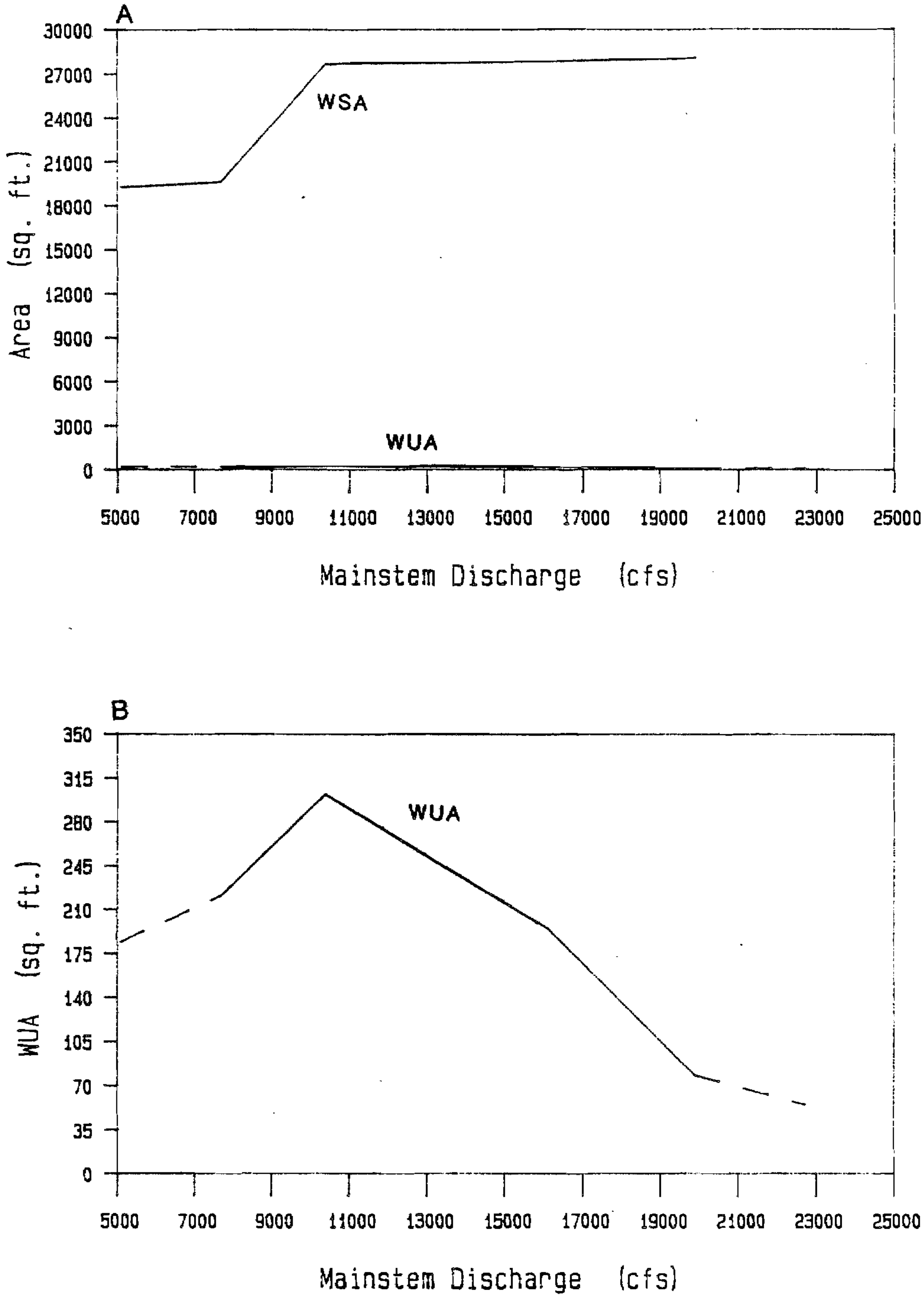


Figure IV-31. Surface area and spawning chum habitat response curves for site 133.8R. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

Time series plots of WUA as a function of mainstem discharge are presented in Figure IV-32.

Site 137.5R

Site Description: This study site is located one mile upstream of Gold Creek on the east bank of the Susitna River (Plate IV-10). The study reach is 550 feet long and varies from 100 to 30 feet wide. The substrate is predominately boulder and cobble covered with a layer of silt and sand. Two cross sections were established to describe the shallow, low velocity area throughout the entire site. Cross section 3 describes the riffle area at the head of the study reach (Figure IV-33).

This backwater study site was selected because upwelling was suspected with chum salmon spawning observations made in 1982 and adult chum and juvenile chinook salmon were observed in 1984 (Hoffman 1985). Upwelling was observed throughout the study reach during the streambed profile survey. During part of the 1984-85 winter season, nearly 50 percent of the site was open. This is an indication that the upwelling is slight to moderate in strength.

Spawning Habitat: The WSA and WUA curves are provided in Figure IV-34a for study site 137.5R. Figure IV-34b is plotted at an expanded scale to emphasize the response of WUA to discharge.

One data set was collected at 19,000 cfs. The entire study area is influenced by backwater at mainstem discharges greater than 11,800 cfs. Data sets at 5,100, 16,000 and 21,000 cfs were simulated for the site. Nearly all of the

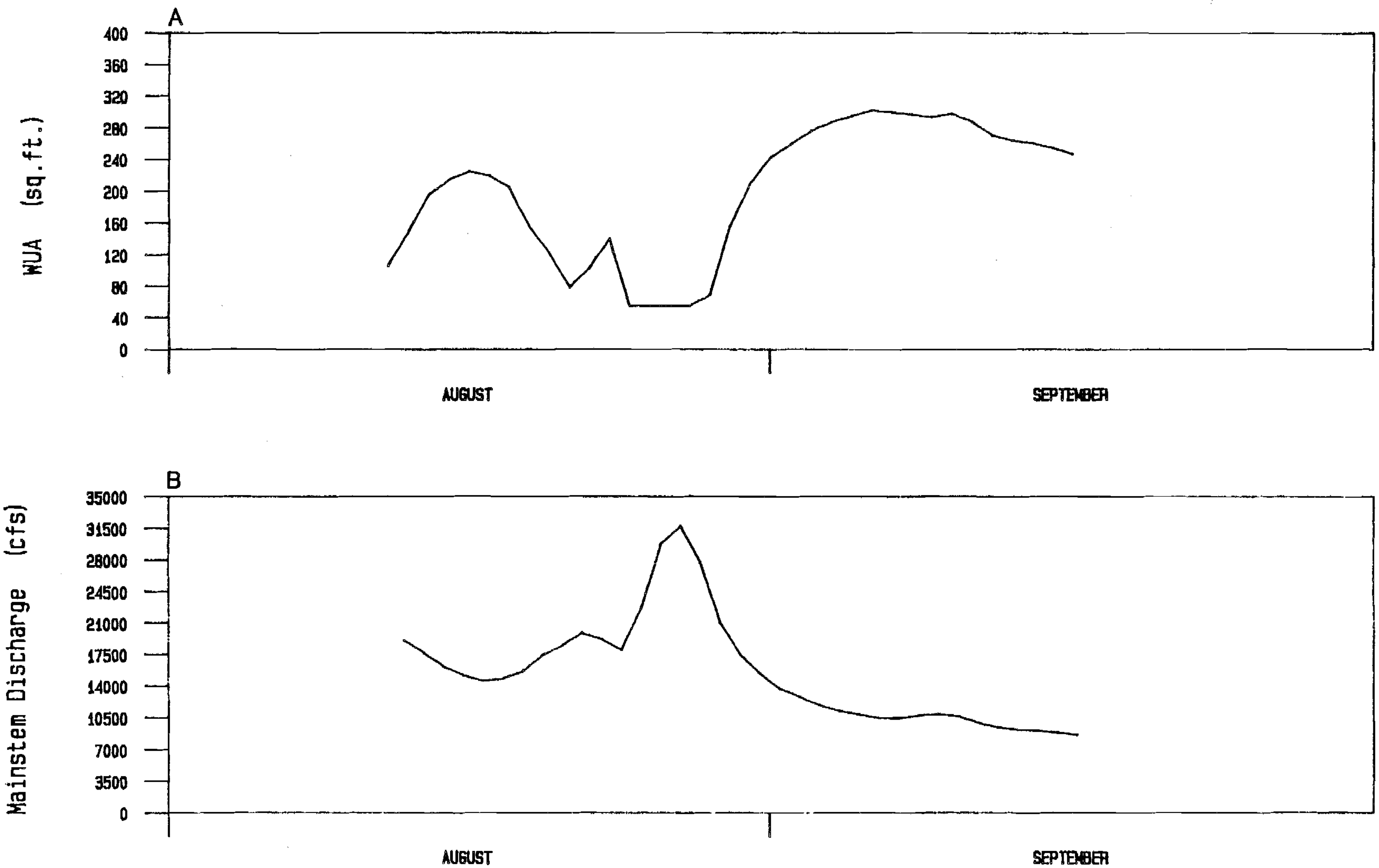


Figure IV-32. Time series plots as a function of time for site 133.8R. A - Spawning chum WUA. B - Mainstem discharge.

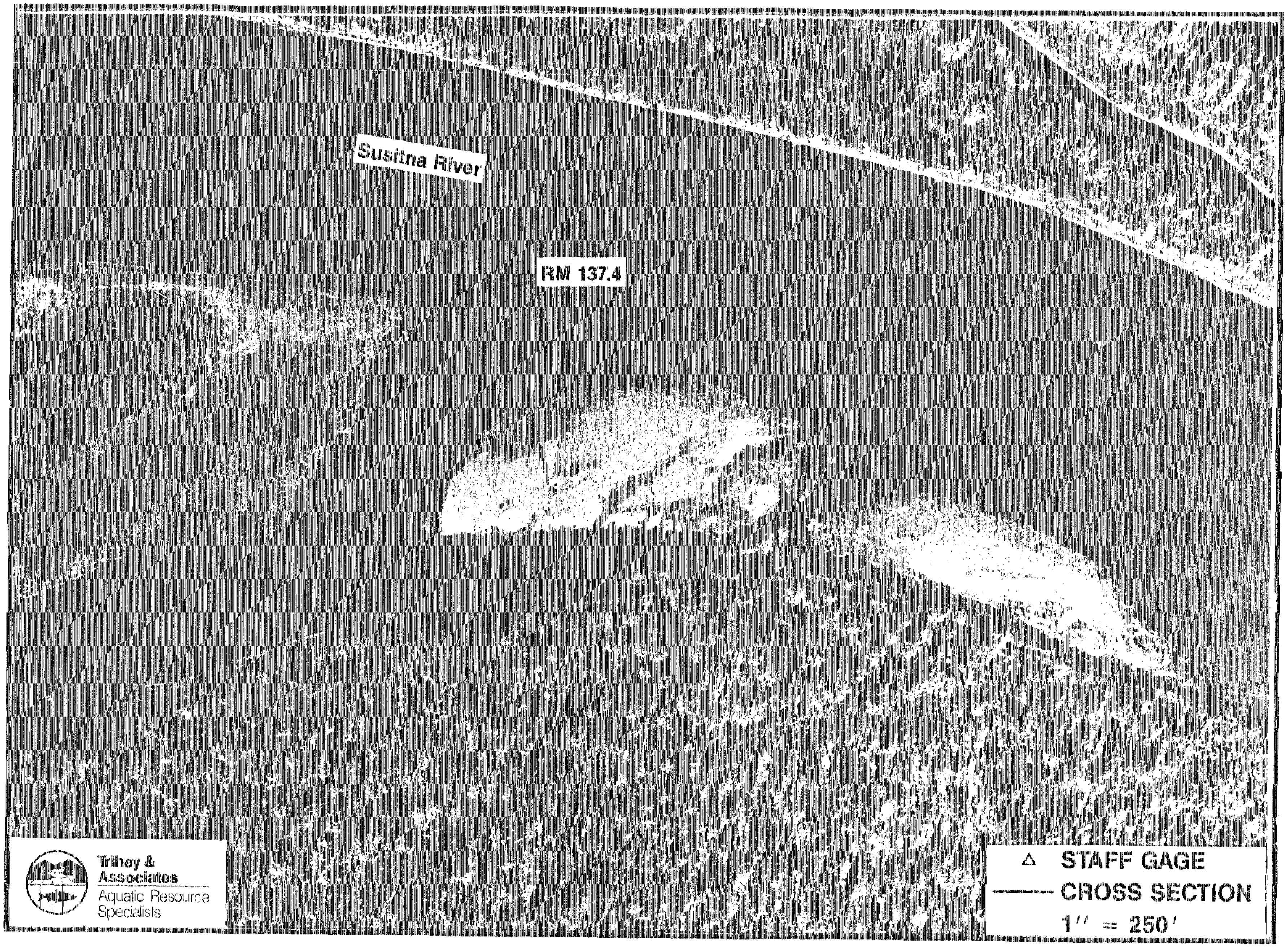


Plate IV-10. Modeling site 137.5R on June 1, 1982 at mainstem discharge: 23,000 cfs.

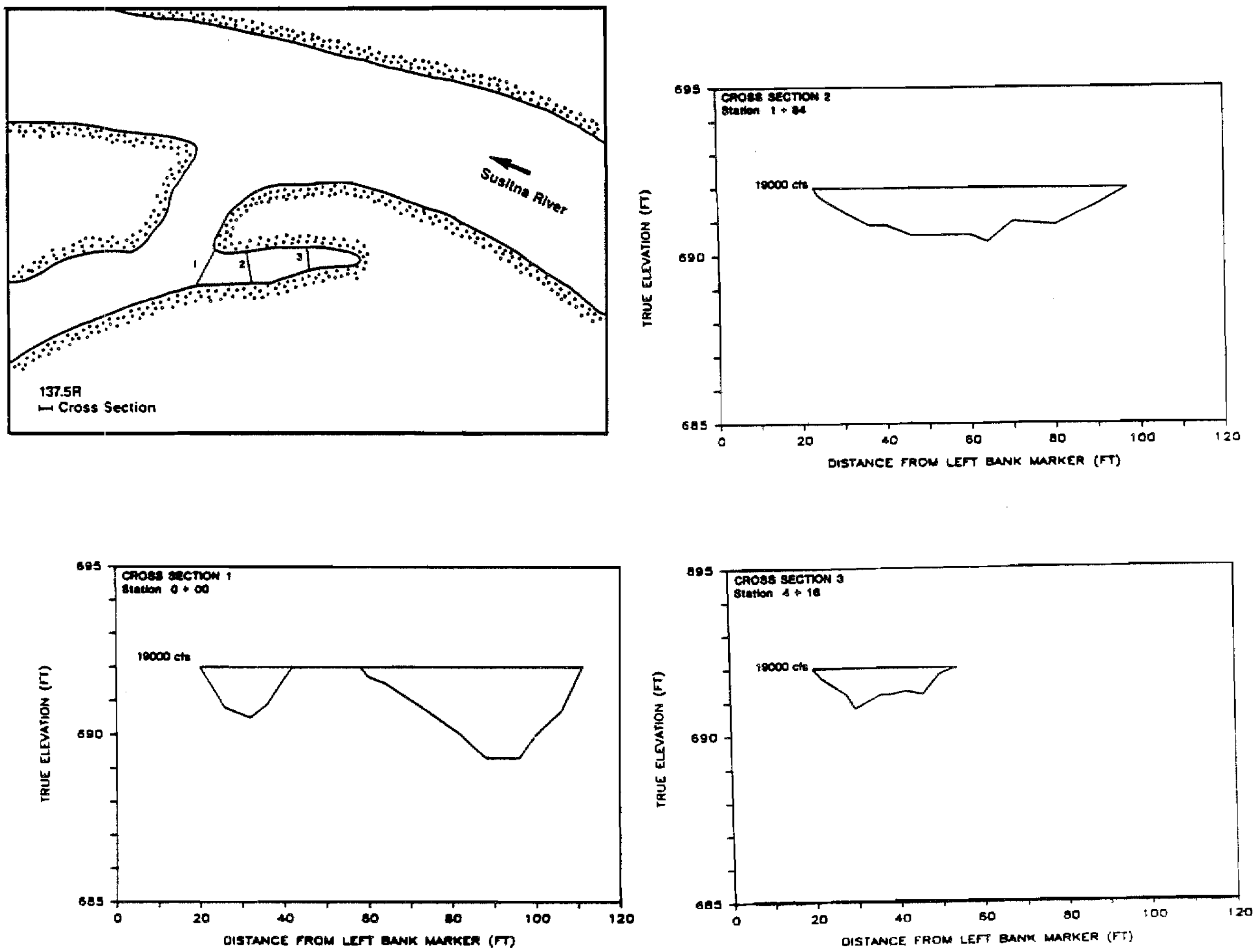


Figure IV-33. Cross sections for site 137.5R depicting water surface elevations at discharges of 19,900 cfs.

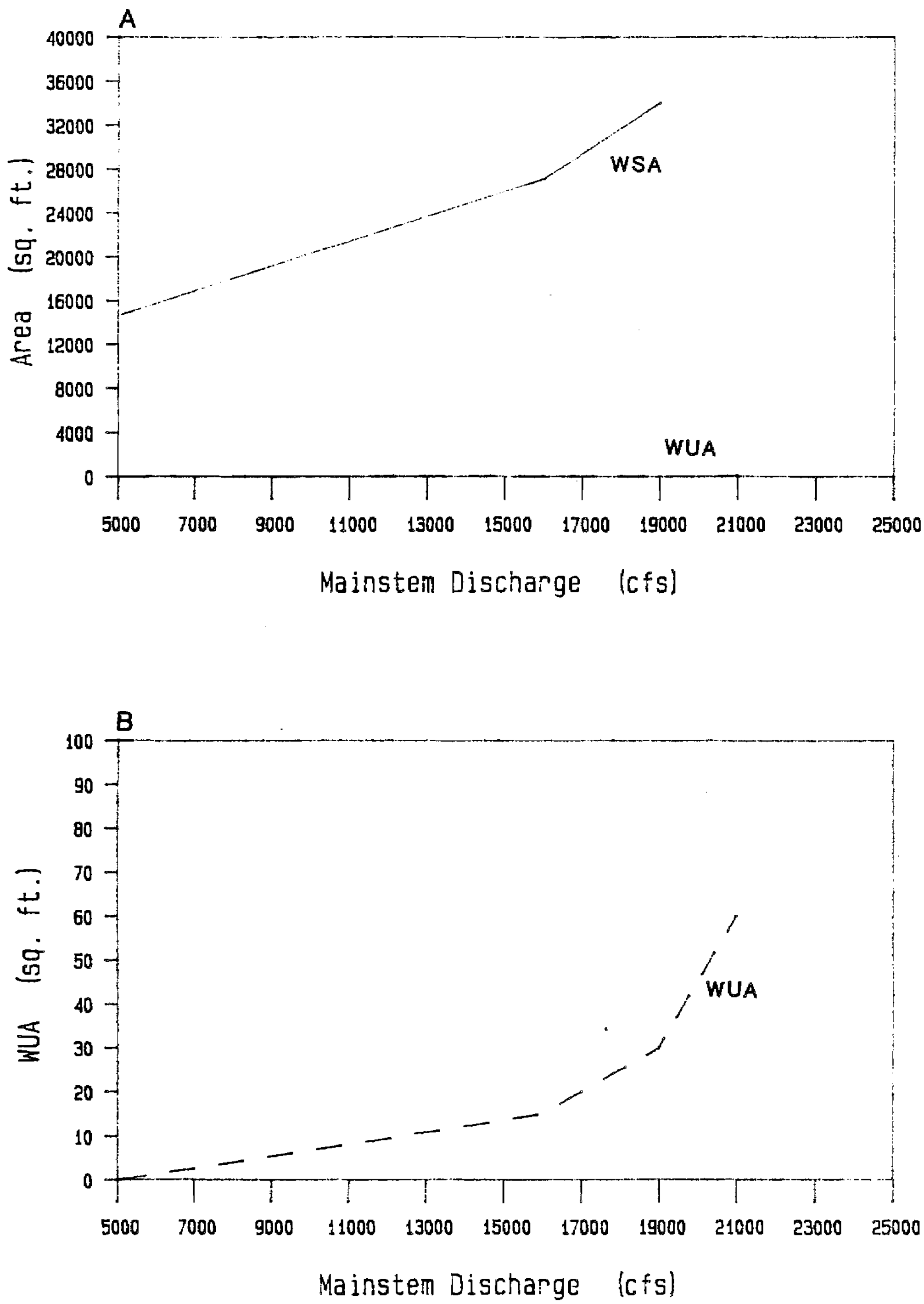


Figure IV-34. Surface area and spawning chum habitat response curves for site 137.5R. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

upwelling areas are too shallow to be utilized by spawning chum salmon at 5,100 cfs, but as discharge increases and the backwater area extends into the study area, the depths were no longer limiting. The habitat response curve climbs upward, which then begins to decrease just prior to the overtopping of the gravel bar separates the site from the mainstem. The upwelling area at cross section 2 provides most of the WUA for the site with substrate limiting at the remaining cross sections. Time series plots are shown in Figure IV-35.

Site 138.7L

Site Description: This mainstem margin study site is located immediately upstream of the confluence of Indian River with the Susitna River on its west bank (Plate IV-11). The study area is 675 ft long and has substrate varying from small and large gravel along the bank to rubble and boulder in the main channel. The lower two cross sections describe mainstem habitat along a gentle slope into the main channel, while cross section 3 describes steeper slopes with some debris (Figure IV-36).

This study site was selected as a suspected upwelling area where no adult chum salmon have been previously recorded (Hoffman 1985). Adult chum, however, were observed in the site in 1984 along with juvenile chinook. Large amounts of bank seepage were observed from the mouth of Indian River upstream to an area above cross section 2; the amount of upwelling decreased near cross section 3.

Spawning Habitat: Figure IV-37a has WSA and WUA plotted on the same scale, and Figure IV-37b is a plot of WUA at an expanded vertical scale. Five data

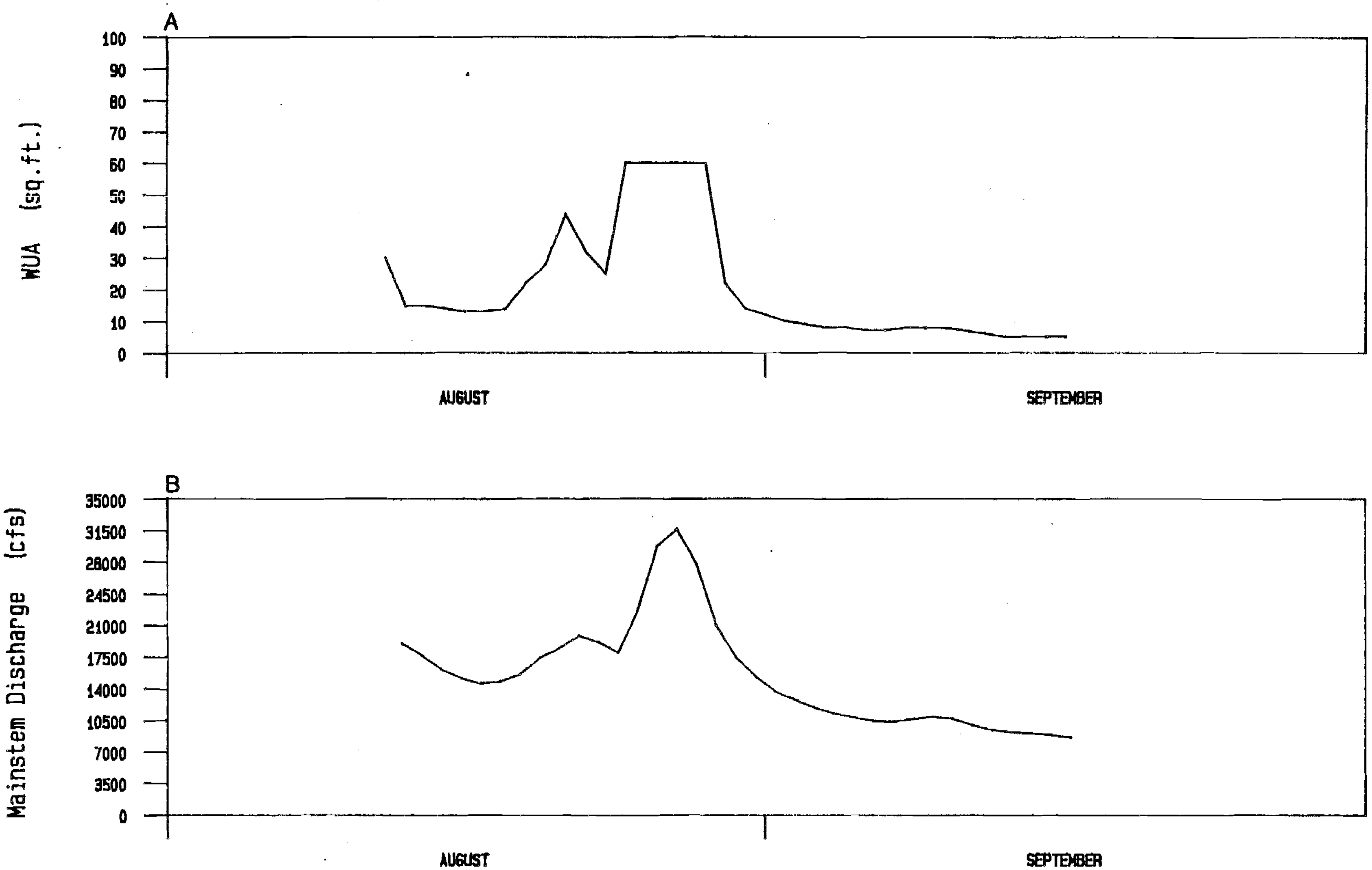


Figure IV-35. Time series plots as a function of time for site 137.5R. A - Spawning chum WUA. B - Mainstem discharge.

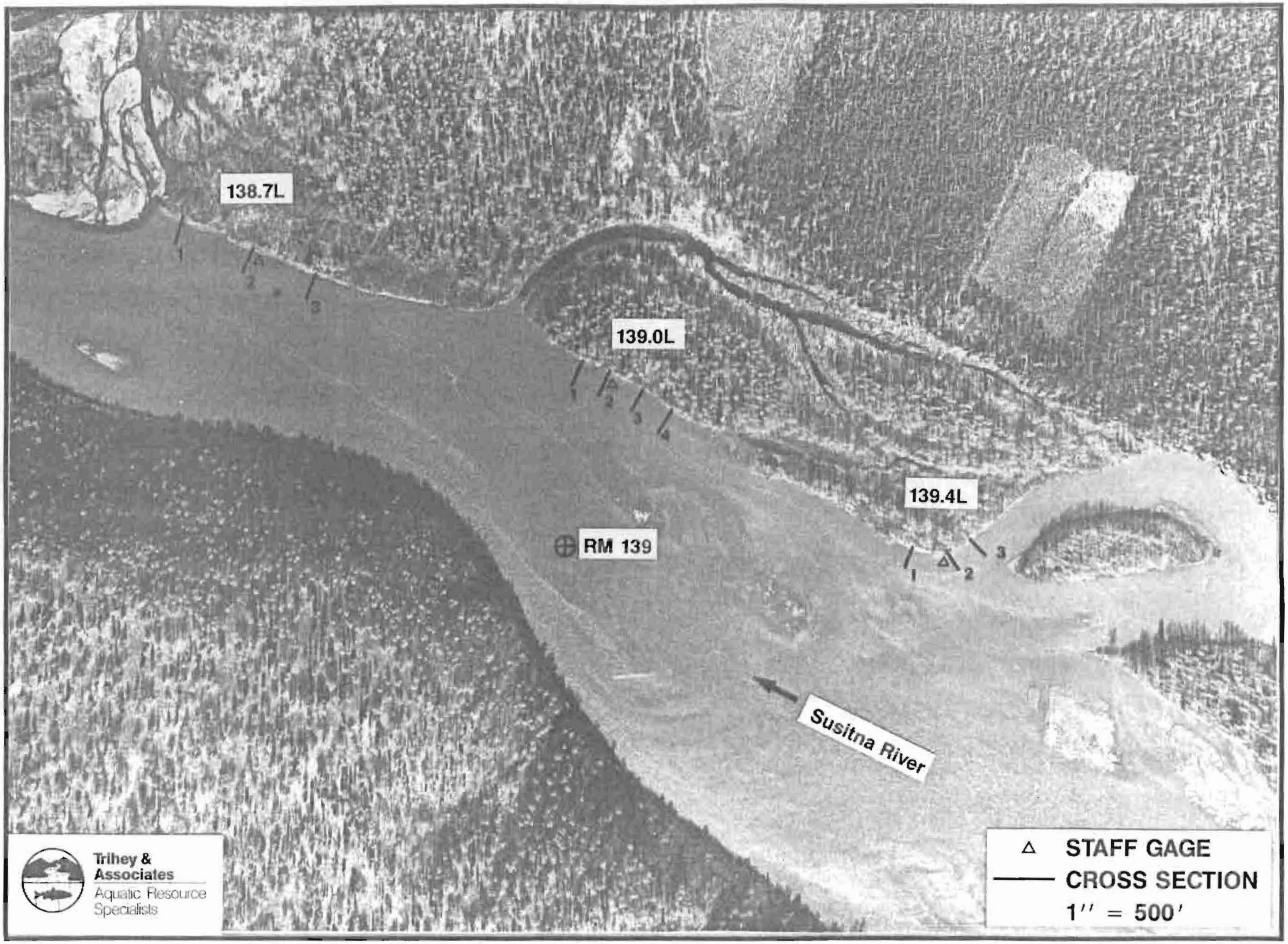


Plate IV-11. Modeling sites 138.7L, 139.0L and 139.4L on June 1, 1982 at mainstem discharge: 23,000 cfs.

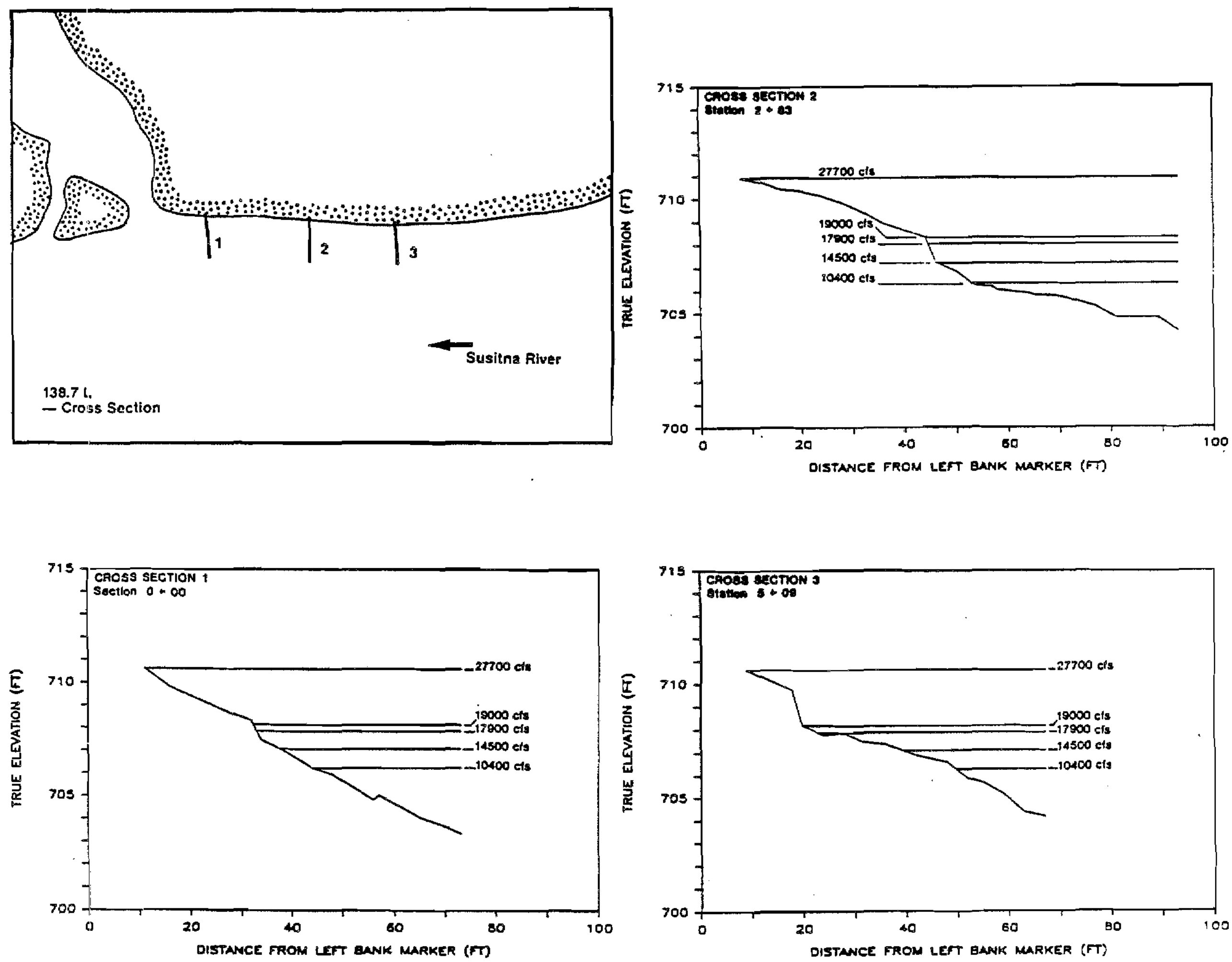


Figure IV-36. Cross sections for site 138.7L depicting water surface elevations at discharges of 10,400, 14,500, 17,900, 19,000 and 27,700 cfs.

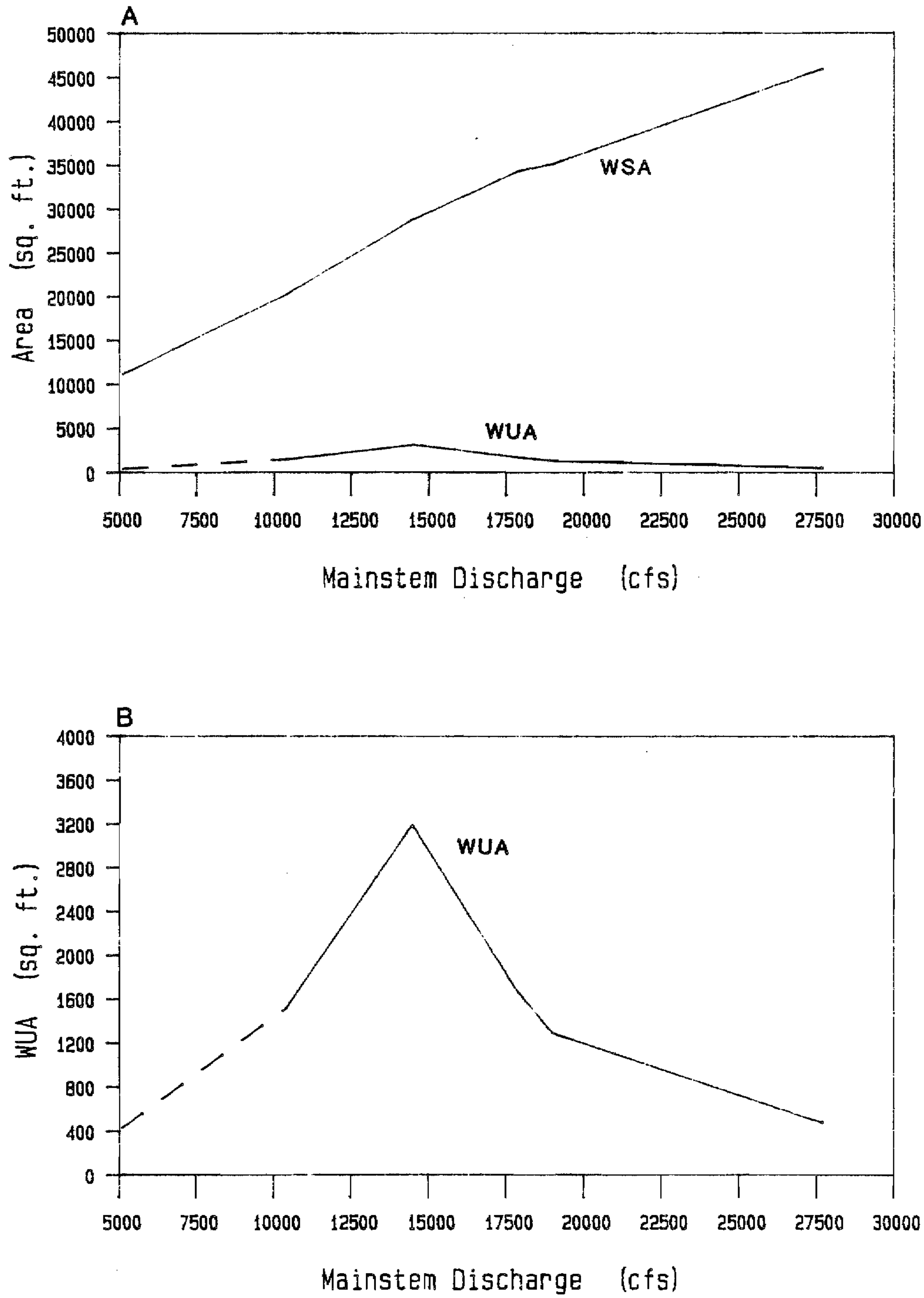


Figure IV-37. Surface area and spawning chum habitat response curves for site 138.7L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

sets were collected at discharges from 10,400 to 27,700 cfs. Up to 14,500 cfs, depths are less than optimum for spawning chum salmon. Above 14,500 cfs, higher velocities present in the upwelling areas reduce WUA. A small percentage of the total study area is influenced by upwelling and suitable spawning substrate.

An additional simulated data set at 5,100 cfs was developed to determine the habitat response at low discharges. The stage-discharge curve for the site (Part II) and the cross section elevations were used to develop the depths at 5,100 cfs. A multiplier of 0.49 was used to adjust the velocities measured at 10,400 cfs to provide estimates of the velocities associated with the 5,100 cfs. The suitability values of the depths and velocities, as well as the substrate and upwelling were then combined to determine WUA at 5,100 cfs. Time series plots of WUA and mainstem discharge are presented in Figure IV-38.

Site 139.0L

Site Description: Slough 17 is located directly downstream of this site on the west bank of the Susitna River (Plate IV-11). The study area lies along the mainstem margin and is 750 ft long. Gravel and rubble are predominant substrate throughout the site. Four cross sections describe a small channel along the shoreline margin (Figure IV-39). A gravel bar extends into the mainstem separating the study area from the main channel at discharges below 12,500 cfs.

This mainstem margin study site was selected as a suspected upwelling area known to be used by spawning chum salmon. Spawning chum and sockeye salmon

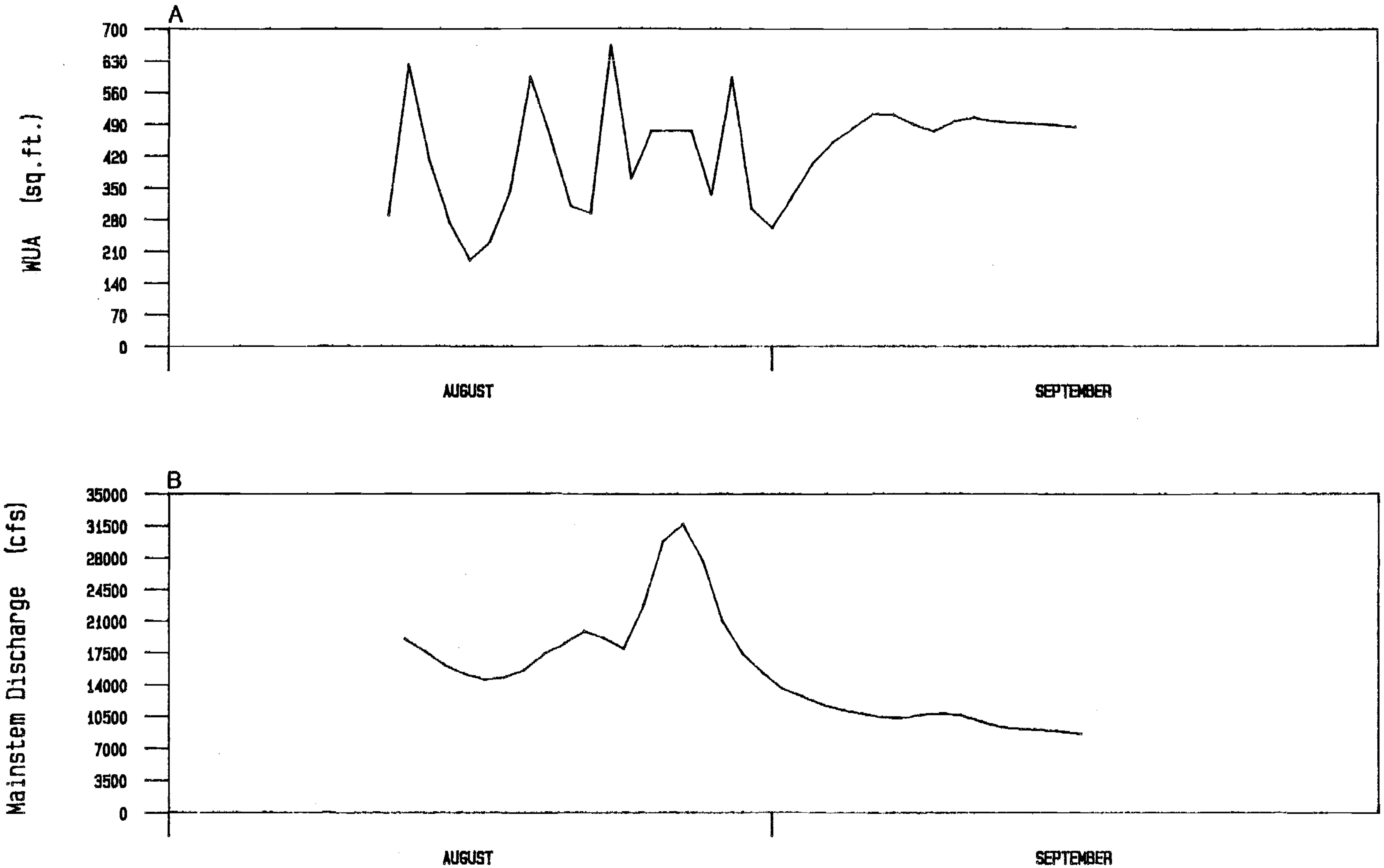


Figure IV-38. Time series plots as a function of time for site 138.7L. A - Spawning chum WUA.
B - Mainstem discharge.

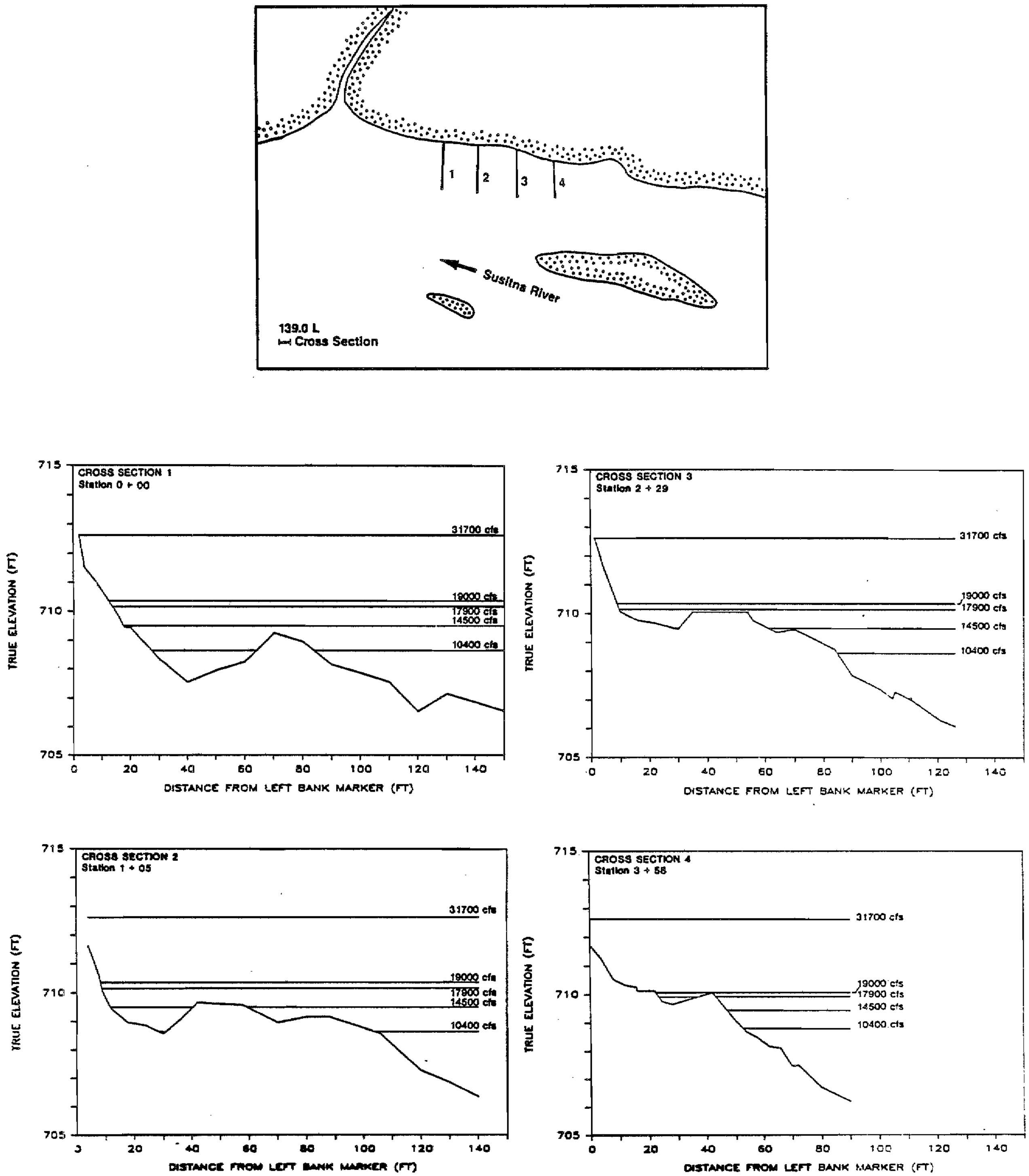


Figure IV-39. Cross sections for site 139.0L depicting water surface elevations at discharges of 10,400, 14,500, 17,900, 19,000 and 31,700 cfs.

have been observed in this area as well as chinook and coho juvenile salmon (Hoffman 1985). Upwelling was observed to begin just upstream of cross section 2 and in the clear water areas below cross section 1.

Spawning Habitat: WSA and WUA curves are plotted in Figure IV-40a. Both curves are plotted to the same scale. The largest proportion of wetted surface area provides WUA at discharges between 14,500 and 19,000 cfs.

The WUA curve, plotted in Figure IV-40b at an expanded vertical scale, increases up to 14,500 cfs to when the depths are no longer limiting spawning. Upwelling and groundwater inflow maintain approximately the same stage at discharges below 10,400 cfs. A large backwater area forms above 10,400 cfs and extends upstream with increasing discharge. The gravel bar which separates the study area from the mainstem is overtopped above 12,500 cfs and velocities increase in the upwelling areas. Near 20,000 cfs, the velocities exceed the optimum usability range, decreasing the habitat response curve.

An additional simulated data set at 5,100 cfs was developed using stage and cross section data. The constant stage below 10,400 cfs implies that WUA at 10,400 is the same as that at 5,100 cfs. Time series plots of WUA and mainstem discharge are shown in Figure IV-41.

Site 139.4L

Site Description: This mainstem margin study site is located about 0.7 miles upstream of Indian River on the west bank of the Susitna river (Plate IV-11).

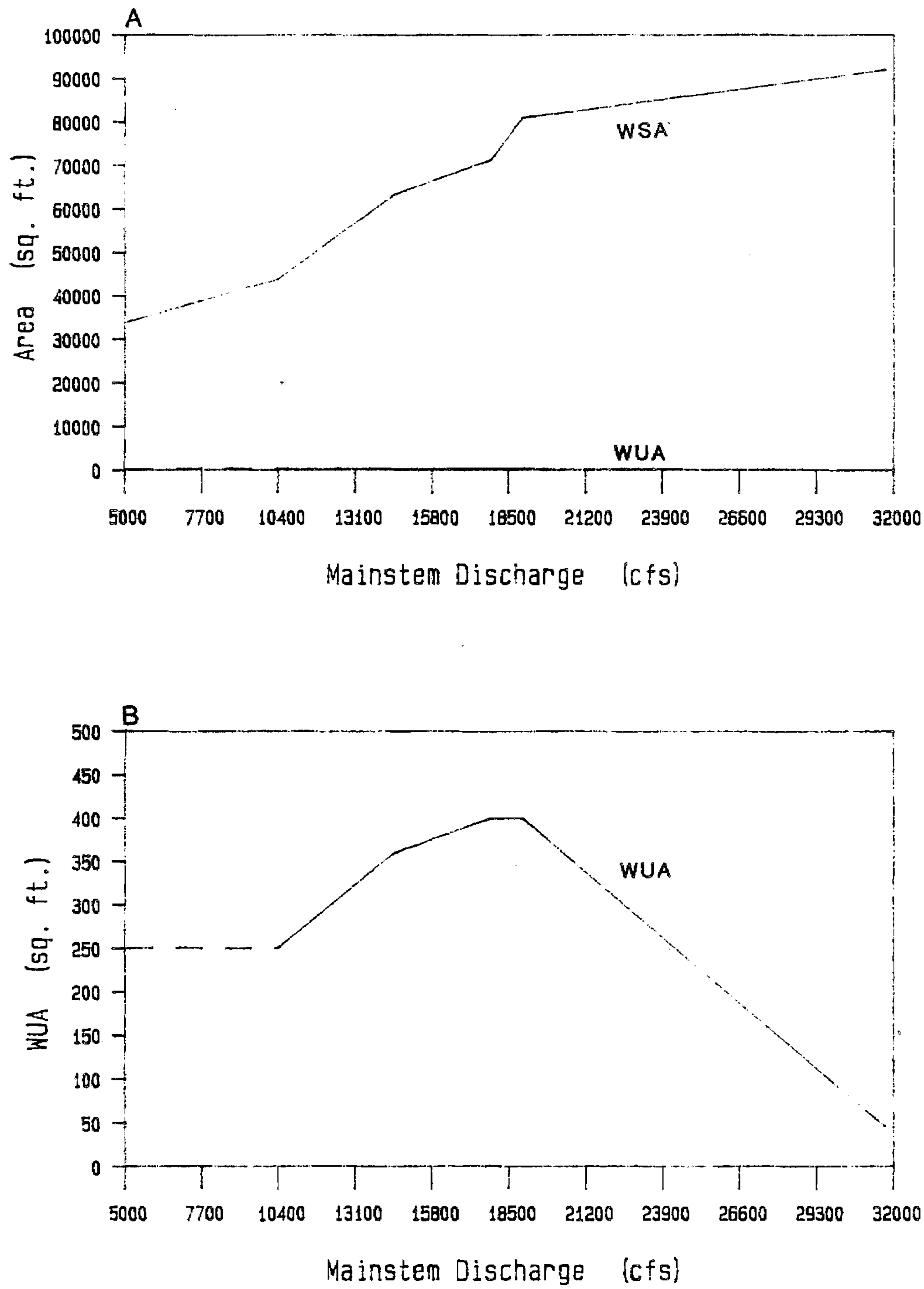


Figure IV-40. Surface area and spawning chum habitat response curves for site 139.0L. A - Wetted Surface Area (WSA) and Weighted Usable Area (WUA). B - Weighted Usable Area (WUA).

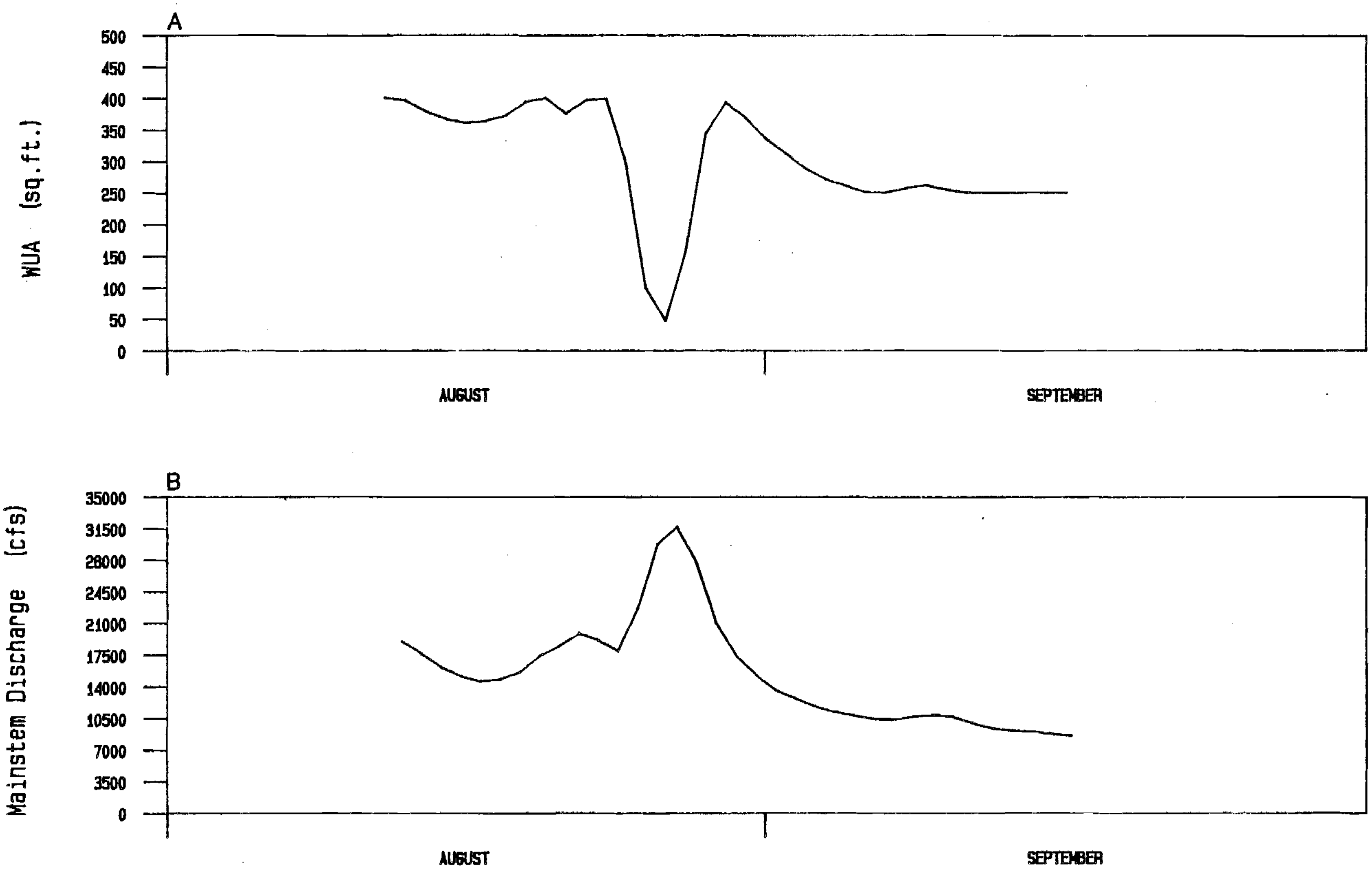


Figure IV-41. Time series plots as a functionof time for site 139.0L. A - Spawning chum WUA. B - Mainstem discharge.

The study area is 575 ft long. Three cross sections were established to model the mainstem margin (Figure IV-42). Cobbles and boulders are present in the upper study reach near cross sections 2 and 3, with gravel and rubble present at cross section 1.

This study site was selected as a suspected upwelling area though spawning chum salmon have not been observed. No adult salmon but juvenile chinook were observed in the study area during 1984 (Hoffman 1985). A small open thermal area in the ice was recorded near cross section 2 for a short period of time before freezing over.

Spawning Habitat: No upwelling areas were observed throughout the 1984 and 85 field season. Therefore, no habitat response curves were developed for the site.

DISCUSSION

The results of this section show that side channel areas influenced by backwater had increasing trends in the WUA as mainstem discharge increased, with WUA leveling off when depth are no longer limiting. In addition, high velocities were not present in these areas at the range of modeled mainstem discharge (5,000 to 25,000 cfs).

Mainstem margin areas had downward trends in WUA as mainstem discharge increased, with depths usually not limiting in these areas. The amount of available habitat was influenced instead by high velocities. As velocities

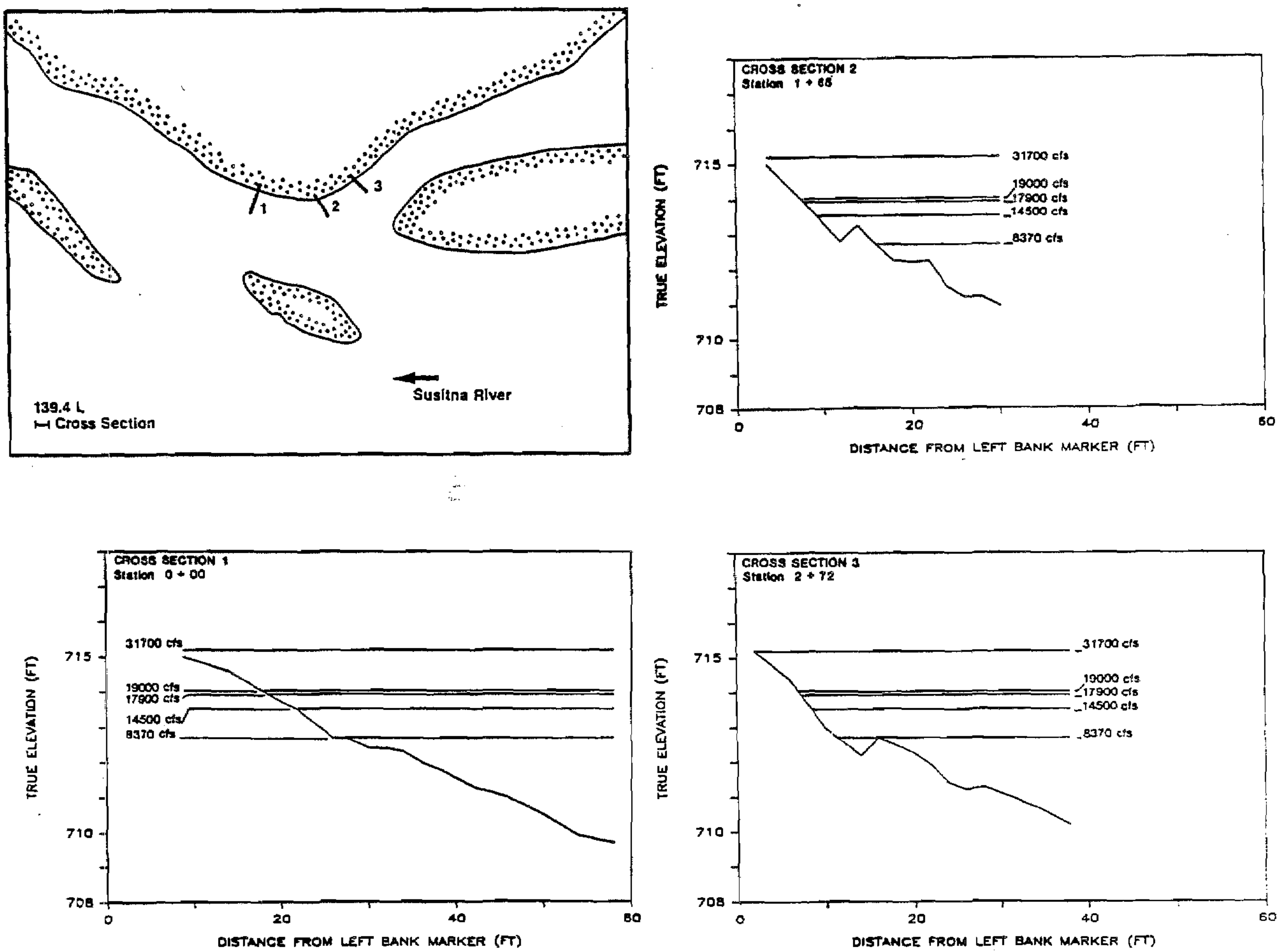


Figure IV-42. Cross sections for site 139.4L depicting water surface elevations at discharges of 8,370, 14,500, 14,900, 19,000 and 31,700 cfs.

increased with an increase in mainstem discharge, the amount of suitable habitat for spawning chum salmon decreased.

Side channel study areas that were not located in backwater areas appeared to have both increasing and decreasing trends in WUA as a function of mainstem discharge, with these areas limited by depths at lower discharges. As discharges increased, the depths in the upwelling areas became usable (greater than 0.8 ft). Also, the velocities in the upwelling areas exceeded 1.3 fps, the WUA values decreased.

The amplitude of the WUA curve was determined by both the amount of upwelling and quality substrate present within the site. Quality substrate in upwelling areas yielded higher WUA values than sites where either the upwelling was associated with poor spawning substrate or where quality substrate existed with no upwelling.

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